TUM School of Social Sciences and Technology

Negotiating Beyond-Planetary Challenges: The European Space Sector in the New Space Age

Michael Andreas Clormann

Vollständiger Abdruck der von der TUM School of Social Sciences and Technology der Technischen Universität München zur Erlangung des akademischen Grades eines Doktors der Sozialwissenschaften (Dr. rer. soc.) genehmigten Dissertation.

Vorsitzender:
Prof. Dr. Sebastian Pfotenhauer

Prüfende der Dissertation:
1. Prof. Dr. Sabine Maasen
2. Richard Tutton, Ph.D.
3. Prof. Dr. Sascha Dickel

Die Dissertation wurde am 30.08.2021 bei der Technischen Universität München eingereicht und durch die TUM School of Social Sciences and Technology am 26.11.2021 angenommen.

There also exist, and this is probably true for all cultures and all civilizations, real and effective spaces which are outlined in the very institution of society, but which constitute a sort of counter-arrangement, of effectively realized utopia, in which all the real arrangements, all the other real arrangements that can be found within society, are at one and the same time represented, challenged and overturned: a sort of place that lies outside all places and yet is actually localizable. In contrast to the utopias, these places which are absolutely other with respect to all the arrangements that they reflect and of which they speak might be described as heterotopias.

(Foucault 1997, 332)

Contents

Abstract

Recent spectacular spaceflight missions have revived public attention for outer space as a realm of excitement and technological marvel. Seemingly reminiscent of the Space Age of the 20th century, on the one hand, astronauts and spaceflight visionaries evoke awe and fascination. On the other hand, spaceflight activities continue to mainly serve the clandestine interests of national security, lofty science, or mundane economic profit. As such, they continue to be driven by national space sectors – assemblages of highly specialized institutions, expertise, cultures, and politics, that have largely monopolized access to outer space. However, this status quo is increasingly challenged, as the rising dependence of global societies on spaceflight activities becomes more and more apparent: for example, through the advent of extensive commercial spaceflight ambitions in the so-called "New Space Age" and simultaneously arising sustainability problems in outer space. Making use of an array of conceptual tools from STS and related fields like organization studies, this cumulative dissertation explores how the European space sector is encountering these challenges and associated demands arising with them. Providing two article-based case studies on the issues of space debris and New Space innovation culture, it analyzes how these demands are unpacked and negotiated by European space sector professionals and what implications the discursive practices emerging out of these negotiations have for the societal relevance and accessibility of European spaceflight activities. For this purpose, it employs a qualitative research approach drawing primarily from qualitative expert interviews but also document analysis and field observations.

1. Introduction

For the past few decades, making spaceflight activities and technologies possible has seldom been perceived as shaping contemporary societies and the lives of those living in them. Yet, throughout the history of the Space Age, this was not always the case. During the Space Race of the Cold War, the management of individuals and societies in the same vein as technologies and infrastructures emerged as a promising and desirable undertaking, mirroring technocratic ideas of “steering" societal progress (Hecht 2009, 28). Following political and technological theories of that time, sociotechnical entities, people, technologies, organizations, and ultimately societies were thought of as interlinked systems, each following its own internal logic. These systems, it was widely assumed, could be understood and ultimately governed by experts (Centeno 1993, 309f). In the realm of technology development, such approaches to control systems allied themselves with assumptions of scientific positivism and technological determinism – in short, the idea of more-or-less simultaneous societal progress at large (Brose 2004, 6). Spaceflight technologies and the associated imaginaries of societal futures, arguably peaking in public perception in the early 1970s, featured as prime examples of “big science”, pushing for systematizing and rationalizing control of sociotechnical systems (Trischler 2002, 17; Kaminski 2016, 219). Paradigms like systems engineering, which focused on the systemic interaction of technological system components, were introduced as a standard approach to developing complex technologies and prominently applied to spaceflight (Sato 2005, 562).

As has been studied within Science and Technology Studies (STS) and related fields, later decades, particularly the late 1970s and 1980s, saw a crisis and waning belief in the

appropriateness and effectiveness of steering complex sociotechnical systems and planning the advancement of societies, like that of the rockets of the Space Age, on the drawing board (Luhmann 1997, 41). At the same time, and following the then-recent glory of NASA's Apollo moon missions, public interest and government funding in space activities began to slowly crumble. Despite still being under the institutional and budgetary umbrella of governments and their respective public space agencies, starting in the 1980s, satellite development, commercial applications, and rocket launches were increasingly privatized. Space exploration ceased to raise significant public attention or enthusiasm for spaceflight. Even the famous "Space Shuttle," NASA's technological figurehead project at the time, failed to generate excitement on the Apollo 11 moon landing scale. Finally, in the aftermath of the 1986 Challenger disaster, space technologies no longer seemed to offer or at least symbolize a satisfying path towards a bright future in outer space (Mütter 2012, 159).

This trend was supported by a turn to planetary introspection, represented by the Club of Rome's famous report "The limits to growth" (Meadows et al. 1972) or the UN's similar publication entitled "Only One Earth: The Care and Maintenance of a Small Planet" (Ward and Dubos 1983), which led to increasing awareness of Earth's limits and the importance of social, economic, and especially ecological sustainability. This introspection was soon accompanied by similar propositions in the (popular) scientific realm, like the "Gaia hypothesis" (Lovelock 1979), which was influential in the formation of a variety of different scientific fields and theories in the following years. The rising star of environmentalism accompanying this new planetary perspective questioned seemingly naïve attempts to rationalize human life and technology on Earth for the sake

of a better future – ideas that had inspired the previous decades. As Jasanoff (2001) notes, environmental onto-epistemologies of the time therefore built on the technologized iconography of the Space Age, e.g., the famous "Blue Marble" photographs taken by the Apollo 17 moon mission (the last of its kind) in 1972. Ironically, genuinely global vision and a return to societal introspection were thus made possible by the very tools designed and intended to extend human reach beyond the planet's confines.

As others have observed, spaceflight activities after the turn of the millennium continued to follow these dual strains of extrospection, aiming to explore and exploit outer space, and introspection, establishing an outside view of human life on planet Earth from outer space (Praet and Salazar 2017, 317f). Today, this is true for publicly funded scientific space probes whose sensors analyze Venus, Mercury, or Mars – most recently, the NASA Mars rover "Perseverance" touching down on our neighboring planet in early 2021. It also describes current private initiatives to establish habitable bases on the Moon or Mars and, somewhat more modestly, operate space stations open for tourism in Earth's orbit. Lastly, it accounts for the myriads of satellites, privately or publicly launched, that allow for satellite navigation, instantaneous global communication, and the continual surveillance, measurement, and mapping of our planet's atmosphere and surface[1]. Still firmly rooted in Space Age traditions, institutions, and expertise, such spaceflight technologies successfully maintain their reputation as either sensitive security tools to be kept secret (Sheehan 2019); agents of distant, often utopian societal futures (Kilgore 2003); or tools

[1] Following Havercroft and Duvall (2009, 50f), such knowledge gained from access to outer space is closely related to what has been termed “geo-power”, “the functioning of geographical knowledge not as an innocent body of knowledge and learning but as an ensemble of technologies of power concerned with the governmental production and management of territorial space.” (O’Tuathail 1996, 5).

to satisfy and justify the technoscientific curiosity of researchers and experts (Geppert 2012).

The author claims that this framing of spaceflight technologies, to some extent, continues today. Unlike energy-neutral cities, autonomous cars, social household robots, or medical biogenetics – contemporary technologies easily accepted as defining the *human condition*, or the "basic conditions under which life on earth has been given to man" (Arendt 1998, 7) – spaceflight technologies are seldom staged as tools to shape and be shaped by immediate societal needs – that is, to shape "life on Earth," in Arendt's words. Accordingly, most forms of broader public influence on technology development, including institutionalized democratic processes, public interest group initiatives, and direct consumer interactions, appear absent or far-fetched when applied to spaceflight technologies. While witnessing a revitalization of spectacular spaceflight activities in recent times[2], societal stakeholders hardly claim or demand opportunities to shape the development or application of the associated technologies (nor are they generally expected to). Indeed, the space activities they enable are rarely perceived as societally relevant but rather as extraordinary special-interest endeavors.

The underlying assumption is that such a "business as usual" of how spaceflight activities are recognized – or rather *not* recognized – as societally relevant requires exploring what is usually described as the *space sector*. Such a research interest is motivated by the realization that a lack of recognition of the societal significance of spaceflight activities

[2] One example would be the "billionaire-space race" between Richard Branson and Jeff Bezos, both successfully launching spacecraft constructed by their respective private space companies into outer space in July of 2021.

becomes increasingly implausible inside *and* outside the space sector. For example, technologies like satellite communication or navigation have clearly emerged as increasingly critical within global societal contexts and thus demand societal participation in the governance of spaceflight activities. This dissertation is thus guided by the overarching observation that, while the space sector as a whole does not so far appear challenged by these changing conditions, some of its parts are becoming susceptible to new kinds of demands that challenge the existing status quo.

The following analysis thus explores two questions: 1. how the challenges described above are currently being unpacked and negotiated on the stage of the *European space sector*[3] and 2. what implications these processes have for the societal relevance and accessibility of spaceflight activities. For this purpose, the sector is understood as a heterogeneous assemblage demarcated by a historically contingent set of interacting issues, institutions, technologies, practices, identities, and narratives (DeLanda 2006, 3ff). This approach requires some initial contextualization of such an assemblage, which will follow in Section 2 of this dissertation. There, two of the aforementioned challenges are also introduced in more depth as settings on which the following analysis will focus. They refer to the rise of the so-called "New Space Age"[4], which is shaped by the growing numbers of private and commercial spaceflight activities and the accumulation of ever-larger amounts of space debris[5] as a result of past, present, and future spaceflight conduct.

[3] With the exception of Section 3, which contains the peer-reviewed articles around which this cumulative dissertation revolves, the following framework paper will use the acronym "ESS" to describe the term "European space sector".
[4] The terms "New Space Age" and "New Space" typically describe the same phenomenon and are thus used interchangeably.
[5] Space debris describes a variety of potential artifacts left behind by human activities in outer space. It ranges from small parts of rockets like bolts, fuel drops, or even just flakes of paint to whole satellites that

The research program underlying this dissertation is presented in Subsection 2.3 and described there as "space sector research." Section 2.4 then concludes with an overview of materials and methods, paying special attention to the limits and opportunities introduced into the at-hand research perspective through the author's personal and professional status in the field.

Section 3 contains the two journal articles that form the analytical groundwork of this dissertation. The case studies presented in Articles 1 and 2 correspond with the two settings introduced above.

In Section 4, the findings of both articles are first consolidated and evaluated under the overarching perspective of "space sector research." Thus discussion focuses on the implications of non-simultaneities lying at the heart of European space governance and their interplay with the two challenges emerging in the two settings analytically explored in this dissertation. This entails reviewing the implications for more open future spaceflight activities and a more societally engaged ESS. Section 4 concludes by relating these implications back to the question of the societal relevance of spaceflight activities and identifies opportunities for critical social science perspectives on the future human condition in outer space.

The following subsections of this introduction draw a more detailed picture of the ESS assemblage. In a first step, they lay open specific properties and path dependencies of the European case. These require special attention, as they partially differentiate the ESS

are long defunct but still circulate in orbit. Section 2.2 and Article 2 explain the phenomenon in more detail.

from some of its global counterparts and at the same time have a significant impact on the understanding of currently proposed transformations of spaceflight activities.

1.1. Outlining the European Space Sector

Generally, worldwide space sector activity has historically been closely tied to various aspects of international relations, particularly strategic interests and technoscientific cooperation. Since its earliest days of industrial-scale application in the German military rocket programs of the 1940s, spaceflight technologies have been the target of (violent) political ambitions and techno-utopist dreams of peacefully conquering the cosmos. In some cases, one reason has served to justify the other[6]. At the heart of this entanglement of motivation and imagination lies the "dual-use" capability of spaceflight technologies (Peoples 2011). The establishment of rockets and satellites as multi-purpose tools useful for civil and security, even military, purposes has shaped the space sector (Sheehan 2009, 182f). It has promoted a network of state funding and departmental science as well as brought up several influential industrial contractors (e.g. Airbus in Europe or Boeing in the US) that have since the 1950s largely monopolized spaceflight activities – often on the national level of industrialized spacefaring nations. Most prominently, the United States and the Soviet Union consistently used spaceflight technologies for strategic defense purposes and to showcase technological superiority in the Cold War's ideological competition (Migaud, Greer, and Bullock 2021, 4).

[6] A famous example being Wernher von Braun, who, after the war, explained his collaboration with the national socialist regime by pointing to his long-standing vision of peaceful human access to outer space (MacDonald 2015, 220).

Since its early days after the Second World War, the ESS added to this global context the conviction that European intergovernmental cooperation could be fostered through collaborative national spaceflight activities. This vision prominently influenced early European spaceflight efforts and aimed to copy the successful European Organization for Nuclear Research (CERN), which had emerged during the 1950s as a prototype of cooperative research. The distinctive way of approaching big science that developed at CERN was seen as a guide to reconsolidate European political, scientific, and industrial capabilities and strategically position efforts in the rising Cold War confrontation (Krige 2006). In fact, some of the foundations of what would later become public institutions of the ESS, including the European Space Agency's (ESA) organizational predecessors, were laid explicitly with CERN in mind (Krige 2013, 34).

Historically, it has been ESA, founded in 1975 as an independent, international organization, that has governed large parts of European space policy and technology in the second half of the 20th century on behalf of its member countries' governments. Importantly, these activities have taken place outside the institutional boundaries of the European Communities (EC) and later the European Union (EU), with their explicitly transnational political agenda. At the beginning of 2021, ESA had 22 member states, not all of which were members of the EU or vice versa.

Despite ESA's unique status, the EU has significantly extended its involvement in spaceflight activities and thus become an integral part of the ESS since the Lisbon treaty in 2007 (Ryan 2016, 39). This has happened through EU-funded spaceflight activities like the European satellite navigation system "Galileo" and the Earth observation network "Copernicus" – both collaborative projects shared between ESA and the EU. In 2019, the

EU decided to establish its own space agency, the European Union Agency for the Space Programme (EUSPA), which, renamed in 2021, stands alongside ESA and other, smaller organizations (Spude 2013, 105) in assuming responsibility for coordinating and conducting European spaceflight activities. As a new kind of space agency, it is envisioned to operate in accordance with overarching EU policy agendas. Because of this, it questions some traditional aspects of European space policy – like the sensitive handling of dual-use spaceflight technologies – in favor of EU efforts to address pressing societal challenges. In this context, spaceflight technologies are assumed to "play a crucial role in effectively tackling new challenges such as climate change, sustainable development, border control, maritime surveillance and security of Union citizens" and "benefit from synergies between civil and security activities." (European Commission 2018, 1). While attempting to address these kinds of societal challenges, new ones, including those exemplarily studied in this dissertation, directly face the ESS itself: the rise of a New Space paradigm and space debris as it pertains to beyond-planetary sustainability.

Though private and commercial initiative in outer space is on the rise, public institutions and their strategic interests still guide space sector activities (Barbaroux 2016, 13). In the ESS and elsewhere, they do so on different levels. Direct or indirect funding even of private spaceflight activities that can be placed under the label of New Space plays a decisive role. On the one hand, European political institutions remain the primary customers of commercially oriented spaceflight businesses (Barbaroux 2016, 21). For example, private space companies are increasingly tasked with providing governments, as paying clients, access to outer space by building rockets – so-called launchers – to

bring satellites into orbit. Such a setting fits the description of the public procurement of innovation (PPI) approach, where public actors not only support creating a market for certain innovation outcomes, acting as "catalysts," but are themselves major market players (Wesseling and Edquist 2018, 494f). In the ESS in particular, public funding also directly enables entrepreneurial New Space activities by providing startups with infrastructures like business incubators, angel investors, and venture capital opportunities (European Space Policy Institute 2020, 10). Overall, different funding schemes by ESA and the EU's framework programs make up the lion's share of ESS funding (Concini and Toth 2019, 10f), determining the direction of its activities. These and other aspects have led to an extraordinary scenario in which ESS activities are currently addressing new issues, like demands for New Space transformation and management of space debris. Yet, at the same time, the ESS finds itself newly challenged by an extended European context, which reaches beyond traditional space sector boundaries.

1.2. The Transatlantic Mirror: The US Space Sector

As already hinted at, the ESS is not directly equivalent to other space sectors around the world. To emphasize its particularities, it is helpful to characterize one of its historically closely connected counterparts, the US space sector.

Contrasting the influence transnational policy goals have on the governance of European spaceflight activities, recent US spaceflight activities continue to be shaped to a large extent by three forces: national strategic and domestic interests in outer space (Bormann 2009, 83), the aspiration to lead worldwide techno-economical competition (Darnis 2019, 3), and cooperation in outer space following the end of the Cold War (Doboš 2019, 99ff).

Before decisive efforts to reform the US space sector were introduced in recent years, it faced challenges due to the centralization of its space industry in the 1990s and newly assumed commitments to large-scale internationally cooperative projects like the International Space Station (ISS), operated together with the newly founded Russian space agency and other partners since 1998. With the emergence of new and influential players, such as China, and with unclear and underfunded long-term visions after the turn of the millennium (except to extend the now operational ISS), public space activities in the US and elsewhere came under pressure (Cornell 2011).

The reorientation of the US space sector thus came with the rise of the New Space paradigm and the privatization of large parts of formerly public research, development, and operation of spaceflight activities. From the early 2000s onwards, and amplified in the new US space strategy introduced during the Obama administration, extensive government contracting of core space sector tasks and responsibilities to private space industry players shaped a distinctly US-take on New Space privatization. For example, after the Space Shuttle program's slow demise, leading to a final launch in 2011, private companies became the sole providers of future US astronaut-bearing spacecraft (Migaud, Greer, and Bullock 2021, 2). With this approach, the role of governmental bodies shifted away from direct involvement in technological development and towards policymaking – that is, defining and guiding private spaceflight efforts (Darnis 2019).

Thus, regarding the rising importance of the policy dimension, US developments partially converge with recent European trajectories of governing space sector activities. However, as is elaborated in the following, the European setting remains unique in how it assembles different entities to shape societal futures through space governance.

2. Setting the Stage for the European Space Sector

Emerging from a historical setting of European political cooperation and continuing to exist in a unique technopolitical environment, the ESS inherits a "contingent ensemble of diverse practices and things" (Ong 2005, 338) – a heterogeneity (or multiplicity) of entities acting simultaneously yet according to different, non-simultaneous path dependencies (Deleuze and Guattari 1987 24f, 43f). As hinted at before, the heterogeneity of entities assembled within the ESS exists on the level of institutionalization, sectoral culture, and field-specific expertise. However, it is added to by non-simultaneities inherent to the European governance of technological innovation at large, as will be discussed in Section 4.2. This assemblage makes the ESS unique from space sectors in other parts of the world – e.g. the US space sector sketched out in the previous section.

To understand how spaceflight activities in Europe are partially challenged – the initial assumption of this dissertation – the following analysis focuses on two settings in which the societal context of such activities is currently most visibly and profoundly negotiated. Both of these settings emerge as representative "sore spots" in which spaceflight futures within contemporary technosocieties are "rehearsed" and in which the ESS encounters new demands for the public governance of spaceflight technologies.

The first of these two settings can be narrowed down to the space sector's innovation culture, which is being challenged by demands to privatize and commercialize. These demands, which herald the advent of a New Space Age, call for spaceflight innovation to be driven by market forces in order to provide societal benefits from space sector activities.

The second setting is the increasingly critical nature of space infrastructures, which raises the challenge of environmental sustainability in outer space. Its urgency derives from the fact that space debris, resulting from 70 years of spaceflight and added to by New Space launch activities, questions the viability of future human engagement in outer space.

Both settings are briefly presented here, while their in-depth analysis is conducted in the two journal articles that have been published as part of this cumulative dissertation (see Sections 3.1 and 3.2).

2.1. Setting 1: New Space Innovation

The first setting in which spaceflight activities are currently negotiated in the context of their societal importance, is that of space sector innovation cultures in the so-called New Space Age. As already mentioned, since the turn of the millennium, the New Space Age has been credited with the potential to significantly transform the ESS. In particular, it is expected to change how agencies operate missions, how industry manufactures satellites, and how space-based technologies accommodate new applications for private and public customers.

Instead of relying on expensive and slow-moving governmental space programs, New Space protagonists envision sociotechnical futures that rely on large-scale private and commercial business approaches to conduct spaceflight activities. These ideas, which have been propagated over the past few years, build partly on enticing opportunities like colonizing Mars, extracting outer space resources from asteroids, or making space travel affordable for everyone (Valentine 2012; Tutton 2018). However, they also strongly focus on opening outer space to innovation, entrepreneurial activity, and capitalist

ventures (Tutton 2021). Here, narratives of ambitious, adventurous, and efficient private spaceflight activities challenge those of traditional, publicly funded space missions. Where the latter limit themselves to a niche role in shaping societal futures – e.g. by promoting only specific, politically sanctioned goals like basic research or the provision of satellite infrastructures for data transfer or global navigation – New Space discourses promise a revolutionary approach with the potential to transform societies.

This perspective on what spaceflight activities are supposed to accomplish and how they are to be undertaken is elaborated in detail in Article 1[7]. There, the author analyzes in what way innovation constitutes a core issue within space sector professionals' discursive practices and how the field stages the innovation of spaceflight technologies as societally impactful. This is achieved by observing what role New Space visions play in space sector innovation culture and how they are negotiated – adopted, refuted, or modified – within that field's community. To that end, the author proposes that New Space innovation narratives are shaped and motivated by a fundamental assumption: that market logics need to be established within the space sector to ensure its capability to innovate. This assumption, per the article's observation, introduces the negotiation of new values and modes of innovation within the ESS's innovation culture – primarily via the role identity pattern of the spaceflight engineer that emerges as being crucial to field professionals. One of the article's findings is that market logics of innovation go hand in hand with demands for new approaches to spaceflight innovation, e.g. the use of mass-produced, small satellites instead of exhaustively expensive, highly reliable, failsafe satellites

[7] Article 1 refers to the journal article entitled "Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation" that is presented in Section 3.1. and will be abbreviated as such within the framing sections of this dissertation.

developed following traditional space sector engineering paradigms. This is also true for the rising demands of New Space innovation logics that spaceflight engineering orients itself towards more agile, economic thinking instead of upholding technological excellence in a philosophy of "rocket science" engineering established in the 20th century Space Age.

Article 1 explains that, while these claims derived from New Space logics of market-oriented innovation are successfully adopted within the ESS, they do not replace established notions of innovation engrained in sector culture. Instead, they constitute an additional innovation logic on which field professionals regularly draw upon but do not perceive as replacing the field's traditional engineering culture. The analysis of Article 1 shows, that ESS professionals expertly *switch* between upholding the market logic of New Space innovation and established narratives of rocket science-style spaceflight innovation – depending on particular discursive requirements they encounter (Clormann 2021, 8).

At its core, the approach taken by Article 1 aims to distill what initial shifts in understanding innovation within the space sector might mean for societal relations to outer space. In this, the article perceives the ESS as an assemblage currently (re-)negotiating its culture of innovation under simultaneous yet conflicting assumptions: on the one hand, in the self-perception of field professionals, the sector lags behind other technology sectors in adopting market logic schemes of leaner, more agile, and more entrepreneurial innovation (Johannsson et al. 2015). On the other hand, space sector activities continue to be seen as a benchmark of technological leadership through

innovation (Gisler and Sornette 2009) – borrowing plausibility from the considerable reputation of the past century's Space Age.

As techno-economic reasoning is adopted and disruptive technological innovation heralded as a means to conquer or create new markets for spaceflight activities, space sector professionals seek to highlight their efforts as valuable products or services to society. However, the article finds that they often withdraw from this aspiration of societal benefit to promote performing rocket science for its own sake – that is, to secure outer space *for* space sector applications *by* space sector means of innovation that are not driven by market demands. Article 1 concludes that this switching between fundamental innovation logics in the space sector results from field professionals negotiating demands for "better" innovation, which they encounter in European innovation policies. It also highlights the potential for societal responsiveness of spaceflight innovation inherent to EU innovation paradigms. As such, it identifies entry for non-traditional space sector actors to engage in spaceflight activities, as the space sector now seeks the support of larger societal groups than before – most immediately but not only that of stakeholders involved in emerging spaceflight markets.

2.2. Setting 2: Space Debris Sustainability Beyond Earth

The second setting in which changing societal relations of European spaceflight activities are currently negotiated is that of space debris, which has been identified only recently as being a pressingly relevant challenge. Since the turn of the millennium, roughly simultaneously with the emergence of the New Space paradigm, space debris has not only impacted space sector discourse but also appears to be on the verge of raising considerable

and persistent concern for ESS activities beyond the confines of the sector itself, for example by achieving mass media coverage (Skidmore 2021). This is because space debris presents a dual threat by being continuously at risk of either descending to the planet's surface – thereby causing damages or casualties on the ground[8] – or of hitting and thereby disabling or destroying spacecraft currently operating in Earth's orbit. Both risks are steadily becoming more severe, as the materiality of space debris in orbit is expected to grow exponentially due to ever-increasing New Space launch activities and an ongoing lack of effective strategies to remove existing space debris fragments from densely populated near-Earth orbits.

For ESS professionals, this phenomenon has come with the striking realization that spaceflight activities have direct and potentially momentous impacts on societies today, as space debris poses a major and growing threat to vital public satellite infrastructures like navigation or Earth observation satellite networks. Should such infrastructures in outer space be destroyed by colliding with space debris, provisions vital to the functioning of technologized societies today will fail: air traffic, logistics, global data streams, and even disaster warning or climate monitoring. As the lives and the well-being of many are at stake if these infrastructures should give out, space debris is a global risk phenomenon – and perceived as such within the ESS. There, it raises questions as to the role of the

[8] The first prominently recorded incident of this type featured a US-citizen getting hit by a falling fragment of space debris – a part of a US-launched rocket's fuel tank – in 1997 (Aerospace Corporation 2018; Long, January 22, 2009). It should however be noted that space debris impacts are more likely to happen in equatorial regions. The post-colonial implications of this circumstance are briefly discussed in Section 2.4.

sector as a responsible technopolitical “intermediary” between societal needs and space endeavors.

The implications of this status quo are discussed throughout Article 2[9]. It identifies that the sector professional’s handling of space debris as a sustainability challenge presents an intriguing case, as it transcends commonly applied scales of planetary environments. Due to its extraterrestrial nature, space debris demands discursive practices within the field to consider a new type of extended, "orbital-planetary" environment. Article 2 elaborates on this environment being defined by risks emanating from space debris and reaching beyond the Earth's surface and even its atmosphere to incorporate orbits inhabited by satellites. Space debris, in this context, is acting as a boundary infrastructure to connect these planetary and orbital realms. While it is also subject to risk minimization efforts and even some attempts of infrastructural maintenance, attributes typically associated with Earthly infrastructures, space debris significantly differs from them in a particular respect: unlike such infrastructures, which are typically explored by STS, the decay and breakdown of satellites, *resulting* in space debris, is also the very *cause* of said infrastructural failure: as satellites go defunct or are destroyed by space debris impact, they themselves turn into threatening debris (Clormann and Klimburg-Witjes 2021, 20).

