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The African Strategy of Fundamental and Applied Physics

Report of the 2020–2024 Community Study on the Future of Fundamental and Applied Physics in Africa

Organized Through Broad Grassroots Community Consultations

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Acknowledgements

The African Strategy of Fundamental and Applied Physics brought together over 600 participants worldwide to develop a strategic vision, with practical recommendations, to enhance physics research and education in Africa.

Foreword

In this space, the ASFAP Steering Committee will describe their view of the Study, and thank everyone who needs to be thanked.

Executive Summary

The African Strategy of Fundamental and Applied Physics brought together over 600 participants worldwide to develop a strategic vision, with practical recommendations, to enhance physics research and education in Africa.

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Ethics in Physics

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2.1 Introduction

Ethical behavior within the African Strategy on Fundamental and Applied Physics (ASFAP) has been governed by a code of conduct (COC) [1], which is a set of core principles and community guidelines to which members of the ASFAP community must adhere. Registration to any working group implies that the member has read and accepted the ASFAP COC. The COC was drafted by the ASFAP steering committee but it subsequently fell under the responsibilities of a four-member ethics committee, which had been established to review and act as custodians of this document. It has been the task of the ethics committee to amend this document whenever necessary, while ensuring that ASFAP remains a community where everyone feels welcome and respected. In addition, members of the ethics committee have been mandated to serve as ombudspersons if need arises. We're pleased to report that, so far, we have not received any reports of conflicts within the ASFAP community requiring our intervention. Therefore, this report only outlines amendments we have made to the COC to date.

2.2 Amendments to the code of conduct

Between June 2021 and March 2022, we held several meetings to review contents of the COC and made adjustments and addendums in addition to some general textual editing. We also incorporated a few suggestions received from the steering committee. The current version of the COC was implemented in March 2022. Highlighted below are some of the "major" edits/addendums to the document.

2.2.1 Authorship

Very often there are ethical questions raised around large authorship papers in terms of each author's contribution to the body of work that has been published. In some cases, names are included as authors 'only because it was always done'. Therefore, the ethics committee decided that this matter needed to be covered in the COC. The following text was thus added to section 3(d) of the COC [1].

“Authorship offers credit for an individual’s contributions to a study. It also holds the author accountable for the content in a published paper. All individuals who carried out the work are responsible for the decision on who should be listed as an author when that work is published. Any individual who makes a significant contribution to the work (as agreed by everyone contributing to the paper) should be listed as an author. Any other individual or organization should be acknowledged accordingly. In case of conflict, working group conveners should be contacted in order to help resolve the conflict. If the conveners and the contributors are unable to reach a consensus, the ethics committee should be contacted.”

2.2.2 Email Communication

For a community involving hundreds of people, poor use of email communication could be problematic if not addressed. For example, one member could send a personal email to another member (e.g to congratulate them on an important achievement) but adding a larger email group in cc. This may be an issue if several other members reply to this email with everyone in copy. The ethics committee felt that this borders on the “unethical use of email communication”. Hence, the text below was added to the COC as a bullet point in section 3(c).

“**Ethical use of email communication**: If your email concerns an individual person or a closed group of individuals, do not write to or reply to everyone in a general list. In addition, email communication should be done in a respectable manner, respecting the rest of this document’s guidelines. Be also conscious of the fact that members of the ASFAP community are in different time zones. Therefore, prompt responses should not always be expected.”

2.2.3 Guidelines on Virtual Meetings

Given that ASFAP meetings were mostly virtual and a number of them were held during the covid-19 pandemic, the steering committee advised the ethics committee to add a section on guidelines for such meetings to the COC. The text below was thus added to section 3(e).

“As members of ASFAP are located in various places across the globe, virtual meetings are inevitable. In addition, due to the ongoing pandemic, virtual or hybrid conferences/workshops may also be inevitable. To facilitate the smooth running of such meetings, members of the ASFAP community and invited guests should adhere to the guidelines listed below:

- Meeting times should accommodate participants from all time zones. Meeting minutes and/or recordings should also be made available on the meeting web page.
- Meeting hosts should ensure that only the speaker’s microphone is ON at any given time.
- Participants should use the raise hand feature found in online meeting solutions (e.g. Zoom), or type their comments/questions in the chat box. Otherwise, participants should wait for an appropriate opportunity to comment or ask questions without interrupting other participants.
- Conveners should ensure that each participant receives an equal opportunity to participate in the discussion.

- Given that many individuals are currently working remotely, conveners should ensure that the meeting durations are respected. Virtual meetings tend to go overtime, but participants' time zones and personal lives should be respected."

Even though we have now gone past the pandemic, many individuals have continued to work from home for various reasons. Therefore, we believe that the last bullet point above still applies, and we have decided to keep it in the COC.

2.2.4 General Edits

- In section 5(b), we replaced "moderator/host/code of conduct committee" by "convener/host/observer/ethics committee" because we believe that members of the observers committee should also be able to speak up in case of violation.
- Throughout the COC document, we removed parts that mention contacting an individual's institution if the individual violates the COC. We believe this is unnecessary as in many cases, members of ASFAP are by no means representing their institutes

2.3 Conclusion

We have highlighted the major addendums and edits that we have made to the COC document since our engagement as its custodians. To date, no violations to the COC that needed our intervention have come to our attention. We believe that we would have done our job very well if there are zero complaints that come to us. Therefore, rather than being passive about these matters, our plan was to implement a way to constantly educate the community about these issues in a smart and non-intrusive manner. This could, for example, be a five minute slot at every meeting with conveners to remind them of the COC and its importance. However, we have not been able to enforce this during this strategy and we hope that future custodians of ASFAP's COC will keep these ideas alive and discussed in the public domain from time to time.

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Accelerators Working Group

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5.1 Introduction and Motivation

Accelerator physics is the study of the design, operation, and applications of particle accelerators, which are devices that use electromagnetic fields to accelerate and manipulate charged particles. Particle accelerators have many uses in science, medicine, industry, and security, such as producing beams of high-energy photons, electrons, protons, or ions for nuclear physics, nuclear medicine, materials science, radiation therapy, and nuclear security. This field holds the key to transformative advancements in various scientific and technological domains. While this discipline has made significant strides globally, the landscape of accelerator physics in Africa presents a unique set of challenges and opportunities.

In recent years, accelerator facilities have become indispensable tools for fundamental research, material science, medical applications, and industrial processes. However, despite the increasing importance of accelerator-based technologies, Africa faces distinctive hurdles in establishing and maintaining state-of-the-art accelerator facilities. The demand for accelerator physics expertise in Africa is experiencing remarkable growth, fueled by the continent's ambitious pursuit of scientific and technological advancements. However, this progress is met with considerable challenges arising from limited resources, infrastructure, and research funding. Despite these barriers, notable strides are being made in accelerator science across the continent. With over 324 facilities distributed in 56 countries around the world, several accelerator facilities have been established in Africa, showcasing a commitment to advancing nuclear and particle physics research [1]. Notably, Algeria hosts one Electrostatic Accelerator at the Centre de Recherche Nucleaire d'Alger [2], while Tunisia operates an Accelerator-Based Neutron Source at the Centre National de Sciences et Technologies Nucleaires. In Egypt, the Atomic Energy Authority oversees one Electrostatic Accelerator, and Zagazig University houses an Accelerator-Based Neutron Source. Ghana boasts an Electrostatic Accelerator at the Accelerator Research Centre, while Nigeria is equipped with an Electrostatic Accelerator at the Centre for Energy Research and Development. South Africa leads the continent with six accelerator facilities, including two Accelerator-Based Neutron Sources at Nesca and iThemba, and three Electrostatic Accelerators at the University of Pretoria, iThemba Labs in Johannesburg, and iThemba Labs in Cape Town. These installations stand as beacons of scientific progress, contributing to the broader landscape of accelerator physics in Africa.

Nevertheless, the field of accelerator physics in Africa has witnessed a growing momentum as researchers and institutions strive to harness the potential of particle accelerators for diverse applications. From fundamental research in nuclear and particle physics to applications in medical diagnostics and materials science, African scientists are actively engaged in pioneering initiatives. Several countries on the continent have made notable strides in accelerator-based research, showcasing the commitment to advancing scientific frontiers. Collaborative efforts among African nations and international partnerships have resulted in the establishment of accelerator facilities aimed at addressing both local and global challenges.

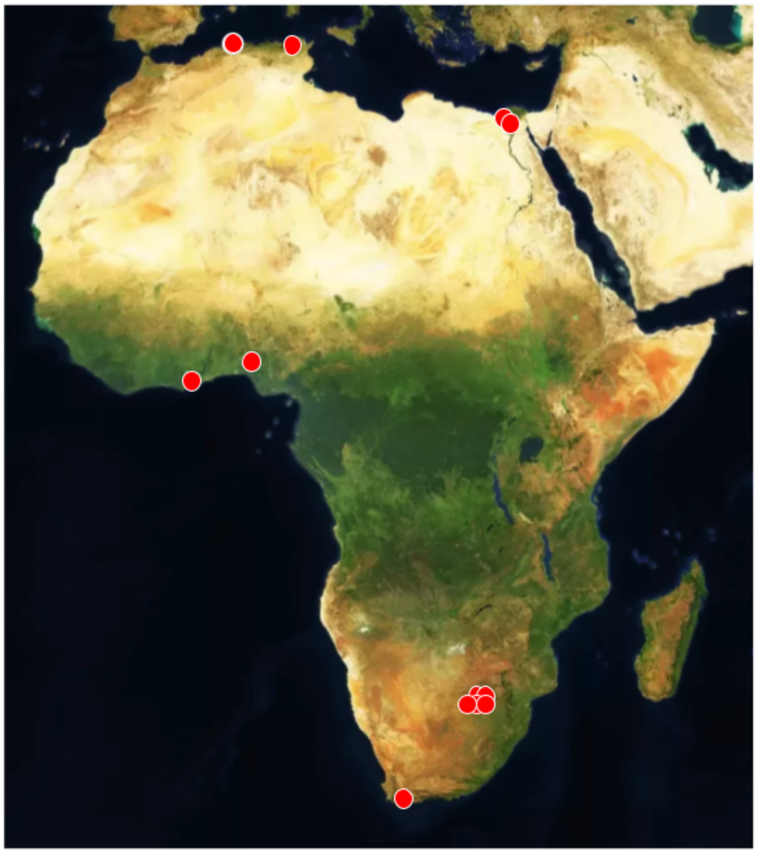

Figure 5-1. *IAEA Physics Section's Developed and Maintained Interactive Map Showcasing Accelerators Across Africa [1]*

5.2 Accelerator Physics Capacity in Africa

Within the realm of accelerator physics in Africa, a spectrum of scientific activities unfolds, reflecting a diverse range of research endeavors. Countries such as South Africa, Nigeria, and Egypt, among others, have emerged as focal points for accelerator-based investigations. These endeavors encompass fundamental studies in nuclear and particle physics, exploring the fundamental building blocks of matter and unraveling the mysteries of the universe.

One noteworthy example is the iThemba LABS facility in South Africa, a prominent accelerator center that serves as a hub for nuclear and particle physics research. Researchers at iThemba LABS are engaged in investigations spanning nuclear structure, astrophysics, and materials science, contributing valuable insights to both fundamental science and applied technologies.

Collaborative efforts are a hallmark of the accelerator physics landscape in Africa. Initiatives like the African School of Fundamental Physics and Applications (ASP) bring together physicists from across the continent to share expertise, foster collaborations, and train the next generation of scientists. ASP not only facilitates knowledge exchange but also strengthens the scientific network within Africa, positioning the continent as an active participant in the global scientific community. Moreover, accelerator applications extend beyond theoretical explorations to practical solutions for societal challenges. Medical physics research, utilizing accelerators for cancer treatment and diagnostic imaging, is gaining momentum in several African countries. These initiatives aim to enhance healthcare infrastructure and address pressing medical needs, showcasing the tangible impact of accelerator physics on improving lives.

In energy research, accelerator-driven systems are explored as potential solutions for sustainable power generation. African researchers are actively involved in studying accelerator-driven subcritical systems for nuclear energy applications, contributing to the quest for cleaner and more efficient energy sources.

As we delve into the scientific activities of accelerator physics in Africa, this section will provide a comprehensive overview of key projects, collaborative initiatives, and advancements that underscore the vibrant and dynamic landscape of accelerator research on the continent.

5.2.1 The iThemba LABS

The main facility for accelerator physics research and facilities in Africa is iThemba Laboratories for Accelerator Based Sciences (LABS), which is a business unit of the National Research Foundation (NRF) in South Africa. iThemba LABS operates the only cyclotron facilities in the African continent and the separated sector cyclotron is the largest accelerator facility in the Southern Hemisphere. The k-200 separated sector cyclotron can accelerate protons to energies of 200 MeV, and heavier particles to much higher energies. iThemba LABS provides access to state-of-the-art research infrastructure, both locally and globally, to facilitate activities that probe the nature, structure and properties of matter and materials, and to produce radioisotopes that can be used for diagnostics, imaging and therapy in nuclear medicine applications.

iThemba LABS has embarked on a recapitalization program, the overall objective of which is to safeguard the long-term sustainability of Africa's most unique Accelerator Based research facility. The first pillar of this program is the South African Isotope Facility (SAIF) [3], which is dedicated to research infrastructure renewal whose accomplishment is geared to achieve the twin objectives of increase in radioisotope production and research on the one hand, and the freeing up (on the other hand) of beamtime from the 200 MeV Separated Sector Cyclotron which will be dedicated for sub-atomic physics research and applications. The first phase of SAIF is centred around the acquisition of a 70 MeV Cyclotron to enhance research and production of radioisotopes for nuclear medicine. In addition, iThemba LABS has two laboratories dedicated to research at the atomic scale using particle beams from a 3-MV Tandetron and a 6-MV Tandem accelerator. These laboratories offer various techniques for ion beam analysis, ion implantation, subatomic physics, and environmental isotopes. iThemba LABS also collaborates with other international facilities and networks, such as the African light Source (AfLS), which is an initiative to build a synchrotron light source on the African continent.

5.2.2 CERD Nigeria

The Particle Accelerator Facility located at the Centre for Energy Research and Development (CERD) within Obafemi Awolowo University, Ile-Ife, Nigeria, was inaugurated on September 28, 2008, primarily for Ion Beam experiments utilizing a single beam line. The establishment of this facility was made possible through the collaborative efforts of the Federal Government of Nigeria and the International Atomic Energy Agency Technical Cooperation (IAEA TC) Project NIR 1010. The accelerator itself is a NEC 5SDH 1.7MV Pelletron Accelerator, a product of the National Electrostatics Corporation (NEC) based in Middleton, WI, USA. Notably, in 2016, a significant enhancement was made to the facility by introducing a second beam line, complete with an NEC RC43 end-station, thus further augmenting its capabilities and research potential.

The Ion Beam Analysis (IBA) facility at CERD revolves around the utilization of a NEC 5SDH 1.7 MV Pelletron Accelerator, incorporating an RF charge exchange ion source capable of generating both proton and helium beams [4]. Although the accelerator can accommodate up to five beam lines, our current configuration focuses on maintaining two operational beam lines. One of these lines is furnished with a versatile End Station designed for four distinct analytical techniques: Particle Induced X-ray Emission (PIXE), Rutherford Backscattering (RBS), Elastic Recoil Detection Analysis (ERDA), and Particle Induced Gamma-ray Emission (PIGE). Meanwhile, the second beam line houses an NEC RC 43 End Station, similarly equipped with these four techniques, with added capabilities for conducting grazing experiments on thin samples, thereby enhancing our capacity for material studies. The application spectrum of our facility spans across a multitude of fields, encompassing mineralogy, geological analysis, agricultural assessments of soil and plant samples (including leaves, fruits, and seeds), biomedical and biological research, environmental pollution monitoring, air quality assessments, materials science investigations, thin film studies, as well as archaeological and cultural heritage analyses.

5.2.3 PELLETRON Accelerator in GHANA

The Ghana National Accelerator Project, initiated in 2008, aimed to acquire and install a 1.7MV Pelletron Accelerator in Ghana, facilitated through cost-sharing with the International Atomic Energy Agency (IAEA). This endeavor saw the generous donation of the accelerator, complete with Ion Source and high-energy end components, from the Government of the Netherlands. The refurbishment of the accelerator and the procurement of a complete beamline, as well as its subsequent installation, were financed by the IAEA. In turn, Ghana contributed by providing essential local infrastructure, including the construction of the facility building, electrical installations, air conditioning, and water and compressed air systems. Furthermore, the project prioritized human capacity building, with support from the IAEA. This included sponsorship for staff training in accelerator technology and applications, such as through the IAEA sandwich PhD program in advanced accelerator laboratories. Additionally, technicians received specialized training in accelerator systems maintenance, fostering local expertise in maintaining and operating the facility. Staff members also actively participated in the refurbishment of the accelerator in Groningen and were involved in the installation process alongside NEC Technicians, culminating in an Acceptance Test conducted by IAEA experts. This concerted effort not only realized the establishment of the Pelletron Accelerator in Ghana but also empowered local personnel with the necessary skills and knowledge to effectively utilize and maintain this advanced scientific infrastructure.

The accelerator was commissioned on March 2016, while its performance since its installation has been generally satisfactory, there have been some challenges and breakdowns encountered along the way. However, most of these issues have been successfully resolved, in some cases with or without the assistance from the

NEC supporting Team. This collective effort not only ensured the establishment of advanced scientific infrastructure in Ghana but also facilitated the development of local expertise in accelerator technology and operations. Through continuous maintenance and improvement efforts, the accelerator continues to contribute significantly to scientific research and educational initiatives in the region, further solidifying Ghana's position in the field of accelerator physics and related disciplines.

5.3 Instrumentation and Control Systems Capacity in Africa

South Africa leads the continent in instrumentation and control systems with several institutions and initiatives driving advancements in this field. iThemba LABS, SARAO, SKA, Necsa, and St. James Software are key players, each contributing expertise and infrastructure to various scientific endeavors. iThemba LABS, for instance, not only houses advanced accelerators but also excels in instrumentation and control systems crucial for monitoring and managing these facilities. SARAO and SKA are at the forefront of radio astronomy, deploying cutting-edge instrumentation and control systems to operate telescopes and process vast amounts of astronomical data. Necsa, the Nuclear Energy Corporation of South Africa, focuses on instrumentation and control systems for nuclear applications, ensuring safety and efficiency in nuclear facilities and research. Moreover, entities like St. James Software provide innovative solutions such as the JlogBook e-log-book, enhancing data management and collaboration across scientific disciplines. Furthermore, African countries actively participate in international collaborations like CERN, where they engage in technology transfer, operations, upgrades, and instrumentation development, leveraging advancements in areas such as artificial intelligence to drive scientific progress and innovation both locally and globally. These efforts collectively demonstrate Africa's growing expertise and capacity in instrumentation and control systems, essential for driving scientific research and technological innovation across various disciplines.

5.4 Diverse Applications of Accelerator Physics Across Various Fields

Accelerated particles are used in a wide range of applications spanning various scientific disciplines and industrial sectors. From fundamental research in nuclear physics to practical applications in medicine, materials science, and beyond, accelerator-based techniques play a pivotal role in advancing scientific knowledge, technological innovation, and societal progress. In this section, we explore the diverse array of applications enabled by accelerator physics.

5.5 High-priority future needs

- **Infrastructure Development**: Accelerator physics in Africa faces a crucial need for the development and enhancement of research infrastructure. Investing in state-of-the-art accelerator facilities, upgrading existing ones, and establishing new centers will be pivotal for conducting cutting-edge experiments and staying at the forefront of global scientific advancements.

- **Human Capital Development**: The shortage of skilled personnel poses a significant challenge. Initiatives for training and capacity building in accelerator physics are essential. Collaborative programs, workshops, and educational partnerships can play a vital role in nurturing the next generation of African physicists, engineers, and technicians.

- **International Collaboration**: Strengthening collaboration with international partners is a high-priority need. This involves fostering partnerships with established accelerator centers worldwide, participating in joint research projects, and facilitating knowledge exchange. International collaborations provide access to expertise, resources, and opportunities for African scientists to contribute meaningfully to global scientific endeavors.

5.6 Synergies with neighbouring fields

Accelerator technologies play a pivotal role in medical physics and healthcare, contributing to cancer treatment through radiation therapy and medical imaging. Moreover, accelerator-based techniques in materials science and nanotechnology significantly impact research and development, offering powerful tools for ion-beam analysis and materials characterization. Environmental science and geophysics benefit from accelerator applications, particularly in studies related to archaeology, climate change, and geological processes. The intersection of accelerator physics with nuclear physics and astrophysics is evident in research exploring nuclear structure, reactions, and astrophysical phenomena. Accelerator technologies also drive technological innovation and industry applications, influencing semiconductor manufacturing, ion implantation, and non-destructive testing. Furthermore, accelerator initiatives contribute to education and capacity building, offering training programs and workshops that empower the next generation of scientists and technologists. Collaborations with international research institutions underscore Africa's role in global scientific endeavors, fostering knowledge exchange and joint projects. Through these synergies, accelerator physics emerges as a catalyst for holistic scientific progress, bridging diverse fields and expanding the frontiers of knowledge in the African context.

5.7 Clinical Linacs Driving Cancer Treatment Across Africa

Clinical Linacs, short for Clinical Linear Accelerators, are sophisticated medical devices primarily used in the treatment of cancer through a process called radiation therapy. These machines generate high-energy X-rays or electrons, which are directed towards the patient's tumor to destroy cancerous cells while minimizing damage to surrounding healthy tissues.

he proliferation of clinical Linacs across Africa marks a significant advancement in the region's capacity to provide essential cancer treatment services. According to the IAEA DIRAC (DIrectory of RAdiotherapy Centres), there are approximately 432 Linacs dedicated to MV Therapy spread across the continent [5]. Notably, North Africa boasts the largest share with 237 Linacs, followed by 107 in the southern region and 88 in the central part of the continent (see Fig. 5-2).

This distribution underscores the commitment of African nations to improve access to radiotherapy services, addressing the pressing healthcare needs of their populations. With Linac technology widely available across different regions of Africa, more patients can receive timely and effective treatment, contributing to improved cancer outcomes and enhanced healthcare infrastructure continent-wide

5.8 Conclusion and perspectives

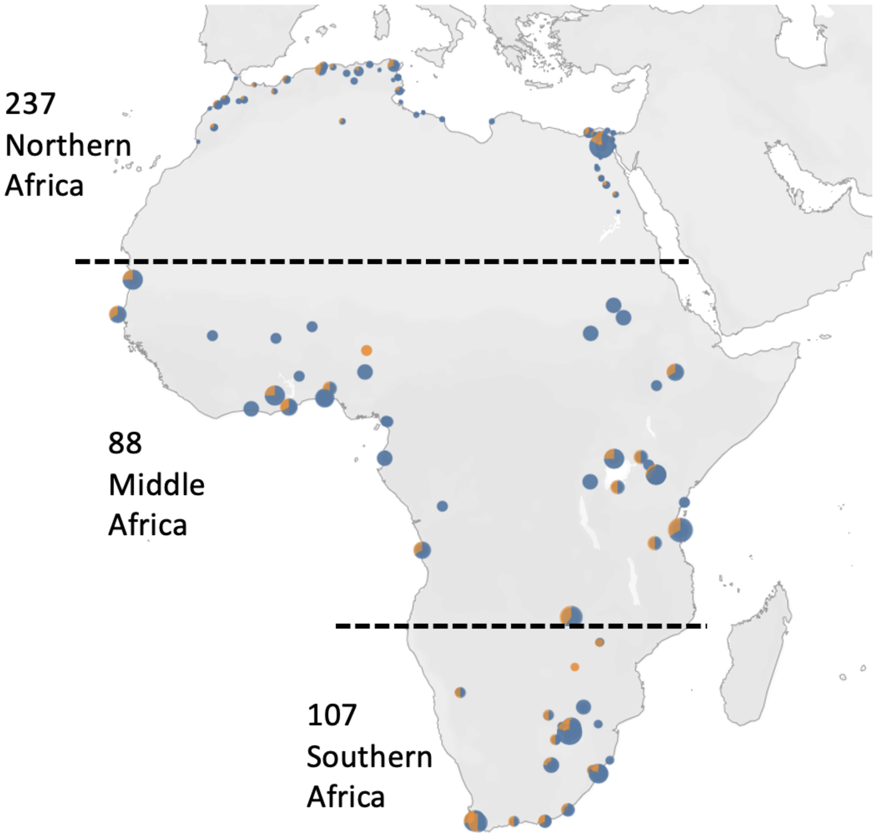

Figure 5-2. *Status of Radiation Therapy Equipment in Africa*

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6

Astrophysics & Cosmology Working Group

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Abstract

This report summarises the current status and future plans of the Astrophysics and Cosmology Working Group (WG) under the African Strategy for Fundamental and Applied Physics (ASFAP). It gives a brief introduction to astronomy developments in Africa in the last ten years, showing that astronomy is one of the emerging fields of science on the continent. It describes the structure of the ASFAP Astrophysics and Cosmology WG, its objectives, and the activities carried out. It finally describes the received Letters of Interest and the way forward in the development of the Strategy.

6.1 Status of astronomy developments in Africa

Astronomy is currently one of the emerging science fields in Africa. This can be observed through different activities, from institutional and infrastructure developments, human capacity building, research and publications, creation of professional societies and networks, up to the growth in outreach activities and amateur astronomical societies.

