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Let's Not Talk About Science: The Normalization of Big Science and the Moral Economy of Modern Astronomy

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Abstract

In the 1990s, the Dutch astronomical community had to choose its next big telescope project. The starting point of their discussions was not a plan in search of support, but a scientific community in search of a plan. Their discussion demonstrates how big science projects are an integral part of the moral and institutional economy of modern astronomy. Large telescopes are unique but not exceptional: big science has become part of "normal science," both scientifically and institutionally. In retrospect, the discussions anaylized in this paper discussions concern the earliest phase of three major astronomical instruments: the Atacama Large Millimeter Array (ALMA), the Square Kilometer Array (SKA), and the Low Frequency Array (LOFAR). Interestingly, the Dutch astronomers focused on what they called

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"strategic" arguments, explicitly excluding arguments regarding scientific merit. I demonstrate how this should be understood in the context of the moral economy of the community. This analysis, based on rich archive material and background interviews with key actors, adds to our understanding of big science or "megascience" in the post–Cold War era.

Keywords
academic disciplines and traditions, politics, power, governance, big science, moral economy, astronomy

In 2010, Queen Beatrix of the Netherlands officially opened the Low Frequency Array (LOFAR), a network of highly sensitive antennas centered in Drenthe in the quiet Northeastern part of the country. LOFAR was hailed as a new generation radio telescope, continuing a Dutch tradition of high-profile radio telescopes that included instruments in nearby Dwingeloo (opened in 1956) and Westerbork (opened in 1970). But on paper, it was not a telescope at all. LOFAR was funded primarily as an IT project, out of a special government fund for "economic infrastructure." The political support focused on the high-speed data connections between its many antennas and on developing the extreme computing power needed to process the data that they collected. What the data were about was less important, although it was specified that the precise calibration needed for astronomical measurements could also be used for geodetic and even agricultural purposes.

At first sight, the astronomers were the happy beneficiaries of the political circumstances that had created the infrastructure fund. They obtained a unique instrument to conduct observations in a relatively understudied part of the electromagnetic spectrum. But behind the scenes of the Dutch astronomical community, the LOFAR project nearly caused a major crisis when first proposed. Nobody contested the scientific merits of the instrument, but some astronomers feared that it would threaten another large project: the Dutch contribution to a large international millimeter telescope (which later became the Atacama Large Millimeter Array [ALMA]). The Dutch astronomical community had just decided to make participation in that project its top priority, after several years of highly sensitive discussions about which project to pursue. LOFAR threatened to overturn the carefully negotiated long-term planning of the Dutch astronomical community, in which large instruments played a central role.

In this paper, I will analyze the discussions about future large telescopes within the Dutch astronomical community in the 1990s and early 2000s. These discussions concerned participation in three major astronomical instruments: ALMA, which opened in 2013; the Square Kilometer Array (SKA), which is still under development; and the LOFAR, which was proposed later than the previously mentioned instruments, but which was opened first, in 2010.

This case study demonstrates how big science projects are an integral part of the moral and institutional economy of modern astronomy. One could say that big science, which by definition would seem to concern rare and unique projects, has become part of "normal science." This adds to our understanding of big science or "megascience" in the post–Cold War era.

The level of coordination of the Dutch astronomical community is unusual, which makes it an interesting case study. But the values and concerns that are so clearly visible in this case are not unique. All scientific communities have a moral economy that includes scientific, institutional, and—for lack of a better word—moral values. This case is especially instructive for disciplines in which large instruments play a central role. Astronomy and high-energy physics are the most-studied examples, but one could also think of other explorative, often nationally coordinated sciences such as polar or oceanographic research, that also require highly specialized and expensive research infrastructures.

ALMA, SKA, and LOFAR can all be classified as "big science" projects, albeit in different ways. They are expensive projects (ranging from EUR100 million for LOFAR to around EUR1 billion for ALMA and SKA), built by consortia involving academic, government, and private organizations, held together by a tailor-made management structure. Operating them required large teams of scientists, engineers, and managers.

"Big science" is a major theme in the historiography of science, especially of science policy. Two classic studies, Galison and Hevly (1992) and Capshew and Rader (1992), provide an overview of the historiography up to the end of the Cold War. This was appropriate, since the concept has been associated strongly with the Cold War, especially with large particle accelerators such as Brookhaven, Fermilab, European Organization for Nuclear Research (CERN), and the ill-fated Superconducting Supercollider (Kevles 1997). Since then, several scholars have tried to adapt the concept for the post–Cold War era, when these kinds of projects continued to be developed even though the Cold War rationale disappeared, and the role of the military–industrial–academic complex in big science projects seemed to be taken over by innovation policy networks and guided by economic considerations (Elzinga 2012).

One concept that has been used to describe post–Cold War projects is "megascience," a term that was popularized by the "Megascience Forum" of the Organisation for Economic Co-operation and Development (OECD) that was established in 1992 (OECD 1993; the forum was later renamed Global Science Forum). The term has more recently also been used in science studies literature (e.g., Langford and Langford 2000; Hoddeson, Kolb, and Westfall 2008; Bodnarczuk and Hoddeson 2008; Jacob and Hallonsten 2012; Elzinga 2012). "Megascience" suggests big science on an even bigger scale than Cold War big science. Paradigmatic examples include multibillion instruments such as CERN's Large Hadron Collider, which entered operation in 2009 to find the Higgs boson, and the International Thermonuclear Experimental Reactor (ITER) nuclear fusion project, a global project that is under construction in France. These projects are strongly international, another aspect associated with megascience (Elzinga 2012). They are so large that only one of a kind can be built: they require global cooperation. This explains the involvement of the OECD, an international organization focused on economic development. The OECD Megascience Forum was intended to coordinate funding for projects on this scale. ALMA and SKA have both been described as "megascience" projects, and they have been discussed at the Megascience Forum (OECD 1998).

In their study of Fermilab, Hoddeson, Kolb, and Westfall (2008) use the concept of "megascience" to describe projects that involved constantly developing strings of experiments, without a well-defined end goal. This sets them apart from typical big science physics instruments, which were designed with specific experiments in mind, or from projects such as the Human Genome Project that have a well-defined end goal. Hoddeson, Kolb, and Westfall analyzed how Fermilab became involved in all sorts of experiments, ranging from "pure science" to application-oriented research in material science. The experimental setup could be changed and updated as required by different users. They suggest that this was a new way of working, specific for the late– and post–Cold War era, when big science machines needed to appeal to more stakeholders than just scientists and government agencies that worried about national security (Bodnarczuk and Hoddeson 2008; Crease and Westfall 2016). But the setup also resembles the long-standing way of working of astronomical telescopes, which often have multiple generations of instruments (detectors) attached to them throughout their, in principle endless, lifetime.

