BRICS Intelligent
Telescope and
Data Network

A BRICS Astronomy Flagship Proposal

The BRICS Intelligent Telescope and Data Network (BITDN)

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Executive Summary

As emerging economies, the BRICS countries face a specific set of challenges, but are also uniquely placed to act on the opportunities that the fourth industrial revolution presents. This proposed flagship astronomy programme is a collaborative scientific enterprise, drawing on the strengths of all five BRICS partners, while at the same time seeking to address in-country socioeconomic development challenges. Framing development imperatives in the context of the United Nations Sustainable Development Agenda, this programme will clearly impact Goals 4 (Quality Education), 9 (Industry, Innovation & Infrastructure) and 17 (Partnerships) and has the potential to advance others. It will also have a strong component of Capacity Development, particularly building for the 4th Industrial Revolution, through the training of students and young researchers.

The flagship scientific programme will develop a network of astronomical telescopes, some already existing, and an associated intelligent data network which is the enabler for the science programme. This will leverage existing and planned new telescope and cyber facilities within the BRICS countries and will also draw on the opportunities presented by other multi-wavelength space- and ground-based facilities within, or accessed by, the BRICS group. The programme focuses on two key areas: 1) the scientific advance, within the BRICS partners, of the rapidly expanding domain of wide-field multi-wavelength imaging sky surveys and the detection and study of transient and time-variable phenomena in the Universe, one of the pillars of modern astrophysics, and 2) technical solutions to the associated enormous Big Data and Big Compute challenges arising from such worldwide networks of transient detectors and imaging surveys, including the Square Kilometre Array (SKA) and the Rubin Observatory's Legacy Survey of Space and Time (LSST), leading global projects in which many BRICS countries are actively involved.

Thanks to their unique, worldwide geographical distribution, BRICS countries are well placed to take the global lead in this quickly evolving and compelling research area, utilizing both existing and future telescopes within BRICS. The latter includes an ambitious plan for a global network of optical telescopes with the unprecedented ability to observe the entire sky continuously on a timescale of less than an hour, greatly increasing our ability to monitor the changing cosmos. New science would not happen without innovation in both instruments and big data science methods and systems, and this project will therefore bring together teams within BRICS to lead programmes in data innovation in each partner country.

The collaboration will include academia and industry from partner countries and will focus on developing technologies of the 4th industrial revolution. An essential human capital development programme is designed to create a new generation of data-savvy scientists and engineers within BRICS, strengthening the scientific community in the global South. Cross disciplinary and links with industry will be a key focus of this project, accelerating technological spin-offs and working actively to promote science for development. The depth and breadth of this network, embedded through this project, will benefit the BRICS participants beyond what we could achieve as individual countries.

The nature of this proposed flagship programme is such that it creates the potential to stimulate conversations across disciplines to tackle current global challenges such as COVID-19, using data skills, training and infrastructure.

1. Background to the BRICS Astronomy Flagship

Astronomy was established as one of five thematic science areas within BRICS at a ministerial meeting held in South Africa in 2014. The BRICS Astronomy Working Group (BAWG) was then established the following year. BAWG is responsible for promoting cooperation activities in astronomy priority areas. At the 2017 annual BAWG meeting is was resolved to establish a BRICS "flagship" programme and a subsequent call for concept proposals was initiated. Eighteen proposals for flagship projects were presented during the 2018 BAWG meeting and a Task Team selected 3 thematic areas which would be taken to the next proposal stage:

- Optical transient network
- Big data/compute in the era of large surveys (e.g. SKA, Rubin Observatory LSST).
- Neutral Hydrogen / 21 cm cosmology

The criteria for the selection of these thematic areas were based on:

1. Representation and involvement by all BRICS countries where possible but with a minimum of three countries.
2. Scientific excellence and international competitiveness
3. Socio-economic impact which includes but is not limited to technology development and transfer, outreach, human capital development programmes (student exchanges, etc.), relevance to the next/4th Industrial Revolution, involvement of the private sector.
4. Ability at leveraging existing and future national facilities.
5. A scalable project with a phased approach.

The three fully developed proposals were presented, discussed and rated at the October 2019 BAWG meeting, with the result that the BAWG elected to support a flagship programme based on a merger of the transients and big data proposals. The combined programme, entitled the *BRICS Intelligent Telescope and Data Network (BITDN)* will involve astrophysical transients, survey science and time domain astronomy. It will involve forefront observational facilities and the big data/compute infrastructure needed to support them. Existing and new facilities in all 5 BRICS countries will be harnessed and developed to support the programme. The programme strongly supports the human capacity development agenda within BRICS and will foster scientific collaboration in the frontiers of astronomy between scientists in all the BRICS countries and beyond.

