ALMA Observing Tool User Manual

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www.almascience.org

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User Support:

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

Revision History:

Version	Date	Editors
0.5, Ver. 1.0	March 2011	Rein Warmels
0.5, Ver. 1.1	August 2011	Rein Warmels
1.5, Ver. 1.0	May 2012	Rein Warmels
1.5, Ver. 1.1	October 2012	Andy Biggs
1.5, Ver. 1.2	February 2013	Andy Biggs
1.5, Ver. 1.3	February 2013	Andy Biggs
2.5, Ver. 1.0	October 2013	Andy Biggs
3.5, Ver. 1.0	March 2015	Andy Biggs
4.5, Ver. 1.0	March 2016	Andy Biggs
4.5, Ver. 2.0	May 2016	Andy Biggs
5.5, Ver. 1.0	March 2017	Andy Biggs
5.5, Ver. 2.0	June 2017	Andy Biggs
6.5, Ver. 1.0	March 2018	Andy Biggs
7.5, Ver. 1.0	February 2019	Andy Biggs
7.5, Ver. 2.0	June 2019	Andy Biggs
8.5, Ver. 1.0	January 2020	Andy Biggs
8.5, Ver. 1.1	March 2020	Andy Biggs
8.5, Ver. 1.2	March 2021	Andy Biggs
9.5, Ver. 1.0	March 2022	Andy Biggs
10.5, Ver. 1.0	March 2023	Anna Miotello
11.5, Ver. 1.0	March 2024	Katharina Immer
12.5, Ver. 1.0	February 2025	Anna Miotello
13.5, Ver. 1.0	February 2026	Katharina Immer

Contributors

The ALMA OT Team, and the many Testers.

In publications, please refer to this document as:
ALMA Observing Tool User Manual, ALMA Doc. 13.5, Version 1.0

Contents

Chapter 1

Introduction

The OT User Manual describes the ALMA Observing Tool (OT) that is used to prepare observing proposals (Phase 1) for the Atacama Large Millimeter/submillimeter Array (ALMA). The OT is a web-based application consisting of a set of user interfaces that are needed to prepare an ALMA observing project.

1.1 What's new in Cycle 13?

The most important changes to the Observing Tool (OT) since the last release are the following:

- The OT is now a web-based application. The URL is `https://cycle-13.sps.alma.cl/`.
- New capabilities:
  - Band 2 is available, except for VLBI, Phased Array or solar projects. Observations with the Atacama Compact Array (ACA), also known as the "Morita Array"), or TP arrays are not allowed with Band 2.
- "Single" has been removed from the Desired angular resolution options. If a user wants to specify only one angular resolution value, then they need to enter the same value twice in the "Range" option.
- The OT now validates the full range of angular resolution coverage for the most compact and most extended configurations.

1.2 How to Use this Manual

Firstly, it is important to explain what this manual is *not*.

- It is not a step-by-step guide to creating an ALMA proposal. Especially for inexperienced users, such a step-by-step guide to proposal creation is available in the form of video tutorials which can be obtained from the ALMA Science Portal.
- This manual is also not designed to describe everything that can possibly be done with the OT, and in particular does not give an explanation of what each and every entry field in the OT does. If this is desired, then the OT Reference Manual should be consulted.
- Detailed technical information about ALMA is also not provided although, particularly with regard to the tuning and correlator setups, the basics are covered. The ALMA Technical Handbook is highly recommended for those users who want to know, well, everything.

Instead, this manual attempts to give an overview of what is possible with the OT by a typical science user, without going in to the kinds of detail covered in the resources mentioned above. Therefore, observing proposals are described in terms of their main components, their purpose and what kind of information should be entered. Where detail is given, it generally covers aspects of the OT that are not obvious. A list of acronyms (Appendix B) may prove useful.

Users who are completely unfamiliar with the OT are recommended to read the following chapters: Chapter 2 describes the main components of an observing proposal and Chapter 3 provides a general overview of the OT.

In order to create an ALMA proposal, all the essential information is covered in Chapter 4 – this describes the process in some detail and should be read by all users. Complementary to this is Chapter 5 which describes various OT tools and Chapters 5.4 and 5.5 that give detailed information on how to use the spatial and spectral editors.

1.3 User Support

In each of the three partner regions, an ALMA Regional Centre (ARC) has been established. Each ARC provides scientific user support in the core areas of proposal preparation, observation program preparation and data analysis to users in their respective communities. The ARCs will also host copies of the ALMA Archive and will deliver data packages to users. Hence, the ARCs are the ALMA interfaces to the user.

More detailed information about the ARCs and how the interaction with the user communities is organised can be obtained from their Web sites. The following three URLs point to the European, North American, and East Asian ARC sites:

Europe: `http://www.eso.org/sci/facilities/alma`
North America: `https://science.nrao.edu/facilities/alma`
East Asia: `https://researchers.alma-telescope.jp/e/ea-arc/`

Before and after the observations you will have regular interaction with your ARC. The degree of interaction will vary and depend on your experience and the complexity of the project undertaken.

In the event you encounter a problem or need support when using the ALMA Observing Tool you can contact the ALMA User Support Service at your ALMA Regional Centre (ARC) or use the ALMA Helpdesk. All of these can be reached via the ALMA Science Portal: `http://www.almascience.org`

1.4 Release Information

This version of the manual is intended for the OT that will be used to submit all proposal types except DDT[1] proposals for Cycle 13. The OT can be accessed via `https://cycle-13.sps.alma.cl`. The OT is supported on latest version of the web-browsers Chrome, Firefox and Safari.

1.5 Credits and Acknowledgements

The ALMA OT is a software product of the ALMA Observation Preparation Software Team and is developed on the basis of the ALMA Science Software Requirements (SSR) and the ALMA High Level Analysis (HLA) documents, produced by the respective groups. The OT software group acknowledges the valuable inputs of these groups during the development phases of the OT. Testers from the external community are also thanked for their valiant efforts over the years.

[1] Cycle 12 DDT proposals will still need to be submitted with the Java-based desktop OT for Cycle 12.

Chapter 2

Basic Concepts

The OT introduces a number of concepts that will generally be unfamiliar to users who are new to ALMA, perhaps the most significant of which is the Science Goal. This and other features that are essential to the way that proposing for and observing with ALMA works are now introduced, before being explained in more detail in subsequent chapters.

2.1 Observing Proposals

The very first item to work on for obtaining ALMA observing time is the creation of an observing proposal that successfully passes scientific and technical evaluation. The emphasis of the information provided is on the scientific requirements as opposed to the technical details of the telescope's operation. The proposal should be submitted during the proposal submission period which is announced via the Call for Proposals once a year.

Key components of an observing proposal are Science Goals, each of which, broadly speaking, encompasses one task the user wishes to perform e.g. an observation of a number of sources at a particular frequency at a particular resolution. Each Science Goal contains a number of panels, each of which covers a different aspect of the proposed observations, including the source list and the spectral setup.

2.2 DDT Proposals

The OT also allows the possibility of submitting proposals for Director's Discretionary Time (DDT). Unlike normal proposals these can be submitted at any time, but the user must ensure that the OT version used corresponds to the cycle that is currently being observed. For example, during the Call for Proposals for Cycle N, Cycle N-1 is currently being observed and thus the Cycle N-1 OT must be used to submit a DDT proposal. *For Cycle 12 DDT proposals, this is still the Java-based desktop OT.* Within a particular cycle, DDT proposals can be submitted from the beginning of the actual observations for that cycle which is usually at the beginning of October.

Proposal codes use letters for the subcycle field i.e. the first DDT proposal of Cycle 12 had the code 2025.A.00001.S.

2.3 Stand-alone ACA

It is possible to request only time for the Atacama Compact Array, without observations with the 12-m Array. This is referred to as the Stand-alone ACA (SACA) and allows a user to request time on the 7-m Array, together with the TP Array if required. It is not possible to request only the TP Array in the OT.

Most observing modes available on the 12-m Array can also be requested with the SACA.

2.4 Observing Programs

After the successful submission of an ALMA proposal and having obtained observing time, the complete set of technical details of the observations need to be defined. This information is contained within Scheduling Blocks and will be filled by the observatory on the basis of the provided information in the proposal.

2.5 Science Goals

Science Goals are integral to the definition of an ALMA proposal as they describe the observations that are to be performed. In order to make applying for time as easy as possible, Science Goals have been designed such that it is unnecessary to have a deep understanding of the technical details of an instrument as complicated as ALMA, or of interferometry. Therefore, a Science Goal takes as input the scientific aims of an observation i.e. the sources and transitions that are to be observed and the required sensitivity and angular resolution. How these goals are to be achieved in practice should not necessarily concern a user and the OT will ensure through its validation process that only proposals that are technically feasible can be submitted.

2.6 Project Submission

Observing proposals are submitted to the ALMA archive in Chile, with each submission resulting in an email acknowledgement being sent to the PI and all other investigators. For non-DDT proposals, multiple submissions before the deadline are possible. Once submitted, projects can be retrieved from the archive using a search interface.

No proposals from previous cycles that are stored in the archive should be in the Phase 1 state. They will have either been rejected or be in a Phase 2 state, in which case SBs will almost certainly have been created. In either case, these cannot be simply retrieved from the archive and submitted as a new proposal – instead the “Open Project as New Proposal” option should be used. This will convert the Phase 2 project into Phase 1 and remove any references to the previous cycle i.e. no project code will be set and the Proposal Cycle will be set to the current value. Both types of Phase 1 proposals (Main Call, DDT) can be created in this way.

2.7 Project Validation

In order to ensure that the user’s specifications for an observation are indeed possible, in particular that they satisfy the capabilities for the current cycle, the OT provides a number of validation checks. Part of the validation is performed automatically when observing parameters are entered and invalid input will be immediately colored in red. Other warnings will also appear without any intervention by the user.

A complete validation is only possible by requesting this manually, most conveniently by using the icon in the header bar. ALMA proposals can only be submitted to the ALMA archive if there are no validation errors. Therefore, it is essential to check the validity of the input regularly. Regardless of this, a separate validation will be performed at submission time, thus ensuring that no invalid proposals can be submitted to the archive.

2.8 The staging area

The staging area (Fig. 2.1) gives access to all proposals for which the user is PI, Co-PI or Co-I. This staging area can either be accessed via the buttons "Retrieve a project from the server" or "Open project as new proposal". The projects can be filtered by PI, Co-I or Co-PI ALMA ID, Project Name, Project Code or Cycle as well as by project status "Draft", "Submitted" and "Unsubmitted changes".

When a proposal is first created, it gets the status "Draft" which it keeps until first submission. After submission, the status changes to "Submitted". If further changes are then conducted on the proposal, the status changes to "Unsubmitted changes". Only once the user hits the "Submit" button again, these changes are transmitted to the archive and become visible to the observatory. Then, the status changes back to "Submitted".

Draft proposals can be deleted from the staging area with the "Delete" button next to each proposal and a pop-up will ask for confirmation of this action. Once a proposal is submitted and receives a project code, it can only be reverted to the submitted version. If the user wants to retract a submitted proposal, they have to submit a helpdesk ticket. It cannot be deleted from the staging area.

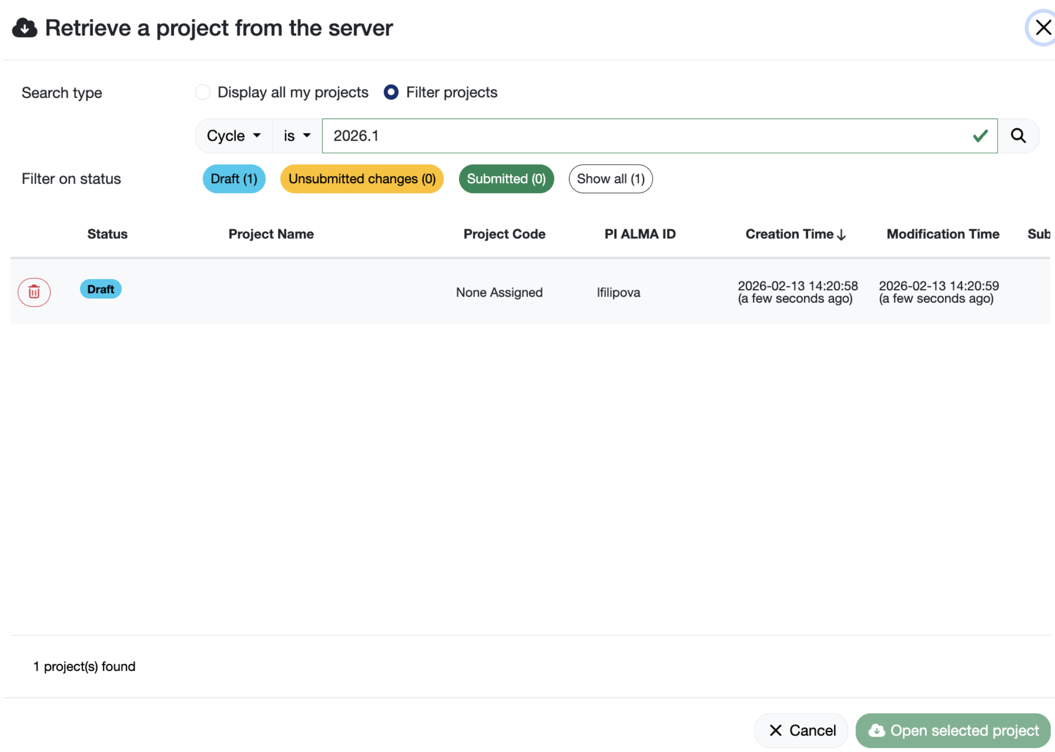

Figure 2.1: The staging area of the observing tool. Here, the user can find all their draft proposals, submitted proposals and submitted proposals with unsubmitted changes, both as PI and co-(P)I.

2.9 The autosave function

Edits in the Project Name, Abstract, and Duplicate Observation fields are saved when the user stops typing for 500 ms. In all other fields, the input is saved once the user leaves the field. Any changes to the proposal thus overwrite the previous version. Users are recommended to work on copies of their proposal (via "Open project as new proposal") if they want to try out different versions. It is not advised to open the same proposal in multiple browser windows. If the OT detects a newer version existing in the staging area, it forces a reload of the proposal. PIs, Co-PIs, and Co-Is have equal access to the proposal. If multiple users wish to work on the proposal, it is recommended to coordinate the work so that only one user at a time makes significant changes to the proposal. Quasi simultaneous access might otherwise lead to frequent requests of the OT to reload the proposal to ensure that the users are working on the latest version.

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Chapter 3

Overview of the Observing Tool

This chapter provides a brief overview of the layout of the OT and how it is operated. The OT is a fairly complicated piece of software, in that it contains many different input pages, organised and accessible from a number of different panels. For the novice user particularly, it is recommended that this chapter be read in order to become familiar with the layout and various important functions and features.

3.1 Help

A number of different ways of receiving help during an OT session are provided. These include:

- User Manual (this document) – provides comprehensive information about how to create a project.
- Reference Manual – gives a brief description of every button and input field.
- Contextual Help – clicking on the "question mark" symbols scattered throughout the OT displays a panel with the relevant section of the Reference Manual (Fig. 3.1).

In the header bar of the OT interface, you'll find a link to the OT user documentation. This provides access to the User Manual, the Reference Manual, the OT video tutorials and general information about the OT.

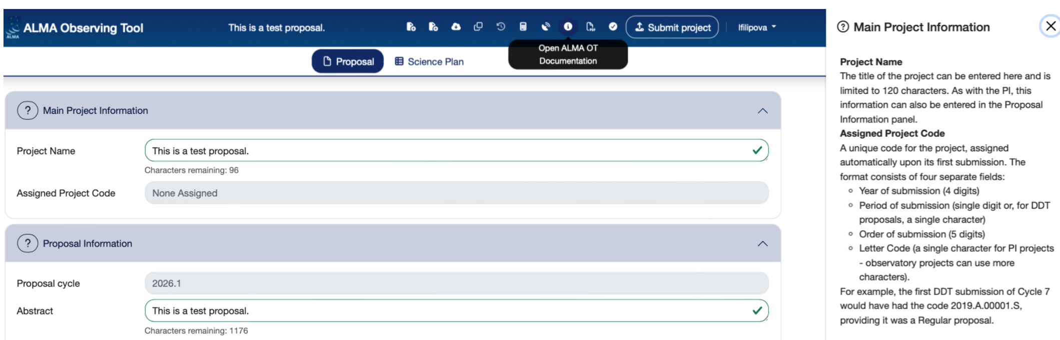

Figure 3.1: When clicking on a "question mark" icon, the contextual help opens on the right side of the tool, displaying the relevant section of the Reference Manual.

3.2 The OT Interface

After logging into the ALMA OT, you will see a start-up screen (Fig. 3.2) that offers different options: Create a new proposal, Create a new DDT proposal, Retrieve a project from the server, Open project as new proposal or

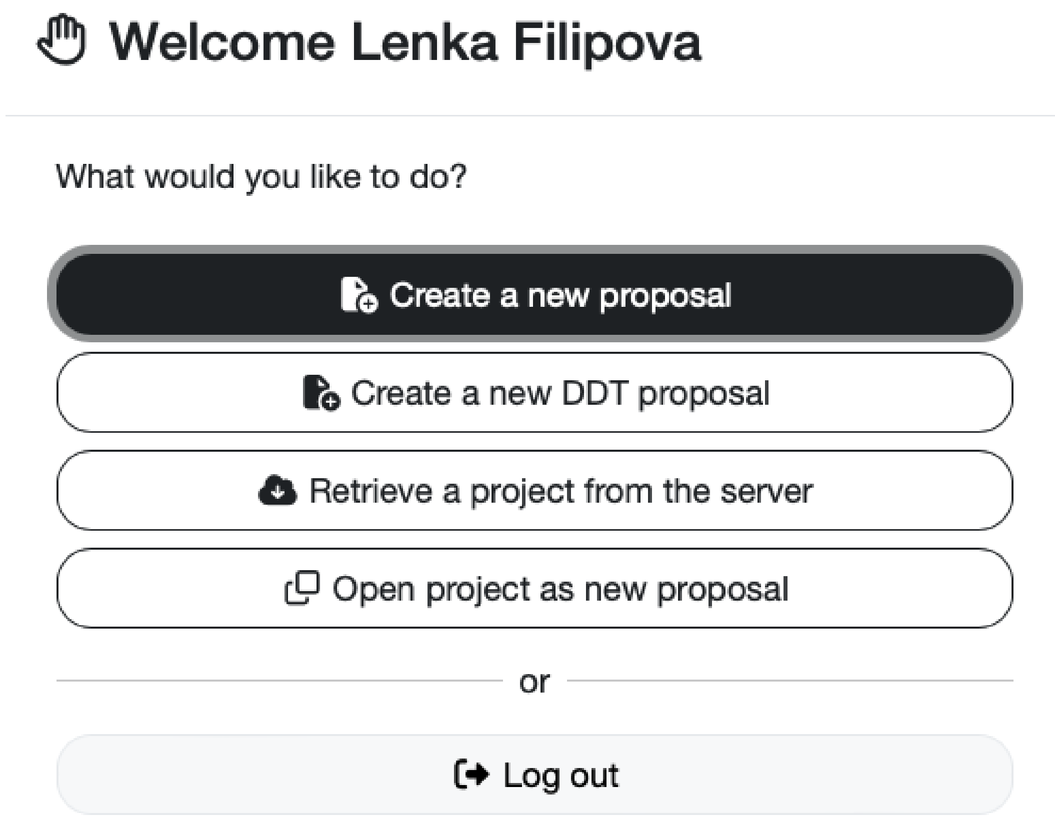

Figure 3.2: After logging into the ALMA OT, the start-up screen is display which offers different options to access proposals.

Log out. After choosing one of the options, the main interface opens which contains two major components: the Header bar at the top and the Navigation bar, immediately below, where you can choose between the Proposal and the Science plan panels. The remaining part of the page displays the content of either panel.

3.2.1 Parameter Fields

The OT contains a large number of text and numerical input fields, many of which require units (e.g. angles, temperatures, fluxes, etc.). Units for the parameter fields can be selected from a drop-down list located to the right of the input field.

When double clicking in a field, the value in the field is selected and typing will replace the value. Simple clicking in the field or moving to a field via tab will allow to append to the content of the field.

The way that the OT deals with “illegal” input varies throughout the tool. It will often be the case that when a bad value is entered e.g. a character where numerical input is expected, the input will be colored red. For other fields, the OT will reinsert the value that had originally been entered. Finally, validation will capture the remaining instances of where a value doesn’t make sense.

