Doc 9.2, ver.1.4 | 23 March 2022

ALMA Cycle 9 Proposer's Guide

www.almascience.org

ALMA, an international astronomy facility, is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

User Support:

For further information or to comment on this document, please contact your regional Helpdesk through the ALMA User Portal at **www.almascience.org**. Helpdesk tickets will be directed to the appropriate ALMA Regional Center at ESO, NAOJ or NRAO.

Revision History:

Version	Date	Editors
1.0	04 March 2022	George Privon, Hiroshi Nagai, David Rebolledo, María Díaz Trigo
1.1	11 March 2022	George Privon, Hiroshi Nagai, David Rebolledo, María Díaz Trigo
1.2	13 March 2022	George Privon, Hiroshi Nagai, David Rebolledo, María Díaz Trigo
1.3	16 March 2022	George Privon, Hiroshi Nagai, David Rebolledo, María Díaz Trigo
1.4	23 March 2022	George Privon, Hiroshi Nagai, David Rebolledo, María Díaz Trigo

In publications, please refer to this document as:
G. Privon et al. 2022, ALMA Cycle 9 Proposer's Guide, ALMA Doc. 9.2 v1.4

Table of Contents

Cycle 9 Call for Proposals

The ALMA Director, on behalf of the Joint ALMA Observatory (JAO) and the partner organizations in East Asia, Europe, and North America, is pleased to announce the ALMA Cycle 9 Call for Proposals (CfP) for scientific observations to be scheduled from October 2022 to September 2023. We encourage interested parties to follow the ALMA Science Portal for the latest information.

The JAO anticipates allocating 4300 hours on the 12-m Array and 4300 hours on the Atacama Compact Array (ACA), also known as the Morita Array, for successful proposals in Cycle 9. The ACA allocation includes 4300 hours each on the 7-m Array and the Total Power (TP) Array. Proposals must be prepared and submitted using the ALMA Observing Tool (OT), which is available for download from the ALMA Science Portal (*www.almascience.org*).

Proposal reviews will be conducted via a dual-anonymous process. While proposers will still enter their names and affiliations in the OT, their identities will be concealed from the science reviewers. It will be the responsibility of the investigators to write their proposals such that anonymity is preserved. In addition, ALMA is using distributed peer review for proposals requesting less than 50 hours on the 12-m Array and for ACA stand-alone proposals requesting less than 150 hours on the 7-m Array. The PI for such proposals or a designee from the list of investigators will review and rank 10 submitted proposals from this Call, for each proposal submitted.

ALMA Cycle 9 proposal submission will open at **15:00 UT on Thursday, 24 March 2022**. The Cycle 9 proposal submission deadline is **15:00 UT on Thursday, 21 April 2022.** These and other important milestones for Cycle 9 are summarized in Table 1. PIs are responsible for submitting their proposals successfully by the deadline, and are strongly advised to submit proposals early.

Cycle 9 will not include a Supplemental CfP for stand-alone ACA observations. The community is encouraged to submit ACA projects, especially in the LST range of 20h to 10h, for the April 2022 deadline.

ALMA provides continuum and spectral-line capabilities for wavelengths from 0.32 mm to 3.6 mm, and angular resolutions from 0.0088″ to 3.4″ on the 12-m Array. In Cycle 9, the following configuration and observing band combinations will be offered for the 12-m Array: configurations C-1 through C-10 for Bands 3 through 8, C-1 through C-9 for Band 9, and C-1 through C-8 for Band 10. These combinations will provide angular resolutions as fine as 0.0091", 0.0088", and 0.011", respectively. Cycle 9 will bring several new observational capabilities to ALMA, including submillimeter (Band 7) VLBI, spectral line VLBI, fast regional mapping for solar Total Power, and high-frequencies at long-baselines. Proposals with observations in the highest-frequency Bands 8, 9, and 10 are strongly encouraged.

This Proposer's Guide provides an overview of significant changes since Cycle 8 2021 made in both the technical capabilities and observing strategies (Section 1), an overview of the ALMA organization (Section 2), the proposal types offered in Cycle 9 (Section 3), information on proposal planning (Section 4), proposal submission (Section 5) and post-proposal activities (Section 6), an overview of the offered technical capabilities (Appendix A), and guidelines for writing a Technical Justification (Appendix B).

Table 1: The ALMA Cycle 9 timeline

Date	Milestone
24 March 2022	Release of Cycle 9 Call for Proposals, Observing Tool, and supporting documents, and opening of the Archive for proposal submission
21 April 2022 (15:00 UT)	Proposal submission deadline for Cycle 9 Call for Proposals
1 June 2022 (15:00 UT)	Deadline to submit reviews for the distributed peer review system
August 2022	Announcement of the outcome of the proposal review process
1 October 2022	Start of ALMA Cycle 9 Science Observations
30 September 2023	End of ALMA Cycle 9

1 What's new in Cycle 9

This section summarizes significant changes made since Cycle 8 2021. Any changes, clarifications, or bugs that are discovered after the publication of this Proposer's Guide will be documented in the Knowledgebase Article**:**

What Cycle 9 proposal issues and clarifications should I be aware of before submitting my proposal?

Proposers should check this article regularly, especially just before submitting their proposals.

1.1 Technical and observing capabilities

Observing capabilities are given in Appendix A and fully described in the ALMA Cycle 9 Technical Handbook (hereafter, the Technical Handbook). New capabilities in Cycle 9 include:

- **Fast Regional Mapping (FRM) for solar Total Power observations.** The size of the field of view for solar Total Power observations can be specified by the PI.
- **Spectral line Very Long Baseline Interferometry (VLBI).** This capability is offered in Band 3 only, in conjunction with the Global Millimeter VLBI Array (GMVA).
- **Submillimeter VLBI.** A continuum VLBI capability will be offered for Band 7 (0.87 mm) in conjunction with the Event Horizon Telescope (EHT).
- **Longer baseline high-frequency observations: Band 8 up to C-10, Band 9 up to C-9, and Band 10 up to C-8.** The band-to-band (B2B) calibration mode[1] may be triggered by the OT for long baseline high frequency observations in order to find a suitably close and strong phase calibrator. Some science targets, particularly at the highest frequencies and longest baselines, may not be possible even with B2B (see Section A.9.6).

[1] The total time allocated to projects requiring band-to-band calibration techniques will be limited to 45 hours. For more information about band-to-band calibration, see Section 4.2 of this document or Section 10.5.3 of the Technical Handbook.

1.2 Proposal review

1.2.1 Distributed peer review

ALMA is using a distributed peer review system for proposals requesting less than 50 hours on the 12-m Array and for ACA stand-alone proposals requesting less than 150 hours on the 7-m Array (i.e., for all proposals except Large Programs and Director's Discretionary Time). For each proposal submitted, the PI or a designee from the list of investigators will review and rank 10 submitted proposals from this Call. Review assignments will be made based on the expertise of the designated reviewer, specified by including one or more scientific keywords on their ALMA user profile. Additionally, in Cycle 9 reviewers are allowed to provide a list of their conflicts of interests; if this list is provided, reviewers will not be assigned to review proposals on which the PI or one of the co-Is is in their list of conflicts. **Reviewers are advised to update their user profiles as necessary in the Science Portal, paying special attention to the specification of their expertise.** The deadline to provide scientific expertise is 26 April 2022. See Section 5.7.1 for more information on distributed peer review.

1.2.2 Large Programs review

Proposals for Large Programs will be reviewed by a single panel, the ALMA Proposal Review Committee (APRC). Large Programs will also be reviewed by external Science Assessors, who will provide written reviews to the APRC but will not participate in the APRC meeting.

1.3 Observing Tool Installation

The Web Start installation is no longer available for the OT. It has been dropped from Java starting with version 11. Instead, a new installer has been created with a modern interface that guides the user through the steps necessary for installation. A separate installer is available for Linux, Mac OS, and Windows and it includes a self-contained distribution of Java 11. It is therefore no longer necessary for users to install Java themselves. The alternative tarball distribution remains available and this will also include Java. Installation instruction and new features are described in more detail in the OT documentation.

2 ALMA overview

2.1 The ALMA partnership

ALMA, an international astronomy facility, is a partnership of the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile. ALMA operations are led by ESO on behalf of its Member States; by the National Radio Astronomy Observatory (NRAO), managed by Associated Universities, Inc. (AUI), on behalf of North America; and by the National Astronomical Observatory of Japan (NAOJ) on behalf of East Asia. JAO provides the unified leadership and management of the commissioning and operation of ALMA.

2.2 The ALMA telescope

ALMA contains 66 high-precision antennas. Fifty of these are 12-meter dishes in the 12-m Array, used for sensitive, high-resolution imaging. The remaining sixteen make up the ACA, used to enhance wide-field imaging: twelve are closely spaced 7-meter antennas (7-m Array), and four are 12-meter antennas for single-dish observations (Total Power Array or TP Array). The wavelengths covered by ALMA range from 0.32 mm to 3.6 mm (frequency coverage of 84 GHz to 950 GHz).

The Array is located on the Chajnantor plateau of the Chilean Andes at latitude = –23.029°, longitude = –67.755° and an altitude of 5000 m. The site (referred to as the Array Operations Site, AOS) offers the exceptionally dry and clear sky conditions required to operate at millimeter and submillimeter wavelengths. The AOS is connected via gigabit fiber links to the Operation Support Facility (OSF), located at an altitude of 2900 m and 40 km from the town of San Pedro de Atacama. Science operations are conducted from the OSF and coordinated from the JAO Santiago Central Office (SCO).

The Technical Handbook contains a detailed description of the ALMA technical characteristics.

2.3 The Joint ALMA Observatory and the ALMA Regional Centers

The JAO is responsible for the overall leadership and management of ALMA operations in Chile. The JAO solicits proposals to observe with ALMA through Calls for Proposals and organizes the peer review of the proposals by science experts. In addition, the JAO schedules all science observations and places the data in the electronically accessible Archive.

The three Executives maintain the ALMA Regional Centers (ARCs) within their respective regions. The ARCs provide the interface between the ALMA Observatory and its user communities. The ARCs are responsible for user support, mainly in the areas of proposal preparation, observation preparation, acquisition of data through the Archive, data reduction, data analysis, data delivery, face-to-face visitor support and workshops, tutorials, and schools. Each ARC operates an archive that mirrors the SCO Archive. Browsing and data mining are done through the ARC mirror archives.

The East Asian ARC (EA ARC) is based at the National Astronomical Observatory of Japan (NAOJ) headquarters in Tokyo. It is operated in collaboration with Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) in Taiwan and Korea Astronomy and Space Science Institute (KASI) in Korea and supports the astronomical communities of Japan, Taiwan[2] and the Republic of Korea.

European researchers are supported by the European ARC (EU ARC), which is organized as a coordinated network of scientific support nodes distributed across Europe. The EU ARC is located at ESO Headquarters in Garching bei München (Germany), where many of the ARC activities take place. Face-to-face support and additional services are provided by seven regional nodes. The regional nodes are currently: Bonn-Cologne (Germany), Bologna (Italy), Onsala (Sweden), IRAM, Grenoble (France), Allegro, Leiden (The Netherlands), Manchester (United Kingdom) and Ondřejov (Czech Republic).

The North American ARC (NA ARC) is contained within the North American ALMA Science Center (NAASC), based at NRAO headquarters in Charlottesville, VA, USA. It is operated in collaboration with the National Research Council of Canada (Canada) and Academia Sinica Institute of Astronomy

[2] Support of the Taiwanese astronomical community is shared by the EA and NA ARCs.

and Astrophysics (Taiwan), and supports the astronomical communities of North America and Taiwan[2].

2.4 The ALMA Science Portal

The ALMA Science Portal (SP), accessible at *http://almascience.org*, is the primary access point to ALMA for science users. It provides a gateway to all ALMA resources, documents and tools relevant to users for proposal preparation, proposal assessment, project tracking, project data access and data retrieval, as well as access to the ALMA Helpdesk.

From the Science Portal, anyone can:

- Register as an ALMA user.
- Access ALMA user documentation and software tools, including the ALMA Sensitivity Calculator, observing simulators, and the ALMA spectral-line database (Splatalogue).
- Download the OT.
- Access Helpdesk "Knowledgebase" articles, which provide answers to common questions.
- Access non-proprietary data from the ALMA Archive.

In addition, registered users may:

- Manage their user profile. Here, users can specify their area of expertise and conflicts of interest, set an option to receive automatic email notifications of the progress of their observations, grant access to proprietary data for other ALMA users, and delegate the right to trigger Target of Opportunity (ToO) observations to another selected ALMA user.
- Access SnooPI, the tool for PIs, co-PIs, co-Is, and any other user designated by the PIs, to monitor the status of their scheduled observing projects.
- Submit Helpdesk tickets.
- Trigger ToO observations.
- Access their proprietary data through the ALMA Archive.

The Science Portal also includes links to the ARC's webpages, from which users can access regional information and specific services of each ARC. This includes visitor and student programs, schools, workshops, and outreach materials and activities.

Users must update their ALMA user profile, rather than registering multiple accounts, whenever there is a change in their personal information such as a new email address or a change of affiliation (see Section 2.1 of the ALMA Users' Policies). Finally, users are encouraged to complete the "Demographics" section of their profile to help ALMA provide adequate user support.

2.5 ALMA proposal eligibility

Users of any nationality or affiliation may submit an ALMA proposal. All proposals are evaluated on the basis of scientific merit by a distributed peer review system or by a panel-based proposal review system.

Each proposal must have a PI who is the official contact between ALMA and the proposing team for all correspondence related to the project. Large Programs proposals may designate co-PIs, who will share the overall responsibility of conducting the proposed science. If co-PIs are identified, the requested observing time will be split among the regions (North America, Europe, East Asia, and Chile) in proportion to the affiliations of the PI and co-PIs (see Section 5.7.3).

Regardless of the inclusion of co-PIs, the PI has proprietary access to the ALMA data during the proprietary period, and is in charge of the delivery of the value-added data products in the case of Large Programs, in accordance with the ALMA Users' Policies. Any other individuals who are actively involved in any proposal may be designated as co-Is. There is no limit to the number of co-Is or co-PIs who may appear on a proposal.

Additional rules apply for qualification to use the Chilean share of the time and they are described at *http://www.das.uchile.cl/~alma_crc/*.

ALMA Users' Policies prohibit multiple submissions of the same proposal using different regional affiliations. If such proposals are detected, only the first submitted version will be considered by the reviewers.

3 Proposal types

3.1 Regular proposals

Regular proposals relate to observations that can be fully specified by the proposal submission deadline and whose estimated execution time does not exceed 50 hours on the 12-m Array or 150 hours on the 7-m Array in stand-alone mode. Regular proposals may involve time-critical, multiple-epoch observations, and the monitoring of a target over a fixed time interval.

Figure 1 (left panel) shows that most Cycle 8 2021 proposals requested between 2 and 20 hours of 12-m Array time. However, the success rate of proposals was roughly constant up to 40 hours of requested 12-m Array time (Figure 1, right panel). The JAO aims to have a diverse scientific portfolio by executing a balance of programs with various sizes in terms of observing time.

No restrictions are imposed on the size of the time window specified by PIs for time-critical observations. The scheduling feasibility of any proposal will depend on the total number of constraints that are imposed (see Section 4.3). Importantly, any time constraint, as with any other type of observational constraint, must be scientifically and technically justified.

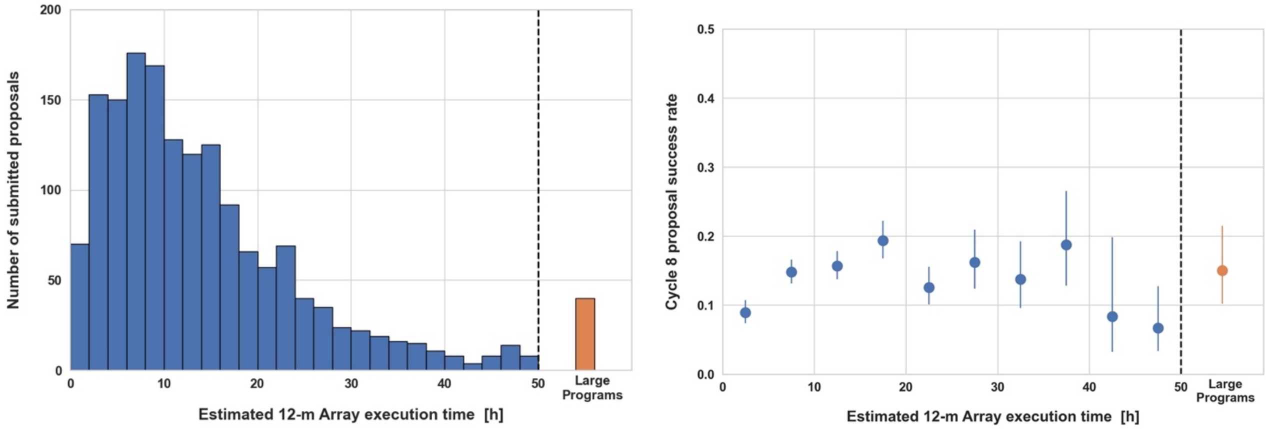

Figure 1: (Left) Number of proposals submitted as a function of the 12-m Array execution time in Cycle 8 2021. (Right) The fraction of proposals (with 1σ confidence intervals) that were assigned priority Grade A or B as a function of the estimated 12-m Array time.

3.2 Target of Opportunity proposals

Target of Opportunity (ToO) proposals should be submitted for observations that can be anticipated but whose targets and/or time of observation are not known in advance. Like Regular proposals, these proposals must be submitted by the Cycle 9 proposal deadline. As for all other types of proposals, observing modes and sensitivity requests must be specified at the time of submission. In contrast, the target list may be specified at the moment of triggering the proposal. For each triggered Scheduling Block (SB) the proposal should specify the number of triggers needed, what the trigger event will be, and the necessary reaction time for scheduling the observation after it is triggered. Regular proposals wrongly submitted by the PI as ToO proposals may be rejected on technical grounds.

The JAO will give priority to observing ToO proposals during the time period requested by the PI after a trigger request has been submitted, provided the appropriate scheduling conditions (mainly weather and antenna configuration, see Section 4.3) are met and the observations do not conflict with critical engineering and development activities or critical observations with a higher grade. For requests of reaction times under 24 hours, PIs are recommended to give notice as early as possible about target coordinates or redshift for preparation of the Phase 2 SBs. PIs will trigger observations from accepted ToO proposals through the Project Trigger Submission Page available at the ALMA Helpdesk. Further instructions on how to trigger a project are available at the ToO Activation page on the Science Portal. Upon receiving a trigger, the Observatory will communicate with the PI through the Helpdesk ticket to clarify any remaining issues.

3.3 Large Programs

Large Programs are proposals with an estimated execution time of greater than 50 hours on the 12-m Array (with or without accompanying ACA time) or 150 hours on the 7-m Array in stand-alone mode. Large Programs should not involve time-critical or ToO observations, and may not include full polarization measurements, solar observations, VLBI, Phased Array mode, Astrometric observations (see Section A.9.5) or observations requiring band-to-band calibration or bandwidth switching calibration (see Section A.9.6). Large Programs may fill up to 33% of the available time for a given LST range in the 12-m Array configurations C-9 and C-10 and up to 50% of the time in the remaining Cycle 9 configurations (i.e., the ACA and C-1 through C-8). Section 4.3.3 shows the configuration schedule and time available per configuration.

A Large Program proposal should address strategic scientific issues that will lead to a major advance or breakthrough in the field, be a coherent science project and not reproducible by a combination of Regular proposals, lead to value-added data products, and contain a solid management plan ensuring an efficient utilization of the data. Consequently, the proposal team should not submit one or more Regular proposals for the same observations in parallel with a Large Program. In such a case, the Regular proposals would not be considered. Further details are available in the Knowledgebase article "Are there policies specific to Large Programs?".

Large Program teams are expected to deliver their proposed value-added data products and documentation describing the data products to ALMA within one year of the final delivery of calibrated products. The value-added data products and documents will be made available to the community at large. The Science Portal contains a document describing the standards for Large Program enhanced products to ensure their proper ingestion into the ALMA Science Archive.