In Article 2, the authors thus focus on space debris' infrastructural and material properties to establish a conceptual grasp of space sustainability as a rising concern among ESS professionals. They therefore trace these professionals' discursive practices in negotiating

[9] Article 2 refers to the journal article entitled “Troubled Orbits and Earthly Concerns: Space Debris as a Boundary Infrastructure” that is presented in Section 3.2 and will be abbreviated as such within the framing sections of this dissertation.

the role of space debris as a beyond-planetary issue in the above-mentioned sense. Within the context of this dissertation, this approach attempts to systematically account for space debris as a transformative challenge for ESS practices of imagining, developing, and operating spaceflight technologies in near-Earth space. By tracing how orbital spaces affected by space debris are being promoted as environments within ESS narratives, future reference scales for political epistemologies of sustainability beyond Earth are explored.

While it yet remains unclear how the wider technopolitics of outer space might transform once issues like space debris become matters of concern for larger groups of stakeholders outside the space sector, e.g. when orbital spaces are publicly perceived as valuable environments, such a scenario casts its shadows ahead. Thus, Article 2 also observes how field professionals, such as satellite operators or space policymakers, feel increasingly incentivized to establish sustainability beyond Earth and, in the same vein, to engage in renegotiating their role as societally responsive agents. It highlights that ESS professionals, due to their privileged positions, play a crucial role in establishing space debris as materiality that might change societies' ways of relating to outer space. One of the article's conclusions is that they do so motivated by their vested interest in continuing spaceflight activities, which can only be sustained if accumulating space debris is framed as a societal challenge and thus tackled with help from outside the space sector. As will be discussed in more detail below, this setting produces significant ambivalence, as it entails momenta for both – opening up spaceflight activities to new stakeholders and protecting ESS hegemony over issues concerning outer space.

2.3. ‘Space Research’ as Space Sector Research

At first glance, New Space innovation and space debris sustainability might seem to represent two distinctly unrelated research cases. However, the analyses of Articles 1 and 2, summarized and contextualized in the above descriptions of Settings 1 and 2, show them to both provide insight into the challenged nature of current ESS activities. This cohesiveness is introduced through a common denominator shared by the conceptual perspective on both phenomena and the interest that motivates it: exploring New Space market logic innovation as a challenge to space sector culture and space debris as a catalyst for promoting beyond-planetary sustainability merits rethinking the meaning of outer space accessibility and the technologies that enable controlling, exploring, making use of, or discursively interpreting it. In both of the explored case studies, the space sector, an assemblage of highly specialized institutions, expertise, cultures, and politics, emerges as a critical passage point for societal engagement with outer space ranging from the level of envisioning spacefaring futures to that of actively shaping them.

As is shown in both articles, this space sector, while fundamentally challenged in certain areas, has to a considerable degree retained its discursive authority over spaceflight activities in the New Space Age. However, as both settings also demonstrate by focusing on the prototypical examples of innovation culture and space environmental sustainability, parts of the space sector's assemblage are today increasingly being questioned from within and without. For example, and as already mentioned in the introductory sections, the ESS faces political demands to provide tangible socioeconomic benefits (OECD 2014, 10) and accountability in line with environmental protection goals in outer space (European Commission 2017, 49).

Interestingly, both market logic thinking (Godin 2012) and sustainability (Vogt and Weber 2019) are highly ubiquitous demands facing technological innovation in contemporary technosocieties. However, they are still relatively new requirements for spaceflight activities compared to other industries and technological fields today often identified as deeply embedded in collective imaginaries of sociotechnical futures. For this reason, both settings represent critical points from which to investigate the ESS's exposure to and coping with broader societal demands that have previously not been or needed to be considered.

This thesis intends to present and explore them as extraordinarily contingent issues in the context of which the ESS's legitimacy to speak for and enact current and future spaceflight activities is negotiated. As such, the research program presented here does not primarily follow recent changes in the technopolitics of outer space in the New Space Age but instead aims to *explore how the space sector is exploring itself*. It zooms in on the discursive practices of field professionals, emphasizing a much-needed transformation of spaceflight activities in the New Space Age to make it more innovative and sustainable. The author thus identifies the ESS as frequently being the self-observant enabler *and* target of such discursive practices. Because external demands from different policy levels are leveled at it to perform differently than before, the ESS is centrally important to the negotiation of transformative processes in the New Space Age. However, as this dissertation shows, it is the ESS that constantly presents *itself* as the central stage on which narratives on the transformation of spaceflight activities take hold and are processed and modified by sector professionals. This dimension of self-observance makes the approach presented here a new kind of endeavor in "space research" – one based on

the assumption that second-order observations of the space sector can best help understand societal relations to outer space activities. It traces the discursive practices of space sector professionals that perceive the need to re-order the assemblage they themselves are a part of and re-explain to societal stakeholders what they are doing – providing societal benefits – how they are doing it – by innovating – and where they are doing it – in a sustainable space environment that is not detached from planetary concerns.

In this sense, space sector research as performed within this dissertation distinguishes itself in two ways: 1. from the hegemonial form of knowledge production that is space research in the technoscientific sense of astronomy, planetary science, and spaceflight engineering, and 2. from previous social science engagement with outer space in political science, anthropology, history of technology, and even STS, which have paid little attention to the constitutive character of the ESS in spaceflight activities or have accounted for it only as an explanandum – a set of clearly demarcatable institutions subject to changing technopolitical conditions in the New Space Age.

The latter approach is still justified, as in some respects, the space sector's contributions to the needs of 21st-century technosocieties are unchanged, e.g. to provide sensitive security infrastructures or enable climate research via Earth observation satellites. However, other phenomena like New Space entrepreneurial exploitation or the threat of lasting cosmic pollution by space debris emerge as new challenges that require paying greater attention to how the ESS fits into an updated understanding of space activities as a central puzzle piece. After all, both traditional and newly emerging responsibilities of spaceflight activities are negotiated primarily within the sector through, among other foci, space sector innovation cultures and beyond-planetary sustainability. Within these two

settings, the inertia of 20th-century Space Age conduct meets that of a perceived need for change to meet newly arising challenges. This dissertation aims to show that field professionals are not only experiencing the ambivalent co-existence of upheaval and continuity but are actively aware of it – co-shaping it in their discursive practices. New Space innovation culture and space debris sustainability are thus settings where 1. a clash of old and new spaceflight narratives and practices is currently taking place and 2. the challenges and consequences of this clash are also realized, accepted, and acted upon by members of the ESS.

2.4. Material and Methods

Conducting space sector research as a research agenda in the sense mentioned above heavily relies on data gathered *on* the ESS *within* its boundaries. This is true especially for the primary data on which this dissertation predominantly rests and the analysis is performed in both of the contributing articles. To trace the ESS's handling of perceived transformative demands in the New Space Age and its co-authorship in the narratives that emanate such demands, the analysis performed in Article 1 and Article 2 relies mainly on expert interviews of ESS professionals conducted between 2017 and 2020. These were designed and performed as semi-structured interviews to account for a diverse set of professional and institutional backgrounds, including individuals working for space agencies, larger industrial players, startups, universities, insurance companies, consultancies, activist initiatives, and other ESS institutions. For this reason, a scheme of questions was set up to, on the one hand, relate interviews to relevant research questions, while on the other hand, give enough leeway to account for potential unexpected yet illustrative emphases and deviations in the narratives of interlocutors. To draw a

conclusive picture of these narratives in the two settings explored here, a total of twenty-five interviews[10] were conducted featuring experts from the above-mentioned types of space sector institutions in six European states.

This dissertation also draws from several loosely structured explorative interviews conducted mostly during the early stages of the research project in 2017. These often took place on short notice during field stays at conferences and sometimes crossed over to informal conversations between the author and the respective field professionals. Nevertheless, these initial interviews proved to be essential in that they allowed the author to forge contacts within the ESS, which had been somewhat inaccessible in the beginning. Some of the early contacts gained during this explorative phase culminated in long-term working relationships between the author and ESS professionals. One of them ultimately led to a three-week ethnographic stay at a European space agency in the spring of 2020. This stay in the field enabled the author to successfully approach several interviewees inside and outside the agency, validate the representativeness of data generated thus far, and enrich the interpretation of field narratives previously and subsequently identified through conducted interviews. With similar intentions, extensive document analysis of policy and regulatory documents, media outreach, and science and engineering publications coming out of the ESS was undertaken by the author to bolster the empirical grounds of both articles included in this dissertation. This data was particularly helpful, as publicly available space sector documents reemphasized and tied together some of the

[10] The diverse composition of interviewees is addressed in more detail in the methods section of Article 1. This includes a table summarizing the institutional background, work experience within the European space sector, gender, and the national location of employing institutions for the set of interviewees. Additionally, professional and disciplinary backgrounds of interlocutors are presented throughout the analytical sections of Article 1 and Article 2.

threads of self-reflection in current ESS discourse which also consistently emerged in the interviews.

2.4.1. Challenges in Generating Data

Together, the semi-structured interviews, the ethnographic field stay, and the document analysis enabled a programmatic approach to "space sector research" that would not have been possible without this mixed-methods approach. One reason for this was the fact that, as mentioned before, the ESS presented itself as a highly exclusive technopolitical field, resulting in difficulties regarding field access[11]. Indeed, many relevant institutions and potential experts contacted with interview requests were either unresponsive to phone or email or provided no meaningful, publicly available contact details. The latter aspect presented itself through a lack of suitable channels for communicating with ESS institutions and their employees. Individual email addresses are kept strictly non-public, institutional hierarchies and other organizational structures are not openly disclosed, and public relations departments and administrative contact points act as uncooperative gatekeepers to potential interlocutors.

This status can be partially attributed to the institutional and technopolitical heritage of secrecy and institutional autarchy of the ESS, as outlined above. However, it should also be seen as part of the very phenomenon observed in this dissertation: the ubiquitous non-simultaneities, uncertainties, and ambivalences of transformation towards the New Space Age that are perceived by field professionals to reconfigure the assemblage of the ESS. As shown in Article 1, this transformation is continuously (de-)constructed by ESS

[11] The methodological section of the enclosed articles elaborates further on this point.

professionals in a delicate and ongoing effort to re-negotiate sectoral culture and associated professional role identities within the ESS. These professionals, represented by interviewees, are neither inclined to abandon ESS traditions nor miss out on the opportunities of becoming proponents and drivers of New Space imaginaries. They represent a field that appears to carefully regulate external access to a "culture under construction" – currently encountering self-inflicted challenges like space debris (see Article 2) – a culture that is uncertain of its current and future place in society. It is this tentative status that drives the programmatic focus of "space sector research" that this dissertation proposes.

2.4.2. 'Collateral Realities' and the Role of the Researcher

The author encountered this program as a methodological challenge partly due to his role as a social scientist and STS scholar. Some field actors seemingly associated this role with the inherent authority of *speaking for society*. Thus, speaking of innovation and sustainability in space sector contexts frequently resulted in interviewees justifying what they perceived as the ESS's (in-)action towards societal demands and needs. In some instances, the author was directly addressed or questioned in the capacity of a social scientist thought to represent the needs of society. For example, asking one interviewee, a space agency representative, about whether space debris threatening critical satellite navigation infrastructure might be described as a *grand challenge*, she rebutted by stating that "today the life of [a] person is not affected by the fact that he has a GPS or not. But it's becoming more and more ... and that's the part that *you* study: 'what is the impact of space in our society?'" Similar but less pronounced statements arose throughout the set of

interviews to responsibilize the author based on his suspected knowledge or representation of societal concerns.

Meanwhile, other interviewees appeared to do their best to *not* mention any societal implications or even avoid directly addressing the author as a social scientist in this context. The majority of those that did, implicitly yet frequently indicated worries about new political and societal expectations towards the space sector, which they perceived as part of the currently ongoing transformation of their field. Sometimes, these comments appeared to test the author's reaction to uncertainties and insecurities in narrating the societal implications of new challenges like space debris beyond the purely technical domain.

These effects, caused by the author being a social scientist, demand reflecting on what Law calls "collateral realities" (2017, 40) produced while doing STS research. More generally, it permits reflection on the fact that especially the most mundane pre-assumptions and a taking-for-granted of seemingly obvious given realities impact the critical potential of methods employed in the interest of STS (Law 2017, 40). This entails the realization that performing interviews for this dissertation was likely to some degree co-productive of the negotiations observed to occur regarding the conduct of spaceflight activities and their shifting societal stakes. This means understanding the interviews not only as a “communication process in which the two partners jointly construct the meanings of both, questions and answers” (Laudel and Gläser 2007, 98) but as a process of engaging with and in the narration of transformative change in the ESS.

For example, "collateral realities" are created through the choice of focusing empirically on the ESS as the central stage on which future spaceflight realities are negotiated. Other foci and thus the co-production of other realities would have been possible by featuring different regional, political, or institutional assemblages that currently engage in spaceflight activity. These could have included, for example, southern hemisphere space sectors or civil society actors politically shaping outer space futures without engaging in technoscientific endeavors at all. Such approaches might have proven equally insightful in exploring contemporary relationships between spaceflight and society and provided a counterpoint to focusing on the space sector seemingly inheriting a 70-year monopoly on the technoscience of outer space. However, and this becomes clear in the articles in enclosed Section 3, the space sector as a heterogeneous assemblage still retains much of its authority in shaping the realities of change in spaceflight activities and thus justifies its role as a primary focus of concern. Nonetheless, the research presented here, to some extent, reproduces the authority of the space sector over human interests in outer space by making it its field of inquiry – a fact the author is conscious of.

2.4.3. Caring for Outer Space

In addition to the reasons mentioned in the previous section, the ESS as a focus also resulted from the author's long-standing involvement with the sector's institutional framework. This involvement came through family ties, recurring professional activities in the European space industry as a student, and the author's occupation as a freelance journalist covering space sector activities. As such, both the empirical focus on the ESS and the inclination to trace its practices through its professionals' narratives coincides with a desire to, following Donna Haraway, "critically analyze, or 'deconstruct,' only that

which I love and only that in which I am deeply implicated" (Haraway 2018, 151). As Haraway points out, this possibility arises within the methodological logic of STS, as it questions the assumption of unattached or "neutral" scientific observation often taken for granted even in reflexive social science research. It offers the realization that precisely the situated research subject, realizing his or her entanglement in technoscientific assemblages, can adequately explore them (Haraway 2018, 150f). Instead of trying to disentangle him- or herself from the research field, its actors, and the specific cases explored, the researcher must reflect upon this relationship and acknowledge it.

Realizing, questioning, and where necessary, severing ties with the ESS and reflecting upon existing sympathies was both a challenge and an opportunity working on this dissertation project. It required and enabled critically reexamining imaginaries shared by the author and the field, the validity of previously taken-for-granted techno-solutionist approaches encountered within the ESS, and the author's intimacy with the technologies around which they revolve. On the other hand, inherent interest in and familiarity with space sector sets of knowledge, practices, and technologies made it possible for the author to navigate and highlight complex configurations like that of the ESS innovation culture described in Article 1. Indeed, it led to the core assumption of this dissertation: that the field of the ESS is perceiving and narrating its own transformation and that this profoundly impacts the potential for societal engagement with outer space in the New Space Age. The author's previous space sector experience helped to position himself as an observer of these already reflexive field narratives, to identify discursive elements establishing the advent of New Space, and to explore their intermingling with previous space sector discourse rooted in the 20th century Space Age.

Given this involved connection with the ESS, the research presented here exercises not only a second-order inquiry into the sector in order to trace its constitutive role in shaping its own future in society. It is also a unique exercise in re-exploring the individual's relation to the field as an engaged researcher – in this case the author, a former member of the field, caring for the ESS assemblage and for outer space as an inherently social and tangible environment (Dunnett et al. 2019, 322f). This approach is similar to what Maria Puig de la Bellacasa proposes as cosmopolitics of care (Bellacasa 2011, 90) – a methodology that does not exclude but rather actively requires the researcher to care for and keep a say in the material politics at stake (Bellacasa 2015, 704). The author follows this path by critically exploring both how outer space and human technomaterial intervention are narratively reconfigured under the influence of New Space ideologies as well as how ESS professionals negotiate specific, non-simultaneous regimes of innovation and sustainability in outer space by selectively promoting a more societally accessible space environment. In this scenario, the author himself is implicated as a social science researcher because he has engaged with the ESS and its various degrees of (in)accessibility as a field. These (in)accessibilities are not only institutional in nature but also extend to the epistemic, cultural, and techopolitical dimensions of the ESS assemblage that still predominantly mediates societal access to outer space concerns. Thus, the dissertation presented here can, in some respects, itself emerge as an experiment in the accessibilities of outer space and the ability and commitment to care for it – a challenge that also faces other stakeholders increasingly affected by the ESS's future handling of spaceflight activities.

3. The Articles

3.1. Article 1: Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation

Michael Clormann: "Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation"

Accepted for publication in: Science and Public Policy (Oxford Academic 2021) – Accepted Version

(Published under DOI: 10.1093/scipol/scab038)

Abstract

With the advent of the so-called *New Space Age*, promoted by private actors and driven by market logic innovation, the European space sector meets significant challenges over recent years. This paper explores the implications of New Space's emergence for contemporary societies that increasingly rely on space technologies as critical infrastructures. It does so by analyzing conflicting logics of innovation within the sector arising from a clash of *Old Space* and New Space cultures and associated role identities. To this end, it combines concepts of institutional culture and role identity from STS and organization studies. Tracing the identity work performed by members of the European space sector through qualitative interviews, it concludes that new demands of market logic innovation are negotiated within a mode of *switching* between different sector cultures. It concludes that this mode provides opportunities for the responsible future governance of critical space infrastructures.

Introduction

The Apollo moon program is remembered today as a period of intense innovation, referred to as 'one of the most challenging technological achievements of the 20th century' (Brown 2019). In the past few years and with increasing public displays of spectacular spaceflight success, new kinds of private space actors have begun receiving widespread acclaim as innovators or even visionaries of a so-called *New Space Age* (Tutton 2020). This trend is often referred to as an institutional, technological, and, most of all, economic transformation towards private spaceflight and the large-scale commercial exploitation of space technologies – striving for a more agile, entrepreneurial, and market-driven approach to spaceflight innovation (Valentine 2012; Vidmar 2019).

One example is Elon Musk, whose SpaceX company successfully launched the reusable *Falcon Heavy* rocket in 2018. Rather than relying on massive state funding and *big scienc*e approaches to technology development – as was characteristic for the (post-)Apollo era of the *Old Space Age* –, such entrepreneurs aim to build on private capital and innovative applications of existing technology.

Meanwhile, within contemporary western societies, spaceflight technologies not only co-produce global geopolitics, as they did in the Cold War, but are becoming an integral part of everyday lives, as they bring about critical infrastructures within or beyond the planetary environment (Gärdebo et al. 2017; Olson and Messeri 2015; Clormann and Klimburg-Witjes, manuscript in preparation). These are, for example, satellites, which enable a delicate system of international relations and security policies, the global exchange of information, goods and people, and other public provisions to flourish.

This dependence might further increase due to the advent of the New Space Age, as, since shortly after the millennium, intensified launch activities multiply the number of objects in outer space and the number of players involved. Consequently, privatized New Space emerges as an alternative or at least an addition to a hitherto state-driven space sector, considered an assemblage of professional organizations, technologies, practices, and identities. It raises questions about how spaceflight technologies might be developed and operated as critical infrastructures to future societies.

Learning more about changing conditions for space sector innovation appears urgently necessary to foster appropriate innovation to shape our infrastructural future living on and beyond planet Earth. More concretely, a better understanding of the space sector's current challenges as it encounters the proposed New Space Age appears necessary.

This paper analyzes how space sector culture is influenced by recent narratives of market logic innovation that co-emerge with the New Space paradigm of a privatized, commercial space sector. Focusing on the regionally and historically distinct case of the European space sector, the paper asks how its members negotiate sector culture through their 'identity work' (Lok 2010) influenced by demands for market logic innovation. Notions of markets and innovation in demands for New Space thereby regularly refer to each other and emerge together – conforming to Callon's observations on marketization narratives (Callon 2016: 27).

The analysis will show how they primarily rely on role identity patterns of the *spaceflight engineer* in negotiating European space sector culture. This focus acknowledges spaceflight engineering's key role in space sector culture, as it is considered a vital aspect

of successful space sector innovation. The paper proposes that European space sector culture is negotiated through values associated with engineering-centered role identities and modes of innovation staged as inherent to this culture by field professionals. It finds that these professionals, as part of their identity work, adopt the strategy of switching cultural logics to adhere to both an Old Space sector culture and the novel demands for market logic innovation akin to a New Space culture of innovation. The paper explores how this is done, as it is essential to understand the European space sector's current opening up towards market logic innovation and thus identify potential future responsible innovation goals. The paper concludes that responsibility primarily emerges in the dimension of *responsiveness* to global societal demands by value-based engineering, as outlined by Stilgoe et al. (2013: 1573).

The European space sector proves a relevant unit of analysis as it has inherited a public sector institutional culture centered mainly on the implementation of governmental space policies. As such, it now perceives itself as strongly challenged by New Space market logic innovation. Consolidating themselves from the 1960s through the 1970s into the newly founded European Space Agency (ESA), European spaceflight activities emerged as a project of European unification (Sheehan 2020: 107) and thus as an inherently political endeavor. For this reason, the European space sector, in contrast to, e.g. its considerably privatized US counterpart, even today remains strongly guided by its transnational nature and the institutional politics that shaped it – despite experiencing more systematic privatization efforts since the mid-1990s (Petroni and Santini 2012: 26). As it was formed to further European technopolitical agendas in outer space, it is often

perceived as a prototypical example of a space sector driven by Old Space traditions manifesting in a persistent sector culture.

This paper begins with an overview of the New Space phenomenon and its importance to the European space sector amplified by certain formations within space policy discourse. This overview is followed by a summary of relevant literature in STS and organization studies that addresses market logic innovation meeting existing cultures in technological sectors. It also contains a brief introduction to previous studies analyzing the advent of New Space innovation. Section three sketches out conceptual approaches to sector culture, highlights the significance of role identity patterns in negotiating them, and proposes ways of tracing identity work in the case at hand. Entering analytical ground, the paper explores how interviewees negotiate demands for market logic innovation as part of a New Space culture. The concluding section elaborates on the political implications of this strategy and focuses on the crucial role of identity patterns of the spaceflight engineer within European space sector culture and the opportunities for introducing responsibility into the field as a complementary cultural logic.

The Advent of New Space Age Market Logic Innovation

Over the first decades of the 20th century Space Age, Europe has seen a relatively stable oligopoly of spaceflight activity under the umbrella of public institutional funding and governance (Petroni and Santini 2012: 28). Interestingly, a recent turn towards New Space market logics is heralded by the very public institutions that have traditionally governed this Old Space age. The European Union and other European institutions (van den Hove et al. 2012) today highlight market logic space sector innovation as an integral

part of their innovation policies. The EU framework program Horizon 2020, for example, aims to provide a 'business- and innovation-friendly ecosystem' (European Commission 2018: 4) for European spaceflight activities. The proposition is, that such innovation 'will contribute to the achievement of the Europe 2020 objectives [by] boosting the […] market uptake' (Delponte et al. 2016: 11) of space technologies. In the eyes of these policy actors, the extensive private transformation of the European space sector is both necessary and inevitable to keep European spaceflight technologies globally competitive and make Europe a hub for spaceflight commerce 'in particular [for] small and medium-sized enterprises, startups and innovative businesses' (European Commission 2018: 1).

At its core, the European New Space sector today exhibits a two-digit number of these mostly small yet often well-established and independent companies with at least 1500 employees in Europe (Lionnet 2021: 2). Due to European policy institutions' leading role, these small space enterprises and startups forming a transnational New Space community are largely dependent on public funding (Concini and Toth 2019: 9). This is a stark contrast to other New Space contexts, especially in the US, which rely on few but high-profile New Space ventures like SpaceX.

The European Commission and the European Investment Bank consider New Space innovation to 'allow more innovative space products to flourish more rapidly and be readied to scale for commercial markets' (Concini and Toth 2019: 111). Like in this case, spaceflight technologies are addressed as an untapped resource of innovation that is crucial for shifting technopolitical agendas towards a concept of innovation driven by market forces. The narrative implies that such innovation needs developing as the mechanism that enables tackling regional or even global challenges. '[A] globally

competitive and innovative European space sector' (Reillon and Pawlak 2016: 2) is to constitute the setting in which such innovation will emerge.

These European takes on the New Space Age share a desire for meaningful societal impacts and encompass the goal of creating a market for those technologies that contribute critical infrastructure to global societies, e.g. commercially realized rocket launches or communications satellites. For example, the European New Space telecommunications company OneWeb strives to 'connect communities, businesses' but also 'governments in all the places which don't yet have high-speed broadband connectivity.' (OneWeb Ltd. 2020). Central to the paradigm of such New Space innovation, as framed by OneWeb and other players, is reducing the cost and size of spaceflight technologies like satellites compared to Old Space products. Larger numbers of smaller, cheaper, and readily replaceable satellites, to them, promise more agile innovation within a market of commercial satellite applications (Vidmar 2019).

As demonstrated above by public institutions like the European Union, the demand for a new way of performing spaceflight innovation is closely linked to New Space narratives foregrounding market conformity and economic viability. It is important to note that such a concept of innovation is relatively new to the European space sector and differs significantly from the Old Space tradition of perceiving innovation primarily as a technologically rather than economically focused high-tech endeavor (Paulino 2020: xvii). This culture, which has thrived for decades within the somewhat closed, state-funded institutions of the European space sector, inherits little inclination to engage in market logic thinking. It was not bound to develop explicitly commercially viable

technologies, nor did it necessarily care for the institutional affordances of large-scale privatization or competition (Trischler 2002).

Literature Review

This paper draws on literature from several strands of science and technology studies (STS), innovation studies, and organization studies to explore how European space sector culture is (re)negotiated by professionals facing market logic innovation demands.

Recent works in STS and innovation studies have focused on how discursive practices in technological research and development are driven by market-driven innovation logic on the meso-level of institutional environments. Studies by Callon (2016), Neyland et al. (2019), and Godin (2017) have proven particularly helpful in laying out an understanding of *market logic* that acknowledges the conceptual ambiguities and pitfalls associated with trying to present a comprehensive reading of what a market might be.

By exploring how such market-oriented rationales challenge institutional setups like that of the European space sector, this paper draws inspiration from neo-institutionalist work focusing on managerialism and the New Public Management (NPM) of science and technology. It pays particular attention to institutional logics – market logic innovation being of particular interest in this case – and how they shape and are shaped by the institutional, technological, or regional context they exist in (Lok 2010; Meyer et al. 2014; Pfotenhauer and Jasanoff 2017; Skelcher and Smith 2015).

Many studies of institutional logics have so far focused on the organizational level, e.g. to study university management (Sporn 1996), the institutional culture of museums

(Harrison 2005), or that of state agencies (Lægreid et al. 2011). In turn, Child et al. (2016) have argued that attention should be paid to alternative institutional configurations in which such logics can emerge. As shown below, this paves the way for an analysis of institutional setups like the European space sector, whose members experience sector culture rather than particular organizations as their primary reference point in narrating innovation.

Comparatively, little effort has been made to sketch out how institutional cultures encounter new innovation logics on the larger scales of strongly demarcated high-tech sectors. This is particularly true in settings like the (European) space sector, which are subject to considerable strategic governmental interest, funding and, in turn, secrecy in the conduct of sector innovation.

