South American - African Astronomy Coordination Committee (SA3CC) Meeting Report

May 6 - May 7, 2025

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This SA3CC activity is supported by the National Science Foundation (NSF) through the IRNC: Core Improvement: Americas-Africa Lightpaths Express and Protect (AmLight-ExP) project (NSF Award #2029283). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

Executive Summary

This report documents the proceedings of the AmLight SA3CC Meeting, on May 6 - May 7, 2025, from the astronomy community and the Research & Education Networks (REN) that participate in the AmLight-ExP project. Researchers from universities, organizations and research institutions from the USA, Latin America, Africa, and Europe attended. The SA3CC Meeting was comprised of two sessions: Science Requirements & Activities Updates, and Providers Updates.

The Science Requirements & Activity updates session started with welcome remarks and an introduction by Co-Chair Julio Ibarra followed by presentations from the Vera C. Rubin Observatory, NOIRLab, GMTO, CTAO, FYST (a.k.a. CCAT), Simons Observatory, CMB-S4, NRAO, SKA, NOIRLab Data Management and Software Division, EHT, ngVLA, ALMA, and GSNF, after which a lively Open Discussion followed. The Providers Updates session included network presentation updates from the Vera Rubin Observatory Network, SANReN/TENET Network, SKA, GÉANT, AmLight-ExP, REUNA, RedCLARA, RNP, rednesp, USDF, Internet2, and ESnet, with another Open Discussion concluding the session.

1 Introduction

1.1 SA3CC Meeting

The South American-African Astronomy Coordination Committee (SA3CC) is comprised of representatives from the various astronomy projects that conduct science and operate observatories in the Americas and Africa. The SA3CC meeting was hosted in-person and virtually by REUNA on May 6-7, 2025, from 9am to 5pm to accommodate the different time zones. The meeting program can be found here: SA3CC Meeting 2025.

The two-day meeting gathered 66 astronomy researchers and network engineers (See Appendix A & C for the agenda and participants list). Presentations and lively discussion took place among all the representatives, of which the following organizations were in attendance:

- Argentine Institute of Radio-astronomy (IAR)
- Cherenkov Telescope Array Observatory (CTAO)
- CIENA-External Research(CIENA)
- Cosmic Microwave Background – Stage 4 (CMB-S4)
- Council for Scientific and Industrial Research (CSIR)
    - South African National Research Network (SANReN)
    - Tertiary Education and Research Network of South Africa (TENET)
- Energy Sciences Network (ESnet)
- Event Horizon Telescope (EHT)
    - MIT Haystack Observatory
- São Paolo Research Foundation (FAPESP)
- Fermi National Accelerator Laboratory (FNAL)
- Florida International University (FIU)
    - Americas Africa Lightpaths (AmLight)
    - Center for Internet Augmented Research and Assessment (CIARA)
- Fred Young Submillimeter Telescope, a.k.a. Cerro Chajnantor Atacama Telescope (FYST/CCAT)
- Giant Magellan Telescope Organization (GMTO)
- Gigabit European Academic Network (GÉANT)
- Global Science Network Forum (GSNF)
- Indiana University (IU)
    - Global Network Operations Center (GlobalNOC)

- Internet2
- **J**oint **I**nformation **S**ystems **C**ommittee (JISC)
- **K**orea **I**nstitute of **S**cience and **T**echnology **I**nformation (KISTI)
- Latin American Cooperation of Advanced Networks (RedCLARA)
- **L**awrence **B**erkeley **N**ational **L**aboratory (LBNL)
- Brazilian National Education and Research Network (RNP)
- **N**ational **R**adio **A**stronomy **O**bservatory (NRAO)
  - **A**tacama **L**arge **M**illimeter/submillimeter **A**rray (ALMA)
  - **N**ext-**G**eneration **V**ery **L**arge **A**rray (ngVLA)
- **N**ational **S**cience **F**oundation (NSF)
  - **N**ational **O**ptical-**I**nfrared Astronomy **R**esearch **Lab**oratory (NOIRLab)
- Chilean National University Network (REUNA)
- São Paolo State University (Unesp)
  - **R**esearch and **Ed**ucation **Ne**twork of **S**ão **P**aolo (rednesp)
- Simons Foundation
- **SLAC** National Accelerator Laboratory, a.k.a. **S**tanford **L**inear **A**ccelerator **C**enter (SLAC)
  - **U**nited **S**tates **D**ata **F**acility (USDF)
- **S**quare **K**ilometer **A**rray (SKA)
- **U**nited **S**tates **E**xtremely **L**arge **T**elescope **P**rogram (US-ELTP)
- **U**niversity of **C**alifornia **S**an **D**iego (UCSD)
  - **S**an **D**iego **S**upercomputer **C**enter (SDSC)
  - **N**ational **R**esearch **P**latform (NRP)
- **U**niversity of **H**awaiʻi (UH)
- **U**niversity **o**f **M**anchester (UoM)
- **U**niversity of **S**outh **C**alifornia **I**nformation **S**ciences **I**nstitute (USC-ISI)
- Vera C. Rubin Observatory, a.k.a. **L**arge **S**ynoptic **S**urvey **T**elescope (LSST)
- **V**anderbilt **U**niversity (VU)

1.2 Vera C. Rubin NET Meeting

The Vera C. Rubin Network Engineering Taskforce (NET) annual meeting took place on May 8 – May 9, 2025, from 9am to 5pm following the SA3CC meeting. The NET meeting has the objective of continuing the planning, development, and deployment of a collaborative purpose-built network to support the needs of the Vera Rubin Observatory in Chile.

The two-day meeting gathered 29 network engineers from the following institutions (See Appendix B & D for the agenda and participants list): ESnet, Fermilab, FIU AmLight, French National Center for Scientific Research (CNRS), French National Institute of Nuclear and Particle Physics (IN2P3), GÉANT, GlobalNOC, NSF NOIRLab, RedCLARA, REUNA, RNP, SLAC, USP, and Vera C. Rubin Observatory.

2 Goals and Objectives of the AmLight SA3CC Meeting

AmLight-ExP builds upon the results of the WHREN-LILA project, Award# OCI-0441095, and the AmLight IRNC projects, Award# OCI-0963053. Over the last 20 years, these projects have effectively fostered a cooperative and collaborative consortium among R&E network providers and users in the Western Hemisphere. The success of previous U.S. & Latin American networking activities has led to a groundswell of change for research instruments. Data-intensive and data *dependent* instruments operate in South America and South Africa, with new projects in the pipeline. The Vera Rubin Observatory is a significant example of a data-dependent instrument and has from the beginning been part of the planning for AmLight-ExP (NSF award #1451018 and #2029283) and the predecessor awards. The focus of AmLight-ExP is an open instrument for collaboration that interconnects open exchange points. AmLight-ExP provides a means to leverage collaborative provisioning and network operations that effectively maximize the benefits to all members of the consortium. AmLight-ExP manages the NSF investment in the context of leveraging international partnerships to attain the greatest benefits for all participants (See Appendix A and C for the Agenda and Participants List, respectively). A key goal of the SA3CC meeting is to gather input and collect information from participants about the activities of the astronomy projects and the R&E networks supporting them over the previous twelve months as well as plans for the future.

3 Activities of the SA3CC Meeting

The meeting was organized in two sessions and presentations (See appendix A) from the following institutions were included:

3.1 Science Requirements & Activities Updates

- Vera C. Rubin Observatory Operations (Bob Blum)
- NOIRLab Science Programs (Stuartt Corder)
- GMTO (Sam Chan)
- CTAO (Gareth Hughes)
- FYST/CCAT (Mike Nolta)
- Simons Observatory (Simone Aiola)
- CMB-S4 (Eli Dart)
- ALMA – NRAO Data Transfer (Sanford George)
- SKA/MeerKAT (Keith Grainge)
- NOIRLab Data Management and Software Division (Hubert Condoretti)
- EHT (Jason SooHoo)
- ngVLA (Sanford George)
- ALMA Network Infrastructure (Jorge Ibsen)
- GSNF (Enzo Capone)

3.2 Research and Education (R&E) Network Providers Updates

- Vera C. Rubin Observatory Network (Cristian Silva)
- NOIRLab – ITOPs (Mauricio Rojas, Edward Toro)
- South African NREN Connectivity (Renier van Heerden)
- SKA Networks (Richard Hughes-Jones)
- AmLight1: Network Connectivity (Jeronimo Bezerra)
- AmLight2: Monitoring and Measurement Improvements (Renata Frez)
- REUNA (Albert Astudillo)
- RedCLARA (Marco Teixeira)
- RNP (Aluizo Hazin)
- rednesp (Ney Lemke)

- Vera C. Rubin Observatory US Data Facility (Adam Bolton)
- USDF Infrastructure (Omar Quijano)
- Internet2 (Chris Wilkinson)
- ESnet (Kate Robinson)
- NREN Community Support to HEP Science (Edoardo Martelli)
- EU NREN for GEANT & CTAO Data Transfer (Enzo Capone)

4 Science Requirements & Activities Updates

Section 4 summarizes the updates presented by each of the astronomical observatories. The slides for each of the summaries in this section can be found at the 2025 SA3CC meeting page on the AmLight project website.

4.1 Vera C. Rubin Observatory Operations (Bob Blum)

The Vera C. Rubin Observatory has made significant strides in its mission to deliver the Legacy Survey of Space and Time (LSST), a decade-long initiative aimed at capturing nightly images of the Southern Hemisphere sky. This ambitious project will generate a 500-petabyte dataset to support groundbreaking research in four key areas: understanding dark matter and dark energy, creating a comprehensive inventory of the Solar System, mapping the structure of the Milky Way, and exploring transient optical phenomena. The observatory remains on track to achieve these goals through the Rubin Operations Plan.

Over the past year, the observatory has transitioned from construction to operations. The Summit Facility is now fully operational, with nighttime teams conducting observations in both commissioning and scheduler-driven modes. These efforts are supported by a dedicated group of scientists, IT professionals, and observing specialists. The LSSTCam, a critical component of the observatory, was successfully transported to Chile and installed in early 2025. First light was captured in April 2025, marking a major milestone toward full survey operations.

The U.S. Data Facility (USDF) is also operational and actively processing nightly data. Preparations are underway for the release of Data Preview 1 (DP1) in June 2025, which will offer early insights into the observatory's capabilities. The Long Haul Network is functioning effectively, enabling efficient data transfer between Rubin's three data facilities located in the U.S., France, and the UK. These facilities are being integrated to support prompt data processing, long-term storage, and public data releases.

Community engagement and early science planning are also progressing. The Community Science Team is preparing for DP1 through educational initiatives and citizen science programs. Challenges remain, including optimizing on-sky data collection, ensuring hardware availability at the USDF, and finalizing maintenance plans. A joint agency review is scheduled for July 2025 to assess readiness for full operations. DP1 is expected to be more comprehensive than initially projected, with DP2 planned approximately six months after the official handover. Full LSST survey operations are expected to commence in late 2025.

4.2 NOIRLab Science Programs (Stuartt Corder)

Stuartt Corder provided an overview of the origins and mission of the National Optical-Infrared Astronomy Research Laboratory (NOIRLab), which was established in 2019. The lab was formed by consolidating three distinct organizations operating from the summit at Cerro Pachón, with the goal of streamlining operations and enhancing scientific collaboration. NOIRLab's mission centers on enabling science for the broader astronomical community by operating ground-based observatories, delivering high-quality data products, and offering both hardware and software services.