Over the last ten years, there has been a strong institutional development in astronomy, with many newly established space agencies, research centers, and astronomy departments under the universities (e.g., in Egypt, Ethiopia, Gabon, Ghana, Kenya, Morocco, Nigeria, Rwanda, South Africa, Sudan, etc.; see Ref. [1] for more information). Infrastructure development has been also remarkable, building from small to some of the largest telescopes in the world. Figure 6-1 (central map) shows some of the existing and forthcoming telescopes and observatories. In radio astronomy, the Square Kilometer Array (SKA)[1] together with the African Very-Long-Baseline Interferometry (VLBI) Network (AVN)[2] are some of the principal initiatives, with the center in South Africa and partnership with Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia. All of these countries signed in 2019 a memorandum of understanding to work jointly on the development of radio astronomy. The MeerKAT[3] radio interferometer, the African SKA precursor, with 64 dishes located in South Africa, already started its operation in 2018 and is producing some of the most detailed images of the Universe in radio. In addition, Namibia is building the African Millimeter Telescope (AMT [2, **?**]), the very first millimeter radio telescope on the African continent, while South Africa is working on the establishment of the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX)[4] radio interferometer. All of the mentioned telescopes form a part of large international collaborations. In optical astronomy, South Africa is hosting the largest 11m South African Large Telescope (SALT)[5] , and a number of different optical telescopes at the South African Astronomical Observatory (SAAO)[6] in partnership with different countries. Morocco also established through different international collaborations several small telescopes at the Oukaïmeden Observatory[7]. Small, 1 - 2m optical telescopes have also been established in several other countries and/or are in the process of being established soon, like in Algeria, Burkina Faso, Egypt, Ethiopia, and Kenya [1]. In addition, Namibia, in collaboration with Germany, is hosting the High Energy Stereoscopic System (H.E.S.S.)[8] Cherenkov telescope for the study of cosmic gamma rays.

New post-graduate programs (MSc and PhD) in astronomy and astrophysics increased across the continent, as well as the number of professional astronomers (e.g., in Algeria, Botswana, Burkina Faso, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Mauritius, Morocco, Namibia, Nigeria, Rwanda, Senegal, South Africa, Sudan, Uganda, Zambia, Zimbabwe, etc.). This brought a strong development in astronomy research across the continent (e.g., the number of published research papers tripled from 2011 until 2021; source SRJ-Scimago Journal and Country Rank). As a result, the African Astronomical Society (AfAS)[9] was re-established in 2019, with strong support from the South African Department of Science and Innovation, with an aim to become a voice of astronomy development in Africa. In close collaboration with AfAS, several other initiatives arose such as the African Planetarium Association (APA)[10], the African Network of Women in Astronomy (AfNWA)[11], the African Science Stars (ASSAP)[12], or the Africa-Europe Science Collaboration and Innovation Platform (AERAP)[13]. Africa is also hosting the International Astronomical Union (IAU) Office of Astronomy for Development (OAD) , including three Regional OAD[14] Offices in Ethiopia, Nigeria, and Zambia. Finally, public awareness and outreach activities increased exponentially across Africa in the last ten years, including the establishment of more than 70 amateur astronomical societies, as can be seen in Figure 6-1(left bottom map).

Despite strong astronomy developments, there are still many challenges and needs to be addressed. For example:

[1]https://www.skatelescope.org/africa/
[2]https://www.sarao.ac.za/science/avn/
[3]https://www.sarao.ac.za/science/meerkat/
[4]https://hirax.ukzn.ac.za/
[5]https://www.salt.ac.za/
[6]https://www.saao.ac.za/
[7]http://moss-observatory.org/
[8]https://www.mpi-hd.mpg.de/hfm/HESS/
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[10]https://africanplanetarium.org/
[11]https://afnwa.org/
[12]https://assap.co.za/
[13]https://aerapscience.org/
[14]https://www.astro4dev.org/

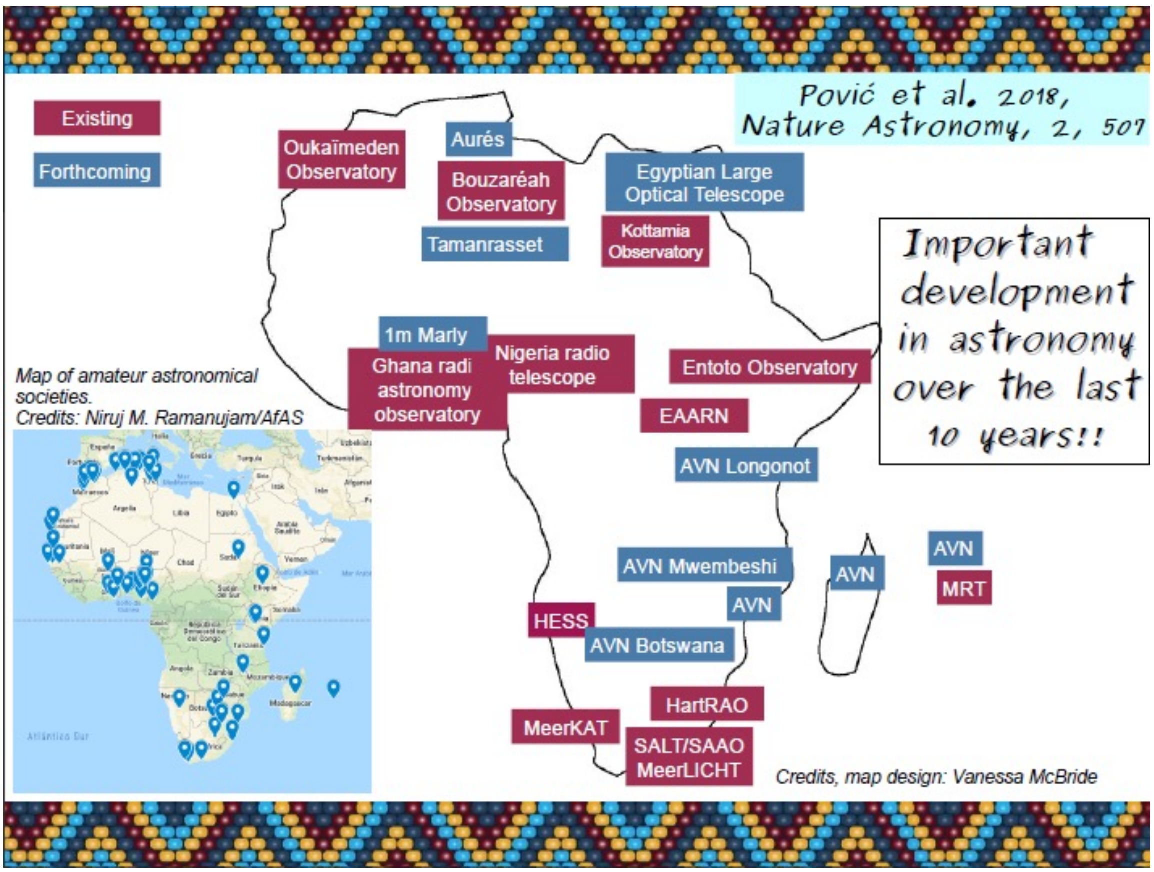

Figure 6-1. *Central map: Existing and forthcoming telescopes and observatories in optical, radio, and gamma-rays, produced by Vanessa McBride using the data from Ref. [1]. Left bottom map: Amateur astronomical societies in Africa produced by the Niruj M. Ramanujam, under the African Astronomical Society (AfAS).*

- Most of the countries are starting from scratch with astronomy developments and therefore need significant support;
- There is a limited number of human resources, plus the limited qualified sector to support all the needs and perform all the activities (this includes a small number of available MSc/PhD scholarships in astronomy and open job positions);
- There is often a lack of supportive infrastructure for scientific (astronomy) developments;
- There is a lack of funding (secured in the long term) and support from local governments;
- Many countries suffer day-to-day difficulties with power and internet cuts that may have a significant impact on scientific developments;
- Astronomy in Africa is still not accessible to everyone; and
- There is a need for more awareness to be done among the general public, policy- and decision-makers regarding the importance of astronomy and science for African growth and socio-economical and environmental development [4].

ASFAP is therefore timing, to address the strong current developments in astronomy in Africa, but also to highlight the current and future needs.

6.2 ASFAP Astrophysics and Cosmology Working Group

The Astrophysics and Cosmology Working Group (WG) is one of the 16 created ASFAP physics WGs. It was established with the aim to inform the public and decision-makers about the impact that astronomy may have on African growth and to develop a part of the Strategy that will serve as a Road Map for future astronomy developments. The principal objectives of this WG are:

- To give more visibility to the current astronomy developments in Africa, including some of the long-term initiatives and international partnerships related to institutional/infrastructure developments and human capacity building;
- To bring together all astronomical community for designing the Strategy that will summarise the vision of professional astronomers where astronomy and science in Africa shall be in the future and how they will benefit African social and economical development;
- To facilitate the decision- and policy-makers to develop their strategies toward sustainable African growth through astronomy/physics, science, technology, and innovation.

The WG is coordinated by five co-conveners, Bernard Asabere (Ghana/The Netherlands), Lerothodi Leeuw (South Africa), Sivuyile Manxoyi (South Africa), Priscilla Muheki (Uganda), and Mirjana Pović (Ethiopia/Spain). It currently has more than 130 members, from 34 countries (including 20 from Africa, 8 from Europe, and 5/1 from Asia/South America). Members cover all professional stages, from MSc and PhD students, through early-career researchers, up to senior researchers. Regarding gender identity, 64%/34%/2% of members identified as male/female/other, respectively. All members were invited to join one or more of the 11 defined working subgroups. These subgroups are: solar physics, solar system, planetary sciences, and astrobiology, stellar astronomy, galactic and extragalactic astronomy, cosmology and gravitational astronomy, transients and pulsars, high-energy astrophysics and astro-particle physics, astronomical instrumentation and infrastructure, astronomical methods and data, ethno-archeoastronomy (cultural astronomy), and astronomy for development. Figure 6-2 shows the number of members per working subgroup. It can be seen that the majority of members (> 60%) are interested in the use of astronomy for the development of our society. Astronomical methods and data is the second most populated subgroup, followed by cosmology and gravitational astronomy, and galactic and extragalactic astronomy. Figure 6-2 also broadly reflects which fields of astronomy are less developed in Africa and have a smaller number of experts, such as solar physics and transients and pulsars.

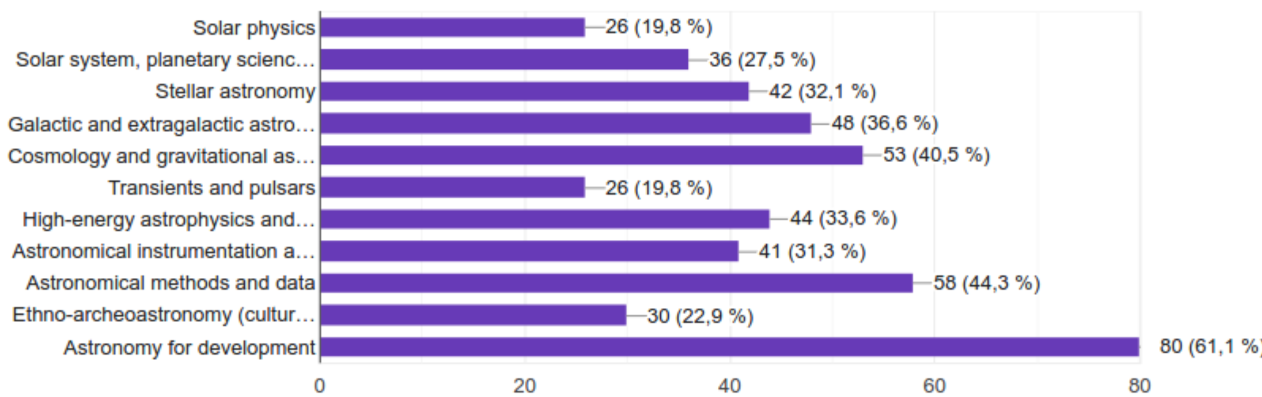

Figure 6-2. *The number of ASFAP Astrophyisics and Cosmology WG members per each defined working subgroup.*

Some of the principal activities carried out under the Astrophysics and Cosmology WG include:

- Promotion of ASFAP through different professional networks for inviting the professional community to join the WG.
- Organisation of several meetings for giving information about ASFAP and for creating the proper strategy of Astrophysics and Cosmology WG.
- Participation of the WG in the African Physics Conference in March 2022.
- Promotion of ASFAP and Astrophysics and Cosmology WG through more than 10 invited talks, including the summary given during the AfAS annual conference in March 2022 and during the special session on African-European collaborations in astronomy at the annual meeting of the European Astronomical Society in August 2022.
- Participation of the WG in the discussion led by the ASFAP Youth in Physics Forum about the WG strategy and the importance of astronomy for African development.
- Distribution of the call for ASFAP Letters of Interest (LoI) among the astronomical community.
- Discussion about received LoI, and identification of those that are still missing and that shall be addressed in the coming White Papers.

6.3 Status of received Letters of Interest

Until the date of this report, we received 13 LoI (out of 68, 20%) with Astrophysics and Cosmology being indicated as the primary physics WG. The received LoI cover radio astronomy, gamma-rays and optical observational astronomy, cosmology, and astronomy for development. Most of them, describe the initiatives/projects that are already running, but there are also several LoI with new proposed developments. In continuation, we are providing a summary of received LoI and their suggestions:

- African Radio Astronomy Network (James Chibueze, NWU/South Africa), suggests building a network of small and cheap radio telescopes, with an aim to provide training in radio astronomy across Africa and to undertake research with the ultimate aim of getting African astronomers to participate in the SKA science.
- Astro-particle and cosmology potential in the underground of Africa (Fairouz Malek, CNRS/France, and Yasmine Sara Amhis, IJCLab/France), addresses the opportunity for African countries to contribute to the enhancement of the knowledge and understanding of the fundamental aspects of the Universe by building and leading underground experiments similar to IceCube, ANTARES, Kamioka neutrino observatory, SNOLAB, etc.
- Continued gamma-ray observations with H.E.S.S (Michael Backes, UNAM/Namibia), addresses the importance of H.E.S.S telescopes for the current gamma-ray observations, and for the development of the future Cherenkov Telescope Array (CTA).
- Development in Africa with Radio Astronomy (Melvin Hoare, University of Leeds/UK), describes the DARA project that has provided basic training in radio astronomy to over 300 young graduates across eight African countries, and scholarships to 26 MSc and 9 PhD African students, with perspectives to continue with the work in future.
- Furthering the sustainable development goals in Africa by exposing young children to the beauty, excitement and perspective of astrophysics (George Miley, Leiden University/The Netherlands), suggests that ASFAP incorporates into its strategy the use of physics in the education of very young children (4 - 10 years old), particularly those in underprivileged communities.
- Gamma-ray astronomy in the context of multi-wavelength astronomy and multi-messenger astrophysics (Markus Boettcher, NWU/South Africa), summarises opportunities for Africa to take on a driving role in the field of multi-wavelength and multi-messenger astrophysics.
- Low-frequency (¡ 1GHz) radio interferometric arrays and radio astronomy/cosmology (Patrice Okouma, Rhodes University/South Africa), suggests the development in space science and low-frequency (¡ 1.2 GHz) radio astronomy and cosmology.
- Observational astronomy in North Africa (Fairouz Malek, CNRS/France, and Mourad Telmini, University of Tunis El Manar/Tunisia), addresses the opportunity for North African countries to unite in contributing to build and lead a series of local observatories and/or one large facility.
- The first millimetre-wave radio telescope in Africa: the Africa Millimetre Telescope (Michael Backes, UNAM/Namibia), introduces the AMT and its impact on human capacity development in Namibia and Africa.
- The importance of the financial and technical support for the improvement of cosmology in Cameroon and in Africa (Ragil Ndongmo, University of Yaoundé I/ Cameroon), addresses the current difficulties in Cameroon regarding the studies in cosmology and brings some suggestions on how to overcome the existing challenges.

- The Lofar global citizenship radio array "GLORAY" (George Miley, Leiden University/The Netherlands), summarises a proposal to be submitted to ASTRON and to the International LOFAR Telescope Board to carry out a design study for a project that would transform LOFAR into a multidisciplinary facility that would span 3 continents, including Africa (in particular North Africa).
- The South African Radio Astronomy Observatory (SARAO) (Rob Adam, SARAO/South Africa), describes SARAO's vision, mission, objectives, and research infrastructure for radio astronomy developments in South Africa and Africa.
- Using Astronomy for Development in Africa (Kevin Govender, OAD-IAU/South Africa), summarises the activities, vision, and strategy behind the OAD, and suggests to ensure the growth of astronomy in Africa and to use the experience of the OAD to ensure that developmental impacts are fully realised.

These received LoI will provide the starting point for the development of White Papers under the ASFAP Astrophysics and Cosmology WG.

6.4 Conclusions & Recommendations

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Atomic & Molecular Physics Working Group

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7.1 Introduction

Recent advances in experimental and theoretical scanning probing methods at the atomic scale have led to tremendous applications in biology, medicine, electronics, quantum technologies, spintronics or heterogeneous catalysis. For example, insight into the structure of living cells, the single molecule transistor, the minute working of catalytic reactions allowing the rational design of catalysts and improvement of properties, just to cite a few. However, probing matter at the nanoscale on the African continent is still challenging, both theoretically and experimentally. This stems from the various limitations in research facilities.

Despite the population of about 1.3 billion, which are mainly youth, the research and development output of Africa is quite low in virtually all areas of physics. To quantitatively understand this abysmal performance, we analyse the amount of research articles published by African scientists (based in African institutions) from 2000 – 2021, see Figure 7-1. Over the last two decades, the total research output from Africa stands shy of 70,000 articles with about 6,000 per year in recent times. It will be interesting to know that these are comparable to the Brazil scientific research output over the same period. However, the dramatic rise of India over the same period clearly shows the need for understanding the problem facing African scientists. This graphical illustration could readily be linked to the poor economic performance of the Africa continent, the world's poorest inhabited continent according to the World Bank. This is basically demonstrated by the difficulty to access energy for community services (health, education and so on) as well as the lack/inadequate information and communication technologies among others [1]. Moreover, only Egypt and South Africa made it in the Top 40 of the world's research and development index in 2021 [2]. However, Africa Union Agenda 2063 has identified Physics – fundamental and applied as a key solution to address the developmental problems facing the continent [3].

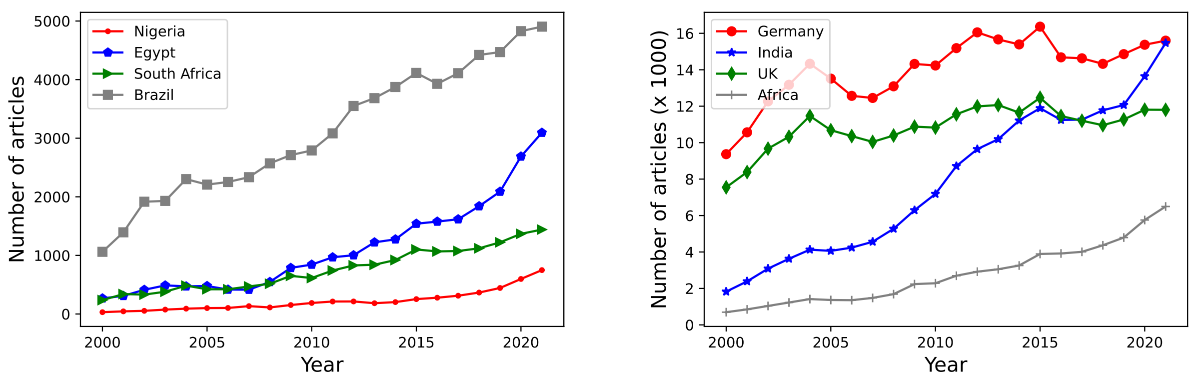

Figure 7-1. *Research output per year from 2000 – 2021 for search keywords: atoms, atomic, molecular, molecules, or ions.* ***Left panel*** *– The number of articles published by some African countries (Egypt, Nigeria, South Africa) compared to the Brazil.* ***Right panel*** *– The total articles published by African scientists (Algeria, Cameroon, Congo, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, South Africa, Tunisia) compared western countries (Germany and UK) and India. Source: Scopus – accessed October 8, 2022.[6]*

7.1.1 Challenges facing African scientists/physicists

On a theoretical point of view, electrical power instability in many countries does not allow sustainable computing and computational facilities are scarce, see Ref.[4] for more discussion. Most sub-saharan countries barely have supercomputers available for research. The few available facilities on the continent are concentrated in Northern Africa and South Africa. Researchers rely on the latter and on external partners such as the Abdus Salam International Centre for Theoretical Physics, Italy. A dependence that limits the productivity but also the size of the system to study simple molecules. Experimentally, resources are also scarce. For example, it is only recently that central Africa got its first operational AFM apparatus in what is likely the first nanotechnology laboratory in the Republic of Congo. Besides, the light source community is still to build the first synchrotron on the continent and relies on external sources and networks like the Synchrotron-Light for Experimental Science and Applications in the Middle East (SESAME) and the free and open-source software such as Large-scale Atomic/Molecular Massively Parallel Simulator (LAAMPS). Unfortunately, for Africa, international organizations often support research of their interest and are compounded by the government's ill-advised policies towards education.

Current support towards enhance research output

During the last decades, various research groups and networks have been active on the continent, thanks to some foreign collaborations/donors. These include Physics Department, Marien Ngouabi University (Brazzaville, Congo), CEPAMOQ (Douala, Cameroon), Lasers Atoms Laboratory, Cheikh Anta Diop University (Dakar, Senegal), Atomic Molecular Spectroscopy and Applications Laboratory, University of Tunis El Manar (Tunisia), Medical University of Southern Africa (South Africa), African Laser Atomic Molecular and Optical Science Network. In addition, there is growth in the study of materials sciences in Africa through the African School for Electronic Structure Methods and Applications (ASESMA).

As an extension of these efforts, African physicists from a variety of specializations are developing an African strategy for basic and applied physics, see https://africanphysicsstrategy.org/ [5]. Organized into several working groups, committees, and forums, they are working to produce a report to inform the African and broader community of strategic directions that can positively impact physics education and research over the next decade [7, 8].The report is intended to help African policy makers, educators, researchers, communities, and international partners prioritize resources and activities for physics education and research at the national, regional, and pan-African levels. As part of this group of African physicists, we have the task of coordinating the activities of the Atomic and Molecular Physics working group.

Atomic and molecular physics working group – journey so far and way forward

In the spirit of the ASFAP, the Atomic and Molecular Physics (AMP) working group aims at reporting on the state of research and knowledge transfer of these groups and their derivatives on the continental level but also on the various research carried by African scientists in AMP performed all over the world and that align to sustainable development goals. From the above-mentioned research groups and networks, we have identified and have traced the various African scientists still active in the field, their research interests and compiled their various achievements.

As part of this, we have successfully organised meetings and had an online workshop on Atomic and Molecular Physics in January 2022 during which the discussion is cantered on identifying challenges facing different research groups across the continent among others. These efforts, in conjunction with other ASFAP working group, have resulted in some letter of intents (LOIs) submitted for the strategies. In addition, after deliberation with the ASFAP Steering committee members and the Photonics and Optics working group during the second African Conference of Fundamental and Applied Physics ACP2021, there is a unilateral decision to merge the two working groups – *Atomic, Molecular and Optical Physics.* We believe that this will synergise interdisciplinary activities towards industrial and technological advancements.

To conclude, we advocate for physics-based policies in the various country, region and the continent at large. These will be geared towards development of human capital as well as engaging the private sectors for support. Finally, with the support of international collaborations, qualitative increase in the research output of Atomic, Molecular and Optical Physics in Africa will become a fruition.

7.2 High-priority future needs — on LOIs received

7.3 Synergies with neighbouring fields

7.4 Conclusion and perspectives

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8

Biophysics Working Group

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Abstract

This report is a serious call to scientists, innovators, investors, and policymakers to invest in the development of biophysics in Africa. The complex problems of our day demand multidisciplinary approaches, and biophysics offers training in much-needed multi- and cross-disciplinary thinking. Biophysics is a research field at the forefront of modern science because it provides a powerful scientific platform that addresses many of the critical challenges humanity faces today and in the future. It is a vital source of innovation for any country interested in developing a high-tech economy. However, there is woefully little biophysics educational and research activity in Africa, representing a critical gap that must be addressed with urgency. This report suggests key research areas that African biophysicists should focus on, identifies major challenges to growing biophysics in Africa, and underscores the high-priority needs that must be addressed.

8.1 Introduction and Motivation

Since the COVID-19 pandemic, many governments have expressed the need for Africa to be able to make its own therapeutics and vaccines. The first step for that to happen is investing in the basic and applied sciences and engineering research, and that especially means biophysics.

Why biophysics? This unique interdisciplinary field brings our understanding of biological processes to an unprecedently detailed level. Only when we understand nature's processes at a sufficiently deep level can we make reliable predictions and obtain sustainable technological solutions.

This is realised by numerous pharmaceutical companies where biophysics forms an indispensable component of drug discovery [1]. Dr. Martin Friede from the World Health Organization's Initiative for Vaccine Research took it a step further by stating, "It is impossible to develop the next generation of vaccines without biophysics" [2].

Consider Structural Biology, a subdomain of biophysics that aims to resolve and study the structure and dynamics of biological macromolecules such as proteins – the molecular machines of biological cells. Knowing the protein structure at the atomic level has enormous commercial potential in areas such as industrial enzymology and drug discovery. A fully resolved protein structure enables us to engineer proteins that can make new chemicals and to design molecules that interfere with the life-giving reactions of harmful pathogens or pests (i.e., drugs and pesticides). Structural Biology is therefore an important step to the global economic success of a country. It is particularly telling that over 80 Nobel prizes have thus far been awarded to the field of Structural Biology: 70 prizes for scientific discoveries and 11 prizes for experimental methods that enabled these discoveries [3].

Biophysics is not only concerned with scientific research. An integral component of scientific discovery in biophysics involves technological development. Innovative experimental and computational methods pave the way for new scientific discoveries and provide practical solutions across the broad domain of biological sciences. In this sense, biophysics is more than a basic science that feeds innovation, because innovation is an integral part of research in biophysics.

Biophysics revolutionised medical research and technology in the 20th century. It provided both the tools and the understanding for treating various diseases. These developments are accelerating in the 21st century. Biophysics addresses not only human health challenges but also plant and animal health. By understanding the minutiae of photosynthesis through decades of scientific research, rice and soy plants were recently engineered with 20–30

Biophysics research features in various aspects of the global effort to combat climate change. An important area of research and technological development in this regard is biomimetics, which originates from biophysics [7]. The design of environmentally friendly materials such as biodegradable plastics is one example. Another example is how biomimetics offers a useful perspective in addressing food security and sustainable energy, two of the great challenges of our time: we can gain inspiration from the efficacy and adaptability of photosynthetic organisms to produce food or fuel from sunlight using materials that are very abundant in nature (i.e., inexpensive and scalable) [8]. In addition, meeting food, water, and energy demands is not limited to mankind, but it is a basic need of essentially every cell of every living organism. It is therefore prudent to investigate how other living organisms meet these demands at various levels.

