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Sociotechnical Imaginaries of Sharing and Emerging Postdigital Meaning-Making Practices in the Astronomy Community

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Abstract
For decades, science communities have had digital technology embedded in their everyday work. However, new research infrastructures are amplifying the presence and use of digital technologies for scientists. In that respect, radio astronomy is undergoing a major transformation causing the community to enter a phase of post-digital work, due to the construction of the most sensitive telescope, the Square Kilometer Array Observatory (SKAO), which scales the presence of digital technology and the amount of data generated. As new digital research infrastructure is set up, sociotechnical imaginaries—symbols and visions of a shared future—emerge, while others become obsolete thus impacting structures and practices of meaning-making. In this paper, we explore the disruptive potential of sociotechnical imaginaries and how astronomers using SKA pathfinder and precursor telescope data respond to these imaginaries and incorporate them into their meaning-making. The analysis shows that postdigital imaginaries related to data circulation, storage, archiving, and reuse have been amplified as SKA facilities and services are set up. Two changes are highlighted regarding a new postdigital condition within the astronomy community. Firstly, as astronomers engage in new postdigital forms of collaboration, they need to reach a consensus on what types of analyses to use by agreeing which methods are appropriate. This affects how scientific questions and research proposals are negotiated collectively, impacting the agency of astronomers. Secondly, as digital tools are increasingly part of astronomers' daily work, they have to rely on new data analysis methods, which determine what evidence is uninteresting. Overall, these changes pose new questions regarding how meaning-making processes are altered and the way science is undertaken because of these new entanglements of human and non-human actors.

Keywords Sociotechnical imaginaries · Postdigital · Meaning-making · Knowledge · Sharing

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Introduction: Research Infrastructures and Postdigital Technoscientific Normative Principles

Science communities engaged in empirical scientific work are struggling with the volume, velocity, and variety of data available due to the use of large-scale Digital Research Infrastructure (DRI). DRI enables researchers to analyse and understand complex topics by supporting scientists to work with data and computation efficiently and securely at scale. DRI includes large-scale compute and data storage facilities, advanced research computing, software, and shared code including AI and software algorithms. In the UK, organisations such as the UK Research and Innovation Funder (UKRI) are working towards building an exascale capability, to push the frontiers of data-intensive research through modelling, simulation, and analysis.

As DRIs continue to evolve, new or renewed postdigital normative principles and knowledge-making practices emerge, while others become obsolete or are recontextualized. One such normative principle is openness or Open Science (OS), which aims to make research data, outputs, documentation, and methods widely available for sharing and reuse within and beyond the scientific community. Open Science has gained momentum due to the investment in new technologies that generate and mobilise vast amounts of data, thus making the digital inseparable from the non-digital. However, different scientific communities have interpreted and implemented this ideal according to their unique values, social norms, and epistemic cultures (Knorr-Cetina 1999). Therefore, the extent to which Open Science is embraced or resisted as a new postdigital practice depends on empirical, technological, and social aspects of knowledge production. In other words, the acceptance or rejection of Open Science, or any other ideal, varies according to a community's dynamics, human and non-human relationships, technological advancements, value systems, and structural inequalities.

By postdigital in scientific investigation, we refer to a societal and cultural condition within and across science communities where the digital is no longer separated from material, political, economic, biological, and environmental factors (Fawns 2019; Jandrić et al. 2018). Put differently, the postdigital designates the idea that digital cannot exist without multiple forms of hybridity with analog (Cramer 2015). Interestingly, if digital presence scales further, questions about its invisibility, ephemerality, seclusion, and copresence—'fugitive practices'—will arise (Gourlay 2023). That is, the development of new DRIs leads to reconsider how technoscientific normative principles reactivate meaning-making and knowledge-making practices, or as Gourlay (2023) has suggested, to questions about what kind of 'fugitive practices' emerge in the postdigital work of scientists—e.g. the copresence aspect of scientific collaboration may be eroded by digital technologies and performativity practices. Similarly, if these new digital technologies aim to transform the way astronomers explore the universe, what is at stake is the 'formation and creation of meaning: the desire to "know the unknown"' (Aarseth 2022: 1).

Studies in the field of science have shown that research infrastructures express political values and transform knowledge-making practices. These infrastructures shape practice and culture, as shown by scholars such as Larkin (2013) and

Jensen and Morita (2017). For instance, Science and Technology Studies (STS) have examined how large-scale digital infrastructures created for border security generate shared visions of border insecurity (Trauttmansdorff and Felt 2021). Biomedical research infrastructures, on the other hand, result in conflicting views on usefulness amongst researchers and policymakers (Aarden 2017). In addition, CERN, one of Europe's largest research infrastructures, has been found to be performing Europeanness in multiple ways and shaping scientific institutional identity (Mobach and Felt 2022). Other studies have highlighted how research infrastructures change ways of working and research practices such as collaboration (Cramer 2017; Cramer and Hallonsten 2020), how meaning is recontextualised when there are non-human actors involved (Bhatt 2023), or how virtues are transformed when work increasingly relies on autonomous systems (Vallor 2024; Vallor and Ganesh 2023).

In this article, we explore the emergence of technoscientific normative frameworks attached to large-scale and transnational research infrastructure and the transformation of knowledge-making practices. To do that, we use the concept of *sociotechnical imaginaries* (Jasanoff and Kim 2009) to discuss the mutual shaping of these imaginaries and meaning-making within science communities when new research infrastructures are set up. We use the notion of sociotechnical imaginaries since they 'are associated with active exercises of state power, such as the selection of development priorities, the allocation of funds, the investment in material infrastructures, and the acceptance or suppression of political dissent' (Jasanoff and Kim 2009: 123). Sociotechnical imaginaries have a specific target and provide a well-defined action framework.

