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Infrastructure on/off Earth

Edited by: Christine Bichsel

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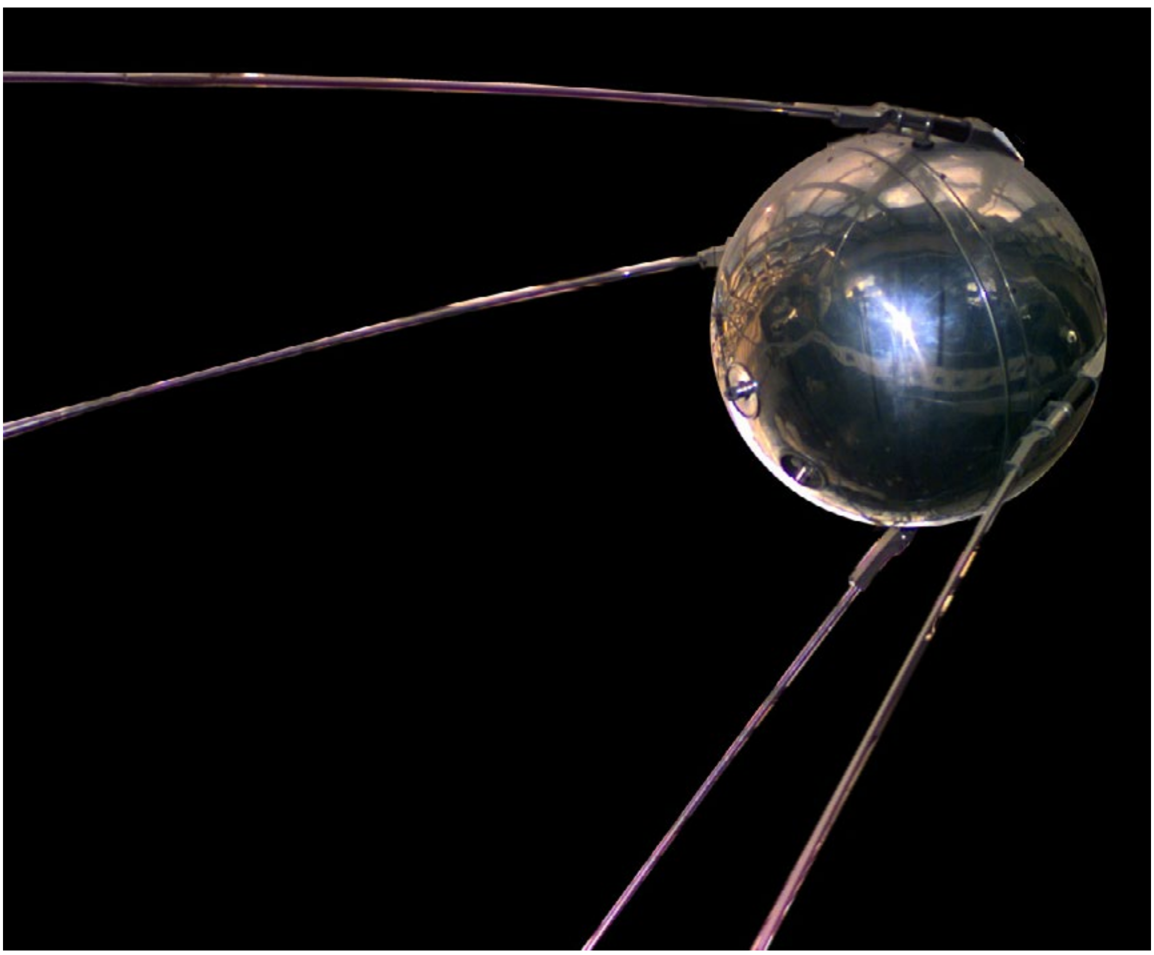
Introduction: Infrastructure on/off Earth

Christine Bichsel

"Interrogate the slash!" *Roadsides*' edited collection no. 003 examines the meanings embedded in the slash between "on" and "off" for the infrastructure of space exploration and outer space. This slash implies simultaneity, but also distinction. It both connects and separates (Friedman 2010: 475). "On/off" alludes to a switch that has two positions, but also refers to a process that is not continuous, one that repeatedly starts and stops. These ideas serve as an entry point to think through the relationships between the states of "on Earth" and "off Earth." At first sight, these two states appear self-evident, representing separate geographical domains with a more or less defined boundary. As the atmosphere fades away, "on Earth" is phasing out and "off Earth" begins. However, this edited collection argues that there are many nuances in these two states and in the relations between them. We address the following question: How does a conceptual and empirical focus on infrastructure advance our understanding of the cultural, political and economic relationalities of outer space?

This collection brings into conversation two fields of the social sciences: the emerging social studies of outer space (Messeri 2016: 16) and recent social science research on infrastructure. First, it provides insights into how social science scholarship of space-related activities can contribute to infrastructure studies. The contributions demonstrate that a focus on space infrastructure helps to unpack the terracentric assumptions and boundaries currently informing infrastructure studies, such as the prevalence of gravity and air pressure, and fixity in space-time with its Cartesian coordinates. Second, the collection shows how insights from the "infrastructural turn" in the social sciences can advance social studies of outer space. To date, infrastructure has figured in these studies as the "hardware" or "backdrop" for analyzing the social relations of outer space. However, this collection suggests that infrastructure may be a key entry point for unravelling the relationalities of Earth and outer space (Battaglia et al. 2015; Valentine 2016). Infrastructure studies offer the conceptual tools for such an analysis.

The model of Sputnik 1.
Credit: https://nssdc.gsfc.nasa.gov.



In physical terms, the boundary between "on Earth" and "off Earth" has always been porous. For example, Earth not only experiences atmospheric weather but also "space weather" – the latter designating conditions in the Sun and the solar wind that can affect instrumentation and human health on Earth (Taylor, this issue). The very idea of the boundary is culturally and historically contingent, too. Since antiquity, Western imagination has conceived and represented Earth as a globe (Cosgrove 2001), a mental operation that requires defining Earth's boundaries and its relation to the "outside." Moreover, throughout history, the idea of a bounded Earth has acquired great epistemological and normative power. Terracentric boundaries inform philosophies of human existence and sociality (Lazier 2011), and are involved in constructing social theory more generally (Olson and Messeri 2015). The practice of humans going "off Earth" through space exploration since the mid-twentieth century has raised new questions about this boundary (Battaglia et al. 2015; Praet and Salazar 2017).

In interrogating the connections between "on Earth" and "off Earth" through the lens of infrastructure, this collection argues that the conceptual and empirical analysis of space infrastructure – that is, the infrastructure of space exploration and outer space – can further our understanding of how these two states relate to each other. Space exploration is a highly material and technology-intensive activity, as contributions to this collection demonstrate. To escape Earth's gravity, humans require engineered vessels and strong propulsion produced by launching facilities (Peldszus, this issue). Once in space, humans are fully dependent on a highly elaborate built environment which creates the necessary conditions for survival under extreme conditions (Damjanov and Crouch, Bichsel, this issue). In turn, most of outer space only becomes accessible to the senses when mediated through technology such as radio telescopes (Hoeppe, Merron, this issue). Contemporary society on Earth relies heavily on a dense network of satellites for telecommunication and navigation purposes (Luk and Wijeyeratne, this issue). Yet imaginaries become infrastructure too, as they enable and sustain aspirations for human expansion into outer space (Dunnett, Popper, this issue).

The nine contributions making up Roadsides 003 explore space infrastructure for its on/off Earth relations. **Katarina Damjanov** and **David Crouch** analyze the International Space Station (ISS) as a media infrastructure. They demonstrate how the specific configuration of modules, cables and wireless networks produces a closed system that is, at the same time, intimately linked to Earth through material and signal traffic, including live feeds. The essay by **Götz Hoeppe** engages with the sky as an infrastructural medium. He shows how the sky itself becomes a resource for infrastructuring practices in astronomy, the latter creating epistemic communities in science that form around methods of instrumentation. **Joseph Popper** considers imaginaries of private and commercial space exploration as infrastructure. He offers insights into how material and representational artefacts collapse the near and distant future, stabilizing aspirations for human expansion into outer space. **Regina Peldszus** focuses on space launch systems with a view to infrastructure resilience. She shows how disparate launch debris from the explosion of the Ariane 5 rocket epitomizes the ever more complex system-of-systems of space infrastructure, of which human actors can only grasp and act upon a microscopic section. **Oliver Dunnett** explores the space elevator as imaginary infrastructure in science fiction literature. He reveals how this literature anticipates the geographical, cultural and political ramifications of fast access from Earth to outer space by means of a tether linking a point on the equator to a point in geostationary orbit. **Christine Bichsel**'s paper looks at the former space station Mir as cinematographic infrastructure. She sheds light on how Mir as a representational object is closely interwoven with the political turmoil of Soviet disintegration in 1991. In their contribution, **Christine Luk** and **Subodhana Wijeyeratne** examine the satellite architecture for global positioning systems as geopolitical infrastructure. They elaborate on how competing satellite systems are a means for and expression of claims to global control over terrestrial navigation. **A. R. E. Taylor** focuses on space weather to think through critical infrastructure. He demonstrates how public and political perceptions of solar conditions as a threat to ground-based terrestrial infrastructure reconfigure relations of connectivity between Earth and Sun, and redefine the scope of space infrastructure. **James Merron**'s essay investigates a radio astronomical observatory as ambient infrastructure. He reveals how the production of astronomical knowledge of the Universe bears the inscriptions of contemporary terrestrial life and local contestations from the surrounding space.

Let me draw attention to three cross-cutting themes that emerge in these contributions. First, there is the historical contingency of space infrastructure. This manifests in the ISS's interconnected American and Russian sections (Damjanov and Crouch), as the latter was originally meant to become space station Mir-2; in the conversion of an obsolete broadcasting dish into a radio telescope (Merron); the trajectory of the space elevator as "almost possible" infrastructure from Soviet space science to British and American science fiction (Dunnett), and in the adaptation of former NASA imagery by NewSpace actors for the projection of their business aspirations (Popper).

Second, we see the tension between humanist framing of and particular interests in space infrastructure. Labeled as "for all of humanity" in representations of future human habitation in space or scientific knowledge of the Universe, space infrastructure embodies geopolitical and ideological projects such as the Chinese Space Silk Road (Luk and Wijeyeratne) or pan-African aspirations (Merron), provides a nucleus for epistemic communities in science (Hoeppe), and creates complex multinational technological assemblages with unpredictable dynamics (Peldszus).

The third strand is the normative and epistemological centrality of "on Earth" against "off Earth." Even if humans escape Earth's gravity by dwelling on space stations (Damjanov and Crouch; Bichsel), they remain within the intellectual force field of Earthbound frames of reference (Clark 2013). Space exploration itself is defined by Earthbound epistemologies. As a project of knowledge production, it is driven by "on Earth" assumptions and purposes. "On Earth" and "off Earth" are thus not solely relational states, but mutually constitutive domains exposing a power asymmetry. "On Earth," so far, remains the singular and dominant framework within which space infrastructure's materiality and imaginaries take shape.

This introduction took as a starting point the slash in "on/off Earth", aiming to examine this apparent division and its embedded meanings. The slash, it has proved, reveals a complex set of relationships inviting us to question whether it makes sense to distinguish and separate those two states. Should we then do away with the slash in order to overcome the dichotomy of "on Earth" versus "off Earth," replacing it with a more encompassing and relational concept? The nine contributions show that thinking with and through the slash is productive. While they demonstrate that the separation and distinction between "on Earth" and "off Earth" is in many ways arbitrary and unhelpful for analyzing space infrastructure, they also show how terracentric boundaries powerfully shape scientific and popular thought. As such, the slash might be worth keeping for the time being. Undoing the "on/off Earth" distinction too early risks losing sight of how it is continuously constructed and maintained in societies. The slash forces us to engage further with this very particular relationship.

I would like to express my gratitude to the scholars who have acted as reviewers for this collection (in alphabetical order): Victor Buchli, Julie Chu, Götz Hoeppe, Agnieszka Joniak-Lüthi, Madlen Kobi, Valerie Olson, Alessandro Rippa, Rory Rowan, Martin Saxer, Fred Scharmen, Joanne Sharp and Max Woodworth. I would also like to thank Agnieszka Joniak-Lüthi for her editorial work, David Hawkins for copy-editing and Chantal Hinni for design. Finally, I extend my thanks to the authors of this collection, whose fascinating contributions have given me the chance to closely engage with and further develop my thinking on infrastructure and space.

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Mooring a Space Station: Media Infrastructure and the Inhuman Environment

Katarina Damjanov and David Crouch

Among various ventures to extend earthly activities into Earth's inhuman exterior, space stations occupy a special place. Designed to provide inhabitable enclosures, their operations highlight the mediatic capacity of infrastructures to condition our environmental circumstances. Media infrastructures have long been integral to the development of human settlements (Mattern 2015) and their potential to interfere with our material and social relations is more advanced in the setting of outer space, where their complex technological and organisational edifice must be mobilised to sustain human ways of life (Damjanov 2015). Space stations in this sense constitute media infrastructures par excellence. They envelop complex configurations of the technological moorings and data-gathering, storing and relaying capacities of media, at once embodying a range of the structural groundings and operative logics of media infrastructures, and protracting them into a novel environmental situation. Such arrangements provide a testing ground for probing into the limits and possibilities of our infrastructural lives, offering a condensation of their socio-technical features and effects, but also an expansion of the problematics that surround their assertion and control.

Several stations have occupied Earth's low orbit thus far, for various lengths of time, from the Soviet Union's Salyut 1 (1971) and the United States' Skylab (1973–79) to Mir (1986–2001) and the International Space Station (ISS, 1998–). Their historical development marks advances in human infrastructural endeavour – each subsequent station providing a more sophisticated and durable dwelling environment. Currently, the ISS is the sole such settlement in space, having been continuously occupied since the arrival of the first crew. A joint project between a number of space agencies and various scientific, commercial and military interests, it constitutes unique infrastructural entanglements involving an orbital choreography of still-malleable socio-technical systems and their political, economic and cultural scaffolding. The ISS is designed to provide a safe harbour amid its unforgiving surroundings, necessitating experimental approaches to upholding the courses of life as we know it, but at the same time demanding their highly regimented distribution and arrangement (Damjanov and Crouch 2019). A scripting of media infrastructures in progress with the capacity to further assert their high-tech systems and processes, the ISS encapsulates a host of strategies intended to upend our environmental confines.

The International Space Station.
Credit: https://www.nasa.gov.

The ISS features an intricate infrastructural configuration. Its modular architecture comprises two main sections operated respectively by the United States' National Aeronautics and Space Administration (NASA) and Russia's Roscosmos, and interconnected through an Environmental Control and Life Support System that conducts multiple subsystems, from sanitation facilities to atmosphere control systems. The whole station is strapped together with "eight miles of wire" that links an electrical power system generated by solar arrays (NASA 2019). The American section is maintained by "more than 1.5 million lines of flight software code run on 44 computers communicating via 100 data networks transferring 400,000 signals" (NASA 2019). It sends transmissions to ground stations via the Tracking and Data Relay Satellite System, while communication between nodes is conducted through an internal wireless network. The airlocks and arrays, docking ports and cargo bays, laboratories and cupolas all form a sealed and pressurised habitat that conditions life in a casing of software and hardware. It has thus far been occupied by over two hundred astronauts, several space tourists, various plants and animals and a range of assistive technological apparatus, all working in tandem to facilitate trials across the domains of science – from physics, the geosciences, astronomy and robotics, to chemistry, biology, medicine and meteorology. The ISS encloses all of its components, human and non-human, biotic and abiotic, within an intricate ecology reliant on the design of its interlocking life support systems, recasting a gamut of both "natural" and "artificial" terrestrial processes in purely infrastructural terms.

Edible plants ready for harvest.
Credit: https://www.nasa.gov.

