# Communication to remote observatories is a science enabler

G. Filippi[a], S. Jaque[b], R. Chini[c], S. Mieske[a], G. Hau[a],
A. Astudillo[b], M. Zambrano[d], A. Schemrl[d], J. Parra[d], J. Ibsen[d]

[a]European Organisation for Astronomical Research in the Southern Hemisphere (ESO[1]),
Karl-Schwarzschild-Strasse 2, D-85428 Garching, Germany;

[b]Corporación REUNA[2], Canadá 239, Providencia, Santiago de Chile, Chile;

[c]Ruhr-Universität Bochum Astronomisches Institut[3], Universitätsstraße 150 D-44801 Bochum, Germany

[d]Joint ALMA Observatory[4], Alonso de Córdova 3107, Vitacura, Santiago de Chile, Chile.

## ABSTRACT

The environmental conditions that allow optimal astronomical observations are often coupled with sites that are far away from human settlements and of difficult access, implying limited infrastructure availability that translates in excessive costs and limited bandwidth. With the availability and more affordability of optical based technologies, the astronomical scientific community, alone or joining forces with other actors, has managed in the last decade to boost the communication capability available to several of the astronomical installations in the northern Chilean region, the Atacama Desert, and to successfully increase the efficiency and effectivity of the existing Observatories and setting the basis for the coming ones. The paper, after providing a short summary of the projects developed to enable better communications and the future initiatives currently foreseen, focuses on the following show-cases, from users that differ in size and aims, in served communities and in geographical locations: a) the observation of the First Light from Gravitational Wave Source (ESO, ALMA, et Al.); b) the use of virtual presence to bring the observer where things happen (ESO/PARANAL); c) remote operations for robotic installation (OCA); d) Contributing to develop the local environment (REUNA); e) provide the “muscle” for the current and future data challenge (ALMA). These examples, by illustrating how communication transformed the way research and education are done, demonstrate that improved communication is paramount in achieving better and, in some case, new astonishing results, both in terms of science and as well as enriching the communities, both scientific and in general.

**Keywords:** high speed network, EVALSO, DWDM, fiber, high performance network, high capacity network, communication system, WAN, MAN.

## 1. INTRODUCTION

The environmental conditions that allow optimal astronomical observations are often coupled with sites that are far away from human settlements and of difficult access. On top of this, a majority of then nowadays most relevant astronomic facilities operate (or will be installed) in the Southern Hemisphere, namely in the northern region of Chile, whilst the scientific user communities are distributed worldwide, mostly in the Northern Hemisphere.

Remote places usually imply lack of or at least limited infrastructure availability and, among these, communications may have very often to be built from scratch, at least for the portions needed to reach whatever structure already existing. This traditionally has been implemented using microwave bridges, with prohibitive costs, limited bandwidth, as well as some other service limitations due to harsh weather, line of sight, etc.

Section 2 provides a quick look at the state of the art of communication in Chile and towards the Northern hemisphere.

Section 3 provides five examples on how communication can transform the way research and education are done.

Section 4 provides a cross cases summary of the key aspects.

Section 5 provides links to other projects and possible future developments.

Section 6 provides the conclusions.

## 2. THE COMMUNICATION INFRASTRUCTURE AS OF 2018

Astronomy sites are often chosen to be far away from human settlements to reduce man-induced interferences, like light and radio contamination. Very often this also means that the pristine sites have limited or null communication infrastructures, though availability of networking is a key success factor for nowadays observatories.

With the availability and more affordability of optical based technologies, the astronomical scientific community, alone or joining forces with other actors, has managed in the last decade to boost the communication capability available to several of the astronomical installations in the northern Chilean region, the Atacama Desert, and to successfully increase the efficiency and effectivity of the existing Observatories and setting the basis for the coming ones.

The building blocks for the high capacity national and international academic communication are:

- the National Research and Education Networks (NREN)s, like REUNA in Chile or DFN in Germany;
- the continental networks, like GEANT[5], RedCLARA[6] (Figure 1) Internet2, each connecting the NRENs of a wide geographical area and peering with the other continental areas;
- some ad hoc development target to improve connectivity between two areas, like the Ampath/AmLight[7] (Figure 2) initiative between the Americas.