Crease and Westfall (2016) and Hallonsten (2016) used the slightly different notions of "new" or "transformed" big science to describe post–Cold War big science, not focusing on its scale but on the changing policy context: big science projects were increasingly subjected to "normal" science policy criteria (Elzinga 2012). Although the instruments were still stand-alone projects, their funding had to come out of normal science and innovation budgets, requiring the same political—and increasingly economical—legitimation as other research projects. Hallonsten (2016) also emphasized continuities as well as differences with earlier big science: according to him, the policy context changed more than the nature of the projects themselves.

By analyzing how "normal big science" worked in the Dutch astronomical community, this paper complicates the picture of "new big science" and "megascience." The Dutch participation in the biggest projects, ALMA and SKA, did not have to appeal to external stakeholders, precisely because they only required funding that was already allocated for science. Besides, the fact that the cost of megascience projects were shared between many countries, and spread out over many years, meant that on the national level, the amounts of money involved looked more like normal science and less like "big science."

LOFAR, on the other hand, was a much smaller telescope, but it was much more exceptional in the Dutch political context. It was perceived as a national rather than an international project, by the scientists but also by the government. Its funding structure meant that it had to be legitimized in terms of innovation and (regional) economic development as well as scientific value. Innovation policy is mostly made by national governments and aimed at national innovation systems and, ultimately, national economic growth. (Burch and Tegart [1997] argued that this is especially the case in small nations.) The number and variety of stakeholders increased to include not only scientific institutes and government organizations but also, for example, industry and regional interest groups. It was a textbook example of "new big science."

So far, the concepts of "megascience" and "new big science" have been analyzed largely from institutional and policy perspectives (Hallonsten [2016] provides a good overview). Historical accounts usually start with the first ideas for an instrument and then go on to narrate how funding and political support were obtained. In this paper, I take a different perspective: that of a highly organized scientific community that was planning its own future, up to two or three decades ahead. In practice, this planning took the shape of discussions about which large telescope project to pursue. Rather than a plan in search of support, I analyze a scientific community in search of a plan. These discussions demonstrate that also on the scientific level, big science or megascience projects have become integrated in the normal long-term planning of the scientific community.

While each telescope is a big science project with unique scientific and technical specifications and its own institutional infrastructure and funding arrangements, these projects are also part of "normal" science operations in astronomy. Astronomers count on a continuous succession of these projects. In other words, large telescopes are unique but not exceptional. For the Dutch astronomical community, ALMA and SKA were part of the planned succession of large projects, which explains why the discussions about them could be conducted in a highly planned and centralized way.

I will focus on the very first phase in which new plans are selected, immediately after the first ideas have been raised. This is an often overlooked but very important phase in the development of big science: most proposed plans are probably killed at this stage. Based on rich archive material as well as on background interviews with key actors, my analysis of these discussions provides unique insight into the way in which a scientific community discussed its future. These discussions reveal *why* large telescopes are so important, *what* they mean for the astronomical community, and *how* this community is shaped by the instruments as much as the instruments are shaped by the scientists.

My focus on internal discussions within scientific discipline does not imply that the debates only concerned "internalist" scientific arguments. In fact, the Dutch astronomers focused on what they called "strategic" arguments, explicitly excluding arguments regarding scientific merit. The arguments were clearly for internal use; they differ from the later "public" arguments, aimed at funding agencies, politicians, and the public. They reflect the moral economy of the community: internal values and concerns of the community that guide the internal functioning of the community, not as strict (moral) directives nor as pragmatic guidelines, but rather as implicit, internalized standards of how the community should function in an ideal world.[1]

One important strategic concern was future influence. What was at stake was not just access to potentially groundbreaking instruments but also influence on their design, an important and complex issue in large, international projects with many stakeholders. The fact that these instruments are so big that they will dominate a research field means that it is important to join them at an early stage, for both scientific and institutional reasons. This also demonstrates that the "necessity" of internationalization goes two ways. International cooperation is needed because of the cost and scale of megascience projects, but joining international projects can also be important to strengthen the position of local communities. Hoeneveld (2018) has described this strategy of anticipating on future cooperation structures as "voorsorteren," getting in lane.

A second strategic concern was visibility: astronomy needed a flagship project to gain political support domestically and to strengthen the bargaining position within the international astronomical community. Having access to telescopes was not enough; at least one of them should be seen as a "Dutch" instrument.

The discussions were also shaped by more general concerns, however, related to the fundamental structure of the astronomical community. Interestingly, these values primarily concerned the national level: the interests of the Dutch astronomical community as a whole took precedence over individual institutions and also over international astronomy. They determined which arguments could be used and which not.

One such value was unity: the various Dutch astronomical institutes had always carefully coordinated their political lobbying and fund-raising, keeping disagreements behind closed doors. This had proved extremely successful. For that reason, they worked hard to maintain the appearance of unity, especially when the stakes were as high as in the discussions about future large telescope projects. This influenced the way in which the discussions were conducted: they explicitly avoided comparing the merits of each other's research fields.

But the most important value was continuity: a continuous string of large projects was needed to be able to maintain staff and thereby expertise. In other words: participating in a large project was important in itself. Continuity was the starting point of the search for a new large project. Big science had become an indispensable part of "normal science."

I will start with a brief historical background of the Dutch astronomical community, before describing its discussion about a new project. I will analyze the kind of arguments that were brought forward in three stages of the discussions: first, the question of why to build a large instrument at all; second, the first selection of options; and third, the debate about the two remaining proposals. I will then discuss how the plan to build LOFAR reopened the debate. I will end with some concluding reflections on the meaning of big science projects in a modern scientific community.

The Dutch Astronomical Community

In the early twentieth century, an active astronomical community was established in the Netherlands, with research schools in Leiden, Utrecht, Groningen, and later Amsterdam (Baneke 2010, 2015). It lacked access to large telescopes, however, in part because of financial constraints but also because the Dutch climate is unsuitable for astronomical observations.

Dutch astronomers were highly dependent on observations made elsewhere. At the end of the nineteenth century, J. C. Kapteyn created an “astronomical laboratory,” an astronomical research institute without its own telescope, an international novelty (van der Kruit 2015). The development of radio telescopes after the Second World War changed this situation. Radio waves are not hindered by clouds and atmospheric turbulence that disturb observations. Led by J. H. Oort, Dutch astronomers continued Kapteyn’s research program into the structure of the Galaxy, with observations made with the radio telescopes of Kootwijk (1951), Dwingeloo (1957), and Westerbork (1970; van der Kruit Forthcoming).

