Capacity-Building for Big Science in the Global South: Lessons Learned from the Square Kilometer Array

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Executive Summary: Hosting a big science project, a research facility that is anchored around large and complex instruments in the billion-dollar class, presents both an opportunity and a challenge for countries from the Global South. On the one hand, big science projects may foster a host country's local and national capacities in science and technology (S&T). On the other hand, contenders need solid S&T capacities to bid for a big science facility. In the Global South, and in particular on the African continent, few countries currently have such capacities. With the exception of South Africa, which is host to the Square Kilometer Array (SKA), a billion-euro radio astronomy facility, no African country hosts a big science project. This essay outlines how South Africa, which initially lacked human capital and infrastructure in radio astronomy, succeeded in building capacity for SKA. In addition, it draws two lessons from South Africa's capacity-building efforts. These lessons could prove useful for countries from the Global South that are keen to strengthen their S&T capacities for big science.

I. Introduction

Big science, large research projects anchored around expensive and complex instruments that run for several decades and involve thousands of experts, often foster local and national capacity-building in science and technology (S&T) (Börner, Silva, and Milojevic 2021; American Academy of Arts & Sciences 2022). They can, for instance, enhance capacity-building through knowledge transfer, innovation, and spillover effects (Scarrà and Piccaluga 2020). Arguably one of the most famous spillovers from big science is the World Wide Web, which was originally invented by CERN scientist Berners-Lee to meet the organization's demand for automatic information-sharing (CERN, n.d.). In addition, big science projects may foster capacity-building by nurturing domestic research communities and promoting international collaboration in S&T (D'Ippolito and Rüling 2019). For example, some 3,000 scientific authors from 42 countries have contributed to publications resulting from CERN's ATLAS experiment (CERN 2022).

Given the economic benefit and scientific prestige that are attached to big science, it comes as no surprise that many countries are keen to host such projects. However, due to the solid S&T capacities that are required to host a big science facility, few contenders are able to bid. Countries in the Global South, and in particular in Africa, often lack capacities and resources for big science projects and, as a result, rarely host such facilities. South Africa is a notable exception. It is host to the Square Kilometer Array (SKA) and covers a substantial part of the project's construction costs through in-kind contributions.

SKA is a multi-billion euro radio astronomy project in the making that aims to explore a range of fundamental cosmological questions (Pozza 2015). Consisting of two radio telescopes and one observatory, it will eventually be the largest scientific instrument on Earth, both in terms of physical scale and volume of data it will generate

(Berry 2021; Clery 2018). SKA's origins go back to the early 1990s, but the intergovernmental organization responsible for operating and constructing SKA, the so-called SKA Observatory (SKAO), was created in 2019.

Commentators have repeatedly referred to SKA as a textbook example of diplomacy for science; that is, governments cooperating "to create major scientific infrastructures that would be too complex and expensive for one single country to build and maintain on its own" (Gual Soler and McGrath 2017; Pozza 2015). Moreover, they have praised SKA for fostering S&T capacity-building on the African continent and in South Africa (American Academy of Arts & Sciences 2022; Berry 2021). What is often neglected is that, to host SKA, South Africa first had to invest considerable resources to strengthen its capacity in radio astronomy, as it was lacking human capital and infrastructure in this research area. In the run-up to SKA's site selection, South Africa managed to gradually build up its radio astronomy community. Once chosen as project host, the country further strengthened its S&T capacities by building two cutting-edge SKA precursors. This essay uses interview data to outline how South Africa succeeded in its capacity-building efforts for SKA and draws two lessons from these efforts. Both lessons could prove useful for countries from the Global South that are keen to strengthen their S&T capacities for big science.

II. From afro-pessimism…

The impetus for South Africa's participation in SKA came a few years after the country's Department for Science and Technology (DST)[1] issued its seminal 1996 White Paper on S&T. In this paper, DST identified astronomy as one of four focus areas for South Africa's science, technology and innovation (STI) sector (Department of Science and Technology 1996). Astronomy was chosen as an area of strategic interest for South Africa because the country had "good access to Southern skies" and thus a natural geographic advantage to conduct research in the field (Department of Science and Technology 2002). In addition, DST perceived astronomy as a fundamental science which could enhance national skills, capacity-building, and by extension contribute to the development of a South African knowledge society (Tiplady 2022). Looking to diversify its economy after the fall of the apartheid regime, astronomy also presented a "benign environment for the development and exploitation of technological innovation," a function that had historically been centered on the defense industry (ibid.).