Figure 1- RedCLARA

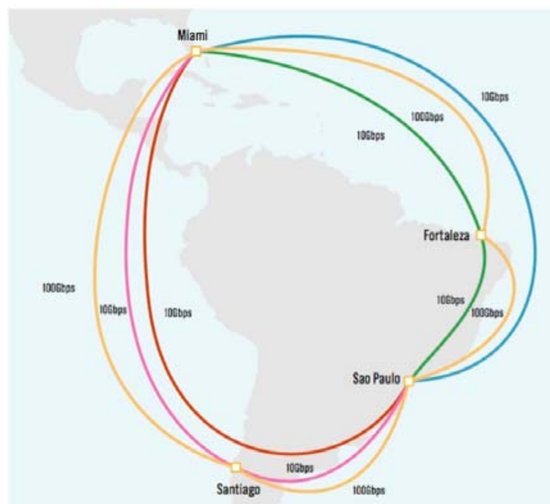

Figure 2- AmLight/AmPath

To cover the “last mile”, actually in many case the last 100ths miles, projects targeted to connect the Observatories to the national gateway are needed. To this last category belong:

- (Figure 3) the EVALSO-FP7 initiative [8][9] (started in 2007 and completed in 2011) that delivered the first Gbps capable backbone between the ESO and OCA Observatories to Santiago, providing also to strengthening REUNA capability to serve other Observatories, like Cerro Tololo and Las Campanas;

- (Figure 4) the extension of the network to the ALMA installation[10] (started in 2012 and completed in 2015) to provide Gbps links to ALMA installations at the Chajnantor plateau and, potentially, to other Observatories in the area;

- (Figure 5) the replacement of the Santiago to la Serena segment with dark fiber based infrastructure capable of multiple 100 Gbps channels (started in 2016 and completed in 2018) as part of the REUNA-AURA agreement for the LSST[11].

The main common element is that all projects have been done in strong collaboration with REUNA, the Chilean NREN, that is currently operating them in an effective synergy with the Observatories and other actors.

Figure 3 - 2011: EVALSO

Figure 4 - 2014: ALMA link was added

Figure 5 - 2018 dark fiber to LSST

The current REUNA backbone in the Northern part of Chile up to the Atacama area is therefore the result of the implementation year after year the various contributions: EVALSO for the Santiago Antofagasta 10Gbps, plus the dark fiber to Paranal area; ALMA for the extension to ALMA; the dark fiber between Santiago and La Serena.

## 3. CASE STUDIES

The experiences reported below are from users that differ in size and aims, in targeted served communities and in geographical locations. Among the several one-of a-kind or day-to-day events, the following have been selected and are discussed in the following subsections:

- the observation of the First Light from Gravitational Wave Source (ESO, ALMA, et Al.);
- the use of virtual presence to bring the observer where things happen (ESO/PARANAL);
- remote operations for robotic installation (OCA);
- Contributing to develop the local environment (REUNA);
- provide the “muscle” for the current and future data challenge (ALMA).

### 3.1 The observation of the First Light from Gravitational Wave Source (ESO, ALMA, et Al.);

The GW170817 event that took place in August 2017 and was publicly reported on October 25th by many organizations in the world (see [12] as one example), is an incredible achievement made possible by the cooperation among different disciplines and Institutions, ranging from Gravitational Wave to Optical or Radio Observatories, from small wide field to giant telescopes units.

From the initial detection, thanks to LIGO–Virgo observatory in the Northern hemisphere, that positioned the source within a large region of the southern sky, the ball passed to the optical and radio telescopes in the Southern Hemisphere, and more precisely in Chile due to the night time. Data and information had to be exchanged rapidly from the initial detection to the observing units and back to the scientists trying to understand what was going on, being the first time, such a complex situation and evidences had been offered to their attention. Among the Chilean Observatory (Figure 6) that participate at the investigation one can mention telescopes at the ESO Paranal Observatory and ESO’s La Silla Observatory, at the Las Campanas Observatory, at Las Cumbres Observatory, at the Cerro Tololo Inter-American Observatory, and the Atacama Large Millimeter/submillimeter Array (ALMA). As night marched west across the globe, the Hawaiian island telescopes Pan-STARRS and Subaru also picked it up and watched it evolve rapidly, now from the Northern Hemisphere.

