HEAD IN THE STARS, FEET ON THE GROUND: Scale and Astronomy Initiatives in Southern Africa

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"We sometimes have our heads in the stars, but we really do need to have our feet firmly planted on the ground." This is how Vanessa comments on the challenge of being an astronomer in South Africa during a podcast interview.[1] Vanessa's voice is calm; she listens to the questions, considers them carefully, and gives responses that clearly show that she has been thinking a lot about what it means to be a white astronomer in South Africa. While the topics shift between astrophysical research and local conditions for doing this research, her sense of responsibility permeates the entire podcast conversation. Vanessa combines astronomy's preoccupation with the immense vastness of outer space and the socioeconomic conditions of people on the surface of our planet. The excitement that astronomy elicits, she contends, should be tailored to "improv[e] people's lives in some way . . . , because at the end of the day, we are in a country where we are facing these challenges of poverty and unemployment."

About 700 kilometers northeast of Cape Town, in the semi-arid South African Karoo, I, Davide, find myself standing before a large billboard that welcomes visitors to the small town of Carnarvon, proudly declaring it as the "home of the

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Square Kilometre Array," or the "SKA in Africa" (Figure 1). The sign stands as a symbol of transformation, capturing the shift of the surrounding rugged landscape into a hub of astronomical discovery—a shift that geared up in 2012 when South Africa won the international bid to host the majority of the SKA project, set to become the world's largest radio telescope. The billboard sparks my imagination, offering a glimpse into the blend of local history and global scientific ambition. It weaves together the story of this marginalized region with a mission to explore the cosmos. Though my focus is on the SKA's intricate narrative, this billboard, even as a simple surface, hints at the interplay between the Karoo's past and the expansive possibilities of space exploration.

Another 2,850 kilometers northeast of Carnarvon, close to Antananarivo, Madagascar, I, Hanna, listen to Professor Charles who is jangling a set of keys. We stand at a decommissioned telecommunication facility earmarked for conversion into a radio telescope that proved decisive for Madagascar becoming an SKA "African partner country." However, conversion has not yet begun, and possibly never will. Unhappy with the uncertainties of such conversion, the Malagasy minister of scientific research gave way to turn the facilities into a hospital, which would forestall the conversion plans. Angry about such negligence of science's value, Professor Charles pulled a lot of strings, made numerous phone calls, and mobilized his influential networks, to avert the hospital plans and maintain the possibility of turning the dish into a telescope—the jangle of the keys in his hands indicates his success.

The thread connecting these three stories is how research on outer space entangles scales of human social life and knowledge-making. The cosmic dynamics in outer space's vastness and terrestrial conditions on Earth appear to be set apart, and "scale" is the concept used to mark this difference. How do outer space and Earth inform each other and what keeps them ontologically and epistemologically different? Tracing how Vanessa, Davide's encounter with the billboard, and Professor Charles relate outer space to specific grounds, we argue, requires us to treat scale both as an analytical category for ontological difference and as a socially produced practice. The first approach treats scale as a fixed measure of differences between ontologically stable objects, while the second sees it as a flexible tool for understanding variations in quantity, size, or complexity.

Recent social science literature has emphasized this second aspect, contending that scale research is principally epistemological, not ontological (Neumann 2009), and that research needs to attend to "scalar practices of social actors," not to scale itself as an analytical category (Moore 2008, 212). Critiquing

perspectives that regard scale as fixed in space and time, recent studies have thus emphasized scale as a "process rather than product" (Carr and Lempert 2016), and "emergent rather than eternal" (Hecht 2018). As objects circulate, they "make or break relations" and are thereby "adding to or subtracting reality from worlds and worths . . . , *scaling them up or down*" (Jensen 2023, 255; emphasis in original). Scales may become stabilized through sociopolitical hierarchies, or within the discursive and material apparatuses of modernity and economic structures of global capitalism, something that does not happen automatically but requires work (Tsing 2012). Scales are operationalized in techno-optimistic modes of governance (Avle et al. 2020) and thereby affect epistemology and representation (De Landa 2000); scaling up is a key feature of modernity (Tsing 2012); scales carry ideological value: the bigger the better (Irvine 2016). Such social theory on scale helps scrutinize socioeconomic activities and proves crucial in understanding situated sociomaterial practices of astrophysicists in Africa. Whether framing scale as "process," "emergence," or "result of work," these theories help complicate our experiences of scale as stable without turning them into indisputable ontological facts.

While emphasizing that the social construction of scale is important to capture relationships among multiple scales and the politics of nesting scalar units, we contend that astronomers like Vanessa do not only produce scale as they relate outer space to Earth but require scale to mark the ontological difference between that which is "outer space" and that which is terrestrial "ground" for the undertaking of science.[2] We take our cue from Zachary Horton (2021, 11) who contends that scales are characterized by "ontological difference that is independent of experience," and, simultaneously, they are also "epistemological milieu-building tools for us to isolate, order, represent, and group knowledge objects that we can measure with instruments." Outer space, the domain that describes the spatial configuration of maximally large scales, is both socially constructed—our understanding of it is heavily influenced by cultural narratives, scientific frameworks, and political agendas—and void of human experience: our knowledge of it is mediated through technology, like telescopes, satellites, or space missions. Thus, scale, scaling, and scalarity are crucial concepts in the anthropology of outer space. Peter Redfield (2000) and Sean Mitchell (2017) have shown how differently scalable issues create tensions at rocket launching sites. Lisa Messeri (2016; 2017) investigated how the scales of outer space are mediated and made commensurable, giving analog astronauts the capacity to collapse the difference between Earth and places in outer space. Valerie Olson

(2018) scrutinized how design concepts scale the notion of "home" from Earth into the solar system and beyond and evoke sensibilities of scalarity. With outer space, scale's characterization of "ontological difference" proves as important as its epistemological function to order knowledge objects.

In this article we will show how these two dimensions of scale—as analytical category describing ontological difference and social practice attending to epistemological configurations, both of which are relevant to define astrophysical activities in Africa, become entangled. Tracing "scale effects" (Clark 2012) of astrophysics in Africa, we show how scales matter and articulate the social production of difference in the world. Such scalar difference, we find, always refers to the grounds where scalar practices take place.