Specifically, we focus on the Square Kilometer Array Observatory (SKAO) and UK SKA Regional Centre (UKSRC) as a case study. SKA telescopes will be the next-generation radio astronomy infrastructure facility that 'will mark a paradigm shift not only in the way we see the Universe but also in how we undertake scientific investigation' (Hartley et al. 2023: 2). We analyse the ways in which recurrent narratives circulate within the astronomy community as SKA facilities and services are established and examine how they affect knowledge-making practices, which we understand as a form of what linguistic anthropologists call entextualization (Canagarajah 2021). This implies that we investigate how astronomers transform their agency—the articulation of meanings and practices—by taking symbols and textual materials that represent sociotechnical imaginaries and incorporating them into their discourses and practices.

Based on document analysis and interviews with astronomers, we have identified a narrative that has gained more attention in recent years and has become more stable and recurrent as research infrastructures are set up—that narrative is *sharing* (Gehl 2015). The construction of SKA facilities and services has further moved the discourse of Open Science, or 'the freedom to share' (Leonelli 2023: 6), data reusability, and collaboration amongst astronomers, thus impacting how they relate to knowledge creation (Hoeppe 2020). We explore how sharing has been mobilised as a stabilised discourse through official reports and activities over the past three years. We focus on this discursive framing because it is associated with national and international policies, the allocation of funds, and the construction of infrastructures, which is, as we have highlighted, what makes sociotechnical imaginaries possible (Jasanoff and Kim 2009).

The paper is divided into three sections. Firstly, we explain the concept of sociotechnical imaginaries and the methods used to examine the relationship between these imaginaries and knowledge-making practices. Secondly, based on document analyses, we describe how the sharing narrative leads to the creation of sociotechnical imaginaries related to circulation, storage, archiving, and reuse. Thirdly, based on interviews with astronomers, we analyse how astronomers take symbols and textual materials from sociotechnical imaginaries and incorporate them into their discourses and practices thus impacting more-than-digital meaning-making in the astronomy community.

Sociotechnical Imaginaries and Postdigital Meaning-Making in Science

The ability to envision possible futures is a fundamental aspect of social and political existence, as noted by Jasanoff and Kim (2009). Science communities are particularly adept at creating visions of the future and constructing systems of meaning that enable collective interpretations of social reality, especially when new technologies or scientific discoveries are involved. The history of scientific advancement, as well as the creation of new devices, tools, and algorithms, provides unique opportunities for expectations and promises regarding the future of nature and society to emerge. In other words, imagination plays a crucial role in shaping the development of technology in science, and technology, in turn, provides new elements for envisioning shared futures (Beckert 2016).

The concept of sociotechnical imaginaries helps in understanding the promises, visions, and expectations that arise from new digital research infrastructures (Fujimura 2003). As an analytical concept, it provides theoretical insights to explore how imagination, research infrastructures, and social action interact and shape each other. It has been argued that the emergence of sociotechnical imaginaries related to research infrastructures depends on a complex interplay between social, technical, textual, natural, and architectural factors (Law 1990). In other words, promises from science and expectations from society are shaped by both human and non-human relationships (Mobach and Felt 2022). These promises, expectations, and visions are feasible futures, pointing to a potential reality that is socially, culturally, and technologically possible. Therefore, imagination plays a twofold role: it provides insights to imagine a better future, but also warns about potential hazards or negative consequences that may arise from new technological innovations.

An important aspect is the recognition that sociotechnical imaginaries have power effects—i.e. they 'serve as a key ingredient in making social order' (Jasanoff and Kim 2009: 122). These imaginaries play a role in both transforming and stabilising social relations that generate power effects on identity formation practices (Foucault 2007; Law 1990). Thus, questions around what stabilises social relations can be addressed by considering the role played by sociotechnical imaginaries. When these imaginaries are embedded in a scientific community's values, social norms, and meanings, they engender changes in practices (Borup et al. 2006). Therefore, sociotechnical imaginaries have the capacity to disrupt or exceed existing ways of working and research practices. Put differently, they can alter the values and ethical standpoints of scientists (identity) in a way that leads to a transformation of their knowledge-making practices.

However, the way these imaginaries are conceived has implications that can limit their impact in transforming practices. For example, by neglecting the socio-materiality and inequalities of epistemic cultures, current imaginaries may reduce practices to mere abstract principles that can be supported through instrumental adaptations (such as technical standards for data sharing). For example, it is worth noting that Open Science was originally created with two main goals: to make information and knowledge accessible to everyone, both inside and outside of science communities, and to increase scientific accountability by making science more open to scrutiny. However, at the same time, some people have used Open Science to establish certain standards that do not necessarily consider the sociocultural aspects of science communities, like differences in meaning-making, or unfair treatment of some groups (Leonelli 2023). This indicates that sociotechnical imaginaries are powerful forces that circulate across various disciplines (Rahm 2023). They represent conflicting views and practices within science communities and are both dynamic and compelling.

Crucially, these imaginaries can become objectified narratives and be used as 'powerful instruments of meaning-making' (Jasanoff and Kim 2009: 123). In other words, when new sociotechnical imaginaries emerge or become obsolete, meaning-making, discourses, and knowledge practices are recontextualised and reactivated. If we assume that the development, deployment, and application of new digital technologies in scientific investigation determine the trajectories of these imaginaries, then meaning and technology have a close relationship. For example, as research practices become more automated by non-human actors, such as software algorithms and artificial intelligence (AI), meaning- and knowledge-making practices are transformed altogether.

In what follows, we describe the approach used to explore the intersection of sociotechnical imaginaries and knowledge-making practices at the crucial moment when a new digital research infrastructure is established in the astronomy community.

Methods

To understand how sociotechnical imaginaries emerge, deploy, and shape astronomers' agency, the articulation of meanings and practices, we used two methods. Firstly, we analysed official reports and presentations related to the SKA project since its inception. Based on Shankar et al. (2017), we analysed 'documents that document' (2017: 61). We focused on two key aspects of these documents: (1) how they represent the process of infrastructuring and (2) how they influence actions within scientific communities, serving as guidelines. This helped us understand how institutions think (Prior 2008). It is important to note that as SKA facilities and services evolve, the documentation analysed may describe something that has already taken a different direction or will take one in the future. Although the SKA may look quite different when ready, we focus on imaginaries regardless of their practical form.

