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Guest Editors: K. A. Assamagan, M. Backes, D. Charlton, S. Muanza , D. Sahu, and D. Singh

The African Light Source Project

S.H. Connell[1], S.K. Mtingwa[2], T. Dobbins[3], B. Masara[4], E.P. Mitchell[5], L. Norris[6], P. Ngabonziza[7,1], T. Ntsoane[8], M. Sekota[9], A. Wague[10], H. Winick[11], M. Yousef[12]

1. University of Johannesburg, South Africa
2. TriSEED Consultants, LLC, North Carolina, USA
3. Rowan University, USA
4. South African Institute of Physics, Executive Office, South Africa
5. European Synchrotron Radiation Facility, Grenoble, France
6. African Physical Society
7. Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany
8. The South African Nuclear Energy Corporation SOC Ltd (Necsa), Pretoria, South Africa
9. National University of Lesotho, P.O. Roma 180, Lesotho
10. Tamaro Toure University of Science and Technology, Dakar, Senegal
11. SLAC National Accelerator Laboratory, Stanford University, Stanford, California, USA
12. Cairo University, Egypt.

The global science endeavour drives technological development in both the short and longer term and has a large impact on socioeconomic development. There are however other benefits, such as the culture of enlightenment, the eradication of ignorance and prejudice, the promotion of large-scale boundary-crossing collaborations and a real, fundamental appreciation of all diversity. In this context, large-scale research infrastructures play an important role. Amongst these, one of the most transformative mega-research entities is the modern advanced light source (AdLS). Research using these facilities is fundamental, applied and industrial. The first case is a truly universal endeavour, and in the latter cases, there will be regional priorities. For all these reasons, research has to be carried out everywhere and by all peoples. The passionate belief in this positive role for science and technology in society has driven the call for the African Light Source (AfLS). The call was first sounded in 2002, and it has been repeated by many sources on many platforms. African scientists are strongly participating in research exploiting the power of modern AdLSs, both from within African institutions, and from other institutions, as the exercise of the African science Diaspora. In addition, the global science community has also strongly supported the worldwide proliferation of the benefits of access to large-scale research infrastructures, and to extending the collaborative participation as widely as possible. This combination of African and International leadership towards an AfLS is embodied in a fully mandated international committee whose vision and goal is an AdLS in Africa. This AfLS would be supported by extensive local and regional research infrastructure and also local and regional human and industrial capacities.

1. Introduction

An modern-day advanced light source (AdLS) is a very large-scale research infrastructure. It embraces essentially all "light"-based spectroscopy, scattering and imaging techniques, utilising radiation from the infrared through to the soft gamma ray portion of the electromagnetic spectrum. The "light" is orders of magnitude brighter than traditional laboratory-based lasers and X-ray sources, which for decades have transformed science and technology. The various research techniques supported represent extremes of performance and discovery potential. It is the leading example of a resource hosting multi/inter/trans-disciplinary research activities. These include the medical sciences, cultural heritage sciences, geosciences, environmental sciences, energy sciences, nano-sciences, materials sciences and mineral sciences amongst others. An AdLS supports parallel, not sequential access by many tens of groups at the same time, almost continuously, around the clock, year in and year out. It seeds a combined science and industry park that springs up around it. It becomes a clustered science-megalopolis of globally competitive research, training, innovation and outreach activities. It should therefore be highly accessible internationally, have a lot of space around it, be imbedded within or close to a city and also be very well connected to communication and energy grids. It is however, an expensive facility, up to several hundred million dollars to construct and tens of millions of dollars annually to operate. It is usually a nationally or internationally supported resource. This significant cost is more than justified because of its enormous productivity in all aspects of science delivery mentioned above. Specifically, it is also exploited by industry, in models from open collaborations to confidential research, and via the large-scale high technology procurement required to support it.

The extremely high photon brightness and flux provided by AdLSs have allowed significant advances to be made in numerous applications for the benefit of society, including drug discovery and development; better understanding of diseases, based upon the deciphering of protein, bacterial and viral structures; and advances in data storage through studies of electronic structure and magnetism in selected materials. AdLSs show tremendous promise in direct medical applications, allowing innovative imaging techniques of such organs as the heart, lungs, brain and breast, leading to exciting new diagnostic techniques and therapies. More recently, AdLSs have been used in palaeontology and cultural heritage studies. For example, three-dimensional tomographic images have been made of fossils, rock art and other artefacts. A key feature of AdLSs is their power to observe materials during their manufacturing, processing and end-use conditions, making them second-to-none in providing key insights to dynamic and transient processes such as catalysis, fuel injection and additive manufacturing.

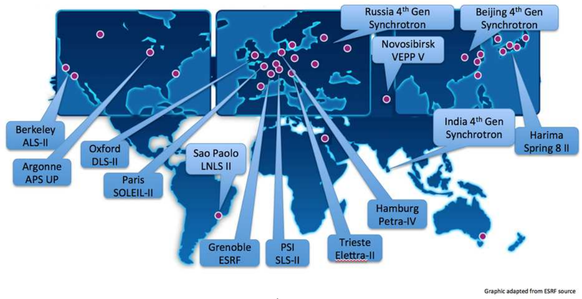


Figure 1. Thirty one 3rd generation advanced light sources and fourteen major upgrades / new builds [1].