In what follows we explore the concept of scale through three moves. First, we examine how astrophysics explores vast, unknown scales, relying on stabilized orders of magnitude that create opportunities for difference but risk falling into ontological essentialism. Vanessa's perspective reminds us to balance "the heads in the stars" with "the feet on the ground." Second, we focus on the billboard in Carnarvon and the grounds of the SKA's core site, questioning how large-scale observations of the universe relate to the physical ground where these observations occur, within the logic of array telescopes. This move considers the impact of the SKA on South Africa's historically significant grounds and its role in shaping international and African relations, highlighting scaling as a practice rooted in history. Third, we look at Madagascar's unfinished radio astronomy infrastructure, where people are laying the groundwork for future opportunities. Here, grounds become both the foundation and limit of scalability. Taken together, these three moves configure scale as ontological and epistemological category, both of which stand in irreducible relation to ground.

Methodologically, we view scales as relations (Strathern 2004; see also Howitt 1998), and our collaboration reflects a scalar relation between our two field sites in South Africa and Madagascar, as well as between the scales each of us is most comfortable exploring—something neither of us could achieve alone. Marilyn Strathern (2004, 75, 108) argues that anthropologists must create scales to enable comparison without assuming a complete, all-encompassing view. In our fieldwork analysis, we see scale not only as a "category of practice" to be explored, but also as a "category of analysis" (Hecht 2018, referring to Carr and Lempert's "pragmatics of scale" [2016]), where our positionality proves crucial in defining the network of scalar relations that we aim to describe. Adapting Vanessa's perspective, we focus on the ambitious future of the SKA while remaining grounded in the histories and potential futures of our field sites.

ONTOLOGICAL ESSENTIALISM

Vanessa's research has taken her away far beyond Earth, past the solar system and the Milky Way, to study the Small Magellanic Cloud.[3] Talking about her research, she is full of contagious excitement. Her eyes are sparkling and her voice lures listeners into the "out there." She is particularly fascinated by binary stars, focusing on their role in star formation and the physics under extreme gravity, temperature, and magnetic fields—a subject that has defined much of her astrophysical career. With ease that attests to her professional experience, she explains how her work combines evolving mathematical and computational models with established methods like photometry and spectroscopy to understand stellar dynamics at these vast scales. Advanced telescopes and cutting-edge technology expand human capacity to explore and comprehend such enormous cosmic distances.

Magnifying observations on larger cosmic scales is tantamount to peering into the past, effectively scaling back in time. For instance, the image of an object situated 200,000 light years away—such is the approximate distance of the Small Magellanic Cloud from Earth—serves as a snapshot frozen in time, representing the state of that object 200,000 years ago. When the "head" is "in the stars," the scales of outer space can easily become all-consuming and leave little room for anything else. For most of the astrophysical discourse, the dynamics at these large scales are disconnected from what is happening on Earth; even more so when the galaxy of interest is different in type from the Milky Way. Yet the possibilities of having the "head in the stars," of doing astrophysical research, are historically situated and bound to national science policies.

The podcast that invited Vanessa proudly highlights the achievements of astrophysicists in South Africa and across Africa.[4] Each episode features a guest who not only explains their research or projects in accessible terms but also shares their personal stories and motivations. For Vanessa, this invitation offers a chance to reflect on the history of astronomy in South Africa, its present opportunities, and the effort required to realize its potential—emphasizing what it truly means to keep "the feet on the ground" as an astrophysicist.

As a scientific discipline, astronomy in South Africa began to take shape in the colonial period, when the British established the Royal Observatory in 1820 at the Cape. The historian Saul Dubow (2019) contends that astronomy was the first scientific discipline to root itself institutionally in the country, serving important ideological and material purposes for the colonial project. Astronomical facilities served as a platform for European scientists to conduct observations,

using science's practical applications—such as navigation and timekeeping—to justify the colonial project's civilizing mission.

The apartheid years marked an attempt by the white minority government to institutionalize astronomy as a national endeavor, especially during the period of South Africa's international isolation during the 1980s. However, collaborations with Britain and the United States were not completely discontinued and remained under the surface (Dubow 2019). With the end of apartheid in 1994, a shift occurred as the African National Congress (ANC) government sought to redefine the role of astronomy, rebranding it into a new force of transformation—one example of the new political elite's continental and global ambitions.

These post-apartheid principles were first made clear in the 1996 White Paper on Science and Technology, the key document outlining the country's investment strategy in science and technology, in which the scientific endeavor is freighted with important cultural, social, and developmental values (Republic of South Africa 1996, 16). With the presidency of Thabo Mbeki from 1999 to 2008, astronomy and other key natural sciences assumed a specific value in relation to discussions of the African Renaissance, a line of political thought inspired by pan-Africanism and humanism in the heyday of decolonization, in which the progressive force of science was identified as the baseline through which African countries could finally break away from the legacy of colonialism, repositioning the continent as the cradle of human civilization (see Mavimbela 1998).

Precisely in this historical moment, South Africa made its first steps toward joining international discussions about the SKA telescope project. The preparations for the SKA marked the culmination of a political discourse in which astronomy assumed a specific value in breaking away from the legacy of colonialism and apartheid, despite its clear colonial roots.

Situated in South Africa, Vanessa has always connected her interest in astrophysics to a striving for understanding Earth. In a blog post, she contends: "For me the night sky has always evoked two distinct feelings: curiosity about what's in our universe, and a sense of complete insignificance at being a tiny speck of organic matter on a tiny planet orbiting a bog-standard star in a rather run-of-the-mill galaxy."[5] The pivotal moment in Vanessa's career occurred when she realized her desire to contribute to education and societal development by leveraging her skills as an astronomer. This move allows her to connect the awe that outer space inspires with possibilities to act on Earth and not succumb to a sense of insignificance. With excitement, she fosters collaborations with the academic, science communication, and amateur communities to establish best practices for astronomy-based development work.

