Funding Academic Excellence in Africa – The African Millimetre Telescope and Its Fellowship Programs

Heino Falcke
2023 Balzan Prize for High Resolution Images:
From Planetary Objects to Cosmic Objects

Affiliated Institution: Radboud Universiteit, Nijmegen, The Netherlands
Deputy Supervisors: Sera Markoff, University of Amsterdam, Marc Klein-Wolt, Radboud University (AMT Project Director)
Duration: 2024-2029

Heino Falcke is Professor of Astroparticle Physics and Radio Astronomy at Raboud University Nijmegen and Guest Scientist at the Max Planck Institute for Radio Astronomy in Bonn.

Introduction

Black holes are an enigma and the centrepiece of current theoretical physics and astrophysics. Their event horizon, a virtual surface shielding a region of no return, marks fundamental limits of space, time, and scientific understanding. For the first time this region can now be studied experimentally. In 2019 the **Event Horizon Telescope (EHT),** a global network of mm-wave radio telescopes, published the very first image of a supermassive black hole, providing direct evidence of their existence and forming important proof of fundamental predictions of Einstein's theory of General Relativity. Combining such images with detailed supercomputer simulations of black holes now provides an unprecedented view into the physics near the event horizon.

To make the next step, Falcke's team is extending the EHT network with the **Africa Millimetre Telescope (AMT)**, a 15-metre size radio telescope on or near the Gamsberg in Namibia, operating at wavelengths from 24 - 0.8 mm. The AMT will be the first of its kind in Africa and a key contribution to the global EHT network. Its main goal will be to enable the first ever colour movies of black holes, to understand the dynamics of magnetised gas near the event horizon, to develop a comprehensive understanding of black hole astrophysics, significantly improve parameter estimations of black holes, and to test new theories of gravity. Due to its unique geographical location, the AMT increases the quality of images, improves the robustness of the EHT network, and more than doubles the available time for making dynamic images of the central black hole in the Milky Way and other sources.

In addition, the AMT will also operate independently. It will be the first mm-wave telescope to be operated and scheduled autonomously. On its own it can efficiently monitor many different black holes and quickly react to external alerts of newly appearing, transient cosmic sources, such as supernova explosions or gravitational wave emitting mergers of black holes and neutron stars. This provides a wealth of new time-dependent multi-wavelength information, thus opening a huge discovery potential and providing a wide range of science to be conducted even by small groups of individuals.

The AMT project is led by Heino Falcke as main PI and supported by a broad consortium of European and African partners. Construction and operations of the telescope are secured by a grant from Radboud University, a grant from the Dutch funding organization NWO, and an ERC Synergy grant. A key principle of the AMT project is to realize its aims in close partnership with the host country, hence participation of the University of Namibia is an important factor, but the number of physics and astronomy MSc and PhD students is very low. Therefore, the initiative is accompanied by a societal impact program which aims to engage and educate the next generation of Dutch and Namibian scientists to support the AMT project in the short and long term, as well as to increase awareness of the importance of fundamental science for Namibian society.

A key problem in Namibia for many bright students interested in fundamental science is lack of funding and family pressure based on the perceived lack of usefulness of a fundamental science education for well-paid jobs. In addition, it is often not clear to students or their family members which job opportunities there are after graduating or the transferrable skills the students learn during their degrees. This results in reluctance to commit to fundamental scientific research degrees.

The AMT established a fellowship program in 2021 with the aim of supporting students to pursue postdoctoral and MSc studies in astrophysics and (electrical or mechanical) engineering to support building capacity for the AMT. An advisory committee consisting of experts in astronomy and education selects proposals to be converted into a funded stipend at the University of Namibia. The first fellow is currently working toward testing the weather conditions at both potential sites for the telescope.

Astronomy is traditionally an effective gateway subject to spark inspiration for and interest in science. The AMT project currently runs an educational program that brings an inflatable planetarium to schools – even in remote and rural areas. The program is run by volunteer students from the UNAM physics and astronomy program. The goal is to inspire more school children with a curiosity and interest in science to go into STEM-related jobs and research. With the increased international scientific and business fields becoming interested in Namibia to host large infrastructure projects, the country will need an increased pool of skilled workers and scientists to support those projects.