2. Programme Rationale

The emergence of global data networks, coupled with tremendous advances in imaging technologies and automation, has lead to an explosion in the detection of transient phenomena in astronomy. In the next decade, large-scale all-sky surveys across the electromagnetic spectrum will produce enormous amounts of data and provide unprecedented discovery opportunities. This field is now a driving force expanding the frontier of modern astrophysics. Multi-wavelength observations of all types of transient signals, from nearby Solar System objects to the most distant and energetic sources in the Universe, are revealing previously unknown phenomena and unlocking the nature of their cosmic sources. Below we outline the principal arguments for a BRICS Astronomy flagship project in this area.

1. The BRICS countries are well placed to take a global lead in the rapidly expanding domain of wide-field imaging sky surveys and the study of the dynamically changing Universe on unprecedented hourly timescales. These are becoming the quickest evolving and most compelling astronomy research areas of this century, opening new horizons for discovery. This BRICS programme will harness existing and planned infrastructure, as well as developing new prototype purpose-built telescopes for an eventual global network within BRICS.

2. A pilot project utilizing the available infrastructure can be completely enabled by the development of specific software to integrate the operation and the data acquired by existing instrumentation, at relatively low cost. The full potential of such a programme for transient science, nevertheless, can only be unlocked by means of a more ambitious plan for a global network of optical telescopes, to be hosted by the BRICS countries, with the unprecedented ability to observe the entire sky continuously on timescales of less than an hour, thus greatly increasing our ability to monitor the changing cosmos. This capability would not only bring the BRICS to the forefront and global leadership of transient and multi-messenger astronomical research, but would also significantly open the discovery space for new types of objects and phenomena, including the monitoring of potentially hazardous near-Earth objects, like small, but still threatening, asteroids.

3. The new telescopes and technologies that can open up this discovery space will generate unprecedented quantities of data. Rapid imaging of large volumes of the Universe over many wavelengths, and a network of coordinated, globally distributed telescopes for automated transient observations based on machine learning and artificial intelligence, are key to this endeavour, and constitute what we call "an intelligent telescope network". This forms the first pillar of the present proposal.

4. The second pillar is the establishment of a BRICS-wide collaboration for the development of new technologies and systems that will meet the big data challenges of forefront astronomical facilities, and the BRICS all-sky transient network. The programme will prototype and demonstrate scalable big data technologies needed for the BRICS telescope network, as well as the major projects in which the BRICS are involved, such as SKA and LSST regional science and data centres. It will do so by establishing a BRICS multi-national cloud network for collaborative programmes in data intensive multi-wavelength astronomy.

5. Strategic to these scientific and technical activities is (i) the joint support and mentoring of students and young researchers by the collaborating BRICS scientists, (ii) the development of community relationships between different astronomy groups within the BRICS family, (iii) the sharing of data and working together on the scientific returns, as well as (iv) allowing for the establishment of community-developed and maintained software systems.

6. The project will build on well-governed open-source models, and in particular it will benefit of the support from a number of open-data projects, such as the recently established United Nations Open Universe Initiative, for the public release and easy access to data. Regular exchange visits within the BRICS countries, research schools, data workshops and conferences, especially for early-career scientists, students and engineers involved in the programme are also planned, through financial support provided by the project.

7. Beyond the development of scientific and technical skills, participants in the programme will be trained in communications and outreach, and will be groomed as role models to engage the communities they are issued from, ensuring that their successes are seen and known. They will also be exposed to industry and trained in transferable skills, to ensure that they in future can build solid collaborations with the industry.

3. Science Overview

Astrophysical phenomena radiate over a broad range of the electromagnetic spectrum, each window providing complementary physical insights, and multi-wavelength astronomy (the merging and joint analysis of such several data sets) is a critical requirement to achieve the science goals set out by modern astronomy programmes.

Beyond the multi-wavelength explorations of the electromagnetic spectrum, the field of multi-messenger astronomy today has made a quantum leap, with the inclusion of other domains such as cosmic rays, neutrinos and gravitational wave astronomy. There is tremendous scope of synergy of these with traditional astrophysics, including optical and radio astronomy, thereby adding another dimension to combining large data sets to extract the maximum information about our Universe. In this context, we can cite the plans to have a LIGO gravitational wave detector in India and experiments already underway with BRICS radio facilities such as the uGMRT (India), MeerKAT (South Africa) and FAST (China) to carry out radio follow-up of gravitational wave events, all of which offer an exciting new area of exploration for BRICS Astronomy.

