Session 6: Literacy in Astronomy

Education and Heritage in the era of Big Data in Astronomy
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Introduction

Carolina Ödman begins this session with an invited talk for "Astronomy for Development - A story from South Africa." In her paper she describes the development of astronomy in Africa and its inspiration for young astronomers. She begins with its history and continues by outlining its development. Ultimately she says that the new astronomy heritage is the hands of the young and also includes Indigenous astronomy as a valued factor.

After the talk Claudio Pastrana asked:

By the end of this century, Africa will have almost half the world's population. I know of the efforts you make for education from your place. (You even help others who are on the same latitude).

Do you think that the rest of Africa will accompany the effort and bring the educational reality to the level of the reality of the expected increase in population? I'm asking to you for your very subjective, but very trusted insight.

Carolina answered:

It is a very difficult question you ask. I think we are not in control of what will happen, but I am optimistic! Wherever I look, there are fantastic young people taking on the challenges we have. And thank you for all the fantastic work you are doing and have been doing for so long!!

Rosa M. Ros, Beatriz García, Ricardo Moreno, Mahdi Rokni, and Noorali Jiwaji give us more insight into NASE with "NASE workshop: Eclipses with models and camera obscura." They explore the history of the camera obscura and both how it has been and how it can be used to better understand such as solar eclipses and Moon phases. This was correlated with the solar eclipse of December 14th, 2020. Lunar eclipses are discussed as well. The camera obscura is highlighted as a tool to fascinate people with such astronomy, and that eclipses play a significant role.

Walter Guevara asked following the talk:

In my work in solar radio astronomy, and I would like to make some experience of detecting the eclipse without seeing it, perhaps with the level of melatonin in the blood. I suggest putting a group of blind people with a watch, and recording their sensations. I have several students developing tools to record the average amount of light a week, and compare it with measurements during the eclipse, which will be partial from Peru.

Beatriz answered:

She has a project with Harvard University to transform light into sound. It was used last year so that blind people could follow the eclipse with the sound. They brought microphones and speakers. Other people, listeners, also wanted to continue with the sound, the eclipse. Regarding Walter's proposal, it is good to mention that since the temperature drop is great during the eclipse, it is not easy for blind people to detect other parameters, such as the melatonin level.

Rosa commented:

A few years ago of an activity to calculate the power of the Sun using the cheek as a detector. Blind people had a great sensitivity, greater than that of hearing people.

Manuel Núñez Díaz added:

In my center we has lasted all year, of drawing a solar analema, with stickers. We were occasions to explain concepts to the students, and to teach them that many times the result of an experiment or observation requires many months of collecting data.

David Gastelu continued:

In Uruguay, in my country there is a plan for the use of technology in the classrooms, and we are working with Arduino boards with light sensors, and the students are going to record changes in lighting during the eclipse.

Cristian Goez then added:

I attended the 2017 eclipse in the USA, and recorded the meteorological data with an SQM station. It was no possible to travel in 2019, and it will not be able to go now, and it was requests that someone collect the data and share it, so that it will be possible compare them.

Adita Quispe followed with:

From the Planetarium of the Geophysical Institute of Peru. It was a magnificent experience in observing the 2019 eclipse from Arequipa. Many people were exciting, and gathered at the stadium where they installed the instruments for observation. It is important to comment on the great capacity of the NASE Course Workshops to transmit knowledge in a practical and economical way. In particular, it is necessary to mention the NASE materials are adapted to the North or South hemisphere according each country

Next Franz Kerschbaum and Magdalena Brunner describe "Herschel and the invisible end of the rainbow." This article discusses the application of infrared radiation through diverse methods and media. A historical approach is taken and current method are discussed. Means of different and complimentary means of communication are offered.

Sara Ricciardi writes of "Engaging young people with STEAM : Destinazione Luna." In it Sara describes an initiative inspired by the 1969 NASA landing on the Moon. This was used to reach many children surrounding Bologna and Sara described its evolution. She describes evolution from STEM to STEAM and the importance of including Art. Anna continues that astrophysics is a history of light and related activity can inspire curiosity on students.