After the Westerbork radio telescope, all major new astronomical instruments were built by international collaborations. For example, Dutch astronomers joined the European Southern Observatory (ESO), an international organization that developed large optical telescopes in the Chilean Andes (Madsen 2012), and they developed astronomical satellites in cooperation with the National Aeronautics and Space Administration (NASA) and the European Space Research Organization (ESRO), which was succeeded by the European Space Agency (ESA) (Baneke 2014a). They were often inspired by political opportunities or technological developments.

The radio telescopes were operated by ASTRON, a nonprofit organization, on behalf of the entire Dutch astronomical community. It became the main national center of technological expertise for astronomical instrumentation (except space instruments). In the 1970s and 1980s, all instrumentation workshops of the Dutch astronomical institutes had been concentrated at ASTRON in Dwingeloo (Baneke 2015). It was directly funded by the Netherlands Organisation for Scientific Research (NWO). But ASTRON also had an extra role: administering smaller NWO grants for astronomical research projects at other institutes. At the same time, it developed into a research institute in its own right, with ASTRON staff initiating instrument development and observational programs.

Because of its central role in Dutch astronomy, the ASTRON board consisted of representatives of the four academic astronomical institutes, and it had an advisory board that represented the entire astronomical community. It was, in other words, a locus of national cooperation and coordination. This was characteristic for the structure of the Dutch astronomical community. After the retirement of Jan Oort in 1970, there was no single leader, but informally, the community was highly centralized (Baneke 2014b). It was also small: the core consisted of about fifty-five tenured scientists.

Important decisions were made by an informally organized group of leading researchers from all institutes, who met in the ASTRON board or in other committees, most notably the rather informal but highly influential *Nationaal Comité Astronomie* (NCA), which included representatives of all astronomical institutes, including ASTRON. The NCA was also responsible for the long-term Strategic Plans for Dutch astronomy, comparable to the American "Decadal Plans," in which research programs and instrumentation priorities were formulated.

Both within the institutes and within the various national committees, there was little formal hierarchy. The institute directors had few official powers; the community was supposed to be governed by consensus among senior researchers. This can explain why the minutes of most meetings do not attribute comments to specific speakers, and why opinions are often ascribed to institutions ("Leiden wants to prioritize . . . "). That said, some astronomers were more influential than others. In the 1970s, Harry van der Laan combined leading positions at Leiden Observatory, ASTRON, and the NCA, for example. In the 1980s and 1990s, Ed van den Heuvel, director of the astronomical institute of the University of Amsterdam, was one of the leading voices. Other notable people in the discussions described in this article were ASTRON director, Harvey Butcher, Jan van Paradijs from Amsterdam, George Miley and Harm Habing from Leiden, Piet van der Kruit (who chaired the ASTRON board) and Tjeerd van Albada from Groningen, and Max Kuperus from Utrecht. Upcoming researchers among the younger generation included Ewine van Dishoeck, Tim de Zeeuw, and Michiel van de Klis.

The discussions about a new large instrument project that I analyze in this paper started within ASTRON; later they moved to the NCA. But because of the overlapping mandates that I described above, many of the same people were involved. In practice, discussions in the ASTRON board already involved the entire Dutch astronomical community.

Why Build a Large Telescope

The discussions started in the early 1990s, when the Westerbork telescope was due for what was expected to be its last major upgrade (though it was not indeed to be its last; several upgrades later, the telescope is still operational). This naturally led astronomers to think about the post–Westerbork era. For ASTRON, the institution that operated the telescope, this was an institutional issue: after the upgrade was done, it needed a new project to legitimize maintaining its budget, staff, and expertise. For this reason as well as scientific ones, ASTRON staff started preliminary studies on possible new projects (paper Braun, March 1992, ASTRON inv. 98; ASTRON 1993a; Noordam 2012).

The timing was important. It was noted that, internationally, various governments had just committed funding for several ongoing large international projects in the first half of the 1990s, including ESO's Very Large Telescope (VLT). This meant that the next "window" to request funding for new projects was several years away, probably around 1998-2000. In order to be successful, preparations for proposals needed to start several years before that—in other words: now. Besides, it was important to know which instruments would be coming available in the next few decades to be able to adapt research programs to make the best use of them (notes in ASTRON inv. 256; NCA 2001).

Finding a new project was important not just for ASTRON; it mattered to the whole Dutch astronomical community. At a "national discussion day" on September 20, 1993, it was stressed that Dutch astronomers needed to have access to telescopes in all wavelength ranges, but also be "deeply" involved in at least one of them (ASTRON 1993b). This was an ambition for the community at the national level since the individual institutes were too small to do all of this. For several decades, the Westerbork telescope had performed the "deep" function: it was the Dutch flagship instrument.

Why was it so important to have a large stake in an instrument? The Dutch astronomical community was already involved in several large projects, including the Westerbork upgrade, contributions to ESO's VLT, joint United Kingdom–Dutch telescopes on La Palma and Hawaii, and several ESA and NASA space observatories. Tjeerd van Albada of the University of Groningen already worried about "imperial overstress" [*sic*] (quoted in paper Van den Heuvel, June 15, 1994, ASTRON inv. 67). It had already been difficult to mobilize enough staff and resources for the La Palma telescopes, so why add more work? Besides, how necessary was it to contribute directly to new telescopes? In a survey of the future priorities of the various institutes, Leiden Observatory noted that there was no need for a new ASTRON project; it would be more efficient to join ongoing international projects (reports of the survey in ASTRON inv. 67.).

By this time, most large telescopes were international, and all astronomers could apply for observing time. Langford and Langford (2000) have shown that Canadian astronomers were happy to use existing telescopes, without contributing directly to their development. This did, however, lead to accusations of "freeriding," demonstrating that this strategy somehow violated the moral code of the astronomical community. Besides, as Jacob and Hallonsten have pointed out, internationalization of megascience was a "mixed blessing." It allowed for cost sharing and increased collaboration, both important issues in post–Cold War science policy. But, Jacob and Hallonsten (2012) write,

> most of the scientific proponents of these projects prefer that the project remains national. This is primarily because it would grant the home team significant advantages in terms of prestigious prizes, etc. if the research infrastructure is national. A second argument against internationalism is that it increases the administrative difficulties in managing these facilities.