Figure 1 above depicts the location of thirty-one 3rd generation AdLSs and fourteen major upgrades / new builds worldwide. There is clearly an enormous imperative worldwide to host such a facility and to develop it further. Each AdLS boasts a research infrastructure with high expectations of scientific and technological productivity for many years into the future. Africa is presently the only habitable continent without an AdLS. African countries participate in this research by performing experiments at facilities abroad. An AdLS in Africa would enable thousands of African scientists, engineers and students to gain access to this superb scientific and technological tool. Indeed, in order to be competitive socially, politically and economically in the years to come, access to a nearby AdLS will be an absolute necessity.

There would be many socio-economic benefits to positioning an AdLS in Africa, including the following:

- Boosting excellence in scientific research, research capacity and capacity-building in Africa.
- Tackling diseases endemic to Africa from a molecular level using protein crystallography.
- Pursuing other research of particular relevance for Africa, including the environment, energy, agriculture, clean water, mineral extraction, human origins and the origins of human culture.
- Using Science for Peace, similar to the now well recognized role played by CERN globally [2], or SESAME in the Middle East [3,4].
- Retaining skills and encouraging the return of the African Science Diaspora, establishing a global research community on the continent of Africa.
- Developing the spin-off benefits for technology development, innovation and industrial competitiveness.
- Attaining higher PhD throughputs, thereby attaining more quickly the critical mass needed for a knowledge-based economy.
- Enabling users to become experts in AdLS based techniques at an early age, thereby maximising their productive career in cutting edge research.
- Affording African countries the opportunity to work together in taking control of their destinies and become major players in the international community.

An AdLS in Africa could surely play a significant role in driving Pan African science and socio-economic development. It is, indeed, the next must-have large-scale scientific and technological asset for Africa.

2. Early history

The history of SESAME, an AdLS in the Middle East hosted in Jordan, provides many inspiring lessons for the African Light Source (AfLS) [5]. It was conceived in the early 1980s. A proposal emerged in 1997 to use components of Germany's decommissioned BESSY I as a basis for a new facility. The UNESCO Executive Board approved the establishment of SESAME under its auspices in 2002. The official birth of SESAME is taken as the ratification of its statutes by the six initial potential member states in 2004. Egypt is now a participating African state. SESAME began hosting its first users in mid 2018. While SESAME is of course open for African users, it is still very important, geographically and for societal and educational benefits, that there also be constructed an AdLS on the African continent.

The likely first published measurements involving African scientists at synchrotrons occurred circa 1990 in the North of Africa [6] and circa 1994 [7] in the South. A synchrotron is a circular electron accelerator/storage ring, which for the purposes of this article, is especially designed to emit "light" (from the infra-red to the hard X-rays) at specific points along its circumference. From this point, the African user base of international AdLSs grew steadily. The first formal call for a Pan-African AdLS was recorded into the *2002 Strategy and Business Plan* of the aspirant African Laser Centre (ALC), which was then established the next year [8]. This early formal proposal for a synchrotron in Africa was something strongly encouraged by the Edward Bouchet-Abdus Salam Institute (EBASI), which is an Institute inspired and supported by the Abdus Salam International Centre for Theoretical Physics (ICTP). This broad partnership of scientists and institutions from both within Africa and beyond, in the common vision of an AdLS for Africa, has been a hallmark of the development of the AfLS project. The conversations, writings and calls for an AdLS in Africa grew so that the number of both individuals and institutions involved soon became too numerous to mention explicitly. Likewise, the developments within each African country of smaller-scale local laboratory-based research exploiting similar techniques to those at large-scale AdLSs grew, as did the use of external national and international AdLS facilities. It is not the purpose of this paper to chronicle this development at a national scale, but simply to recognise that these national-level developments took place in parallel with conversations surrounding a joint Pan-African AdLS.

In this way, momentum was built towards an African Light Source (AfLS). It became necessary to draw all the participants together into a common, coherent, fully mandated vehicle. Electronic media was scoured for the many participants of this conversation, and was used again to collectively advertise as widely as possible for nominations to the Interim Steering Committee (ISC) for the AfLS. Finally, on 16 August, 2014, all the nominations were accepted as constituting the ISC - AfLS, which inaugurated itself electronically on this date. It had representation from the following countries or regions: Egypt, Ethiopia, Nigeria, Rwanda, Senegal, South Africa, Zimbabwe, United States, Europe and Japan. The ISC - AfLS had the limited mandate to initiate a transparent, inclusive and democratic process, incarnated finally in a Conference and Workshop, where it would then dissolve itself, as the more representative and inclusive Steering Committee for the AfLS would be born. With this foundation, the vision for an African Light Source could be expected to take form and mature, attracting support.