The ISS itself relies on continued assistance from the world below. Work and life aboard are contingent upon the station's terrestrial moorings. Most essential resources are delivered – food, air, water, various tools and materials, instruments and specimens, from toilet paper to solar panels, are all supplied every few months at high cost (NASA 2018). Seemingly separated from Earth, the ISS is in fact closely interlinked with the planet through the signal traffic between it and its ground controls. The very materiality of these signal exchanges establishes underlying structures of connection and direction. All activities at the ISS are continually monitored through multiple forms of scrutiny, which include comprehensive details about the status and operations of all its systems and subsystems, including the biometric data of its inhabitants – as NASA describes: "on-orbit software" and "approximately 350,000 sensors" monitor "crew health and safety" (NASA 2019). The station's modular segments, robotic arms, living quarters and experiment bays are all part of an architecture that constantly collects and distributes data, evidence and information. It is this intense, all-encompassing mediation that shapes and gives form to life in orbit. Highlighting the infrastructural capacities of "technical networks" to create "communicative spaces" (Mattern 2015: 98), the ISS ecosystem establishes a unique social space that also maintains forms of contact with both its terrestrial and orbital exterior. As media infrastructure, it is in this sense a multilayered orchestration of "communication and communion" (Mattern 2015: 95), which enables the station's connectedness, but also its thorough control.

The hermetic enclosure, containment and rigorous observation of the ISS cultivate particular infrastructural responses to the strategic management and organisation of human settlements in extreme environments. Innovative technologies are regularly recruited to assist in developing more amenable and efficient day-to-day operations – such as the dexterous humanoid robot, Robonaut, which has worked alongside crews since 2012 (Badger 2019). Simultaneously, continuous improvements are made towards securing the station's greater autonomy – in 2014, a 3D printer was brought to the station to enable astronauts to manufacture small tools and hardware rather than wait for them to be dispatched (NASA 2014).

An astronaut and Robonaut work together. Credit: https://www.nasa.gov.

At the same time, better connections with the planet below are established; in 2019, NASA upgraded the internet communication systems with the station, achieving speeds greater than on Earth (Peters 2019). Organised and operated as a multifaceted media infrastructure, the ISS becomes both increasingly self-sustaining, but also systematically conditioned.

An astronaut holds a 3D-printed wrench. Credit: https://www.nasa.gov.

These provisions are not purely technical; they also involve particular political and cultural economies and agendas. Based around an idea of international cooperation in the commons of outer space, the ISS suggests successful connection and exchange, but also various kinds of social restriction and all-inclusive interference. The proceedings of everyday life aboard the station are video-streamed in real time to global audiences, while actually accessing the station is difficult; very few humans qualify for residence, only particular nations participate, only selected projects and experiments are permitted and only certain technologies recruited to assist (Damjanov and Crouch 2019). Restrictions and regulations abound – from the chemical composition of objects, to the health of biological subjects. On the other hand, the station captures planetary attention;

sometimes visible with the naked eye, it appeals to the collective imagination as a revolving symbol of human progress in space. Entangled with Earth, the ISS reproduces all the tensions that undergird the terrestrial settlements of the species – its hierarchies, exclusions and uneven exchanges – but juxtaposes these earthly problems in unusual ways, condensing and refracting them amid the inhuman environment of space. As media infrastructure, it connects these experimentations and rearrangements with life on Earth, opening up social and material traffic that continues to reshape human techno-environmental relations.

The ISS, however, will not last forever – beyond the station's eventual decommissioning, its fate is uncertain. Boeing is currently contracted to maintain the hardware until 2028 (Maass 2015), and in 2018 the United States passed the Leading Human Spaceflight Act, intending to prolong the activities aboard until 2030 (Smith 2018). Roscosmos and NASA have each considered the station's afterlife. Parts of the Russian segment are proposed as the groundwork for another piloted complex, forming "the core of a new orbital outpost, which would serve as a haven and assembly shop for deep space missions heading to the Moon, Mars and beyond" (Zak 2009). In 2011 Boeing suggested using leftover ISS hardware to construct an "Exploration Gateway Platform" that would contribute to "long duration habitat evolution" and provide a "flexible path to exploration" (Raftery 2011). Such plans for off-Earth settlement are both highly speculative and already in motion, and perhaps made more pressing by the spectre of planetary precarity. Offering the foundational steps and systems needed to maintain life in space, the ISS may play a pivotal role in the "media-infrastructural historiography" (Mattern 2015: 105). It constitutes a significant new form in the ongoing development of complex infrastructure, highly networked systems and the corresponding formation of human social, political and cultural milieus. As both an experiment in life at the edge and also a platform from which further to advance the expansion of its infrastructural logics, the "groundwork" of the ISS continues to concentrate and "uplift" human prospects in space.

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A Sky to Work With: Astronomers, Media, Infrastructures

Götz Hoeppe

A few years ago, while doing ethnographic fieldwork on data uses in astronomy, I was struck by a remark made by the astronomer David Hogg. He wrote in a blog post that "[a]ll of astronomy and astrophysics is built on the observation and reobservation of sources on the sky."[1] This apparently self-evident statement intrigued me as I witnessed research carried out at an institute in Germany and observatories in Chile and Spain. I noticed that the phenomenal properties of the sky – its apparent immutability and the richness of its visible features – pervaded astronomical work and provided infrastructural resources for actions that astronomers rarely acknowledged in their publications.

If time-keeping and navigation count as infrastructural practices, as John Durham Peters (2015) contends, the sky has been an infrastructural medium for many societies since time immemorial. Here I argue that, thanks to the use of recording media, the sky is not only a topic of scientific curiosity and research but also an infrastructural resource for astronomical work that is essential but easy to overlook. Having a shared sky to work with can be a hard-won achievement for an epistemic community.

Figure 1: The dome of the 3.5m telescope at Calar Alto Observatory (Andalusia, Spain) at twilight.
Photo: Götz Hoeppe.

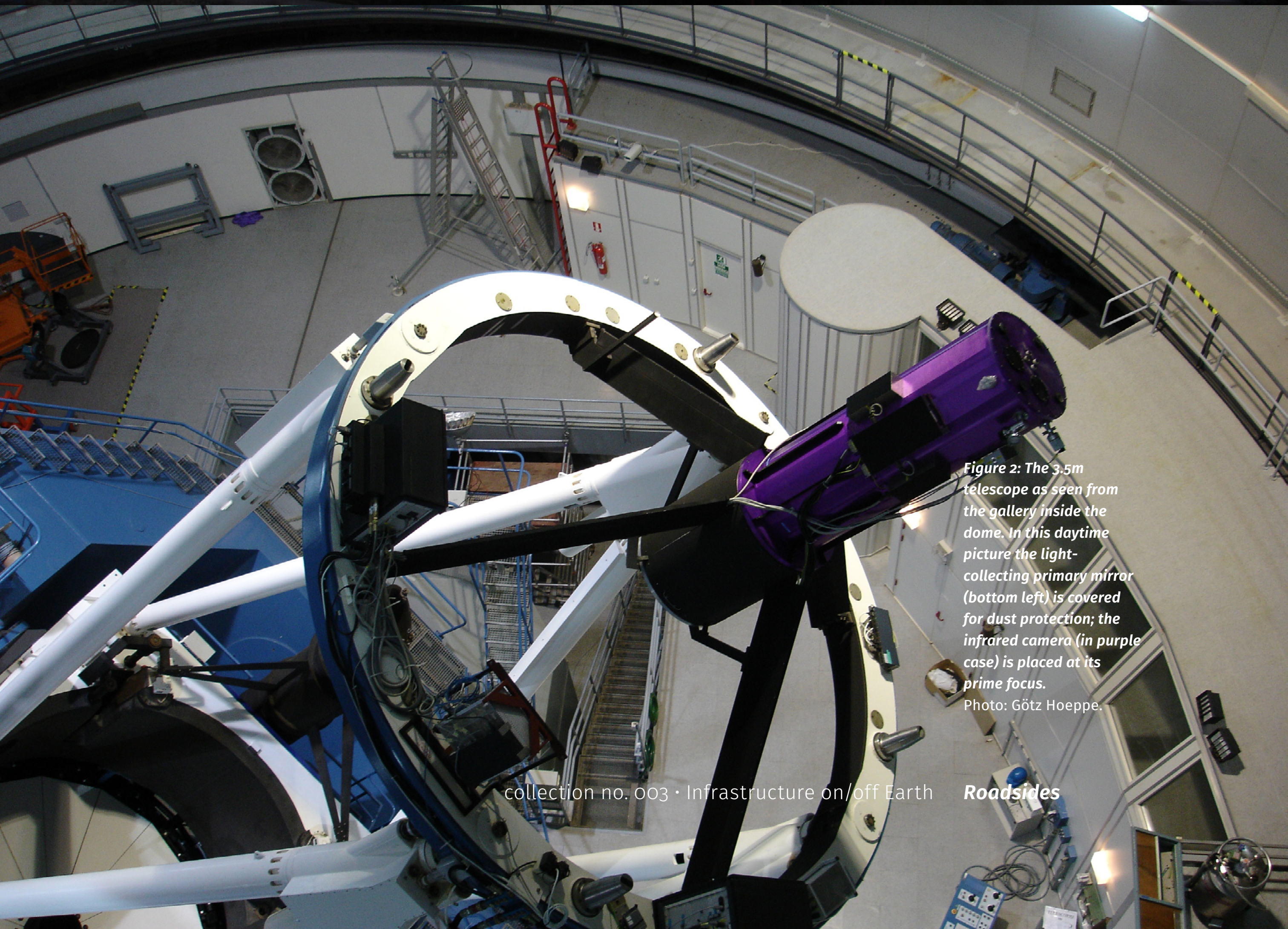

Figure 2: The 3.5m telescope as seen from the gallery inside the dome. In this daytime picture the light-collecting primary mirror (bottom left) is covered for dust protection; the infrared camera (in purple case) is placed at its prime focus.
Photo: Götz Hoeppe.

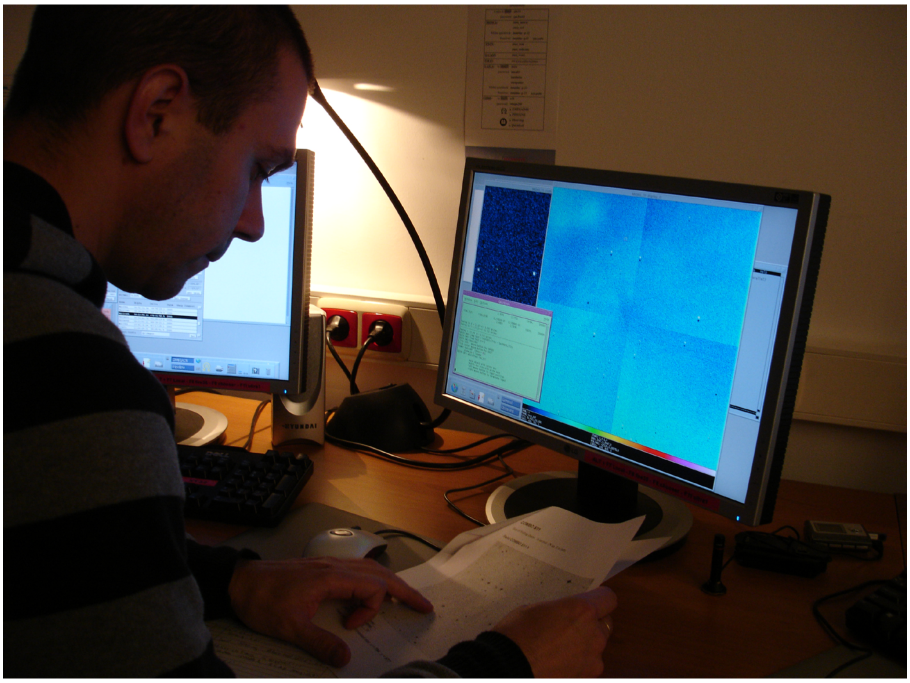

Figure 3: At night in the control room of the 3.5m telescope: Jorge aligns a snapshot exposure (on screen) with a finding chart.
Photo: Götz Hoeppe.

I begin with a night of observing, at the controls of the 3.5m telescope of Calar Alto Observatory in Spain (Fig. 1 and 2). Jorge (pseudonym), a staff astronomer, is about to take photographic exposures of a distant galaxy cluster in infrared light for a research astronomer who has not come to the mountain. After Jorge enters the cluster's celestial coordinates, the telescope slews to the cluster location in the sky. Jorge then captures a brief exposure and brings it up on screen (Fig. 3). Now he can compare the pattern of stars – visible as black dots on a blue background – with those seen on a photographic negative, a finding chart prepared years ago at another observatory. Thus, Jorge can determine the position for the long exposures that he will subsequently take. Materializing it on paper and a computer screen – two dominant media of contemporary scientific work – Jorge aligns the otherwise immaterial pattern of cosmic radiation with a substratum of existing data.

Months later, Nadine (pseudonym), a PhD student, combines Jorge's exposures of the galaxy cluster with some made previously in visible light using a telescope in Chile (Fig. 4). Instructed by senior scientists, she soon discovers that all "raw data" contain artefacts, caused, for example, by stray light in the telescope, cosmic rays or radioactivity in the ground nearby. Seeking to distinguish signals from noise, she proceeds in her data analysis, but has to retrace her steps occasionally, such as when encountering implausible or contradictory consequences. Then she refines her data reductions and proceeds again from there – a sort of reflexivity.[2] Mediated through digital exposures and tabulations of measurements, the sky provides various saliences for this work. For example, stars seen in multiple digital images can be used secondary calibration sources. Nadine learns to decide what to take as the stable background (a resource for her research) and what as foreground (its topic), using the sky as an organizational resource. Such work is therefore fundamentally relational and context dependent (Hoeppe 2014).

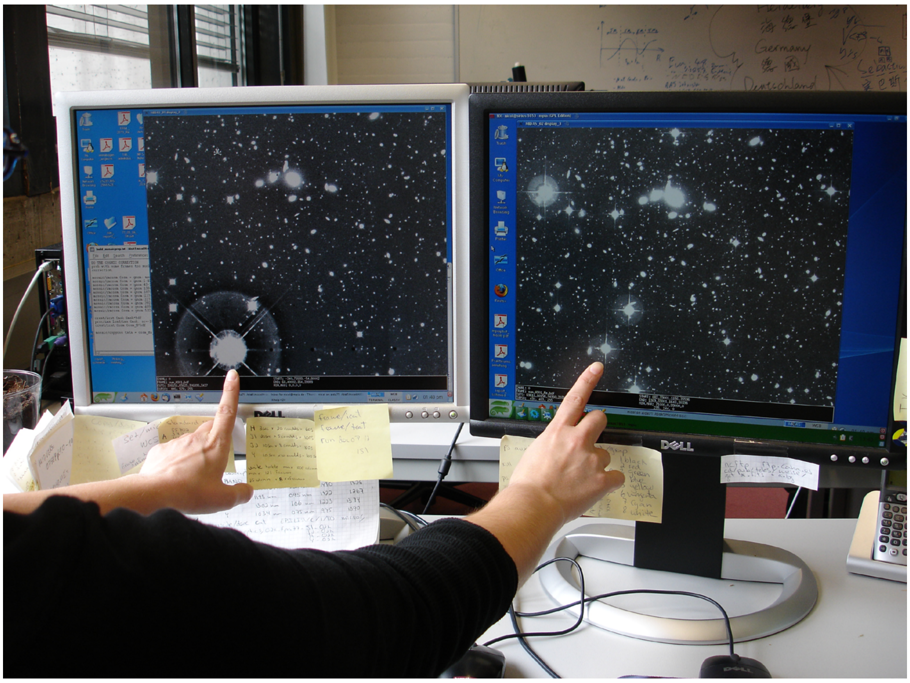

Figure 4: Nadine compares her newly reduced digital infrared image of a galaxy cluster (left) with an image reduced by a former PhD student in the research group (right).
Photo: Götz Hoeppe.