Variable phenomena sit at the very heart of this multi-messenger revolution in astronomy, and the future prospects for the detection and study of transient phenomena in the Universe heralds a new era in time domain astronomy. Below we detail the case for a dedicated BRICS-wide flagship programme to develop a network of ground-based optical telescopes for an all-sky survey with the goal of detecting short-lived optical transients, and to allow the follow-up of multi-wavelength and multi-messenger transient phenomena. As stated in the previous sections, this will leverage existing and planned new facilities within the BRICS countries and will also draw on the opportunities presented by other multi-wavelength space- and ground-based facilities that exist within the BRICS group.

The BRICS countries are already taking the lead in developing the new scientific methods required by the vast amounts of data that will be generated by such an observational endeavour. For example, many of the BRICS countries are already involved in the two largest astronomy projects of the 21st century, namely the SKA and the Rubin Observatory LSST, both of which will have a huge impact on the study of the structure and the variability of the Universe on unprecedented scale, across the radio and optical domains, respectively. Such projects represent a new era of mega-data production that will render conventional research and collaboration methods, as well as current data and visual analytics tools, ineffective. The SKA and LSST are driving the most significant big data challenges of the coming decades, and the required data solutions pave the way for the BRICS Intelligent Telescope Network here proposed, as a unique and strategic project under the complete leadership of the BRICS countries.

3.1 Telescope Network for Transient and Survey Science

Astrophysical transients are objects that can suddenly appear for the first time, or known objects which brighten considerably, and then fade, sometimes to oblivion. Many transient events can carry unique messages about fundamental laws of physics and the nature of our Universe, while others closer to us have a much more direct impact on humanity. The detection of transient phenomena relies on utilizing multi-messenger facilities to detect signals, either through electromagnetic radiation, gravitational waves, neutrinos or cosmic rays. Multi-wavelength astronomy has seen an enormous growth in telescopes across the electromagnetic spectrum, from radio to γ-ray wavelengths, with ever increasing performance, particularly in terms of sensitivity and resolution. In the next decade the Square Kilometre Array, SKA, and the Legacy Survey of Space and Time, LSST, in which many BRICS scientists are already involved, will produce enormous amounts of data and provide unprecedented discovery opportunities, both in survey and transient science.

Transient phenomena are seen across a wide range of object classes, from the nearest to the farthest, and covering a wide range in luminosity, some being the most energetic events in the Universe. The latter often hold the key to our understanding of universal physical laws in conditions of extreme energy. We typically know of their existence because we detect powerful bursts of energetic radiation; however, despite all the technological developments and improvements in telescopes, instruments and detectors over the last few decades, we still know very little about transient events in the optical band on timescales of less than a day or so (2/3 of the area represented in Figure 1). We have already discovered signals from some of these short-lived energetic events with X-ray, γ-ray, and radio telescopes, and more recently with multi-messenger gravitational wave and neutrino detectors. However, obtaining simultaneous optical information remains challenging due to the lack of facilities giving complete sky coverage at a high enough cadence (< 1 day). We show the “discovery space” for transients in Figure 1, in terms of luminosity and typical timescales of variability.

In addition, optical observations of transients may lead to important discoveries in other fields of astronomy: nearby asteroids potentially dangerous for Earth, Near-Earth Objects (NEOs), new extra solar planets; variability of super massive black holes in galaxies; stellar flares; gravitational lenses; and probably several other yet-unknown types of fast-changing phenomena that have not yet been discovered. Time domain astronomy, where repeated observations can be undertaken over a range of timescales (from sub-second to seconds, minutes, hours, days, months, years), is key to obtaining data of sufficient cadence to unlock the nature of transient objects.

LSST on the Rubin observatory will be the next big optical transient detection survey, surveying much of the southern sky to an unprecedented depth (to g $\sim$ 25 in a single exposure), once it begins operations in early 2023. However, its scanning cadence will only be several days for the main survey, thus missing or poorly sampling many classes of fast transients. Also, as the Rubin observatory is a single telescope, located in Chile, it will miss all the fastest transients and those that occur during daytime, or if they are located in the northern sky.

In order to address this shortcoming, and to advance our understanding of fast transients, we need a network of globally distributed wide-field telescopes that can rapidly scan the entire night sky, many times per night. This is the ultimate aim of this ambitious BRICS flagship astronomy programme, namely to construct a network of 70 globally distributed optical 1-m telescopes, with wide fields of view (25 square degrees each), to continuously monitor the sky in three filters (g, r, i). Transient radio emission is associated with essentially all explosive phenomena and high-energy astrophysics in the universe. It acts as a locator for such events, and a measure of their feedback to the local environment. Because of this, radio transients are invaluable probes for subjects as diverse as stellar evolution, relativistic astrophysics