Quantum Biology is a new, emerging research field with enormous potential for science and technology. This field of research investigates how biological organisms use the principles of quantum mechanics to gain a physiological advantage in executing their physiological functions [**?**]. During the past few years, several research programmes focussing on Quantum Biology have been launched across the world [11]. It is important that Africa actively contributes to the development of this promising field of research. Applications of Quantum Biology could impact many technologies, such as energy, environment, health, sensing, and information technologies [**?**]. Learning from life will not only lead to new technologies but also to new fundamental insights in physics, chemistry, and biology. For example, in the medical field, it is known that light enhances wound healing and effectively treats different types of cancer, and when applied to the brain it can have a range of physiological effects such as improved attention, memory, executive function, and rule-based learning [12]. Identifying how quantum effects might play out in the brain could offer a completely new way of imagining medical intervention beyond the purely chemical.

The term "century of biology" was coined for the 21st century in the context of biotechnological development [13] to address several critical global challenges. Biophysics plays an indispensable role both in establishing the crucial scientific basis and in bridging the gap between science and technology.

A strong and diverse biophysics research and commercial sector is essential for the success of the African economy. The importance of the bioeconomy has been recognised by numerous countries. For example, the UK [14], EU [15], USA [16] as well as South Africa [17] have formulated strategies to move away from the traditional industrial base and instead develop a strong bioeconomy. Notably, biophysics is an indispensable component of these bioeconomy strategies.

8.2 Key research areas requiring biophysicists

The most important Sustainable Development Goals (SDGs) of the United Nations that biophysics addresses directly are 2. Zero Hunger, and 3. Good Health and Wellbeing. Biophysics research contributes to several additional SDGs, albeit usually indirectly, viz. 1. No Poverty; 8. Decent Work and Economic Growth; 9. Industry, Innovation and Infrastructure; 12. Responsible Consumption and Production, 13. Climate Action; 14. Life below Water, and 15. Life on Land. In addition, the development of biophysics on the African continent requires a strong commitment to quality education (SDG 4).

Zero Hunger (SDG 2) is addressed through biophysics research and development in agribusiness and food security, which involves important aspects such as food nutrition and the understanding, prevention, and treatment of animal and plant diseases. An improvement in food security is directly linked to Good Health and Wellbeing (SDG 3), which also involves the large research field of human health and medicine. These two SDGs are a particularly pressing need for Africa, but biophysics offers an abundance of opportunities to address them in tangible ways.

1. Medicine

We wish to focus specifically on diseases that constitute the most significant health, social, and economic burden to the African continent. These include (i) poverty-related diseases such as HIV/AIDS and tuberculosis, which kill millions of people annually, (ii) neglected tropical diseases that affect in the order of 400 million people on the continent according to the World Health Organization, (iii) malaria with an annual mortality rate of about half a million African people, and (iv) cancer, for which the mortality rate increases every year and is predicted to reach ca. 1.4 million annual deaths in Africa by 2040 [18].

Most of these mortality cases can be linked to the patient having limited access to treatment or the inability to afford the treatment. African countries therefore have a desperate need for robust, cost-effective diagnostics and low-cost innovations to address local needs – and biophysics plays a crucial role in the development of these technologies.

Another key area of research is the development of drugs and vaccines for which research in Structural Biology is indispensable. By resolving molecular structures of macromolecules, Structural Biology provides the tools to understand the molecular basis of diseases, which guides the rational design of new drugs and the optimisation of existing medicines.

Besides Structural Biology, other key areas of biophysics research in the health sector include biosensing and quantum biology to enable sensitive diagnostics, biophotonics for numerous applications including light therapy and sensitive diagnostics, cost-effective imaging solutions, and computational approaches to complement experimental work and deepen our understanding of diseases.

2. Agribusiness/food security

Biophysics can also contribute significantly to agribusiness in several ways, in particular by scientific and technological solutions to improve plant health. Growing food insecurity and sustained malnutrition are a major concern in the developing world. The rapidly growing food demand is due to the combination of a growing African population and a reduction in fertile farmland. This requires drastic agricultural intensification, which means that plant health becomes an increasingly important demand every year.

Currently, at least half of agricultural loss occurs due to biotic or abiotic stressors. Biotic stressors are stress factors of a biological origin, for example, pathogens, insects, fungi, parasites, worms, and weeds. Abiotic stressors are non-biological factors such as non-optimal soil salinity, nutrient deficiency, drought, extreme temperature, and excess light.

Early plant disease detection is an emerging area of research, constituting non-invasive methods – typically remote sensing technologies – that enable early, pre-symptomatic diagnosis of plant stress [?]. These methods enable the farmer to treat diseases or optimise abiotic factors at the earliest stages, which can be several days before the plants would show symptoms that are observable by the eye. Early treatment curbs the spread of diseases, increases the chances of successful treatment, and reduces the resources required for treatment. The non-invasiveness of these methods also enables precision agriculture and plant phenotyping for resistance breeding [?]. Remote sensing includes numerous promising spectroscopy-based methods such as hyper- and multispectral imaging and pulse-amplitude-modulation fluorometry. Owing to their deep understanding of spectroscopy, modelling, and device development, biophysicists are apt to enhance the sensitivity of these technologies, devise ways to relate spectroscopic changes to particular stress factors, and translate the detected signals between different environments (e.g., from indoor to outdoor) and across different scales (e.g., from the leaf to the canopy level). This is a largely unexplored area of research but crucial for maintaining crop productivity and food security.

Another promising area of biophysics research is to provide a basis for finding alternative treatments for plant diseases. Reducing chemical use for pest management is an urgent need in Africa for cost, food safety, and environmental sustainability. Key problems of the use of pesticides and fungicides are the growing resistance of pests and fungi, and their toxicity to humans, animals, and the environment. We therefore urgently need to develop alternative ways to enable more accurate use of fungicides in the short term and explore less toxic alternatives in the long term. An example is to control spore dispersal from fungi, which can only be done when understanding the mechanics of fungal dispersal [23]. Again, biophysicists are needed to provide such a mechanistic understanding. This is one of numerous underexplored areas of research.

Biophysics is also paramount to obtaining a deep understanding of the complex photosynthetic process. The onset of biotic and abiotic stressors triggers a series of photoprotective mechanisms. It has been demonstrated that the genetic modification of some of these mechanisms can significantly improve crop yields [?].

The biophysics research methods of relevance to agriculture are similar to those needed in medicine, namely, biosensing, quantum biology, biophotonics, imaging, and computational approaches. Structural Biology is equally important. In addition to explaining basic life processes, structural techniques are routinely employed in the pharmaceutical industry, agrochemical industry, and biotechnology communities around the world in support of efforts to understand molecular disease mechanisms, the rational design of pesticides, herbicides, small molecule and biologic medicines, and in optimising and designing biocatalysts.

8.3 Major challenges to growing biophysics in Africa

The best way to grow and establish biophysics on the continent is to create adequate opportunities for state-of-the-art research on home soil. The major challenges to this goal are discussed here. It is important to note that these challenges feed one another. In other words, addressing one requires addressing them all.

1. Vastly inadequate infrastructure and resources

All research and development require appropriate infrastructure and resources. This is even more so for biophysics research operating at the forefront of science and technology. There are a handful of research centres scattered across Africa that house relevant infrastructure [24]. This is a good start but undoubtedly markedly insufficient. Most African countries do not have even basic equipment for biophysics research, while the equipment hosted by the rest of the countries is vastly inadequate [24]. The severe lack of equipment is a very demotivating factor for aspiring biophysicists on the continent.

Acquisition of equipment is only one side of the coin. Equally important is the need to maintain technical infrastructure by equipping our own people and providing sufficient funds. It has happened too often that state-of-the-art specialised equipment gets wasted because of inadequate resources to sustain it – due to a lack of expertise or funds for maintenance or both.

Consider as an example the infrastructure required for Structural Biology. Determining the structure of biological macromolecules requires the establishment of a workflow that includes the ability to prepare the material, test its functionality, obtain the data necessary for structure determination, process this data, and interpret the outcome. Both X-ray crystallography and cryo-electron microscopy lead to directly interpretable, near-atomic-resolution visualisations of biomolecular structures and are currently the most widely used structure determination techniques. The value of structural insights is recognised internationally to the extent that industries as well as governments abroad have invested billions in building and staffing shared, large-scale, centralised infrastructure for Structural Biology. In comparison, due to the high cost of the technology and the critically scarce skills required to operate such equipment, only limited structural investigations are possible at select sites in Africa, all of which are currently in South Africa. The technology and thus critical insights remain elusive to both local industry and academic researchers. Where resources have been committed, appropriate equipment and skills have been spread over many sites and this has meant that a productive critical mass that could lead to development and innovation has never been established. Trained students have in general not been retained and many have found employment in the field abroad, where they have been highly successful.

It is also important that one or more of the societal activities in which structural biology is needed must exist in a country interested in developing this field of research. For example, there should be companies researching novel agrochemicals, medicines, or industrial enzymes for which protein structural information is a sine qua non. Given the poor state of development of the discipline in Africa, it is unlikely that entrepreneurs will invest without substantial government intervention.

2. Very low critical mass

TThe present state of affairs is that very few students and research scientists in Africa venture into biophysics. One major reason is a lack of awareness of the importance of this field of research. This leads to limited funding opportunities supporting biophysics research and development, which, in turn, discourages scientific work in this area.

Another major reason for Africa's low critical mass in biophysics is the exodus of skilled scientists. Most Africans interested in biophysics study abroad and do not return to Africa, while most of those who returned to their home countries have remained in biophysics for short periods. The primary reason for this is the severe shortage of infrastructure and resources for biophysics research. These scientists have the necessary knowledge and skills but they lack the capacity to execute the research. Opportunities are urgently needed to support and help these scientists to excel in their research.

3. Limited educational, training, and mentorship opportunities in Africa

Going hand-in-hand with the previous two challenges is the need to educate, train, and mentor our current and aspiring biophysicists in Africa. Only a few African universities offer biophysics courses and even fewer offer biophysics degrees. In addition, general and specialised biophysics schools and workshops in Africa are organised too infrequently. Combined with education and training is the need for mentorship to encourage and nurture aspiring and established biophysicists on the continent.

8.4 High-priority future needs

1. Capacity building

An earnest investment in educational opportunities is a low-hanging fruit for the growth of critical mass and knowledge in biophysics. This must be done through the development of biophysics curricula and the hosting of general and specialised biophysics schools, workshops, seminars, and expert lectures. Biophysics programmes and degrees would need to be established as a pipeline in developing curricula along both academic and vocational lines. Both Africans and non-Africans can help significantly to address these needs. In this regard, the International Union for Pure and Applied Biophysics (IUPAB) and the Biophysical Society (BPS) have ample resources that can be tapped into.

The development of biophysics research should be a natural outflow of biophysics education and training. Again, support from IUPAB and BPS as well as numerous other international societies would be of immense help, for example, to bring international experts to Africa through the organisation of workshops and conferences. Collaboration with well-established biophysicists in other continents through multinational research programmes and consortia is an excellent way to boost research quality and opportunities. This becomes a realistic opportunity when African researchers strive for excellence.

Lastly, the severe lack of awareness of biophysics on the continent must additionally be addressed through public awareness activities such as popular science literature, news reports, science festivals, roadshows, and school visits and demonstrations. In general, the profile of scientists must be raised in the public eye. They are the people expending great effort in training the next generation of leaders and developing innovative technological solutions. If scientists – and biophysicists in particular – could be elevated to the same level as sports stars, this would immediately attract significant attention from the public and governments. In addition, if scientists do not actively define their role in society, their relevance will be determined by society – and this will be a vastly underappreciated role.

2. Investment in infrastructure and equipment

As motivated above, the acquisition and maintenance of modern infrastructure and equipment is key to the development of biophysics research and innovation. Funding for this requires governmental support, which should grow through policy development and high-level discussions with governments convincing them of the need to support the work of African biophysicists, build the necessary infrastructure, and encourage African industries to invest in the bioeconomy strategy.

Governing bodies and investors must make adequate funding available for the procurement of necessary facilities for biophysics research. Funding incentives should also be provided to researchers to establish and develop biophysics research in important areas. To this end, governments may develop multiple-department initiatives to support the work of biophysicists. They should incentivise our universities to build infrastructure in all the fields that support biophysics and make funding available for basic and advanced equipment.

African home countries need to invest in their own research. Currently, the weakest link is the fact that we get most funding from outside Africa and no or very limited buy-in from our own continent. Africans must be convinced that their support is indispensable.

Investment in infrastructure and human capacity development must be seen for what it is: an investment – not for a limited number of elite persons but for the country and ultimately for the whole continent! A growing body of expertise will attract industrial development, which, in time, will inevitably lead to direct foreign investment and the development of intellectual property and products. Consider as an example the study of protein structure. Proper investment in the development of infrastructure and scientists to do cutting-edge Structural Biology research will enable the development of local industries concerned with drug discovery and development, advanced agrochemicals, and fourth-generation industrial biotechnology.

Biophysics research depends on a very broad spectrum of experimental techniques, and it is therefore impossible to house all the necessary equipment on the African continent. But it is also unnecessary to try and collect all types of equipment. Firstly, we must be selective in our focus, specifically addressing the key research areas stated above. Secondly, we must follow the example of European countries that similarly do not house all the necessary equipment but, instead, form consortia to share expensive equipment, which can also be accessed by scientists from non-member countries.

3. Low-cost innovations to address local needs

Although the importance of acquiring and maintaining expensive equipment for state-of-the-art biophysics research and development cannot be understated, a particularly pressing need for Africa is to find inexpensive technologies for the vast majority of its people who cannot afford expensive solutions. In this regard, it is important to note that for most applications, only a dedicated technology is needed, not a versatile one. This requirement may significantly decrease the price of the technology. Connected with this is the need to develop methods that are specific to particular contexts. Such affordable solutions require innovative thinking.

Consider as an example a quantum light imaging device to improve the resolution of medical images for people living in remote areas. This technology is out of place for its target group because, firstly, such equipment is very expensive; secondly, it requires a well-isolated (vibration-free) environment and reliable electricity supply; and, thirdly, it requires highly skilled staff to operate and maintain. Instead, a significantly cheaper instrument can be used to acquire an image at a lower resolution, after which machine learning techniques can be employed to optimise the image resolution.

Another example of an inexpensive innovative instrument is a homebuilt hyper- or multispectral camera, which can be a few orders of magnitude cheaper than state-of-the-art commercial ones. Such a camera can be built using a 3D printer and Raspberry Pi kit, the latter of which is then used to control inexpensive camera sensors and filters. Running the output through a machine-learning algorithm can again improve the image and spectral resolution. The cost of this instrument can be cut further when dedicated to a specific application. Possible applications are diverse and may include the sensing of particular stressors in plants, drug sorting, detection of tainted drugs, diagnosis of traditional medicines, food diagnosis to determine its safety for consumption (e.g., detection of pesticides, rot, or diseases), or investigation or detection of plastics.

These examples highlight the importance of translating scientific work from the laboratory to society by finding inexpensive, dedicated solutions. This is in line with the World Health Organization's set of criteria for ideal diagnostic test development based on the acronym REASSURED, which refers to **R**eal-time connectivity, **E**ase of specimen collection, **A**ffordable, **S**ensitive, **S**pecific, **U**ser-friendly, **R**apid and robust, **E**quipment-free or simple, and **D**eliverable to end-users.

8.5 Synergies with neighbouring fields

The broad scope of biophysics demands a broad range of experimental and modelling approaches. Even within a focused area of biophysics, numerous experimental and modelling approaches are often used to obtain a holistic picture and a deep understanding of the complex system at hand. Therefore, biophysics has synergy with many other fields of physics. ASFAP subgroups with which there is significant overlap include Accelerators, Atomic & Molecular Physics, Computing & 4IR, Instrumentation & Detectors, Light Sources, Condensed Matter & Materials Physics, Medical Physics, Optics and Photonics, and Complex Systems. In addition, some research areas within biophysics have synergy with the ASFAP subgroups Earth Science, Energy, and Fluid and Plasma.

Adopting a broad definition of biophysics here, biophysics has a strong overlap with many other disciplines such as biochemistry, bio-computing, bio-mathematics, biomedical engineering, biotechnology, botany, chemistry, crystallography, genetics, genomics, molecular biology, neuroscience, oceanography, pharmacology, physiology, structural biology, synthetic biology, systems biology. Professional African Societies for many of these disciplines already exist and biophysics initiatives must cooperate with these societies [24].

Cross-pollination of biophysics with the various sub-disciplines of physics and the other related scientific disciplines is strongly recommended because this encourages lateral, cross-disciplinary thinking.

8.6 Conclusion and perspectives

Africa, with its wealth of human capital, has enormous potential to revolutionise the continent for the welfare of its people and the rest of the world. A strong investment in biophysics must form a vital component to re-imagine its economic growth and increase its prosperity. The reason is that the complex world that we live in demands multidisciplinary approaches – and biophysics is by definition a multidisciplinary science that is strongly rooted in the useful value system of physics, endowing its adherents with critical thinking and problem-solving skills. The core questions of our day may come from one discipline, but the solutions are often found from its integration with other disciplines, and the integration of physics to resolve questions in biology is a beautiful example of this.

African universities should now begin to craft cross-disciplinary degrees – at the undergraduate and postgraduate levels – because it is cross-disciplinary research that is going to transform science in the decades to come. Biophysics is again an excellent example of such a cross-disciplinary approach.

To put Africa on the global biophysics maps, it is essential to establish multinational research programmes, consortia, and training events across the continent. There are already a number of exemplary initiatives. They must be sustained and inspire the development of many more initiatives.

8.7 Acknowledgements

We are grateful for contributions from the following people:

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22

Computing Working Group

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22.1 Introduction and Motivation

Research needs nowadays strong computing services to treat big data, to extract results, to make discoveries and to improve the life of the citizens.

What we define as computing service is made of many layers, from the underlying hardware structure namely networks, computers, storage, to applications and software. And we observe since decades the advent of new fields that have revolutionised data handling and treatment such as Artificial Intelligence and Deep Learning.

Even though Computing is by itself a science and a field of research and technology, and we would certainly not forget at this stage Quantum Computing, it is also transverse to all the fields explored in this document and gives major advantage to countries or organisations that master this field.

A large fraction of the information collected in this report is based on a survey launched in mars 2022, including participants to ASFAP as well as attendants to the 2nd African Conference of Fundamental and Applied Physics ACP2021 [1] held in mars 2022 in Casablanca, Morocco. More details can be found in ref [1].This survey was launched to evaluate the status of computing resources in the field of African Physics Research. The panel was mainly composed from participants working and leaving in Africa (more than 82%), the rest being in big majority what was called Africans from the diaspora. 26 countries were represented in the panel.

22.2 Computing Challenges for Scientific activities

Scientific activities fields that need to rely on data treatment to extract knowledge are infinite. They can span over various fields: Physics, Astrophysics, Biomedical , environmental research, etc. The survey cited above has gathered participants belonging to more than 30 different fields. Most of them highlighted the lack of computing infrastructure and often the lack of understanding from their stakeholders of the need of computing in their field.

The last decades have shown the need of providing computing resources and services without which, as an example, the discovery of the Higgs Boson at the Large Hadron Collider at CERN would not have been possible: The size and the complexity of the data sample, the drastic selection on the real data to find "a needle in a haystack", the need of generating billions and billions of events to compare data and discriminate over theoretical models, all this requested an unprecedented level of computing resources. This example highlights the need of resources that have to be shared and distributed in an organized and inter-operable way and on a large community of scientists all over the world.

Another computationally challenging field is the need of simulating more and more complex physical phenomena that require different heterogeneous architectures as well as a level of coding that would allow to exploit more cleverly parallel units such as GPU (Graphical Processing Unit). Active research, in particular using Deep Learning, Natural Language Processing, Graphical Networks and other AI-related techniques is ongoing to produce code that would be optimized for specific infrastructures

Not all the fields are demanding of so large amount of resources: but as modest as can be the data sample, it may need a complex treatment that cannot anymore be done with a pencil.

22.3 Synergies with neighbouring fields

The need for more computational power in many fields of science is driving the search for more powerful computational architectures and applications. We have seen above that very close neighbouring fields can and will develop with a development of the need of powerful computing for Physics. The most obvious ones are the fields related to Artificial Intelligence and Quantum Computing. These two fields are and will provide an unprecedented boost in the power of computing for any research thematic.

22.3.1 Artificial Intelligence

Artificial Intelligence (AI) is already widely used in many domains in industry, research, communications, etc. and it is not the place to describe the role it has taken in our every day's life. Particle physics was one of the first sciences in late 1960s to study and use AI in particular Neural Networks to discriminate more accurately between signal and background but also Deep Learning to reduce and increase the performances in the analysis of the immense amount of data delivered by the powerful colliders. It is used in many other fields some of them being security, machine control, work in extreme environments. Such AI techniques have accelerated the progress in research and they contribute to considerable savings in resources, tackling the computing and data challenge.

22.3.2 Quantum Computing

Quantum Computing uses a qubit, "similar" to the bit in classical computing, but offering the advantage of multiple outputs, as opposed to 2 outputs, 0 and 1 for the standard electronic bit. This quantic property if embedded in a quantum computer would allow to resolve complex problems in an exponentially faster time than with a classical computer: in 2019, Google claimed solving a sampling problem in 200sec while it would have taken 10,000 years in classical computer. But, engineering qubits has proven to be very challenging, and worldwide, many national governments and private firms are heavily investing in this research. Not only it is a challenge to build a processor based on qubits but other related challenge is to build software and algorithms to exploit its capability. Progresses in AI, Quantum Computing and in general in Computing Sciences are one of the most important piste to deal with the avalanche of data in all sciences and to speedup the process of discoveries that impact our everyday life. Synergy between the work of research scientists and computing experts are essential to explore the quantum world. The rapidly growing field of quantum information and quantum enginering will require quantum-aware engineers [3].

22.4 High priority Future Needs from Scientific Community Consultations

We have consulted a scientific community belonging to more than 15 research fields about their experience to access computing facilities and their training and education in computing sciences. Part of the answers is summarized in figure 22-1: the largest number of responses stress as well the lack of budget for computing, the lack of technical support and the fact that the hierarchy does not understand the need of computing for research.

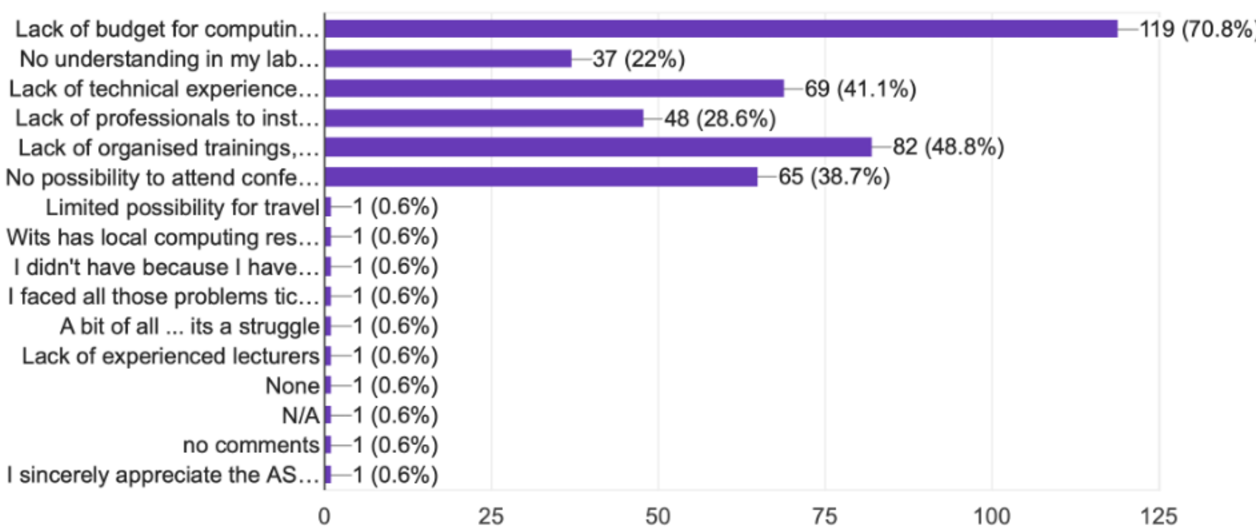

Figure 22-1. *Main obstacles to the use of computing by scientists: the largest bottleneck is the lack of budget for computing in physics sciences. The problem might arise as well from the lack of funding as from the largely spread opinion that scientists do not need computers and computing infrastructures to perform their research. This last point is also raised as we see in the graph that 22% of the answers highlight a "No understanding in their lab" of the necessity of computing.*

On computing resources available to achieve their work,the largest number of responses, more than 50%, find the computing resources to be highly insufficient and the percentage goes to 66% when counting only scientists using their local resources. They point at the lack of budget for computing, the lack of technical support and the fact that the hierarchy does not understand the need of computing for research.

On Education and Training,the participants stress the lack of organised training and workshops and the difficulty to attend those meetings organised abroad. Concerning this specific point, more detailed information is found in figure 22-2: 74.4% of the scientists are not provided courses and lectures, or at an insufficient level. More detailed study can be found in [1].