Fields like STS, innovation studies, and organization studies have so far paid scant overall attention to the implications of the New Space Age. Only few efforts have been made to grasp the reconfiguring practices, institutions, cultures, materialities, and narratives of space sector innovation that no longer seamlessly resemble those of the twentieth century (Old) Space age. Among these are enlightening studies of the onto-epistemologies of outer space (Gorman 2014; Messeri 2016; Vertesi 2014), the histories, technopolitics, and imaginaries of spaceflight technologies (Geppert 2018; Redfield 2002; Tutton 2020; Witjes and Olbrich 2017), as well as their problematic materialities beyond Earth (Damjanov 2017; Rand 2016).

STS scholars have rarely engaged in recent research on precisely the rise of market-driven New Space innovation within the space sector. Valentine's work on the imaginative

quality of New Space innovation (2012) and Vidmar's exploration of associated practices in the Scottish space sector (Vidmar 2019) being notable exceptions. Instead, economists, management, and policy researchers (Paulino 2020; Petroni and Santini 2012; Weinzierl 2018), together with the empirical field of the (European) space sector itself (Johannsson et al. 2015; Venet 2013), appear particularly interested in the issue. However, these latter efforts often lack qualitative considerations of space sector culture and related role identities that play an essential role in grasping New Space challenges to the European space sector.

In summary, these bodies of work have analyzed cultural logics and how they are constitutive to institutional assemblages on different levels. They have also inquired into the impact of new demands for innovation in the (European) space sector. This paper seeks to combine both perspectives to provide an up-to-date image of the European space sector being fundamentally challenged by the presence of multiple cultural logics. It develops an empirical perspective focusing on identity work throughout the European space sector to understand it as a sector in action that currently needs to re-evaluate its function as a critical infrastructure provider to societies.

Conceptualizing Sector Culture and Role Identity

To understand how the European space sector tackles increasing demands for market logic innovation, this paper focuses on sector culture and associated role identities. This perspective is based on the conviction that frequently '[c]ulture […] provides not the explanation but the entity that demands explanation' (Hecht 2009: 8) within the empirical study of scientific and technological fields. This insight is useful, as certain latencies and

contested grounds apparent in the way members of the European space sector engage demands for New Space market logic innovation are ultimately rooted in the domain of sector culture. Namely, they correspond to persistent beliefs about what European spaceflight activity is, what it should be, and how sector professionals should conduct it.

Exploring sector culture like this borrows mainly from the notion of organizational culture employed most frequently in organization studies. In such contexts, culture is understood as:

> [having] to do with the informal norms and values that inform the activities of an organization. Agencies are thus regarded as value-bearing institutions with their own identities and opinions about what is appropriate behaviour. The basic idea according to this perspective is that aspects of organizational culture affect whether and how innovative behaviour is regarded as appropriate. (Lægreid et al. 2011: 1328)

While not systematically focusing on the level of organizations, as authors in the field of organization studies often do, norms, values and identities emerge as important conceptual terms factors for tracing innovation as a part of sector culture. This approach helps to consider sector culture as corresponding with the identity harbored by those who – like many within the European space community – consider themselves members of such a sector, whatever their different professional backgrounds and specific tasks. Specifically, it accentuates the importance of role identity patterns, such as that of the Old Space and New Space engineer analyzed below as focal points of identity work by members of the empirical field. These figures of the spaceflight engineer play a key role

in space sector culture. Their technical skills (Paulino 2020: 121) are often assumed to shape space sector conduct and the field considers them to be the main drivers of innovation (Denis et al. 2017: 431). For this reason, space sector professionals relating to new and different kinds of identity patterns of the spaceflight engineer seem implicated in the process of re-negotiating space sector culture. Thus, identity patterns of the *Old Space* and *New Space engineer*, due to their vital role in the space sector's self-image, work as vehicles for narrating space sector culture independently of the professional background of narrators themselves – being engineers themselves or not.

This approach follows Watson (2008) to assume that the close relationship between cultures and identity work is not always straightforward, as the culture within a particular sector environment cannot be regarded as comprehensively shaping its members' identity work. Nor, however, is it anything more than the total of this identity work. To put sector culture and identity work into perspective, we can assume instead that certain narratives, enabled by a distinct sector culture, condense into semi-manifest role identity patterns. To varying degrees, these can influence the identity work of those inheriting and acting within such a culture (Watson 2008: 127f). In this case, as the analysis will show, the European space sector professionals interviewed primarily refer to both figures of the spaceflight engineer in negotiating sector culture through their identity work.

Where role identity 'is thought to form an important link between institutional logics and the behavior of individuals' (Lok 2010: 1305), established sector role identity patterns like those of the Old Space and New Space engineer can be seen as representing a robust sector culture that sponsors distinct narratives of European space sector innovation. As members of the European space sector *talk innovation*, how they understand it and how

they see it as changing space sector activity with the advent of the New Space Age, they engage in identity work. This is relevant to the research question, as Lok proposes that 'a focus on the identity work of the identity targets of institutional logics may explain why and how some logics are embraced, but others are contested, resisted, translated, and/or ceremonially accommodated.' (2010: 1308).

Thus, how market logic innovation is negotiated within the European space sector can be traced via the sector's members' identity work. They adapt to partly incompatible sector reference cultures and their respective logics: those traditionally found within the European space sector on the one hand and those adopting the market logic rationale of the New Space Age on the other. Thus, this study follows European space sector professionals' efforts to perform what, to them, appears plausible and coherent role identity in the face of demands to adopt a new logic of innovation while maintaining affiliations to that ingrained in Old Space culture (Lok 2010: 1330ff).

This makes their identity work an exercise in hybridization (Skelcher and Smith 2015), as they face demands from more than one institutional logic within the framework of their institutional culture. This circumstance is of great importance in this paper, as '[c]ontests between logics are played out at an organizational level through the politics of form and structure, and at an individual level in the politics of identity' (Skelcher and Smith 2015: 444). It suggests that grasping how individual members of the European space sector handle hybrid logics of innovation within their field may allow inferences of how sector culture plays out on a larger institutional level and points to the fact that identities in such institutional settings are inherently political agents.

The aspects on which identity work is focused may vary depending on the culture and the patterns of role identity it relates to (Meyer et al. 2014). This study looks at role identities challenged within the European space sector as primarily constituted by *values* and *modes of innovation* to which members of the empirical field relate in identifying themselves with spaceflight professionalism. As neither values nor modes of identity can be operationalized directly based on available interview data, this paper focuses on identity work performed by interviewed members of the European space sector. This approach presumes that following the identity narratives (Czarniawska 1997; Ibarra and Barbulescu 2010) interviewees create throughout the interviews lays open professional values and modes of innovation that define prevalent role identities and sector culture in the European space sector.

Material and Methods

This paper draws from twenty-five semi-structured qualitative interviews with individuals from different sets of personal and professional backgrounds working for different European space sector institutions. Interviewees are professionally involved in areas such as spaceflight research, technology development, policy and regulatory work, and entrepreneurial or company activity in Europe. All interviews took place between 2017 and 2020, about one-third of them remotely owing to Covid-19 related restrictions.

Interviewees were approached with the goal in mind to represent a broad range of personal and professional backgrounds and to account for their diversity in the analysis of narratives speaking to European space sector culture. This diversity becomes visible in table 1, which gives an overview of the distribution of affiliations among interviewees.

Additional information on the professional qualifications and institutional positions is provided in the context of quoted material throughout the empirical part of this paper.

Table 1. Contextual information on interviewee affiliations

Nationality of institution	Institutional background	Gender	Old Space professional
Germany: 17 Sweden: 3 Netherlands: 2 UK: 1 Italy: 1 France: 1	Space Agencies: 11 Startup: 6 Industry: 5 Consultant: 2 University: 1	M: 21 F: 4	Yes: 15 No: 10

Due to the author's academic location and the domestic location of many relevant European space sector institutions, professionals affiliated with such institutions based in Germany are strongly represented within the sample. The same is true for male interviewees, which make up for most interlocutors and attest to the still remarkably low portion of female European space professionals. Most importantly for the following analysis, the interview sample contains many interviews with long-term space sector professionals who have worked in the space sector before the New Space Age's suggested advent[12]. However, 40% of interviewees joined the European space sector and thus began their careers only since then. Remarkably, all interviewees across different institutional affiliations or personal backgrounds did engage in similar strategies of narrating European space sector innovation. This point is explored in the analysis below, which in

[12] For this classification the 2005 conclusion of the Ansari X-Prize – a large-scale competition to launch the first private suborbital human spaceflight – is adopted as a reference point for the beginning of the New Space Age.

total quotes eight out of twenty-five interviews to represent recurring narratives that can be found throughout the dataset.

The data collection experienced several setbacks due to the exclusive and sometimes secretive nature of the empirical field. Many institutions seemed anxious to shield themselves and their employees from what they perceived as unwanted outside interest. This obstacle was overcome by employing a snowball strategy of seeking help from recruited interviewees in establishing further contacts. Due to this approach, and while some interviewees were thus considered and contacted upon the recommendations of previously interviewed experts, attention was paid to maintaining diversity within the resulting sample of interviewees.

All interviews were fully transcribed and subjected to iterative category building. Through several stages of work on this data, categories pointing to European space sector culture, prevalent role identity patterns, and professionals' identity work were inductively established. These were then used for informing the paper's conceptual approach and subsequently consulted for thorough analysis. Wherever necessary, relevant passages were translated into English.

Tracing European Space Sector Culture Through Identity Work

This section shows how interviewees from the European space sector, within their identity work, negotiate demands for market logic innovation challenging the Old Space culture of innovation. For this purpose, I will pursue how interviewees relate to two figures of the spaceflight engineer as central role identity patterns that shape sector culture through

the implicit values and modes of innovation they associate with it (Lægreid et al. 2011). As acknowledged above, these values and modes of innovation can be traced indirectly through interviewees' conflicted identity work trying to negotiate their sector culture.

Throughout the interviews, remarkably, almost all interviewees frequently talked sector culture. From an outsider's perspective, it would have been entirely plausible for them not to care too much or even hesitate to comment on how they perceive changing space sector innovation logics. Nevertheless, they openly engaged in narrating past, current, and future states of their field. This often included casual juxtaposition of Old Space and New Space logics, whether prompted or not by the interviewer. L., a consultant in the European space sector, is a good example:

> In my opinion, New Space is – and this is kind of a demarcation from Old Space – New Space, first of all, means commercial orientation. Yes. Together with an entrepreneurial approach. So already everything is different [laughs]. If you want to do those two things, then you would have to do everything differently to the old players. And this is factually … these are the two determinants. But what then comes into play in my opinion: this forms organization, culture, and processes. (Interviewee L.)

The same is true for C., a mid-level space agency official, who sees the status quo of the Old Space sector as losing relevance and being involved in a catch-up process to be as modern as New Space when it comes to marketability: 'I mean and that's of course a risk, that Old Space, which is kind of institutionalized, wants to modernize, be relevant, and

do New Space stuff … that they actually do the New Space stuff in places where it could actually be a real market.' (Interviewee C.)

Both interviewees reflect on innovation activity in their sector by narrating a dichotomy of New Space and Old Space. While L. envisions radical change that might merge the two approaches, C. questions the desirability of this outcome, however likely. To her, Old Space innovation, harbored by public institutions, would not succeed in and therefore should not adopt New Space market logic innovation. To L., C., and other interviewees, Old Space and New Space emerge as relevant categories to describe a process of cultural challenge. Induced by demands for market logic innovation that space policy discourse promotes, they use these categories to situate themselves in their roles as space sector professionals. Such staging of traditional space sector innovation culture as contrasting New Space market logic innovation is thus a central element of their role identity work. It can be observed particularly well in the practices of interviewees narrating values and modes of innovation which are, in their perspective, appropriate for Old Space or New Space sector innovation.

Valuing the Spaceflight Engineer

Zooming in on this identity work performed by interviewees, I focus on the dual role identity patterns of the spaceflight engineer, as these regularly referenced by interviewees as vehicles to narrate Old and New Space cultures of innovation. I do so with reference to their significance for space sector culture as repeatedly ascribed by different interviewees. This is exemplified by W., engineer and owner of a small space company. When asked about cultural sensitivity to sustainability developing within the European

space sector, he immediately identified spaceflight engineers as the protagonists of space sector culture:

> Concerning space debris and reentry, we have not come quite as far yet in the space sector. Maybe in five years or so. Then it might … yes, then sustainability might be taken up. These are just simply generational changes. Then, the current veteran engineers […] are retiring. My generation … we have been introduced to space debris already in university. I think we probably might have been the first. We still were only a few. But all these other young engineers who are now around in those [space sector] companies … they were taught this in university. (Interviewee W.)

In this case, identity patterns of the spaceflight engineer, when it comes to space sector responsibility for outer space sustainability, are persistently ascribed importance. They are not entirely replaced by market-related role identity patterns, such as the successful business owner or a business-driven entrepreneur. Instead, interviewees like C. continue to perceive the spaceflight engineer, both as an Old Space *rocket scientist* or a New Space *entrepreneurial engineer*, as a vehicle to narrate sector cultures and situate demands for market logic innovation within it. They do so independently of the nature of their self-identification with what they perceive as Old Space or New Space innovation paradigms.

This narration attributes values to the role identity patterns of the spaceflight engineer addressing how they should contribute to particular activities of the European space sector. Notions of the spaceflight engineer highlighted by interviewees like W., regularly

reference value-driven space sector professionalism based on ethical engineering conduct – 'as what is considered to be good and valued' (Jimenez and Roberts 2019: 186). W. illustrates this in bringing up space debris[13] as a sustainability challenge demanding responsible space sector action and identifies particularly young engineers as those to tackle it.

Like other interviewees, C., the mid-level space agency official, uses the spaceflight engineer's identity patterns to narratively juxtapose Old Space and New Space logics of innovation. Asked to describe her perception of changing demands for innovation in the European space sector, C. states that

> one of the […] obstacles at least for the European space sector is that it's kind of a lot of focus on invention and great inventions […] of brilliant engineers and so on but it's a little bit less focused on this innovation part, really taking things to market, or really letting the market say what the demand is.' (Interviewee C.)

Here, she refers to the extraordinary inventiveness she perceives as a key feature of traditional European space sector culture. This quality, she mentions, rests in the brilliant engineer performing great inventions. Instead of paying attention primarily to engineering work's marketability, the Old Space engineer described here primarily values technological excellence – and is therefore revered by C. and other similarly minded interviewees. This has policy implications for implementing values like sustainability into

[13] Space debris consists of defunct rockets, satellites and other residues, which continuously accumulate in Earth's orbits as remains of past and present spaceflight activities and give rise to questions of sustainability and security of outer space environments.

European spaceflight, as they mirror some of the value bases of the rocket scientist in devising the best-possible technology.

At another point of the interview, C. disassociates herself from this Old Space understanding of spaceflight innovation. Seeing the Old Space engineer as mostly synonymous with traditional space sector professionalism, she clarifies that the aim of excellent technological invention, perceived as a core value of the spaceflight engineer, can and should be regarded as outdated. She adopts a critique of Old Space innovation, which, in her view, seeks to invent for the sake of invention rather than to innovate. Real innovation, she insinuates following Schumpeter's popular market-logic concept of innovation, would follow the assumption that '[i]nnovation, at its core, is change that can be measured because it generates profits.' (Vinsel and Russell 2020: 10):

> I think that they regarded themselves as innovative even if they really to some extent didn't have that market. You couldn't fulfill the full innovation. If you say that you should turn knowledge into something that creates money, then it's not necessarily that they were really innovative. But they were inventing really great stuff. They were doing things on the edge of what was really possible, and what people were capable of. […] So, it wasn't really about markets and about creating money in that sense. (Interviewee C.)

The Old Space rocket scientist engineer, as envisaged here, recurs in several interviews as representing a space sector culture that ultimately fails to innovate. With these narratives, she and other field professionals point to a technological innovation focus being fundamentally unsuitable for competing within the rulesets of current, market-

driven logics of innovation that they feel the European space sector increasingly has to address. C. goes on to highlight the severity and difficulty of the changes needed to meet these market demands: '[I] t's a difficult shift to go from this conservative craftsmanship excellent engineering, towards this "well we send them up, and if they work, they work, and then we make some changes and we send up more". So, it's really this agile, ever-changing thing I think that's difficult to get into.' (Interviewee C.).

Here, she hints beyond the problems that accompany cultural change within the European space sector, to a fundamental conflict of values that emerge with it. She insinuates that where rocket scientists in the traditional sense care for reliable technologies that last, their New Space counterparts consider them replaceable. This value-based thinking, again, has considerable implications on the policy level. As for European space sector professionals, the spaceflight engineer's responsibility appears as a question of valuing sustainable versus profitable technology development.

The central importance of engineering role identity and its values is emphasized by C., stressing that the advent of a New Space logic goes beyond transforming engineering practice but impacts spaceflight engineers' attitude towards space sector innovation: how to establish an agile and entrepreneurial culture instead of chasing technological excellence. C., like other interviewees in the sample, hints, though, that this goal contradicts long-held space sector values.

L., the consultant, emphasizes these points even more bluntly. He describes current and future space sector success depending on the ability to innovate in an emerging market-driven sector culture.

> There is quite some reservation of the Old Space community – at least some of them – towards the New Space community. […] In part rightfully so. But to be smart and to be very good at what you do just doesn't cut it anymore because the system doesn't automatically yield money anymore. Now, you have to be clever, too. And many in the Old Space community are not that clever in an entrepreneurial or innovation kind of way. (Interviewee L.)

He characterizes the space sector professional in such a setting as having to approach innovation quite differently to his Old Space counterpart, who innovated under the comforting conditions of long-term state funding. In J's narrative, aiming for entrepreneurial *cleverness* instead of expertly *smartness* is inevitable in space sector innovation today. This new culture of innovation values market expertise before the proverbial rocket science expertise; the latter, however, is not lost out of sight.

While interviewees like L. and C. emphasize the inevitability of market demands steering technological developments and European spaceflight activity today, they never engage in deconstructing the values of technological excellence associated with Old Space sector culture. Despite to some extent echoing demands for a European space sector guided by the logic of marketable innovation, they inscribe themselves into a story of successful sector transformation to entrepreneurial innovation. Testifying the intricacy of their identity work, L. and other interviewees continue to highlight the excellence of spaceflight technology as a benchmark of successful innovation. While, in their view, market success is no longer guaranteed by the technical quality of the spaceflight engineer's achievements, the latter is still continuously referenced as an innovative figure. In contrast, they seem to accept market success as a new core value of innovative culture

in the space sector today and stage the New Space' entrepreneurial engineer' as an alternative role identity pattern to that of the Old Space rocket scientist.

Sector Modes of Innovation

Implicating *modes of innovating*, interviewees again make great efforts to establish a clear distinction between what they consider Old Space processes and outcomes of innovation and those driven by the market logic of New Space. In narrating this distinction, they construct outer space as an extraordinarily challenging innovation *environment* that again relates to both associated figures of the spaceflight engineer as innovation protagonists:

> Let me say that the space sector is quite a conservative sector in comparison. […] It's hard to get into orbit. And so … if you have a good design, let's say, of a rocket to go, you are not in a position to change it if there is no specific need to change. Because to attain the conventional level of availability and reliability and safety of that rocket, it took decades of studies and research and tests and failures and whatever. (Interviewee B.)

B., a senior space agency representative, emphasizes this. As equipment located in outer space does not permit upgrading, maintenance, or any margins of error in design and construction, it requires the particular approach to innovation pursued in *conservative*, Old Space sector culture. His fellow interviewee, E., a young, recently employed innovation officer at a space agency, shared this notion. To him, 'it's natural to be conservative when faced with the challenge of the fact that we are playing with toys [satellites] that are already up there [in Earth orbit]. We can change hardly anything about

them if we can at all. It's not like a 100 percent change – it's five percent of the lines of code.' (Interviewee E.)

To B., successfully innovating under such circumstances means the excellent design of spaceflight technologies by Old Space-type spaceflight engineers that 'deal with a lot of standardization models and techniques and standards to be compliant with.' (Interviewee B.) He considers approach inherent to European space sector culture to achieve optimal technical solutions and flawless functioning of technologies, which is necessary to prevail in the hostile innovation environment of outer space: '[Y]ou have to deal with these kinds of standards. You cannot avoid them. Otherwise, your program could fail.' (Interviewee B.)

However, at some point, such conservative innovation culture appears to also strike interviewees as problematic. Some of them address the lengthy development cycles prevalent in publicly sponsored space projects mentioned by B. as affecting innovativeness in the European space sector. One of them is O., an engineer in a senior management position at a public-private European space company:

> We worked on ExoMars [a European-Russian research space probe] and we have a processor in the comm-system [communications system] in ExoMars – and that is so obsolete that it was phased out of washing machines in the 1980s. […] So, forty years ago it's been phased out. So, it's very conservative. And now the innovation has actually gone to the point where you can try these things out. (Interviewee O.)

Here, the approach of innovating upon technologies under the premise of optimizing reliability and preventing unintended malfunction is presented as outdated. In contrast, O. points to what he perceives as a recent and welcome shift towards a mode of market logic innovation by New Space culture. This is also a concern for Z., an engineer employed at yet another national space agency. He stages the Old Space mode of innovation as pursuing 'an excess qualification of systems' which could and should be challenged 'to steer the space sector towards becoming something resembling a normal economic sector' (Interviewee Z.). This, in his mind, would mean a shift towards a New Space innovation that 'would open up new markets.' (Interviewee Z.).

L. subscribes to this notion by presenting New Space innovation as relying on adapting non-space technologies cost-efficiently. To meet the specific demands of outer space environments, spaceflight engineers should *normalize* their ways of innovating by opening up to innovation beyond their own sector:

> The bottom line of New Space is that some company harnesses something [non-space technologies] that is already commercially available – qualifies it for spaceflight purposes – and then uses it as a space infrastructure to do whatever. And this is always cheaper than, let's say, Old Space, as many call it – the established space industry – that basically always strives to develop something specifically for spaceflight applications. (Interviewee L.)

A similar conclusion is drawn by C., the mid-level space agency official. For her, innovation traditionally performed in the European space sector is problematic, as 'you want to work with stuff that you know works, which is prohibiting innovation.'

(Interviewee C.). Instead, as shown in her statement in section 6.1., an innovative approach would necessitate sector culture pivoting towards a *trial-and-error* mode of innovation which compensates for lack of engineering quality by providing cheap and easy replacement of equipment. Instead of multi-million Euro investments in expensive and sophisticated satellites, mass-production of satellites, to her, seems equally viable in the context of New Space innovation. These portrayals of New Space innovation by L. or C. strike as problematic when transferred to the policy level, where responsible spaceflight innovation calls for sustaining outer space environments instead of considering their wasteful use out of economic market rationale.

N., the head of a department at a transnational European public space institution, also acknowledges this and tells a remarkably similar story. To him, trial-and-error innovation appears to be a viable option to achieve market-conformity of space sector engineering. He presents himself as welcoming this new way of innovating that enhances the innovation process as a whole:

> A big advantage of this New Space Age is that you're getting new ideas in. I mean the problem with space agencies is that to a certain extent they are conservative […]. Our credo here is: "failure is not an option". When you are from the industry you can accept it. For you, failure is an option. In particular, if I'm launching now 1,000 satellites to have a service and they are cheap … if 100 of them fail, so what? […] And if you find in industry somebody who is able to finance it and is interested in that one, can put some money in, you can be faster in introducing new technologies – new ideas also. (Interviewee N.)

However, N. implies that the mode of innovation that fits the New Space thinking is contradictory to a European space sector built around government-funded and publicly accountable institutions. While highlighting and admiring a trial-and-error mode of innovation as providing considerable advantages, N. does not perceive a challenge or even a threat to Old Space institutions, which, in his mind, continue to operate in their traditional mode of innovation.

This perspective is partly shared by E., the innovation officer, who said he had been recruited from a consulting firm specifically to promote a more innovation-savvy culture at the space agency where he works now. He states that '[w]e don't change stuff that works. If it works, it works. You don't play with it. It's a way of thinking – to some extent, it's rational […] with the economy as a paradigm. That you cannot run experiments within the economy.' (Interviewee E.). Preserving an Old Space sector innovation logic that has worked for decades in the European space sector appears to him not only as a legitimate and reasonable goal as N. makes it out to be. Going a bit further, E. formulates it into an economic counter-narrative to challenge New Space pursuits of trial-and-error marketization of spaceflight innovation as irrational to adopt into publicly sponsored institutions of the European space sector.

This ambivalent coexistence of two seemingly contradictory European space sector logics of innovation in the narratives of N. and E., representing those of other interviewees, has far-reaching implications. To a certain extent, it points to the sector embracing what could be called *innovation logic pluralism* – an ability to tolerate the arising contradictions between two logics of innovation that characterizes part of the identity work of interviewees. This factor can prove crucial on the policy level, as it hints to the possibility

of strengthening future notions of responsible engineering within the European space sector.

Identity Work between Old Space and New Space

The above subsections explored how interviewees negotiate demands for market logic innovation encountering traditional European space sector culture. It paid particular attention to how they narrated values and modes of innovation associated with figures of the spaceflight engineer. This section shows how these efforts reveal identity work as *switching* and point to the potential of alternative logics to gain hold within European space sector culture.

The above negotiation of appropriate modes of innovation by interviewees seems keen to combine *the best of both worlds* – expertly and alternately referring to the logics of both Old Space and New Space innovation cultures. In this effort, they consequently distinguish between these sector cultures and emphasize their respective distinct or even opposing innovation logics. By constructing these logics throughout their narratives, interviewees as European space sector professionals selectively align themselves with them. Both the unique, optimization-focused innovation approach of the Old Space engineer and the price-sensitive trial-and-error innovation of the New Space engineer serve as reference points for the identity work performed by interviewees as skillful travelers between the two worlds of European space sector innovation culture.

This competent construction of a dichotomy of cultural logics is the dominant form of hybridization performed by members of the field. The hybrid nature of this practice

emerges, as interviewees virtuously switch between these logics to embrace an efficient and functional role identity. This is important, as 'identity work is required to sustain feelings of authenticity […] and to fashion a "culturally appropriate self"' (Ibarra and Barbulescu 2010: 136) under challenging institutional conditions of facing demands for cultural change. As the observations above suggest, this authenticity is mainly produced by mobilizing the role identity patterns of the spaceflight engineer as a device capable of traversing the cultural gap underlying Old Space and New Space innovation logics. Figures like the spaceflight engineer, it appears, can be imagined by members of the European space sector as fitting both sector cultures: either as a rocket scientist, devising superior technologies or as an entrepreneurial engineer, securing the market compatibility of spaceflight technologies using a cheaper, trial-and-error approach to innovation. In both narratives, the spaceflight engineer remains the key figure within space sector culture, as it interacts with outer space as a particularly demanding innovation environment.

As members of the European space sector are exposed to demands for market logic innovation which are now promoted by policy institutions like the EU or the UN, they partly detach themselves from traditional, in their words, conservative, space sector culture. Despite this, they do not stage this culture as intrinsically inappropriate in terms of its values, dysfunctional as to its mode of innovation, or even necessarily economically inefficient (not even retrospectively). Nonetheless, even those members of the field socialized within traditional space sector culture frequently advocate the necessity and inevitability of New Space modes of innovation. This is a testament to the power of market logic innovation discourse, as even the European space sector, whose members

still actively evoke a sector culture established over many decades, does not seem able to refuse the appeal of more agile, demand-driven, and open innovation.