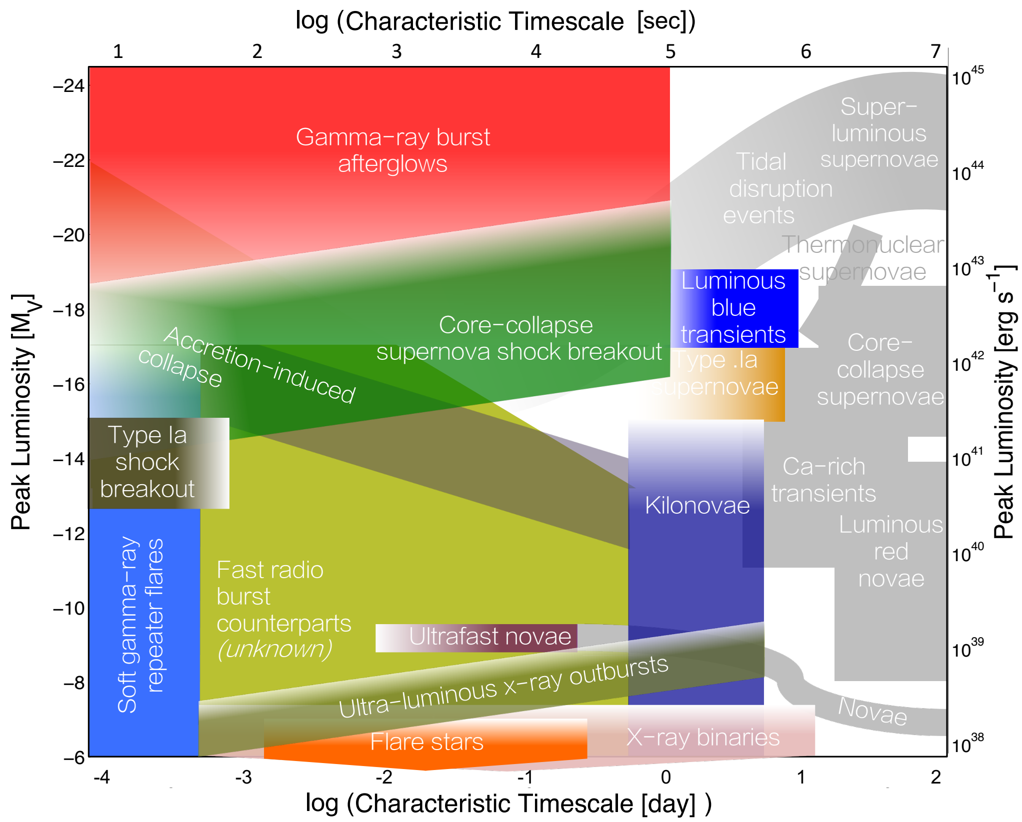

Figure 1: Luminosity−Timescale plot for transient phenomena, with approximate characteristic timescales and peak luminosities (credit: Jeff Cooke/Swinburne University of Technology)

and cosmology. In South Africa, ThunderKAT is a MeerKAT large survey programme to detect and study such phenomena using the high sensitivity and wide area imaging capability of the MeerKAT. As well as performing targeted programs, ThunderKAT will co-observe with other MeerKAT large survey projects and search their data for transients. The uGMRT in India also provides for significant capabilities for detection of transient phenomena in the Universe. Ultimately, the immense rapid imaging capability of the SKA will revolutionize transient science at radio wavelengths, with similar impact at radio to what the LSST will achieve at optical wavelengths.

Our ambitious but fully realizable proposal is for BRICS astronomers to *globally lead* the effort in advancing our ability to continuously monitor *entire sky* on an hourly timescale. This would expand, by a factor of $>$50 more than LSST, the unprecedented ability to detect rapid changes in hosts of objects throughout the Universe, near and far. This would be as revolutionary as the advances of video over still cameras, expanding the frontiers of time domain astronomy. This will lead inevitably to the discovery of unthought-of new types of phenomena, objects and processes in out Universe, giving a whole new perspective. The BRICS Intelligent Telescope and Data Network (BRICS-ITDN) will be initially constituted using existing facilities within (or currently accessible to) the BRICS countries, but intelligently connecting them into automated transient follow-up ”machines”. The programme will involve the development of software, including for the robotization of existing telescopes, to facilitate rapid, automated and coordinated response to fast multi-messenger transients from multiple telescopes across the BRICS countries. Thus the programme can begin modestly, using existing resources, and building the required underlying computing technology, to then expand to add new facilities as funding allows. The eventual full network will allow for both the independent discovery and rapid follow-up of newly discovered transients from many sources, including the network itself, LSST and other multi-messenger alert facilities, both ground-based and space-based. This proposed BRICS Network will allow for the expansion of the transient ”discovery space" into regions hitherto unexplored by any other infrastructure of this kind worldwide.