Secondly, we conducted 18 interviews with astronomers using data from SKA pathfinders and precursor telescopes and the UK SKA Regional Centre (UKSRC). We explored the experiences of both early-career and established researchers from different subfields (SKAO Science Working Groups), with a balanced sample in terms of gender, race, and location. Using a 'thinking with theory' approach, we analysed the data thematically and highlighted the most relevant issues through an iterative and reflexive process (St. Pierre and Jackson 2014).

The SKA–UKSRC Case: Sharing as a Sociotechnical Imaginary

For decades, the astronomy community has had digital technology embedded in their everyday work. Since the 1970s and 1980s, astronomy has been a data-intensive science using multiple digital technologies and distinctive forms of collaboration, data processing, and communication. Over the past twenty years, projects like the Hubble Space Telescope (HST), the Very Large Telescope (VLT), and the Atacama Large Millimeter/submillimeter Array (ALMA) have challenged the work of astronomers in different ways (Lehuedé 2023). However, the Square Kilometer Array Observatory (SKAO) is a quantum leap, causing the community to enter another new phase, where the presence of digital technology and the amount of data are scaled further. The development of the SKA facilities and services will change how data is gathered, transported, and analysed (Quinn et al. 2020; Scaife 2020).

The SKAO will be a complex operational system of one observatory, two telescopes, three sites, and a network of Regional Centres (SRCs) (Quinn et al. 2020). The observatory has a global footprint and consists of the SKAO Global Headquarters in the UK, the SKAO's two telescopes at radio-quiet sites in South Africa (SKA-Mid) and Australia (SKA-Low), and facilities to support the operations of the telescopes. The international network of SKA Regional Centres (SRCNet) will be made up of SRCs (nodes) distributed around the world in SKA member countries. These facilities will be the only route for scientific users to access and analyse SKA data (Fig. 1).

The SKAO is an intergovernmental organisation that can be traced back to the early 1980s when a group of astronomers imagined the next-generation radio astronomy observatory. They mobilised around one question: 'How can we fill in the gaps in our understanding of the Universe by reading its history as written in the language of its most abundant constituent, Hydrogen?' (SKA Observatory n.d.). To answer this question, a novel radio telescope needed to be built, 'a telescope with a collecting area approaching one square kilometre (one million square metres)' (SKA Observatory n.d.). Over the last decades, astronomers and engineers have been working together to make this ideal technologically possible. Thus, in 2005, a document was published with six potential technologies for SKA, and during the following years, a provisional governance structure was put in place and working groups were created. Since 2010, the SKA has started to become real, with the establishment of the SKA organisation in 2011, the dual site selection for the telescopes in South Africa and Australia in 2012, and the establishment of the SKAO's Global Headquarters in the UK in 2015. In 2022, SKA Regional Centre Network formed

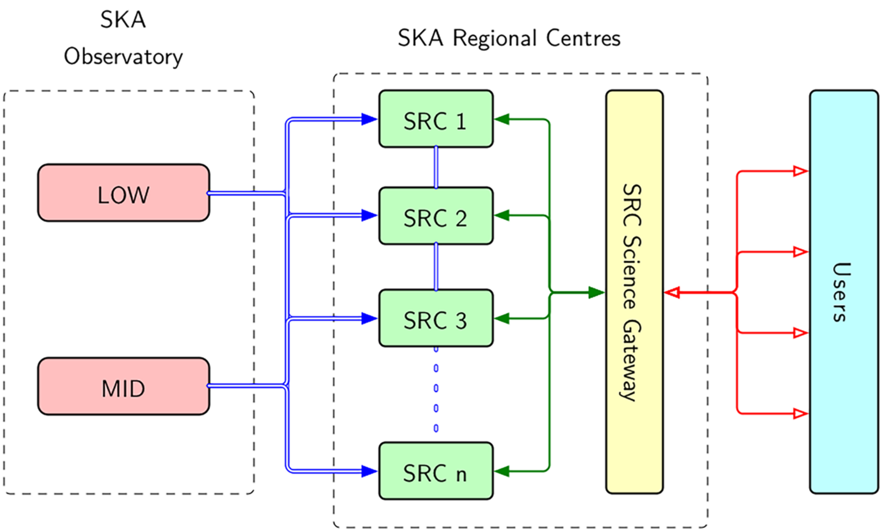

Fig. 1 The SKA's data journey, © Square Kilometer Array Observatory 2024, reproduced with author's permission

teams which started prototyping the technical solutions required. By 2029, the telescopes will be capturing data.

Astronomers will be experiencing a significant social transformation that is affecting their work and research practices. One notable change is the shift towards collaboration and sharing. Instead of working in small groups with local resources, astronomers are now working with global communities, utilising shared equipment such as the SKA Science Archive, and creating shared outputs like datasets and publications (Hartley et al. 2023).

SKA as a Global Network

The SKA telescopes and the SKA Regional Centres have been established with a focus on collaboration, sharing, and Open Science. According to official reports, the SKAO's mission is to 'build and operate cutting-edge radio telescopes that will help us better understand the Universe and deliver benefits to society through global collaboration and innovation' (SKA Observatory 2021: 19). Collaboration is also defined as one of the key values of the SKA organisation: 'We are aligned around common goals and actively create and promote collaborative working across cultural and geographical, functional and specialist boundaries. In doing this, we will communicate appropriately and in an open manner, delivering on commitments and building long-term, supportive, trusting, and professional relationships' (SKA Observatory 2021: 21). In other words, the success of the project relies on collaboration, sharing, and openness on a global scale.