In the podcast, Vanessa connects her work as an astronomer to several nested scales of social life. She links her passion for researching the universe to her location at the South African Astronomical Observatory, the city of Cape Town, the country of South Africa, and the continent of Africa. From the observatory, she situates current astronomical activities within South Africa's scientific history. In Cape Town, she fosters connections between research institutions. Within South Africa, she emphasizes the role of citizens in addressing socioeconomic issues. Across Africa, she proudly supports the growth of the continent's astronomy community. Vanessa uses these different scales to highlight or downplay specific narratives, "jumping scales" to focus on issues relevant to each context.

Zachary Horton (2017, 52, 54), in analyzing the book *Cosmic View*, which comprises a series of drawings, "each to a different scale and containing a miniature version of the one before," speaks of "material limitations of resolution and the discontinuity between scales" that the reader creates "virtual connections" between. He furthermore says that "certain details are available to us at each scale that by necessity disappear at most other scales. . . . we cannot change scales without losing as much as we gain" (Horton 2017, 54–55). This appears similar to Strathern's (2004, xxi, xv) observation that the capacity to differentiate stays the same irrespective of the scales employed, and that "scale switching not only creates a multiplier effect, it also creates information 'loss.'" Thus, the "complexity" of academic writing "keeps its own scale" (Strathern 2004, 108), "every level of complexity replicates itself in scale of detail" (Strathern 2004, xvi). Resolution (Horton) and capacity to differentiate (Strathern) both serve to describe the ever-partial character of any scale. By jumping scales, Vanessa makes use of this partiality, tapping into the scales that help her raise awareness for certain issues knowing that she cannot cover all of these issues by staying on any one of these scales.

When Vanessa speaks about the "feet on the ground," she evokes all these scales and their potentials for jumping between them in meaningful ways. These scales are embodied, traversed by human histories, politically contested, and constituted through power relations. When, in the podcast, Vanessa prompts her fellow astronomers in (South) Africa to connect the "head in the stars" with the "feet on the ground," she does not subsume the scales of "the stars" into her engagement with the feet's "ground." In fact, she maintains them as markedly different scalar registers. Deploying scale in the work of astrophysics differs from using scale to show the multifaceted significance of development work on the ground.

Describing this with Horton (2021, 11), the scales of the stars mark "ontological difference that is independent of experience." The use of stabilized orders of magnitude enables scientists to categorize, compare, locate, and characterize astronomical objects consistently, expanding their ability to interpret new and unexpected phenomena. In the work of astrophysicists, scale marks the possibility of difference in the moment it is emptied of human history and experience. We call this feature ontological essentialism, which describes how scientists deploy outer space as an analytical category independent of the human experience of space and time.

Vanessa urges astronomers not to forget their "feet on the ground" while keeping their "head in the stars," encouraging a form of scalar thinking that involves both "ontological essentialism" and an "epistemological tool." A key point is that, unlike many astronomers who scale up from Earth to the cosmos, she places "the stars" and "the ground" side by side, without treating them as a simple hierarchy. By shifting from a purely scientific career to a role as a development practitioner, Vanessa embodies the balance she advocates for within the African astrophysics community: the idea that the "head in the stars" and "feet on the ground" are inseparable. She implies that staying grounded proves essential to reaching for the stars.

In what follows, we will focus on particular grounds of astrophysics in South Africa.

GROUNDING OUTER SPACE IN THE SOUTH AFRICAN KAROO

Terrestrial radio telescopes are built to look beyond the Earth's surface. For us, the ground is the planet's crust—manifesting as landmasses, continents, and islands—and gravity pulls us toward it. Ground provides stability; it shapes our ways of knowing (Jue 2020), anchors research, and fosters a "surface bias" (Bebbington and Bury 2013). It shapes the objects we study (Fortun 2017), even though we need scalar practices to recognize stars as "figures." Ground-breaking research must discover new grounds, discard old ones, and explore what lies beyond the familiar. This process requires "breaking," disrupting, and opening up old grounds to create space for new insights to emerge.

The more than nine-hour drive from Cape Town into the northern interior of South Africa, through the semi-arid Karoo, provided me, Davide, with a tangible sense of this landscape. Eventually, I arrived in Carnarvon, a small town near the core site of the Square Kilometre Array (SKA). Standing on a dusty road leading into town, I encountered a large billboard, previously mentioned

Figure 1. Billboard in Carnarvon. Photo by Davide Chinigò.

in the introduction (Figure 1). The billboard features the iconic semi-arid Karoo landscape, dotted with numerous satellite dishes. Above them, the Milky Way shines brightly in the starry sky, symbolizing the connection between the local landscape and our galaxy's center—a view uniquely visible from the southern hemisphere.

In the foreground of the billboard, a detailed image of a satellite dish points toward the night sky, emphasizing the area's link to the universe. Closer still, a meerkat—a native rodent and the namesake of the Karoo Array Telescope (MeerKAT), inaugurated in 2018—stands watchfully. The name MeerKAT also cleverly references the Afrikaans word *meer*, meaning "more," alluding to the expansion from the original seven Karoo Array Telescope (KAT 7) dishes of the 2000s to the ambitious plans for additional dishes across South Africa and beyond.

The depiction on the billboard stirred my imagination, illustrating a future where the landscape is filled with countless satellite dishes. My attention was drawn to the meerkat, whose gaze seems to reach beyond the frame. Is it searching for a new home as this area becomes home to these technological structures? The meerkat serves as an anthropomorphic symbol, yet it lacks specific markers of identity such as gender, class, or race. It subtly redefines the human subject in relation to science and technology, reflecting the expansive scale that astronomy

introduces when considering the vastness of the universe. The billboard suggests how the introduction of a telescope transforms the landscape, connecting it to broader cosmic scales while diminishing the everyday social dimensions of human life. The billboard serves as a significant illustration of ontological essentialism, highlighting how outer-space research holds the potential for difference while stripping the ground of human history and experience.