3.2.2 Header bar

The Header bar gives access to a variety of OT functions and tools through a number of buttons with different icons, all associated with a tooltip for easier explanation. The validate button is a particularly useful shortcut as this should be pressed at regular intervals.

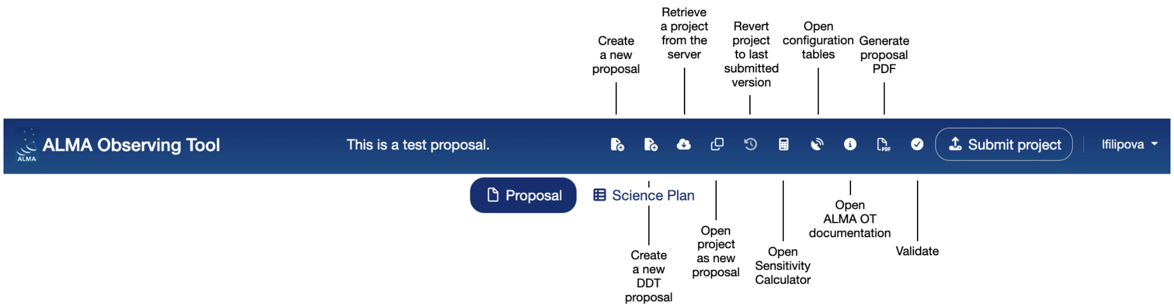

Figure 3.3: The Header and Navigation bars, displaying a variety of OT functions and tools.

3.2.3 The OT panels

The area below the menu bar is divided into two panels (Fig. 3.3). Each of these has a couple of subpanels that determine which information is displayed. The panels can be collapsed and expanded by the small arrows on the boundaries of the panels.

3.2.3.1 The Science Goals

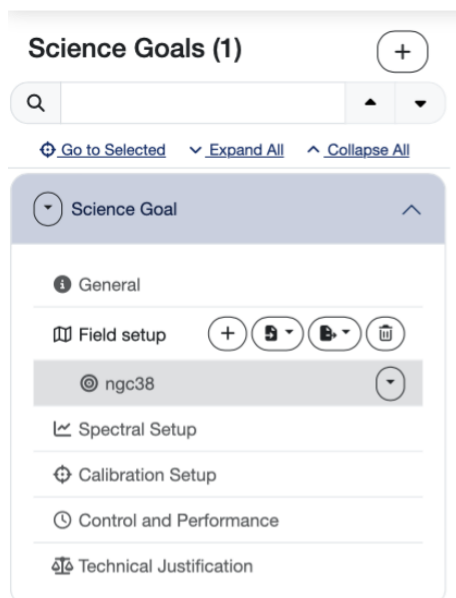

Figure 3.4: Science Goal side bar. Science goals can be added with the "+" icon at the top. For each science goal, the panels General, Field Setup, Spectral Setup, Calibration Setup, Control and Performance and Technical Justification need to be filled.

Each ALMA proposal consists of Science Goal(s) whose subpanels are listed in the Science Goal side bar (Fig. 3.4) on the left side of the page. By default, one Science Goal is created by the interface. In order to add new ones, one can use the "+" button at the top-right corner of the side bar. This creates a new collapsible panel and increments by one the counter in parenthesis. The buttons "expand all" and "collapse all" allow to manipulate all the Science Goal collapsible panels at once. The button at the left of the title of each SG allows to copy that particular SG in a new one, or to delete it. Note that no confirmation is asked before the SG is deleted. At the top of the side bar, a search bar is visible. This allows to search by SG name and by source name.

When clicking on one of the items of a SG, the corresponding content opens on the right side of the interface.

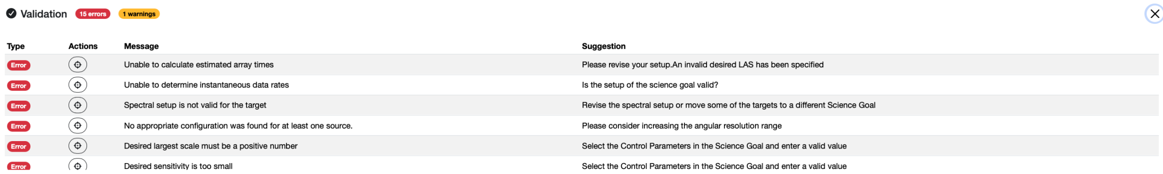

Figure 3.5: The Feedback Window that shows the validation errors and warnings for the proposal. The icons in the Action column bring the user to the content of the proposal which raised this error/warning.

3.2.3.2 The Feedback window

The Feedback window (Fig. 3.5) is intended to help the user to act on errors and warning messages that are revealed after the project is validated. It is not possible to submit a project to the ALMA archive if there are any errors (warnings are allowed) and so it is extremely important to validate before submission and, preferably, regularly during a project's creation. The Feedback window appears automatically when the validation command is executed, even if it has previously been hidden. Clicking on the Actions button of the error/warning brings you to the science goal content that raised this error/warning.

Chapter 4

Observing Proposal

This chapter guides you through the steps needed to produce an observing proposal that can be submitted to the ALMA archive. To follow the descriptions, it is recommended that you have an open OT session in front of you at the time of reading.

Most proposals submitted to ALMA are submitted during the Call for Proposals for a particular cycle which is usually issued once a year. In addition, it is possible to submit a Director's Discretionary Time (DDT) proposal at any time during that cycle's observing period (usually starting in October).

4.1 Create a new Proposal

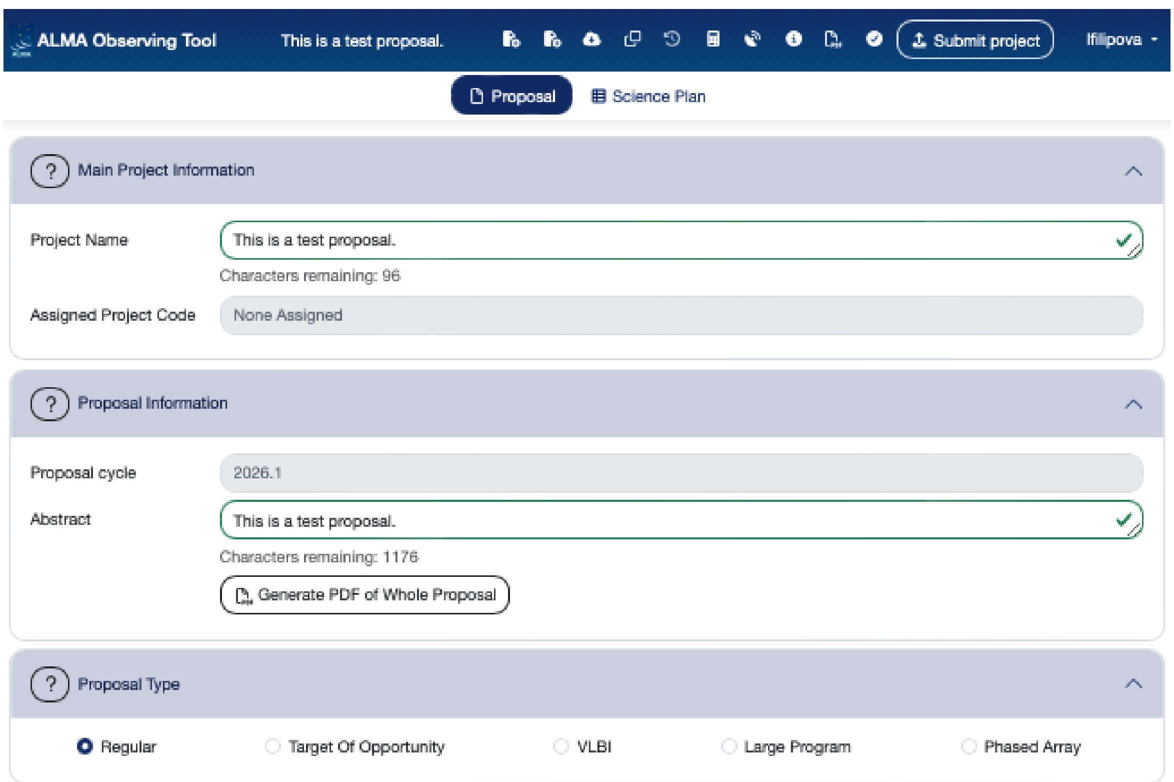

Figure 4.1: Top of the Proposal tab, showing some of the proposal information that need to be filled.

A proposal is either created from scratch or from a draft or previously-submitted proposal from the staging area. Proposals in the staging area can be opened as new with the corresponding button in the Header bar. Previously-submitted proposals, retrieved from the archive, have attached Scheduling Blocks (SBs) and cannot be used to create a new proposal as is. By opening them as a new proposal, the SBs are removed and the proposal data structure is converted to the current Cycle.

The first task is to provide information about the proposal itself, including the title, the abstract, the proposal type, the scientific category and the investigator list, by selecting the Proposal tab (Fig. 4.1). Once the proposal title has been entered, it will be shown in the Header bar. A project code will be added once the proposal has been submitted for the first time.

4.2 The Proposal panel

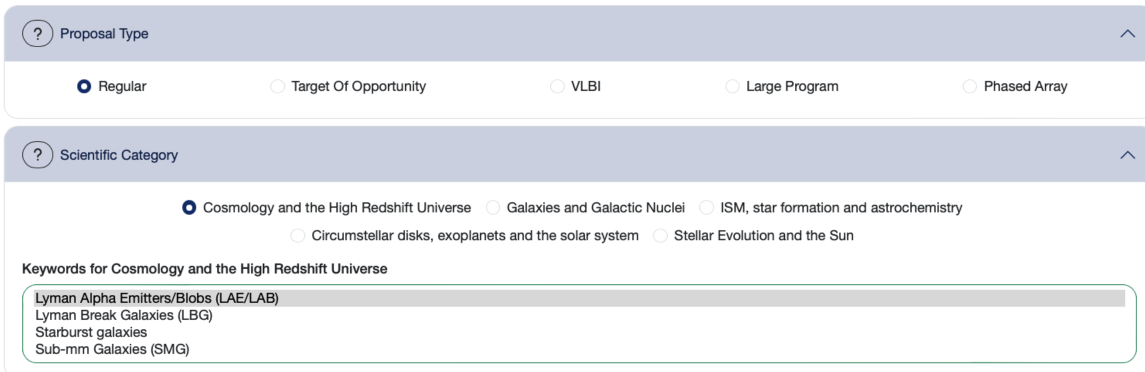

Figure 4.2: Proposal Type and Scientific Category panels.

Completing the information in the proposal panel should be straightforward and the meaning of the fields, and whether they need to be filled in, self-explanatory. Note though that the proposal type can only be edited for proposals before their first submission – after this, no further edits are possible. The available proposal types (Fig. 4.2) are:

- Regular: these proposals request relatively modest amounts of time and are submitted by most users.
- Large: these are defined as proposals that require more than 50 hours for the 12-m Array or 150 hours for the stand-alone ACA (measured by the 7-m time only). These projects must receive an A grade in order to receive time and are allowed a longer Scientific Justification.
- Target Of Opportunity: for proposing the observation of an unpredictable sudden astronomical event, such as a Gamma-ray burst. Source coordinates do not have to be entered at proposal submission time.
- Phased Array: observe an object (currently restricted to pulsars) using ALMA operating as a single dish i.e. the signal from each dish in the array is phased up and summed. Passive phasing must be used with this mode (it is assumed that the sources are too faint to be used for phasing, this certainly being true for pulsars) and is available in Band 1, 3, 6, and 7.
- VLBI: ALMA can observe as part of a VLBI array due to the installation of hardware that allows the signals from each antenna to be summed. However, a VLBI proposal must also be submitted to the VLBI array in question e.g. the Global mm-VLBI Array (GMVA).

After you select a Science Category, a list of related keywords will appear. You can choose one or two keywords. Use the Shift key to select two adjacent keywords, or the Control/Command key to select two separate keywords, just as you normally would.

4.2.1 Joint Proposals

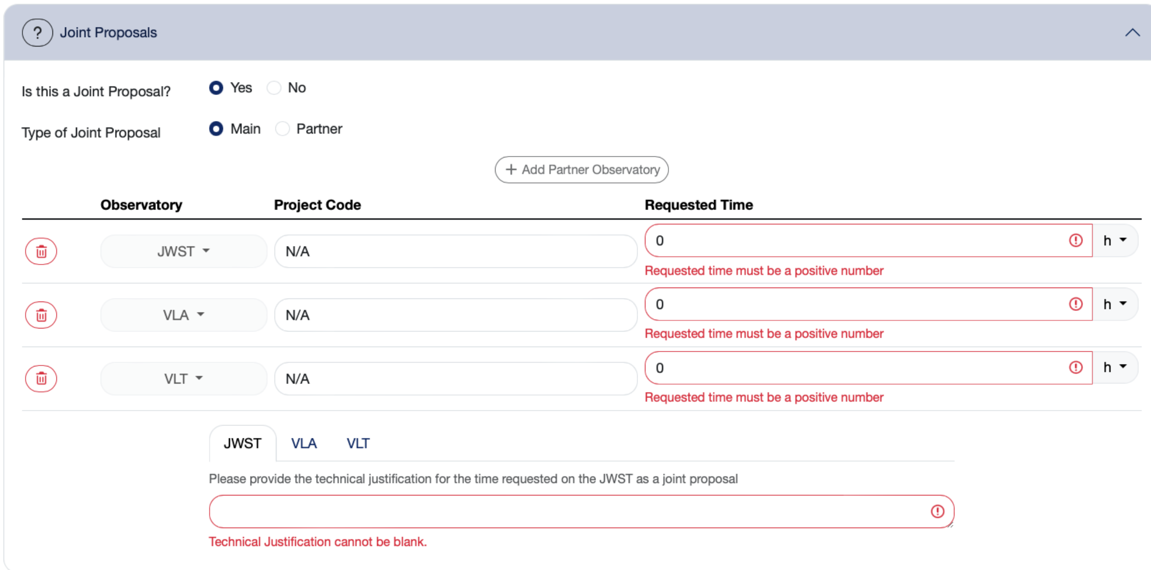

Figure 4.3: Joint Proposal panel. Depending on the amount of requested ALMA time in relation to the other observatories, Main or Partner needs to be selected.

Joint Proposals with other observing facilities – including JWST, VLA, and VLT – are possible. A panel is presented in the OT to allow the PIs to select if their proposal is a Joint Proposal. If Joint Proposal (Fig. 4.3) is selected then the PI should declare if ALMA is the Main Observatory or a Partner Observatory.

- Main: ALMA is the main observatory, meaning it is the observatory where the largest amount of time is requested, either on the 12-m Array, or on the 7-m Array for ACA-only projects. One or more Partner Observatories can be selected among JWST, VLA, and VLT, the project codes can be entered, and the amount of requested time is required. A technical justification of the requested time on each partner observatory is required.
- Partner: ALMA is one of the partner observatories, or the only partner observatory. The Main Observatory and one or more Partner Observatories can be selected among JWST, VLA, and VLT, the project codes can be entered, and the amount of requested time is required.

For Partner Joint Proposals, Large Programs, VLBI, and Phased Array observations are not allowed.

4.2.2 Adding Investigators

Further down the page is a panel (Fig. 4.4) for adding Principal, Co-Principal and Co-Investigators – these must all have registered in the Science Portal before they can be added in the OT and we strongly advise that this is done well in advance of the proposal deadline.

A project can have only one PI, but any number of Co-Is. Large Programs can in addition have multiple Co-PIs. By default, the user that created the proposal is selected as PI. The PI of a proposal cannot be removed. Instead, the PI can be changed with the option “Select PI” and the previous PI is then automatically added as a Co-I. Only the PI is allowed to remove collaborators, change the PI or submit the proposal.

Clicking on e.g. “Add CoI” will start up a window which allows you to search for and select users from the ALMA user database. Within this, users can be identified by their name or ALMA ID (username). To find matching users, select which attribute should be searched for from the drop-down list, enter a valid constraint into the text field and press enter or click the icon of the magnifying glass. If the entered constraint is invalid, it will be highlighted in red and searching will be disabled. A valid constraint consists of:

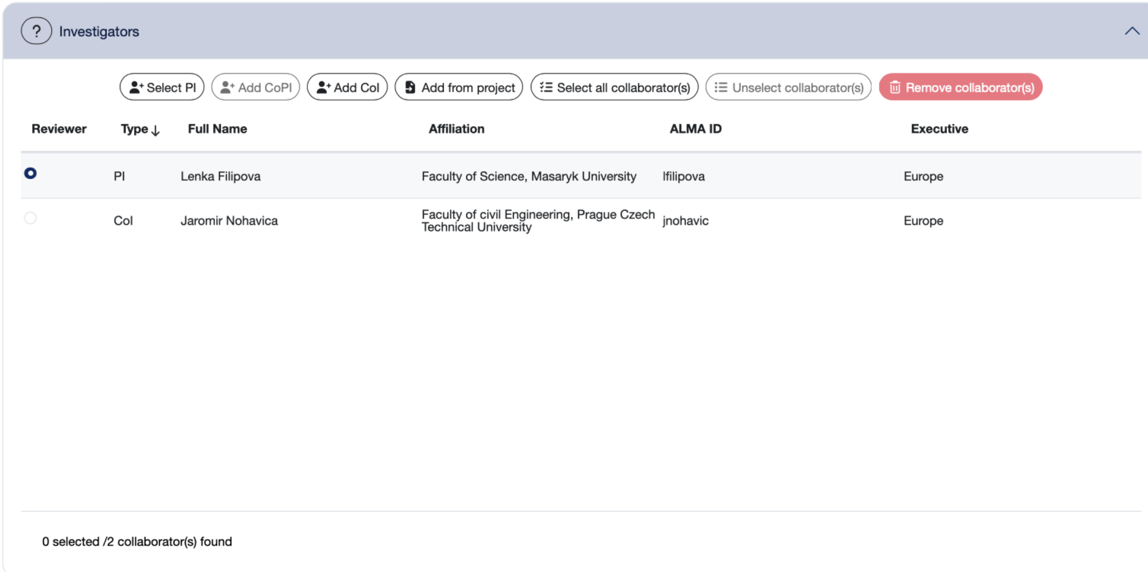

Figure 4.4: Investigator panel. Only the PI can change the PI, add collaborators from project or remove collaborators.

- Name: at least 3 characters (partial matches are reported)
- ALMA ID: at least 3 characters (only exact matches are reported)

All searches are case-insensitive. Double-clicking any row will enter this user into the table of investigators. In the case of Co-Is, highlighting multiple entries will cause these to be entered into the table. Collaborator(s) can be removed from the investigator list by highlighting them and then pressing the corresponding button.

When there are many investigators, these can be added from a previous proposal that contains all or some of the desired investigators using the “Add from project” button. These can either be a draft proposal in the staging area or an already submitted proposal from the archive.

One of the columns in the table shows a user’s Executive. Currently, the Executive of the PI determines whether the time required for a project is charged to the East Asian, North American, European or Chilean share of available observing time and is usually set at the time of registering in the Science Portal. Taiwanese investigators though must set this in the OT as they can decide, per proposal, between charging all of the project’s time to NA or EA, or to split it evenly between the two. Although this only has an effect for PIs, the OT still allows a Taiwanese Co-I’s Executive to be set in this way. For Large Programs, the executive share is split between the Co-PIs.

As astronomers move between institutes from time to time, the affiliation details in a proposal can end up not matching those in the User Registry. If a project is submitted by the PI when it is in a Phase 1 state (e.g. during the Call for Proposals for non-DDT projects) the OT will update the details of any investigators if these are different to those stored in the User Registry. This will happen either at submission time, or at the creation of a new proposal if the “Open Project as a New Proposal” option was used. If any of the investigators has moved to a Taiwanese institute, the submission will be terminated and the PI asked to check that the executive share is set correctly – it will default to ‘EA’.

4.2.3 Reviewer Information

A reviewer (Fig. 4.5) must be nominated for proposals (except Large Programs) submitted as part of the Main Call, as they will ultimately be asked to participate in the distributed peer review. All Large Programs will instead be reviewed by panels. More information can be found in the Proposer’s Guide.