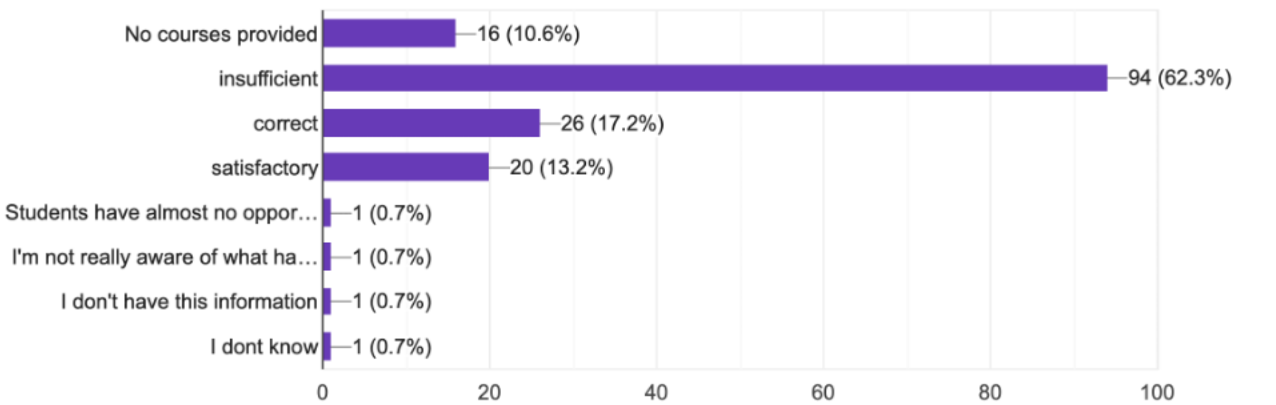

Figure 22-2. *Teaching and Training: details are provided about the status of the computing know-how: more than 70% of the answers point to an nonexistent or insufficient level of courses and training.*

22.5 Recommendations and perspectives

Considering the answers provided by the survey cited above and to improve the situation and boost the scientific research in Africa, we draw the following guidelines:

- **Develop computing infrastructure and build a know-how**: Infrastructure should be made available and, if already existing, improved at a significant level in order to provide easy access to data and enough power to treat the massive and/or complex data samples. Major components of the underlying infrastructure are:
  - **Network**: One essential part of the Computing situation is the access, availability and performance of the Network, i.e., Academic and Research Network, in Africa. Networks are vital for the access to data and information. This is not only true at the local level in the universities and research centres, but even more at national and international level with connection to other countries. Most of the countries are, at scientific level, a poor network and little connections to each other: one needs to get a global picture of the existing situation, compile the needs of the to eventually draw the strategy for improvement. Same as with routes and tracks in countries, there is no possibility of exchanges and sharing of knowledge. An African coordinated initiative would be a real asset at the level of the continent.
  - **Storage and computing power**: these are necessary to store and process the data, which is the only way to produce results and science. The computing needed is more and more sophisticated now that Artificial Intelligence and Deep Learning have entered the game in all sciences. As suggested by some of the participants, large data centres shared within a country or with other countries within Africa would certainly be a solution that would federate the resources, decrease the costs and the disparities between universities and countries.
  - **Qualified technical staff** are necessary to deploy and run these computing resources and make them available to the physics research scientists that would not be able to deal with Cloud deployment or computer access to storage. Here a collaboration between different African countries and foreign countries could be a fruitful initiative to share IT technicians, setup few test sites, and start having an infrastructure on site.

- **Build Knowledge and include computing in Education**: The poll has highlighted the insufficient level of education in computing. Many solutions should be envisaged simultaneously:
  - **Increase the number of computing courses** in the cursus of physics' and other sciences' students.
  - **Train IT professionals** to prepare and operate the infrastructure. These professionals are an important piece of the game as they are the ones that can deploy the complex structures and follow up on the progresses in the field.
  - **Organise regular workshops and trainings**. This would be highly beneficial for knowledge sharing and knowledge update to stay in the forefront in computing where evolution is very fast. But this would have an important positive side effect: Researchers have highlighted the fact that they quite often work isolated. These workshops are the best place to meet their peers and initiate collaborations that would only be beneficial to raise the research productivity.
  - Last but not least, **national and international collaboration** with others more advanced in these fields throughout the world would speed up the knowledge transfer and build collaborations that would be mutually beneficial.

22.6 Conclusion

The unavoidable and exponential increase of computing in all science fields including fundamental and applied sciences necessitates the availability of computing resources, the growth of computing awareness in the scientific communities and the inclusion of computing in education. Although certainly not extensive and complete, some key recommendations are drawn in the section above that might fill the gap that is actually present if one compares African research with that of other continents. Investing in computing is one of the highest return on investment that a country can expect. It would provide to the youth of all countries a horizon at the level of their hope and ambition.

The top priority is raising the awareness of governing bodies and stakeholders at each level: continent, state, university, research centres about the crucial role of computing in research and sciences. But beyond sciences, it would have a large societal impact and would keep Africa in the race for knowledge, better living and peace.
Global and long scale planning is necessary as this evolution needs building networks, facilities and educating new generation of women and men to the rapidly evolving computing landscape.
Budget should be expressly dedicated to computing: it would include all equipment needed for scientists, students and technicians for education, research, and R&D (Research and Development) and the budget to build, connect and run large-scale facilities to host and access the exponentially increasing volume of data.
As the demand of computing capacity is growing enormously, close collaboration between countries is the most efficient way to provide the needed resources. None of the main discoveries of the last decade would have been made possible without the collaborative work effort and the setup of closely connected powerful data centres distributed all over the world.

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11

Earth Science Working Group

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11.1 Introduction and Motivation

The earth sciences represent a major and interdisciplinary field that is fundamentally underpinned by physics and physical principles. The term ‘Earth Sciences’ is thus a broad umbrella term that encompasses scientific investigation a variety of different scales (sub-micrometer through to planetary scale), and which focusses on a variety of different environments. These environments include those located at earth’s surface (the so-called critical zone which includes the biosphere, the hydrosphere, and the geosphere), but also extends inwards deep into the earth’s mantle and core, and outwards through the atmosphere and out to the cryosphere. Although the specific scientific sub-disciplines that fall within the realm of the earth sciences are too many to enumerate, those that are most reliant on a strong physics foundation include: hydrogeology, geophysics, geophysical fluid dynamics, atmospheric physics and aeronomy, ocean physics, space physics and astronomy, environmental physics, meteorology, climatology, tectonics, seismology, gravity and magnetism, mineralogy and petrology, geochronology, ecotoxicology, among others. Additionally, almost all sub-disciplines or the earth sciences rely on measurements of physical properties to characterize and understand observed phenomena (e.g., Syono and Manghnani, 1992 [1]; Doel, 2013 [2]; von der Heyden et al. 2020 [3]). As such, inclusion of the Earth Sciences is a crucial addition to any documents or policies related to the future of physics on the African continent (e.g., the African Strategy for Fundamental and Applied Physics (ASFAP)).

As anthropogenic impacts continue to change the planet in which we live (e.g., Cracknell and Krapivin, 2008 [4]), it is becoming ever more important to understand how natural processes are being affected by this change. This understanding will help both to inform the design of any mitigation measures that are put forward, and to predict the environmental responses in a case where human activity continues under a ‘business-as-usual’ scenario. Multiple references have highlighted that Africa is particularly vulnerable to environmental change (Stige et al. 2006 [5]; Nkomo et al. 2006) especially given that a vast proportion of its inhabitants live life at, near, or even below the bread-line (Nkomo et al. 2006 [6]). For these reasons, a road map detailing the current state of affairs and future (envisaged) directions of the Earth Sciences is of both highly timeouts and of distinct geographic importance.

11.2 Challenges

Two considerations posed moderate challenges towards the overarching goal of uniting the earth sciences as a single entity under the greater umbrella of the African Society for Fundamental and Applied Physics (ASFAP). The first of these is the sheer number of sub-disciplines and communities that identify as earth scientists (see an incomplete list of sub-disciplines detailed in section 11.1). To identify and develop rapport with key individuals situated within each of these sub-disciplines required some effort from the two conveners of the working group, whose respective networks were somewhat limited to those of geology, geochemistry and environmental sciences. The second challenge relates to the multi-disciplinary nature of the earth sciences, which results in some workers struggling to identify their affiliation to physics, versus to other key disciplines that underpin earth sciences. For example, a geochemist may feel that his or her field is more closely aligned with chemistry rather than with physics. An important aspect that should be included in any physics policy document, that encompasses earth sciences, is a formal definition that delineates the relationship between the two.

11.3 Scientific activities

The activities of the Earth Sciences working group have arguable not been as prolific as those undertaken by several of the other ASFAP working groups. Despite this, the working group has experienced some successes and highlights. These include:

- Ongoing scientific and strategy related interactions with the broader ASFAP community (Haddad et al. 2022 [7]);
- A planned mini-symposium to coincide with International Earth Week 2021 (ultimately postponed to avoid a clash in dates with the African Geophysical Society);
- Development of a mailing list comprising twenty-three email addresses of individuals who are passionate about the future of earth sciences on the African continent;
- Successful presentation of the Earth Sciences working group achievements at a major regional earth sciences conference (Geocongress 2023 (11-13 January 2023; Stellenbosch, South Africa));
- Successful design and distribution of a targeted survey investigating the perceived future needs of the African earth sciences community (see Section **??**).

11.4 Survey design and responses

The developed survey comprised ten questions of which four probed insights into the meta-data of the respondent (e.g., experience level, field of study, country of habitation), and four questions provided the main source of data for further scrutiny. These four questions were open-ended, and sought to elucidate which issues are most prevalently impacting the African earth sciences, and how additional funding would serve to further improve the status of this important field of science. These four questions were:

- Please detail any barriers (e.g., access to students, funding, analytical equipment, researcher support, etc.) that currently hinder your abilities to conduct earth science research on or for the African continent?

- If you were awarded US$ 1000 towards advancing the physics-related needs or future goals of the earth sciences, kindly explain how you would best spend it?

- If you were awarded US$ 1 million towards advancing the physics-related needs or future goals of the earth sciences, kindly explain how you would best spend it?

- Please leave any other remarks which may serve to advise future physics strategy development for advancing the status of earth sciences on or for the African continent.

An advantage to this open-ended style of questioning is that it opened up opportunity for unforeseen responses (i.e., the responses are not limited to those on a prescribed list). Over thirty respondents completed the survey, with respondents comprising a broad array of nationalities including 30% of respondents each from west Africa and southern Africa, 20% from east Africa, and 10% each from north African and other countries outside of Africa, as shown in Figure 11-1.

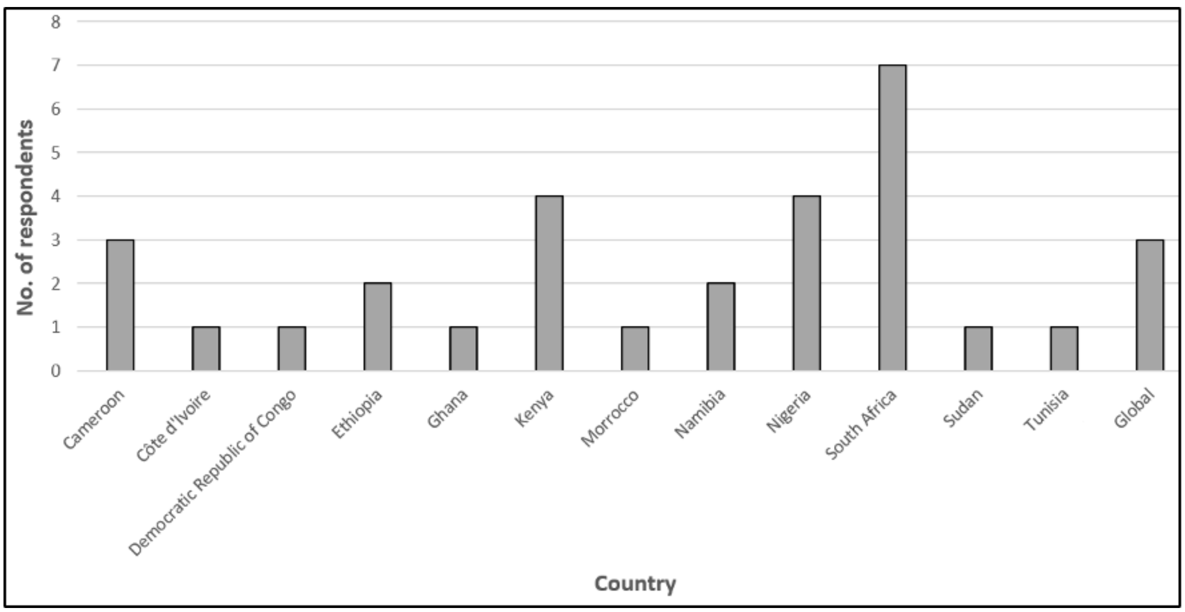

Figure 11-1. *A summary of the respondents' countries of employment. 'Global' refers to countries outside of Africa.*

Moreover, there was a good spread of experience levels and earth science sub-fields represented in the survey, Figures 11-2 and 11-3. Survey responses were interpreted following qualitative data analysis protocols, using the 'data that glows' methodology of MacLure, 2013 [**?**].

11.5 High priority future needs

Based on survey responses, the needs of the African Earth Sciences community can be divided broadly between those requiring high monetary inputs, those requiring smaller monetary inputs, and those that require other forms of support or incentivisation.

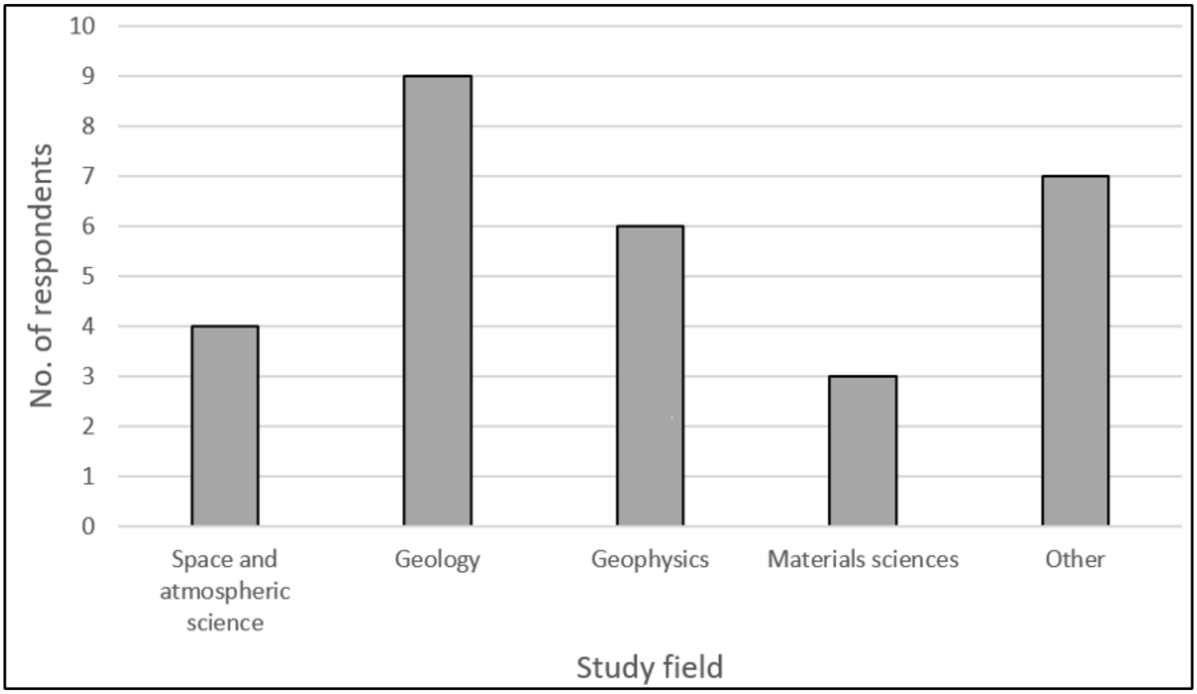

Figure 11-2. *A summary of the respondents' study fields. 'Other' includes a diverse array of study fields including remote sensing, geoscience education, particle physics, among others.*

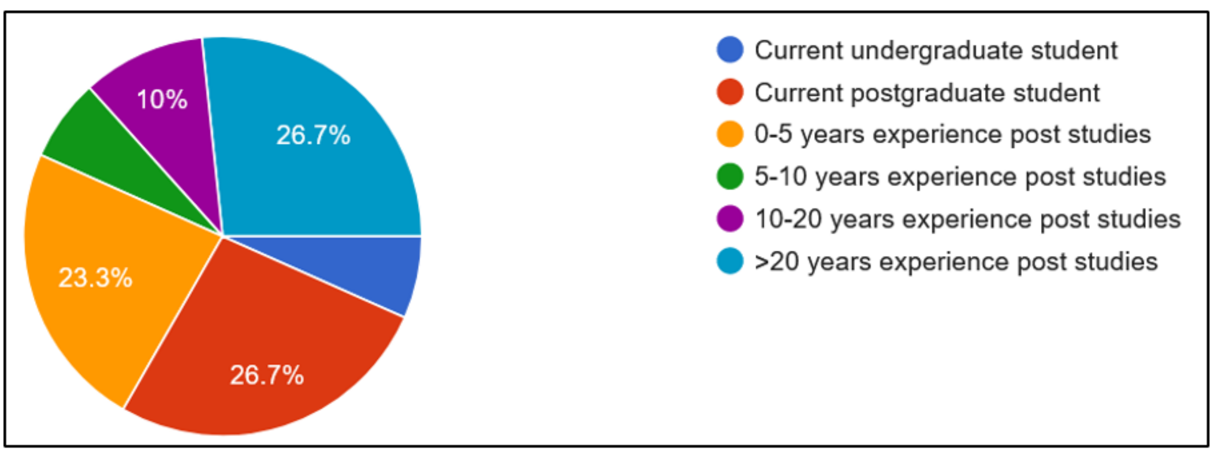

Figure 11-3. *Summary of the indicated experience levels of the different respondents, showing a good mix in experience.*

11.5.1 Needs requiring high degrees of financial support

In a hypothetical scenario in which survey participants were offered one million USD towards achieving their research goals, the majority of respondents indicated that they would utilize this money towards setting up high-end laboratory facilities that could be utilized towards investigating local- and global research questions. This response was received from respondents ranging across all of the different sub-disciplines of the earth sciences, and across all of the nationalities and experience levels. Examples of the types of large analytical labs suggested include broad-band and short period seismic equipment; a flume for fluid dynamics research; multiple meteorological mini-weather stations; among others. Interestingly, two different models for research equipment were proposed. Some respondents felt that large research equipment should be housed at a centralized and stable research facility (e.g., a well-established and reputable university). This is captured by the following statement:

Anonymous respondent A: "Provide critical research equipment to one of the universities that has the capacity to house and operate it, provided that the facility be available to other researchers within the country."

An alternative model suggested a series of small laboratories set up across a more expansive geographic area, importantly comprising rural regions where labs must necessarily be run by off-grid e.g., photovoltaic power solutions. Most respondents highlighted that for any funding awarded towards a new laboratory, a subset of the funding needs to be set aside for technical staff training, for operating expenses and for funding of associated student projects. Some respondents also highlighted that large amounts of financial support could also be split into smaller tranches for utilization towards enhancing student and researcher training. Suggested training vehicles included bursaries for undergraduate and post-graduate students, overseas visits and conference/workshop attendance for researchers, and towards attracting international post-doctoral research fellows to African laboratories.

11.5.2 Needs requiring lower degrees of financial support

In line with the responses received for the larger grants, most respondents highlighted that smaller grants (i.e., 1000 USD) would be best utilized towards acquiring smaller items of equipment or towards funding student bursaries. Concerning the latter point, several respondents indicated that these bursaries should be awarded on a competitive basis and according to merit-based criteria. Surprisingly, several respondents indicated that the funding would be used to repair or upgrade existing equipment, with the concerning implication being that these items are currently not operating at their optimum performance levels. Other uses for the small grant awards included field trips, capacity building through local workshops, publication costs, and towards partnering with science communication companies to help develop ongoing popular media such as apps, comics, TV, etc. that advocate for the earth sciences.

11.5.3 Other needs and suggestions arising

The final open question of the survey attracted a range of other recommendations, all geared towards enhancing the status of earth sciences on or for the African continent. A large proportion of these focused on the need for enhanced collaboration and networking between African researchers. Collaboration, and vehicles that drive collaboration, need to be enhanced both for intra-country and intra-continent interactions.

Vehicles identified that would help facilitate collaboration include improved across-border data sharing, and development of more enabling government policies, funding and academic/research support. It was also suggested that improved industry-university linkages should be facilitated and nurtured, since these linkages are mutually beneficial (e.g., Heath, 2000; Agrawal, 2001; von der Heyden, 2019 [10, 9, 11]).

A second key focus area relates to ensuring a sustained talent pipeline for future generations of African earth scientists. This may be achieved by establishment of outreach programs aimed at attracting High School students to our important discipline. Dedicated investment into Geoscience education initiatives would also be useful, particularly if they are underpinned by good educational research, and designed to have longevity. As indicated in previous sections, offering bursaries to dedicated and hard-working students will also help to ensure a sustained supply of future thought leaders and industry professionals who will drive the science and its various practical applications forward. Also indicated previously, these students will need to be trained in good laboratories, of which there are currently a dearth. This again underpins the need for financial investment into state-of-the-art equipment.

Anonymous respondent B: “Doing Research in physics needs quality equipment.”

Anonymous respondent C: “It is necessary to modernize the laboratories of the earth sciences to supervise many students for their Ph.D.”

Other approaches that would serve to strengthen the standing of earth sciences on the African continent would be through focus on issues that are topical both to the continent and globally. For example, topics such as green energy, global climate change and critical metals all fall within the focus area of the earth sciences and are all relatively easily supported by large international funding bodies. Linked to accessing large grants, an important skillset that needs better development among local researchers is the ability to write strong and competitive research grants. This is succinctly captured in a statement by Anonymous Respondent D: “Spread, democratize as aggressively as possible the skills of successful writing of large grant proposals.”

11.6 Conclusions and perspectives

Based on the somewhat limited feedback received from a survey initiative set up by the ASFAP earth sciences working group, the largest and most inhibitory barriers affecting the African earth sciences are 1) a perceived dearth of funding and, 2) limited access to high-end analytical facilities. Towards negating the first inhibitor, funders are encouraged to open up new funding vehicles that explicitly aim to advance the African earth sciences, particularly if the research areas are topical and of societal and environmental relevance to our continent (and globally). Furthermore, African researchers need to be better equipped to write, defend and deliver on large grant proposals. There is a great opportunity to introduce greater circularity into the training provided to upcoming researchers. That is, not only should next generation scientists deliver good science, but they should also be trained to write highly-competitive grants.

Anonymous Respondent E: “Postgraduate Students willing to work on the use of physics and physics concepts and methods will be encouraged and drawn into the multidisciplinary research consortium which will be established with a solid foundation/background underpinned by Physics. The above mentioned research and education consortium will then apply and submit research funding proposals for more research funds. Physics education and research, physics concepts and methods will be used as background for a greater societal and industry impact leveraging of localized and decolonized African realities.”

Towards mitigating the perceived dearth of analytical facilities, a worthwhile departure point would be to compile a list of all earth sciences analytical facilities located on the African continent. This list should be augmented with details of the associated research costs and the availability/openness of the unit to intra-continental collaborative efforts. Collaboration can be stimulated by developing strong and mutually-beneficial research agreements between countries, laboratories, research institutions and industry on the continent. Whereas other parts of the world are engaging in anti-globalisation movements, a general absence of this attitude on the African continent will be beneficial towards preferential and expedited local advancements.

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12

Energy Working Group

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12.1 Introduction

Access to modern energy services is essential to achieving basic social needs by promoting economic development. Modern energy services, particularly electricity and gas, affect productivity, health, education, safe water, and communication [1]. Energy has a significant impact on socio-economic development in any country because it encourages investment, innovation, and the formation of new businesses that promote the creation of jobs, inclusive growth, and shared prosperity throughout the entire economy [2]. This fact, along with the strong links between energy and the Millennium Development Goals (MDGs), makes it even more important to address the challenges and prospects of energy service provision in Africa. Developing countries' decisions on the growth of their energy sectors will significantly impact future energy consumption trends, fuel preferences, trade patterns, and other relevant aspects in addition to their development. Over the past two decades, Africa has exhibited a significant increase in energy consumption, with a reported 45% increase [3]. However, the energy infrastructure in many areas remains underdeveloped, leaving the demands of the population unmet. Despite the wealth of energy resources available to cater to domestic needs, many countries continue to lack access to modern energy services. Approximately 620 million Africans, which account for two-thirds of the population, do not consume electricity, and a further 730 million rely on traditional biomass for cooking. Even for those with access to energy, the quality and cost of supply are often found to be subpar [3].

The energy sources used in Africa vary from country to country. However, the most commonly utilised energy sources on the continent are oil, coal, natural gas, hydroelectricity, and renewable sources such as solar, wind, and geothermal power. It is worth noting that the International Energy Agency (IEA) states that Africa possesses 60% of the world's best solar resources, yet only 1% of the installed solar PV capacity. Furthermore, the IEA predicts that solar PV will be the most cost-effective power source in many regions of Africa by 2030. Affordable and dependable energy are key factors in Africa's economic and social progress. The COVID-19 pandemic has highlighted the importance of a stable energy supply. Without electricity, the measures put in place by the government to contain the virus would have been unbearable. Access to electricity allowed people to work from home; schools continued functioning through online classes; and governments continued their operations (e.g., through virtual court systems). Electricity also facilitated water utilities to continue supplying clean water for handwashing, which was an essential guideline for reducing the spread of the virus [4], [5]. Increased access to affordable and dependable energy can play a significant role in mitigating economic disruptions caused by the pandemic. As countries prepare for economic recovery, African governments must focus on creating more job opportunities and stimulating economic growth. Investing in energy access can help achieve both goals[6].

The transition towards clean energy on a global scale presents promising prospects for the economic and social growth of Africa. As of May 2022, countries committed to achieving net zero emissions accounted for more than 70% of the century. This includes 12 African nations contributing to over 40% of the continent's total CO2 emissions [7]. The commitment of these nations to achieve net zero emissions contributes to the transformation of the global energy sector due to the declining costs of clean technology and shifting global investments. African nations, the majority of which are signatories to the Paris Agreement on Climate Change, are well-positioned to benefit from technological advancements and attract increasing amounts of climate finance [6].

For the African government to ensure greater energy access to its population, diversification of energy sources will play a key role, which will include investing in new sources of energy, especially renewables such as wind and solar energy, as well as pooling them together to ensure sufficient supply.