Nonetheless, whenever it suits them, members of the sector appear quite capable of rejecting market logic innovation wherever it strikes them as inappropriate for achieving a goal that they deem essential: successfully developing and operating technology under outer space conditions. In such cases, the Old Space engineer as a figure holding together the threads of European space sector identity prevails as strong enough to 'tam[e] the disruptive quality of innovation through what is imaginable and permissible in a given social, political, and historical context.' (Pfotenhauer and Jasanoff 2017: 788)

In this context, identity work in the form of switching presents itself as more than a coping strategy. Instead of being ambivalent about both logics or aligning themselves with just one in particular, European space sector professionals confidently tap into both logics. Following Lok (2010), such action might explain the success of New Space market-logic innovation within the European space sector, as

> identity work of actors in response to a new institutional logic is an important form of agency through which they can resist some of a new logic's identity and action implications, while paradoxically reproducing the logic at the same time. (Lok 2010: 1306)

According to this reading of identity work, the rise and success of a New Space culture fits the observation of interviewees frequently abandoning market-logic innovation paradigms in favor of Old Space rocket science – and vice versa. In fact, the frequent

switching in self-identification of field actors can thus be interpreted as a scenario of strengthening and maintaining them as perpetually reproduced counterparts.

Conclusion

Several aspects of the analysis above provide an insight into the future handling of outer space innovation in the European space sector. The increasingly critical nature of outer space infrastructures in the context of contemporary societal demands to shed light on the challenges of sector innovation culture being negotiated within the space community.

One conclusion concerns the ongoing strategy of switching shown to be part of the identity work of members of the European space sector to situate themselves between Old Space and New Space logics of innovation. Switching characterizes the stance adopted by members of the European space sector in their attitude towards the innovation logics of either Old Space or New Space culture. While often unquestioningly promoting the outset and means of a market logic innovation, they equally consistently revert to promoting traditional space sector values.

Viewed against the background of an increasing societal need for the European space sector to provide and sustain space infrastructures, such as satellite networks in orbit, the prevalence of switching cultural logics of innovation within the space sector emerges as a future challenge. How will the European space sector translate societal needs into responsive practices of innovation? How can responsibility for existing challenges to outer space infrastructures be traced? This challenge demands to be addressed in the space sector's future governance. It appears crucial to account for the political dimension of

European space sector professionals' ability to inscribe themselves in multiple innovation cultures and effortlessly switch between them. In contrast to other types of hybridization that segment, segregate, assimilate, blend or block (Skelcher and Smith 2015: 440) newly emerging cultural logics, switching places especially high demands on institutional actors and policies intended to guide their sector activities.

For example, observing the necessity of actors to alternate between both logics continually challenges the suggestion of an uncontested cultural transformation to take place in the European space sector successfully. Instead, in the case discussed here, European space policy actors' demands to accelerate a sector transformation towards New Space market conformity appear successful precisely because they remain partial – sticking to pre-existing cultural values. This observation offers an essential lesson to future introductions of value-based demands into the European space sector. As Old Space innovation logics prove indispensable to sector professionals' role identity, newly emerging space policy goals like that of societally responsive and responsible spaceflight innovation should not be framed as replacing existing space sector values. Instead, it can be prudent to induce them as additional and attractive value sets for field professionals to switch to.

This proposition emphasizes the critical role of the spaceflight engineers' identity patterns for the future conduct of societal responsive spaceflight activities in the European space sector. As shown above, space sector identity work revolves around these identity patterns as a central motive – the figurative rocket scientist now becoming complemented by a more entrepreneurial counterpart. This circumstance comes with new opportunities, as indeed the reference figure of the spaceflight engineer in both versions presented emerges

as inherently value-based. This suggests that ethical values and responsible action demanded by the rising importance of outer space infrastructures might relatively easily be integrated into identity narratives of space sector professionals constituting future sector culture.

In fact, the analysis above shows that the cultural logics observed do already connect to value sets in line with societally responsive spaceflight innovation. This is true especially for Old Space innovation culture aiming for high-standard, flawless engineering solutions. As explored, the rocket scientist-style engineer innovating with this logic in mind is revered in space sector culture exactly for caring for the secure, reliable, and sustained functioning of singular spacecraft she develops. This presents an entry point for implementing future measures furthering responsible innovation in the sense of responsive and inclusive innovation (Stilgoe et al. 2013). For example, in ensuring sustainable use of orbital environments instead of adopting a throw-away mentality of simply launching *enough* cheaper satellites to get a job done – the latter being an entirely rational approach in market-driven spaceflight innovation logic.

This realization has profound implications for adopting future space policies, as it suggests the identity work of European space sector professionals to be a suitable point of intervention for encouraging more responsible innovation. As the analysis in this paper presents, the spaceflight engineer's different identity patterns guide this identity work of field professionals. Thus, to successfully align the European space sector and its members with new policy objectives might require interfacing these with compatible engineering value sets. As emerging European New Space privateers currently still rely primarily on public funding to establish their businesses, European funding policies emerge as an

obvious point of intervention. However, as the analysis of this paper indicated, this would require responsible innovation to become more than a policy *buzzword* and address New Space actors at the level of innovation cultures – appealing instead to new sets of engineering values.

Accordingly, as values and modes of innovation are often negotiated in relation to engineering contexts, they are a key target for ensuring societally desirable handling of increasingly critical space infrastructures. As new figures of the spaceflight engineer like the entrepreneurial engineer are focal points of shifts in sector culture, so can be potential future iterations of this identity pattern. Complementing the entrepreneurial engineer, who, as has been shown, has largely been accepted by the field as an addition to the identity of the Old Space engineer, the *responsible spaceflight engineer* might stand for another future European space sector. It could inherit a logic of space sector innovation that values sustainable outer space environments by managing rising risks like that of space debris, which threatens both critical outer space infrastructures and individual lives and well-being on the Earth's surface (Clormann and Klimburg-Witjes, manuscript in preparation). This would be a culture based neither solely on the pursuit of technological excellence nor on market competitiveness at all costs but rather on democratically producing societally desirable outcomes in outer space.

References[14]

Brown, D. (2019), Four surprising technological innovations that came out of the Apollo moon landings (The Conversation; pubd. online 3 July 2019) <https://theconversation.com/four-surprising-technological-innovations-that-came-out-of-the-apollo-moon-landings-119605>, accessed 23 November 2020.

Callon, M. (2016) 'Revisiting marketization: from interface-markets to market-agencements', Consumption Markets & Culture, 19/1: 17–37.

Child, C., Witesman, E., Spencer, R. (2016) 'The Blurring Hypothesis Reconsidered: How Sector Still Matters to Practitioners', Voluntas, 27/4: 1831–52.

Concini, A. de, Toth, J. (2019), The future of the European space sector: How to leverage Europe's technological leadership and boost investments for space ventures (Report for the European Commission by Innovation Finance Advisory) <https://www.eib.org/attachments/thematic/future_of_european_space_sector_en.pdf> accessed 23 November 2020.

Czarniawska, B. (1997) 'A Four Times Told Tale: Combining Narrative and Scientific Knowledge in Organization Studies', Organization, 4/1: 7–30.

Damjanov, K. (2017) 'Of Defunct Satellites and Other Space Debris: Media Waste in the Orbital Commons', Science, Technology, & Human Values, 42/1: 166–85.

Denis, G., et al. (2017) 'Towards disruptions in Earth observation? New Earth Observation systems and markets evolution: Possible scenarios and impacts', Acta Astronautica, 137: 415–33.

Delponte, L., Pellegrin, J., Sirtori, E. et al. (2016), Space Market Uptake in Europe (Report for the European Parliament by Directorate General for Internal Policies)

[14] The style of referencing used in this article is identical to that of its published version. It thus deviates from the style used in the framing sections of this dissertation.

<https://www.europarl.europa.eu/RegData/etudes/STUD/2016/569984/IPOL_STU(2016)569984_EN.pdf> accessed 23 November 2020.

European Commission (2018), Questions and Answers on the new EU Space Programme (European Commission - Fact Sheet) <https://ec.europa.eu/commission/presscorner/api/files/document/print/en/memo_18_4023/MEMO_18_4023_EN.pdf> accessed 23 November 2020.

Gärdebo, J., Marzecova, A., Knowles, S. G. (2017) 'The orbital technosphere: The provision of meaning and matter by satellites', The Anthropocene Review, 4/1: 44–52.

Geppert, A. C. T. (2018) Limiting Outer Space. Astroculture After Apollo. London: Palgrave Macmillan.

Godin, B. (2017) Models of innovation: The history of an idea. Cambridge, MA and London: The MIT Press.

Gorman, A. C. (2014) 'The Anthropocene in the Solar System', Journal of Contemporary Archaeology, 1/1: 87–91.

Harrison, J. (2005) 'Shaping collaboration: Considering institutional culture', Museum Management and Curatorship, 20/3: 195–212.

Hecht, G. (2009) The radiance of France: Nuclear power and national identity after World War II (Inside technology). Cambridge, MA: The MIT Press.

Ibarra, H., Barbulescu, R. (2010) 'Identity as Narrative: Prevalence, Effectiveness, and Consequences of Narrative Identity Work in Macro Work Role Transitions', Academy of Management Review, 35/1: 135–54.

Jimenez, A. and Roberts, T. (2019). 'Decolonising Neo-Liberal Innovation: Using the Andean Philosophy of 'Buen Vivir' to Reimagine Innovation Hubs'. In: Nielsen, P., Kimaro, H. C. (eds.) Information and Communication Technologies for Development. Strengthening Southern-Driven Cooperation as a Catalyst for ICT4D, pp. 180–91. Cham: Springer International Publishing.

Johannsson, M., Wen, A., Kraetzig, B. et al. (2015) 'Space and Open Innovation: Potential, limitations and conditions of success', Acta Astronautica, 115: 173–84.

Lægreid, P., Roness, P. G., Verhoest, K. (2011) 'Explaining the Innovative Culture and Activities of State Agencies', Organization Studies, 32/10: 1321–47.

Lionnet, P. (2021), The current structure of the European space manufacturing sector (Report) < https://eurospace.org/wp-content/uploads/2021/01/structure-of-the-space-manufacturing-sector-v2021.pdf> accessed 22 February 2021.

Lok, J. (2010) 'Institutional Logics as Identity Projects', Academy of Management Journal, 53/6: 1305–35.

Messeri, L. (2016) Placing Outer Space: An Earthly Ethnography of Other Worlds (Experimental Futures). Durham: Duke University Press.

Meyer, R. E., Egger-Peitler, I., Höllerer, M. A. et al. (2014) 'Of Bureaucrats and Passionate Public Managers: Institutional Logics, Executive Identities, and Public Service Motivation', Public Administration, 92/4: 861–85.

Neyland, D., Ehrenstein, V., Milyaeva, S. (2019) 'On the difficulties of addressing collective concerns through markets: from market devices to accountability devices', Economy and Society, 48/2: 243–67.

Olson, V., Messeri, L. (2015), 'Beyond the Anthropocene: Un-Earthing an Epoch', Environment and Society, 6/1: 28–47.

OneWeb Ltd. (2020), Our Company. Bridging The Digital Divide (Company Website) <https://www.oneweb.world/our-company> accessed 23 November 2020.

Paulino, V. d. S. (2020) Innovation Trends in the Space Industry (Innovation, Entrepreneurship, Management Series: Smart Innovation Set 25). London, Hoboken: ISTE, Wiley.

Petroni, G., Santini, S. (2012) Innovation and change? The evolution of Europe's small satellite manufacturers', Space Policy, 28/1: 25–32.

Pfotenhauer, S., Jasanoff, S. (2017) 'Panacea or diagnosis? Imaginaries of innovation and the 'MIT model' in three political cultures', Social Studies of Science, 47/6: 783–810.

Rand, L. R. (2016) Orbital Decay: Space Junk and the Environmental History of Earth's Planetary Borderlands, Diss., <https://repository.upenn.edu/cgi/viewcontent.cgi?article=3749&context=edissertations> accessed 23 November 2020.

Redfield, P. (2002) 'The Half-Life of Empire in Outer Space', Social Studies of Science, 32/5-6: 791–825.

Reillon, V., Pawlak, P. (2016), EU space policy: Industry, security and defence (European Parliamentary Research Service; pubd. online November 2016) < https://www.europarl.europa.eu/RegData/etudes/ATAG/2016/593529/EPRS_ATA(2016)593529_EN.pdf> accessed 23 November 2020.

Sheehan, M. (2020). 'West European Integration and the Militarization of Outer Space, 1945–70'. In: Geppert, A. C., Brandau, D., Siebeneichner, T. (eds.) Militarizing Outer Space. Astroculture, Dystopia and the Cold War, pp. 93–116. London: Palgrave Macmillan UK.

Skelcher, C., Smith, S. R. (2015) 'Theorizing Hybridity: Institutional Logics, Complex Organizations, and Actor Identities: The Case of Nonprofits', Public Administration, 93/2: 433–48.

Sporn, B. (1996) 'Managing university culture: an analysis of the relationship between institutional culture and management approaches', Higher Education, Higher Education, 32/1: 41–61.

Stilgoe, J., Owen, R. and Macnaghten, P. (2013) 'Developing a framework for responsible innovation ', Research Policy, 42/9: 1568–80.

Trischler, H. (2002), The "Triple Helix" of Space. German Space Activities in a European Perspective (ESA History Study Reports 28) <http://www.esa.int/esapub/hsr/HSR_28.pdf) accessed 23 November 2020.

Tutton, R. (2020) 'Sociotechnical Imaginaries and Techno-Optimism: Examining Outer Space Utopias of Silicon Valley', Science as Culture, <https://www.tandfonline.com/doi/abs/10.1080/09505431.2020.1841151> accessed 23 November 2020.

Valentine, D. (2012) 'Exit Strategy: Profit, Cosmology, and the Future of Humans in Space', Anthropological Quarterly, 85/4: 1045–67.

van den Hove, S., McGlade, J., Mottet, P. et al. (2012) 'The Innovation Union: a perfect means to confused ends?', Environmental Science & Policy, 16: 73–80.

Venet, C. (2013) 'The European identity in space: An international relations perspective'. In: Venet, C., Baranes, B. (eds.) European Identity through Space (Studies in Space Policy), pp. 44–59. Springer: Vienna.

Vertesi, J. (2014) Seeing like a Rover: How robots, teams, and images craft knowledge of Mars. Chicago, London: The University of Chicago Press.

Vidmar, M. (2019) 'Agile Space Living Lab – The Emergence of a New High-Tech Innovation Paradigm', Space Policy, 49: 1–11.

Watson, T. J. (2008) 'Managing Identity: Identity Work, Personal Predicaments and Structural Circumstances', Organization, 15/1: 121–43.

Weinzierl, M. (2018) 'Space, the Final Economic Frontier', Journal of Economic Perspectives, 32/2: 173–92.

Witjes, N., Olbrich, P. (2017) 'A fragile transparency: Satellite imagery analysis, non-state actors, and visual representations of security', Science and Public Policy, 44/4: 524–34.

3.2. Article 2: Troubled Orbits and Earthly Concerns: Space Debris as a Boundary Infrastructure

Michael Clormann & Nina Klimburg-Witjes: "Troubled Orbits and Earthly Concerns: Space Debris as a Boundary Infrastructure"

Accepted for publication in: Science, Technology & Human Values (Sage Publishing 2021) – Accepted Version

(Published under DOI: 10.1177/01622439211023554)

Abstract

Like other forms of debris in terrestrial and marine environments, space debris prompts questions about how we can live with the material remains of technological endeavors past and yet to come. Although techno-societies fundamentally rely on space infrastructures, they so far have failed to address the infrastructural challenge of debris. Only very recently has the awareness of space debris as a severe risk to both space and Earth infrastructures increased within the space community. One reason for this is the renewed momentum of interplanetary space exploration, including the colonization of the Moon and Mars, which is part of transhumanist and commercially driven dreams of the so-called "New Space Age." Understanding space infrastructures as inherently linked to earthly infrastructure, we attend to the ways in which space debris, a once accepted by-product of scientific-technological progress, economic interests, and geopolitics, increasingly becomes a matter of concern. Drawing on qualitative interviews with European space sector representatives and STS-work on infrastructures, we argue that their discursive efforts and visual representation strategies co-produce space debris as a boundary infrastructure. We suggest considering this boundary infrastructure as relating

orbital environments and the planet through enacting sustainability and responsibility for beyond-planetary environments.

Introduction

Over the last decade, space debris has become a growing concern in the global space community. Space debris—defunct rockets stages, old satellites, objects released during space missions, and thousands of small fragments generated by their collision[15] —became well-known beyond the space sector with the Hollywood drama *Gravity*. In this movie, two astronauts struggle for survival as pieces of space debris damagingly hit their spaceship. In real life, space debris incidences are not less spectacular: The accidental collision of two communication satellites, Cosmos 2251 and Iridium 33 in 2009, created over 140,000 pieces of space debris and contributed significantly to the total number of debris fragments accounted for today. Due to the high speed with which space debris circulates in Earth's orbit, even tiny pieces can cause severe damage when impacting operational spacecraft like satellites or the International Space Station. In 2018, news outlets worldwide covered the story of Tiangong-1: The Chinese-operated space station became dysfunctional and uncontrollably re-entered Earth's atmosphere, potentially threatening both space infrastructures and lives on Earth.

With the dawning, commercially-driven "New Space Age," space debris is increasingly framed by space policymakers as a sustainability risk: private space entrepreneurs,

[15] In this context, policymakers and space experts regularly evoke the notion of the so-called "Kessler syndrome." It describes a scenario of cascading space debris collisions, and thus self-multiplying debris fragments leading to increasing orbital pollution. The term is proliferated within the space community referring to a paper published by Donald Kessler, a NASA-scientist, in 1978. This paper is considered to be one of the first published systematic accounts of long-term sociotechnical impacts of space debris.

spearheaded by Silicon Valley tech-capital, begin adding to the large pile of 20th-century space debris by launching unprecedented numbers of new satellites into orbit. Although the notion of a vast universe is persistent, orbits, the "roads" on which satellites can circulate the Earth, are far from endless. As contemporary societies largely depend on functioning satellite networks for data transfer, communication and navigation services, and climate and crisis monitoring, space debris is understood as a threat to planetary and orbital infrastructures. For some, the congested orbits might even put an end to transhumanist ideas of escaping our planet for other places in the cosmos, as safe launches of future spacecraft would be hindered by space debris. This new risk awareness is particularly strong in Europe, with the European Space Agency (ESA) aiming to take the lead in space debris removal efforts (European Space Agency 2013) and EU institutions repeatedly calling for action to reduce potential space debris emissions already in the construction phase of space infrastructures (European Parliament and Council 2014).

In this paper, we argue that space debris is anything but a distant outer space phenomenon and has become a concern transgressing the boundaries between the planet and its orbits in outer space. As such, it closely links to questions of responsibility and sustainability, which are adopted by space sector experts to make plausible what we propose calling inherently inseparable *orbital-planetary environments*.

We explore this notion by tracing how European space professionals construct space debris as an issue that links notions of orbital and planetary sustainability. We observe that in doing so, they dissolve traditional (discoursive) boundaries between orbital and planetary responsibility and instead relate to an orbital-planetary risk environment constituted by the presence of space debris. In our analysis that builds on 17 expert

interviews, we specifically focus on the strategies of European space sector professionals in linking space debris to broader environmental concerns, thereby framing it as a rising sustainability risk. More specifically, we attend to the specific sites of discursive and representational practices by which the encompassing orbital-planetary nature of space debris sustainability is co-produced. Our approach draws on the concept of boundary infrastructures understood as “objects that cross larger levels of scale than boundary objects” (Bowker and Star 1999, 287) to account for how interviewees describe space debris as constituting a “shared space” (Star 2010, 602f) that encompasses Earth and its orbital “backyard” in outer space. It also conceptually refers to sites of co-production (Jasanoff 2004) to account for field actors' political and ontological troubles in constructing this notion of an inherently interrelated orbital-planetary environment by referring to space debris.

Structuring the paper, we first provide an overview of the literature in STS and the emerging interdisciplinary field of "social studies of outer space" (SSOS) on the cultures, (techno)politics, and environments of outer space. Second, we introduce our conceptual approach to understanding space debris as a co-produced orbital-planetary infrastructure. The empirical part is structured along the lines of discursive storylines and representational strategies employed by European space professionals and the ways they attempt to link orbital and planetary sustainability. Lastly, the discussion and conclusion contextualize our findings considering current STS debates on infrastructures and sustainability. We propose that a better understanding of how we want to live with over 30,000 known debris objects orbiting above our planet is crucial for working towards and caring for sustainable (beyond-)planetary futures – assuming that the way in which space

debris is perceived will have strong implications for conceptions of Earth as a socio-ecological moral entity among the space sector in the future.

The making of interplanetary spaces: co-production and boundary infrastructures

This paper contributes to a growing body of work at the intersections of STS, anthropology, and sociology that investigates how outer space is linked to terrestrial concerns and how extraterrestrial materialities and imaginaries impact life on Earth (and vice versa). As spaceflight activities increasingly aim to (re-)establish a new "frontier" for exploration and exploitation in outer space (Olson 2012), scholars have recently attended to how interplanetary and Earthly spaces are intrinsically linked (Olson and Messeri 2015)—ontologically, politically, economically, and ecologically. Research in this field has shown how satellite technologies shape security and environmental politics (Rothe and Shim 2018; Witjes and Olbrich 2017; Parks 2005; Redfield 1996), explored how planetary sciences contribute to new place-making practices, and explained how exoplanets become places to be known and explored (Messeri 2016; Valentine 2012).

Specifically, work in SSOS has contributed much to our understanding of how the material politics of single artifacts (e.g., spacecraft) emerge as "global boundary objects" (Rand 2016, 72), transgressing the spatial boundaries that constitute many planetary ontologies (Olson 2013). Conceptual approaches like that of the technosphere (Haff 2014) describe a large-scale sociotechnical system shaped but not entirely managed by human action. These considerations have questioned merely anthropocentric perspectives and

dominant pre-occupations with planetary problems (Olson and Messeri 2015; Gorman 2014). As Gärdebo, Marzecova, and Knowles (2017, 47) have shown, such anthropocentrism prevents us from recognizing that "the continual use of satellite technology […] generates new layers of spatial conceptualizations, technological infrastructures, and legislative strategies concerning the management of both, orbital space and the Earth's surface."

Although this emerging body of work provides a valuable point of departure for exploring outer space as co-constitutive of scientific-technological, political, and cultural activities, space debris and the issue of crowded orbits have not been sufficiently empirically addressed. Valuable exceptions are the work of Damjanov, who analyzes space debris as media technology and stresses that "space waste is imbricated in the management of the future as a material force […]" (2017, 180), and Gärdebo, Marzecova, and Knowles (2017) who argue that the space debris layer formed in orbit around Earth challenges the notion of the technosphere. Existing STS work on waste, recycling, sustainability, and caring for infrastructures, in contrast, primarily addresses planetary concerns. For instance, Bedsworth, Lowenthal, and Kastenberg (2004) convincingly dissect risk narratives on infrastructural remains like nuclear waste as embedded in policy controversies. Similarly, Gabrys (2011; 2009) explores the unruly agency of waste, challenging concepts of sustainability within demarcated systemic boundaries. However, as orbital and planetary environments are inherently related and co-constitutive of each other, what has been missing so far is analytical attention to the question of how orbital sustainability becomes a matter of concern.

Thus, our article adds to recent work in both STS and SSOS by empirically analyzing how, in the discourses among European space professionals, space debris becomes a narrative ground of arguing for an orbital-planetary relatedness. We do so by building on two specific strands of conceptual work in STS: the idiom of co-production (Jasanoff 2004; Felt 2015; Hilgartner, Miller, and Hagendijk 2015; Pfotenhauer and Jasanoff 2015) and infrastructure studies—in particular the notion of boundary infrastructures (Bowker and Star 1999; Edwards et al. 2009; Dagiral and Peerbaye 2016).

The idiom of co-production builds on a long tradition in STS that has examined science and technology as social practices that shape, and are shaped by, social and political order. Co-production, as Jasanoff has outlined, is "shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from how we choose to live in it. Knowledge and its material embodiments are at once products of social work and constitutive of forms of social life" (Jasanoff 2004, 2). Such a perspective on the mutual shaping of science, technology, and social order helps to understand how contextualizing orbital environments and their planetary counterparts as mutually constitutive renders visible the interdependencies of world-knowing and world-making (Gärdebo, Marzecova, and Knowles 2017).

Jasanoff identifies four sites of co-productive relationships: the making of collective identities, public discourses, representations, and the governing of institutions (2004, 6). For this article, *discourses* and *representations* are particularly relevant sites to trace co-production of orbital and planetary domains in the storylines among European space professionals of how they know about and relate to space debris as a sustainability concern. Following Hajer (1995; 2009), we understand storylines as simplified and

condensed articulations of a certain *discourse's* key elements. In our case this relates to the political regulation of outer space, the technological and economic limits and potentials of spaceflight technologies, and the challenges and opportunities in communicating the societal value of spaceflight to a broader public. With regard to *representations*, we explore how practices of visualizing space debris are negotiated and validated among European space sector professionals. We specifically focus on their sense-making practices in referring to space debris visualizations and how these engage in the construction of an interrelated orbital-planetary environment.

While such co-productionist lenses attune us to the discourses and representations of space debris, they are less sensitive to its material characteristics as an orbital waste formation. Therefore, we draw on the concept of boundary infrastructures (Bowker and Star 1999), which enables us to explore the role of infrastructures in an outer space environment where space debris is moderating the inherent interrelation of orbital and planetary realms. Boundary structures "deal in regimes and networks of boundary objects (and not of unitary, well-defined objects)" (Bowker and Star 1999, 313), and thus allow us to explore how space debris is co-produced as a distributed, yet global infrastructural phenomenon that is more than the sum of individual debris objects: It threatens intact global satellite networks and thereby creates a relationship of infrastructural risk that spans both planetary usage of space-related services and the orbital technologies providing them.

As we show in section 5, space debris is often considered invisible and rendered visible only through standardized ways of visual representation. This characteristic corresponds with the notion of infrastructural systems that are "often intended to be so standardized

and reliable that they fade into the background, [while] in other circumstances, they are made very visible, by accident or by design" (Henke and Sims 2020, 19f). Space debris, as a global phenomenon, can thus be understood as a boundary infrastructure that calls for infrastructural maintenance work by current and future space actors. Debris removal efforts are neither limited to national borders nor single debris fragments belonging to any particular state (European Space Agency 2019).

Acknowledging these aspects, we propose that linking a co-productionist perspective to the concept of boundary infrastructures is helpful to understand how space professionals discursively frame space debris as an orbital-planetary challenge and how they visually represent the corresponding environment as inhabited by debris as a material infrastructure.

Material and methods

Our material consists of 17 semi-structured interviews with European space sector professionals conducted between 2017 and 2020. The sample includes a broad range of actors from industry, space entrepreneurs, policy advisors, and public administration officials with technical, legal, or policy expertise that have prominently contributed to storylines of space debris within their respective fields[16]. As our focus is on the prevalent storylines *shared* across the sector, we deliberately refrained from analyzing the interviews according to the interviewees' affiliations with specific communities of

[16] The references of each quote in the empirical part provide more detail on interviewees' respective affiliations: Policy Advisor (PA), Public Administration Official (PAO), Industry (IN), Entrepreneur (SE). We also mention professional and disciplinary backgrounds of interviewees within our analysis.

practice or institutional regimes within the European space sector. All interviews were recorded, transcribed, and analyzed using transcription and content analysis software.