Despite transporting our (human) imagination into outer space, radio telescopes themselves operate on the terrestrial ground. Their locations are significant: because the Southern hemisphere sky has not been very well explored and studied, the SKA's location south of the equator promises new insights; its situatedness in Africa fills the gap of the global east-west spread of telescopes, which provides a solution for Earth's rotation. Furthermore, radio telescopes are increasingly set up in arrays, making them more sensitive to radio sources and thus able to look deeper into space. When a cosmic wave meets these dishes, the data captured by each dish shows a particular phase of the wave. Using the exact location of the dishes and high-precision clocks, the phase differences can be measured and properties of the wave deduced. In effect, the dishes of an array act as if they were a single dish with a diameter equal to the distance between the dishes. Thus the further apart the dishes, the better the spatial resolution. With approximately 200 dishes located at carefully chosen distances at the core site in the Karoo, and additional dishes spread across the African continent, the SKA is planned as an extremely powerful and sensitive telescope.

The terrestrial grounds where telescopes are erected are neither neutral, nor empty. Notably, the Thirty Meter Telescope project on Mauna Kea in Hawaii elicited a lot of resistance (Miller 2016; Prescod-Weinstein 2021; Maile 2021). Scientists searching for ideal conditions on top of the mountain on the island, with clear skies and little atmospheric pollution, met protests by local Indigenous communities, who saw their sacred space desecrated. Similarly, in Chile, uncertainties around legal land issues in times of political instability interrupted the construction of a telescope in the Atacama Desert (Lehuedé 2022; Hoeppe 2012). Such conflicts reveal how, on the ground, the imaginary of science's universal value reaches its limits, where the risk of ontological essentialism is greatest. The installation of the SKA in South Africa proved no exception.

MeerKAT National Park

Gesturing toward Carnarvon's new connections to the scales of outer space, the billboard obscures what the Karoo's involvement in scientists' scalar

practices means for its population. I sit across from Louise, an elderly resident of Carnarvon who has a long history of political grassroots activism and who takes pride in voicing the concerns of Carnarvon's inhabitants. She is well respected for her initiatives, and when I met her, some months after my encounter with the billboard, her hands-on mentality caught my attention. She explained to me how in the beginning, when project managers of the SKA first arrived in Carnarvon and made their plans public to the local population, she was a big fan of the project. Like many others, she expected a rejuvenation of the local economy. Finally, she thought, the Karoo's remoteness does not equate with marginalization, but with a future driven by science. Some background is needed to understand Louise's hopes.

Carnarvon, located in what historian Nigel Penn (2005) calls South Africa's "forgotten frontier," marked the first encounter between European settlers and the semi-nomadic Khoisan societies in the late 1600s. Today, the majority of its population, like Louise, are classified as "coloureds" under apartheid-era racial categories. The legacy of segregation remains evident both in the spatial organization of the town and the local economy. The economic elite consists of a few white Afrikaner families who own large-scale commercial sheep farms and dominate the local economy.

Carnarvon's marginality persists, reflecting broader regional decline. This marginality manifests differently across groups. For white farmers, diminishing profitability in sheep farming and debates about land reform contribute to a sense of insecurity. For coloureds, unemployment constitutes a major issue, as modern agriculture relies less on farmworkers, leading many to depend on state social grants. Migration is often not an option, further deepening people's sense of marginality. This situation is exacerbated by high levels of drug and alcohol use, rooted in the apartheid legacy and ongoing political neglect from broader national priorities.

Louise was among the leading figures protesting against the implementation of the Group Areas Act in Carnarvon, a key piece of apartheid legislation designed to enforce systematic racial segregation. Louise recounts a pivotal moment in the mid-1980s when the government attempted to demolish De Bult, a neighborhood classified as coloured under apartheid law. The community resisted. Protests swelled in the streets, voices rising in defiance. "We would not let them erase us," Louisa says, her voice firm. The resistance bore fruit—after a ruling by the Provincial Court in Kimberley, the demolition was abandoned. When democracy dawned in the early 1990s, residents were finally granted title deeds to their homes, a long-overdue recognition of their right to belong.

For Louise, this victory marked just one chapter in the long history of what she calls Carnarvon's "cosmopolitan spirit," a defiant openness shaped by struggle and endurance. She carried this spirit forward into South Africa's first democratic government, serving as a Member of the Provincial Parliament under Nelson Mandela. The end of apartheid, she reflects, was not just a political shift—it was the long-awaited chance for the coloured majority to reclaim agency over their own future.

When the plans for the SKA telescope were formalized in the mid-2000s, Louise felt something stir—a sense that history was turning again. "I thought, the time to harvest the sacrifices of my generation had finally come," she says. The SKA was more than a scientific endeavor; it was a promise, a chance to invert Carnarvon's long history of marginalization. Expectations soared—of economic rejuvenation, of newfound pride in hosting a world-class research facility. For Louise, the telescope's massive dish antennas, reaching skyward, symbolized something profound: the possibility of rewriting the past, of finally seeing a future beyond the scars of apartheid. Louise displays scale both as an analytical category and as an epistemological tool. As she envisions the opportunities that the astronomy project brings to Carnarvon, she does so from within a history of persistent political and economic marginalization. Scale, in this sense, delineates the ontological gap between past constraints and future aspirations—it marks the difference in expectations for a better future, while simultaneously serving as a means to construct that future. The astronomy project, then, becomes more than just an economic or scientific initiative; it is an instrument for bridging this scalar divide, a way to project Carnarvon beyond its historical marginality and toward a reimagined, more inclusive trajectory.

This optimism peaked in October 2012, when then president Jacob Zuma celebrated South Africa's successful bid to host the SKA. The former minister of Science and Technology Naledi Pandor commented that

> The SKA is a game-changer for Africa, bringing about a science Renaissance across the continent . . . , giving effect to our dream that Africa must become a global science and technology destination and that cutting-edge science will be done in Africa by African scientists. . . . The SKA has put Carnarvon on the world map! Let's continue using it to make South Africans proud and to inspire young people about a future in science and technology.[6]

Yet the reality of implementing the SKA has faced challenges, particularly the need to reduce radio noise from everyday devices like mobile phones, Wi-Fi, and petrol cars. To protect radio astronomy, South Africa introduced the Astronomy Geographic Advantage (AGA) Act in 2007 (Republic of South Africa 2007), granting powers to limit activities that generate radio frequency interference in the Northern Cape. This led to the creation of the Karoo Central Astronomy Advantage Areas (KCAAAs), an "astronomy reserve" with progressively stricter regulations over 100,000 square kilometers (Chinigò 2019). As these restrictions have potentially relevant impacts on everyday life, many residents, including Louise, began to question whether the SKA would deliver on its promise to transform the region.