Following Sara's talk Claudio Pastrana asked:

How can I get the permissions to copy the model? I am thinking of doing it with polystyrene foam of the high density of about 5 cm of thickness, which would make possible the transport and would reduce the weight. Some written permission or some paperwork it's needed?

Sara responded:

No permission needed don't worry. It will be super nice if you can send me a picture. I can also send plans (I have a simple cad) and there are the files online if you what to 3dprint. Any question or comment send me a line sara.ricciardi@inaf.it

Durruty Jesús de Alba Martínez stated:

For the Constelacione Luna Project are considered stories and literature as Cyrano and Fontanelle?... We have one by Fr. Manuel Antonio de Rivas: Sizigías y cuadraturas lunares

and Sara Ricciardi responded:

We used contemporary picture book selected together with picture book expert for example Moon Man by Tomi Ungherer. Another we used a lot is Professor Astrocat and the frontier of Space. We got a bunch of book available and kids can choose. Every workshop *was a bit different. The bibliography is very long (and we are adding). If you have other idea send me a line sara.ricciardi@inaf.it*

The last article for this session is “Impact of language, culture and heritage on the way we learn and communicate Astronomy” by Basilio Solís-Castillo. In it the author describes the significance of language and culture in the way that people learn astronomy. The importance of learning astronomy in native language is emphasized for assuring inclusion, diversity, and equity. The article highlights the different perspective of learning astronomy from a Southern Hemisphere perspective. The article concludes with a discussion of the future of Chilean astronomy.

After the talk Walter Guevara Day stated :

The astronomical heritage of the Andean countries is wonderful, and there are still many places to discover.

Basilio replied:

There is so much to study and to learn from our ancestors. I think it is necessary to build our own identities... as countries and as cultures.

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Astronomy for Development – A story from South Africa

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Abstract. In this article we describe the recent history of astronomy in South Africa from the perspective of development. We describe how all major astronomy initiatives have carried a component of development with them, be it capacity building or socio-economic development. We highlight some activities and conclude that South Africa's coherent and ambitious strategy has led to substantial changes in the astronomy research community in South Africa and that the young astronomers now starting their careers are taking possession of a bright future.

Keywords. Development, South Africa

1. Introduction

When we talk about astronomy for development, we combine two very different fields of human endeavour. One, broad ranging, with a strong focus on the well-being of people and of the planet, development. The other, a very specific area of pure science, rarely seen as applied, astronomy. For the purpose of this article, we adopt the United Nations definition of development embodied by the Sustainable Development Goals (SDGs, United Nations 2015). These are a set of 17 internationally agreed-upon goals summarised in table 1. The goals are decomposed into 169 targets and measured by 231 unique indicators (United Nations 2017–2020). The principles defining the SDGs can be summarised as follows: All human actions and activities must be inclusive and sustainable, all people and institutions must be resilient, and solidarity underpins the attainment of the goals, in particular solidarity with developing countries.

These principles are applied to human health, education, industry and work, and to the environment, with specific attention paid to water, land and food production. The last goal is one of global partnership, reinforcing the call for international solidarity. Some of the 169 targets are very clear, while some are more nebulous, describing an intention rather than a measurable number. This is to be expected, as many of the SDGs have to do with the layered and complex functioning of human societies and are therefore difficult to reduce to numbers. The indicators, however, are all numerical and translate the targets into measurable quantities. Notwithstanding the arguably reductionist approach, the SDGs with their targets and indicators form a global, tangible set of development goals, to which people and organisations can attach their work, and the achievement of which is expected to lead to the betterment of humanity and of planet Earth.

Table 1. The 17 Sustainable Development Goals.