3.4 mm-VLBI and Phased Array proposals

ALMA VLBI proposals are made in concert with either the Global Millimeter VLBI Array (GMVA) at 3 mm (Band 3) or the Event Horizon Telescope (EHT) network at 1.3 mm (Band 6). New for Cycle 9, proposals for 3 mm spectral line VLBI observations in conjunction with the GMVA and continuum VLBI at 0.87 mm (Band 7) in conjunction with the EHT will also be accepted. For all 3-mm VLBI observations, PIs must have submitted a proposal to the GMVA network by 1 February 2022 in addition to their ALMA VLBI proposal.

ALMA-specific VLBI considerations are given in Section A.12 of this document. Further details on submitting 3-mm VLBI proposals to the GMVA are available from the GMVA website. Further details on submitting 1.3-mm and 0.87-mm VLBI proposals to the EHT are available from the EHT website.

Proposals should include a quantitative justification describing why ALMA is essential for the project. VLBI observations cannot be included in Large Programs. VLBI observations that include ALMA will likely be carried out in March/April 2023.

Given that the outcome of VLBI Cycle 8 2021-proposals may not be known before the ALMA Cycle 9 proposal deadline, PIs of such proposals may wish to resubmit their proposals in Cycle 9 in case the Cycle 8 2021 observations are unsuccessful. No resubmission to the GMVA network call for proposals is needed in such cases. Further details on the handling of resubmitted proposals are available in Section 4.4.2.

Pulsar observing capabilities using ALMA's Phased Array observing mode are described in Section A.13 of this document. A maximum of 50 hours of Cycle 9 time will be available for Phased Array mode observations. These observations will take place during the VLBI time blocks, anticipated to be in March/April 2023. Phased Array observations cannot be included in Large Programs.

3.5 Director's Discretionary Time proposals

Director's Discretionary Time (DDT) proposals may be submitted at any time. To qualify for DDT, proposals must fulfill the conditions specified on the Science Portal. Capabilities, time tolerance restrictions, and science assessment will be based on the same criteria as for Regular and ToO proposals, and DDT proposals must comply with the anonymization rules. DDT proposals will be considered for approval by the ALMA Director based on the advice of a Standing Review Committee, with members from the JAO and the four regions, appointed by the Executive Directors and the ALMA Director. In exceptional cases, the ALMA Director may approve DDT proposals that would benefit from a very rapid response, and inform the Standing Committee and science operations team of this decision within 24 hours. Further DDT policies are described in the ALMA Users' Policies.

4 Proposal planning

4.1 Time available in Cycle 9

Cycle 9 will span 12 months, starting in 2022 October and finishing in 2023 September.

The JAO anticipates allocating 4300 hours on each of the 12-m, 7-m, and TP arrays for successful PI programs, including DDT proposals as well as Cycle 8 2021 grade A proposals that are carried over. VLBI and DDT projects are limited to a maximum of 5% each of the available time (Sections 3.4 and 3.5). There is no overall cap on Large Programs, but they may fill no more than 33% of the time at a given LST for configurations C-9 and C-10 and no more than 50% of the time at a given LST for the remaining configurations (ACA and C-1 through C-8; see Section 3.3).

4.2 Summary of capabilities offered in Cycle 9

The Cycle 9 capabilities are described in Appendix A. In summary, they are:

Number of antennas

- At least forty-three antennas in the 12-m Array.
- At least ten 7-m antennas (for short baselines) and three 12-m antennas (for single-dish maps) in the ACA.

Receiver bands

- Receiver Bands 3, 4, 5, 6, 7, 8, 9, and 10 (wavelengths of about 3.0, 2.0, 1.6, 1.3, 0.85, 0.65, 0.45, and 0.35 mm, respectively).

12-m Array Configurations

- Cycle 9 includes configurations C-1 through C-10.
- Maximum baselines between 0.16 km and 16.2 km depending on array configuration and subject to the following restrictions:
    - The maximum possible baseline for Bands 3, 4, 5, 6, 7, and 8 is 16.2 km.
    - The maximum possible baseline for Band 9 is 13.9 km.
    - The maximum possible baseline for Band 10 is 8.5 km.

Some ALMA subsystems (e.g., the OT) may report configurations of the form "C43-X"; these are equivalent to the "C-X" configurations described here and in the Technical Handbook. Configurations with maximum baselines equal to or longer than 3.6 km (i.e., C-7 through C-10) are considered "long-baseline configurations". Observations in these configurations include more frequent calibration compared to more compact configurations to ensure the quality of the observations. Files containing notional antenna configurations for the 12-m and 7-m Arrays suitable for Common Astronomy Software Applications (CASA) simulations are available from the ALMA Science Portal.

Spectral-line, continuum, and mosaic observations

- Spectral-line and continuum observations with the 12-m Array and the 7-m Array in all bands.
- Single-field interferometry (all bands) and mosaics (Bands 3 to 9) with the 12-m Array and the 7-m Array.
- Single-dish spectral-line observations in Bands 3 to 8.

Polarization

- Single-pointing, on-axis, full linear and circular polarization for both continuum and full spectral resolution observations in Bands 3 to 7 on the 12-m Array. The field of view of linear and circular polarization observations is limited to the inner one third and the inner one tenth of the primary beam, respectively. The minimum detectable degree of circular polarization is 1.8% of the peak flux for both continuum and full spectral resolution observations
- Mosaics for continuum linear polarization observations for the 12-m Array in Bands 3 to 7.
- Single-pointing, on-axis linear polarization on the stand-alone 7-m Array in Bands 3 to 7. The field of view is limited to the inner one third of the primary beam. A maximum of 75 hours will be offered for this mode.

Band-to-band calibration

- Observations in Band 7-10 that require 12-m Array configurations C-8 to C-10 may require band-to-band (B2B) calibration in order to find a nearby and sufficiently bright phase calibrator to ensure phase calibration quality. The OT will automatically check the availability of suitable phase calibrators during proposal validation and will automatically trigger the B2B mode where required.
- B2B observations are subject to the availability of suitable calibrators as checked by the OT. Some science targets, particularly at the highest frequencies and longest baselines, may not be observable even with B2B. The OT will emit an error if a source does not have a suitable calibrator. PIs are advised to begin preparing their proposals early to ensure that a suitable calibrator is available for their targets. See Section A.9.6; for technical details, see Section 10.5.5 of the Technical Handbook.
- A maximum of 45 hours of Cycle 9 observing time will be available for observations requiring the B2B calibration mode.

4.3 Scheduling considerations

Apart from time-constrained observations, various aspects of a proposed observation such as weather conditions or requested angular resolution and Largest Angular Structure (LAS) may affect when an observation is scheduled. This section describes the most important scheduling considerations that investigators should be aware of when preparing their ALMA proposal.

4.3.1 Weather

Chajnantor is one of the best sites in the world for ground-based observations at submillimeter wavelengths (Evans et al 2002, ALMA Memo No. 471, available from the ALMA Memo Series). The opacity (primarily determined by the Precipitable Water Vapor – PWV) and the phase stability of the atmosphere are the two primary factors that dictate when ALMA can observe at certain frequencies, in particular in the higher-frequency bands and at frequencies near water absorption lines. Both transmission and phase stability follow a yearly cycle (late southern winter is best – see Figures 2 and 4 of Memo 471) and a diurnal cycle (late night and early morning are best – see Figures 3 and 5 of Memo 471). In addition to the transmission and phase stability criteria, the low wind speeds that typically occur during night and early morning provide optimum observing conditions.

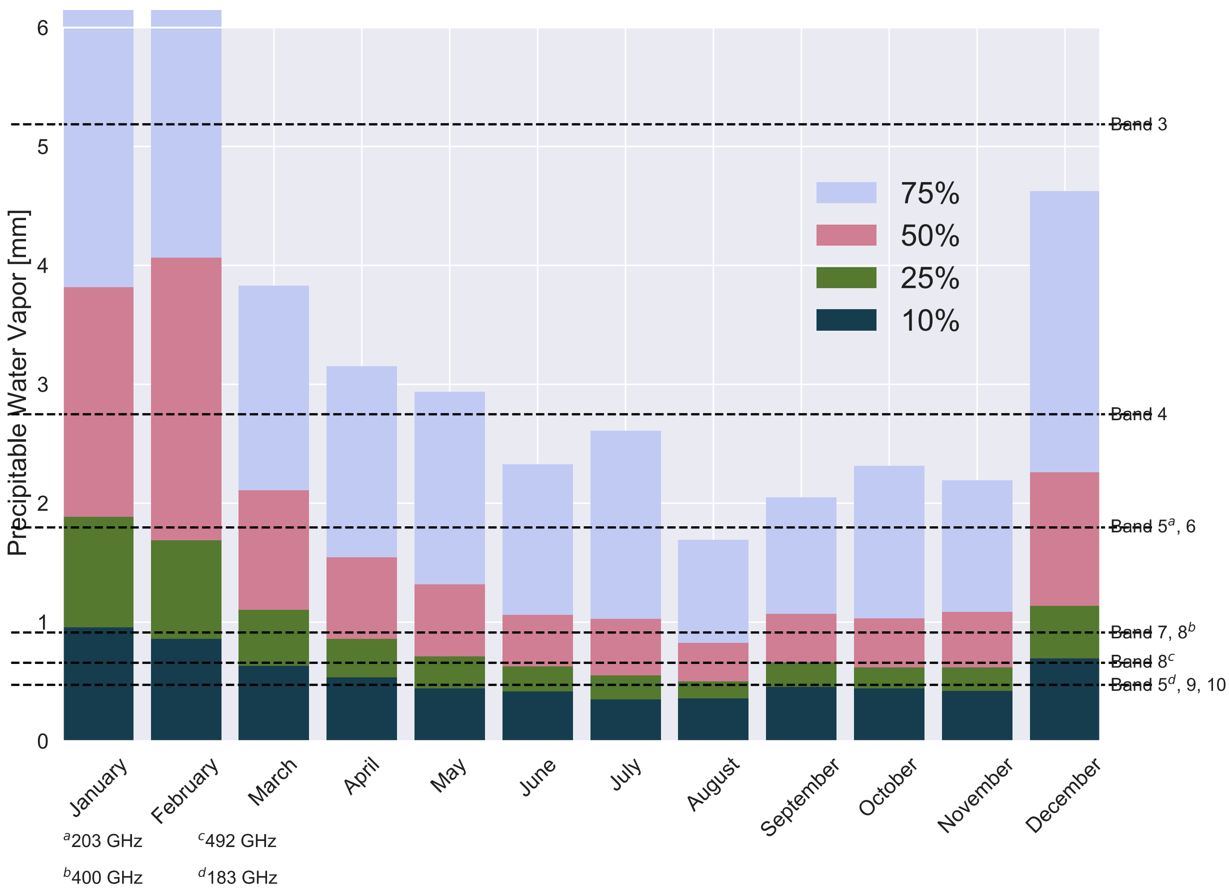

Figure 2: Fraction of time that the PWV falls below a given value along the year. The percentages shown indicate the fraction of time that the PWV is under the PWV value indicated on the y-axis. For example, in March 75% of the PWV measurements are under 3.8 mm, and in June 75% of the PWV measurements fall below 2.3 mm. The data were obtained with the APEX weather station, ALMA measurements, and weather forecast data between January 2010 and January 2022. The horizontal dashed lines show the PWV observing limits adopted for the ALMA bands for an elevation of 60 degrees.

Figure 2 shows the PWV measurements per month, illustrating the yearly cycle. The best months for high-frequency observations are from May to November. Figure 3 shows the percentage of time when the PWV is below the observing thresholds adopted for the various ALMA bands. The time percentage is shown per month and separately for day and night to highlight the daily and monthly variations. For a given time of the day and a given month, the PWV measurements still show a large scatter due to the differences in weather from year to year. During parts of the year, such as the Altiplanic winter[3] season (December-March), it may be difficult to carry out submillimeter observations. For this reason, an extended maintenance and upgrade period is scheduled each February, during which no science observations are scheduled.

[3] During southern summer, the high-pressure system over the Pacific Ocean weakens and moves southwards, allowing warm humid air from the Amazons to flow over the Andes into northern Chile, causing rain and occasionally snow to fall on the usually dry Altiplano: this phenomenon is known as Altiplanic winter.

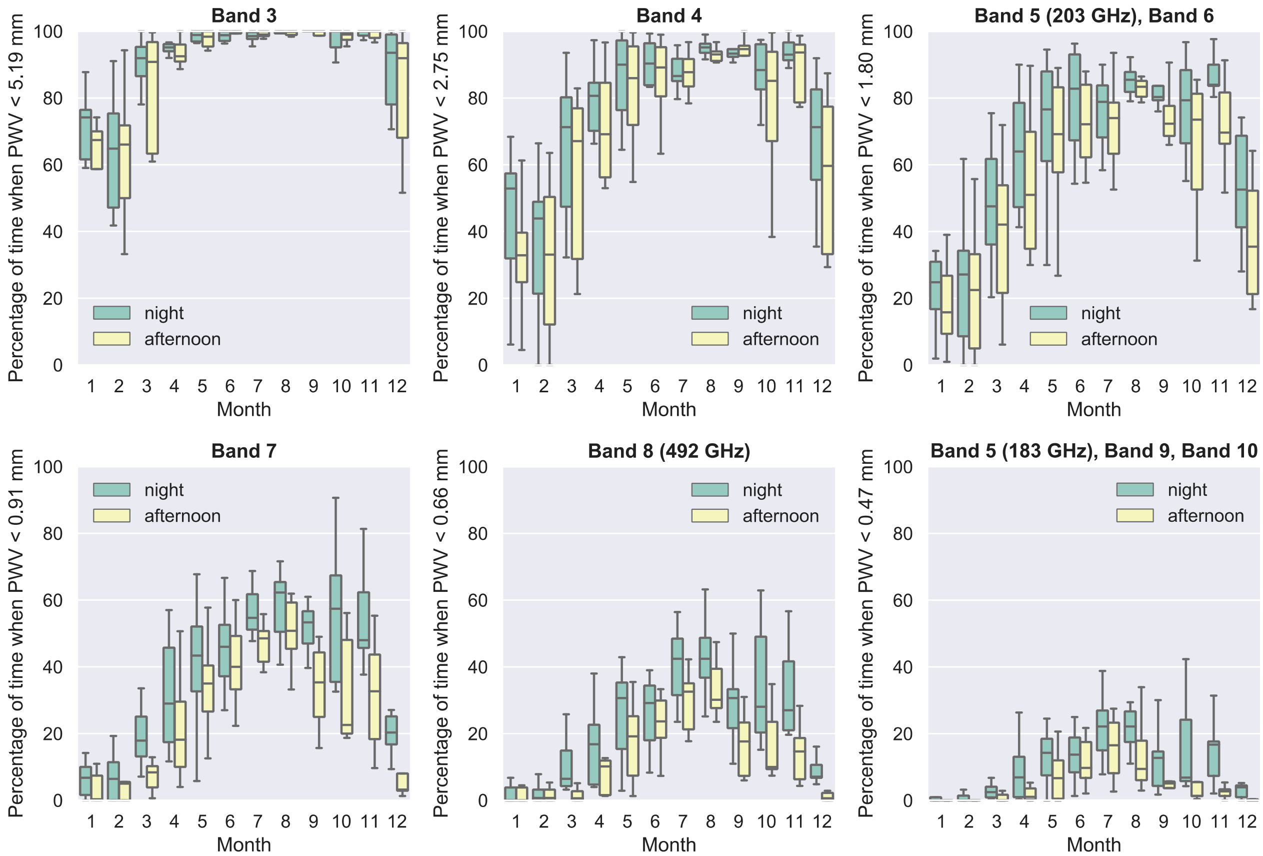

Figure 3: The percentage of time when the PWV is below the observing thresholds adopted for the various ALMA bands for night-time (green) and afternoon (yellow) and for an elevation of 60 degrees. The horizontal line within the box indicates the median. Boundaries of the box indicate the 25th- and 75th-percentile, and the whiskers indicate the highest and lowest values of the results. The data were obtained with the APEX weather station, ALMA measurements, and weather forecast data between January 2010 and January 2022.

The JAO will schedule the observations during appropriate weather conditions to ensure good data quality. In particular, high-frequency projects will be prioritized when weather conditions are appropriate for them.

4.3.2 Angular resolution

PIs can enter a single value or a range when specifying acceptable angular resolutions for a given Science Goal (SG) in the OT (see Section 4.5 for more on Science Goals). Whenever feasible, PIs are encouraged to enter a range spanning more than one configuration. Such a choice may improve chances of having the SB observed, especially for SBs with an intrinsically low probability of execution (e.g., due to weather or time constraints).

In practice, the OT will assign to a given SB any number of configurations that fulfill the angular resolution range requested by the PI. For scheduling feasibility and Quality Assurance (QA) purposes, the following will also be considered:

- If the PI selects a single value for the angular resolution or a range narrower than 20% around its center value, a range of ±20% around the single or center value specified will be enforced.

- If the requested range (after applying the previous rule) does not include the resolution of at least one of the notional configurations, the range will be extended to include the resolution of the closest notional configuration.
- *If the requested range includes both long-baseline and more compact configurations, only the latter will be considered*. An exception is constituted by ToO observations that can be triggered in any configuration if the angular resolution requested by the PI is "any" (see Section 3.2).

The final range of angular resolutions (i.e., after all the above factors have been considered) can be viewed via the "Planning and Time Estimate" button in the OT "Control and Performance" panel. This range and the associated configurations will also be displayed in the Phase 2 SBs in the OT so that they can be reviewed by PIs. Users should note that the synthesized beam shape can be elongated, in particular for sources at high or very low declinations (see Section 7.4 of the Technical Handbook for details). For reference, the OT will show the expected 2-D beam dimensions and maximum axial ratio based on observations near transit for a given source. Observations away from transit will result in a higher axial ratio than that shown.

PIs aiming to obtain a specific surface brightness sensitivity may enter their request in temperature units. In this case, if a range of acceptable resolutions is specified by the PI, the time estimate will be determined by the time needed to achieve the surface brightness sensitivity requested at the resolution of the most extended configuration fitting the provided range (i.e., highest resolution). ALMA QA processes are defined in terms of resolution and flux density sensitivity, so the actual surface brightness sensitivity delivered will depend on the resolution achieved by the observations (see Chapter 11 of the Technical Handbook for more details). Thus, a temperature sensitivity worse than requested could be obtained if the resolution achieved in the delivered images is still within the requested range but higher than that of the most extended configuration assigned to that SB.

4.3.3 Configuration schedule for the 12-m Array

The ALMA 12-m Array will be configured in 10 different configurations during Cycle 9. While each configuration contains fifty 12-m antennas, only a subset of the 50 antennas will be available for most observations due to maintenance activities, calibration observations, and testing new capabilities. These operational factors impact the actual configuration achieved for a given observation, so the configurations used for simulations and planning are referred to here as "notional configurations." The OT assumes 43 antennas are available when calculating the time estimates and image characteristics based on these configurations. Configurations are now denoted as C-x, with x=1 for the most compact configuration and x=10 for the most extended (see Section A.2 and Chapter 7 of the Technical Handbook for details)[4]. The notional configurations C43-1 through C43-10 used in Cycles 6 and 7 may be used to simulate observations using C-1 through C-10. Files describing the notional configurations are available on the SP. The planned 12-m Array configuration schedule for Cycle 9 is given in Table 2. This schedule may be modified depending on the results of the proposal review process and the proposal pressure in the different configurations. Changes to the configuration schedule will be announced on the SP. On average, configurations change once every three weeks. Observations will not be scheduled in February 2023 because of poor weather during the Altiplanic winter.

[4] These configurations are equivalent to the "C43-X" configurations reported by the OT and other ALMA subsystems.