When astronomy was identified as a focus area for South Africa's STI sector in the mid-1990s, the country's radio astronomy community was small, with less than ten "professional radio astronomers split between a couple of universities and the Hartebeesthoek Observatory" (Jonas 2022). In 2000, most of these radio astronomers attended a National Research Foundation organized workshop "on what the next big thing should be for astronomy" (ibid.). During the workshop, they advocated for South Africa to participate in SKA. Justin Jonas, now Chief Technologist at the South African Radio Astronomy Observatory, was present at said workshop and contacted some of his peers abroad to find out whether it would be possible for South Africa to contribute to SKA. Professor Jonas' international colleagues responded very positively to his request and invited him to attend meetings of the SKA Steering Committee (ISSC) as South Africa's representative. As such, Jonas pitched the idea of a South African SKA bid to Robert Adam, who, at the time, was director general of DST (Fanaroff 2022). Jonas' pitch was backed by George Nicholson and Bernard Fanaroff, two important and influential figures in South Africa's astronomy community. Because DST had identified astronomy as one of its focus areas a few years earlier, Jonas, Nicholson and Fanaroff did not have to do a lot of convincing to get Adam's support for their proposal (ibid.).

While Jonas and his colleagues were confident that South Africa could host SKA, most ISSC representatives were less optimistic when it came to South Africa's scientific and technical abilities (Reich 2022). In fact, some SKA partners from the Global North, such as the United States and Australia, were convinced that South Africa "couldn't possibly contribute much to technology" (Fanaroff 2022). What they had not considered, however, was that due to its isolation under apartheid rule, South Africa had developed a very advanced defense and electronics industry. Moreover, the country's engineering standard and education had always been high (ibid.). Most importantly, some SKA partners clearly underestimated South Africa's

[1]Now called the Department of Science and Innovation.

ambition in SKA. Contrary to Chile, whose universities and research institutes were initially not very involved in the European Southern Observatory, South Africa did not want to only "offer a piece of land" for SKA (Jonas 2022). Instead, it aspired to be a strong project partner whose radio astronomy and engineering community would be fully involved in the operation and construction of SKA (ibid.). This meant that South Africa "[had] to have people" working in these fields (ibid.). To expand the country's small radio astronomy community, DST and a group of radio astronomers made the "conscious decision" to invest into human capital (ibid.). They also agreed that South Africa should build a precursor for SKA "to give people confidence" in the country's abilities and to work against the Afro-pessimism that was prevalent among some SKA partners (Fanaroff 2022).

III. …To afro-empowerment

Since submitting its site bid for SKA in 2003, South Africa has invested considerable resources in national[2] S&T capacity by setting up a Human Capital Development Program (HCDP) and few but state-of-the-art domestic radio astronomy facilities. In doing so, the country addressed two major challenges it faced when it first got involved in SKA. First, when it proposed to host SKA, South Africa did not have the supervision capacity for a new generation of radio astronomers. Thus, it was initially difficult for the country to build up human capital in the field (Jonas 2022). To solve this problem, South Africa's existing radio astronomy community made "maximum use of [its] international connections" and began to supervise the country's aspiring radio astronomy researchers in collaboration with colleagues abroad (ibid.). Through this joint effort, the number of radio astronomers in the country began to increase at the beginning of the 2000s. In addition to radio astronomers, South Africa also needed capable engineers to construct a project as technically demanding as SKA. Thus, some radio astronomers approached engineering faculties at South Africa's leading universities to inquire whether they would be interested in "doing radio astronomy" (ibid.). Although some of these faculties had been attached to the country's "military complex", radio astronomers were aware that the skills taught there "were exactly what [they] needed for astronomy" (ibid.). Ultimately, the faculties they approached responded positively to the collaboration proposal (ibid.) and, as a result, a number of engineers soon began to work on joint projects with radio astronomers.

