Union Radio-Scientifique Internationale — International Union of Radio Science

Monthly Newsletter of International URSI Commission J – Radio Astronomy

January 2020

Officers

Chair: Richard Bradley
Vice-Chair: Douglas Bock

ECRs: Stefan Wijnholds
Jacki Gilmore

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News Items - Greetings from the Chair!

- **PAPER SUBMISSION FOR THE 2020 URSI GASS IS NOW OPEN!!** Present your work at the Scientific Symposium! Our Commission J program is listed in the Newsletter. URSI GASS details may be found at https://www.ursi2020.org/

The abstract / paper submission deadline is January 31, 2020!

- **Nominations for Commission J Vice-Chair and Early Career Representative (ECR) is open.** An official invitation mailing was distributed last month that provided additional information and a nomination form. I will resend these materials again this month. **Nominations must be received by me no later than March 1, 2020.**

- Our Activities Spotlight this month is on the Atacama Large Millimeter/submillimeter Array (ALMA). John Carpenter (Joint ALMA Observatory), Daisuke Iono (National Astronomical Observatory of Japan), Francisca Kemper (European Southern Observatory), and Al Wootten (National Radio Astronomy Observatory) give us a comprehensive look of the ALMA development program that is planned for the next decade. I want to thank John and his colleagues for this wonderful contribution to our Newsletter.

- Looking for a past issue of the "J" Newsletter? The Newsletters and other URSI Commission J documents are archived at http://www.ursi.org/commission.php?id=J#tab-section4 .

2020 URSI General Assembly and Scientific Symposium (2020 URSI GASS)

Rome, Italy 29 August - 5 September 2020

***** Program for Commission J – GASS 2020 *****

General Sessions

J01: New Telescopes on the Frontier

Conveners: Nipanjana Patra, Jeff Wagg, Arnold van Ardenne, Pietro Bolli

We have entered a golden age for radio astronomy, with new facilities coming online around the globe. During the next several years, these telescopes will pave the way for the two SKA1 telescopes to be built in Western Australia and South Africa. Collectively, they work at the frontier of technology and science. This session will highlight new and upgraded cm-to-m wavelength interferometers that will be operating before SKA1 early science begins.

J02: Recent and Future Space Missions

Conveners: Joseph Lazio, Heino Falcke, Yuri Kovalev

Space missions have enhanced VLBI capabilities and are close to opening up the radio window below 30 MHz by (swarms of) small satellites in space. These developments are facilitated by the advent of the standard CubeSat platform, which reduces mission costs significantly.

J03: Single Dish Instruments

Conveners: Alex Kraus, Anish Roshi, Jin Chengjin

Even in the age of interferometers, single-dish telescopes are important instruments for radio astronomical research, either for the detection of diffuse emission (sometimes in combination with interferometers to provide "zero spacings"), for observing pulsars or monitoring variability of flux density or line emission. New technology like Phased-Array-Feeds may greatly enhance the ability and efficiency of single-dish telescopes, e.g. by providing a FoV an order of magnitude larger than with conventional receivers. This session should be dedicated to the discussion of new or planned single-dish telescopes as well as to their instrumentation.

J04: Very Long Baseline Interferometry

Conveners: Francisco Colomer, Taehyun Jung, Chris Jacobs, Tiziana Venturi

Very Long Baseline radio Interferometry (VLBI) is a mature technique, whose applications in astronomy, geodesy and planetary sciences are unique now that the need for milliarcsecond angular resolution and for extremely accurate localisation are the ultimate frontiers for some of the hottest scientific areas. For this reason, VLBI is in the heart of some of the most advanced present and future instruments and developments (EHT, ngVLA, SKA, VGOS). This session will bring together experts in each field of application, to provide a view of the state-of-the-art and the desired developments, and to assess the central relevance of VLBI in the continuously evolving landscape of astrophysics, Earth and planetary sciences.

J05: Millimeter/Submillimeter Arrays

Conveners: Sheng-Cai Shi, Raymond Blundell

This session will focus on results and developments in (sub-)millimeter instrumentation covering the following broad areas:

- Current performance and future capabilities of major interferometric arrays. A few science results should be included that demonstrate performance.
- Design and/or development of heterodyne instrumentation for radio telescopes, both interferometric arrays and single-dish. A summary of the scientific rationale for any developments should be included.

J06: Antennas and Receivers: Simulation, Design and Calibration

Convener: Jacki Gilmore, Douglas Hayman, Pietro Bolli, David Davidson

In this session we address the antenna and receiver technologies which enable new radio telescopes. We focus on the importance of practical calibration for detailed system design, including how advances in simulation enable the new calibration strategies needed for all-sky instruments. We also highlight advances in single components of the receiving chain such as low noise amplifiers.

J07: Digital Signal Processing: Algorithms and Platforms

Conveners: Grant Hampson, Albert-Jan Boonstra

Beam forming, spectral filtering, online RFI mitigation, FPGAs and otther hardware platforms

J08: Short-Duration Transients, FRBs, and Pulsars: Observations, Techniques, and Instrumentation

Conveners: Jason Hessels

Gravity wave detections, coordination in transient events, FRBs, pulsars

J09: The Impact of Radio Astronomy on Technology and Society

Conveners: Richard Schilizzi, Leonid Gurvits, Ken Kellermann, Richard Wielebinski

This session is being organized by the URSI-IAU WG on Historical Radio Astronomy and will comprise invited talks and contributed posters that focus on a number of the developments and inventions in the history of radio astronomy that have directly or indirectly impacted society. The invited talks will cover The story of Wi-Fi; VLBI, navigation and geodesy; Radio interferometry and medical imaging; Cold-war diplomacy and related activities at Jodrell Bank Observatory; Deep space navigation; and Parkes and Apollo 11. Posters are welcomed on these topics as well as others that fit within the subject of the session.

The invited talks and speakers are:

1) The Story of Wi-Fi - David Skellern (RoZetta Institute, Sydney)

2) VLBI, Navigation, and Geodesy - Megan Johnson (USNO)

3) Cold-war diplomacy at the Jodrell Bank Observatory – Simon Garrington and Tim O’Brien (JBCA)

4) Radio Interferometry and Medical Imaging – Ilana Feain (CASS)
5) Deep Space Navigation – Les Deutsch (JPL)
6) Parkes and Apollo 11 - Jasper Wall (UBC)

J10: Latest News and Observatory Reports

Conveners: Rich Bradley, Douglas Bock

This session will retain the traditional reports from the observatories. In addition, it will include a section for the latest news / results - allowing for very brief, last minute presentations.