Table 2: Planned 12-m Array Configuration Schedule for Cycle 9

Start date	Configuration	Longest baseline	LST for best observing conditions
2022 October 1	C-3	0.50 km	~ 22—10 h
2022 October 20	C-2	0.31 km	~ 23—11 h
2022 November 10	C-1	0.16 km	~ 1—13 h
2022 November 30	C-2	0.31 km	~ 2—14 h
2022 December 20	C-3	0.50 km	~ 4—15 h
2023 January 10	C-4	0.78 km	~ 5—17 h
2023 February 1	*No observations due to maintenance*		
2023 March 1	C-4	0.78 km	~ 8—21 h
2023 March 20	C-5	1.4 km	~ 9—23 h
2023 April 20	C-6	2.5 km	~ 11—1 h
2023 May 20	C-7	3.6 km	~ 13—3 h
2023 June 20	C-8	8.5 km	~ 15—5 h
2023 July 11	C-9	13.9 km	~16—6 h
2023 July 30	C-10	16.2 km	~17—7 h
2023 August 20	C-9	13.9 km	~19—8 h
2023 September 10	C-8	8.5 km	~20—9 h

Notes for Table 2:

1. Configuration properties are given in Section A.2

The first column of Table 2 gives the planned start date for each configuration. These dates are subject to change because of weather conditions. The second column gives the 12-m Array configuration, and the third column lists the longest baseline for the configuration (see Table A-1 for corresponding resolutions and maximum recoverable scales). The fourth column lists the LST ranges when the observing conditions are most stable, approximately two hours after sunset to four hours after sunrise (Section 4.3.1). The effective observing time available per configuration for executing PI projects (excluding time spent on observatory calibration, maintenance, reconfigurations, and other activities – see Section 4.3) is shown in Figure 4.

Given the anticipated configuration schedule and weather constraints, the following considerations apply:

- Band 9 and 10 observations will be scheduled during the LST ranges given in the fourth column of Table 2, corresponding to more stable weather conditions (Section 4.3.1). The amount of time with stable atmospheric conditions suitable for Bands 7 and 8 observations outside of those LST ranges is limited (see Figures 2 and 3). To maximize the completion of high-frequency observations, such projects are given priority in the observing queue when the weather conditions are suitable (Section 4.3.1).
- High-frequency projects (Bands 7 to 10) and Band 5 observations near the atmospheric absorption feature at 183 GHz are not recommended during the Altiplanic winter (December to March) at any LST.
- The probability of an observation being scheduled depends on the over-subscription for the given LST and configuration in addition to the required weather conditions.
- Projects that have imaging requirements (constraining the necessary configuration) and other time constraints (e.g., due to coordination with other observatories) that do not coincide cannot be scheduled.

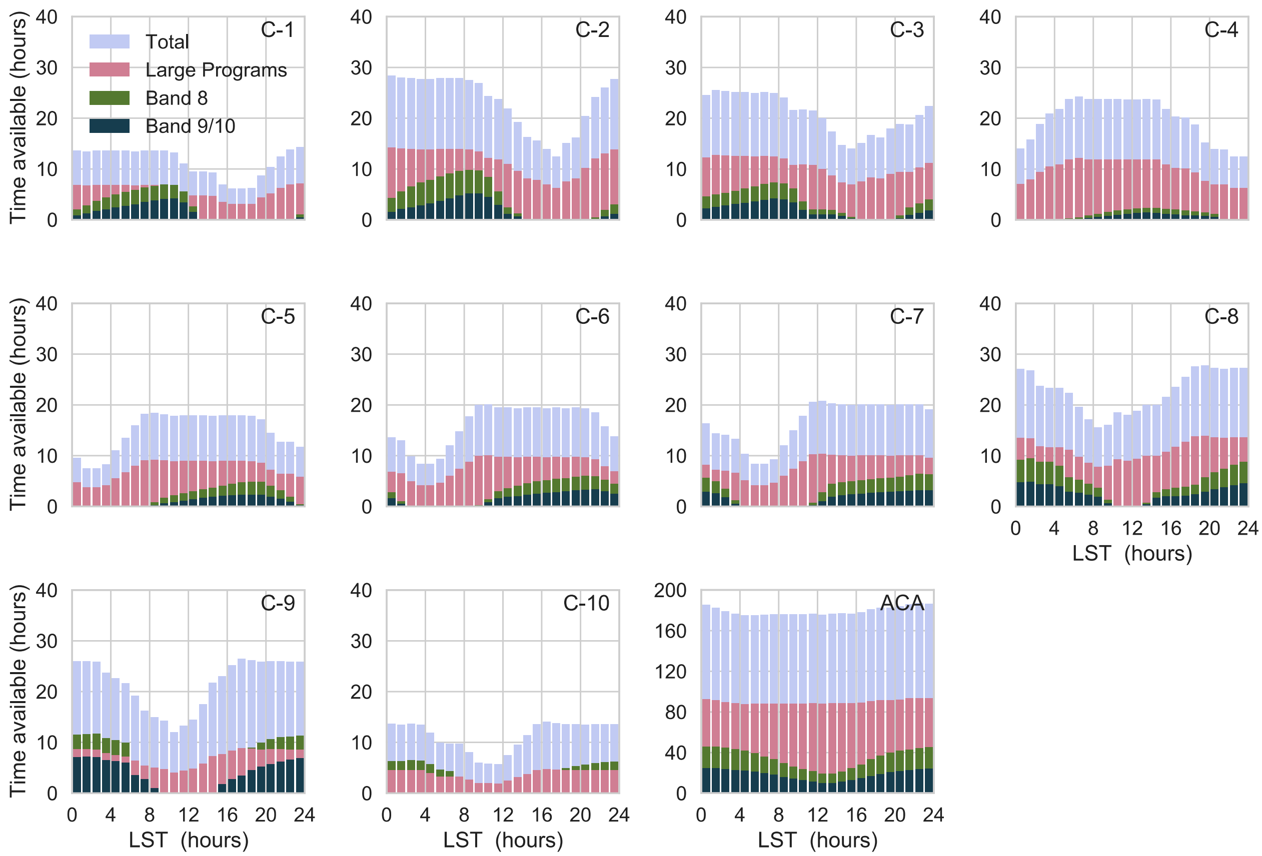

Figure 4: Estimated observing time available per configuration for executing PI projects, based on precipitable water vapor (PWV) only. For example, approximately 24 hours are expected to be available in C-4 at LST 05 h for all observations and up to 12 h of those may be allocated to Large Programs. The time available for Large Programs is shown in pink and time for high-frequency observations in green and dark blue. While Band 9 and 10 have the same PWV limits, Band 10 will only be offered up to C-8 in Cycle 9 – in the C-9 panel the histogram labeled "Band 9/10" only applies to Band 9. The configuration schedule and, consequently, the total number of hours available per configuration may change in response to proposal pressure (Section 4.3.3). The data files containing these histograms are available here.

4.3.4 Observing pressure

Figure 5 shows the LST distribution of Cycle 8 2021 submitted proposals and of those awarded grades A, B, or C by configuration and array type. While some LST ranges such as 2-6 h or 12-19 h show over-subscription in several configurations, the degree of over-subscription differs significantly for different configurations. In general, proposals will have a higher probability of acceptance if they request time in less subscribed LST ranges.

The range of angular resolutions provided by PIs (Section 4.3.2) will have a direct impact on the observing pressure per configuration. Proposals that specify a broad range of acceptable angular resolutions (i.e., several acceptable configurations) increase their likelihood of being scheduled and executed. However, PIs should only request the range of angular resolutions that is acceptable for their science goals, as this choice will be evaluated during the proposal review process.

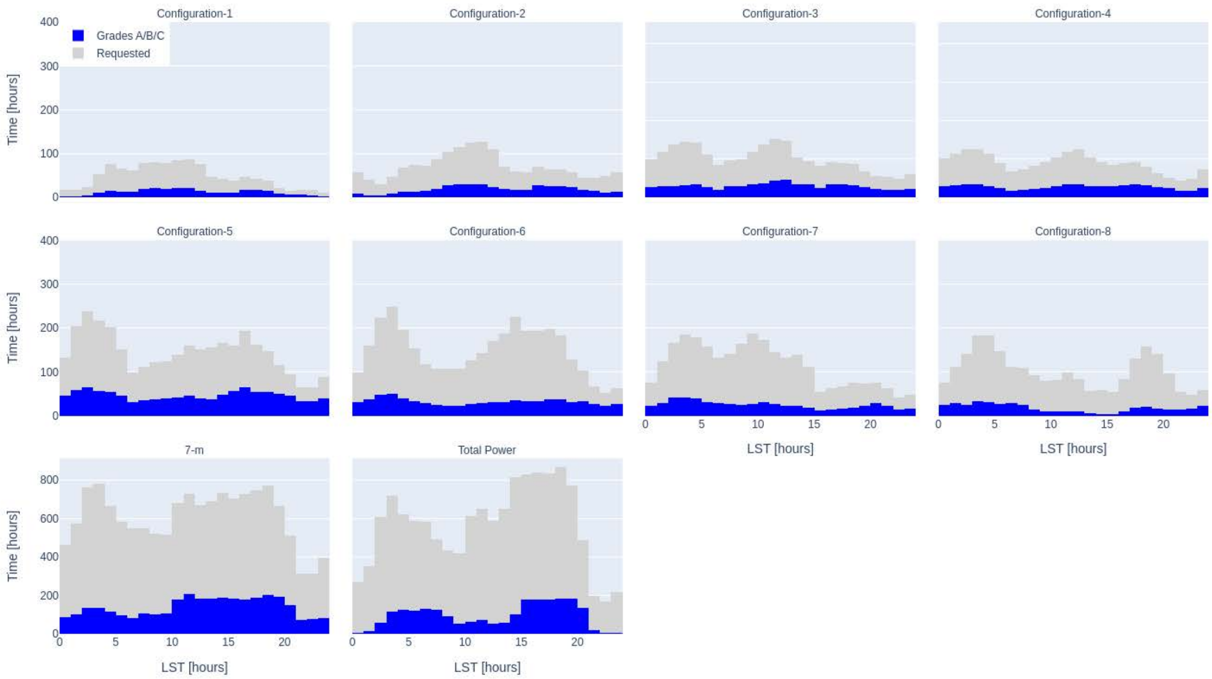

Figure 5: Distribution of estimated execution time in Cycle 8 2021 for all submitted proposals (gray) and proposals assigned Grade A, B, or C (blue). The figure does not include the unfinished Cycle 7 Grade A proposals carried over to Cycle 8 2021. Configurations C-9 and C-10 were last visited during Cycle 7; for historical LST pressure in those two configurations, please refer to the Cycle 8 2021 Proposer's Guide.

4.4 Duplicate observations and resubmissions

4.4.1 Checking for duplications

Duplicate observations of the same location on the sky with similar observing parameters (frequency, angular resolution, coverage, and sensitivity) are not permitted unless scientifically justified. Detailed criteria of what constitutes a duplicated observation are specified in Appendix A of the Users' Policies.

PIs are responsible for checking their proposed observations against the Archive and the list of Grade A projects in the observing queue provided on the Science Portal to avoid duplicate observations. PIs proposing duplications of previous cycle observations will not have their proposals marked as duplications if they had no way to know about the previous cycle observations, using the resources listed above, by the release of the Call for Proposals. Information on checking for duplications is available on the Duplicate Observations page on the Science Portal.

The proposal cover sheet contains a section where PIs can justify observations known to be duplicate. PIs may wish to justify their proposed observations in cases where they are similar to previously executed or accepted programs but are not formal duplicates. This will help the reviewers understand why new observations are requested.

Examples of duplicate observations that may be approved include:

- Observations of time-variable phenomena.
- A large-area survey where cutting out a smaller area to avoid overlap with a previous observation will make the observation inefficient and increase the overall execution time.

- Spectral scan surveys where excluding a frequency range covered by a previous observation will make the observation inefficient and increase the overall execution time.

4.4.2 Resubmission of an unfinished proposal

Proposal teams that submit a Cycle 9 proposal to observe some or all the SGs of an unfinished project will have the relevant SGs identified as a "resubmission". An SG is deemed a resubmission if it constitutes a duplication of an existing SG following the rules specified in Appendix A of the Users' Policies and the PI of the relevant Cycle 8 2021 project is listed as a PI, co-I or co-PI of the corresponding Cycle 9 proposal or the Cycle 9 PI is listed as an investigator on the Cycle 8 2021 proposal. For such resubmissions, the relevant portion of the Cycle 9 proposal will be cancelled if the observations are successfully completed in Cycle 8 2021. Observations started in a previous cycle and accepted as a resubmission in Cycle 9 will continue to be observed with the setup of the previous cycle.

A Scientific Justification must be provided if the proposers request one or more additional epochs of observations in Cycle 9 even if the Cycle 8 2021 observations are completed.

4.5 Estimated observing time

Proposal requests are cast in terms of SGs, each containing a complete observational setup (desired sensitivity, range of angular resolutions and LAS, frequency band, spectral windows, and spectral resolutions) to be applied for one or more targets. The OT Quickstart Guide and the OT User Manual provide extensive details and guidance for preparing the SGs. Experienced users who wish to understand how ALMA observations are set up may refer to Chapter 8 of the Technical Handbook.

The observational setup of a given SG is used to estimate a total observing time for that SG (except for solar or VLBI observations or when overridden by the PI - see Appendix B). This observing time is the sum of the required time on source for all science targets, time for all calibrations including overheads, and the time for any additional array configurations needed to meet the specified LAS. The estimated observing time for the proposal is the sum of the times for all SGs. The actual observing time to reach a given sensitivity, resolution, and LAS will depend on the prevailing conditions when the project is observed, the number of antennas available, and the actual array configuration.

The estimated time on source is calculated with the ALMA Sensitivity Calculator (ASC), available within the OT or as a stand-alone web application on the Science Portal. The parameters that affect these time estimates include requested sensitivity, source declination, observing frequency, spectral bandwidth, number of antennas, angular resolution (if the sensitivity is specified in temperature units[5]), and default weather conditions. A description of the ALMA Sensitivity Calculator is given in Chapter 9 of the Technical Handbook.

The estimated time for calibrations and overheads is calculated by the OT and will depend on the frequency, configuration, and type of observation (e.g., full polarization observations require additional calibrations). Proposals requesting the suppression of some or all calibrations in one or more SGs may be deemed technically infeasible if the request is not properly justified in the proposal (see Section B.4 for details).

For each SG, one or more SBs are generated during Phase 2 depending on the distribution of sources in the sky and the number of configurations needed (Sections A.8.1 and A.4, respectively). Each SB

[5] Since Cycle 5, the time estimate adopts the configuration that fulfills the highest angular resolution requested if the sensitivity is specified in temperature units (Section 4.3.3).

contains all the commands needed to perform the observations and a complete set of calibrations. The minimum duration of the SB is constrained by a minimum time on source of 5 minutes for the sum of all the sources in the SB or 50% of the total calibration time (see Section 5.3.5.3 of the OT User Manual). For SGs that require a combination of arrays but have short time on source that is increased to the 5-minute minimum by the OT, the time multipliers given in Table A-2 may not be preserved (see Section A.4). The maximum duration of a SB is around 2 hours (determined by a maximum time on source of 50 minutes) and each SB will be re-run as many times as needed to achieve the requested signal-to-noise (S/N) ratio. Consecutive executions of a given SB (if needed) are favored during scheduling to maximize *uv*-coverage. However, if *uv*-coverage is fundamental for the scientific goals of a proposal, PIs should specify this request as a time constraint and, if necessary, override the OT time estimate with the time needed to achieve such *uv*-coverage (see Section B.2 for details). Data from each SB will be processed, assessed, and delivered independently.

The final factor in the time estimate is the possible addition of configurations needed to reach the LAS specified by the user. The LAS is compared to the "Maximum Recoverable Scale" (MRS) of the configurations that best match the requested range of angular resolutions. The MRS for each configuration is listed in Table A-1. If the LAS exceeds the MRS of all matching configurations, then additional configurations, if allowed (Section A.4), are added with a time estimated using the multipliers given in Table A-2. If the array combinations are not allowed (Section A.4), the OT will give a validation error. If the LAS can be achieved with one or more of the best-matching configurations, the remaining configurations meeting the angular resolution but not the LAS request will not be considered.

The PI may include additional SGs for array combinations not allowed in a single SG, but each SG must be separately justified and have its own performance specifications (sensitivity, range of angular resolutions, and LAS).

Observations that require only the ACA are selected by checking a specific box in the OT interface. When calculating the time required for the ACA, for each Science Goal the OT uses the TP Array time if this array is required (based on LAS) or otherwise the 7-m Array time; i.e., it is not the sum of the 7-m and TP Array time. In case of simultaneous observations in the 12-m and 7-m Arrays, the estimated time for the 7-m Array will be set equal to that of the 12-m Array.

Note that snapshots with the 7-m Array are strongly discouraged for imaging. For single pointings, integrations of at least one hour are necessary for sufficient *uv*-coverage to achieve good image quality. Ensuring sufficient *uv*-coverage for mosaics with the 7-m Array can be problematic because the integration time is spread out over many pointings. For this case, simulations that assume the minimum number of guaranteed antennas are strongly encouraged to help set the per-pointing integration time. See Chapter 7 of the Technical Handbook for more information on imaging with ALMA.

Time estimates for each SG are available in the OT by clicking "Planning and Time Estimate" in the "Control and Performance" panel. A summary of the time estimate of each SG can be viewed by clicking the "Time Summary" button on the OT toolbar. The times for the 12-m Array, 7-m Array, and TP Array are tabulated separately on the proposal cover sheet.

4.6 Supporting tools and documentation

4.6.1 The Observing Tool documentation

The ALMA OT, a Java-based application that resides and runs on the user's computer, is used to prepare and submit observing proposals (Phase 1) as well as to prepare the observations for execution on the telescope (Phase 2) if the proposal is accepted. The OT includes a number of tools and checks to ensure submitted proposals conform to the Cycle 9 capabilities.

The OT is most conveniently installed using the new installer option, which is available for Linux, Mac OS, and Windows. The installer contains its own version of Java and thus it is not necessary for users to install Java themselves. As of Cycle 8 2021 the Web Start installation is no longer available for the OT.

The OT documentation suite, which provides all the basic information required to complete the proposal preparation and submission, includes:

- The OT Phase 1 Quickstart Guide: A guide to proposal preparation for the novice ALMA OT user. It provides an overview of the necessary steps to create an ALMA observing proposal.
- The OT Video Tutorials: A visual demonstration of proposal preparation and submission with the OT. Users should note that these videos were produced in Cycle 6 and therefore do not include the changes implemented since then.
- The OT User Manual: A manual intended for all ALMA users, from novices to experienced users. It provides comprehensive information on creating valid Phase 1 proposals and Phase 2 programs for observing astronomical objects. It is also included as part of the "Help" documentation within the OT itself.
- The OT Reference Manual: A manual providing a concise explanation for all the fields and menu items in the OT. It is also included as part of the "Help" documentation within the OT itself.
- The OT trouble-shooting page: A list of the OT installation requirements and workarounds for common installation problems.
- The known OT issues page: A list of known bugs, their status, and possible workarounds. This page may be updated during the proposal submission period and should be checked first if problems are experienced with the OT.

4.6.2 Additional proposal preparation tools

Two tools are available to help users produce simulated images of ALMA observations of simple or user-provided science targets. The first simulation tool is integrated into CASA, the offline data reduction and analysis tool for ALMA data. CASA includes the tasks "simobserve" and "simanalyze", which generate simulated visibility data and make images from these simulated data sets. An additional CASA task, "simalma", simplifies the process for ALMA data by combining data from multiple arrays, including the TP Array, if needed. These CASA tasks require configuration files that specify the layout of ALMA antennas. To simulate observations for Cycle 9, investigators can use the Cycle 9 configuration files available on the Science Portal. The CASA simulation tasks are described in the CASA documentation and detailed examples can be found in the CASA guides. Additional information on CASA, including hardware requirements and download instructions, is available at the CASA website.

The second simulation tool is the ALMA Observation Support Tool (OST). The OST uses a simplified web interface to help users generate ALMA simulations. Users submit jobs to the OST and are notified by email when the simulations are completed. The OST documentation is available at the OST website.

A guide for simulating ALMA observations with either tool is available at the CASA guides website.

Splatalogue is a database containing frequencies of atomic and molecular transitions emitting in the radio through submillimeter wavelength range. This database is used by the ALMA OT for spectral-line selection. More information is available in the Splatalogue QuickStart Guide.