That developing new instruments brings scientific benefits was well established. Astronomy is, to a large extent, an exploratory science. New discoveries are mainly driven by expanding the reach of observations: exploring new parts of the electromagnetic spectrum or significantly increasing the sensitivity of the instruments, either by improving the technology or simply by making them bigger. Especially after 1945, the development and application of new technologies determined the growth of the discipline, with the development of radio astronomy, space research, and electronic detector technology. Each time, new instruments yielded new and prestigious discoveries (Harwit 1981; R. W. Smith 1997; Dick 2013). The most novel discoveries were to be expected in the first years of operation, when access is hardest to secure because much of it is reserved for institutions that were involved in the development of the instrument, as a direct reward for their contributing. Dutch astronomers have had this experience, for example, with the Dwingeloo and Westerbork radio telescopes, which were highly productive in their first years, and with the IRAS infrared satellite.

Having your own instrument also made it possible to do large-scale research projects that required a lot of observing time (ASTRON 1993a), or observations that required quick access, with no time for formal application procedures. This last fact was illustrated by the breakthrough discovery of the optical "afterglow" of a gamma-ray burst in 1997: Jan van Paradijs could react very quickly, using the Dutch–British William Herschel Telescope (Schilling 2000).

Getting involved in developing an instrument also made it possible for researchers to influence its design, tailoring it to specific research needs. Ed van den Heuvel, chair of the NCA and one of the leading Dutch astronomers, noted that the most important discoveries, and the Nobel Prizes that came with those, were made by people who built an innovative instrument, rather than using an instrument that was intended to serve a large community of users, as the design of such instruments inevitably involved compromises (EPJH inv. 1577). Besides, instruments were often so complex that researchers who had intimate technical knowledge of their capabilities had a head start when using them.

The great discovery potential of new instruments not only benefited existing scientific staff, it also attracted prominent researchers and students. In Westerbork, this noticeably changed in 1980, when the telescope was surpassed in scale by the American Very Large Array (VLA; Baneke 2015) and some high-profile researchers left, including, for example, Ron Ekers, who became director of the VLA. Apparently, top staff follows top instruments.

Van den Heuvel also stressed how important access was for students:

> We want to train a new generation of astronomers so that they will build new facilities, not just use "common-user" instruments. It is a focus of "how to do science." (Van den Heuvel, notes in EPJH inv. 1577; cf. report of NCA meeting, June 24, 1994, ASTRON inv. 67)

In other words, he considered developing new instruments a moral imperative for astronomers. It is part of how astronomy should be done.

Apart from these direct benefits, there were also more indirect advantages. For one thing, having a cutting-edge instrument helped to get access to other telescopes. Observing time is scarce, especially on the most advanced telescopes. It is a jealously guarded commodity. Other than, for example, physics, astronomy had a tradition of reserving access to large facilities for its members or sponsors (Langford and Langford 2000; McCray 2000; DeVorkin 2000). Exchange agreements are not uncommon, and controlling access to a desirable instrument provides scientists with a strong bargaining position. Again, the Westerbork telescope in the 1970s provided a good example of this (this was noted in ASTRON [1993a] and in a letter by Van den Heuvel, June 15, 1994, ASTRON inv. 67).

Several astronomers, especially from Leiden Observatory, argued that these scientific considerations did not necessarily require developing an entire telescope. One could also make a substantial contribution to a big international project in the shape of an "instrument" in a more specific sense. In astronomical terminology, "instrument" often does not refer to the entire telescope system but to a camera or spectrograph that is attached to the telescope. In this context, the telescope itself is seen as a "light bucket," a device that gathers light from celestial objects and sends it to the "instruments." A large modern telescope can have multiple "instruments," which can be as complex and expensive as a smaller telescope. These instruments can be updated or replaced throughout the operational lifetime of the telescope.

A Dutch contribution to an international telescope could involve supplying an "instrument" in this latter sense. For example, ESO asked member countries to submit proposals for instruments on its Very Large Telescope (VLT), a practice modeled after space research (Madsen 2012, 217). Contributing instruments gained the supplier credit and access to the telescope as well as providing the scientific benefits that came with designing your own instrument. In policy documents, developing instruments was described as "complementary policy" (*flankerend beleid*), intended to enhance the benefits membership of international organizations such as ESO or ESA.

The Leiden astronomers stressed that making a substantial contribution to a big international project would be more cost efficient than building a complete telescope system. They argued that this was no less ambitious: instruments could make a telescope unique. Moreover, by supplying an instrument, one could be involved in groundbreaking science with a relatively modest budget and at relatively short timescales (KNAW 1991; ASTRON 1993a; survey of future priorities, 1994, ASTRON inv. 67).

There was one thing, however, that instruments in this sense, contrary to full telescopes, could not provide: visibility. Having a well-defined flagship instrument was important for political reasons as well as public relations. To obtain political support, it was important to be able to have a "Dutch" telescope since politicians like to be able to show concrete, material results of government spending. At the start of the planning, Robert Braun of ASTRON pointed out that any new plan should have popular appeal in order to have any chance of funding (report Braun, March 1992, ASTRON inv. 98). Influential astronomers such as Van den Heuvel and Michiel van der Klis remarked that this aspect should "not be underestimated" (Van den Heuvel, June 15, 1994; Van der Klis to De Zeeuw and Verbunt, June 16, 1994, ASTRON inv. 67).

The Options

In 1992, ASTRON director Harvey Butcher asked various working groups to formulate proposals. The working groups included scientists from all Dutch astronomical institutions. They used the following boundary conditions (Proposal WG Zon en Sterren, 1992; proposal WG Galaxies, November 1992, ASTRON inv. 256):

- A budget of c. 50-100 million guilders, spread out over 10 years;
- The project should build on existing technical expertise of the Dutch institutions;
- The project should be unique, meaning that the instrument should be at least one order of magnitude better than existing facilities (in terms of spectral-, time-, or spatial resolution or sensitivity; or a combination of those factors);
- It should appeal to the research interests of the majority of "a considerable part of Dutch astronomical community"; and
- In case of participation in a larger project, the Dutch share should be at least 30 percent, with the allocation of Dutch observing time controlled in the Netherlands.