Significantly, to secure land for constructing the core infrastructure, SKA South Africa initiated a program of compulsory land acquisition between 2016 and 2017, resulting in the purchase of more than thirty commercial sheep farms, covering about 130,000 hectares. In 2021, this core area was designated as a "special nature reserve" under the management of South African National Parks and was renamed Meerkat National Park. As a result, this area has effectively become a conservation zone, closed to all individuals not involved in scientific research.

The initial excitement surrounding these initiatives has been frustrated by a lack of trust between project management and local communities, as well as by a fear of future restrictions. This erosion of trust worried people like Louise, whose hopes had once been high. She might still look at the billboard that welcomes her to the "home of the SKA in Africa," but now she sees the area she considers home as one full of constraints. The restrictions associated with the telescopes' operations—like those on certain technologies that emit radio waves—have altered daily life, making it feel less like the place she once knew. Though Louise is thankful that the small town of Carnarvon remains exempt from many of these restrictions, she cannot ignore the broader changes in the region. Promises of the SKA for a brighter future in Carnarvon now seem distant, overshadowed by tensions between local needs and scientific goals.

Yet Louise remains undeterred. With a conspiratorial smile, she shares plans with the local church to turn the shared frustration of Carnarvon's residents into a political movement. After all, their generation knows how to mobilize and protest. The arrival of astronomy in Carnarvon has made visible the complex dynamics between scientific progress and the region's marginalized communities, revealing both the colonial and postcolonial legacies that continue to shape its impact.

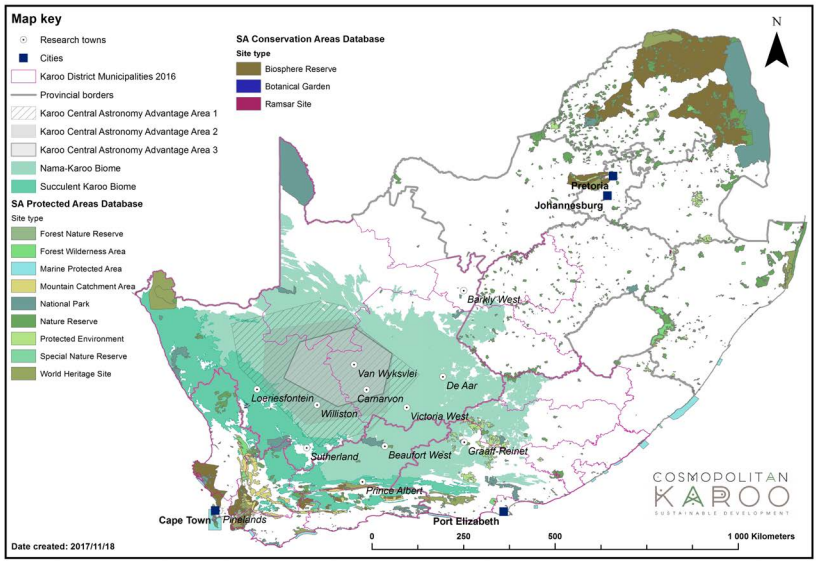

Figure 2. Map of South Africa depicting the Karoo Central Astronomy Advantage Areas. Map produced by © Cosmopolitan Karoo.

This is not to ignore that the South African Radio Astronomy Observatory (SARAO), the organization in charge of project management, has actively tried to mitigate and reframe some of these tensions. The organization employs people who, similar to Vanessa, care for "the feet on the ground" and has established a stakeholder management office in Carnarvon. They brought residents in touch with development initiatives, most notably a bursary program in STEM-related fields for students. Although the international SKA website initially stated that the telescope site was in the "Karoo desert," thus reverberating with colonial imaginaries of Africa's emptiness, the project managers have learned to discursively attune to the concerns of local residents. Phil Diamond, the director of the international SKA, put it like this in a speech at the official construction start of SKA phase 1 in June 2021: "We're working with local and Indigenous communities. We recognize that we are guests on their land and we will be having various programs to work with the local communities and ensure that they benefit as much as possible from the contracts that will be let." At different scales, efforts to facilitate groundbreaking research on outer space reveal aspects of the complex politics and history of the Karoo's grounds.

The Karoo ground both enables and limits the potential for difference introduced by astronomical research. Reversing its long history of marginalization makes for a complex, large-scale effort that the SKA initiative alone is unlikely

to accomplish. In this context, the region's marginalization resurfaces alongside the astronomy infrastructure, underscoring the inherent limits of socially produced scale on the ground.

International and African Grounds

Before we travel from Carnarvon to Madagascar—and to understand why this journey makes sense—we need to first jump scales, explore the dynamics at a larger level, and then return. As Gabrielle Hecht (2018) puts it, we need to board "interscalar vehicles." For this journey, we ground ourselves by focusing on the map of the international consortium of countries involved in the SKA project—another graphic representation produced by the SKA, closely connected to the narrative on the billboard.

One way to view the map, as emphasized by SKA project managers, is that the SKA represents a historic moment where Africa takes a leading role in producing astrophysical knowledge. With this project, South Africa becomes a new center for the universalizing pursuit of science, contributing significantly to astronomy and creating economic spillovers for the South African economy.

Yet the map also highlights ongoing power dynamics rooted in colonial histories between Africa and Europe. The global headquarters of the project remain in the United Kingdom—a former colonial power—and European countries provide much of the funding, influencing access to telescope time and data. The absence of the United States and Russia, but the inclusion of China and India reflect shifting global power structures.