One is always amazed at how many parallel efforts there are in Africa related to the development of Science, Technology, Engineering and Mathematics (STEM) and also how this relates to socio-economic development and the strengthening of democracy. This paper cannot mention all these efforts related to AdLSs. However, one significant milestone must be mentioned. The 1st African Higher Education Summit on Revitalizing Higher Education for Africa's Future, was held in Dakar, Senegal from 10-12 March 2015. The summit was organized by several key Pan-African organizations, including the African Union Commission (AUC), TrustAfrica, the Council for the Development of Social Science Research in Africa (CODESRIA), the United Nations' Africa Institute for Development and Economic Planning (IDEP), the Association for the Development of Education in Africa (ADEA), the Association of African Universities (AAU) and the African Development Bank (AfDB), as well as other national and international partners. An outcome of this meeting was a Declaration and Action Plan (Figure 2) to bring about a shared Strategic Framework for inclusive growth and sustainable development and a global strategy to optimize the use of Africa's resources for the benefit of all Africans. Article 5.3.3 on page 22 recommends establishing a Synchrotron as a centralized African scientific facility. This represents the second major Pan-African statement identifying the crucial significance of an AdLS for Africa.

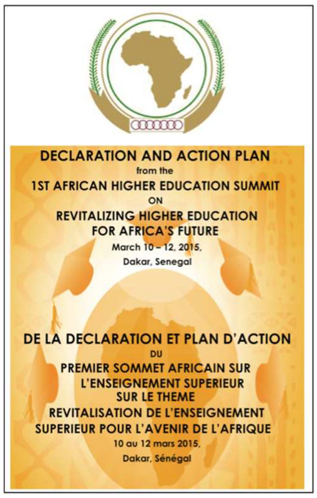


Figure 2. The Declaration and Action Plan of the 1st African Higher Education Summit on Revitalizing Higher Education for Africa's Future [9].

3. The 1st AfLS Conference and Workshop

The 1st AfLS Conference and Workshop was held at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France during 16-20 November 2015. Figure 3 shows that there were a total of 98 delegates, representing 13 countries in Africa and 12 from the rest of the world. The strong African participation was a clear indication of the extent of African users of AdLSs and the scope of the projects. An early conclusion from the Workshop was that indeed Africa is ready to have a mandated vehicle to drive the vision of the AfLS.

Figure 4 depicts the 68 presentations which were delivered, many highlighting research of Africans performed at AdLSs. The full spectrum of interdisciplinary topics was represented. This included research that addressed the social, environmental, economic and scientific challenges confronting Africa. Palaeontology had a significant African footprint with 12 African countries involved in ongoing research programmes associated with the ESRF alone. Industry was already engaged, as evidenced by a strong participation of the SASOL energy and chemicals company. In the biosciences, studies on diseases and developing new drugs particularly relevant for Africa were well advanced, for example for malaria, HIV, tuberculosis and Ebola.

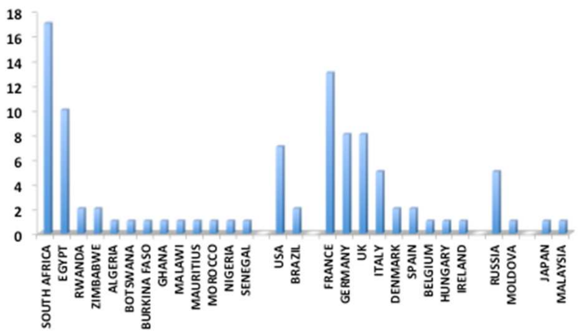


Figure 3. 40 African delegates and 58 delegates from beyond Africa participated in the 1st AfLS Conference held at the ESRF on 16-20 November 2015.

Materials science also had a strong showing. There were reports of the beginnings of a local infrastructure in some countries, showing the potential for growth of the feeder instrumentation needed to produce and screen samples before more detailed beam studies at AdLSs.

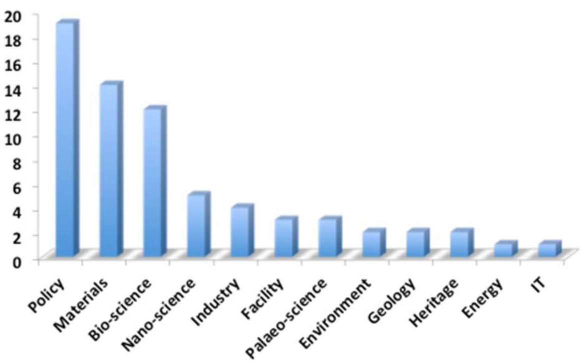


Figure 4. 68 presentations at the 1st AfLS Conference held at the ESRF on 16-20 November 2015.

The last two days were dedicated to discussing the strategic and policy objectives, intended as specific and concrete outcomes of the Conference and Workshop. These discussions were based on documents that had been drafted and advertised in the weeks leading up to the meeting. The three major outcomes were the *Grenoble Resolutions*, the *AfLS Roadmap* and the election and establishment of the fully mandated *AfLS Steering Committee*. These have been discussed before [8]. Here we publish them in full as Appendix 1 within the **African Light Source Manifesto.** This document has sections for the Grenoble Resolutions and the Roadmap in its detail, and also a Vision and Mission section for the AfLS Steering Committee.