We used Hajer's (2009) approach to discourse analysis that considers discourse "an ensemble of notions, ideas, concepts, and categorizations through which meaning is ascribed to social and physical phenomena, and that is produced in and reproduces, in turn, an identifiable set of practices" (60). Hajer conceptualizes storylines as condensed articulations of key discourse elements. This approach helps us identify how diverse actors within the space sector discursively refer to questions of space sustainability and the need for responsibility and care for orbital-planetary environments. As storylines are "summarizing complex narratives, used by people as 'shorthand' in discussions" (Hajer 2009, 61), such a focus also allows us to handle the often buzzword-heavy narratives prevalent in sustainability discourse (Müller and Witjes 2014).

To analyze the visual representation of space debris encountered in the discursive practices of interviewees, we draw on work in STS and related fields to discuss the nexus of visuality and materiality. In particular, we focus on how and which things are made visible and investigate the ontological and political implications attached (Rose and Tolia-Kelly 2016). As Witjes and Olbrich (2017) have argued, visualization technologies do not only enhance human vision but also (re)constitute depicted objects, issues, and processes by making them visible through their socio-technological arrangements (see also: Ruivenkamp and Rip 2014; Haraway 1988; Latour 1986). Studying how researchers of NASA's Mars Exploration Rover Mission used images to investigate the Red Planet, Vertesi (2014) has shown how visual representations are themselves theory-laden and purposeful practices. We adopt this approach to investigate what challenges interviewees

encounter in discussing artificial imagery of space debris originally produced for monitoring, observing, and publicly representing space debris.

Relating orbital-planetary sustainability issues

In the following section, we attend to those discursive practices by which our interviewees raise space debris as a concern. We outline how the storylines they use for this purpose can be seen as enacting an orbital-planetary environment through the notion of responsibility for space debris.

Space debris as a concern

Throughout our interviews, interlocutors drew attention to space debris as a tangible, material risk in different ways. However, space debris has not always been a concern for the space community. During the so-called "Old Space age," beginning in the 1950s, geopolitical concerns about competitiveness and leadership in space exploration sidelined efforts towards a more sustainable technological usage of outer space; the development of self-disposing satellites or the reusability of rockets were not prominent ideas at that time. Only recently has space debris become a concern within the space community and in public perception. This was reflected in many interviews. For instance, interviewees pointed to the need to take urgent action given the negative impacts of continued unsustainable use of Earth's orbits, as the following quote of a space policy advisor and activist shows:

> I think one of the main challenges arising is how ... stemming from the fact that our society is so dependent, at least our Western society, has become so dependent on space technologies, how we can sustain that and how we can protect ourselves from when things go wrong. (PA 1)

In a similar vein, PAO 1, a space agency engineer, lamented a lack of awareness about the sustainability risk emanating from space debris and the potentially catastrophic consequences that space debris collisions would have for technologized societies.

> If we at some point would say that all our systems would collapse when [space] infrastructure stops working the way we expect it to—if they are not resilient enough, for example. And then, if something happens in outer space—be it the Kessler syndrome or, for example, space weather like a coronal mass ejection that paralyzes our satellite infrastructure, which might very well happen. Would we, as a society, be able to absorb the shock, to compensate for this whole thing or not. (PAO 1)

Portrayals of looming infrastructural collapse, such as this one, were often accompanied by storylines about the impact of space debris on the sustainable future use of outer space. As one of our interviewees put his worries, "[t]he threat is, simply put, that the more debris revolves around in outer space, the more difficult it becomes to conduct spaceflight activities under safe conditions. And if this is not guaranteed, then systems like a satnav become more prone to blackouts in the long run" (PAO 2). He emphasized that rocket launches can only continue if their flight paths in orbit remain safe and unobstructed. In a similar vein, some interview partners voiced concerns about the obstacles that space

debris poses to futures space activities, often by drawing on transhumanist narratives of human colonization of outer space (Dunnett et al. 2019).

Such transhumanist visions saw a recent revival and are prominently embraced by New Space entrepreneurs such as Elon Musk. They assume that the ongoing destruction of our home planet through human activity—from devastating natural resources to war and climate disaster—requires a "planetary backup plan" beyond Earth; a last resort on another planet that allows humanity to avoid the need for maintaining planetary sustainability on Earth at all costs. As IN 1, an engineer at a big European space industry company stated, this would require "transfer[ing] some part of humanity to Mars "(IN 1) or to "one day fly to Mars in case Earth is no longer habitable" (IN 1). In this storyline, polluted orbits would make an exodus to Mars ultimately impossible: If the challenge of space debris in orbit is not tackled, future spacecraft might not be able to launch safely and leave Earth.

Here we can see how concerns for the sustainability of orbital spaces are intertwined with imaginations of human expansionism beyond the planet. In some interviews, this perspective was complemented by concerns about how orbital pollution by space debris would eventually hinder critical infrastructures like communication or Earth observation capabilities to function. The following quote by an engineer and startup entrepreneur shows the growing concern about our dependence on outer space sustainability:

> [O]ne would need to take quite different [more rigorous] actions by now and implement them after decades of controversy on the international level. This is, as sooner or later, orbits in some altitudes are already under threat of

> becoming unusable. That will happen. And only if something happens at some point, something really severe […] the European Space Agency loses a 300-million-dollar asset [satellite] … or the Americans. Then maybe something will change. (SE 1)

By relating planetary to orbital concerns, another interviewee highlighted the need "to take steps toward sustainable development and maybe backup solutions" (PAO 1). This necessity, as PA 1, the space policy advisor and activist, stresses, stems from "the dependence that we have grown on space technology as a society as a civil society […] and how we can mitigate any man-made or natural threats to that" (PA 1).

These concerns are in line with recent literature that sees the accessibility of low altitude orbits as critical to national sovereignty in military reconnaissance, civilian Earth observation, and essential mobile telecommunications systems (Al-Rodhan 2012). While, by international treaty, Earth's orbits are global commons and belong to all humankind in the sense of vertical public space (Parks 2013), the question of how this space is organized and shared remains contested. Space debris and its increasing presence due to New Space endeavors seems to bring a novel sense of urgency to these debates.

Despite this urgency to act as put forward in many interviews, we also identified more attenuating narratives regarding orbital-planetary sustainability. Often, interviewees simultaneously engaged in both: providing storylines promoting *and* defusing concern for the risks involved. This ambivalence also translates into their daily work, as one interviewee stressed:

> Even our own colleagues have to be frequently told [that] sitting in the middle of a hurricane, one believes everything around to be a storm. But a few meters along, it already ceases. In other words: one has to be careful not to perceive it in too much of a distorted way. (PAO 1).

Such seemingly varying levels of emphasizing space debris as a concern indicate more than mere ambivalent attitudes among space professionals toward sustainability and risk. Instead, we understand them as a way of coping with the ambivalence that comes from dealing with orbital-planetary concerns as inherently related.

This became particularly visible in the metaphor of the "eye of the storm," that one interviewee used in the above quote to refer to space debris as a concern that encompasses both Earth *and* its orbital surroundings. He implied that, while fearing an engulfing "storm" (space debris encircling Earth) might be sensible for those caught within it (the planet's inhabitants), their concerns should be regarded as highly situated, locally and temporally, rather than of global significance. From the outside of such a storm, PAO 1, the space agency engineer suggested, the risk it poses might turn out to be much more limited and accessible to rational judgment. He implied that those concerned with space debris would thus need to assume a dual perspective: one as being subjected to the risk emanating from space debris through its potential impact on the ground or operational satellites in orbit, and one as outside observers to such a threat. This dual perspective seems to point to a transgression of "inside" and "outside" epistemologies of concern that mirror the orbital-planetary challenge posed by space debris.

This interpretation is also supported by our interviewees repeatedly referring to broader storylines of sociotechnical risks and the adverse effects of contemporary ways of living on the environments we live in, as the following quote shows. PAO 2, a space agency lawyer, referred to space debris as an encompassing worldwide challenge to sustainability:

> The problem is that there are no borders up there. And even if only two states or two private companies or even just one produce extreme amounts of debris, this ultimately affects all others or most others that want to use the orbits. It is a global problem in the truest sense of the word […] because the orbits just go around the Earth. (PAO 2)

With this storyline, he linked concerns about space debris to broader, global scale sustainability discourses such as those addressing climate change and marine debris. However, this quote also shows how space debris is not only seen as an impactful sustainability concern but also recognized as material heritage of human spaceflight activities in a global sense—precisely because it questions the notion of global concerns being confined to planetary environments alone.

Responsibility for space debris

In framing it as a concern, space sector professionals thus aim to draw attention to space debris as a phenomenon that calls for taking on responsibility beyond the planetary scale.

A recent key objective of the European space sector, as SE 1, the engineer-entrepreneur, outlined, is the "transfer of environmental protection as a goal that we know on Earth and

by now consider normal to spaceflight activities" (SE 1). Using analogies like environmental protection, he framed responsible action towards outer space environments as a sustainability challenge similar to those evoked in Earthly sustainability discourses.

Another interlocutor elaborated on this argument further when stating that "over the decades, actually very, very few have added to the problem, meaning really just those that have actually conducted spaceflight activities for decades—a handful of nations that now slowly grows" (PAO 2). He understood this unequal contribution to pollution as "[…] an analogy to the issue of climate change, greenhouse gases, etc.," where "industrialized nations have emitted CO2 for 150 years and now want to instruct developing countries what they have to do" (PAO 2). According to PAO 2, like with other sustainability challenges, commercial actors and emerging space nations who are just beginning to use satellite infrastructures would mostly reject to take on responsibility for the material legacies of previous spaceflight activities. Many interviewees stressed that the Old Space actors—nation-states and their space agencies such as NASA and Roscosmos—should take the lead in removing space debris. At the same time, they argued that it would be necessary to enforce more responsibility on the current space debris producers, including commercial New Space companies. One interviewee with a background in engineering and space agency management made this point particularly clear by drawing on the comparison with climate change:

> We need to, in a way, impose "polluter pays"-regulation. Meaning: You want to pollute—you pay the cleaning. And we are not there yet. "Polluter pays" is something that industry doesn't like because they say "it will impact my business, and I have to consider the cleaning up in my business plan." I'm

> sorry—you have to! […] It's all this … like climate change again. If we go back … it's somewhat the same story. (PAO 3)

Referring to the intensified economic usage of orbits in the New Space Age, another interlocutor stated that she is "not so much concerned about the space debris that they will create, but about the sheer number of operational payloads [satellites] they will create" (PA 1). Alluding to future obligations towards these new satellites and the space debris they eventually might turn into, she strongly emphasized the material-infrastructural continuity of space debris as a matter of responsibility. Precisely because near-future risks through debris are already materially present in the ever-growing numbers of commercial satellites envisioned today, sustainability seemed to strike her as an immediate concern.

One reason for this is that satellites are not only almost always at risk of being destroyed by their non-functional predecessors that have turned into space debris. In turn, they also already represent a threat-to-be for future satellite networks. Under these conditions, functional satellites become indistinguishable from space debris in terms of their material quality as "risk objects." In this regard, orbital-planetary infrastructures differ from traditional terrestrial infrastructures that *turn* into risks only by a linear process of decay and neglect (Tutton 2020; Graham and Thrift 2007; Denis, Mongili, and Pontille 2015). In contrast, satellite networks and space debris constitute two sides of the same infrastructural coin, as they are both agents of destruction and subject to infrastructural breakdown.

In that sense, notions of orbital-planetary responsibility often clash with institutions, practices, and materialities of previous decades of spaceflight activities as they become

reconfigured due to the economization of space activities in the New Space Age. On the one hand, our interviewees stated that orbital-planetary environmental sustainability is negotiated through institutional legacies and their respective responsibilities toward human material heritage in outer space. They framed spaceflight activities of previous decades as clashing with the New Space paradigms' more economically driven approaches. On the other hand, many interviewees considered an increased responsibility for space debris as key to ensuring the sustainable use of Earth's orbits vis-à-vis an economically driven governance of outer space and increasingly crowded orbits. In the following quote, SE 1, the engineer-entrepreneur, anticipates such shifts in how responsibility is enacted:

> Who is going to take responsibility for this? Maybe something will arise out of this "New Space thing." That once big money enters the sector—that they will, out of self-interest … "Hey, we now have 100 billion up there. We now spend one billion to protect those 100 billion." It is possible that something along this way might happen. (SE 1)

This interviewee concluded that financial self-interest might motivate New Space companies to take responsibility for space debris mitigation, as their own defunct satellites might at some point threaten the future sustainability of the outer space environments they depend on commercially. Even if outer space becomes more and more a place of economic competition, as PAO 4, a space agency engineer and manager stressed, it would be a limited common resource:

> We have one problem. That to launch satellites … it gets easier. It means more people launch; there are more satellites. We are creating more garbage in space, so space debris. And it is very quickly within a few years that we are getting to a state where we cannot operate anymore because we have so many satellites in the near-Earth [orbit] that you cannot even launch anymore. You have no place in space anymore. (PAO 4)

This notion was taken up by another interviewee, who underscored that space debris is not only affecting those actors with stakes in the form of established satellite infrastructures. Instead, he stressed that all stakeholders, even future ones, should be equally responsible for sustaining outer space environments:

> Who, in my view, now also bears responsibility, is someone who launches his very first satellite in 2019 and does not care about the problem, even if he is launching his very first satellite saying "I don't care—I pollute." This person bears responsibility, too. (PAO 2)

This statement connects orbital-planetary sustainability to discourses of stakeholder-based responsibility for the commons: an idea frequently used to address planetary issues of environmental responsibility yet not univocally shared within the global space community. Especially US New Space actors often understand outer space sustainability as the ability to engage in the long-term human colonization of other planets, thereby rewriting or even opposing terrestrial concepts of sustainability (Valentine 2012).

In the case of European space professionals, we observed that attributing responsibility for space debris was seen as key to sustaining orbital-planetary environments as a

common good. As IN 3, a space industry PR official mentioned, responsible action towards space debris mirrors the need for environmental protection on Earth.

> I think space plays an important key role in the global world for understanding the environmental impact that we have. […] If you have too much debris in there, we will kind of destroy that resource. So for me to use kind of the same terms that we do when it comes to the environment is pretty easy. But, of course, I've heard … I mean people talk [about] it from a political and geopolitical kind of view as well. (IN 3)

In addressing space debris as a global concern, she described it as embedded in orbital-planetary interactions that shape societies' perception of sustainability. She implied that outer space environments enable a global perspective on human "environmental impacts" in a twofold way. First, by rendering visible the human environmental impact on Earth itself—amply documented by satellites in orbit. Second, by pointing to space debris' role as not only disrupting global satellite networks surveilling planetary environments but also polluting outer space itself. In that sense, space debris here emerges as an infrastructure that "transcends its regional context to connect with other systems and gains national or global reach" (Henke and Sims 2020, 12)—e.g., regimes of Earth observation and "geopolitical" concerns, as mentioned by IN 3.

Representing infrastructure: space debris as elusive materiality

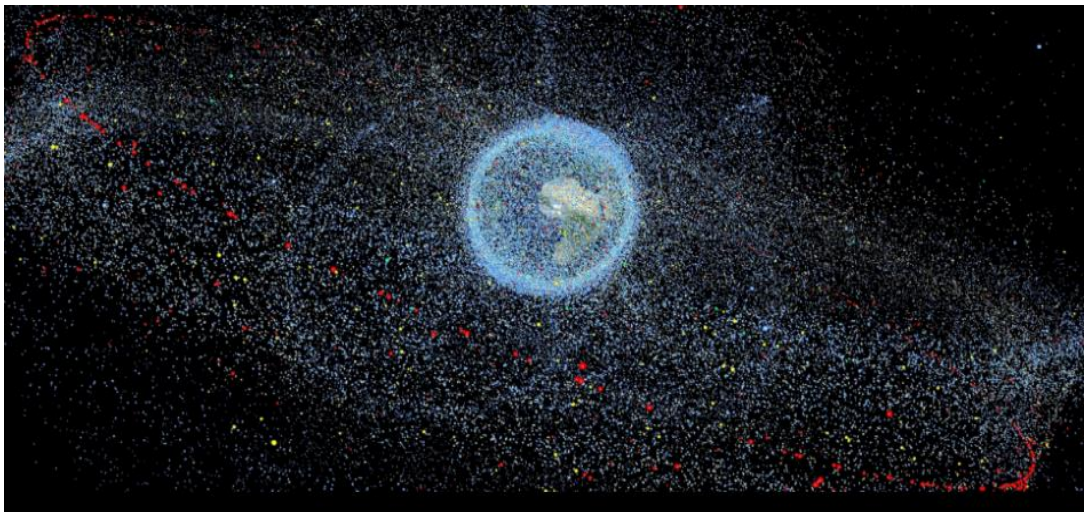
In the previous section, we have shown how interviewees enacted orbital-planetary relatedness by crafting storylines of space debris as a sustainability concern demanding

responsible action. In this section, we trace how interviewees engaged with visual representations of space debris as a second site of co-producing orbital-planetary sustainability as an overarching concern.

Visualizing concern through "orbital-planetary clouds"

Space debris is often visually represented as what we want to call "orbital-planetary clouds." (see Figure 1). These are computer-generated images that follow a distinctive and mostly uniform principle: They depict planet Earth surrounded by myriads of small, pixel-sized dots meant to represent space debris in orbit. The planet itself and the cloud-like orbiting rings or spheres of debris sharply contrast the vast, black background of outer space.

Figure 1. Example of an "orbital-planetary cloud" as visualized by the European Space Agency (European Space Agency 2019)



Throughout our interviews, it became apparent that this orbital-planetary cloud-style of visualization is highly charged with meaning. One interviewee remarked that the

computer-generated visualizations he and his colleagues create contrast standard representational practices displaying Earth as a singular, pristine yet fragile place in the vastness of outer space. According to PAO 1, these visual representations

> simply show this beautiful planet Earth and its surroundings—the Moon and the Sun—and one simply marvels at this great vastness like astronauts that, for example, take pictures of Earth and tell the story of a very beautiful blue sphere. But otherwise, there is really not much to see in these pictures. Then we come along with our animations and bring in all these—well, at the moment, there are about 30,000 dots […] suddenly orbiting the Earth. (PAO 1)

While initially referring to Earth as an untainted "natural marvel" represented in such imagery, the interviewee pointed to what he sees as a disturbing contrast: the awe-inspiring representation of the planet being tainted by depicting space debris surrounding it.

This ambivalence in visualizing space debris as a source of irritation points back to the representational practices of the Old Space age. For instance, the "Blue Marble" picture taken by astronauts of the Apollo 17 mission in 1972 memorably depicts an encompassing global view of Planet Earth, surrounded by the dark vacuum of outer space. As Jasanoff (2001) notes, it "symbolizes planetary togetherness," but also "ironically undermines its own authority […]. It promises an imagined community as encompassing as the Earth itself, but is this a community in which those without the power to patrol the heavens, to map and perhaps to devastate the Earth, can ever meaningfully participate?" (335). This question translates to the "orbital-planetary cloud"-type of visualizations as well, as these

challenge the imagery of planet Earth as a confined space for humanity and instead reinforce the extension of power asymmetries to impact environments beyond the planet: those actors able to launch significant numbers of satellites in the past shape visual planetary imaginations today. "Orbital-planetary cloud"-style visualizations make particularly clear that power not only extends beyond the boundaries of the planet but is also inherently linked to the material agency of orbital-planetary environments—hybrid spaces that are constituted by space debris and at the same time threaten critical satellite infrastructures. Although many interviewees expressed a certain sense of unease with these representations, they saw them as necessary depictions of a severe challenge. A challenge that "is difficult to get your hands on. It's… for most people, it's literally far away. In Dutch you say 'it's far away from my bed,'" (PA 1), as one of them, the space policy advisor and space activist, explained. As a representational practice, orbital-planetary clouds aim at disrupting the established visual narrative of planetary limits of the "Spaceship Earth," which has supported the perception of outer space as far removed from planetary concern.

Scaling visualizations: space debris as a boundary infrastructure

"Orbital-planetary clouds" represent the planetary environment and its inhabitants as inevitably surrounded by their infrastructural remains. As IN 2, a space insurance professional, remarked, they are "very easy to spot or visualize—looking like a ring originating in nature, revolving around us. Despite it being anthropological [sic!]" (IN 2). As visual representations, they create a sense of urgency, as this interviewee pointed out:

> One recognizes the effect that this whole thing has. That suddenly, this whole anthill of debris is revolving around our Earth—looking considerably worse in these animations than it actually is. […] This conveys quite a bit, I think, … that we suddenly see that all that revolves around Earth was brought there by us and most of it is no longer functional. (PAO 1)

The ontological uncertainties inherent in the "orbital-planetary clouds" sometimes raised discomfort among our interview partners, who were often hesitant to represent the visualized debris as nothing more than technological residue. After all, it appears to constitute an outer space environment well beyond planetary scales—an assemblage that has claimed a territory beyond Earth as its own. However, the thoroughly artificial origin of space debris' materiality can hardly be naturalized. Thus, demarcations of "the natural" and "the technological" often called upon in earthbound sustainability discourses seem somewhat problematic when projected to beyond-planetary scales.

This is especially the case when applied to orbits as ontological transition zones demarcating Earth from outer space. Like this agency official, interviewees engaged in creating visualizations were concerned about the potential impact of scaling frames of reference for space debris:

> These images that you often see, that also we ourselves distribute … with these white dots. […] This is, of course, graphically distorted because once you get the Earth as a "big something" on a piece of paper and put those dots around it, each dot is massively over-scaled. If you would do it to scale, meaning the correct relative size, you would see nothing. After all, these are screws flying

> through outer space. But I do not want to downplay or trivialize it. It is a problem. (PAO 2)

Expressing his unease with the fact that dots representing debris are usually visualized disproportionally large in computer-generated images of space debris in Earth's orbit, he worried about the potential misrepresentation of the magnitude of the challenge posed by space debris. At the same time, realistic scales would make visualization impossible, as PAO 2, the space agency lawyer, stated.

Regarding what they see as potential misrepresentation, our interlocutors found themselves confronted with contradictions regarding their practices of infrastructural boundary work, in that visualizations of "orbital-planetary clouds" do not allow them to localize infrastructural risk to planetary or orbital environments alone. Visually suggesting planetary intactness, to them, would negate the tangible presence of space debris as a material risk. Representing space debris by myriads of dots, on the other hand, would immediately render debris as a concern relevant not only to outer space affairs but also very imminently to terrestrial societies.

Here, our interlocutors' constant struggle with the decreasing plausibility of representing planetary and orbital environments as separate became visible. To them, space debris constituted a challenge that can neither be represented as fully terrestrial nor as situated in outer space alone. To raise awareness of space debris as a concern, they saw no alternative to constantly visualizing it as an inherently multi-sited “disturbance.” As a boundary infrastructure, space debris thus appears to enable what Olson and Messeri (2015) have called "scalar politics of cosmologies" (31). As it requires speaking of

orbital-planetary environments by always referring to a multitude of scales, it also mirrors what Gärdebo, Marzecova, and Knowles (2017) define as an interscalar vehicle: An "empirical object […] that simultaneously occup[ies] different political, ethical, epistemological, and affective scales and contexts that are usually 'kept apart'" (Gärdebo, Marzecova, and Knowles 2017, 45).

Conclusion

In this article, we have shown how the material relations of orbital-planetary environments came to matter in the storylines of European space sector experts and how they constructed space debris as an orbital-planetary challenge. From a co-productionist perspective, and in conjunction with the concept of boundary infrastructure, we traced the discursive and representational practices through which these experts enacted orbits as parts of orbital-planetary environments and space debris as the material infrastructure inhabiting them. We focused on discourses and representations, as this conceptual and methodological choice allowed us to trace how interviewees "talked about" space debris as a hard to grasp infrastructural phenomenon. It also helped us to account for visualizations as a significant part of discursive practices within our material.

Specifically, we attended to those storylines and visual representations by which space sector professionals attempted to establish a common ground for relating to orbital-planetary concerns and beyond-global scales of sustainability. Through these storylines, and by relying on metaphors from broader environmental discourses, interviewees aimed to raise awareness of space debris risks in unsustainable orbital-planetary environments. Regarding representations, we identified visualizations of "orbital-planetary clouds" of

space debris as a critical point of reference for interviewees in (re)scaling orbital-planetary environments.

We conclude that, not unlike the oceans, outer space has long been conceived as infinite. Accordingly, the emerging awareness of space debris as a sustainability concern has only recently led to novel ways of thinking about matter, responsibility, and sustainability as co-produced beyond the planet—as a sociotechnical risk and side effect of our lifestyle on the environments we occupy. In the advent of the economization of space activities in the New Space Age, notions of responsibility become increasingly reconfigured in the space community. They seem to clash with the institutions, practices, and ideas of previous decades of spaceflight. In a sense, today's crowded orbits and the growth of space debris resemble the well-known tragedy of the commons (Hardin 1968; Damjanov 2017). This is, as those performing spaceflight continue to pollute a common good without—individually and collectively—taking responsibility for developing more sustainable ways of using the shared resources that outer space provides.

We suggest that understanding space debris as a boundary infrastructure is a first step in acknowledging how it (con-)tests the traditional demarcations of orbital and planetary environments. Unlike many other infrastructures, space infrastructures always incorporate the material source of their future demise in the form of space debris, as the risk environment created by space debris proliferates the decay of further space infrastructure. At a certain point in their life span, orbital-planetary infrastructures transition from infrastructure at risk to *putting* at risk other infrastructure. Unlike other artifacts, e.g., consumer objects, which typically meet their end by engineered obsolescence, extensive use, or destructive external influence, space infrastructures are at

once the immediate cause and victim of breakdown. This characteristic of space debris as an inherent sustainability risk calls for further explorations of currently ongoing satellite launch activities by private space ventures. As New Space actors and policymakers alike support launching unprecedented numbers of new satellites into orbit, humanity actively and knowingly continues to generate unavoidable future threats today.

However, similar to other forms of human-made waste, such as micro-plastics in global ecosystems (Schönbauer and Bergmann 2019), we are now witnessing a shift in how these once accepted by-products of technoscientific progress, economic interests, and geopolitical relations increasingly become matters of public and political concern. Regarding space policy, a new epistemic and political relatedness of orbits and planetary concerns is established through the enhanced awareness of space debris as a boundary infrastructure. This poses novel questions about the responsibility for the space technologies' material legacies and possible forms of orbital-planetary care. These have not been paid considerable attention throughout the 20th-century space age in which the sustainability of outer space environments has received only marginal attention.

Space debris is not a distant outer space phenomenon but rather in many ways closely bound to planetary concerns; as a boundary infrastructure it connects envisioned futures of space exploration and exploitation to their material technopolitical legacies. Utopian imaginaries of colonizing Mars (Tutton 2018), for example, remain clouded by the potential risk of debris. Future work at the intersections of STS and SSOS appears well suited to explore the material enactment of orbital-planetary infrastructures as a means to understand sociopolitical sustainability discourses in techno-societies at large.

References[17]

Al-Rodhan, Nayef. 2012. Meta-Geopolitics of Outer Space: An Analysis of Space Power, Security and Governance. Basingstoke: Palgrave Macmillan.