The impact and effectiveness of these measures will be investigated as part of a PhD project at the intersection of science and society, funded by Dutch national resources. The prize money from the Balzan Foundation will be used to create excellence-based fellowships in Namibia, enabling the AMT project to support young students in (astro)physics and other fields, during all stages of their career, from the Bachelor to the PhD level. This will increase the pool of skilled academics who will be available to make use of the new facility for their home country, and who can benefit from the international links the AMT project will provide for higher education in Namibia. In addition, the fellowships will increase visibility and support for the project with the general public.

1. AMT Research Goals

The study of gravity and the structure of spacetime is one of the most fundamental frontiers in modern physics. Black holes are ideal research objects in this context, as the extreme curvature of spacetime close to their horizons is predicted to give rise to a wide range of observable phenomena. Event horizons—the point of no-return for light or any information entering black holes—are also the place where theories of large-scale physics (general relativity) clash with theories of the smallest scales (quantum physics). Black holes are also important actors in the universe, because they attract gas and matter in turbulent hot accretion flows and eject part of the matter again with the help of powerful magnetic fields via ultra-hot plasma jets that can impact entire galaxies. They come in two basic masses and sizes: stellar-mass black holes with a diameter of human cities and supermassive black holes with the size of the solar system. Supermassive black holes are millions to billions of times more massive than their stellar-mass counterparts. Black holes of all sizes are the most efficient power generators in the universe as well as giant particle accelerators. They reveal themselves by luminous and highly variable bursts of radiation across the entire electromagnetic spectrum (from long wavelengths and low frequencies in the radio regime to short wavelengths and high frequencies in the gamma-ray regime) and as energetic elementary particles. For supermassive black holes these variations occur on much longer time scales than for the smaller and lighter stellar-mass black holes. In order to make headway in understanding the physics of gravity and spacetime via black hole event horizons and what lies beyond them, an understanding of the astrophysics of the processes happening there is necessary.

To achieve this, a truly holistic paradigm of black hole astrophysics must be developed: a single model that spans the entire range of phenomena and mass scales, from the inner edge of the accretion flow near the event horizon, where all energy is generated, to the outermost scales of the powerful jets that shape galaxy evolution and thus the cosmos. Only by combining all spatial and temporal scales of black holes and the radiation they emit across wavelengths will it be possible to develop a comprehensive view of black holes. Such a model will form a cornerstone of black-hole research and is key to experimental black hole physics exploring new ideas unifying general relativity and quantum physics. To establish such a model, it needs to be rigorously tested against observations of black holes.

In recent years, the study of black-hole-horizon-scale physics has finally moved into the experimental realm: first, through the detection of merging stellar-mass black holes by means of gravitational waves with the LIGO and Virgo gravitational-wave detectors (LIGO/VIRGO 2016), which measured the ripples in spacetime that are produced in the last stages before the horizons of two black holes merge; second, through the precision weighing and probing of black holes with near-infrared tracking of stellar orbits (Do et al. 2019, Gravity collaboration 2021); and third, by the imaging of horizon-scale structure in the plasma flow around supermassive black holes (EHT Collaboration 2019), which shows that black holes can deflect and absorb light. This image was made with the Event Horizon Telescope (EHT), a network of eight telescopes around the world, organised by a global collaboration of which Radboud University is one of thirteen stakeholders—an idea pioneered by PI Falcke (Falcke et al. 2000), who is also one of the founding members of the EHT. Thanks to these discoveries, black-hole research has become a booming field. Black hole research is also a highly visible field of study in the general public, as illustrated by the fact that over 4.5 billion people saw the first black hole image made by the EHT (Christensen et al. 2019). It is also a source of inspiration for many young students.

In order to test a holistic black hole model, the EHT will be upgraded to go beyond the current "snapshot" paradigm to capture movies of black holes over a broad range of spatial and temporal scales. Adding multi-band "colour" information (as opposed to the currently monochrome still images) will complete the picture, giving a comprehensive view of black hole physics. The Africa Millimetre Telescope (AMT) will be a key contribution to the next generation EHT and an important step for fundamental black hole physics research. The AMT will improve the imaging quality, sensitivity, and redundancy of the EHT, and thus make it possible to capture rapid changes in black hole images at multiple different frequencies at the same time, i.e., to actually make "colour movies" of black holes.