In summary, the Roadmap has short-, medium- and long-term goals. The short-term goals are applicable throughout the Roadmap period. These include activities that develop human capacity (including visits, schools, workshops, internships); developing international collaborations, linkages and partnerships related to AdLSs; promoting mobility and access to currently operating AdLSs; developing local feeder infrastructural capacity to support access to AdLSss; broadening the user base; involving industry; and building formal structures and procedures in support of the Roadmap. As the Roadmap develops the activities become more structured and formal, requiring greater planning, investment and partnership with government and policymakers. The Pan-African content increases. This is discussed further in Section 9. Ultimately there will be a Feasibility Study, Business Plan, Governance Model and Technical Design Report, leading to an African Light Source.

To progress the Roadmap, the AfLS Steering Committee currently has 62 members, and it remains open for addition of new members. As shown in Figure 5 below, the following countries are represented: Algeria, Benin, Botswana, Burkina Faso, Cameroon, Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Kenya, Lesotho, Morocco, Nigeria, Rwanda, Senegal, South Africa, Zimbabwe, Brazil, Japan, Germany, Italy, Mexico, Spain, France, Trinidad and Tobago, United Kingdom, and United States.

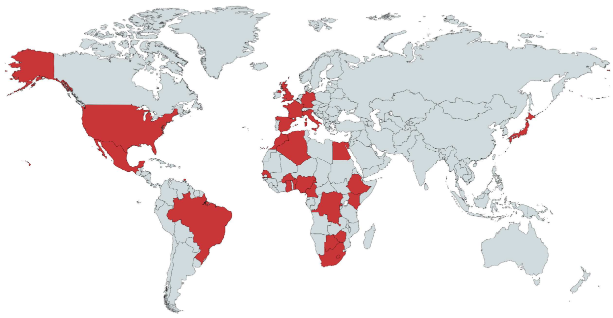


Figure 5. The representation by country on the AfLS Steering Committee, dated September 2018.

The African Light Source Steering Committee has an Executive, where the membership is as in the author list above, with the Chair and the Deputy Chair being the first and second authors.

4. General activities of the AfLS Steering Committee

Members of the AfLS Steering Committee (AfLS-SC) have promoted the AfLS project widely at various Conferences and Meetings. A partial list includes the annual Science Forum South Africa (SFSA), the 2017 World Science Forum (WSF) in Jordan, the 2016 and 2018 instances of the International Conference on

Research Infrastructures (ICRI) in South Africa and Vienna, and the American Physical Society. The AfLS has featured regularly in the biennial programme of the African School of Fundamental Physics and its Applications. The AfLS-SC does not have its own resources to fund a mobility programme at this stage. However, African scientists and students have used existing funding instruments to conduct working visits to AdLSs. These have proved difficult to audit and track, and they are most likely underestimated. An example is that in South Africa, there are two formal funding agency sponsored access routes. One is via South Africa's Scientific Association with the ESRF at the 0.3% operating budget level, and the other is a Mobility Fund dedicated to AdLSs. Nonetheless, an audit of just these two under-represents the usage from this country. The Roadmap envisages longer-term training visits. An example of this is that following the 1st AfLS Conference and Workshop, the ESRF took on an African Postdoctoral student for a two-year period.

Another example that is well compatible with the AfLS Roadmap is the UK's Global Challenges Research Fund-Synchrotron Techniques for African Research and Technology (GCRF-START) Programme between a large group of African researchers and the Diamond AdLS. It connects scientists in Africa and the UK focussing on novel energy materials (catalysts and photovoltaics) and structural biology (studying diseases and developing cures). START is also about training the next generation of researchers (leaders) in these fields. It currently includes 16 different institutions.

Other examples of increasing activity in-line with the AfLS Roadmap are conferences dedicated to research based at AdLSs. For example, the Council of the International Union of Pure and Applied Biophysics with responsibility for Education and Capacity-Building is supporting a meeting in January 2019 called “Biophysics and Structural Biology at Synchrotrons” in South Africa. The general field of crystallography is growing strongly within Africa. This field covers many research disciplines, and research may be carried out either in local or regional-scale laboratories, but also including AdLSs. In fact, we find that modern technology is boosting diagnostic power and research potential of smaller scale local facilities considerably. The new Pan-African Conference on Crystallography (PCCr) series supports this significant field. The first such conference was PCCr1, held in Cameroon in 2016. The next edition is PCCr2 to be held in Ghana in early 2019.

The Roadmap also includes the development of local laboratory-based facilities, especially for X-ray related research or in support of this research. This allows local capacity-building and research, and is considered essential for competitive access to global infrastructures. There are many examples but we mention here the International Union of Crystallography and UNESCO (IUCr-UNESCO) OpenLabs project. This is a network of operational crystallographic laboratories world-wide, including within Africa (Morocco, Ghana, Algeria, Tunisia, Kenya, Senegal, Cameroon and Côte d'Ivoire). Of course there are also many institutions in Africa other than this list with X-ray related research capacity. This list is to illustrate a directed programme to develop capacity.

