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NSF Program(s): International Research Network Connections

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Executive Summary

The AARCLight project has created several critical components to revolutionizing U.S. collaboration with the African continent. AARCLight has created a critical mass of connectivity by signing contracts with funding outside this proposal for spectrum between the U.S. and Luanda, Angola that will last 35 years. AARCLight has fostered critical research collaborations with the nascent and established African regional network consortiums- WACREN and UbuntuNet (section 5.1). AARCLight has developed a critical connection in partnership with SANREN to extend 100G connectivity from Angola to South and on to East Africa. AARCLight has further strengthen the partnership with RNP and ANSP to ensure Brazilian collaboration in the operation and the development of U.S.-Brazil-Africa network connectivity.

AARCLight has created a critical mass of connectivity by entering into an unprecedented contract with Angola Cable to secure lifetime-of-the-cable access to unlit spectrum on both Monet and on SACS submarine cable systems (section 5.2). This provides a new rising tide that lifts the paths of interconnectivity from the U.S. to Africa in a seamless submarine solution. This time frame, and the flexibility to light at whatever technology is currently available, provides a baseline for planning the next generation of collaborations and major instruments, safe in the understanding that there will be efficient, available, and unmediated connectivity between the continents.

AARCLight has fostered critical research collaborations towards linking the U.S. to the research and education communities in the nations of Africa. This strategic priority with Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the US and Africa. Of striking scientific importance to US researchers are the astronomy projects located in South Africa, some of which will lead the way to the Square Kilometer Array (SKA) construction and first light planned for 2022. Just as LSST in Chile has been a pathfinder project for the US' IRNC Backbone project for Latin America, so too will SKA act in that capacity to build out robust redundant network paths between S. Africa and the US. This report Section 7 will detail the data requirements, researcher requirements, and collaborative opportunities to provide US researchers with the connectivity to enable them to lead astronomical scientific discovery from the SKA.

AARCLight has developed a critical connection in partnership with SANREN (section 5.1 Milestone 3). Through detailed negotiations in December 2017, SANREN has pledged its commitment to meet AARCLight in Luanda and extend 100G to UbuntuNet. This provides a world first connectivity from East to West Africa for research and education networking, for the benefit of AARClight and investigators throughout Africa.

AARCLight has further strengthened the partnership with RNP and ANSP (section 5.3, G3 Milestone 3). The partnership creates an unprecedented opportunity for the stakeholders in the U.S., Africa, and Brazil to coordinate planning efforts to strategically make use of the offered spectrum towards serving the broadest communities of interest in research and education. The AmLight consortium partners are the (Brazilian Education and Research Network (RNP), Academic Network of São Paulo (ANSP), Latin American Cooperation of Advanced Networks (CLARA), Chile's Red Universitaria Nacional (REUNA), Florida LambdaRail (FLR), Association of Universities for Research in Astronomy (AURA), Internet2, and TI Sparkle (formally Latin American Nautilus or LAN). We plan to involve the Canadian Research and Education Network, CANARIE in our year two planning as Canada will host one of the SKA data repositories (section 8.5, G8 Milestone 2).

The opportunities exist with AARCLight's accomplishments to begin a new era or large scale, high speed collaboration between the U.S. and Africa. The two years of AARCLight have created a firm and extensive foundation for exponential growth and research collaborations.

1 Project Participants

1.1 People

Julio Ibarra, Principal Investigator, focuses on managing the procurement, provisioning, network engineering, budgets and fiscal operations, and support of the AARCLight project. Interfaces with U.S. and international research and education backbone networks, coordinating project management and oversight activities with the NSF. Provides overall leadership and planning for the AARCLight project and chair the AARCLight Steering Committee.

Heidi Morgan, Co-Principal Investigator, is the Research Coordinator, working with application communities to ensure effective utilization of the network resources. Responsibilities include working with science groups to document their utilization of the network, and forecast future demand. She coordinates application specific key personnel.

Donald A Cox, Co-Principal Investigator, is the AARCLight Project Manager, and responsible for day-to-day operations of the infrastructure. His responsibilities include coordinating network operations, deployment, and upgrades, ensuring availability of network resources, coordinating technology transfer to providers, and developing new operations models for AARCLight.

Luis Lopez, Co-Principal Investigator, is the Engineering Coordinator and responsible for effective communication and coordination among the engineering managers and the AARCLight Engineering Committee (AEC).

1.2 International Organizations

UbuntuNet Alliance is a regional research and education network in eastern and southern Africa, that works with its member NRENs, and coordinates and collaborates with peer regional R&E networks, such as GEANT and RedCLARA. The UbuntuNet Alliance seeks to extend the capacity and resilience of its broadband research and education backbone network - UbuntuNet - with high-speed connections to NRENs worldwide and the Internet.

TENET: The Tertiary Education and Research Network of South Africa is South Africa's national research and education network organization. TENET operates the South African National Research Network (SANReN). South Africa does not have single NREN organization. SANReN and TENET jointly form South Africa's NREN.

SANReN: The South African National Research Network (SANReN) is a business unit inside the South African CSIR's Meraka Institute and is responsible for the design, acquisition and roll-out of national and international capacity for the South Africa NREN, as well as the development and incubation of advanced services. SANReN is a key component of the South African government's National Integrated Cyberinfrastructure System (NICIS), alongside the Centre for High Performance Computing (CHPC) and the Data Intensive Research Initiative of South Africa (DIRISA).

SABEN: South African Broadband Education Networks (SABEN) is a non-profit company that connects schools networks and the Technical and Vocational Education and Training (TVET) sector in South Africa to SANReN. SABEN is supported by TENET and SANReN to assist colleges self-fund connections to the

NRENs and aggregate traffic from schools, hospitals, libraries, hosting, VOIP and video conferencing services.

West and Central African Research and Education Network (WACREN) is a regional research and education network serving the West and Central African Research and Education community for its development.

Academic Network of São Paulo (ANSP, Brazil) provides connectivity to the top R&E institutions, facilities and researchers in the State of São Paulo, that links 20 research institutions in the State of São Paulo in Brazil; and GridUNESP, one of the largest computational clusters in Latin America, supporting interdisciplinary grid-based science.

Rede Nacional de Ensino e Pesquisa (RNP, Brazil): RNP operates the national research and education network in Brazil, consisting of a national backbone network, 40 dark fiber-based metropolitan networks in major cities, and other access links, providing high-capacity access to more than 1,200 sites, serving all the best research groups in the country, as well as large national laboratories and data centers in HPC, Synchrotron Light, Biodiversity, Agricultural Sciences and e-Health.

CLARA: CLARA is the Latin American Regional R&E network in Latin America, providing access to national R&E networks in the region, connecting them to the global academic Internet.

1.3 US Collaborators

Florida LambdaRail (FLR): FLR is the regional optical network of Florida, formed as a consortium of Florida's research universities, to support their research and education mission.

Internet2: I2 is a consortium of leading US research universities working in partnership with industry and government to develop and deploy advanced network applications and technologies. Internet2 is the representative for MAN LAN, participating in the AtlanticWave project.

2 Background

Florida International University and AmLight consortium partners are planning, designing, and defining a strategy for high capacity connectivity research and education network connectivity between the US and West Africa, called AARCLight: Americas Africa Research and eduCation Lightpaths. Science is being conducted in an era of information abundance. Sharing science resources, such as data, instrumentation, technology, and best practices, across national borders, can promote expanded scientific inquiry and has the potential to advance discovery. Linking the U.S. and the nations of Africa's researcher and education communities is an increasingly strategic priority. Africa offers research and education communities with unique biological, environmental, geological, anthropological, and cultural resources. Research challenges in atmospheric and geosciences, materials sciences, tropical diseases, biology, astronomy, and other disciplines will benefit by enhancing the technological and social connections between the research and education communities of the US and Africa.

The planning project is largely based on the planned availability of submarine cable spectrum for use by research and education communities. It creates an unprecedented opportunity for the stakeholders in the U.S., Africa, and Brazil to coordinate planning efforts to strategically make use of the offered spectrum towards serving the broadest communities of interest in research and education. The AmLight consortium partners are the (Brazilian Education and Research Network (RNP), Academic Network of São Paulo (ANSP), Latin American Cooperation of Advanced Networks (CLARA), Chile's Red Universitaria Nacional (REUNA), Florida LambdaRail (FLR), Association of Universities for Research in Astronomy (AURA), and Latin American Nautilus.

3 Major goals of AARCLight project for year 1

The major goals of AARCLight project for year 1 are the following:

- Establish collaborative partners in AARCLight
- Establish a contract with Angola Cable for Spectrum
- Develop a network design in coordination with AARCLight partners
- Develop a plan to integrate the science disciplines with the network strategy
- Develop a community engagement plan

4 Major Activities/Milestones for the AARCLight project year 1

This section describes the accomplishments of the AARCLight team for year 1. The section is organized by the goals in year 1. For each goal, the milestones of that goal are described followed by a description of the work accomplished.

4.1 Goal 1: Establishing the partners in AARCLight

G1 Milestone 1: *Establish AARCLight collaboration with UbuntuNet, WACREN, SANReN, TENET and other regional national research and education networks in addition to the U.S. and South American Partners (Foley, 2016).*

Each of the Co-PIs worked during the year to understand potential partnership benefits with all of the major players in this space. Meetings were held in the U.S. (e.g. Internet2 Global Summit) and abroad (e.g. UbuntuNet, WACREN, TNC, etc) with the primary result that collaborative partnerships be formed to move forward. Below we will summarize some of these meetings, including primary contacts.

Dr. Julio Ibarra attended WACREN 2017 and UbuntuNet-Connect 2017 conferences, where he gave a presentation about the AARCLight project, and met with the leaders of WACREN and UbuntuNet. At WACREN, he met with Dr. Boubakar Barry, CEO, and Omo Oaiya, CTO of WACREN, and NRENs in WACREN to further discuss the goals of the AARCLight project and the opportunity to use the new SACS submarine cable.

In conjunction with the Internet2 Global Summit, FIU organized a meeting with NSF OISE program directors Lara Campbell and Mangala Sharman to meet with Boubakar Barry, CEO of WACREN, and IRNC PIs Ibarra, Jen Schopf, and Steve Huter. The goal of this meeting was to introduce Boubakar to NSF and to its international programs, and to stimulate discussion on possible collaborations. Research areas of potential interest were discussed, such as water sustainability, hygiene program, African Centers of Excellence (ACE), African Geo-Sciences community (Afri-GEOS), and Space and solar weather in Africa. Astronomy, in particular the Square Kilometer Array (SKA), was discussed. The U.S. has a very large interest in the SKA data. Section 5.5.2 covers SKA in more detail. Workshops were discussed as providing a venue to attract U.S. and Sub-Saharan Africa researchers. Climate and ecological modeling were two domains discussed for workshops with the potential for deeper and more targeted exploration, which could lead to collaborations, and outcomes to the science (section 5.5 reports on science drivers).

Dr. Julio Ibarra discussed forming a collaboration between AARCLight, the UbuntuNet Alliance, and WACREN, with Pascal Hoba (CEO) and Joe Kimbali (CTO) from the UbuntuNet Alliance, Boubakar Barry (CEO) and Omo Oaiya (CTO) from WACREN, during his participation at the UbuntuNet Connect 2017 Conference in Ethiopia. Both UbuntuNet and WACREN are interested in using SACS and forming a collaboration to enhance R&E activities between the U.S., the nations of Africa, Brazil and the nations in Americas. Both have signed MOUs with Angola Cable (AC) expressing interest to use SACS. PI Ibarra was informed that SANReN and, jointly constituting the NREN of South Africa, has bandwidth capacity on the West African Cable System (WACS). Angola Cable will be interconnecting SACS and WACS cable systems. A description on the interconnection of these two cable systems is provided in section 5.3. Network topology maps for WACREN, UbuntuNet and SANREN can be found in the Appendix.