This narrative systematically emerges from multiple sources. For instance, in the SKA Regional Centre White Paper (Quinn et al. 2020), which is intended to provide a common descriptive framework to define the forms of collaboration between Regional Centres, it is pointed out that.

> As previously experienced by the Large Hadron Collider (LHC) project, the SKAO and the international SKA science community will need to work collaboratively to shape and establish a shared, distributed data, computing and networking capability that draws on international cooperation and supports the broad spectrum of SKA science. (Quinn et al. 2020: 1)

Collaboration amongst astronomers is not a new concept. However, the SKA project is generating new ways of collaborating using an overwhelming amount of data and distributed data systems and automated processing. This collaboration involves astronomers working across countries and disciplines, such as data scientists and engineers, and utilising shared resources like high-performance and cloud computing to enable data flows. Collaborative work and the use of shared resources have become essential components of astronomy research for a collective and progressive future.

To facilitate global collaboration, the SKA has formed the SRC Network which refers to the 'the collection of both services and infrastructure that constitute a global SRC capability' (Quinn et al. 2020: 3). Recognising the differences in scale, timeline, and resources, each Regional Centre:

> will need to contribute to a converged, coherent, and logistically centralised international SRC network that meets the needs of an operational observatory while being responsive to the needs of key projects, teams and science cases identified by SKAO and of the full cycle of SKA data use (Quinn et al. 2020: 4).

The SRC Network will be an essential tool for global collaboration amongst dispersed Regional Centres. Its primary purpose is to enable researchers to deal with data on larger scales that cannot be stored in one single country. The network aims to meet the needs of both the observatory to provide user data and the user community to achieve scientific outcomes. It comprises six functionalities: data logistics, commonality, data processing, data archiving and curation, scalable resource management and allocation, and user support. These functionalities ensure data accessibility, define common standards for users, and provide resources to interact with and analyse data and 'a functional and persistent SKA Science Archive incorporating FAIR and Virtual Observatory services that allows data discovery, access, use and reuse, new science and scientific reproducibility as well as data provenance all along the full data cycle' (Quinn et al. 2020: 8). Crucially, the SKA Science Archive 'will be designed as a distributed, but logically centralised, system across the SRC network' (Quinn et al. 2020: 20).

The SRC Network is an essential part of the operational, technical, and infrastructural capacity required to make collaboration, openness, and data circulation possible. By offering services to the user community for data access, data processing, workflow design, repurpose/reuse, and execution, the SRC Network will enable the visions of the possible future of astronomy investigation. Therefore, the functionality, operability, and sustainability of the SRC Network are critical factors in determining the success of these visions.

Jasanoff and Kim (2009) argue that sociotechnical imaginaries are associated with potential risks. In the case of the SKA project, official reports have mainly focused on technical, operational, financial, and managerial risks. For example, the SRC White Paper highlights that '[a] failure of those relationships to provide persistence and capacity in the SRC network, should be considered one of the highest level risks for the SKA that needs to be addressed in the short-term' (Quinn et al. 2020: 20). Along with these internal risks, the SKA organisation and astronomers have anticipated other risks or challenges related to the global nature of the project, such as the carbon footprint due to the use of HPC.

Data Circulation, Storage, and Archiving

If the amount of data gathered is scaled further, data circulation or data flows become a priority (Leonelli and Tempini 2020; Scaife 2020). However, to make this possible, astronomy community needs to process, store, curate, and make data accessible. The data will circulate from two telescopes to the SKA Regional Centre Network, where it will be stored and shared with community users. The diagram in Fig. 2 provides a general overview of the new data journey from SKA telescopes to users, highlighting the role played by the Science Data Processors and SKA Regional Centre Network.

Astronomers will have less involvement in data calibration and imaging due to the SKA Central Signal Processor and SKA Science Data Processors (Scaife 2020). These processors will use high-performance computing and pre-defined algorithms to clean and reduce the volume of data. The astronomers will then be provided with 'observatory data products' that are ready for analysis (Breen et al. 2021). To move the data out of the telescopes, it will be replicated across SKA Regional Centres (Fig. 3).

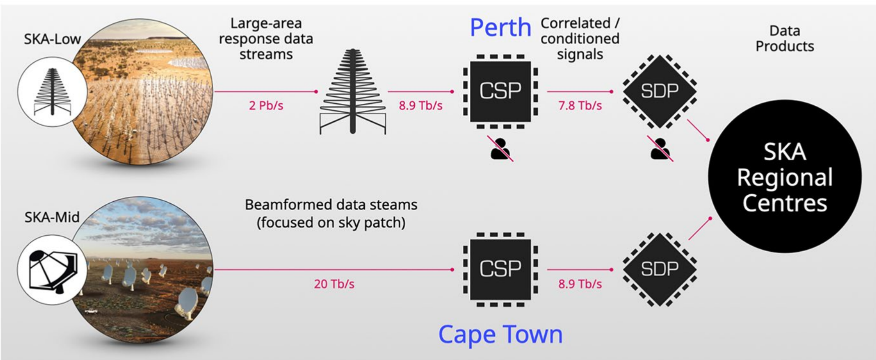

Fig. 2 The SKA's data journey and the Astronomy Community, © Square Kilometer Array Observatory 2024, reproduced with author's permission