Corder emphasized NOIRLab's pivotal role in shaping the future of U.S. astronomy, particularly through its involvement in the U.S. Extremely Large Telescope (ELT) program. The lab supports a wide range of infrastructure, including advanced telescopes, robust software tools, and state-of-the-art data centers. These resources are designed to facilitate cutting-edge research and ensure that data from observational campaigns are accessible and usable by scientists worldwide.

In addition to its core scientific mission, NOIRLab is actively engaged in efforts to mitigate light pollution, preserving the quality of astronomical observations. The lab also participates in major collaborative initiatives such as the Dark Energy Survey, contributing to the global understanding of cosmic phenomena. Looking ahead, NOIRLab plans to develop a fully integrated system for scientific data analysis, with the potential to unify data from various observational platforms into a single, comprehensive framework.

4.3 Giant Magellan Telescope Organization (Sam Chan)

The Giant Magellan Telescope (GMT) project, led by the GMTO Corporation, is a collaborative effort among 15 premier research institutions from the United States, Australia, Brazil, Chile, Israel, South Korea, and Taiwan. The observatory is being constructed at Las Campanas in Chile and will feature a 25.4-meter aperture composed of seven 8.4-meter mirror segments. As of 2025, significant progress has been made in mirror fabrication, with multiple segments completed or in advanced stages of production at the University of Arizona's Mirror Lab. The Adaptive Secondary Mirror (ASM) subsystem has also reached key milestones, including the completion of its first unit components and the initiation of integration testing in Italy, sponsored by the NSF.

The GMT's global network infrastructure spans multiple international sites, including data centers and offices in Pasadena, Santiago, La Serena, and the summit site in Chile. It utilizes a robust combination of commercial and institutional internet services, VPNs, and fiber optic links to support remote operations and data transfer. The observatory is expected to generate approximately 2.4 petabytes of data annually, primarily telemetry and environmental data, with around 31 terabytes of science data transferred to NOIRLab for analysis and archiving. Infrastructure upgrades include new fiber optic installations connecting the summit to regional substations and technical offices, enhancing data flow and operational resilience. Overall, the GMT project has transitioned from construction and development into early operational planning, with a projected completion in the early 2030s.

4.4 Cherenkov Telescope Array Observatory (Gareth Hughes)

The Cherenkov Telescope Array Observatory (CTAO), established as a European Research Infrastructure Consortium (ERIC) in 2025, builds upon years of planning and collaboration among over 1,500 scientists and engineers. Its mission is to explore cosmic rays, probe extreme environments, and uncover new physics phenomena. The observatory will deploy three types of telescopes, Large-Sized Telescopes (LSTs), Medium-Sized Telescopes (MSTs), and Small-Sized Telescopes (SSTs) across two sites: the Observatorio del Roque de los Muchachos in Spain (CTAO-North) and the Paranal Observatory in Chile (CTAO-South). These instruments will span an energy range from 20 GeV to 300 TeV, enabling the detection of thousands of gamma-ray sources and potentially revealing entirely new classes of emitters.

The CTAO has made significant progress in its organizational and infrastructural development. Key milestones include the approval of the Alpha Configuration in 2021, the prioritization by ASTRONET in 2023, and the opening of the Science Data Management Centre in 2024. The observatory's computing and data management strategy is central to its operations, with hundreds of petabytes of data expected annually. This data will be processed through a distributed network of data centers located in Spain, Germany, Switzerland, and Italy. The computing model outlines detailed workflows, data versioning, replication policies, and quality of service standards. Data will be collected and initially processed at on-site centers before being transferred to off-site facilities for long-term storage and scientific analysis. The storage model includes raw data, processed outputs, and extensive simulations, each governed by specific retention and backup policies.

Network infrastructure is a critical component of the CTAO's data strategy. The South site will connect via a 12 km fiber link to ESO Paranal, leveraging REUNA for national connectivity and BELLA for intercontinental data transfer. European connectivity will be supported by GÉANT, with national research networks (NRENs) such as RedIRIS, DFN, SWITCH, and GARR providing high-performance access. The observatory is actively forming agreements with these network providers and off-site data centers to ensure seamless data flow and processing. The Alpha Configuration at the South site alone is expected to generate up to 6 PB of data annually, with online data reduction techniques employed to manage volume without compromising performance.

Construction activities are underway, with foundational work at the South site beginning in 2025 and telescope deployment scheduled for 2026. The initial phase will include approximately seven telescopes and the establishment of the on-site data center and network infrastructure. Despite the limited number of early instruments, the data output will be substantial, necessitating robust replication and transfer protocols. The CTAO continues to align its infrastructure development with its integrated project schedule, ensuring that scientific operations can commence smoothly.

4.5 Fred Young Submillimeter Telescope, a.k.a. Cerro Chajnantor Atacama Telescope (Mike Nolta)

The CCAT/FYST project, formerly known as CCAT-prime, is a collaboration involving institutions from the United States, Germany, Canada, and Chile. The U.S. consortium is led by Cornell University and includes partners such as Arizona State University, Duke, and the University of Chicago. Germany's involvement is coordinated by the University of Cologne, with contributions from Bonn and the Max Planck Institute for Astrophysics. Canada's consortium, under the Canadian Atacama Telescope Corporation (CATC), is led by the University of Waterloo and includes a wide range of universities across the country. Chilean participation includes several major universities, and the project benefits from partnerships with national research councils and observatories.

The Fred Young Submillimeter Telescope (FYST) is designed to be the highest throughput submillimeter telescope ever constructed, operating across a frequency range of 210-850 GHz. It features a 6-meter cross-Dragone mirror design with high surface accuracy and a large field of view. Located on Cerro Chajnantor at an altitude of 5612 meters, the site offers exceptional atmospheric conditions for submillimeter observations, particularly at 350μm. However, the extreme altitude imposes logistical and regulatory challenges, including health requirements and limitations on fuel delivery, necessitating remote generator siting and trenching for power and data lines. FYST will host several advanced instruments. The CHAI instrument is a multi-pixel heterodyne spectrometer with two frequency bands and high spectral resolution, enabling detailed mapping of molecular and atomic lines. Its surveys focus on galactic ecology, including star formation and interstellar medium chemistry. Prime-Cam, another key instrument, includes seven optics tubes and multiple polarimeter and spectrometer modules, targeting science goals such as the epoch of reionization, galaxy evolution, cosmic microwave background (CMB) foregrounds, and time-domain phenomena. Mod-Cam, a scaled-down version of Prime-Cam, is the first-light instrument and has already completed initial cooldowns, with deployment to Chile planned ahead of Prime-Cam.

Infrastructure development has been a significant focus, including trenching for power and fiber optics. The project has secured a fiber agreement with ALMA, allowing access to dark fibers and connection to the REUNA network. Bandwidth tests between the AOS site and partner institutions in Toronto and Cologne have demonstrated high data transfer rates, essential for handling the telescope's expected data output of 3 to 8TB per day. Despite progress, challenges such as cable cuts and road washouts have occurred, underscoring the difficulty of operating at such a remote and high-altitude location.

Construction of the telescope began in Germany and is now underway in Chile, with final acceptance expected by the end of 2025. The Mod-Cam instrument is ready, and first light for the telescope is anticipated in Q2 2026. Fiber connectivity is expected to be operational in the upcoming months.

4.6 Simons Observatory (Simone Aiola)

The Simons Observatory (SO) is a collaboration involving students, postdoctoral researchers, and faculty from institutions around the world. Its mission is to conduct a multifrequency millimeter-wave survey of the sky, targeting key cosmological questions such as the signature of inflation, primordial perturbations, neutrino mass, relativistic species, reionization, dark energy, galaxy evolution, and transient phenomena. The observatory employs two types of telescopes: Small-Aperture Telescopes (SATs) designed for large-scale polarization studies, particularly B-mode polarization in low-dust regions covering 10% of the sky, and a Large-Aperture Telescope (LAT) that surveys approximately 40% of the sky with overlap with other large-scale structure surveys like the Rubin Observatory/LSST.

The site in Chile is now fully deployed and operational, including its data management (DM) infrastructure. Remote operations are conducted daily, and the observatory currently includes three SATs and one LAT, with a total of 7,000 detectors actively observing the sky. All three SATs achieved first light in October 2023 and have undergone extensive commissioning. Full science operations are expected to begin shortly. Collaborators across all career stages are actively engaged in data analysis using the observatory's DM tools and infrastructure.

Data from the observatory is transmitted to North America and Europe within three hours, a significant improvement over previous methods. This rapid transmission is facilitated by REUNA and AmLight networks, enabling end-to-end connectivity to institutions such as NERSC, Princeton, and Manchester. The current data transfer rate from the ALMA site to North America is 1 gigabit per second, with plans to upgrade to 10 gigabits per second following the Wideband Sensitivity Upgrade to accommodate increased data volumes. Looking ahead, the Simons Observatory plans to expand its capabilities by adding more telescopes and increasing the focal plane size to enhance mapping speed. These upgrades aim to optimize the observatory's infrastructure for transient detection and improve overall scientific output. Periodic data releases will include cosmic microwave background (CMB) maps, lensing maps, source and cluster catalogs, and transient event data, contributing significantly to the broader astrophysical research community.

4.7 Simons Observatory and Cosmic Microwave Background – Stage 4 Networking Update (Eli Dart)

The Simons Observatory and CMB-S4 networking initiative has made significant strides in establishing robust data transfer capabilities between Cerro Toco and key research facilities. The project leverages a dedicated fiber path connecting the Simons Observatory to the ALMA site, enabling efficient data transfers to NERSC. Performance metrics over both 24-hour and 30-day periods demonstrate the system's reliability, with notable recovery following outages. This infrastructure supports the observatory's growing data demands and lays the groundwork for future scalability.

The current optical network employs a passive multiplexer with eight available channels, each capable of 10Gbps throughput. Presently, the Simons Observatory utilizes a single channel at 1Gbps, but the system is designed to accommodate increased bandwidth through additional 1GE links or upgrades to 10GE and potentially 100G per channel, depending on optical component availability. This forward-looking design ensures the network can evolve alongside scientific needs. Collaboration with REUNA, particularly contributions from Albert Astudillo, has been instrumental in enabling this flexible and scalable architecture.

Plans for CMB-S4 are progressing, with a Chile-only deployment strategy that includes increased data rates at Cerro Toco. The existing fiber infrastructure is sufficient to support both the expansion of the Simons Observatory and the deployment of CMB-S4, with no shared active equipment between experiments. This passive setup eliminates electrical dependencies, allowing each project to operate independently. A proposed addition to the network is a perfSONAR server dedicated to CMB-S4, intended to provide network measurement capabilities and operational experience without imposing high-bandwidth demands. Despite some delays on the CMB-S4 side, the collaboration has remained productive and forward-moving. The perfSONAR deployment, while slower than anticipated, is a key milestone that will offer tangible evidence of progress to funding agencies and help characterize network paths as data strategies mature.

4.8 Data Transfer from ALMA to North America (Sanford George)

The Atacama Large Millimeter/submillimeter Array (ALMA) represents a landmark in astronomical instrumentation, being the largest telescope of its kind ever constructed. Operated as an interferometer, ALMA synthesizes signals from 66 antennas to produce high-resolution images of the cosmos. These antennas are divided into sub-arrays, allowing simultaneous observation of multiple projects. ALMA functions in a "space mission" style, with automated data processing and archiving conducted primarily at the Joint ALMA Observatory (JAO) in Santiago, Chile, and distributed across three regional centers: North America (NRAO), Europe (ESO), and East Asia (NAOJ). Since the release of its first Principal Investigator (PI) projects in 2013, ALMA has continued to expand its scientific reach, with Cycle 11 observations beginning in October 2024 and Cycle 12 proposals completed by April 2025.