J11: Big data: Algorithms and Platforms

Conveners: Stefan Wijnholds, Maxim Voronkov, Urvashi Rau

Given the ever increasing data volumes produced by current and future radio interferometers (LOFAR, ASKAP, SKA, ngVLA, …), radio astronomy has entered the Big Data era. New data processing methods need to be developed that effectively exploit the capabilities of new hardware technologies to keep up with the deluge of data. This session aims to provide a forum to present and discuss the (co-)development of algorithms and computing platforms to deal with the Big Data challenges posed by current and future radio astronomical instruments. It intends to cover a broad range of astronomical applications, including (but not limited to):

- calibration and imaging algorithms at scale (designing scalability into the algorithms, adapting existing algorithms to new frameworks, etc..);
- real-time analysis for transient science, pulsars, RFI excision, SETI (voltage streams and in-correlator, handling algorithms at high data rates);
- pipeline operations, algorithm automation and HTC (the concept of science-ready-data-products and what it takes);
- software paradigms and compute frameworks (optimized code on dedicated hardware versus generic high level code and cloud platforms)

Workshops and Shared Sessions

<u>Workshop</u>: Characterization and Mitigation of Radio Frequency Interference (Commissions JEFGH)

Conveners: Amit K. Mishra (F), David M. Levine (F), Frank Gronwald (E), Richard Bradley (J)

Radio Frequency Interference (RFI) has become a critical issue for many users of the electromagnetic spectrum. This is especially true for observational sciences such as radio astronomy, microwave remote sensing of the Earth, and Solar and ionospheric studies where highly sensitive measurements are necessary. The move of the observational sciences toward non-traditional (i.e. unprotected) frequencies to increase bandwidth and improve observations, only makes the problem worse. In addition, the advent of new-age telecommunication standards (like 5G and 6G) to enable new applications will make the already scarce bandwidth more scarce. This session invites papers that document and characterize RFI and describe the methodology to operate in an environment with unavoidable RFI.

<u>Workshop</u>: Some aspects of radio science in space weather (Commissions GHJ)

Conveners: Iwona Stanislawska (G), Richard Fallows (J), Patricia Doherty (G), Mauro Messerotti (H/J), Baptiste Cecconi (H/J), Vivianne Pierard (H), Janos Lichtenberger (H), Willem Baan (J)

Goal: write a “white paper” on radio science, space weather and relevant services
Format: 3 panels of experts and related open discussion towards 3 topics:

- New radio science tools for space weather
- Radio science challenges for speace weather services
- Radie science in planetary exploration

Rapporteurs will be identified in order to highlight the key aspects, gaps and pitfalls that will drive the white paper. It is intended to prepare a note on the 3 topics to be made available for the Radio Science community in advance in order to inform and get feedback useful for the best preparation of the 3 panels of experts.

J-ITU: Next Generation Radio Astronomy Science and Technologies (Joint URSI/IAU Session)

Conveners: Anthony Beasley, Carole Jackson, Gabriele Giovannini, Melissa Soriano

In this session we bring together URSI and IAU Commission B4 (radio astronomy) to explore how frontier astronomy is pushing radio astronomy technologies. This astronomy will exploit the major instruments of the next decade and beyond i.e. SKA, ALMA2030, ngVLA and many others. This session will be wide-ranging, looking to major trends in photonics, computing and multi-messenger physics, but also the raw reality of increasing billion-dollar telescopes. How will these mega-instruments keep pace, how early do they need to foresight revolutions in technologies, and how does science drive these to fruition?

Mutual benefit between radio astronomy and ionospheric science
(Commissions JG)
Conveners: Claudio Cesaroni (G), Maaijke Mevius (J)

The ionized atmosphere significantly affects radio waves propagation and this can lead to misinterpretations of data of radio astronomical observations. Astronomical science studies using radio waves acquired at ground, especially at the lowest frequencies (e.g. LOFAR/MWA, and in the future the SKA), should therefore definitely take up-to-date atmospheric parameters into account. On other hand, radio signals disturbances can be used to retrieve information about the morphology and dynamics of the ionosphere. Typically, radio astronomical observations are sensitive to small scale disturbances in the ionosphere, with scales ranging from 100s of meters to 100s of kilometers and second to minute timescales.

To pose a solid bridge between the ionospheric and radio astronomical scientific communities, this session solicits contributions to facilitate exchange of information on their respective states of the art as well as on their future needs.

Contributions are welcome from both communities:

- Scientists studying the ionosphere presenting climatology studies, small scale disturbances like TIDs and scintillation and abnormal behaviors of the ionosphere during extreme events are welcome.
- Scientists dealing with radio astronomy that need to remove or mitigate the ionospheric contribution from their measurements or that can contribute to the understanding the ionospheric physics with their studies.

Spectrum Management
(Commissions ECJ)
Conveners: Amir Zaghloul (C), Tasso Tzioumis (J), Jose Borrego (E)

Solar, Planetary, and Heliospheric Radio Emissions
(Commissions HJ)
Conveners: Patrick Galopeau (H), G. Mann (H) and H.O. Rucker (H), Pietro Zucca (J)

As the space weather workshop will consist of overview presentations and panel discussions, this session should also provide room to present results related to space weather as obtained by radio observatories around the globe. To accommodate this, I have increased the number of available slots.

The Polar Environment and Geospace
(Commissions GHJ)
Conveners: Lucilla Alfonsi (G), Nicolas Bergeot (G), Mark Cliverd (H), Stefan Lotz (H)

Activities Spotlight

The ALMA Development Program: Roadmap to 2030

John Carpenter (Joint ALMA Observatory),
Daisuke Iono (National Astronomical Observatory of Japan),
Francisca Kemper (European Southern Observatory),
and
Al Wootten (National Radio Astronomy Observatory)

1 Introduction

The Atacama Large Millimeter/submillimeter Array (ALMA) is the premier telescope for sensitive, high-resolution observations at millimeter and submillimeter wavelengths. The array consists of fifty 12-m diameter antennas that can be reconfigured to baselines as long as 16 km, twelve 7-m antennas that sample the short visibility spacings, and four 12-m antennas that provide total power capabilities for spectral line and continuum observations. Located in the Atacama desert in northern Chile at an elevation of 5000 m on the Chajnantor plateau, the ALMA site provides excellent observing conditions with low precipitable water vapor. The large number of antennas, the high-altitude site, and excellent receivers with low-noise performance provide an extremely sensitive, flexible instrument for submillimeter imaging.

The broad theme of ALMA science is to understand our cosmic origins, from the formation of galaxies to the formation of planets. Figure 1 illustrates the spectacular science return from ALMA across a breadth of fields. Galaxies have been detected at redshift as high as $z = 9.11$, which implies the onset of star formation began as early as 250 Myr after the Big Bang (Hashimoto et al., 2018). Very Long Baseline Interferometry (VLBI) with ALMA and the Event Horizon Telescope has produced the first image of a black hole (Event Horizon Telescope Collaboration et al., 2019). High resolution ALMA images are revealing the formation of young stars (see, e.g., Matsushita et al., 2019). The iconic image of the cirumstellar disk associated with the young star HL Tau revealed a nested network of concentric rings that suggest the onset of planet formation is much earlier than previously thought (ALMA Partnership et al., 2015).

In addition to providing funds for the annual operating budget, the ALMA partners[1] contribute funds for new ALMA developments. This development fund is designed to enhance ALMA as the start-of-the-art and world leading facility for millimeter/submillimeter astronomy by promoting hardware, software, and infrastructure improvements for ALMA. The development program relies on a close collaboration between ALMA and the broader community. ALMA provides high-level guidance on the overall priorities for the development program and provides funding support for innovative ideas from the community to achieve these goals.

As ALMA approaches completion of its initially envisaged capabilities, the original fundamental science goals of ALMA have essentially been demonstrated. Looking to the future, the ALMA Board tasked the ALMA Science Advisory Committee (ASAC) to recommend future developments that ALMA should consider implementing by the year 2030. A working group prioritized those

[1] ALMA is a partnership between the European Southern Observatory (ESO), the National Science Foundation (NSF) of the United States and the National Institutes of Natural Sciences (NINS) of Japan in collaboration with the Republic of Chile. ALMA is funded by ESO in representation of its member states, by NSF in collaboration with the National Research Council (NRC) of Canada and the National Science Council (NSC) of Taiwan, and by NINS in collaboration with the Academia Sinica (AS) in Taiwan, and the Korea Astronomy and Space Science Institute (KASI) of South Korea.