We board the interscalar vehicle again and, zooming in on the continental aspects of the project, we realize that South Africa is the only full member from Africa in the SKA consortium. Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia are "partner countries," slated to host additional infrastructure in phase 2, but without direct involvement in scientific production or budget commitments. Some scientists question the feasibility of phase 2 because of technical and sociopolitical challenges, but intra-African collaborations are emerging through the SKA Africa/SARAO organization. South Africa supports these partner countries with training, regulatory advice, and institutional capacity-building, reinforcing its leadership and claims of exceptionalism in Africa.

The map shows how astrophysics' large-scale research objects intersect with the physical infrastructure and governance required on Earth. The SKA's research interests attract global scientific communities, funded and managed by

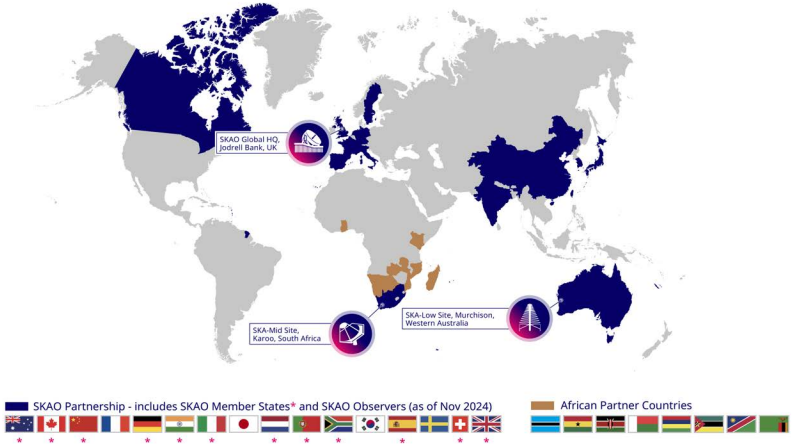

Figure 3. Participating countries in the SKA Organization with "African Partner Countries" marked in beige. Image created by Square Kilometer Array Organization.

various nations, reflecting geopolitical dynamics. For South Africa to strengthen its position, the "African partner countries" prove crucial, offering potential to scale the infrastructure beyond national borders to a continental level. Yet the map also marks these partner countries as different, suggesting they do not operate on the same level as other members. While preparations for phase 2 integrate these countries into the broader SKA vision, the actual implementation remains uncertain, leaving their full participation in question. Essentially, the partner countries provide their grounds for the SKA's celestial research, but the decision to include them is made at a different, more global scale.

THE LIMITS TO SCALABILITY: Madagascar's Insular Grounds in Time

In Madagascar's case, it was not a vision of emptiness that put it on the SKA map, but rather an existing satellite communication dish near Arivonimamo. The idea of converting this dish into a training telescope—similar to a refurbished one in Ghana, another "African partner country"—initially made Madagascar's connection to outer space research seem feasible. Yet the instability of Malagasy political support and the realization from Ghana's experience that such conversions prove costly and inefficient led the SKA to withdraw its support for the Arivonimamo project.

Despite losing interest in the Arivonimamo dish, the SKA continues to see value in Madagascar as a partner, envisioning a new dish at a designated astronomical reserve, modeled after South Africa's Karoo reserve. The focus has shifted to finding an ideal, radio-quiet location with negotiable land-use contracts. For

the SKA consortium, Madagascar's inclusion forms part of a broader vision of modernity, scaling up beyond national borders to meet the demands of large-scale outer space research. Madagascar fits the political and geographic criteria to support an expanded African SKA.

While Professor Charles backs the search for a new location, he remains committed to preserving the potential of the Arivonimamo site. His dedication suggests a vision of scalability that values the existing ground beyond just its modern scientific utility. When Professor Charles and I, Hanna, arrived in Arivonimamo, Madagascar, we first had a proper look at the dish, the reason for Madagascar becoming a SKA "African partner country" and, related to this, the reason for this place being interesting to us. This former telecommunication dish is currently leased to the Malagasy Ministry for Scientific Research, because it has the potential to be converted into an astrophysical telescope. Professor Charles, an astronomy enthusiast and science education professor, was appointed to oversee this actualization, but due to a lack of funding, waning support from the SKA, and unstable political conditions, no conversion has happened so far—and maybe never will. Although currently not used, the dish's sturdy metalwork and impressive size tells a story of grandeur.

Built in 1972, the site once connected Madagascar to global events, embodying some of the aspirations of the newly independent state. After inspecting

Figure 4. On the way to the dish in Arivonimamo. Photo by Hanna Nieber.

the dish, Professor Charles unlocked the building from which the dish was operated. I was thankful for the chance to step inside, as he had fought to retrieve the keys. The entrance opened into a reception area with two doors, left and right. He first unlocked the left door, saying, "Now comes the interesting part for you," as he swung it open.

This wing housed the control center for the dish, the place where Professor Charles envisions future astrophysical observations taking place. Everything was left as it had been in 2005, when the dish stopped being used for telecommunications—dusty desks, an outdated computer, stacks of paper, landline phones, file cabinets, and switchboards. Further inside, another room contained more switchboards and space for computers, along with a view of the dish itself. Professor Charles confirmed my guess that this room controlled the dish's movements. Though the ceiling had started to collapse in one corner, it was easy to imagine this place as a busy workspace.

Professor Charles then moved to the door on the right, leading to a hallway with several rooms. He checked each room to see how far the hospital-repurposing had progressed and was relieved that, aside from signs indicating potential hospital functions, little had changed. He explained that these rooms could house scientists conducting short-term observations. As we moved through the rooms, he took note of the building's overall condition—inspecting the ceiling, floors, and windows.

The building's two wings reflect competing visions for these grounds, each tied to different scales of influence. One wing hints at the potential to connect with outer space, as it houses the control center where the dish's movements might be monitored and directed. The other wing serves as a reminder of national politics, reflecting the state's interest in repurposing the space as a hospital. This contrast highlights a tension between the visionary possibility of engaging with the cosmos and the pragmatic demands of national governance. While the universe's larger scales may seem irrelevant to national politics, practical considerations of the state affect the site's potential for space observation. For Professor Charles, the difference between the aims of outer-space science and those of the state becomes a struggle—one symbolized by his efforts to retrieve the keys from the ministry to keep the grounds open to the possibility of space exploration.