The working groups came up with several proposals that were discussed at two meetings: of the ASTRON advisory board on March 31, 1993 (ASTRON 1993a), and a "national discussion day" on September 20, 1993 (ASTRON 1993b). The most conventional ones involved expanding the Westerbork radio telescope or buying into one of the large (8-10 m) optical or infrared telescopes that were being developed internationally. This last suggestion was quickly dismissed because it was not unique enough—a scientific as well as a strategic argument because of the visibility consideration (report "brainstorm session" WG Zon en Sterren, May 19, 1992, ASTRON inv. 256). A more ambitious proposal was the "Whole Earth Telescope": a ring of medium-sized (5 m) optical telescopes around the equator, which would enable observing celestial phenomena twenty-four hours per day. This, however, was dismissed because of the high operating cost and the fact that the same observations could be made by combining existing telescopes (ASTRON 1993a).

The two most promising proposals involved a new radio telescope and a telescope for the millimeter wavelength range. The radio telescope was a new idea, developed by ASTRON staff including Robert Braun, although it soon emerged that radio astronomers elsewhere were discussing similar ideas (Ekers 2012; Noordam 2012). To be an order of magnitude better than the largest existing facilities, it would have to have a total receiver surface area of about a square kilometer, divided over many smaller receivers. The name "Square Kilometer Array" was quickly adopted. The project would certainly be unique, and it would make use of Dutch technological and scientific expertise in radio astronomy. Its capabilities would serve the ongoing investigation of interstellar hydrogen gas at increasingly far distances (larger redshifts/longer wavelengths), a project started by Jan Oort in the 1940s (in early discussions, the plan was sometimes called the "Oort Telescope"). The telescope could also be used for the research on pulsars and other high-energy objects that was being done by Van den Heuvel, Van Paradijs, and other researchers from Amsterdam, who supported the proposal for that reason. It was clear that this project would require international partners because of its scale, especially the large area over which the receivers would be spread. The actual facility would have to be built outside the Netherlands (Australia, South America, and the former Soviet Union were mentioned), but the Dutch were well placed to take the lead, because of their experience with the Westerbork telescope (see proposal in ASTRON inv. 256).

The alternative plan involved participating in a large "millimeter array." Ewine van Dishoeck of Leiden Observatory was one of the main proponents. In this case, the novelty did not just lie in increased power but in exploring a relatively unexplored part of the electromagnetic spectrum: millimeter wavelengths, between infrared light and radio waves. This plan could be realized more quickly than the radio telescope because several concrete projects were already being developed in Europe and the United States (ASTRON 1993a; Vandenbout 2004). Scientifically, the millimeter project would be related to infrared observations of interstellar matter, molecules, and other "cold" objects in the universe, which was done especially in Leiden. Technologically, it would use both ASTRON's expertise in interferometry and highly specialized expertise in supercooled heterodyne detectors, first developed in Utrecht by Thijs de Graauw and others, which had been used in several infrared space instruments.

How to Choose

The square kilometer radio telescope and the millimeter array were different instruments, not only technologically but also with respect to the researchers they served, and which institutions would be most closely involved. How to manage such a sensitive choice without dividing the community? The Dutch astronomical community had a long tradition of coordinating its activities on a national level. They made sure that large funding applications were publicly supported by the whole community, without dissenters, and worked together to mitigate the effect of budget cuts in the 1980s (Baneke 2015). Unity, or at least the appearance of unity, was highly important.

There had never been such a head-on clash of potential projects before. The radio telescopes of Dwingeloo and Westerbork had been uncontested;

in space, the main priorities had been mostly dictated by technological possibilities and political circumstances (Baneke 2014a), and the British–Dutch cooperation on La Palma and Hawaii was the result of unique circumstances and quick action by Harry van der Laan (F. G. Smith 1985). But now, there were two seemingly equal proposals.

The national meeting on September 20, 1993, concluded explicitly that none of the proposals could be dismissed on scientific grounds. Acknowledging this, the astronomers decided to diffuse potentially disruptive discussions by focusing on "strategic" arguments. They would not assess which project was better scientifically, but only which was most beneficial on the institutional level, which promised most benefits in the context of international competition, and which had the best chance of being funded (ASTRON 1993b; M. van der Klis to F. Verbunt, June 16, 1994, in ASTRON inv. 67). Apparently, the unity and (institutional) continuity of the community were important enough to avoid trying to compare the scientific merits of the two proposals.

The main strategic argument for the radio telescope was that it clearly played to local strengths. Dutch astronomers had significant expertise and a strong reputation in radio astronomy. Around this time (1993), an institute for coordinating joint observations of the main European radio telescopes was established in Dwingeloo (JIVE, the Joint Institute for Very long baseline interferometry in Europe). The new project would reinforce this Dutch "niche," and it would be highly visible nationally, which was a political advantage. Also, it meant that the Netherlands could take the lead in a unique, groundbreaking project. In fact, the lack of an international organization for radio astronomy offered the chance to create an international center in the Netherlands (interim report SKAI, January 1997, ASTRON inv. 98). The fact that it involved building an entire telescope system rather than supplying a part would give the Dutch community relatively much control over the allocation of observing time.

The project was especially pushed by the technical specialists at ASTRON, the radio telescope institute. The expected timescale was long—it was not expected to be operational before 2010. This was advantageous for the institutional continuity of ASTRON since it meant that the project could gradually take over the man power of currently ongoing projects such as the Westerbork upgrade. On the other hand, its technical specifications were still rather vague, and it was not yet clear what kind of international cooperation would be necessary or possible.

The millimeter project would not so much build upon an existing tradition as open up a new field, broadening the range of available observations.

It would involve joining an existing international project rather than starting a new one, which meant that it was well defined and could be realized relatively quickly. The shorter timescale also meant that it would require a lot of man power during a short period, however, making it less appealing from an institutional perspective. Besides, the Dutch role would be less influential and less visible than in the radio telescope.

A sensitive point was that the number of users of the millimeter telescope within the Dutch astronomical community was probably smaller than those of a radio telescope. On the other hand, the leadership of Leiden Observatory thought the project was vital to keep Ewine van Dishoeck, one of the greatest talents of her generation, in Leiden (notes on NWO–Groot proposal, January 12, 1996, ASTRON inv. 137).

The millimeter project was promoted mostly by academic researchers, rather than instrument developers, a division that threatened to develop into a real fault line within the community. There had already been some discussion about the role of ASTRON: should it just provide technical expertise as a service to academic researchers, or should it operate as a research institute in its own right, with its own research staff and its own scientific priorities? This is a recurrent theme in organizations that operate large scientific instruments (McCray 2004; Woltjer 2006; Madsen 2012; Hermann et al. 1987-1996). Finally, several people suggested that the Dutch participation in a milliliter telescope project should go through ESO, an existing organization for international telescopes, of which the Netherlands was a founding member (ASTRON 1993b; also Van den Heuvel, June 15, 1994; Van de Klis, June 16, 1994, ASTRON inv. 67).