4.6.3 The ALMA Regional Center guides

The ARC Guides contain user support details specific to each ALMA regional partner. They are:

- The **East-Asian ARC Guide**
- The **European ARC Guide**
- The **North American ARC Guide**

4.6.4 Supplemental documentation

The documents described below supplement this Proposer's Guide for the preparation of Cycle 9 proposals, for either the novice or advanced users. All documents can be accessed via the ALMA Science Portal.

The **Proposing Guidance page** from the Science Portal summarizes the steps involved in the preparation and submission of an ALMA observing proposal. It is designed to help users find the relevant documents and sources of additional information in each step of creating a proposal.

Observing with ALMA: A Primer is a brief introduction to ALMA observing, submillimeter terminology, and interferometric techniques that should prove useful for those new to radio astronomy. Several example science projects are described.

The **NAASC video series**, the **EU ARC network's Interactive Training in Reduction and Analysis of INterferometric data** and the **ALMA Explained** series have video tutorials on a wide range of topics related to interferometry and ALMA data analysis and archival queries.

The **ALMA Users' Policies** document contains a complete description of the applicable users' policies. The long-term core policies for usage of ALMA and of ALMA data by the user community are presented.

The **ALMA Cycle 9 Technical Handbook** describes the technical details of ALMA during Cycle 9, including but not limited to receiver characteristics, array configurations, available observing modes, and correlator setups, and the basis of the OT time estimates.

The **ALMA Memo Series** and **ALMA Technical Notes Series** include technical reports on various aspects of ALMA project development and construction and from the extension and optimization of capabilities.

4.7 The ALMA Helpdesk

The ALMA Helpdesk can be accessed from the ALMA Science Portal or directly at *http://help.almascience.org*. Submitted tickets are directed to the user's ARC, where support staff are available to answer any question related to ALMA, including but not limited to ALMA policies, capabilities, documentation, proposal preparation, the OT, Splatalogue, and CASA. Users may also request information on workshops, tutorials, or about visiting an ARC or ARC node for assistance with data reduction and analysis. Users must be registered at the ALMA Science Portal to submit a Helpdesk ticket. Replies to an already existing ticket can be sent by the user by logging into the SP or via email (see "Can I respond to my helpdesk ticket through my email?" for more details). ALMA staff aim to answer Helpdesk tickets within two working days.

ALMA staff will create a project ticket in the Helpdesk for each accepted proposal. Investigators can use this ticket for questions and communication on their project throughout its lifetime. Finally, investigators can also trigger ToO observations using the Helpdesk (see Section 3.2).

The "Knowledgebase" of the Helpdesk is a database of answered questions and articles on all aspects of ALMA. Users can search the Knowledgebase to find answers to common queries. Knowledgebase articles that match their query are automatically suggested to users as they type. The Knowledgebase query interface also searches all the documentation available on the ALMA Science Portal and provides a direct link to the documentation that may answer a user's question.

5 Proposal preparation, submission, and review

The following sections contain guidelines regarding proposal format and preparing the Scientific and Technical Justification. The setup of Science Goals is only briefly explained here. Users are referred to the extensive suite of OT documentation for details (Section 4.6.1). ALMA novices are encouraged to start with the **OT Quickstart Guide** and the OT **video tutorials.**

5.1 Proposal format

An ALMA proposal consists of basic proposal information that is entered directly into the ALMA OT (Section 4.6.1). Proposal information includes a Science Justification uploaded to the OT as a PDF file, and one or more Science Goals (SGs). SGs contain the technical details of the proposed observations and must include a Technical Justification.

After entering the basic proposal information and completing the SGs in the OT, the PI can generate the PDF of the complete proposal, including the Scientific Justification, SGs, and Technical Justification that will be distributed to the reviewers for evaluation. The first page of the PDF (the "cover sheet") includes the title and abstract together with a summary of the SGs. ALMA implements a dual-anonymous proposal review so the names of investigators are not listed on the cover sheet or elsewhere in the PDF seen by the reviewers.

5.2 Dual-Anonymous proposal review

To ensure that the proposal review process is as fair and unbiased as possible, proposals at ALMA are reviewed under a dual-anonymous system. In a dual-anonymous review, the proposal team does not know the identity of the reviewers and the reviewers do not know the identity of the proposal team. While proposers will still enter their names and affiliations in the OT, this information will not appear on the proposal cover sheet, or in the tools used by the reviewers. It is the responsibility of the proposers to ensure anonymity is preserved when writing their proposals. Proposers are recommended to review the PDF file of their complete proposal (generated using the OT) to ensure that anonymity is preserved throughout the whole document. Proposals that do not follow the dual-anonymous guidelines may be subject to disqualification. Details and specific guidelines on how to write your proposal following the dual-anonymous requirements are provided in the Guidelines for Dual-Anonymous Proposals on the Science Portal. Proposers with resubmissions are encouraged to be particularly cognizant of changes needed in their text. All proposers are encouraged to use the Helpdesk for any questions relating to dual-anonymous review.

5.3 Preparing the Scientific Justification

ALMA Cycle 9 proposals must include a single PDF document that includes a science case written in English. The document may include figures, tables, and references. The maximum permitted file size is 20 MB.

5.3.1 Page limits and fonts

The total length of the PDF document is limited to four pages for Regular, ToO, VLBI, Phased Array, and DDT proposals and six pages for Large Programs (A4 or US Letter format), **with a font size no smaller than 12 points**. The OT will check the font size of the PDF and issue an error during proposal validation if more than 15% of the text is smaller than 12 points. To submit the proposal, any problems with small fonts must first be fixed. Note that the OT may issue errors by detecting "hidden text" when figures are cropped from other PDFs. See the Knowledgebase article on font size problems for further details.

The recommended breakdown is two pages for the science case and two pages for figures, tables, and references, but proposers are free to adjust these numbers within the overall page limit. The document for Large Programs, which are allotted two additional pages, must also include a description of the value-added data products and their value to the community, the publication plan, and a discussion of the scheduling feasibility. Large Programs are also required to submit a separate one-page PDF document with their management plan through the OT at the time of proposal submission (see Section 5.5 for more details).

Figures and tables may be embedded within the science case so that they appear close to the location where they are referenced in the text. Although the Technical Justification for each Science Goal is entered in the OT, any figure required for it needs to be placed in the Scientific Justification PDF document. Users are encouraged to prepare their Scientific Justifications using the LaTeX template available on the Science Portal.

Proposals must be self-contained. Reference can be made to published papers (including arXiv.org preprints) as per standard practice in the scientific literature and they must be listed at the end of the science case. Consultation of those references should not, however, be required for understanding the proposal.

5.3.2 Science case

Each proposal must describe the scientific importance of the proposed project and include a clear statement of its immediate observing goals, including the suitability of the observations to achieve the scientific goals (see Section 5.6.2 and guidelines for reviewers). It is also recommended to provide a brief justification of the requested sensitivity and angular resolution, with full details provided in the Technical Justification (Section 5.4).

Proposers can simulate ALMA observations using different array components and configurations (see Section 4.6.2). Simulations are not required. However, if they are discussed in a proposal to justify any technical aspects of an observation, their results (i.e., images and simulation details) should be included in the Scientific Justification and referenced in the relevant Technical Justification.

Proposal reviewers are selected with expertise that covers the various topics within a proposal category. Therefore, the Scientific Justification should be written for a knowledgeable but broad-based audience.

5.3.3 Figures, tables, and references

Figures, tables, and references that support the science case and the Technical Justification may be included. **Figure captions, tables and references must use a font size no smaller than 12-points** and, together with the science case, must fit within the overall page length and 20 MB size limit of the PDF proposal.

5.4 Preparing the Technical Justification

Each SG within a proposal must contain a Technical Justification (TJ), which is entered directly into the OT in the TJ node of each SG. Any figures associated with the TJ must be included in the Scientific Justification PDF file and clearly referenced in the TJ. The TJ must include a quantitative description and justification of the expected source brightness, the requested sensitivity and S/N ratio, angular resolution, and spectral setup. An incomplete TJ may lead to the rejection of the proposal on technical grounds. The TJ must abide by the guidelines of dual-anonymous review.

Each SG has its own TJ because the technical setup of the observations will often vary substantially from one SG to the next. If a TJ is applicable to more than one SG, the TJ node can be easily copied and pasted (or dragged and dropped) between SGs. The TJ node contains three sections – sensitivity, imaging, and correlator configuration – corresponding to the main aspects that need to be assessed for the technical feasibility of any proposal. Each section includes at least one free-format text box that must be filled in (50 characters minimum), as well as a number of parameters computed from the user input captured in that Science Goal. This information is designed to help with the writing of the TJ, and will also highlight potentially problematic setups (in blue text) if applicable. Please see the relevant sections in the OT Reference Manual (accessible by clicking the "**?**" symbols within the OT) for details. If the OT detects any technical choices that require an extra justification (e.g., time-constraints), appropriately labelled text boxes will appear in an additional "Choices to be justified" section.

Given that the information and the text boxes displayed in the TJ node are dependent on information provided elsewhere in the SG (including the Expected Source Properties entered in the Field Setup node), the Science Goal should be completed before filling in the TJ. Specific guidelines on filling out the TJ are given in Appendix B.

If a proposal does not conform to the advertised capabilities, it can be declared technically infeasible either during the proposal review process or during Phase 2 (Section 6.1). The final decision will be made by the Head of Science Operations at the JAO.

5.5 Management Plan for Large Programs

In addition to their Scientific and Technical Justifications, all Large Programs must include a one-page management plan. This document should demonstrate that the proposal team is prepared to complete the project in a timely fashion, including the data analysis, generating the value-added data products for the community, and publishing the results. The plan should outline the major participants of the project team and their responsibilities. Each Large Program is unique in terms of its computing and data processing requirements. The management plan should indicate the amount of data that their project expects to generate and demonstrate that the proposal team has access to sufficient computing resources and storage to process the data. The OT reports estimated data rates and overall data volumes that can be used as a guide to estimate the volume of raw data that would be delivered. It is not uncommon for the final data volume to double after full calibration and the generation of imaging products.

The ARCs can provide assistance to Large Program teams to optimize the observing strategy for their proposals and to prepare the management plans. PIs are encouraged to contact their ARCs early in the proposal process to receive assistance on any of these needs and to ensure the availability of the necessary computing and storage resources.

5.6 Proposal validation, submission and withdrawal

After the proposal is validated within the OT, it can be submitted to the ALMA Archive. Validation could take up to 5 minutes (or longer!) if the program contains complicated setups or a large number (hundreds) of sources. PIs of such programs should submit their proposals well before the deadline. A proposal can be updated and submitted again to the ALMA Archive as many times as needed by the PI before the proposal deadline. Each time a proposal is submitted, the previous version of the proposal is overwritten (Section 5.6.1). Submitted proposals cannot be modified after the deadline. DDT proposals are not overwritten when submitted again, so they should only be submitted once.

Proposals will be accepted starting at 15:00 UT on 24 March 2022 and until **the proposal deadline at 15:00 UT on 21 April 2022**. No proposal submissions or updates will be accepted after the deadline. It is the PI's responsibility to submit the proposal successfully before the deadline. PIs are encouraged to submit their proposals early.

In addition, the following considerations apply:

- PIs, co-Is and co-PIs can retrieve proposals from the Archive both before and after the deadline.
- PIs who successfully submit their proposal will receive a confirmation e-mail from ALMA that includes the assigned project code.
- DDT proposals may be submitted at any time. Like all other proposals, they must include a detailed science case and Technical Justification.
- A Helpdesk ticket should be submitted if the PI needs to withdraw a proposal that has already been assigned a project code.

5.6.1 Proposal updates

PIs who need to update and then resubmit a proposal should ensure that this is done using the last submitted version either by (i) modifying the proposal saved after submitting it (i.e., saved from the OT as a .aot file), or (ii) downloading and then modifying the submitted proposal from the Archive using the OT. If a PI tries to submit a version of the proposal that had been saved on disk before it was first submitted, it will be rejected by the Archive. An earlier version that was never submitted (and which therefore contains no proposal code) will produce a new (duplicate) submission with a new code.

Users wishing to generate a new proposal starting from a proposal from the current submission period should save the original one to disk before it has been submitted. Otherwise, the second proposal will contain the original proposal's code and will overwrite it when submitted. Alternatively, the OT's "Open Project as New Proposal" (available from the File menu) could be used. Users wishing to generate a new proposal from a project file corresponding to a proposal submitted in a previous cycle should use "Open Project as New Proposal" to open the project as an unsubmitted proposal for the current cycle.

5.7 Proposal evaluation and selection

5.7.1 Peer review

ALMA will continue the use of a distributed peer review process for scientific review of most proposals submitted to Cycle 9. Proposals requesting less than 50 hours on the 12-m Array and all ACA stand-alone proposals requesting less than 150 hours on the 7-m Array will be evaluated in this way. The review process is summarized below; for additional details, including guidelines for the reviewers and the expected timeline, see the Proposal Review section of the Science Portal.

Except for Large Programs, the PI of each proposal must designate themselves or a co-I as a reviewer at the time of submission. In most cases the PI will be the designated reviewer. Nonetheless, to keep the review workload to a manageable level, PIs are encouraged to designate one of their co-Is as reviewer when planning to submit multiple proposals.

After the proposal deadline, the Proposal Handling Team (PHT) at the JAO) will assign ten proposals to the designated reviewer of each proposal. The proposal assignment will be done based on the expertise of the designated reviewer as specified in their user profile[6]. The assignment process will also consider possible conflicts of interest. If the designated reviewer provides a list of their conflicts of interest in their user profile, the assignment process will take this information into account and the reviewer will not be assigned proposals for review in which the PI, a co-PI, or a co-I are in their list. If no list of conflicts is provided, the assignment process will identify conflicts based on the designated reviewer's past ALMA collaborations. During the review process, if the reviewer identifies a conflict of interest in their assigned proposals, they can request a replacement proposal through the Reviewer Tool. Then during Stage 1, the reviewer will rank the ten proposals (1-10, strongest to weakest) in order of scientific priority and write a review for each proposal. **If ranks and reviews are not submitted by the Stage 1 review deadline at 15:00 UT on 01 June 2022, the proposal on which the reviewer is acting as the designated reviewer will be declined.**

After the Stage 1 review deadline, each reviewer will have the option to participate in Stage 2 of the review process, where the anonymized comments from the other reviewers of the same proposals will be made available. During Stage 2, reviewers can modify their own ranks and comments if desired. After this second stage is completed, the ranks from all reviewers of each submitted proposal will be combined to produce a global ranked list of proposals.

Any PI and most co-Is can be designated as a reviewer. If the PI does not have a Ph.D. at the time of proposal submission (e.g., a student), the PI can still be the reviewer, but a mentor (who must have a Ph.D.) must be identified at the time of the proposal submission. A PI may designate a co-I as the reviewer as long as the co-I has a Ph.D. in astronomy or a closely related field. When planning to submit multiple proposals, PIs are encouraged to designate a co-I as reviewer. The reviewer and (if needed) mentor must be designated in the OT at the time of proposal submission.

Large Programs will be reviewed by a single panel, the ALMA Proposal Review Committee (APRC). The APRC will be composed of 16-18 members of the scientific community drawn from the five ALMA science categories. Barring conflicts of interest, all members of the APRC will review all

[6] We encourage all ALMA users to go to the ALMA Science Portal to update their user profiles and select keywords pertaining to their expertise. The distributed review proposal assignment algorithm will use the selected keywords of the reviewer's expertise for matching assignments; if reviewers do not submit them, the algorithm will use the keywords of the submitted proposal. Review assignment matching is therefore optimized for individual reviewers' expertise when the information provided in the users' profile is up to date and accurate.

submitted Large Programs. Proposers should take special care to write their proposals for a broad audience considering the different expertise of the members of the APRC. For each Large Program, the JAO will select one member of the APRC to act as the Primary Assessor; they will be in charge of leading the discussion and write the consensus report. This assignment is done based on the expertise of the APRC members and the science category selected by the PI when submitting their proposal (see Appendix D for the list of scientific categories). To gain further expertise, Large Programs will also be reviewed by external Science Assessors, who will provide written reports for the APRC to consider during the meeting. The APRC will take all reviews into consideration and will recommend which Large Program to schedule.

After the outcome of the proposal review process is approved by the ALMA Director's Council and a Chilean representative, the results will be communicated to the PIs. The notifications will include the assigned grade and a consensus report from the APRC that summarizes the strengths and weaknesses of the proposal.

5.7.2 Evaluation criteria

The primary criteria to rank all proposals are the overall scientific merit of the proposed investigations and their potential contribution to the advancement of scientific knowledge. The guidelines for the reviewers contain detailed review criteria. The proposals will also be evaluated for technical feasibility to ensure they are consistent with Observatory best practices.

Given the significant investment of ALMA resources for Large Programs, the APRC will also consider the following factors for these programs:

- Scheduling feasibility

  A Large Program should be designed such that the observations are likely to be completed within Cycle 9 given the antenna configuration schedule and weather constraints (see Sections 3.3 and 4.3). The scheduling feasibility of each Large Program will be evaluated and the and communicated to the APRC.
- Value-added data products and publication plan

  A Large Program should describe the value-added data products that will be produced to achieve its science goals and their value to the community, as well as present a plan to publish the results of the project. The program teams will be expected to deliver these data products to ALMA so that they can be made available to the community at large.
- Management plan

  The APRC will evaluate the management plans to assess if the proposal team is prepared to complete the project in a timely fashion, both in terms of personnel and computing resources. The management plans will be evaluated only after the APRC has completed the scientific rankings of the Large Programs. The evaluation of the management plan will not be used to modify the scientific rankings. Any concerns that the APRC has about the management of a Large Program will be communicated to the ALMA Director, who will make the final decision on whether to accept the proposal.

5.7.3 Proposal selection

The APRC will evaluate the management plans to assess if the proposal team is prepared to complete the project in a timely fashion, both in terms of personnel and computing resources. The management plans will be evaluated only after the APRC has completed the scientific rankings of

the Large Programs. The evaluation of the management plan will not be used to modify the scientific rankings. Any concerns that the APRC has about the management of a Large Program will be communicated to the ALMA Director, who will make the final decision on whether to accept the proposal.
The results from the APRC and the distributed peer review will be used to form an observing queue based primarily on the scientific rankings from the review process.[7] The formation of the observing queue will also take into account the scheduling constraints dictated by the configuration schedule and weather, the share of observing time for each region, and the time constraints on Large Programs and VLBI.

Up to 33% of the nominal time specified in Section 4.1 will be assigned to Grade A proposals and 67% to Grade B proposals. Grade C will be assigned to proposals for filler time to ensure that an adequate number of projects are available for all configurations and LST ranges in case the actual observing efficiency or weather conditions differ from expectations.

The shares of the observing time among the regions are:

- 33.75% for the European Organisation for Astronomical Research in the Southern Hemisphere (ESO).
- 33.75% for the National Science Foundation of the United States (NSF).
- 22.5% for the National Institutes of Natural Sciences of Japan (NINS).
- 10% for the Chilean community, which is administered jointly by the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT) and the Universidad de Chile.

All regions contribute toward “Open Skies” to enable all eligible Principal Investigators (Section 2.5) to apply for ALMA time.

5.8 Proposal confidentiality

For proposals assigned Grade A or B, the project code, the proposal title and abstract, the name and region of the PI, and the names of co-Is (and co-PIs, in the case of Large Programs) will be made public soon after PIs are informed of the outcome of the proposal review process. For proposals assigned Grade C, the corresponding information will be made public as soon as its first data are archived.

Proposal metadata (for example the source positions, observation frequencies, and integration times) for Grade A will become public soon after the proposal review process is completed. For Grade B and C proposals, metadata will be made public as soon as the first data are archived. The metadata for proposals with Grade U or unobserved Grade B or C proposals will remain confidential.

The Scientific and Technical Justifications of all submitted proposals remain confidential, except for proposals for 0.87 mm and 1.3 mm VLBI proposals, which will be sent for technical review by the Event Horizon Telescope Consortium (EHTC) VLBI network.

[7] For VLBI proposals, both ALMA and the appropriate VLBI network must accept a given proposal for the observations to be scheduled.