12.2 Sources of energy and resources in Africa

Africa is endowed with various resources that meet the energy needs of different countries. Different countries in Africa have different energy mixes as their sources of energy, including

- Hydroelectric energy: in Africa, several countries are tapping hydroelectric as part of the source of utility energy; the following are some of the biggest in Africa.
  - The Grand Ethiopian Renaissance Dam (GERD) – 6,450 MW: Previously known as the Millennium Dam, the Grand Renaissance Dam in Ethiopia has been under construction since 2011 and is set to become the largest dam on the continent upon completion. Located on the Blue Nile, the dam will generate an estimated 6, 450 MW per year in the Benishangul–Gumuz region near Ethiopia's border with Sudan.
  - Aswan High Dam – 2,100 MW: Located near the city of the same name in southern Egypt, the Aswan High Dam ranks as the continent's second-largest dam. Built across the Nile, the dam is the largest embankment dam in the world, with a height of 111 m and length of 4,000 m. By powering 12 generators, each at a rate of 175 MW, the dam has a total generation capacity of 2,100 MW.
  - Cahora Basa Dam – 2,070 MW: One of the two major dams on the Zambezi River, the Cahora Bassa Dam in Mozambique is the largest hydropower plant in southern Africa. Power was generated through five 415 MW turbines with a combined capacity of 2,070 MW. Most of the power generated by the Cahora Bassa Dam is exported to South Africa through the Cahora Bassa high-voltage direct current (HVDC) line system, with two conversion stations located in Songo, Mozambique, and Apollo, South Africa.
  - Gilgel Gibe III Dam – 1,870 MW: The Gilgel Gibe III Dam located southwest of Ethiopia's capital, Addis Abeba, is a roller-compacted concrete dam and hydroelectric power plant built on the Omo River. The Gibe III power station forms part of a cascade of dams, including the Gibe I dam, with a capacity of 184 MW, and the Gibe II power station, with a capacity of 420 MW. Plans are currently underway to add Gibe IV and V dams with capacities of 1,472 MW and 560 MW, respectively, to the Gibe Cascade. Currently, during its commissioning process, the future electricity generated by the plant is expected to provide half of its capacity to Ethiopia, with the other half expected to be exported to Kenya (500 MW), Sudan (200 MW), and Djibouti (200

MW). Under the country's current development plans, Ethiopia has pledged to generate 95% of its energy generation from hydropower.

- Inga Dams – 1,775 MW: Comprised of two single dams, the Inga 1 (351 MW) and Inga II (1,424 MW), Dams in the Democratic Republic of Congo (DRC) currently operate at a combined capacity of 1,775 MW. Built on Inga Falls, one of the largest waterfalls in the world, hydroelectric dams currently work at merely half of their potential capacity. The expansion of the dam has generated interest from nations and power companies all over Africa that have expressed interest in the pursuit of a Grand Inga project estimated to cost $80 billion, which would become the largest power station in the world with a capacity of up to 70 GW.
- The Kariba Dam, 1,626 MW, is located between Zimbabwe and Zambia. It is 128 m tall and 579 m long and is the largest man-made dam in the world. Currently, with a total installed capacity of 1,626 MW, the dam is under expansion to increase its yield. Power stations located on the north and south banks of the dam provide Zambia and Zimbabwe with their respective energy sources.
- Merowe Dam – 1,250 MW: In terms of its size, with a length of 7km and height of up to 67 meters, the Merowe Dam in northern Sudan is the largest contemporary hydropower project in Africa by size. Situated on the Nile, the hydropower dam consists of 10 turbines, each with a capacity to produce 125 MW for a combined total of 1,250 MW.
- Tekezé Dam – 1,200 MW: With a height of 188 meters, the Tekezé Dam in Ethiopia is the tallest dam on the continent. Situated on the Tekezé River, a tributary of the Nile, the $360 million dam is one of the largest public works projects in the country. The dam's powerhouse contains four 75 MW turbines, each generating 300 MW of electricity for a combined total of 1,200 MW. Akosombo Dam – 1,020 MW: Located at the base of Lake Volta, the Akosombo Hydroelectric Dam in southeastern Ghana draws its hydropower from the world's largest person-made lake in the world, with a surface area of 8,502km2. Initially constructed to provide electricity for the country's aluminum industry, the power plant currently has an installed capacity of 1,020 MW, and provides electricity to Ghana, Togo, and Benin.
- Kainji Dam – 760 MW: Built on the Niger River in Nigeria, the Kainji Dam provides electricity to all of the west-African country's major cities. Despite the intention of designing a dam with an installed capacity of 960 MW, only eight of the proposed twelve turbines have been installed, reducing the capacity of the plant to 760 MW. The Kainji Dam, with a length of 10km, is one of the longest dams in the world.

- Thermal energy
- Wind power
- Solar power
- Geothermal energy

12.3 Energy pooling in Africa

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13

Fluid and Plasma Working Group

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Abstract

Abstract: In physics, a fluid is a liquid, gas, or other material that continuously deforms under an applied shear stress, or external force. They are substances which cannot resist any shear force applied to them. Meanwhile, plasma refers to an electrically conducting medium in which there are roughly equal numbers of positively and negatively charged particles produced when the atoms in a gas become ionized. In this report, the concept of fluid and plasma physics is briefly outlined, followed by an overview of the status and impact of fluids and plasma physics education and capacity development in Africa.

Keywords: Fluids and plasma physics; Magnetohydrodynamics; Education and capacity development in Africa

13.1 Introduction

Adequate knowledge in fluid and plasma physics is a necessary prerequisite for development of technology and innovation, and thereby constitutes a key input into the transition to a knowledge-based economy [1]. Applications of fluids and Plasma physics range from energy production by thermonuclear fusion to laboratory astrophysics, creation of intense sources of high-energy particle and radiation beams, and fundamental studies involving high-field quantum electrodynamics [2]. Plasma is being used in many high tech industries. It is used in making many microelectronic or electronic devices such as semiconductors. It can help make features on chips for computers. Plasma is also used in making transmitters for microwaves or high temperature films. Fluids and Plasma research are leading to profound new insights on the inner workings of the sun and other stars, and fascinating astrophysical objects such as black holes and neutron stars. The study of fluids and plasma enable prediction of space weather, medical treatments, and even water purification [3]. Majority of plasma phenomena observed in real experiments can be explained by a fluid model, in which the identity of the individual particle is neglected, and only the motion of fluid elements is taken into account [4]. The theoretical study of plasma as fluids are governed by the concept of magnetohydrodynamics which involved a combination of conservation of conducting fluid mass, charges and momentum equations coupled with state equation and Maxwell equations of electromagnetism [5]. Plasma may involve the dynamics positively charged ion fluid and negatively charged electron fluid. In a partially ionized gas, for the dynamics of fluid of neutral atoms may also be involved. The neutral fluid will interact with the ions and electrons only through collisions. The ion and electron fluids will interact with each other even in the absence of collisions, due to the generation of the electric and magnetic fields [6]. The magnetohydrodynamic approach treats the plasma as a single fluid with mass density $\rho_m = n_e m_e + n_i m_i$, charge density $\sigma = q_e ne + q_i n_i$, mass velocity $V = (n_e m_e v_e + n_i m_i v_i)/\rho_m$, current density $j = q_e n_e v_e + q_i n_i v_i = q_e n_e (v_e - v_i)$ and total pressure $p = p_e + p_i$ as outline in the equations below [7, 8, 9]:

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (nV) = 0 \ \text{(Mass conservation);} \tag{13.1}$$

$$\frac{\partial \sigma}{\partial t} + \nabla \cdot (nj) = 0 \ \text{(Charge conservation);} \tag{13.2}$$

$$\rho \left(\frac{\partial V}{\partial t} + V \cdot \nabla V \right) = \sigma E + j \times B - \nabla P \ \text{(Momentum conservation);} \tag{13.3}$$

$$P = Cn^{\gamma} \ \text{(Equation of state);} \tag{13.4}$$

with the addition of Maxwell equations.

where the subscripts i and e represent the ions and electrons, respectively, C is a constant, γ is the ratio of specific heat C_p/C_v, t is the time, B is the magnetic field strength, E is the electric field, T is the temperature, n is the particle density, η is the resistivity.

13.2 Status of Fluids and Plasma Physics in Africa

Due to lacks of necessary research laboratories infrastructure, technical support, and so forth in many academic and research institutions in Africa, relatively few scientists in the field of fluids and plasma physics have managed to perform at a level competitive with the best in the world. The figure 1 below depicts the level of research output in the fluids and plasma physics in Africa [10].

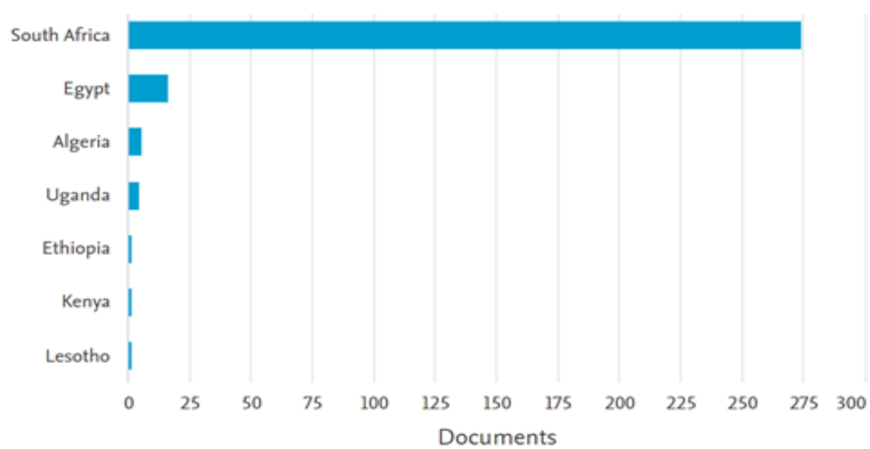

Figure 13-1. *Fluids and plasma physics research output in Africa (source-SCOPUS database [10])*

From figure 13-1, it is obvious that very few countries and scientists within Africa are engaging in productive research in the field of fluids and plasma physics. The largest visible research output on fluids and plasma physics comes from the institutions in South Africa, followed by the institutions in Egypt, Algeria, Uganda, Ethiopia, Kenya and Lesotho. Although research and academic institutions in other African countries may be engaging in some research activities in fluids and plasma physics, however, most of the output are not visible on the SCOPUS database.

13.3 Fluid & Plasma Physics Education and Capacity Development in Africa

The challenges of education and capacity development in the field of fluids and plasma physics in Africa include inadequate funding of science education at secondary and tertiary levels, lack of infrastructure, absent of physics-based industries, poverty, etc. [11]. To excel in physics & science education and training in Africa

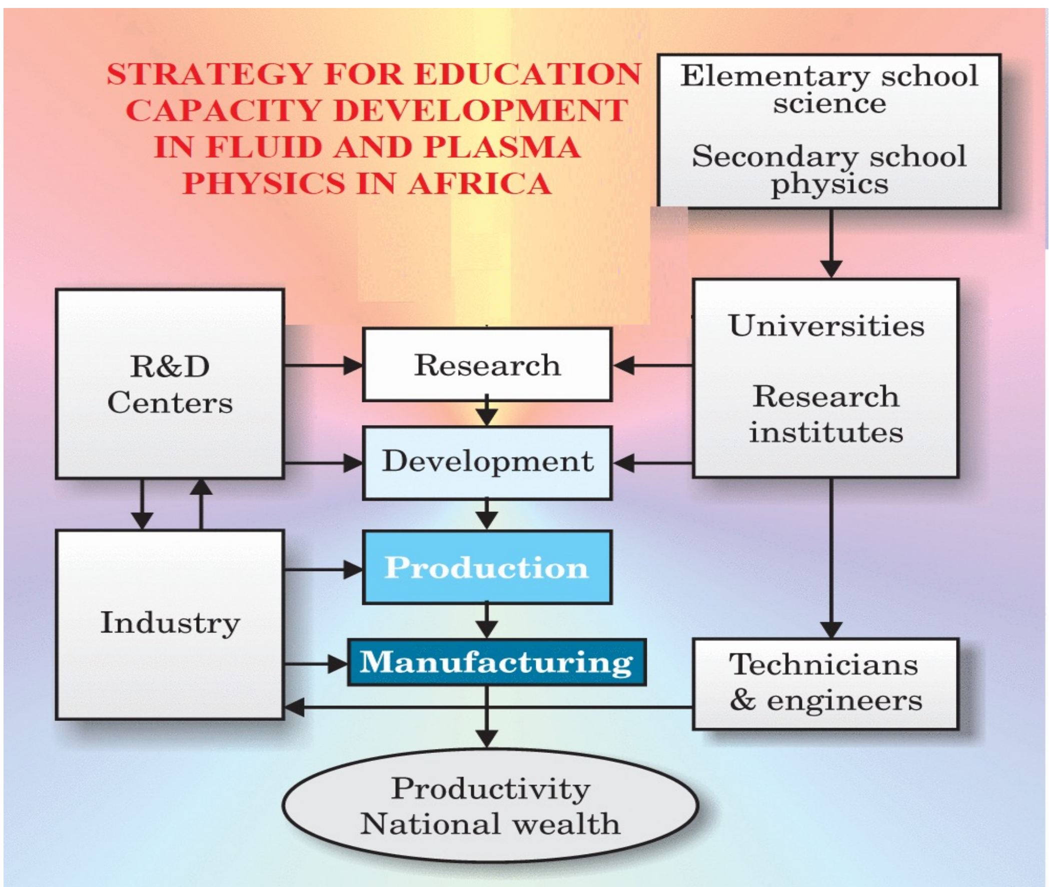

Figure 13-2. *Strategy for education capacity development in fluid and plasma physics in Africa*

is to conquer Mount Everest without the aid of additional oxygen. Meanwhile, scientific advancement cannot occur without quality education; to achieve that quality, African countries will require significant investment at all educational levels. African scientists have to convince their governments, businesses, and the public that investment in physics education is beneficial and will lead to economic development and an enhanced quality of life [1]. Physics curricula should emphasize project work and problem solving, with a complement of activities in entrepreneurship. Figure 13-2 below depicts a strategy that African countries' may adopt for education and capacity development in fluid and plasma physics.

The proposed capacity development strategy envisages a close and mutual interaction between the African educational institutions, research institution and industries. Moreover, post-doctoral research activities should be encouraged in the field of fluid and plasma physics in Africa tertiary and research institutions, scientists in Africa should be encouraged to publish their research outputs in the main stream peer-review academic journals for global visibility.

13.4 Conclusions

The status and impact of impact of fluid and plasma physics in the scientific and technological advancement of Africa can be enhanced through adequate educational training, research and mutual interaction of African scientists with the related industries. This can only be achieved through national, regional and international collaboration coupled with sufficient investment from their governments, businesses and private sectors into capacity development in the field.

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14

Instrumentation and Detectors Working Group

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14.1 Introduction and Motivation

By construction this working group is transversal and multi-disciplinary and its activities are related to all other physics groups. The Instrumentation and Detectors Physics Group aims to identify existing or new initiatives and projects within a wide range of instrumentation, which should be further developed in order to become valid proposals to create new facilities in Africa. The role of the WG is to coordinate and to encourage these initiatives and to help in the process of writing the so-called "White papers".

14.2 Major challenges for scientific activities

In the early phase of the WG a small and probably insufficient attempt was made to obtain an approximate overview over existing facilities in Africa by going through web pages, conference proceedings and other miscellaneous sources of information. This turned out to be fairly difficult, especially in the physics domains outside of the competences of the WG conveners. Nevertheless the prejudice that most of the instrumental centres are concentrated in South Africa, Namibia and in the Northern part of Africa seemed to be confirmed while very few are located in the sub-Saharan countries of central Africa.

Examples of relatively large centers are the Nuclear facilities with accelerators at iThemba Labs and several astrophysics observatories (SAAO, HESS, SKA), and the Centre National de l'Énergie, des Sciences et des Techniques Nucléaires (CNESTEN, Morocco) or the Center for Development of Advanced Technologies (CDAT, Algeria). Other smaller instrumentation focused centres exist also in other countries, such as the Lasers Atoms Laboratory at Cheikh Anta Diop University (Senegal), the Atomic Molecular Spectroscopy and Applications Laboratory at the University of Tunis El Manar (Tunisia), the Radiocarbon laboratory of the Institut Fondamentale d'Afrique Noire (IFAN, Senegal), and the Centre for Energy Research and Development (CERD, Nigeria). There exist several more laboratories on the continent with various instruments to conduct research however the vast majority being unknown to the African scientific community.

A first meeting of the WG took place in November 2021, with the principal goal to help the submission of Letters of Intent (LoIs) by structuring the collected information on existing facilities. This initial survey was complemented with other ifnformaiton gathered from presentations at various scientific meetings, conferences and workshops such as ACP2021 and others. There is a strong consensus that the main problem researchers are facing is the need and easy accessible for experimental facilities to conduct their research. The second essential need is the availability of educational training centres in instrumentation for basic and advanced experimental physics.

14.3 Analysis of submitted Letters of Intent (LoIs) related to instrumentation

After the first set of submitted LoIs, several were identified that possibly relate to instrumentation needs. These LOIs wer grouped in three categories as listed below (the numbers in the brackets refer to the submission identification of the LoI):

1. Extensions of existing facilities:
    - (Radio)-Astronomy (51, 54, 56, 67)
    - Accelerator centres (17, 24)
2. New facilities
    - Astronomy: local observatories for North Africa (14)
    - Astroparticle underground (15)
    - African millimetre telescope (33)
    - Am-Be neutron source (39)
    - AfLS (not a special LoI)
    - Instrumentation for AfLS (58, 59, 61,66)
3. Centres of Excellence (the instrumentation part is not always explicit or clear)
    - Graphen Flagship (4)
    - Energy centre of excellence (5)
    - NANOAFNET(10)
    - Quantum physics and biology (19, 23, 27, 49)
    - Education, ICEPA (68)

In the Spring 2022 the conveners of the WG started to approach the authors of the existing LoIs directly in order to require more details and to encourage a plan for the organization of a global collaborative effort to coordinate concrete action items to assist in instrumentation needs. Two meetings were held one on May 5^{th} and June 9^{th}, gathering a total of 21 and 14 participants, respectively. Further meetings were planned but cancelled due to problems identifying dates accomodating the speakers and conveners and the beginning of the Summer 2022 break puts an end to that round of meetings.

On May 5^{th} the three LoIs that were discussed were #39-Am-Be neutron source, #54-Low Frequency (< 1 GHz) RadioInterferometric Arrays, and #33-The first millimetre-wave radio telescope. The following meeting on June 9th centered on two existing facilities at iThemba Labs (#17, #24) and one on the UNESCO-UNISA and the NANOAFNET (#10).

All these projects are built on some existing experiences and activities with the potential for the future to create African wide collaborations. The existing facilities at iThemba Labs do already attract scientists from other countries like Algeria, Senegal, Burkina Faso, and Nigeria, however there is quite some room to further increase such collaborations. In the discussions following the presentations, it became evident that one of the most important short comings was in fact the problem to find enough person power to widen the scope of these projects beyond the country where these activities are presently located. Especially for the astrophysical related projects this is a bit surprising because Africa has a fairly large astronomy community, particularly in East Africa. Unfortunately this start of the LoI-review could not be continued after the summer break, for various reasons, which have to be reviewed and analysed before restarting this process in the future.

14.4 A High-priority proposal

Within the Instrumentation and Detector working group a proposal for an "International Centre for Experimental Physics in Africa (ICEPA)" was discussed in order to address the lack of experimental training facilities in Africa. Some ideas were sketched and then submitted as LoI (#68). The LoI was also presented at a meeting of the Physics Education working group. The idea for such a school was born from the apparent lack but high needs for experimental education and know-how in most African countries. The concept is very much inspired by the African Institute for Mathematical Sciences (AIMS) and other educational centres like the Southern African Institute for Nuclear Technology and Sciences (SAINT) or the Sèmè City in Benin. The proposed centre would consist of a master-like curriculum of typically one and a half year, including a 6-month research project and would include high-level lectures combined with hands-on experiences. A final examination and a recognised diploma (the association to a university will be required in such case) would conclude the cursus. While the proposed training centre is conceptually very similar to AIMS, it focuses on experimental physics techniques and strongly oriented towards instrumentation. For the latter, the idea is to build experimental installations and facilities at strategic locations on the African continent, which partially could be contributed and/or donated by international collaborators or universities. These donors would also ideally take the responsibility to maintain the equipment, at least for the first years, until local staff has been trained and qualified.

14.5 Conclusion, synergies with other fields and perspectives

After an enthusiastic start in 2021/2022 in the context of the ASFAP townhall meeting in the Spring 2022, the activities of the Instrumentation and Detector working group came to an apparent hold during the Summer 2022 that will need to be revived to pursue the review of LoIs and guide their proponents to generate White Papers. The activities also suffered from a lack of interaction with the other working groups, whose input is urgently required because instrumentation can only be developed in a global physics context. The other short coming of the working group is the still insufficient mobilisation of the African community itself for ASFAP in order to construct and to develop the proposed projects and to find African leaders as spokes persons for them.

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17

Medical Physics Working Group

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17.1 Introduction and Motivation

Africa is rapidly acquiring high-tech medical imaging equipment such as multi-slices helical computed tomography (CT) scanners, as well as hybrid imaging technologies like combining single photon emission tomography (SPECT) and positron emission tomography (PET) with CT. However, without proper specialized support, this advancement in technology has the potential of significantly increasing the population's exposure to ionizing radiation. The safe use of these technologies requires proper quality assurance procedures, calibration of imaging equipment and optimization of the radiation dose to the patient, which may not be properly done in the absence of a qualified medical physicist. The degree of involvement of the medical physicist is determined by the complexity of the radiological procedures and the associated radiation risks [1].

The essential responsibility of the Qualified Medical Physicist's clinical practice is to assure the safe and effective delivery of radiation to achieve a diagnostic or therapeutic result as prescribed in patient care [2,3,4]. The responsibilities of the medical physicist include: protection of the patient and others from potentially harmful or excessive radiation; establishment of adequate protocols to ensure accurate patient dosimetry; the measurement and characterization of radiation; the determination of delivered dose; advancement of procedures necessary to ensure image quality; development and direction of quality assurance programs; and assistance to other health care professionals in optimizing the balance between the beneficial and deleterious effects of radiation; and compliance with applicable federal and state regulations [5] .

Unfortunately, in most African countries, there is a critical shortage or absence of qualified medical physicists in hospitals, clinics and other health care facilities that use radiation technology. This problem is particularly critical in diagnostic imaging units (either in diagnostic radiology or nuclear medicine) that usually have no qualified medical physicist in their workforce. This may lead to patients receiving non-optimized radiation procedures, resulting in inadequate diagnosis or treatment, or in extreme cases from the harmful effects of radiation due to overexposure.

17.2 Major challenges Scientific activities

Medical physicists play a vital role in ensuring the safe and effective use of radiation and imaging technologies in diagnostic and therapeutic medical procedures. However, several factors pose challenges to the field that can impact their work and the quality of healthcare services in the region requiring strategic solutions and priority actions. Some of the key challenges include :

17.2.1 Limited Resources

Many African countries face challenges in terms of limited financial resources, leading to inadequate funding for healthcare infrastructure, including radiation therapy and diagnostic imaging facilities.

17.2.2 Shortage of Qualified Personnel

There is often a shortage of qualified medical physicists in Africa. This shortage may result from limited training programs, brain drain (qualified professionals leaving for better opportunities abroad), and difficulties in attracting and retaining skilled professionals.

17.2.3 Inadequate Infrastructure

Some regions lack the necessary infrastructure for advanced medical physics services. This includes a shortage of modern equipment, such as linear accelerators, CT scanners, and other advanced imaging devices.

17.2.4 Education and Training Gaps

Insufficient training opportunities for medical physicists can lead to a lack of specialized skills. Comprehensive education programs, including postgraduate training and continuous professional development, are crucial to ensuring a competent workforce.

17.2.5 Regulatory Frameworks

Inconsistent or inadequate regulatory frameworks for radiation safety and medical physics may exist in some countries. A robust regulatory system is essential to ensure the safe and effective use of radiation in medical procedures. In most of African countries, medical physicist is not recognized as a profession

17.2.6 Access to Continuing Education

Limited access to ongoing training and continuing education programs can hinder the professional development of medical physicists. Staying updated with the latest advancements is crucial for maintaining high standards of care.

17.2.7 Geographic Disparities

Disparities in healthcare infrastructure and services can exist between urban and rural areas, with more resources concentrated in urban centers. This can result in uneven access to advanced medical physics services.

17.2.8 Lack of Research Opportunities

Limited research opportunities in medical physics may hinder the development of innovative solutions and the advancement of the field in the region.

17.2.9 Technological Obsolescence

The rapid evolution of medical technology means that equipment may become obsolete quickly. Limited financial resources make it challenging for healthcare facilities to keep up with technological advancements.

17.2.10 Public Awareness

Lack of public awareness about the role and importance of medical physicists in healthcare may contribute to a lower appreciation of their contributions and the challenges they face.

Efforts to address these challenges often involve collaboration between international organizations, governments, non-governmental organizations (NGOs), and educational institutions. These collaborations can focus on improving education and training opportunities, investing in infrastructure, and implementing effective regulatory frameworks to enhance the practice of medical physics in Africa.

17.3 Progress, Achievements, Solutions

While challenges exist, there have been notable progress, achievements, and ongoing efforts to address issues in the field of medical physics in Africa. Some positive developments include:

17.3.1 Training Programs

Expansion of educational programs in medical physics: Several African countries have taken steps to establish or expand educational programs in medical physics at the undergraduate and postgraduate levels, contributing to a growing pool of qualified professionals [5,6] .

17.3.2 International Collaboration

Collaborative initiatives with international organizations: Partnerships with organizations such as the International Atomic Energy Agency (IAEA), World Health Organization (WHO), ICTP, and other international bodies have facilitated knowledge exchange, training opportunities, and resource mobilization.

17.3.3 Capacity Building

Capacity-building projects: Various projects focus on enhancing the capacity of medical physics services. These projects often involve the donation or support for acquiring modern equipment and technologies.

17.3.4 Research and Innovation

Growing research activities: Some African medical physicists are actively engaged in research, contributing to advancements in the field. Research can lead to innovative solutions tailored to the specific needs and conditions in the region.

17.3.5 Advancements in Telemedicine

Utilization of telemedicine: Telemedicine applications have been employed to provide remote support, consultation, and training for medical physicists in underserved areas, overcoming geographic disparities.