These initial capacity-building efforts were institutionalized and expanded through an HCDP. Today, the scheme consists of several complementary components, including training partnerships, communication and science engagement as well as engineering, technical skills, internship, graduate and bursary programs (South African Radio Astronomy Observatory 2022a). Among these components, the HCDP's bursary program stands out most. By 2017, 815 postdoctoral fellows, postgraduate students, and undergraduates from South Africa and its partner countries received grants and bursaries under the program (Atkinson, Kotze, and Wolpe 2017, 42).[3] 485 scholarships were awarded in the fields of physics, astrophysics and astronomy. The remaining 330 bursaries were allocated to the field of engineering (ibid.).

Since its initiation in 2005, the HCDP has produced impressive results. For instance, the pass rates of students which have received a bursary through the HCDP are on average much higher than national pass rates (ibid.). Most alumni of the program have moreover gone on to work in academia, for example as lecturers or professors.[4] Over time, the HCDP has thus "contributed to the creation of an interactive, collaborating and informed science community now comprising more than 200 practicing radio astronomy researchers in Africa," many of whom currently work for SKA (ibid.).

[2]South Africa has also invested into capacity-building across its African partner countries by establishing the SKA Africa Program. This scheme consists of three pillars: human capital development, research and technology infrastructure and funding, governance and partnerships (South African Radio Astronomy Observatory 2022a).

[3]By 2022, close to 1400 postdoctoral fellows, postgraduate and undergraduate students obtained grants and bursaries.

[4]Bursary students from South Africa's partner countries have largely returned to their home countries to start astronomy undergraduate courses at local universities (Atkinson, Kotze and Wolpe 2017, 1-136).

Second, when South Africa entered the site bid for SKA, it lacked adequate research infrastructure in radio astronomy to train prospective radio astronomers and engineers. To address this challenge, South Africa invested into few but cutting-edge radio astronomy research facilities. For example, the country built KAT-7, a seven-dish compact radio telescope (South African Radio Astronomy Observatory 2022b). KAT-7's original purpose was to demonstrate South Africa's ability to construct and operate a state-of-the-art radio astronomy infrastructure. Today, however, it is recognized as a pioneering scientific instrument in its own right (ibid.). This also applies to the 64-dish MeerKAT radio telescope, SKA's precursor, which was treated as "an engineering project led by science" rather than a science project (Fanaroff 2022). Many engineers were recruited for the project, some of whom had originally been trained to work in South Africa's defense industry. Their skills proved crucial for MeerKAT's success.

Today, SKA's precursor attracts countless international scientists to its site in the Northern Cape of South Africa. It also draws in international investments, for example from leading research institutes, such as the German Max Planck Society (Jonas 2022). Over the past decade, South Africa's involvement in MeerKAT has also helped to develop local manufacturing skills and capabilities since several cutting-edge technologies for the telescope are produced locally. For instance, local manufacturers develop the high-performing computing which is needed for the instrument (Atkinson, Kotze, and Wolpe 2017, 38). Through these investments in radio astronomy research infrastructure, SKA's Northern partners have come to see South Africa as a scientifically and technically competent partner for SKA (Fanaroff 2022; Jonas 2022). More generally, South Africa's SKA-related investments into its STI sector have also strengthened its image as a S&T powerhouse on the African continent.

IV. Lessons learned

There are two important lessons that can be drawn from South Africa's capacity-building efforts for SKA. These lessons are likely to be particularly useful for countries in the Global South that have similar economic and S&T capacities as South Africa when it joined SKA. This includes Southern emerging economies like Indonesia, Brazil, and India.

i. Prioritize quality over quantity when developing S&T policy and infrastructure

Following the fall of the apartheid regime, South Africa prioritized quality over quantity in developing its national S&T policy and radio astronomy infrastructure. In the long run, this strategy facilitated capacity-building for SKA.

DST's decision to focus "on areas where [the country] was most likely to succeed because of a natural (…) advantage" in its 1996 S&T White Paper (Department of Science and Technology 2002), guaranteed that a few fields of research in South Africa had a safe and steady stream of resources. Astronomy was one of them. As a result, South Africa's astronomy community could build on government support when it sought to initiate new projects. Radio astronomers like Jonas, Fanaroff and Nicholson were able to tap into this governmental support system in the early 2000s when they advocated for a South African site bid for SKA.