Goal 1.	End poverty in all its forms everywhere
Goal 2.	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3.	Ensure healthy lives and promote well-being for all at all ages
Goal 4.	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5.	Achieve gender equality and empower all women and girls
Goal 6.	Ensure availability and sustainable management of water and sanitation for all
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8.	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9.	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10.	Reduce inequality within and among countries
Goal 11.	Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12.	Ensure sustainable consumption and production patterns
Goal 13.	Take urgent action to combat climate change and its impacts*
Goal 14.	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15.	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16.	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17.	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Notes:
* Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

2. Science in Development

Certain areas of science have a direct footprint on development target. Examples include public health, energy, resource management, agricultural sciences, etc. Table 2 lists examples of applied sciences and their connection with the SDGs.

These fields of science are able to influence measures for development when they have a voice in policymaking. Evidence-based decision-making (EIDM) is increasingly favoured not just in health sciences but also in social sciences, economics and the humanities. When such informed policies are followed by effective implementation, it can be said that science had a direct impact on development, although some research seems to indicate that the gap between research and implementation in heath sciences for example, is around 17 years (Morris *et al.* 2011).

What then about fields of science that are not directly related to development? How do astronomy, quantum computing, pure mathematics or philosophy influence, let alone impact, on the development of nations and societies? An argument against those sciences is often that they represent a vain pursuit of knowledge for the sake of knowledge. Others believe that dreaming big is what gives rise to big ideas. That latter argument, when the budget for fundamental research is compared to that of social development and social services in government becomes quite compelling and has enabled countries other than high-income countries, to pursue some fundamental research.

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Table 2. Connections between the sciences and the SDGs.

Science	SDGs	Example subfields with a direct link to the SDGs
Physics	6, 7, 12, 13, 15	Nanophysics, materials science, energy, fluid dynamics
Chemistry	6, 7, 12, 13, 15	Pharmacology, organic chemistry, Eeergy
Biology	2, 3, 6, 7, 13, 14, 15	Ecology, Biodiversity, Epidemiology
Mathematics	5, 8, 10	Statistics
Computer Science	4, 7, 9, 11	Machine learning, natural language processing, internet of things
Medicine	3, 6, 8, 15	Public Health, non-communicable diseases, epidemiology, mental health
Engineering	6, 7, 9, 11, 12	Civil engineering, electrical engineering, environmental engineering, robotics

Notes:
We acknowledge the multi- and inter-disciplinarity of the fields above. This classification is for illustration purposes.

found in the 1996 South African White Paper in Science and Technology (South African Government 1996), which states that:

> Scientific endeavour is not purely utilitarian in its objectives and has important associated cultural and social values. It is also important to maintain a basic competence in "flagship" sciences such as physics and astronomy for cultural reasons. Not to offer them would be to take a negative view of our future – the view that we are a second class nation, chained forever to the treadmill of feeding and clothing ourselves."

This perspective is often credited for South Africa's continued investment in modern astronomy, described in the section below. This white paper is now replaced with a new one (South African Government 2019), concerned more over the fourth industrial revolution, and concretising the benefits of investments in science, with a strong emphasis on capacity building, and astronomy has to demonstrate that it remains relevant in an evolving context.

When considering the contribution of astronomy to development, scientific education and the technical skills astronomers develop has been the most obvious element. As described in the IAU's 2010–2020 and 2020–2030 decadal strategies (IAU 2009, IAU 2019), education is at the centre of making astronomy contribute to a better world. And indeed, education leads to development in principle, but the studies demonstrating this link in the case of astronomy are short in supply. Another aspect of astronomy is inspiration. Indeed, it is considered a gateway science to other fields because it is so attractive. Astronomers produce beautiful images that capture the imagination and have set off many on the path of becoming astronomers. The experience of peering through a telescope can be life-changing, and as formulated in the 1994 White Paper, dreaming big should not be a privilege, but is essential to development of a nation.