Having a sky to work with, as Jorge and Nadine do, is not something that all astronomers are used to. Various kinds of radiation – be it radio, infrared or ultraviolet waves – are detected using distinct technologies. Each constitutes a separate window on the Universe, and a distinct sky, if the latter is defined as "a two-dimensional distribution of intensity of electromagnetic radiation" (Léna 1989: 245). That astronomers speak with ease of the "radio sky," the "infrared sky" and the "ultraviolet sky" reveals how profoundly their access to the universe is mediated technologically.[3]

One of the newest skies assembled by astronomers is the cosmic microwave background (CMB) radiation of the '"microwave sky," interpreted as relic radiation of the Big Bang almost 14 billion years ago. Astronomers measure its intensity and polarization patterns to gain clues about the early Universe. In March 2014, Princeton University astrophysicist David Spergel gave a talk on the state of this field. Somewhat reminiscent of Jorge's alignment of finding chart and snapshot exposure, Spergel began his presentation by comparing two greyscale pixel maps of the fluctuation pattern of the microwave background in a patch of the sky. One was based on measurements taken with the Atacama Cosmology Telescope in Chile using a very sensitive semi-conducting detector; the other was made using a different detector design (a bolometer) onboard the Planck satellite (see Fig. 5). Pointing to similarities of the patterns visible in the two maps, Spergel explains (<u>underscoring</u> indicates emphasis):

> *These are <u>completely</u> different experimental set-ups … and [yet] you see the <u>same thing</u> … and this is true with a host of experiments … One of the things I want you to take away from this is the remarkable* agreement *we have between independent experiments at this point … making these measurements … So if you actually look at the same part of the sky the <u>agreement</u> here is really remarkably good.*[4]

Improvements in the sensitivity and angular resolution of microwave observations make such an agreement possible. Seeing "the same" sky again through different technologies has made these technologies trustworthy for Spergel. This is what philosophers of science call "robustness reasoning" (Wimsatt 2012).

Note that Spergel talks about experiments – reminiscent of laboratory work in science – whose phenomena are contingent on lab infrastructures. Of course, literally speaking, the Big Bang (as the object of these studies) is unavailable for scientific experimentation. Earlier "CMB experiments" were designed for measuring specific observables in single campaigns of observing patches of the sky that, typically, no other team studied. By contrast, observatories are now made to "observe and re-observe" signals from an ambient, shared environment again and again. What Spergel thus describes is a step in the maturation of this scientific field. This entails novel possibilities for reflexive data uses.

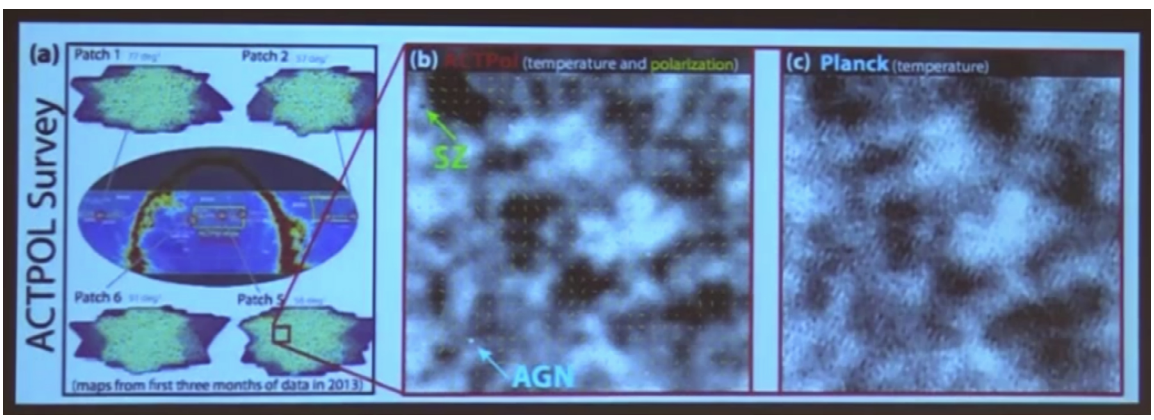

Figure 5: A slide from David Spergel's presentation: two greyscale pixel maps of the fluctuation pattern of the microwave background in a patch in the sky, one made with the Atacama Cosmology Telescope (center), the other with the Planck satellite (right). Source: https://www.youtube.com/watch?v=j3fHkQa6818.

A month after Spergel's lecture, at a discussion at the Perimeter Institute for Theoretical Physics in Waterloo (Canada), other CMB researchers shared his excitement. Addressing fellow panellist Barth Netterfield, a physicist from the University of Toronto, McGill University astronomer Matt Dobbs said:

> *We can make a measurement and other people can go out and verify that measurement and show real science, Barth! [laughter] … and show that that is a reproducible thing that is on the sky.*[5]

Spergel's talk and this discussion happened in the wake of the announcement of the BICEP2 collaboration, which had claimed the detection of a weak but characteristic polarization pattern in the microwave sky that was presented as evidence of cosmic inflation, a previously theorized phase of rapid expansion of the early Universe.[6] Spergel criticized the BICEP2 interpretation by demonstrating the researchers had ignored the fact that their processed data did not show a consistent, immutable sky. Arguably, the BICEP2 team – perhaps still bound by an experimental attitude – had not properly used the sky as an organizational resource for its data analysis (Hoeppe 2019).

The progress from making experiments to observing and re-observing the sky as a shared environment allows for a new reflexivity of data work that scientists regard as essential for "doing astronomy" – in distinction to "doing lab physics." It also marks an extension of the "instrumental communities" (Mody 2011) involved – such as the users of the Atacama Cosmology Telescope, the Planck satellite and BICEP2 – opening up new possibilities for sharing expertise and securing scientific robustness.

A century ago, writing in a quite different context, sociologist Georg Simmel noticed:

> *That a sense like vision, which alters that which is seen simultaneously for everyone due to their specific viewpoint, nevertheless has an object in common – the sky, the sun, the stars – must imply on the one hand the transcendence from the confinement and particularity of the subject that marks any religion. On the other hand it carries and enables a moment of the union of believers that also pertains to any religion* (Simmel 1992: 731; translated by author).

I like to think that Simmel's point extends beyond religion. Infrastructuring always creates and reconstitutes inclusions and exclusions (Star and Bowker 2006). Yet there is also the possibility that observing a shared environment allows the creation of more inclusive communities of those who learn and know. The hope remains that this could be a lesson for the human exploration of space, on and off Earth.

Notes:

[1] http://hoggresearch.blogspot.ca/2008/03/budavari-and-szalay.html Accessed 11 January 2020.

[2] This view of reflexivity is informed by ethnomethodology (Garfinkel 1967). As Rawls (2008: 713) puts it, "[b]y 'reflexivity' Garfinkel means that the next thing said, done or seen reflects back on the last thing and has the potential to show it in a new light." Always temporal, sequential and witnessable, it is different, for example, from the postmodern concern of ethnographers about their role in doing fieldwork.

[3] The difference of these perspectives is illustrated, for instance, by representations of the Milky Way as observed at different wavelengths: https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html Accessed 19 February 2020.

[4] David Spergel, "Cosmology after Planck", lecture at New York University, 27 March 2014, https://www.youtube.com/watch?v=j3fHkQa6818, *c.* minute 6 and 10. Accessed 11 January 2020.

[5] http://www.perimeterinstitute.ca/videos/prospects-future-measurements, *c.* minute 38. Accessed 11 January 2020.

[6] This discovery claim is discussed in greater detail in Hoeppe 2019.

[7] Note that laboratory experiments rely on artificial, human-made infrastructures, whereas the sky is the most stable (infrastructural) element of astronomical practice.

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Lunar Landers and Space Elk: The Imaginary as Spaceflight Infrastructure

Joseph Popper

On Tuesday the 22 October 2019 in Washington DC, Jeff Bezos accepted an award for Excellence in Industry on behalf of his company, Blue Origin, at the 2019 International Astronautical Congress (IAC). Bezos used the acceptance to announce his new project – a partnership of Blue Origin with Draper, Lockheed Martin and Northrup Grumman. Together, this self-styled "national team" are pitching to develop and build a lunar lander for the NASA Artemis mission that aims to return American astronauts to the Moon in 2024. In another plenary at the congress, Blue Origin CEO Bob Smith presented speculative imagery of floating space colonies, replete with megacities and natural parks, as a future destination for a thriving and spacefaring humankind. Here, two very different space futures are found projecting from the same conference centre, by the same spaceflight company.

The International Astronautical Congress is the world's largest astronautics and space engineering conference, and in 2019 was held in Washington DC to mark the fiftieth anniversary of Apollo 11. Involving actors in science, industry, and culture, it arguably represents a microcosm of the space field. Jeff Bezos' pitch for the next NASA moon shot is further indicative of the changing industrial landscape, where public–private partnerships of state agencies and commercial companies are increasingly becoming normal. These partnerships also reflect the growing influence of NewSpace – the collective title for private spaceflight actors, industries and other public-facing societies that advocate the human colonising and commercialising of outer space. Along with Elon Musk, Bezos is a leading figure of a powerful social and economic movement, one that is shaping the physical infrastructures of outer space practices and also stabilising a grander vision of the human place in the universe.

Blue Origin has become a major firm in the spaceflight industry and, as primary sponsor to the congress, its ascendancy and ambition were on display in Washington. At the top of the steps on the way to the congress expo, Blue Moon stood proudly – a full scale model of the company's first lunar lander prototype. However, a return to the Moon is but one step in a much grander mission. Bezos envisions himself and Blue Origin as the pioneers of a "multi-generational vision," where his generation is building the "road to space" for the future benefit of humankind and the Earth. This is a future of millions of people living and working in space, with "thousands of future entrepreneurs building a real space industry" (Bezos 2019b). The Blue Moon lander and the road to space form different "material instantiations" (Messeri and Vertesi 2015: 56) that reveal the influential mechanisms of imagining futures at different scales. By analysing the material and representational space productions of Blue Origin in Washington, this essay explores the idea of the imaginary as infrastructure – an infrastructure that bridges the gap between futures near and far, and between real and ideal outer space.

I was there in the audience to hear Bezos and Smith speak. On stage, Bezos' award acceptance was a highly choreographed performance. In a "fireside chat" with International

Jeff Bezos announces the "national team" at the 2019 International Astronautical Congress, Washington DC.
Credit: https://www.blueorigin.com.

Astronautical Federation chief, Pascale Ehrenfreund, he reflected upon his childhood inspiration by the Apollo programme, before espousing values of growth and dynamism, the need for long-term visions, and sharing his ambition to turn Earth into a natural park. He was flanked by enormous screens, playing a series of videos capturing the successful testing of multiple Blue Origin rockets. This cinematic imagery prefaced the closing pitch for the Artemis lander partnership, pointedly styled as a "national team for a national priority." As Bezos received the award to a standing ovation, he completed a successful exercise in "projectory" choreography (Messeri and Vertesi 2015). The rhetoric, the videos and the Blue Moon lander together consolidate a near future vision, orienting the audience along a commercial roadmap to the Moon. For Bezos, the message is: this time, "we are going back to the Moon to stay" (Bezos 2019). Here is a future path grounded in, and stabilised by, publicly performed, documented, and streamable feats of technological prowess.

The Blue Origin lunar lander model "Blue Moon" stands in the foyer at the Walter E. Washington Convention Center for the 2019 International Astronautical Congress. Credit: https://www.iac2019.org.

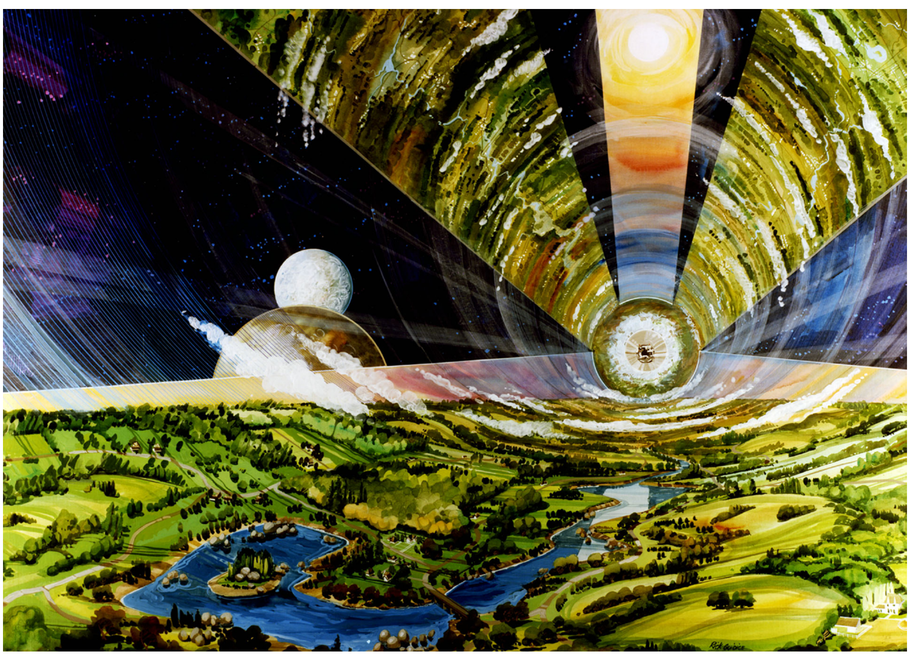
Reflecting upon Bezos' performance and my broader experience at the IAC, it helps to articulate the imaginary – a collectively held and publicly performed vision or narrative – as a powerful social, political, and economic force (Valentine 2012; Messeri and Vertesi 2015; Ormrod 2016; Geppert 2018). Sheila Jasanoff and Sang-Hyun Kim's (2015: 4, 19) concept of the sociotechnical imaginary becomes central for framing the imaginary as infrastructure. The sociotechnical imaginary pairs performance with stabilisation, where fictions – bound to technological projects – organise societies around common visions of desirable futures. Such powers of organisation and mediation also apply to "narrative infrastructure," a term introduced by Rob Coley (2018: 305) to describe how stories actively shape our perceptions of, and actions in, the world. Relating to events in Washington, James Ormrod (2016: 385) further complements this infrastructural sense by conveying the pro-spaceflight movement as "held together" by the shared vision of a spacefaring civilisation. Here, Blue Origin materialises the road to space by launching and landing reliable, reusable rockets. Bezos champions reusability as crucial for lowering the price of entry to the space frontier and to allow more entrepreneurs, in his image, to operate off-planet. Bezos' infrastructural imaginary draws upon the story of his company Amazon, where the "heavy-lifting" of building the internet had already been accomplished by others – enabling a Silicon Valley start-up to grow into a global corporate monolith, and Bezos himself to become one of the richest people in the world.

Moving from the near to the far future, Bezos has promised that "we are going to build a road to space [...] and then amazing things will happen" (Blue Origin 2019a). According to the Blue Origin mission statement, these things are both "amazing" and "unimaginable" (Blue Origin 2019b). Nevertheless, in Washington, CEO Bob Smith

An artist's rendering of a space colony for Blue Origin, presented by Jeff Bezos and Bob Smith. Credit: https://www.blueorigin.com.

did present a series of speculative imagery, describing the kind of future the road could lead towards. The series heavily tropes, to the point of "pastiche" imitation (Scharmen 2019), the renderings of space settlements directed by physicist Gerard O'Neill in the 1970s. One notable image is foregrounded by an elk, standing high on a mountain ridge overlooking a natural park, where waterfalls cascade into a green, wooded valley. Behind the elk, a river runs to the horizon, passing grand cityscapes along its winding path into the distance. The scene is enveloped by a vast cylindrical architecture, placing the landscape in the interior of an enormous artificial habitat. Outside, the whole Earth rises to frame a spectacular vision of a splendorous space colony. To the plenary audience, Bob Smith wryly offered the space elk as "a thing we can actually have" (Smith 2019).

Despite the seemingly creative leap implied by the space elk, Blue Origin's obvious troping of the O'Neill designs suggests a lack of, or limit to, the imaginations of NewSpace actors. The imagery is further reminiscent of particular, familiar future paths that large swathes of the space industry use to project their ambitions and justify their work in the present (Messeri and Vertesi 2015: 80). The artificial world of the space elk is also a future imagined very, very far away – exceeding the NewSpacers' capacity to describe it in detail (Valentine 2012: 1058). Borrowing from sociologist Richard Tutton's (2017: 5) writing on multiplanetary futures, the space colony presented by Smith is a vision evidently more "desirable" than "hopeful," in that this future arguably has no substantial grounding in the possible. In other words, the floating space colony also floats free from any tangible path towards it.



Space settlement interior rendering by Rick Guidice for Gerard O'Neill and NASA in 1975.
Credit: https://space.nss.org/settlement/nasa/.