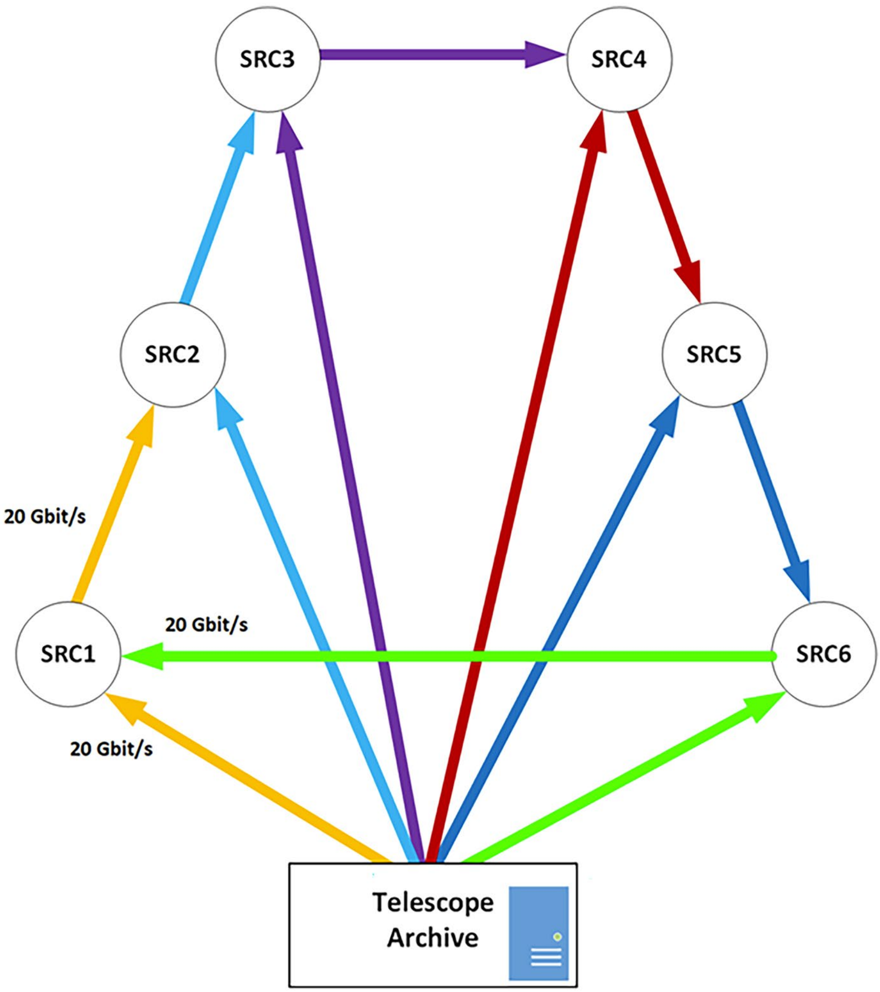

Fig. 3 Data replication across SRC, © Hughes-Jones et al. (2019), reproduced with author's permission

The process of transporting data from telescopes to data archive, storage, and researchers for analysis is a crucial step in the field of astronomy. It involves global data transport across countries and continents, which is essential for collecting and analysing vast amounts of astronomical data. This data is collected from telescopes located in South Africa and Australia. The following image is remarkable as it envisions the scope and dynamics of data circulation from two telescopes. It highlights the complexity of the data transmission process, which involves a network of interconnected data centres and communication channels. The image provides a visual representation of the vast amounts of data that are collected by telescopes and the intricate process of transmitting this data to a central location for analysis (Fig. 4).

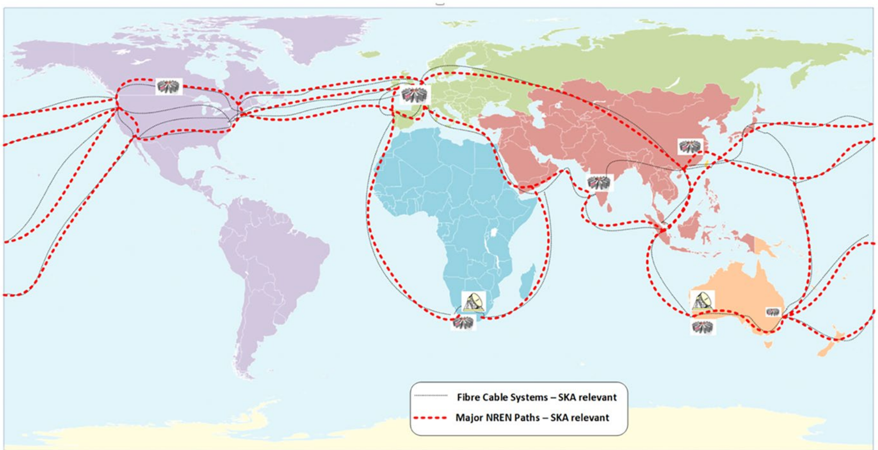

Fig. 4 Data circulation, © Square Kilometer Array Observatory 2024, reproduced with author's permission

This image represents the idea of a worldwide network driven by the exchange of data, or 'a network of links around the globe' (Quinn et al. 2020). Data will flow in various directions, spanning across land and sea, and astronomers will utilise shared resources and generate collective outcomes for scientific exploration. This embodies a future for astronomy research based on global cooperation, transparency, and sharing that fosters ideas of immediacy and universality.

To make data easily shareable and reusable, research infrastructures need to provide archive and nearline storage facilities and services such as data clouds, accessibility protocols, and data management policies. We argue that these services create a vision of *infinite circulation*, *storage*, *archiving*, and *reuse*. This idea resonates with the concept of effective communication (Leonelli 2023) or perfect communication (Halpern 2015: 75), which emphasises the need for 'immediate, and immediately effective form of interaction' between data and researchers, as well as amongst researchers themselves. The ultimate goal is to achieve an interface that enables real-time interactions, thereby demanding total commensurability or translatability, which refers to the emergence of data-driven communicative objectivity (Halpern 2015)—i.e., a form of knowing that emphasises how researchers can analyse large volumes of data and find patterns in it, or how well-prepared and trained researchers are to systematically analyse a lot of data, rather than just capturing data. SKA's facilities and services are a step closer to achieving what has been referred by Halpern (2015) as communicative objectivity.