Although the overall data transfer may have not been a challenge for the backbone capacity, being able to access a reliable and performant network was paramount for the coordination of the observing teams both at the Observatories and at the home institutes by using collaborative tools like videoconferences, remote access, etc.


Figure 6 - Nearly all unit in Chile shared the same communication infrastructure, built years before without knowing – but having aimed to serve – such an unexpected opportunity.

### 3.2 The use of virtual presence to bring the observer where things happen (ESO/PARANAL)

The use of virtual presence allows to bring the observer and the engineers where things happen without the time and money cost of a long trip. The possibilities of virtual presence were explored as part of the EVALSO activities [13][14][15] and now they are reality.

As part of the internal reorganization of the scientific operations [16], since 2014 ESO is experiencing the use of remote operation of some of the facilities of the Paranal Observatory from the ESO Vitacura offices (Chile) and more recently from the ESO Headquarter in Garching, Germany. The Remote Access Facility (RAF) in Chile and its clone the Garching Remote Access Facility (G-RAF), are an IT installation located in both ESO offices in Vitacura (Chile) and in Garching (Germany) that allows staff to remotely connect to the instrument workstations located in the VLT Control Building in Paranal (Figure 7). This introduces a high degree of flexibility, as engineers and scientists do not need any more to be scheduled together on the mountain to work on operational projects.

Figure 7: the pictures show the duplication of the main displays (instrument workstation, observing and data management consoles) to the Remote Access Facility (RAF): in ESO-Santiago premises allowing collaborative work between staff located at Paranal and colleagues in Santiago.

Its purpose is to facilitate having astronomers and engineers in all ESO locations, namely Paranal, Vitacura, and Garching, working together without strictly requiring to be physically on the mountain, for activities like:

- emergency support when the required expertise (e.g. Instrument Scientist, or another instrument expert) is located in Santiago

- support of planned activities, in complement of the mountain-team already involved in carrying out commissioning tasks or technical tests
- training of Science Operations (SciOps) staff
- exceptional support of science observations of high complexity, when the instrument expert is in Santiago.

For the moment, it is not intended for routine operations, nor for the support of visiting astronomers. For the latter, the POEM system is provided (described further in the section).

A second improvement that was made possible by the availability of robust communication backbone between the Paranal Observatory and the supporting offices in Vitacura, Santiago de Chile, was the possibility to relocate the Data Handling Activities from the mountain to the city offices. Beyond the obvious life quality improvement for the operators, this represents a significative saving in terms of trips and board and lodging costs.

Last but not least, in addition to the well-known visiting mode (the astronomer is physically present at the telescope console) and service mode (the observation is executed by a local crew according to a program set by the astronomer several months before), since 2017, ESO offers the "Paranal Observatory Eavesdropping Mode" (POEM) for observers in designated visitor mode. Here, the observer can attend from his/her own location the ongoing activities thanks to the available communication infrastructure that allows the virtual presence in the control room from the chair of the home institute. Not to be confused with remote operation, where the facility is totally controlled from another – normally far away - location, an option that for a complex installation, like the VLT, is not for the moment a realistic scenario. Virtual presence is the possibility to enable a remote user to participate and interact with the activity that it is taking place in a remote location with a high level of comfort and efficacy, leading to a user experience very close to the real presence at the place where the action takes place.

In the new scenario, one or more of the astronomer that are forming the team that designed the observation, from their home or institute locations may actively participate and interact with the crew that is performing the observation in the ESO Paranal observatory, at the top of a 2600m high mountain in Chile, thousands of km away from where they are sitting, with no accumulated jet lag and no physical stress else than, may be, a little bit of missing sleep due to the time difference and the night nature of the optical observation.