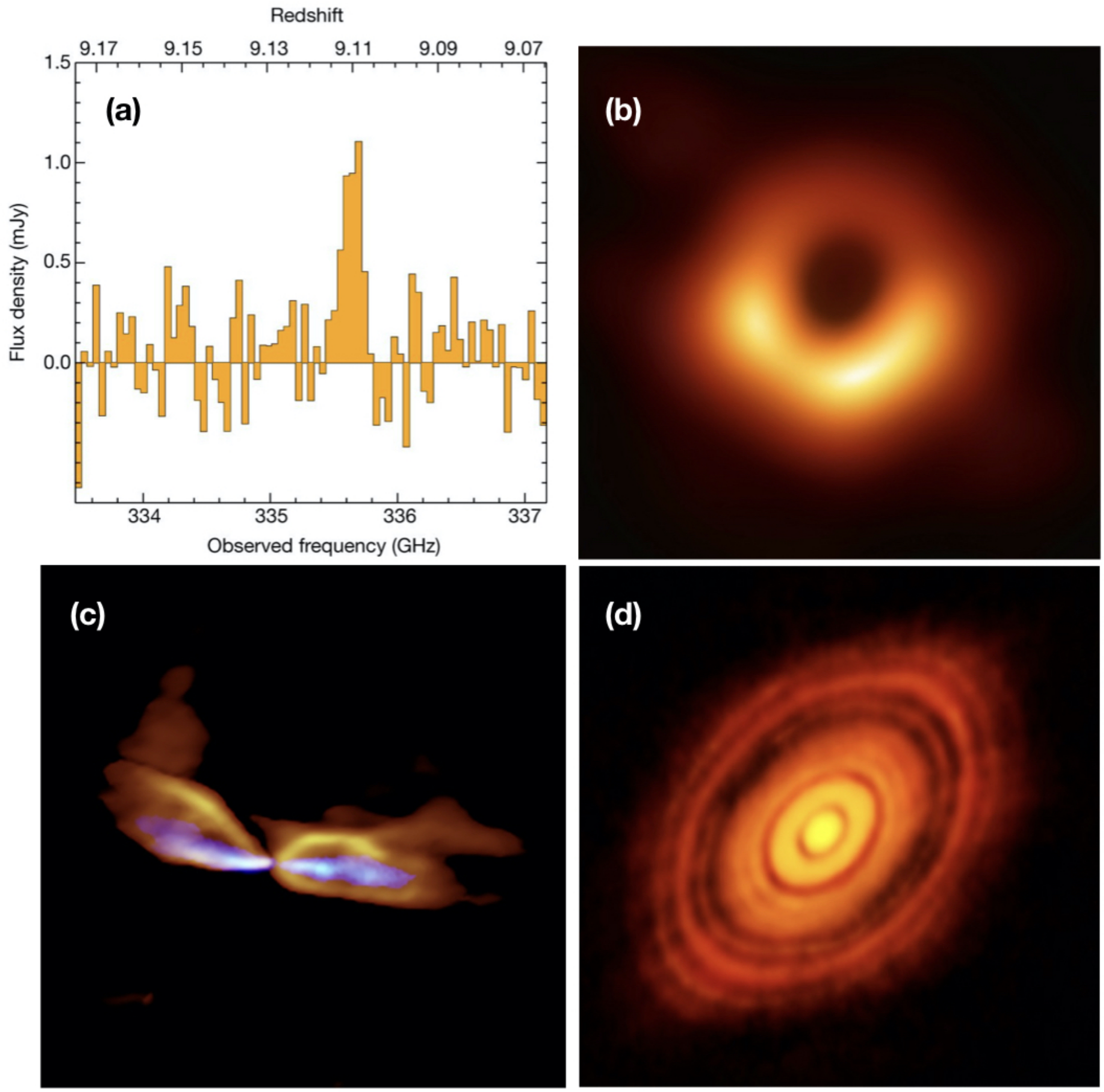

Figure 1: A small sample of ALMA observations. (a) Detection of [O III] toward a galaxy at redshift $z = 9.11$ (Hashimoto et al., 2018). (b) Image of the super massive blackhole at the center of the galaxy M87 produced by ALMA and the Event Horizon Telescope (Event Horizon Telescope Collaboration et al., 2019). (c) Images of the low velocity outflow (orange) and the high velocity jet (blue) from a protostar in Orion (Matsushita et al., 2019). (d) ALMA continuum image of the protoplanetary disk surrounding the young star HL Tau (ALMA Partnership et al., 2015).

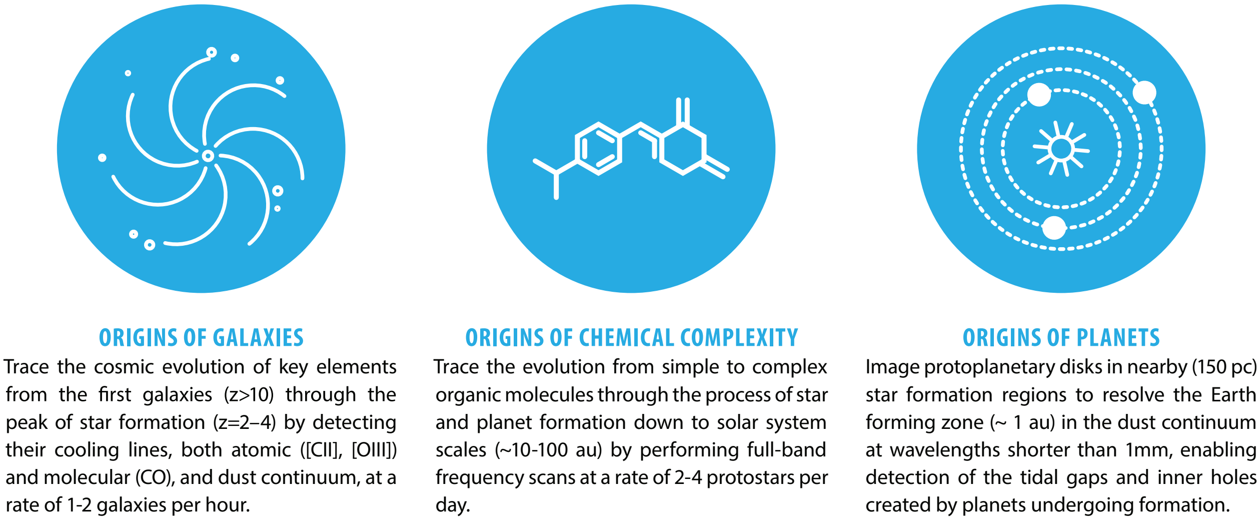

Figure 2: Science goals for the ALMA 2030 Development Roadmap.

recommendations into a strategic ALMA2030 Development Roadmap, which was endorsed by the ALMA Board in 2017 (Carpenter et al., 2019). The Roadmap identifies new science goals to motivate technical developments over the next decade under three themes: Origins of Galaxies, Origins of Chemical Complexity, and Origins of Planets (Figure 2). Achieving these science goals requires major advances in ALMA capabilities, and in particular by improving the instantaneous bandwidth of the receivers, the associated electronics, and the correlator.

In this article, we provide an overview of the ALMA development program. We begin by summarizing the organization of the regional development efforts. We then describe the current characteristics and performance of the ALMA receivers. We conclude with a summary of the ongoing progress toward achieving the Roadmap and the development workshops in the upcoming year that are being organized by ALMA.