One of ALMA's most notable achievements includes the detection of oxygen in a galaxy 13.28 billion light-years away, marking the most distant oxygen ever observed and suggesting star formation occurred just 250 million years after the Big Bang. This discovery underscores ALMA's capability to probe the early universe. The telescope's imaging process relies on aperture synthesis, where multiple antennas emulate a large dish through radio interferometry. Signals are processed by a high-throughput supercomputer known as the Correlator, which performs complex Fourier transformations to construct images. The Correlator system includes thousands of custom chips and FPGAs, achieving a cross-correlation rate of 17 Peta operations per second.

Data transfer and archiving have evolved significantly over the course of the project. Initially, data flowed from JAO to the regional centers, with most processing centralized in Santiago. The North American ALMA Science Center (NAASC) in Charlottesville, Virginia, hosts the archive and computing resources for North American users. Data transfer rates have varied, with typical peaks reaching 300Mb/s and occasional bursts up to 600Mb/s. A Memorandum of Understanding between AUI and REUNA facilitates the metro link to Santiago, with a joint AURA-AUI agreement supporting a 1Gbps connection, burstable to 10Gbps, via AmLight and Internet2. However, disaster recovery remains a concern, as restoring the North American archive (~1.3PB) over the current link could take up to six months.

Looking ahead, the Wideband Sensitivity Upgrade (WSU) promises significant improvements in receiver bandwidth, sensitivity, and spectral tuning. The preliminary design review for the new Data Transmission System (DTS) was completed in December 2024, with NRAO personnel contributing to the WSU Data Transfer and Archive Storage Working Group Report. While the current network infrastructure can support early WSU data rates with software optimizations, future scenarios will require bandwidth upgrades. The expected data volume post-upgrade ranges from 1TB to 125TB per dataset, with annual data volumes projected to reach 3.6 to 6.6 petabytes by the 2030s. To accommodate these demands and support bulk reprocessing, a dedicated 10Gbps link to Chile is deemed essential within the next one to two years.

4.9 MeerKAT / SKA South Africa (Keith Grainge)

Located in the Karoo desert of South Africa, and comprising 64 antennas operating across three frequency bands (0.58-3.5 GHz), MeerKAT has been operational for five years and is recognized as the most sensitive radio telescope in the southern hemisphere. Its capabilities have been further enhanced through the MeerKAT+ expansion, which adds 14 additional antennas. The telescope has supported large-scale surveys such as MeerKLASS, which in just one hour can cover 300 square degrees in the UHF band, detecting approximately 35,000 sources at 100µJy sensitivity.

The broader Square Kilometre Array (SKA) initiative encompasses both SKA-MID and SKA-LOW components. SKA-MID integrates the existing MeerKAT dishes with 133 new SKA1 dishes, covering frequencies from 350 MHz to 15 GHz. SKA-LOW, based in Australia, consists of 131,000 aperture array dipoles organized into 512 stations, operating between 50 and 350MHz. These instruments aim to achieve groundbreaking scientific goals, including the detection of all pulsars in the Milky Way, testing Einstein's General Relativity, and identifying gravitational waves. The SKA also contributes to cosmological research through weak lensing techniques that map large-scale structures, and has played a pivotal role in the discovery and study of Fast Radio Bursts (FRBs), which are mysterious signals originating from cosmological distances. Further scientific objectives include exploring cosmic magnetism via Faraday rotation, which provides insights into magnetic fields crucial for galaxy formation and evolution. The project also investigates the "cradle of life" by observing protoplanetary disks, extrasolar planets, and complex organic molecules around protostars, with ambitions to detect signs of extraterrestrial intelligence, such as radar signals from distant planets.

International collaboration is a cornerstone of the SKA project, with 12 full member countries, two in the accession stage, and two others in discussion. This focus on collaboration is further emphasized by ongoing participation from countries like the US, who currently has eight NSF-awarded projects either underway or recently closed, despite the US not being a formal member country. The SKA headquarters, established at Jodrell Bank in July 2019, coordinates efforts across South Africa and Australia, employing around 150 staff. The project faces substantial data transport challenges, needing to move data from remote desert locations over 900 km. With 197 antennas, each generating 100 Gbit/s, the system handles approximately 20,000 Gbit/s, resulting in 350 PB of data annually. This data is processed and distributed to SKA Regional Centers (SRCs), which provide storage, computing resources, and user support, enabling global scientific access and collaboration. Currently, MeerKAT continues to deliver high-quality scientific results, while SKA construction progresses steadily. The first SKA-MID dish was installed on July 4, 2024, and SKA-LOW has already produced its first light image, marking a major milestone in the project's development.

4.10 NOIRLab Data Management and Software Division (Hubert Condoretti)

The NOIRLab Data Management and Software Division (DMS) is a new division within NOIRLab, responsible for managing all Software, Data and IT Programs, and Operations. Guided by recommendations from pivotal reports such as Astro2020 and Future of Astronomical Software Infrastructure, the initiative emphasizes treating software as critical infrastructure. This includes investing in sustainable, open-source development and recognizing software as a first-class scientific output. The project also aims to build scalable, interoperable systems by coordinating national efforts to standardize and integrate astronomical data systems, while empowering cross-disciplinary expertise through funding in astro-informatics and statistics. Central to the initiative is the establishment of a dedicated organization to manage software and data standards, tools, and community engagement. This body is tasked with enabling petabyte-scale science by aligning infrastructure to support next-generation data volumes through streamlined pipelines, smart storage, and fast access. The DMS division is structured to deliver high-performance solutions by leveraging industry standards, agile methodologies, and strong collaboration with scientific and technical stakeholders.

The architecture of the DMS is built on modern principles such as API-driven microservices and unified cloud strategies, which facilitate modular, scalable integration and innovation. A unified data management and science platform is being developed to collect, prepare, process, and analyze data, thereby promoting scientific productivity. This includes standardizing protocols and interfaces, such as those defined by the International Virtual Observatory Alliance (IVOA), to ensure interoperability and consistency across systems. Software reusability is a key focus, with efforts directed at identifying and leveraging existing software components to accelerate development and reduce duplication. The division promotes modularity and standardization in coding practices, tools, libraries, and frameworks. New software development is aligned with the DMS philosophy, emphasizing scalability, quality, and alignment with scientific goals.

To deliver incremental value, the DMS adopts a modern software culture supported by agile methodologies and automation. Continuous feedback loops and performance tracking through Key Performance Indicators (KPIs) ensure rapid iteration and customer-centric outcomes. The overarching goal is to build a NOIRLab culture that prioritizes shared software, modularity, and best practices from industry, positioning NOIRLab as a national resource for astronomy software well into the 2030s. This initiative builds on the legacy of NOIRLab's programs and is deeply rooted in the evolving needs of the astronomical community.

4.11 Event Horizon Telescope (Jason SooHoo)

The Event Horizon Telescope (EHT) project has evolved into a globally coordinated effort to observe supermassive black holes using Very Long Baseline Interferometry (VLBI). Initiated with contributions from the MIT Haystack Observatory and other international partners, the project has steadily expanded its technical capabilities and observational reach since its inception. The EHT functions as a network of millimeter and sub-millimeter wavelength telescopes distributed across the globe, effectively creating an Earth-sized aperture. Each pair of stations contributes to the VLBI baseline, enhancing resolution and coverage. Phased array stations like ALMA significantly improve observational fidelity. Data collected at each site is digitized and recorded onto modules, which are then shipped to correlators at MIT Haystack Observatory and the Max-Planck Institute for Radio Astronomy for processing. Calibration algorithms and imaging techniques are applied to generate high-resolution images of astronomical phenomena such as black holes, including the well-known images of M87 from 2017 and 2018.

The 2025 EHT observing campaign, held from April 4 to April 14, involved eleven stations and achieved observations on four nights. The campaign operated at 230 GHz and 345 GHz with dual polarization and double sideband configurations, recording data at 64 Gbps per station and generating approximately 700 TB of raw data per site. Staffing included on-site observers and specialists, as well as remote support from the Array Operations Center (AOC). Real-time monitoring was facilitated through VLBI scripts that pushed station statistics to a central Grafana server, enabling efficient oversight and troubleshooting. Remote access capabilities allowed technical teams to assist with system failures and configuration tasks without being physically present, optimizing resource allocation. Fringe tests conducted in January and April 2025 were critical for validating station configurations and preventing data loss. These tests involved sending sample data to correlators to confirm timing and setup accuracy, serving as a safeguard against misconfiguration.

The EHT has also focused on strengthening its research network infrastructure. Collaborations with institutions such as FIU, Indiana University, University of Hawaii, and MIT have supported demonstrations of fringe tests and data transfers at conferences like SC24. The project leverages high-speed networks like AmLight, Internet2, Pacific Wave, and Northern Crossroads to facilitate large-scale data transport and improve operational efficiency. Looking ahead, the EHT aims to increase observational frequency, expand data recording capabilities, and add new stations such as KVN Pyeongchang, TEA in the Canary Islands, AMT in Africa, and OVRO. Challenges remain in managing a heterogeneous array of stations and ensuring reliable network connectivity, particularly in remote areas. Upgrades like the 100Gbps enhancement at Haystack are part of ongoing efforts to accelerate data correlation and fringe validation.

4.12 next-generation Very Large Array (Sanford George)

The Next Generation Very Large Array (ngVLA) project represents a transformative leap in radio astronomy, designed to deliver thermal imaging at milli-arcsecond resolution with ten times the sensitivity and up to one hundred times the resolution of the current VLA. Operating across a broad frequency range of 1.2 to 116 GHz, the ngVLA is envisioned as a proposal-driven, pointed telescope capable of deep field imaging and small area mapping. Strategically centered in the southwestern United States, the array will bridge capabilities between the Square Kilometre Array (SKA) and the Atacama Large Millimeter/submillimeter Array (ALMA), reinforcing its role as a critical scientific infrastructure. The Astro2020 Decadal Survey has identified ngVLA as a high-priority ground-based facility, recommending its construction begin within this decade.

Significant progress has been made in the development of the ngVLA prototype. Following the completion of the Preliminary Design Review (PDR) in December 2022, fabrication commenced, with factory acceptance testing scheduled for late 2023 and site acceptance testing beginning mid-2024. By April 2025, the prototype was officially handed over to the National Radio Astronomy Observatory (NRAO) by Mtex Antenna Technology for testing. The reference design includes 214 offset Gregorian antennas (18m) for the main array, supplemented by short and long baseline arrays to enhance imaging capabilities. Long baseline antennas will be distributed across the continent, including sites in Puerto Rico, Hawaii, Florida, and other strategic locations, enabling baselines up to 8,860 km. The ngVLA's data infrastructure is engineered for high-throughput performance, with each antenna capable of transmitting up to 723 Gbps over dual 400 Gbps fiber links. Real-time correlation across all 244 antennas will be supported, with post-processing systems designed to handle average data rates of 8 GBps and peak rates of 128 GBps. The computing architecture, estimated at 60 PFLOPS/s, is tailored to meet the demands of time and spectral resolution, as well as complex imaging requirements. Data will be served to users through a "Science Ready Data Products" model, offering both low-level and high-level data products, with potential for distributed archiving and reprocessing among international partners.

The project timeline outlines key milestones from the initial submission to Astro2020 through to full science operations. Following the delivery of the prototype in 2025, the ngVLA will enter its construction phase, with early science operations expected to surpass current VLA capabilities beginning in 2031. Full operational capacity is projected for 2038, marking the culmination of nearly two decades of planning, development, and collaboration.