3. Brief history of astronomy in South Africa

Modern astronomy in South Africa has colonial origins. The Royal Observatory in Cape Town was founded in 1820 by the British to map the Southern skies and to keep time. This was important for navigation and for the colonial trades, in goods and in people. The observatory became South African in 1972 when it merged with the Republic Observatory in Johannesburg and became known as the South African Astronomical Observatory (SAAO). It is now a research facility of the South African National Research Foundation (NRF). The Johannesburg Observatory had been set up in 1903 for meteorological purposes.

Radio astronomy did not begin in earnest in South Africa until later. In 1961, NASA set up a satellite monitoring dish at Hartebeesthoek, north of Johannesburg. NASA used the station, known as Deep Space Station 51, until 1975, when it was handed over to South African Council for Scientific and Industrial Research (CSIR) and became the Hartebeesthoek Radio Astronomy Observatory (HartRAO).

Fast forward to 2005, when the Southern African Large Telescope (SALT) was inaugurated (Physics Today 2006). The fruit of South African ingenuity and labour, it was opened as a symbol of Southern Africa carrying out its own science, with world-class instruments. SALT is the biggest single-dish optical telescope in the Southern Hemisphere and therefore provides a unique view towards the centre of our galaxy and its neighbours, the Magellanic clouds. It was constructed on a budget estimated to be 5 times smaller than a similar telescope elsewhere, mainly because it houses a spherical mirror. The mirror is segmented into 91 hexagonal elements, each about 1m in diameter. With a spherical mirror, all the elements are identical as opposed to unique for a parabolic mirror, and this is a major contributor to the reduced cost of the telescope. The telescope has some teething engineering issues in the beginning but is now contributing a steady flow of new research, and is part of international networks, such as the identification of optical and infrared counterparts to gravitational waves (B. P. Abbott *et al.* 2017).

The construction of SALT was accompanied by an innovative programme called the SALT Collateral Benefits Programme (SCBP). The goal of this programme was to ensure socioeconomic benefits locally, regionally, nationally and internationally from the existence of a world-class scientific facility. This was the first attempt at bridging the practice of a fundamental science with societal benefits directly. During the construction phase of the telescope, this ensured employment of local artisans and labourers, the upgrading of local infrastructure, and more. Once the telescope was up and running however, the question of how to develop the country through the presence of a telescope remained. SCBP has pursued and tested answers to this question since 2005. They have worked with teachers and schools with a national impact. They have unearthed the importance of cultural dimensions and indigenous knowledge and star lore to the world. They have pioneered the use of indigenous astronomy as an attractor to the modern science of astronomy. The SCBP has also constantly underlined the importance of science and mathematics for young people, an area where South Africa sadly underperforms (Reddy, V. *et al.* 2019).

To astronomers who are used to thinking that astronomical events are few and far between, the SCBP experience has demonstrated that when working with communities, any event is astronomical and that looking through a telescope at the moon remains inspiring and impactful. But the experience also shows that only through sustained activity can one truly impact communities. While the experience of SCBP is large, the evidence is still anecdotal. Academic research into the impact of SCBP was never part of its mandate, but social scientists and others are starting to show interest (see Walker, C. *et al.* 2019 and references therein) and ensuring local and regional socioeconomic development from astronomical facilities has become a flagship of the International Astronomical Union's Office of Astronomy for Development (OAD), which is hosted at the SAAO in Cape Town.

The next step in South Africa's history of astronomy is the participation in the Square Kilometre Array (SKA). The SKA, a radio telescope envisioned to have a square kilometre's worth of collecting area, was dreamt up and emerged from several proposed large scale radio telescopes in the 1990's. Ekers (Ekers, R. 2012) describes the history of the SKA. In the year 2000, a Memorandum of Understanding (MoU) between representatives of 11 countries in Europe, North America and Asia. This committed the parties to working towards the establishment of the SKA. In 2003, two years before the inauguration of SALT, and realising the quality of its sky, decided to enter the

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international competition to host the telescope. In 2006, the shortlisted countries were Chile, South Africa, China, Australia and New Zealand who were proposing to host the telescope jointly. After long years of proposals, technical documentation and site evaluations, the site selection was finalised in 2012, with the decision to build the SKA in both South Africa and in Australia. In 2018, on time, on budget and above specifications, the MeerKAT radio telescope was inaugurated. The MeerKAT is South Africa's 64-dish precursor radio telescope to the SKA. Since its inauguration, it has resulted in many discoveries already, including a paper in Nature (Heywood, I. *et al.* (2019)).