3.2 Data Network Challenges and Developments

Projects undertaken by large global collaborations, in which large amounts of observing time are devoted to major key science programs that create vast data sets, is becoming the new paradigm. This mode of observing combined with the new instrumental capacities is driving an exponential growth in the rate of data confronting researchers. As illustrated in Figure 2, the BRICS community is at the forefront of this challenge. New and upcoming major BRICS facilities, in particular the SKA and its pathfinders, present the biggest data challenges of the coming decade. Developing the systems to support effective analysis of vast amounts of data has become an integral part of how we approach modern science and technology. We must development of the necessary skills and tools that astronomers will need, many of which can be borrowed by, and applied in, other fields of science and engineering.

Learning how to efficiently process large data sets and optimally extract all of the required information has thus become a central challenge of large projects, including the proposed BRICS transient follow-up network, which is at the core of this programme. Transient detection and the associated multi-messenger science in the era of the large surveys will necessarily involve Big Data, Big Compute, Machine Learning and Artificial Intelligence, all of them aspects of data-driven science, critically supported by developments associated with the 4th industrial revolution. In addition, other machine learning and artificial intelligence systems will need to be developed to intelligently network and automate the telescopes, both nationally and globally, which will comprise by the BRICS-ITDN.

To support the operation of the proposed BRICS telescope network, and its scientific exploitation, the programme will thus provide the big data and computing tools and machine learning data analytics necessary, fully exploiting the 4th industrial revolution innovations. Deep learning techniques, running on high performance computing facilities, will allow for the necessary design and training of neural network models using datasets of TB size, delivered by the large surveys.

In this regard, data fusion work matching observations and data from different telescopes operating at different wavelengths and with different resolutions has already been started in a collaboration between Chinese and South African co-investigators, who are currently developing this line of research for application to LSST data as prototype to this project. This will not only allow us to play a key role in the joint exploitation of LSST and MeerKAT-SKA, where South Africa will be able to effectively leverage MeerLICHT/MeerKAT observations as a pathfinder toward LSST/MeerKAT-SKA science, but will enable the development of the Data matrix for our BRICS Telescope Network. As a matter of fact, the technologies, systems and algorithmic approaches to convert the coming vast and diverse data sets into scientific discovery do not yet exist, and the next five years are thus a crucial time for the global community to come together to solve these challenges.

The proposal team includes leaders of large programs on new SKA pathfinder facilities and in multi-wavelength astronomy, most of which involve collaborations among researchers in the BRICS partners. The data solutions to be developed will thus advance key science projects that address the fundamental questions driving multi-national investment in megascience projects in the coming decade.

Further to those, other aspects of the Big Data and Big Compute challenges that this flagship aims to tackle include:

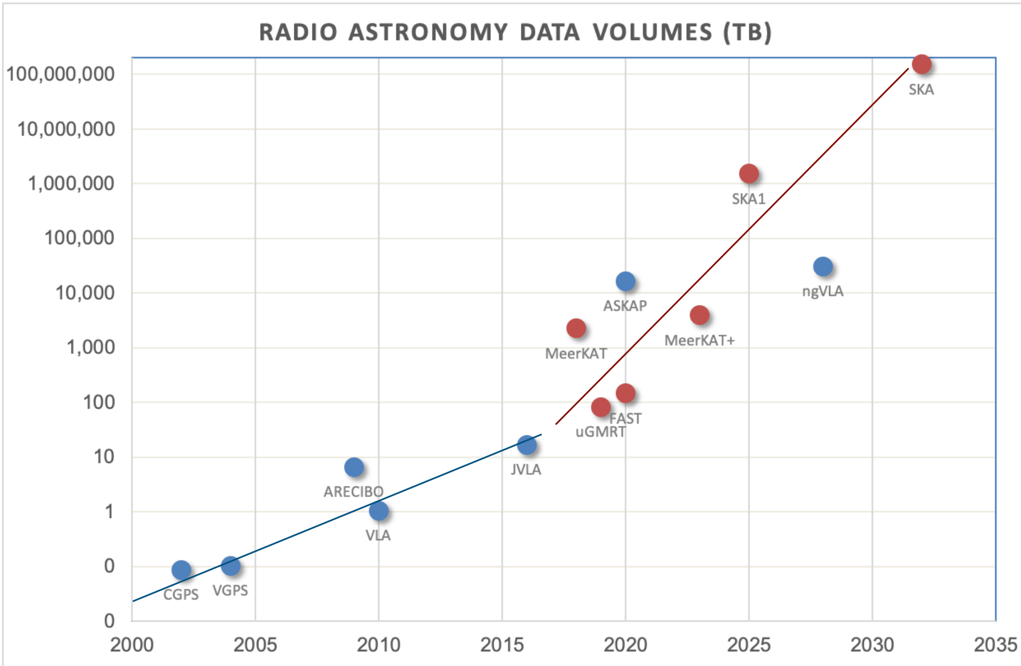

Figure 2: Data volumes for large projects on radio astronomy facilities as a function of time. Current and planned BRICS facilities are indicated in red. BRICS researchers are being confronted with a data deluge in the coming decade characterized by exponential growth that is much faster than has been experienced by the rest of the world to this point.