4.13 ALMA Network Infrastructure (Jorge Ibsen)

The ALMA network infrastructure has undergone a significant transformation through a collaborative effort between ESO and the Joint ALMA Observatory (JAO), aimed at modernizing the optical transport network and ensuring continuity beyond the EVALSO project's end-of-life. Jorge Ibsen, Head of Computing at JAO, presented the initiative, emphasizing the strategic upgrade of the optical transfer network and the ALMA links between sites, particularly between the observatory in San Pedro de Atacama and the ALMA office in Santiago. From there, an ongoing agreement between AURA and NRAO, under AUI management, secures a dedicated 1Gbps (burstable to 10Gbps) link from Santiago to NRAO in North America, leveraging the AmLight and Internet2 backbones. Together, these enhancements are essential to support growing data volumes and the evolving demands of data science workflows across the observatory's distributed locations.

The project focused on replacing aging DWDM equipment with modern CIENA systems and increasing the network capacity from 2x1Gbps to 4x10Gbps, a twenty-fold improvement. This upgrade was implemented across key segments of the network, including the Calama to Antofagasta route (handled by Telefónica), and the Antofagasta to Santiago backbone (managed by REUNA). The transition to CIENA equipment was the result of a competitive bidding process, with the selected vendor meeting the technical and operational requirements of the project. The implementation also required updates to existing contracts with Silica Networks, Telefónica, and REUNA to ensure seamless integration and administration of the upgraded infrastructure.

The technical enhancements were completed in October 2024, marking a major milestone in ALMA's network modernization. The upgraded links now support OTU4-level transport, enabling end-to-end 100Gbps capabilities and significantly improving data throughput and reliability. Jorge clarified that the network itself is no longer a bottleneck for operations; instead, scheduling remains the primary challenge in optimizing data flow and scientific output. In parallel, the Wideband Sensitivity Upgrade Program is underway, aiming to further enhance ALMA's scientific capabilities by upgrading hardware and acquisition points. This initiative is designed to accommodate increased data volumes and improve observational sensitivity, aligning with the broader goals of ALMA 2.0. The program is expected to receive full funding in the coming year, positioning ALMA to meet future astronomical research demands with a robust and scalable infrastructure.

4.14 Global Science Network Forum (Enzo Capone)

The Global Science Networking Forum (GSNF) was conceived as a strategic initiative to enhance collaboration and foresight within the global research and education (R&E) community. Its primary objectives include providing deeper insights into the evolving landscape of scientific collaboration, supporting the shaping of future plans, anticipating emerging trends across scientific, technological, and political domains, and co-developing solutions that align with the missions of participating organizations. The forum is designed to foster mutual support among stakeholders who are committed to advancing science and preparing for future challenges.

The GSNF is composed of individuals working within Research and Education Networks (RENs) or scientific collaborations, all of whom share a dedication to scientific progress and strategic readiness. The initiative aims to establish a permanent platform for high-level, long-term strategic discussions, complemented by periodic face-to-face meetings held every one to two years. These gatherings are intended to facilitate continuous dialogue and coordination with technical forums such as LHCONE-OPN and SKA SRCnet, ensuring that strategic planning is informed by operational realities. The forum officially launched during the TNC24 conference, where approximately 100 participants attended in person. A mailing list has been established to maintain ongoing communication among members, and a steering group has been formed, comprising representatives from CERN (Eric Grancher), ESnet (Eli Dart), and GÉANT (Enzo Capone).

4.15 Summary of Science Instruments

The following table summarizes the information on instruments reported in section 4. It contains the name of the instrument with a link to its website, its location, sites where data is archived, what stage the instrument is in (planning, construction, operation), the estimated start and end date, and data flow characteristics from the instrument to archive.

Instrument	**Location**	**Data archive**	**Stage**	**Start - End date**	**Data flow characteristics**
Vera Rubin Observatory	La Serena, Chile	US: SLAC, EU: In2p3, UK	Operation	First light captured April 2025; Survey 2025 - 2033	20TB per night, Image must be transferred within 7 seconds from the Base to the USDF. The telescope will produce 10 million transient events per night, which will be distributed in real time within 60 seconds to community brokers. Data flow from Chile to USA and EU. US partners: NSF, DOE, IN2P3; Managed by AURA
Cherenkov Telescope Array Observatory (CTAO)	Chile and Spain	Distributed: Spain, Germany, Switzerland, Italy	Construction	2025 - onwards	Hundreds of PBs annually; South site Alpha Configuration generates ~6 PB/year
Next Generation Very Large Array (ngVLA)	Puerto Rico (Arecibo Site), St. Croix (VLBA Site), Kauai, HI (Kokee Park Obs.), Hawaii, HI (Not MK Site), Hancock, NH (VLBA Site), Green Bank, WV (GBO), Brewster, WA (VLBA Site), Penticton, BC (DRAO), North Liberty, IA (VLBA site), Owens Valley, CA (VLBA site)	Distributed archive	Planning / Construction	2025-2038	The data rate of 723Gbps per antenna will aggregate to 800Gbps links on ngVLA installed fiber. For example, ~3 antenna LBA site will equal ~1Tbps link. The LBA sites (UPR, U Central Florida, Arecibo Observatory) proposed to NSF a 100Gbps link to I2. US partners: NSF; Managed by NRAO, NSF, and AUI
Atacama Large Millimeter/submillimeter Array (ALMA)	San Pedro de Atacama, Chile	NRAO, Charlottesville, VA, USA; EU: ESO, Garching (Munich), Germany; NAOJ, Mitaka (Tokyo), Japan	Operation	2011-present	1TB per day, total volume will be ~220TB; Typical rate obtained during peak data transfer periods is 2-300Mb/s, with bursts up to 600Mb/s. A new correlator will increase the data to 1PB/year in 2030. Data come from Chile to USA, EU, and Japan. US partners: NRAO; Managed by Associated Universities, Inc. (AUI)/NRAO. **Future Projections**: Data volumes are projected to reach 3.6 to 6.6 petabytes by the 2030s following the Wideband Sensitivity Upgrade.

Simons Observatory	Chajnantor, Chile	USA: NERSC, UCSD/SDSC, Princeton	Operation	2023-2028	The data rate is estimated to ~132 Mbps during the day with 40-50 TB data volume per month. The raw data for the 5-year survey will be ~3PB. There is NO strict requirement on data getting to the US. Data flow from Chile to Princeton USA. 1 Gbps transfer rate, with a planned upgrade to 10 Gbps following the Wideband Sensitivity upgrade.
Cosmic Microwave Background (CMB-S4)	Chile and at the South Pole	NERSC	Planning	2029-2036	The compressed data rate is ~1.2Gbps with real time transfer (transient events) to NERSC using FABRIC nodes; 1 month data will be at on-site storage ~400TB connected with 10Gbps and it will take 4 days to clear a month-long backlog. Managed by DOE & NSF
MeerKAT	South Africa	SARAO, Cape Town/CSIR, South Africa	Operation	2018-present	Data is archived at Centre for High Performance Computing (Cape Town/CSIR). Academic research and computing are done at Inter-University Institute for Data Intensive Astronomy (Cape Town/UCT) and Ilifu Cloud
SKA (Mid & Low)	South Africa & Australia	SKA Regional Centers (SRCs)	Construction	2024 - 2028	20 Tbps aggregate; 350 PB of data annually
FYST (a.k.a. CCAT)	Cerro Chajnantor, Chile	Cornell University, Ithaca, NY, USA, Cologne, Germany Toronto, Canada	Construction	Q2 2026 (first light)	~3-8 TB/day; connecting to dark fiber at ALMA Pad 409 Dark Fibers; During CHAI observation, the data will be sent to Cologne, Germany (~685Mbps) and Toronto, Canada (~13Mbps). During pre-Cam observation, the data will be sent to Cornell University, USA (~386Mbps) and Toronto, Canada. Data flow from Chile to Germany, Canada, and USA.
US ELT: GMT & TMT	Chile and Hawaii (or La Palma, Canary Island)	Tucson AZ	Construction	Start date to the early 2030s	Projected 10-40 TB per night. Data flow from Chile and Hawaii; Managed by NSF & NOIRLab. Will generate 2.4 PB of telemetry and environmental data annually, with 31 TB of science data transferred to NOIRLab for analysis

EHT	ALMA, APEX, GLT, JCMT, KP, LMT, NOEMA, SMA, SMTO, and SPT	MIT Haystack Observatory Correlator in Massachusetts, USA and the Max-Planck Institute for Radio Astronomy Correlator in Bonn, Germany	Operation	varies	2023 Campaign notes: Observations were at 230GHz & 345GHz, Dual pole and double side band, Station recorders at 64Gb/s, Collecting about ~2PB raw data per station. The data is then shipped to the MIT Haystack Observatory Correlator in Massachusetts, USA and the Max-Planck Institute for Radio Astronomy Correlator in Bonn, Germany for processing. **2025 stats**: 700 TB per site; 100Gbps upgrade at Haystack for correlation

5 Research & Education Provider Updates

Section 5 summarizes the updates provided by each of the R&E networks supporting the astronomy observatories.

5.1 Vera C. Rubin Observatory: US Data Facility Networking Update (Matthew Mountz)

Missing Presentation

5.2 NOIRLab – ITOps (Mauricio Rojas, Eduardo Toro)

The NOIRLab IT Operations (ITOps) team is undertaking a comprehensive infrastructure enhancement initiative aimed at strengthening cybersecurity, improving network performance, and enabling seamless collaboration across its various centers. Key milestones include the deployment of Privileged Access Management (PAM), End-Point Detection and Response (EDR), and Multi-Factor Authentication (MFA) across internal and external services using PingOne and Duo. These efforts are part of a broader strategy to lock down and harden systems and services, aligning with zero-trust principles. Network segmentation and isolation are ongoing, with restricted traffic flows implemented through next-generation firewalls (NGFW) and access control lists (ACLs) on core switches.

Remote access capabilities have been significantly improved to support staff, external collaborators, and vendors, with strict approval protocols and risk mitigation strategies in place. The Tucson Data Center has seen advancements in hardware and software standardization, and remote observing functionalities have been expanded through limited tunnel profiles. Security operations have been bolstered by OmniSOC, which provides 24/7 monitoring, dynamic blocking lists, and log ingestion. Backbone network upgrades are underway at key locations including Tucson (TUC), La Serena (LSC), and Hilo (HBC), with new topologies being planned using high-availability (HA) implementations and automated network administration tools like Ansible and GitHub.

The backbone network activities span critical links between Chile and the USA, including connections from La Serena to Santiago and Cerro Pachón, as well as Tucson to Kitt Peak and Hilo to Mauna Kea. These upgrades are designed to support high-speed data transfers and future-proof the infrastructure. The La Serena Center has completed its Wi-Fi upgrade and is preparing for further LAN and WAN enhancements, including VPN site-to-site matrix updates and Next Generation Firewall (NGFW) standardization. Program integration efforts are focused on aligning services across CSDC, Gemini, MSO, and Vera Rubin, with shared infrastructure administration and cybersecurity protocols. Data archive statistics highlight the scale of operations, with MSO generating 500 GB per night, KP 200 GB, and Gemini 20 GB. Integration projects such as WLC and Zoom VoIP prototypes are progressing, particularly at Rubin. The network upgrade project continues with LAN designs being implemented across all locations, and migration setups being prepared in La Serena using unified management tools and optics hardware.