By using its S&T funds to construct few state-of-the-art rather than several mediocre telescopes, South Africa furthermore enabled its science and engineering community to gain crucial hands-on experience on instruments that were qualitatively comparable to SKA. Investing in two sophisticated telescope projects, KAT-7 and SKA's precursor MeerKAT, also helped develop local manufacturing skills and capabilities which remain relevant for SKA's operational phase. Most importantly, both telescopes are today considered some of the best astronomy instruments in the world, strengthening South Africa's reputation as a regional S&T powerhouse. This reputation, in turn, may help the country attract additional big science projects in the future.

ii. Build up human capital through national and international partnerships and investments in education

When Jonas and his colleagues first pitched the idea of bringing SKA to South Africa, the country lacked human capital in radio astronomy. Realizing that South Africa would need a thriving engineering and science community to build and operate SKA, the country committed itself to invest considerable energy and resources into educating a new generation of researchers in radio astronomy and adjacent research fields.

Before its HCDP was launched, South Africa used its international partnerships in astronomy to build up a base of young radio astronomers. At the time, this was necessary because South Africa only had a handful of professional radio astronomers and hence lacked supervision capacity at home to train a new generation of researchers. Since radio astronomy is an extremely international discipline, South Africa's more experienced astronomers could easily tap into their international network to initiate multi-national supervision teams for their students. Over time, this helped South Africa to gradually increase its numbers of radio astronomers.

South Africa's astronomers not only capitalized on their international network to train a future generation of radio astronomers; they also built up national partnerships to strengthen capacity-building for SKA. Having recognized that South Africa had a highly advanced engineering sector, early on in their efforts to host SKA, Jonas and his colleagues approached engineering faculties in South Africa to find out if they would be interested in collaborating on astronomy projects. Later on, these contacts between radio astronomers and engineers were expanded when work on MeerKAT began, and Bernard Fanaroff, who was in charge of the project, recruited engineers that had previously worked in South Africa's defense industry for the telescope's construction. Hiring experienced engineers for the technical work of the project saved him and his colleagues precious time and resources because they did not have to train astronomers to become engineers.

In 2005, South Africa complemented its national and international partnerships for human capital capacity-building through an HCDP. With this program, South Africa aimed to promote excellent training and education through bursaries and scholarships, amongst other things. Up until now, the HCDP has proven highly successful as many alumni have moved on to work for SKA or South Africa's academic sector. In addition to building up a base of talented engineers and astronomers, South Africa's HCDP helped tackle equitable access to education as a share of scholarships specifically targeted students from less privileged backgrounds and underrepresented groups.

V. Conclusion

When South Africa first considered hosting SKA at the beginning of the 2000s, the country lacked human capital in radio astronomy and cutting-edge research infrastructure in the field. Yet, in a short period of time, South Africa managed to build up capacity for a big science project like SKA. This essay outlined how it succeeded in doing so and drew two important lessons from South Africa's capacity-building efforts.

The first lesson that can be learned from South Africa's capacity-building efforts for SKA is that prioritizing quality over quantity in developing a national S&T strategy and cutting-edge research infrastructures pays dividends in the long run. Targeted investments in a few national STI sectors ensures that research fields relevant to a prospective big science project have the necessary funds and political support. Having a few state-of-the-art research infrastructures instead of several mediocre ones moreover enables a country's science and engineering community to gain vital hands-on experience on instruments that are qualitatively comparable to a big science installation. A second lesson from SKA is that building up capacity for big science requires a solid base of human capital. For this purpose, it may prove useful to capitalize on national and international partnerships in S&T and to invest in excellent education, especially in research fields that are relevant to a big science project.

Given that each state's STI sector has different strengths and weaknesses, the lessons learned from SKA do not provide a blanket recipe for success. Rather, it is likely that big science projects in other research fields will require strategies different from those that worked for South Africa in the case of SKA. Yet, for countries from the Global South, lessons drawn from SKA can function as a broad guideline for the development of national capacity-building strategies. To be effective, such strategies should reflect that diplomacy for science efforts like SKA necessitate not only international collaboration but, more importantly, also strong national advocacy.

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