6 Post-proposal activities

6.1 Observation preparation and submission: Phase 2

Once a project has been approved for scheduling, the project passes into Phase 2. PIs will not be required to submit Phase 2 Science Goals in Cycle 9 (see ALMA Users' Policies for further details). Each approved project will be assigned an ALMA Contact Scientist (CS) at the associated ARC or ARC node and a project Helpdesk ticket will be opened on behalf of the PI for communication with the CS and others. Necessary minor changes may be requested through this Helpdesk ticket and will be implemented as long as they do not impact the science scope or increase the total execution time. Any significant change may only be made after the approval of a PI-initiated change request through the Helpdesk (Section 6.2). The CS can assist the PI with any questions during Phase 2.

ALMA staff will generate the Scheduling Blocks and, in case of problems, will contact the CS and the PI. If no problems are found, the project will be submitted to the ALMA observing queue to await execution at the telescope. PIs may track the status of their SBs through the Snooping Project Interface (SnooPI), accessible from the ALMA Science Portal.

For approved solar observations, the ALMA staff will coordinate with the PI to get an updated target ephemeris at least 24 hours in advance of the proposed observation. PIs of observations with ephemeris targets other than the Sun are responsible for providing a valid target ephemeris file during the Phase 2 process and any updates during the Cycle if necessary.

6.2 Changes to submitted programs

Changes to a submitted proposal will not be permitted prior to the completion of the review process. Therefore, PIs should carefully check source coordinates, frequency and angular resolution settings, and calibration needs before submitting their proposal. PIs are encouraged to use the Helpdesk if they need support.

PIs of proposals assigned a grade of A, B, or C may request changes to their projects subject to the ALMA Change Request policies described in the Users' Policies. Minor changes can usually be made, but PIs are strongly encouraged to make any necessary requests well in advance of the potential scheduling of observations. Major changes are allowed only if additional information that may seriously affect the scientific case of the project has become available since the time of submission, when there is a demonstrable mistake, or when there is the potential for interesting scientific optimization.

All change requests are made through the ALMA Helpdesk. The request must include a clear description of the proposed change along with a clear, substantive justification for the change. Major change requests are treated case-by-case and evaluated taking into account the increase in science scope, change of observing time, changes in the observing setups, and other factors. Change requests leading to duplications against ALMA proposals in the observing queue or archival observations will not be approved.

6.3 Data processing and data delivery

ALMA staff, assisted by the ALMA Data Reduction Pipeline, will conduct quality assurance on ALMA data and will provide processed data products through the respective ARC archives. Quality Assurance Level 2 (QA2) is performed on the data that result from all executions of an SB. In particular, the data are checked for calibration accuracy and to assure there are no imaging artifacts (see ALMA QA2 Data Products for more details). Data that meet the PI-specified goals within cycle-specific tolerances (see Chapter 11 of the Technical Handbook) are made available to the PI. Once the products have been identified as suitable for delivery, the PI is notified that the data are available for download through the ALMA Archive. PIs are requested to check the delivered data as soon as practical. If the PI discovers a problem in the delivered data other than any caused by a PI mistake, they must submit a Quality Assurance Level 3 (QA3) request to the Helpdesk as soon as possible, since such problems will have implications for re-observations and the proprietary period. For a more detailed description of the Quality Assurance process, see Section 6.3 of the ALMA Users' Policies and Chapter 11 of the Technical Handbook.

By default, data obtained as part of an ALMA science program are subject to a proprietary period of 12 months (except DDT programs, which have a proprietary period of 6 months), starting for each data package when the PI is notified that the data are available (see Section 8.4 of the ALMA Users' Policies).

At any time, a PI can request access to raw data for any execution that has passed Quality Assurance Level 0 (QA0). This request modifies the start of the proprietary period: once the raw data are staged for PI access, the proprietary time starts for that SB. See Section 8.4 of the ALMA Users' Policies for more details on requesting raw data or contact the ARC for support.

6.4 Opportunities for public promotion of ALMA

If a PI believes their results are newsworthy or of interest to a broader community, the PI should contact the ALMA Education and Public Outreach (EPO) team to develop materials for presentation to the media and the public (e.g., press releases), including support in the preparation of visuals, if relevant. EPO may ask for cooperation on the scientific content and for the PI to be available for possible interviews. The e-mail address for the ALMA EPO team is alma-iepot@alma.cl.

Appendix A ALMA Cycle 9 Capabilities

This appendix describes the characteristics and capabilities of ALMA offered for Cycle 9. All submitted proposals must be compliant with these capabilities or they will be judged as infeasible. Where possible, the ALMA OT has validation checks to warn the user or to prevent the user from entering unallowed values.

A.1 Number of antennas

At least forty-three 12-m antennas in the main array (hereafter the 12-m Array) will be offered. The ACA will have available at least ten 7-m antennas (hereafter the 7-m Array) for short baselines and three 12-m antennas (hereafter the Total Power Array or TP Array) for making single-dish maps. The ACA will be offered both to complement observations with the 12-m Array and as a stand-alone capability. The stand-alone ACA is offered either with the 7-m Array alone or with the 7-m Array and TP Array combined. The OT currently does not permit users to request only the TP Array (see Section A.3 if TP Array observations are needed to supplement archival 7-m Array data). Proposals requesting stand-alone ACA time are subject to certain restrictions, including no bandwidth switching, no solar observations, no user-specified calibration, and no Astrometric observations. The use of the TP Array is limited to spectral-line observations (not continuum) in Bands 3 to 8.

The number of antennas available may sometimes be fewer than the numbers given above due to unforeseen problems with the equipment, or during array reconfigurations. During these times, ALMA staff aim to schedule observations that will not be seriously affected by having a slightly smaller number of antennas and may increase the integration times to compensate for the reduced sensitivity or reduced instantaneous *uv*-coverage, whenever practical.

A.2 Array configurations

As detailed in Section 4.5, a Science Goal is defined in terms of a desired range of angular resolutions (ARs) and the Largest Angular Structure (LAS) to be imaged. ALMA will meet these requirements by taking observations in one or more array configurations, which are characterized in terms of their AR and Maximum Recoverable Scale (MRS, the largest smooth angular structure to which a given array is sensitive – see Chapter 7 of the Technical Handbook for details). The properties of these configurations, and the allowed combinations, therefore define the imaging capabilities of ALMA.

The antennas in the 12-m Array will be staged into configurations that transition from the most compact (with maximum baselines of ~160 m) up to the most extended configuration (maximum baselines of 16.2 km in Cycle 9). Ten 12-m Array configurations have been defined to represent the possible distribution of antennas over this range of maximum baselines. These are denoted as C-x, with x=1 for the most compact configuration and x=10 for the most extended. These configurations are equivalent to the “C43-X” configurations reported by the OT and other ALMA subsystems. One 7-m Array configuration has been defined to represent the possible distribution of the ten 7-m antennas. The imaging capabilities of these configurations are given in Table A-1.

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 9 configurations

Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	185 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m	45 m	AR	12.5”	8.35”	6.77”	5.45”	3.63”	2.72”	1.93”	1.44”
	9 m	MRS	66.7”	44.5”	36.1”	29.0”	19.3”	14.5”	10.3”	7.67”
C-1	161 m	AR	3.38”	2.25”	1.83”	1.47”	0.98”	0.74”	0.52”	0.39”
	15 m	MRS	28.5”	19.0”	15.4”	12.4”	8.25”	6.19”	4.38”	3.27”
C-2	314 m	AR	2.30”	1.53”	1.24”	1.00”	0.67”	0.50”	0.35”	0.26”
	15 m	MRS	22.6”	15.0”	12.2”	9.81”	6.54”	4.90”	3.47”	2.59”
C-3	500 m	AR	1.42”	0.94”	0.77”	0.62”	0.41”	0.31”	0.22”	0.16”
	15 m	MRS	16.2”	10.8”	8.73”	7.02”	4.68”	3.51”	2.48”	1.86”
C-4	784 m	AR	0.92”	0.61”	0.50”	0.40”	0.27”	0.20”	0.14”	0.11”
	15 m	MRS	11.2”	7.50”	6.08”	4.89”	3.26”	2.44”	1.73”	1.29”
C-5	1.4 km	AR	0.55”	0.36”	0.30”	0.24”	0.16”	0.12”	0.084”	0.063”
	15 m	MRS	6.70”	4.47”	3.62”	2.91”	1.94”	1.46”	1.03”	0.77”
C-6	2.5 km	AR	0.31”	0.20”	0.17”	0.13”	0.089”	0.067”	0.047”	0.035”
	15 m	MRS	4.11”	2.74”	2.22”	1.78”	1.19”	0.89”	0.63”	0.47”
C-7	3.6 km	AR	0.21”	0.14”	0.11”	0.092”	0.061”	0.046”	0.033”	0.024”
	64 m	MRS	2.58”	1.72”	1.40”	1.12”	0.75”	0.56”	0.40”	0.30”
C-8	8.5 km	AR	0.096”	0.064”	0.052”	0.042”	0.028”	0.021”	0.015”	0.011”
	110 m	MRS	1.42”	0.95”	0.77”	0.62”	0.41”	0.31”	0.22”	0.16”
C-9	13.9 km	AR	0.057”	0.038”	0.031”	0.025”	0.017”	0.012”	0.0088”	N/A
	368 m	MRS	0.81”	0.54”	0.44”	0.35”	0.24”	0.18”	0.13”	
C-10	16.2 km	AR	0.042”	0.028”	0.023”	0.018”	0.012”	0.0091”	N/A	N/A
	244 m	MRS	0.50”	0.33”	0.27”	0.22”	0.14”	0.11”		

Notes for Table A-1:

1. See Chapter 7 of the Technical Handbook for relevant equations and detailed considerations.
2. AR and MRS values evaluated for source at zenith. For sources transiting at lower elevations, the North-South angular measures will increase proportional to 1/sin(ELEVATION).
3. Lmax and Lmin are the maximum and minimum baseline lengths in the array, respectively.
4. All angular measures scale inversely with observed sky frequency.
5. Angular resolutions assume Briggs weighting with *robust = 0.5*.

A.3 Total Power Array

The TP Array is used to recover extended emission when mapping angular scales up to the size of the requested map areas. TP Array observations are included only if the LAS cannot be achieved with the 7-m Array, and the TP Array can only be used for spectral-line observations (not continuum) in Bands 3 to 8. No Band 9 or Band 10 TP Array observations are offered for this cycle. Thus, angular scales greater than the 7-m Array MRS listed in Table A-1 cannot be recovered for any observations in Bands 9 and 10, or for continuum observations in any band.

The TP Array cannot be requested in a standalone mode using the OT. However, if a user has existing 7-m Array data through their own program or through archival data, but now realizes that TP Array data are needed to obtain short spacings, they can submit a proposal requesting both the 7-m Array and TP Array. The proposal should indicate that only the TP Array is needed and that the 7-m Array should be descoped if the proposal is accepted. This option is available only if the 7-m Array data have already been obtained.

A.4 Allowed array combinations and time multipliers

Only certain array combinations are allowed to meet the specifications of a given Science Goal (SG). A SG can use no more than two 12-m Array configurations, and 7-m Array observations are only allowed in conjunction with 12-m Array observations if one of the three most compact 12-m Array configurations is required. TP Array observations are allowed only if 7-m Array observations are also obtained (and subject to the restrictions in the preceding section). The allowed combinations are given in Table A-2 (with empty cells indicating combinations that are not allowed), and are built into the OT validation.

For the resulting data to be combined based on the sensitivity and weighting between the allowed 12-m, 7-m and TP Array configurations, the different arrays must be observed in the correct proportion, depending on the number of overlapping baselines (see Chapter 7 of the Technical Handbook for details). These are expressed in terms of multiplicative factors with respect to the time required in the most extended configuration (which in turn is set by the user-requested sensitivity and angular resolution). The adopted time multipliers are given in Table A-2, and are reported in the OT.

Table A-2: Allowed Array Combinations and Time Multipliers

Most Extended configuration	Allowed Compact configuration pairings	Extended 12-m Array Multiplier	Multiplier if compact 12-m Array needed	Multiplier if 7-m Array needed	Multiplier if TP Array needed and allowed
7-m Array	**TP**			1	1.7
C-1	**7-m Array & TP**	1		7.0	11.9
C-2	**7-m Array & TP**	1		4.7	7.9
C-3	**7-m Array & TP**	1		2.4	4.1
C-4	**C-1 & 7-m Array & TP**	1	0.34	2.4	4.0
C-5	**C-2 & 7-m Array & TP**	1	0.26	1.2	2.1
C-6	**C-3 & 7-m Array & TP**	1	0.25	0.6	1.0
C-7	**C-4**	1	0.23		
C-8	**C-5**	1	0.22		
C-9	**C-6**	1	0.21		
C-10	**-**	1			

Notes for Table A-2:

1. See Chapter 7 of the Technical Handbook for relevant equations and detailed considerations.
2. If the array configuration that meets the AR request according to Table A-1 has a MRS that is smaller than the LAS request, the OT checks if adding more compact array configurations, following the restrictions of this Table, fulfills the LAS request. If so, the final setup consists of the selected combination of arrays. Otherwise, the OT returns a validation error.

If more than one configuration is needed to satisfy the AR and LAS constraints of a given SG, separate Scheduling Blocks (SBs) will be prepared during Phase 2 (Section 6.1) for each required configuration. These will be observed independently, and the data from the different SBs will be calibrated and imaged separately.

An exception to the rules above occurs when requesting simultaneous observations with the 7-m Array and the 12-m Array. In this case the 12-m Array configuration is limited to C-1 through C-6 and only a single 12-m Array configuration will be observed (e.g., if observations are taken in C-6, C-3 will not be observed). The TP Array also be included if required to satisfy the LAS constraints. See the Technical Handbook for more details.

A.5 Receivers

Bands 3 to 10 are available on all antennas. For Cycle 9, observations with Bands 3 through 8 are offered in 12-m Array configurations up through C-10, Band 9 in 12-m Array configurations up through C-9, and Band 10 in 12-m Array configurations up through C-8 (see Section A.2). Band 3 to 10 are offered on the 7-m Array. Observations with Bands 3 through 8 are offered on the TP Array (see below).

There are two types of receivers: dual-sideband (2SB), where the upper and lower sidebands are separated in the receiver and then processed separately, and double-sideband (DSB), where the sidebands are super-imposed coming out of the receiver but are separated in later processing. All bands receive dual linear polarizations (X and Y).

Table A-3 summarizes the properties of the receiver bands offered in Cycle 9. Details can be found in Chapter 4 of the Technical Handbook.

Table A-3: Properties of ALMA Cycle 9 Receiver Bands

Band	Frequency range[1] (GHz)	Wavelength range (mm)	IF range (GHz)	Type
3	84 – 116	3.6 – 2.6	4 – 8	2SB
4	125 – 163	2.4 – 1.8	4 – 8	2SB
5	158 – 211	1.9 – 1.4	4 – 8	2SB
6	211 – 275	1.4 – 1.1	4.5 – 10	2SB
7	275 – 373	1.1 – 0.8	4 – 8	2SB
8	385 – 500	0.78 – 0.60	4 – 8	2SB
9	602 – 720	0.50 – 0.42	4 – 12	DSB
10	787 – 950	0.38 – 0.32	4 – 12	DSB

Notes for Table A-3:

1. These are the nominal frequency ranges for continuum observations. Observations of spectral lines that are within about 0.2 GHz of a band edge are not possible (at present) in Frequency Division Mode (FDM, see Section A.6.1) because of the responses of the spectral edge filters implemented in the correlator. IF is the intermediate frequency.

The capability to switch rapidly between receiver bands within the same SG (except for the purposes of data calibration) is not offered.

Water Vapor Radiometer (WVR) measurements to correct for fluctuations in atmospheric water vapor are available for all 12-m antennas. No WVRs are installed in the ACA 7-m antennas and no WVR corrections will be applied to 7-m Array observations.

A.5.1 Bands 9 and 10 considerations

For Bands 9 and 10 observations, PIs should take the following considerations into account. Because the sidebands can be separated reliably only in interferometric observations, single-dish Bands 9 and 10 observations with the TP Array will not be offered in Cycle 9. At Bands 9 and 10, a special correlator mode (90-degree Walsh Switching) is available. For every spectral window defined by the user, enabling this feature will produce another spectral window in the other sideband, mirrored around the value of Local Oscillator 1 (LO1). This mode doubles the continuum bandwidth to 15 GHz, thus producing a $\sqrt{2}$ improvement in sensitivity or reducing the time required to achieve a particular sensitivity by a factor of 2. In addition, the greater bandwidth coverage allows more spectral lines to be observed simultaneously, although aligning the spectral windows such that they cover additional transitions is difficult and thus this mode is currently restricted to the widest-bandwidth spectral windows. In Cycle 9, 90-degree Walsh Switching will be activated by default for continuum and spectral-line setups, although for the latter it will be possible (but not recommended) to deactivate it.

Owing to the complexity of the atmospheric absorption in Bands 9 and 10, calibration will be more problematic (this also applies to Band 8 and the high-frequency end of Band 7). Band 9 and 10 ACA 7-m Array observations will be more difficult to calibrate than the corresponding 12-m Array observations because the rapid atmospheric phase correction cannot be applied and the smaller collecting area will limit the network of usable calibrators. In particular, bright calibrators are sparse at these high frequencies. When possible, the JAO will include 12-m dishes from the TP Array in the 7-m Array observation to support calibration; no special action or request is required by the PI. All these factors (in addition to the limited *uv*-coverage) will affect imaging at Bands 9 and 10 and will limit the achievable dynamic range with the ACA 7-m Array. Imaging dynamic ranges up to 50 are typical for these bands (see Section A.9.1 for more details).

No mosaics are offered for Band 10 observations.

A.6 Spectral capabilities

A.6.1 Spectral windows, bandwidths and resolutions

The ALMA Intermediate Frequency (IF) system provides up to four basebands (per parallel polarization) that can be independently placed within the two receiver sidebands. For 2SB receivers (Bands 3 to 8 – see Table A-3), the number of basebands that can be placed within a sideband is 0, 1, 2, 3, or 4. The placement of the basebands is restricted for these receivers in that it is not possible to place three basebands in one sideband and the fourth baseband in the other (see Chapter 6 of the Technical Handbook for details). This restriction does not apply for DSB receivers (Bands 9 and 10).

The 12-m Array uses the 64-input Correlator, while the 7-m and TP arrays use the ACA Correlator. Both correlators offer the same spectral setups. The 64-input Correlator operates in two main modes: Time Division Mode (TDM) and Frequency Division Mode (FDM). TDM provides modest spectral resolution and produces a relatively small data set. It is used for continuum observations or for spectral-line observations that do not require high spectral resolution. FDM provides high spectral resolution and produces much larger data sets. A total of six correlator setups with different bandwidths and spectral resolutions are available (see Table A-4).

Table A-4: Properties of ALMA Cycle 9 Correlator Modes, dual-polarization operation [1,2]

Bandwidth (MHz)	Channel spacing[3] (MHz)	Spectral resolution (MHz)	Number of channels	Correlator mode[4]
1875	15.6	31.2	120	TDM
1875	0.488	0.976	3840	FDM
938	0.244	0.488	3840	FDM
469	0.122	0.244	3840	FDM
234	0.061	0.122	3840	FDM
117	0.0305	0.061	3840	FDM
58.6	0.0153	0.0305	3840	FDM

Notes for Table A-4:

1. These values are for each spectral window and for each polarization, using the full correlator resources and no on-line spectral binning.
2. Single-polarization modes are also available, giving twice the number of channels per spectral window, and half the channel spacing of the above table.
3. The "Channel spacing" is the frequency separation between data points in the output spectrum. The spectral resolution – i.e., the FWHM of the spectral response function – is larger by a factor that depends on the "window function" applied to the data to control the ringing in the spectrum. For the default function – the "Hanning" window – this factor is 2. See Chapter 5 of the Technical Handbook for details.
4. Only for the 64-input Correlator

For each baseband, the correlator resources can be divided across a set of "spectral windows" (spw) that can be used simultaneously and positioned independently. Up to four spectral windows per baseband are allowed. The correlator can be set to provide between 120 and 3840 channels within each spw, and the fraction of correlator resources assigned to each spw sets the number of channels and the bandwidth available within it. The sum of the fractional correlator resources spread across all spectral windows must be less than or equal to one (120 or 3840 channels in total).