4. The development story of astronomy in South Africa

South Africa is a developing country. It is classed among low-to-middle income countries owing to its infrastructure, but is facing a number of development challenges, has high youth unemployment, a shrinking manufacturing sector and a large proportion of the population living in poverty. Nonetheless, the newly democratic government of South Africa from its transition from the Apartheid regime in 1994, had a vision and great ambitions, as quoted earlier from the White Paper on Science and Technology. But astronomy was not to be funded without a vision of development arising from its practice. And that's why, for example, the SCBP was originally set up. Similarly, for South Africa to engage in bidding for hosting the SKA, it had to show convincing arguments that this bid would lead to development, both to its own government and to its neighbours. These arguments were indeed convincing, and the African Union lent its support to the bid in 2010 (African Union (2010)).

In 2007, South Africa passed a piece of legislation, the Astronomy Geographic Advantage Act (AGAA, South African Government (2007)), which legally limited the creation of light pollution and radio frequency interference in a large area of the Karoo desert, where SALT is located, and where the SKA was proposed to be built. The AGAA was adopted in 2009 and defines core, central and coordinated astronomy advantage areas with regulations on the use of the electromagnetic spectrum, air traffic, land use, and more to shield astronomical facilities, built and planned, from any kind of interference. While the act has not made everyone happy in the affected areas, the seriousness of the legislation lent further credibility to the bid.

Such a law could be interpreted as a brake on development, but instead, it led to domestic technological innovation. A local cellular phone operator, wanting to provide service right to the edge of the allowed area designed new antennae that would emit in all directions but one, towards the protected area. In an interview†, the engineers explained:

> Mayhew-Ridgers and van Jaarsveld looked at a range of options, but settled on developing their own antenna technology to solve the problem. The solution was an antenna based on phased-array principles, providing omnidirectional coverage but also blocking the RF transmissions along a single direction (that would correspond with the bearing of the SKA core site). "The antenna has since been tested in the Karoo and performs extremely well. Trialling measurements have shown that the RF signal levels at the proposed SKA core site can be reduced significantly, while at the same time, much of the original GSM coverage can be retained," Vodacom said.

The South African commitment to the SKA also facilitated foreign direct investment, which is key to growth in developing countries (OECD (2002)). One example of that is cisco's investment to set up a Centre for Broadband Communications at Nelson Mandela University in the Eastern Cape province of South Africa. Cisco directly attributes the

† https://mybroadband.co.za/news/cellular/37130-quiet-cellular-antenna-technology-for-ska.html

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decision to invest to the SKA efforts‡. This is not one of the few internationally famous South African universities, which is in itself worth noting.

South Africa's SKA programme has from the very beginning had a strong focus on human capacity development (HCD). The programme stems from a realisation that South Africa lacked the skills to benefit fully from the SKA should it be hosted in the country, both to build the facility and to do astronomy with it. SKA Africa (as it was known) embarked on a programme to fund study and professional development bursaries to build a critical mass of skilled young South Africans in all professions needed for the SKA: From vocational training in electronics to computer science to postdoctoral fellowships in astronomy. As of 2019, well over 1100 bursaries had been awarded. The SKA bursaries have also been higher than other government bursaries, ensuring good living conditions for the students (students on bursaries in South Africa live on shoestring budgets and are often struggling to make ends meet).