The AMT will become crucial to the development of the holistic black hole model in three ways:

- by enabling the dynamical measurements of event horizons and jet structures of black holes across the mass scale as part of the EHT (black hole imaging);
- by detecting the radio emissions of merging black holes and neutron stars emitting gravitational waves and other short-lived, transient events (transient detection);
- by adding a crucial missing colour in the monitoring of black holes in close collaboration with other facilities in the same region (supermassive black hole monitoring).

Hence, apart from black hole imaging, the AMT will also be a cornerstone in multi-wavelength discoveries and studies of explosive and transient astrophysical events. This is how a relatively small facility can punch well above its weight. The observations will be complemented and interpreted with detailed supercomputer simulations and theoretical analyses needed to develop a general framework for describing black hole physics from stellar mass to supermassive black holes.

Figure 1 - Left: an IRAM 15 m NOEMA dish at Plateau de Bure, chosen as the base design for the telescope. Centre: The Gamsberg, Namibia, primary choice for the AMT site. Right: the first image of a black hole in the galaxy M87 as released by the EHT consortium in 2019.

The planned location for the AMT is Namibia, near or on the summit of the Gamsberg (Figure 1), a geographic location perfectly suited to peer into the heart of the Milky Way that passes almost overhead.

This is not only where the supermassive black hole Sgr A* (the centre of the Milky Way) resides, but also most of the stellar mass black holes. This geographical position is also ideally suited to expand the EHT. The EHT employs a measurement technique called Very Long Baseline Interferometry (VLBI), which connects telescopes across the world into one virtual earth-sized telescope. The more stations in the network, the higher the quality of the reconstructed image, and the larger the separations between the stations (baselines), the higher the resolution of the image. As most telescopes that are currently part of the EHT are on the Northern hemisphere and in the Americas, the AMT fills a crucial gap on the Southern hemisphere and in the East of the array (Fig. 2), adding much needed baselines.

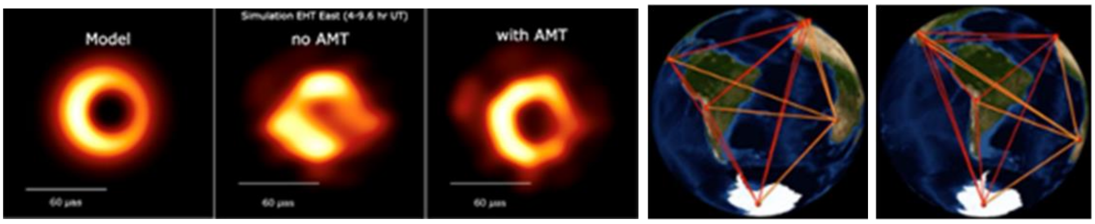

Figure 2: Simulated average movie image of the Galactic Centre black hole Sgr A* with and without the AMT, using only the first half of the EHT observations (4-9.6 hrs, see also Fig. 3a) when the source is visible for the European & African telescopes (right). From the left, in order: Simulated input image, simulated recovered image without the AMT, simulated recovered image with the AMT (La Bella et al., in prep., PhD). Right: the EHT array seen from the centre of the Milky Way with AMT baselines coloured in orange as the earth rotates. Without the AMT this “EHT Eastern Array” is not able to make meaningful dynamical images at all in the first few hours of observations due to lack of baselines and data.

The AMT will enable the EHT to accomplish dynamical black hole imaging by filling a strategic gap in the EHT array, where coverage is currently lacking in the Southern hemisphere and in the East. Filling that gap with the AMT provides better aggregate coverage of the targets during observation (Figure 2). The more telescopes, the more robust the image. To see dynamical changes in M87 on the event horizon scale, many telescopes must observe one day every few weeks. To make movies of Sgr A*, many telescopes must observe every few minutes. To follow stellar-mass black hole outbursts, one needs to quickly respond and follow ejecta over several weeks and months—not at pre-programmed times, but when the source has become active. The AMT is ideally placed, as the Galactic plane has the highest concentration of stellar-mass black holes and is best seen from the Southern hemisphere. Moreover, there is no other mm single dish in the southern hemisphere that can quickly react to target-of-opportunity (ToO) alerts.