2 Overview of the ALMA Development Program

NAOJ, ESO, and NRAO administer their respective regional contribution to the ALMA Development Program. Each executive holds development workshops to gather input from the community on future developments, release call for proposals for new development programs, oversee the selection of the proposals, and administer the selected programs.

ALMA has two categories of development programs: *studies* and *projects*. Studies are funded by and managed at the discretion of the regional executives. Studies are designed and intended to allow an initial exploration of concepts that may be of interest to ALMA development in the near or long terms. Projects are larger-scale programs that provide specific deliverables (either hardware or software) to ALMA. Because of the unique circumstances in each region, the detailed implementation of studies and projects vary between the regions. The following subsections describes the local execution of the regional development programs and ongoing activities.

2.1 East Asia

The East Asia (EA) ALMA development program is driven by community input in the annual EA development workshop as well as the development priorities recommended by the EA ALMA Scientific Advisory Committee (EASAC) and the ASAC. NAOJ leads the development activities in EA ALMA, and collaborates with its partner institutes in Taiwan (ASIAA) and Korea (KASI). EA ALMA has organized seven development workshops since 2011, with the main aim of discussing the technical feasibility and science demands from the EA ALMA science community.

Besides collaborating with ESO on development of the Band 2 receiver (see Section 3.2), EA ALMA currently leads two development projects:

- The Band 1 receiver, which will provide frequency coverage between 35 and 50 GHz. Section 3.1 discusses the Band 1 receiver development.
- The Atacama Compact Array (ACA) spectrometer for the Total Power Array. The ACA spectrometer development is a project led by KASI in collaboration with NAOJ. This new GPU based spectrometer improves the linearity, dynamic range and spectral response over the existing ACA correlator. The proposed simple architecture and the software nature allows seamless implementation of new capabilities in the future. Science observations with the total power spectrometer are expected to begin in October 2021.

In addition to the two development projects, the EA ALMA leads four important development studies which can significantly enhance the future capabilities of ALMA. They are (1) a state-of-the-art high-Jc SIS junction studies for wide IF/RF, (2) an Artificial Calibration Source for polarization calibration, (3) a stable LO reference source for future longer baselines, and (4) a multi-beam receiver using an on-chip integrated circuit. All of the development studies are aligned with the recommendations given in the Roadmap.

2.2 Europe

ESO coordinates and funds the European development program on behalf of the ESO member states. Development studies are organized in 3-year cycles, in which roughly 5-10 studies are approved for a budget not exceeding 50 kEUR/yr per study over at most a 3-year period. The most recent call for proposals for development studies was issued at the end of May 2019 with a deadline in September 2019. In this call, proposal teams were encouraged to aim for alignment with the Roadmap. The call was accompanied by a European ALMA development workshop, held at ESO Garching from 3-5 June 2019. The workshop was open to participants from all ALMA regions, and the full breadth of the ALMA development program was discussed[2]. A list of approved European development studies is maintained online[3].

Current European development programs encompasses a small number of recently finished and on-going projects:

- The Integrated Alarm System is a software development project run by ESO that allows the ALMA telescope operators to monitor several systems at once, including weather stations and antenna status monitors. The software has been running at ALMA since late August 2019.

[2] https://www.eso.org/sci/meetings/2019/ALMADevel2019.html
[3] https://www.eso.org/sci/facilities/alma/development-studies.html

- The Band 2 receiver development is a project coordinated at ESO with contributions from institutes worldwide, including many across Europe, Japan, Chile, and the United States. Section 3.2 discusses the current status of the Band 2 receiver development.
- The Additional Representative Images for Legacy project (ARI-L) is a development project led by the Istituto Nazionale di Astrofisica (INAF) in Bologna, which also hosts the Italian ARC-node. The project formally began in June 2019. The goal is to reprocess eligible data from Cycles 2-4 with the current data reduction and imaging pipelines in order to produce quick-look images and spectral datacubes for >70% of the data. These data products will be ingested into the ALMA Science Archive to facilitate archival science. The project will also provide the pipeline-calibrated measurement sets.

2.3 North America

The North America (NA) development program is open to the NA ALMA Operations Partnership, which is defined as the community of astronomers and scientists in related fields from North American ALMA partner countries. Since 2011, thirty-nine study proposals and eleven project proposals from the NA community have been funded. Reports from these studies are available at the NRAO website[4].

A Call for Study proposals in North America is issued on a yearly basis, with the most recent call[5] issued in December 2019 for FY2021. Studies are generally funded for one year up to $250,000 USD per individual award for FY2021. Priority is currently given to those studies which align with the Roadmap. Study topics of particular interest to the NA ALMA Partnership include larger bandwidths and improved receiver sensitivity, longer baselines, increasing wide field mapping speed, phased array feeds, and improvements to the ALMA Science Archive.

An independent review panel is established with consent of the NSF to evaluate and rank the proposals. The ranked list then receives consent from NRAO and NSF and is incorporated into a recommendation to the NA ALMA Executive. The NA ALMA Executive has funding authority and responsibility for executing the NA ALMA Development Studies plan.

The active NA projects are as follows:

- Expansion of the Central Local Oscillator Article (CLOA) to Five Subarrays: This project, led by NRAO, procured and tested all the required modules and equipment to complete Photonic LO subarray five. The complete chain was installed, tested, and commissioned at the Array Operations Site (AOS) Technical Building. The completed system was integrated into the current software control system. The completion of this project is pending final test results and acceptance of the final report by ALMA.
- Band 3 Cold Cartridge Assembly (CCA) Magnet and Heater Installation for Deflux Operations: This project, led by the NRC-Herzberg Astronomy and Astrophysics Research Center (NRC-HAA), is modifying the Band 3 CCA to add a heater element in order to reduce observed azimuth-dependent total power variations. The heater solution was successfully tested at NRC-HAA and underwent verification testing by the JAO. The design has now been finalized and NRC-HAA is now building the initial heater kits for delivery in 2020. Integration into each Band 3 CCA will continue over the successive three years.

[4] https://science.nrao.edu/facilities/alma/alma-develop-old-022217/alma-develop-history
[5] https://science.nrao.edu/facilities/alma/science_sustainability/cycle8-cfs

- ALMA Phasing System Phase 2 (APP2): This project, led by MIT Haystack, will further improve VLBI capabilities and performance for ALMA. Major components include enabling spectral line VLBI, extending the frequency range of phasing to Bands 1–7, improving the calibration mechanism to allow observations on weaker sources, the introduction of a single-dish VLBI mode, and a pulsar mode. On-sky testing has been conducted during multiple VLBI campaigns at ALMA in coordination with other observatories. Passive phasing and pulsar mode will be offered in Cycle 8.

3 ALMA receivers

The ALMA front end can accommodate up to 10 receiver bands covering most of the wavelength range from 8.5 to 0.32 mm (35–950 GHz). Each band is designed to cover a tuning range which is approximately tailored to the atmospheric transmission windows. These windows and the tuning ranges are indicated in Figure 3.

The ALMA receivers in each antenna are located in a single front-end assembly. The front-end assembly consists of a large cryostat containing the receiver cold cartridge assembly for each band, including the Superconductor-Insulator-Superconductor (SIS) mixers and Local Oscillator (LO) injection, and the Intermediate Frequency (IF) and LO room-temperature electronics of each band. The cryostat is kept at a temperature of 4 K through a closed cycle cooling system. Each receiver cartridge contains two complete receiving systems sensitive to orthogonal linear polarizations. The designs of the mixers, optics, LO injection scheme, and polarization splitting vary from band to band, depending on the optimum technology available at the different frequencies.