The bursary holders in astronomy and related fields are invited annually to a bursary holders' conference, which has become an inspirational key event on the international radio astronomy conference calendar. At that event, all bursary holders get to give talks about their research to an audience of their peers and international radio astronomers. This gives them critical practice in the skill of presenting their work as well as visibility and networking opportunities with the global well established radio astronomy research community and leadership. This has led to many South African radio astronomers having experiences abroad before coming back to South Africa to fill in research positions in academia and join the South African Radio Astronomy Observatory (SARAO). SARAO is the name of the NRF research facility under which all radio astronomy activities, SKA Africa and HartRAO have been consolidated. SARAO is tasked to manage the MeerKAT telescope and SKA-phase 1 currently under construction in the Karoo and the transition from construction to operations of the SKA is currently planned for 2028.

To teach this new cohort of radio astronomy students, the country also set up a generous SKA Research Chair programme aimed at attracting key international and national talent that can teach and supervise this new generation of astronomers. This has been very effective as South Africa is now firmly on the world map of excellence in radio astronomy, from having the humble beginnings of inheriting a NASA satellite monitoring dish in 1975.

The South African university system carries the legacy of segregated education that was in place under Apartheid. Many universities are what is called "Historically Disadvantaged Institutions" (HDIs). Much effort is put into trying to uplift those institutions. The University of the Western Cape for example, was founded in 1960 as a "coloured" university. It started an astronomy group just over a decade ago and in 2016, was ranked number one in Physical Sciences in Africa by Nature†. The Northern Cape Province of South Africa is both the largest in terms of land and the least populated one, due mostly to its unforgiving semi-desert climate and arid land. It is also home to the modern astronomical facilities. The Northern Cape is also known for its large mining industry, but until recently there was no university in the province. Inspired by the SKA's arrival as a big data machine, a new University, Sol Plaatje, was opened in Kimberley, the capital of the Northern Cape, with a specific focus on Data Science. It started off as a teaching university and is now building capacity in research as well.

As time went on, the need to develop the capacity in South Africa to handle the large amounts of data from the MeerKAT and eventually the SKA became urgent. Indeed, what would be the use of building a telescope if all the data just went abroad for ithers to

‡ https://www.cisco.com/c/en_za/about/press-releases-south-africa/2017/201712041.html

† https://www.uwc.ac.za/news-and-announcements/news/uwc-shines-brightest-of-all-in-physical-science-943

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make discoveries with? This motivated the establishment of the Inter-University Institute for Data Intensive Astronomy (IDIA). A partnership of the University of Cape Town, the University of the Western Cape and the University of Pretoria, IDIA was set up to build within the South African university research community the capacity and expertise in data intensive research to enable global leadership on MeerKAT large survey science projects and large projects on other SKA pathfinder telescopes.

The Institute developed a cloud computing infrastructure installed at the University of Cape Town and allowing researchers in the partner universities and their collaborators to process MeerKAT data. To achieve that, fast and reliable data transport had to be guaranteed between the Centre for High Performance Computing, where SARAO stores and distributes the MeerKAT data from, and the IDIA infrastructure. To allow research to be done on the data, a large software development effort was also carried out, creating an imaging pipeline and visualization software for large radio astronomy data sets. Using web interfaces through Jupyter notebooks, researchers and graduate students are able to work with MeerKAT data in ways that were not possible before. The institute researches scientific software as well, developing immersive technologies for scientific data visualization using full digital dome projections and virtual reality for example.

In this data-intensive research initiative, the importance of development is not neglected. IDIA has an office for Development and Outreach that runs several capacity development programmes. In collaboration with SARAO, the OAD and Development in Africa using Radio Astronomy (DARA), a UK Newton Fund programme, IDIA has organised and hosted many big data research schools, where over a week, students from the Africa VLBI Network (AVN) countries – the original SKA Africa partners – come together and learn machine learning and artificial intelligence through diverse science projects. The institute also contributes industry skills training for the participants, helping them see themselves in private sector careers and in entrepreneurship. This includes role playing start-up pitches, industry-formatted workshops and CV labs, where students get advice on how to write their CVs for industry employment. While the skills acquired through astronomy are transferrable, they don't translate into other industries without an awareness of their applicability, so this is an important element of the training.