If the reviewer is the PI and doesn’t have a PhD then it is possible to nominate a suitably qualified mentor

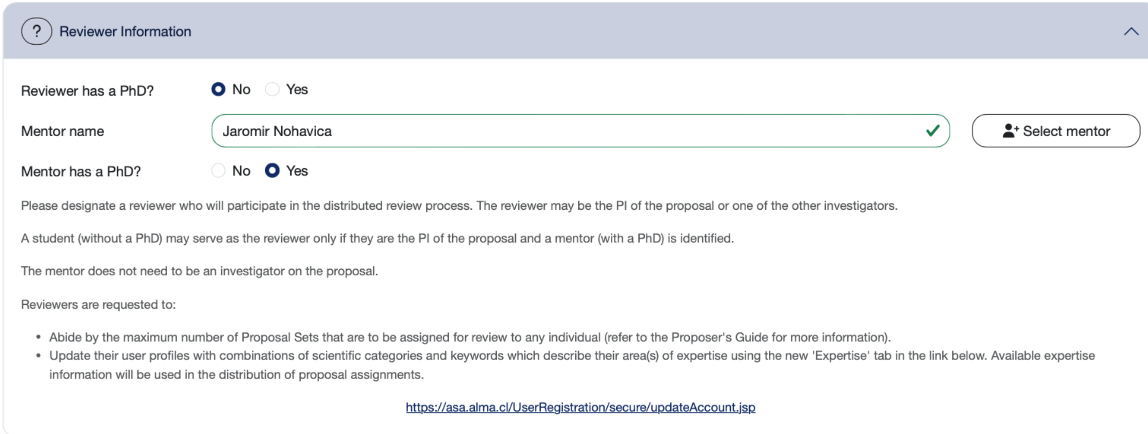

Figure 4.5: Reviewer panel. If the PI does not have a PhD, a mentor with a PhD needs to be chosen to monitor the distributed peer review of the PI's proposal stack.

who will provide support. The mentor needs to have a PhD. Co-Is cannot be the reviewer if they do not have a PhD.

4.2.4 Science Case

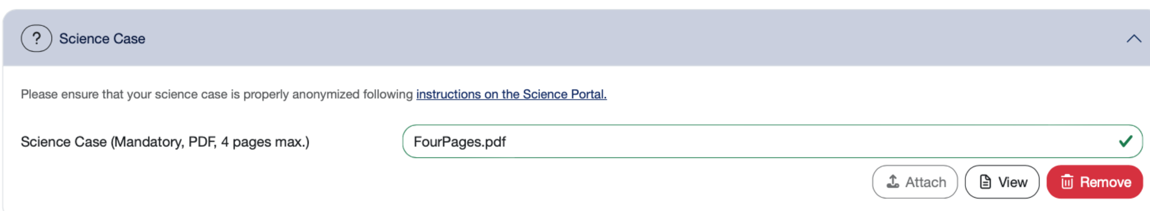

Figure 4.6: Science case panel. The PDF is limited to a maximum of four pages (seven for Large Programs) and must not exceed a total size of 20 MB.

Below the list of investigators, the PDF document to support the science case must be attached (Fig. 4.6). This is limited to a maximum of four pages (seven for Large Programs) and must not exceed a total size of 20 MB. Figures can be included if desired. Once attached, the PDF file can be removed and replaced with another and can also be viewed.

The minimum font size for the PDF is 12 point. If more than 15 per cent are smaller than this font size, the OT will raise a validation error. Sometimes the amount of small text is larger than expected due to a figure having been extracted from a PDF document e.g. using Preview on a Mac. This can lead to all the text on the page from where the figure was extracted to appear in the resultant figure, albeit invisible. If you receive the warning and think this is erroneous, then this possibility should be investigated.

The technical justification should not be included in the PDF, this information is instead placed in a dedicated panel of each Science Goal.

4.2.5 Team Expertise

Large Programs must include a single-page PDF describing how resources will be made available to ensure that the large volumes of data will be dealt with (Fig. 4.7). The font-size restrictions also apply here.

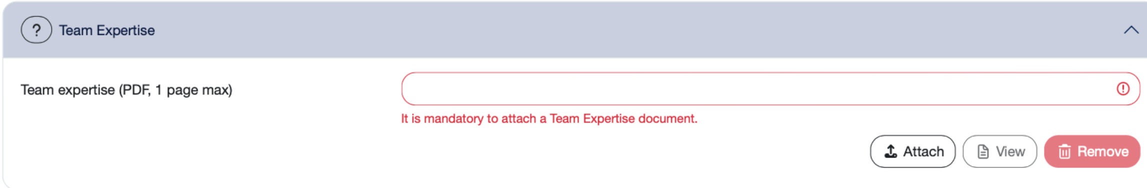

Figure 4.7: Team Expertise panel. This only appears for Large Programs. A single-page PDF should be uploaded here.

4.2.6 Scheduling Feasibility

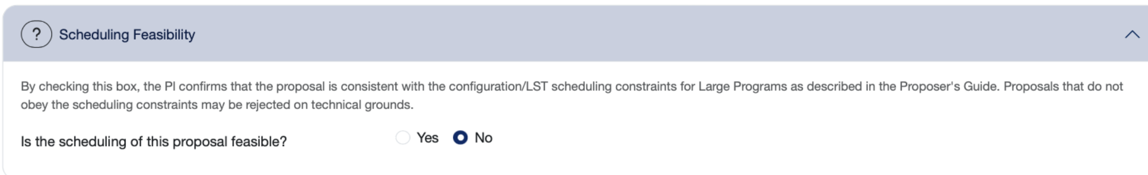

Figure 4.8: Scheduling Feasibility panel. This only appears for Large Programs.

For Large Programs, the PI has to confirm that the proposal is consistent with the configuration/LST scheduling constraints for Large Programs as described in the Proposer's Guide (Fig. 4.8). As long as "No" is selected, the proposal does not validate.

4.2.7 Duplicate Observations

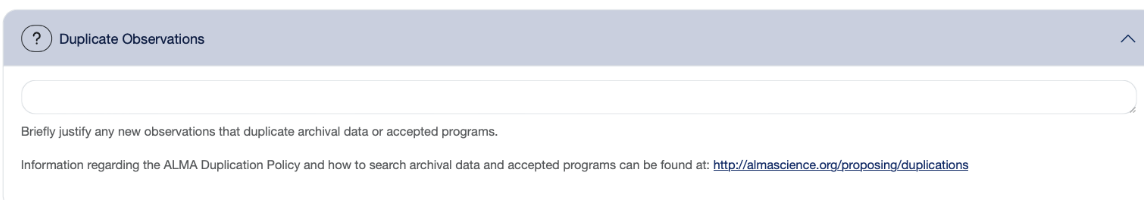

Figure 4.9: Panel to declare the reasoning for duplicating observations.

The ALMA Science Archive (ASA) is continually growing and now contains a very large number of calibrated datasets. It is expected that every prospective ALMA user has searched the ASA to check that their proposed observations are not duplicated by previously observed programs. If the current proposal does duplicate a previous observation then this should be justified in the appropriate pane (Fig. 4.9). A failure to do so may result in the proposal being rejected by the observatory. More information on what constitutes a duplication can be found in the Science Portal.

4.3 The Science Plan

The Science Plan (Fig. 4.10) displays the list of science goals with their subpanels on the left as well as three panels for the Project Overview, Time Summary and Data Volumes & Data Rates at the center of the page. The Project Overview lists the Science Goals, number of sources, assigned observing band, spectral type, number of spectral windows, polarization products desired, calibration setup, representative frequency, angular resolution, largest angular scale and requested sensitivity. In the Time Summary, the 12-m, ACA, and TP time for each science goal is listed, subdivided for each cluster. The Data Volumes & Data Rates tab lists the Data Volume and Average Data Rate for each of the arrays and science goals, subdivded for each cluster.

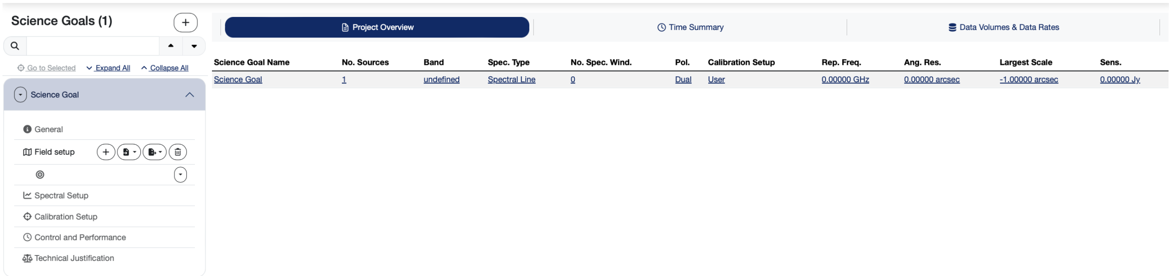

Figure 4.10: List of science goal(s) on the left. Tables for the Project Overview, Time Summary and Data Volumes & Data Rates in the main part of the page.

4.3.1 Adding Science Goals

By default, an empty science goal is set up in the science goal list on the left of the page. Further science goals can be added by clicking the "+" button next to the total number of science goals at the top of the science goal list. There is no limit to the number of SGs that can be added.

4.3.2 General

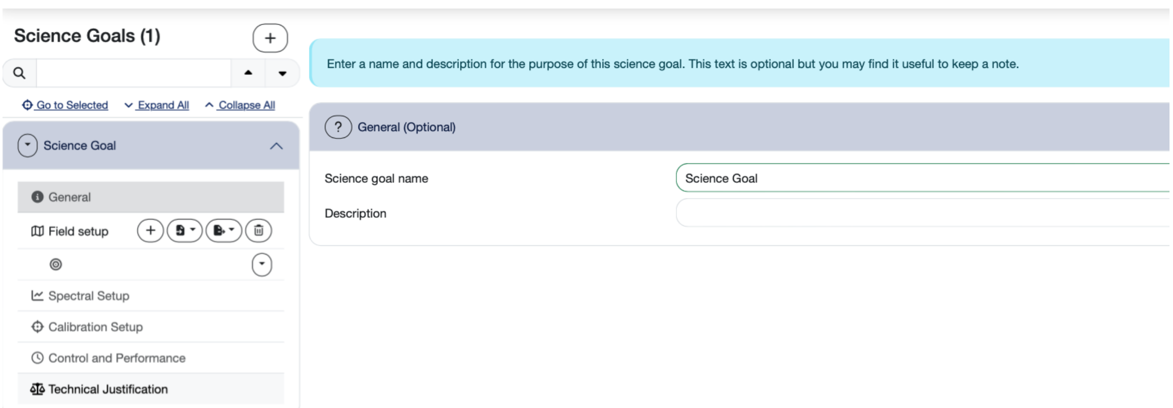

Figure 4.11: Panel to change the science goal name and add an optional description.

The Science Goal name and a description of the Science Goal can be placed here if desired (Fig. 4.11). Each science goal needs to have a unique name, otherwise a validation error is raised.

4.3.3 Field Setup

4.3.3.1 Source

In the Field Setup panel, the user is asked for source parameters, the most important of which are the name, coordinates and velocity (Fig. 4.12). The source names should only contain the following characters: a-z, A-Z, 0-9, -,+, _ or a . (full stop). Characters other than these will be removed or replaced when the project is validated. Source names which are composed of only numbers are also invalid.

By default, an empty source field is set up in the Science Goal. Once a source name is defined, the name will appear next to the "bull's eye" icon. Sources can be added manually by clicking the "+" icon on the Field setup tab in the Science Goal list or by copying the source information with the downwards pointing arrow next to each target. The same arrow also allows to delete a source (except if there is only one source left). A source

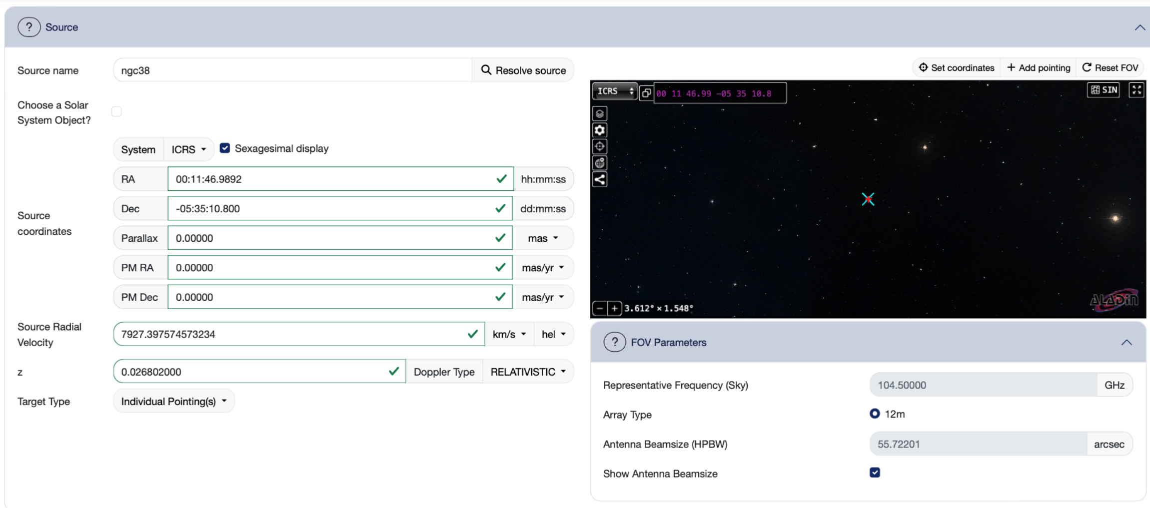

Figure 4.12: Source panel in the Field Setup panel. On the left, coordinates and velocity of the target have to be added. The spatial visualizer on the right shows the location of the source, either on pre-selected images or on user FITS files.

list can either be appended to the source list or replace the source list (for more details see Section 4.3.3.7). The trash bin icon allows to delete all sources.

Apart from Galactic coordinates, the only system that should be used is ICRS. The two components of the source proper motion, Dec. and R.A. (cross declination), are both true angles on the sky and are used to convert the given source position to an observable one assuming that it refers to epoch J2000.0.

The ALMA telescope control system recognises a limited number of solar system objects that can be selected from a drop-down list. This same list also allows the use of an ephemeris for any object for which the coordinates as a function of time can be provided. This is loaded as a text file from the local disk and must be in the JPL HORIZONS format. For details on how to generate HORIZONS ephemeris files, please check Appendix A. When using an ephemeris at Phase 1, it is recommended that only a skeletal example be attached to the Science Goal, using a time interval of one day to cover the period over which the observations are likely to take place. An ephemeris is also required for Solar observing and a tool is available in the Science Portal for generating these.

The velocity can be specified using the optical, radio, or relativistic convention. A number of different frames are available and the most useful of these are barycentric, heliocentric[1], topocentric and LSRK. The velocity is used to convert the rest frequencies of the spectral windows to the observed equivalent and for barycentric and heliocentric, this is done in the same frame i.e. the "observed" velocity will remain in that frame. In the case of LSRK though, the OT performs an additional conversion to the barycentric frame. When changing the source velocity reference system between the available options of heliocentric, barycentric, topocentric and LSRK, the OT is not able to convert the velocity and you will be reminded of this via a pop-up dialogue box.

The velocities must be sufficiently similar such that all the sources can be observed in a single band. In addition, a maximum of five tunings per Scheduling Block are allowed and thus the sources must be grouped in velocity space in such a way that this limit is not exceeded, otherwise a validation error is raised. This issue is explained in more detail in Section 4.3.4.12.

The target type offers the choice between 1 Rectangular Field or Individual Pointing(s). All sources in one SG need to have the same Target Type (see Section 4.3.3.5 for more details on those two types).

[1]Barycentric and heliocentric only differ by $\sim$12 m s^{-1} and the telescope control system will actually use barycentric if heliocentric is requested.

4.3.3.2 Source clustering/Pseudo-Science Goals

It was previously the case that all sources in a Science Goal had to lie within 10 degrees of each other, but that restriction has now been dropped. Instead, the OT now includes a "hierarchical clustering" algorithm which will automatically split the sources into 10-degree clusters. Each of these is henceforth treated as if it were a separate Science Goal and, during development of this feature, these have indeed been referred to as Pseudo-Science Goals (PSG). Users who wish to observe many sources across the whole sky, but for which a single set of performance parameters (angular resolution, sensitivity) apply, will hopefully find this feature useful. For long-baseline Science Goals, a smaller clustering length is used (1 degree) as the phase calibrators need to be relatively close to the science targets.

As each PSG is treated exactly as a normal Science Goal, the 150-source and five-tuning limits now apply to the PSG. Array selection is also performed as for a normal SG and different arrays can potentially be selected for each PSG given that the array properties (angular resolution and maximum recoverable scale) are source declination-dependent. How the sources have been split into clusters will be made clear using the various summary tools of the OT, including the time estimate tab and the project time summary. Each PSG will generate its SBs into a completely separate OUS structure.

There may be issues with slow response times due to the extra computation that the OT has to perform. In addition, the range of angular resolutions that can be entered into the Science Goal is restricted compared to what would be possible if the project were created as separate SGs. This is because the angular resolution range is declination-dependent and thus differs for each cluster. In order to avoid unexpected validation errors, the displayed angular range limits on the Control & Performance panel are therefore restricted to those values that will not produce a validation error for any of the clusters that currently exist. This restriction will probably only matter if the required angular resolution might require either the smallest or largest 12-m configuration and, in this case, it might be necessary to split the sources manually into separate SGs.

4.3.3.3 Resolving source information

Source details can be automatically filled in by "resolving" a recognized source name. The OT uses the Sesame[2] web service to first query SIMBAD[3] and then, if no source with that name is found, NED[4]. It is not possible to select which server is queried although the OT will state which one gave the displayed result. The entered source name must correspond exactly to that contained within SIMBAD or NED or else no match will be found. The coordinate system of all sources will be set as ICRS.

Be careful with the proper motions of bright quasars. The Hipparcos mission measured non-zero values for many of these although, reassuringly, the associated uncertainties mean that the results are consistent with zero. Nonetheless, it is the measured, non-zero, values that will be entered into the OT. Parallax can also sometimes be negative, but again this is due to the measurement uncertainties. Where spurious, these properties should all be set to zero manually.

Although an extremely useful tool, resolving source information should be used with care and the returned details checked very carefully. For example, the origin of the coordinates will often be from an optical or infrared telescope and may not be appropriate for the science you want to do with ALMA. The SIMBAD or NED websites should be checked for this kind of information. The OT will present a table containing the source information that has been resolved, before this is entered into the Field Setup form, and warn if proper motions or a velocity have not been found. The name contained in this table will usually be different to that searched for, but this is nothing to worry about. The actual name that was entered by the user will not be changed.

The user has the ultimate responsibility to ensure that the source details are correct!

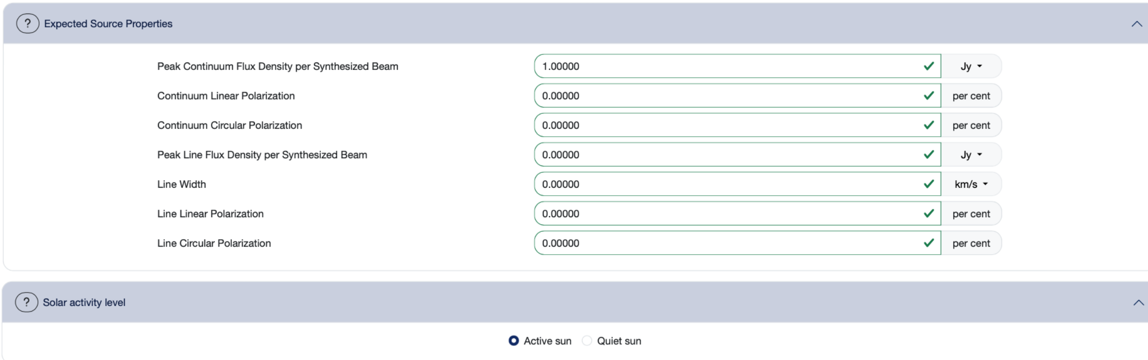

Figure 4.13: Panel listing the expected source properties for non-solar targets (top). Depending on the chosen spectral type and polarization product, different properties need to be filled. Bottom: Panel to choose the solar activity level. Only visible if Sun is selected as target.

4.3.3.4 Expected Source Properties

Once the source position and velocity information has been completed, details of the source brightness, polarization (linear and/or circular) and line widths should be added (Fig. 4.13). These numbers are used mostly for technical assessment of the proposal and as such are used extensively in the information presented to the user in the Technical Justification panel (Section 4.3.7).