The default correlator setup for FDM modes applies a spectral averaging factor of 2. This has the advantage of halving the data rate to produce more manageable data cubes, while reducing the spectral resolution by only 15%. However, an additional consideration when selecting the spectral averaging is that data taken over different time periods (e.g., different configurations or multiple observations within the same configuration) are not guaranteed to be precisely aligned in frequency. Therefore, the spectra will need to be interpolated onto a common frequency grid in CASA. If the expected linewidth is poorly sampled at the resolution of the spectrometer, it is recommended that no channel averaging be applied (i.e., a spectral averaging value of 1) to improve the accuracy of the interpolation (see Chapter 5 of the Technical Handbook for more information). Each correlator has a maximum data rate (70 MB/s for the 64-input Correlator) and the OT will issue a validation error if a given SG exceeds that data rate. For any spectral setup requiring an average data rate of more than 40 MB/s, PIs will be contacted during Phase 2 to discuss the possibility of reducing the data rate.

Different correlator modes can be specified for each baseband, but all spws within a given baseband must use the same correlator mode. For example, a high-resolution FDM mode can be used for spectral-line observations in one baseband (with up to four independently placed FDM spectral windows), while the other three basebands can be used for continuum observations using the low-resolution TDM mode. And while each spw within a baseband must use the same correlator mode, they can each be assigned a different fraction of the correlator resources and each use a different spectral averaging factor, providing a broad range of simultaneously observed spectral resolutions and bandwidths. Spectral windows can overlap in frequency, although the total continuum bandwidth for calculating the sensitivity is set by the total non-overlapped bandwidth.

Users are encouraged to enter the redshift or velocity of the target in the OT when feasible, as opposed to calculating the sky frequency themselves. Entering the expected redshift or velocity will allow automated line searches and identifications in the Archive or with external tools.

A.6.2 Science Goals with more than one tuning

An SG can include up to five tunings per group of sources within 10 degrees on the sky, except for SGs that request long-baseline configurations, for which the grouping is limited to sources within 1 degree. Spectral scans or observations of targets with different radial velocities can thus be achieved within the same SB.

Each SB is self-contained for calibration. Therefore, multi-tuning SGs result in bandpass, amplitude, and gain calibrators being observed for each tuning in the SB. For SBs that can be completed in a single execution, this scheme is quite efficient. However, for SBs that require multiple executions, the available time for science targets in each execution is reduced, and the resulting SBs can be quite inefficient. For such observations, separating each tuning into its own SG can lead to more efficient SBs and lower overall time estimates.

Spectral scan mode

A special case of the multiple tuning SG is the Spectral Scan mode, which is useful for spectral surveys or redshift searches. The OT will automatically configure a set of contiguous spectral windows to cover a specified frequency range. The following restrictions apply:

- Angular resolution and LAS are computed for the Representative Frequency of each SG.
- No more than five frequency tunings per target are used, all in the same band.
- Only one pointing per target is used (no mosaics or offsets are allowed).
- Full polarization cannot be selected.

A.7 Polarization

In addition to the dual-polarization (XX, YY) and single-polarization (XX) modes, observations to measure the full intrinsic polarization (XX, XY, YX and YY) of sources are also offered for 12-m Array TDM and FDM observations in Bands 3 to 7 as well as the stand-alone 7-m Array in Bands 3 to 7. For the 7-m Array, only linear polarization is guaranteed to meet the ALMA specification, and only within one third of the primary beam. While PIs will receive data that will allow them to generate circular polarization data, scientific commissioning has not been done and the quality and/or accuracy of that data at this time is not assured.

When a **Dual Polarization** setup is used, separate spectra are obtained for the cross-correlated parallel hands (XX and YY). These will give two independent estimates of the source spectrum that can be combined to improve sensitivity.

In **Single Polarization** mode, only a single input polarization (XX) is recorded. For a given resolution, this results in reduced sensitivity (by a factor of $\sqrt{2}$) compared with the Dual Polarization case, but one can use either a factor of two more bandwidth for the same spectral resolution (unless the maximum bandwidth was already being used) or a factor of two better spectral resolution for the same bandwidth.

For single-pointing polarization observations, targets must have a user-specified largest angular structure less than 1/3 of the primary beam for linear polarization, and less than 1/10 of the beam for circular. The expected minimum detectable degree of linear polarization, defined as three times the systematic calibration uncertainty, is 0.1% of the peak Stokes I (i.e., total unpolarized) flux for on-axis sources for both TDM and FDM observations within 1/3 of the primary beam. This limit does not depend on the source size (i.e., compact or extended). The minimum detectable degree of circular polarization is 1.8% of the peak Stokes I flux for both TDM and FDM observations within 1/10 of the primary beam. **Note that the systematic calibration uncertainty can degrade by a factor of ~2 depending on the quality of the polarization calibrator and observation conditions** (see Chapter 8 of the Technical Handbook for more details). The frequency settings for single-pointing continuum polarization measurements can be specified by the user, but the OT supplies default setups as detailed in Table A-5. For FDM mode, polarization observations at any frequency setting within Bands 3, 4, 5, 6 and 7 are allowed, but the spectral setup has to be the same for the polarization calibrator and the science target.

Table A-5: Default frequencies for Continuum Polarization Observations[1]

Band	spw1 (GHz)	spw2 (GHz)	LO1 (GHz)	spw3 (GHz)	spw4 (GHz)	Maximum Velocity Resolution (km/s)
3	90.5	92.5	97.5	102.5	104.5	5.603
4	138.0	140.0	145.0	150.0	152.0	3.852
5	196.0	198.0	203.0	208.0	210.0	2.788
6	224.0	226.0	233.0	240.0	242.0	2.420
7	336.5	338.5	343.5	348.5	350.5	1.671

Notes for Table A-5:

1. Fixed central frequencies for four TDM spectral windows, each of width 1.875 GHz, and the corresponding LO1 setting. Frequencies were chosen to optimize spectral performance, and they are centered in known low noise and low instrumental polarization tunings of the receivers. The last column shows the maximum allowed spectral resolution for mosaics in full polarization, corresponding to a spectral resolution of 1.953 MHz in each Band.
2. This table assumes that each baseband is populated with a single spectral window (spw) centered on the baseband frequency.

Mosaics are supported for linear polarization continuum maps using the 12-m Array but not yet for the stand-alone 7-m Array. The spectral setup for polarization mosaics is limited to the current default continuum frequency setups. Therefore, the PI will not be able to choose the frequency tuning of a given spectral window freely for a polarization mosaic. The PI can, however, choose between the TDM and FDM modes, but with a restricted frequency resolution when the FDM mode is chosen. This scheme has been implemented to allow for better continuum identification when mapping some sources of interest. The maximum spectral resolution that can be selected for FDM polarization mosaicking is 1.953 MHz, and the corresponding velocities for each Band are shown in Table A-5.

For linear polarization mosaics, the 150-point restriction per SG remains in place. The mosaic pattern can be arbitrary, but ALMA recommends a hexagonal grid when possible. While Nyquist sampling (half a beam overlap) is sufficient, a sampling sparser than Nyquist (i.e., a more “loosely packed” mosaic) must be justified. A proposal requesting a mosaic sampling rate sparser than Nyquist may be rejected on technical grounds. The average error estimates for linear polarization mosaics are 1 degree in polarization position angle, and 0.1% in polarization fraction in the regions of the mosaic that correspond to the inner 1/3 FWHM of a given pointing. Near the FWHM of a given pointing, the estimated upper limits are 4 degrees and 0.5% (see Chapter 8 of the Technical Handbook for details).

A.8 Source restrictions

Source positions are designated by: 1) fixed RA and DEC; 2) RA and DEC at epoch 2000.0 with a linear proper motion; or 3) an ephemeris that gives the RA and DEC as a function of time. All positions should be in ICRS (J2000).

At low elevations, it is possible for foreground array elements to block or "shadow" the signal received by background antennas, compromising the sensitivity and imaging characteristics of an observation (see Section 7.3 of the Technical Handbook for details). Therefore, observations of extremely high and low declination targets should be avoided, particularly in compact configurations. For the 12-m Array, this shadowing becomes significant (> 5%) in the most compact configuration for sources with declinations lower than −65° or higher than +20°. For the ACA, shadowing becomes significant for sources with declinations lower than -70° or higher than +25°. The adopted upper declination limit for ALMA is +47°, corresponding to a maximum elevation of 20 degrees at the ALMA site. The OT gives a warning for objects from +37 through +47° declination, corresponding to transits between 20- and 30-degrees elevation. The ALMA Sensitivity Calculator takes shadowing into account when determining time estimates.

A.8.1 Source Science Goal restrictions

A single SG is constrained to include one set of observational parameters that apply to all sources included in that goal. This includes a single angular resolution, sensitivity, LAS, and receiver band. There is no restriction on the number of SGs per proposal.

For sources distributed widely in the sky the SG will be split by the OT into different "clusters", each grouping all sources within 10 degrees (1 degree for SGs requiring long-baseline configurations). For each grouping within the SG, the total number of pointings must be less than or equal to 150. Pointings with the ACA, if used in concert with 12-m Array observations, do not count against this 150-pointing limit.

The sources in a SG are further subjected to the following restrictions:

- All the sources in a SG must be defined by the same field setup – either all as rectangular fields, or all as individual positions.
- Sources must use the same spectral setup (relative placement and properties of spectral windows).
- For a given group of sources clustered within 10 degrees on the sky (or 1 degree for long-baseline configurations), there cannot be more than 5 separate tunings.

A.8.2 Rectangular field

A rectangular field (also referred to as a mosaic) is specified by a field center, the length, width and orientation of the field, and a single spacing between the pointing centers. Observations are conducted using the "mosaic" observing mode. This mode repeatedly cycles through all the pointings in the mosaic so that the imaging characteristics across the map are similar.

The OT will set up a uniform mosaic pattern based on a user-specified pointing separation, and will calculate the time to reach the required sensitivity considering any overlap. Non-Nyquist spatial samplings are allowed but must be justified in the Technical Justification.

If ACA observations are requested as part of a mosaic, then a corresponding 7-m Array mosaic will also be observed. If these include TP observations, the mosaic area(s) will be covered by the TP Array using on-the-fly mapping.

An SG may include multiple sources, each of which can have a differently sized rectangular field. The collection of mosaics is subject to the source SG restrictions given above.

A.8.3 Individual pointings

PIs may choose to define a "custom mosaic" by specifying a set of individual, overlapping, pointing positions. Gaps in pointings are not allowed. Custom mosaics are subject to all the source SG restrictions given above.

The interferometric data will be combined in post-processing to produce a single image. If ACA observations are requested as part of a 12-m Array SG, then the corresponding 7-m Array observations will be obtained using a Nyquist-sampled mosaic pattern that covers the 12-m Array pointings. If these include TP observations, the mosaic area(s) will be covered by the TP Array using on-the-fly mapping.

Pointings that do not overlap within a given SG must be included as different field sources within the SG.

A.9 Calibration

The ALMA Observatory has adopted a set of strategies to achieve good calibration of the data (see Chapter 10 of the Technical Handbook). Requests for changes in these strategies will only be granted in exceptional circumstances and must be fully justified. The default option is automatic calibrator selection by the system at observing time, but some flexibility exists in choosing the actual calibrator sources in the OT. User-selected calibrators must be justified as they may result in decreased observing efficiency and/or calibration accuracy.

A.9.1 Imaging dynamic range

The standard ALMA data reduction with nominal phase stability should be sufficient to produce images with dynamic ranges (peak continuum flux to map rms) up to ~100 for the ACA and for compact 12-m Array configurations. For configurations more extended than 2 km and at frequency Bands 8, 9, and 10, the imaging dynamic range may be closer to 50.

Images of bright sources may be dynamic-range-limited rather than sensitivity-limited. Their image quality may be improved with self-calibration. For more information please see the Knowledgebase article "What is meant by imaging dynamic range?" and Section 10.5.1 of the Technical Handbook.

A.9.2 Absolute flux accuracy

Absolute amplitude calibration will be based on observations of objects of known flux density, including eight Solar System objects and a set of 40 quasars whose flux densities are monitored every 15 days. It is expected that these calibrators provide an absolute flux accuracy better than 5% for Bands 3, 4 and 5; 10% for Bands 6, 7 and 8; and 20% for Bands 9 and 10. The decrease in accuracy at the higher frequencies is caused by variable atmospheric opacity, pointing errors, and coherence loss due to phase fluctuations.

A.9.3 Bandpass accuracy

The amplitude and phase shape of the spectral response for each antenna in the array is measured by observing a bright source, usually a quasar, for the time needed to reach the desired spectral sensitivity for the relevant spectral resolution. The accuracy of this shape particularly affects projects that intend to observe spectral features that cover a significant fraction of a spectral window, and/or study faint spectral features in the presence of strong continuum. A spectral dynamic range (i.e., the desired signal-to-noise ratio per spectral resolution element) of 1000 has been demonstrated for Bands 3, 4, and 6, and a spectral dynamic range of 400, 250, 170, and 150 has been demonstrated for Bands 7, 8, 9, and 10, respectively. For Band 5, a limit similar to Band 6 may be assumed, except for setups near the 183 GHz atmospheric absorption line. The achieved spectral dynamic range will depend on the brightness of the bandpass calibrator, the observing frequency, and spectral resolution (see Section 10.4.6 of the Technical Handbook for details). Proposals that request higher accuracies need to provide a feasible calibration strategy in the Technical Justification or the proposal may be rejected on technical grounds.

A.9.4 Total Power calibration

The intensity calibration for single-dish observations with the TP Array is made by using the Amplitude Calibration Device (ACD), which results in an intensity scale in terms of the corrected Rayleigh-Jeans antenna temperature T_A^* (K). To combine the TP data with the interferometric data, the intensity scale is converted from K to Jy. The conversion factor is a function of the observed frequency, half-power beam width, and aperture efficiency of the TP Array antennas. The latter two are derived from regular single-dish calibration observations. The overall accuracy for the total power calibration is about 5% at Bands 3 to 7, increasing to 15% at Band 8.

A.9.5 Astrometry

The absolute positional registration of an ALMA image on the sky depends on the angular resolution and the quality of the phase calibration. With a stable atmosphere, a calibrator-target separation of less than about four degrees, and a signal-to-noise ratio of the target image >20, the nominal accuracy of the absolute position measurement (standard deviation) is at best ~5% of the synthesized beam for angular resolutions larger than about 150 mas. At higher angular resolutions, the best absolute astrometric accuracy decreases to ~10% of the synthesized beam. If the astrometric goals are within these ranges, then the observing schedule, observations, and data reduction will be similar to a standard imaging proposal. This option appears explicitly in the ALMA OT as a button labeled “Standard positional accuracy (default)” (see Section “a” below) in the “Astrometry” panel in the Calibration Setup editor.

The “Enhanced positional accuracy” option (Section “b” below), meanwhile, applies to astrometric projects in which the main scientific goals include measuring the celestial position of the science target to better than the nominal expectation, or measuring the position change of a target over a period of hours to years in a multi-epoch experiment.

To reach the desired astrometric accuracy, the optimum choices of the observing frequency, configuration, and time on target will depend on the properties of the target (spectrum, angular size, brightness) and should be chosen by the PI (see Section "a" below). Proposers of astrometric-type projects with the science goal of measuring a source's position are also encouraged to seek help via the Helpdesk.

In the ALMA OT, the editor panel referring to the positional accuracy can be found in the Calibration Setup editor. The default “Standard positional accuracy (default)” option provides the same default calibration strategy as in previous cycles.

a. Standard positional accuracy (default): The choice of observing frequencies and configurations will depend on the science goal and source properties (see more details in the Technical Handbook, Chapter 10). Many previous astrometric programs requiring high precision have used Band 6 or 7 with configurations similar to C-4 to C-7, since these combinations commonly provide good phase stability and are less constrained by weather conditions than higher frequencies and longer baselines. Note that increasing the S/N of the image peak intensity above 20 will not improve the absolute astrometric accuracy. For lower values (<20), consider the equation in the Astrometry section of Chapter 10 of the Technical Handbook, but a minimum S/N of 15 is recommended.

b. Enhanced positional accuracy: An astrometric proposal should select the “enhanced” option in the Calibration Setup if (1) significantly better than nominal astrometric accuracy is needed, or (2) multi-epoch observations over weeks or months are requested (i.e., using different 12-m Array configurations). In these cases, the PI should contact ALMA staff through the Helpdesk. The reason for selecting the “enhanced” option must be justified in the Technical Justification (see Section B.4).

For Cycle 9, the PI should contact ALMA staff via the Helpdesk concerning the possible choices of phase calibrators and the choices of configurations and observation dates for longer-term multi-epoch observations. Experienced PIs may use the “User-defined calibration” option to request the use of multiple or specific calibrators. Nevertheless, while doing so, the PI is requested to select the “Enhanced positional accuracy” and, again, to double check the strategy with ALMA staff via the Helpdesk. The proposed strategy must be described in the Technical Justification.

A.9.6 Phase calibrator search in Bands 7 to 10 at the longest baselines

To ensure accurate phase calibration and successful imaging in Bands 7-10 with the longest baseline configurations (C-8, C-9, and C-10), the phase calibrator must be located close to the science target and must be observed frequently to correct for the variable atmospheric phase fluctuations. To achieve the former, the phase calibrator must be within the separation angles listed in Table A-6. In order to achieve the latter, the phase calibrator is typically visited more frequently than other long baseline observations (see Section 10.5.5 of the Technical Handbook for details).

Table A-6: Maximum separation angle between phase calibrator and science target

	C-8	C-9	C-10
Band 7	5 degrees	5 degrees	5 degrees
Band 8	5 degrees	5 degrees	4 degrees
Band 9	4 degrees	4 degrees	
Band 10	3 degrees		

In the cases of Bands 7 to 8 for configurations C-8 to C-10, Band 9 for C-8 to C-9, and Band 10 for C-8, the OT checks whether a suitable phase calibrator exists within the specified separations on the sky from the science target given in Table A-6, by searching the online ALMA Calibrator Source Catalogue. This happens automatically during proposal validation and submission. The default spectral setup for the phase calibrator is the same as for the target source. If the OT cannot find a suitable phase calibrator within the allowable separation on the sky and the total bandwidth of the spectral setup is narrower than 937.5 MHz, the OT then automatically switches to search for a phase calibrator by widening the aggregate bandwidth of the phase calibrator (bandwidth switching mode). If the OT still cannot find a suitable phase calibrator, or the bandwidth of the spectral setup is already wider than 937.5 MHz, the OT automatically switches the phase calibrator's spectral setup to a lower frequency band (B2B mode – see details below) to search for a stronger phase calibrator. No input is required from the PI when this occurs.

Proposals with targets that do not have a suitable phase calibrator found by the OT will trigger a validation error and such proposals cannot be submitted.

B2B phase calibration

B2B mode uses a phase calibrator observed at a lower frequency as compared with the science target frequency. Because phase calibrators are brighter at lower frequencies, B2B calibration increases the chances that a suitable phase calibrator can be found close enough to a science target for accurate phase transfer. In addition to the phase calibrator being observed at a lower frequency, there is an added short bandpass observation at the low-frequency and an additional strong calibrator - the Differential Gain Calibration (DGC) source – which is observed at both frequencies to facilitate the calibration of the gain offsets between the high (science) and low (reference) frequencies. The band pairings are listed in Table 10.1 of the Technical Handbook. Note that there are two types of B2B mode, the harmonic and non-harmonic types, which allow the full coverage of Bands 7 to 10 when B2B is triggered. The former type allows frequency switching within ~ 3 s, while the latter takes ~20 s and has a lower overall efficiency. The type of B2B used depends primarily on the frequency of the science target tuning and is selected automatically by the OT. Further details can be found in Section 10.5.3 of the Technical Handbook.