The AMT helps in several ways. Firstly, it makes the array more robust and flexible for long duration and target-of- opportunity campaigns as needed to follow the dynamics of the black hole in M87. If currently vital central EHT stations are unavailable during any given night, the AMT ensures that the EHT retains imaging capability when making weekly images. Secondly, it also pushes the number of telescopes that are able to simultaneously see the Galactic Centre within 12 mins above a critical limit that even allows intra-day dynamical imaging. The addition of the AMT more than doubles the observing time available for dynamical imaging (Figure 3) for the supermassive black hole Sgr A*, thus enabling the EHT “Eastern array” (Africa+Europe) for imaging for the first time. It also makes the average image better and more robust, which is used as an input into all dynamical imaging schemes (e.g., Johnson et al. 2017). Moreover, the AMT can be used to monitor the flux variability of supermassive and stellar-mass black holes and essentially trigger the right moment to observe. All of this is what allows the EHT to transition from being able to record only single images to being able to record many “snapshots” and extended dynamical movies reliably, thereby revealing for the first time the details of the time evolution of accreting black holes on the smallest scales.

The increased observing time offered by the addition of the AMT makes it possible, for example, to address questions related to jet launching and particle acceleration by studying flares, during which short bursts of activity reveal localised particle acceleration. The spatial distribution of these accelerated particles around black holes with the EHT can be traced, and their flux evolution followed with single dish monitoring over longer timescales at multiple wavelengths. This can be combined with the near-infrared interferometer GRAVITY (2018), which resolves slightly larger scales in the near-infrared, and measures the temporal evolution of the multi-band spectral energy distribution with the AMT alone (mm-waves) plus, e.g., JWST (near-infrared space telescope, time granted), Chandra/NuSTAR (X-ray space telescopes), and H.E.S.S./MAGIC/CTA (very-high-energy gamma-ray telescopes). These observations are then combined with high-dynamic range modelling that includes improved treatments of particle acceleration (e.g., Crumley et al. 2019, Ripperda et al. 2022).

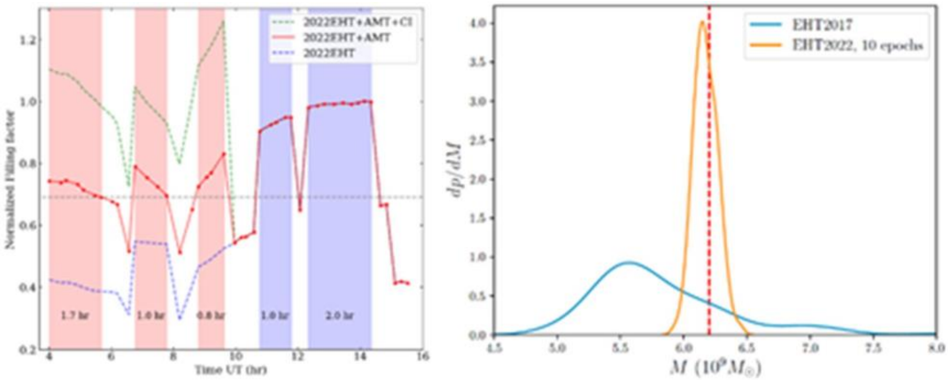

Figure 3: Left: The impact of the AMT on imaging the supermassive black hole in the Milky Way with EHT. The filling factor indicates how 'complete' the coverage is at any given time; a higher filling factor corresponds to a better imaging capability. The times where EHT has a filling factor above 0.7 are highlighted as dynamical imaging intervals (La Bella, PhD). Addition of the AMT (red) increases this useful time (shaded regions) by more than a factor of 2 over the non-AMT array (blue) and enables the first half of the EHT (4-9.6 hrs, Eastern Array) to be used for imaging. This will improve even further if the proposed Canary Island telescope is built (green). Right: The AMT also improves robustness of the array, allowing more images to be made, which improves the accuracy of tests of general relativity. The figure shows the simulated error distribution of M87* ring sizes (black hole mass) for a single image (blue) and ten images (orange), which is much narrower (Roelofs et al. 2021).

2. AMT & Excellence Fellowships: Use of the Second Half of the Balzan Prize

While the AMT is focussed on making black hole colour movies and detecting transients, its science case is much broader than that what was touched upon above. Most of these programs have a time scale of one decade to extract all the physics. However, the AMT is expected to operate well beyond ten years. In fact, the typical lifetime of radio telescopes is several decades.