All the relevant values should be filled in, even if exact quantities are not known – reasonable estimates should be entered. Which fields should be filled in depends on the type of observation being created and the OT will issue a validation error if, for example, a line width is not entered for a spectral line project or a polarization percentage is not given, or is below the instrumental limits, when full polarization has been selected. For spectral-line projects, a spectral line flux is mandatory and this should always be entered relative to the continuum (if any). If the line is in absorption, the depth of the line relative to the continuum should be entered as a positive flux density.

For solar observing, the source property panel looks very different. Here, all that is requested is an assesment of whether the solar feature being observed corresponds to an "active" or a "quiet" Sun. This will be used to select the corect debiasing mode when observing.

VLBI is another special case – more information is required than for solar, but still much less than for a regular ALMA project. An important VLBI-only feature is the ability to request that "passive phasing" be used during VLBI-type observing (for targets weaker than 0.35 Jy in Band 1, 0.5 Jy in Bands 3 or 6, or 0.7 Jy in Band 7). For spectral line observing the flux thresholds are calculated using the formula reported in the Proposer's Guide. If the appropriate checkbox is ticked, a nearby (phase) calibrator should be defined in the Calibration Setup panel and justified in the Technical Justification panel. Spectral-line VLBI requires that the width of the line be entered – this is to ensure that the line fits into the spectral window which is fixed at a specific frequency.

4.3.3.5 Field definitions

The observing patterns that are used to observe a source fall into two categories (Fig. 4.14):

- Rectangular area – a uniformly-spaced pointing pattern that covers the rectangle is calculated by the OT, for both the 12- and 7-m Arrays. The TP Array will observe a larger version of the user-defined rectangle and this is displayed in light blue in the visual editor. If one of the sources is defined using a rectangle, all the sources in the SG must be.
- Multiple individual pointings which are to be mosaiced together – if the source extent is not easily ap-

[2] http://cds.u-strasbg.fr/cgi-bin/Sesame
[3] http://simbad.u-strasbg.fr/simbad/
[4] http://ned.ipac.caltech.edu/

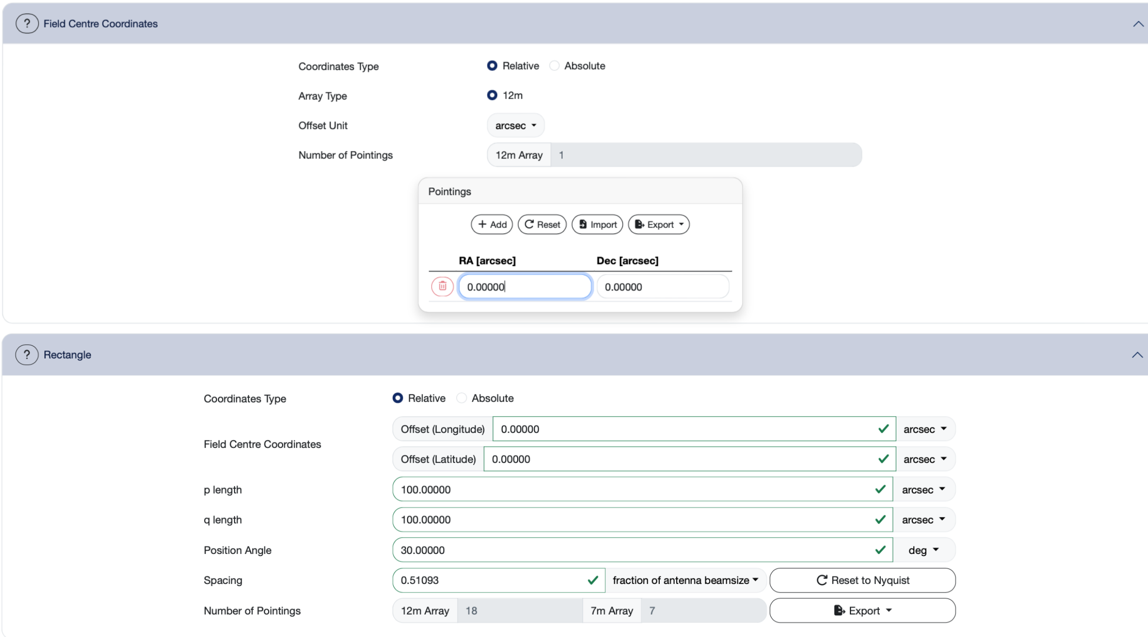

Figure 4.14: Observing pattern panel. Top: Individual pointings. Bottom: Rectangular field.

proximated with a rectangle, then a custom mosaic can be used to cover the source more efficiently. All the pointings must overlap and the Pipeline will produce a single image. If the ACA is required, the OT will automatically calculate the smallest rectangle that encompasses the 12-m pointings. This will then be tiled with 7-m Array pointings using Nyquist sampling and redundant pointings removed. The TP Array will raster scan the rectangle.

In both cases all the pointings must overlap such that there are no gaps in the coverage i.e. one contiguous source is being mapped. If it is desired to map multiple separated areas of emission, each must be entered as a different source.

For rectangles, the 12- and 7-m Array pointings that are calculated by the OT are overlapped so that the final map will have approximately the same sensitivity at each point – this is necessary as the sensitivity of a radio telescope drops away from the pointing centre. The spacing parameter defaults to the Nyquist value, $\lambda/(\sqrt{3}\,D)$, this being appropriate for the OT's hexagonal/triangular mosaic pattern. As the antenna beam size is $1.13\,\lambda/D$, the actual value reported in beam units is $1/(1.13\,\sqrt{3})$ i.e. 0.51. Particularly for projects that are mapping large structures, this should not be changed, but projects that aim to cover a large area of relatively small sources can use a larger value. The value of λ is set from the Representative Frequency (Section 4.3.4.10).

Both rectangles and individual pointings can be defined using the Spatial Visualizer (Chapter 5.4) if desired. This shows the user-defined rectangle, the 12- and 7-m antenna pointing positions, as well as a larger rectangle that corresponds to the area that will be covered by the Total Power Array. Individual pointings can additionally be read into the OT from an ASCII file, whilst all pointings can be written to file, including those derived by the OT from a rectangle.

Under some circumstances it is only possible to define a single pointing, including all Band-10 observations, spectral scans and VLBI. If observing mosaics in full polarization it is recommended that Nyquist sampling or higher is used.

4.3.3.6 Solar total-power observing

Observing the Sun with the Total Power array is significantly different to TP observations of other sources. In the latter case, the TP antennas perform a raster scan of the source, observing along successive rows with increasing vertical offsets until a rectangular area has been covered. For the Sun though, the TP observations must use

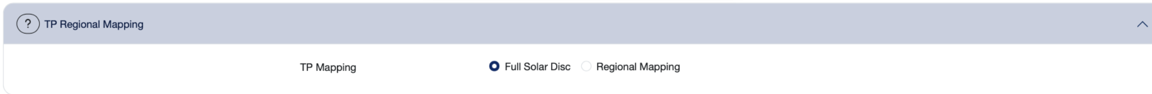

Figure 4.15: Panel to specify which TP Regional Map is supposed to be observed. This panel is only visible if the Sun is selected as target.

so-called "fast" scanning in order to map this large source quickly enough such that the changing properties of the solar disc can be properly resolved in time.

Besides TP maps of the full solar disc, it is possible to request TP observations of the region covered by the interferometer (Fig. 4.15).

How the TP observations are carried out is specified in a special panel ("TP Regional Mapping") where the user can, for example, indicate whether they want just the full solar disc or maps of the interferometric region as well.

At the moment, in regional mode it is only possible to observe a circular area mapped using a so-called "double-circle" pattern – for this the user only needs to define the diameter of the circle which should be somewhat larger than the interferometric mapping area.

4.3.3.7 Import/Export of Source Information

Positions, velocities and the "expected properties" of multiple sources can be added to a Science Goal from an ASCII file using "Load sources from file..." (second icon next to Field Setup in the Science Goal list). This can be used to either load a set of additional sources, or to completely replace the list of currently-defined sources. Before appending or replacing the source list, the desired Target Type should be set in the existing source(s) since this determines the Target Type of the imported sources.

The format of the ASCII source list (case-insensitive) is shown below; it should be possible to cut and paste this into a text editor. Alternatively, the "Export sources to file..." option can be used to create a template (third icon next to Field Setup in the Science Goal list).

```
Name, RA|Galactic Long (Degs), Dec|Galactic Lat (Degs), PMRA(mas/yr), PMDec(mas/yr),
vel(km/s), Ref frame, Doppler type, peak cont flux(mJy), peak line flux(mJy), cont pol(%),
line pol(%), line width(km/s), cont circular pol (%), line circular pol (%)
--   This signals end of the header
ngc253, 00:47:33.134, -25:17:19.68, 0.0, 0.0, 258.6, lsrk, RADIO, 200, 1000, 2, 0, 1500, 0, 0
ngc1068, 02:42:40.771, -00:00:47.84, 0.0, 0.0, 1142.0, topo, OPTICAL, 1100.0, 30, 0, 0, 20, 0, 0
```

If the source coordinates are entered as decimal degrees, the OT will interpret these as Galactic.

In addition, the individual pointings that make up a field definition can also be imported or exported to file, on a source-by-source basis. An example of the format is:

```
RA , Dec, Coordinate Type, Coordinate Units
--   This signals end of the header
 04:31:38.4369, 18:13:57.651,Absolute,Sexagesimal
 04:31:40.5426, 18:13:57.650,Absolute,Sexagesimal
 04:31:36.3312, 18:13:57.650,Absolute,Sexagesimal
```

The "Absolute" coordinate type can be combined with the units "Sexagesimal", "Degrees" or "Radians", whilst "Offset" pointings can be defined in "Arcsecs", "Arcmin" or "Degrees". Both the unit and coordinate type are case-insensitive. It is not possible to read the pointings in for a rectangle.

4.3.4 Spectral Setup

The Spectral Setup panel contains fields to specify spectral windows, each of which samples a source's spectrum over a particular range of frequencies. These are defined either manually or with the Spectral Line Picker (SLP, Section 5.2). All setups should be inspected using the Spectral Visualizer (Chapter 5.5).

As mentioned in Section 4.3.3.1, the OT will convert all rest frequencies to their observed equivalent, most obviously using the source velocity. However, if the entered velocity is in the 'LSRK' frame, the entered frequencies are additionally transformed to barycentric. Ideally, the OT would perform a full conversion to topocentric (reference frame of the antenna) but this is not possible as the OT does not know when the observations will take place. The telescope control software then makes the final 'bary' to 'topo' conversion. Single-continuum and spectral-scan setups are explicitly in the topocentric frame, regardless of the frame specified in the Field Source definition.

4.3.4.1 Spectral Type

The OT offers three kinds of spectral observation:

- Spectral Line – offers maximum flexibility for the placing of spectral windows, with user-defined centre frequencies and correlator modes
- Single Continuum – automatically defines a maximum bandwidth (7.5 GHz), low spectral resolution correlator setup. This is most useful for measuring a continuum, but can also be used for observing broad lines
- Spectral Scan – automatically defines a set of multiple tunings which cover a continuous frequency range. This is particularly useful for observations of sources with dense forests of lines, or for redshift searches.

4.3.4.2 Recovering image sidebands at Bands 9 and 10 (90-Degree Walsh Switching)

ALMA uses three types of receivers, "single-sideband" (Band 1), "two-sideband" (Bands 2 to 8) and "double-sideband" (Bands 9 to 10). The main difference is that double-sideband receivers need special processing (90-degree Walsh switching) in the correlator in order to recover the two sidebands of each spectral window. This can be selected via a checkbox.

For single-continuum observations the advantages of using this feature are clear as it doubles the effective bandwidth, thus halving the observing time necessary to achieve a given continuum sensitivity. The image sidebands are thus always produced in this case. Spectral scans will also usually benefit from this as the whole point here is to cover a large bandwidth efficiently and doubling the bandwidth clearly facilitates that.

For spectral-line observations the situation is less straightforward. The reason for this is that it is not possible to define the centre frequency of both the signal and image sidebands for each spectral window and therefore it is difficult to create setups where a spectral window contains a spectral line in one sideband and a different one in the other. The most obvious application of 90-degree Walsh switching is therefore combined spectral-line/continuum observations where, for example, one spw might observe a spectral line in one sideband whilst the other three spws observe the continuum. In both cases a large bandwidth makes most sense (to increase the chances of a line falling in the image sideband and to maximise the continuum sensitivity) and thus 90-degree Walsh switching is only allowed if all spectral windows have the maximum-allowed bandwidth of 1875 MHz. It is expected that use of the Spectral Visualizer (together with the line-overlay feature) will greatly help in creating a 90-degree Walsh setup.

One important consequence of using 90-degree Walsh switching is that it nominally doubles the data rate. This can be a problem for setups that use all four spws with no spectral averaging, especially if the requested angular resolution is such that a "long-baseline" configuration, and thus short integration durations, is required. Although 90-degree Walsh switching is applied to every spectral window and thus the image spw is always produced, it is possible to indicate per spw that this should be discarded by unchecking the "Store Image" checkbox.

Note that 90-degree Walsh switching is only available for interferometric observations and therefore it is not currently possible to observe at Band 9 or 10 with the TP Array.

4.3.4.3 Polarization Products

All ALMA receivers detect two orthogonal senses of linearly-polarized radiation (X and Y). For maximum sensitivity, dual-polarization observations correlate both signals, producing XX and YY for each spectral window. For each baseband, a total of 8192 channels are available and these are divided up between the two polarization pairs. Single polarization (XX) is rarely observed, but as this can place the full 8192 channels across a single spectral window, it can be useful when the highest possible spectral resolution is required.

Full polarization (XX, YY, XY and YX) should only be selected if a measurement of the source linear or circular polarization is desired. As twice as many products are being created, the spectral resolution is reduced by a factor of two compared to dual polarization. Full polarization is now also available for the Stand-alone ACA (single pointing only per source) but not for the TP Array or for 7-m Array observations added to a 12-m Science Goal for purposes of imaging the largest angular scale. There is a limit on the lowest polarization that can be detected – 0.1 per cent in linear and 1.8 per cent in circular polarization.

Mosaics are now possible for continuum observations of linear source polarization only – circular polarization mosaics are not allowed. Where mosaics cannot be performed there are restrictions on the maximum source size that can be observed (different for linear and circular polarizations) and Single Continuum with the default frequencies must be used.

For projects using the VLBI system (including the Phased Array) technical issues require that full polarization be used.

Band 3 full polarization is allowed for Solar observing. This is only allowed in single continuum.

4.3.4.4 Spectral-window placement

Before going on to discuss the various ways in which spectral windows can be defined, it is interesting to consider a few aspects of spectral-window placement that can be easily overlooked.

Firstly, although one only receives data from the defined spectral window, the receivers also detect power from the other sideband. For example, if a spw is defined at 637 GHz (Band 9) the default setup is to place this in the USB with the LSB lying over a very deep atmospheric absorption line. The two sidebands are separated in the correlator, at which point it is not possible to remove the noise contribution from the other sideband. Thus, in Bands 9 and 10 we advise that sidebands not be placed over prominent absorption features, if at all possible.

In Bands 3-8 the situation is less serious as the sidebands are separated in the receivers and thus the noise from the other sideband *is* rejected (by $\geq$10 dB). However, it can still be a good idea to avoid deep absorption lines (such as the water lines in Bands 5 and 7) as this can cause problems with $T_{\rm sys}$ measurement and flux calibration.

Another issue concerns the placement of the spws within the basebands. Each baseband is 2 GHz wide and the edges (30-60 MHz) should usually be avoided due to various issues that lead to deterioration of the sensitivity and accuracy of flux calibration. For example, two narrow ($\sim$ 60-MHz) spws placed in the same baseband and separated by 1.9-GHz will significantly encroach into these relatively poor edge regions. This can be difficult to see visually as the SG's Spectral Visualiser does not show basebands, but the OT will warn if any part of a spw lies within 30 MHz of the baseband edge.

4.3.4.5 Spectral Line – one spectral window per baseband

Spectral setups are usually created with up to four spectral windows, one per baseband. If so, each spectral window is completely independent in terms of the bandwidth and spectral resolution (correlator mode) that it can use. The modes come in two flavours, one with high spectral resolution (Frequency Division Mode, FDM) and one with much lower resolution (Time Division Mode, TDM) that is often used for continuum measurements.

There are many FDM modes and these have bandwidths ranging between 58.6 and 1875 MHz. All the TDM modes have a bandwidth of 1875 MHz and appear in bold text in the drop-down menu. For dual polarisation, not only 2x2-bit but also 4x4-bit correlator modes can be selected. Compared with their 2x2-bit equivalent, 4x4-bit modes have the same bandwidth, but half the spectral resolution, allowing PIs to reach better sensitivities.

The spectral resolution is set firstly by the number of channels produced by the correlator over the bandwidth. When processing dual polarization, the correlator produces 4096 channels for FDM (the half for 4bit modes) and 128 for TDM, with double this for single polarization and half for full polarization. The channel separation implied by the bandwidth and number of channels would correspond to the spectral resolution, but, as the data are by default Hanning smoothed, the spectral resolution is actually larger than the channel width. Note that none of the channels are thrown away in this process i.e. the channels in the output spectrum are not independent.

For FDM spectral windows it is possible to average groups of 2, 4, 8 or 16 channels together such that the total number of channels is reduced by the same factor. The original spectral resolution is often higher than required and averaging reduces the data rate (particularly important for long-baseline observations as these can approach the maximum allowed) and data volume (speeding up analysis). As the spectra are also Hanning smoothed, the spectral resolution does not degrade linearly and averaging by a factor of two only reduces the resolution by $\sim$15 per cent – this is the default for all FDM spws. Any averaging should still allow the spectral lines to be well resolved, especially if multiple observations (EBs) are required and will need to be combined during data processing into a single spectrum.

Spectral windows are positioned by setting their central frequency, either in the rest or observed frame. The only real restriction on where they can be placed is that the *relative* positions of each must be such that they all lie within the sidebands of the receiver. The most common sideband arrangement is used by bands 3, 4, 5, 7 and 8 where there are two 4 GHz-wide sidebands separated by 8 GHz. The other bands have different arrangements, but are easily visible on the Spectral Visualizer (Chapter 5.5) where they are displayed as vertical bands.

Each time a spectral window is created or edited, the OT will automatically attempt to calculate a tuning solution. If one can be found, the sidebands in the Spectral Visualizer will be coloured yellow and no errors will be reported. If errors are reported, the sidebands will be grey and the best course of action is to examine the visual editor and see which spectral windows (blue) need to be moved in order to fit them all into the sidebands.

4.3.4.6 Spectral Line – more than one spectral window per baseband

It is possible to have more than one spectral window per baseband (Fig. 4.16) and this is known as multi-region mode (4x4-bit modes are an exception, as only one 4x4-bit spectral window per baseband is allowed). In the correlator, this works by splitting a single FDM spectral window into multiple sections (regions), each of which can be placed independently within the baseband. Notice that this does not change the spectral resolution – the bandwidth per channel stays the same. Although the correlator could create more, users are currently restricted to a maximum of four spectral windows per baseband. TDM spectral windows cannot be split in this way.

Setting this up in the OT is slightly different to that described above as one doesn't explicitly choose a specific correlator mode and then split that into smaller sections. Instead, one just creates the spectral windows that would result from following such a procedure, using the fraction parameter to change the available spectral window bandwidths in the drop-down menu. For example, using the default fraction of unity, there are six available FDM spectral windows. If the fraction is then changed to $1/2$, the same spws are displayed, but their bandwidths are one half of their previous value. Also, there is one less spw available as it is not possible to split the narrowest spw. This is illustrated in Table 4.1 for the 2x2-bit modes.

As usual, the OT will warn if anything illegal is attempted. The main things to be aware of are that the total fraction cannot exceed 1 and that each spectral window must have the same spectral resolution (before spectral averaging).

An example of a multi-region mode is shown in Fig. 4.16 where a 937.5 MHz-wide mode has been split up into two spectral windows. In addition to the restrictions on spectral window placement mentioned in Section 4.3.4.5, in multi-region mode the windows must all lie within the 2-GHz baseband width. Technically speaking it is not necessary to use the whole of the original spectral window i.e. the sum of the fractions can be less than one.