The emergence of sociotechnical imaginaries of sharing, characterised by infinite circulation, storage, archiving, and reuse, has brought about significant changes in the way astronomers approach inquiry and knowledge. These changes are manifold and complex, encompassing a range of factors that include the democratisation of access to information, the growing importance of collaborative research, and the increasing reliance on digital tools and platforms. One of the most striking aspects of this shift is the way in which it has transformed the role of data in astronomical research. With the proliferation of digital archives and repositories, researchers now have access to vast amounts of data that were previously inaccessible or difficult to obtain. This has opened up new avenues of inquiry and created opportunities for interdisciplinary collaboration, as researchers from different fields will share and analyse data in ways that were previously impossible. Overall, the sociotechnical imaginaries of sharing have a profound impact on the field of astronomy, leading to a new structure of meaning-making including ways of thinking and knowledge-making practices. In the next section, we explore how these practices are further reorganised due to these changes.

Sharing and Meaning-Making Practices

In this section, we examine how sociotechnical imaginaries of sharing, which include infinite circulation, storage, and archiving, shape astronomers' agency—i.e., the articulation of meanings and practices. Based on the interviews, astronomers have emphasised issues around collaboration and communication and interactions between people, technologies, and algorithms to explain changes in meaning-making practices. Also, astronomers have highlighted the need to produce replicable data analysis methods, processes, and data products that can be shared or transferred to any environment. In what follows, we explore these issues considering sociotechnical imaginaries of sharing as 'powerful instruments of meaning-making' (Jasanoff and Kim 2009: 123).

Collaboration, Communication, and Epistemic Trust

As mentioned earlier, handling larger amounts of data requires a new approach to knowledge-making. Astronomers have moved from working with data collected by them or others in their team to using data that has been collected and processed by (unknown) people or systems outside their immediate group: 'the scale of the data, the volume of the data, the complexity of the data is going to require astronomers to work at a higher level of organization than they have in the past' (participant 4). That is, '[y]ou have to collaborate with people you never thought about collaborating with before' (participant 6).

Astronomers are fully aware of the changes and how they affect meaning-making. One astronomer explains how the use of shared resources pushes forward the presence of digital technology in their daily work, impacting the way astronomers collaborate: 'You've got to collaborate with others to do it [science] because you got to use shared resources' (participant 12). That is, 'you move from an interactive model where you do what you want to one where you're sharing resources' (participant 12). The fact that SKA facilities and services are based on shared resources—SKA cloud, data processors, algorithms, and storages—that produce new global networks (SKA Regional Centres) leads astronomers to find new ways to collaborate. Astronomers envisage working in more extensive and more specialised teams:

> … the number of people in the typical projects, maybe 20 years ago, was 20 or 30. Now it's 400, you know, bigger … because you require much more broad range of expertise. You get people with very bespoke skills, the mechanical sort of the end. And then there's people who have very, very bespoke skills at the image processing end … and they all work together, and there's lots of expertise and lots of things all over the place, and people get, you know, people contribute in different ways. (participant 15)

This new way of working, which includes epistemic dependency between disciplines—astronomers, engineers, and data scientists—adds complexity to how epistemic trust is built amongst scientists and people supporting their work. Trust issues arise because this epistemic dependency is underpinned by changes in how astronomers are 'physically present *with* others in the same material space at the same time' (Gourlay 2023: 62). This shift in interaction is due to the SKA's implementation of digital technologies and networks (postdigital condition), which will alter aspects of research practices, including copresence.

Interestingly, it is argued that epistemic trust 'enables epistemically dependent scientists to acquire knowledge they otherwise would not be able to have' (Wagenknecht 2016: 132). An astronomer describes this:

> So, to verify the quality of the data, we need to rely on processing that we have not done ourselves. So, I think that's also a change in the mentality that we need to, and that will be a hard thing for astronomers in general to have to trust that someone else – in this case observatory – will have been processing the data, and we will not be able to access that. (participant 5)

The same astronomer continues and highlights the need to receive 'much information, or as detailed as possible, to trust the system' (participant 5). Therefore, an important feature of epistemic trust in epistemically dependent groups but physically distant is communication amongst people with various expertise and from different disciplines. Epistemic cultures embody different values, commitments, and standards that often conflict (Heidler 2017). Effective communication becomes crucial, since there is a tendency amongst epistemic cultures to emphasise their professional identity when the social division of labour is scaled further, as was famously pointed out by Durkheim (2013). These diverse groups tend to differ in the terminology they use, their social norms, and values that might inhibit coworking.

In that respect, one astronomer describes the situation in this way: 'Scientists are impatient, and engineers don't like things to be changed from under them. So, I think there's always going to be some conflict.' (participant 13) that is to say: 'Expressing yourself to another scientist who is not an expert in your thing, is actually, I personally feel, an even bigger challenge, because there are some things they do not understand.' (participant 1)

Communication and trust are two crucial aspects that astronomers consider when they ponder about meaning-making and the future of their work. Astronomers emphasise the importance of working in bigger and more diverse teams that share resources to reshape their approach to acquiring knowledge. When astronomers embark on a new investigation, using shared resources has a transformative effect on their practices. As this astronomer explains:

> When I get people coming in saying, can we use LOFAR data? I say, yeah, go use it. Here's what you need. *We'll sort out the politics later*. Let's see what science looks like. [With SKA] will still be possible to do that but you've got to be aware that … you're not the only person seeing them [data], and that does change things. (participant 12)

What does 'sort out the politics later' mean, and why will SKA facilities and services change this approach to inquiry and knowledge? Drawing on this astronomer's view, SKA will need to 'sort out the politics' partly because researchers need to agree on how they collectively organise their research before starting detailed analysis:

> Instead of having, say, 10 astronomers that have 10 small questions, and they're each investigating them individually, you can think of those 10 astronomers working together with the same much larger set of data, and then that slowly splits off into more detailed questions that each one of them is addressing. (participant 4)

This means astronomers work together using the same dataset. In that case, they have to 'sort out the politics' associated with their research before they begin—not only so they have to agree on acknowledged issues such as the quality, accessibility, operability, and reproducibility of data; they also need to come to an agreement around more tacit issues such as what kinds of analysis will be carried out and what methods are suitable. This is particularly important when research proposals are written collaboratively in bigger teams.