5. African participation in International Advanced Light Sources

The AfLS Roadmap envisages an increasing participation by African scientists at AdLSs. This would start with African scientists collaborating on international projects and grow to projects proposed by African scientists to the international AdLS facilities. As the need for such facilities grew, it would develop to include participation in the development and operation of a beamline(s) at a national or international AdLS facility. A next step would be country-based membership of an international AdLS facility.

Egypt is the first African country to do this last step. It participates as a member of SESAME along with the Middle East countries of Cyprus, Iran, Israel, Jordan, Pakistan, the Palestine and Turkey. This is a very important step for Africa, as it involves participation of government, policymakers and funding agencies directly, as well as engineers and technicians, and therefore is an involvement well beyond that of the scientists (both from academia and industry). This is the level of involvement that is more likely to access the full range of benefits, leading to globally competitive research. It would have more significant training of a wider spectrum of skills, technology transfer, spin-off benefits to competitive industry, innovation, and also the crucial experience in the governance of large-scale international facilities. Of course, in the case of SESAME, the aspect of science diplomacy and the role of Science for Peace are very significant both in a regional and international level by creating long-term links between countries nearby and with the rest of the world (for example through programmes like the OPEN SESAME [10] training programme supported by the European Union where there are staff exchanges between SESAME and European facilities, generating durable collaborations).

On 21 May 2012 South Africa signed a medium-term arrangement with the ESRF at a level of 0.3% and, in doing so, became the 20th country to join the European synchrotron, which is an international facility. The first South African experiments at the

ESRF began in 1994. These and other early efforts grew, leading to the emergence of a vibrant and interdisciplinary South African synchrotron AdLS user community. Collaborations with the ESRF has continued to strengthen and flourish and important breakthroughs have been achieved, notably in the domains of palaeontology, palaeoanthropology, materials science and macromolecular crystallography. Palaeontology in Africa more generally has been one of the big success stories of AdLS science, with the involvement of some 12 African countries. Figure 6 below shows some recent spectacular results on *Australopithecus sediba*, where high precision computed tomography revealed insights into the evolution of the human brain.

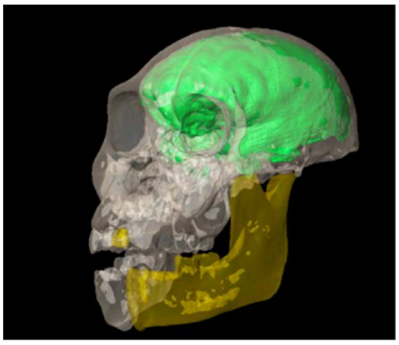


Figure 6: Virtual endocast (green) of a juvenile male *Australopithecus sediba*. Yellow indicates portions of the skull that were reconstructed by mirror-imaging the anatomy on the opposite side [11].

World AdLSs generally have been very supportive of the AfLS project. This support has involved expert contributions and financial support to schools, conferences and other activities, willingness to provide research partners and collaborators for African research programmes; mentoring and supervision of young African researchers, partnering in funding proposals or offering direct financial support to AfLS and related activities, and collaborating with the AfLS project generally. In fact, the AfLS project has found that it has collaborated with and found friends in almost all world AdLS facilities and related large-scale infrastructures and institutions.

6. The African Academy of Sciences and the AfLS

The African Academy of Sciences (AAS) participated in the 2nd Specialized Technical Committee on Education, Science and Technology (STC-EST) of the African Union held in Egypt from 21-23 October 2017. The President of the AAS, delivered a presentation on the Pan-African AdLS project. There had been a previous meeting between the AAS President and several members of the AfLS SC Executive, and the AAS presentation to the STC-EST included some slides from the AfLS SC. The Report of this meeting records the call to the African Union Member States to support the Pan-African AfLS initiative. The AAS has also issued a general Call for Letters of Support and Endorsements, and it is hosting an online petition on its Website.

7. The Lightsources for Africa, the Americas, Asia and Middle East Project (*LAAAMP*)

There are other international efforts that have supported the goals and objectives of the AfLS initiative. One such example is *LAAAMP*. To establish this project, the International Union of Pure and Applied Physics (IUPAP) and the International Union of Crystallography (IUCr) partnered with 32 other scientific organisations, including 16 AdLSs, received a 300,000 Euro grant from the International Council for Science (ICSU) as part of ICSU's *2016-2019 Grants Programme*. The goal of *LAAAMP* is to enhance AdLS science and crystallography in Africa, the Caribbean, Mexico, Southeast Asia, and Middle East.