5.3 South African NREN Connectivity (Ajay Makan)

The South African National Research and Education Network (SA NREN) is a collaborative initiative between SANReN and TENET, designed to provide high-bandwidth connectivity and advanced services to the country's research and education sectors. SANReN is responsible for building and expanding the network infrastructure, while TENET operates the network and hosts services under a collaboration agreement with the Council for Scientific and Industrial Research (CSIR). Together, they support over 1.3 million users across more than 400 connected sites, with a total international bandwidth capacity of 360 Gbps distributed across five undersea cables. The network includes a core national dark fibre backbone, regional extensions, and metropolitan area networks, with multiple 100Gbps backbone links between major cities. The SA NREN plays a critical role in supporting South Africa’s astronomy and space science initiatives. It provides connectivity to key research facilities such as the South African Astronomical Observatory (SAAO), the South African Radio Astronomy Observatory (SARAO), and the South African National Space Agency (SANSA). These connections enable high-speed data transfers from telescopes and observatories located in remote areas like Sutherland, Losberg, and Hartebeesthoek. Infrastructure developments include a 180km dark fibre build from Carnarvon to Beaufort West, which is being transferred to the SKA Observatory, and ongoing upgrades to 10Gbps and 100Gbps links to support the Square Kilometre Array (SKA) project.

SANReN offers a suite of services to enhance network performance and facilitate large-scale data transfers. The Performance Enhancement Response Team (PERT) uses tools like perfSONAR to diagnose and resolve throughput issues, with a network of 100G and 10G nodes deployed across the country. The Data Transfer Service includes FileSender for sharing files up to 100GB and specialized Data Transfer Nodes (DTNs) using Globus software for transferring terabytes of data. These DTNs are strategically located in Johannesburg, Cape Town, Durban, and Losberg, with benchmarking results showing transfer speeds of up to 5.48 GB/s. SANReN continues to collaborate internationally, including with the EPOC the AmLight team at FIU to optimize its data transfer capabilities.

The project is part of the broader National Integrated Cyberinfrastructure System (NICIS), which encompasses SANReN, the Centre for High Performance Computing (CHPC), and the Data Intensive Research Initiative of South Africa (DIRISA). Hosted by the CSIR under the Department of Science, Technology and Innovation (DSTI), NICIS aims to support human capital development and provide integrated cyberinfrastructure for research and innovation. SANReN's ongoing efforts in expanding connectivity, supporting scientific research, and enhancing data transfer capabilities reflect significant progress in building a robust digital foundation for South Africa's research community.

5.4 Square Kilometre Array Networks (Richard Hughes-Jones)

The Square Kilometre Array (SKA) project represents a major international effort to construct the world's largest radio telescope, with two primary components: SKA1-Mid in South Africa and SKA1-Low in Australia. SKA1-Mid comprises 64 existing MeerKAT dishes and 133 new SKA1 dishes operating between 350 MHz and 14 GHz, while SKA1-Low consists of 131,000 dipole antennas grouped into 512 stations, covering frequencies from 50 to 350 MHz. Each telescope is supported by three distinct networks: a data network for science data transport, a synchronization and timing network with picosecond accuracy, and a non-science data network for control, monitoring, and communications.

The infrastructure supporting these telescopes is extensive and technically sophisticated. SKA1-Mid features a central processing facility (CPF) in the Karoo region, with dishes connected via high-capacity optical links ranging from 100GBASE-LR4 to ZR4 depending on distance. The correlators for SKA1-Low and SKA1-Mid have been relocated to Perth and Cape Town respectively, enabling long-haul optical transport of science data, 20 Tbps from Karoo to Cape Town and 9 Tbps from Murchison to Perth. Construction updates for SKA1-Low include the deployment of temporary CPF facilities and advanced optical transport technologies using 200G and 800G wavelengths, while SKA1-Mid has begun signal chain testing and dish surface installations. The data generated by SKA is immense, with expected flows reaching up to 2 Pbps and annual data volumes of 300 PB. This data is processed and disseminated through SKA Regional Centers (SRCs), which are globally distributed and interconnected via academic networks and submarine cables. Each SRC receives a portion of the Observatory Data Products and redistributes replicas to other SRCs, maintaining a continuous 20 Gbps flow between centers. The SRCs also provide compute and storage resources, scientific analysis capabilities, and user support, although these fall outside the construction budget.

To facilitate data management and scientific workflows, the SRCNet 0.1 infrastructure is being deployed across eight sites, including SKAO. Core services such as Rucio, FTS, IAM, and the Science Gateway are operational and resilient, with over 750,000 successful data transfers recorded. A series of test campaigns have been conducted throughout 2025, focusing on network and storage performance, integration, scalability, and stress testing. These efforts aim to ensure a stable and scalable deployment of SRCNet software by early 2026, in preparation for science verification activities in AA2 scheduled for Q4 2026. The overall SKAO project timeline currently targets completion by the end of June 2028.

5.5 AmLight: Network Connectivity (Jeronimo Bezerra)

The Americas Lightpaths (AmLight) project (NSF Award# OAC-2029283) is a distributed academic exchange point designed to foster collaboration among researchers and network operators across Latin America, Africa, and the United States. Built on principles of trust and openness, AmLight integrates infrastructure and human resources from multiple regional research and education networks. Its overarching vision is to provide reliable, scalable, and high-performance network connectivity and services that support SLA-driven science applications, improve network visibility, and minimize manual intervention in network operations. In pursuit of this vision, AmLight's network connectivity has significantly expanded, currently offering 6x100Gbps upstream capacity between the U.S. and Latin America, and 1x100Gbps to Africa, with plans to add 700Gbps in 2025. This will bring the total international connectivity to 4.9 Tbps. The network spans multiple points of presence across the Americas and Africa, including Florida, Georgia, Brazil, Chile, Puerto Rico, Panama, and South Africa. The infrastructure is SDN-based, utilizing custom orchestration and telemetry solutions to enhance performance and reliability.

Since the 2024 SA3CC meeting, AmLight has focused on advancing its network performance measurement and control capabilities. Innovations include BERToD (Bit Error Rate Test on Demand), a traffic generator tool that isolates packet loss with high granularity, and its integration with the SDN controller for fault recovery testing. The deployment of new perfSONAR nodes and MaDDash tools further supports performance monitoring. Enhancements to the SDN control plane, particularly the Kytos-ng controller, have introduced advanced pathfinding and traffic engineering policies, enabling better separation of experimental and production traffic. Network visibility has also improved through the deployment of an INT Collector capable of detecting microbursts and the use of optical telemetry to anticipate link faults. Bandwidth upgrades and resilience improvements have also been a priority, with the Monet optical spectrum extended to 187.5 GHz, increasing its capacity from 400 Gbps to 1.1 Tbps. AmLight has also strengthened its connections to other U.S. Open Exchange Points, activating multiple 400 Gbps links and installing high-capacity switches in key locations such as Buenos Aires, Miami, Jacksonville, and Atlanta. These upgrades support the growing demands of international research collaborations.

The evolution of AmLight's SDN architecture from 2014 to 2025 reflects a shift toward greater automation and intelligence. The current architecture includes q programmable data plane, enhanced management visibility through telemetry, and a robust control plane powered by the Kytos-ng controller. The newly developed Intelligence Plane profiles network traffic every 100-500ms, identifies anomalies, and suggests real-time adjustments to the control plane. This closed-loop orchestration system enables sub-second reactions to network conditions, ensuring optimal performance for critical science applications. AmLight's support for the SA3CC community is rooted in its ability to provide a complex, high-capacity topology with over 25 potential paths from Chile to major U.S. networks like Internet2 and ESnet. The architecture is designed to meet the stringent requirements of SLA-driven, packet-loss-intolerant, and low-latency science applications. Through automation and engineering, AmLight is reducing the need for manual operations, enhancing responsiveness, and proactively managing network health to support international scientific collaboration.

5.6 AmLight: Monitoring and Measurement Improvements (Renata Frez)

AmLight has made significant strides in enhancing its network monitoring and measurement capabilities. The initiative is driven by a commitment to improving infrastructure visibility, fault isolation, and performance analysis across its international research and education network. A diverse suite of tools and frameworks is employed, including Zabbix for general infrastructure monitoring, SNMP and sFlow for event troubleshooting and reporting, and perfSONAR for user-perspective testing. These tools are complemented by advanced telemetry solutions such as the Juniper Telemetry Interface (JTI) and In-band Network Telemetry (INT), which provide granular insights into short-duration events and device-specific metrics. A major innovation introduced in the last year is BERToD (Bit Error Rate Test on Demand), a hardware-based traffic generator that enables automated, high-precision testing of network paths. BERToD conducts latency, jitter, frame loss, and out-of-sequence tests every 30 minutes across all links, using multiple frame sizes and up to 500,000 frames per test. Results are visualized through Grafana dashboards, offering both granular and historical views, with filters for frame size and path-specific analysis. This tool has proven invaluable for identifying performance anomalies and correlating events over time, especially in ultra-long paths where packet loss is critical.

The integration of BERToD with the Kytos-ng SDN controller marks a leap forward in automation. Following a link flap, the controller initiates a quarantine mode and triggers BERToD to validate the link's integrity before it is returned to service. This process ensures that only clean, stable links are used for production traffic, aligning with the stringent requirements of SLA-driven scientific applications. The automation of fault isolation using AI/ML techniques is a key area of ongoing development, leveraging data from SDN logs, topology changes, optical monitoring, and other sources. AmLight's monitoring ecosystem also includes the perfSONAR Central Measurement Archive (ps-CMA), which runs version 5.1.4 and integrates Grafana for visualization and OpenSearch with Logstash for archiving. Public dashboards are available for both AmLight and the Vera Rubin Observatory, providing transparent access to performance data. The legacy Maddash server continues to operate in parallel, ensuring continuity and redundancy in monitoring capabilities.

Overall, the combination of tools and frameworks used by AmLight has significantly enhanced operational visibility and responsiveness. The daily use of these systems by the AmLight operations team enables proactive management of network health and user experience. Future efforts will focus on refining BERToD, expanding ps-CMA capabilities, and further automating fault isolation processes. These advancements underscore AmLight's dedication to supporting high-performance, reliable connectivity for international scientific collaboration.

5.7 REUNA Updates (Albert Astudillo)

REUNA has played a pivotal role in Chile's digital development for over three decades, establishing a robust academic and research network infrastructure. With 18 points of presence across major cities and over 11,000 km of network infrastructure, REUNA connects more than 50 organizations, including universities and research institutions. The network has recently expanded to over 1,300 km with the Patagonia Project, extending connectivity to Punta Arenas and laying the groundwork for future Antarctic connections. REUNA's services span academic networking, cloud operations, security, videoconferencing, and federated identity management, supporting a wide range of digital and collaborative needs. Historically, REUNA has maintained strong ties with the astronomical community, with key milestones including the 2010 EVALSO Project with ESO, the 2012 MoU with ALMA for network management, and the 2018 connection of the Vera Rubin Observatory via a 100 Gbps link. In 2020, REUNA and AAP signed an MoU to support infrastructure on the Chajnantor plateau, and in 2022, ESO officially became a REUNA member. The installation of the Chajnantor Point of Presence (PoP) in 2023 marked a significant step in connecting observatories in the Atacama Desert, including the Simons Observatory, which celebrated its first anniversary of connectivity in May 2025.