By pulling strings to secure the keys, Professor Charles preserves the facility's uncertain future and its potential for space exploration. He acknowledges that hospitals can be built almost anywhere and supports investment in health

Figure 5. Keys in Professor Charles' hands. Photo by Hanna Nieber.

care. However, while outer space surrounds Earth, the ability to conduct astrophysical research depends on specific sites, not just any location. The grounds in Arivonimamo already possess more infrastructure, legal agreements, and personal investment than any other place in Madagascar. The sturdy metalwork from the old telecommunication dish holds the potential to connect with the vast scales of space—if its future remains open. Without this indeterminacy, such a future cannot happen. Professor Charles actively seeks opportunities, political backing, and donor interest to convert the facilities into a telescope. Yet the effort to retain the keys reflects the ongoing challenge of safeguarding this possibility.

Professor Charles is not the only one who cares about these grounds and their potential for a connection to outer space. After Madagascar had become an "African partner country" and thus part of the African Very Long Baseline Interferometry Network (AVN), preparations for astrophysics education took shape immediately, and since 2014 the University of Antananarivo offers an astrophysics master's program. In the meantime, two astronomy clubs have emerged, catering to many more astronomy enthusiasts committed to sharing their knowledge and passion with even more people; they walk Malagasy grounds and spread excitement about knowledge that concerns the unimaginably vast scales of the universe. Through their continuous promotion of converting the dish at Arivonimamo, Professor Charles, astrophysics students and graduates, and a growing number of club members have turned the dish into a symbol of hope for the future of radio astronomy in Madagascar. A documentary on women in science in Africa featuring one of Madagascar's first professional astrophysicists (2019, see

Figure 6) and a 2023 film about the "mystery of Arivonimamo" (see Figure 7) have further cemented the dish's iconic status, engaging broader audiences in the vision of Madagascar's potential in radio astronomy.

As an iconic symbol, the dish does not yet provide a scientifically useful connection to outer space, but it embodies hopes for such a future. These hopes are partly tied to the potential conversion of the Arivonimamo dish, and also to the possibility of building a new radio telescope elsewhere in Madagascar. This vision has inspired many to learn about astronomy, creating a community eager to engage in astrophysical research. A growing number of people hold a vision of gathering data from the stars while their feet remain firmly grounded on Malagasy soil. When Vanessa emphasizes the need to stay grounded, she assumes the possibility for a disconnect between "the stars" and "the ground." In Madagascar, the uncertain prospects for a new radio telescope keep local astronomers mindful of their reality and thereby constantly reminded of their feet on the ground. As a symbol and a static presence, the Arivonimamo dish blends aspirations for space research with the challenges of state-centered politics and difficult funding, leading to emotions that range from hope to frustration, and sometimes, indifference (see Yarrow 2017; Witte 2018). The dish "grounds" Malagasy aspirations to contribute to astrophysical research, even as people continue to strive

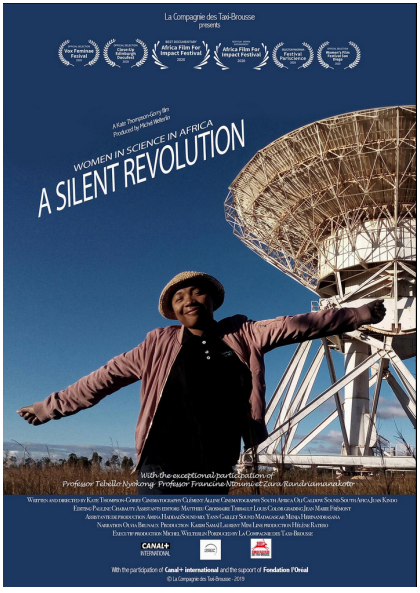

Figure 6. Movie poster of "Women in Science in Africa: A Silent Revolution," produced by La Compagnie des Taxi-Brousse.
Figure 7. Movie poster of "Le Mystère d'Arivonimamo," produced by Franc Clerc.

for that distant connection to the stars. Hope bridges the material disconnect between the "heads in the stars" and the "feet on the ground."

Professor Charles's retrieval of the keys for the facilities in Arivonimamo makes for a powerful gesture to maintain indeterminacy about the dish and thus to maintain anticipation and excitement about the very large scales of the universe that astrophysics engages with. Students of astrophysics and amateur astronomers continue to prepare for a future in which the Malagasy grounds will prove relevant for astrophysics. Their communal tasks to learn about outer space, their training, and their capacity-building practices are scalar practices. By maintaining the indeterminacy of the dish in Arivonimamo, Professor Charles enables the continuation of other people's anticipatory scalar practices. Furthermore, we argue, his effort to maintain indeterminacy itself constitutes a scalar practice, working with and on intersecting local scales to retrieve keys from the minister while keeping the study of phenomena at the very large scales of the universe as an aspirational goal in mind.

The activities of the growing number of astronomy enthusiasts pave the ground for scientific engagement with outer space to take place in a future that has already arrived otherwise. Their efforts have attracted the interest of a French astrophysicist passionate about promoting astronomy in francophone Africa. He organized funding and installed an optical telescope, now managed in collaboration with a Malagasy astronomy club. Located at a school in a remote village near the west coast, the site offers the darkness and clear skies needed for observations, while the school provides infrastructure and security. The telescope's primary scientific goal is to gather data on asteroids, contributing to global efforts to protect Earth from potentially hazardous space objects.

While the SKA project brought astronomy to Madagascar, this new telescope has broadened aspirations for the field's future in the country. Both the existing optical telescope and the prospect of a SKA radio telescope raise hopes for Malagasy contributions to astrophysical research. Enthusiasts have worked to make Madagascar suitable for engaging with these scales, though the conversion of the Arivonimamo dish remains uncertain. Even if Arivonimamo never becomes a center for radio astronomy, people's dedication has already attracted the optical telescope. Though this telescope may focus on solar system-scale research rather than the vast universe beyond the sun's influence, it still attests to the achievements of the Malagasy astronomy enthusiasts to make Malagasy grounds relevant for scientific inquiry about (near) outer space, supporting a global effort to protect Earth from space-based threats.