- Establish a prototype BRICS network of federated cloud-based infrastructure and 4th industrial revolution technologies for e-science and distributed data to support collaboration on data intensive astronomy, and to exploit synergies between BRICS partners for enhanced research through joint big data astronomy science programs.
- Create new technologies and modalities for visualisation and machine learning enhanced visual analytics of cloud based remote distributed big data, as well as cloud-based tools for collaborative exploration by distributed research teams.
- Develop cloud-based provisioning of HPC for automated processing workflows. Provisioning flexible containerised analytics environments allowing both real-time and interactive engagement with the data to empower research teams to work with big data. Such workflow systems will also address the challenges of reproducible science with big data.
- Develop cloud-enabled systems and environments for the fusion of multi-wavelength data sets and for multi-messenger and transient science, including data from the SKA, LSST and the optical transient network. An objective here is to develop and incorporate machine learning to analyse data and enable us to characterise, classify (and discover) the unknown and prioritise rapid response programs.
- Develop scalable knowledge bases and data lakes to provide access to integrated and correlated knowledge transforming raw data into scientific knowledge on a global scale.

4. Socioeconomic benefits

Human capital development (HCD) is a key aspect of the project. An integral part of the new approach to science driven by big data, big compute and large international collaborations is to create and embed the science platforms within the research communities so that researchers may work collaboratively on these large, diverse multi-wavelength data sets. Such platforms are best developed through extensive, international programmes such as the one proposed here. It promotes sustained collaboration between partners from the BRICS countries, and prevents duplication of efforts in developing such platforms in individual countries, while concurrently cultivating the expertise that forms a core component of knowledge-based economies. There are also wider socioeconomic benefit implications, and these include building bridges with industry and across academic disciplines, engaging society and working towards preserving life on Earth. These topics are discussed below in reference to the Sustainable Development Goals (SDGs) - see also Figure 3.

Figure 3: The United Nations Sustainable Development Goals (SDGs), with the brightly coloured goals showing those potentially impacted by the BRICS Intelligent Telescope and Data Network.

4.1 Training young scientists & technicians

The project budget supports training of both scientists and technicians (impacting on SDG 4 - quality education) through postgraduate scholarships, research schools, data workshops and hackathons, as well as conference participation. While exchange visits and workshops are essential tools for knowledge transfer, this project will provide innovative alternatives to residential workshops through virtual training hubs. Significant limitations in travel are likely in the near future, driven by both containment of Covid-19 and growing concerns over the carbon footprint of air travel.

Working with the industry (see also §3.2 below), and building on existing and forthcoming tools for international scientific collaboration on large datasets, the project will explore and develop a virtual training hub that is able to operate across multiple languages, time zones and learning modes to provide state-of-the-art training and collaboration opportunities to students in the network, while minimizing travel. Such a training hub, addresses also SDGs 13 (climate action) and 9 (industry, innovation and infrastructure), and can be a tool to encourage and retain women in the programme, addressing SDG 5 (gender equality). Benefits of this hub have the potential to be much broader, impacting the BRICS consortium as a whole, and potentially also the education sector (SDG 4).

The HCD programme will focus on developing leadership opportunities for early career researchers. This is essential to drive both scientific excellence and transformation (SDG 10), and to strengthen the independence of the scientific community in the global South. These opportunities will include:

a. Communications training
b. Outreach training
c. Teaching opportunities
d. Speaking opportunities at conferences
e. Stimulating media engagements

4.2 Bridges with industry

The data and compute requirements that drive this project lend themselves to joint industry-academic programmes, internships and cross-disciplinary interventions. Tools and skills will be developed that have potential impacts broader than astronomy. For example, accurate analysis of large quantities of real-time (streamed) data is necessary to meet the science goals of this project. But the computing infrastructure and software required to build such systems can likely be applied in medicine (SDG 3), sentiment analysis and a myriad of other fields. Part of this project will include actively seeking out such opportunities to contribute tools and skills to industry and other disciplines, thereby contributing to SDG 17 (partnerships) and SDG 9 (industry, innovation), as well as exchange and internship programmes attached to projects carried out in partnership with industries (SDG 4 - education).

4.3 Public science awareness & development of communities

Specific initiatives are planned to develop outreach resources showcasing the facilities, science collaborations and technology developments in the project. These are based on the expertise developed in this arena in the BRICS countries.