Key to the successful operation of the telescope in Namibia in the medium and long term will be:

- full support of the project from government level down to the local population;
- a growing pool of local young scientists that can not only benefit from the project for their own research, but also are able to bring their own ideas and visions to the table.

It would be strange, to say the least, to have a project on Namibian soil where Namibian scholars are left out. Hence, the program is accompanied by a societal impact plan which includes a mobile planetarium visiting schools in Namibia and a fellowship program for African PhD students to work on the AMT at UNAM. The societal impact plan is aimed to build capacity in Namibia and lay a foundation for the next generation of scientists, researchers, and problem solvers. The mobile planetarium itself has been donated to Namibia and is under the stewardship of the University of Namibia (UNAM). This project is supported by the Radboud University and receives technical support and training from The Netherlands Research School for Astronomy (NOVA). The first presenters were trained in May 2022 by NOVA. Since then, the team has travelled to more than 60 locations and has hosted more than 10,000 attendees (of which more than 80% are school-going learners) across the country. With this success, the planetarium project has been attracting support from local role players from industry, NGOs, and the government alike.

One key problem for attracting Namibian PhDs is that there is not yet a smoothly functioning educational chain from secondary education up to the PhD level that allows talented young researchers to live up to their promise. There is not yet a significant tradition of cherishing fundamental sciences in Namibia, in particular among native communities. University studies are expensive and difficult to fund for students, especially from poor areas. An added challenge is studying a subject like physics is not considered a stepping stone towards a money-making career, and hence not to be invested in. Parents and families paying for the studies do not have a clear idea of which transferrable hard and soft skills students learn during their academic careers, and which job sectors are open to them once they have their degrees. Nonetheless, when the team goes to schools or gives public lectures, they are always met by intelligent, talented young learners who are driven by their curiosity and love for understanding nature.

Hence, the Balzan Prize will be used to fund young university scholars and researchers. The project will be divided into two parts to guarantee that the funding serves the whole educational chain, and that the students, Namibian society as well as the AMT project and EHT science all benefit.

Capacity building for AMT – the AMT-Balzan Fellowship

First, four MSc and two PhD students in astrophysics will receive funds to work on the AMT scientifically. Their key goal will be to develop automated operational modes for VLBI observations and transient detections. This program will be supplemented with funding from other sources, such as the recent ERC Synergy grant, to eventually fund four PhD and eight MSc students in total for astrophysics at UNAM over the course of the next six years. This creates a cohort of students that can support and learn from each other, and also makes the program robust against the uncertainties of individual career developments and choices. Good PhD students will have multiple options as not all will pursue a purely academic career.

A larger cohort of students for the AMT will also increase the number of publications and visibility at conferences in the academic community worldwide. AMT-Balzan fellows will be required to publish their research in open access journals and give (poster) presentations at international conferences and workshops in their field. Travel, accommodation, and living expenses are fully covered by the fellowships. There are also plans to bundle academic output in booklets to be published bi-annually, so as to record a comprehensive overview of research to date and use these as examples to attract external investors for the AMT and Balzan fellowships.

The share of the Balzan Prize funds will be deposited under the current AMT Fellowship Program, with the working title: *Heino Falcke AMT-Balzan Fellowships*. The AMT Fellowship is a dedicated fellowship to build capacity for the AMT and nurture Namibian talent. Fellows will be students at UNAM and work on a variety of research topics which are related to the AMT. These projects can be in the field of astrophysics, engineering, or otherwise related fields necessary to run the scientific and operational projects in the years to come. The first AMT fellow started in 2022 and works on testing weather conditions at both potential sites for the telescope and the expected influence on scientific output.

The AMT Fellowship is managed by the Radboud Foundation in The Netherlands, which is affiliated with Radboud University, though an independent foundation. An advisory committee of experts in astrophysics and (former) directors of large internationally renowned radio-astronomical institutes select proposals for fellowships. The committee consists of Prof. Rob Adam – former Director of SKA South Africa (chair); Prof. Jessica Dempsey – Director of ASTRON Netherlands Institute for Radio Astronomy; Prof. Pedro Russo – chair of IAU Astronomy for Education division; Dr. Marc Klein Wolt – Director of the AMT project and Prof. Anicia Peters – CEO of National Commission on Research, Science and Technology (NCRST) of Namibia.