The objectives of *LAAAMP* are the following:
1. Develop a *Strategic Plan* for each region to grow and enhance its AdLS and crystallography user communities.
2. Establish a *Colloquium Programme* for each region to recruit new AdLS and crystallography users and to advertise *LAAAMP* projects via invited talks at targeted venues. Also, launch a series of new *IUCr-UNESCO OpenLabs*, which is a network of operational crystallography laboratories in developing countries aimed at increasing the access to, and utilisation of, crystallography in all regions of the world.
3. Publish an *Informational Brochure* that describes AdLSs, crystallography, and the many fields that they impact.
4. Facilitate Researchers' Training Visits to AdLS and crystallography facilities.
5. Convene a Meeting at UNESCO to present the regions' *Strategic Plans* and define the charge for more detailed *Business Plans* that include feasibility studies of constructing AdLSs in regions where they do not yet exist.

An Executive Committee leads the management of *LAAAMP*, and each region has an AdLS Usage and Strategic Plan Committee whose responsibility is to carry out local tasks and develop a Strategic Plan to enhance AdLS and crystallography utlisation in the region. Also, there is a Steering Committee of international AdLS experts that provides important input as to overall operation of the project.

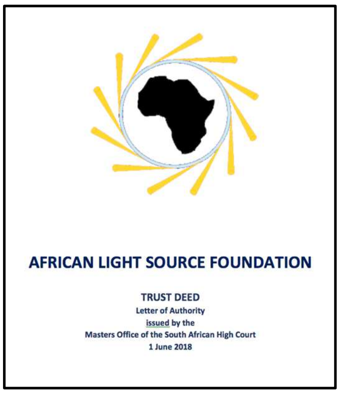
There have been a number of significant achievements of *LAAAMP*, including the following:

1. The initiation of a project to establish a crystallography lab and training program in Benin called *X-Ray Techniques for Sustainable Development (XTech-SD)*, which will offer crystallography training to approximately 100 students per year, with many coming from neighboring countries, such as Nigeria, Togo, Burkina Faso, and Niger.
2. The establishment of the first *LAAAMP* OpenLab in San José, Costa Rica during 4-9 December 2017.
3. The printing of a 24-page informational Brochure entitled, *Advanced Light Sources and Crystallography: Tools of Discovery and Innovation* in English, French and Spanish. It provides a non-technical description of AdLSs for governmental officials and the public.
4. Three *Calls for Applications for FAculty-STudent (FAST) Teams*, consisting of one faculty and one graduate student to spend two months at participating AdLSs. To be eligible, applicants must have less than a year's experience in conducting research at AdLSs. For 2017, *LAAAMP* funded seven teams, namely 14 individual grants covering airline travel expenses. The host AdLSs provided accomodation and subsistence expenses not covered by the *LAAAMP* grant. For 2018, *LAAAMP* funded 18 FAST Teams from Botswana, Cyprus, Egypt, Kenya, Mexico, Senegal, South Africa, Thailand, Trinidad and Tobago, and Uganda to visit the following AdLSs: ALBA (Spain), Canadian Light Source, Delta (Germany), Elettra (Italy), European Synchrotron Radiation Facility (France), National Synchrotron Light Source-II (USA), Siam Photon Source (Thailand), National Synchrotron Radiation Research Center (Taiwan), and Stanford Synchrotron Radiation Lightsource (USA).

To assess its progress, *LAAAMP* convened a Midterm Workshop on 24 August 2018 at the Abdus Salam ICTP in conjunction with the Annual Meeting of the IUPAP C13 Commission on Physics for Development. There were reports on the current status and future plans of Elettra (Italy), SESAME (Jordan), and the Siam Photon Source (Thailand). Also, there were reports on the African and Mexican AdLS initiatives. A number of important suggestions were made to assist in driving LAAAMP forward.

8. The AfLS Foundation

A recent important step was to develop the AfLS Steering Committee into a sustainable organisation with a legal basis. It has been registered as a Trust in the Masters Office of the High Court in South Africa with a constitution and an audited bank account. The Name of the Trust is the African Light Source Foundation Trust, shown in Figure 6.


AFRICAN LIGHT SOURCE FOUNDATION

TRUST DEED
Letter of Authority
issued by the
Masters Office of the South African High Court
1 June 2018

Figure 7: The Trust Deed of the AfLS Foundation.

9. The 2nd AfLS Conference and Workshop

The 2nd African Light Source Conference and Workshop (AfLS2) will be held as a Joint Conference with the Pan-African Conference on Crystallography in Accra, Ghana from 28 January to 2 February 2019. AfLS2 will review AdLS-based science and also progress the vision of an African AdLS. Participants will be African scientists and students, and also international colleagues, who have conducted research related to or enabled by the crystal state of matter, and also research enabled by modern AdLSs.

AfLS2 will cover topics that include Medical Sciences, Cultural Heritage Sciences, Geosciences, Environmental Sciences, Energy Sciences, Nano Sciences, Materials Sciences, Mineral Sciences, Accelerator and Detector Sciences, Competitive Industry, Capacity-Building and Infrastructures. There will also be sessions on the strategy and vision for an African AdLS. The strategic components will discuss topics that include:

- Policy-making sessions in which policy-makers from different African countries will come together to discuss the vision and impact of an AfLS and how African countries can take part in this project.
- Discussion of a proposal for an African Consortium beamline at a major international facility that will help to progress engineering and technical aspects of training and capacity-building, as well as the research that would pave the way for an AfLS. Research done at such a beamline would mostly

address problems of the continent such as cures for diseases that need urgent attention for Africa.