Bedsworth, Louise W., Micah D. Lowenthal, and William E. Kastenberg. 2004. "Uncertainty and Regulation: The Rhetoric of Risk in the California Low-Level Radioactive Waste Debate." Science, Technology & Human Values 29 (3): 406–27. https://doi.org/10.1177/0162243904264904.

Bowker, Geoffrey C., and Susan L. Star. 1999. Sorting Things Out: Classification and Its Consequences. First paperback edition. Inside technology. Cambridge, Massachusetts, London: The MIT Press.

Dagiral, Éric, and Ashveen Peerbaye. 2016. "Making Knowledge in Boundary Infrastructures: Inside and Beyond a Database for Rare Diseases." Science & Technology Studies 29 (2): 44–61.

Damjanov, Katarina. 2017. "Of Defunct Satellites and Other Space Debris: Media Waste in the Orbital Commons." Science, Technology, & Human Values 42 (1): 166–85. https://doi.org/10.1177/0162243916671005.

Denis, Jérôme, Alessandro Mongili, and David Pontille. 2015. "Maintenance & Repair in Science and Technology Studies." Tecnoscienza: Italian Journal of Science & Technology Studies 6 (2): 5–15.

Dunnett, Oliver, Andrew S. Maclaren, Julie Klinger, K. Maria D. Lane, and Daniel Sage. 2019. "Geographies of Outer Space: Progress and New Opportunities." Progress in Human Geography 43 (2): 314–36. https://doi.org/10.1177/0309132517747727.

[17] The style of referencing used in this article is identical to that of its published version. It thus deviates from the style used in the framing sections of this dissertation.

Edwards, Paul, Geoffrey Bowker, Steven Jackson, and Robin Williams. 2009. "Introduction: An Agenda for Infrastructure Studies." Journal of the Association for Information Systems 10 (5): 364–74. https://doi.org/10.17705/1jais.00200.

European Parliament and Council of the European Union. 2014. "Decision No 541/2014/EU of the European Parliament and of the Council of 16 April 2014 establishing a Framework for Space Surveillance and Tracking Support." Accessed July 09, 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0541&from=EN.

European Space Agency. 2019. "ESA commissions world's first space debris removal." Accessed December 17, 2020. https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal.

European Space Agency. 2013. "The Right Response at the Right Time." Accessed December 15, 2020. https://www.esa.int/Safety_Security/Clean_Space/The_right_response_at_the_right_time_Holger_Krag_interview.

Felt, Ulrike. 2015. "Keeping Technologies Out: Sociotechnical imaginaries and the formation of Austria's technopolitical identity." In Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power, edited by Sheila Jasanoff and Sang-Hyun Kim, 103–25. Chicago: University of Chicago Press.

Gabrys, Jennifer. 2011. Digital Rubbish: A Natural History of Electronics. Ann Arbor: The University of Michigan Press.

Gabrys, Jennifer. 2009. "Sink: The Dirt of Systems." Environment and Planning D: Society and Space 27 (4): 666–81. https://doi.org/10.1068/d5708.

Gärdebo, Johan, Agata Marzecova, and Scott Gabriel Knowles. 2017. "The Orbital Technosphere: The Provision of Meaning and Matter by Satellites." The Anthropocene Review 4 (1): 44–52. https://doi.org/10.1177/2053019617696106.

Gorman, Alice C. 2014. "The Anthropocene in the Solar System." Journal of Contemporary Archaeology 1 (1): 87–91. https://doi.org/10.1558/jca.v1i1.87.

Graham, Stephen, and Nigel Thrift. 2007. "Out of Order: Understanding Repair and Maintenance." Theory, Culture & Society 24 (3): 1–25. https://doi.org/10.1177/0263276407075954.

Haff, Peter. 2014. "Humans and Technology in the Anthropocene: Six Rules." The Anthropocene Review 1 (2): 126–36. https://doi.org/10.1177/2053019614530575.

Hajer, Maarten A. 2009. Authoritative Governance: Policy-Making in the Age of Mediatization. Oxford: Oxford University Press.

Hajer, Maarten A. 1995. The Politics of Environmental Discourse: Ecological Modernization and the Policy Process. Oxford: Oxford University Press.

Haraway, Donna. 1988. "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective." Feminist Studies 14 (3): 575–599. https://doi.org/10.2307/3178066.

Hardin, Garrett. 1968. "The Tragedy of the Commons." Science 162 (3859): 1243–48. https://doi.org/10.1126/science.162.3859.1243.

Henke, Christopher R., and Benjamin Sims. 2020. Repairing Infrastructures: The Maintenance of Materiality and Power. Infrastructures series. Cambridge, Massachusetts: The MIT Press.

Hilgartner, Stephen, Clark A. Miller, and Rob Hagendijk, eds. 2015. Science and Democracy: Making Knowledge and Making Power in the Biosciences and Beyond. New York, London: Routledge.

Jasanoff, Sheila. 2004. States of Knowledge: The Co-Production of Science and Social Order. International library of sociology. London, New York: Routledge.

Jasanoff, Sheila. 2001. "Image and Imagination: The Formation of Global Environmental Consciousness." In Changing the Atmosphere: Expert Knowledge and

Environmental Governance, edited by Clark A. Miller, and Paul N. Edwards, 309–37. Cambridge, Massachusetts: The MIT Press.

Latour, Bruno. 1986. "Visualisation and Cognition: Drawing Things Together." In Knowledge and Society: Studies in the Sociology of Culture Past and Present 6, edited by Henrika Kuklick and Elizabeth Long, 1–40. Greenwich: JAI Press.

Messeri, Lisa. 2016. Placing Outer Space: An Earthly Ethnography of Other Worlds. Durham: Duke University Press.

Müller, Ruth, and Nina Witjes. 2014. "Of Red Threads and Green Dragons: Austrian Sociotechnical Imaginaries about STI cooperation with China." In The global politics of science and technology: concepts and perspectives 2, edited by Maximilian Mayer, Mariana Carpes, and Ruth Knoblich, 47–65. Heidelberg: Springer.

Olson, Valerie, and Lisa Messeri. 2015. "Beyond the Anthropocene: Un-Earthing an Epoch." Environment and Society: Advances in Research 6: 28–47. https://doi.org/10.3167/ares.2015.060103.

Olson, Valerie A. 2013. "NEOspace: the Solar System's Emerging Environmental History and Politics." In New Natures: Joining Environmental History with STS, edited by Dolly Jörgensen, Finn-Arne Jörgensen, and Sara Pritchard, 195-211. Pittsburgh: Pittsburgh University Press.

Olson, Valerie A. 2012. "Political Ecology in the Extreme: Asteroid Activism and the Making of an Environmental Solar System." Anthropological Quarterly 85 (4): 1027–44. https://doi.org/10.1353/anq.2012.0070.

Parks, Lisa. 2013. "Orbital Ruins." NECSUS. European Journal of Media Studies 2 (2): 419–29. https://doi.org/10.5117/NECSUS2013.2.PARK.

Parks, Lisa. 2005. Cultures in Orbit: Satellites and the Televisual. (Console-ing Passions: Television and Cultural Power). Durham: Duke University Press.

Pfotenhauer, Sebastian, and Sheila Jasanoff. 2017. "Panacea or Diagnosis? Imaginaries of Innovation and the 'MIT Model' in Three Political Cultures." Social Studies of Science 47 (6): 783–810. https://doi.org/10.1177/0306312717706110.

Rand, Lisa R. 2016. "Orbital Decay: Space Junk and the Environmental History of Earth's Planetary Borderlands." PhD diss., University of Pennsylvania.

Redfield, Peter. 1996. "Beneath a Modern Sky: Space Technology and Its Place on the Ground." Science, Technology & Human Values 21 (3): 251–74. https://doi.org/10.1177/016224399602100301.

Rose, Gillian, and Divya P. Tolia-Kelly. 2016. "Visuality/Materiality: Introducing a Manifesto for Practice." In Visuality/Materiality: Images, Objects and Practices, edited by Gillian Rose, and Divya P. Tolia-Kelly, 1–12. Farnham: Ashgate.

Rothe, Delf, and David Shim. 2018. "Sensing the Ground: On the Global Politics of Satellite-Based Activism." Review of International Studies 44 (3): 414–37. https://doi.org/10.1017/S0260210517000602.

Ruivenkamp, Martin, and Arie Rip. 2014. "Nanoimages as Hybrid Monsters." In Representation in Scientific Practice Revisited, edited by Catelijne Coopman, Janet Vertesi, Michael Lynch, and Steve Woolgar, 177–200. Cambridge: The MIT Press.

Schönbauer, Sarah, and Sven Bergmann. 2019. "Microplastics by other means? How microplastics can be a tool for inter/trans-disciplinary engagement." Marine Coastal Cultures. June 12, 2019. https://marinecoastalcultures.com/2019/06/12/microplastics-by-other-means-how-microplastics-can-be-a-tool-for-inter-trans-disciplinary-engagement/.

Star, Susan L. 2010. “This is Not a Boundary Object: Reflections on the Origin of a Concept.” Science, Technology & Human Values 35 (5): 601–617.

Tutton, Richard. 2020. "Sociotechnical Imaginaries and Techno-Optimism: Examining Outer Space Utopias of Silicon Valley." Science as Culture: 1–24. November 5, 2020. https://doi.org/10.1080/09505431.2020.1841151.

Tutton, Richard. 2018. "Multiplanetary Imaginaries and Utopia." Science, Technology & Human Values 43 (3): 518–39. https://doi.org/10.1177/0162243917737366.

Valentine, David. 2012. "Exit Strategy: Profit, Cosmology, and the Future of Humans in Space." Anthropological Quarterly 85 (4): 1045–67. https://doi.org/10.1353/anq.2012.0073.

Vertesi, Janet. 2014. Seeing Like a Rover: How Robots, Teams, and Images Craft Knowledge of Mars. Chicago, London: The University of Chicago Press.

Witjes, Nina, and Philipp Olbrich. 2017. "A Fragile Transparency: Satellite Imagery Analysis, Non-State Actors, and Visual Representations of Security." Science and Public Policy 44 (4): 524–34. https://doi.org/10.1093/scipol/scw079.

4. Discussion and Conclusion

To paint a satisfying picture using the insights gained from the research program of "space sector research" proposed in this dissertation, the findings derived from both of the articles just presented require joint consideration linked to the underlying research interest. This entails carving out the non-simultaneities experienced and produced by the ESS assemblage as they become visible in the analysis of both settings presented above: the ESS's negotiation of New Space innovation culture and space debris sustainability. For this purpose, a special emphasis is put on contexts of European innovation governance that decisively influence demands leveled at the ESS assemblage. This also involves pointing to how policies and institutions of European innovation are themselves emerging as integral parts of this assemblage, blurring the boundaries of what has traditionally been identified as the ESS. Following up on this overarching discussion, the conclusion aims to establish a connection between these findings and this dissertation's objective: to speak analytically and normatively of emerging opportunities to open spaceflight activities and the ESS itself to new groups of societal stakeholders. By returning to care as a conceptual tool to envision more inclusive ESS activity, the conclusion also illustrates potential theoretical lessons learned for social studies of outer space.

4.1. Case Studies in Perspective

To help navigate the following discussion, this subsection presents a brief recapitulation of the two articles' findings. Starting with Article 2, outer space sustainability emerges as a core challenge in current ESS narratives of change, as it ultimately requires field actors

to narrate a new environmental relation between outer space and the planetary sphere. As observed, sector professionals who are engaged in co-producing this beyond-planetary environment present space debris as a fundamental concern not only to their own field but to societal prospects in outer space. At the same time, they carefully refrain from depicting space sustainability threatened by space debris as a challenge that cannot be tackled by means of sociotechnical intervention. Thus, in their narratives of space sustainability, the interviewed professionals carefully walk the line between attracting attention to space debris as an environmental issue – thus partly normalizing outer space as facing familiar, ultimately planetary-like sustainability challenges – and defending technopolitics of outer space that rely on space sector privileges to access and govern outer space differently from Earth. Ultimately, they accommodate these conflicting narratives by co-producing an ambivalent understanding of orbital-planetary relatedness moderates through space debris as a boundary infrastructure.

Article 1 finds that transformational change perceived by field professionals to affect the ESS in the wake of an unfolding New Space Age is substantially challenging the sector's professional culture. It affects the role identities of field professionals and how they perceive themselves: not only as (disruptive) innovators but also as "custodians" of technoscientific endeavors in outer space. As with the scenario described in Article 2, this leaves them in a difficult situation, where on the one hand, embracing (disruptive) innovation is perceived as necessary to adapt to increasingly market-driven spaceflight activities, while on the other hand, traditional space sector professional culture persists in claiming authority over and responsibility for spaceflight technologies in the extraordinary innovation environment that is outer space.

The analyses of Article 1 and Article 2 provide several common and enlightening insights into the perspective of "space sector research." The first concerns discursive practices of field professionals in negotiating the ESS's societal status in a time of perceived transformation: *how* to perceive outer space in relation to planetary concerns, *who* should be involved in outer space activities, and *what* activities can and should take place in the future. As both articles show, by focusing on orbital sustainability and New Space innovation – challenges that have almost simultaneously manifested in space sector discourse in recent years – ESS professionals are deeply implicated in these questions. For them, they are linked to the overarching concern as to whether spaceflight activities should and still can be framed as extraordinarily fascinating, uniquely complex, and exclusive human endeavors set apart from other technoscientific projects of the current age – claims that were part of the space sector's nimbus in the previous Old Space Age.

Articles 1 and 2 also show that ESS professionals take ambivalent narrative positions, simultaneously stabilizing and destabilizing the space sector's exceptional role in engaging with outer space. For example, they highlight the somewhat exclusive and arcane competence of space sector professionals to visualize and thus interpret outer space phenomena like space debris, thus reinforcing the notion of outer space as a realm not easily engaged with by non-experts. At the same time, however, they advocate for space debris to be seen as a sustainability issue, requiring the engagement of new stakeholders. This way, they actively try to normalize outer space, staging it as part of an orbital-planetary environment. Similarly, ambivalent narratives are fostered around the sector's innovation culture, which Article 1 finds to align with field professionals "switching" between Old Space and New Space role identity patterns.

Viewed together, these ambivalent positionings emerging together in different settings concerning the ESS assemblage encompass not only sector institutions but also beyond-planetary ontologies, orbital epistemologies, environmental politics, and technoscientific identities. It is notable that their occurrence and negotiation in ESS discourse – prototypically visible in the emergence of New Space innovation and space debris sustainability – is accompanied by different non-simultaneous trajectories of the ESS assemblage in its European environment. To understand the narratives put forward by field professionals, these non-simultaneities need to be taken into account.

The importance of demands for market logic innovation encountering the sector in a New Space paradigm cannot be understood without its antithesis: the highly functional practices of non-disruptive, politically driven "rocket science." These practices continue to function well, thus retaining plausibility in large parts of the ESS. Similarly, the notion of not only outer space as an environment but also the space sector increasingly interacting with the challenges and needs of global societies is complemented by a seemingly conflicting concept: the traditionally widely accepted space sector assumption that outer space activities are insofar spatially and politically independent from planetary concerns, as they fall under the professional responsibility of the space sector.

Through both of these examples derived from the articles' analyses, it seems clear that one key finding of this dissertation regarding its first research question is the importance of meaningful interactions between what has been introduced as "non-simultaneit[ies] of the simultaneous" (Basaure 2018, 125) within the ESS in Section 2 – continuous conjunctions of assembled entities in time, which adhere to different temporal logics or historical points of reference and thus sometimes clash (Brose 2004, 10). These highly

specific interactions, the way they are performed and made plausible, not only lead to understanding ongoing negotiations of current challenges within the ESS but also underline its persistently important role in currently unfolding and envisioned future spaceflight activities. This role of the ESS is no coincidence. It can be attributed to the unique way in which it assembles the aforementioned dimensions and remains the central point of reference through which field professionals experience and promote transformational change, while in other narratives and practices, deliberately and sometimes unquestioningly retaining space sector traditions and frames of reference akin to the 20th century Space Age. The following section will discuss the aspects of such non-simultaneities and their role in the ESS by returning to the context of European innovation governance, in which the space sector is embedded.

4.2. Governing Non-Simultaneous Innovation in the European Space Sector

The configuration of assembled non-simultaneities, presented earlier, gains additional relevance when taking into account the non-simultaneities inscribed in processes of European unification (Brose 2004, 17) and, similarly, in ubiquitous contemporary commitments to govern societal change as a whole through innovation (Brose 2004, 6). Both aspects have already been introduced earlier in this dissertation to represent distinctive features that make the focus on the European case both intriguing and in some respects different from other regional or national cases. As mentioned before, they closely relate to the institutional contexts of European Union innovation governance, which has recently become a more prominent part of the ESS, e.g. through the establishment of the EUSPA. In such a setting, where today's ESS heavily interacts with other European

institutional frameworks, non-simultaneities inherent to those frameworks increasingly entangle themselves with those already assembled within the sector.

However, the implications of the ESS being embedded in specific European contexts are not limited to the level of institutions. By newly negotiating society's relations with outer space, a work-in-progress that this dissertation shows is performed through narrating cultures of spaceflight innovation, for example, the ESS emerges as an assemblage of *multiple spatialities*:

On the one hand, it takes part in "creating a [European] culture of synchronicity […] in a social space of increasing non-synchronicity among those moving in this space." (Eder 2004, 97). As such, it acts in a European context that can be understood as a social space in which technopolitical action (e.g. in identifying and tackling societal challenges) is intended to produce political cohesion where cultural non-simultaneities among national political interests, economic concerns, and technologies continue to exist or even grow in number. On the other hand, through its unique access to outer space, the ESS emerges as an essential player in *expanding* the boundaries of this European social space beyond planetary confines – for example, by engaging in narratives of orbital-planetary environmentalism as explored in Article 2. Following Eder, such a discursive expansion of the external boundaries of a governable social space into, for example, outer space, reemphasizes European political unity by presenting a simultaneous, "internally unbounded space" (2004, 99). It thus can generate internal cohesion in a European setting where otherwise the existence of ever more non-simultaneities, due for example, to regional or national disparities, could threaten the persistence of a common social space.

This is particularly relevant for the context of European innovation governance, which is characterized by multitudes of non-simultaneities – different agendas, fields, speeds, and even modes of innovation that nonetheless can be seen to stabilize and legitimize European transnational cooperation exactly because they are demonstrated to co-exist in a common space and time. This is also emphasized by political claims like that of the "Innovation Union" (Gouardères and Keravec 2021, 1) promoted in Horizon 2020, the 8th European Union framework program for research and innovation, which states that the Union's cohesion is built around the element of a common space for innovation. This notion of European commonality is emphasized and made plausible through the ESS and the access it promises to outer space as either a "constitutive outside," the representation of a new outer boundary, *or* as part of a joint European innovation space, which would be an inherently global space that now also extends beyond planetary confines. As Articles 1 and 2 explore, the narratives of field professionals on space sustainability and New Space innovation can be understood as efforts to position the ESS in such a way that it remains central to both of these concepts simultaneously, thus providing a uniquely useful resource for enabling European political cohesion through innovation.

However, it is not just the context of European innovation governance that depends on the ESS to provide a framework for balancing inherent non-simultaneities of European integration. The dependence is mutual, as European innovation policies and institutions play an important role in challenging space sector activities, confronting it with demands to be "more innovative" and "more sustainable," as Articles 1 and 2 showcase. It is these demands that are regularly perceived within the sector as calling for its transformation. At the same time, however, the framework of recently emerging European innovation

policies provides the space sector with opportunities to cope with challenges arising from these demands and the non-simultaneities surfacing within the field. This configuration, which has not been broadly discussed in the articles, is crucial to understanding both the ongoing negotiation of challenges encountered by the ESS as well as its implications for the societal relevance and accessibility of European spaceflight activities. It is also one aspect that makes the European case unique, as the European innovation policy landscape provides a very specific and highly contingent framework in which ESS conduct takes place.

Some elements of this policy framework lend themselves particularly well to discussion, as they are already hinted at in both of the empirical cases at hand: the notion of Responsible Research and Innovation (RRI) and the concept of global challenges presented by the European Commission's Horizon Europe framework program for research and innovation starting in 2021. These will be discussed in the following sections as examples of simultaneities and non-simultaneities in European innovation governance relevant to ESS conduct.

4.2.1. Responsible and Mission-Oriented Research

As suggested, the ESS currently experiences a previously unseen large-scale commitment from European Union institutions to play an active role in the development and operation of spaceflight technologies (European Parliament 2021). Consequently, RRI, as an integral part of the Union's research and innovation agenda, at least since the introduction of Horizon 2020 in 2014, has been introduced into space sector innovation efforts. Addressing all areas of EU-funded research and innovation anchored in the framework

program, RRI strongly considers space research and technologies to be areas where responsible innovation can and should be applied (European Commission 2018). It promotes responsible public and private European initiatives in outer space (European Space Policy Institute 2020, 80) and presents this notion of responsibility as a response to global challenges faced by today's European societies. Picked up by ESA, notions of responsible innovation highlight immediate public benefits as "science for society" (European Space Agency 2021) – for example, providing Earth observation services via satellite. As such, it shapes the conditions in which the ESS currently acts and is confronted with expectations of societal responsiveness and responsibility (Ryan 2016, 37).

To fulfill these expectations regarding societal challenges, the notion of mission-oriented innovation has co-emerged with that of RRI to allow for the compartmentalization and translation of political goals into discrete demands for technological innovation. While resurfacing in contemporary European policy discourse, it originates in technoscientific paradigms of the Space Age – among them the 1960s' Apollo moon program (Wanzenböck et al. 2020, 474f). At the time, such large-scale programs were primarily envisioned to demonstrate technological prowess and indirectly generate economic benefits specified by governmental actors. By contrast, current mission-oriented innovation approaches like the paradigm of RRI are geared towards addressing strategic political needs that arise out of persistent challenges facing global societies (Kuhlmann and Rip 2015, 16). As such, they describe efforts to

> rethink European space innovation policy to provide not only science and spin-off technologies and services (the earlier model of innovation stemming from

> public-funded space activities) but to include products and services for consumers as well as public goods that address societal challenges. (Robinson and Mazzucato 2019, 941)

As such, concepts of mission-based innovation in current European innovation policy agendas can be seen as having initially emerged as tools of space sector governance shaped by space sector institutions and sector-specific practices. Now returning to this field, they take the shape of highly specific policy agendas charged with additional meaning as compared to the innovation governance of the Old Space Age. While, for example, mission-oriented innovation in the US space sector is directed much more strongly towards market-driven New Space privateering, ESS policies highlight the character of "missions" as challenges (Robinson and Mazzucato 2019, 945). This becomes visible, for example, through the ascent of the concept of Technology Readiness Levels (TRLs) as a tool to govern innovation within the terminology of European framework programs as well as that of ESS research and development activities. Initially adopted to enhance 20th-century space research and development efforts (Olechowski, Eppinger, and Joglekar 2015, 2084), TRLs now serve as metrics to measure and distribute large parts of current Horizon 2020 and future Horizon Europe funding aiming for a responsible, multi-staged innovation process from basic research to market application (European Commission 2017, 2019).

This adoption of RRI and mission-oriented innovation by European innovation governance, and thus also by the ESS, is guided by a pro-innovation bias insofar as it highlights the potential of *market-driven* and *technological* innovation to enable societal benefits of spaceflight activities (Arnould 2019, 137). In this context, societal challenges

are understood as "favouring capital-intensive technoscientific solutions, at the expense of other approaches" (Levidow and Neubauer 2012, 5). This double-meaning of innovation is essential, as Article 1 observes notions of responsibility and responsiveness underlying European innovation policies like RRI to be accepted within the ESS exactly because they connect to both the discursive practices of responsible technological innovation that, as Article 2 shows, are already established in traditional sector innovation culture, *and* transformative narratives of market-logic New Space innovation. The European innovation framework built around RRI and mission-oriented innovation can thus be seen as enabling and making plausible the practice of switching between two co-existing yet non-simultaneous logics of innovation that Article 1 distills as a key challenge for ESS professionals.

4.2.2. Outer Space Solutions for Global Challenges

As the ESS seeks to address societal challenges through responsible innovation conducted as publicly procured, mission-oriented research, “society” as the beneficiary of such action, is differently and not always clearly defined. In many contexts, alignment between policy goals like societal responsibility and ESS commitments is constructed by addressing societies as something similar to one diffuse stakeholder – a “global society” that is to profit from outer space infrastructures. This is the case, for example, in the previously mentioned concept of "global challenges" (European Commission 2020, 6), which prominently features in the EU's Horizon Europe framework program and is also picked up by private actors in the European New Space sector. An example of this is OneWeb, a relatively young company aiming to provide global internet access via

satellite and one of the posterchild private initiatives fostered by European innovation policies in the space sector. In its mission statement, the company concludes that

> the emerging Space industry has a tremendous opportunity to develop communications and create new pathways for economic development, global education, rural health care and advancements in environmental science […]. OneWeb also believes industry and governments have an exciting, shared opportunity to facilitate […] the development of a sustainable, innovative and vibrant ecosystem, and for the benefit of all co-participants in this new era of Low Earth Orbit constellations. (OneWeb 2021)

Here, European innovation policies are explicitly referenced as tackling grand societal challenges, as outlined by the Lund Declaration (Swedish Research Council 2015), which are now identified as global challenges[18]. In doing so, OneWeb and other emerging private companies in the ESS present their efforts to provide solutions to EU-defined high-level societal challenges. They do this by not only promoting internet access via large satellite networks in remote or underdeveloped areas but also disaster management using Earth observation satellites (German Aerospace Center 2021).

[18] To some extent, such global perspectives have always been rooted in space sector narratives to legitimate spaceflight activities, as they have continuously lent plausibility to efforts of technologically pushing towards outer space. As discussed above, this applied to the early days of 20th-century space exploration, which promised humanity the adventures of expanding its reach beyond the globe, which had just been devastated by a World War – a global conflict that had conceived the very same weapons that should now provide benefit to all. It also became visible in Cold War era efforts to increase global security by either weaponizing outer space to achieve lasting peace by the threat of global devastation or by deploying technologies of comprehensive surveillance that would prevent such conflict. Additionally, civil applications of remote sensing satellites promised unparalleled scientific sensor access to Earth and came with the pledge to enable a better understanding and ultimately control of planetary environments and the human habitat.

This approach also becomes visible in propositions to address the challenge of space debris, which, as is elaborated in Article 2, is identified within the ESS as a significant threat. This is because space debris, if unchecked, might render future spaceflight activities impossible and thus prevent solutions to Earth-based societal challenges, which are expected to come from innovative spaceflight technologies. As such, the sustainability of outer space itself calls for attention because it hampers not only opportunities *in* outer space but also the potential to solve planetary challenges *from* outer space. Regarding space debris, European space policy narratives challenge planetary boundaries (e.g. regarding the pollution of various planetary environments or the depletion of resources) (Rockström et al. 2009) by prominently pointing to questions of space sustainability as a matter of responsibility.