The Cascade Outreach model, as developed in South Africa, works to promote young scientists as role models while reducing the load on established minority minority scientists who are disproportionately asked to represent their science as efforts are made to diversify the field. It serves to offer a sustainable solution to practical outreach and communication training for students and researchers, and can be very simply translated to different contexts.

This project is committed to the principles of open science and aims strengthen the impact of the scientific programme in the training of young scientists and community outreach through a citizen science approach. Tools such as the Open Universe Initiative (under the coordination of the United Nations Office for Outer Space Affairs) aim to improve the accessibility and sharing of astronomical data from many different facilities. As such it supports engagement through citizen science projects, as well as supporting scientific partnerships across the BRICS countries.

India has developed models for science engagement that can be scaled up to accommodate large numbers of visitors. This is part of a campaign to engender a "scientific temper" and ease the tensions between science and superstition. Lessons from these efforts can be translated across the BRICS network.

The Office of Astronomy for Development, together with a number of international partners, has identified a model for development of local communities around an astronomical facility, such as an observatory. Benefits could include job creation through astronomy-related tourism, education programmes, the development or training of specific skills within a community, stimulation of local innovation and activities that may draw youth away from negative or harmful pursuits. The specific implementation is context-specific, but close collaboration between the astronomy facility, local community and the government is key to sustainability.

4.4 Life on Earth

Increasing efforts are being made to map and track asteroids that could be potentially devastating to life on Earth. With a high cadence window on the whole sky, which is the target of this project, we stand a better chance to catalogue near earth asteroids and identify those on hazardous orbits. Early warning systems give time to prepare, evacuate or deflect to minimise catastrophe, impacting on all 17 SDGs.

4.5 Relevance in a COVID-19 world

The COVID-19 pandemic has had an unprecedented social and economic impact on all countries of the world, with BRICS countries being particularly hard hit. There is immense potential for the skills and data infrastructures within this flagship programme to contribute to alleviating the effects of this pandemic.

All around the world non-medical scientists have found ways to contribute to new and existing efforts to combat COVID-19, ranging from data analysis and modelling, to the design and production of ventilators, to supporting virtual education systems at all levels (a study by the OAD can be found at https://tinyurl.com/y696r2h5, describing efforts and roles played by scientists who are usually working in areas not related to infectious diseases, especially astronomers, in the fight against the COVID-19 pandemic and its impact on development). The nature of this flagship programme is such that it creates the potential to stimulate conversations across disciplines to tackle current global challenges such as COVID-19, using data skills, training and infrastructure.

5. Budget & Management

The budget for the BRICS Intelligent Telescope and Data Network (BRICS-ITDN) consists of funds to support the following:

- *BRICS-OTN annual project meeting*.
- *Travel for joint technical work, research collaboration meetings and workshops*
- *BRICS post-doctoral (12) and post-graduate (12) fellowships*.
- *Project management and software & systems development*.
- *Outreach and Astronomy for Development activities, including a Co-ordinator*
- *Equipment and Infrastructure*
- *SALT and other large telescope access costs*

- *Costs for 4 prototype new wide-field 1-m telescopes*

For the first year of the project, 2021, we request funds for travel and for the BRICS-OTN project meeting and for appointing a Project Manager. At that meeting we would implement the project governance and management structure, create detailed plans and agreements for programs and activities in the thematic areas, finalize projects for initial post-doctoral and post-graduate appointments. Funds for the full projects, including fellowships and appointment of technical staff would be required beginning in the second year. In addition, we would request funds for SALT access to allow collaborators within the BRICS-OTN to undertake follow-up observations of transients immediately.

The budget amounts for each category by year are provided in budget table below.

Budget ('000 Euros)									
Item	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Annual Meeting	9	9	10	10	11	12	12	13	14
Travel									
Annual Meeting	132	186	195	205	215	226	238	240	249
Visits/workshops		49	51	55	57	59	62	64	68
HCD									
Postdoc Fellows		224	236	247	260	272	286	292	300
Postgrad Students		210	220	230	242	254	268	272	276
Staff									
Project Manager	46	93	98	102	108	114	118	124	130
Software Engineers		232	244	256	269				
Technical Support		232	244	256	269	282	297	311	327
Admin & Logistics	9	17	18	19	20	21	22	24	26
Outreach/development									
Coordinator		46	48	51	54	56	60	64	69
Tech support		46	49	51	54	57	59	62	65
Interventions/Hackathons		11	12	12	13	13	14	15	16
Computing resources		26		60		70			90
Infrastructure		26		95		60			
Networking hardware		22	35	50					
SALT access (10%)	330	360	400	440	480	520	560	600	650
New telescopes (4)			7,500	7,500					
Annual Totals	526	1,789	9,360	10,499	2,052	2,016	1,996	2,081	2,280