Table 1: The ALMA receivers

Band	RF (GHz)	IF (GHz)	Mixer type
1	35–50	4–12	SSB
2	67–90	4–12	2SB
3	84–116	4–8	2SB
4	125–163	4–8	2SB
5	158–311	4–8	2SB
6	211–275	4.5–10	2SB
7	275–373	4–8	2SB
8	385–500	4–8	2SB
9	602–720	4–12	DSB
10	787–950	4–12	DSB

Table 1 summarizes the basic characteristics of the bands, include the Radio Frequency (RF) range, the IF range, and mixer type (2SB: dual sideband receiver; SSB: Single sideband; DSB: double sideband). Figure 4 shows the measured noise temperatures for the current receivers. For Bands 3–7, the receiver temperatures are approximately $4h\nu/k$ and are approaching quantum-limited performance. Detailed receiver characteristics are available in ALMA Technical Handbook available on the ALMA Science Portal[6]. The following subsections highlight the anticipated characteristics of Band 1 and Band 2, which are the next ALMA receivers to be installed.

3.1 Band 1

The Band 1 receiver covers the lowest frequency band of ALMA from 35 to 50 GHz, and it is a development project led by ASIAA in collaboration with NAOJ, NRAO, University of Chile and NRC-HAA. As described in Di Francesco et al. (2013), the range of Band 1 science is very broad, from solar studies, nearby stars, protoplanetary disks, and molecules in nearby molecular clouds to distant galaxy clusters and the re-ionization edge of the Universe.

[6] https://almascience.org/documents-and-tools/latest/alma-technical-handbook

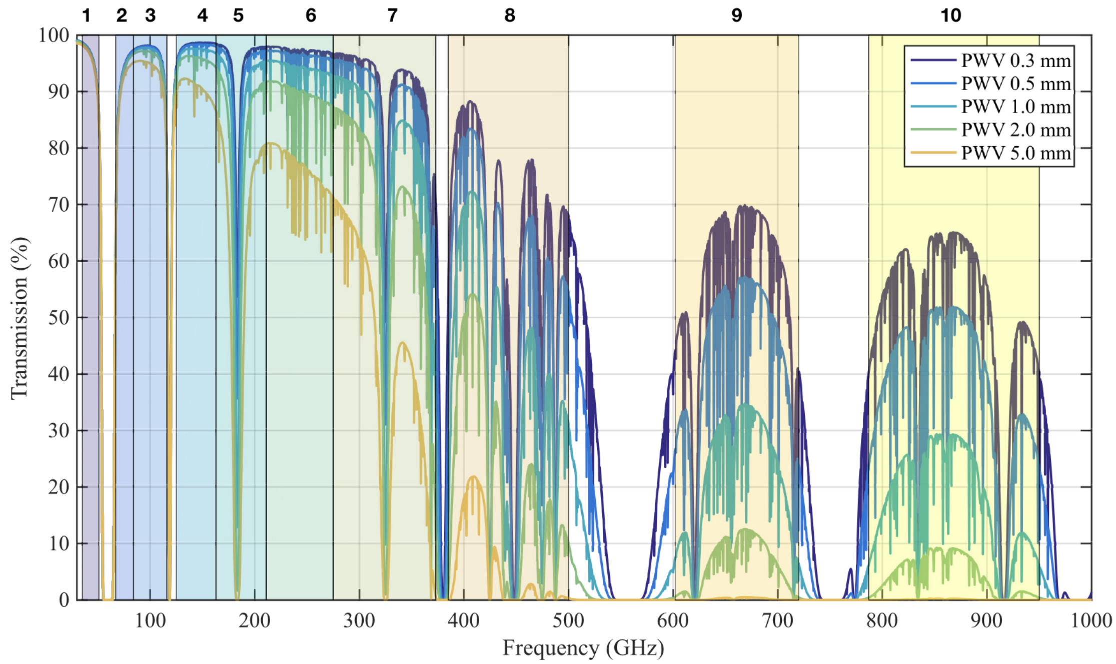

Figure 3: The ten ALMA receiver bands along with atmospheric transmission. The receiver coverage is shown shaded, superimposed on a zenith atmospheric transparency plot at the AOS for 0.3, 0.5, 1.0, 2.0 and 5.0 mm of precipitable water vapor (PWV). The ALMA band numbers are indicated at the top of the figure in bold.

One of the primary science drivers for Band 1 is to measure the grain properties in protoplanetary disks. The formation of planets require the agglomeration of dust grains into larger particles. The long wavelength observations provided by Band 1 can probe larger particles than the higher-frequency ALMA bands, and the optical depth of the continuum emission in the disk will also be reduced. By observing a diverse sample of disks in Band 1, it will be possible to explore where and when in the disk that dust agglomeration takes place. A second primary science driver for Band 1 is to identify galaxies in the epoch of reionization. By targeting known candidate high-redshift galaxies, Band 1 will measure the spectroscopic redshift, especially using the J=3-2 transition of carbon monoxide (CO), which is redshifted into the Band 1 frequency range for redshifts of $6 \lesssim z \lesssim 9$.

The technology used for Band 1 is dual-polarization, SSB heterodyne receiver covering the specified frequency range with an IF band of 4-12 GHz. Band 1 integration at the ALMA Operations Support Facility (OSF) will start in the early part of 2020, with a target completion to outfit all 66 antennas with Band 1 receivers by the end of 2022. Figure 5 shows the measured noise performance of a prototype Band 1 receiver.

3.2 Band 2

The goal of the Band 2 receiver project is to cover a RF bandwidth of 67–116 GHz, making use of the full atmospheric window that includes ALMA Band 2 (67–90 GHz) and Band 3 (84–116 GHz). Fuller et al. (2016) present the detailed science case for Band 2. A key science driver is to measure