Dr. Pascal Hoba informed PI Ibarra that he met with the Angola Science and Technology (S&T) minister and the higher eduction minister. Representatives from the ministries agreed to appoint a coordinator to form an NREN in Angola. Pascal is waiting to receive the name of this person. Once Angola appoints a coordinator, Pascal will offer this person a roadmap for how to establish an NREN. He will facilitate the launch of the NREN into UbuntuNet. Angola and the Democratic Republic of Congo are strategic countries for UbuntuNet.

G1 Milestone 2: *Establish AARCLight partnerships with US NSF awarded principal investigators with active projects in the AARCLight service area in Africa to understand their short and long- term network support needs.*

Dr. Morgan met with Professor A. Russell "Russ," Taylor, Director / SKA Research Chair from Department of Astronomy Western Cape Data Initiative Facility in South Africa. University of Western Cape has many international collaborations with Large Synoptic Survey Telescope (LSST), Very Large Array (VLA), and Arecibo observatory. South Africa LSST Committee members are Markus Bottcher (NWU), Fernando Camilo (SKA SA; Chair), Roger Deane (RU), Russ Taylor (UCT, UWC), Patricia Whitelock (SAAO, UCT), and Ted Williams (SAAO). The specific objectives of these meetings were to a) understand the collaborative needs of the S. African research and education network users with regard to connectivity to the U.S. and South America and b) understand the data requirements of collaborations such as HERA, MeerKAT and eventually SKA between South Africa, North and South America.

Significant Results: The table[1] below shows the results of the interviews Dr. Heidi Morgan conducted from her meetings. Table 3 lists U.S. researchers interested or currently working on projects with scientist from Africa. The results represented in Table 3 show active collaborative research in multiple science domains.

Table 1 U.S. researchers interested or currently working with scientists from Africa

Area Research	Name	Email	Organization	Project
Astronomy, Mathematical & Physical Sciences (MPS)	Aaron Parsons	aparsons@astro.berkeley.edu	University of California-Berkeley	Illuminating our Early Universe with HERA, the Hydrogen Epoch of Reionization Array
	Aaron Parsons	aparsons@astro.berkeley.edu	University of California-Berkeley	HERA: Illuminating Our Early Universe
	Kelly Holley-Bockelmann	k.holley@vanderbilt.edu	Fisk University	Graduate Opportunities at Fisk in Astronomy and Astrophysics Research (GO-FAAR)
	Richard Bradley	rfb7m@virginia.edu	University of Virginia Main Campus	Collaborative Research: Precision Array for Probing the Epoch of Reionization (PAPER)
	Anamparambu Ramaprakash	anr@caltech.edu	California Institute of Technology	A New Instrument to Remove the Effects of Interstellar Dust Masking Faint Radiation in the Universe
	Ximena Fernandez		Rutgers	Measuring the Gas Content of Extreme Star-forming Galaxies across Cosmic Time
	Miguel Morales	mmorales@phys.washington.edu	University of Washington	Collaborative Research: From 21 cm Observations to Precision Reionization Science
	Andrew Rivkin	andy.rivkin@jhuapl.edu	Johns Hopkins University	The Visible Spectral Properties of Trojans and NEOs

[1] Data for Table 3 was sourced from the NSF awards database and from interviews conducted by Co-PI Dr. Heidi Morgan

	Daniel Jacobs	Daniel.C.Jacobs@asu.edu	Arizona State University	Charting the history of reionization with radio observations of the early universe
	Daniel Jacobs	Daniel.C.Jacobs@asu.edu	Arizona State University	Collaborative Research: From 21 cm Observations to Precision Reionization Science
	Jonathan Pober	Jonathan_Pober@brown.edu	Brown University	Collaborative Research: From 21 cm Observations to Precision Reionization Science
	David Trilling	david.trilling@nau.edu	Northern Arizona University	The compositions of outer Solar System icy surfaces from ultra-low resolution spectroscopy
Biology (BIO)	Ramunas Stepanauskas	rstepanauskas@bigelow.org	Bigelow Laboratory for Ocean Sciences	Collaborative research: Untangling the Deep Genealogy of Microbial Dark Matter
	Alexandra Wilson	acwilson@bio.miami.edu	University of Miami	IOS: Nutrient Exchange and Regulation at the Aphid Symbiotic Interface
	Robert Habig			NSF Postdoctoral Fellowship in Biology FY 2017: Patterns and processes in the evolution of nest construction in Ploceus weaverbirds
	Duane Moser	Duane.Moser@dri.edu	Nevada System of Higher Education, Desert Research Institute	Collaborative research: Untangling the Deep Genealogy of Microbial Dark Matter
Computer & Information Science & Engineering (CISE)	Jennifer Schopf	jmschopf@indiana.edu	Indiana University	IRNC: Backbone: NEAAR: Networks for European, American, and African Research
	Rajarathnam Chandramouli	rchandr1@stevens.edu	Stevens Institute of Technology	Collaborative Research: SAVI: iCON: Institute for Cognitive Networking
Education & Human Resources (EHR)	Eric Delson	eric.delson@lehman.cuny.edu	CUNY Herbert H. Lehman College	IGERT--Interdisciplinary Evolutionary Primatology: Conservation and Human Evolution join Behavior, Bones and Genes
	Marisa Wolsky	marisa_wolsky@wgbh.org	WGBH Educational Foundation	Design Squad Global
	Heather Lewandowski	lewandoh@colorado.edu	University of Colorado at Boulder	Incorporating Modeling into Upper-division Physics Labs
Geosciences (GEO)	Lisa Beal	lbeal@rsmas.miami.edu	University of Miami Rosenstiel School of Marine&Atmospheric Sci	Agulhas System Climate Array (ASCA)
	Christian Sidor	casidor@u.washington.edu	University of Washington	ELT Collaborative Research: Restructuring of terrestrial environments following the

				Permian-Triassic mass extinction
	Rebecca Flowers	Rebecca.Flowers@colorado.edu	University of Colorado at Boulder	CAREER: Evolution of the Southern African Plateau Using Advances in (U-Th)/He Thermochronometry, and Enhancing Student Critical Thinking in Science
	Alexandra Davatzes	alix@temple.edu	Temple University	CAREER: Field Studies of Precambrian Impacts and Implications for the Early Crust and Environment
	John Tarduno	john@earth.rochester.edu	University of Rochester	Archeomagnetism of Southern Africa: Implications for Longevity of the South Atlantic Anomaly
	Jillian Banfield	jbanfield@berkeley.edu	University of California-Berkeley	Biotechnology of thiocyanate degradation: an exploration using meta-omics tools to understand the microbial communities responsible for remediation of mining wastewater
	Jeffrey Baumgardner	jeffreyb@bu.edu	Boston University	CEDAR: The First All-Sky Airglow Imaging Studies at Geomagnetic Conjugate Sites in Europe and Africa
	Jonathan Makela	jmakela@illinois.edu	University of Illinois at Urbana-Champaign	CEDAR: Winds Over Africa - Investigation of Thermospheric Dynamics via Multi-site, Multi-instrument Observations
Int'l Activity	Mark Moldwin	mmoldwin@umich.edu	University of Michigan Ann Arbor	IRES: The University of Michigan and South African National Space Agency (SANSA) Space Weather International Research Experiences for Students Program
	Natalie Mladenov	nmladenov@sdsu.edu	San Diego State University Foundation	IRES: US-South Africa Collaboration on Sustainable Sanitation and Energy and Resource Recovery from Wastewater
Social, Behavioral & Economic (SBE)	Curtis Marean	curtis.marean@asu.edu	Arizona State University	IPG - Developing and Testing an Integrated Paleoscape Model for the early Middle and Late Pleistocene of the South Coast of South Africa
	Brian King	bhk2@psu.edu	Pennsylvania State Univ University Park	CAREER: Political Ecologies of Health: Coupling Livelihood and Environment Responses to HIV/AIDS

	Nathan Hultman	hultman@umd.edu	University of Maryland College Park	CAREER: Policy for low-carbon technology investment: A comparative international perspective on emerging economy responses to climate change
	Noah Tamarkin	tamarkin.7@osu.edu	Ohio State University	Genetic Technology Development and International Security Efforts
Radio Astronomy - MeerKAT	Eric Wilscots, Jay (John) Gallagher	ewilcots@astro.wisc.edu, jsg@astro.wisc.edu	University of Wisconsin-Madison	MIGHTEE (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey) - Deep continuum observations of the earliest radio galaxies.
Radio Astronomy - MeerKAT	Eric Wilscots	ewilcots@astro.wisc.edu	University of Wisconsin-Madison	MHONGOOSE (MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters) - a survey of local galaxies; dark matter and the cosmic web.
Radio Astronomy - MeerKAT	Matthew Bershady, Eric Wilscots	mab@astro.wisc.edu, ewilcots@astro.wisc.edu	University of Wisconsin-Madison	LADUMA (Looking at the Distant Universe with the MeerKAT Array) - an ultra-deep survey looking for neutral hydrogen in the early Universe
Radio Astronomy-SKA	Brian Glendenning	bglenden@nrao.edu	National Radio Astronomy Observatory (NRAO)	Board of Science And Engineering Advisory Committee (SEAC)
Radio Astronomy - SKA	Matthew Bershady	mab@astro.wisc.edu	University of Wisconsin-Madison	Galaxy structure & evolution; Spectroscopic instrumentation.
Radio Astronomy-Hartebeeshoek, Pretoria	Timothy Pearson	tjp@astro.caltech.edu	California Institute of Technology	The C-Band All Sky Survey: Diffuse Galactic Emission and CMB Polarization
Optical Astronomy - SALT Telescope in Sutherland	Ken Nordsieck - Share time SALT	khn@astro.wisc.edu	University of Wisconsin-Madison	Commissioning MOS and Fabry-Perot modes for the Robert Stobie Spectrograph on the Southern African Large Telescope
	Gerald Cecil - 11 Nights /year	cecil@unc.edu	University of North Caroline (UNC) Chapel Hill	SALT Board, SALT Fabry-Perot
	Brian Chaboyer - 9% share time	brian.c.chaboyer@dartmouth.edu	Dartmouth University	Astronomy Foreign Studies Program in South Africa
	John Thorstensen	John.R.Thorstensen@Dartmouth.edu	Dartmouth University	Astronomy Foreign Studies Program in South Africa
	Ted Williams - 10% share time	williams@physics.rutgers.edu	Rutgers University	Astronomy

G1 Milestone 3**:** *Document partnerships through letters of collaboration.*

Significant Results: One of the outcomes from Dr. Morgan's visit to South Africa was to form a collaborative partnership with SANReN and TENET for a participation in AARCLight. All parties, Leon Staphorst, Director SANReN; Duncan Greaves, CEO TENET; Len Lotz, TENET, have agreed to write letters of support for the proposal, as well as start the MOU process. All parties are enthusiastic to take the next steps to work together on a longer term AARCLight proposal to the NSF.

4.2 Goal 2: Establish a contract with Angola Cable for Spectrum

G2 Milestone 1: *Negotiate an agreement with Angola Cable for an IRU on the spectrum that contractually binds the terms detailed in the memorandum of agreement.*

This goal was modified when the backbone proposal was descoped to a planning grant for two years. We successfully executed an MOU with Angola Cables (Appendix A Press Release) outlining an agreement to collaborate and to develop a connection between Luanda, Fortaleza and Boca Raton, as well as:

- Help to establish a logical connection point in Luanda for the African R&E networks
- Help to establish an open exchange point in Fortaleza operated by the AmLight Consortium
- Help to establish a point of presence in Boca Raton where the cable lands in Florida to connect to AMPATH.