- Discussion of a proposal for a Consortium of African countries to constitute a joint membership at a major international AdLS facility. There would be an African Consortium government level participation in the Council of the International AdLS. This would increase the access of Africans to an international AdLS and allow Africa to develop additional experience in the governance and financing issues of these large-scale international facilities.
- Establishment of African regional facilities equipped with state-of-the-art experimental equipment and infrastructures that would allow excellent research to be conducted on the continent and also to attract excellent young Africans in the Diaspora to return home.

10. Conclusions

Advanced light sources are now *de facto* elements of the modern research scene, providing research tools of the finest quality. They are international scientific and cultural hubs, providing training, education and powerful research outputs and insights into our world and universe, and supporting industry. As detailed above, an AdLS is a "must have" facility for Africa.

The mission of the African Light Source Steering Committee, and scientists across Africa and further afield, as well as all stakeholders in the African Light Source project, is now to realise the construction of this important large-scale scientific tool. We have all now embarked for some years on the Roadmap to the AfLS. A number of significant milestones have been achieved, and the ones ahead become ever more crucial. All the while the capacity-building, human and infrastructure, continues. The user base grows, the participants in the vision grow, and the African and global networks of collaboration continue to grow as well. We have seen an increasing financial investment by African countries in supporting conferences and schools, and in building their own local infrastructure (indeed often with the support of international institutions). A current effort is to increase yet more, and in a coherent way, the involvement of African Governments, directed to a political will, and also concrete Pan-African Consortia in the larger projects of the AfLS Roadmap.

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Appendix 1

The African Light Source Manifesto

The first meeting of the African Light Source Conference and Workshop was held from 16-20 November 2015 at the ESRF in Grenoble. This was the first in a series of conferences, leading ultimately to the establishment of an AdLS in Africa. This Manifesto presents the 1st African Light Source Conference Resolutions as well as the African Light Source Roadmap.

1. Introduction

Light sources (LSs), based at either Synchrotron or Free-Electron laser facilities, are currently the most transformative state-of-the-art research instruments for application to a broad spectrum of disciplines. They embrace essentially all spectroscopy, scattering and imaging techniques, utilising radiation from the infrared (IR), to the visible, ultra-violet (UV), X-ray, and even to the soft gamma ray portion of the electromagnetic spectrum. They are orders of magnitude brighter than traditional lasers, which for decades have transformed science and technology. Though costly, LSs have become clear leaders for research outputs, graduate student training, and drivers of technological innovation. Thus, they benefit nations far more than they cost. Among scientific instruments, their usage produces the most *Nature* and *Science* (considered to be among the most prestigious scientific journals) papers per project, and supports the highest density of researchers from the widest range of disciplines. These researchers all work in close proximity, since as many as fifty (50) or more beamlines can operate simultaneously, with some beamlines supporting more than one experiment. LSs are not used solely by academic researchers, as an increasing number of industrial entities purchase beamtime at many such facilities.

The extremely high photon brightness and flux provided by LSs have allowed significant advances to be made in numerous applications for the benefit of society, including drug development and better understanding of diseases, based upon the deciphering of protein, bacterial and viral structures; and advances in data storage through studies of electronic structure and magnetism in selected materials. LSs show tremendous promise in direct medical applications, allowing innovative imaging techniques of such organs as the heart, lungs, brain and breast, leading to exciting new diagnostic techniques and therapies. More recently, LSs have been used in palaeontology and cultural heritage studies. For example, three-dimensional tomographic images have been made of fossils, rock art, and other artefacts. The use of LSs in palaeontology in South Africa has been one of the big success stories of synchrotron science, especially as regards the recent spectacular results on *Australopithecus sediba*, leading to a revolution in the field.

The figure below depicts the location of operating LSs worldwide. Several facilities operate more than one storage ring, so that more than 47 storage rings are in operation. As seen prominently in the figure, Africa is presently the only habitable continent without a LS. Dozens of scientists from African countries now perform experiments at facilities in Europe and elsewhere. Their numbers are limited mostly by distance and travel costs. A LS in Africa would enable thousands of African scientists, engineers and students to gain access to this superb scientific and technological tool. Indeed, in order to be competitive socially, politically and economically in the years to come, access to a nearby LS will be an absolute necessity.

Figure A1: Locations of Synchrotron Light Sources [1]

2. Grenoble Resolutions towards the African Light Source

1. Advanced light sources are the most transformative scientific instruments similar to the invention of conventional lasers and computers.

2. Advanced light sources are revolutionizing a myriad of fundamental and applied sciences, including agriculture, biology, biomedicine, chemistry, climate and environmental eco-systems science, cultural heritage studies, energy, engineering, geology, materials science, nanotechnology, palaeontology, pharmaceutical discoveries, physics, with an accompanying impact on sustainable industry.