Though without a path, this speculative imagery also serves a purpose – and has an effect. It performs as a kind of "projectory" (Messeri and Vertesi 2015: 56), by orienting the conference audience towards not only a vision, but a belief in a social and technological progress to be catalysed by the infinite potential of outer space. The space elk, then, acts as a placeholder for the dynamic, thriving space future of "amazing things" promised by Bezos and other NewSpace actors. This far future vision also reveals another infrastructural dimension of the spaceflight sociotechnical imaginary, rendering the artistic pastiche as powerful as the reusable rocket engine. Here, the history of the Apollo programme and the successful launching of reusable spacecraft become the foundation for projecting a confident certainty in the unforeseeable and the unimaginable.

Peter Dickens and James Ormrod (2016: 19) describe a "substantial and growing gap between outer space as an 'ideal space' and outer space as a 'real space'." This gap mirrors the distance between imagined futures near and far, plausible and implausible; between the Blue Moon lander and the floating space colony presented by Blue Origin at the IAC. The lander materialises part of a "road to space" as envisaged by the company, grounded in affirmative demonstrations of technological mastery; whereas the colony represents the boundless promise of a space frontier opened up to entrepreneurial dynamism. Synthesising these different projectories – and orienting their intended audience – is the common vision and ambition for humankind to get off-planet and become a spacefaring civilisation. This spaceflight imaginary bridges the distance from near to far futures, and further enables the gap between grand visions and the physical reality of the space industry to productively form the basis for actual political negotiations and economic transactions. As infrastructure, the imaginary elevates anticipatory discourse regarding the very far future that commercial roads to space are speculatively building towards. This means lunar landers and space elk become not only meaningful but complementary in the collective imaginations found in Washington. Together, they work to direct the movement of an entire industry reaching beyond Earth.

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Space Infrastructure Resilience:
Reflections on Recovered Launch Debris

Regina Peldszus

On 4 June 1996, thirty-seven seconds after engine ignition on its inaugural flight as the first in a new generation of European launch systems, the Ariane 5 rocket veered off course, disintegrated, and self-destructed. Ripped apart by the powerful explosion, at an altitude of approximately 4,000 metres the launcher and its payload fragmented, scattering pieces across twelve square kilometres, close to its tropical launch site in Kourou, French Guiana. After the event, the debris was painstakingly recovered from the swamps and thick mangroves surrounding the launch pad. Together with data transmitted from the rocket itself and from radar stations tracking its trajectory, the fragments became the primary source material for the official inquiry that followed (Lions 1996: 2), allowing investigators to retrace all the strands leading to a single disruptive moment. In their granularity and immediacy, the images of the captured fragments – seemingly suspended in time – today testify to an instance when the interdependencies and entanglement inherent in large-scale systems led to momentary but consequential breakdown; they represent the ripple effects of human agency on the infrastructures we conceive, deploy, operate, maintain, dismantle, optimize, and try to safeguard.

*Visual study on launch explosion fragments by **Sascha Mikloweit**, created during a residency at the European Space Agency (ESA), after the pieces were archived for several decades. While the work was part of a multimedia installation at ESA's mission control centre, the images are here understood in their own right as points of departure for systems-theoretical considerations of the infrastructure they originated from.*

The debris of the Cluster I mission was archived at the European Space Agency, and captured afresh three decades later.

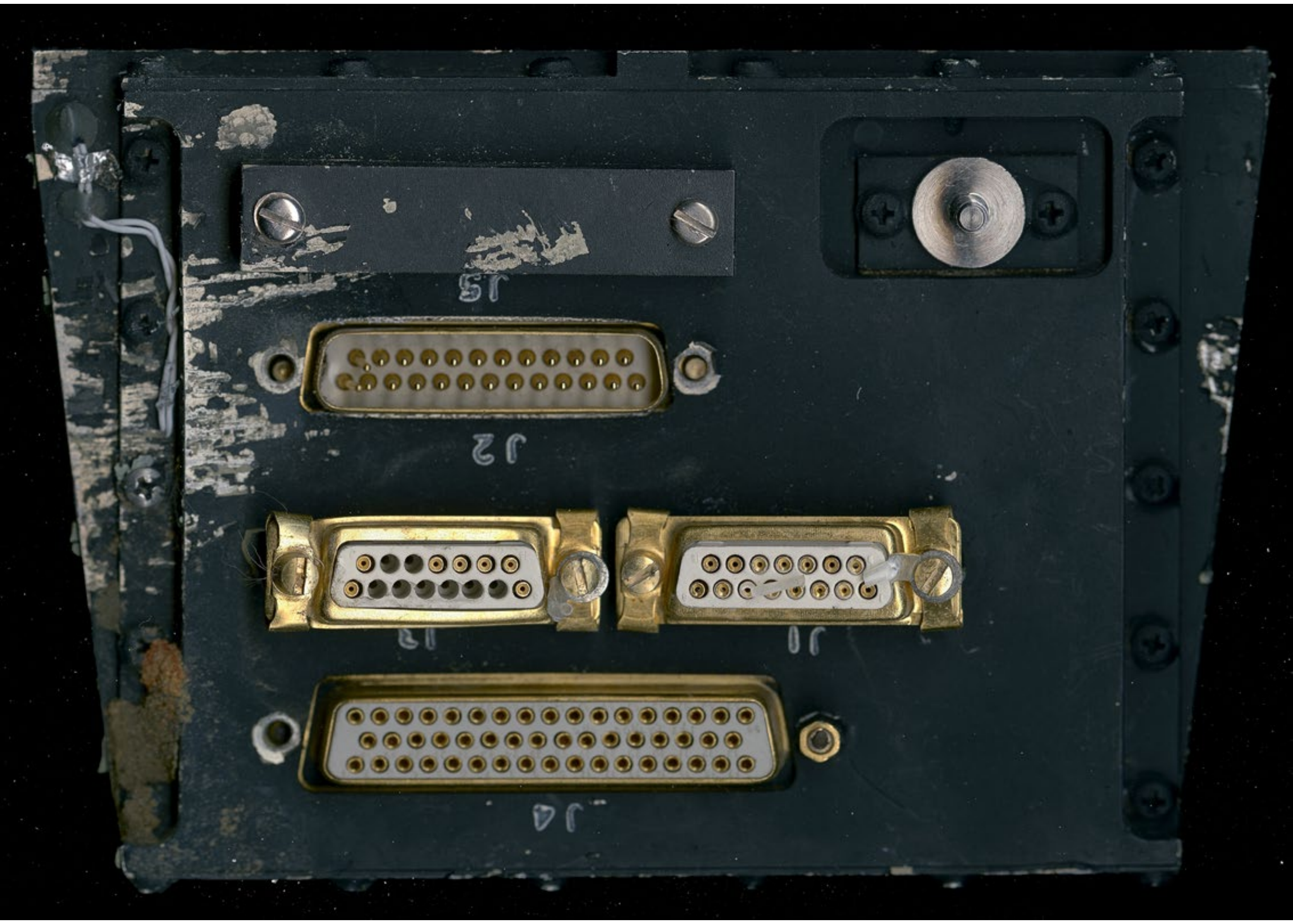
Debris recovered after the launch failure and explosion of Ariane 5 on 4 June 1996.
Image: © Sascha Mikloweit & VG Bild Kunst 2020.

Failure as an inherent possibility of space infrastructure

Failure is understood to be an intrinsic reality of highly complex domains – inevitable, normal even (Perrow 1999). In an almost Boolean logic, the largest and most consequential incidents are ideally characterized by their absence; yet this absence is only made possible through a continuous engagement with their potential emergence.[1] In the development, operation, and governance of large-scale complex sociotechnical systems or infrastructure, we hope to eclipse this emergence through a preoccupation with failure and anticipation of the factors contributing to it (Weick and Sutcliffe 2001). The ensuing adaptation instils resilience – less a property, but rather a constant practice of individuals, teams, and organizations acting within and upon a system (Reason 2008: 8).

Incidents of failure represent a "temporal inability to cope effectively with complexity" (Hollnagel, Woods and Leveson 2006: 3). They are effects of a combination of conditions and decisions, rather than of the failure of a single function or component: Although the Ariane report identified as an immediate cause of the launch failure the "complete loss of guidance and attitude information … due to specification and design errors in the software of the inertial reference system" of the launcher (Lions 1996: 12), it also recommended greater transparency in cooperation between different participating project entities and the inclusion of external experts for critical reviewing (Lions 1996: 14). Other analyses framed the underlying issue through a wider lens, suggesting the key to understanding this specific event lay in the application of systems engineering methods and their intersection with software development and its implementation in organizations (Le Lann 1996). Indeed, contemporary ideas on safety identify one particular area of potential for systems failure: software requirement flaws – that is, determining precisely the affordances, functions and constraints of software rather than software error per se – and their interaction with the overall system (Leveson 2011: 48).

The fragments pictured here were part of the payload, which consisted of four spacecraft in the Cluster I science mission. Image: © Sascha Mikloweit & VG Bild Kunst 2020.



Remnants of the battery regulator unit of one of the spacecraft onboard the exploded launcher.
Image: © Sascha Mikloweit & VG Bild Kunst 2020.

Space infrastructure as product of constant human engagement

In analyses of other catastrophic launch failures, problems with general organizational aspects of communication and joint decision-making in complex structures of space programmes were also highlighted as crucial contributing factors (compare Vaughan 2016). This potential is compounded by the fact that while launch systems are already highly complex undertakings, they slot into an even wider infrastructure with added interdependencies and nestled layers of complexity. The ground segments of space infrastructure – launch sites, tracking stations, mission control centres (Holdaway 2003) – constitute nodes in a network of command and control of any activity performed to access and utilize space. In order to design this distributed infrastructure, approaches to systems engineering evolved in the course of space activities since the 1950s (Booton 1984; Johnson 2006) that were able both to allow for, and leverage, high complexity, and can also be employed in promoting integrity and reliability (Leveson 2011).

At a scale where infrastructure is understood as a system-of-systems, design operations are only possible through the collaboration of large teams-of-teams. Here, human agency on a variety of levels (compare Vicente 2010) holds the key to resilience – from the individual designers or operators who may programme a scheduling tool to allocate time slots in a network of ground station antennae or command pre-planned manoeuvres on a satellite, to cross-disciplinary teams who jointly control a crewed mission. Despite the highly proceduralized field of mission control – and in contrast to automated agents that purely follow pre-programmed routines – these human operators intentionally vary their performance to suit the needs of an evolving situation, thus keeping a system within a boundary of safe operations (Hollnagel et al. 2008).

Finally, it is an organizational aggregation of public and private actors in government, industry, science, and military that define and execute the functions of space infrastructure, that determine its overall purpose, appraise its merits as part of a regulatory process, and ultimately decide whether and how a large-scale programme,

Blown up honeycomb sandwich panels used as part of the spacecraft structure on which instrumentation was mounted.
Image: © Sascha Mikloweit & VG Bild Kunst 2020.

Close-up of the honeycomb panels of the Cluster I spacecraft. After the satellites were lost during the launch explosion, a fresh set was built and the mission relaunched in 2000 as Cluster II.
Image: © Sascha Mikloweit & VG Bild Kunst 2020.

system, or infrastructure is set up, sustained, or discontinued. Spaceflight increasingly relies on this multilateral engagement (compare Zabusky 1995), due to the sophistication and global significance of the technology or missions involved. In turn, this cooperation drives the fundamental values imparted – deliberately and inadvertently – in the overall infrastructure, as a collage of converging or conflicting agendas, goals, demands. If collaborative practices in constructing or augmenting space infrastructure are both a means and an end in themselves (i.e. a raison d'être for embarking on a common space endeavour, but also way to achieve it, and thus by default a defining feature thereof), they are also both a source of and countermeasure against failure. Yet, today, ever more diverse actors with multifaceted interests, capabilities, and legacies engage in space activity together or in parallel (Al Rhodan 2012). Space infrastructure and its related policy developments are hence subject to a hitherto unseen "acceleration of technology proliferation and associated human networks" (Mineiro 2012: 34). In view of potentially conflicting interests and goals, how do the different stakeholders effectively govern and operate a set of global infrastructure(s)?

The debris was retrieved immediately after the explosion from terrain surrounding the launch pad in French Guiana.
Image: © Sascha Mikloweit & VG Bild Kunst 2020.

What does this mean for the concept of failure, and our thresholds for the acceptance of risk? How do we weigh and interpret events and their scale, extent, and impact when our perspectives are determined by our levels of participation in the ownership of or access to infrastructure?

Space infrastructure as critical infrastructure

Three decades after the end of the Cold War, we find ourselves on the cusp of a paradigmatic change in the utilization of orbit. An unprecedented number of spacecraft are planned for launch as part of large satellite constellations by a new generation of spacefaring actors, along with a resultant proliferation of heterogeneous ground-based infrastructure (Lal et al. 2018). Space systems – particularly those affording position, navigation and timing, earth observation, and communication applications – are today considered critical infrastructure (Hesse and Hornung 2015).

In this new era of increased complexity, space infrastructure is exposed to new levels of risk, such as accidental collisions with other active satellites or orbiting debris (McCormick 2013), but also to potential deliberate disruption (Harrison et al. 2019). Ensuring the resilience of space infrastructure therefore necessitates a twofold approach; it is understood both as a means to ensure the reliability of space systems against the inadvertent hazards of a busy operating environment and as a means of dissuading potential adversaries from manipulating space assets (Peldszus 2019). As legacy systems that have been in operation for decades, both on the ground and in orbit, will need to be integrated with cutting-edge new systems, failure, and the preoccupation with it, will become more pertinent and even more impactful.

As a new reality of space gains momentum, what may the battered remnants of a twenty-year-old incident tell us today? Reviewed afresh, the fragments of the Ariane 5 launch failure are concrete markers of an otherwise intangible domain: Not only is orbit remote, but as a large, globally distributed assemblage of networks, the ground segment also remains distant from its human actors, who by default may only grasp and act upon either a comparably microscopic aspect of it in great detail, or its entirety but at a very coarse level of abstraction. The pieces of debris compel us to desist from the hubris of believing ourselves able to fully absorb and control a burgeoning class of infrastructure, in view of the inevitable and continuous entropy of degradation and breakdown.

Notes:

[1] Compare Weick (2011) for the notion of safety as “dynamic non-event.”