The experimentation went through various steps, from basic eavesdropping to more improved interaction using video and voice system as well as replication of screens, and open to the community in 2017. The successful deployment of the POEM system allowed:

- Improved observing experience
- Less error and confusion
- Better real-time feedback
- Less noise in the control room
- reduces the need for the operator to make decisions for the Visiting Astronomer (VA).
- Training possibility (e.g. student VA + experienced remote supervisor)
- Observers from multiple sites
- Quick look and feedback by colleagues off site
- Target of Opportunities user input
- No restriction to number of people observing (e.g. commissioning)
- Develop future capabilities (E-ELT).

Further considerations to promote the use of eavesdropping are:

- People are now more concerned for the environmental impact of travelling to the Observatory (fuel for the trip and to sustain the presence at the Observatory);
- There is a limitation to the number of people that can physically sit at the console (for practical reason, today only one Visitor Astronomer is allowed per experiment);
- It allows to send younger team members to the mountain and obtain remote support from senior staff at home institutes;
- by allowing remote attendance, an observation can become part of dissemination events, like presentation, conferences, etc., opening the "science sanctuary" to normal people allowing them to participate to the knowledge journey);

- lowers the accessibility barriers including individuals that would not be in the condition of attending physically either because of the economic cost, like travel, lodging, etc., as well as body fitness to face harsh conditions, as altitude, long travel time, etc.

### 3.3 Remote operations for robotic installation (OCA)

Not all experiments have the size and the resources to support local crews and hefty installations. Good communication availability becomes the enabler to access and operate from the home institute the observation facilities in remote locations. For instance, this is the case of the “Observatorio de Cerro Armazones” (OCA), a joint effort between the Ruhr University Bochum (RUB) and the Catholic University of the North (UCN). In addition to allow a more sustainable operation of the existing facilities, improving the accessibility as consequence of better communications allowed also to open them to more users, like students and teachers. To fly a class 15.000km away to attend an observation session does not seem feasible, but it can become a customary practice when it happens “by network”.

Long before ESO selected Cerro Armazones as the site for the E-ELT, UCN developed a small observatory on a side hill of Cerro Armazones. OCA started in 2006 with the installation of the famous 1.5 m Hexapod Telescope and was continuously complemented by five smaller instruments with apertures between 15 and 80 cm.

The scientific purpose of the observatory is to study the time domain of astrophysical objects which requires the performance of long-term observations that usually are difficult to host at large international observatories. Simultaneously there was the educational aspect to train young astronomers at various telescopes and instruments to prepare them for applying and conducting astrophysical projects at large observatories.

The limited funds of a university institute allowed travelling from Europe to Chile and lodging at the site only on a limited scale. This is why only two dormitories could be built and students/observers had to stay on the mountain typically for one month to ensure a continuous operation. Furthermore, observing during the night and various technical duties during the day did not allow an immediate data reduction/inspection on site but had to await the return of the observers to Europe who carried their data on hard disks.

Very soon, the bottle neck of OCA became obvious: On one side there were six telescopes at a fantastic site which produced tons of data – on the other side there was the old-fashioned data transfer by hand. Almost equally bad was the radio transmitter connection of the personnel at site with the outside world. Fortunately, there was never a medical emergency but also technical repairs which required advice from “outside” took forever. A fiber connection was the only solution to make OCA to a well-functioning astronomical observatory but unfortunately this was way out of the capabilities of both universities.

In 2011 EVALSO changed the situation drastically. The 1 GB/sec fiber that connects since then OCA with the Chilean internet allows the robotic operation of all telescopes with the exception of the Hexapod Telescope. Observing scripts for each night and each telescope are prepared on a daily basis in Bochum and loaded up to the servers at OCA. Master and PhD students are trained in Bochum to organize the observations and to supervise individual projects during the Chilean night. The data secured during the night are transmitted to Bochum after Chilean sunrise. There they are pipeline reduced and stored in the archive. Collaborators in Hawaii and Poland can access their data a couple of hours after their observation, check their quality and plan subsequent observations for the coming night.

From the technical point of view, maintenance of the control software of the telescopes and software updates are done in real time. IT specialists who developed particular control software for both telescopes and instruments log in from their companies in Germany or in the U.S. and fix bugs. The fast data connection allows continuous visual inspection of all telescopes and the remaining infrastructure via web cams. Eventually the complicated energy management of solar panels, wind turbines, batteries, and back-up generator is only possible via real time control and emergency alarms.