17.3.6 Public Awareness and Advocacy

Increasing public awareness: Efforts to raise awareness about the role of medical physicists and the importance of radiation safety have been made through public health campaigns and educational programs.

17.3.7 Regulatory Enhancements

Strengthening regulatory frameworks: Some countries are working to enhance and enforce regulatory frameworks related to radiation safety and medical physics practices, ensuring compliance with international standards.

17.3.8 Professional Networks

Development of professional networks: Networking opportunities, both within Africa and internationally, have facilitated information sharing, collaboration, and mentorship among medical physicists.

17.3.9 Support from NGOs and Foundations

Support from non-governmental organizations (NGOs) and foundations: Various NGOs and philanthropic foundations provide financial and technical support to improve medical physics services in Africa.

17.3.10 Focus on Sustainable Solutions

Emphasis on sustainable solutions: Initiatives are increasingly focusing on developing sustainable models for maintaining and upgrading medical physics infrastructure, considering long-term viability.

While progress has been made, ongoing efforts are necessary to sustain and expand these achievements. Key solutions involve continued investment in education and training, infrastructure development, regulatory enforcement, and international collaboration. Encouraging local leadership, empowering healthcare professionals, and advocating for policy changes are integral parts of fostering sustainable improvements in medical physics across the African continent.

17.4 High priority future needs

As medical physics in Africa continues to evolve, several high-priority future needs have been identified to address challenges and enhance the quality of healthcare services. Some of these needs include increase the awareness and recognition of role of medical physicists in medical imaging, in addition to the following.

17.4.1 Capacity building for medical physicists in imaging

- Implement and extend the educational to reach across the continent to new Members who have requested assistance to move forward with national cancer control plans.
- Increase the frequency of teaching and formal training activities in the centers and abroad.

- Establishment an education and training programme in Zones and affiliated to the university to promote the education and training programme.
- training of the existing qualified therapy medical physicists to support Diagnostics Radiology and Nuclear Medicine.
- E-learning platform for training [5]
- Regional guidelines for academic education and training programs for imaging physicists e-learning [8].

17.4.2 Establish diagnostic reference levels (DRLs) for nuclear medicine(NM) and diagnostic radiology (DR)

- Standardizing the procedures and optimizing the parameters affecting the dose delivered to patients.
- Focus on paediatric imaging by way of examination of a certain number of criteria linked to these practice.

17.4.3 Expansion of Training Programs

- Establish and expand educational programs in medical physics at both undergraduate and postgraduate levels to meet the increasing demand for qualified professionals.

17.4.4 Continued Professional Development

- Develop ongoing training and professional development opportunities to ensure that medical physicists stay abreast of advancements in technology and best practices.

17.4.5 Research and Innovation

- Foster a culture of research and innovation within the field of medical physics to address local challenges and contribute to the global body of knowledge.

17.4.6 Infrastructure Development

- Invest in the development and maintenance of modern infrastructure, including upgrading existing equipment and acquiring new technologies for diagnosis and treatment.
- Harmonization of quality assurance/quality control programme in medical imaging in Africa [7]
- Facilities and technical equipment for quality control as well as radiology and nuclear medicine.
- Training on QA/QC in Nuclear medicine and diagnostic radiology.
- Implement & develop QA Programme.

17.4.7 International Collaboration

- Strengthen and expand collaborations with international organizations, institutions, and professionals to facilitate knowledge exchange, training, and resource mobilization.
- Collaboration among African member states will be elevated regional guidelines for academic education and training programmes.

17.4.8 Telemedicine Integration

- Promote the integration of telemedicine solutions to provide remote support, consultation, and training, especially in under-served and remote areas.

17.4.9 Patient Safety and Quality Assurance

- Emphasize patient safety through the implementation and enforcement of rigorous quality assurance programs in medical physics practices.
- Training workshop on the acceptance testing and commissioning of diagnostic/interventional radiology machine used for paediatric patients
- Increase the awareness about the radio sensitivity of pediatric patients by educating or having workshops with hospital managers, government policy makers and recruiters, radiologist, radiographers, clinicians about the need and role of the medical physicist.

17.4.10 Standardization and Certification

- Work towards standardizing medical physics practices and certifications across the region to ensure consistency and adherence to international standards.

17.4.11 Regulatory Framework Strengthening

- Strengthen regulatory frameworks related to radiation safety and medical physics practices to ensure compliance with international guidelines and standards.

17.4.12 Application for the official accreditation

- or registration of Medical Physicists by the Health Professions Council or appropriate body to ensure that minimum training requirements must be implemented by the Health Authority that employs Medical Physicists.

17.4.13 Public Awareness Campaigns

- Conduct public awareness campaigns to educate the public, healthcare providers, and policymakers about the critical role of medical physicists in healthcare and the importance of radiation safety.

17.4.14 Networking and Collaboration

- Encourage the establishment of professional networks and collaboration platforms to facilitate information sharing, mentorship, and collaborative research initiatives.

17.4.15 Improve the quality of the service provided

- Continue to develop and implement quality procedures ; request to the IAEA to support with manual and ICT material on the quality management system.

17.4.16 Sustainable Funding Models

- Develop sustainable funding models for medical physics services to ensure consistent access to resources for education, infrastructure development, and ongoing operations.

17.4.17 Local Leadership Empowerment

- Empower local leadership within the field of medical physics to take ownership of initiatives, advocate for policy changes, and drive sustainable improvements.

17.4.18 Capacity Building for Healthcare Providers

- Provide training and capacity-building programs for healthcare providers to enhance their understanding of medical physics concepts and the safe use of radiation in medical procedures.

17.4.19 Adaptation to Technological Advances

- Prepare for and adapt to technological advances in medical physics by incorporating new equipment, treatment techniques, and imaging modalities. By addressing these high-priority needs, stakeholders can contribute to the growth and sustainability of medical physics in Africa, ultimately improving patient care, enhancing safety, and advancing the field.
- Collaboration among governments, healthcare institutions, educational bodies, and international partners is essential to successfully meet these needs.

17.5 Conclusion

The field of medical physics in Africa presents both challenges and promising opportunities for improvement in healthcare delivery. Despite facing issues such as limited resources, a shortage of qualified personnel, and disparities in infrastructure, there are ongoing efforts to address these challenges.

Key solutions involve the expansion of training programs, international collaborations, infrastructure development, continuous professional development, and research support. Prioritizing capacity building, regulatory compliance, and public engagement are crucial for the sustainable growth of medical physics services across the continent.

As Africa works towards strengthening its medical physics capabilities, the concerted efforts of governments, healthcare institutions, educational bodies, and international partners will play a pivotal role in shaping a future where quality and safe medical physics practices contribute significantly to the advancement of healthcare in the region. Through these endeavors, the potential for positive impact on patient care, technological advancements, and overall healthcare infrastructure in Africa remains promising.

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High Energy Physics Working Group

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20.1 Introduction and Motivation

High Energy Physics (HEP) reveals the profound connections underlying all observed phenomena, ranging from the smallest to the largest structures in our Universe. Everything in our universe is found to be made from elementary particles, as a few basic matter blocks, governed by four fundamental interactions. Our best knowledge of how these particles interact is encoded in the Standard Model of particle physics (SM). The SM developed in the seventies has become an established and well tested theory. This document is divided in two section, the first one focuses on theoretical HEP physics while the second one is dedicated to experimental particle physics in Africa. For each field, the activities are reported per country by alphabetical order. If an important activity had been forgotten please contact the authors. To contribute in a significant way to the development of HEP in Africa, we believe that we should focus on maintaining leadership of the organization of HEP education programs in some targeted institutes, with involvement of African governments and policy makers. To this end, ASFAP has dedicated a working group to Particle Physics with the aim to build an African network, support and expand the activities in this field, and ultimately prepare a road map based on collected letter of intents proposed by particle physics community. The list provided in Table 20-1 is a tentative summary of the current (as of 2022) involvements of African countries in particle physics experiments.

We attempt to describe HEP activities and efforts in Africa. The report is not exhaustive and materials shown are based on the expert knowledge of the authors at the time of information gathering. It builds upon prior work done in the context of US particle physics prioritization exercise as detailed in Ref. [1] where the reader may find additional useful information.

The narrative will require periodic updates, as the HEP landscape evolves and changes across the world.

Experiment	Institution	Country
ANTARES	Faculté des Sciences, Université Mohammed 1, Oujda	Morocco
ANTARES	Faculté des Sciences, Université Mohammed V, Rabat	Morocco
ANTARES	Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech	Morocco
KM3Net	Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech	Morocco
KM3NeT	Faculté des Sciences, Université Mohammed 1, Oujda	Morocco
KM3Net	Faculté des Sciences, Université Mohammed V, Rabat	Morocco
KM3Net	Universities of Johannesburg/Witwatersrand/North-West	South Africa
DUNE	The University of Antananarivo	Madagascar
ATLAS Morocco Cluster	Faculté des Sciences Ain Chock, Université Hassan II, Casablanca	Morocco
	Faculté des Sciences, Université Ibn-Tofail, Kénitra	Morocco
	LPHEA, Faculté des Sciences Semlalia, Université Cadi Ayyad, Marrakech	Morocco
	LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda	Morocco
	Faculté des sciences, Université Mohammed V, Rabat	Morocco
	Mohammed VI Polytechnic University, Ben Guerir	Morocco
ATLAS South Africa Cluster	Department of Physics, University of Cape Town, Cape Town	South Africa
	Department of Mechanical Engineering Science, University of Johannesburg	South Africa
	University of South Africa, Department of Physics, Pretoria	South Africa
	iThemba Labs, Western Cape	South Africa
	University of South Africa, Department of Physics, Pretoria	South Africa
	University of Zululand, KwaDlangezwa	South Africa
	School of Physics, University of the Witwatersrand, Johannesburg	South Africa
ATLAS Technical Associate Institute	Ecole Nationale Supérieure d'Informatique (ESI)	Algeria
CMS	Academy of Scientific Research and Technology, Cairo	Egypt
CMS	Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum	Egypt
ALICE	iThemba LABS, Universities of Cape Town/Witwatersrand	South Africa

Table 20-1. *Overview of ongoing High Energy Physics activities and institutions in Africa.*

20.2 HEP in Africa

Figure **??** shows the African countries with HEP physics programs. A handful of African countries—Morocco [2], Egypt [3, 4] and South Africa [2, 5, 6, 7]—have HEP programs in theory and experiments at the LHC as described in Ref. [1]. Morocco has been involved in the neutrino astrophysics experiments of ANTARES [8] and KM3Net [9]. The South African – CERN program is managed at iThemba LABS, a nuclear and high energy physics research and education facility [10]. South Africa has had a strong participation in JINR [11] and is a member of nEXO, a neutrinoless double beta decay experiment [12]. In 2016, Madagascar joined the DUNE Collaboration [13]; more recently, Nigeria and Tunisia joined the CMS Collaboration [1, 3]; Algeria has become technical associate institute in ATLAS [2]. Algeria, Morocco, Senegal, South Africa, Tunisia and Zambia have joined the EIC Collaboration [14].

20.3 Overview on Theoretical physics in Africa

In July 2012, ATLAS and CMS experiments at LHC have announced the discovery of a scalar particle, later identified as a Higgs boson, the last missing piece of the Standard Model [16, 17]. However, despite its success, there are still many fundamental questions awaiting a clear answer, which require the construction of new theoretical models, beyond the SM, which is then treated as effective theory of a more fundamental description. Among unsolved problems and experimental data that cannot be explained by the SM , we can cite: the neutrino mass generation, pattern of fermions hierarchy, and dark matter/energy. possible extensions of the SM This means that we have to look at alternatives beyond Standard Model (BSM) that could solve those issues and could be tested at the LHC and future colliders. So far, many theoretical proposals are on the shelves: The most attractive one are BSM Models involving Higgs fields with higher representation: more doublet, more singlet, doublet and triplet, etc.

Several African groups have strong expertise in phenomenology of the beyond the Standard Model Physics. Theses groups have gained footholds in dealing with multi-Higgs models with an emphasis on the symmetries of the scalar sector and Dark Matter candidates arising from these models.

The Egyptian team, from the Center for Fundamental Physics (CFP) at Zewail City Research areas, is specialist in many high energy theory topics including: Susy phenomenology, early Universe and astro-Particle Physics (selected references [18]).

The Moroccan groups, from Cadi Ayyad and Abdelmalek Saadi Universities, have relevant expertise in phenomenological studies in BSM physics including non-minimal Higgs models and supersymmetric scenarios with a particular focus on Higgs phyics , theoretical and EW precision constraints on scalar sectors in various extensions of the SM, including their implementation in high energy physics tools (selected references [19]).

The East African Institute for Fundamental Research (EAIFR), at the University of Rwanda has research interest in fundamental physics with a focus on collider physics, physics beyond the Standard Model, cosmic inflation, Dark Matter and Dark Energy. EAIFR has produced significant papers on the impact of additional Higgs bosons on signal rates and study of possible deviations from the SM (selected references [20]).

The South African HEP groups are strongly involved in development of BSM phenomenology and analysis of the data collected by the ATLAS experiment at the LHC. They are mainly affiliated to University of the Witwatersrand, University of Johansburg and iThemba LABS (selected references [21]).

At last, a team from Madagascar is specialist of non perturbative methods in strong interactions. More precisely, they use QCD sum rules to predict hadron properties, such as masses and coupling constants(selected references [22]).

20.4 Experimental physics

The Large Hadron Collider is the largest and most powerful collider in the world. It is located at CERN between Switzerland and France. The first proton beams started to circulate in 2008. Four major experiments, ATLAS, CMS, LHCb and ALICE are located across the ring. A sketch of ATLAS and CMS can be found in Figure 20-1. Their purpose is complementary and aims at understanding the behaviour of fundamental particles and their interactions. An upgrade of the LHC, HL-LHC, is foreseen in 2025. After a successful period of data taking (Run1/2) the detectors are being upgraded in many phases. A detailed list of the associated institutes can be found in Table 20-1. The information collected in this document is based on the material that was presented at the First ASFAP Particle Physics Day.

20.4.1 Algeria

A computing group contributes to ATLAS to face future computing challenges during the HL-LHC upgrade. This body of work consists of two projects porting of ATLAS software to parallel architectures and monitoring of conditions database access.

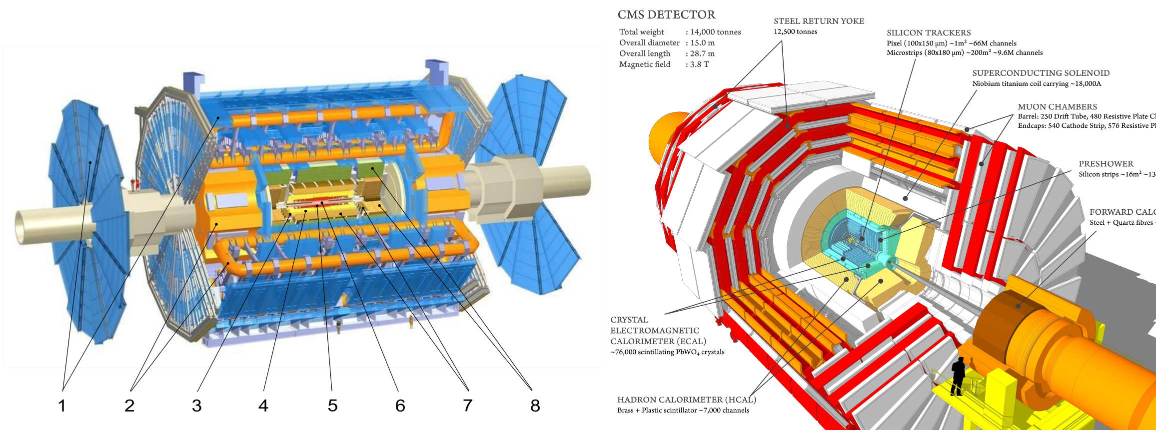

Figure 20-1. *ATLAS (left) and CMS(right) detectors.*

20.4.2 Egypt

The cluster of groups contributes to the CMS experiment. On the physics analyses side, Beyond Standard Model searches have been or are being conducted. For instance a Z' search, Kaluza Klien excitation from Extra-dimensions, and also Dark matter searches signatures combined with mono-Z mono-Higgs or mono-Z' topologies. On the detector side the groups are involved in developments of the Resistive Plate Chamber (RPC) as well as Gas Electron Multiplier (GEM).

20.4.3 Madagascar

DUNE is an international flagship experiment to unlock the mysteries of neutrinos. The group contributed to the Near Detector Conceptual design report and to the SAND-System for on-Axis Neutrino Detection.

20.4.4 Morocco

ATLAS: Since 1996, Morocco has been an indispensable part of the ATLAS international collaboration at CERN, underscoring the country's profound expertise in this field. Actively involved in both the construction and data analysis of the ATLAS detector at CERN, Morocco has also led endeavors to enhance and upgrade this cutting-edge technology. ATLAS, renowned for its wide-ranging exploration in physics, from the monumental discovery of the Higgs boson in July 2012 to the investigation of extra dimensions in space-time and the search for particles constituting dark matter, stands as a testament to Morocco's commitment to groundbreaking scientific exploration. Notably, Morocco distinguishes itself as the sole Arab nation participating in this pioneering experiment and, until 2009, held the exclusive distinction of being the sole African representative in this monumental scientific endeavor. The establishment of the Moroccan High Energy Physics Cluster (RUPHE) in 1996 epitomizes the nation's unwavering dedication to advancing science, technology, and innovation. RUPHE's central mission revolves around enriching the scientific education of emerging scholars and pushing the boundaries of pure scientific understanding. Serving as a hub for ATLAS collaborators from esteemed institutions such as the University of Hassan II in Casablanca, the University of

Mohammed V in Rabat, the University of Mohamed Ist in Oujda, the University of Cadi Ayyad in Marrakech, the University of Abdelmalek Essaadi in Tangier, and the University of Ibn Tofail in Kenitra, RUPHE fosters collaboration and excellence in scientific research. In September 2020, the Moroccan Foundation for Advanced Science, Innovation, and Research (MAScIR) achieved recognition as an Associated Technical Institute within the ATLAS experiment. Moreover, in 2021, the Mohammed VI Polytechnic University (UM6P) was officially admitted as a member institute of the Moroccan ATLAS Cluster. Facilitating the exchange of knowledge and fostering innovation, the Moroccan Academic and Research Wide Area Network (MARWAN) stands as the national computer network dedicated to education, training, and research, overseen by CNRST. Since its inception in 1998, MARWAN has been instrumental in driving Moroccan universities to develop novel services in education, technology transfer, and scientific research, with support from the Minister of Higher Education, Research, and Innovation and the National Center for Scientific and Technical Research (CNRST). Morocco's involvement in ATLAS predates its official membership approval in 1996. As early as 1992, Moroccan researchers made significant contributions to the construction of a neutron irradiation station. This initial engagement laid the foundation for further collaboration, with Moroccan researchers playing a pivotal role in the construction, testing, and commissioning of the ATLAS Electromagnetic Calorimeter Presampler from 1998 to 2003. Since then, Moroccan researchers have remained dedicated to strengthening the enduring partnership with CERN. In Morocco, our primary research endeavors focus on exploring new physics phenomena, particularly in conjunction with top physics, the Higgs boson as a portal, B physics, and CP violation. Moroccan researchers also play a significant role in investigating detector performance. Their contributions during LHC Run-1 and Run-2 were pivotal to the success of the ATLAS project. The achievements and insights gleaned from Run-3 have ignited fresh enthusiasm among our researchers, fueling their anticipation for another productive phase. In addition to data analysis, we actively engage in distributed data analysis through grid computing. As the era of ATLAS data acquisition progresses, providing user support has become a paramount challenge. With numerous scientists analyzing data dispersed across hundreds of computing sites globally, effective user support is crucial to ensure everyone can navigate and interpret collision data accurately. To tackle this challenge, the coordination of the ATLAS Distributed Analysis Support Team (DAST), established in 2008, falls under the purview of a member from the Morocco cluster. This collaborative endeavor underscores our commitment to facilitating seamless data analysis and nurturing a vibrant scientific community. The involvement of UMP6 in ATLAS presents a noteworthy opportunity for both the Moroccan ATLAS groups and the broader ATLAS Collaboration. Leveraging UMP6's extensive and state-of-the-art computing facilities, it is poised to serve as a crucial Moroccan Tier-3 center supporting ATLAS research, with aspirations to evolve into an ATLAS Tier-2 center. UMP6's direct contribution to particle physics research is anticipated through the in-depth analysis of ATLAS data. The expertise of engineers and technicians from UMP6, collaborating through MAScIR, will further enhance the development and construction of the innovative ATLAS High-Granularity Timing Detector. This collaboration underscores the impactful synergy between UMP6 and the broader ATLAS project, promising advancements in both research capabilities and technological contributions.

ANTARES/KM3Net KM3NeT, the legitimate successor of ANTARES, is a new research infrastructure consisting of a network of deep-sea neutrino telescopes in the Mediterranean Sea. The main objectives of the KM3NeT1 Collaboration are: i) the discovery and subsequent observation of high- energy neutrino sources in the Universe and ii) the determination of the mass hierarchy of neutrinos (MHN). These objectives are strongly motivated by two recent important discoveries, namely: The high- energy astrophysical neutrino signal reported by IceCube, and the sizeable contribution of electron neutrinos to the third neutrino mass eigenstate as reported by Daya Bay, Reno and others. To meet these objectives, KM3NeT is building two detectors ORCA and ARCA. Morocco has signed an agreement to join KM3NeT collaboration in 2017. So far three universities (Mohammed V U., Cadi Ayyad U., and Mohammed 1 U.), currently full members of the collaboration, are actively participating in the production line of optical modules in a national site located in Rabat. Besides, the Moroccan team is also involved in the physics analysis of many topics, essentially related to search for magnetic monopoles, search for nuclearites, and study of the neutrino mass hierarchy [23].

20.4.5 South Africa

There are multiple South African experimental HEP research groups active in both the ALICE and ATLAS experiments.

ALICE The group contributes to upgrade projects towards a common read out unit for the muon identifier, the Low-Voltage System for muon tracking, and online data processing for the Transition Radiation Detector. Given the travel restrictions, the possibility to work operate the systems remotely has been utilised. The ALICE experiment explores the outcomes of heavy ion collision, the group worked on W and Z boson tests of the Standard Model via the study of the cross-sections in lead-lead and proton-lead collisions.

ATLAS On the hardware side the following activities are ongoing:

- Silicon detector developments on both the SCT and ITk system including, data acquisition electronics development, evaporative cooling systems, material description in simulation, firmware and test QC for EoS redout cards, polymoderator design, procurement, and fabrication.
- Muon New Small Wheel work including, material description in simulation, manufacturing and assembly of components and installation tools as well as commissioning.
- ATLAS Local Trigger Interface boards were installed in the TTC crates of LBA, LBC, EBA, EBC and the Laser crate.
- Assembly, quality checks and installation of the gap scintillator counters on the ATLAS detector
- Phase-II upgrade of the Tile Calorimeter, 50% of the production of the Low Voltage Power Supplies (LVPS), 24% of the production of the Tile Preprocessor (PPr).
- Participation to ATLAS TileCal November 2021 Test-beam.
- CFD simulations for temperature and humidity distributions inside the detector ITk volume.
- Operation of the TDAQ SysAdmin and Network, Muon ConfigDB in the Control Room
- Detector Lab – Micro-Megas NSW.

On the physics analyses side, the following analyses are or have been pursued:

- Top quark mass measurement utilising leptonic J/ψ decays.
- Higgs boson production in association with a W/Z boson, with the Higgs decaying to two bottom quarks.
- New Physics searches via the study of top electro-weak couplings in rare processes (ttW, tWZ)
- Boosted Heavy Neutrino Search.

- Dark and semi-visible jets: unusual signatures emanating from strongly interacting dark sector.
- Anatomy of the multi-lepton anomalies.
- The Higgs Portal to the Dark and or Hidden sector for example $H \to Z_d Z_d \to 4e, 4\mu, 2e2\mu$, $H \to \gamma\gamma_d$

20.5 Challenges Hindering the Growth of HEP in Africa

Growing particle physics in Africa faces numerous significant challenges that must be addressed to cultivate a thriving and sustainable research environment. Let's delve into some key considerations:

- Infrastructure and Funding: One of the foremost hurdles is the absence of adequate infrastructure and funding for particle physics research across many African countries. Constructing and maintaining particle accelerators, detectors, and other critical facilities demand substantial financial investment. The scarcity of funds inhibits the establishment of top-tier research centers and the acquisition of state-of-the-art equipment, thereby impeding the ability to compete globally.
- Education and Expertise: Nurturing a proficient workforce in particle physics necessitates a robust educational framework. Unfortunately, several African nations encounter difficulties in providing quality education in physics and related disciplines. Targeted programs are imperative to train scientists, engineers, and technicians equipped with the specialized knowledge essential for particle physics research. Moreover, attracting and retaining skilled researchers poses a challenge amidst global competition for talent.
- International Collaboration: Collaboration with international institutions is pivotal for the advancement of particle physics in Africa. However, navigating logistical, bureaucratic, and communication barriers can pose challenges in establishing and sustaining such partnerships. Fostering collaborations with established research institutions can grant access to expertise, resources, and collaborative prospects, thereby assisting African researchers in overcoming local constraints.
- Political Stability and Support: Political stability and governmental backing are indispensable for the enduring viability of particle physics endeavors. Political unrest and fluctuating climates can disrupt research endeavors, jeopardizing progress and investments. It is imperative to advocate for stable political environments and underscore the significance of particle physics research for the scientific and technological progression of the continent.
- Public Awareness and Engagement: Heightening awareness about the significance and potential impact of particle physics research is pivotal for garnering public support and securing funding. Educating both the public and policymakers about the contributions of particle physics to technological innovation, medical advancements, and our comprehension of the universe can foster a supportive atmosphere for research initiatives.
- Access to Data and Publications: Ensuring open access to data and research publications is critical for the growth of particle physics in Africa. Restricted access to scientific literature and data can impede researchers' progress and hinder the dissemination of knowledge. Initiatives promoting open science practices and facilitating information-sharing across borders are essential.