The Compromise

Since a new major instrumentation project would require the support and participation of the entire Dutch astronomical community, the new projects had to be included in a new Strategic Plan. For this reason, once two proposals had emerged, the discussions was moved from ASTRON to the NCA—although, in practice, many of the same people were involved, including, for example, Van den Heuvel and Butcher.

At the NCA meeting of June 2, 1994, the need to commit to a new project was again emphasized—the minutes stated that the credibility of Dutch astronomy was at stake (meeting report in ASTRON inv. 67; the remark was not attributed to a specific person). A survey of the desires of the various astronomical institutes revealed that Groningen, Amsterdam, and Utrecht supported a new large ASTRON project, while Leiden did not

(ASTRON inv. 67). It was not specified which persons had been consulted at the various institutes, which perhaps indicates how the astronomical community perceived its own sociological structure. There were no powerful institute directors; institutes were supposed to be managed by consensus among the senior research staff. Any hierarchical relation was implicit, not formalized.

The NCA did not immediately reach consensus. In 1995, however, an international committee that assessed the quality of Dutch astronomy criticized the Dutch astronomers for treating both projects as competitors (AFEC 1995). The science case for both was strong, but their time frames differed. Why not pursue both, prioritizing the millimeter array in the near future while pursuing the SKA as a longer-term project? This solution was adopted in a joint meeting of the NCA and the ASTRON board in Vught on February 14, 1995 (report of NCA and ASTRON board retreat, ASTRON inv. 98; no list of participants). The joint meeting showed that the mandates of the various boards were never clearly defined, but, at the same time, there was a clearly identifiable group of people who formed the leadership of the astronomical community. The impact of this compromise is illustrated by the fact that someone has scribbled "De Vrede van Vught" (the peace of Vught) on the meeting report in the ASTRON archives.

It was also decided to immediately start negotiations with the various international millimeter array projects. At this time, there were several independent projects in development, both in Europe and the United States. The Netherlands Organisation for Scientific Research (NWO) cited the unclear relation between them as a reason to reject an early funding application (meeting report ASTRON–NWO, June 13, 1996, ASTRON inv. 98). The proponents argued that the Dutch could play a role in negotiating a merger between the American and European projects in a later stage. This appealed to a common Dutch trope: the role of a small-but-sophisticated country as a mediator between large nations (notes on NWO–Groot proposal, January 12, 1996, ASTRON inv. 137; Somsen 2008).

Negotiations about merging the American and European projects, including Dutch participation, formally started in June 1997 (Vandenbout 2004). A Japanese project was also included at a later stage. Eventually, they led to the joint project ALMA, in the Atacama Desert in Chile at an altitude of more than 5,000 m. European participation, including that of the Netherlands, was coordinated by the ESO. The Dutch contribution consisted, among other things, of one of the receivers in each of the array's sixty-six dishes. Ewine van Dishoeck and Thijs de Graauw played leading roles in the project. ALMA started operations in 2013.

Meanwhile, ASTRON continued its development of technology for the square kilometer radio telescope. It also initiated an international working group to develop the idea in collaboration with other radio astronomy institutes who had started discuss similar ideas. The project rapidly grew in scale, until it was big enough to be discussed at the OECD Megascience Forum. Again, the relation between international participants was not very clearly defined: the Megascience Forum report on radio astronomy referred to "various initiatives that are under study can collectively be referred to as the Square Kilometer Radio Telescope" (OECD 1998). They finally came together at the General Assembly of the International Astronomical Union in Manchester in 2000, with the ceremonial signing of a Memorandum of Understanding to jointly develop the SKA. By then, it was a fully international project. In 2003, a coordinating project office was established at ASTRON in Dwingeloo, directed by Richard Schilizzi. This can be seen as a vindication of the "strategic" consideration: the early investments in design studies paid off. In 2008, a SKA Project Development Office was established in Manchester. It has become a global project, including American, African, Asian, and Australian partners. In 2012, it was decided that the telescope itself would be built in two locations such as South Africa and Australia. South Africa's strong participation has been hailed as a symbol of Africa's upcoming technological and economic power (e.g., by *The Economist*, August 9, 2014). On 12 March 2019, representatives of seven countries signed a treaty to establish the Square Kilometre Array Observatory (SKAO) as an intergovernmental organization. The telescope itself is still under development.

A National Plan

After several years of debate, a workable compromise had been reached in 1995. Both the millimeter and the radio telescope would be developed, one after the other. The unity of the astronomical community was saved, but not for long. The compromise was quickly put to the test when a new plan was brought forward in 1997: to build a relatively small radio telescope that would observe very low frequencies (below 50 MHz; wavelength in the order of meters). The LOFAR, as the project became known, was not mentioned in any Strategic Plan.

The plan reportedly originated at a discussion in Leiden on June 2, 1997, where Leiden astronomer George Miley discussed it with the prominent radio astronomer Ron Ekers, who had worked at Groningen and Dwingeloo before moving to the United States and Australia. Miley explained the plan a month later to Van den Heuvel, chair of the NCA:

> To me the most exciting aspect is that we could effectively open up one of the few remaining windows in the [electromagnetic] spectrum and that it would be a project of the scale that could carry out [*sic*] mainly in the NL and which exploits the radio astronomical expertise in ASTRON to do unique new astronomy, without waiting for [the Square Kilometer Array], when many of us may be well in our seventies. Purely sociologically, I think that this proposal might help to bridge some of the distance that has separated ASTRON from the universities during the last few years. (Miley to E. P. J. van den Heuvel, e-mail, July 2, 1997, in EPJH inv. 1577)

The science case was strong: observing a little-studied part of the electromagnetic spectrum almost guaranteed new discoveries (the "low hanging fruit" argument). Strategically, the fact that it could be built relatively quickly and within Dutch borders was appealing: it would keep the organization simple, it would offer Dutch astronomers easy access, and it would be a national flagship that could be used politically. Significantly, he also referred to the unity of the astronomical community, explicitly mentioning the relation between instrument specialists (ASTRON) and the academic research community. The project would, however, require a significant reallocation of ASTRON's resources.