Recent developments since the 2024 SA3CC meeting include the connection of three new institutions to REUNA (Duoc UC, Universidad Diego Portales, and Pontificia Universidad Católica de Valparaíso) and the implementation of new infrastructure for ESO and ALMA. This upgrade provides 80 Gbps of shared bandwidth, with scalability up to 100 Gbps. REUNA has also installed a PoP at the ALMA data center, enabling collaborative connectivity for future astronomical projects such as ASTE. The use of CWDM infrastructure allows each project to operate on its own dedicated wavelength, enhancing flexibility and performance. Moreover, the Patagonia Project continues to advance, with two new institutions connected to the Punta Arenas PoP, which serves as a gateway to Chilean Antarctica. A feasibility study funded by CAF and the Chilean Telecommunication Subsecretary is underway to explore the deployment of a submarine cable linking Chile to Antarctic research bases. REUNA has been invited to participate as a stakeholder in this strategic initiative, which aims to support earth sciences and global research efforts.

Internationally, REUNA maintains a 100 Gbps connection with RedCLARA, with the potential to scale to 200 Gbps. As a founding member of RedCLARA and a partner in initiatives like BELLA and AmLight, REUNA continues to strengthen its global connectivity. Collaborative efforts with BELLA 2 are underway to further expand international bandwidth and support the growing demands of scientific and academic communities across Latin America and beyond.

5.8 RedCLARA Updates (Marco Teixeira)

RedCLARA (Latin American Cooperation of Advanced Networks) is a non-profit entity dedicated to building a high-capacity digital infrastructure throughout Latin America to support research and education. Its foundation is based on the collaboration of National Research and Education Networks (NRENs) from countries including Brazil, Colombia, Costa Rica, Chile, Ecuador, Guatemala, Mexico, and Uruguay. Covering a geographic area larger than the United States and the European Union, RedCLARA's network significantly boosts regional connectivity for academic and scientific cooperation. The infrastructure features cutting-edge technologies such as the Ciena Waveserver AI, capable of delivering up to 2.4 Tbps in a compact design, and the ASR9904, which supports up to 16 Tbps in a larger configuration. Major network routes include links between Santiago and Buenos Aires, and Buenos Aires and Porto Alegre, backed by long-term agreements that ensure high-capacity services and spectrum access. These connections are essential for enabling efficient data transmission across vast distances and reinforcing regional integration.

RedCLARA also leads the BELLA 2 initiative, a four-year program aimed at strengthening the digital landscape in Latin America and the Caribbean. This project promotes collaboration among businesses, research institutions, universities, and networks, with a focus on education, science, technology, and innovation. Key strategic priorities include shared infrastructure, user-centric connectivity, and fostering synergy among stakeholders. BELLA 2 is designed to address digital disparities in areas such as connectivity, high-performance computing (HPC), blockchain, cybersecurity, artificial intelligence (AI), and the Internet of Things (IoT). To realize this vision, RedCLARA is forming consortia that bring together government, academic, financial, corporate, and social sectors. These groups will work to improve connectivity and deliver value-added services. Through BELLA 2, RedCLARA will provide financial support, with most of the funding allocated to enhancing network infrastructure. Additionally, efforts are underway to establish new NRENs in countries like Argentina, El Salvador, Peru, Paraguay, Panama, Bolivia, Venezuela, Nicaragua, and Honduras, further extending RedCLARA's influence and reach.

5.9 RNP Updates (Aluizo Hazin)

The Brazilian Academic Network (RNP), a non-profit private association funded by an inter-ministry program, has made significant strides in expanding and modernizing its infrastructure to support Brazil's research and education communities. With over 1,800 connected customer sites, 180,000 researchers, 4,000 postgraduate programs, and 4 million end users, RNP has illuminated 15,000 km of fiber through its own

DWDM system, with plans to exceed 20,000 km by 2026. The Infovia Nacional project, an upgrade of the Ipê Network, includes 32 backbone circuits at 100G, balancing OPGW fiber activation with market-based optical channel swapping. Nine Points of Presence (PoPs) at public universities are being revitalized with new equipment and a redesigned architecture, pending the outcome of an RFP. The network's mission-critical infrastructure ensures all PoPs are interconnected for high reliability.

The Infovias Estaduais initiative is deploying high-speed networks across 19 Brazilian states, with eight expected to be completed by 2026. This effort includes approximately 42,000 kilometers of network paths, 30,000 of which will be finalized by the same year, and the creation of 79 new metropolitan networks. Complementing this is the e-Science project, which shares infrastructure with the Ipê Network but operates with dedicated 100G capacity. It involves 15 universities and research institutions, selected through a competitive proposal process and legacy projects. The network is designed with security in mind, featuring no internet access, point-to-point connections with redundancy, and plans for end-to-end encryption using MAC-SEC. It also supports a mission-critical control and management network for operational oversight.

RNP is evolving its mission-critical network from last year’s out-of-band deployment using Cisco Meraki MX SD-WAN routers. The upgraded system includes high hardware availability, multiple WAN connectivity options, IPsec site-to-site tunneling, and a hub-spoke architecture with regional redundancy. Services under this umbrella include equipment monitoring, telemetry, secure access, continuous penetration testing, and infrastructure-as-code provisioning. Additionally, RNP is planning connection upgrades for key astronomy institutions outside the e-Science scope, such as the interinstitutional Laboratory of e-Astronomy (LIneA) and the Brazilian National Observatory, with 100G connections targeted for 2025 and 2026 respectively.

Internationally, RNP maintains strong collaborations with initiatives like BELLA (RedCLARA + GÉANT) and AmLight. Connection points in Fortaleza, São Paulo, and Porto Alegre link Brazil to global research networks. A joint effort with Florida International University is doubling the Monet submarine cable capacity to 800G. RNP also supports AmLight’s new São Paulo–Buenos Aires connection via the Tannat cable, providing colocation and local services in São Paulo. These efforts underscore RNP’s commitment to advancing Brazil’s digital research infrastructure and fostering international scientific collaboration.

5.10 Rednesp Updates (Ney Lemke)

The Research and Education Network of São Paulo (rednesp), spearheaded by a collaborative academic committee comprising USP, UNESP, and UNICAMP, and supported by FAPESP (São Paulo Research Foundation), has become a cornerstone of high-speed connectivity for research and education across Brazil. Over the past 16 years, FAPESP has invested approximately USD 5 million annually to support international links through the AmLight cooperation, connecting São Paulo to key global hubs such as Miami, Panama, Santiago, and Fortaleza. These resilient connections, including Monet and Ella links, are managed through partnerships with AmLight, RNP, and European initiatives, and are backed by cutting-edge infrastructure such as Juniper PTX10004 routers with capacities reaching 57.6 Tbps.

The network has undergone a major infrastructure transformation over the past year, replacing outdated 100 Gbps systems with new 400 Gbps capabilities. This upgrade supports the integration of eight academic institutions at 100 Gbps, with two additional institutions joining in 2025. The Backbone-SP initiative provides a robust, protocol-transparent, point-to-point connectivity backbone for research centers, HPC server integration, and high availability teaching and research infrastructure. Key institutions now connected include the National Institute for Space Research, the Brazilian Synchrotron Laboratory, and the Brazilian Army Research Group, among others. Technological advancements within rednesp also include the deployment of a Software Defined Networking (SDN) platform, orchestrated via REST APIs and a Web UI. This platform supports features such as LLDP topology discovery, bidirectional forwarding detection, and in-band network telemetry. The open-source framework, Kytos-ng, has seen significant contributions from rednesp, including upgrades to its core UI and NApps interface using Vue.js 3, and improvements to its unit testing infrastructure.

Looking ahead, rednesp is involved in high-impact scientific collaborations such as the Cherenkov Telescope Array (CTA), which aims to link observatories in Chile to Europe for advanced astrophysical research. This includes exploring phenomena like dark matter and supermassive black holes. Additionally, rednesp is facilitating the integration of High-Performance Computing Centers in São Paulo under a 20 million USD cooperation agreement between FAPESP, MCTI, and MCom. The network's governance includes a dedicated executive and technical team, with leadership from Prof. Dr. Ney Lemke (UNESP), and contributions from a broad university committee representing institutions across São Paulo.

5.11 Vera C. Rubin Observatory: US Data Facility Overview and Update (Adam Bolton)

The Rubin Observatory's Legacy Survey of Space and Time (LSST) represents a monumental effort to image the entire visible sky every 3-4 nights over a ten-year period. Utilizing the world's largest digital camera and highest-etendue telephoto lens at a premier astronomical site in the Chilean Andes, the project aims to build a time-resolved, six-color database of 20 billion stars and 20 billion galaxies. This data will be made available to scientists globally, enabling transformative research across astrophysics, cosmology, and time-domain astronomy. A central component of the project is the US Data Facility (USDF), which plays a critical role in data stewardship, computing infrastructure, and inter-facility data movement. The USDF is responsible for the curation of raw and processed data, disaster recovery, and the operation of a hybrid US Data Access Center (DAC). It supports prompt processing, alert generation, and data release workflows, while also facilitating distributed multi-site processing and mirroring of data between USDF and other facilities such as FrDF, UKDF, and other international data access centers (IDACs). The facility also ensures secure and performant data transfers and implements Rubin's data security policies.

The SLAC Shared Science Data Facility (S3DF), hosted within Stanford's Research Computing Facility, provides high-throughput computing infrastructure for Rubin and other large-scale experiments. With over 100 racks and 400 Gbps networking, it supports data-intensive workflows and is operated by SLAC's Scientific Computing Division. This infrastructure underpins the Rubin Observatory's ability to manage vast volumes of data efficiently and reliably. Recent progress includes successful multi-site exercises involving the Campaign Management Team, which orchestrated data movement and pipeline execution using tools like PanDA and Rucio. Notably, Rucio-based input data transfers for Data Preview 1 were completed successfully, and daily exports of calibration exposures have been ongoing. Efforts are underway to address transfer error rates and expand Rucio usage to additional IDACs. File zipping strategies have also been implemented to reduce stress on data systems, particularly in response to the billions of small files generated annually.

The USDF hosts a wide array of applications and services critical to Rubin operations, including data management tools (Rucio, Butler), workflow systems (HTCondor, BPS), databases for alert and prompt products, and platforms for scientific analysis and visualization. Current USDF focus areas include support for on-sky engineering, facility performance monitoring, data security, and preparation for Data Preview 1. The team is also working on standardizing application deployment, developing real-time dashboards, and evolving hardware and cybersecurity models. Major milestones in 2025 include the installation of LSSTCam, the "First Photon" event, the public release of early Rubin images, and the commencement of the 10-year Legacy Survey in early October 2025.

5.12 US Data Facility Infrastructure (Omar Quijano)

The USDF infrastructure project has undergone significant evolution, marked by strategic enhancements in storage architecture, network design, and performance monitoring. Initially, the Embargo layout was designed with key requirements such as resiliency, encryption, and a steady-state capacity of 800 TiB, aiming for a latency of 7 seconds. The delivered configuration exceeded expectations, providing a usable capacity of 1.3 PiB. As the project matured, the existing configuration was restructured to increase capacity to 3 PiB using current hardware and maintaining performance standards. This resulted in a usable capacity of 4.7 PiB on HDD and 2.1 PiB on NVMe. Security was reinforced through LUKS for data encryption and TPM for key encryption, with access controls managed via Splunk for audit logging and CrowdStrike for endpoint detection and response. Server uniformity and consistency were ensured through Ansible-Pull.

The network layout also saw substantial upgrades. The Embargo network was optimized for security and performance, with throughput tests showing transfer rates exceeding 5 Gbps. Key changes included upgrading Arista EOS to version 4.34.0F, adding VLAN sdf-rubin-pub for public IPv4 access, and implementing ACLs on tunnel interfaces to restrict connections to Summit VPN peers, mitigating brute-force attacks. The S3DF network adopted the BowTie model, integrating Layer 2 and Layer 3 configurations to enhance connectivity and routing efficiency. The use of VARP over VRRP enabled active routing from both switches in an MLAG pair, reducing latency and improving resilience. The backbone was scaled to 1600Gb across cores, with leaf switches connected via dual 400Gb links to each core.