Excellence in fundamental science

Furthermore, to increase the pool of excellent candidates in fundamental science, BSc fellowships in the form of "excellence awards" will be funded. Each year for 6 years, 1-2 "excellence fellowships" will be awarded to outstanding Namibian secondary school learners to put towards university study in natural sciences in Namibia. The excellence fellow can choose a degree based on their interest, also in fields not related to the AMT. The aim is to nurture talent and build capacity in STEM-fields, which will benefit Namibia's need to serve large and complex (inter)national projects in the future.

The excellence fellowships work on a yearly incentive basis. A learner who does well in secondary school – or if applicable first year BSc degree – is selected to become an Excellence Fellow. The learner will have to maintain their grades and be motivated to keep their studies up and receive the next portion of the fellowship the next year. By the time they receive their BSc degree, they will have 'saved up' for payment towards their BSc degree and be debt free. If applicable, a one-year honours degree is also included in the fellowship. Excellence fellows who are interested in pursuing a degree in (astro)physics or AMT-related fields of study are then also eligible to apply for the AMT-Balzan fellowship on the MSc and PhD levels.

In addition to tuition fees, the excellence fellowship also covers the cost of living if needed, a laptop computer, and a return trip home once a year to visit family. The size of the country also influences learners' and parents' choice to go to university, especially for learners from rural areas. The move to a town or city outside the region is a very significant change for these learners. It is even more difficult for those who do not have the funds to travel home often. Lack of travel funds and an established social network in the university town creates a very real danger for the student to feel and become isolated. The need to maintain the connection with family is crucial for the student to feel supported and connected, and ultimately to succeed in getting the degree.

Administration of the Excellence Fellowship

The yearly awarded portion of excellence fellowships will be kept in trust by the Lithon Foundation until the learner pursues their degree. This approach ensures the funding will be used for its purpose and not be spent for non-academic reasons by the fellow or their family members or guardians.

The awardees will naturally include learners from some of the best schools in Namibia. However, one of the project collaborators will be EduVision, an organisation that supports schools from the most disadvantaged regions in Namibia by providing additional education from EduGate schools through internet links. They have the insight and the possibility to propose outstanding students from these schools for the fellowship as well. While these learners should be equally talented, they might have a knowledge deficit and may need a few extra months to receive special preparation courses for university. This will be organized together with EduVision and Lithon Foundation, who are setting up a trainee and leadership program for promising students. Both organisations also have experience in looking after students' mental wellbeing when moving to university. They have agreed to assist the excellence fellows throughout their fellowship.

The excellence fellowship stipulates the condition that the student must try to their utmost to maintain the grades needed to proceed to the next academic year. During the academic year, Lithon Foundation and the supervisor will regularly check in to discuss progress. Tutoring or other assistance will be offered if necessary. However, should the student not graduate to the next year, the remaining bursary will be retracted. The remaining portion of the fellowship will fall back to the Radboud Foundation to supplement the remaining fellowship funds, or another destination will be found according to the advisory committee's judgement.

Selection procedure and governance

The selection of fellows will be based on demonstrated academic excellence at secondary school or on university, leadership, and social skills; different backgrounds will be taken into account. A committee of independent Namibian and international experts – chaired by Heino Falcke – will be formed within 3 months of the award to establish the rules and regulations of the fellowship and review candidates. It is envisioned the committee will meet and select candidates once a year before the new academic year starts.

The Lithon Foundation was set up by a leading Namibian engineering company with an excellent industrial network. They are already partners in the AMT Mobile Planetarium project and are well aware of the need to increase capacity in STEM and engineering in Namibia, and their network may be of assistance in increasing the number of fellowships by attracting additional donations from industry. In this way the Balzan prize funds will be used as a seed to grow a program that is sustainable after the Balzan Prize Research Project has ended. Awarding the fellowships will be a highly visible event in Namibia, and the fellowships that are funded by the Balzan Prize will be clearly indicated. Bringing these experienced partners together for this part of the Balzan foundation prize money will raise the visibility of the program in the country and serve as example for other initiatives such as these on the African continent.

Mentors and role models

The Balzan Foundation prize money will make an important contribution to supporting capacity building for STEM education and fundamental science in Namibia. However, the success of the program depends on the prospects of finding jobs once a fellow finishes their degree. Youth unemployment rates for academics is very high in Namibia. It is imperative that during the fellow's academic career they learn hard and soft skills which are useful on the job market, as well as a sense of entrepreneurship and ownership of their potential for Namibian society.