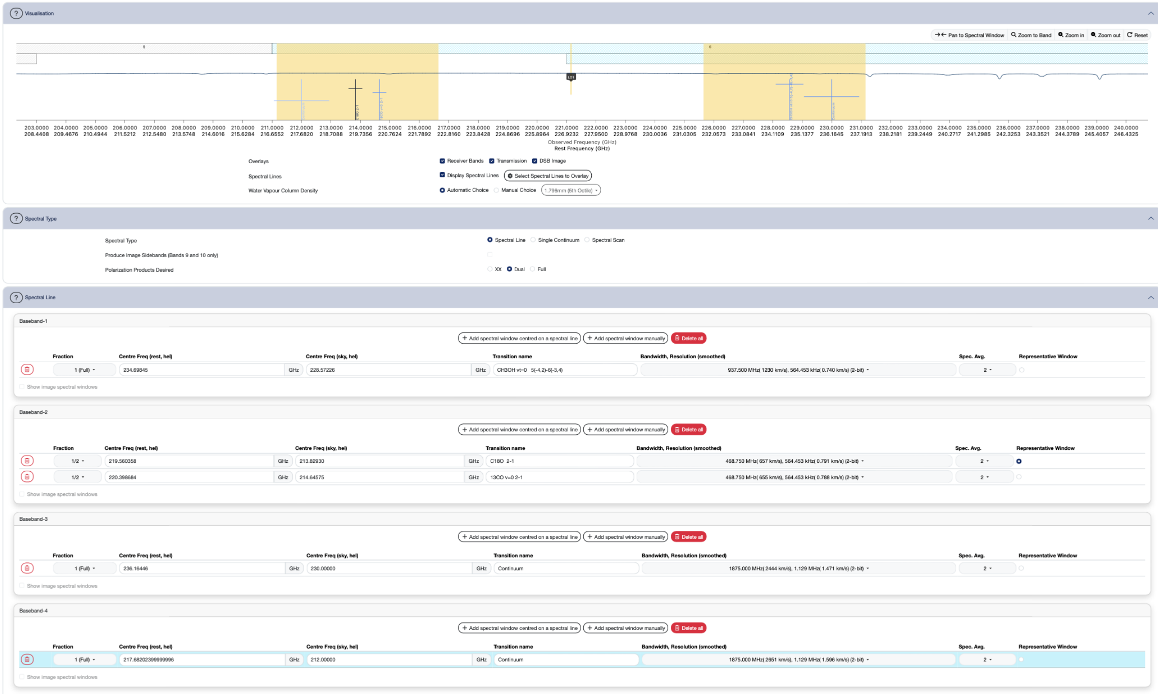

Figure 4.16: Panel to define a spectral line setup. Spectral window frequencies can either be entered manually or selected via the spectral line picker.

4.3.4.7 Spectral Line – VLBI

Spectral-line observing with VLBI is significantly different (Fig. 4.17). At the moment it is only possible to carry out line observing in Band 1, 3, 6 and 7. For Band 1 and Band 3, baseband 1 needs to be in VLBI mode, i.e., its bandwidth must be 1875 MHz, and only one spectral window is allowed there. For Band 6 and Band 7 at least one of the basebands must be in VLBI mode (but not necessarily baseband 1) and only one spw is allowed there. The other three basebands can be used to define additional spectral windows that will produce ALMA-only data. Their frequencies can be freely chosen, so long as a valid tuning solution can be found.

Another aspect of spectral-line VLBI that is non-standard is that the user must enter an observing date for the observation using the time-constraint interface (single visit). This is needed in order for the OT to confirm that the full width of the line will fall into the central 234 MHz of spectral window on the expected date, given the source's velocity relative to the telescopes. For this reason it is also necessary to define the expected line width in Expected Source Properties. If the line cannot be observed then there will be a validation error.

Table 4.1: Available spectral windows in multi-region mode (dual polarization, 2x2-bit modes). Each time the fraction is changed, the number of channels and bandwidth of a particular correlator mode is halved. Each row corresponds to a particular spectral resolution.

Fraction = 1		Fraction = $1/2$		Fraction = $1/4$	
Bandwidth (MHz)	# channels	Bandwidth (MHz)	# channels	Bandwidth (MHz)	# channels
1875	4096	937.5	2048	468.75	1024
937.5	4096	468.75	2048	234.375	1024
468.75	4096	234.375	2048	117.118	1024
234.375	4096	117.118	2048	58.594	1024
117.118	4096	58.594	2048	not available	
58.594	4096	not available		not available	

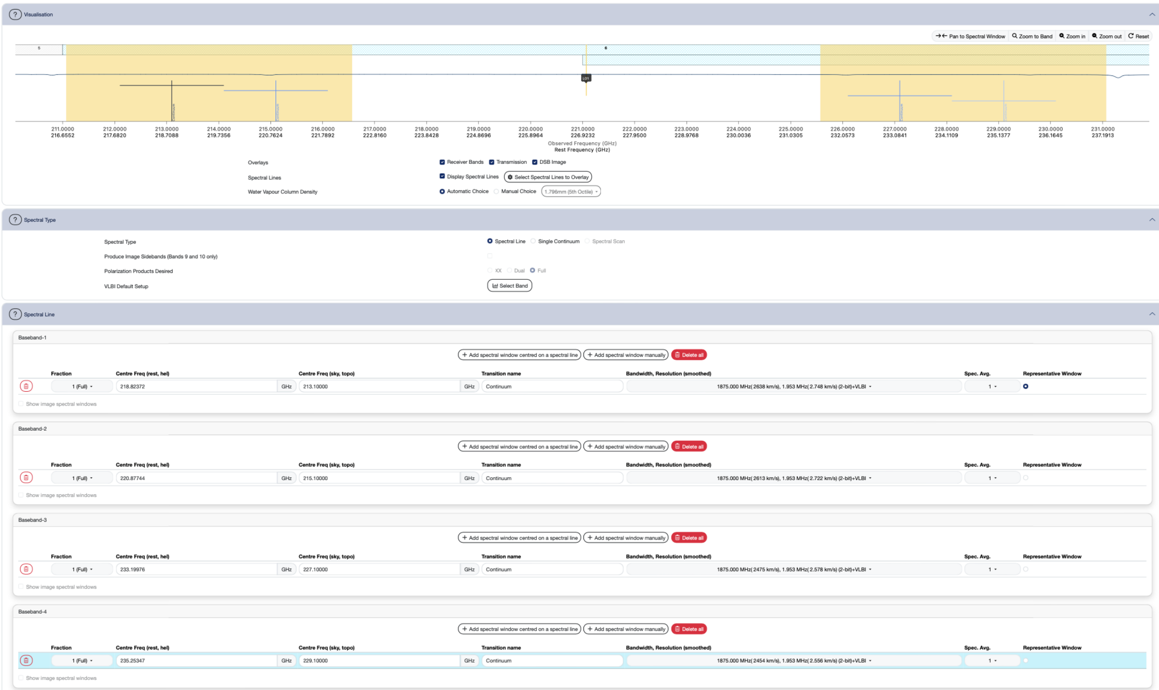

Figure 4.17: Panel to define a spectral line setup for VLBI. Pre-defined setups can be chosen from the drop-down menu.

4.3.4.8 Single Continuum

The Single Continuum interface (Fig. 4.18) automatically creates four spectral windows located such that they cover the maximum possible bandwidth. The default centre frequencies are also placed such that the atmospheric transmission is maximised and thus the single-continuum interface is ideally suited to providing the highest-sensistivity continuum maps of a source. For 2SB receivers (bands 2–8) two spectral windows are placed in each sideband. For bands 9 and 10 (DSB) all four are placed in the same sideband. If necessary, the frequencies of the spectral windows can be changed by setting a different average frequency i.e. the relative positions of the spectral windows is fixed.

The Representative Frequency (Section 4.3.4.10) will default to being the central (sky) frequency of the last spectral window. As with the spectral line interface, this can be changed, both by selecting a different spectral window and by moving the frequency within this. However, it is not possible to change the other parameters of the individual spectral windows.

Single Continuum setups are intended for continuum observations. The user can select either TDM mode (low spectral resolution) or FDM mode (same bandwidth but significantly higher spectral resolution). FDM mode can be useful when observing a continuum that is contaminated with spectral lines which must be removed during data processing. This significantly increases the size of a dataset and so should only be selected if absolutely necessary. If the FDM mode has been selected, spectral averaging of the spws is possible.

For solar observations, the use of Single Continuum is currently enforced and the frequencies of the spectral windows are fixed i.e. it is only possible to select which band one wants to observe in, not what the spw frequencies within the band are.

4.3.4.9 Spectral Scan

A spectral scan is defined by entering a start and stop frequency, in the observed/sky frame only, as well as the correlator mode that should be used (bandwidth $\geq$ 468.75 MHz, Fig. 4.19). Using these parameters, the OT will then attempt to cover the requested frequency range using a maximum of five tunings. The OT will display a

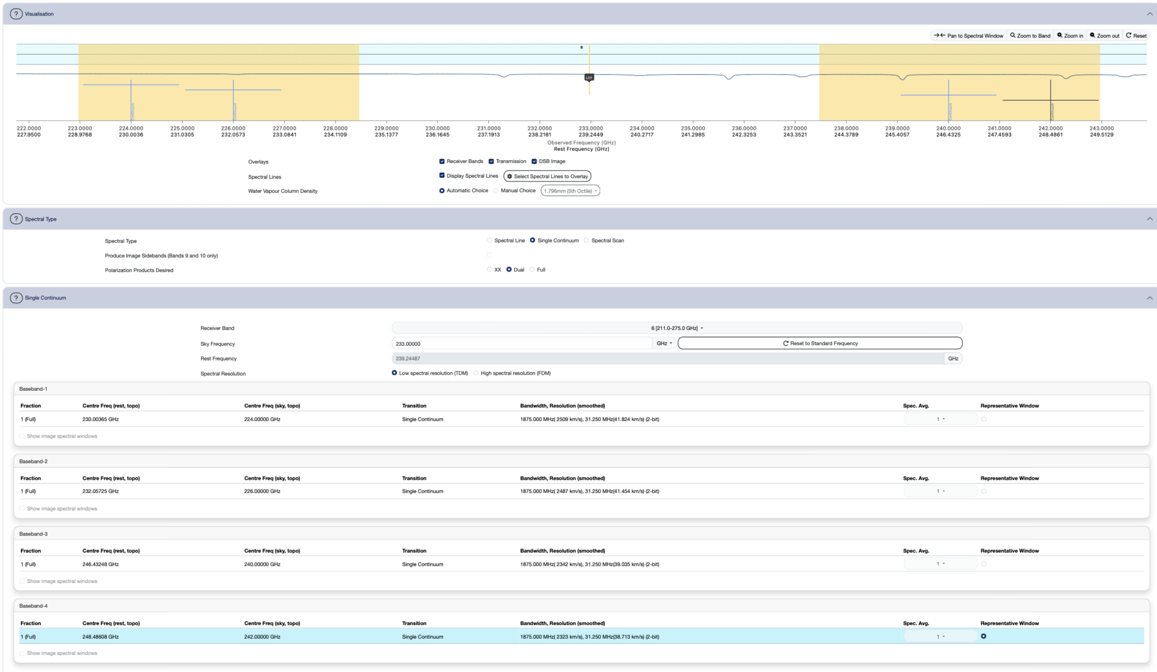

Figure 4.18: Panel to define a single continuum spectral setup. Here, the default Band 6 setup is shown.

warning message if the requested frequency range can't be achieved because more than five tunings are required. It is generally not possible to cover the exact requested frequency range and the OT will usually provide more coverage than requested. Spectral averaging is available for the high-resolution modes, but will be the same for each spectral window of each tuning.

The OT tries to select the most efficient way of covering the requested range and will, generally speaking, use a single sideband for a relatively narrow range and two sidebands otherwise (this will activate 90-degree Walsh switching at Band 9 or 10). A single sideband is always used with the 468.75 and 937.5 MHz spws. Tunings and spws are all slightly overlapped so as to avoid problems with edge channels. With two sidebands there is always a frequency range that is covered by more than one tuning and this unavoidably leads to non-uniform sensitivity across the scan.

The best way of seeing how the spectral windows are placed is by using the Spectral Visualizer. Spectral windows corresponding to the same tuning are plotted with the same y-offset and displayed with the same colour. Also shown is the requested frequency range for easy comparison with the actual frequency coverage.

4.3.4.10 Representative Frequency

A very important parameter that should be carefully set is the Representative Frequency (RF, Fig. 4.20). This is done by selecting one of the spectral windows to be the Representative Window and this automatically sets the RF to the centre frequency, as measured in the rest frame of the source. Using a rest frequency is important as this is common to all sources, even if they have different velocities. For actual application (e.g. to calculate the required time) the rest frequencies are converted to their sky equivalents using the source velocity. If desired, the RF can be changed to another rest frequency within the spectral window.

This parameter is important because it is used when determining the time required to achieve the requested sensitivity. If the spectral window frequencies correspond to relatively uniform atmospheric transmission, this being especially the case in bands 3, 4 and 6, the exact choice of the RF is usually not crucial. However, where the transmission is changing rapidly (Band 8 is particularly non-uniform) which spectral window is chosen to set the RF can make a huge difference to how much time the OT will calculate.

The Representative Frequency should therefore usually be placed at the centre of the line that one is most

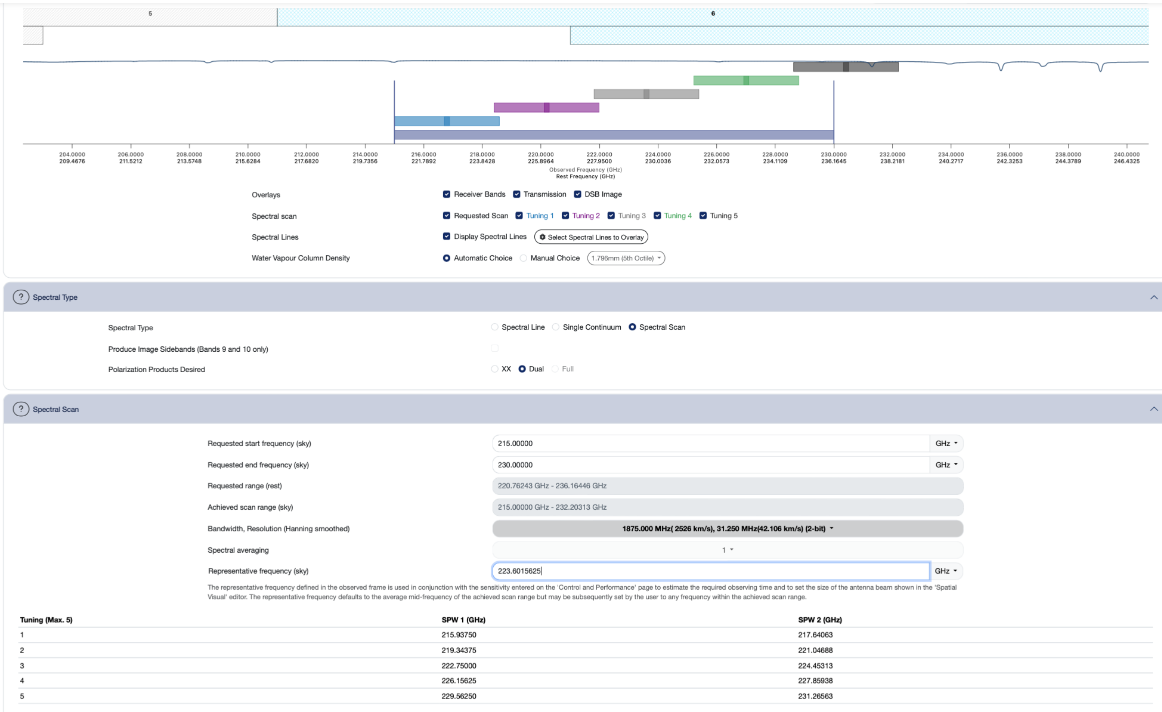

Figure 4.19: Panel to define a spectral scan setup. Here, a frequency range from 215 to 230 GHz was chosen.

interested in, and the requested sensitivity usually also applies to the RF. This is not the case for continuum projects because the sensitivity is usually being measured over multiple spectral windows. Here, one should probably select the spectral window with the poorest atmospheric transmission, but continuum measurements are usually made at frequencies where the transmission curve is fairly flat.

The Representative Frequency also sets the antenna beamsize and therefore the spacing parameter for mosaics (Section 4.3.3.5). For this reason, with all other things being equal it can be a good idea to use the highest-frequency spectral window for setting the RF, and single continuum setups default to this. If the lowest were used, the sampling of the spectral windows at higher frequencies (smaller beam) would be less than that requested.

4.3.4.11 Rest Frequencies

During data reduction, it is desirable to know the rest frequencies of those transitions that are contained within each spectral window so that the velocity scale can be set. Another reason is that this information can be used to enhance the search interface of the ALMA Science Archive and the user is strongly encouraged to enter the rest frequencies of all targeted transitions.

Many spectral windows are created by searching the Splatalogue using the Spectral Line Picker (Section 5.2) and for these the rest frequency, Splatalogue ID and transition label (e.g. SiO v=1 6-5) are all stored. So long as the spectral window isn't subsequently moved such that the original transition no longer falls into the spw, this information will automatically be written to the SB. However, it is often the case that a spw will observe multiple transitions, or that it was created manually and therefore contains no Splatalogue information. If this is the case, the user should manually add the rest frequencies of the additional spectral lines.

The easiest way to do this is by overlaying the spectral lines using the version of the Spectral Line Picker that is attached to the Spectral Visualizer (Section 5.5). This is often a good thing to do anyway as it can greatly aid in placing spectral windows, but the advantage here is that the rest frequencies of any overlaid lines that lie within a spw will also be automatically written to the SB. This is the recommended way of entering rest frequencies.

If this is not done, an alternative is provided by the Rest Frequency SLP which can be found on the Spectral

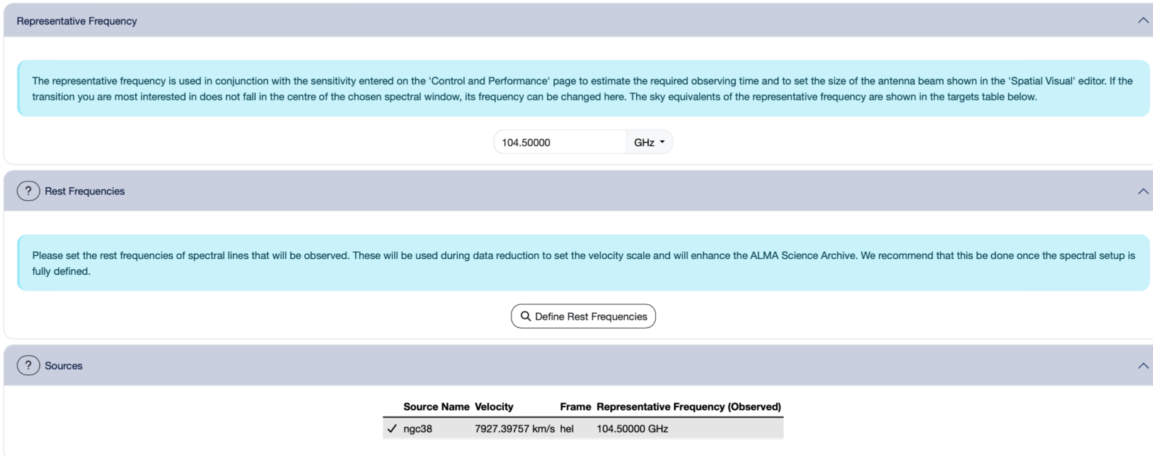

Figure 4.20: Panels to set the representative frequency (top), define rest frequencies of covered spectral lines of interest (middle), and the source table (bottom) which shows the observed representative frequency depending on the velocity/redshift of the source.

Setup page (Fig. 4.20).

4.3.4.12 Multiple velocities and tuning solutions

In both Spectral Line and Single Continuum cases, it is possible to enter sources with different velocities. For Single Continuum, this is irrelevant as the setup is defined in the sky (topocentric) frame and thus the source velocities are ignored. For Spectral Line though, the velocities are crucial as these are used to convert the rest frequencies to their observed equivalents. In general, this means that each source requires its own tuning and its own set of calibration observations. This greatly increases the complexity and time required to complete a project and thus each Scheduling Block is restricted to five separate tunings.