Dr. Donald Cox represented the AARCLight project in meetings with the Ministry of Science and Angola Cable in Luanda. The goal of his visit was to develop a plan to integrate the science disciplines in the U.S. and West Africa with the network infrastructure resources. An objective of this plan was to foster successful multi-national research collaborations between the U.S. and African nations, investigate the development of an open exchange point, and develop design links for researchers, students, and knowledge sharing communities of the U.S. and the nations of Africa. As the project manager, Dr. Cox is responsible for the engagement and partnership development with NRENs and organizations in Africa to participate in forming the AmLight-Africa consortium; and the development of the contract with the vendor, Angola Cable, for the spectrum requirement in the project.

4.3 Goal 3: Develop a plan to integrate the science disciplines with the network resource

G3 Milestone 1*: The potential to deliver a high capacity network link between the U.S. and Southwest Africa will enable the AARCLight team to engage network operators, NRENs, researchers, and other prospective multi-national research collaborators to establish a community of interest.*

During this past year we established partnerships between the AARCLight team and the three major regional African Research and Education Network organizations. During year 2 of this project we will memorialize the partnerships by developing MoUs and / or letters of collaboration:

- Eastern and Southern Africa Research and Education Network (UbuntuNet Alliance)
- West and Central African Research and Education Network (WACREN)
- South African National Research Network (SANReN) and TENET: The Tertiary Education and Research Network of South Africa

G3 Milestone 2*:* Identify prospective early adopters at the national level and in the research community in Africa and U.S.

The AARCLight team identified prospective early adopters at the national level and in the research community in Africa and U.S. African network operators have expressed interest in participating in the global network via subsea cable infrastructures connecting Africa, South America and North America.

Ibarra's participation at the NREN conferences in Africa (see Section 7) identified communities that expressed interest in using the South Atlantic Cable System (SACS) cable (Fortaleza, Brazil to Luanda, Angola). Both UbuntuNet Connect and WACREN have already signed MOUs with Angola Cable.

SANReN has a 7.3% right-of-use (which calculates to approximately 220Gbps of capacity currently between SA and the UK) in the West Africa Cable System (WACS) connecting Cape Town, South Africa (as well as various other West African countries) and London, UK. SANReN and TENET have also established an open exchange in Cape Town in 2016.

SACS and WACS will be connected at the Sangano Cable Station in Luanda, Angola, shown in Figure 2 below, which creates an opportunity for an exchange point for local RENs to connect to the global networks. The SACS cable interconnects with the Monet submarine cable (Fortaleza, Brazil to Boca Raton, United States). Figure 1 shows a topology map of the SACS, WACS and Monet cable systems.

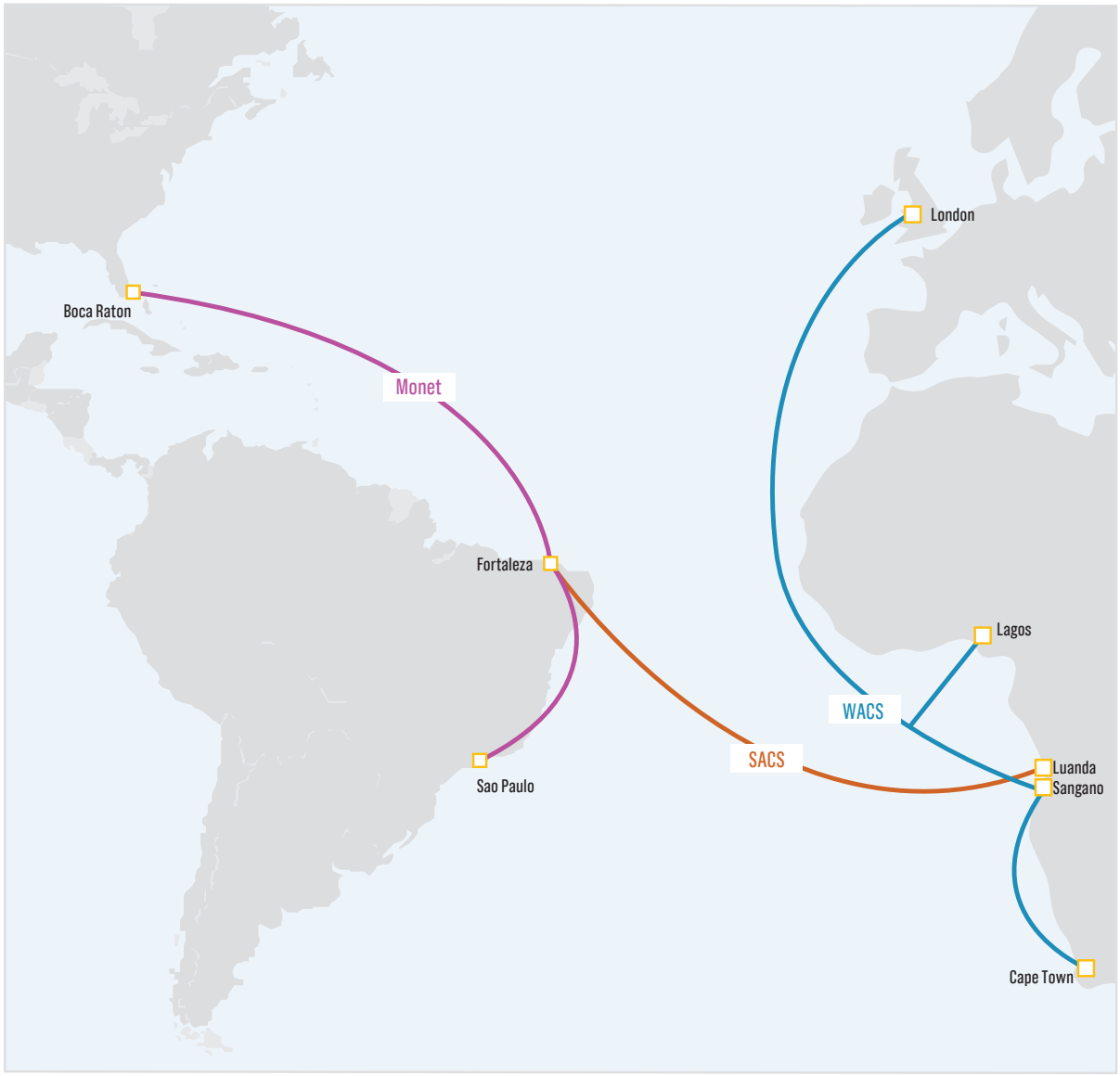


Figure 1 Monet, SACS and WACS submarine cable systems

Figure 2 below provides a logical diagram of how the submarine cable systems will be connected. The left side of Figure 2 represents the SACS and Monet landing stations in Fortaleza. Using its own underground fiber infrastructure, Angola Cables has established a backhaul infrastructure between both landing stations and interconnect SACS and Monet. On the right side of Figure 2, the SACS and WACS cable meet in the Sangano cable landing station, where they are both interconnected.

An open exchange point is already under construction in Fortaleza, Brazil that will be joined to the AtlanticWave SDX topology supporting the AmLight-ExP consortium. AARCLight is discussing interest and planning a complimentary topology in Luanda, Angola with the international collaborators.

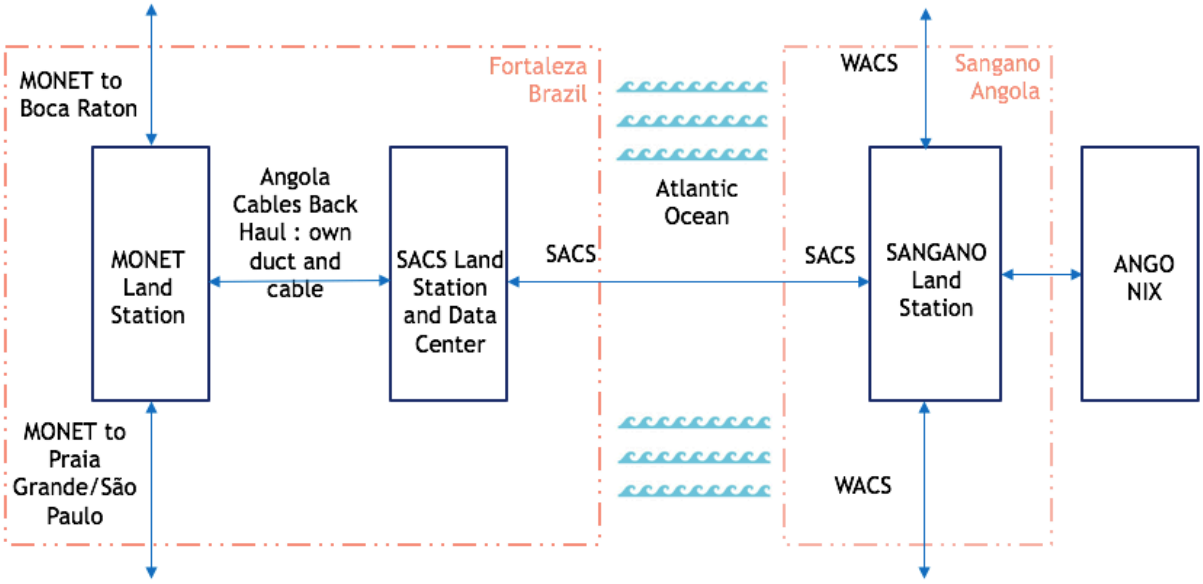


Figure 2 Monet, SACS, and WACS Subsea cable systems

The AARCLight goal is to form a collaborative partnership with SANReN and to coordinate planning efforts among stakeholders in the U.S., Africa, and Brazil. To close the Atlantic Ring, one of the goals of the Global Network Architecture (GNA), SANReN needs a connection to Brazil (which will continue over AmLight ExP links to USA and Canada), but a larger scale investment will be challenging. WACS investment swaps could be a possible tool to be a consortium member with AARCLight.

SANReN and TENET report to different ministries of the government, and are funded differently. SANReN receives the funds to negotiate and purchase the actual infrastructure, and TENET runs it. TENET is responsible for the service delivery for SKA, including the accounting and billing; SANReN represents South Africa in the Research Counsel. Note that SANReN reports to the Department of Science and Technology (DST) directly, while TENET reports to its own Board. TENET's Board is populated by its members, which includes both universities and science organizations. Hence, it does not report to the Department of Higher Education and Training (DHET) directly. Also, note that sometimes SANReN operates services and sometimes TENET invests in infrastructure - the role-split between SANReN and TENET has become somewhat blurred over time.

As a long-range planning, there are initiated upgrades for the use of WACS: SANReN to participate with 800G in early 2019, and future 400G wavelength and 900G planned 2-3 100G Waves. SANReN will have in excess of 800Gbps WACS capacity following the second upgrade of WACS. It is at this stage what future upgrades of WACS will entail, but it will most probably be multiple 100Gbps per wavelength, or 400Gbps per wavelength.

G3 Milestone 3: Develop a clear and coherent articulation of the challenges and a description of how to use the new networking capacity towards solutions, in collaboration with community-of-interest participants and early adopters.

In year 1, the AARCLight PIs and partners in Africa and Brazil have started to articulate a strategy towards the effective use of the proposed network capacity on the SACS submarine cable system. This section provides an initial description of the strategy.

The strategy that is being discussed first considers the established and planned infrastructures of each of the partners:

- SANREN operates an open exchange point in Cape Town, and has capacity on the WACS submarine cable system.
- WACREN operates an open exchange point in Lagos that connects to London on a 10G link.
- FIU has contracted 37.5GHz of spectrum capacity on the SACS cable, and 225GHz of spectrum capacity on Monet from Angola Cables.
- RNP is building an open exchange point in Fortaleza that will connect to Angola Cables to establish connectivity to both SACS and Monet submarine cables. From Fortaleza, there will be connectivity to both AmLight Express and Protect services.
- RNP will extend connectivity from Fortaleza to Sao Paulo to provide connectivity to both AmLight Express and Protect Services, and connectivity to ANSP and CLARA.

This milestone is still under development and we are working toward its completion by December 1, 2018.

G3 Milestone 4*:* A goal of the plan is to foster successful multi-national research collaborations between the U.S. and African nations.