CONCLUSION

For astronomers, the challenge of keeping their heads in the stars while maintaining their feet on the ground involves thinking and acting across scalar difference. As astrophysical instruments expand, crossing national borders and invoking broader frameworks for organizing knowledge and managing activities on Earth, scale must be understood in relation to the grounds on which it takes shape. The relationship between scale—viewed both as a historically contingent product and as an evolving process—and the ground on which it materializes is, we argue, irreducible. Astrophysics, with its focus on the largest conceivable scales, provides a compelling case for exploring this concept. The inseparability of the head in the stars from the feet on the ground proves especially relevant in the context of the ongoing construction of the SKA radio telescope in South Africa and the opportunities and challenges it brings for its African partner countries.

The Karoo region is "home to the SKA," a telescope project aimed at exploring the *universe*, managed and funded by an *international* organization. Situated within the South African *state*, it is tied into South Africa's long history of hosting telescopes to study the *Southern hemisphere's* sky—a legacy tied to the country's role in the colonial project of European expansion, where astronomical time measurement played a part. While being a center for *global* radio astronomy today, the Karoo's history of marginalization endures through the colonial, apartheid, and post-apartheid eras. In the Karoo, these histories converge through different scaled frames of reference, creating the "grounds" where present and past are intertwined.

As South Africa prepared its bid to host the SKA, it needed to expand its framework from a *national* to a *continental* scale, positioning itself as part of Africa. Within this larger vision, the inclusion of Madagascar as an African partner brought additional scalar dimensions into play. Madagascar was approached as a *state* partner and established the master's program at its *national* university. Graduates of this program have gained *global* recognition, building *international* careers that engage with the *universe's* events and forces. Madagascar was chosen not only because of its geographic location on the African *continent* but also because it already had a *sufficiently large* dish to function as a radio telescope. This dish has a legacy of connecting the newly independent *state* with *global* information networks, while also holding the unrealized potential to foster a scholarly connection to the *universe at large*.

The "ground" that Vanessa's expression inspired us to contemplate kept shifting throughout our narrative, which used outer space research through the SKA as a lens. In the Karoo, the ground referred to the territory shaped by

national legislation, as well as the open spaces for sheep grazing. It encompassed the region's semi-arid, sparsely populated environment and its history of marginalization. In Madagascar, the ground was defined by the clearly marked premises of the disused satellite dish and its facility in Arivonimamo, as well as the broader Malagasy territory retrieving astrophysical data that students and graduates value deeply as a national contribution to a global project of astrophysical science. It also includes the sociopolitical and financial conditions that challenge dreams, visions, and hopes. These shifting grounds, all of which anchor the concept of *scale* to Earth (see Valentine 2017), reflect the changes in scale required by our narrative.

The vast scale of astrophysical infrastructure in Africa requires our collaborative effort not to remain focused solely on the grand narrative attached to scaling up. Instead, we must navigate across different scales to do justice to the scalar practices connected to grounds with diverse histories and aspirations.

The scalar practices we have outlined, mainly in terms of social categories, intersect with the scales used by astrophysicists—scales that we can only briefly reference here. In both the Karoo and around the prospective telescope site at the existing telecommunication dish in Arivonimamo, the onto-epistemological scales of physics intersect with those of geopolitical dynamics, national and continental imaginations, and global alliances. Carnarvon, a town at the margin of South Africa's economic life, becomes—due to its absences—the center of a global radio astronomy infrastructure. South Africa's Department of Science and Technology (now Science and Innovation), transcending human differences, invests in the broader idea of "Africa." Similarly, the disused satellite dish in Arivonimamo, with its potential to become a telescope feeding data into a supercomputer, involves the Malagasy government's Ministry of Scientific Research and shapes the work of local astronomers, both amateurs and professionals. From the small scales of information technology and data processing to national decision- making, global management, and financial frameworks, all the way to the vast scales of extragalactic radio wave emissions probing the origins of time itself, radio astronomy instruments in Southern Africa bring together historically established scales. They require agile scalar practices that are always tied to specific grounds, both as a condition and as a limitation.

ABSTRACT

This article explores the evolution of radio astronomy in South Africa and Madagascar, focusing on how "scale" functions as both a way of understanding the world and marking differences in existence. In outer space research, the ground is crucial but often overlooked. By collaboratively examining the expansion of infrastructure

for radio astronomy, driven by the goal of scaling up research objectives, we navigate across different scales to present this story through three key perspectives. We attend to Vanessa, an astronomer in Cape Town caring for the conditions on the ground; we explore the historically contingent situation in the South African Karoo, hosting the core of the world's largest radio telescope; and we scrutinize the potential of a telescope in Madagascar, and its role in the country's space research ambitions. Together, these perspectives illustrate how scale operates as both an ontological and epistemological concept, closely tied to the ground. [scale; Square Kilometre Array; Africa; astrophysics; ground; infrastructure]

NOTES

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1. Names of public figures have not been anonymized. All other names are anonymized.
2. For astronomers, the scales of outer space have an ontological character. General relativity, incommensurable with the laws of quantum mechanics, accounts for gravity and is needed for descriptions of large-scale structures in outer space but is negligible for the physics of objects on earth and does not describe dynamics at the quantum level. However, experienceable scales are used to extrapolate what becomes modeled as the very large and the very small. This rests on the assumption that scalability describes the capacity to expand without changing (Ehrenstein and Neyland 2018).
3. Debates about renaming the large and small MC are currently gaining steam. See https://www.space.com/astronomers-rename-magellanic-clouds-coalition (last accessed December 18, 2023).
4. The podcast we are writing about is called *The Cosmic Savannah* and can be found at https://thecosmicsavannah.com/
5. For more details, please see https://www.astro4dev.org/vanessa-mcbride-astronomer-at-oad/
6. Quoted in the African-European Radio Astronomy Platform, by Marina Joubert, "South Africa's President Zuma Visits Core Site of SKA in Africa for the First Time," October 9, 2012, available at http://www.aerap.org/news.php?id=69 (last accessed on 25 October 2022).

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