As part of the award, excellence fellows will be paired with a PhD/MSc AMT student mentor. They will be free to choose a course of study of their liking, but they are expected to conduct a small research program related to the AMT. This will be mutually beneficial to both BSc and MSc/PhD students in that they will learn to work together with people in different fields, learn to teach, and take responsibility for a project. In fact, the students involved in the planetarium project have already learned leadership skills that are valuable even if they do not continue in astronomy.

In addition, Bazan Excellence Fellows and AMT fellows are required to participate in the mobile planetarium project on a regular basis. This can be as presenter, coordination assistant, marketing and pr, maintaining the planetarium software, or creating educational material. All fellows are required to travel with the planetarium through Namibia to act as role models with whom children might interact. As scientists sharing their knowledge as well as their cultural heritage or backgrounds, they could have a great impact on their wishes to pursue a certain career or dream.

For fellows who do not wish to continue in academics after graduating BSc or MSc, internships will be offered at companies and organisations who are partners in the mobile planetarium project and share the AMT values. The following have already expressed their interest: Lithon Corporation for engineering and project management, Paratus for software development, FlyNamibia for aviation and mechanical maintenance, Kelp Blue for marine conservation and biochemical engineering.

The Balzan Foundation prize money is a gamechanger for Namibia's talented youth because new perspectives can be created on so many levels: on the universe by contributing to world class science; on academic excellence in Namibia; on realistic job opportunities for young people; and finally on Namibia's potential to claim its place in the world and contribute to a green and digital age.

References

Bright, J. S., et al., "An extremely powerful long-lived superluminal ejection from the black hole MAXI J1820+070", NatAs, Vol. 4, Issue p. 697-703 (2020)

Brünken, S., et al., "Detection of the Carbon Chain Negative Ion C_8H^- in TMC-1", ApJL, Vol. 664, Issue 1, p. L43-L46 (2007)

Brünken, S., et al., "H_2D^+ observations give an age of at least one million years for a cloud core forming Sun-like stars", Nature, Vol. 516, Issue 7530, p. 219-221 (2014)

Cernicharo, J., et al., "Pure hydrocarbon cycles in TMC-1: Discovery of ethynyl cyclopropenylidene, cyclopentadiene, and indene", A&A, Vol. 649, Issue p. L15 (2021)

Christensen, L. L., et al., "An Unprecedented Global Communications Campaign for the Event Horizon Telescope First Black Hole Image", CAPJ, Vol. 26, p.11 (2019)

Crumley, P., et al., "Kinetic simulations of mildly relativistic shocks - I. Particle acceleration in high Mach number shocks", MNRAS, Vol. 485, Issue 4, p.5105-5119 (2019)

de Jong, S., "The importance of being Earnest – the relation between Hendrik Witbooi and the Gamsberg", Namibia Scientific Society, Journal 62, p. 41-55 (2021).

Do, T., et al., "Relativistic redshift of the star S0-2 orbiting the Galactic Center supermassive black hole", Sci, Vol. 365, Issue 6454, p. 664-668 (2019)

EHT Collaboration, "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole." ApJL, 875, p. 1 (2019) EHT Collaboration, "First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon", ApJL, Vol. 910, Issue 1, p. L13 (2021)

Falcke, H. D. E., et al., "Viewing the Shadow of the Black Hole at the Galactic Center", ApJ, Vol. 528,