The fast fiber connection provided by EVALSO has turned OCA into a modern, well-functioning observatory which operates with high efficiency. Although there are still two observers at site – e.g. for the production of liquid nitrogen and cooling the infrared camera – all telescopes and technical systems are securely controlled in collaboration with remote – often robotic – support from Bochum. The financial advantages are tremendous; everyday life at the observatory has become convenient due to frequent official and private video chats. Students, who usually did practical telescope training in Germany, and wasted most of their nights by waiting for clear skies, now use the telescopes at OCA during the morning hours in Bochum.

The pleasant infrastructure of OCA has attracted other scientific institutes: Currently the Leibniz-Institute for Astrophysics, Potsdam, is installing a 30cm telescope to support the PLATO mission. The Nicolaus Copernicus Astronomical Center, Warsaw, is planning to install further telescopes for their Cepheid project.

Since OCA is located on ESO terrain the telescopes have turned into national telescopes under the rules of ESO. As a consequence, OCA will soon be connected to the electrical grid of ESO. If it can be arranged that also the liquid nitrogen will be delivered by ESO, OCA could be operated completely from Bochum or any other place in remote control.

### 3.4 Contributing to develop the local environment (REUNA)

Scientific facilities are definitely better perceived by the local communities than mining installations as being less intrusive interventions. Unfortunately, they might still be seen as distant, being installed because the conditions are more favorable than other places, but without perceivable direct gain for the local community. The implementation of communications backbones in close cooperation with the local NREN and other entities has allowed to strengthen and extend the local infrastructure used for purposes other than purely shoveling astronomical data. After being one of the member of the EVALSO project, REUNA, the Chilean NREN, counted with a high standard communication system to be made available and offered to the local academic entities.

The Chilean network for research and education REUNA (Figure 8), with a current extension of 3000Km, of which 50% during 2018 will be based on a pair of fiber with multiple channels of 100G and 10G, the other 50% is based on leased capacity from 10G to 1G (will be upgraded in the next 2 to 3 years).

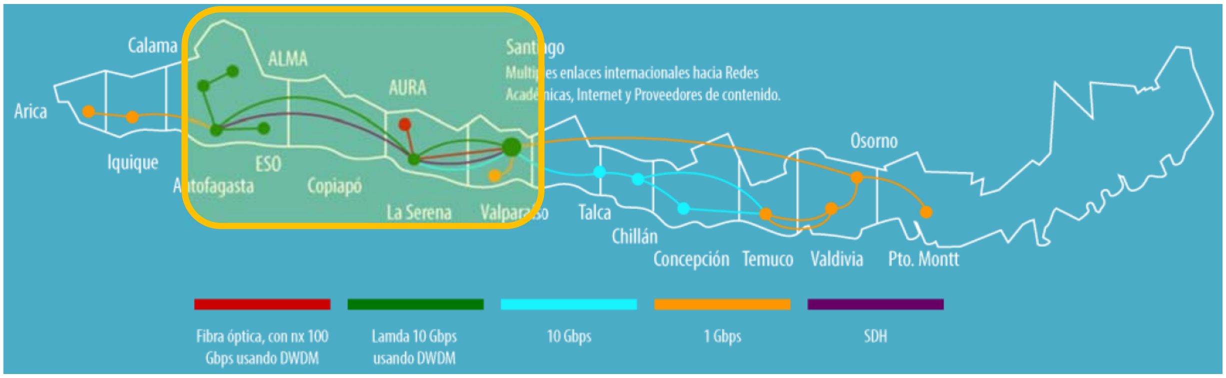


Figure 8 - REUNA overall infrastructure and the contribution coming directly from astronomy related development

This backbone will transport by 2020 mostly the 70% of astronomical data generated in the world, huge observatory locations located in Chile are and will transporting its data from Chile to its home institutions by REUNA backbone, one of this is the LSST observatory[17] that will need to transport 30TBytes each night from Chile to USA, this volume includes the transient alerts consisting of 12.7GB every 7 seconds, twice per minute each night. Current experiments have allowed to transfer in the order of 50Gbps from summit to abroad (limited by server Hardware), one dedicated channel of 100Gbps is being used by REUNA backbone.