The number of required tunings is calculated automatically by the OT in the following way:

- Firstly, a tuning solution is calculated for each of the N sources that lie within a 10 degree-wide cluster. As described in Section 4.3.3.2, the OT can now automatically split the sources present in a SG into these clusters.
- For each cluster, the OT then selects a source (n) and loops through all the other $N-1$ sources to see if they could be observed with n's tuning i.e. does a line at the centre of each spectral window fit into the spectral windows of source n? In performing this check, the OT takes the user-defined line width into account.
- This is then repeated for every source n. This leads to, for each source, a list of other sources that are compatible with its tuning. These are referred to as "sets".
- Any sets that are a subset of another are discarded at this point.
- Finally, the OT tries to find the smallest subset of these sets which would enable all sources to be observed. This part of the process is computationally intensive and the time required grows rapidly with the number of input tunings. The OT therefore has a limit of 16 input sets. If this number is exceeded, the OT will issue a validation error and the user will need to reduce the number of sources that have been entered.

The final number of tunings (sets) found by the algorithm is reported in the Time Estimate dialogue box (Section 4.3.6.3). As already stated, no more than five are allowed per SB and the user may have to split the sources into multiple SGs.

4.3.5 Calibration Setup

4.3.5.1 User-defined calibration

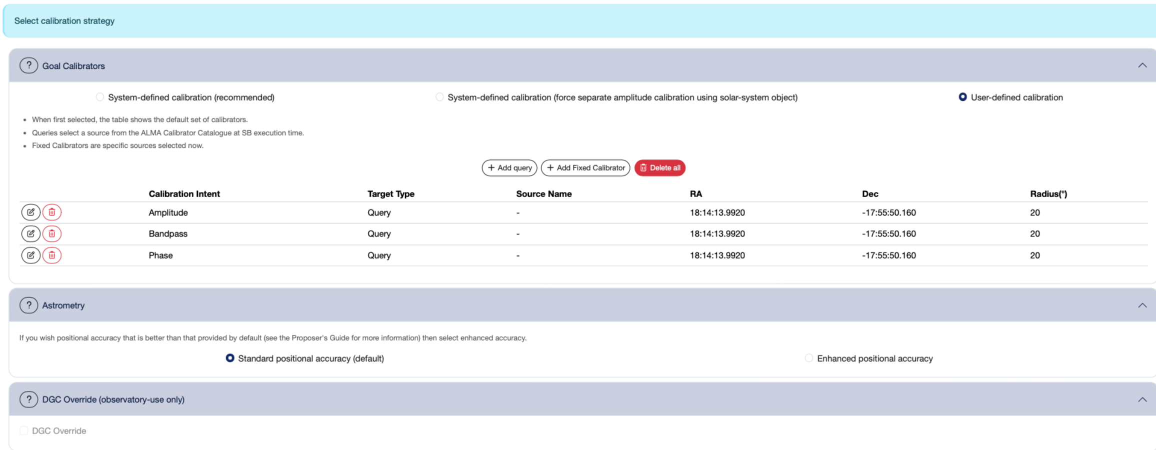

Figure 4.21: Panels to specify the calibration setup (top) and positional accuracy level (middle).

The Calibration Setup panel (Fig. 4.21) allows a user to choose between user-defined and system-defined calibration schemes. It is recommended that the system-defined option be chosen as the observatory will ensure that suitable calibrators are used. If user-defined calibration is chosen, the reasons why and the choice of calibrators must be described in the Technical Justification panel (Section 4.3.7).

Two system-defined calibration choices are available. With the default mode the bandpass calibrator also serves as the amplitude calibrator and thus the observing time is reduced. The source will be a bright quasar whose flux is regularly monitored and thus known fairly well. If higher flux accuracy is required, another mode is available whereby a separate amplitude calibration is carried out using a solar-system object if such an object is available at the time of SB execution.

If user-defined calibration is specified, a table appears that shows the initial list of calibrators – calibrators can either be deleted from or added to this list. Two types of calibrator are available: fixed and dynamic. Fixed calibrators request a specific source whilst the dynamic variant consists of criteria (position, search radius, flux limits) that are used to choose a source from the ALMA calibrator database at the time that the SB is executed. Dynamic queries can be tested during proposal preparation, but the database is likely to change between proposal submission and program execution.

4.3.5.2 Astrometry

ALMA's default calibration strategy will provide some level of positional accuracy for e.g. a point source in an image. If better than the default accuracy is required, this should be indicated by selecting enhanced positional accuracy (Fig. 4.21). Although ALMA does not yet have a commissioned astrometry mode, this information will be used to determine those projects that might benefit from a custom calibration strategy e.g. the use of additional phase calibrators, or from observing in better than the default weather conditions.

If enhanced accuracy it selected then it is necessary to complete a special section in the Technical Justification panel.

Requesting enhanced positional accuracy is not allowed for Large Programs, VLBI or Stand-alone ACA.

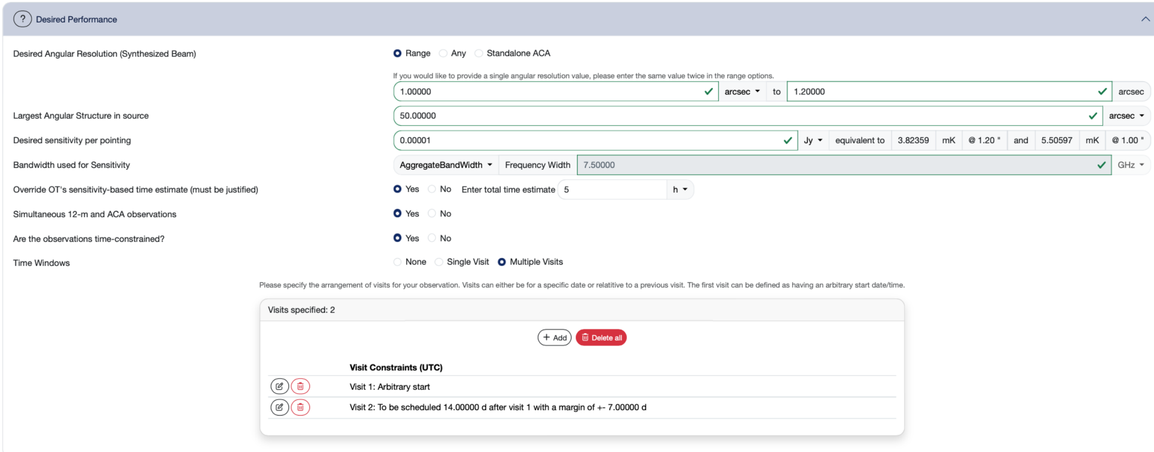

Figure 4.22: Control and Performance panel.

4.3.6 Control and Performance

This panel of the Science Goal (Fig. 4.22) allows the user to enter important scientific objectives that will determine many aspects of how the observations will be executed. These include the desired angular resolution and the largest angular structure that needs to be imaged – these determine which arrays and configurations need to be scheduled. As the opacity of the atmosphere at mm/submm wavelengths is large and highly frequency-dependent, the user requests a 1-σ rms sensitivity instead of a time. The OT will then derive a time estimate based on expected observing conditions, although the actual observing time may be different because of different observing conditions at the telescope (number of antennas, atmospheric conditions, etc.). Solar, VLBI and Phased Array observations are different as the user requests a time and does not enter a desired sensitivity. The Science Goal's time estimate can be requested by clicking on the Planning and Time Estimate tab (Figure 4.24) within the Control & Performance panel.

4.3.6.1 Imaging considerations: arrays and configurations

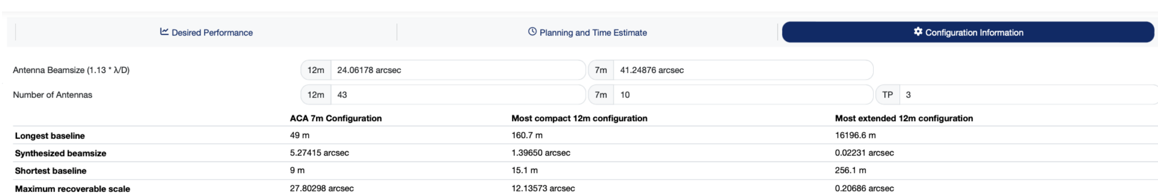

Figure 4.23: Table containing important configuration information.

For the imaging goals of a project to be met, a suitable range of antenna baselines must be observed such that the requested angular resolution is achieved (longest baselines) and the largest angular structure in the source reliably imaged (shortest baselines). It will often be the case that the required range of baselines cannot be achieved with a single array configuration and that additional ones, including the ACA and/or the Total Power Array, might be needed. Which arrays are required will be decided by the OT automatically based on the user input.

To guide a user in entering parameters on the Control & Performance panel, the OT displays various information regarding the configurations that are available in the advertised cycle. Information is displayed in a compact table in the "Configuration Information" tab for the ACA 7-m array, the most compact 12-m configuration, as well as the most extended 12-m configuration that is available in the cycle (Fig. 4.23). The information displayed includes the angular resolution ($\lambda/L_{\rm max}$) and Maximum Recoverable Scale ($0.6\,\lambda/L_{\rm min}$) which have been calculated using simulations. The displayed values are declination-dependent and assume a robustness of 0.5 during imaging (the ALMA Pipeline default). Also shown is the beamsize of both the 12-m and 7-m antennas ($1.13\,\lambda/D$) the size of which will determine whether multiple pointings are required to image the requested area. The Representative Frequency that was entered on the Spectral Setup page is used to calculate λ. Note that the largest configurations (C-7–C-10) trigger a "long-baseline" observing mode whereby the phase-referencing cycle time is much shorter than is usually the case. Which configurations trigger this mode varies from cycle to cycle. An icon in the Header bar opens the configuration information of all 12-m arrays as well as the ACA, for a frequency of 100 GHz, listing minimum and maximum angular resolution and maximum recoverable scale for source declinations in steps of three degrees.

A number of options are available for indicating the required angular resolution and the recommended approach is to enter a range of angular resolutions as this provides flexibility when scheduling the observations and increases the chance of an SB being executed. Similarly, "Any" indicates that any non-long-baseline 12-m configuration is acceptable. It remains possible to enter a single value of the desired angular resolution. Herefore, the same value has to be entered twice in the "Range" option. Finally, requesting stand-alone ACA observations is possible without needing to enter an angular resolution.

Any value can be entered for the Largest Angular Scale (LAS) and this should reflect the best estimate of the largest structure in the source that needs to be imaged. If the source is much smaller than the requested angular resolution, then entering a value of zero is acceptable, but otherwise the user should try and enter a realistic, non-zero value. No value can be entered if the angular resolution has been set to "Any" as only a single 12-m configuration is observed and thus it is assumed that the source is small enough that its structure can be imaged with all of the non-long-baseline configurations. If this is not the case, then this option should not be chosen.

Once the angular resolution and LAS have been entered, the OT can calculate which configurations are necessary. If the OT has split the sources into multiple clusters (Section 4.3.3.2) the algorithm is applied separately to each Pseudo-Science Goal. If a single angular resolution has been entered, the algorithm can be summarised as follows:

- Based on the requested angular resolution, the OT will choose the 12-m configuration whose angular resolution is closest to the one requested.

- The OT then checks to see whether a second, smaller one is necessary to achieve the requested LAS. If one of the larger 12-m configurations has been selected, it will not be possible to add another 12-m configuration and it might be necessary to reduce the requested LAS to avoid a validation error. Similarly, if the 12-m configuration is relatively small, a second 12-m configuration will not be selected.

- If the LAS still cannot be achieved after considering 12-m configurations, it will be necessary to include the ACA 7-m Array and perhaps the TP Array as well, although this is not always possible e.g. for projects using single continuum setups.

The procedure if a range has been entered is similar except that the OT will first find multiple 12-m configurations that lie within the requested range and for each of these it will find the additional configurations/arrays required to achieve the LAS. At this point, the OT will discard any combination of configurations that require more than the minimum e.g. if one combination requires 2 12-m configurations to achieve the LAS and another only 1 (because it is smaller and contains shorter baselines) then the OT will only consider the one with the single 12-m configuration. Similarly, if the range implies a mix of long-baseline and smaller configurations, only the non-long-baseline ones will be considered further. All combinations that are not discarded are shown in the time-estimate dialogue box.

An important consequence of the above points is that the *effective* angular-resolution range used to schedule the observations may be significantly narrower than that requested, especially if an extended source is being observed. Users should experiment with their inputs and consult the time-estimate tab when selecting a range of angular resolutions.

4.3.6.2 Sensitivity considerations

The time required to achieve the requested sensitivity depends crucially on the spectral setup, particularly the Representative Frequency (this sets, among other things, the atmospheric opacity) and the spectral resolution. If the sensitivity is requested in kelvins, the angular resolution will also have an effect. The Representative Frequency should have been chosen to reflect the most important spectral feature that is to be imaged, although in parts of the spectrum where the opacity is well behaved, which spectral window is chosen will actually make very little difference to the time estimate.

How the entered sensitivity is interpreted also depends on whether a rectangular field definition has been selected. If so, the sensitivity entered should be that required in the final mosaiced map, not that corresponding to a single pointing. As the pointings in a mosaic usually significantly overlap, the combined sensitivity is higher and thus requires less time per pointing. For Nyquist sampling, and assuming a Gaussian beam shape, the sensitivity of a mosaic is 68 per cent better than that of a single pointing and the time required per pointing is reduced by a factor 2.8. The OT will calculate this factor for the selected spacing and use it when estimating the time for the project. In contrast, the sensitivity entered for a custom mosaic is always for a single pointing.

It is also necessary to define the bandwidth over which the sensitivity should be calculated. This will depend on the scientific goals, but usually refers to the full usable bandwidth for continuum observations, or to some fraction of the line width otherwise. The OT provides a number of shortcuts for completing this parameter and “AggregateBandwidth” (the sum of the non-overlapping bandwidth of all spectral windows) and “RepWindowEffectiveChannelWidth” (the resolution of the representative spectral window, including Hanning smoothing and any spectral averaging) are the defaults for Single Continuum and Spectral Line setups, respectively. Finally, a user-defined value is possible, this usually being set to a width in velocity units.

At this point, enough information has been entered for a time estimate to be calculated.

4.3.6.3 Time Estimation

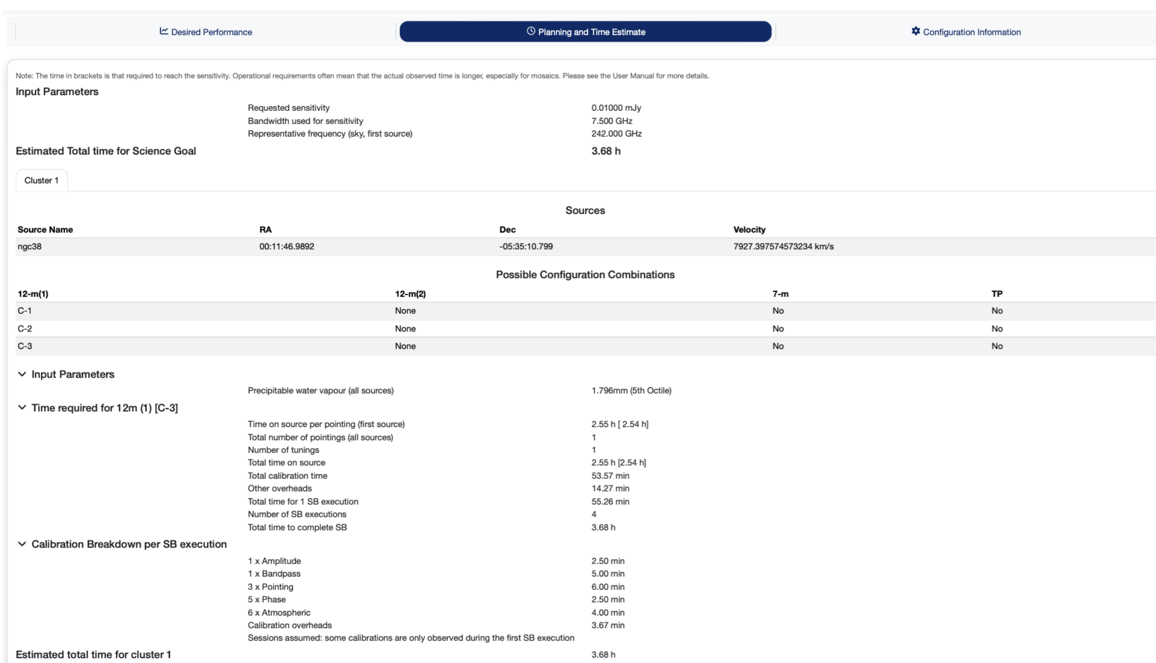

Figure 4.24: Example of the Time Estimate tab. The user has entered a range of angular resolutions and the OT has calculated that three possible configuration combinations fulfill the requested range and allow the source LAS to be properly imaged.

The Science Goal’s time estimate can be requested by clicking within the Control & Performance tab on the Planning and Time Estimate tab (Figure 4.24) that summarizes how the total time, including calibration and overheads, was arrived at. On-source times are derived using the ALMA Sensitivity Calculator (described in detail in the ALMA Technical Handbook) and, in the same way as the array characteristics, assume that imaging will be done using a robustness parameter of 0.5. If the OT has split the sources into multiple clusters (Section 4.3.3.2) the time-estimate is tabbed.

Broadly speaking, the OT time estimates are arrived at by (silently and invisibly) converting the information in the Science Goal into the Scheduling Blocks that will be executed at the telescope. It does this by taking the required on-source times, the default times for the various calibrations (both of which are frequency- and array-dependent), the best estimate of the current overheads and latencies, as well as a standard time for how much on-source time an SB will typically contain (50 minutes for a 12-m Array SB). Required integration times that are longer than this will therefore require multiple executions of the same SB (each of which is called an Execution Block, or EB). On the other hand, the requested sensitivity can imply a very short amount of observing time and therefore the OT enforces a minimum amount of time that can be spent observing a single pointing (10 seconds). In addition, the total time for all sources combined cannot be less than 5 minutes (or 50 per cent of the calibration time, whichever is largest).

In addition to the minimum time, the time spent observing will often be a bit longer than that required based on the requested sensitivity alone. This is because each observation of a source is broken down into so-called subscans. A subscan is the fundamental quantum of ALMA observing, typically has a duration of 30.24 s and, once one is started, will always run to completion. Therefore, if 61 s were required to reach the sensitivity, 90.72 s would actually be observed. The time estimate tries to convey this to the user by displaying two values for the time per pointing (Fig. 4.24). The number in brackets is the time required based on the sensitivity, whilst the other is the time that will actually be spent observing. The OT has limited freedom to lower the subscan duration from its default value in order to avoid cases where much more time is spent observing than necessary.

An SB will normally include a bandpass/amplitude and phase calibrator and each of these has an associated pointing calibrator. The time spent observing a calibrator at each visit, and the time between visits (cycle time) is a function of band, the integration times being longer and the cycle times shorter at higher frequencies. Observations that require either long baselines or high frequencies also have a “check” source included. This is similar to a phase calibrator, but has a longer cycle time and can be used to check that the phase calibration has worked. Full-polarization observations also include a dedicated polarization calibrator.

In deriving its time estimates, the OT assumes that each cluster of sources within a Science Goal will go into a single SB. This is even the case if multiple tunings are defined i.e. spectral scans or sources with different velocities. Every band is calibrated separately and therefore this is not a particularly efficient observing mode and the OT will warn a user if more than one EB is required. Under these circumstances, it might be advantageous to the user if they split the different tunings into separate SGs.

Other interesting cases include:

- Polarization – this requires that a calibrator be observed over a wide range of parallactic angle. In practice, this will done by running the SB several times consecutively such that the necessary time coverage is built up. The OT therefore assumes a minimum time of 3 hours for a polarization Science Goal (including calibrations and overheads). The polarization calibrator is observed at the beginning and end of the first SB and once in subsequent executions.

- Mosaics – the OT will always ensure that an integer number of complete mosaics are scheduled per SB execution, including custom mosaics. The subscan duration (see above) has particular significance for mosaic observations as each pointing in the mosaic is observed for a single subscan. As mosaics can include up to 150 pointings, the OT will actually reduce the subscan in order to make a complete mosaic fit into the allowed 50 minutes per EB. More generally, the OT includes an algorithm which will try and ensure that multiple mosaics per SB will be observed an integer number of times, this integer and the subscan duration potentially being different for each mosaic. This is a tricky calculation to get right and observing inefficiencies in these cases cannot be ruled out.