These new postdigital forms of collaboration in scientific investigation—the digital is no longer separated from material and political factors—influence how astronomers generate new research questions. As this astronomer explains:

> [before] I [had] a science idea, and I get some data. You write the proposal. The proposal is reviewed. It's accepted. You wait for them to observe it. You get the data. The data comes back. You reduce the data. Then you've got the image you're looking for. Now a lot of the time these new facilities will say instantaneously, you have access to the best quality data you could possibly have. What are you going to do with it? So, it changes your approach to knowledge and to inquiry. I guess, you know, you start asking different questions (participant 12)

An astronomer adds the following:

> Instead of thinking, I have this scientific question, I'm going to look at one star and see if I can answer that question, the thinking is much more the telescope is going to collect a lot of information about a lot of stars, what are the types of scientific questions that we can answer with that. (participant 4)

In the same vein, an astronomer put it this way:

> I honestly find this quite challenging myself [write research questions]. I mean, there's so much you could do. Where do you start? We could get a nice sample of objects and observe them this way, and then we'd be able to answer

> this specific question. But if it's already there [data], do you know what is the step you're going to do? What's the first? Which project should you pick? (participant 12)

It appears that the way astronomers approach research questions has undergone a significant change. This shift has brought about a fundamental transformation in how they conduct scientific investigations. Although sharing of data has become possible through the development of new technologies that produce visions of infinite circulation, storage, archiving, and reuse, it has not elicited entirely positive responses. This new approach to science has led to varying and conflicting opinions about working collaboratively. In essence, there is a transformation at the core of each astronomer's scientific self (Daston and Galison 2007) which may either enhance or impede their creativity, curiosity, and imagination, or the sociomaterial nature of meaning-making.

Replicable Data Analysis Methods and Sharing

In order to use the next-generation facilities and services of radio astronomy, astronomers have concentrated their efforts on developing replicable and shareable data analysis methods. To support researchers to scaling data and change how they work, the SKAO has organised a series of Data Challenges intended to 'allow the science community to get familiar with the standard products the SKA telescopes will deliver and optimise their analyses to extract science results from them' (SKA SDC3 2024). These challenges are an 'opportunity for the researchers to evaluate existing methods and to develop new approaches for data analysis in preparation for SKA telescope data' (SKA SDC3 2024).

An astronomer described changes in work as follows:

> I guess our working has changed … the way we focus on theory or simulations, or analysis methods has sort of changed with the SKA … even though simulations are relevant, the most important thing is to actually get our data methods and analysis pipelines ready. That's why a lot of us now focus on the Pathfinder data products. So that might be MeerKAT or might be LOFAR or MWA. But I feel like the whole community is very much shifted now on really focusing on the data analysis from the Pathfinders, because that's what's really getting us ready for when the SKA data will come. (participant 9)

The same astronomer emphasises how the community have reoriented their efforts towards data analysis methods:

> Now it's shifted to what we need more and more people doing data which means a lot of people have to retrain a bit from a theory background to a data analysis background, and PhD students who've done a theory, they need to reshape their focus on data, really. So, you can see sort of that shift in the community that we just need people developing methods for data analysis … And that's really what we need right now rather than more theorists … There's still a need for it. We still need those 2 branches when we do science,

> but where the focus it's getting now, we need more people on the on the data side. (participant 9)

This means that astronomers who focus on data analysis methods have to abandon some habitual practices that are deeply ingrained in their scientific routine. These changes in approach may affect their professional identity and influence how they perceive the essence of their work and how they make meaning from it. An astronomer highlights this shift as follows:

> I've definitely changed from theory and simulation much more into the data side. And I'm really enjoying digging into the data, but also think back about the actual instruments where they are actually located, to understand what happened to our data and the process of it until we get it on. (participant 2)

In other words, data scaling encourages the development of shared data analysis methods, which enable commensurability and translatability. This, in turn, can lead to a change in individual scientific interests amongst astronomers, prompting them to re-evaluate their time, commitments, and expectations. Thus, for example, transitioning from theory to data may require a reorganisation of priorities and a shift in how astronomers approach research proposals and scientific questions. Therefore, in order for astronomers to effectively share and translate data, it is crucial that they adopt new approaches to data analysis. This requires the SKA Data Processors to develop, as one astronomer put it, the 'perfect algorithm' that enables flawless communication. By doing so, astronomers can achieve commensurability and translatability, leading to greater collaboration and advancements in their understanding of the universe:

> The SKA will operate in in a way where, because the amount of data that it's flowing so huge, you will not be given that – into it [is] that raw information and you will be given various higher-level products. So, being already processed by standard algorithms. Well… And this is a big worry. Basically, the algorithms need to be perfect. (participant 15)

The postdigital and sociotechnical imaginary of the 'perfect algorithm' is driven by the need to remove any differences that may hinder the communication between data and researchers. This vision, one could argue, illustrates the entanglement of the digital and non-digital in a way that determines the future of astronomy investigation. The algorithm (digital) needs to be perfect (epistemological and political factor); otherwise, the entire network could fail. Thus, to ensure quick and efficient interaction, the SKA facilities and services must eliminate any potential obstacles within the datasets that may prevent smooth translation and transmission of information (Halpern 2015). An astronomer describes this situation in this way: 'You have *algorithms filtering out* a lot of what seem to be *uninteresting events*.' (participant 11) this quote is relevant since it shows that some astronomers are searching for an ideal algorithm that can eliminate all the obstacles in translating and transmitting information, including what they consider 'uninteresting events'. This algorithm will be able to filter out irrelevant data, making it easier to identify important information.