While the discussions I described in the previous sections were carefully planned, the discussions about this plan were not. It was an ad hoc plan, not related to the existing long-term planning of the astronomical community. Moreover, there was some time pressure: one of the advantages of the projects was that it could be realized relatively quickly. But what would that mean for the existing commitments to the millimeter telescope? Once again, the astronomical community had to rethink its priorities, and again, the discussions reveal some of the core values of the community, in relation to big science projects.

After some initial hesitation, ASTRON-director Butcher supported the plan, not least because it would provide a strategic advantage in the run-up to the SKA, which by now had become an international megascience project (ASTRON 1999). LOFAR was explicitly presented as a "pathfinder" for SKA. Its innovative technology, most notably the "phased array" technology that enabled the telescope to look in all directions at once, vastly expanded the chance of observing transient phenomena—technology that would probably also be central to SKA (Garrett 2012). The technology was known from other sectors, including radar research. Engineers at ASTRON were working on adapting it for astronomical use. Realizing LOFAR would put ASTRON, and thus the Dutch astronomical community, in a strong position to claim a central role in the development of SKA.

Interestingly, a cost-benefit analysis report by an ASTRON employee stated that the alternative to LOFAR was not to *not* build the instrument but to leave it to be built somewhere else, thereby playing the card of (international) competitiveness (Bentum 2002). The instrument was presented as inevitable.

The plan was controversial. The proponents of the millimeter telescope had struggled to deal with the competition of SKA, and just as a compromise had been reached, LOFAR seemed to reopen the discussions. Old worries about *hubris* and overstretch also resurfaced. Could the astronomical community handle yet another large project?

A complicating issue was that just around this time, the Ministry of Education was reviewing a funding application for a "national research school of excellence" for astronomy (*toponderzoekschool NOVA*). This was a joint application from the academic astronomical institutions, for a new kind of funding program. Formulating a joint proposal had been quite difficult, because of an old division between Leiden and Groningen on the one side and Utrecht and Amsterdam on the other. Now that the application was submitted, it was vitally important to maintain the unity of the community. Any internal controversies would seriously harm the chances of getting the joint research school funded (e.g., e-mail Habing, September 26, 1996, in EJPH inv. 1547). There were also worries about the credibility of the community: would the astronomers look too greedy if they proposed yet another big project? Van den Heuvel went as far as to prepare a list of things Dutch astronomers did *not* do, such as planetary or lunar research (undated notes in inv. 1577).

The discussions about LOFAR were "not good for the unity of Dutch astronomy," as one participant put it diplomatically in a conversation with the author. Personal and institutional interests clashed, as academic researchers accused the ASTRON leadership of acting too independently. In the end, however, a new compromise was reached: ASTRON could pursue the project, on the condition that it did not threaten any other projects. This meant that it had to be funded with "new" money, several tens of millions of (then) guilders. Since the government's science budget for large instruments had already been allocated, new sources had to be found.

As it happened, there was a promising government fund that could be used. It would, however, require a significant reinterpretation of the plan. The Dutch economy was flourishing in this period, the late 1990s—so much so, that the government of Prime Minister Wim Kok was debating how to invest surplus money. One of the plans was to use revenue from natural gas mining in the Northern part of the country to create a fund for "economic infrastructure."[2] This money was primarily intended for traditional infrastructure (highways, railroads), but a percentage was allocated for "knowledge infrastructure." In order to apply, a project had to prove both its scientific and its economic value, stressing "innovation" rather than pure science. In other words, this part of the budget was intended for "new big science" projects (*Kamerstuk Tweede Kamer* 25 017, March 26, 2002 accessed 29 January 2019; Versleijen 2007).

This was new for astronomical instruments. To be sure, earlier projects such as the Westerbork radio telescope or the ANS and IRAS astronomical satellites had also been supported for economic reasons, including supporting the research and development departments of companies such as Philips Electronics and Fokker aircraft, training engineers, and using the instruments as a showcase for Dutch technological prowess (Elbers 2012; Baneke 2014a; see Agar 1998 for a comparable case). But in these cases, the economic value was in the technology, not in the science that could be done with the final product. LOFAR was different: now the instrument itself and the data it produced had to be economically valuable. Being a technological novelty was not enough anymore.

In the end, LOFAR was presented primarily not as a telescope but as an IT project. The receivers, which were spread over a large area, would be connected by a high-speed data network, and it would require an extremely powerful central data processing system. Moreover, its network of highly sensitive sensors could also be used for geophysical and meteorological observations, which in turn could be used for highly localized climate research and "high-precision agriculture." The telescope morphed into a multifunctional data collecting and processing network.

The project was also strongly supported by local authorities in the Northern Netherlands, including the Provincial authorities of Drenthe and Groningen. As said, the fund for economic infrastructure was based on natural gas revenue, which originally came from the area. Ever since natural gas had been discovered in the 1950s, the Northern provinces had complained they had not benefited enough: most of the money disappeared to the economic and administrative centers in the Western part of the country. Now, the Northern provinces felt they had a moral claim to the fund. They expected great benefits for the local economy (see, e.g., *Kamerstuk Tweede Kamer* 25 017, December 8, 2003 accessed 29 January 2019; *Nieuwsblad van het Noorden*, April 17, 2003).

Jon Agar has described how the meaning of the Jodrell Bank radio telescope varied for different audiences and also changed over time (Agar 1998, 235). This also happened with LOFAR. For research astronomers such as George Miley, it was a way to obtain exciting new observations without having to wait for SKA. For ASTRON, it was a way to obtain a strong position in the run-up to SKA development and construction. For political reasons, it was presented as an investment in information technology and a boost for the economy of the Northern provinces.

Initially, the LOFAR proposal got excellent reviews from the scientific evaluation committee (chaired by an astronomer), but a more mixed assessment of its socioeconomic benefits (CPB 2003). An intense lobby, supported by the Northern provinces and officials from the Science department (there was some interdepartmental rivalry between the Science and Economics departments), was eventually successful, however: in November 2003, the government, uniquely, decided to overrule the recommendation of the evaluating committees and fund the project to the tune of 52 million euros (*Kamerstuk Tweede Kamer* 25017-45, November 28, 2003 accessed 29 January 2019).

LOFAR was thought of as a national project, but throughout the preparations, there had been talks with American and Australian institutes about collaboration of some kind. Although once the funding was secured, the foreign partners withdrew (Van Haarlem et al. 2013). It was clear that this was going to be a predominantly Dutch project, as it had always been in the minds of the Dutch. Something similar had happened with the Westerbork telescope in the 1960s: the first plans involved Belgian participation, but the Dutch astronomers were happy to continue on their own when that became possible (Elbers 2017). Apparently, if presented with the option, a national project was preferred over an international one (Jacob and Hallonsten 2012). Later, it became international again, as receivers were added, spreading out over much of Northwestern Europe. The core remained in Drenthe, however, with the core computing facility hosted by the University of Groningen, which obtained an IBM Blue Gene supercomputer for the purpose. LOFAR was officially opened in 2010.