Appendix

Names of Co-Investigators

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Bruno Schulze	National Laboratory of Scientific Computing
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Roberto Pinto Souto	National Laboratory of Scientific Computing
Carlos Alex Wuensche	National Institute for Space Research
Artur Ziviani	National Laboratory of Scientific Computing

Russia

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Dmitry Bisikalo	Institute of Astronomy of the Russian Academy of Sciences
Paul Boley	Ural Federal University
Rustam Dagkesamanskii	Puschino Radio Astronomy Observatory
Leonid Elenin	Keldysh Institute of Applied Mathematics of the RAS
Maxim Eselevich	Institute of Solar-Terrestrial Physics of Siberian Branch of the RAS
Sergei Grebenev	Space Research Institute of the Russian Academy of Sciences
Dana Kovaleva	Institute of Astronomy
Alexander Lutovinov	Space Research Institute of the Russian Academy of Sciences
Igor Molotov	Keldysh Institute of Applied Mathematics of the RAS
Sergey Naroenkov	Institute of Astronomy
Konstantin Postnov	Moscow State University after M.V.Lomonossov
Alexei Pozanenko	Space Research Institute of the Russian Academy of Sciences
Vasily Rumyantsev	Crimean Astrophysical Observatory of the Russian Academy of Sciences
Vladimir Samodurov	Puschino Radio Astronomy Observatory
Andrey Shugarov	Institute of Astronomy of the Russian Academy of Sciences
Sergey Tyulbashev	Puschino Radio Astronomy Observatory

India

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Ramana Athreya	Indian Institute of Science Education and Research, Pune
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Hum Chand	Aryabhatta Research Institute of observational sciences
Ishwara-Chandra CH	National Centre for Radio Astrophysics
Neeraj Gupta	Inter-University Centre for Astronomy and Astrophysics
Yashwant Gupta	National Centre for Radio Astrophysics
Ruta Kale	National Centre for Radio Astrophysics
Brijesh Kumar	Aryabhatta Research Institute of observational sciences
Kuntal Misra	Aryabhatta Research Institute of observational sciences
Jayant Murthy	Indian Institute of Astrophysics
Divya Oberoi	National Centre for Radio Astrophysics
Divendra Ohja	Tata Institute for Fundamental Research
Shashi Pandey	Aryabhatta Research Institute of observational sciences
M.C. Ramadevi	U. R. Rao Satellite Centre
Margarita Safonova	Indian Institute of Astrophysics
D. K. Sahu	Indian Institute of Astrophysics
K.P. Singh	Indian Institute of Science Education and Research Mohali
C. S. Stalin	Indian Institute of Astrophysics

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Shanshan Li	National Astronomical Observatories, CAS (EPO)
Changhua Li	National Astronomical Observatories, CAS (VO Platform)
Dezi Liu	South-Western Institute For Astronomy Research (SWIFAR)
Dongwei Fan	National Astronomical Observatories, CAS (VO RandD)
Zuhui Fan	South-Western Institute For Astronomy Research (SWIFAR)
Nicola Napolitano	Sun Yat-sen University (LSST)
Bo Peng	National Astronomical Observatories, CAS (SKA, FAST)
Zhiqiang Shen	Shanghai Astronomical Observatory, CAS (SKA, VLBI)
Roberto Soria	National Astronomical Observatories, CAS (NAOC)
Dong Xu	National Astronomical Observatories, CAS
Hua Feng	Tsinghua University
Ce Yu	Tianjin University (HPC, Clouding Computing)
Weimin Yuan	National Astronomical Observatories, CAS
Chichuan Jin	National Astronomical Observatories, CAS
Fengchun Shu	Shanghai Astronomical Observatory, CAS (VLBI)
Yihan Tao	National Astronomical Observatories, CAS (Data Mining)
Ge Zhang	Alibaba Cloud (Cloud industry partner)
Shu Zhang	Institute of High Energy Physics, CAS
Shuang-Nan Zhang	Institute of High Energy Physics, CAS
Qingguo Zhou	Lanzhou University (Cloud Computing)

South Africa

Bruce Bassett	South African Radio Astronomy Observatory
Markus Böttcher	North-West University
Sarah Blyth	University of Cape Town & IDIA
Christopher Cleghorn	University of Pretoria
Roger Deane	University of Pretoria & IDIA
Nicholas Erasmus	South African Astronomical Observatory
Kevin Govender	IAU Office of Astronomy for Development
Paul Groot	University of Cape Town & IDIA
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Vanessa McBride	IAU Office of Astronomy for Development
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