Issue 1, pp. L13-L16 (2000) Ghisellini, G., et al., “Structured jets in TeV BL Lac objects and radiogalaxies. Implications for the observed properties”, A&A, Volume
432, Issue 2, pp. 401-410 (2005)
GRAVITY Collaboration, R. Abuter, et al., "Detection of orbital motions near the last stable circular orbit of the massive black hole SgrA*", A&A, Vol. 618, Issue p. L10 (2018)
GRAVITY Collaboration, R. Abuter, et al., "The mass distribution in the Galactic Centre from interferometric astrometry of multiple stellar orbits", arXiv:2112.07478 (2021)
Ho, A. Y. Q., et al., “AT2018cow: A Luminous Millimeter Transient”, ApJ, Vol. 871, Issue 1, p. 19 (2019)
Hovatta, T., et al., “A combined radio and GeV γ-ray view of the 2012 and 2013 flares of Mrk 421”, MNRAS, Vol. 448, Issue 4, p. 3121- 3131 (2015)
Ioppolo, S., et al., “A non-energetic mechanism for glycine formation in the interstellar medium”, NatAs, Vol. 5, Issue p. 197-205 (2021)
Irwin, J.A., et al., “CHANG-ES V: Nuclear Outflow in a Virgo Cluster Spiral after a Tidal Disruption Event”, ApJ, Vol. 809, Issue 2, article id. 172, p. 26 (2015)
Johnson, M.D., et al., “Dynamical Imaging with Interferometry”, ApJ, Vol. 850, Issue 2, p. 15 (2017)
Kudriashov, V., et al., “Laboratory Demonstration of the Local Oscillator Concept for the Event Horizon Imager”, JAI, Vol. 10, Issue 3,
p. 2150010-1826 (2021a)
Kudriashov, V., et al., "An Event Horizon Imager (EHI) Mission Concept Utilizing Medium Earth Orbit Sub-mm Interferometry", arXiv, Vol. Issue p. arXiv:2105.06882 (2021b)
LIGO/Virgo Collaboration (Abott, B.P., et al.), “Observation of Gravitational Waves from a Binary Black Hole Merger”, Phys. Rev. Lett., 116, 061102 (2016)
LIGO/Virgo Collaboration et al., “Multi-messenger Observations of a Binary Neutron Star Merger”, ApJL, 848:L12 (2017)
Ligterink, N. F. W., et al., “The prebiotic molecular inventory of Serpens SMM1, I. An investigation of the isomers CH3NCO and HOCH2CN”, A&A, Vol. 647, A87 pp. 32 (2021)
Maccarone, T. J., et al., “Eclipses of jets and discs of X-ray binaries as a powerful tool for understanding jet physics and binary parameters”, MNRAS, Vol. 499, Issue 1, pp.957-973 (2020)
McGuire, B. A., et al., "Detection of the aromatic molecule benzonitrile (c-C_6H_5CN) in the interstellar medium", Sci, Vol. 359, Issue 6372, p. 202-205 (2018)
McGuire, B. A., et al., “Laboratory spectroscopy techniques to enable observations of interstellar ion chemistry”, NatRP, Vol. 2, Issue 8, p. 402-410 (2020)
Pesce, D. W., et al., “The Megamaser Cosmology Project. XIII. Combined Hubble Constant Constraints”, ApJL, Vol. 891, Issue 1, p. L1 (2020)
Petroff, E., et al., “Fast radio bursts”, A&ARv, Vol. 27, Issue 1, p. 4 (2019)
Planck Collaboration, “Planck early results. XV. Spectral energy distributions and radio continuum spectra of northern extragalactic radio sources”, A&A, 536, A15 (2011)
Psaltis, D., et al., “Probing the black hole metric: Black hole shadows and binary black-hole inspirals”, Phys. Rev. D, 103, 21 (2021) Ripperda, B., et al., “Black Hole Flares: Ejection of Accreted Magnetic Flux through 3D Plasmoid-mediated Reconnection”, ApJL, Vol.
924, Issue 2, id.L32, 15 pp. (2022)
Roelofs, F., et al., "Black hole parameter estimation with synthetic very long baseline interferometry data from the ground and from space", A&A, Vol. 650, Issue p. A56 (2021)
Russell, T. D., et al., “Rapid compact jet quenching in the Galactic black hole candidate X-ray binary MAXI J1535-571”, MNRAS, Vol.
498, Issue 4, pp.5772-5785 (2020)
Tetarenko, A. J., et al., “Measuring fundamental jet properties with multiwavelength fast timing of the black hole X-ray binary MAXI J1820+070”, MNRAS, Vol. 504, Issue 3, pp.3862-3883 (2021)

Van Langevelde, H., et al., "The Synergy between VLBI and Gaia astrometry", 14th EVN Symposium & Users Meeting. 8-11 October, 2018. Granada, Spain. Online at https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=344, id.43 (2018)

Venturi, T., et al., "VLBI20-30: a scientific roadmap for the next decade -- The future of the European VLBI Network", arXiv:2007.02347 (2020)

Yuan, Q., et al., "Catching jetted tidal disruption events early in millimetre", MNRAS, Vol. 461, Issue 3, p.3375-3384 (2016)