3. The community of researchers around the world are striving collaboratively to construct ever more intense sources of electromagnetic radiation, specifically derived from synchrotron light sources and X-ray free-electron lasers (XFELs), to address the most challenging questions in living and condensed matter sciences.

4. The African Light Source is expected to contribute significantly to the African Science Renaissance, the return of the African Science Diaspora, the enhancement of University Education, the training of a new generation of young researchers, the growth of competitive African industries, and the advancement of research that addresses issues, challenges and concerns relevant to Africa.

5. For African countries to take control of their destinies and become major players in the international community, it is inevitable that a light source must begin construction somewhere on the African continent in the near future, which will promote peace and collaborations among African nations and the wider global community.

3. Vision

For Africa to construct, operate, maintain and continuously enhance a world class light source facility on the African soil for the benefit of the scientific community of the member states and of the scientific community at large in order to stimulate and support the development and growth of knowledge-based socio-economic systems to improve the quality of human life and sustainable environment.

4. Mission

To support and facilitate the development and growth of light source based science in Africa, thereby contributing to excellence in science, innovation, social and industrial development, via the following:

a. Driving the implementation of the Roadmap towards the African Light source
b. Developing human capital, including enhancing education, attracting world class talent to Africa, attracting back the African scientific Diaspora (brain gain), thereby mitigating the brain drain of young Africans who have recognised this as a key research tool for their career development
c. Developing key and/or strategic international collaborations
d. Ensuring financial support for Africans to access international light source facilities
e. Promoting awareness and use of light source science and its capacity to enable the exploration of new frontiers of science and technology.

5. Roadmap Summary for an African Light Source

In order to make its vision a reality and fulfil its mission, the AfLS Steering Committee decided upon the following short-, medium-, and long-term goals:

a. Short-term (0-3 years)
   - i The short term goals focus on the following issues: building awareness of the benefits of light source based research; enhancing education; developing human capacity; developing international collaborations, linkages and partnerships related to light sources; promoting mobility and access to current light sources; developing local infrastructural capacity to support access to light sources; and building formal structures and procedures in support of the Roadmap.
   - ii Promote human capacity development in Africa by doing the following:
     1. Encouraging and training large numbers of scientists, engineers, technicians, students in fundamental, as well as applied, light source science.
     2. Developing and expanding the LS user community.
     3. Growing and enhancing the relevant engineering technical expertise.
   - iii Encourage and commit to light source radiation studies at existing international facilities.
   - iv Form focused formal relationships/memberships with existing LSs.
   - v Promote the involvement of industry via the appointment of Liaison(s) between the AfLS Steering Committee and the business sector.
   - vi Establish a viable communication structure for the African light source science community.
   - vii Promote outreach and communication around light source based science.
   - viii Establish and enhance the current and needed critical feeder infrastructure that empowers light source science, which ultimately allows for the generation of successful proposals to LSs and the training of students.
   - ix Study the feasibility of constructing African multinational beamlines at existing LSs, perhaps with partners from other regions of the world.
   - x Develop a Strategic Plan for submission to African Ministries.
   - xi Convene a Meeting to present the African Light Source Strategic Plan, launching the establishment of the Pre-Conceptual Design Report (Pre-CDR, non-site specific, candidate sites only) which specifies the scientific case and the characteristics of the future light source, including accelerator complex specifications, experimental beamlines and ancillary facilities, and in parallel developing a detailed Business Plan. Those attending should include African Ministers of Science, Technology, Health, Education, Culture, Agriculture, Energy and Natural Resources; representatives from the African research community; and other international stakeholders and interested parties.

b. Medium-term (0-5 years)
   - i Continue all the activities towards the Short-Term Goals as required.
   - ii Evolve the Steering Committee to become a mandated AfLS Task Team.

iii Conduct a feasibility study, including costs, for an African fourth generation LS, with requisite infrastructure (including such items as information technology and guest housing).
iv Develop a detailed Business Plan.
v Develop a Governance Model.

c. Long-term (0-beyond 5 years)
   i Continue all the activities towards the Short- and Medium-Term Goals as required.
   ii Complete the Technical Design Report (TDR). This includes the site selection and the establishment of the AfLS as a legal entity. When approved by a sufficient number of African governments, begin the construction of an African fourth generation LS, with requisite infrastructure.

6. Conclusion

LSs have been of tremendous benefit to many countries' socio-economic development. In particular, Brazil and Taiwan began planning the construction of LSs more than twenty (20) years ago when they were considerably less developed than they are now. Despite those countries' limited experience with accelerators, limited funds, and small initial light source science user communities, they enthusiastically endorsed the construction of LS facilities. A major benefit of the LSs that they built is that many mid-career scientists and engineers have returned home, thus reversing the brain drain. An AfLS would surely lead to a similar brain gain in Africa.

Finally, a LS called Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) is now operational in Jordan as a collaboration of eight Middle East governments, namely Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine, and Turkey. SESAME is closely modeled after CERN, is being developed under the auspices of UNESCO. Indeed, Africa should consider adopting the CERN/SESAME model.

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