- In collaboration with AARCLight partners, leverage mechanisms between NSF and African funding agencies to develop proposals that will support student exchange and project specific workshops.
- Possible mechanisms are international programs NSF offers (e.g., Early-concept Grants for Exploratory Research (EAGER), and the International Research Experiences for Students (IRES)) in coordination with peer African funding agencies.

This milestone is still under development and we are working toward it's completion by December 1, 2018.

4.4 Summary of Accomplishments in Year 1

This section summarizes the accomplishments described above in sections 5.1-5.3 as follows:

- Established relationships with the partners in AARCLight
  - UbuntuNet, WACREN, TENET, and SANReN are the proposed partners for a future AARCLight proposal.
- Established an agreement with Angola Cable for Spectrum
  - Documented partnerships through letters of collaboration.
  - Negotiated an agreement with Angola Cable for an IRU.
- Developed a plan to integrate the science disciplines with the network resource
  - Described a strategy to deliver a high capacity network link between the U.S. and Southwest Africa with the support of the AARCLight partners.
  - Identified prospective early adopters at the national level and in the research community in Africa and U.S.
  - Started the development a clear and coherent articulation of the challenges with partners in Africa and Brazil
  - Plan to foster successful multi-national research collaborations between the U.S. and African nations

4.5 Significant results for Year 1

This section describes research projects on the major science drivers by discipline in Africa during the past year. The information was gathered from several sources, including the NSF current awards abstract database, where approximately $38 Million is dedicated to US – African collaborations. The section on

astronomy collaborations between the US and S. Africa is the result of a multi-month investigation and visit to Cape Town.

4.5.1 Advanced Cyber Infrastructure (ACI)

Dr. Julio Ibarra discussed the complimentary possibilities of developing the AARCLight infrastructure with the Networks for European, American, and African Research (NEAAR) project with Jennifer Schopf , the principal investigator from Indiana University and Kathrin Stover, the Co-PI representing GÉANT, the European research and education network (REN). NEAAR is funded by the US National Science Foundation (NSF Award #1638863) and adds a 100 Gbit/s connection between exchange points in New York City and London.

The NEAAR project provides services and bandwidth connecting researchers in the US with their counterparts in Europe and the African regional RENs: the UbuntuNet Alliance, WACREN, TENET, SANReN, and the Arab States Research and Education Network (ASREN). The West African Cable System (WACS) makes connections from Cape Town all along the Western coast of Africa to London. Through the European Africa Connect infrastructure funding overseen by Stover this forms the only R&E networking route between Africa and the US. AARCLight would offer a southern route of complimentary connectivity.

Project Title	**Networks for European, American, and African Research (NEAAR)**
Institution	Indiana University
Summary	The NEAAR collaboration is a cross organizational plan to provide services and bandwidth connecting researchers in the US with their counterparts in Europe and Africa. This project will have an immediate impact on the research environment and also supports future application and technology advances.
Collaborators	**International:** GÉANT, UbuntuNet Alliance, Arab States Research and Education Network (ASREN), West and Central African Research and Education Network (WACREN), South African National Research Network (SANReN), Tertiary Education and Research Network of South Africa (TENET) **USA:** Internet2 and the Energy Sciences Network (ESnet)

4.5.2 Astronomy Sciences (AST)

Dr. Heidi Morgan met with multiple researchers, industry leaders and scientists in South Africa to discuss network infrastructure and astronomy instruments located there. She provides a detailed description of her interviews and observations.

The South African Radio Astronomy Observatory (SARAO) is a National Facility managed by the National Research Foundation (NRF) and incorporates all national radio astronomy telescopes and programs. Co-PI Morgan met with Dr. Rob Adams, NRF Managing Director for SARAO and Francisco Camilo, Chief Science Officer SKA & SARAO, Simon Radcliff, Technical Lead of Scientific Computing for MeerKAT array radio telescope facilities, Khutso Ngnoasheng, Manager for SKA MeerKAT data processing building, and Len Lotz, TENET Executive Officer operating the SANReN network.

The **MeerKAT collaboration** has chosen 8 PIs for a guaranteed 2/3 of the observing time for the telescope's first phase of observing before SKA integration. The other 1/3 of time is allotted to general observers, and the call for proposals is open to US scientists. MeerKAT will have a data archive (MeerKAT Mirror) that will be publicly released in 2020, and the collaboration currently does not have a plan for how to manage the archive and queries for data as well as transfer.

Project Title	**MeerKAT**

Summary	The MeerKAT array, currently being built in the Karoo region of South Africa, will be the largest array in the southern hemisphere until the SKA itself is complete in the 2020s. The South African MeerKAT radio telescope is a precursor to the Square Kilometre Array (SKA) telescope and will be integrated into the mid-frequency component of SKA. The telescope was originally known as the Karoo Array Telescope (KAT) that would consist of 20 receptors. When the South African government increased the budget to allow the building of 64 receptors, the team re-named it "MeerKAT" – i.e. "more of KAT". The current plan is that MeerKAT will be merged into the SKA1-Mid array in the early 2020's.
Collaborators	**United States:** Berkeley Wireless Research Center – member of Collaboration for Astronomy Signal Processing and Electronics Research (CASPER, https://arxiv.org/pdf/1611.01826.pdf), NSF funded organization. UC Berkeley Radio Astronomy Lab – member of CASPER; Jack Hickish, Zuhra Abdurashidova, Matthew Dexter, Rachel Simone Domagalski, David MacMahon, Aaron Parsons, Daniel C. Price, Andrew Siemion, Dan Werthimer. NRAO – Green Bank, Green Bank Observatory; John Ford (also affiliated with Steward Observatory, University of Arizona), Randy McCullough, Jason Ray, Verees´e Van Tonder, Mark Wagner. NRAO – Socorro, Allen Telescope Array. NRAO – Charlottesville; CASPER Members: Joe Greenberg, Rich Lacasse. MIT Haystack Observatory. Harvard-Smithsonian Center for Astrophysics, Submillimeter Array – Lincoln Greenhill, Rurik A. Primiani, Jonathan Weintroub. Caltech, Owens Valley Radio Observatory. Cornell University. NAIC – Arecibo Observatory. UC Berkeley – Leuschner Observatory. New Jersey Institute of Technology. West Virginia University Department of Physics and Astronomy: PI Institution for the NSF funded North American Nanohertz Observatory for Gravitational Waves (NANOGrav) collaboration; the collaboration needs as much of the data produced at high cadence preferably asap. University of Iowa Department of Astronomy and Physics. Ohio State University Electroscience Lab. NRAO – Tucson / University of Arizona Department of Astronomy. Stanford University, Center for Nanoscale Science and Engineering. North Dakota State University, Center for Nanoscale Science and Engineering. Columbia University – Ximena Fernandez. Rutgers University – Andrew Baker, Jack Hughes.
	Canada: University of Toronto – Member of CASPER; Rachel Simone Domagalski.

	Africa: MeerKAT / Karoo Array Telescope / SKA – SA – CASPER **Members**: David George, Adam Isaacson, Francois Kapp, Henno Kriel, Jason Manley, Andrew Martens, Wesley New, Dr. Rob Adam (SKA SA Managing Director, rob@ska.ac.za), Dr Fernando Camilo (Chief Scientist, fernando@ska.ac.za), Professor Justin Jonas (Chief Technologist, justin@ska.ac.za), Anita Loots (Head: Africa Planning, aloots@ska.ac.za). University of Cape Town Department of Electrical Engineering (South Africa). Hartebeesthoek Radio Astronomy Observatory (South Africa). Rhodes University (South Africa) Griffin Foster (also affiliated with SKA). University of Western Cape: Professor Mario Santos.
	Asia: GMRT (India). National Centre for Radio Astrophysics (India). Institute of Astronomy and Astrophysics, Academia Sinica (Taiwan). National Astronomical Observatories, Chinese Academy of Sciences (China). Hong Kong University Department of Electrical and Electronic Engineering (Hong Kong, China). Kagoshima University (Japan). Xinjiang Astronomical Observatory, Chinese Academy of Sciences (China). **Oceania:** CSIRO – Canberra Deep Space Communications Complex, Australia Telescope National Facility (Australia). Parkes Observatory (Australia). Center for Astrophysics and Supercomputing (Australia). Swinburne University of Technology (Australia).
	Europe: Nancay Observatory (France). Oxford University Astrophysics (UK). Cavendish Laboratory, University of Cambridge (UK). INAF – Osservatorio Astronomico di Cagliari, Istituto di Radioastronomia (Italy). Sardinia Radio Telescope (Italy). Aalto University Metsähovi Radio Observatory (Finland). Northern Cross Radio Telescope (Italy). University of Manchester, Jodrell Bank Centre for Astrophysics (UK). Max Planck Institute for Radio Astronomy (Germany).
Network requirements	Currently MeerKAT generates data at a rate of 4.7 Gbps. Data is either being transferred via tapes or scientists are travelling to South Africa (SA) to perform research. 8 PIs (possibly 1 US PI), who receive 2/3 of the observing time have already decided how they're going to get the data. 1/3 of the time is open to General Observers (GO). MeerKAT personnel have not yet determined how to move the data to the GOs. First light is projected to be the end of 2018. Proposal season for GO starts in 2019. MeerKAT intends to make an archive of all data collected publicly available.

The MeerKAT array is a precursor to the Square Kilometer Array (SKA). The plans for the data is to be piped out to regional science data centers. US could still put in a request for a center, but has not thus far. USA has not yet partnered with SKA. Canada does have a center designation for this project. The table below shows the identified collaborators and the future network requirements.

The Square Kilometer Array (SKA)

The SKA will be fully operational in 2022 and the data will be piped out to regional science data centers, using data cubes to handle large amounts of data. Some of the scientists want to do their data processing in Cape Town and some in their countries (Netherlands and India may want data in their countries). Canada does have a center designation, and USA could still put in a request for a center, but has not thus far. One US team, co-lead by American Andrew Baker at Rutgers, has approximately 70 people with PhDs around the world and students. If the US science community puts a pitch to SKA to host a regional center, then the data needs would change significantly. A 100G link minimum is targeted for all SKA1 data transfer.

"*With SKA's presence in South Africa, a larger astro research presence will begin to take root in the region that will demand access to the global treasure-trove of data currently generated by six telescopes supported by the U.S. National Science Foundation, and complementary instrumentation, such as the Murchison Widefield Array (MWA), a precursor to SKA, in Western Australia at the Murchison Radio-astronomy Observatory (MRO)"* (Leake, 2018).

Project Title	**Square Kilometer Array (SKA)**
Summary	The Square Kilometer Array (SKA) project is an international effort to build the world's largest radio telescope, with eventually over a square kilometer (one million square meters) of collecting area. The scale of the SKA represents a huge leap forward in both engineering and research & development towards building and delivering a unique instrument, with the detailed design and preparation now well under way. As one of the largest scientific endeavors in history, the SKA will bring together a wealth of the world's finest scientists, engineers and policy makers to bring the project to fruition.
Collaborators	Note: National funding agencies listed for institutions within their nations
	North America: National Research Council Canada National Science Foundation
	Africa: National Research Foundation South Africa
	Europe: National Institute for Astrophysics Italy Onsala Space Observatory Sweden Netherlands Organization for Scientific Research Science and Technology Facilities Council United Kingdom
	Asia: National Astronomical Observatories of the Chinese Academy of Sciences China National Centre for Radio Astrophysics India
	Oceania: Department of Industry and Science Australia Ministry of Economic Development New Zealand
Network requirements	There is a desire to reach hundreds of Gigabits per second. Specifically anticipate generating 960,000 TB/day or close to an Exabyte of raw data per day when fully operational. SKA has not thought long term about how to transfer data to observers yet other than the model for MeerKAT. SKA will face many of the same conundrums as MeerKAT with regard to transferring data; will most likely imitate a model set up with MeerKAT in the next few years. First light for SKA is projected to happen in 2020.