A.10 Time-constrained observations

Monitoring observations and time-constrained projects are offered subject to the following restrictions:

- Observations to be performed with two 12-m Array configurations to satisfy the PI requests of AR and LAS within a SG are not allowed to have time constraints.
- Observations with one 12-m Array configuration and the ACA are allowed to have time constraints only if simultaneous observations with the two arrays have been requested.
- No restrictions will be imposed on the size of the time window specified by PIs for time-critical observations. The scheduling feasibility of any proposal will depend on the total number of constraints that are imposed and on whether the time window takes place during other activities on the array such as engineering or computing time. Whether such observations are technically feasible will be decided on a case-by-case basis. In particular, observations with strict timing constraints but many possible time windows may be feasible.
- Programs that require more than two hours of continuous observations to monitor a source cannot be guaranteed due to variable weather conditions and system interruptions. Proposers may request monitoring observations longer than two hours, but if the observations fail after two hours, the observations will not be repeated. Monitoring observations will be interrupted by regular calibrations. Investigators should contact their ARC through the Helpdesk for support on such observations.

Stand-alone ACA proposals requesting only observations on the 7-m Array are allowed to have time constraints.

A.11 Solar observations

Proposals will be accepted for ALMA interferometric and Total Power observations of the Sun with the following capabilities and restrictions:

- Solar observations will be conducted only during the periods when the 12-m Array is in one of the allowed configurations for the requested band, namely C-1 to C-4 for Band 3, C-1 to C-3 for Band 5, C-1 to C-3 for Band 6, and C-1 to C-2 for Band 7 (see configuration schedule in Section 4.3.3).
- The interferometric component of solar observations will be conducted using a special combined array comprising both 12-m and 7-m antennas (to ensure sufficient short-spacing information is observed), and will be processed with the 64-input Correlator (Section 5.1 of the Technical Handbook). Observations with only the 12-m Array or only the 7-m Array are not offered.
- To minimize shadowing of 7-m antennas, observations will be carried out between 10:00 and 17:00 CLT (13:00 UT and 20:00 UT) when antenna elevations are above 40 degrees.
- PIs may designate a desired range of angular resolutions. However, the available range is restricted to the range provided by the 12-m configurations allowed for Bands 3, 5, 6, and 7, as described above.
- The Total Power component of solar observations consists of fast-scanning mapping observations to recover the largest angular scales for interferometric observations. Proposals requesting only Total Power single-dish observations will not be accepted. The Total Power observations will be taken contemporaneously with the interferometric observation. These observations will not be executed when the Sun is at elevations above 70 degrees because the required fast-scan azimuth slew speeds are too high. The time cadence of full-sun images obtained from Total Power observations is about 10, 13, 15 and 25 minutes for Bands 3, 5, 6, and 7, respectively.
- There are two options for the field of view of the Total Power solar observations. One is covering a full sun. Its shape and size of the field of view is a circle with 2400 arcseconds diameter. The time cadence of full-sun images is about 10, 13, 15, and 25 minutes for Bands 3, 5, 6, and 7, respectively. The other option is a small field of view around a region of interest, called "Fast Regional Mapping" (FRM). The shape of a field of view is a circle, the same as the full-sun scan, but the diameter of the circle can be changed by PI. The center coordinate of the field of view is fixed by the ephemeris used for the interferometric observation. When a science goal has multiple fields, FRM cannot be chosen for the science goal. The time cadence of solar images obtained with FRM depends on the receiver band and the diameter of the field of view. Table A-7 shows examples of the time cadence for several combinations of observing band and field of view.

Table A-7: Time cadence of images obtained with FRM

FOV Diameter	Band 3	Band 5 and Band 6	Band 7
100 arcsec	n/a[1]	11 sec	14 sec
200 arcsec	13 sec	21 sec	27 sec
300 arcsec	19 sec	32 sec	40 sec

Notes for Table A-7:

1. 100” is comparable to the size of the Band 3 primary beam (60”). Hence, such a field of view is not suitable for FRM.

- In order to flux calibrate solar images obtained with FRM, it is assumed that the field of view includes a quiet region and that the brightness during the observation does not vary significantly. Hence, PIs should carefully select the FRM field of view, considering these assumptions, and may wish to justify their choice in the proposal. When there is no quiet region in the field of view the precision of the flux calibration may be compromised and Quality Assurance Level 2 may fail, but the observation will not be repeated.
- Proposers will specify their solar target by providing a target position in Heliocentric coordinates. The ALMA Observatory will coordinate with successful PIs to get an updated target position at least 24 hours in advance of the proposed observation. The interaction will be done via the Helpdesk. The ALMA Solar Ephemeris Generator tool is available for PIs to help them generate the ephemeris.
- Only proposals for continuum observations in Bands 3, 5, 6 and 7 will be accepted. For interferometric observations, these will be obtained using the low spectral resolution (TDM) mode (see Section A.6.1). The individual integration times for this mode are fixed to 1 second, and the frequencies are fixed to four 1875 MHz-wide spectral windows centered on the frequencies shown in Table A-6. The high spectral resolution (FDM) observing mode is not offered for solar observations.
- The observing frequencies of the Total Power observations are as shown in Table A-8, but the Total Power data only include one channel per spw; a correlator will not be used for Total Power observations so autocorrelation measurements will not be available.

Table A-8: Observing frequencies for Cycle 9 solar observations

Band	spw1 (GHz)	spw2 (GHz)	LO1 (GHz)	spw3 (GHz)	spw4 (GHz)
3	93.0	95.0	100.0	105.0	107.0
5	191.0	193.0	198.0	203.0	205.0
6	230.0	232.0	239.0	246.0	248.0
7	339.6	341.6	346.6	351.6	353.6

Notes for Table A-8:

1. This table assumes that each baseband is populated with a single spectral window (spw) centered on the baseband frequency.

- Simultaneous observations with Bands 3, 5, 6 and 7 are not offered: each Science Goal can only include one band.
- Observations may be performed using dual linear polarization (XX, YY) or single polarization (XX) correlations; full polarization measurements are not currently offered for solar observations.
- Because the WVR receivers are saturated when the antennas point at the Sun, WVR corrections for on-source (solar) data are not possible (See Section 8.10.2 of the Technical Handbook).
- Absolute calibration of single-dish brightness temperatures is currently no better than ~10% but is more realistically ~15%. While efforts are on-going to improve solar calibration, Science Goals that require absolute temperatures more accurate than this, and in particular comparisons of absolute temperatures between Bands 3, 5, 6 and 7, will be difficult to carry out successfully.

A.12 VLBI observations

Proposals will be accepted for VLBI observations that include ALMA as a phased array, with the following capabilities and restrictions:

- VLBI observations will be conducted in "campaign mode", whereby specific dates are reserved for the execution of VLBI programs in coordination with the other facilities in the VLBI network. This ensures that VLBI experts are available to help with program execution. Observing windows will be identified during the periods when the 12 m Array is in one of the three most compact configurations (with maximum baselines ≤500 m; see configuration schedule in Section 4.3.3). The actual campaign dates will be set after the proposal review process, but are expected to be in the March/April 2023 time frame.
- Standard VLBI observations perform phase-up of the array directly on the science target. To ensure adequate SNR for the phase solving algorithm it is required that continuum targets have a correlated flux density on intra-ALMA baselines of ≥500 mJy (Bands 3 and 6) or ≥750 mJy (Band 7). Spectral line targets should have a peak flux density in the spectral line of interest of ≥ 4 Jy at the time of the observation.
- VLBI continuum observations of science targets with correlated flux densities <500 mJy require the use of *passive phasing* mode. Typical passive phasing observing sequences will consist of a short (~1–3 min) VLBI scan on the phasor, immediately followed by a longer scan on the science target itself (up to ~5 min). To perform array phase-up, the user must select a

bright (≥500 mJy) phase calibrator ('phasor'), ideally within 6 or 3 degrees of the science target in Band 3 or 6, respectively. The user-defined calibrator interface is enforced for passive phasing and the default dynamic phase calibrator should be replaced with a fixed calibrator (see Section B.6.1). The choice of calibrator should be justified in the Technical Justification. In Cycle 9, passive phasing is not allowed for Band 7 VLBI or for spectral line VLBI.

- VLBI proposals for continuum mode observations will only be accepted for Bands 3, 6, and 7. These observations will be obtained in full polarization using the widest bandwidth FDM configuration of 64-input Baseline Correlator (see Section A.6.1). Observing frequencies are fixed to four 1875 MHz-wide spectral windows centered on the frequencies shown in Table A-9 below.

Table A-9: Observing Frequencies for Cycle 9 VLBI Observations

Band	spw1 (GHz)	spw2 (GHz)	LO1 (GHz)	spw3 (GHz)	spw4 (GHz)
3	86.268	88.268	93.268	98.328	100.268
6	213.1	215.1	222.1	227.1	229.1
7	335.6	337.5414	342.6	347.6	349.6

Notes for Table A-9:

1. This table assumes that each baseband is populated with a single spectral window (spw) centered on the baseband frequency.

- Spectral line observations are offered only in Band 3 for Cycle 9 and are subject to the following restrictions: (i) only emission line targets sufficiently bright to allow active phase-up of the array using the line emission may be observed (see above); (ii) only a single baseband (spw1) will be recorded for VLBI; (iii) the tuning of spw1 will be fixed as specified in Table A-7 (see "Spectral line" in Section B.6 for additional details); however, the three non-VLBI spectral windows (spw2, spw3, spw4) may be flexibly configured in the OT with different tunings, spectral resolutions, and/or polarization setups subject only to ALMA's standard tuning restrictions.

- Proposers are required to enter a VLBI total time requested. Here, they should enter the amount of time requested for ALMA (and not the total time requested to the GMVA/EHT networks, which may be longer). Note that this time must include overheads. For ALMA + GMVA or ALMA+EHT the total observing time (including overheads and ALMA calibrations) is a factor of four times the expected time on source (i.e., a 25% duty cycle).

- If multi-epoch observations are requested, they must fit within the two-week ALMA VLBI observing window and the total time request must be the aggregate time of all observations.

- GMVA and EHT sites record data on a circular polarization basis, while ALMA records linear polarization products. A minimum of three observing hours are required to ensure accurate linear to circular polarization transformation of the ALMA VLBI data.

For 3-mm VLBI (both spectral and continuum experiments), a proposal must have been submitted to the GMVA network by their 1 February 2022 deadline (see the GMVA website that also provides a sensitivity calculator). Another sensitivity calculator is available at the European VLBI Network site.

For 1.3-mm and 0.87 mm continuum VLBI, the ALMA Observatory will forward the submitted proposals to the EHT network for technical assessment. Thus, proposers do not need to send their proposal to the EHT directly.

A.13 Phased Array observations

The 12-m ALMA dishes may also be used as a stand-alone phased array, where signals from individual antennas are summed after phase alignment (i.e., so that the array functions like a large single dish telescope), for pulsar science in Band 3. As these are ALMA-only observations, a copy of the proposal should not be sent to the GMVA.

- This mode is available by selecting the Phased Array proposal type. In Cycle 9, only pulsar science projects will be accepted for this mode, so the PI should select the scientific keyword “Pulsars and neutron stars” in the scientific category “Stellar Evolution and the Sun”. The proposal code will have the “.P” suffix.
- The capabilities are similar to those currently available for continuum VLBI, i.e., a single source per Science Goal with a maximum-bandwidth, pseudo-single-continuum spectral setup, but only Band 3 is available. The spectral window frequencies are the same as those used for VLBI (Table A-9).
- As in standard VLBI continuum modes, VLBI recordings of the phased sum signal are made while the ALMA interferometric data are archived in parallel.
- Since this mode is limited to observations of pulsars, which are generally faint at mm wavelengths, passive phasing (see A.12) is enforced by the OT. A fixed phase calibrator ('phasor') will need to be selected and justified (see Section B.6.1)
- Typical passive phasing observing sequences will consist of a short (~1–3 min) VLBI scan on the phasor, immediately followed by a longer scan on the science target itself (up to ~5 min).
- The phased-array data from all four available basebands (derived from the VLBI recordings) will be made available to the PI in PSRFITS format.
- Observations using this mode will be scheduled during the time periods assigned for VLBI. For Cycle 9 this is expected to be in March/April 2023.
- As for VLBI proposals, the total array time required by each Science Goal must be provided (see Section B.7). This should be set to a minimum of 3 hours to allow for proper polarization calibration. The requested array time should be justified in the box entitled “Phased Array Technical Justification including Post-Processing”.
- Contact your ARC through the Helpdesk for additional assistance in planning observations with this mode.

Appendix B Technical Justification guidelines

The Technical Justification must be entered directly into the OT for each Science Goal. Below are guidelines on issues to consider in the different sections. Sections B.5, B.6, and B.7 point to specific items that need justification for solar, VLBI, and Phased Array (pulsar) observations, respectively. In general, PIs should justify all the parameters requested in the OT.

B.1 Sensitivity

At the top of the sensitivity section, the OT will display the calculated sensitivity and S/N ratio achieved for different bandwidths (bandwidth requested for sensitivity, aggregate bandwidth, a third of the linewidth) as appropriate for the spectral setup and the defined Expected Source Properties. While the justification for the requested sensitivity or S/N ratio should be included in the Scientific Justification (Section 5.3.2), the TJ must explain which sensitivity or S/N ratio are expected for all the parts of the spectrum that are of interest, e.g., for a spectral setup targeting a weak and a strong spectral line as well as the continuum, and the means by which the proposed technical setup will achieve those requests.

The fluxes in the Expected Source Properties must be entered **per synthesized beam;** i.e., proposers may have to correct any available flux measurements for the fact that the requested source is spatially resolved by ALMA and the flux is distributed over several synthesized beams (see Knowledgebase articles "*How can I estimate the Peak Flux Density per synthesised beam using flux measurements in Jy or K from other observatories?*" and "*How do I convert flux measurements given in Jy km/s or K km/s into the peak flux density required by the OT?*" and this video for more details on using fluxes/brightness temperatures from other facilities).

Users should be aware that the sensitivity requested may not be achievable in practice if the observations are dynamic-range limited; e.g., when the field of view contains another, very bright, source or the spectrum has very bright lines. S/N values smaller than three trigger a blue informative message and need to be fully justified; they may lead to a rejection of the proposal on technical grounds if no adequate explanation is given. For setups including spectral lines, another value to double-check is the ratio of the linewidth (entered in the Expected Source Properties) over the bandwidth used for sensitivity (from the Control & Performance editor), which is conveniently displayed by the OT. It is important to understand that the sensitivity requested will be achieved over a frequency bin corresponding to this bandwidth, **not** necessarily over every spectral resolution element. For spectral-line measurements this value should normally be larger than three (or even higher if you want to measure the shape of the line profile). An informative message will appear if this is not the case, and PIs should address this issue in the justification text (e.g., if the sensitivity requirement is driven by the continuum, it may be acceptable to have a very low ratio).

The final parameter to be checked for observations measuring both line and continuum emission is the spectral dynamic range, defined as the continuum peak flux divided by the line rms. Limits on the spectral dynamic ranges offered in Cycle 9 for the different ALMA bands are given in Appendix A (Section A.9.3); an informative message will appear in the OT if these are exceeded and the proposal may be rejected on technical grounds unless justified. The spectral dynamic range is important especially when trying to detect a weak line on top of a strong continuum, and high spectral dynamic ranges may require a better bandpass accuracy than possible with a standard calibration. If a high spectral dynamic range is required, extra bandpass calibrations may need to be obtained selecting "User-defined calibration".

B.2 Imaging

When planning ALMA observations, the complexity of the emission in the science target field should be considered, in addition to the sensitivity goals. In this section, proposers should justify their AR and MRS requests on the basis of the field's complexity and their scientific goals. An interferometer's ability to reconstruct complex emission is directly related to the *uv*-coverage of the data. The AR and MRS needed to image complex emission should be carefully justified (if necessary, using simulations), especially if multiple antenna configurations are required. Proposers should also consider the overall *uv*-coverage of their observations as this directly impacts image fidelity, particularly for snapshot observations (See Chapter 3 of the Technical Handbook). The number of required antenna configurations is listed in the observing time estimate of the project time summary in the OT.

The "snapshot" (i.e. short observation) *uv*-coverage is excellent for the compact ALMA 12-m Array configurations C-1 to C-3 and still reasonably good for C-4 to C-6, but for the longer baseline configurations, C-7 to C-10, it is quite sparse even with 50 antennas (see Section 7.5 of the Technical Handbook). Therefore, more observing time must be spent to "fill in" the missing *uv*-coverage, as much as possible. Thus, high fidelity imaging of complex and/or high dynamic range emission may require a longer observing time than implied by sensitivity requirements alone, and this is especially true for the long-baseline configurations. Consecutive executions of a given SB (if needed) are favored during scheduling to maximize *uv*-coverage. Nonetheless, if more extensive *uv*-coverage is required to satisfy the imaging requirements, the OT's sensitivity-based time estimate can be overridden (see below). PIs are strongly encouraged to use the ALMA simulator tools to assess the potential need for extra *uv*-coverage.

For single pointings with the 7-m Array, integrations of at least one hour are recommended to achieve good image quality. Ensuring sufficient *uv*-coverage for mosaics with the 7-m Array can be problematic because the integration time is spread out over many pointings; for this case, simulations that assume the minimum number of guaranteed antennas are strongly encouraged to help set the per-pointing integration time. See Section 7.7 of the Technical Handbook for more details.

For single or non-overlapping pointings, the source should fit within the inner one third of the primary beam (field of view), or the PI should discuss the effects of the sensitivity loss towards the beam edges.

PIs should also pay attention to the expected image dynamic range (see Section A.9.1) if attempting to detect a weak signal that falls in the same pointing as a much brighter source. The OT cannot identify such cases automatically since it has no knowledge of the flux structure of the field to be observed. See the Knowledgebase article "What is meant by imaging dynamic range?" for details.

B.3 Correlator configuration

For spectral-line observations, the OT reports the number of (Hanning smoothed) spectral resolution elements per linewidth, taking into account any spectral averaging, and the width of the representative spectral window. PIs have to make sure to select the correct representative spectral window. If the spectral resolution is larger than one third of the linewidth from the Expected Source Properties, an informative message will appear, and if not suitably justified this will lead to the rejection of the proposal on technical grounds. Note that the spectral resolution is not necessarily the same as the bandwidth for sensitivity.

The requested correlator setup and the placement of spectral windows should be carefully justified in the free-format text box. In the case of multiple spectral lines and/or narrow spectral windows in particular, PIs should double-check that the line profiles are fully covered by the selected spectral windows.

PIs should also check whether any of the spectral windows are severely impacted by atmospheric absorption, which can affect Bands 5 and 7 to 10 especially. If necessary, the representative frequency should be modified to be at the most restrictive part of the atmosphere where a line needs to be detected, thus impacting the time estimate. Any continuum windows should be moved to avoid areas of reduced transmission.

For the double sideband receivers (Bands 9 and 10), the atmospheric transmission in the mirrored spectral window due to the 90-degree Walsh Switching (Section A.5) impacts the sensitivity achieved in the spectral window and therefore the time estimate. PIs may wish to modify the spectral setup accordingly. The best practice for good calibration is to add continuum spectral windows in any unused basebands, in particular for high-frequency SGs. The Phase 2 Group assigned to the project can add these windows, if needed.

For sources with known high line density (~1 spectral feature per 10 MHz), PIs are particularly encouraged to set up all the spectral windows in FDM mode. This will allow a more robust determination of the line-free channels used to form the aggregate continuum during data processing and imaging.

B.4 Choices to be justified

The OT will automatically catch a number of user choices that must be explicitly justified in a text box. These choices are:

- Override of OT's sensitivity-based time estimate: Proposers may wish to override the OT's time estimate to monitor a source over a certain time range or to build up the *uv*-coverage for imaging a complex source. When using this option, proposers should keep in mind that programs that require more than two hours of continuous observations cannot be guaranteed due to variable weather conditions and system interruptions (Section A.10). The time entered refers to that of the largest array requested, includes all calibrations, and must be fully justified. Note that the OT assigns the PWV based on the representative frequency of the requested observations and the declination of the source to ensure data quality. Thus, it is not possible to request specific weather conditions for the observations.
- Time-constrained observations: the OT allows you to specify two types of time-constrained observing: single visit and multiple visits. In the first case, one or more time windows are specified, but the observations will only be carried out once during any of these time windows. In the second case, the Science Goal is observed in each of the time windows specified. The technical feasibility of time-constrained observations will be decided on a case-by-case basis.
- User-defined calibration: the default system-defined calibration option ensures that the proper calibrations for the flux scale, bandpass, and relative antenna gains are obtained. Observations making use of the full polarization capabilities of ALMA will also include the necessary calibrations by default. User-defined calibrations should be necessary only in rare cases, e.g., if a very high spectral dynamic range is required, it may be necessary to perform additional calibrations and/or use specific sources. Such requests must be explained and justified in detail. Programs that cannot be calibrated or that significantly increase the complexity of data reduction will not be allowed and will be flagged as technically infeasible and rejected.