- Angular-resolution range with sensitivity in kelvins – due to the dependence on the square of the angular resolution, the time estimates can vary greatly between different configurations. The OT will always use the angular resolution of the largest possible 12-m configuration for the time estimate as this will require the most time. As the observation may actually take place using a smaller configuration, the expected surface-brightness sensitivity that would be provided by the smallest 12-m configuration is also reported.

- Total Power with multiple sources – as stated above, all sources in a cluster are placed into a single SB, one for each array i.e. 12-m, 7-m and TP. However, if multiple sources are given for a SG that requires a TP SB, it is possible that multiple TP SBs might be created. This is because it takes a minimum time to complete one pass through each TP raster scan (mosaic) and if the size of the rasters and the number of sources mean that a single pass through all could not be completed in the maximum-allowed on-source time (currently 40 min) then the OT will split the sources into multiple TP SBs.

If any other configurations are required (a more compact 12-m configuration and/or the ACA 7-m and TP Arrays) then their times are calculated as a multiple of the *on-source* time required for the largest configuration. To this are then added the expected calibration time and overheads.[5] The TP on-source time which is reported in the time estimate will generally be larger than that implied by the multipliers (given in the Technical Handbook) due to the need to observe integer numbers of TP rasters.

As before, it is assumed that the ACA 7-m and TP Arrays will be able to observe in parallel and therefore the multiplicative factor used for both ACA Arrays in total will actually be equal to that for the TP Array alone, as that is larger. As the compact configuration multiplier is less than 1, a minimum time for the resulting SB is enforced that is equal to the time required to perform the various calibrations.

4.3.6.4 Differential Gain Calibration

Sometimes it is not possible to use standard calibration techniques due to a lack of SNR on the phase calibrator. This can result from the aggregate bandwidth of the spectral setup being too low or observing at high frequencies where calibrators are fainter. Observing in large configurations can also present difficulties due to the phase stability being poor. For these reasons, some observations are now carried out using Differential Gain Calibration (DGC), a technique whereby an additional spectral setup is used that gives sufficient SNR on the phase calibrator. As there is generally a phase difference between this spectral setup and that used for the science observations, additional observations are made of a strong source ("DGC calibrator") in order to determine the phase difference.

There are two varieties of DGC observing:

- Bandwidth Switching (BWSW) – the additional spectral setup uses the same frequencies as the science setup, but the maximum bandwidth is used in order to produce enough SNR on the phase calibrator.
- Band-To-Band Observing (B2B) – sufficient SNR on the phase calibrator is instead achieved by using an additional spectral setup with a maximum-bandwidth setup at a lower frequency band.

B2B has allowed ALMA to accept proposals requesting the highest frequency bands (7–10) with the largest configurations (C-8–C-10). The need for B2B is checked by performing a search of the calibrator catalogue to see whether a phase calibrator is present that is both bright and close enough to the science target. If yes, then in-band (normal) calibration will be assumed. If not, the OT will assume that B2B must be used, but will now check if a suitable calibrator is available at the lower frequency. If there still is no calibrator available, the OT will issue a validation error.

The additional calibration time required for DGC is included in the OT's time estimates.

4.3.6.5 Solar and VLBI

Solar and VLBI projects are special as a sensitivity cannot be entered i.e. the user must enter a time request (Fig. 4.25). In the case of VLBI, the time must correspond to the total observing time (plus calibration) and it is assumed that VLBI observers know what they're doing in this regard. There is also no need to enter an angular resolution as the user has no control over this. The VLBI observations are generally hold during times

[5] This was new in Cycle 7 – in previous cycles the 7-m and TP times were calculated by applying the multipliers to the total observing time. This is simpler, but less accurate.

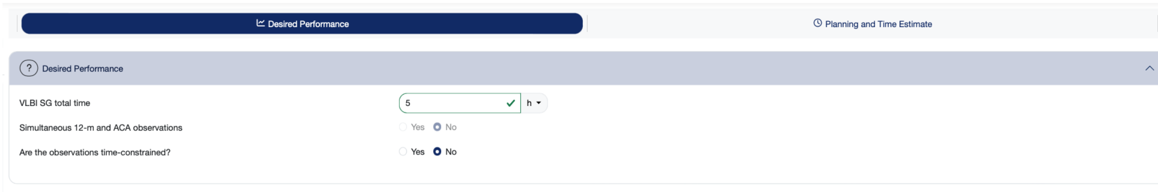

Figure 4.25: Control and Performance panel for VLBI observations. Only the VLBI total time and, in case of spectral line observations, time windows need to be specified.

of the year when the 12-m array is in a relatively small configuration as this makes it easier to phase up the antennas.

For solar, the OT is now able to deliver a more accurate time estimate based on the *on-source* time. This is therefore different to the requirement in Cycle 6 and earlier. Based on the entered on-source time, the OT will calculate a total time estimate based on the expected observing strategy, for both interferometric and TP SBs. An angular resolution *is* entered for solar, but only a subset of the configurations are available and this is band-dependent.

4.3.6.6 Overriding the OT's time estimate

There are circumstances under which the OT's sensitivity-based time estimate might not be reliable. For example, although the instantaneous uv-coverage of ALMA is excellent, there might be occasions on which a very bright source with a complicated structure might require more time than estimated by the OT. Another case might be the need to observe a source whose flux density is highly variable and thus the major factor in determining the time is to observe the source for long enough to track a certain number of variability cycles. If this is the case, then it is possible to override the sensitivity-based time with a user-entered estimate (Fig. 4.22). This should be the time required for the most-extended 12-m configuration, including calibration and overheads. If other configurations and arrays are required, the OT will calculate the times for these in the same way as if the 12-m time had been calculated from the sensitivity. Why a user-defined override is necessary must also be rigorously justified in the Technical Justification panel and a detailed description of the user-defined time estimate given.

4.3.6.7 Simultaneous observing

This option is thought to be mainly useful for observations of solar-system objects and specifies that the 12- and 7-m arrays should observe simultaneously (at the same time, for the same amount of time). If this is requested (Fig. 4.22), it must be the case that only a single 12-m configuration and the 7-m array are required or a validation error will result. As implied, the 7-m time will be set to the same as the 12-m. Unlike other observing modes, it is possible to use any 12-m configuration together with the ACA. Please note that configurations C-7, C-8, C-9, and C-10 are however excluded from simultaneous observing, as they cannot be paired with ACA.

4.3.6.8 Time-constrained observing

It is possible to define various timing constraints for the observations that form a Science Goal (Fig. 4.22). In general this is only available when a single array configuration is required (single 12- or 7-m) although it is available if the simultaneous option has been selected. Two kinds of time-constrained observations are allowed:

- Specific dates – the SB can be observed during any of the specified windows. This will be useful for coordinating observations with another observatory or for observing objects that are only visible during certain time windows e.g. comets.
- Multiple visits – if the SB should be repeated several times, each visit can be specified individually and can be either given as a specific date, as a time relative to a previous visit or a mixture of the two. Note, however, that some combinations do not make sense and are thus not allowed by the OT i.e. an arbitrary

start date followed by a specific date. Reasonable margins on the requested times should be entered. If these are too restrictive then it will be difficult to schedule the SB executions.

When defining relative multiple visits, it is perhaps worth noting a subtle difference between the two ways of doing this, namely all visits being relative to the first visit or all relative to the previous visit. In the former case, one can imagine all the visits as defining fixed points in time, the actual observations happening within the defined margin around each grid point. If each is instead defined relative to the previous one, then it's possible that the last observation may end considerably before or after the nominal end date if, for example, some quirk of scheduling leads to all visits being observed at the earliest or latest possible time. In the limit of normally distributed deviations from the nominal time then both approaches are of course identical.

4.3.7 Technical Justification

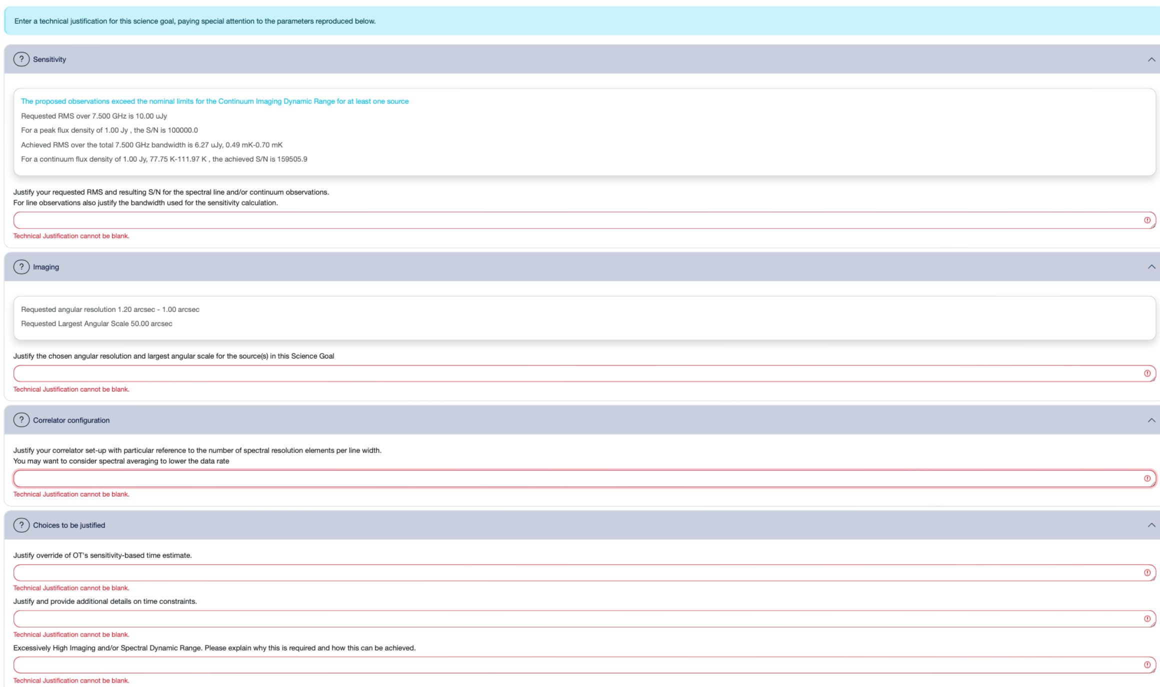

Figure 4.26: Panel for the Technical Justification.

In order for the proposal review committees to judge that the proposed observations are technically feasible and will achieve the scientific objectives, it is necessary for the user to justify the various choices that were made when creating the Science Goal. For example, for a spectral line observation it must be shown that the requested sensitivity and correlator setup will enable the line to be detected with sufficient signal to noise and that the spectral resolution of the correlator mode, perhaps including spectral averaging, is appropriate.

From Cycle 2 onwards, the technical justification is no longer submitted as part of the PDF that contains the scientific case, but is instead created using a panel in the Science Goal. This has been designed to help non-expert users in particular in the writing of technical justifications by presenting various calculations based on the SG contents e.g. the signal to noise ratio on the spectral line and the spectral dynamic range. For most projects, the technical justification panel is split into four separate sections, each of which has a free-format text box in which the relevant item must be justified. The four sections are:

- Sensitivity: The OT presents a number of signal to noise calculations, depending on whether the SG is targeting spectral lines, continuua, or both. The discussion should convince the technical assessor that the line or continuum is being observed with sufficient signal to noise and that there are enough spectral bins across each spectral line to perform the scientific goals.

- Imaging: This should include an explanation of why the specific values of the angular resolution and largest angular scale were requested and discuss whether the arrays selected by the OT will produce a suitable image of the source. Images resulting from simulations that are relevant to this discussion should be attached to the PDF containing the scientific justification.

- Correlator configuration: The main thing to discuss here is the spectral resolution that has been selected and why. Spectral averaging should be mentioned if this has been requested.

- Choices to be justified: There are a number of setup options which, if selected, cause dedicated Technical Justification text boxes to appear. For example, single polarization will normally not be selected as this results in lower sensitivity. However, for a given spectral window width, single polarization gives twice the number of channels and therefore it can be useful when very high spectral resolution is required. As another example, mosaic observations are normally conducted with the individual pointings separated by the Nyquist frequency, but in survey observations where large sources are not being imaged, this is not necessary and larger separations can be used. If this is the case, a brief discussion of the reasons why the non-Nyquist value was chosen can make the job of the technical assessor a lot easier.

The exceptions are VLBI, phased-array and solar projects where fewer free-format text box are presented which require information specific to those modes. As a sensitivity is not entered by the user in these cases, the OT cannot display SNR calculations. In all cases, the justification texts must contain a minimum of 50 characters and no more than 4000 are allowed.

Note that it is possible to copy and paste whole technical justifications from one Science Goal to another by copying the contents of the individual text boxes.

4.4 Proposal Validation

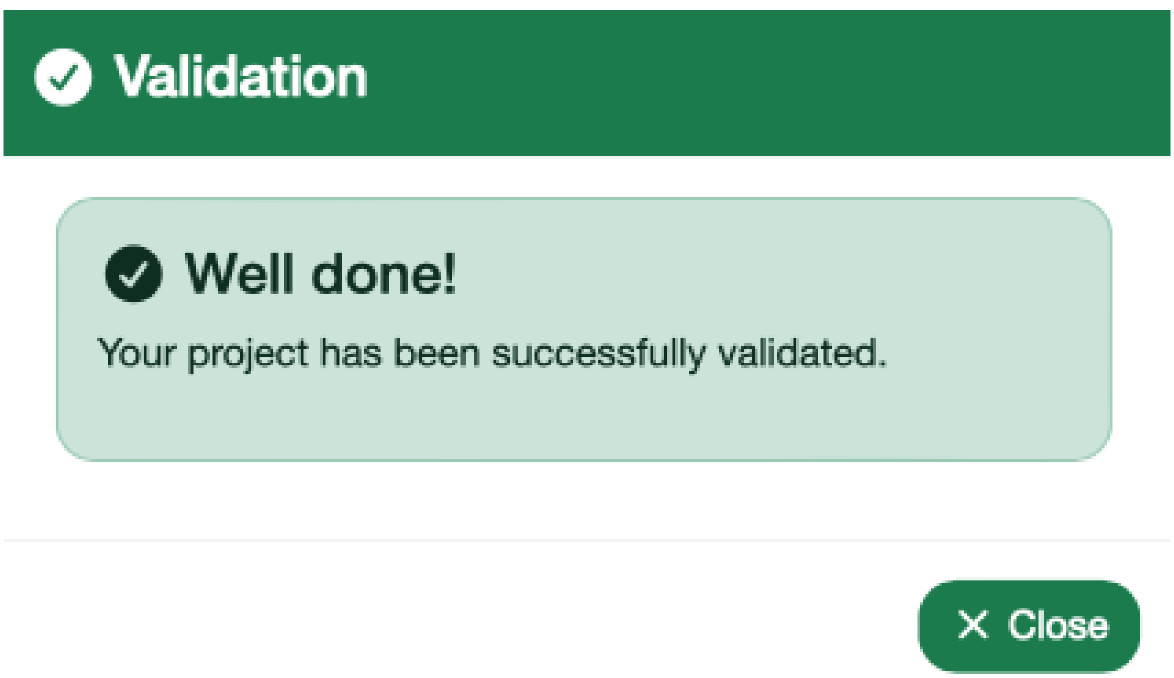

Figure 4.27: Confirmation window if validation was successful and no errors or warnings were found. Otherwise, these are displayed in the feedback window.

Before submitting the proposal to the ALMA archive, it is highly recommended that the validation procedure be run in order to make sure that the proposal contains no errors. In fact, it is even more highly recommended to validate regularly during proposal creation so as to spot mistakes as soon as possible. After a successful validation (Fig. 4.27), the proposal can be submitted. Even if validation is not requested by the user, it will be automatically performed at submission time. If this validation is not successful, submission will fail.

For some large proposals, particularly those that include many sources that are spread over the sky, validation can take significant amounts of time.

4.5 Proposal Submission

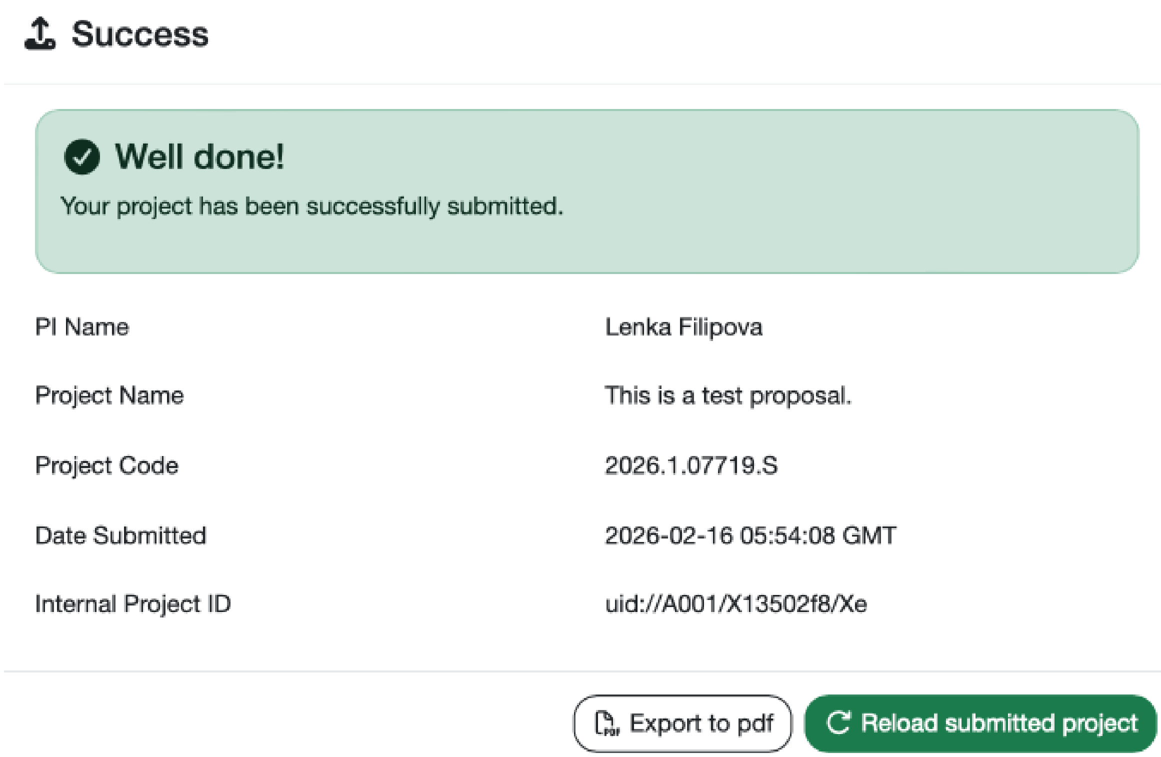

Figure 4.28: Confirmation window if submission was successful, showing the assigned project code.

Proposal submission can only be performed by the PI. As all proposals are validated during submission, this may take several minutes for larger and more complicated projects. After the project has been successfully submitted (Fig. 4.28), an email will be sent to all investigators and the PI will be asked to reload the project. The PI can submit as often as they wish before the deadline, however, each submission overwrites the previous version in the archive. Similarly, the autosave function overwrites the version in the staging area. It is recommended to make copies of the project using the “Open as new” function if significant changes to the proposal setup are to be tested.

Chapter 5

Tools and Visualizers

5.1 Sensitivity Calculator

The ALMA Sensitivity Calculator is most easily accessed via the obvious icon in the Header bar. This will open a new window with the Online Sensitivity Calculator (https://asa.alma.cl/SensitivityCalculator/). The tool will calculate the time required to reach a certain sensitivity, or vice versa, and can be separately configured for the 12-m, 7-m and TP Arrays.