The South African Astronomical Observatory (SAAO) is another facility of the National Research Foundation (NRF), which operates optical telescopes, outreach and research located in Sutherland under the Department of Science and Technology.

Dr. Heidi Morgan met with Ted Willaims, IT manager SAAO, and Steve Crawford, Data Manager for Southern African Large Telescope (SALT). SALT is the biggest telescope and has 5 US partners: University of Wisconsin, Rutgers University, University of North Carolina, Dartmouth University, and the American Museum of Natural History. SALT has a US scientist on the board (ex. Eric Wilcox, University of Wisconsin).

According to Ted Williams the data distribution is “ok” right now, but is predicted to not be sufficient 5 years from now with their current bandwidth. Currently the researchers are unable to do video conference calls on the NREN, which might be more of an issue with funding for expensive bandwidth.

Project Title	**Southern African Large Telescope (SALT)**
Institution	South African Astronomical Observatory (SAAO)
Summary	The Southern African Large Telescope (SALT) is the largest single optical telescope in the southern hemisphere and among the largest in the world. It has a hexagonal primary mirror array 11 meters across, comprising 91 individual 1m hexagonal mirrors. SALT is situated at the South African Astronomical Observatory (SAAO) field station near the small town of Sutherland, in the Northern Cape province, about 400 km from Cape Town. SALT is funded by a consortium of international partners from South Africa, the United States, Germany, Poland, India, the United Kingdom, and New Zealand.
Collaborators	**United States:** University of Wisconsin-Madison Pittsburgh Particle Physics, Astrophysics, and Cosmology Center (PITT PACC) University of Pittsburgh North Carolina (UNC) Chapel Hill Dartmouth University Rutgers Univserity Department of Physics, University of California, Santa Barbara National Radio Astronomy Observatory
	Africa: University of Capetown (South Africa) Department of Physics, University of Namibia (Namibia)
	Europe: INAF – Osservatorio Astronomico di Roma (Italy) Department of Physical Science, The Open University (UK) Anton Pannekoek Institute for Astronomy, University of Amsterdam (Netherlands) ASI Science Data Center (ASDC) (Italy) Warsaw University Observatory (Poland)
	South America: Departamento de Ciencias Fisicas, Universidad Andres Bello Millennium Institute of Astrophysics
Network Requirements	Timeline: 2017: 5-50 GB/night 2019: ~250 GB/night

SAAO has many remote telescopes, see table below, that require enough bandwidth for US based PIs to operate (i.e. Ted Williams, US remote observer). The demand for remote observing is increasing because

of transient (LSST) and gravitational wave (LIGO, VIRGO, IPTA, LISA) ground based follow-up. Currently operating with 35 Mb/s international (budget for bandwidth is $500k/year).

Project Title	**South African Astronomical Observatory (SAAO)**
Institution	National Research Foundation
Summary	The South African Astronomical Observatory (SAAO) is a facility of the National Research Foundation, which operates under the Department of Science and Technology. SAAO's headquarters are in the aptly named suburb of Observatory in Cape Town. The main telescopes used for research are located at the SAAO observation station 15Kms from the small Karoo town of Sutherland in the Northern Cape, a 4-hour drive from Cape Town [8]. SAAO Telescopes on the Sutherland Site: SALT, 1.9m, 1.0m, 0.75m, 0.5m, IRSF, ACT. SAAO Hosted Research Telescopes: BiSON, KELT-South, LCOGT, MONET, Solaris, SuperWASP-South.
Collaborators	**United States:** Vanderbilt University (KELT-South) Harvard-Smithsonian Center for Astrophysics (most SAAO facilities if not all) Lehigh University (KELT-South) Las Cumbres Observatory Global Telescope (LCOGT), CA USA (KELT-South) NOAO, AURA, National Solar Observatory (BiSON) Northern Arizona University (SAAO Collaboration) John's Hopkins Applied Physics Lab (SAAO Collaboration) Jet Propulsion Laboratory (JPL) (SAAO) California Institute of Technology (SAAO)
	Africa: University of Cape Town
	Europe: University of Gottingen (Germany) (MONET) Keele University (UK) (SuperWASP-South) Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences (Poland) (SOLARIS) St. Andrews University (Scotland) (LCOGT)
	South America: Cerro Tololo Inter-American Observatory
Network Requirements	See SALT. Note: This is a South African consortium of telescopes, including SALT, ACT, and meter class telescopes (see summary, http://www.saao.ac.za/about/). There is an increasing demand for remote observing (many US scientists) of the meter class telescopes that SAAO manages, anticipating the need for many GB/night in some cases. Many SAAO employees do not have high enough international internet speeds to video conference with collaborators; this is more a matter of the high cost for international bandwidth through Ubuntu.

4.5.3 Biological Sciences (BIO)

Sensor networks in local, regional, and international networks, involved in molecular biology, has resulted in increased need for bandwidth. To support the extra connectivity the field stations and the remote facilities need networks that will allow scientists to share best practices, protocols, and platforms for data archiving and retrieval (Council, 2014).

Region	Numbers of BFS
Africa	116
Antartica	82
Asia	185
Canada	82
Caribbean	19
Central America	83
Europe	241
Greenland	2
Latin America	88
Oceania	62
USA	308
Grand Total	1268

Figure 3 Biological field stations per region MeerKat

The Organization of Biological Field Stations (OBFS) is an organization that represents field stations, marine labs, and research centers. Many field stations appear to be located in South America, the Caribbean, and west Africa (Tydecks, Bremerich, Jentschke, Likens, & Tockner, 2016), see Figure 2. Dr. Julio Ibarra participated in a NSF call meeting concerning the Cyber Infrastructure activities in support of future development for biology research. According to the NSF program director, Peter McCartney, several collaborative projects are taking place in South Africa (Kruger National Park), West Africa (Mozambique), and Central Africa (Democratic Republic of Congo). Also participating on the call, Craig Stewart of Indiana University, and PI of JetStream cloud[2], supported the reach out to the biological field stations and marine labs where access to clouds is more reasonable.

4.5.4 Earth Sciences

Seismic and geodetic facilities are geographically dispersed and they manage and support continuous observations from distributed sensor packages. UNAVCO and IRIS are the two organizations that support the geosciences facilities worldwide. UNAVCO manages thousands of GPS sites. IRIS is a consortium of 121 US universities and 123 International members and dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data.

We also identified a research on projects involving the expansion of the AfricaArray (AA) Seismic Network with continuous Global Positioning System (CGPS) instruments fitted with meteorological (met) sensors by UNAVCO/Penn State University and AA to create a multidisciplinary research network for the broader Earth science community. AfricaArray Seismic Network participate with a total of 53 stations in 17 countries (Raveloson, 2017):

- 29 seismic stations only
- 20 collocated seismic, GPS and weather stations
- 2 collocated GPS, weather
- 1 collocated seismic, GPS
- 1 weather station only

Project Title	**UNVACO**
Institution	UNVACO, Penn State University, and AfricaArray Observatory Network
Summary	UNAVCO is a non-profit university-governed consortium that facilitates geoscience research and education using Geodesy. The UNAVCO academic and research community seeks to broaden human understanding of the changing Earth by integrating technologies, open geodetic observations, and research. UNAVCO is funded by the National Science Foundation (NSF) and The National Aeronautics and Space Administration (NASA) and supports research around the world.

[2] Jetstream, led by the Indiana University Pervasive Technology Institute (PTI), adds cloud-based, on-demand computing and data analysis resources to the national cyberinfrastructure. https://jetstream-cloud.org/about/index.php

Collaborators	USA: UNVACO, Purdue University, Pennsylvania State University, Penn State, Purdue University; AfricaArray Observatory Network; South Africa: South Africa Geological Survey, Council for Geosciences, University of Witwatersrand; Uganda Geological Survey, University-Tanzania;

4.5.5 International and Integrative Activities

Dr. Julio Ibarra met with Elizabeth Leake at the Super Computing Conference in November 2016 and discussed the activities involving Sub Saharan Africa (SSA), and potential benefits to the global research community. In her InCommon/eduGain project report (Leake, 2018), the African regional-serving universities benefit from fast and affordable bandwidth delivered via NRENs that engage with larger networks, such as the UbuntuNet, and WACREN, to deliver more advanced service options. The major backbone then allies with Internet2 in the U.S. and GÉANT in Europe.

Project Title	**InCommon/eduGain**
Institution	GÉANT - The pan-European data network for the R&E community
Summary	The eduGAIN service interconnects identity federations around the world, simplifying access to content, services and resources for the global research and education community. eduGAIN enables the trustworthy exchange of information related to identity, authentication and authorisation (AAI).
Collaborators	**49 members**: eduGAIN Members: Algeria, Argentina, Armenia, Australia, Austria, Belarus, Belgium, Brazil, Canada, Chile, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, India, Iran, Ireland, ael, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, Norway, Oman, Poland, Portugal, Singapore, Slovenia, South Africa, Spain, Sweden, Switzerland, The Netherlands, U.S., Ukraine, United Kingdom. **eduGAIN Voting**: Bulgaria, Cyprus, Hong Kong, Italy, New Zealand, Turkey eduGAIN candidates: China, Lebanon, Malawi, Mexico, Montenegro, Mozambique, Russia, Serbia, Slovakia, Uganda

Dr. Julio Ibarra met with Steve Huter to discuss the Network Startup Recourse Center (NSRC) University of Oregon, activities in Africa. NSRC promotes collaboration among a community of peers to build and improve the global Internet that benefits all parties. The center facilitates the growth of sustainable Internet infrastructure via technical training and engineering assistance to enrich the network of networks.

Project Title	**Network Startup Resource Center (NSRC)**
Institution	University of Oregon
Summary	The Network Startup Resource Center works directly with the indigenous network engineers and operators who develop and maintain the Internet infrastructure in their respective countries and regions by providing technical information, engineering assistance, training, donations of networking books, equipment and other resources. The end goal in this work is to make it easier for local scientists, engineers and educators to collaborate via the Internet with their international colleagues by helping to connect communities of interest. By strategically working with universities, research institutes, Internet Service Providers, Regional Internet Registries, government agencies, supranational agencies, industry, private foundations and non-governmental organizations, the NSRC helps develop national and regional Internet infrastructure for collaborative research, education, and international partnerships.

Collaborators	**Countries:** Afghanistan, Algeria, Argentina, Armenia, Angola, Azerbaijan, Bangladesh, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Chile, Colombia, Comoros Islands, Congo-Brazzaville, Cook Islands, Costa Rica, Cote d'Ivoire, the Democratic Republic of the Congo, Djibouti, the Dominican Republic, East Timor, Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Guatemala, Guinea, Guyana, Haiti, Honduras, India, Indonesia, Iraq, Jamaica, Kazakhstan, Kenya, Kiribati, Kyrgyzstan, Laos, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mexico, Micronesia, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Caledonia, Nicaragua, Niger, Nigeria, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Rwanda, Russia, Samoa, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Solomon Islands, South Africa, Sri Lanka, Sudan, Swaziland, Tajikistan, Tanzania, Thailand, Togo, Tokelau, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Uganda, Uruguay, Uzbekistan, Vanuatu, Venezuela, Vietnam, Zambia, and Zimbabwe. **Institutions:** National Science Foundation, the Internet Society, the Carnegie Corporation of New York, the International Development Research Centre, NetworktheWorld.org and the O'Reilly Foundation.

In section 5.5, we reported on collaborative projects between the U.S. and nations in Africa, involving major science drivers. Astronomy involves the largest number of international collaborators by country and by people. They expressed the greatest demand for additional network bandwidth.

4.6 Key outcomes or Other achievements for the year 1

This section describes the inception of the relationships among the PI & Co-PI, and the key researchers and scientists involved in projects that are taking place in Africa.

During year 1, the AARCLight PI and Co-PI visited multiple African countries to investigate the opportunities for international collaboration: South Africa, Angola, Ethiopia, Uganda, and Côte d'Ivoire. All sites expressed interest in collaborating with us.