To monitor and troubleshoot network performance, perfSONAR was deployed across three servers. These servers are routed through various paths including LHN to SLAC and IPSEC tunnels, with capacities of up to 100Gbps. While two servers are fully operational, the third—routed via IPSEC—is still in progress. Future steps include finalizing routing for the IPSEC tunnel and integrating with AmLight. Ongoing work focuses on enhancing Embargo storage performance, refining metrics to identify bottlenecks, and improving file visualization within hot and cold pools. Efforts are also underway to complete perfSONAR integration, strengthen internal monitoring and alerting within S3DF, and establish more effective problem escalation protocols. Staffing remains a key consideration to support these initiatives and ensure sustained progress.

5.13 Internet2 Updates (Chris Wilkinson)

Internet2, a non-profit consortium dedicated to supporting research and education, represents a robust and adaptable network infrastructure serving higher education institutions, research organizations, government entities, and cultural institutions. The consortium's National Research & Education Network (NREN) spans 26,000 kilometers of optical fiber and includes over 74 optical add/drop sites and 50 packet sites. This infrastructure supports a wide range of services, including peer exchange, rapid private interconnect, cloud connectivity, and global DDoS protection. The network also offers Layer 1, 2, and 3 services to meet diverse community needs, and facilitates international collaboration through global exchange points.

The current hardware ecosystem includes terabit-scale cloud edge devices, core transport systems, and advanced transponders, such as the WaveServer 5. The network topology features 94 backbone links at 400 Gbps, totaling over 27,600 Tbps of deployed capacity. Internet2 has implemented a disaggregated switching and routing platform with 77 routers across 47 sites, ensuring redundancy and resilience. The Insight Console, a web-based management tool, provides visualization, troubleshooting, and self-service capabilities, with future enhancements planned to support routing intentions and automated policy management. Global exchange points in Boston, New York, and Washington operate independently from the Internet2 backbone and are being upgraded to support advanced automation and interoperability.

The network's optical capabilities are being expanded through coherent pluggables and transponders, enabling high-capacity links and extending connectivity to high-performance computing and AI facilities. These technologies offer significant advantages in terms of power efficiency and scalability, although they present challenges related to distance limitations and spectral efficiency. Looking ahead, Internet2 is undergoing a comprehensive network refresh to ensure its relevance for the next five to six years. This includes growth in packet services, cloud connectivity, and platform adoption, as well as enhanced security features and support for emerging technologies. Collaborative infrastructure development is underway, with expansions planned in multiple metro areas and along strategic corridors. The backbone now includes 20% coherent links, and new nodes are being added to support regional and national connectivity.

5.14 ESnet Updates (Kate Robinson)

The Energy Sciences Network (ESnet) plays a pivotal role in supporting the U.S. Department of Energy's (DOE) scientific research ecosystem by providing high-performance, reliable connectivity across national laboratories, user facilities, and global research collaborations. ESnet's overarching vision is to enable scientific progress without constraints imposed by the physical location of instruments, researchers, computational resources, or data. Its mission—networking that accelerates science—is realized through strategic infrastructure upgrades, collaborative planning, and continuous engagement with the scientific community. A cornerstone of ESnet's strategy is the Requirements Review program, which fosters collaboration and knowledge sharing among DOE Office of Science programs and facilities. This initiative captures critical information about major scientific experiments, data volumes, workflows, and technology capabilities, both current and anticipated. These reviews inform ESnet's service design and network upgrade strategies, ensuring alignment with evolving scientific needs. The program has produced comprehensive reports that are now considered essential strategic documents within the Office of Science, guiding infrastructure development across domains such as high energy physics, nuclear physics, and biological and environmental research.

ESnet documented 14 detailed scientific case studies, encompassing a wide range of experiments including cosmological simulations, dark energy research, neutrino studies, and operations at the Large Hadron Collider. These studies highlight the increasing scale and complexity of data production, with many experiments now operating in the petabyte range and requiring near real-time, multi-facility workflows. The integration of cloud technologies is emerging, though still in early stages, with hybrid models like that of the Rubin Observatory demonstrating promising approaches to balancing user accessibility and backend performance.

Significant progress has been made in transatlantic connectivity, with multiple high-capacity links now in production, including 400G and 100G connections between key U.S. and European research hubs. ESnet is collaborating with GÉANT to expand spectrum access across diverse subsea cables, aiming to enhance redundancy and performance. These upgrades are critical for supporting the growing demands of international scientific collaborations and ensuring robust data transfer capabilities. Monitoring and analysis have also evolved, with ESnet leveraging open-source tools and the NSF NetSAGE project to build an extensible architecture for network measurement. This system supports multiple access methods and data sources, enabling flexible aggregation and storytelling through metadata. The focus is shifting toward programmatic access for machine learning and external collaboration, reflecting the increasing sophistication of scientific data workflows.

A notable challenge addressed in the project involves optimizing data transfers from SLAC's Rubin U.S. Data Facility to Google Cloud Platform (GCP). Despite tuning Data Transfer Nodes (DTNs), performance was hindered by latency sensitivity and architectural limitations. The solution involved modifying TCP configurations on the nginx load balancer to increase the slow start flight size, significantly improving transfer speeds from cache. However, raw storage performance remains a bottleneck, underscoring the need for holistic approaches that consider both networking and storage system capabilities. Overall, ESnet's ongoing upgrades, strategic partnerships, and deep engagement with the scientific community position it as a critical enabler of data-intensive research.

5.15 NREN Community Support to HEP Science (Edoardo Martelli)

The Large Hadron Collider (LHC) at CERN represents one of the most ambitious scientific endeavors in particle physics, supported by a vast and intricate network of computing and data infrastructure. The LHC's major experiments; ALICE, CMS, ATLAS, and LHCb, are monumental in scale and complexity, each designed to explore fundamental questions about the universe. As the LHC transitions into its next phase, the High-Luminosity LHC (HL-LHC), the volume of data generated is expected to increase tenfold, necessitating significant advancements in computing and networking capabilities.

Central to managing this data is the Worldwide LHC Computing Grid (WLCG), a globally distributed infrastructure that enables data storage, processing, and analysis across hundreds of institutions. The WLCG operates through a tiered model: Tier 0 at CERN handles initial data capture and reconstruction, Tier 1 sites provide secondary storage and simulation capabilities, and Tier 2 sites support data analysis and caching. This model is underpinned by two dedicated network systems, LHCOPN and LHCONE, which ensure secure, high-speed data transfers between tiers. LHCOPN connects Tier 1s to Tier 0 using private, high-capacity links, while LHCONE extends connectivity to Tier 2s and other high-energy physics (HEP) collaborations. The National Research and Education Network (NREN) community plays a pivotal role in supporting HEP science through its technical expertise, collaborative spirit, and innovative services. NRENs have enabled the evolution of computing models from localized systems to globally distributed frameworks. Their contributions include the deployment of advanced technologies such as perfSONAR for network monitoring, Fasterdata for performance tuning, and SciTags for enhanced data packet identification. These tools have significantly improved data transfer efficiency and network diagnostics.

To prepare for the HL-LHC era, WLCG and its partners have initiated a series of data challenges aimed at testing and scaling infrastructure to meet future demands. These challenges progressively increase data rates and complexity, with milestones set for 2021, 2024, 2027, and full readiness by 2029. Complementary efforts include the integration of Software Defined Networking (SDN) technologies like ESnet SENSE ,the development of real-time optimization frameworks such as NOTED, and the participation of SPRACE and HEP-GRID in the SC23 NRE challenges in collaboration with AmLight, Rednesp, and RNP to simulate the data flows planned for the DC24 challenge. These innovations are critical for achieving the projected data throughput of up to 9.6 Tbps by 2030. The collaboration between CERN, WLCG, and the NREN community exemplifies a model of international scientific cooperation. Through shared infrastructure, coordinated planning, and continuous innovation, this partnership has laid the groundwork for future discoveries in particle physics. As the HL-LHC and subsequent projects like the Future Circular Collider come online, the role of computing and networking will remain central to the success of these long-term scientific programs.

5.16 EU NREN & GÉANT for CTAO Data Transfer

The GÉANT project, a cornerstone of European research and education networking, has undergone significant advancements in recent years, particularly in support of data-intensive scientific collaborations such as the Cherenkov Telescope Array Observatory (CTAO). The initiative has focused on enhancing high-capacity, cost-effective connectivity across Europe and beyond, leveraging spectrum-based technologies and next-generation optical systems. GÉANT's backbone now supports capacities ranging from 2.4 to 6 Tbps, with spectrum services offering a more economical alternative to full dark fiber, using only a portion of the fiber's capacity at a fraction of the cost.

A major milestone in the project has been the deployment of the Open Optical Line System (OOLS), built on Infinera's FlexILS platform. This modular state-of-the-art infrastructure supports disaggregated optical transmission and native integration of "alien waves", a key feature for flexible, multi-vendor environments. The system is being rolled out across the GÉANT backbone, with framework agreements in place to facilitate adoption by National Research and Education Networks (NRENs). These developments are complemented by the optimization of the optical transmission stack, including the removal of OTN switching and the introduction of spectrum as a substrate connectivity option. The project has also seen the successful implementation of high-performance services such as GÉANT IP, VPN, Point-to-Point, and Open connectivity. These services provide ultra-high-speed, uncontended IP connectivity up to 100 Gbps, dedicated private networking, and flexible interconnection options for both NRENs and approved commercial partners. A notable use case includes the spectrum-based connection between CNAF Tier1 and CERN Tier0 via GARR and GÉANT, which has resulted in significant cost savings and operational efficiencies.

From 2022 to 2025, GÉANT has been executing a comprehensive packet layer renewal project. This includes the procurement, contract award, migration, and eventual retirement of the legacy technology. The new IP-MPLS platform ensures 400G availability across the entire GÉANT footprint, extending high-speed access to the edges of Europe and enabling global partners to connect near landing stations. Key NRENs such as DFN, SURF, RedIRIS, RENATER, JISC, and SWITCH have already upgraded to 400G redundant access, while ESnet peering has been enhanced to 3x400G with complete path diversity. GÉANT's global reach is further exemplified by its collaboration with RedCLARA in Latin America through EU-funded projects like BELLA-2 and BELLA-S. These initiatives have established high-capacity links, such as 100G to Sines/Lisbon and multiple 200G connections to other GÉANT nodes, supporting CTA-related data paths and reinforcing transcontinental research collaboration. The DTN Testing Facility Service, with 100 Gb/s servers in London and Paris, has also been instrumental in validating protocols, optimizing data transfer performance, and supporting projects like SKA, Veera Rubin, ITER/NII, and CERN.