This also becomes visible in the example of ClearSpace, a New Space startup contracted by ESA in 2020 to tackle the issue of space debris by removing some of it from orbit. This is to be achieved by developing and launching a new generation of debris removal spacecraft. As the company states on its website, "[s]pace technology and applications hold immense benefits for humanity" and thus "[r]emoving human-made space debris has become necessary and is our responsibility to ensure that tomorrow's generations can continue benefiting from space infrastructures and exploration." (ClearSpace 2021)

Thus, its mission is described to address a societal challenge by relying on technological innovation. Here again, some of the non-simultaneities pointed out earlier reemerge, as technological solutionism – differently yet deeply inherent to both Old Space and New Space modes of innovation – is called upon to address the political mission of outer space sustainability. As identified in Article 2, the challenge of sustainability raised by the

mounting problem of space debris is thereby addressed as a global one in multiple ways: concerning a global society, extending *beyond* the planet, and being tackled with terrestrial technologies deployed to outer space. The ESS, which is set to deal with the challenge of space sustainability, plays a role here not only in using outer space challenges to provide coherence where non-simultaneities threaten the European integration project – as suggested in Section 4.2. Instead, the multiple spatialities described here partially arise out of European innovation policy frameworks and introduce new non-simultaneities to the European space by offering new interpretations of what *global* challenges might mean taking outer space into account. These interpretations, which meet existing space sector claims and practices of "defining the global from the outside" – from outer space – thus constitute a need for the field to reconsider not only its role as a provider of technological fixes to planetary problems but also its complex situatedness in contemporary and future technosocieties.

4.3. Opening Up Outer Space

The previous section highlighted how non-simultaneities affecting the ESS assemblage emerge in the two settings explored in this dissertation. Article 1 and Article 2 present challenges arising in these settings to be questions of space sustainability and space sector innovation, describing their specific importance for the ESS negotiating its position in the "present future[s]" (Luhmann 1998, 70) of spaceflight activities. Both articles engage with broader discourses on sustainability and innovation, which are producing demands that diffuse into the space sector and influence how its professionals re-explore and re-contextualize the assemblage they are part of. At the same time, the articles provide brief

outlooks on how, in the context of these challenges, the space sector interfaces and might interface in the future with newly relevant societal stakeholders in spaceflight activities.

This section aims to provide context for the conclusions drawn in both articles, as the relationship between the ESS and society is one of the guiding research interests this dissertation pledges itself to. This relationship is inherently intriguing from both the analytical standpoint partially introduced previously and any attempt to responsibly govern humanity's future on and beyond the planet. This is particularly true when building on the introductory observation of a *bidirectional* relationship in which, on the one hand, greater societal access to ESS activities seems appropriate or even mandatory to meet rising challenges, while on the other hand, the sector itself can be expected to exhibit a growing interest in opening up towards society to enable itself as a capable and responsible problem-solver and to keep a say in how and for which stakeholders outer space is opened up and made more accessible.

4.3.1. Terms and Scope of Participation

The case studies in this dissertation show that ESS professionals, while *already* frequently considering themselves to be responsible subjects and responsive to societal demands, e.g. in the domains of environmental protection or responsible innovation, selectively favor public stakeholder engagement for different reasons. Their motivations thus reach beyond common assumptions like the general desirability of engaging broader publics in an effort to enable good governance (Chaffin, Gosnell, and Cosens 2014, 7) or the consideration that participating societal stakeholders might lend additional legitimacy to space sector activities (Kaminski 2016, 223–26). Instead, the findings presented here

indicate that the ESS, while currently doing so in a rather limited manner, might embrace more inclusive and participatory governance of outer space as a potentially helpful tool for stabilizing space sector control over newly contested non-simultaneities in the New Space Age.

As becomes clear when jointly considering Articles 1 and 2, the ESS's self-interests in this regard intersect with notions of societal responsiveness at specific points – e.g. in the realm of outer space sustainability, which is seen by some in the sector as increasingly necessary to ensure future space access to European spacecraft and therefore business, public infrastructure, and science. In these cases, ESS professionals actively link their narrative practices to broader discourses on sustainability to accumulate credibility and influence inside and outside of the field. Similarly, professional values, like careful, high-standard engineering – a practice rooted in Old Space Age role identity patterns of the spacecraft engineer discussed in Article 1 – closely connect to goals of societally responsive and responsible engineering, which members of the field are interested in sustaining.

Overall, however, as Kaminski (2016) has identified for the US space sector, current efforts to open up spaceflight activities beyond the space sector itself are primarily envisioned as invited participation (Wehling 2012, 44f) – a form of engaging publics in technoscientific practices that has been observed and critically examined by social science scholars over the past decade (Chilvers and Kearnes 2020, 355; Bogner 2012, 507, 513f; Maasen and Dickel 2019, 62). The intent of the space sector in welcoming such a participatory modus is to generate ideas for future space missions or make use of participants' expertise in offering technological solutions to certain space sector

challenges – e.g. through prize competitions and hackathons. Similar participative formats have emerged in Europe under the umbrella term of “open innovation.” In 2019, ESA launched its Open Space Innovation Platform (OSIP), intending to "invite[s] novel ideas to address space-related challenges” by “ESA […] opening itself up to early innovation" (European Space Agency 2020). Similarly, EUSPA recently implemented a User Consultation Platform (UCP). This annual format invites stakeholder dialogue with "actual users of the solutions, comprising representatives of associations such as standardization bodies and industry groups, regulatory bodies and other members of the user community" (European Union Agency for the Space Programme 2020).

In these examples, publics are primarily addressed as stakeholders in the relatively narrow sense of users and technically proficient (co-)creators of spaceflight technologies – mirroring concepts of stakeholder participation found in corporate governance literature (Ntim 2018, 1328f) or recurringly discussed in the long-lasting debate surrounding the so-called “prosumer” (Dusi 2017, 664). While the scope of who could qualify as a user is left somewhat open in these participatory examples, they seem to overwhelmingly address technological experts or even already existing users of spaceflight technologies who thus far have not participated in addressing particular technological challenges. Involvement outside the context of such extended professional publics, is in turn hardly imagined or presented as an opportunity to interface with different stakeholders when addressing the new challenges facing the ESS. Approaches aiming for a broader deliberative process, in which “[b]esides the state, citizens themselves emerge as a contracting party of responsive science" (Maasen and Dickel 2019, 56) have not materialized, nor are they yet emerging in current ESS activities.

4.3.2. Participation in the Explored Settings

The status quo of offers for participation only to narrowly defined groups of stakeholders comes as somewhat unsurprising, keeping in mind persistent space sector exclusivities explored in the previous analyses. However, it does seem increasingly implausible in the face of current space sector challenges like space debris or a transformation towards new modes of ESS innovation. Concerning the former, one example is the unprecedented number of satellites, so-called mega-constellations, that are being launched by mostly private space sector protagonists of the New Space Age (European Space Agency 2021). In light of these developments, deliberation on how to utilize outer space appears inevitable from the perspective of, e.g. risk governance, as today's space sector regulations accept scenarios of one human casualty per ten-thousand satellites reentering Earth's atmosphere as space debris (Fuentes et al. 2017, 1). Such a risk threshold presents itself as problematic, with exponentially rising numbers of spacecraft in the New Space Age potentially leading to regular casualties in the near future.

While the ESS already engages in envisioning sector-specific governance frameworks with regard to space debris (Palmroth et al. 2021), such efforts may prove insufficient in the face of beyond-global scales of sociotechnical risk. Instead, the emergence of a delocalized risk of injury due to space debris descending to the planet’s surface might call for a multi-actor and multi-level approach to space sector governance. Such an approach would complement top-down risk management by experts with up-front public deliberation of stakeholders and would entail making spaceflight technology development in the New Space Age a publicly responsive endeavor instead of either a highly exclusive “rocket science” or an equally segregated and potentially underregulated

frontier for private business endeavors. Such an approach would include laying open or even collaboratively deciding upon acceptable risks on local, national, European, and global scales as well as realigning established levels of decision-making with the beyond-global scales of the New Space Age.

Very similar participatory opportunities present themselves when it comes to terrestrial launch infrastructures necessary to sustain intensifying space activities. As Redfield (1996, 2002) demonstrated, spacefaring nations' spaceports are often located and operated extraterritorially in near-equator locations, from where rockets can more efficiently launch satellites into orbit and where many remnants of northern hemisphere colonial empires remain. As such, spaceports, being a vital part of space sector infrastructure, are far removed both from public attention in the operating states as well as from local deliberation in the underprivileged peripheral regions where they are located – in French Guiana, the South American location of Europe's main spaceport; Kazakhstan, a former Soviet and now Russian-operated spaceport; and elsewhere around the world.

Here, two sets of deliberative problems arise out of the challenges of New Space privatization and the growing waste problem of space debris. First, the increasing demand for rocket launches in the New Space Age threatens to outgrow equatorial spaceports as infrastructural epicenters of the Old Space Age. Additional sites for launching into outer space might move to continental Europe, for example Germany (German Offshore Spaceport Alliance 2021), and thus generate local publics as immediate stakeholders to support or question such infrastructure projects. Second, the problematic colonial legacy of many spacefaring-nations or private actors operating spaceports near the equator not only leads to local chemical pollution (Jakhu and Pelton 2017, 401) but also entails a

considerable risk of southern hemisphere residents suffering space debris impacts, as soon-defunct satellites on the brink of breaking down tend to be deliberately disposed[19] of outside of the more densely populated northern hemisphere (Klinkrad 2006, 273). Here too, intensified launch activities and larger numbers of satellites launched in the New Space Age can be expected to increase awareness of regional inequalities and thus equatorial populations as sensitive risk subjects. For both problems, early public deliberation appears plausible as part of an effort to inclusively govern space infrastructures on Earth while being responsive to public requirements and local needs.

These examples make it clear that established technoscientific practices of spaceflight activities are prone to questioning by new stakeholders co-emerging with recently arising challenges to the ESS. This is because these challenges show themselves to have meaningful and obvious impacts on societal living conditions in a "beyond-planetary world." Yet, there is currently a lack of appealing and credible imaginaries of beyond-planetary governance that include different stakeholders in the New Space boom – that is, to the extent of deliberating desirable uses of outer space, especially orbital-planetary environments and spaceflight technologies. However, such imaginaries would likely need to emerge and compete with those put forward by established space sector players, like philanthropist space billionaires or space agencies, to include the still marginalized perspectives of non-experts inheriting the stakes of beyond-planetary futures.

[19] This means old satellites are deliberately descended into the Earth's atmosphere in what is called a "controlled re-entry". One of the reasons for this practice is to reduce space debris in orbit. While satellites are expected to mostly burn up during re-entry, frequently fragements of such "de-orbited" spacecraft still impact on the planet's surface.

In the final section, such imaginaries are shown to revolve around the notion of caring for space environments that, in light of this discussion, appear as new, integral parts of Hannah Arendt's proposition for the *human condition*. This includes a brief outlook on the theoretical implications of such a perspective for future STS research.

4.4. Conclusion

As Hannah Arendt describes in her account of the technoscientific status quo of the 20th century, modernity is characterized by man's[20] ongoing rejection of the cosmos – that is, how living things and the world they inhabit have traditionally been ordered. As she notes, the first rejection – already a fait accompli – is that of the modern man choosing to *unsee* and replace the sky as a divine entity with an endless black tapestry that is the astronomic universe. The second rejection – one Arendt believes to be looming on the horizon of modern times – is that of Earth as a nurturing mother providing a haven for humankind in the vastness of this recently appointed astronomical universe in which no paternal order of life persists:

> Should the emancipation and secularization of the modern age, which began with a turning-away, not necessarily from God, but from a god who was the Father of men in heaven, end with an even more fateful repudiation of an Earth who was the Mother of all living creatures under the sky? (Arendt 1998, 2)

[20] Arendt consistently references the male gender in speaking about human concerns in outer space. This is a practice widely established in spaceflight narratives and still employed today – e.g. in one of the United Nations most recent documents on space policy which refers to the interests not only of "humankind" but of "mankind" (United Nations 2019). Gendered concepts in spaceflight contexts have recently gained some public attention, but are generally only sparsely highlighted in academic discourse (e.g. in Healey 2018). Further mentions of the male gender by the author refer to Arendt's diction for clarity and are not meant to exclude non-male genders.

In this quote from Arendt's opus magnum, The Human Condition (Arendt 1998), she describes the ultimate demise of ancient Greek cosmology in which Gaia, the Earth, and Uranos, the Sky, who together represented reality as archetypes of life on the Earth and under the sky. In Arendt's observation of her own time, this cosmological tradition is finally being replaced by the then-advent of the Space Age. In this Space Age, the sky is no longer a mighty sphere of heavenly power out of man's reach, from which he is forever sheltered in the bosom of the Earth, but a potential future homestead among the stars.

The implications of this shift in cosmological imagery have been critically explored in fields like the history of science, anthropology, and STS, specifically concerning its impact on our understanding of "outer space" and spaceflight activities (Anker 2005; Messeri 2016; Valentine, Olson, and Battaglia 2012; Farman 2012; Olson and Messeri 2015). In particular, these efforts have been made through neo-materialist and feminist theories, in which STS scholars and others have re-examined "the planetary" as a reference scale to reintroduce and reinforce global ontologies like that of the anthropocene or the technosphere (Clarke 2017; Latour 2017; Haff 2014; Hansen 2009; Hörl 2015). Especially within STS and anthropology, such efforts often suggest the need for new ways to care for hybrid environments and entities not represented by the politics of world-making that are inherent to contemporary technoscientific endeavors. In this context, the (female) notion of Gaia, which Arendt thought abandoned, has returned as a proposition to enable genuinely global action by thinking in a situated manner.

In these efforts, social science scholars focusing on researching outer space have acknowledged some of Arendt's thoughts on spaceflight technologies and their implications, for example, her conclusions regarding the political meaning of an

"Earthward gaze" (Kläger 2018, 131) enabled by satellites (Gärdebo, Marzecova, and Knowles 2017), the power asymmetries generated by unevenly distributed access to space among societies (Follis 2018), or the ethical and legal complexities of world-making that emerge through the experience of spaceflight activities reaching beyond the planet (Kearnes and van Dooren 2017). Most importantly, however, Damjanov (2017) observed that the current conduct of spaceflight activities (she mentions space debris as an example) can be understood as an epochal extension of the *human condition* into outer space – not as an attempt to escape it, as Arendt concludes to be the driving force of the Old Space Age she observed from the 1950s onwards (Arendt 1998, 2).

This becomes obvious when space debris is seen as constituting an orbital-planetary infrastructure that deconstructs the demarcation of planetary environments and outer space – as detailed in Article 2. Equally so, market-logic narratives framing outer space as a playground for large-scale innovation, as Article 1 outlines, suggest a process of expanding the human condition beyond Earth by applying a specific, capital-intensive mode of seeking technoscientific answers to societal challenges to outer space. However, both phenomena together, the deconstruction of infrastructural and environmental demarcations and the marketization of outer space solutionism, might constitute what Arendt, almost prophetically, identified as the Achilles' heel of human endeavors in outer space: Emphasizing Space Age spaceflight activities as the ontological and political pinnacle of modern science, she concludes that the only "[v]alid and plausible arguments against the 'conquest of space' could be […] that the whole enterprise might be self-defeating in its own terms." (1969, 276).

Curiously, this description seems to have accurately predicted the challenges facing current spaceflight activities in the proposed New Space Age, as future efforts to reach outer space from Earth are likely to find themselves hampered by space debris gradually enclosing the planet as a consequence of the extensive marketization of orbital realms. This has far-reaching implications, as the human condition, according to Arendt, was preciously not to be found in spaceflight activities as long as it primarily enabled humanity to contextualize itself from the outside but did not directly shape its fate. This was the case as long as spaceflight activities mainly supported the external observation of Earth and human life on it by astronauts or satellites – enabling an "eccentric" epistemology (Fischer and Spreen 2014, 15) in the sense of the philosophical anthropology of Helmuth Plessner; an epistemology in which planetary societies could constitute themselves in contrast to a primordial outside.

Going forward, outer space may no longer provide such a defining outside *contrast* to the human condition. Instead, it is on the path of becoming *part* of the human condition, as debris rises to populate the Earth's orbital surroundings and claims them as a planetary backyard – epistemologically, ontologically, and materially. In Arendt's words, this orbital-planetary environment emerging as a result of spaceflight activities may indeed turn out to be "self-defeating" once it restricts human spaceflight due to orbital congestion. In this scenario, a new kind of "geocentric and anthropomorphic" (Arendt 1969, 278f) world view would arise – though strikingly different than Arendt expected. Instead of societies expanding into outer space and valuing Earth as their cradle – a home left behind – their predicament would lie in the ubiquitous awareness that humanity will *never be able to leave* this home.

However, what does this mean for this dissertation, which understands itself to be one engaged in "space sector research"? For the answer, one must return to the assemblage of the ESS and its professional actors. The Old Space Age, according to Arendt's observations, operated with a status quo of rocket scientists "not even car[ing] about the survival of the human race on earth or, for that matter, about the survival of the planet itself" (Arendt 1969, 276). Paradoxically, in a supposed New Space Age, space sector elites, represented by a new kind of spaceflight engineer identified in Article 1, suddenly *need to care* for what they formerly wanted to leave behind: the situatedness of planetary conditions and life of Earth now extending to outer space in the form of particular infrastructures and the orbital environments they inhabit.

This realization stems from the concluding remarks of Articles 1 and 2 regarding the implementation of responsibility for outer space within the ESS. Article 2 finds that such responsible action can build upon the notion of orbital-planetary environments already being present within the field. Subsequently, Article 1 proposes that future ESS activities could draw on the notion of caring for orbital-planetary concerns by establishing the *responsible spaceflight engineer* as a plausible role identity pattern. Combining the conclusions of both articles, it becomes clear that taking responsibility for orbital-planetary environments as part of the human condition in the New Space Age calls for outer space to be more "open" in the sense mentioned above. Not only because it seems normatively appropriate or even necessary, but also because it poses an opportunity for the ESS to promote orbital-planetary environments as realms of responsible conduct – a modus operandi the field considers to be one of its strengths. Thus, making outer space more accessible to new stakeholders could, in its own perception, enable the ESS to share

responsibility for beyond-planetary futures while also maintaining a privileged position in caring for outer space via technoscientific expertise or transnational regulation.

As already mentioned in the methods section referring to Maria Puig de la Bellacasa, the argument for paying attention to "care" in the case at hand is thus normative, analytical, and theoretical. In presenting soil as a metaphor for exploring the limits and possibilities of care in technoscientific configurations, she proposes that "[m]odes of soil care and soil ontologies are entangled: what soil is thought to be, affects the ways in which we care for it, and vice versa." (Bellacasa 2015, 692). This conclusion can be transferred to space environments, which, as Articles 1 and 2 show, are co-produced by the material infrastructures inhabiting them as well as specific space sector engineering cultures. By establishing care as a core principle of space sector culture, thinking of outer space as an orbital-planetary environment that is intimately interwoven with the human condition of planetary living becomes an engaging thought. The other way around, perceiving outer space as laced with satellite networks representing fragile veins of contemporary technosocieties makes every effort towards a caring conduct more plausible.

Linking back to Arendt's considerations of the social nature of spaceflight and outer space itself, it seems prudent to readjust the perception of care as an activity to nurture Gaia and, in return, being nurtured *by* her – to continue to be able to live inside of a planetary techno-eco-system reaffirmed from the outside by technological achievements (Hörl 2017, 11f) like those of spaceflight. As today's societies already *live* beyond planetary scales and on the fringes of outer space in the very immediate sense of implicating it in their infrastructures of everyday life, the notion of caring for and being cared for by sociotechnical environments extends into outer space. The "Uranian" Sky, as per the

Greek mythology described by Arendt, is thus in the process of being adopted into a new kind of cosmos – one driven by an order of reciprocal care that does not exhaust itself in the colonization of outer space as envisioned by capitalist imaginaries of the New Space Age. Instead, rather than pushing back the skyward realm to the brink of the solar system – to mine asteroids or settle Mars – Earth and its outer space environments, first among them the orbits inhabited by satellites, emerge as constituents of a new cosmology of care.

From the standpoint of STS research, such a cosmology can be recognized as being part of the ontological interest in "accounting for the boundary-making practices by which the 'human' and its others are differentially delineated and defined" (Barad 2007, 136). Some of these "others" can be easily discovered in the hybrid matter of space debris, whose technological nature cannot hide the fact that it is now beyond the ability of contemporary societies to control entirely. Such elusive materialities, boundary infrastructures on the fringes of the sociotechnical world, gain the ability to "negotiate" with humans regarding the shared political realities of an emerging orbital-planetary lifeworld. Thus, the cosmopolitics of care that are outlined in the conclusion of Article 1, and which are extended here to have the potential to govern such realities, turn out to be cosmopolitics of orbital-planetary living in the broad sense of Stengers – the "(re)invention of politics, and the unknown" (2011, 355). They emphasize that "beyond-planetary" does not mean "beyond politics" (Stengers 2011, 356) but instead invites one to recognize and reconsider the role of the ESS in both working towards caring for space environments and opening up the possibility to care – in similar or different ways – for actors so far excluded from orbital-planetary politics. It might "give us the ability to meet and recognize those who should be the coauthors" (Stengers 2011, 355) of such politics.

References (Framework Sections)

Aerospace Corporation. 2018. “Satellite Reentry: Manipulating the Plunge.” Accessed December 12, 2020. https://aerospace.org/article/satellite-reentry-manipulating-plunge.

Anker, Peder. 2005. “The Ecological Colonization of Space.” *Environmental History* 10 (2): 239–68. https://doi.org/10.1093/envhis/10.2.239.

Arendt, Hannah. 1969. *Between Past and Future: Eight Exercises in Political Thought.* 2nd ed. New York: The Viking Press.

Arendt, Hannah. 1998. *The Human Condition.* 2nd ed. Chicago, London: The University of Chicago Press. http://www.loc.gov/catdir/description/uchi051/98017015.html.

Arnould, Jacques. 2019. “Colonising Mars. A Time Frame for Ethical Questioning.” In *The Human Factor in a Mission to Mars: An Interdisciplinary Approach*, edited by Konrad Szocik, 133–44. Space and Society. Cham: Springer International Publishing.

Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* 2nd ed. Durham, London: Duke University Press.

Barbaroux, Pierre. 2016. “The Metamorphosis of the World Space Economy: Investigating Global Trends and National Differences Among Major Space Nations’ Market Structure.” *Journal of Innovation Economics & Management* 20 (2): 9–35.

Basaure, Mauro. 2018. “Non-Simultaneity of the Simultaneous.” *Krisis. Journal of contemporary philosophy* (2): 125–27. https://archive.krisis.eu/wp-content/uploads/2018/07/Krisis-2018-2-Mauro-Basaure-Non-simultaneity-of-the-Simultaneous.pdf.

Bellacasa, Maria Puig de la. 2011. “Matters of Care in Technoscience: Assembling Neglected Things.” *Social Studies of Science* 41 (1): 85–106. https://doi.org/10.1177/0306312710380301.

Bellacasa, Maria Puig de la. 2015. “Making Time for Soil: Technoscientific Futurity and the Pace of Care.” *Social Studies of Science* 45 (5): 691–716. https://doi.org/10.1177/0306312715599851.

Bogner, Alexander. 2012. “The Paradox of Participation Experiments.” *Science, Technology & Human Values* 37 (5): 506–27. https://doi.org/10.1177/0162243911430398.

Bormann, Natalie. 2009. “The Lost Dimension? A Spatial Reading of US Weaponisation of Space.” In *Securing Outer Space*, edited by Natalie Bormann and Michael Sheehan, 76–90. Routledge critical security studies series. Milton Park: Routledge.

Brose, Hanns-Georg. 2004. “An Introduction Towards a Culture of Non-Simultaneity?” *Time & Society* 13 (1): 5–26. https://doi.org/10.1177/0961463X04040740.

Centeno, Miguel Angel. 1993. “The New Leviathan: The Dynamics and Limits of Technocracy.” *Theory and Society* 22 (3): 307–35. https://doi.org/10.1007/BF00993531.

Chaffin, Brian C., Hannah Gosnell, and Barbara A. Cosens. 2014. “A Decade of Adaptive Governance Scholarship: Synthesis and Future Directions.” *Ecology and Society* 19 (3): 1–13. https://doi.org/10.5751/ES-06824-190356.

Chilvers, Jason, and Matthew Kearnes. 2020. “Remaking Participation in Science and Democracy.” *Science, Technology & Human Values* 45 (3): 347–80. https://doi.org/10.1177/0162243919850885.

Clarke, Bruce. 2017. “Planetary Immunity : Biopolitics, Gaia Theory, the Holobiont, and the Systems Counterculture.” In *General Ecology. The New Ecological Paradigm*, edited by Erich Hörl and James Burton, 193–215. Theory series. London: Bloomsbury Academic.

ClearSpace. 2021. “Cleaning Space Is No Longer Optional.” Accessed March 10, 2021. https://clearspace.today/.

Clormann, Michael. 2021. “Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation.” *Science and Public Policy*, 1–10. https://doi.org/10.1093/scipol/scab038.

Clormann, Michael, and Nina Klimburg-Witjes. 2021. “Troubled Orbits and Earthly Concerns: Space Debris as a Boundary Infrastructure.” *Science, Technology & Human Values*, 1–26. https://doi.org/10.1177/01622439211023554.

Concini, Alessandro de, and Jaroslav Toth. 2019. “The Future of the European Space Sector: How to Leverage Europe’s Technological Leadership and Boost Investments for Space Ventures.” Accessed August 25, 2021. https://www.eib.org/attachments/thematic/future_of_european_space_sector_en.pdf .

Cornell, Ariane. 2011. “Five Key Turning Points in the American Space Industry in the Past 20 Years: Structure, Innovation, and Globalization Shifts in the Space Sector.” *Acta Astronautica* 69: 1123–31. https://doi.org/10.1016/j.actaastro.2011.05.033.

Damjanov, Katarina. 2017. “Of Defunct Satellites and Other Space Debris: Media Waste in the Orbital Commons.” *Science, Technology, & Human Values* 42 (1): 166–85. https://doi.org/10.1177/0162243916671005.

Darnis, Jean-Pierre. 2019. “The New Space Economy: Consequences for Space Security in Europe.” In *Handbook of Space Security. Policies, Applications and Programs*, edited by Kai-Uwe Schrogl, Peter L. Hays, Jana Robinson, Denis Moura, and Christina Giannopapa. Cham: Springer.

DeLanda, Manuel. 2006. *A New Philosophy of Society: Assemblage Theory and Social Complexity.* London, New York: Continuum.

Deleuze, Gilles, and Félix Guattari. 1987. *A Thousand Plateaus. Capitalism and Schizophrenia*. Minneapolis, London: University of Minnesota Press.

Doboš, Bohumil. 2019. “The History of the European Space Program.” In *Geopolitics of the Outer Space: A European Perspective*, edited by Bohumil Doboš, 83–105. Contributions to Political Science. Cham: Springer.

Dunnett, Oliver, Andrew S. Maclaren, Julie Klinger, K. Maria D. Lane, and Daniel Sage. 2019. "Geographies of Outer Space: Progress and New Opportunities." *Progress in Human Geography* 43 (2): 314–36. https://doi.org/10.1177/0309132517747727.

Dusi, Davide. 2017. "Beyond Prosumer Capitalism: Retaining the Original Understanding of Prosumption." *Current sociology* 66 (5): 663–81. https://doi.org/10.1177/0011392117697459.

Eder, Klaus. 2004. "The Two Faces of Europeanization: Synchronizing a Europe Moving at Varying Speeds." *Time & Society* 13 (1): 89–107. https://doi.org/10.1177/0961463X04040748.