Dr. Heidi Morgan met with researchers from South African Universities and representatives from SANReN and TENET:

- Leon Staphorst, CEO SANReN
- Duncan Greaves, CEO TENET
- Len Lotz, TENET Executive Officer, operates the SANReN
- Dr. Rob Adams, NRF Managing Director at SARAO
- Francisco Camilo, Chief Science Officer SKA & SARAO
- Simon Radcliff, Technical Lead of Scientific Computing for MeerKAT
- Khutso Ngnoasheng, Manager for SKA MeerKAT
- Russell Taylor, Director / SKA Research Chair, Dept. of Astronomy Western Cape Data Initiative Facility
- Steve Crawford, Data Manager SALT
- Ted Willaims, IT manager SAAO

Dr. Julio Ibarra met with representatives from UbuntuNet Alliance and WACREN:

- Pascal Hoba, CEO of UbuntuNet Alliance
- Joe Kimbali, CTO UbuntuNet Alliance
- Boubakar Barry, CEO WACREN
- Omo Oaiya, CTO WACREN
- Nii Narku Quaynor, WACREN Chairman of the Board

5 Opportunities for training and professional development

Training and professional development has not been provided for year 1; however, we have discussed workshop opportunities with the African REN leadership and will continue to develop these ideas during 2018.

6 Products and Outreach Activities

Section 7 reports on products and outreach activities achieved in year 1.

6.1 Conferences Papers and Presentations (delivered in year 1)

Section 7.1 describes conference presentations that were delivered in year 1 of the project.

6.1.1 UbuntuNet Connect Annual Conference November 3-4, 2016

Dr. Luis Lopez participated at the UbuntuNet-Connect Annual Conference organized by the UbuntuNet Alliance which focuses on research and education networking activities in Africa. The Conference brought together practitioners in the research and education networking community, researchers, policy makers, academicians, connectivity providers, and a pool of expertise from across Africa and beyond.

UbuntuNet-Connect 2016 was held at Golf View Hotel in Entebbe, Uganda on 3-4 November 2016 and was preceded by a series of other pre-conference events from 31 October to 2 November 2016. The events were hosted by the Research and Education Network for Uganda (RENU), the NREN of Uganda. The annual networking conference and pre-conference events provided opportunities for people with special and common interests to share their experiences, ideas and plans in the light of research and education networking and applications.

6.1.2 Meeting with Angola Cable in Luanda January 31- February 5, 2017

Dr. Donald Cox represented the AARCLight project in meetings with the Ministry of Science and Angola Cable in Luanda, from January 31st through February 5th, 2017. The goal of his visit was to develop a plan to integrate the science disciplines in the U.S. and West Africa with the network infrastructure resources. An objective of this plan was to foster successful multi-national research collaborations between the U.S. and African nations, investigate the development of an open exchange point, and develop design links for researchers, students, and knowledge sharing communities of the U.S. and the nations of Africa.

6.1.3 Meeting with Angola Cable in Luanda March 9-12, 2017

Dr. Donald Cox attended one of the first AARCLight Project Meetings in Luanda from March 9th to March 12th, 2017. As the project manager, Dr. Cox is responsible for the engagement and partnership development with National Research Educational Networks (NRENs) and organizations in Africa to participate in forming the AmLight-Africa consortium; and the development of the contract with the vendor, Angola Cable, for the spectrum requirement in the project.

6.1.4 WACREN 2017 Conference March 30-31, 2017

Dr. Julio Ibarra participated at the WACREN 3rd Annual Conference and 4th Annual General Meeting on 30-31 March 2017, hosted by the Ivoirian Research and Education Network (RITER) in Abidjan, Côte d'Ivoire, on March 30-31, 2017.

The conference brought together policy and decision makers, scientists, researchers, network managers, collaboration specialists, e-learning, identity and access management experts, and connectivity and equipment providers from across Africa and the rest of the world. The conference was preceded by two workshops on cybersecurity and engagement with librarians as interfaces with the end-users.

An AfricaConnect2 meeting, a joint MAGIC/TANDEM/Sci-GaIA workshop, and the Final Event of the TANDEM project were also collocated with the conference in a week of activities commencing on 27 March 2017 with the workshops and ended on 31 March 2017 with the WACREN AGM.

The main theme of the conference is: "Catalyzing Quality Higher Education and Research", with the following sub-themes:

- Advanced networks, applications and services (SDN, Cloud services, NOCaaS, etc.)
- Trust, Identity and Security
- NRENs and communities: Business models, Communities of Practice, Use cases and Collaboration

6.1.5 Terena Networking Conference (TNC) May 29- June 2, 2017

Dr. Heidi Morgan, Dr. Julio Ibarra, and Jeronimo Bezerra attended the Terena Networking Conference (TNC) in Linz, Austria from May 29th - June 2nd, 2017. Along with that they participated in a Global Lambda Integrated Facility (GLIF) and Global Network Architecture (GNA) meetings. Through keynotes speeches by renowned specialists, varying parallel sessions, demonstrations and presentations, the Conference presents participants with a unique overview of the latest developments in research networking, both in the technical field and in the area of application and management.

6.1.6 UbuntuNet Connect November 2-3, 2017

Dr. Julio Ibarra introduced "Facilitating content distribution in Sub-Saharan Africa through Software-Defined Exchange Points" at the UbuntuNet Connect 2017 Conference.
UbuntuNet-Connect 2017 was held in Addis Ababa, Ethiopia on 2-3 November 2017 and was preceded by a series of other pre-conference events, hosted by the Ethiopia Education and Research Network for (EthERNet), the NREN of Ethiopia.

UbuntuNet-Connect is the Annual Conference of UbuntuNet Alliance that focuses on research and education networking activities in Africa. It is organized by UbuntuNet Alliance and hosted by member NRENs. The Conference brought together practitioners in the research and education networking community, researchers, policy makers, academicians, connectivity providers, and a pool of expertise from across Africa and beyond.

Conference program: https://events.ubuntunet.net/indico/event/10/page/4
Abstract: https://events.ubuntunet.net/indico/event/10/session/24/contribution/56
Presentation:
https://aarclight.net/wp-content/uploads/2017/11/ibarra_UbuntuNet2017_v2.pdf

6.1.7 South Africa Astronomy project meeting December 13-16, 2017

Dr. Heidi Morgan had a series of meetings with multiple researchers, industry leaders and scientists in South Africa with regards to the scientific astronomy instruments located there. Summary of her meetings was described in section 5.5.

6.2 Online dissemination of results to communities of interest

This section describes the sources where results and information about the AARCLight project are available to communities of interest.

6.2.1 Angola Cable Press release

Angola Cables & Americas Lightpaths Consortium Sign Memorandum of Understanding; Infrastructure for Research and Education; Miami, FL, April 1, 2016, Pdf version
See appendix A for more details.

6.2.2 URISC@SC17 and the #LongestLastMile Press release

URISC@SC17 and the #LongestLastMile; Online, January 2018 (URL: https://aarclight.net/ubuntunet-connect-2017-3-2/), By Elizabeth Leake, STEM-Trek Nonprofit

Press release extract:
"HPC Ecosystems Project sites/NREN Status
It can still require a considerable amount of time to move big data around the world, however. "African network traffic is currently routed via Europe before it travels to the U.S., and elsewhere," said Julio Ibarra (Florida International University AVP for Technology Augmented Research). "Depending on the amount of data transferred among eduGAIN 48 member nations, the distance and number of Internet exchange sites along the way could cause significant delays," he added. HPC Ecosystems Project sites/NREN Status.

Ibarra's HPC On Common Ground @SC16 workshop presentation described a collaborative effort to facilitate "big data" transfers through the development of international software defined exchange points (SDX). The "AtlanticWave-SDX" is an NSF-funded project at Florida International University and the Georgia Institute of Technology, with support from Brazil's NREN, Rede Nacional de Ensino e Pesquisa (RNP, and the Academic Network of Sao Paulo (ANSP). An SDX enables a domain scientist connected to an SDN network to use the network more intelligently; e.g., scheduling use when resources are available, or requesting a more favorable path.

In the future, Ibarra's group hopes to explore the feasibility of establishing an SDX in West Africa, in collaboration with African NRENs, based on future availability of submarine cable spectrum for use by research and education communities between Western Africa and Brazil (scheduled 2018 and beyond, per Foley's report)" (Leake, 2018).

6.2.3 Websites

The AARCLight project web site is at http://aarclight.net/

7 Year 2 Goals and Milestones planning

The previous sections described the achievements in year 1. This section describes the goals and milestones for year 2 of the project. The major activities form the outline of this section, as in the previous section. Milestones are the actionable statements within the major activities.

7.1 Goal 4: Investigation of an Open Exchange point in West Africa

G4 Milestone 1: Survey AARCLight partners to determine if it's of strategic value to the R&E community to establish an open exchange point in Angola, or alternatively, to focus on extending an AARCLight link on the SACS cable to another location.

- Determine if the collaborating partners would find the establishment of an Open Exchange point in Luanda, Angola a valuable infrastructure enhancement in support of more comprehensive research networking connections between Africa and the Americas.

G4 Milestone 2: Document the results of the survey into a report from the AARCLight consortium to the NSF and African stakeholders. For example, What is the recommended type of facility? Open Exchange Point, PoP, Data Center, etc. What is the location? Who will operate it? Single operator? Collaboration of operators?

7.2 Goal 5: Develop a new network design in collaboration with AARCLight partners

G5 Milestone 1: Develop a new network design using data from the achievements of earlier goals.

- AARCLight partners shall discuss the development of a network design that can fully leverage the SACS and MONET submarine cable systems spectrum allocation in collaboration with AARCLight partners.
- The outcome shall be a new network design, agreed to by the partners, which can then be included in a new proposal to NSF

G5 Milestone 2: The new network design shall respond to the following questions.

- How spectrum shall be used on the operational SACS cable?
- How to represent and describe interconnections to AARCLight partners in the U.S., Africa, Brazil, and the Americas?
- How to represent and describe connections to science projects and resources in Africa?

G5 Milestone 3: Representation and description of connectivity to U.S. – Africa science drivers.

7.3 Goal 6: Develop additional goals and strategies to expand the scope of work based on findings from years 1 and 2 activities

G6 Milestone 1: Develop an expanded project plan to report to the NSF. This expanded project plan shall be grounded on the findings and recommendations from year 1 and 2 activities.

- Explore the feasibility of submitting a new five-year proposal to the NSF and other country partner funding agencies based on findings from years 1 and 2 activities.

7.4 Goal 7: Develop an assessment plan for the following objectives

G7 Milestone 1: Assess the engagement level of the community of interest by conducting a formative and summative evaluation.

- Develop an assessment plan for the:
    - engagement level of the community of interest, the spectrum contracts, the shared vision and goals by the AARCLight partners, and the level of engagement with the potential new infrastructure.

7.5 Goal 8: Develop a plan for community engagement

G8 Milestone 1: Conferences, meetings, workshops and other relevant venues attended by representatives of the NREN and science application communities are important for AARCLight members to attend either in person or virtually.

- AARCLight PI, Co-PIs and senior personnel shall continue attending relevant venues in Africa and the U.S. attended by representatives of the NREN and science application communities

G8 Milestone 2: Develop a plan for engaging communities of interest.

- CANARIE (Canada's NREN) is a strategic partner for SKA (regional data center) and could be a strategic partner for AARCLight. AARCLight team plans a future investigation for possible collaboration with the Canadian SKA Data center processing facility with regards to an alternative route via South Africa, Brazil, Florida, and Montreal (where the center will be located).

8 Impact

This section describes the impacts AARCLight achieved in year 1.

8.1 Impact on the development of the principal discipline(s) of the project

Over the past year the project team in collaboration with the international partners and Angola Cables has a preliminary design to connect the SACS and MONET submarine cable systems using spectrum capacity. This planning activity is likely to make an impact on the global research and education networking community, and on the scientific community using very large research instruments, such as optical and radio astronomy.