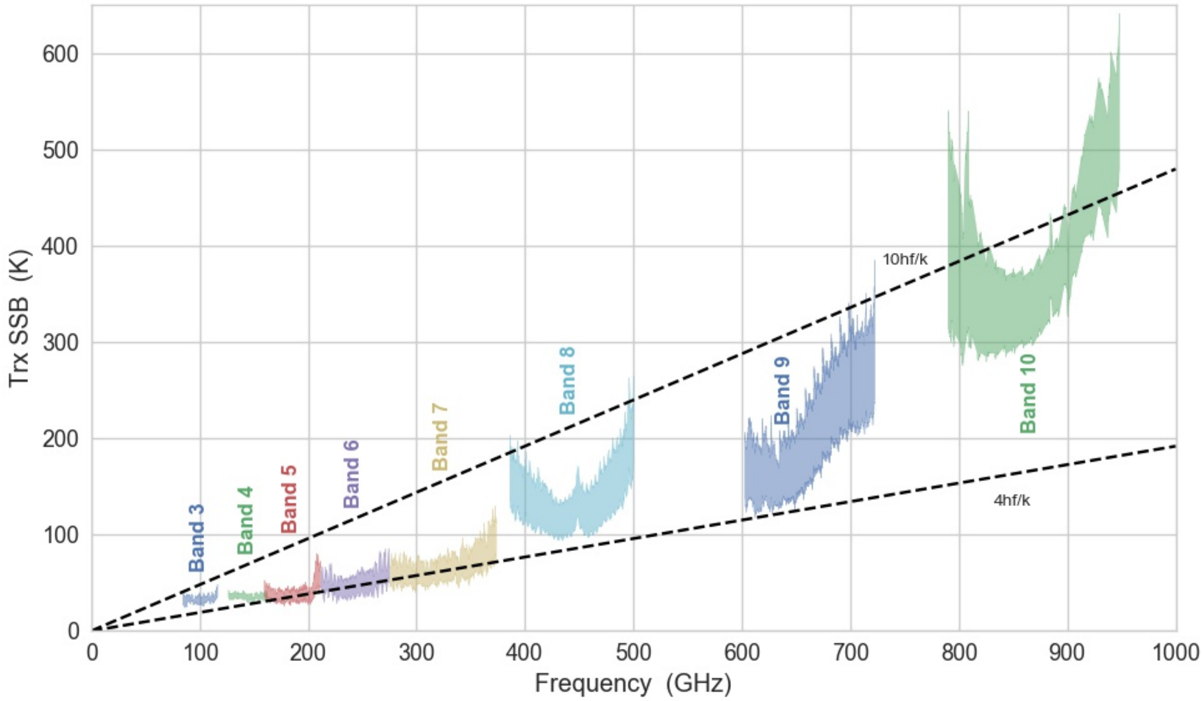

Figure 4: Receiver noise temperature for ALMA receivers Band 3-10. The shaded region encompasses 75% of the receivers about the median receiver temperature. The noise temperature shown for Band 9 and 10 are twice the DSB temperatures. Figure from Carpenter et al. (2019).

the properties of cold, dense, quiescent gas in molecular clouds. The dense regions are the precursors to stars and their properties provide crucial tests of star formation theories. A number of important deuterated molecules emit in the Band 2 region and are key tracers of the physical conditions and dynamics of the cold, dense gas. Another key science driver is to study the redshifted emission from galaxies in CO and other species around a redshift of $1 \lesssim z \lesssim 3$, which corresponds to the peak of the star formation rate density in the universe. Band 2 makes it possible to observe CO both for redshift determination and to measure the mass of cool molecular gas. Band 2 observations will also measure the evolution of the dense gas (via the tracers HCN, HNC and HCO^+) in the crucial redshift range where the cosmic star-formation density is declining rapidly.

Yagoubov et al. (2019) present the design and performance characteristics of a prototype Band 2 receiver. The project is in the prototyping stage with the pre-production of six units. For the optical components, a design from NAOJ has been selected. The selection of the Low Noise Amplifiers (LNAs) is ongoing, with prototypes from the University of Manchester and the Low Noise Factory currently being tested (Yagoubov et al., 2019). Also, a prototype LNA from NRAO in contract with Caltech and developed with the Cahill Radio Astronomy Lab (CRAL) is expected to be delivered in early 2020. The production of the required 73 units is expected to be complete in 2023, and integration and commissioning at OSF will take place over the period 2022–2024.

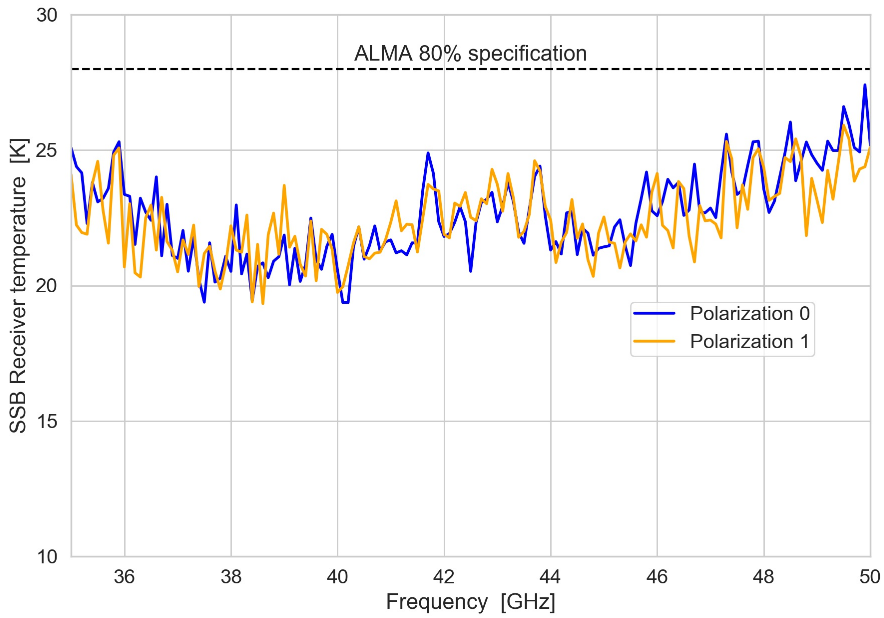

Figure 5: Single-sideband receiver temperature for a Band 1 prototype receiver. The solid curves indicates the measured noise temperature for the two polarizations. The dashed curve indicates the technical specification of the receiver, which is that the noise temperature must be less than 28 K in 80% of the band. Plot courtesy of the Band 1 development team.

4 Toward ALMA 2030

The Roadmap identifies three main areas to drive the developments over the next decade.

- The top development priority, based on scientific merit and technical feasibility, is to broaden the receiver IF bandwidth by at least a factor of two and to upgrade the associated electronics and correlator to process the entire bandwidth.
- Identify and add the functionality needed for the community to mine the ALMA Science Archive efficiently, especially in view of the increased receiver bandwidth envisioned in the Roadmap.
- Continued exploration of development paths which have potentially large impacts on ALMA science, but for which the science case and technical feasibility require further investigation. These include (i) extending the maximum baseline length by a factor of 2–3 to image the terrestrial planet forming zone in nearby protoplanetary disks; (ii) develop focal plane arrays to significantly increase ALMA's wide-field mapping speed; and (iii) increasing the number of 12-m antennas, to benefit all science programs by improving the sensitivity and image fidelity.

The ALMA Development Program already supports studies and projects toward all of these goals and encourages the community to continue submitting proposals. This section highlights two development paths in particular that have made significant progress: increasing the instantaneous IF bandwidth in the next-generation ALMA receivers and extending the maximum baseline length.