European Commission. 2017. "Horizon 2020 Work Programme 2018-2020: 5.Iii. Leadership in Enabling and Industrial Technologies - Space." Accessed August 26, 2021. https://epic-src.eu/wp-content/uploads/h2020-wp1820-leit-space_en.pdf.

European Commission. 2018. "Proposal for a Regulation of the European Parliament and the Council Establishing the Space Programme of the Union and the European Union Agency for the Space Programme and Repealing Regulations (EU) No 912/2010, (EU) No 1285/2013, (EU) No 377/2014 and Decision 541/2014/EU." Accessed August 25, 2021. https://eur-lex.europa.eu/resource.html?uri=cellar:33f7d93e-6af6-11e8-9483-01aa75ed71a1.0003.03/DOC_1&format=PDF.

European Commission. 2019. "Orientations Towards the First Strategic Plan for Horizon Europe." Accessed August 25, 2021. https://ec.europa.eu/info/sites/info/files/research_and_innovation/strategy_on_research_and_innovation/documents/ec_rtd_orientations-he-strategic-plan_122019.pdf.

European Commission. 2020. "Horizon Europe Strategic Plan (2021 – 2024): Analysis." Accessed August 03, 2021. https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_horizon-europe-strategic-plan-2021-24-analysis.pdf.

European Parliament. 2021. “Regulation (EU) 2021/696 of the European Parliament and of the Council of 28 April 2021 Establishing the Union Space Programme and the European Union Agency for the Space Programme and Repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU.” Accessed August 25, 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0696&from=EN.

European Space Agency. 2020. “A Year of Discovering New Ideas with OSIP.” Accessed August 25, 2021. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/A_year_of_discovering_new_ideas_with_OSIP.

European Space Agency. 2021. “ESA’s Annual Space Environment Report.” Accessed August 25, 2021. https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

European Space Policy Institute. 2020. “European Space Strategy in a Global Context.” Accessed August 25, 2021. https://espi.or.at/publications/espi-public-reports/send/2-public-espi-reports/548-european-space-strategy-in-a-global-context-full-report.

European Union Agency for the Space Programme. 2020. “User Consultation Platform Helps Shape the Future of European GNSS.” Accessed August 25, 2021. https://www.gsc-europa.eu/news/user-consultation-platform-helps-shape-the-future-of-european-gnss.

Farman, Abou. 2012. “Re-Enchantment Cosmologies: Mastery and Obsolescence in an Intelligent Universe.” *Anthropological Quarterly* 85 (4): 1069–88. https://doi.org/10.1353/anq.2012.0055.

Fischer, Joachim, and Dierk Spreen. 2014. “Soziologie der Weltraumfahrt: Zur Einleitung.” In *Soziologie der Weltraumfahrt*, edited by Joachim Fischer and Dierk Spreen, 7–19. Kulturen der Gesellschaft 12. Bielefeld: Transcript Verlag.

Follis, Luca. 2018. “The Province and Heritage of Humankind: Space Law’s Imaginary of Outer Space, 1967–79.” In *Limiting Outer Space. Astroculture After Apollo*, edited by Alexander C. T. Geppert, 183–205. Palgrave Studies in the History of Science and Technology. European Astroculture 2. London: Palgrave Macmillan.

Foucault, Michel. 1997. “Of Other Spaces: Utopias and Heterotopias.” In *Rethinking Architecture: A Reader in Cultural Theory*, edited by Neil Leach, 330–36. London, New York: Routledge.

Fuentes, Irene Pontijas, Davide Bonetti, Federico Letterio, Gonzalo de Miguel Vivario, Gonzalo Blanco Arnao, Pedro Palomo, Cristina Parigini, Stijn Lemmens, Tobias Lips, and Ronny Kanzler. 2017. “Upgrade of ESAs Debris Risk Assessment and Mitigation Analysis (DRAMA) Tool: Spacecraft Entry Survival Analysis Module.” In *7th European Conference for Aeronautics and Space Sciences*, 1–14. https://www.eucass.eu/doi/EUCASS2017-569.pdf.

Gärdebo, Johan, Agata Marzecova, and Scott G. Knowles. 2017. “The Orbital Technosphere: The Provision of Meaning and Matter by Satellites.” *The Anthropocene Review* 4 (1): 44–52. https://doi.org/10.1177/2053019617696106.

Geppert, Alexander C. T. 2012. “European Astrofuturism, Cosmic Provincialism: Historicizing the Space Age.” In *Imagining Outer Space. European Astroculture in the Twentieth Century*, edited by Alexander C. T. Geppert, 3–24. Palgrave Studies in the History of Science and Technology. European Astroculture 1. London: Palgrave Macmillan.

German Aerospace Center. 2021. “Global Connectivity from Satellite.” Accessed August 26, 2021. https://www.dlr.de/content/en/articles/digitalisation/digitalisation-project-global-connectivity-from-satellite.html.

German Offshore Spaceport Alliance. 2021. “A Spaceport for Germany: The Driver for a Strong Business and Aerospace Location.” Accessed August 26, 2021. https://www.offshore-spaceport.de/en/.

Gisler, Monika, and Didier Sornette. 2009. “Exuberant Innovations: The Apollo Program.” *Society* 46: 55–68.

Godin, Benoît. 2012. “Social Innovation: Utopias of Innovation from C.1830 to the Present.” Project on the Intellectual History of Innovation 11. Unpublished manuscript, last modified August 26, 2021. http://www.csiic.ca/PDF/SocialInnovation_2012.pdf.

Gouardères, Frédéric, and Albane Keravec. 2021. “Innovation Policy.” Fact Sheets on the European Union. Accessed August 26, 2021. https://www.europarl.europa.eu/ftu/pdf/en/FTU_2.4.6.pdf.

Haff, Peter. 2014. “Humans and Technology in the Anthropocene: Six Rules.” *The Anthropocene Review* 1 (2): 126–36. https://doi.org/10.1177/2053019614530575.

Hansen, Mark B. N. 2009. “System-Environment Hybrids.” In *Emergence and Embodiment: New Essays on Second-Order Systems Theory*, edited by Bruce Clarke and Mark B. N. Hansen, 113–42. Science and Cultural Theory. Durham, London: Duke University Press.

Haraway, Donna J. 2018. *Modest_Witness@Second_Millennium: FemaleMan©_Meets_OncoMouseTM*. 2nd ed. New York, London: Routledge.

Havercroft, Jonathan, and Raymond Duvall. 2009. “Critical Astropolitics: The Geopolitics of Space Controland the Transformation of Statesovereignty.” In *Securing Outer Space*, edited by Natalie Bormann and Michael Sheehan, 42–58. Routledge critical security studies series. Milton Park: Routledge.

Healey, Devlin. 2018. “There Are No Bras in Space: How Spaceflight Adapted to Women and How Women Adapt to Spaceflight.” *Georgetown Journal of Gender and the Law* 19 (3): 593–617.

Hecht, Gabrielle. 2009. *The Radiance of France: Nuclear Power and National Identity After World War II.* Inside technology. Cambridge, London: The MIT Press.

Hörl, Erich. 2015. “The Technological Condition.” *PARRHESIA* (22): 1–15.

Hörl, Erich. 2017. “Introduction to General Ecology: The Ecologization of Thinking.” In *General Ecology: The New Ecological Paradigm*, edited by Erich Hörl and James Burton, 1–74. Theory series. London: Bloomsbury Academic.

Jakhu, Ram S., and Joseph N. Pelton. 2017. “Space Mining and Use of Space Natural Resources.” In *Global Space Governance: An International Study*, edited by Ram S. Jakhu and Joseph N. Pelton, 379–413. Cham: Springer International Publishing.

Jasanoff, Sheila. 2001. “Image and Imagination: The Formation of Global Environmental Consciousness.” In *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, edited by Clark A. Miller and Paul N. Edwards, 309–37. Politics, science, and the environment. Cambridge, London: The MIT Press.

Johannsson, Magni, Anne Wen, Benjamin Kraetzig, Dan Cohen, Dapeng Liu, Hao Liu, Hilda Palencia et al. 2015. “Space and Open Innovation: Potential, Limitations and Conditions of Success.” *Acta Astronautica* 115:173–84. https://doi.org/10.1016/j.actaastro.2015.05.023.

Kaminski, Amy. 2016. “What Place for the People? The Role of the Public and NGOs in Space Innovation and Governance.” In *Yearbook on Space Policy 2014: The Governance of Space*, edited by Cenan Al-Ekabi, Blandina Baranes, Peter Hulsroj, and Arne Lahcen, 217–28. Yearbook on Space Policy. Vienna: Springer.

Kearnes, Matthew, and Thom van Dooren. 2017. “Rethinking the Final Frontier: Cosmo-Logics and an Ethic of Interstellar Flourishing.” *GeoHumanities* 3 (1): 178–97. https://doi.org/10.1080/2373566X.2017.1300448.

Kilgore, De Witt Douglas. 2003. *Astrofuturism: Science, Race, and Visions of Utopia in Space.* Philadelphia: University of Pennsylvania Press.

Kläger, Florian. 2018. “The Earthward Gaze and Self-Reflexivity in Anglophone Novels of the 1970s.” In *Limiting Outer Space. Astroculture After Apollo*, edited by Alexander C. T. Geppert, 131–54. Palgrave Studies in the History of Science and Technology. European Astroculture 2. London: Palgrave Macmillan.

Klinkrad, Heiner. 2006. *Space Debris: Models and Risk Analysis.* Springer Praxis Books in Astronautical Engineering. Chichester: Praxis Publishing.

Krige, John. 2006. *American Hegemony and the Postwar Reconstruction of Science in Europe.* Transformations: Studies in the History of Science and Technology. Cambridge: The MIT Press.

Krige, John. 2013. "NASA and Western Europe." In *NASA in the World: Fifty Years of International Collaboration in Space*, edited by John Krige, Angelina L. Callahan, and Ashok Maharaj, 23–124. Palgrave Studies in the History of Science and Technology. New York: Palgrave Macmillan.

Kuhlmann, Stefan, and Arie Rip. 2015. "Research Policy Must Rise to a Grand Challenge." *Forskningspolitikk* (4): 16–17.

Latour, Bruno. 2017. *Facing Gaia: Eight Lectures on the New Climatic Regime.* Cambridge: Polity Press.

Laudel, Grit, and Jochen Gläser. 2007. "Interviewing Scientists." *Science, Technology & Innovation Studies* 3 (2): 91–111. https://doi.org/10.17877/DE290R-983.

Law, John. 2017. "STS as Method." In *The Handbook of Science and Technology Studies*, edited by Ulrike Felt, Rayvon Fouché, Clark A. Miller, and Laurel Smith-Doerr. 4th ed., 31–57. Cambridge, London: The MIT Press.

Levidow, Les, and Claudia Neubauer. 2012. "Opening up Societal Futures Through EU Research and Innovation Agendas." *EASST Review* 31 (3): 4–11.

Long, Tony. 2009. "Jan. 22, 1997: Heads Up, Lottie! It's Space Junk!". *Wired*, January 22, 2009. https://www.wired.com/2009/01/jan-22-1997-heads-up-lottie-its-space-junk/.

Lovelock, James E. 1979. *Gaia: A New Look at Life on Earth.* Oxford: Oxford University Press.

Luhmann, Niklas. 1997. "Limits of Steering." *Theory, Culture & Society* 14 (1): 41–57. https://doi.org/10.1177/026327697014001003.

Luhmann, Niklas. 1998. *Observations on Modernity.* Writing science. Stanford: Stanford University Press.

Maasen, Sabine, and Sascha Dickel. 2019. “Normative Answers – Epistemic Questions. Updating the Science–society Contract.” In *Handbook on Science and Public Policy*, edited by Dagmar Simon, Stefan Kuhlmann, Julia Stamm, and Weert Canzler, 49–66. Handbooks of research on public policy. Cheltenham, Northampton: Edward Elgar Publishing.

MacDonald, Fraser. 2015. “Instruments of Science and War: Frank Malina and the Object of Rocketry.” In *Geography, Technology and Instruments of Exploration*, edited by Charles W. J. Withers and Fraser MacDonald, 219–41. Studies in Historical Geography. Farnham: Ashgate.

Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens. 1972. *The Limits to Growth: A Report for the Club of Rome’s Project on the Predicament of Mankind.* New York: Universe Books.

Messeri, Lisa. 2016. *Placing Outer Space: An Earthly Ethnography of Other Worlds.* Durham, London: Duke University Press.

Migaud, Michael R., Robert A. Greer, and Justin B. Bullock. 2021. “Developing an Adaptive Space Governance Framework.” *Space Policy* 55:1–9. https://doi.org/10.1016/j.spacepol.2020.101400.

Mütter, Bernd. 2012. “Per Media Ad Astra? Outer Space in West Germany’s Media, 1957–1987.” In *Imagining Outer Space. European Astroculture in the Twentieth Century*, edited by Alexander C. T. Geppert, 149–69. Palgrave Studies in the History of Science and Technology. European Astroculture 1. London: Palgrave Macmillan.

Ntim, Collins G. 2018. “Defining Corporate Governance: Shareholder Versus Stakeholder Models.” In *Global Encyclopedia of Public Administration, Public Policy, and Governance*, edited by Ali Farazmand, 1328–36. Cham: Springer International Publishing.

O’Tuathail, Gearóid. 1996. *Critical Geopolitics: The Politics of Writing Global Space.* London: Routledge.

OECD. 2014. *The Space Economy at a Glance 2014.* Paris: OECD Publishing. https://doi.org/10.1787/9789264217294-en.

Olechowski, Alison, Steven D. Eppinger, and Nitin Joglekar. 2015. "Technology Readiness Levels at 40: A Study of State-of-the-Art Use, Challenges, and Opportunities." In *Portland International Conference on Management of Engineering and Technology (PICMET)*, 2084–94. https://ieeexplore.ieee.org/document/7273196.

Olson, Valerie, and Lisa Messeri. 2015. "Beyond the Anthropocene: Un-Earthing an Epoch." *Environment and Society* 6 (1): 28–47. https://doi.org/10.3167/ares.2015.060103.

OneWeb. 2021. "Responsible Space." Accessed August 26, 2021. https://www.oneweb.world/responsible-space.

Ong, Aihwa. 2005. "Ecologies of Expertise: Assembling Flows, Managing Citizenship." In *Global Assemblages: Technology, Politics, and Ethics as Anthropological Problems*, edited by Aihwa Ong and Stephen J. Collier, 337–53. Malden: Blackwell Publishing.

Palmroth, Minna, Jenni Tapio, Alexander Soucek, Adriaan Perrels, Moriba K. Jah, Maija Lönnqvist, Mikko Nikulainen, Viktorija Piaulokaite, Timo Seppälä, and Jenni Virtanen. 2021. "Toward Sustainable Use of Space: Economic, Technological, and Legal Perspectives." *Space Policy* 57:1–12. https://doi.org/10.1016/j.spacepol.2021.101428.

Peoples, Columba. 2011. "The Securitization of Outer Space: Challenges for Arms Control." *Contemporary Security Policy* 32 (1): 76–98.

Praet, Istvan, and Juan F. Salazar. 2017. "Introduction: Familiarizing the Extraterrestrial / Making Our Planet Alien." *Environmental Humanities* 9 (2): 309–24. https://doi.org/10.1215/22011919-4215315.

Redfield, Peter. 1996. "Beneath a Modern Sky: Space Technology and Its Place on the Ground." *Science, Technology & Human Values* 21 (3): 251–74. https://doi.org/10.1177/016224399602100301.

Redfield, Peter. 2002. “The Half-Life of Empire in Outer Space.” *Social Studies of Science* 32 (5-6): 791–825. https://doi.org/10.1177/030631270203200508.

Robinson, Douglas K. R., and Mariana Mazzucato. 2019. “The Evolution of Mission-Oriented Policies: Exploring Changing Market Creating Policies in the US and European Space Sector.” *Research Policy* 48 (4): 936–48. https://doi.org/10.1016/j.respol.2018.10.005.

Rockström, Johan, Will Steffen, Kevin Noone, Asa Persson, Stuart F. Chapin, Eric F. Lambin, Timothy M. Lenton et al. 2009. “A Safe Operating Space for Humanity.” *Nature* 461 (7263): 472–75. https://doi.org/10.1038/461472a.

Ryan, Lorna. 2016. “‘Putting Space More at the Service of Europe and Its Citizens’: The Governance of European Space Policy and the Scientific Citizen.” In *Theorizing European Space Policy*, edited by Thomas C. Hoerber and Emmanuel Sigalas, 37–58. Lanham, Boulder, New York, London: Lexington Books.

Sato, Yasushi. 2005. “Local Engineering and Systems Engineering: Cultural Conflict at NASA’s Marshall Space Flight Center, 1960-1966.” *Technology and Culture* 46 (3): 561–83.

Sheehan, Michael. 2009. “Profaning the Path to the Sacred: The Militarisation of the European Space Programme.” In *Securing Outer Space*, edited by Natalie Bormann and Michael Sheehan, 170–85. Routledge critical security studies series. Milton Park: Routledge.

Sheehan, Michael. 2019. “Defining Space Security.” In *Handbook of Space Security. Policies, Applications and Programs*, edited by Kai-Uwe Schrogl, Peter L. Hays, Jana Robinson, Denis Moura, and Christina Giannopapa, 7–21. Cham: Springer.

Skidmore, Chris. 2021. “Looking After the Planet Also Means Cleaning up Space Debris.” *The Times*, July 14, 2021. https://www.thetimes.co.uk/article/looking-after-the-planet-also-means-cleaning-up-space-debris-nchtht6j8.

Spude, Mathias. 2013. “Does the European Integrated Space Industry Contribute to a New European Identity?” In *European Identity Through Space: Space Activities and Programmes as a Tool to Reinvigorate the European Identity*, edited by

Christophe Venet and Blandina Baranes, 103–18. Studies in Space Policy 9. Vienna, New Delhi: Springer.

Stengers, Isabelle. 2011. *Cosmopolitics II.* Posthumanities 10. Minneapolis, London: University of Minnesota Press.

Swedish Research Council. 2015. "The Lund Declaration 2015." Accessed August 26, 2021. https://www.vr.se/download/18.3d734fc616c30b114486e5/1566398569211/The+Lund+Declaration+2015%20final.pdf.

Trischler, Helmuth. 2002. "The "Triple Helix" of Space: German Space Activities in a European Perspective." Accessed August 26, 2021. https://www.esa.int/esapub/hsr/HSR_28.pdf.

Tutton, Richard. 2018. "Multiplanetary Imaginaries and Utopia: The Case of Mars One." *Science, Technology & Human Values* 43 (3): 518–39. https://doi.org/10.1177/0162243917737366.

Tutton, Richard. 2021. "Sociotechnical Imaginaries and Techno-Optimism: Examining Outer Space Utopias of Silicon Valley." *Science as Culture* 30 (3): 416–39. https://doi.org/10.1080/09505431.2020.1841151.

United Nations. 2019. "Report of the Committee on the Peaceful Uses of Outer Space: Sixty-Second Session (12-21 June 2019)." Official Records Seventy-fourth Session Supplement No. 20. Accessed August 26, 2021. https://www.unoosa.org/res/oosadoc/data/documents/2019/a/a7420_0_html/V1906077.pdf.

Valentine, David. 2012. "Exit Strategy: Profit, Cosmology, and the Future of Humans in Space." *Anthropological Quarterly* 85 (4): 1045–67. https://doi.org/10.1353/anq.2012.0073.

Valentine, David, Valerie A. Olson, and Debbora Battaglia. 2012. "Extreme: Limits and Horizons in the Once and Future Cosmos." *Anthropological Quarterly* 85 (4): 1007–26. https://doi.org/10.1353/anq.2012.0066.

Vogt, Markus, and Christoph Weber. 2019. “Current Challenges to the Concept of Sustainability.” *Global Sustainability* 2 (4): 1–6. https://doi.org/10.1017/sus.2019.1.

Wanzenböck, Iris, Joeri H. Wesseling, Koen Frenken, Marko P. Hekkert, and K. Matthias Weber. 2020. “A Framework for Mission-Oriented Innovation Policy: Alternative Pathways Through the Problem–solution Space.” *Science and Public Policy* 47 (4): 474–89. https://doi.org/10.1093/scipol/scaa027.

Ward, Barbara, and René J. Dubos. 1983. *Only One Earth: The Care and Maintenance of a Small Planet.* New York: W. W. Norton & Company.

Wehling, Peter. 2012. “From Invited to Uninvited Participation (And Back?): Rethinking Civil Society Engagement in Technology Assessment and Development.” *Poiesis & Praxis* 9 (1-2): 43–60. https://doi.org/10.1007/s10202-012-0125-2.

Wesseling, Joeri H., and Charles Edquist. 2018. “Public Procurement for Innovation to Help Meet Societal Challenges: A Review and Case Study.” *Science and Public Policy* 45 (4): 493–502. https://doi.org/10.1093/scipol/scy013.

Annex

Article Abstracts and Mention of Individual Contribution

Article 1

Michael Clormann: "Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation"

Published in Science and Public Policy (2021) – Accepted Version

Abstract

With the advent of the so-called New Space Age, promoted by private actors and driven by market logic innovation, the European space sector meets significant challenges over recent years. This paper explores the implications of New Space's emergence for contemporary societies that increasingly rely on space technologies as critical infrastructures. It does so by analyzing conflicting logics of innovation within the sector arising from a clash of Old Space and New Space cultures and associated role identities. To this end, it combines concepts of institutional culture and role identity from STS and organization studies. Tracing the identity work performed by members of the European space sector through qualitative interviews, it concludes that new demands of market logic innovation are negotiated within a mode of switching between different sector cultures. It concludes that this mode provides opportunities for the responsible future governance of critical space infrastructures.

Contribution Michael Clormann: The empirical, methodical, theoretical, and analytical implementation of this article was entirely done by the author.

Article 2

Michael Clormann & Nina Klimburg-Witjes: "Troubled Orbits and Earthly Concerns: Space Debris as a Boundary Infrastructure"

Published in Science, Technology & Human Values (2021)

Abstract

Like other forms of debris in terrestrial and marine environments, space debris prompts questions about how we can live with the material remains of technological endeavors past and yet to come. Although techno-societies fundamentally rely on space infrastructures, they so far have failed to address the infrastructural challenge of debris. Only very recently has the awareness of space debris as a severe risk to both space and Earth infrastructures increased within the space community. One reason for this is the renewed momentum of interplanetary space exploration, including the colonization of the Moon and Mars, which is part of transhumanist and commercially driven dreams of the so-called "New Space Age." Understanding space infrastructures as inherently linked to earthly infrastructure, we attend to the ways in which space debris, a once accepted by-product of scientific-technological progress, economic interests, and geopolitics, increasingly becomes a matter of concern. Drawing on qualitative interviews with European space sector representatives and STS-work on infrastructures, we argue that their discursive efforts and visual representation strategies co-produce space debris as a boundary infrastructure. We suggest considering this boundary infrastructure as relating

orbital environments and the planet through enacting sustainability and responsibility for beyond-planetary environments.

Contribution Michael Clormann: The author has contributed to the publication of the article as the main and corresponding author. The original idea and case selection of the article were based on the overarching thematic perspective of his dissertation project. Empirically, the article is, with few exceptions, based on empirical material gathered by the author. This is especially the case for the expert interviews upon which its analysis largely rests. Except one, interviews were conducted and transcribed by the author. The author has proposed and implemented the theoretical framework of boundary infrastructures. The author has performed the larger part of operationalizing and analyzing the empirical material. The author has taken the lead role in writing the original version of the article as well as revising it upon request of the reviewers and editors.

Letter of Agreement

SAGE's Author Archiving and Re-Use Guidelines

These guidelines should be followed by authors of Contributions published in a SAGE subscription journal, including authors whose Contributions were published under a previous version of the author guidelines. For a list of exceptions to these guidelines, please see below.

Three versions of the Contribution are referenced in these guidelines:

- **Original Submission:** the version submitted by the author before peer review
- **Accepted Manuscript:** version updated to include the author's revisions after peer review, prior to any typesetting for the journal. This is often the version accepted by the editor
- **Final Published PDF:** copy-edited and typeset Publisher's PDF, the same version published on the journal's website

Green Open Access: SAGE's Archiving and Sharing Policy

You may share the **Original Submission** or **Accepted Manuscript** at any time after your paper is accepted and in any format. Your sharing of the **Original Submission** or **Accepted Manuscript** may include posting a downloadable copy on any website, saving a copy in any repository or network, sharing a copy through any social media channel, and distributing print or electronic copies. Please note some journals will not consider papers that have been posted as preprints prior to submission and you may check a journal's policy regarding considering previously-posted papers by referring to the journal's submission guidelines.

For information on use of Institutional Repository (IR) copies by authors and IR users, see Posting to an Institutional Repository - Green Open Access.

You may use the **Final Published PDF** (or **Original Submission** or **Accepted Manuscript**, if preferred) in the following ways:

- in relation to your own teaching, provided that any electronic distribution maintains restricted access
- to share on an individual basis with research colleagues, provided that such sharing is not for commercial purposes
- in your dissertation or thesis, including where the dissertation or thesis will be posted in any electronic Institutional Repository or database
- in a book authored or edited by you, at any time after the Contribution's publication in the journal.

Provided that:

- Access to the Original Submission and Accepted Manuscript is provided at no charge.

- Any re-use terms for users of websites and repositories (where your **Original Submission** or **Accepted Manuscript** are posted) are restricted to non-commercial and no derivative uses.
- You may not post the **Final Published PDF** on any unrestricted website or repository without permission from SAGE.
- You may not republish or translate any version of your Contribution in another journal without prior permission from SAGE.
- The journal as the original publication of your Contribution is appropriately credited by including the full citation information each time your Contribution, or excerpts, are further distributed or re-used:
    - After your Contribution has been accepted for publication and until it is assigned a DOI, please include a statement that your Contribution has been accepted for publication in the journal.
    - Once full citation information for your Contribution is available, please include this with your posted Contribution, in a format similar to the following:
      Author(s), Contribution Title, Journal Title (Journal Volume Number and Issue Number) pp. xx-xx. Copyright © [year] (Copyright Holder). DOI: [DOI number].

Journal Exceptions

Exceptions to this Author Re-Use policy: The following journals have a different author re-use policy in place. The re-use terms for these journals are stated in the Contributor Agreement used by the Journal.

If you have questions regarding the following titles, contact the permissions team through our SAGE Permissions Portal.

- *California Management Review*
- *Journal of Dental Research*
- *JDR Clinical & Translational Research*
- *Acta Radiologica* (from January 2018)
- *Index on Censorship*
- *Pain News*
- *Political Insight*
- *Recherche et Applications en Marketing*

Related Information

Authors of Contributions published as SAGE Choice or in a Gold Open Access journal should reference Reusing Open Access and SAGE Choice Content. For a list of SAGE's Gold Open Access journals, please see Gold Open Access journals.

Authors of Contributions published under a Creative Commons license may re-use their work under the terms of the Creative Commons license attached to their Contributions and additionally have all rights to re-use their work stated above.

For information about requesting permission for content published in SAGE journals, see Process for Requesting Permission.

For information about author copies, see Author e-prints policy.

If you are submitting a manuscript to a SAGE journal and wish to include

previously published materials within the manuscript, visit our Author Gateway Copyright and Permissions FAQs.

Last updated: 31 July 2020

Journal: Science and Public Policy
DOI: 10.1093/scipol/scab038
Title: Switching Between Worlds Apart: Negotiating European Space Sector Cultures Through Innovation

Standard Licence