A few examples of the benefit for the (non-astronomical) end users using this infrastructure dedicated for research and education, are:

- To be able to integrate research infrastructure resources from Chile to collaborative international projects, one of them is ATLAS in which USM (Santa Maria University in Valparaiso) was the first Tier2 site in Latin America to collaborate with ATLAS project due to the availability of the research network.[18]
- To make more efficient the process and services the Universities bring to the users: with a high capacity backbone is possible to extend the connectivity from the content providers to the Institutions, this is the case of the connectivity that REUNA has stablished in Santiago with Google, Facebook, Microsoft, with a positive impact of using national network capacity instead of the expensive international capacity.[19]
- REUNA network infrastructure based on owned fiber, allow to extend the same conditions of connectivity to all the institutions, not only for the ones in the capital city, this will allow to extend high capacity channels (10G)

to each institution along the 1500Km of the network during 2018, nowadays is economically forbidden to count with this capacity by a traditional telco infrastructure.

### 3.5 provide the “muscle” for the current and future data challenge (ALMA)

It is not a secret that some of the last generation facilities are incredible data producers and could be seen as just another digital industry. ALMA, currently largest operating radio facility, and the projected CTA are good examples. In general, being able to transfer the scientific data gathered on premises to the end communities is essential and communication infrastructure the key enabler to successfully achieve this goal. In addition, remote access and possibility to relocate to easier areas expensive operations may also be relevant.

**Scientific Archive**

In the case of ALMA, the availability of the new link is key to be able to cope with the current needs to transfer the data[20] originated in the ALMA installation in the Andes to the Santiago office and from there to the ALMA Regional Centers (ARCs) (Figure 9). For this, both the Chilean national infrastructure as well as the intercontinental ones are relevant. ALMA is now observing its fifth observation cycle. Its archive size is 597TB. It is currently projected to grow at 400TB of usable space per year with 500.000 new files per observation cycle in average. New correlator upgrades in the future could increase the amount of data by a factor of 8 by 2022.

A last aspect to be mentioned is that, with the growing interest of using cloud based services, an efficient communication is essential to be able to transfer the data to such provider that surely will not be located where the Observatories are.