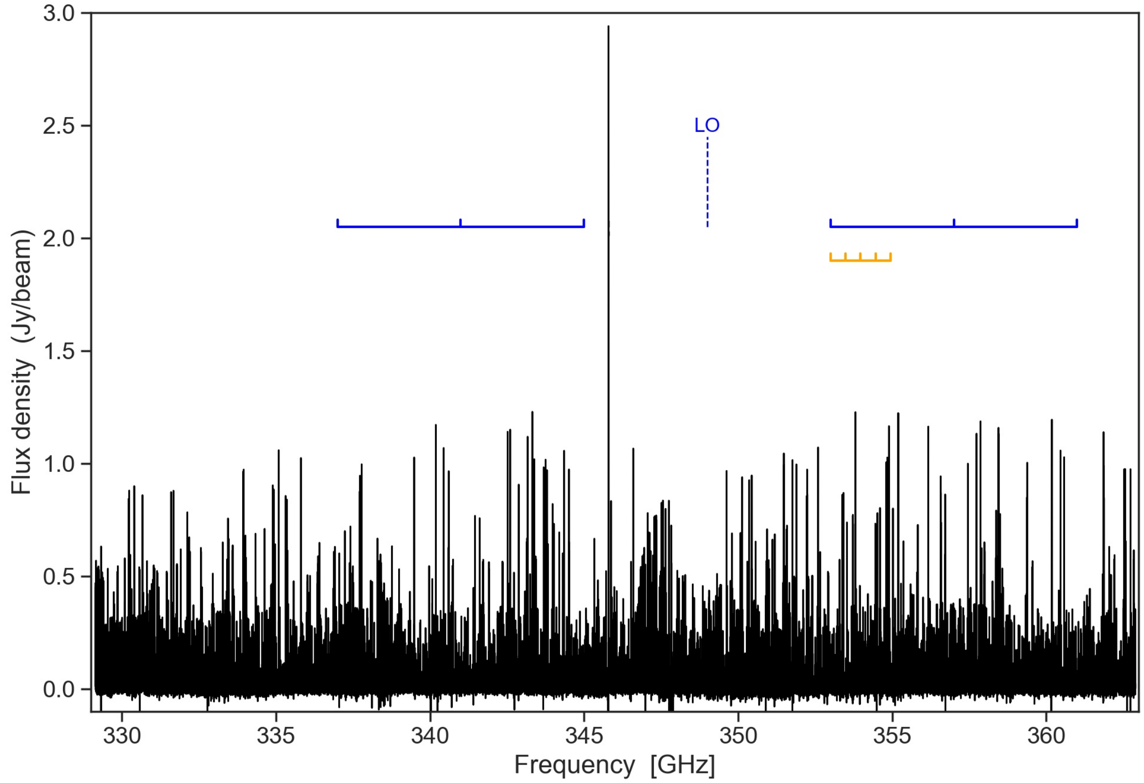

Figure 6: Spectral line survey of the protostellar binary IRAS 16293-2422 obtained using ALMA (Jørgensen et al., 2016). The observations required 18 individual tunings given the instantaneous spectral coverage of the current system at a spectral resolution of 0.2 km s^{-1} (shown in orange). Upgrading the receivers, electronics, and correlator to process the *minimum* IF specifications of the Roadmap (shown in blue) will make spectral surveys at least an order of magnitude faster.

4.1 Next-generation ALMA receivers

The current ALMA digital processing signal and correlator handle 16 GHz of bandwidth (8 GHz per polarization). However, the 8-GHz instantaneous frequency coverage per polarization covers a small fraction of the atmospheric windows. Expanding the throughput by a factor of two or more will reduce the time to conduct blind redshift surveys by the corresponding factor. Wide bandwidths can also observe multiple lines in a galaxy simultaneously to secure redshifts and measure the physical conditions of the interstellar medium. Chemical spectral scans at high spectral resolution, commonly needed for galactic sources, will be an order of magnitude faster when combined with an upgraded correlator (see Figure 6). Increased bandwidth will also improve the continuum sensitivity.

Impressive progress toward wide IF bandwidth receivers is already underway. As shown in Section 3, Bands 1 and 2 will have 8 GHz of IF bandwidth. Designs for even larger bandwidths are being explored. NAOJ is pushing the limits of RF and IF bandwidths of heterodyne receiver front ends based on high-Jc SIS mixers. The utilization of the high-Jc SIS junction offers wide RF and IF bandwidths thanks to their lower RC product. In addition, the wide ranges of Jc and junction sizes increase the design flexibility in the RF and IF circuits. These properties facilitate better IF power coupling from the SIS junction to the standard 50-Ohm IF circuit or better matching

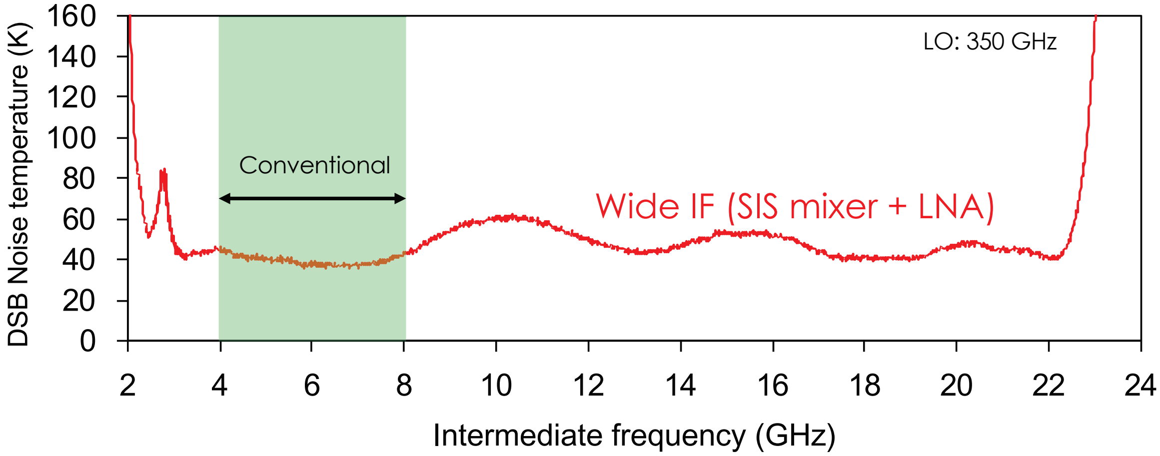

Figure 7: Double sideband noise temperature of an wide-IF SIS receiver at a local oscillator frequency of 350 GHz as a function of intermediate frequency. Figure from Kojma (2019).

between SIS junctions and cryogenic low noise amplifiers. The heterodyne module developed at NAOJ integrates the SIS mixer and cryogenic low-noise amplifier in a single block, omitting an isolator. This work has led to the demonstration of low-noise double sideband SIS mixers covering Bands 7 and 8 and IF bandwidths from 3 to 22 GHz, as shown in Figure 7. NAOJ is studying optimum sideband separating mixer configuration with the wide IF bandwidth and feasibility of a high-speed analog-digital converter in order to implement them into a telescope as a full receiver system, and also plans to apply these technologies to other frequency bands; e.g., ALMA Band 10.

4.2 Baseline extension

An ongoing study led by ESO addresses the feasibility of extending the maximum baselines to as long as 32 km, or double the current baseline length. Figure 8 shows the pad positions within the ALMA concession and the Atacama Astronomical Park that are being considered for additional baselines. The technical feasibility of such long baselines, considering issues such as the impact of long fiber connections, delay tracking, and atmospheric calibration, is being evaluated using a testbed interferometer between telescopes at the AOS and the OSF. The tests have shown repeatably that synchronization, receiver locking and digital data transport can work reliably over the 30 km AOS-OSF fiber connections. Minor upgrades in software and firmware (of the digitizer clock) to increase the usable range of delays and delay rates have been successfully tested, and fringes in Bands 3, 5, and 7 were reliably obtained on a 23.4 km baseline in June 2019. So far all tests have been performed with a single baseline interferometer based on spare correlator and LO resources at the OSF, and future tests will extend this to using the AOS production correlator and LO resources and large arrays of antennas. During 2019, optimizations to delay dispatching in the correlator software have been made which will facilitate extended baselines in addition to improving reliability and lowering overheads for current long baseline observations. In the upcoming year, ALMA will develop a detailed science case for long baselines and designing an array configuration that makes use of all 66 antennas.