8.2 Impact on other disciplines

Although only in the planning phase AARCLight has identified many domain sciences inclusive of astro-physics and genomics, that could benefit from a southern route submarine cable research and education networking resource between South West Africa, South America via Brazil, and the southern USA via Florida to compliment northern networking routes. This infrastructure will significantly enhance international collaboration on big data transfer and analysis to speed the rate of discovery in the areas of dark matter and dark energy exploration, for example.

8.3 Impact on development of human resources

AARCLight has identified the potential to make an impact on human resource development in several science, engineering and technology areas. There is interest from both UbuntuNet and WACREN leadership in hosting one or more workshops focused on future internet architectures, network engineering techniques for SDN, SDX, and optical spectrum management. In the sciences there is early discussion of graduate student and postdoc exchanges between the US and South Africa. There are a number of existing scientific collaborations in place in multiple scientific disciplines between US NSF funded scientific researchers and counterparts in Africa, particularly South Africa and nearby SW African countries. These are documented in Section 5.5 of the report.

8.4 Impact on physical resources that form infrastructure

AARCLight is likely to make a significant impact on the development of physical resources that form the networking infrastructure, high performance computing facilities connectivity, genomics laboratory connectivity, and scientific instrumentation connectivity and ability to transfer large amounts of data quickly and efficiently between the continents of Africa, South and North America.

8.5 Impact on institutional resources that form infrastructure

While there is nothing specific to report regarding institutional resources at this half-way point of the AARCLight planning project, there are several institutional resources that have a preliminary interest in leveraging increased high-performance southern route trans-Atlantic networking resources. We will report more fully on these during 2018.

8.6 Impact on information resources that form infrastructure

Through the collaborations that have been developed over the past year with network operators and scientific researchers there exists great potential to significantly increase information resources with the

implementation of AARCLight as a fully functional production and experimental project. We expect to have more to report during 2018.

8.7 Impact on technology transfer

AARCLight does not aim to substantially modify commercial technology but rather adopt the use of spectrum to R&E networking requirements. These continue to differ substantially from commercial Internet requirements due to very large data transfer needs. With regard to public use, please see the next item which discusses broader impacts.

8.8 Impact on society beyond science and technology

AARCLight will serve to increase the rate of discovery in the U.S. and Africa. Faster discovery means quicker focus on the greatest benefit for society. AARCLight will act as a catalyst for new knowledge and learning communities, providing a bridge towards linking the leaners, educators, researchers and practitioners of the U.S. and western hemisphere with the nations of Africa. FIU is committed to serving the needs graduate and undergraduate education through practices that bring together students and the networking community with scientists from all domains.

9 Changes / Problems

AARCLight was originally submitted under the IRNC: Backbone solicitation as a five year project. Through the peer review process and recommendations by our program officer AARCLight was scaled back to a two year planning grant to give the project team the time it needed to more fully develop the partnerships and research and education use cases to justify a fully functional complimentary infrastructure to the north Atlantic route through Europe connecting US and African communities of interest. The project team has embraced this opportunity to more richly plan AARCLight as a five year project. The first year has provided strong and compelling reasons to suggest that a full five year proposal be considered now. There should not be a gap in activities between this planning phase and implementation.

We anticipate that a delay of a year between the planning and an implementation project could result in loosing valuable momentum gained thus far. We propose that the most effective action is to develop and submit a full five year project proposal for AARCLight to commence in January, 2019. This plan would include signing MOUs with the international partners in Africa as part of that process.

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Appendix A

PRESS RELEASE

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Angola Cables & Americas Lightpaths Consortium Sign Memorandum of Understanding; Infrastructure for Research and Education

Miami, Florida, March 30, 2016 – Angola Cables, SA and Florida International University's Center for Internet Augmented Research and Assessment (CIARA) are pleased to announce the signing of a memorandum of understanding (MOU) to jointly collaborate on the development of a next-generation Internet network for research and education between Africa, the U.S. and Latin America.

The AmLight Consortium is a group of not-for-profit universities, state, national and regional research and education networks including the AmLight ExP (IRNC BACKBONE: Americas Lightpaths Express and Protect) NSF Award#ACI-1451018 who have come together to develop the AmLight Africa project. The AmLight Consortium provides submarine cable connectivity between Miami, FL and Fortaleza and Sao Paulo, Brazil as well as Santiago, Chile for research & education purposes. The AmLight Consortium needs connectivity in the furtherance of its research and educational goals, to promote the development of advanced network applications, content, and services between the US, Brazil and Angola and the rest of Africa.

Angola Cables is a long distance operator based in Angola, managing, operating and maintaining its facilities in the West Africa Cable System (WACS) which is an undersea cable system linking Yzerfontein, in South Africa and Highbridge, in the United Kingdom. Angola Cables is constructing the South Atlantic Cable System (SACS), an undersea cable system linking Luanda, in Angola, and Fortaleza, in Brazil. Angola Cables is offering 33 GHz of optical spectrum in SACS and the **MONET** undersea cable system linking Santos and Fortaleza, in Brazil, and Boca Raton, Florida, in the Unites States of America, during a ten-year period, for usage restricted solely to research and education

applications. This will create a new chapter in research and education between the people of Angola, Brazil, and the U.S. as well as between the Americas and Africa as never before, restricted solely to research and education applications.

The major goal of the MOU between Angola Cables and the AmLight Consortium is to link the researchers, students, knowledge creation, and knowledge sharing communities of the the nations of Africa, the US, Brazil, and other Latin American countries towards building effective multi-institutional research collaborations. The FIU AmLight Consortium Principal Investigator, Dr. Julio Ibarra, said," This is the first step to provide a bridge from the current infrastructure, to one that will provide access to information abundance and unprecedented resources for research and education communities." Antonio Nunes, CEO of Angola Cables said, "The new research and education infrastructure will enable research and education amongst the people of Africa and the Americas through the operation of production network infrastructure for communication and collaboration. This is one of the purposes of SACS, our main project, to give people the opportunity to share ideas and knowledge and improve social and economic development."

Plans are underway to interconnect the research and education communities of the U.S. and Africa by establishing a high-performance network link between the AMPATH International Exchange Point in Miami, and Angonix, a nascent exchange point in Luanda, Angola as well as fostering the development of emerging international exchange points in Fortaleza, Brazil. This infrastructure will connect with the Atlantic Wave-Software Defined Exchange (SDX) in Sao Paulo, Miami, Boca Raton, and Atlanta, GA. The collaboration will work to provide efficient peering between National Research & Education Networks (NRENs) and communities of interest through a distributed open SDX model.

The AmLight Consortium partners include: Academic Network at São Paulo (ANSP: São Paulo, Brazil), Rede Nacional de Ensino e Pesquisa (RNP: Brazil), Association for Universities for Research in Astronomy (AURA, USA), Cooperación Latino Americana de Redes Avanzadas (RedCLARA: Latin America), Internet2 (USA), Red Universitaria Nacional (REUNA:Chile), Canadian Advanced Research and Education Network (CANARIE, Canada), the Florida Lambda Rail (FLR, USA) and Florida International University (AtlanticWave and AMPATH, USA).

Fostering the development of emerging international exchange points (IXPs) in Fortaleza and Luanda: In Fortaleza, RNP will operate a new open exchange point. This exchange point will support both the infrastructure to Luanda and Miami, as well as terrestrial and submarine links to the south, expected future connectivity to Europe, as well as additional newly planned intercontinental connectivity. In Luanda, Angola Cables is coordinating the establishment of a new open exchange point, the Angonix, as well as a national research and education network. The exchange point in Luanda is planning to connect to the EU, developing West African Regional Education Network, and with support from SANReN (South African Research Network) Competency Area (CA), will leverage some existing TENET resources to interconnect with both South Africa, and UbuntuNet.

About Angola Cables: Angola Cables is an Angolan telecommunications company founded in 2009, which operates in the wholesale market and whose core business is the commercialization of capacity in international circuits for voice and data through Submarine Cable Systems throughout the South Atlantic and Africa.

Angola Cables is responsible for the management and development of WACS (West Africa Cable System) providing carrier level services to operators in Angola and in the Sub-saharan region of the African continent, fast becoming one of the leading capacity providers in the region. It also operates the Angonix (Angolan IXP) in its data center in Luanda. Africa is today the fastest growing region of the Internet penetration in the world. Angola Cables's goal is to transform Angola into one of the telecommunication hubs in Africa. For more information visit www.angolacables.co.ao

About CIARA: Florida International University's Center for Internet Augmented Research and Assessment (CIARA), in the Division of IT, has developed an international, high-performance research connection point in Miami, Florida, called AMPATH (AMericasPATH; www.ampath.net). AMPATH extends participation to underrepresented groups in Latin America and the Caribbean, in science and engineering research and education through the use of high-performance network connections. AMPATH is home to the Americas Lightpaths Express and Protect (AmLight-ExP) high-performance network links connecting Latin America to the U.S., funded by the National Science Foundation (NSF), award #ACI-1451018; and the AtlanticWave-SDX: NSF Award# ACI- 1451024, 2015-2020, IRNC: RXP: AtlanticWave-Software Defined Exchange: A Distributed Intercontinental Experimental Software Defined Exchange (SDX).

About ANSP: The Academic Network of São Paulo (ANSP) provides connectivity to the top R&E institutions, facilities and researchers in the State of São Paulo, Brazil, including the University of São Paulo, the largest research university in South America. ANSP directly connects to AmLight in Miami at 20G. ANSP also provides connectivity to Kyatera, a 9-city dark-fiber-based optical network infrastructure linking 20 research institutions in the state and

a number of special infrastructure projects like GridUNESP, one of the largest computational clusters in Latin America, supporting interdisciplinary grid-based science (www.ansp.br).

About RNP: The Brazilian Education and Research Network (RNP), qualified as a Social Organization (OS) by the Brazilian government, is supervised by the Ministry of Science, Technology and Innovation (MCTI), and is maintained through the inter-ministerial RNP program, which also includes the Ministries of Education (MEC), Health (MS) and Culture (MinC). The first Internet provider in Brazil with national coverage, RNP operates a high-performance nationwide network, with points of presence in all 26 states and the national capital, providing service to over 1200 distinct locations. RNP's more than four million users are making use of an advanced network infrastructure for communication, computation and experimentation, which contributes to the integration of the national systems of Science, Technology and Innovatiob, of Higher Education, of Health and of Culture (www.rnp.br/en)

About AURA: The Association of Universities for Research in Astronomy (AURA) is a consortium of 40 US institutions and 4 international affiliates that operates world-class astronomical observatories. AURA's role is to establish, nurture, and promote public observatories and facilities that advance innovative astronomical research. In addition, AURA is deeply committed to public and educational outreach, and to diversity throughout the astronomical and scientific workforce. AURA carries out its role through its astronomical facilities.

About CLARA: CLARA, the Latin American Cooperation of Advanced Networks (Cooperación Latino Americana de Redes Avanzadas), is a non-profit organization whose members are the NRENs of Latin America, and which is in charge of the management, development and operation of RedCLARA as well as the coordination of Latin America's research networking activities. RedCLARA directly connects to AmLight links in São Paulo, Santiago, Miami and Tijuana. Latin American NRENs connected to redCLARA: Argentina (Innova-Red), Brazil (RNP) ,Chile (REUNA), Colombia (RENATA), Costa Rica (RedCONARE), Ecuador (CEDIA), El Salvador (RAICES), Guatemala (RAGIE), México (CUDI), Panamá (RedCYT), Perú (RAAP), Uruguay (RAU) and Venezuela (REACCIUN).

About Internet2: Internet2, U.S. national backbone network, peers with Latin American R&E networks over AtlanticWave and PacificWave, from multiple peering points. Internet2 comprises 252 U.S. universities, 82 leading corporations, 68 affiliate members, including government agencies, 41 regional and state education networks, and more than 65 national research and education networking partners representing over 100 countries.