- Low maximum elevation: sources that transit at a low elevation are difficult to schedule for observation since they suffer from high atmospheric attenuation and require low PWV, especially at high frequencies (see Section A.8). A detailed explanation should be provided as to why these sources need to be observed rather than sources at higher elevation.
- Single polarization: this should only be used when the highest spectral resolution is required, as the sensitivity achieved is lower than when using the default dual polarization. PIs should carefully justify why the high spectral resolution requested is required.
- Sparser sampling than the default $\lambda/\sqrt{3}D$ (Nyquist sampling) can be more effective at covering large areas more quickly, at the price of non-uniform spatial coverage and noise. Deviating from the default mosaic sampling must be justified scientifically, and is to be avoided when imaging extended sources, particularly if image fidelity is an important concern.
- Enhanced positional accuracy: this option should be selected when an astrometric accuracy better than nominal is required (see Section A.9.5). In the corresponding Technical Justification section, the PI must justify the need for the enhanced positional accuracy and give any further details that may have been advised by ALMA staff through the Helpdesk.

B.5 Solar observations

The sensitivity calculator is not adequate for solar observations because the antenna temperature greatly exceeds the system temperature and, moreover, depends on the solar target (e.g., quiet Sun, active region, solar limb). Therefore, solar proposers are asked to enter the total time and justify this request to the extent that depends on technical imaging considerations, not on scientific factors. For example, for a mosaic of a target in a given frequency band, PIs should indicate how many repetitions of the sampling pattern are needed and why. For this calculation PIs should take into account that ALMA observations are comprised of one or more executions of an SB. The total execution time of an SB cannot exceed 2 hours, which will include the time overheads for bandpass and flux calibration. These calibration overheads amount to about 25 mins.

B.6 VLBI observations

B.6.1 Continuum

The VLBI Technical Justification should be tuned to the overall science goals. The ALMA Technical Justification should include a justification for the need for ALMA, the reasons for using the selected band (Band 3, 6, or 7), the flux density of the target on a 1 km baseline, expected correlated flux densities on baselines longer than 5000 km, the total observing time requested (including time for calibration), and potential bandpass, polarization, and delay calibrators. If polarimetry is requested, the expected S/N ratio for the polarized emission should be stated. If imaging is requested, imaging considerations should also be mentioned (e.g., dynamic range issues or complex source structure), as well as any other special technical requirements. Finally, the proposers should specify the EHT or GMVA stations that are requested for VLBI.

The following online material is currently available to help justify the requested observing time:

- At 3 mm: the sensitivity calculator and the 3 mm VLBI page.
- At 1.3 mm: the 1 mm VLBI page.

VLBI targets with correlated flux densities < 0.5 Jy on intra-ALMA baselines out to 1 km may be proposed for observation in either Bands 3 or 6 through use of passive array phasing (see Section A.12). This option is not available for Band 7 VLBI in Cycle 9. Passive phasing requires selection of a suitable phase calibrator (termed a 'phasor' to avoid confusion with other phase calibrator target usages) The suitability of the selected fixed phase calibrator must be justified on the basis of its flux density and proximity to the VLBI target.

There are two ways to search for a phasor candidate: directly from the ALMA OT, or through an initial search on the web-based ALMA Calibrator Source Catalogue.

Searching for a phasor source in the ALMA OT

When proposing a Phased Array project or VLBI-mode observation of targets fainter than 0.5 Jy on intra-ALMA baselines, the "User-defined calibration" option is triggered in the "Calibration Setup" editor. There, in the "Goal Calibrators" panel, one will see four calibration type entries. To select a phasor source, the PI should follow these steps:

- Select the "Phase" entry and click on "Delete Selected Calibration";
- Click on "Add Fixed Calibrator", select "Phase" in the pop-up window, and click "Create";
- Select "Sidereal Target" and click on "Select from Source Catalogue...";
- Set the "Radius (º)" value of the "Cone Search" to 6º for Band 3 or 3º for Band 6 (suggested values);
- In "Flux", set "Min" to 0.5 Jy and click on "Submit Query";
- Ideally, select the entry with the highest "Flux Density", and with empty "UV Min/Max" columns.

Searching for a phasor source in the ALMA Calibrator Source Catalogue

In the "Query Form" tab of the web interface, the RA and DEC information of the target should be entered in the "Position" box. The suggested setting for the search radius is 6º for Band 3 and 3º for Band 6. In the "Energy" box, "Flux Density" should be set to ">0.5". "Band" should be set to "3" for Band 3 observations or "3,6,7" for Band 6 observations. The reason for the latter is that flux check observations are usually executed in Bands 3 and 7, and less often in Band 6. Hence, to retrieve a more contemporaneous flux value, one can interpolate between Bands 3 and 7 when a Band 6 value is not available. After clicking on the "Search" button, the "Result Table" will provide a list of phasor candidates. In case there is a need to interpolate between Bands 3 and 7 fluxes, the PI can use the "getALMAflux" task from the Analysis Utils (which must be installed within CASA). The PI can also use the "Result Plot" for assessment, where pressing a given data point in the RA/DEC plot on the left-hand side will trigger a light-curve plot to appear on the right-hand side. The PI should then provide the identified source in the "User-defined calibration" option (see above). Be aware that if the flux of the selected phasor decreases below the 0.5 Jy threshold closer to the expected observation execution, an alternative source will have to be found in coordination with the Phase 2 Group.

What if no phasor candidate is found to be brighter than 0.5 Jy?

Identified phasor sources will likely be variable, so it is impossible to predict at the time of proposal submission what the flux will be during the observation. If a given candidate source is fainter than 0.5 Jy at the time of proposal submission, but its light curve (available in the ALMA Calibrator Source Catalogue; see above) shows that it has been brighter in the past or shows a rising flux potentially increasing above the 0.5 Jy threshold, the PI can propose that source as a phasor. In this case, PIs may wish to include a justification in the proposal. In this case, the JAO will check the source's flux closer to the VLBI campaign run and the project will be executed only if the selected source is observed to have a flux greater than 0.5 Jy.

What if no phasor candidate is found within the suggested search radius?

If the proposed phasor source is further than 6º from GMVA targets or 3º from EHT targets, there are additional considerations that should be taken into account. The guidelines for angular separation are based on observational conditions during a time of the year (March/April) when VLBI campaigns are usually run. These conditions imply that the phase rms induced by atmospheric turbulence is up to ~25º (84% probability) for the characteristic phasing radius in Band 3 and up to ~45º (84% probability) in Band 6. Assuming a maximum allowed signal decorrelation of 20%, Figure 10.8 in the Technical Handbook suggests the maximum phasor distance of 6º from GMVA targets or 3º from EHT targets. The further from the target one moves, the higher the signal decorrelation. There are limits in how much QA2 analysis can compensate for these decorrelation losses, and this will depend in part on whether the target is sufficiently bright to allow self-calibration during QA2 processing and whether the schedule allows for a robust gain solution interpolation between scans. In such extreme cases, the flux calibration will become highly uncertain. Considering these issues, the PI can still propose a phasor that is farther way than the guidelines suggest, but it must be justified with regard to how it is likely to impact the data quality and whether the science goals can still be achieved.

B.6.2 Spectral line

For spectral line experiments the ALMA Technical Justification should include a justification of the need for ALMA as well as properties of the spectral line of interest, including: rest frequency, expected peak line flux on a 1 km baseline, peak brightness temperature, anticipated correlated flux density on a 5000 km baseline, LSR velocity of line peak, and total line width (in km s^{-1}). The ALMA Technical Justification should also specify the total observing time requested (including time for calibration). If imaging is requested, imaging considerations should be described (e.g., dynamic range issues or complex source structure), along with any other special technical requirements. Lastly, the best available coordinates and proper motion of the line target should be specified.

A caution regarding target coordinate specification for spectral line VLBI: the field-of-view of the phased array beam is limited to the size the synthesized beam of the ALMA array. Because many Galactic sources have significant proper motions, it is essential that these corrections to the target position be accounted for; failure to do so may result in the target falling outside of the phased array beam. Note also that the procedure for specification of proper motion corrections is different for VLBI than for standard ALMA observations. In general, VLBI observations require that the J2000 coordinates of the source include the proper motion corrections appropriate for the epoch of the observation. These PI-specified coordinates will be used directly in the VEX files at all participating sites, including ALMA, and any other proper motion corrections will be zeroed during the observation.

The VLBI Technical Justification for spectral line experiments should describe the overall science goals and should specify the list of GMVA stations being requested. A list of candidate VLBI bandpass, fringe-finder, and polarization calibrators should be indicated, as well as the requested VLBI correlator set-up.

Owing to limited resources at the VLBI correlators, for Cycle 9 only one spectral line (lying within the fixed 3mm observing band; see Section A.12) may be selected for VLBI science utilization and only one correlator pass will be allowed per project. However, unlike continuum experiments which use a default VLBI correlation set-up, spectral line experiments allow the PI some flexibility in specifying details of the correlation setup. These details (and their restrictions due to data volume considerations) are: (i) spectral resolution (in multiples of 15.625 kHz), (ii) frequency center of the correlation passband, (iii) total correlated bandwidth (≤ 128 MHz), and (iv) time resolution (in multiples of 512 milliseconds). By default, all four Stokes products will be delivered for all experiments. At minimum the requested total bandwidth should be sufficient to include all line emission from the target as well as a number of line-free channels (e.g., ~20% of the total band). Details of the correlation set-ups are rather involved and an exact match to the specifications proposed by the PI may not be possible in all cases. Proposers are encouraged to consult the Helpdesk if they are uncertain about the optimum specifications for their science needs.

As noted in Section A.12, spectral line VLBI targets require a peak flux density on intra-ALMA baselines of ≥ 4 Jy to ensure robust performance of the phasing system. Because nonthermal emission lines are often time-variable, it may be impossible to know whether a particular source will meet this criterion at the time of Cycle 9 VLBI session. In such cases proposers may request that JAO perform a test observation 1-2 weeks in advance of the scheduled VLBI session to verify the line flux density of the primary target.

B.7 Phased Array observations

The proposer should first read the Phased Array mode sections of the Technical Handbook, paying particular attention to the items in the “Technical Justifications” section at the end.

As passive phasing is enforced for this mode, the choice of fixed phase calibrator must be justified. Additional inputs are also required to construct the Scheduling Block and these should be provided in the text box entitled “Phased Array Technical Justification including Post-Processing”:

- **Total observing time requested**. To cover a sufficient parallactic angle range on the polarization calibrator, typically ~3 hours are required. However, the proposer should indicate how much time is needed on target for the analysis (see below).
- **The pulsar period (if known).** This value should be provided so that the cadence of the correlator subscans (multiples of 1.008s) does not interfere with the pulsar signal. The time resolution of the PSRFITS file must be a multiple of 8 μs; if lower resolution is adequate, it should be specified to avoid larger than needed PSRFITS files.
- **The polarization of the PSRFITS data product.** The proposer can select from total intensity, dual polarizations (XX and YY), coherence product, or full Stokes.

A caution on target coordinate specification for Phased Array observations: the field-of-view of the phased array beam is limited to that of the synthesized beam of the ALMA array. Because many Galactic pulsars have significant proper motions, it is crucial that these corrections be applied to the target's J2000 coordinates when setting up the observations. *The procedure for specification of proper motion corrections is different for Phased Array observations than for standard ALMA observing.* Phased Array observations require that the J2000 coordinates of the source include the proper motion corrections appropriate for the epoch of the observation. These PI-specified coordinates will be adopted directly in the VLBI schedule used to execute the observations and no other proper motion corrections will be applied by the online system.

B.7.1 Computing the required array time for pulsar observations

When in phased-array mode, the digitized voltage signals from each ALMA antenna of the phased array are phase-adjusted and added to provide the recorded phased signal. This process is done for each polarization, and the phased array includes most, but not all, available antennas. This is different from the interferometric signal that results from the correlated voltage signal from each antenna. On top of that, pulsar observations aim to detect the flux of a pulsed signal rather than a continuous one. As a result, neither the sensitivity calculator within the OT nor the web interface provide the correct sensitivity for phased-array pulsar observations. To compute the required total array time for pulsar observations, one should start by computing the time on source (T_{int}) following the formula in Appendix A1.4 in Handbook of Pulsar Astronomy (Lorimer & Kramer 2004), which we adapt to:

$$T_{int}\ [h] = \frac{W}{P-W} * SEFD^2 \,/\, (rms^2 * N_p * N_{sp} * 1.875E9 * \eta_{eff}^2) \,/\, 3600$$

Here, W is the pulse width; P is the pulse period (typical values are W=C*P where C=0.05 to 0.1); SEFD for 37 phased antennas in Band 3 is 67 Jy; rms is the requested sensitivity; N_p is the number of polarizations and should be set to 2; N_{sp} is the requested number of spectral windows; η_{eff} is the end-to-end passive-phasing efficiency of ~0.74.

To estimate the total required observing time on source (including overheads), the user should multiply the computed T_{int} by three[8]. The result is the value the PI should provide in the OT. Note, however, that to ensure a proper polarization calibration of the data, the total observing time specified should never be less than 3 hr.

B.8 Band-to-band Calibration

There is no additional technical justification required if a science goal using high-frequencies and long-baselines triggers the B2B mode. All additional calibrations and overheads are included automatically by the OT.

[8] This factor is smaller than for the VLBI case since VLBI observations require the observation of specific calibrators that are not needed for pulsar observations.

Appendix C Acronyms and abbreviations

2SB	Dual-sideband
ACA	Atacama Compact Array
ACD	Amplitude Calibration Device
ALMA	Atacama Large Millimeter/submillimeter Array
AOS	Array Operations Site
APEX	ALMA Pathfinder EXperiment
ARC	ALMA Regional Center (for EA and NA) or Centre (for EU)
ARP	ALMA Review Panel
APRC	ALMA Proposal Review Committee
AR	Angular Resolution
ASC	ALMA Sensitivity Calculator
ASIAA	Academia Sinica Institute of Astronomy and Astrophysics
AUI	Associated Universities, Inc.
B2B	Band-to-band
CASA	Common Astronomy Software Applications
Co-I	Co-Investigator
Co-PI	Co-Principal Investigator
CONICYT	Comisión Nacional de Investigación Científica y Tecnológica
CS	Contact Scientist
DDT	Director’s Discretionary Time
DGC	Differential Gain Calibration
DSB	Double-sideband
EA ARC	East Asian ALMA Regional Center
EHT	Event Horizon Telescope
EHTC	Event Horizon Telescope Consortium
EPO	Education and Public Outreach
ESO	European Organisation for Astronomical Research in the Southern Hemisphere
EU ARC	European ALMA Regional Centre
FDM	Frequency Division Mode
FOV	Field Of View
GMVA	Global Millimeter VLBI Array
IF	Intermediate Frequency
KASI	Korea Astronomy and Space Science Institute
JAO	Joint ALMA Observatory
LAS	Largest Angular Structure
LO1	Local Oscillator 1
LSRK	Kinematic Local Standard of Rest
LST	Local Sidereal Time
MOST	Ministry of Science and Technology in Taiwan
MRS	Maximum Recoverable Scale
NA ARC	North American ALMA Regional Center
NAASC	North American ALMA Science Center
NAOJ	National Astronomical Observatory of Japan
NINS	National Institutes of Natural Sciences
NRAO	National Radio Astronomy Observatory
NRC	National Research Council of Canada
NSC	National Science Council of Taiwan
NSF	National Science Foundation
OSF	Operation Support Facility
OST	Observation Support Tool
OT	Observing Tool
OUS	ObsUnitSet
PDF	Portable Document Format
PI	Principal Investigator
PWV	Precipitable Water Vapor

QA2	Quality Assurance Level 2
SB	Scheduling Block
SCO	Santiago Central Office
SG	Science Goal
S/N	Signal-to-noise
SnooPI	Snooping Project Interface
SP	Science Portal
spw	Spectral window
TDM	Time Division Mode
TJ	Technical Justification
ToO	Target of Opportunity
TP	Total Power
VLBI	Very Long Baseline Interferometry
WVR	Water Vapor Radiometer

Appendix D Science categories and keywords

The list below presents the available science categories and the corresponding keywords that can be used in the OT to further specify the scientific area of the proposal. **Proposers must select at least one and at most two keywords.**

Category 1 – Cosmology and the high redshift universe

a. Lyman Alpha Emitters/Blobs (LAE/LAB)
b. Lyman Break Galaxies (LBG)
c. Starburst galaxies
d. Sub-mm Galaxies (SMG)
e. High-z Active Galactic Nuclei (AGN)
f. Gravitational lenses
g. Damped Lyman Alpha (DLA) systems
h. Cosmic Microwave Background (CMB)/Sunyaev-Zel'dovich Effect (SZE)
i. Galaxy structure & evolution
j. Gamma Ray Bursts (GRB)
k. Galaxy Clusters

Category 2 – Galaxies and galactic nuclei

a. Starbursts, star formation
b. Active Galactic Nuclei (AGN)/Quasars (QSO)
c. Spiral galaxies
d. Merging and interacting galaxies
e. Surveys of galaxies
f. Outflows, jets, feedback
g. Early-type galaxies
h. Galaxy groups and clusters
i. Galaxy chemistry
j. Galactic Centers/nuclei
k. Dwarf/metal-poor galaxies
l. Luminous and Ultra-Luminous Infra-Red Galaxies (LIRG & ULIRG)
m. Giant Molecular Clouds (GMC) properties

Category 3 – ISM, star formation and astrochemistry

a. Outflows, jets and ionized winds
b. High-mass star formation
c. Intermediate-mass star formation
d. Low-mass star formation
e. Pre-stellar cores, Infra-Red Dark Clouds (IRDC)
f. Astrochemistry
g. Inter-Stellar Medium (ISM)/Molecular clouds
h. Photon-Dominated Regions (PDR)/X-Ray Dominated Regions (XDR)
i. HII regions
j. Magellanic Clouds

Category 4 – Circumstellar disks, exoplanets and the solar system

a. Debris disks
b. Disks around low-mass stars
c. Disks around high-mass stars
d. Exoplanets
e. Solar system: Comets
f. Solar system: Planetary atmospheres
g. Solar system: Planetary surfaces
h. Solar system: Trans-Neptunian Objects (TNOs)
i. Solar system: Asteroids

Category 5 – Stellar evolution and the Sun

a. The Sun
b. Main sequence stars
c. Asymptotic Giant Branch (AGB) stars
d. Post-AGB stars
e. Hypergiants
f. Evolved stars: Shaping/physical structure
g. Evolved stars: Chemistry
h. Cataclysmic stars
i. Luminous Blue Variables (LBV)
j. White dwarfs
k. Brown dwarfs
l. Supernovae (SN) ejecta
m. Pulsars and neutron stars
n. Black holes
o. Transients

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile. ALMA is funded by ESO on behalf of its Member States, by NSF in cooperation with the National Research Council of Canada (NRC) and the Ministry of Science and Technology (MOST) in Taiwan and by NINS in cooperation with the Academia Sinica (AS) in Taiwan and the Korea Astronomy and Space Science Institute (KASI).

ALMA operations are led by ESO on behalf of its Member States; by the National Radio Astronomy Observatory (NRAO), managed by Associated Universities, Inc. (AUI), on behalf of North America; and by the National Astronomical Observatory of Japan (NAOJ) on behalf of East Asia. The Joint ALMA Observatory (JAO) provides the unified leadership and management of the commissioning and operation of ALMA.