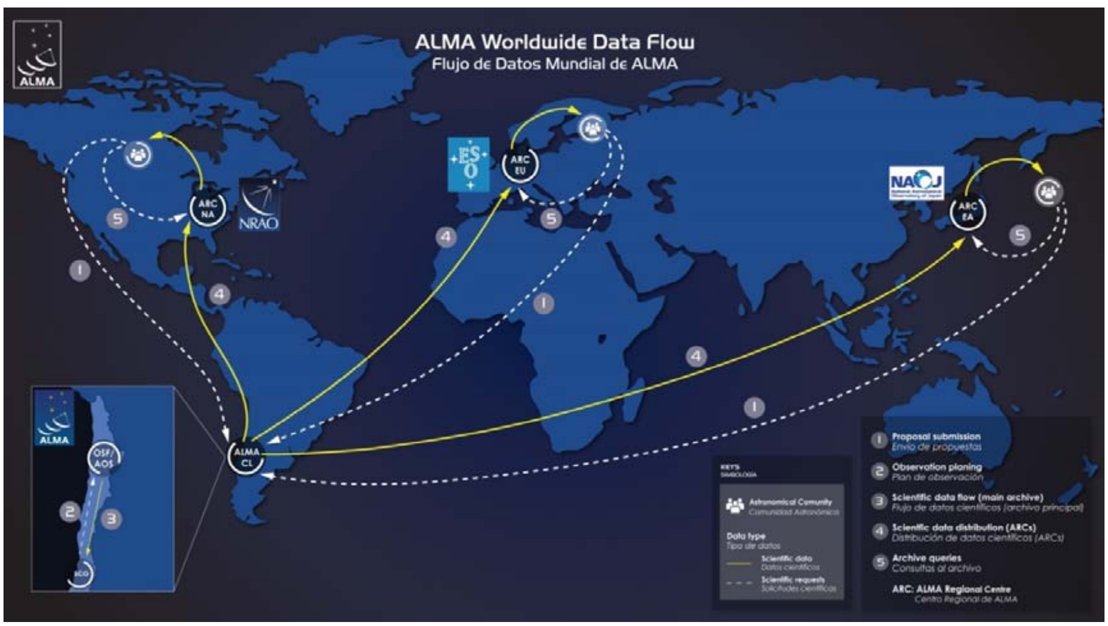


Figure 9 Data replication to the EA, EU, NA ARCs

The graph in Figure 10 show a daily usage profile fo rthe two 1Gbps links providing connection between the ALMA observation installation in the Andes an dthe Santiago Central Office, a 1400km away. As one can see, the links, that are configured as balance links, i.e., the load is shared between the two, are often reaching the maximum capacity of the links. In average the bundled traffic is on the order of 200 to 300Mbps over the 24h. Without links with such capacity, ALMA would not be able to carry the data it is producing.


Figure 10 – an example of daily usage of the two 1Gbps links connecting ALMA Observatory to Santiago Central Office

**Remote Operations**

Another area where the availability of high bandwidth and low and constant latency could be an asset is the remote operations of the Observatory. Already now the control room is at 30km (at OSF) from the antennas installation (AOS). A good link would allow bringing this activity to SCO, 1200km away, still with comparable performances, but lower costs and better comfort for the operators.

This option was originally explored and reported in [21][22] and will be further investigated in the coming years.

**Relocation of computing facilities**

In addition to the obvious increase of the data transfer capability, the availability of the new link allows also the Data Archive team to consider replacing the current dual node scheme with a single database in SCO, with the obvious savings in terms of hardware and operational costs, especially when one is thinking that the data volume will increase in the future. Also, latency, that for this type of applications plays a pivotal role, shall be compatible with the application requirements.

Several experiments have been carried out[22], but unfortunately the current technology does not allow yet to take full advantage of the communication capability. Nevertheless, with improvements in the data base technology it cannot be excluded that in the future it will be possible to relocate some of the equipment and activities that are currently at the ALMA observatory OSF facility, 1400km northern of Santiago.

# 4. COMMON KEY ASPECTS

The use cases in the previous section all indicate that improved communication has been paramount to achieve better and, in some case, new astonishing results, both in terms of science and as well as enriching the communities, both scientific and in general.

These examples illustrated:

- how communication may transform, or limit, the research and education.
- that systems have to cope with the obvious current needs, but built thinking to the future challenges and to be always a step ahead.
- the need for sustainability in terms of investment and operational costs and technical capability to reach remote corners where scientific facilities have to be located to take advantage of the unique environmental conditions.
- the advantages in connecting seamlessly communities in different places and with different focus, like astronomers, engineers, students, so that each can get the best out of the overall system, without limits imposed by location, travel means, conditions, etc.
- that made extremely large amounts of data fast available from remote places to communities scattered in the whole world becomes the rule and not the exception.

- That no matter if is a day-to-day activity or a once in a time event, communication is key to get the best out of the global investment humankind has done and will do, both as facilities as well as knowledgeable people, spread all over the globe.

## 5. A LOOK INTO THE FUTURE

At national level, REUNA in the frame of its infrastructure strategy plan is looking to extend the national backbone beyond La Serena in terms of dark fiber and to add redundant paths, where possible. The availability of dark fibers will allow to operate multiple 100Gbps lambdas. For that the cooperation with both ESO and ALMA are key elements for this effort. Also to be noticed that the current EVALSO infrastructure will come to its end in 2020, pushing both ESO and ALMA to look for a following solution, as they are both currently heavily relying on the links that are provided by EVALSO.

At international level, there are plans to improve and extend all the existing infrastructure (see section 2). In addition, a new player, the BELLA initiative (Figure 11) will provide a new direct link between Europe and Latin America and among Latin American countries.