The institute also organises regular hackathons, shorter-formatted big data science training events, also including connections to the private sector data science context. In 2020 those events were held remotely, as all activities moved online because of the COVID-19 pandemic raging around the world.

These efforts of using astronomy to change the country is starting to bear fruit. The community of young professional astronomers and astronomers in training is reaching that critical mass where they start owning the space of astronomy research in South Africa. They come together boldly and confidently and do not let the rest of the world make them feel inferior as scientists. A great example of this is the "Astronomy in Colour" initiative, started by two graduate students and now beneficiary of a grant to run a series of talks given by trailblazers. Another initiative is the Supernova Foundation, started by a young South African astronomer that offers mentoring for female scientists by connecting them to more senior scientists across the globe.

What is also worth mentioning is that the new generation of scientists see outreach as a part of their work as scientists, not as an ad-hoc activity or an afterthought. They are very conscious that they are opening doors to younger generations to participate in science like their parents' generation could not. Children who see astronomers in South Africa today have role models that weren't there before, and those role models are as diverse as the population itself. This not only changes the face of astronomy but benefits the field enormously as well by generating interest and involvement of communities. So as we look into the universe with sharpened telescopic eyes, we also diversify the eyes that are peering into the distance.

5. Conclusion

The new astronomy heritage in the age of big data is, at least in South Africa, in the hands of young people. Decades of learning to use astronomy as an instrument for development through education, outreach, socio-economic development has proved that it is possible. We feel that it is important to mention role of indigenous knowledge in this conversation even if we have not covered in this article. Lessons learnt are that development is fundamentally interdisciplinary and the work benefits from the involvement of people in other disciplines, including social sciences and economics. But transforming the community and ensuring that the faces of those using astronomical facilities look like the people funding the telescopes is key, and it requires a, authentic effort. Finally, a concerted, coherent strategy to push scientific excellence has placed South Africa firmly on the world map of astronomy, and of science.

References

Abbott, B. P. et al., 2017 *The Astrophysical Journal Letters*, 848 L12.

African Union 2010, *Resolution* Assembly/AU/Dec.303(XV).

Ekers, R., 2012 *Proceedings of Science, Resolving the Sky – Radio Interferometry: Past, Present and Future* Manchester, UK, April 17–20, 2012.

Feder, T., 2006 *Physics Today* 59, 1, 35

Heywood, I., Camino, F., et al., 2019 *Nature*, 573, pages 235–237.

International Astronomical Union 2009, *Astronomy for Development: Building from the IYA2009*.

International Astronomical Union 2019, *IAU Strategic Plan 2020–2030*.

Morris, Z.S., Wooding, S., & Grant, J. 2011, *J R Soc Med.*, 104(12): 510–520.

Committee on International Investment and Multinational Enterprises 2002, *Foreign Direct Investment for Development: Maximising benefits, minimising costs*.

South African Department of Basic Education 2019, *TIMSS 2019: Highlights of South African Grade 9 Results in Mathematics and Science*.

South African Department of Arts, Culture, Science and Technology 1996, *White Paper on Science and Technology: Preparing for the 21st Century*.

South African Government 2007, *Astronomy Geographic Advantage Act 21 of 2007*.

South African Department of Science and Technology 2019, *White Paper on Science, Technology and Innovation: Science, technology and innovation enabling inclusive and sustainable South African development in a changing world*.

United Nations General Assembly 2015, *UN Resolution* A/RES/70/1.

United Nations General Assembly 2017, *UN Resolution*, A/RES/71/313 and *amendments*, E/CN.3/2018/2, E/CN.3/2019/2, E/CN.3/2020/2.

Walker, C., Chiningò, D., & Dubow, S. 2019, *Journal of Southern African Studies*, 45(4): 627–639.