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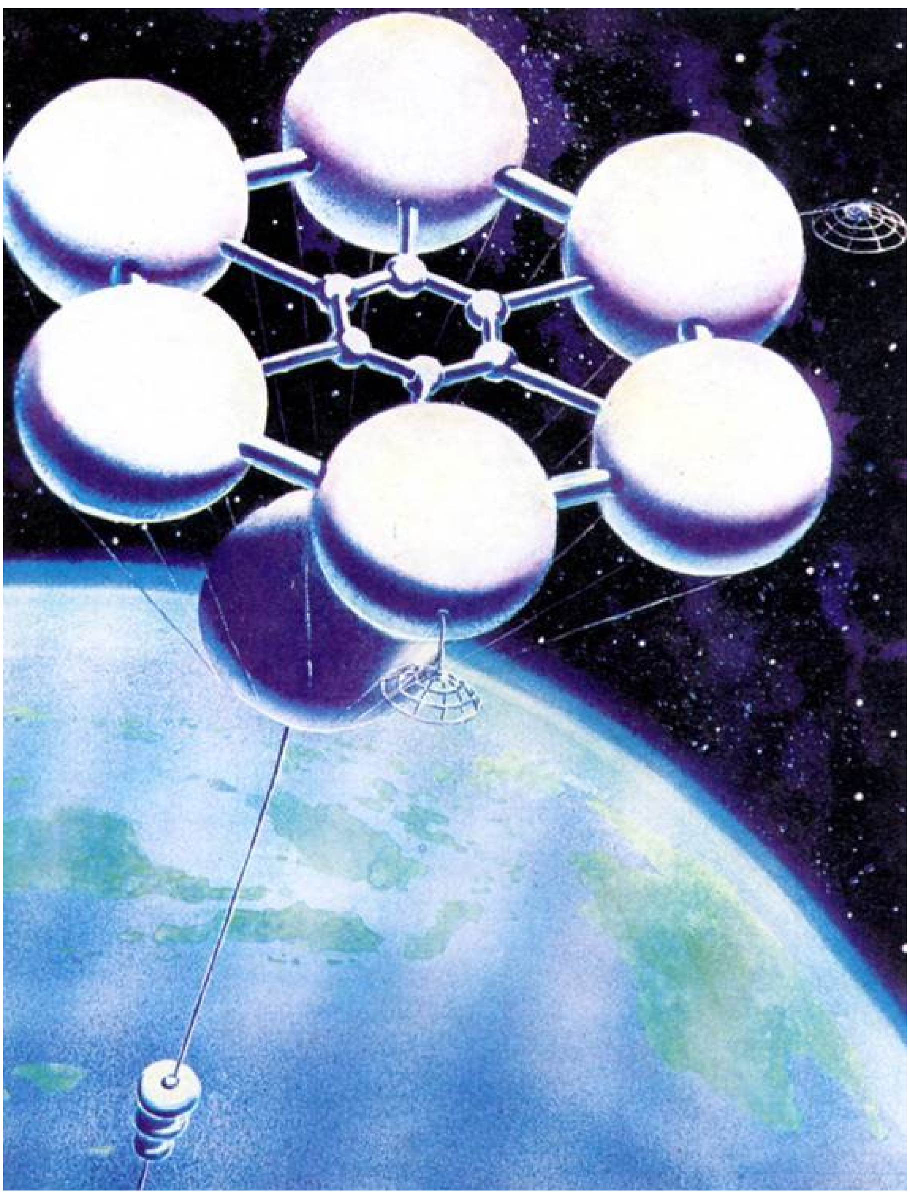
Stairway to Heaven? Geographies of the Space Elevator in Science Fiction

Oliver Dunnett

Outer space is often presented as a kind of universal global commons – a space for all humankind, against which the hopes and dreams of humanity have been projected. Yet, since the advent of spaceflight, it has become apparent that access to outer space has been limited, shaped and procured in certain ways. Geographical approaches to the study of outer space have started to interrogate the ways in which such inequalities have emerged and sustained themselves, across environmental, cultural and political registers. For example, recent studies have understood outer space as increasingly foreclosed by certain state and commercial actors (Beery 2012), have emphasised narratives of tropical difference in understanding geosynchronous equatorial satellite orbits (Dunnett 2019) and, more broadly, have conceptualised the Solar System as part of Earth's environment (Degroot 2017). It is clear from this and related literature that various types of infrastructure have been a significant part of the uneven geographies of outer space, whether in terms of long-established spaceports (Redfield 2000), anticipatory infrastructures (Gorman 2009) or redundant space hardware orbiting Earth as debris (Klinger 2019).

Having been the subject of speculation in both engineering and science-fictional discourses for many decades, the space elevator has more recently been promoted as a "revolutionary and efficient way to space for all humanity" (ISEC 2017). The concept involves a tether lowered from a position in geostationary orbit to a point on Earth's equator, along which an elevator can ascend and arrive in orbit. Essentially, it balances the centrifugal forces of Earth's rotation with the effect of gravity to achieve a stable connection between Earth and outer space. It is also theoretically applicable to other planetary bodies, potentially mitigating many of the difficulties associated with launching from, and landing onto, planets and moons across the Solar System. An embryonic form of the space elevator was conceived in the early twentieth century by the Russian spaceflight theorist Konstantin Tsiolkovskii, who was purportedly inspired by the construction of the Eiffel Tower. In the postwar period, the concept



This painting by Alexei Sokolov is one of the earliest known images of a space elevator (Leonov and Sokolov 1967: 25). Source: https://commons.wikimedia.org/wiki/File:Andrei_Sokolov%27s_painting_of_a_space_elevator.jpg.

was outlined in greater detail by the Russian engineer Yuri Artsutanov (Artsutanov 1960), before attracting broader attention in an article by Jerome Pearson of the US Air Force (Pearson 1975).

Since its initial proposal in various popular-scientific formats, the space elevator (a.k.a. orbital tower, sky-hook or heavenly staircase) has been described in numerous works of science fiction, two of which are the focus of this short article. Arthur C. Clarke's *The Fountains of Paradise* (1979) popularised the space elevator concept for audiences well beyond the engineering and spaceflight circles in which it was conceived, and remains the archetypal exposition of the idea in fiction. Numerous subsequent iterations have appeared in science-fiction narratives, one of which is Kim Stanley Robinson's *Red Mars* (1992), which features a space elevator as part of its narrative of human colonisation of Mars. In both cases, the space elevator plays a pivotal narrative role, representing different kinds of geographical, cultural and political ramifications of space travel.

The space elevator in *The Fountains of Paradise* is conceptualised as a first step in the mass human colonisation of the Solar System. The main part of Clarke's novel assiduously establishes as the setting the island of Sri Kanda, which is loosely based on aspects of Sri Lankan history and geography, and whose society is at a threshold in what is presented as a transition from antiquity to modernity. This is encapsulated in the narrative framing of the space elevator, whose Earth terminus is affixed to the summit of the holy mountain Sri Kanda, itself a model of the actual Sri Lankan mountain, Sri Pada. From here, "for the first time in history," as one character describes, "we shall have a stairway to heaven – a bridge to the stars" (Clarke 1980: 52). In supplanting a monastic site atop Sri Kanda, the space elevator terminus presents technology as a driver of societal progress, and space exploration as the ultimate harbinger of a prosperous future for humanity.

Clarke's novel ends with a far-future vision of a colonised Solar System, with the space elevator becoming "a vertical city", just one spoke in a giant wheel that connects Earth with a vast orbital ring that encircles the globe (Clarke 1980: 226). As such, with the Sun entering a cooler phase in its life-cycle, "the whole terrestrial population had streamed up the equatorial Towers and flowed sunwards towards the young oceans of Venus, [and] the fertile plains of Mercury's Temperate Zone" (Clarke 1980: 224). In this way, the space elevator acts as a bridge to salvation in the cosmos, a triumphant and transformational piece of Earth-space infrastructure. However, considered in the context of Clarke's identity as a western author in a postcolonial space, and noting the significance of the equatorial region to orbital space technologies, *The Fountains of Paradise* also foregrounds earthly geographies of colonialism and tropicality in the articulation of humanity's possible future in space (Dunnett 2019).

In many ways, Kim Stanley Robinson's *Mars* trilogy owes an imaginative debt to Clarke, not just in terms of its "hard" science-fiction style of writing, but in its imagined future colonisation of Mars and indeed its narrative exposition of the space elevator concept. This debt is acknowledged in *Red Mars* by designating the orbital terminus of the Martian space elevator as the asteroid "Clarke," which has, in the novel, been moved into an orbital position above the Martian equator. While the imagined technology of the space elevator is broadly comparable between the two novels, including their planetary position on equatorial mountain-tops, their narrative divergences are significant. While Clarke's space elevator represents a utopian bridge to the stars, Robinson's space elevator acts as a catalyst for violent revolution on the Red Planet.

Human colonisation of Mars takes place continuously over the course of the novel and is tied up with the ongoing terraforming of the planet. As such, the pioneering first hundred settlers are joined by larger groups of emigrants from a politically volatile Earth, and the Martian space elevator plays a pivotal role in the acceleration of this process, easing the transportation of people and goods down to the planet's surface. The elevator cable's descent from the orbiting asteroid to the equatorial volcanic dome Pavonis Mons is described ominously in *Red Mars* – one character "felt as if he were standing on a sea floor observing a fishing line dropped down among them from the plum sea surface" (Robinson 1996: 508). Once the elevator is in place, it causes a huge influx of new colonisers to the Martian surface. These individuals are aligned with the "transnats" on Earth, global corporations that are exerting increasing control over terrestrial politics. The result is "a million people and no law, no law but corporate law" (Robinson 1996: 516).

Red Mars ends with a popular uprising against Earth's pervading influence on Mars. This is encapsulated in the fate of the space elevator, which, through sabotage, is detached from its anchor in space and comes crashing down along the Martian surface, wrapping twice around the planet. One character describes the resultant landform as "an equator just like the one I thought the Earth had when I was four years old. A big black line running right around the planet" (Robinson 1996: 594). As David Valentine has pointed out, the *Mars* trilogy has been praised both by advocates of planetary colonisation and by critics of utopianism, but nonetheless, the novels are characterised by "mapping terrestrial relations onto the Red Planet" (Valentine 2017: 193). The space elevator in *Red Mars*, whether through its construction or its downfall, acts as a conduit for such mappings, and thereby reflects contemporary concerns about "the political-economic dimensions of private space activity" (Beery 2012: 25), and, perhaps more alarmingly, the ways in which plans for the colonisation of other planets could render Earth as "something that can be left behind" amid discourses of uncertain environmental futures (Klinger 2019: 10).

Thinking through space infrastructure as culturally and politically arbitrated in specific geographical contexts helps to overcome grandiose projections of space exploration as a technologically mediated panacea for humankind's problems on Earth, or as a gateway to a bright future in the cosmos. This article has suggested that the space elevator could be better understood in, for example, the historical context of colonialism or through contemporary understandings of planetary environmentalism. In this respect, the intersection of scholarly work in critical geography with critical studies of infrastructure, both actual and anticipatory, has much to offer. While space elevators are towards the extreme end of technologically possible alternatives to conventional space travel, their present-day proponents cite them as just one of the ways in which space travel can benefit human society. Thinking critically about imaginative representations of space technology can act as a reminder that space infrastructure, as with many forms of technology, is culturally and politically situated and can be contested across both fictional and critical scholarly registers.

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Out of the Past: The Space-Time of Infrastructure

Christine Bichsel

Lena, you can turn on the camera now.

The view of the space station changes from monitor to film image. The opening scene of Andrei Ujică's film *Out of the Present* (1997) narrates the arrival of a 35 mm video camera at space station Mir in 1991. To the best of our knowledge, this camera is still orbiting Earth (Zielinski 2006: 2). However, Mir, as its original destination and temporary home, is no longer in orbit. The station burst into pieces over the South Pacific Ocean after re-entry into Earth's atmosphere in 2001. There are other remains of Mir though. The cosmonauts took almost three hundred hours of video footage and sent the tapes back to Earth. Ujică used this footage to tell the story of Sergei Krikalev: the cosmonaut and flight engineer who started his mission in 1991 from the Soviet Union and landed ten months later in independent Kazakhstan. In this article, I explore the representation of Mir in Ujică's film in order to think through the infrastructure of outer space. I argue that his use of past cinematographic records challenges the understanding of infrastructure as fixed in space-time.

Monitor image of Mir from the approaching Soyuz rocket.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

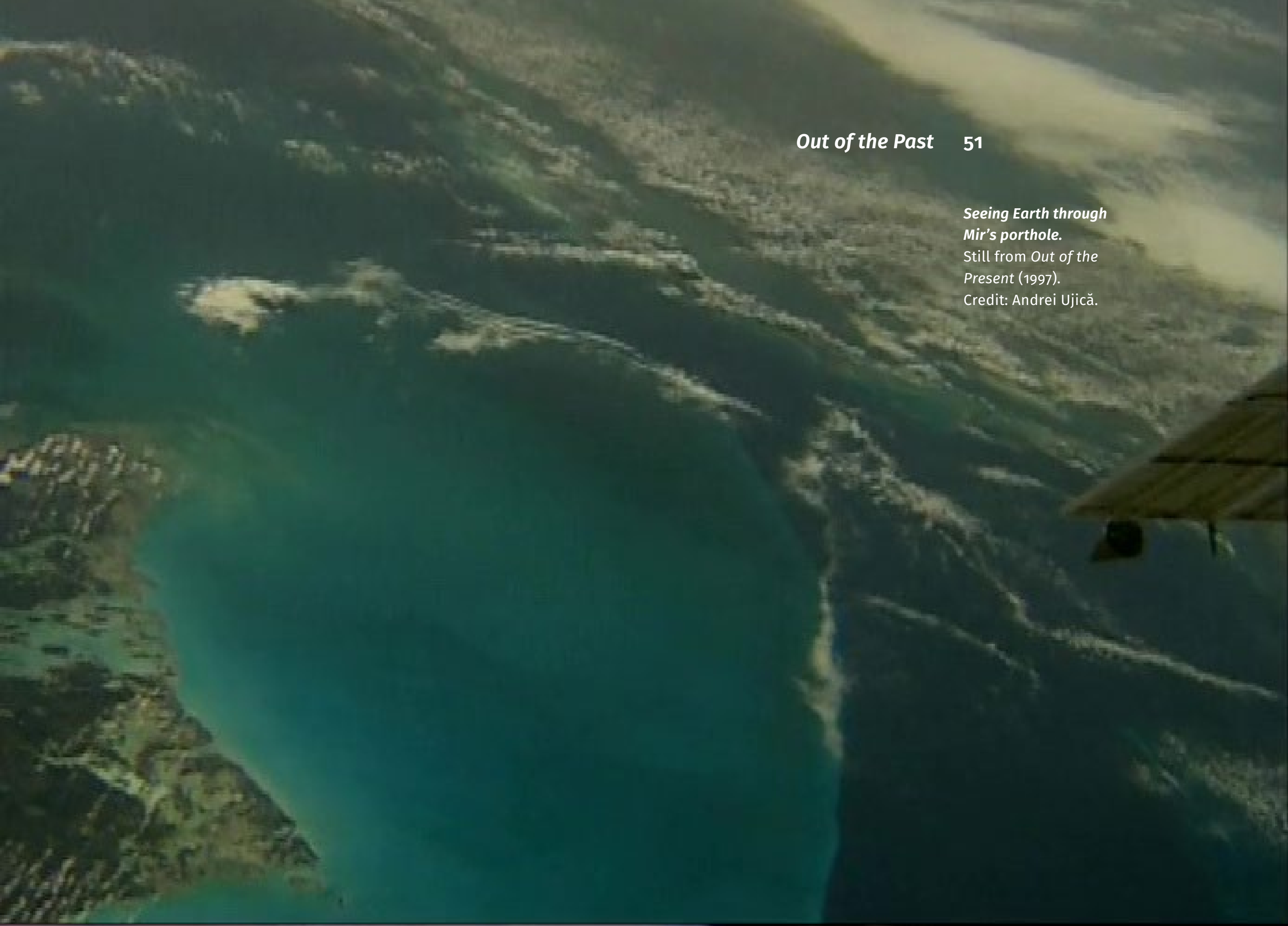
Mir in orbit around Earth.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

Archives exert a strong gravitational pull on those caught in their orbits. After Ujică got hold of the cosmonauts' video, he shut himself up in his apartment in Moscow. The tapes are most extraordinary, belonging to the rare category of objects that have travelled from Earth into space and back again. Moreover, they hold nothing less than the cinematic record of seeing Earth from space. Ujică's immersion in the images created a peculiar sensation: "I had the feeling I was experiencing the flight myself and arrived at the realization that being in space had something elemental about it" (Ujică and Virilio 2003: 62). The sensation of being in space by force of these images must have been very powerful. Ujică kept this detachment from Earth in check by bringing the emerging *Out of the Present* into conversation with the two most influential science-fiction films of the twentieth century: Stanley Kubrik's *2001: A Space Odyssey* (1968) and Andrei Tarkovsky's *Solaris* (1972). Science fiction became his only attachment to the world outside the archive (Ujică and Virilio 2003: 69).