The BELLA (Building the Europe link to Latin America) is supported by the European Commission and includes:

- The BELLA-S that is the participation in the construction of a new submarine fiber-optic cable between Europe and Latin America, linking Lisbon (Portugal) with Fortaleza (Brazil).
- The BELLA-T: a dark fiber based connection of Latin America countries from Colombia to Brazil, and hopefully, in the future, closing it as a ring.

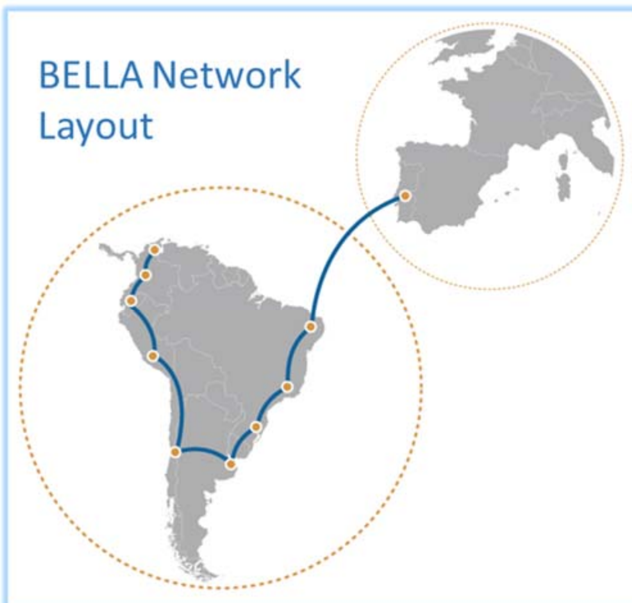


Figure 11 - BELLA

This initiative aims to "boost education, research and innovation as well as business exchanges. It will reduce connection costs and provide many more households, organizations and companies with a high-speed Internet connection"[23].

As REUNA is a member of the BELLA Consortium, the Chilean part of the BELLA-T is organically part of the future REUNA expansion, and will be the REUNA backbone for the coming decade. The projected result of the completed and planned projects is shown in Figure 12.

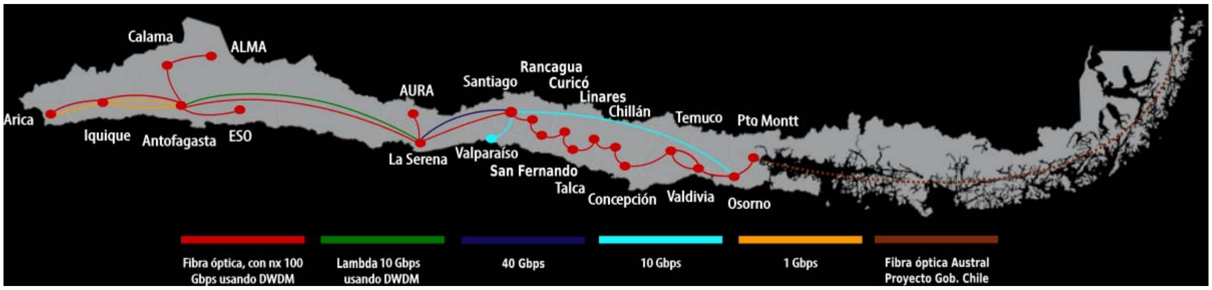


Figure 12 – 2020 projected REUNA infrastructure

Considering (see Figure 13):

- The current existing installations;
- The under construction big projects, like LSST, GMT, ELT, CTA-South;
- The smaller, but not for that less communication hungry, smaller projects, like SIMONS Observatory, CCAT, TAO,
- The upgrade and extension of existing installations like Las Campanas and La Silla, where remote operable facilities are becoming increasingly common;

It is not unrealistic to predict that the future backbone will transport by 2030 more than 70% of astronomical data generated in the world.


Figure 13 – Current and projected astronomy sites in the Northern Region of Chile.

## 6. CONCLUSIONS

High-bandwidth communication is a key factor for scientific installations as Observatories. Beyond purely increasing the bandwidth and lowering latency, boosting performances of applications directly making use of these two parameters, the new system is also an enabler for potential processes transformations that could deliver further advantages.

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