Conclusion

In the end, the Dutch astronomers got all three instruments: LOFAR, ALMA, and SKA (although the last one still remains to be built). In the same period, they also contributed to several other important instruments. They ascribe their success in obtaining funding in no small part to their careful planning and coordination, and especially to the fact that they have always managed to present a united front to the funding agencies, keeping controversies behind closed doors. The Decadal Surveys of the American astronomical community were an inspiration for the Dutch, but they also demonstrate how difficult it is to avoid public disagreements. It requires a high level of loyalty to the national community. Apparently, the members of the Dutch astronomical discipline are, well, disciplined, adhering to a strong moral code in which the continuity of the national community is a prime concern.

Originating as a purely astronomical venture in the context of the preparations for SKA, LOFAR has become a textbook example of post–Cold War "new big science." Even in astronomy, traditionally viewed as the "purest science," driven by curiosity and with no practical application, the new instrument had to prove its usefulness to various stakeholders, including some outside the realm of science or even technological innovation. But this was not because big science was integrated in "normal" science budgets—on the contrary. Big science projects that were part of the normal long-term planning of astronomy and funded out of normal science budgets required no different legitimation than smaller research projects. LOFAR had to be reframed as an innovation project precisely because it was *not* funded by the science department.

Sandell (2013) argued that the "science case" for a new instrument could not be the main driver of the project for philosophical reasons: the design always relies on the *current* state of science and technology or extrapolations thereof. Fundamentally, new science (she uses Rheinberger's concept "epistemic things") can only emerge once the instrument is actually in use, when the case no longer needs to be made. This argumentation is less applicable for a predominantly observational science such as astronomy. Astronomical instruments are mostly intended for exploration, not for a specific experiment. The science case for new telescopes often refers to the potential for discovering unspecified new objects. More importantly, in this paper, I have demonstrated that at some stage in the process of selecting new instruments, there were also practical and moral (in the sense of "moral economy") reasons to sideline the science case. Scientific expectations were important in the first phase of a project: coming up with suggestions for new instruments. But once the scientific community was convinced that a strong science case existed, it ceased to play a role in the discussions. Faced with the necessity of comparing two proposals that were both deemed legitimate, the choice between them was based on considerations other than science.

It is important to realize that this did not mean that science was regarded as unimportant. On the contrary, it was precisely because researchers felt so strongly about science that it had to be put aside. Assessing the relative merit of each other's research programs was so sensitive that it could split the disciplinary community. Only once consensus was reached within the community did the science case become prominent again, in the campaign to secure political support and funding. Clearly, different values had to be stressed for different audiences.

Choosing which instrument to build next is a momentous decision for any scientific community. Smith has characterized the commitment to build a large instrument as a "leap of faith." Not only are research programs at stake but also careers, institutions, and, in some cases, the future of whole disciplines (R. W. Smith 1997; McCray 2004). This is especially the case in astronomy. The role of large telescopes was recently addressed by Ewine van Dishoeck, President of the International Astronomical Union, and a prominent Leiden astronomer who was one of the drivers behind ALMA (for which she received the prestigious Kavli Prize in 2018):

> Astronomy is an observationally driven field, so progress requires increasingly larger telescopes and instrumentation that can see sharper, deeper and more sensitive than previous facilities. We have been fortunate to have an armada of new telescopes and satellites across the electromagnetic spectrum over the past decades, with multi-messenger facilities ramping up. But this steady stream of new facilities cannot be taken for granted. [. . .] Large scientific infrastructures are no longer the domain of just astronomers and physicists: other areas, from atmospheric science, geochemistry, and life sciences to the humanities and social sciences, require increasingly large facilities as well to advance their field (often in the form of large databases). They now also have the ears and eyes of the funding agencies and politicians. (Van Dishoeck, speech at the General Assembly of the International Astronomical Union (IAU), Vienna, August 30, 2018)

Astronomy is dependent on a "steady stream" of new large telescopes, both scientifically and institutionally. Big science has become embedded in normal science; without it, the discipline would face a crisis. The Dutch astronomical community was aware of that, and the realization shaped their long-term decision-making. The continuity of the community and the unity that was required to guarantee this continuity were at the heart of the moral economy of Dutch astronomy.

The discussions also demonstrate that national considerations remain vital, even in a highly internationalized discipline such as astronomy. The interests can be scientific (opportunity to pursue certain research programs, chance of making discoveries), institutional (obtaining funding, ability to maintain staff and expertise), or a mix of the two. The astronomers called these "strategic considerations," which also involve, for example, the ability to influence the design of instruments or obtaining resources that can be traded for access on other instruments. While the OECD Megascience Forum stated that "efforts to promote early co-operation in the development of what is being called the Square Kilometer Radio Telescope [. . .] are noted and applauded" (OECD 1998), the Dutch astronomical community discussed how to make the Dutch influence as large as possible.

The discussions described in this paper demonstrate that unity was an important value in the Dutch astronomical community. They also reveal some of the other values that make up the moral economy of modern astronomy. Access to instruments, especially in the earliest phase of operations, is a highly valued resource for current staff, but also for attracting or keeping prestigious staff, another scarce resource, and for training students. Especially telling were the remarks about educating future generations of astronomers: developing and using advanced instruments were considered essential elements of "how science is done."

Influencing the design of instruments is also an important issue. Or, to be precise, making sure that new instruments match one's research profile is key, because the influence can go both ways: research priorities are also influenced by forthcoming instruments. The SKA is already changing astronomy although the actual instrument has not been built yet. This supports the notion that instruments have "agency" in the sense that Sayes (2014) defined it: they shape research opportunities, and they affect careers and institutions. My case study demonstrates that this agency is not dependent on their physical presence. Large instruments start to impact scientific communities long before they become operational.

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Notes

1. My use of the term "moral economy" follows Kohler (1994), McCray (2000, 2004), and Langford and Langford (2000), who used it to describe the rules that governed priority setting and access to research facilities: exchange mechanisms in which nonmonetary values and rewards play a large role (see also Daston 1995).
2. Fonds Economische Structuurversterking. The part allocated for knowledge infrastructure was known as Besluit Subsidies Investeringen Kennisinfrastructuur.

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