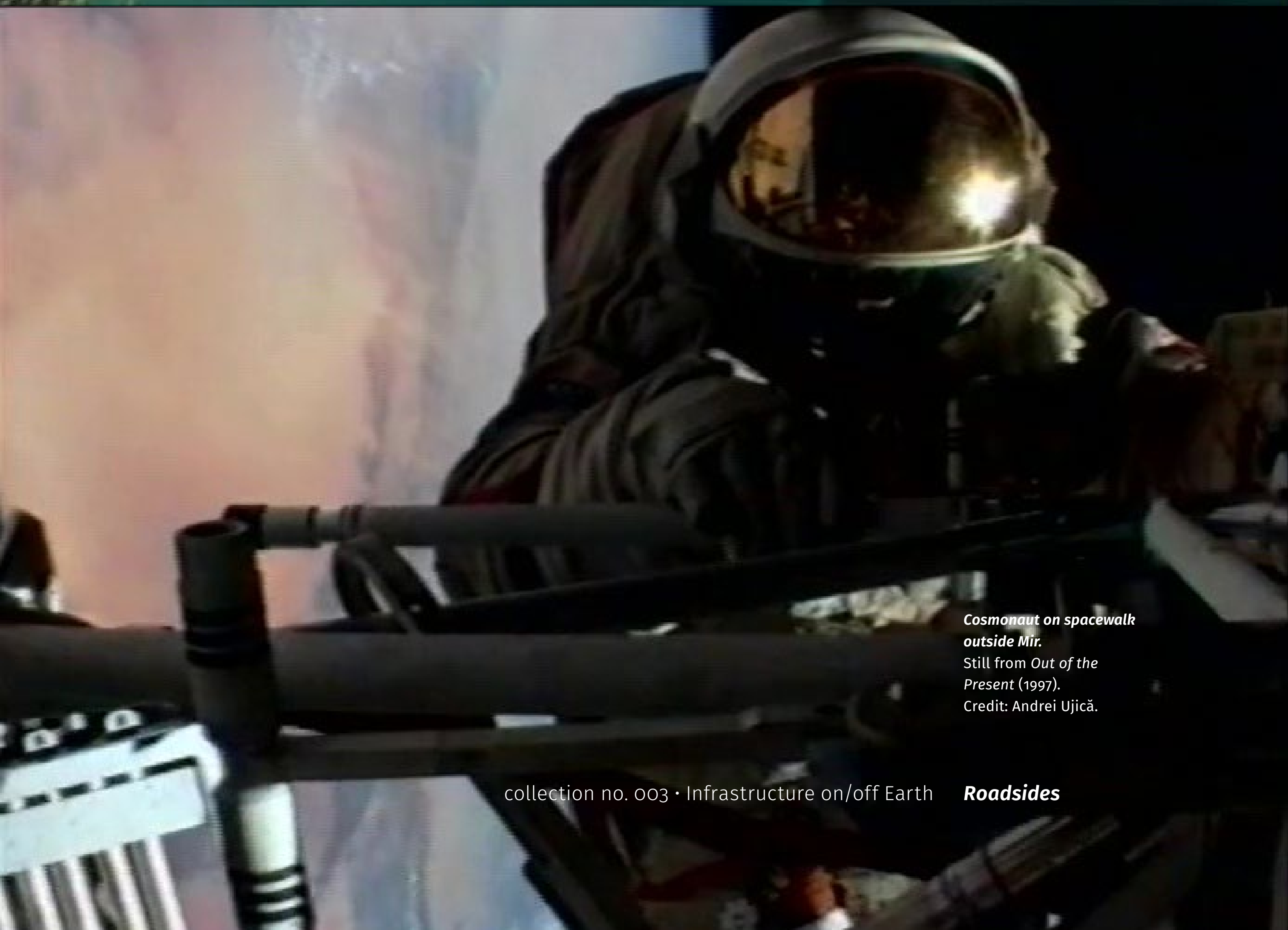
Out of the Present directs our gaze firmly towards Earth – as do *Blue Marble* and *Earthrise*, the iconic images produced from Apollo photographs. But Ujică's view of Earth from space is different. This is no longer the famous "god trick" (Haraway 1988) of a disembodied and transcendent gaze from nowhere. Rather, it comes from a hazard-prone metallic insectoid creature with solar panels for wings, marking the apogee of Soviet scientific-technological progress and hosting humans dubbed cosmonauts by virtue of their ability to survive in outer space. Through the eye of the camera, we experience the cosmonauts' continuous search for Earth-born(e) spatial orientation and share their vertiginous feelings when looking at Earth from outside the space station. The camera presents us with a view far enough from Earth's surface to see its curvature, the thin layer of the atmosphere and the stunning shifts between land, sea and clouds. But not far enough to do away with the feeling of unease about what is going on "down there" at this moment.

Painter of the revolution in Moscow.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

Down on Earth, Mir's superstructure is about to collapse. Halfway through the film, a sudden cut takes us from outer space to Earth. It catapults the viewer into the events of August 1991 in Moscow – tanks, crowds, shouting and high anxiety. Only the solitary figure of an artist sits quietly in the street, painting the revolution unfolding before his eyes. He mirrors the eerie calm of the space station, travelling from horizon to horizon above the events. The panoptic view from Mir puts the turmoil in Moscow into perspective – the scope is planetary rather than terrestrial. Earlier on, *Out of the Present* narrates the phone call the cosmonauts receive from the president. The



Seeing Earth through Mir's porthole.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.



Cosmonaut on spacewalk outside Mir.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

switchboard operator confirms that this is Moscow speaking, and announces that Mikhail Sergeyevich is on the line. “What are you doing just now?” asks Gorbachev. The crew answers: “We are getting ready for dinner.” Gorbachev laughs and answers: “Oh, if it were a little later, we could have dinner together!” The distance of space allows for a paradoxical intimacy, perhaps creating for Gorbachev a momentary escape from Earth in troubled times.

Mir is not just an outpost of humanity, but also a periphery of Moscow as the center of Soviet power. A military command structure and thin lifeline connects Mir to the spaceport at Baikonur. Formerly leased from the Kazakh Soviet Socialist Republic by the Soviet Ministry of Defense, Baikonur became part of newly independent Kazakhstan following the disintegration of the Soviet Union in 1991. Soon after, the Kazakh government began to lay claims to the spaceport, which remained under Russian control. To accommodate Kazakhstan, the Russian flight direction at Baikonur decided to alter the composition of the relief crew. They replaced scheduled Russian flight engineer Sergei Krikalev with research scientist Toktar Aubakirov, the first ethnic Kazakh in space. Tensions arise in *Out of the Present* when Aubakirov is seen playfully enjoying microgravity with a toy airplane while his colleagues carry out scientific experiments. After a few days, he is ordered to return to Baikonur on the flight scheduled for the relieved crew. Krikalev, however, has to stay on Mir and continue his duties as flight engineer for another six months. Thus, political dealing to secure continued rights to launch from Baikonur clashed with Mir’s requirements for technical expertise.

Mir as infrastructure is also in a state of revolution, albeit of a different character. The space station rushes around Earth in a relentless cycle, passing Baikonur every 92 minutes. The viewer is able to sense this time span, as the film’s length matches the duration of one complete orbit. Repetition based on physical laws creates its own temporal regime, utterly at odds with the biological rhythm of humans. Life on Mir thus follows the Earth clock. More precisely, it follows Moscow’s clock – the Soviet empire of time expands into space. Through images of landscapes, *Out of the Present* narrates the change of the seasons on Earth in stark contrast to the absence of any seasonality on Mir itself. These superimposed temporalities subvert orientation in space and time on Mir by suspending earthly frames of reference. Fixes for this blankness include not only the retention of a strict 24-hour schedule, but also the creation of accustomed points of orientation through light and color to simulate floor and ceiling (Ujică and Krikalev 2003: 48). Thereby, the alienation of cosmonauts from their accustomed diurnal and seasonal round is contained within the walls of Mir, provided that they resist the temptation of looking out of the porthole.

The microgravity environment of Mir creates the experience of weightlessness. *Out of the Present* embodies this experience: images of weightless cosmonauts taken by a weightless camera. The cosmonauts’ movements in microgravity lose their habitual angularity, becoming smooth and continuous. Their floating bodies appear abstract and insubstantial, contained only by Mir’s metallic hull. Yet when Krikalev is shown working out strapped to a treadmill, his body becomes familiar again. The movements of running, the play of his muscles and the sweating render it earthly in an erotic way.

Light and colour simulate floor and ceiling.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

Capsule hits the Kazakh steppe.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

Actual Earthfall is harsh though. As viewers, we brace ourselves for impact when the charred capsule hanging from a parachute falls out of the sky. It hits Earth's surface like a meteorite, leaving a small crater on the arid Kazakh steppe. The helpless cosmonauts have to be lifted out of the capsule, weak, dizzy from descent and struggling to cope with Earth's gravity. Becoming Earthbound again is a punishing experience.

A cosmonaut arrives on Mir.
Still from *Out of the Present* (1997).
Credit: Andrei Ujică.

The Russian word *mir* is polysemous, translating as '"world," "Earth" and "peace." In *Out of the Present*, space station Mir becomes the world – a crowded and cluttered space enfolded by the vast reaches of the Universe, to which newcomers are greeted ritually with bread and salt in the Russian tradition. Yet Mir is also Earth's companion: it is subject to the latter's gravitational pull, and its matter is carved out of Earth's body like the Moon billions of years ago. By orbiting, Mir exerts the tiniest bit of gravity of its own on the home planet, yet both infrastructure and cosmonauts age marginally slower than they would on Earth. While all directions are experienced as equal in space, the direction towards Earth represents the emotional and epistemic axis for cosmonauts on Mir. In the absence of terrestrial places of history and attachment, Earth as a whole becomes the frame of reference and embodiment of "our home" (Ujică and Krikalev 2003: 49).

Ujică's work presents an apparent contradiction: *Out of the Present* is a documentary science-fiction film, with a riff on conventional understandings of the genre through repeated docking scenes. Ujică narrates Mir in powerful analogy to Tarkovsky's space station hovering above Solaris's planetary sea, of which the many cinematic allusions to *Solaris* are suggestive. The unfathomable Earth sends traumatic memories to Mir, and its inhabitants struggle to make sense of and reconcile these memories with their current condition of existence. At times, they withdraw in joyful regression to childlike play in weightlessness, or stare at Earth through the porthole, transfixed and mesmerized. Yet they also emit cinematographic memories of their struggle back to Earth. By virtue of these memories from the past, the Mir of *Out of the Present* is an impossible (and yet very real) present. Because of this paradoxical condition, Mir becomes an object of representation that is nonimaginary and yet cognitively estranging (Chu 2010). As cinematographic infrastructure, Mir creates estrangement by subverting our habitual attempts to fix objects in space-time – a taken-for-granted earthly practice that tries to make sense of the world.

Is the camera still rolling?

Yes.

All right, let it roll.

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Alternatives to GPS: Space Infrastructure in China and Japan

Christine Y. L. Luk and Subodhana Wijeyeratne

Control of crucial elements of global infrastructure has long been a sure route to extensive geopolitical influence. Britain's control of the Suez Canal and the USA's of the Panama Canal are both examples of states investing in, and fiercely protecting, key facilitators of the global economy. However, both nations were eventually forced to surrender their grip on these structures. This paper will explore a very similar process underway today: the drift away from the dominance of the US-created Global Positioning Satellite (GPS) system, to a world where multiple similar networks compete for global usage and influence. As we shall see, the consequences of this shift for economics and geostrategy will be profound.

One source of this trend is China. Discussions of Chinese infrastructure usually centre on ground-based infrastructure, such as high-speed railways, ports, and roads built under the Belt and Road Initiative (BRI). However, despite the wide-ranging fixation on this so-called New Silk Road connecting China to Central and South Asia, the Middle East, Europe and Africa, it is pertinent here that a crucial part of this network is in fact being constructed hundreds of kilometres above the surface of Earth—the "Space Silk Road" (Luft 2016). At the heart of this is China's BeiDou Navigation Satellite

System (Ch. 北斗卫星导航系统), sometimes abbreviated as BDS, but commonly known as BeiDou. The system is named after the constellation ancient Chinese used for navigation, the Big Dipper (Ch. 北斗七星). Meanwhile, Japan—China's geopolitical competitor and a close ally of the USA—is busily expanding its own Quasi-Zenith Satellite System (QZSS) into a Japan-centric system capable of providing extensive navigational functions beyond the country's borders. For those doubtful as to the significance of these systems, consider their application in the current Covid-19 viral outbreak. Electronic devices equipped with location-trackers, whether based on GPS or not, are imposed on quarantined travellers and patients to monitor suspected victims in Hong Kong and South Korea (Perrett 2020; Walsh 2020). This is a timely reminder that navigation technology is an integral part of state surveillance systems that can be put in place for control and containment.

Together, BeiDou and QZSS offer alternatives to the dominant global positioning network: the US Navy-controlled GPS, since the 1980s the premier system of its kind in the world. GPS is by far the oldest and best-established network positioning system on Earth; a constellation of twenty-four satellites was fully functional by 1993, five years before the precursors of QZSS, and seven years before BeiDou was initiated. The entire network was primarily conceived of as a military service. However, since around the turn of the millennium, while the younger systems have expanded dramatically, GPS has remained largely stagnant.

Of the two East Asian systems, BeiDou has experienced by far the speediest growth. This is partly because, from the perspective of the Chinese government, there is little doubt that BeiDou is a crucial infrastructural project. Chinese official documents define the system as "space infrastructure of national significance" that offers "all-time, all-weather and high-accuracy positioning, navigation and timing services to global users" (SCIO 2016). Since 2000, China has launched some fifty-three BeiDou satellites, including experimental devices and first-generation platforms that are now defunct (Clark 2019). When completed later in 2020, BeiDou will have a constellation of thirty-five satellites, providing global coverage (Jakhar 2018). Much like GPS, BeiDou's origin was military, and it remains the cornerstone of China's expanding military capabilities. At the same time, though, the network is also being primed for global economic deployment. The cost of BeiDou receiver chips that track and process satellite signals has fallen to the point where for many—particularly countries that have had their communications infrastructure built by Chinese corporations—it is in fact a cheaper option than GPS. BeiDou is already being deployed to cater to the demands of a variety of industries both within and outside of China. Between 2012 and 2017, around 4.8 million commercial vehicles and forty thousand fishing vessels in China were equipped with the system; more than ten thousand fishermen have received assistance or been rescued through utilization of the system, while BeiDou-based automatic driving systems have been in use in more than ten Chinese provinces. In agriculture, herders control their livestock's water use through remote devices operated by sending short messages via satellite. BeiDou has also been widely adopted in the emerging markets of shared bicycles, wearable devices, and as a communication nexus for the Internet of Things (Yu, Wang and Yang 2018)—the integration of communication capabilities into consumer products such as gaming systems and fridges. In 2012, the network extended services across the Asia-Pacific region and is now an essential part of the benefits package China offers to countries along the BRI. Here, the constellation provides basic satellite navigation services not only to people living in these nations, but also to those utilizing long transport networks that span remote locations (Chen and Jiang 2018).

Meanwhile, GPS finds its global dominance challenged even by its own long-term users. A good example here is Japan. In 1998, the country took the historic step of launching its own spy satellites to counter North Korea's rocket launches—a move stemming partly from a sense of dissatisfaction at the perceived lack of responsiveness from the USA to Japan's surveillance needs. This in turn led to broader conversations regarding the possibility of a Japanese-run equivalent to GPS. In a fashion typical of Japan's governmental bureaucracy, the idea was knocked around various departments, but when finally approved it proceeded rapidly. The resulting QZSS was born in 2018. The Michibiki satellites that form the core of this new system were specifically designed to exceed their counterparts in GPS, and the European Galileo system, in capacity. Japan's circumstances are somewhat different to China's—military actions running counter to US interests on the part of the Japan Self-Defense Forces are currently unthinkable, and hence Japan's armed forces can continue to rely on GPS without the fear China has of American sabotage. So, though each Michibiki promises to bring key navigational capacity under Japanese government control, it is the hefty economic advantages that are most seductive—companies such as Hitachi and SoftBank estimate that the new system might generate up to forty-four billion yen's worth of new services over the coming years (Shigenori 2018). The potential uses pitched by these companies include providing navigation for self-driving cars and guidance to large-scale farm equipment. Crucially, the ability to offer these new services will stretch as far as Australia, raising the potential of extensive foreign engagement with the QZSS (Shigenori 2018).

These developments are part and parcel of a more widespread challenge in the twenty-first century to the dominance that GPS has held over global navigation for the better part of half a century. The implications are profound. For the USA, this will mean the end of a crucial strategic capability to interfere with the communications of other countries, particularly in times of war (Crichton and Tabatabai 2018). From an American perspective, it is not immediately obvious that there are alternatives to GPS. On ground level, the USA remains the most powerful country in the world, but that view of American hegemony looks increasingly questionable if we look up and take off-Earth infrastructure into consideration.