Addressing these challenges necessitates a multifaceted approach involving collaboration among governments, educational institutions, international organizations, and the scientific community. By surmounting these obstacles, Africa can make significant contributions to the global field of particle physics and reap the broader scientific and technological advancements stemming from such research efforts.

20.6 Prioritizing Future Imperatives: HEP in Africa

To foster particle physics in Africa effectively, it is imperative to conduct a thorough assessment of the key future requirements necessary to advance the field and nurture a flourishing scientific community across the continent.

- Infrastructure and Technological Advancements: Establishing robust infrastructure tailored to the unique demands of particle physics research is paramount. This entails developing and maintaining particle accelerators, detectors, and computational facilities. Adequate investment in infrastructure equips African scientists with the necessary tools to conduct cutting-edge experiments and make substantial contributions to global scientific endeavors.

- Shared Research Facilities: Encourage the establishment of shared research facilities that can be accessed by scientists from multiple African nations. This can include shared laboratories, data repositories, and computational resources, enhancing the infrastructure available for particle physics research.

- Establish Collaborative Research Networks: Create and support regional networks and consortia dedicated to particle physics research. These networks can facilitate collaboration, information exchange, and joint research projects among institutions and researchers across African countries.

- Cross-Border Collaborative Research Centers: Support the establishment of collaborative research centers that span multiple African countries. These centers can serve as hubs for joint research, fostering a culture of collaboration and providing a focal point for researchers to converge and exchange ideas.

- Promotion of International Collaboration: Facilitating robust collaboration with esteemed research institutions worldwide is indispensable for driving innovation and knowledge exchange in particle physics. By fostering strategic partnerships and participating in collaborative projects, African researchers can leverage resources, expertise, and cutting-edge technologies to advance scientific discovery on a global scale.

- Research Support and Funding: Sustained investment in research and development is crucial for nurturing a conducive research environment. Governments, funding agencies, and private sector entities must prioritize funding for particle physics research initiatives, enabling scientists to explore new frontiers and address fundamental questions in the field. Adequate research support fuels innovation, drives technological advancements, and positions Africa as a key player in the global scientific community.

- Capacity Building and Education: Investment in education and capacity-building initiatives is fundamental. Enhancing the quality of physics education across all levels, from primary to tertiary institutions, cultivates a pipeline of skilled researchers capable of tackling complex challenges in particle physics. Specialized training programs and collaborations with international institutions bolster expertise within the continent, fostering a dynamic scientific community.

- Exchange Programs and Fellowships: Implement exchange programs and fellowships that allow researchers, students, and faculty to spend time at institutions in other African countries. This cross-pollination of ideas and expertise can strengthen research capabilities and foster long-term collaborations.

- Open Access and Knowledge Dissemination: Ensuring open access to data, research findings, and scientific publications is vital for fostering collaboration, transparency, and knowledge dissemination within the scientific community. Efforts to promote open science practices and establish accessible platforms for sharing information empower African researchers to leverage existing knowledge and contribute meaningfully to scientific advancements.

- Advocacy for Policy Reform: Advocating for policies that prioritize scientific research, innovation, and technological development is critical. Governments and policymakers must recognize the strategic importance of investing in scientific infrastructure, supporting research initiatives, and fostering a conducive regulatory framework. By advocating for policy reform, stakeholders can create an enabling environment that stimulates scientific inquiry, drives economic growth, and enhances global competitiveness.

In conclusion, addressing the high-priority future needs for HEP in Africa demands a collaborative and multifaceted approach. By investing in infrastructure, capacity building, international collaboration, research support, and advocacy for policy reform, Africa can harness its scientific potential, contribute to groundbreaking discoveries, and shape the future of particle physics on the global stage.

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21

Community Engagement

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21.1 Introduction

In 2015, countries adopted the UN 2030 Sustainable Development Goals as a universal call to end poverty. Poverty is considered one of the greatest challenges to sustainable development in Africa as approximately 80% of the people in extreme poverty are located in Sub-Saharan Africa. However, Africa has the potential to beat poverty as it has the youngest and fastest-growing population in addition to 60% of the world's arable lands and 30% of the world's minerals being located in Africa (Coulibaly and Golubski, 2020).

Factors contributing to poverty in Africa are closely related to Science and Technology education. These include among others inadequate infrastructures, inadequate resource management, inadequate or lacking long-term policies and strategies for education and human resource development, etc. Africa is lagging far behind in technology and its ability to compete at the international level is impeded by poor education systems (Heckman, 2004). Thus, adequate STEM science education is essential to unlock Africa's potential for sustainable development. We need to address the gaps in science and technology skills in Africa. One very important key in science education concerns improving the teaching and learning of Physics (Babalola and Folasade, 2022). Physics is considered as the basis of all applied sciences; its adequate education can help break the cycle of perpetual poverty in Africa for example by building sustainable clean energy systems and finding solutions to social and environmental problems such as water pollution and climate change.

The main problem with Physics education in Africa is that the enrolment in Physical Sciences is low in high school and university. To mitigate this, collaboration and communication between all stakeholders (local communities, the scientific community, policymakers, regional bodies and international partners) are needed (Sa'id et al. 2020). It is in this context that community engagement initiatives have emerged as a transformative approach to enhancing STEM education in Africa. These initiatives are driven by a deep understanding of the critical role education plays in shaping Africa's future by empowering its youth. Traditional class teaching and learning is vital but community engagement adds a layer of real-world experience and application to STEM concepts. This makes STEM subjects more tangible, accessible, and interesting for students (Sa'id et al. 2020).

In November 2020, the African Strategy for Fundamental and Applied Physics (ASFAP) initiative was launched by African Physicists (Pan-African and Diaspora) and was mandated by the African Physical Society (AfPS) with a mission to develop a strategy to increase Physics education and research capabilities in Africa and improve collaborations between all stakeholders to help Africa take its due place as a co-leader in the global scientific process. This report will explore the advantages of community engagement initiatives in Physics education in Africa, highlighting the thoughts, ideas, and recommendations from different meetings conducted by the ASFAP Community Engagement Working group members. By embracing these initiatives, African countries can forge a strong bond between educational institutions and their communities which will contribute towards scientific progress and sustainable development across the continent.

"Communities count, they are key to improving everything from education and economic development to health care and race relations" (Mattews, 2008)

21.2 Principles and Definitions

Before delving into the work of the ASFAP Community Engagement Working group, it is important to try to understand what community engagement is and why it is important for Physics education in Africa. We will also look at the principles of a successful community engagement initiative.

Definitions

Community engagement can be defined as "the process of working collaboratively with and through groups of people affiliated by geographic proximity, special interest, or similar situations to address issues affecting the well-being of those people" (Centers for Disease Control and Prevention, 1997). Thus, community engagement is a powerful vehicle for bringing about environmental and behavioral changes that will improve "the understanding and practice of Physics" by the physics community, its members and the public at large. Community engagement initiatives "involves partnerships and coalitions that help mobilize resources and influence systems,... and serve as catalysts for changing policies, programs, and practices" (Centers for Disease Control and Prevention, 1997).

Why does community engagement matter?

Community engagement initiatives matter as they increase the likelihood that projects or solutions will be widely accepted, they will create more effective solutions, help to improve people's knowledge and skills in problem-solving, empower and integrate people from different backgrounds, help create local networks of community members as well as opportunities for discussing community problems before they get out of control (Bassler et al. 2008).

Principles of a successful community engagement initiative

To be successful, each community engagement initiative should be guided by clear principles including the following:

1. Careful planning and Preparation (adequate and inclusive)
2. Inclusion and Demographic Diversity (people, voices, ideas, and information)
3. Collaboration and Shared Purpose (work together to advance the common good)
4. Openness and Learning (listen to each other, explore new ideas)
5. Transparency and Trust (clear and open process)
6. Impact and Action (ensure that each effort has the potential to make a difference)
7. Sustained Engagement and Participatory Culture (programs and institutions that support continuous quality engagement) (Matthews, 2008).

21.3 Relationship between Community Engagement and Capacity Building

Each community engagement initiative often involves capacity building of the concerned community. How are the two concepts related? The concepts of "community engagement and capacity building" are closely interconnected and reinforce each other in various ways. Let's see how they complement each other in various ways to develop sustainable education in a community.

- *Empowerment and Skill Development*: Community engagement initiatives often focus on empowering individuals within the community, including students, educators, and local residents. Through active participation in these initiatives, individuals can acquire new skills, knowledge, and competencies. Capacity building, on the other hand, aims to enhance the abilities and potential of individuals, organizations, or communities. By engaging with the community, capacity-building efforts become more effective as they are tailored to address the specific needs and aspirations of the people involved.
- *Collaboration and networking*: Both community engagement and capacity building foster collaboration and networking among various stakeholders. Community engagement initiatives often bring together educators, students, local leaders, non-profit organizations, and government agencies. These collaborations create a supportive ecosystem where capacity-building efforts can be shared, expanded, and sustained, leading to a more comprehensive and lasting impact (Beegle and Christiaensen, 2019).
- *Sustainability*: When individuals are involved in the decision-making process and take ownership of their educational and developmental goals, they are more likely to sustain the outcomes of capacity-building efforts. This sense of ownership and responsibility drives a culture of continuous learning and improvement within the community.
- *Knowledge transfer and sharing*: Community engagement provides a platform for the exchange of knowledge and experiences. Capacity-building initiatives can leverage this shared knowledge to design programs that are inclusive, culturally sensitive, and locally appropriate. In turn, capacity-building activities enhance the expertise and resources available within the community, contributing to its overall growth and development.
- *Developing community-driven solutions*: Community engagement allows for a bottom-up approach, where solutions are developed based on the specific needs and priorities of the community. Capacity-building efforts can then be tailored to address these unique challenges, making them more effective and sustainable in the long run.

In summary, community engagement and capacity building are intertwined in their efforts to empower individuals, promote collaborative learning, and foster sustainable development. By combining these two approaches, communities can harness their collective potential and drive positive change in various aspects of Physics education in Africa. Improved Physics education in Africa can significantly contribute to improved health care, agriculture, natural resources conservation, etc.

Thus, community engagement is an important topic to consider for any attempt to uplift Physics in Africa. As the ASFAP Community Engagement Working Group, we have considered various leads without exhausting them. It is also a topic at the intersection of various other subgroups like Education, Outreach, Young physicists, and women in physics. There is also a need to introduce ASFAP goals and scope of activities to the community members first. This can be done by the representatives of ASFAP in each county. By doing so, we shall be in a position to interact directly with society and get different feedback on common areas of interest. The ASFAP Community Engagement Working Group is made of four active members, and co-conveners from different countries (Rwanda, Algerie, Senegal, and Nigeria). We have met several times and we were able to identify seven potential areas of possible common action:

1. Physics communication and outreach.
2. Technology transfer; Internet connectivity/ internet start-up resources; Applications and industry.
3. E-lab and e-learning.
4. Business development and entrepreneurism
5. Public education and outreach; Diversity and inclusion and equity.
6. Government engagement and public policy.
7. Career pipelines and development; Retention; Capacity development.

21.4 Outreach Goals and community needs

We present below some actions worth engaging the community with which delineate the importance of using physics in solving societal problems.

1. *Physics and Environmental Pollution*:

   How can we use Physics to resolve the problem of environmental pollution? To raise awareness of the local community on subjects that matter to their everyday life. In the cases of plastic and pharmaceutical waste:

   - Recycling methods for plastics
   - Waste burning (e.g., incineration of pharmaceuticals wastes)
   - Pharmaceuticals return to pharmacists or clinics
   - Special collection programs for pharmaceutical waste (old and unused)
   - Education and Awareness campaigns on the safe disposal of pharmaceuticals and plastic waste (e.g., School visits; Radio Talks; Podcasts; website; etc.)

2. *Physics outreach and Education*:

   To create awareness and broaden the community's understanding of Physics

   - Survey on the views of Physics teachers in Africa;
   - Periodic Training of Physics teachers in Africa;
   - Virtual Physics laboratories: for those schools where there is no access to laboratories (+ internet access): classroom demonstrations for teachers and students;
   - Annual Physics community fairs: to show the local community how Physics can help them in everyday life and introduce children to the fun of Physics;
   - Organise campus visits for high school children to observe some fun Physics experiments;
   - Weekend and holidays science classes (for example the University of Johannesburg SOWETO Science Centre in South Africa).

3. *Astronomy at the service of physics*:

   The Cosmos is after all the largest laboratory in the World... by definition and it is a great stage to use various physics branches to illustrate its cognitive.

4. *Introduce the ASFAP initiative to local governments through the African Union (AU)*: There could have been a part in the blueprint engaging with various physicist bodies or governmental ones at the level of each country. This task needs strong connections and we did not attempt to engage with those important actors as it needs members in these various countries and regions that we did not have (Possibly taking India's engagement with it as a showcase).

21.5 Community Goals and Priorities

Among the submitted letters of intent (LOIs) we have noticed that some of them are related to our proposed topics. Most of them underline several community goals and priorities crucial for promoting scientific literacy, fostering interest in Physics, and building a strong foundation for scientific development. As goals and priorities vary across different regions and countries in Africa, some common ones are shown here:

1. *Accessible and Inclusive Education*: Making Physics education accessible to all students, regardless of their socioeconomic background, gender, or geographical location, is a key community goal. This includes providing resources, facilities, and opportunities for underprivileged communities to engage in Physics learning (Makarova, Aeschlimann and Herzog,2019).

2. *Local Relevance*: Emphasizing the relevance of Physics education to the local context and challenges is vital. Aligning the curriculum with real-world problems faced by African communities can motivate students and demonstrate the practical applications of Physics in their daily lives (Heckam, 2004; Sa'id et al. 2020).

3. *Teacher Training and Professional Development*: Prioritizing the training and professional development of Physics teachers is essential to ensure they have the necessary skills and knowledge to deliver quality education (Heckman, 2004). Thus, continuous support and capacity building for Physics educators in Africa can help improve teaching methodologies and inspire effective learning experiences for the students.

4. *Gender Equity and Inclusion*: Promoting gender equity and inclusion in Physics education in African countries is critical as women form a large percentage of the African population. Thus, encouraging girls and women to pursue Physics as a field of study and research can help bridge the gender gap in STEM (Science, Technology, Engineering, and Mathematics) fields and contribute to increased development in Africa (Jolly, 2009; Beegle, and Christiaensen, 2019).

5. *Practical Learning and Laboratories*: Establishing well-equipped Physics laboratories will allow students to engage in hands-on experiments and practical applications of theoretical concepts. Practical learning experiences enhance understanding and stimulate curiosity in the subject (Jolly, 2009).

6. *Collaboration with Local Industries*: Fostering partnerships between educational institutions and local industries can provide students with exposure to real-world applications of Physics principles. This collaboration can also lead to research opportunities and internships, preparing students for future careers in scientific fields.

7. *Public Awareness and Outreach activities*: Increasing public awareness of the importance of Physics education and its role in societal development is essential. Community engagement programs, public

lectures, and outreach events can help generate interest in Physics and inspire the next generation of scientists.

8. *Scholarships and Financial Support*: Providing scholarships and financial support for students pursuing Physics education can alleviate financial barriers and encourage talented individuals to pursue careers in scientific research and innovation.

9. *Research and Innovation*: Encouraging research and innovation in Physics within the African context can lead to solutions for local challenges (health care, agriculture, clean energy, etc) and contribute to global scientific advancements.

10. *Sustainable Development*: Integrating concepts of sustainable development and environmental awareness within Physics education can create environmentally responsible scientists who contribute to sustainable solutions for Africa's development.

11. *Stopping the Brain drain*: Creating interesting and satisfying jobs for African graduates and making sure that they do not immigrate to developed countries will help boost African development.

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23

Physics Education Working Group

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23.1 Abstract

During the ASFAP initiative, several meetings were held in the physics education group and more than 15 Letters of Intent (LOIs) were submitted by physicists based in Africa and abroad. A few issues were raised during the meetings and as well in the LOIs received by the conveners. Current issues are lack of infrastructure, inadequate curricula, lack of funds and collaboration. To these challenges, some proposals were made in the form of using microelectronics to support theoretical teachings, establishing regional physics experiment centers and a pan African science foundation. In this report, are integrated most of the LOIs as well as notes from the online workshops.

23.2 Physics education goals

A countries youth is a countries future and the better the education of its youth, the better a country's chances to succeed economically. Physics is a fundamental science with implications to many other fields of science and it has an important influence to our daily life. Many of the devices we use every day have their origin in discoveries in fundamental physics, be it TV, radio, Wifi, based in electromagnetic waves discovered by H. Hertz, medical imaging not possible without the discovery of X-rays be K. Röntgen or the World Wide Web, invented to get world wide access to documentation on physics detectors at CERN to name only a few.

Physicist do not only work in research at universities or physics research laboratories but you also find them in industry, hospitals or even insurances or banks.

Studies of physics however has the reputation to be difficult. Apart from theoretical knowledge of physics phenomena, good comprehension of mathematics, computer science and electronics is often required. This interdisciplinary approach makes the physicist so valuable to many industries. In order to attract young people to physics education a few conditions must be met:

- There must be a good perspective to find an interesting and well paid job after the studies
- The schools and universities must be able to transmit the knowledge needed to succeed in the job. This means that the curricula must be adapted to the needs of the country's society and the necessary teaching material must be available, including laboratories and computing facilities, where the students

can exercise their skills, later needed. Good teachers, motivating and guiding the students are equally important.

23.3 Learning approach and challenges

Physics education in Africa is often provided through teacher centered, one way presentations, where the lecturer stands in front of a big crowd of students. Communication between the lecturer and the student is hardly possible. This lecturing style is rather easy for the lecturer because he essentially copies the contents of a book onto a black board and he does not have to "fear" difficult questions by students. The other advantage is low cost for the university as a single lecturer can instruct several hundred students.

On the other hand there is little added value to just supplying the student with a book and only theoretical knowledge can be passed on, this way. It is very important for a student however to see the practical implications of the theoretical concepts he has learned. This "coaching style" of lecturing includes demonstrations and activities that the student can follow. Even better is "learning through doing", where the student takes initiative employing the theoretical concepts in practical laboratory experiments. In this case the lecturer acts only as a facilitator to help the student out, when he is blocked. This lecturing style is the most rewarding for the student, giving him the joy of success, when he manages to complete the task on his own. It also permits the student to acquire a style of problem solving that will later be needed in his daily work. It is the student who has to take the initiative to solve a problem autonomously.

Unfortunately learning by doing requires a number of prerequisites which are not necessarily available at all African schools or universities. First of all the amount of effort to be put into this style of lecturing is much higher than for classroom lectures. The lecturer must invent practical exercises and their solutions himself and he has to document these. Secondly, the number of students that can be supervised is much more restricted, increasing the lecturing cost per student significantly. Last not least, the lecturer must be much better prepared because he has to quickly find errors made by students and blocking them from successfully solving the problems.

Also, the relationship between the lecturer and the student changes significantly from a hierarchical lecturer-student relation to a collegian relation where the lecturer and the student act on a coequal level, which is not wanted by quite a few African lecturers.

For practical exercises some laboratory equipment is necessary, but African physics laboratories are often largely underfunded or simply not available. Instruments like oscilloscopes, spectrum analyzers etc. are often very expensive. When selecting laboratory equipment most lecturers will select turn-key equipment, which can be put to use immediately. This type of equipment is usually more costly than partially home build devices and it has the major disadvantage that it cannot be easily maintained locally. Maintenance of laboratory equipment however is one of the biggest challenges African schools and universities face. It is therefore very important that there is a laboratory supervisor who is capable of repairing equipment and who feels personally responsible for the laboratory. In addition he must have the budget needed to keep it permanently updated and functional. Equipment maintenance is often a big problem in African countries.

I have seen fully equipped computing laboratories that are not used because the computers and networks are not regularly serviced, the operating systems not updated etc. Micro controller boards costing several hundred dollars disappear unused in drawers because the 4 Dollar power supply is missing.

Fortunately simple, very low cost sensors and readout processors are available today. These devices may not allow measurement precision needed in industrial applications but they will demonstrate the principles of how these measurements are done. Students can play with these sensors and even if a few of them break because of wrong connections, this is not a big problem.

On the other hand a small initial monetary investment is needed (some 50 US$ per experimental station) and more importantly a local person must learn how to use and how to maintain the equipment. This means a commitment by the lecturer but also be the university or school to support this person.

Such an experimental station can be used to measure:

- Air temperature and humidity
- soil moisture
- magnetic field
- air pollution
- and many other physical parameters

and it can be used to

- switch devices on or off
- drive display devices
- control different types of motors

It is also possible to simulate costly instruments demonstrating how these devices work. A simple oscilloscope can be created with an ADC and a micro-controller, using a PC as display device for virtually no cost. This device may not be apt to be used with real electronics, but the creator of the device definitively understands what an oscilloscope is all about.

A physics laboratory is usually not permanently in use and collaboration between universities or schools may help to utilize it to its full potential. This would also allow to share the cost among several users.

The same is true for its documentation. It is easy to provide documentation in form of Wiki pages on the Internet, which are globally visible. These pages are therefore accessible to any user of the laboratory. Permission can be given to several authors, making sure that the workload for writing the pages, which is not negligible, to be distributed onto several shoulders. The same argument brought forward concerning the maintenance of the laboratory is also valid for WEB pages containing its documentation: If the documentation is not maintained regularly it will be outdated and therefore useless in a very short time.

If it is impossible to provide a laboratory, then computer simulations may substitute it a least partially. However, many of the requirements stated for the laboratory are also valid for simulations: The lecture style should be “learning by doing”, the effort to be invested by the lecturer is much higher than for one way presentations and the number of students is restricted. Most students own a PC, which in most cases is sufficient to run the simulations, but the exercises, solutions and documentation must still be provided and maintained by the lecturer. ”Lecture style” teaching is needed to supply students with basic theoretical knowledge. However, it should not be the only type of lecturing available to students. Demonstrations and learning by doing are just as important.

23.4 Physics education on an international level

In Europe, the USA or Asia, there are big, national or international physics laboratories (CERN, Fermi Lab, BNL, ...) which also act as centers of physics education. Students come to these organizations to work with experienced researchers on their master or PhD thesis or they come for shorter term schools. A typical example is CERN's summer student program.

These programs are very popular because they allow to learn from re-known lecturers, together with students from different countries, in a foreign work environment. Views on their own education can be exchanged with others and friendly connections between young physicists can be established.

Currently there are very few (if any) African Physics laboratories capable of running such programs. If the African Light Source will come into existence, then it might be able to start such type of education in Africa. On a similar track the "African School of Fundamental Physics and Applications" is held in a different African country every second year. The school is currently financed by a big number of international physics laboratories, which is a challenge for each edition. It should be possible that this very successful school gets a stable funding by participating African countries.

23.5 Major challenges facing public schools

23.6 Physics laboratory in High school

23.7 How to promote active learning?

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24

Women in Physics Working Group

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Dephney Mathebula

"It's important to recognize that intelligence is malleable and can be enhanced through a growth mindset. This involves embracing challenges, learning from criticism, viewing effort as a journey toward mastery, persisting in the face of obstacles, and finding inspiration in the achievements of others.", **Dr Cyulinyana**.

24.1 Introduction and motivation

The status of women scientists in research has evolved over the years, but challenges and disparities still exist in many parts of the world. It's important to note that the experiences of women scientists can vary widely depending on factors such as geographic location, cultural context, and specific fields of research.

Overall, women account for a minority of the world's researchers. Despite the growing demand for cross-nationally-comparable statistics on women in science, national data and their use in policy making often remain limited. This fact sheet presents global and regional profiles, pinpointing where women thrive in this sector and where they are under-represented. Researchers are professionals engaged in the conception or creation of new knowledge. They conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods, in the framework of R and D projects [1].

The persistent under representation of women in traditionally male-dominated fields remains a challenge, and despite diverse efforts to eliminate it, breaking the "glass ceiling" for women in the field of science proves particularly difficult. While strides have been taken toward achieving gender parity in higher education, the disparity is more pronounced in scientific disciplines. UNESCO's 2021 [3] estimate revealed that globally, 45-55% of students at the master's and bachelor's levels are women. However, in science-related areas like engineering and computer science, the proportion of female graduates is significantly lower. This gap widens as one ascends the academic career ladder. Presently, women constitute 30% of the world's researchers and a mere 12% of members in national science academies, with even smaller percentages in low-income nations. This trend is also evident in high-tech sectors such as artificial intelligence (AI). According to a Strathmore University study, women make up 29%of the workforce and only 10 % of leadership positions in the AI industry across the African continent [5].

This issue extends beyond a mere concern about representation and is not exclusive to women alone—it is a challenge that impacts all members of society. Those engaged in science, technology, engineering, and mathematics (STEM) bear significant responsibility in devising innovative and enduring solutions to the intricate problems facing our world [2],[4]. Without the contributions of women scientists and the distinct perspectives they offer, scientific possibilities will be constrained, limiting our collective capacity to tackle a range of challenges, spanning from diseases and food insecurity to climate change.

In general, the challenge becomes particularly pronounced when applied to the field of physics, as gender bias and stereotypes persist. Physics lags behind in addressing these issues, necessitating greater efforts to encourage the younger generation both males and females to pursue the subject and shape their future careers around it [6], [7] and [8].

24.2 Goals, challenges and Solutions

24.2.1 Goals

The main goal of a Women in Physics working group in the African context is to promote gender inclusively, empower women in physics, and address barriers, aiming to increase representation, provide support, and foster a collaborative and supportive community for women pursuing physics careers in Africa.

24.2.2 Challenges and Disparities

Women in physics in Africa, like in many other parts of the world, face various challenges that can impact their participation, advancement, and retention in the field. While experiences may vary, some common challenges include:

Underrepresentation: Women are often underrepresented in physics in Africa, both in academic institutions and research settings. This underrepresentation can lead to a lack of visibility and fewer role models for aspiring female physicists.

Gender Bias: Gender biases may exist in hiring, promotion, and funding processes. Preconceived notions about gender roles can affect how women are perceived in the workplace, potentially hindering their career progression.

Sociocultural Factors: Cultural and societal norms may discourage or limit women's pursuit of careers in physics. Stereotypes about gender roles and expectations may influence career choices and opportunities.

Access to Education: Limited access to quality education, especially in rural areas, can disproportionately affect girls and women, limiting their entry into physics and related fields.