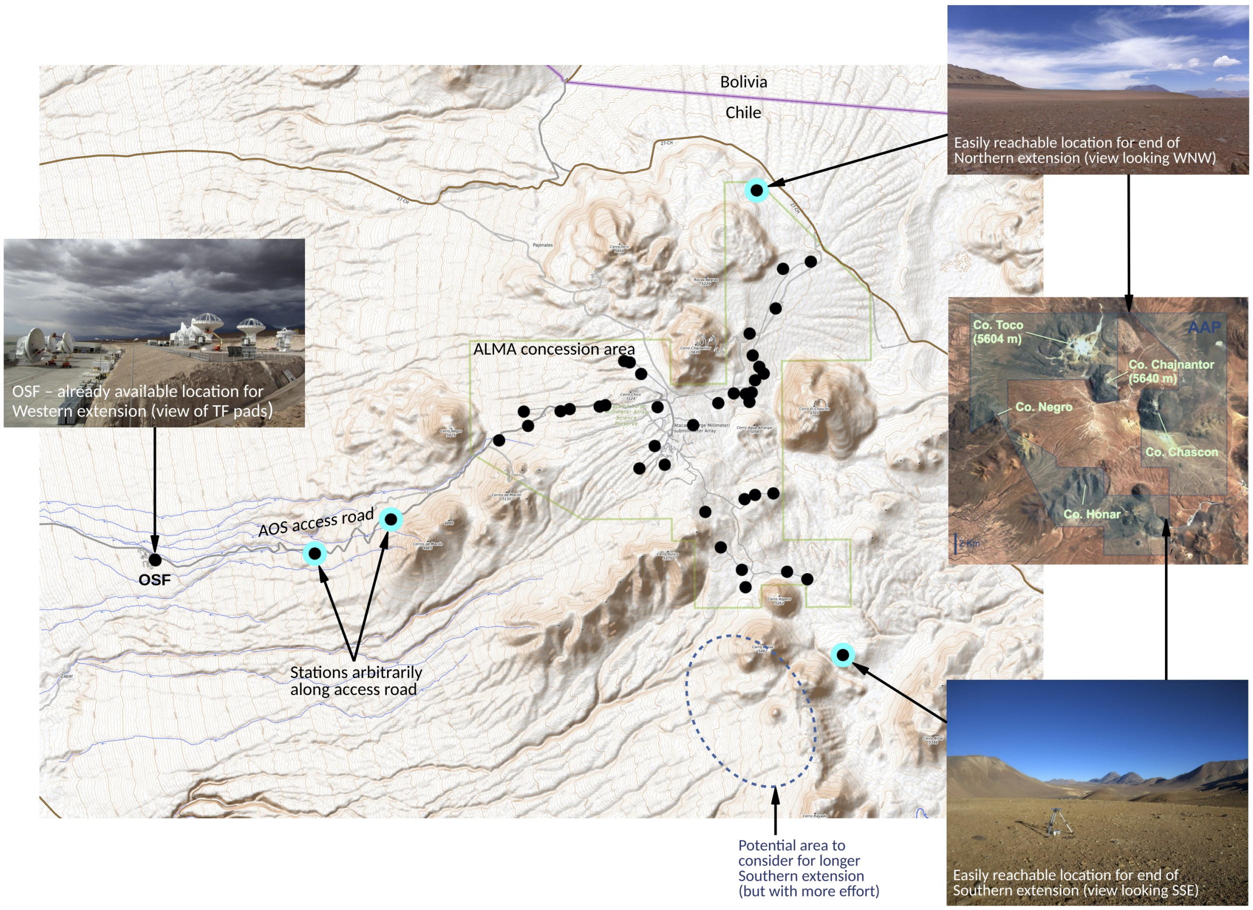

Figure 8: Baseline length extension by up to a factor of ∼2 within the current operational model. On the map, the plain black points denote the most remote existing stations, including at the OSF. The black points highlighted in cyan denote viable new station locations. To the west of the existing array, stations can be added along the AOS access road between the OSF and the AOS. To the north, stations can be added up to 4 km further than now within the existing ALMA concession. To the south, stations can easily be added up to 4 km further than now within the Atacama Astronomical Park area. Technical feasibility is currently being established with an interferometer between array elements at the OSF and the AOS sites on a 23.4 km baseline and 30 km fiber paths.

4.3 ALMA 2030 Development Workshops in 2020

Community involvement is essential to perform the upgrades envisioned in the ALMA Development Roadmap. Over the next year, ALMA is hosting workshops that will help define the technical requirements and select the technologies needed for the upgrades. The workshops include:

- The ALMA2030 Vision: Design Considerations for the Next ALMA Correlator[7]
  The workshop will bring together experts on the ALMA system and modern digital correlator design to (1) discuss design requirements for the next generation correlator that enables the ALMA2030 vision; (2) share pros and cons of recent and currently under design correlator architectures; and (3) identify challenges for implementing and deploying a new ALMA correlator. The workshop will be held 11-13 February 2020 in Charlottesville, Virginia.
- The ALMA 2030 Vision: Design considerations for Digitizers, Backend and Data Transmission System[8]
  The workshop will bring together experts to (1) discuss the status of technology and performance prospects for the next decade for digitizers, backend and DTS; (2) identify the impact on these subsystems due to the increase of the instantaneous bandwidth; (3) discuss the most suitable location of the second generation ALMA correlators in relation with the status of DTS technologies; (4) identify the possibility to use off-the-shelf technologies for the implementation of the second generation of ALMA digitizers, backend and DTS; and (5) discuss possible system architectures to implement the multiplication of the IF bandwidth of ALMA by a factor >2. The workshop will be held 11-13 March 2020 in Mitaka, Japan.
- ALMA is also organizing a workshop to discuss the latest in front-end technology to be held in Europe in late 2020. The details of the workshop will be announced soon.

ALMA strongly encourages the community to participate in the workshops. These workshops will help establish the specific requirements for the next generation receivers and correlators, and determine the technical directions needed to achieve the goals of the Roadmap.

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[7] http://go.nrao.edu/NextALMACorrelator

[8] https://alma-intweb.mtk.nao.ac.jp/~diono/meetings/ALMA2030_Mitaka

Workshop / Meeting Announcements

The ALMA2030 Vision: Design considerations for the Next ALMA Correlator

A meeting to discuss considerations for the design of the next ALMA correlator will be held in Charlottesville, Virginia February 11-13, 2020

The purpose of this meeting is to bring together experts on the ALMA system and modern digital correlator design in order to (1) discuss ALMA design requirements for the next generation ALMA correlator that enables the ALMA2030 vision; (2) share pros and cons of recent and currently under design correlator architectures; and (3) identify challenges for implementing and deploying a new ALMA correlator. Ultimately we hope this meeting encourages and informs the submission of viable designs for the next ALMA correlator in the near future.

Registration and abstract submission opens November 12, 2019: http://go.nrao.edu/NextALMACorrelator

Job Postings – Radio Astronomy and Related Fields

Traineeships in science operations with massive arrays

The Netherlands Institute for Radio Astronomy (ASTRON) and the Joint Institute for VLBI ERIC (JIVE) announce the availability of a minimum of two grants for their Traineeship in Science Operations with massive arrays. The programme enables astronomers (post doc, PhD or graduate student level) to spend a trimester (12 weeks) at the institute in Dwingeloo in the Netherlands. Under the supervision of Telescope Scientists, you will be exposed to the science operations of massive arrays. You will develop fundamental skills and novel experimental methods on systems using technologies that produce cutting-edge science now and contribute to the development of the SKA. ASTRON & JIVE are committed to increasing their staff diversity, and we are especially interested in applications from all traditionally under-represented groups.

The submission deadline is 15 January 2020.

For more information, see http://www.werkenbijastron.nl/en/vacatures/traineeships-in-science-operations-with-massive-arrays-2/