There are broader concerns too. Analysts have pointed out that the growing global reach of BeiDou could translate into a bifurcated global navigational system, with politics and incentives being deployed by both China and the USA to woo countries to join their respective systems (Jakhar 2018). It also raises troubling possibilities for corporations like Apple, which may be forced to place BeiDou functional chips in its devices, in violation of US security policies. This in turn could mean that Apple's ability to sell its products in China would be limited, or that certain products could only work either in China or America—a challenging state of affairs for such a corporation. Similar concerns surely must give chills to technology and hardware companies that rely on space infrastructure to provide crucial services. Indeed, if we include other systems such as Russia's GLONASS (Globalnaja nawigazionnaja sputnikowaja sistema/Global Navigation Satellite System), the European Union's Galileo (which continues to grow in size), and India's mooted IRNSS (Indian Regional Navigation Satellite System), it is not hard to imagine a future in which globally functional phone-sets will require several chips, thus increasing prices and requiring the creation of new supply chains.

Nevertheless, the era of GPS's dominance is far from over. Many of its challengers suffer from drawbacks that may, in the long term, discourage switching between networks. BeiDou, for example, relies on a system, which consumes valuable bandwidth and can slow services. Japan's QZSS (similar to a proposed British system) suffers from a lack of scale – they are smaller systems, which means that production prices for their components will not benefit from the cost savings mass production can provide. As a result, their creation and maintenance will be extremely expensive. Many countries continue to be reluctant to engage with GLONASS for strategic and political reasons, while Galileo, though growing, is still small. Thus, for the foreseeable future, GPS will remain the premier satellite constellation in the skies. It is, however, no longer alone out there.

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Space Weather as a Threat to Critical Infrastructure

A. R. E. Taylor

Critical infrastructure protection is increasingly operating in a post-terrestrial space. Satellites and space stations are key enablers of a wide variety of navigational, communicational, security and scientific activity that is perceived as central to the continuity of industrialised societies. Now recognised as “critical space infrastructure” (Mureşan and Georgescu 2015), there is mounting interest and investment in ensuring their uninterrupted service provision in the face of a plurality of space risks. At the same time, as outer space becomes a new domain for infrastructure security, terrestrial infrastructures that once might not typically have been associated with outer space are also being brought into new threatening relationalities with the Solar System. Pipelines, telecommunication cables and electricity grids, among other ground-based infrastructures, have all been identified as vulnerable to “space weather.” This article explores how growing public and political awareness of the space weather threat is expanding what might count as “space” infrastructure, generating new imaginaries of planet Earth’s place in a dangerously energetic Solar System.

Un-Earthing critical infrastructure protection

Since the mid-1990s, “critical infrastructure protection” has emerged as a key concept and priority target of national and international security regimes (Cavelty 2008; Collier and Lakoff 2008). For growing numbers of government officials and risk professionals, the industrialised societies of the global north are perceived to be increasingly vulnerable to catastrophic collapse due to their dependence on a complex network of interconnected and interdependent “vital systems” (Beck 1999; Collier and Lakoff 2015). In its various national articulations, critical infrastructure protection generally aims to manage the anticipated failure of infrastructure systems and govern the proliferating array of risks that might trigger large-scale infrastructure failure.

Figure 1: Extreme space weather events begin when plasma erupts from the Sun and streams towards Earth. This is an image of the Sun visualised in UV light by NASA's Solar Dynamics Observatory (SDO). Credit: https://www.nasa.gov.

Since 2012, space weather has swiftly moved on to national security agendas across the global north as a key threat to critical infrastructure (Cabinet Office 2012, 2014; White House 2015a, 2015b; European Commission 2016). Space weather refers to a range of radiation events that occur in the near-Earth space environment, often originating from the Sun. During periods of intense magnetic activity, the Sun releases electrically charged plasma from its outer atmosphere, the solar corona. These solar events are known as coronal mass ejections (CMEs) and are often accompanied by explosive solar flares (Fig. 1). This high-energy solar radiation is capable of ionising the fragile microelectronics and memory circuits found in spaceborne infrastructure like satellites and spacecraft, potentially causing component failure and leading to loss of service (Horne et al. 2013).

Space weather not only poses a risk to infrastructure situated in outer space but also to terrestrial infrastructure. When these electrically charged solar particles interact with Earth's magnetic field (Fig. 2) they can generate powerful currents that flow into the earth. These earth currents can damage conducting material such as pipelines and they can induce high-voltage surges in power grids, computer chips and other electronic components of terrestrial critical infrastructure.

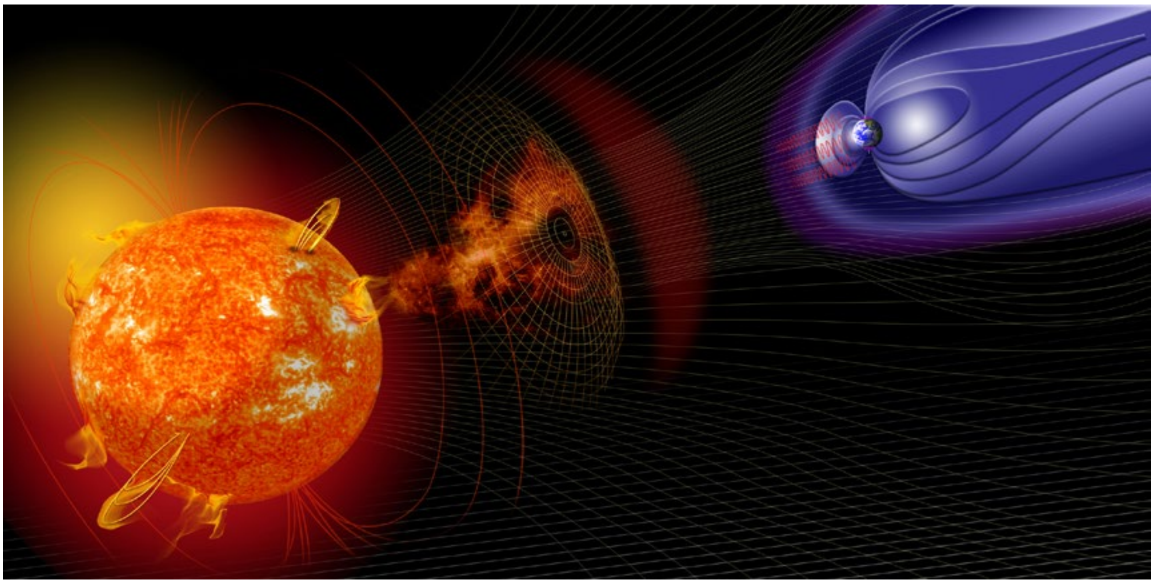

Figure 2: NASA rendering of stellar magnetic fields. In this image, the blue lines represent Earth's magnetic field that is distorted by the "solar wind."
Credit: https://www.nasa.gov.

The space-weathered world

A key visual tool that is widely utilised to communicate the space weather threat is a cross-sectional image of Earth and its space-based and ground-based critical infrastructures situated within the wider solar environment (Fig. 3). Variations of this illustration have been widely circulated in news articles and have become key images in the visual economy of space weather, released by a number of space agencies and scientific institutions (e.g. Fig. 4). Such visualisations serve to highlight the infrastructure and technology systems affected by space weather, inviting viewers to see outer space not as remote and detached from the everyday geographies of their lives but as deeply entangled with earthly "envirotechnical" landscapes (Pritchard 2011).

Jutting up from the surface of the Earth, the exaggerated scale of radio masts, satellite dishes, oil rigs and electricity pylons embeds these infrastructures in atmospheric space. Visually bridging the space between Earth and the upper atmosphere, the infrastructures pictured here draw attention to the relational "bridgework" (Howe et al. 2016: 549) that critical infrastructures (as conduits for electromagnetic currents and energies) facilitate between Earth and outer space. Rather than a picture of Earth safely nested within a protective atmospheric barrier, here, earthly infrastructure is not separate from the energetic fluxes and flows occurring in outer space but is presented as precariously immersed within them.

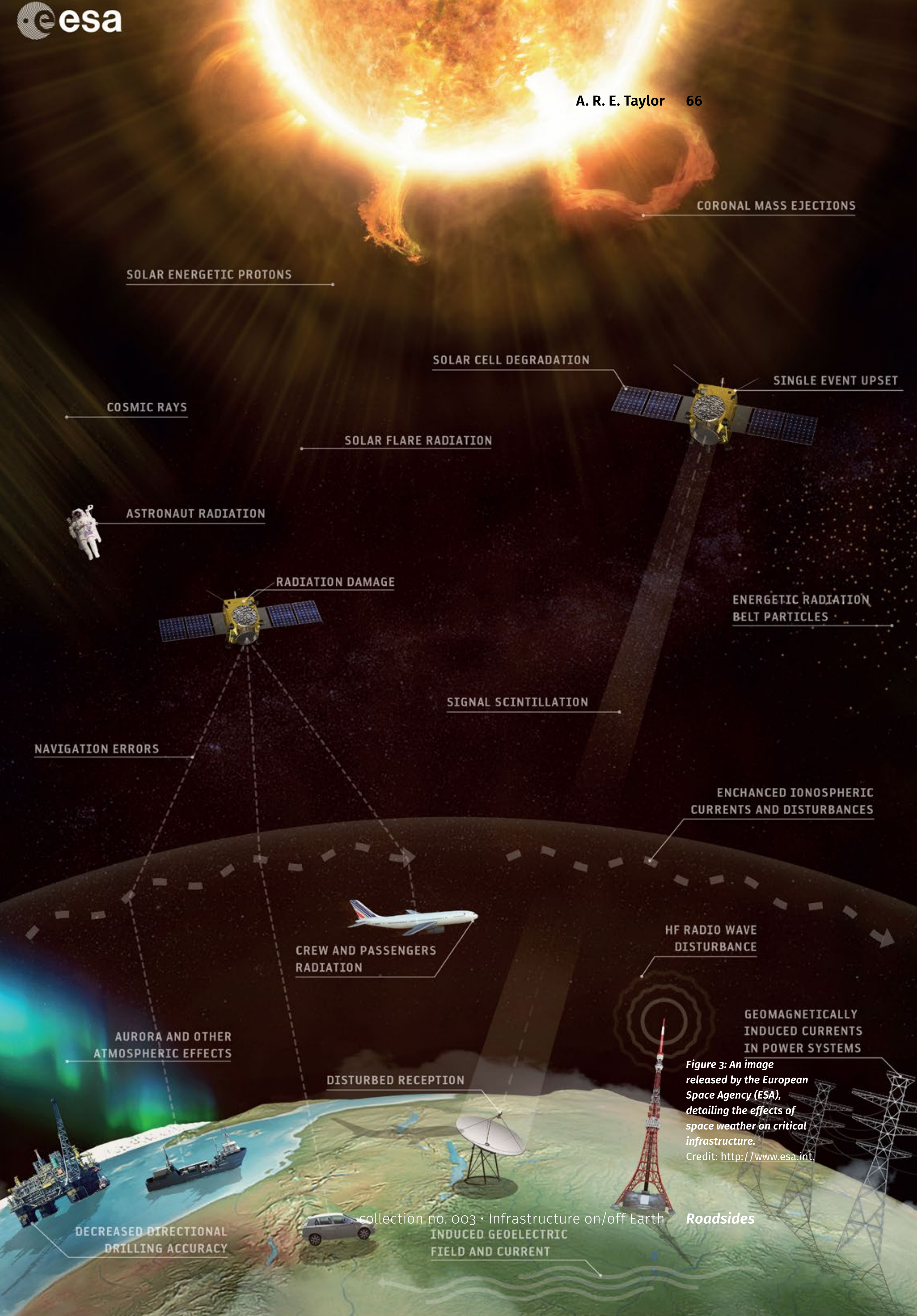

Figure 3: An image released by the European Space Agency (ESA), detailing the effects of space weather on critical infrastructure.
Credit: http://www.esa.int.

Relation as threat

Affecting infrastructure on and off Earth, space weather thus draws infrastructures into threatening relationality with the electromagnetic energy and matter of the Solar System. That infrastructures are not only material technological systems but also profoundly relational entities is one of the key insights to emerge from social studies of infrastructure (Star and Ruhleder 1996; Star 1999; Harvey 2010, 2012; Larkin 2013). During their planning, construction and disintegration, infrastructures produce and perturb relations in ways that are often unintended, sometimes generating unexpected relational configurations that can lead to powerful reorderings of social life. The cross-section image of the space-weathered world thus at once enacts and addresses a relationship of vulnerable permeability between the electromagnetic outer space environment and social life on Earth, communicating a new understanding of how

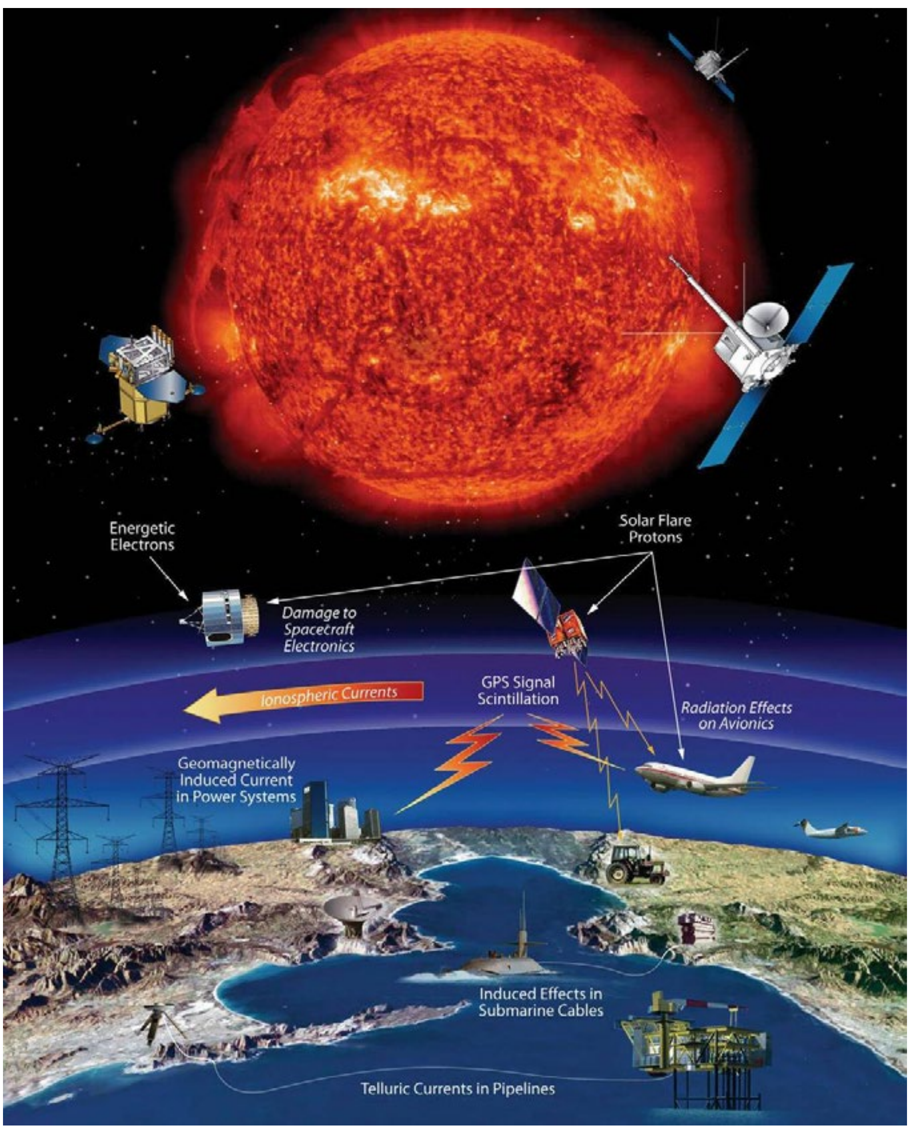

Figure 4: An image of the space-weathered world released by NASA. The caption that accompanies this image on NASA's website reads: "A web of inter-dependencies makes the modern economy especially sensitive to solar storms." Credit: https://www.nasa.gov.

technological infrastructure emplaces and re-scales the planet in (perilous) relation with the Sun. Newly configuring relations of connectivity and proximity between the Sun and Earth, security actors are rethinking the meaning of an infrastructured Earth's place in the cosmos.