Work-Life Balance: The demanding nature of physics research, with long hours and intense workloads, can create challenges for women, especially those balancing family responsibilities. This may contribute to difficulties in maintaining a healthy work-life balance.

Lack of Support Networks: The absence of strong support networks, mentorship programs, and female role models in physics can make it more challenging for women to navigate the academic and professional landscape.

Harassment and Discrimination: Instances of harassment and discrimination, whether subtle or overt, can create hostile work environments, leading to a lack of job satisfaction and hindering career advancement.

Limited Resources: Inadequate resources, including funding for research projects and access to modern laboratories and equipment, can hinder the ability of women physicists to conduct cutting-edge research.

Networking Challenges: Building professional networks is crucial for career advancement, but women in physics in Africa may face challenges in networking opportunities, which can impact collaboration and visibility in the field.

Policy and Institutional Barriers: Institutional policies and practices that are not gender-inclusive may create barriers for women in physics. Lack of family-friendly policies and support for maternity leave can particularly affect women in their career trajectories. Efforts to address these challenges include promoting diversity and inclusion, implementing supportive policies, fostering mentorship programs, and raising awareness about the importance of gender equality in physics. Collaborative initiatives at the institutional, national, and international levels are essential to creating an environment where women in physics in Africa can thrive and contribute fully to the scientific community

Imposter Syndrome Women in STEM fields, particularly in Physics, might encounter imposter syndrome, a phenomenon where they question their capabilities and sense a lack of belonging, even in the face of their achievements and qualifications. This psychological hurdle has the potential to impact self-confidence and impede career advancement.

24.2.3 Progress, Achievements, Solutions

Promoting Gender Inclusivity: Advocate for gender inclusivity and equal opportunities within the field of physics in Africa. Work towards dismantling gender biases and stereotypes that may hinder women's participation in physics.

Empowering Women in Physics: Provide support, mentorship, and resources to women pursuing careers in physics. This could involve establishing mentorship programs, organizing workshops, and creating networking opportunities.

Increasing Representation: Strive to increase the representation of women in physics at all levels, including academia, research institutions, and industry. Encourage women to take on leadership roles and contribute to decision-making processes within the physics community.

Educational Outreach: Engage in educational outreach programs to inspire and encourage young girls to pursue physics. This may involve collaborations with schools, organizing science fairs, and conducting awareness campaigns to showcase the contributions of women in physics.

Addressing Barriers: Identify and address specific barriers that women face in pursuing physics careers in the African context. This could involve advocating for supportive policies, addressing cultural norms, and ensuring that women have access to educational and professional opportunities.

Networking and Collaboration: Foster collaboration and networking among women physicists in Africa. Create platforms for sharing experiences, knowledge, and resources to build a supportive community.

Research and Data Collection: Conduct research on the status of women in physics in Africa, collecting data on representation, challenges, and success stories. This information can be valuable in informing policies and initiatives aimed at improving gender equity.

Partnerships with Institutions: Collaborate with academic institutions, research organizations, and industry partners to create a more inclusive environment for women in physics. This may involve working with institutions to develop and implement policies that support gender diversity.

Advocacy for Policy Changes: Advocate for policy changes at the national and institutional levels to address gender disparities in physics. This could involve lobbying for equal opportunities, fair recruitment processes, and family-friendly policies.

Celebrating Achievements: Recognize and celebrate the achievements of women in physics in Africa. Highlighting success stories can serve as inspiration and motivation for others, helping to create a positive and supportive community for women in the field.

24.3 Conclusion

It is of utmost importance to enhance the involvement of women in physics and address gender disparities in the field to shape a promising future for women in physics. This involves implementing various strategies, such as establishing alliances with other working groups within ASFAP to collaboratively devise inclusive measures for the physics community. We at ASFAP Women in Physics working group (WPWG) strongly support the collection of data through regular surveys to accurately assess the number and status of women in physics across Africa. It is essential to include the voices of men in this endeavor to foster a collective and united approach. Additionally, at the educational level, efforts should be made to make physics an appealing course that attracts the interest and enthusiasm of everyone.

Women in Physics are continually shattering barriers and surmounting daily challenges. Their impactful contributions to fields traditionally dominated by men showcase their resilience and expertise. Although there remains progress to achieve gender parity in Physics, numerous avenues exist to bolster and champion women in this field. Encouraging young girls, championing equal pay and representation, and fostering mutual support can collectively cultivate a more inclusive and diverse Physics community.

The Women in Physics Working Group (WPWG) is dedicated to making a significant contribution to society by actively mentoring young physicists in Africa. Furthermore, the group is committed to fostering research collaborations with underrepresented women physicists on a global scale. In its efforts to advance higher education and support local scientific research projects in Africa, the WPWG is eager to collaborate with policymakers globally, as well as engage with the private sector and business enterprises.

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25

Young Physicists Working Group

Benard Mulilo, Mounia Laassiri, Diallo Boye

Education and scientific research lead to social, economic, and political development of any country. Developed societies like the Group of Seven (G7) countries have not only heavily invested in education, but also in scientific research in their respective countries. Similarly, for African countries to develop socially, economically, and politically, they should follow suit by massively investing in education and local scientific research.

25.1 Introduction and motivation

In 2009, the United Nations Population Fund announced that the population of Africa had reached the one-billion mark and doubled in size in 27 years [2]. Regardless of the size and large pool of the human resource that the continent is endowed with, most African countries continue struggling economically. Based on the World Bank estimates [3], the proportion of Africans living on less than US$ 1.90 per day fell from 56% in 1990 to 43% in 2012. This indicates an improvement of 13% in the living standards of the people in Africa though according to the World Bank Report [3], there were still more poor people in Africa in 2012 than in 1990 estimated to be more than 330 million up from about 280 million due to the rapid population growth [2] that the continent has been undergoing over the years. Furthermore, despite poverty being a major problem in Africa [3], the continent also experiences deadly diseases such as the Acquired-immunodeficiency syndrome (AIDS) caused by the Human-immunodeficiency virus (HIV) believed to have originated from Africa [5, 4]; Ebola-virus disease [6] whose fatality rate is around 50% with case fatality rates ranging from 25% to 90% in past outbreaks [6], and the recent outbreak of the COVID-19 pandemic [7], which has impacted negatively on Africa and the rest of the world. The continent also faces challenges in science and technology [8] with many African countries technologically dependent on other continents in engineering, education, agricultural products, health services, among others. African countries also face inadequate research-output capability or interest with Africa noted to generate only less than 1% of the world's research output [9] despite its increasing population [2]. Due to all these challenges and other factors, the continent has seen young, talented, skilled, and educated Africans leaving the continent in search for better opportunities overseas, a trend referred to as brain drain [10]. To address these challenges, African countries can draw inspiration from developed societies, particularly the Group of Seven (G7) nations [11], renowned for their massive investments in higher education, science, and technology. The establishment of the Young Physicists Forum (YPF) [13] in 2021, under the African Strategy on Fundamental and Applied Physics (ASFAP) [12] amid the COVID-19 pandemic [7], was meant to identify the major challenges that young physicists face and solutions thereof in order to positively contribute to the educational and local-scientific research on the continent, and thus, build capacity for Africa.

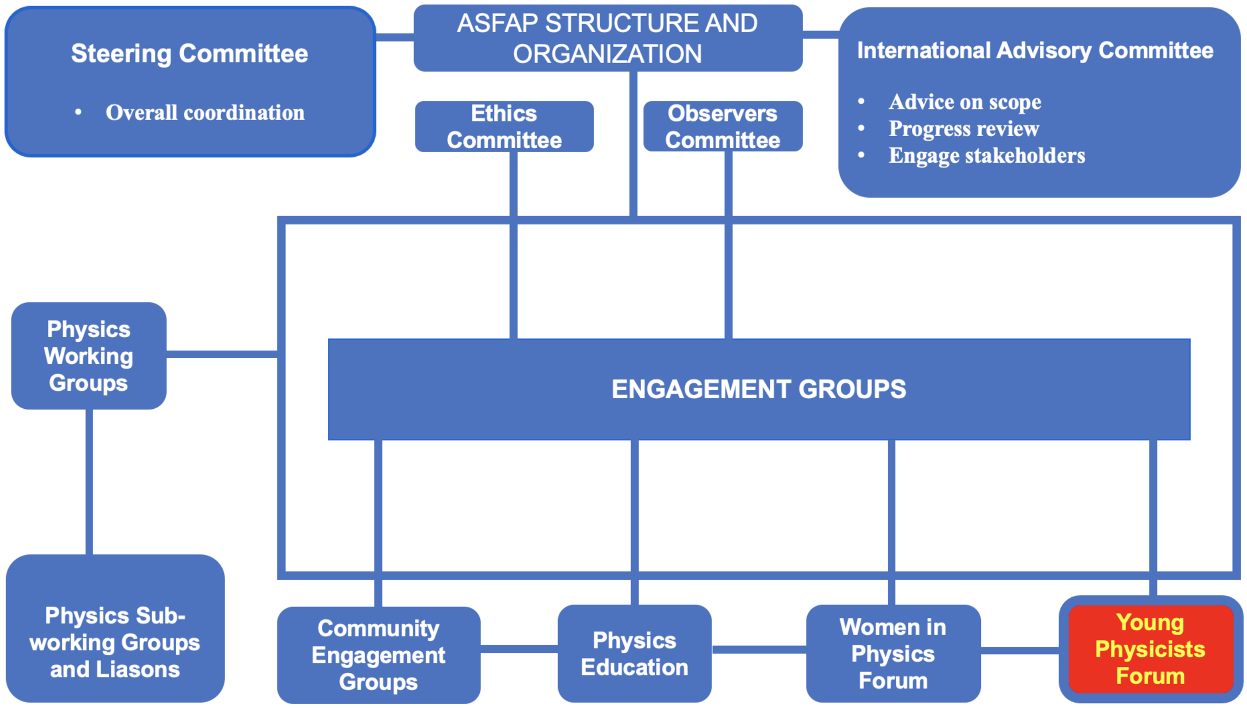


Figure 25-1. *Structure and organization of the African Strategy on Fundamental and Applied Physics.*

The Young Physicists Forum [13] is one of the engagement and physics working groups (PWG) under the African Strategy on Fundamental and Applied Physics (ASFAP) [12]. The forum is driven by three, young, and vibrant physicists who are co-conveners of the group all in possession of a doctor of philosophy in physics [13]. The co-conveners' mandate is, among other things, to ensure that the group remains sharply focused on its aims and objectives. The forum has a total of 76 active members [13], most of whom are in possession of either a master of science degree or doctor of philosophy in physics. There is, however, no discrimination regarding the highest level of education YPF members [13] should meet and, therefore, all interested individuals within and outside the African continent are eligible to join the forum [13] as long as they sign up [13] and get approved by the steering committee of ASFAP [12]. The group also encourages undergraduate students in various science disciplines, particularly physics, from various African universities to join the YPF [13] and enjoy the mentoring/scholarship benefits that YPF members share within the group, and thus increase their chance of embarking on postgraduate studies either within Africa or overseas. The Young Physicists Forum [13] reports to the steering committee of ASFAP [12] in a well organized structure as shown in Figure 25-1.

25.2 Goals, challenges, and solutions

The aims and objectives of the YPF [13] are, among others, to collect ideas, opinions, and experiences on education, physics outlook, careers, workplace environment, and scientific research in Africa. Furthermore, the forum is mandated to clearly identify and raise awareness of the educational challenges and science career opportunities for young physicists in Africa and advocate for change by informing policymakers for action. Last, but not the least, the forum also aims to collect preliminary data for future research.

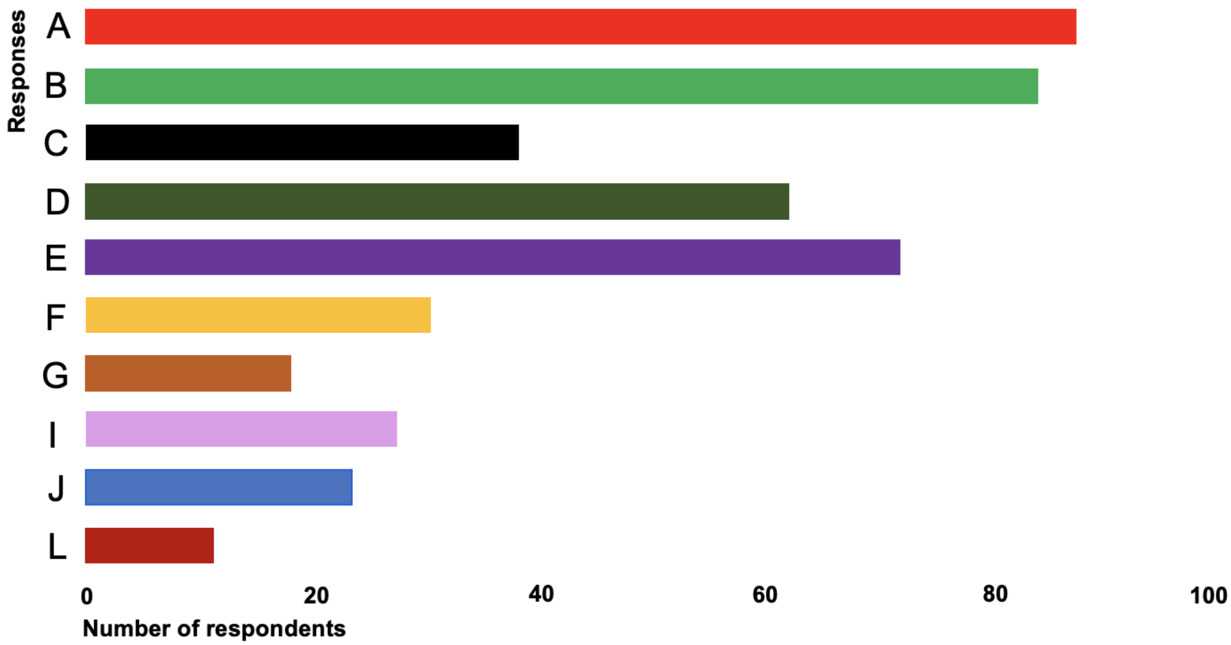


Figure 25-2. *Challenges faced by respondents pursuing their highest level of education in African universities.*

Since the group's inception in 2021, the Young Physicists Forum [13] has made tremendous progress in meeting its mandate (i.e., its aims and objectives) with the main modes of information dissemination being through scheduled meetings within the group and regular co-conveners' meetings, which are usually held on Wednesday at 5:00 PM, Coordinated Universal Time (UTC). The forum also formulated a survey [16] to solicit for a wider community input of ideas. In addition, the group virtually held a successful workshop with stakeholders within and outside ASFAP [12] on 26^{th} January, 2022 tagged *ASFAP: YPF-Challenges and Opportunities* [14]. The YPF [13] also actively participated in the second edition of the African Conference on Fundamental and Applied Physics tagged *ACP2021* [18] and contributed three talks under different themes mainly focused on the status and progress the forum has so far made in line with the aims and objectives of the group.

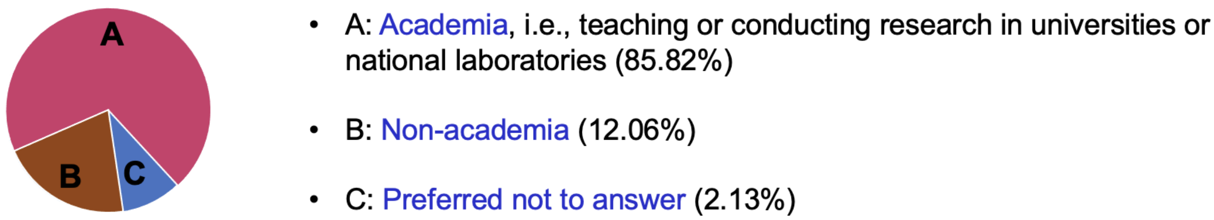
To solicit for a wider community input, the Young Physicists Forum [13] opened a survey [16] to sample African respondents within and overseas, main of whom are alumni of the African School of Physics (ASP) [17]. The survey [16] was aimed at gathering information on the education background, research performance, collaboration opportunities, career development, and workplace environment of the respondents. Survey results [16] show that 79.56%, of the respondents pursued their highest level of education within Africa while 20.44% of the respondents attained their highest level of education outside the continent of Africa. The survey [16] has further revealed that of the respondents who attained their highest level of education within Africa normalized to 100%, only 39.42% were satisfied. Factors leading to the educational dissatisfaction rate by respondents are plotted in Figure 25-2 and outlined in Table 25-1. From Figure 25-2 and Table 25-1, it is evident that good quality education and research in Africa still remain a huge challenge. Other major obstacles of an African educational system include the lack of mentors, skills training, libraries, job insecurity, and to a lesser extent political instability such as wars, among others. Since education, science, and technology are ingredients that contribute massively to a good life and development of global economies, there is need to solicit for remedies that counter the education and research challenges that many African countries have been grappling with for years.

Table 25-1. *Educational challenges faced by respondents pursuing higher education in African institutions*

Responses	Challenges	Rate (%)
A	Lack of research funding	20.35
B	Lack of research equipment	19.26
C	Lack of mentoring support	7.88
D	Lack of mobility opportunities	13.57
E	Lack of proper skills training	15.75
F	Lack of access to libraries	6.35
G	Limitation of academic freedom	3.50
H	Imbalance between work and family demands	5.91
I	Job insecurity	4.81
J	Political instability and wars	2.63

According to the survey [16] conducted by the Young Physicists Forum [13], prominent solutions to educational challenges include raising awareness to African policymakers and private enterprises on the need to fund research through provision of grants, which universities in Africa should utilize to buy experimental equipment and conduct research. African governments should also invest in building higher learning institutions that are well equipped with research facilities such as modern laboratories where academic staff and their students could establish the link between theory and experimental work. This would then help reduce over-dependence on foreign research facilities and contribute to meaningful and reliable collaboration with other institutions and research facilities overseas. Public and private universities should work together and help improve the internet network in universities and research facilities across Africa as a good and stable internet connectivity undoubtedly enhances scientific research output and helps improve the quality of learning.

Other measures that may help counter educational challenges in Africa include revision of the school and university curricula by reducing over-dependence on theoretical work [16], building scientific research facilities, and securing laboratory equipment to encourage research skills and knowledge acquisition through experimental work among African students. Furthermore, the lack of mentors in science disciplines like physics in African universities could be resolved by motivating professors to embark on scientific research projects and closely working with their students [16] once research grants are available to them from governments and private enterprises. Academic staff should also spend more advisory time with their students and try and establish the link between theoretical and experimental work together [16]. Additionally, academic staff should offer more structured feedback to students and also establish research collaborations within and outside the continent so as to expose their students scientifically [16]. Occupational and career guidance should also be provided to students by their advisors in order to motivate them regarding their future endeavours in academia within Africa [16]. A career with occupational development is another huge challenge being faced by young physicists in Africa [16]. According to the population sampled in the survey [16], it is found that roughly 85.82% of the respondents are in the field of academia where they are teaching and conducting research in national universities and laboratories while those in non-academia fields accounted to about 12.06%, and approximately 2.13% preferred not to reveal their occupation as shown in the pie chart in Figure 25-3 by A, B, and C, respectively. Those in academia identified themselves as bachelors, masters, and doctoral students including postdocs, engineers, technicians, physicists as well as faculty members.



Occupation and precent representation of sample									
Current position	Bachelors students	Masters students	PhD students	Postdocs	Engineers	Technicians	Faculty	Physicists	other
Percent (%)	3.55	10.64	44.68	8.51	0.71	0.71	14.18	9.93	7.09

Figure 25-3. *Occupation and percent representation of respondents according to the survey conducted by YPF.*

Results of the survey [16] have further revealed that securing an academia position within African universities and national research facilities poses a major challenge and is, at the same time, a huge sacrifice owing to the fact that the workplace environment is mostly not conducive due to lack of experimental facilities, among other challenges, more so in the last two years with the breakout of the COVID-19 pandemic [7]. Based on the results of the survey [16], the Young Physicists Forum [13] has learnt that the combined effect of the nature of an academia workplace environment in Africa and the impact of the COVID-19 [7] has led to a reduction of academic interactions between academic staff and students according to 19.35% of the respondents. Other effects include the reduction of experimental activities (14.52% of the respondents) and research funding according to 12.50% of the respondents. The nature of the workplace environment with the impact of the COVID-19 pandemic [7] has also led to fewer advisor-student interactions according to 13.91% of the respondents while other effects include physical and mental health problems as well as financial hardships as described in Figure 25-4. The poor currency-exchange rates of African currencies against major world currencies such as the United States Dollars ($), Euro (€), and the British Pound (£), among others, is another major challenge [16] of being in the academia field in Africa as this significantly and negatively impacts scientific collaboration work between Africa and other continents as far as international research visits and conferences by students and academic staff are concerned.

The lack of good will and minimal interest in education, science, and technology in Africa [8] have led to a huge challenge over the years where the world has witnessed a large number of skilled manpower leaving Africa for other continents in search of a more conducive workplace environment and an attractive income to support their families, a trend known as brain drain [10]. The survey [16] conducted by the YPF [13] has revealed some instances of brain drain [16, 10] that have been taking place in Africa over the years. These include young and skilled African students studying abroad on scholarships opting to stay and working overseas after completion of their studies [16]. Researchers and postdocs also feel more comfortable working overseas than in African universities where they are either not welcomed or because of the nature of an African academic-workplace environment and meagre salaries [16]. The lack of academic freedom (i.e., students having no choice of what to study due to financial reasons), inadequate funding, and absence of research equipment disfavor Africa as a good destination for good quality education and research work [16]. Political instability such as wars in some countries in Africa drive away academically qualified personnel to other countries outside the continent where they settle down and continue to contribute to science and technology there than in their African countries of origin [16]. In spite of all these brain-drain

	Nature of workplace and COVID-19 impact	(%)
A	Reduction of research funding	12.50
B	Reduction of experimental activities	14.52
C	Reduction of academic interactions	19.35
D	Less productivity of online classes	8.87
E	Less advisor and student interaction	13.91
F	Physical healthy problems	7.26
G	Mental healthy problems	9.48
H	Financial hardship	13.10
I	None	0.40
J	Not applicable	0.60

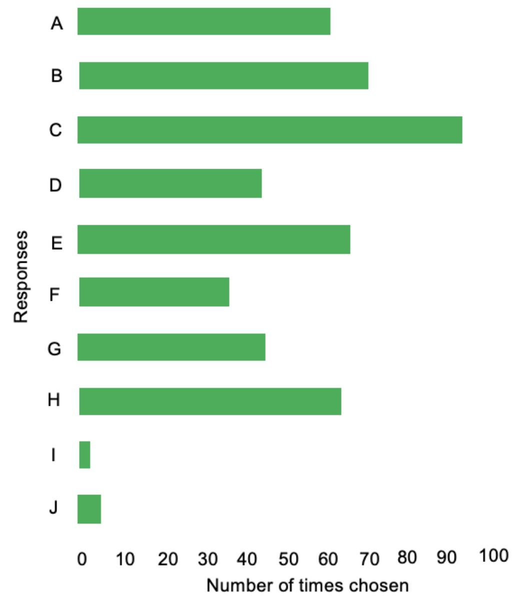


Figure 25-4. *Impact of the nature of the workplace and COVID-19 pandemic on research institutions in Africa.*

Table 25-2. *Measures that may help counter brain drain according to the survey conducted by the YPF*

1	Create a school of excellence within Africa for Africans who have obtained their baccalaureate with honors in order to encourage African academic excellence and experience.
2	Policymakers on the continent should partner with private enterprises and work together to improve the research-workplace environment and conditions of service such as salaries to match foreign-based counterparts in academia.
3	Create national research laboratories and more academic positions in African universities and provide research grants to enable academic staff members to embark on a meaningful scientific research experience within the continent.
4	Policymakers should stabilize African currencies to compete favorably with other major world currencies such that the salaries skilled academic staff are earning in Africa are favourably comparable to salaries fellow counterparts earn abroad.
5	Enhance and connect African academic infrastructures with the rest of the world; promote scientific collaborations with international universities, research institutions, and laboratories and allow creative young Africans to present new scientific research projects.
6	Massive investment in African university education is required that will result in an increase in well paying jobs. A marketing campaign should be setup to encourage the youth to stay and work in their respective countries in Africa.

challenges [16, 10], the hope for Africa in education, science, and technology [8] is still alive. Through the survey [16], the YPF [13] have compiled measures to counter the effects of brain drain [10] and hence help keep alive the hope for African countries to develop their education and build capacity for Africa. These interventions are summarized and listed in Table 25-2.

25.3 Conclusion

The African continent is endowed with abundant natural resources ranging from huge arable land through oil, natural gas, minerals to floras and faunas. It is amazingly puzzling to note that the continent holds a large proportion of the world's natural resources, both renewable and non-renewable and yet, to a large extent, Africa still remains undeveloped with higher poverty levels [3] than other continents. To restrain or minimize these challenges, Africa should heavily invest in higher education and promote local scientific research [16, 8]. Advanced scientific research carried out within Africa would, for example, help find solutions to diseases such as HIV/AIDS [4, 5] that have been ravaging the continent over the years; produce vaccines of its own to cure pandemics such as COVID-19 [7] without having to entirely depend on or solely wait for developed societies [11] to share portions of their vaccines; process its abundant natural resources from raw materials to finished products, and reduce over-dependence on developed countries for finished goods and services [8]. This would, in turn, build an even better relationship between Africa and the rest of the world as far as business is concerned. Since higher education is one of the keys to social, economic, and political independence of any country, it goes without saying that, higher education should be prioritized across Africa. Policymakers should ensure that the educated-human resource is enticed to work within Africa by offering an attractive workplace environment and good conditions of service. These measures would help minimize the brain-drain [16, 10] phenomenon. The YPF [13] is entirely open and solely devoted to identifying the challenges that young physicists face in developing their careers in Africa and finding solutions as well as career opportunities available for young physicists on the continent so as to revamp education and build capacity for Africa. The YPF is also entirely committed to mentor young physicists in Africa and to help promote research collaborations with other young physicists globally [16]. All in all, the YPF [13] is willing to partner with policymakers globally, the private sector, and business enterprises as far as the promotion of higher education and advanced, local scientific-research projects in Africa are concerned.

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