However, the establishment of the 'perfect algorithm' requires a great deal of trust in the coders and engineers who are developing and designing these autonomous systems. Since these systems have replaced human influence, they are expected to be designed with precision and accuracy. The end goal is to create a system that is efficient and reliable, enabling astronomers to access relevant information quickly and without obstruction. Yet the question is about the multi-layered forms of epistemic trust under a postdigital condition, that is, how human relationships—or scientific collaboration between researchers—are shaped by algorithmic agency (MacKenzie and Bhatt 2020). These new relationships lead to more complex challenges concerning the responsibility gap and trustworthiness of autonomous systems (Vallor 2024).

Discussion

The emergence of sociotechnical imaginaries of sharing and the reconfiguration of some aspects of meaning-making practices have, at least, three implications for the astronomy community—and for research communities more generally—which might be relevant to postdigital education.

First, epistemic trust is positioned as a central component of meaning-making. As astronomers' work becomes more collaborative and dependent on non-human entities, trust becomes more critical. As regards people working collaboratively, effective communication is essential since diverse disciplines now involved in astronomy research, from data science, computer science, and engineering, tend to differ in the terminology they use, their social norms, epistemic virtues, and values that might inhibit coworking. As regards human and non-human relations, the postdigital imaginary of the 'perfect' algorithm seems to be a step forward from mechanical to communicative objectivity (Halpern 2015). This means that the main concern around sharing—as a recurrent narrative due to data scaling—is not necessarily about gathering data or building meaningful connections between groups of researchers but producing the most effective data analysis methods and algorithms with potential for being shared and reused. Put differently, the astronomy community seems more focused on finding new ways to mobilise objectivity than truth/discovery. Interestingly, this is not something new amongst science communities. Agazzi (2014) and Daston and Galison (Daston and Galison 2007) have already pointed out this shift in focus from true to objectivity in scientific investigation. What seems to be challenging for the astronomy community is that this represents a fundamental change in their epistemic culture and identity, which may enhance or impede their creativity, curiosity, and imagination and, as a result, the nature and structure of meaning-making in their daily work. The ways new research infrastructure is developed determines which methods and practices will flourish and which will become redundant, impacting astronomers' ways of knowing, seeing, and analysing.

Second, governmentality is more deeply embedded into meaning-making processes. The development of SKA facilities and services has been accompanied by sociotechnical imaginaries of sharing which can be deemed as a form of governmentality (Foucault 2010). This means that changes in the self are needed to make sharing practices possible. Astronomers—and everyone involved in developing sharing practices—need to cultivate a self that can adequately harness the volume of data coming from the SKA. Therefore, when a new research infrastructure is created, what is at stake is not only meaning and knowledge-making but the ontology of the knower, or what Galison (2015) has referred to as the scientific self. If data scaling pushes forward the epistemological position of 'knowing as much as possible'—the acceleration of science—and imaginaries of data circulation, storage, archiving, and reuse, there are implications for astronomers' identity; that is, what needs to be enhanced in the knower to be in a position to harness large volumes of data? This question points to something beyond the development of skills and competencies: the inseparability of ontology, epistemology, and ethics (Barad 2007).

Third, inequalities and vulnerabilities may be heightened through the reorganisation of scientific work. Increased governmentality raises questions about inequality and vulnerabilities as astronomers reorganise their work. One aspect of this issue is that the introduction of the SKA telescopes will benefit astronomers who already focus on data analysis more than those who gather data or focus on theoretical simulations. That is, while data gatherers and theoretical simulators will undoubtedly find value in the SKA telescopes, it is the work of data analysts that will be elevated to new heights, as they explore the vast and complex datasets generated by these powerful infrastructures. But, at the same time, astronomers who may not have well-developed practical ability—i.e. are not able to gather and analyse data—can now engage in analyses using open data. It is important to consider both the advantages and disadvantages of a new research infrastructure, especially if the goal is to benefit all members of the astronomy community. Neglecting to address the potential negative effects of perpetuating inequalities within and across research communities can have a significant impact on scientific careers and the knowledge claims that are made.

All three issues—epistemic trust, governmentality, and inequality—require more detailed consideration to better understand the complexities involved in implementing and using the SKA telescopes or any other research infrastructure in a postdigital era.

Concluding Remarks

We have analysed how sociotechnical imaginaries of sharing—infinite circulation, storage, archiving, and reuse—have scaled further where the next-generation radio telescopes are established to support more detailed study of the universe. By doing so, we have explored how these imaginaries have changed and are expected to change knowledge-making practices in the astronomy community. We have highlighted two significant changes. Firstly, as new postdigital forms of collaborative work are established (epistemic dependency but physically distant groups), astronomers need to agree on which types of analysis and methods to use, which affects how research proposals and scientific questions are negotiated collectively. Secondly, as data analysis methods are developed to handle and share vast amounts of data, astronomers have to abandon some of their established scientific practices and identities, such as moving from theory to data analysis. These methods rely on the development of the 'perfect' algorithm, which determines what evidence is relevant by eliminating unimportant events, and, therefore, how astronomers perceive the truth about the universe.

We have discussed three issues that require further exploration as digitalisation of work is scaled further in research communities: epistemic trust, governmentality, and inequality. While we did not focus on these topics extensively, they are crucial for understanding the effects of reorganising work and research practices due to new research infrastructures. One conclusion resulting from our analysis is that additional studies to investigate these issues in more detail are needed.

In many ways, this paper aims to initiate a dialogue around the impact of new research infrastructures on the meaning-making practices of research communities. The analysis presented here raises a range of questions that may be relevant for postdigital research. For example, can researchers resist these changes in work and research practices triggered by new research infrastructures? What types of resistance emerge as new digital tools are used by researchers? How do they mobilise their agency to respond to the demands arising from these changes in research culture? This paper contributes to longstanding attempts to understand the mutual influence between human and non-human entities by highlighting the intersection of new sociotechnical imaginaries, changes in astronomers' epistemological practices, and potential consequences on identity and power imbalances.

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Declarations

Conflict of Interest The authors declare no competing interests.

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