Dystopian infrastructure futures

While the development and installation of infrastructure often promises to concretise futures of modernity and progress (Edwards 2003; Harvey and Knox 2012, 2015; Hetherington 2014; Anand et al. 2018), the failure or breakdown of infrastructure can threaten to disrupt or even undo modernity. Severe space weather events are often represented in the mass media as entailing the prolonged loss of power grids, computer systems, satellites and other critical infrastructures, on a national, continental or even planetary scale.[1] The imagined technological and societal disruption is typically configured temporally as a violent return to a pre-modern evolutionary stage, with news headlines frequently proclaiming that a severe space weather event would "send us back to the Stone Age" (Anthony 2014). Here, infrastructures are loaded with temporal power, with their continuation or collapse enabling the global north to move forwards or backwards in time respectively.

It has become a commonplace that infrastructures are not only located in space but also in time (Appel 2018; Joniak-Lüthi 2019). In particular, scholars have highlighted the "forward-looking" (Gupta 2018: 63) or future-orientated nature of infrastructure temporalities. But the futures that circulate around infrastructure can also be pasts. In discourse on the space weather threat, infrastructures are decidedly heterochronic sites where narratives of technological progress abut with narratives of technological dependency and societal atavism.

Despite the "global threat" rhetoric, the space weather risk is rooted in uneven techno-geographies and thus unfolds at varying degrees across different national contexts. While the infrastructure-heavy global north is brought into dangerous relationality with a roiling Solar System, those countries in the global south with fewer infrastructure services and where "ruination is a constant companion of infrastructure" (Boyer 2018: 224) remain largely cut off from this cosmic connectivity (it is perhaps not coincidental that the cross-section image depicts infrastructure on "top" of the world, rather than the "bottom" or "sides" of the world; see Fig. 3 and 4). While a severe space weather event could have cascading effects across the global north/south divide, space weather is generally positioned as a problem for heavily technologised countries (Mureşan and Georgescu 2015: 59). For growing numbers of critical infrastructure protection practitioners, lack of infrastructure in the global south is increasingly perceived not as a social disadvantage but as a source of societal resilience. Space weather thus sits at the intersection of shifting spatial and temporal relations between infrastructure and modernity, and shifting distributions of risk and resilience, in the global technoscape.

De-terrestrialising infrastructure studies

Affecting both terrestrial and orbital infrastructure, space weather unsettles the on/off-Earth binary, weaving ground-based and space-based infrastructures into larger Solar System ecologies (Battaglia et al. 2015: 246; Olson 2013, 2018). Space weather therefore invites us to greatly expand the conceptual limits and relational horizons of infrastructure. Turning scholarly attention to the more-than-earthly existence of infrastructures opens opportunities for expanding critical orientations within infrastructure studies. "Infrastructures bridge distance," Appel et al. (2018: 14) observe, but often that distance is conceptualised along a horizontal plane. The "bridge" metaphor itself gives rise to a decidedly horizontalised rendering of infrastructure relationality. Yet, from radio waves bouncing off the ionosphere to satellite data transmissions, infrastructures also mediate exchange upwards and downwards, inwards and outwards (Olson and Messeri 2015). Space weather invites us to unflatten and verticalise infrastructure research and theory (Elden 2013; Graham 2016; Billé 2020). In doing so, it might also newly attune us to the electromagnetic lives of infrastructure, which unfold across regions of the electromagnetic spectrum that exist beyond the threshold of human perception. Following solar physicists and infrastructure engineers as they connect an increasingly technologised Earth to an electromagnetic cosmos could enable us bring into view the more-than-earthly relations and electromagnetic affordances of infrastructure that might otherwise go undetected in terracentric critiques.

Notes:

[1] For a recent televisual rendering of the space weather threat, see Sky One's Cobra (2020).

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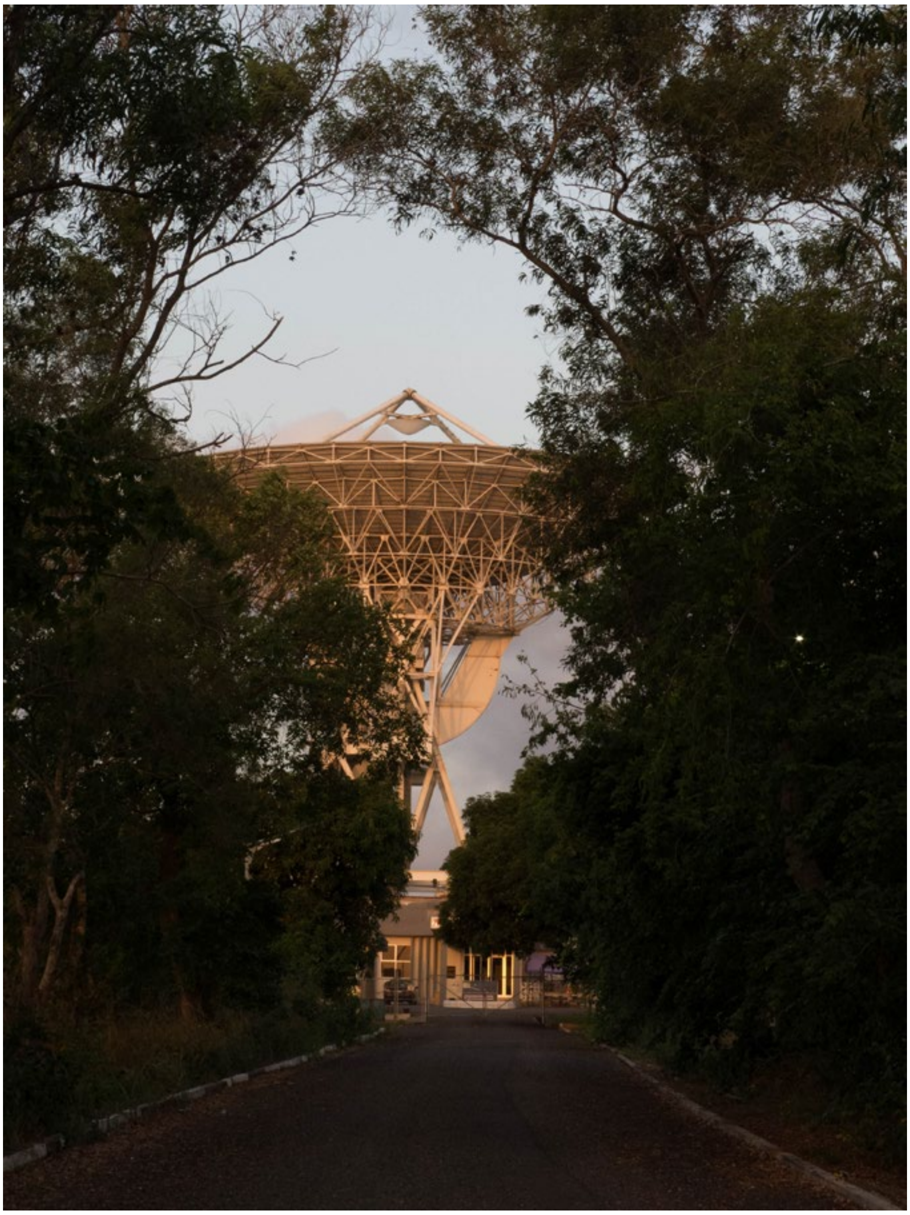
Placing the Cosmic Background: The Ghana Radio Astronomy Observatory as an Ambient Infrastructure

James Merron

Recent years have seen an acceleration and proliferation of space science initiatives across the African continent. Ghana and Kenya established official space programs in 2012 and in 2016 Ethiopia and the African Union adopted a Space Policy (Asabere et al. 2015). These add to existing initiatives in South Africa and Nigeria, inscribing them in both continental and international networks (Camilo 2018; Pović et al. 2018). Notable among these big space science projects is the Square Kilometre Array (SKA), based in South Africa and extending across the continent. Comparable to the human genome project in its scale (Benoit 2018), the network of telescopes exceeds the sensitivity and size of large particle-accelerating machines (Hoeppe 2014). In 2017 Ghana became the second African country to participate in this network, anchoring the African Very Long Baseline Interferometry Network (AVN). As the station most distant from the SKA core site in South Africa, the Ghana facility – because it is close to the equator – is able to cover both the northern sky and underexplored southern sky. Operating alongside the SKA, although at different frequencies, the AVN will train radio astronomers to sense and make sense of hyperobjects as vast as the center of the Milky Way galaxy.



The Ghana Radio Astronomy Observatory, part of the Square Kilometre Array (SKA). Photograph: James Merron, June 2018.

Lisa Messeri (2016) has argued that producing science is producing place. Bringing the extra-terrestrial ambitions of astronomy down to Earth therefore needs to be understood within worldly concerns and local contestations (Twidle 2019: 6). In terms of the SKA/AVN, radio frequency interference (or RFI) exposes the contextual relations surrounding these big space science infrastructures (Agar 1994: 12–13). Every time a person living near a telescope uses a microwave or cell phone, they emit a signal that distorts the astronomers' data. One solution is to locate radio observatories in remote locations. When this is not feasible, negotiations between astronomers and residents about electromagnetic interference index a sensorial politics that is often enmeshed within other local conflicts. Based on my account, the SKA/AVN can be read as part of an "ambient infrastructure" (Larkin 2016), shaping the way space is produced, organized and experienced.

The SKA/AVN are radio astronomy projects based on the technique of interferometry, which – simply put – is the scientific practice of linking together a network of individual telescopes in order to create a single large (virtual) dish. The future SKA/AVN infrastructure will be composed of over 3,000 fifteen-meter telescopes and thousands of receivers, making it the world's "largest telescope and the largest science project in Africa" (Gastrow 2015: 2), not to mention the "largest scientific structure on the planet." Its design is similar to the collaboration that produced the first image of a black hole in April 2019, which involved transporting tons of hard drives from observatories in Hawaii, Antarctica and Chile to central correlators in Massachusetts (USA) and Bonn (Germany) where the data was processed and translated into an image (Doeleman 2017).

A student in the Development in Africa with Radio Astronomy program detecting radio frequency interference near the Ghana Radio Astronomy Observatory. Photograph: James Merron, June 2018.

Interferometry – like other techniques of multi-wavelength astronomy – is directed at producing data that is made accessible for combination with other data from instrumentation elsewhere in the world (Hoeppe 2012: 1149). As a thing and a relation between things, the SKA/AVN infrastructure provides the grounds upon which other objects operate – in this case, radio telescopes in Africa. And when they operate, they operate as a system, mediating the exchange of information over distance and bringing people, objects, and spaces into interaction with one another (Larkin 2013). Besides the central correlators and high-performance computers that are usually located in the global north, another contact zone of this exchange is the rhizomatic networks of cables that transport power and signals to and between individual telescopes. In the process of cleaning data, the humming of cables indexes another local trace that is erased, since interferometry relies on clean inscriptions.

Cable wraps that transport data and power from the receiver to high-performance computers in the laboratory below. Photograph: Andrea Zimmermann, August 2019.

The SKA will progress in two phases. Phase One, which ended in 2019, involved the establishment of a network of telescopes in South Africa and Australia. Phase Two is premised on developing radio astronomy science, technology and infrastructure across the African continent. But unlike the individual telescopes built in South Africa, those in the African partner countries will not be built from scratch. Rather, the telescopes are (and will be) constructed from recycled materials sourced from ground-based telecommunications satellite dishes (Hoare 2012), made redundant through the advancement of fiber optics across the African continent (Emmanuel et al. 2014). This idea was conceived by the late Michael Gaylard who, during two years of repair to the Hartebeesthoek Radio Astronomy Observatory in South Africa, used Google Maps to scour the continent for old telecommunications dishes that could be converted into radio telescopes (Gaylard 2013; Thondikulam et al. 2013).

West Africa's first radio telescope is located on the periphery of Ghana's rapidly urbanising capital city, Accra, at a site called Kuntunse. In its previous existence, the device had already made possible the exchange of information over long distances. In 1981, President Hilla Limann of Ghana used the facility to make a phone call to Margaret Thatcher, which was the first call made by international direct dial in Ghana and one of the first in Sub-Saharan Africa (Amoah 2014). Dr. Abdul Ibrahim – lecturer in Geographic Information Systems at the University of Ghana – recalled during a conversation we had in 2018 that the commissioning of the satellite dish also coincided with Princess Diana's wedding in 1981 (which, like the call to Thatcher, was broadcast throughout Ghana to all who could receive the signal). In 2008 the satellite receiver was sold to telecommunications giant Vodafone, which temporarily made use of the facility until 2015, when the company handed it back over to the Ghanaian Government.

Before the ground-based telecommunications satellite receiver became a radio telescope in 2017, residents of Kuntunse had already occupied the unused land surrounding the facility. The afterlife of this space infrastructure has now intensified a land dispute between Vodafone (which still owns the land), the Ghana Atomic Energy Commission (which oversees the facility's operations), and the people of Kuntunse. Based on my observations though, the farmers and residents living adjacent to the telescope do not threaten it in any material sense. The trouble only begins once they turn on their cell phones, televisions or microwaves, since these devices interfere with the cosmic signals that the scientists are trying to detect with the telescope. Devices that emit electromagnetic signals produce a local trace that astronomers construct as "noise," an impurity and a threat to their ability to make authoritative claims. Thus, while premised on producing and sharing "clean" data within transnational networks, the interferometry infrastructure is emplaced within distinctly local conditions constituted by this unwanted interference.[1]

There are, broadly stated, two kinds of astronomy: optical and radio.[2] Optical astronomy is mediated by lenses through which galactic sources are tracked and interpreted. In this format, interference is generated by light pollution, mostly originating from nearby cities. On the other hand, radio astronomers "see" beyond the visible spectrum of light, transducing invisible radio waves into images. Somewhat paradoxically, this vision is achieved by telescopes that "listen" to radio waves (Twidle 2019).

The Ghana Radio Astronomy Observatory from a distance. Photograph: James Merron, June 2018.

In this sense, Jon Agar (1994: 13) has posited that while optical astronomers are concerned with "dark skies," radio astronomers seek "quiet skies." However, alluding to interference in this way confuses the form and function of radio astronomy and the exact type of sensorial politics it makes possible. Do astronomers "hear" radio waves, "listen" to the cosmos, or "see" images? Addressing these ambiguities would lead to a better understanding of the relationality of outer space and the ambient conditions it produces on Earth, particularly in terms of the radio frequencies that technologies compete over.

The "encroachment" of Kuntunse residents around the Ghana Radio Astronomy Observatory is defined in relationship to the electromagnetic spectrums they inhabit, which construct them (and their devices) as ambient. Brian Larkin (2016) defines ambience as "a bodily reaction to lived reality and a cognition achieved through taste, touch, hearing, seeing and smell." This account, however, is limited to the human body, whereas the sensorial politics of radio astronomy emerges when technologies and frequency interfere with one another. Inspired by Larkin's analysis, my account takes a different approach in order to highlight conceptual entanglements at the intersection of astronomy, infrastructure and senses that go beyond human eyes, ears, mouths and noses. Of course, there is a diversity of ways through which to conceive of and analyse infrastructures, and the act of defining something as an (ambient) infrastructure is ultimately a categorization moment through which certain epistemological, methodological and political commitments become important (Larkin 2013: 330).

Treating radio astronomy in terms of its ambient conditions places outer space infrastructures, bringing their ambitions down to Earth and situating them in the context of local conditions and competing claims over space, on and off Earth (see Chinigò 2019; Walker 2019).

Notes:

[1] This also includes instrumentation and modes of usage (Hoeppe 2012: 1149). For instance, non-cosmic noise helps maintenance workers find and repair problems in the devices they use, as Stephan Helmreich (2016) has pointed out apropos the large interferometer used to detect a gravitational wave for the first time in 2015.

[2] This is a simplification, since doing astronomy at any wavelength – from x-rays, ultraviolet light and infrared to gamma rays – can be considered another "kind" of astronomy. The rendering of astronomy as either radio or optical simply serves my purpose of highlighting different sources of interference (credit to Götz Hoeppe for making this clear to me).

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