About REUNA (Chile): Red Universitaria Nacional, REUNA, provides a leading digital platform that articulates, connects, and fosters collaboration between those entities that based in Chile belong to the fields of science, education, and the Chilean local culture, connecting them to the rest of the world throughout innovating services. With over 20 years' experience and currently made up of 31 institutions, REUNA's digital platform covers 13 regions between the northern city of Arica and the southern city of Osorno.

About CANARIE (Canada): Canarie, Canada's NREN, interconnects with U.S. R&E networks at PacificWave (Seattle), StarLight (Chicago), MANLAN (New York), and peers with Latin American NRENs over AtlanticWave and PacificWave. One million researchers, scientists and students at nearly 2,000 Canadian institutions, including universities, colleges, research institutes, hospitals, and government laboratories have access to the CANARIE Network.

About Florida LambdaRail: FLR is the regional optical network of Florida, formed as a consortium of the Florida's research universities, to support their research and education mission. FLR operates a robust and scalable 1,540-mile 100G capable network that spans the state of Florida, and provides members and affiliates with a cost effective, ultra-high speed, interconnected, broadband service delivery network.

Appendix B: WACREN Network Map

Figure 4 is a representation of the WACREN network map. WACREN is the West and Central African Research and Education Network. For a more complete description of WACREN, please visit their About page at [About WACREN](#).

As of Q1 2018, Lagos, Accra and London PoPs were delivered in first phase. Burkina Faso, Cote d'Ivoire, Mali and Togo are in procurement. Bids are being evaluated, and then contracting is scheduled to start by end of Q3.

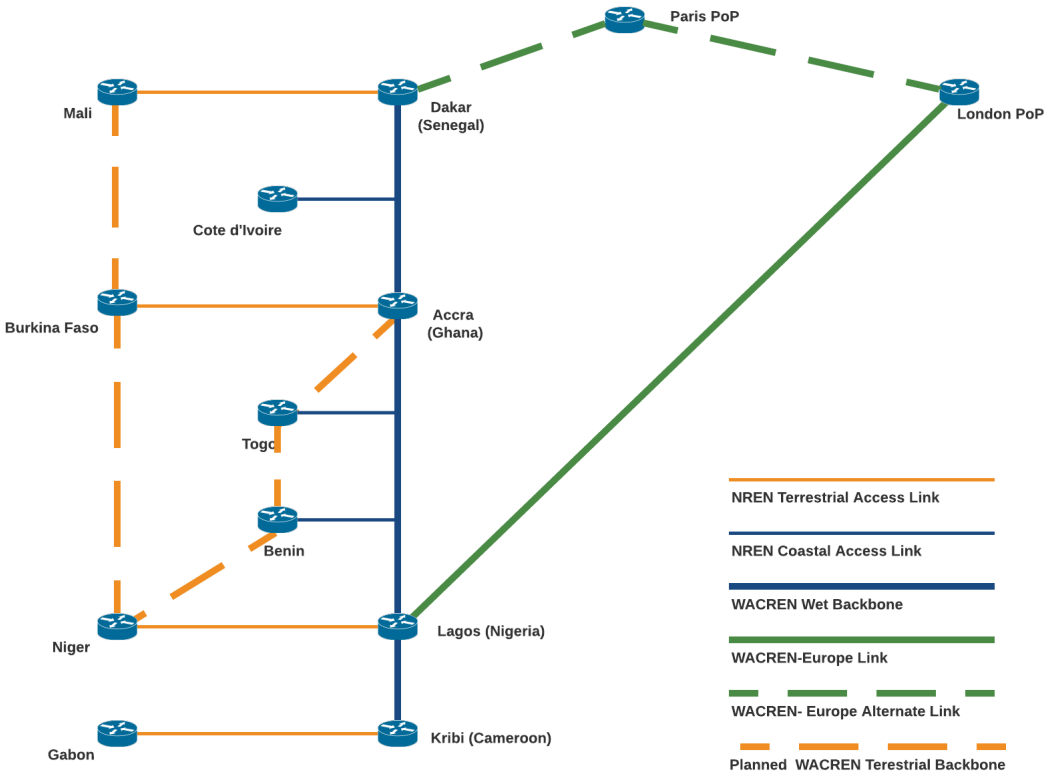


Figure 4 WACREN Network Map

Appendix C: UbuntuNet Network Map

Figure 5 is a representation of the UbuntuNet network map. Since Q4 2017, some of the newly procured links were implemented and some are still under implementation. For a more complete description of UbuntuNet, please visit their About page at About UbuntuNet.

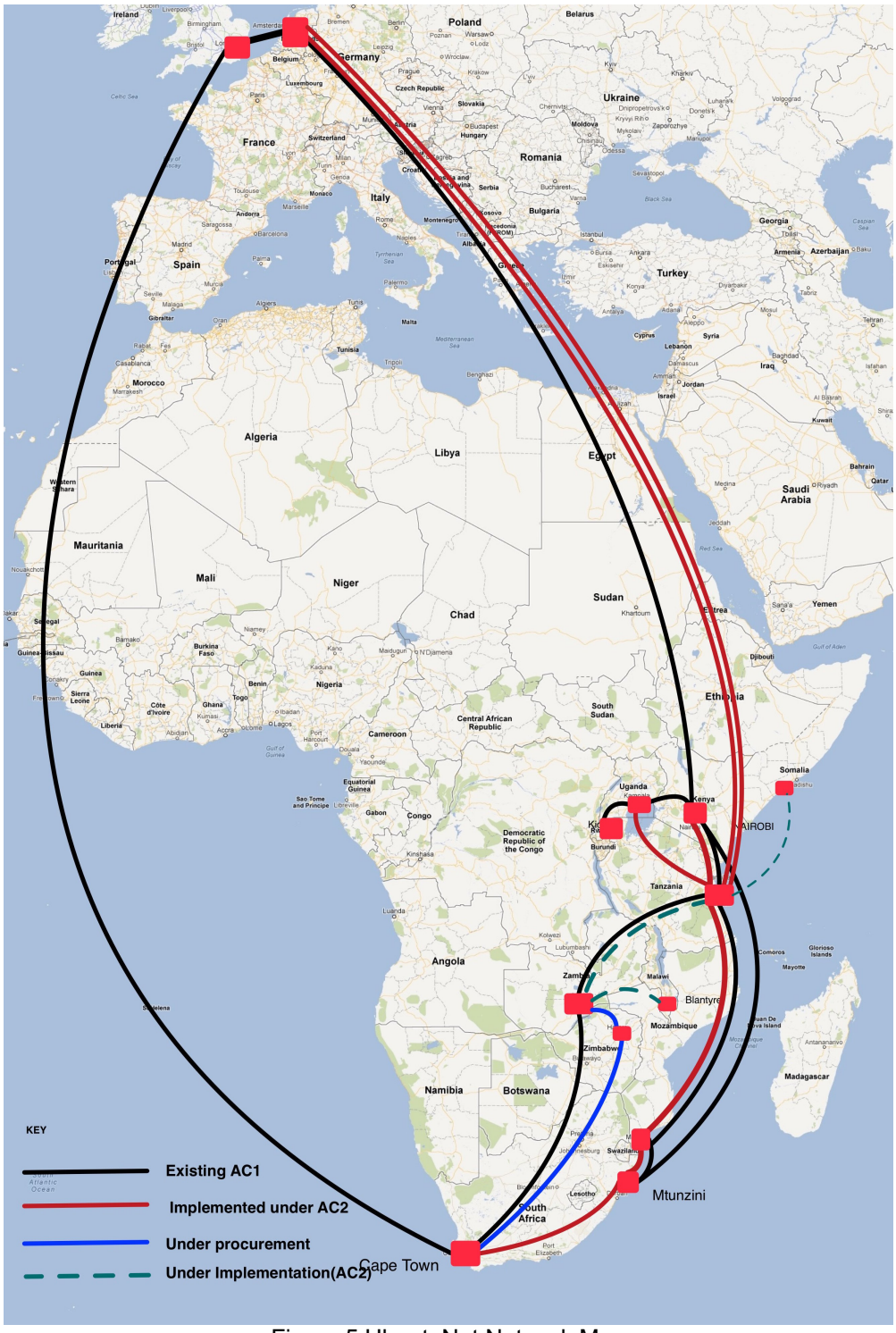


Figure 5 UbuntuNet Network Map

Appendix D: SANREN Network Map

Figure 6 is a representation of the SANREN network map. SANREN is the National Research and Education Network of South Africa. For a more complete description of SANREN, please visit their About page at [About SANREN](#).

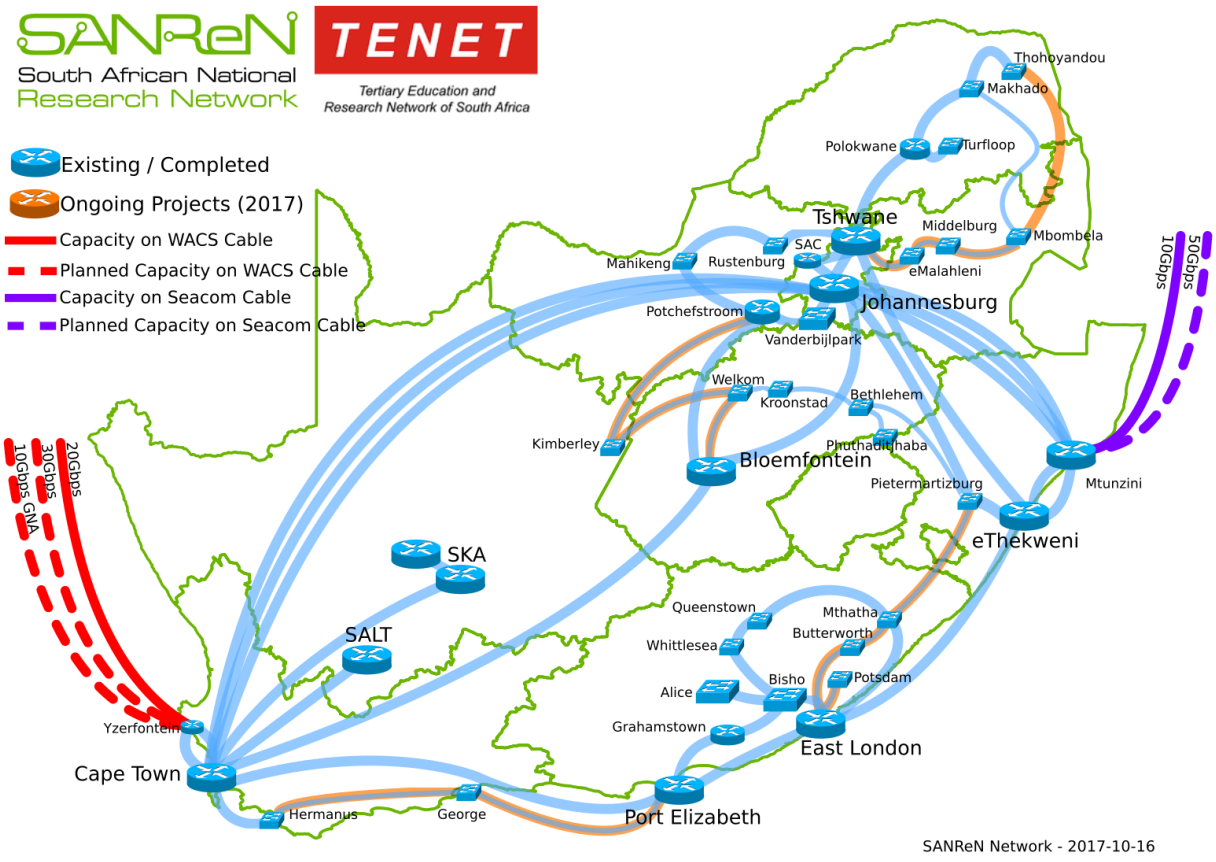


Figure 6 SANREN Network Map