6 Appendix A. Program for the SA3CC Meeting

Monday, May 5, 2025

9:00 – 5:00 Visit to Very Rubin Observatory

Tuesday, May 6, 2025

9:00 – 9:10 Welcome (Julio Ibarra) | Download presentation

Session I: Science Requirements & Activities Updates

9:10 – 9:30 Vera C. Rubin Observatory Operations (Bob Blum) | Download presentation
9:30 – 9:50 NOIRLab science programs (Stuartt Corder)| Download presentation
9:50 – 10:10 GMTO (Sam Chan) | Download presentation
10:10 – 10:30 CTAO (Gareth Hughes, Stefan Schlenstedt) | Download presentation

10:30 – 11:00 *Refreshment Break*

11:00 – 11:20 FYST (a.k.a. CCAT) (Mike Nolta) | Download presentation
11:20 – 11:40 Simons Observatory (Simone Aiola) | Download presentation
11:40 – 12:00 CMB-S4 (Eli Dart) | Download presentation
12:00 – 12:20 ALMA NRAO (Sandy George)| Download presentation

12:20 – 13:50 *Lunch*

13:50 – 14:10 MeerKAT/SKA South Africa (Keith Grainge) | Download presentation
14:10 – 14:30 NOIRLab Data Management and Software division (Hubert Condoretti) | Download presentation
14:30 – 14:50 Event Horizon Telescope (EHT) (Jason G SooHoo) | Download presentation
14:50 – 15:10 ngVLA (Sandy George) | Download presentation

15:10 -15:40 *Refreshment Break*

15:40 – 16:00 ALMA Network Infrastructure (Jorge Ibsen)| Download presentation
16:00 – 16:20 The Global Science Network Forum workshops series (Enzo Capone) | Download presentation
16:20 – 16:40 Open Discussion

Wednesday, May 7, 2024

9:00 – 9:10 Welcome

Session II: Providers updates

9:10 – 9:30 Vera Rubin Observatory Network (Cristian Silva) | Download presentation
9:30 – 9:50 NOIRLab – ITOPS (Mauricio Rojas, Eduardo Toro)| Download presentation
9:50 – 10:10 SANREN/TENET Network (Renier van Heerden, Ajay Makan) | Download presentation
10:10 – 10:30 SKA network (Richard Hughes-Jones) | Download presentation

10:30 – 11:00 *Refreshment Break*

11:00 – 11:20 AmLight1: International links (Jeronimo Bezerra) | Download presentation
11:20 – 11:40 AmLight2: Monitoring and Measurement Improvements (Renata Frez) | Download presentation
11:40 – 12:00 REUNA (Albert Astudillo) | Download presentation
12:00 – 12:20 RedCLARA (Marco Teixeira) | Download presentation

12:20 -13:50 *Lunch*

13:50 – 14:10 RNP (Ari Frazão, Aluizio Hazin) | Download presentation
14:10 – 14:30 rednesp (Ney Lemke) | Download presentation
14:30 – 14:50 USDF data movement and multi-site processing (Adam Bolton) | Download presentation
14:50 – 15:10 USDF infrastructure (Omar Quijano & Riccardo Veraldi) | Download presentation

15:10 -15:40 *Refreshment Break*

15:40 – 16:00 Internet2 (Chris Wilkinson) | Download presentation
16:00 – 16:20 ESnet (Paul Wefel & Kate Robinson) | Download presentation
16:20 – 16:40 The NREN community support to HEP science (Edoardo Martelli)| Download presentation
16:40 – 17:00 Global Science Network Forum: EU NREN for GEANT & CTAO Data transfer (Vincenzo Capone) | Download presentation
17:00 – 17:20 Visit to NOIRLab & Open Discussion

7 Appendix B. Program for the Vera Rubin Observatory NET Meeting

Thursday, May 8, 2025

9:00 – 9:30 Welcome and Introductions:

- Goals and Objectives – Cristian Silva, Julio Ibarra, and Phil DeMar (10 minutes)
- Rubin Observatory Network Status Overview – Cristian or Bob Blum (10 minutes)
- Q&A (10 minutes)

Session I: Review and Update LHN Status and Milestones as Rubin Observatory Begins Operations

Objective: Current state of Operations of LHN

9:30 – 9:40 LHN milestones achieved and LHN milestones remaining, as the LSST Survey moves into operational mode. (Cristian Silva):

- Results of the image transfers
- Status of the Summit network
- Status of the data production at the Summit
    - Status of the first photon

Session II: LHN Service Provider Updates

9:40 – 9:50 Report on the current status of the network infrastructure and services that providers currently provide for the LHN, including the following (as applicable):

- LHN network infrastructure topology & status update:
    - Provide figure for updating the LSE-479 end-to-end LHN topology figure:
    - Include in the network diagram where the LHN is in the Pixel Zone and in the Rubin - Summit network.
    - Identify the demarc of the LHN at the Summit and USDF
- Alert/Alarm services being provided for VNOC services
- Status of PerfSonar monitoring infrastructure being provided for LHN performance monitoring:
    - Systems, their locations, NIC types, PS version
- Planned modifications/changes or upgrades to LHN infrastructure or associated services, and their expected timelines
- If multiple paths, what's the mechanism for switching between paths?
- If internal testing on resources Vera Rubin uses, what tests are you using? For example:
    - BER tools for acceptance testing of circuits?
    - Continuous PerfSonar active testing on links. Routine active monitoring.
    - Tools you expect to use, in the event of service impact to Rubin?
    - Tools to verify network segments are error free?
    - Use of PerfSonar or other tools for path switching?

South America

9:50 – 10:05 Vera Rubin Observatory Network (Julio Costanzo)
10:05 – 10:20 RENATER/IN2P3 (Fabio Hernandez)
10:20 – 10:30 UK/JANET (George Beckett)
10:30 – 10:40 SLAC-Europe (Matthew Mountz)
10:40 – 10:55 ESnet-Europe (Kate Robison)

10:55 – 11:10 *Break*

Contiguous United States

11:20 – 11:35 FIU-AmLight (Jeronimo Bezerra)
11:35 – 11:50 ESnet (Kate Robinson)
11:50 – 12:00 SLAC (Mark Foster)
12:00 – 12:10 USDF (Adam Bolton)
12:10 – 12:20 Closing Remarks, Q&A

12:20 – 13:30 *Lunch*

Session III-a: Services for Monitoring & Measuring LHN Performance

Objective: Cover current state & configuration of services that monitor or measure LHN performance.

13:30 – 13:50 FIU-AmLight LHN perfSONAR Monitoring/Measurement (Renata Frez)
13:50 – 14:10 Summit-to-USDF End-to-end Performance Measurement Services (Julio Costanzo)
14:10 – 14:30 Data Management Transfer Performance Measurement Capabilities (KT)
14:30 – 14:40 ESnet Hi-Touch Services (Bruce Mah)
14:40 – 14:50 Near-term Performance Engineering Tasks (Eli Dart)

14:50 – 15:05 *Break*

Questions to answer:

- How much delay does the IPSec tunnel add to the 7s window?
- What is the degree of retransmits?
- Are retransmits having a negative impact on image transfers?

Session III-b: Enhancement of LHN Monitoring/Measurement

Objective: Cover current state & configuration of services that monitor or measure LHN performance.

15:05 – 15:50 Open discussion of how to improve & better integrate existing services:

- What dies LHN want to see out of perfSONAR
- Integration of monitoring data into VNOC
  - High-level display of status of LHN condition/status
- Detect when perfSONAR infrastructure isn't working

15:50 – 16:20 Rubin Observatory Operations End-to-end Dashboard (Adam Bolton)

16:20 – 16:40 Discussion on what/how to integrate LHN status into dashboard

16:40 – 17:00 Roadmap to reach these goals/outcomes

17:00 – 17:10 Wrap-up, action items, and adjourn (Christian Silva, Julio Ibarra, Phil Demar)

Friday, May 9, 2025

9:00 – 9:10 Welcome, Goals, and Objectives (Philip DeMar, Cristian Silva, and Julio Ibarra)

- Overviews of May 8 meeting and roadmap for Day 2

Session IV-a: VNOC Services Status & Future Plans

9:10 – 9:55 Status update from the GNOC on the LHN VNOC service(s):

- Description/update on VNOC services currently being provided
- Future developments and ideas/suggestions for VNOC service enhancements
- Interactions with service providers:
  - What's working well
  - What are the areas of improvement
  - Long term vision

Outcome: Documented the view and vision for the VNOC from the GNOC.

Session IV-b: NOC Functionality – How Can It Be Most Useful for the Project?

Objective: To facilitate a structured discussion around service provider & user expectations

9:55 – 10:55 Gather feedback to shape VNOC operations and future improvements:

- Who are the users of the VNOC?
- How do of should users interact with the VNOC?
- What information us most useful for specific groups of users?
- How does/should the VNOC interact with the LHN providers?
- How does/should the VNOC interact with the Project?

10:55 – 11:10 *Break*

Outcome: Develop a roadmap with documentation for the enhancements of VNOC services.

Session V-a: VNOC Operational Procedures & Workflows

Objective: To describe the procedures and workflows that the Vera Rubin Observatory is establishing to facilitate smooth & integrated operational support by the LHN and its VNOC services for the Project.

11:10 – 12:15 Discussion of procedures & processes for handling:

- Provider alerts/alarms on their LHN services
- Provider LHN service maintenance plans/requirements/limitations
- Change process for provider LHN modification/upgrade
- Troubleshooting processes& expectations on providers
- Failover testing needs & procedures
- What is the procedure for emergency maintenance?
  - Rubin will come back with a list of criteria based on scientific impact and tell LHN what the threshold is. Decision tree for during the night to be woken up to make a decision
- Scheduling maintenance windows:
  - Coordination Activities Planning (CAP) meeting to schedule
  - Who participates in the CAP meeting?
  - Cristian attends the CAP meeting
  - All maintenance must be known one week in advance

- VNOC can help with coordination of announcing events
- VNOC can also attend CAP meetings

12:15 – 13:30 *Lunch*

Outcome: A common understanding across the LHN provider community of the proper procedures and processes to follow in maintaining a common operational model for the LHN.

Session V-b: VNOC Operational Procedures & Workflows Part II

13:30 – 14:15 Differentiate the boundaries between the Vera Rubin Obs.'s Jira system and the GNOC's ServiceNow system and establish that the appropriate interaction between the two systems will be.

Outcome: Established and understood the interaction between the two service ticket systems.

Session VI: Trouble-shooting Walk-throughs

14:15 – 15:00 Discuss recent and current troubleshooting activities:

- Primary Backup shifts - Cristian Silva/Julio Costanzo
  - Post-mortem analysis of the event KT reported on April 16th on Slack
- LHN packet-out-of-order issues (Bruce Mah, Jeronimo Bezerra)
- Troubleshooting procedures for events that impact the LHN
- Troubleshooting procedures for events that impact layers above the LHN
- Status of describing well defined troubleshooting steps
- A predefined playbook for the VNOC describing the operations/troubleshooting procedures

- Escalation procedures:
  - If the VNOC cannot isolate the problem, it should trigger an escalation. The escalation goes to the end-to-end LHN manager, which is Cristian and the Rubin LHN team.
  - What if the solution to a troubleshooting scenario involves a change to the network? Who has the authority to proceed with making a change? What is the process to communicate and get the authority to make a change to the network?
    - Personalized phone number and email address for Rubin VNOC
    - Action: Definition, who and by when to get procedures written

15:00 – 15:15 *Break*

Outcome: Broadened understanding of current troubleshooting activities, their status, and methodologies utilized to facilitate detecting & debugging them.

Session VII: Additional Discussion Topics and Q&A

15:15 – 16:00 Open time slot for additional topics that emerge as part of workshop discussions, or additional time as needed for already-discussed agenda topics

Session VII: Roadmap, Action Items, and Next Steps

16:00 – 16:10 Deadline and pending items
16:10 – 16:20 Roadmap and vision (Bob Blum)
16:20 – 16:40 Closing comments (Cristian Silva, Julio Ibarra, Phil DeMar)
16:40 *Adjourn*

8 Appendix C. List of Participants for SA3CC Meeting May 6-7, 2025

Name	Email	Organization	Work Country
Adam Bolton	abolton at slac.stanford.edu	SLAC	US
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