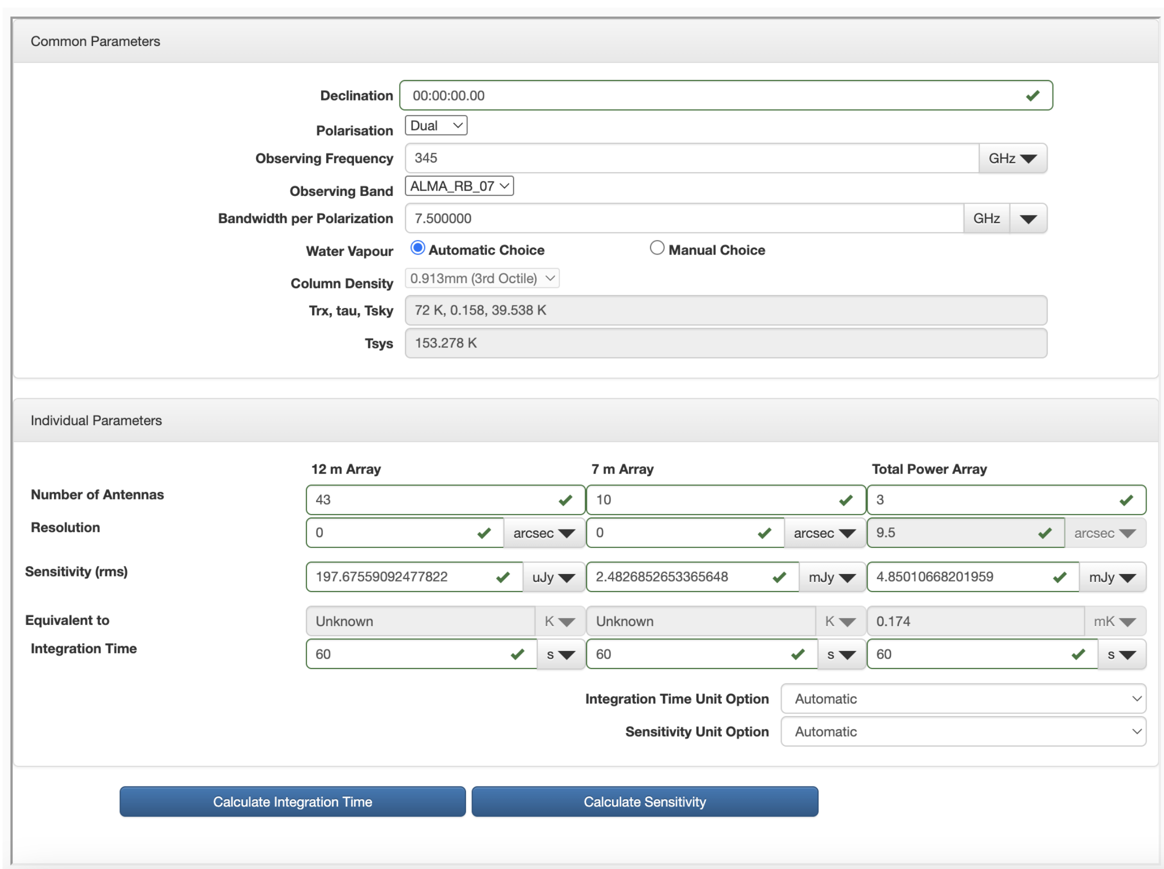

Figure 5.1: The ALMA Sensitivity Calculator.

After having defined the input parameters (Observing Frequency, Bandwidth, Water Vapour, etc.) in the common area in the upper part of the interface, using the number of antennas and required sensitivity, the tool now calculates the integration times for the ALMA 12-m Array, the ACA 7-m Array and the ACA Total Power Array. Note that the numbers of antennas will be set to their default values for the present cycle. The tool also provides the inverse facility, i.e. estimating the sensitivities given an input integration time. The layout of the Calculator is displayed in Figure 5.1.

In the window, the user has to specify the bandwidth per polarisation. Multiplying this number by the number of polarizations gives the effective bandwidth. Sensitivity is treated as a flux density for point source detection if the unit is either Jy or mJy, and as a brightness temperature of an extended source if the unit is either K or mK. Therefore, an angular resolution must be entered if temperature units are to be used. Note that system temperature and atmospheric parameters are displayed for the specified frequency. There are seven octile choices (0.472 mm, 0.658 mm, 0.913 mm, 1.262 mm, 1.796 mm, 2.748 mm, and 5.186 mm) for the Precipitable Water Vapour (PWV) and these can either be selected manually, or chosen automatically by the calculator. It is very important to realise that changing the PWV from its default value in the ASC has no effect on the OT's time estimate for your project. This uses the ASC code, but always chooses the automatic PWV option.

When the user enters a flux density sensitivity, a brightness temperature equivalent to the flux density value is also displayed, if an angular resolution has been entered. Conversely, when a surface brightness is entered, a flux density equivalent to the surface brightness value is displayed. Finally, `Integration Time Unit Option` allows a choice between the calculator automatically choosing an appropriate unit (recommended) or specific user-defined units.

A much more detailed guide to the ALMA Sensitivity Calculator can be found in the ALMA Technical Handbook.

5.2 Spectral Line Picker

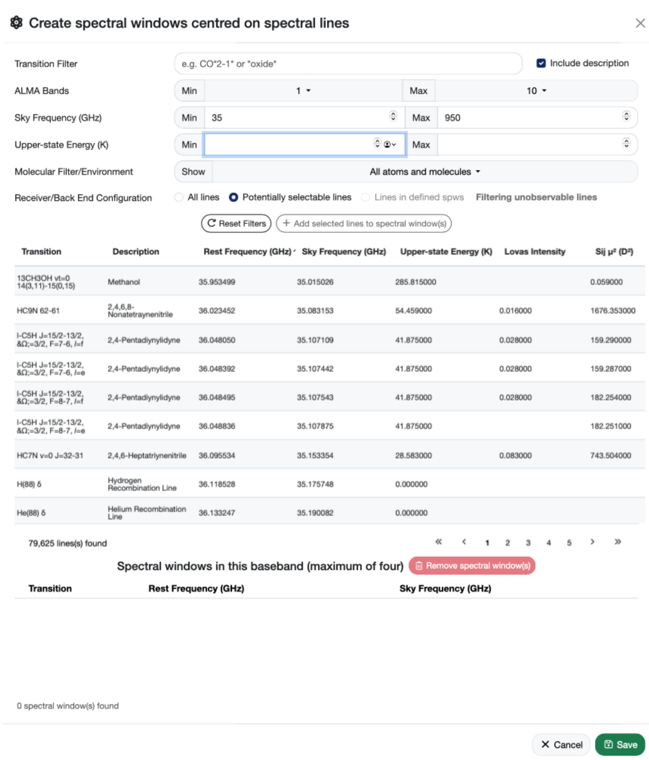

Figure 5.2: The ALMA Spectral Line Picker.

The spectral line catalogue used by the OT is Splatalogue[1] and the millions of spectral line transitions contained within this catalogue can be searched for and selected using the Spectral Line Picker. This appears

[1] https://splatalogue.online

at various points in the OT where it fulfills different functions: creating spectral windows (see Section 4.3.4), overlaying lines in the Spectral Visualizer and defining rest frequencies (Section 4.3.4.11).

When the transition selector dialog opens, every transition in the catalogue is available for selection. Specific transitions can be located by using the controls in the top panel to set your search criteria. String matches to the transition name or description are possible, as is matching by frequency and ALMA instrument band by using the frequency input boxes. The string matching is not standard: a bare piece of text will only match the beginning of a string, but if a wildcard ('*') is placed at the beginning, the text will match anywhere (and not just at the end). Clicking on the column headings will cause the table to be sorted according to the values in that column. The arrows indicate the direction of the sort and subsequent single clicks will reverse this.

Having located a target transition, it can be copied into the table of selected transitions by selecting it and clicking the button "Add selected lines to spectral window(s)", or simply by double-clicking. When creating a spectral setup, up to four lines can be chosen at a time. However, when overlaying, there is no restriction on how many transitions to add via the button "Add to selected transitions". Closing the tool using the "Save" button will cause the selected frequencies to be entered into the OT.

An important part of the Spectral Line Picker (SLP) is its ability to only allow lines to be selected that can be observed together in a single tuning solution. This now has two modes – one which shows all lines that *could* be observed given the currently defined spws and another which only shows those lines lying within the spws. When adding spws, note that this feature makes no allowance for the width of a spectral line so it is important to check that all spectral lines are properly covered by their spectral window.

Note that the filter which looks for potential lines has two layers, one for sidebands and one for basebands. Let's deal with those in turn. The baseband filter only considers those lines which might fit into the currently defined 2-GHz-wide baseband. So, if a spw has already been defined (either with the SLP or manually), using the SLP again to add lines to the same baseband will only show those which will fit into all possible locations of the 2-GHz-wide baseband.

If the SLP is instead used to search for transitions in another, empty, baseband, there is much more freedom as to where a line could potentially be placed and a tuning solution be found. This is where the sideband filter comes into play. For example, if a line has been defined somewhere near the middle of a band in one baseband, it could potentially lie in either the upper or lower sideband (the OT uses USB as a default where possible). The SLP considers both scenarios and will show all transitions that might lie in the same sideband, or in the other sideband i.e. LSB if the original line would be in USB and vice versa.

5.3 Calibrator Selection Tool

Calibrators can be added to the observing proposal using a standard calibrator search tool when defining a user-defined calibration in a Science Goal. The user has the choice between adding a query for a specific calibrator type (Amplitude, Bandpass, Phase, Polarization, CheckSource) or adding a fixed calibrator.

The search interface is shown in Figure 5.3. Calibrators are found by matching a set of search criteria, consisting of the centre position and radius of a cone search and a set of minimum and maximum values for the flux as well as the frequency over which this is valid. Criteria are enabled by the presence of non-zero values and a symbol next to the field will give a visual sign of whether a particular feature is enabled or not. Searching with all filters disabled will return the entire catalogue! A final field sets how many matches will be returned. From the total number of sources that match the search criteria, these will always be those with the lowest values of Right Ascension.

Once the search constraints have been entered, the ALMA online catalogue can be searched by clicking the "Submit Query" button. As with many other tables in the OT, the results can be sorted by clicking on a column header; the direction of the arrow indicates the sort order which can be reversed with subsequent clicks. Secondary sorts are not possible. Alternatively, the OT's list of non-sidereal calibrators can be displayed.

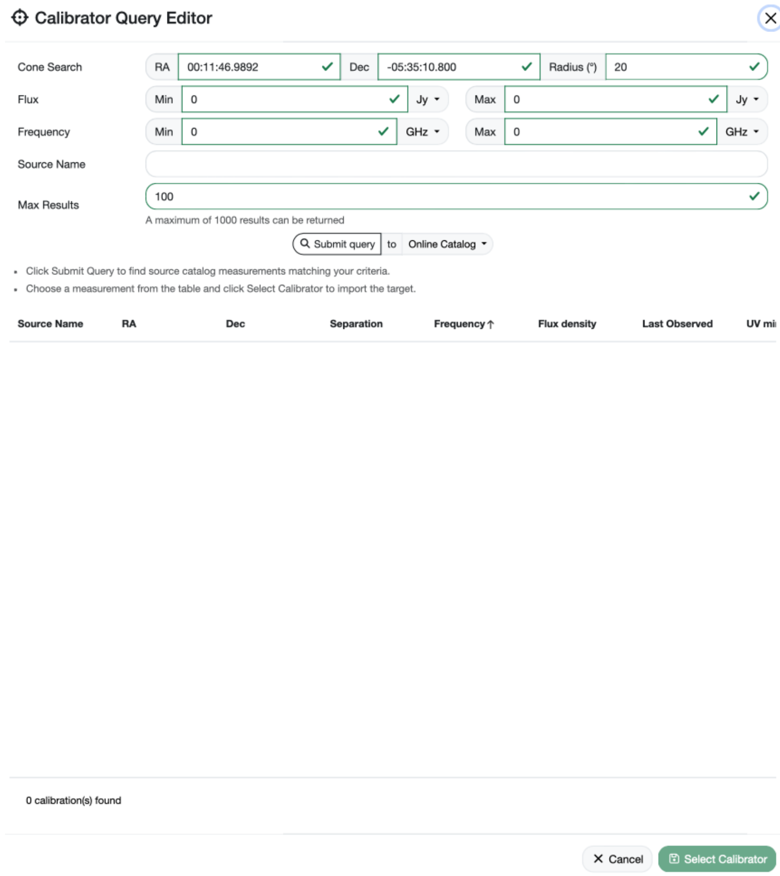

Figure 5.3: The Calibrator Selection Tool as used in the Calibration Setup of a Science Goal.

5.4 The Spatial Visualizer

The Spatial Visualizer allows an image of the source that you wish to observe to be loaded and can subsequently be used to determine where the telescopes should point, either by defining individual pointings or rectangular mapping areas.

5.4.1 Overview of the Graphical Interface

The Spatial Visualizer (Fig. 5.4) is located in the Field Setup panel of each Science Goal. Its graphical window displays the browser version of the Aladin interactive Sky Atlas (Aladin lite; see https: //aladin.cds.unistra.fr/). It retains most of its functionalities in the toolbar available on the left side of the interface:

- Open the overlays menu: This opens a panel with several items that can be shown or hidden in the displayed image; furthermore, by clicking on the "+" button next to "Surveys", the user can open a local FITS file to be shown as background image.
- Settings: Some general settings, including for instance grid properties.
- Simbad pointer tool: Allows to search the Simbad database by coordinates, chosen clicking in the graphic window.
- Display the coordinate grid
- Share: Share the displayed view, as a link (to Aladin), as a FITS cutout, or as a snapshot of the panel.

There are other buttons available to manipulate the graphic window. In particular, in the top-left corner the user can select between ICRS and galactic coordinates. In the top-right corner, the full-screen mode can be activated.

Above the graphic window, several buttons are available:

- Set coordinates: When this is selected, one can input the source coordinates (see Sect. 4.3.3.1) directly by clicking on a position in the maps shown by the visualiser.
- Add pointings: This is available only when Individual Pointing(s) is selected in the Source panel (see Sect. 4.3.3.1). When selected, a new pointing can be added by clicking on the desired position on the map. The new pointing will appear in the Field Centre Coordinates table (see Sect. 4.3.3.5).
- Reset FOV: This button re-centers the displayed image in the source's coordinates.
- Show pointing positions: This is available only when 1 Rectangular field is selected in the Source panel (see Sect. 4.3.3.1). It shows/hides the pointing positions (beam sizes) of the rectangular field.

Below the graphical window is one collapsible panel that controls various display options.

- Representative Frequency (Sky): The sky equivalent of the Representative Frequency is used to determine the antenna beamsize.
- Array Type: If both the 12- and 7-m configurations are required, this button will determine which array's pointings are displayed.
- Antenna Beamsize (FWHM): Indicates the size of the primary beam at the Representative Frequency.
- Show Antenna Beamsize (circle): Tick to display the chosen antenna beamsize.

An image can be loaded in one of two ways, either by loading a local one from disk using the Survey's option in the Overlay menu, or by querying an image server, a large number of which are available through a drop-down menu. If querying a server, the image will be centred on the source coordinates. These are indicated on the map by a cyan x-shaped cross which will move if the coordinates are changed.

Once an image has been loaded, if any pointings or a rectangle were previously defined, they will appear on the image. At the time of loading an image, the type of field definition must already have been chosen, either a rectangular area or multiple pointings (the latter by default).

An important part of the Spatial Visualizer is the ability to display the pointings for either the 12- or 7-m arrays together with their antenna beamsizes. For this to be possible though, the Representative Frequency must have already been defined in the Science Goal's Spectral Setup. Therefore, it is recommended that this section be completed before using the Spatial Visualizer.

5.4.1.1 Single Pointings

Multiple instances of single pointings can be added to the field definition by using the "Add Pointing" button on the top of the Editor and then clicking at the position in the image where the antenna should point – this must be clicked every time a pointing is to be added. For your convenience, a single pointing is created by default at zero offset from the source coordinates.

The pointings defined in the Spatial Visualizer are displayed in the Field Centre Coordinates section where they can be edited or deleted.

5.4.1.2 Rectangular Areas

The mosaic pattern is not currently drawn by default and so the appropriate button on top of the graphical window must be selected. The mosaic pattern for either the 12-m or 7-m Array can be selected and the number of pointings will be displayed in the Field Centre Coordinates section - as the spacing is usually a function of antenna beamsize, the mosaic patterns will therefore be different for the two arrays.

If the ACA has been selected, also displayed will be a turquoise rectangle that is a little larger than the user-defined rectangle. This indicates the area that will be mapped by the ACA Total Power Array and is non-editable.

5.4.1.3 Offset Versus Absolute Coordinates

When a pointing area is created using the Spatial Visualizer, its coordinates are interpreted by the OT as an absolute position (R.A. and Dec.) or as an offset from the source coordinates, depending on what is selected in the Field Centre Coordinates section at the time of creation. Because pointing areas are being added with the mouse, which is chosen is not terribly important and subsequently changing from one to another will convert all positions to the new system. However, if the source coordinate is changed, the outcome depends crucially on which is currently selected, namely that offset positions will move within the image whilst absolute positions will not. Be very careful when changing the source coordinate after setting up a field definition with the Spatial Visualizer!

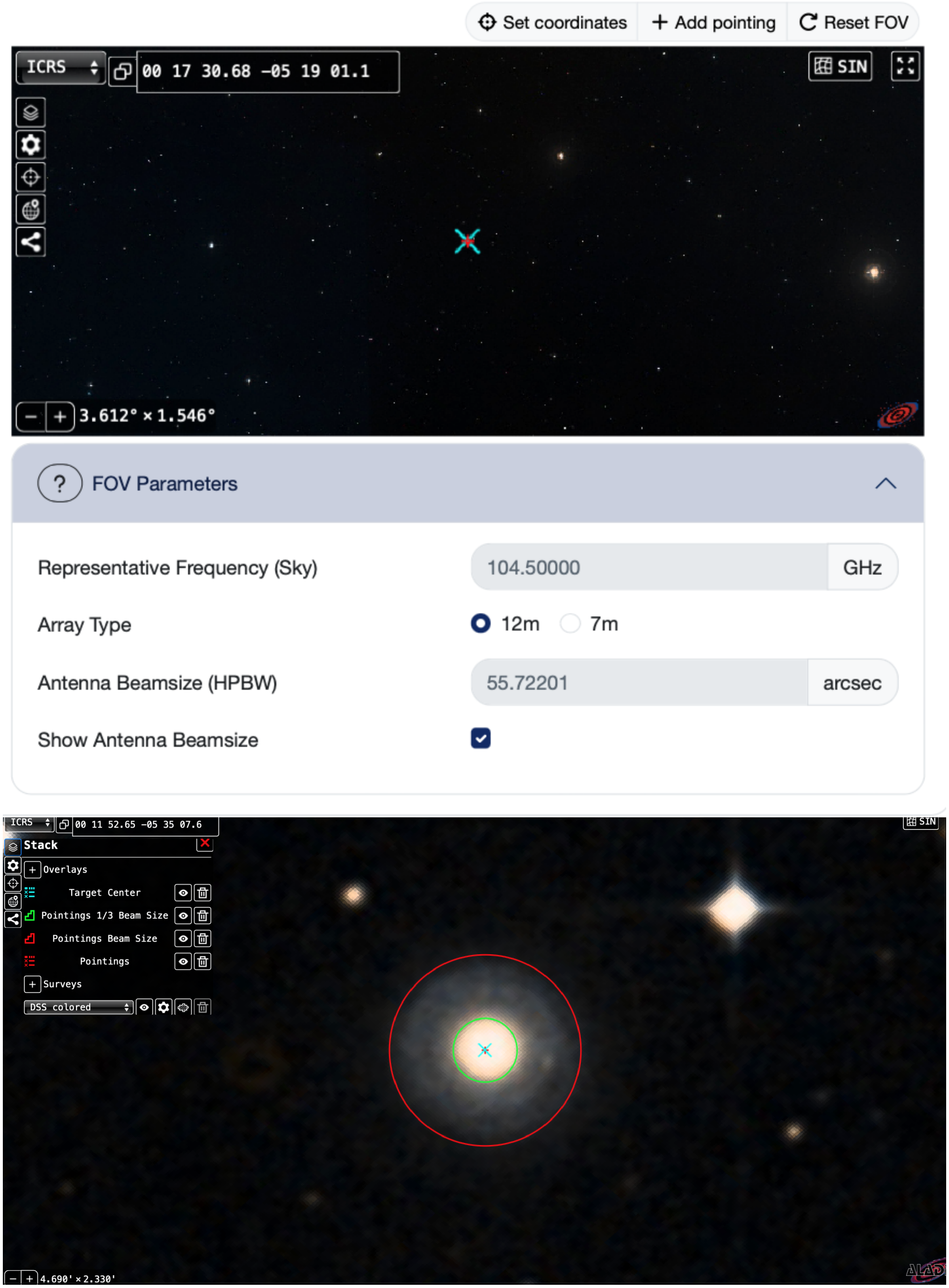

Figure 5.4: The Spatial Visualizer (bottom in full screen mode) is using the Aladdin interface with most of its functionality.

5.5 The Spectral Visualizer

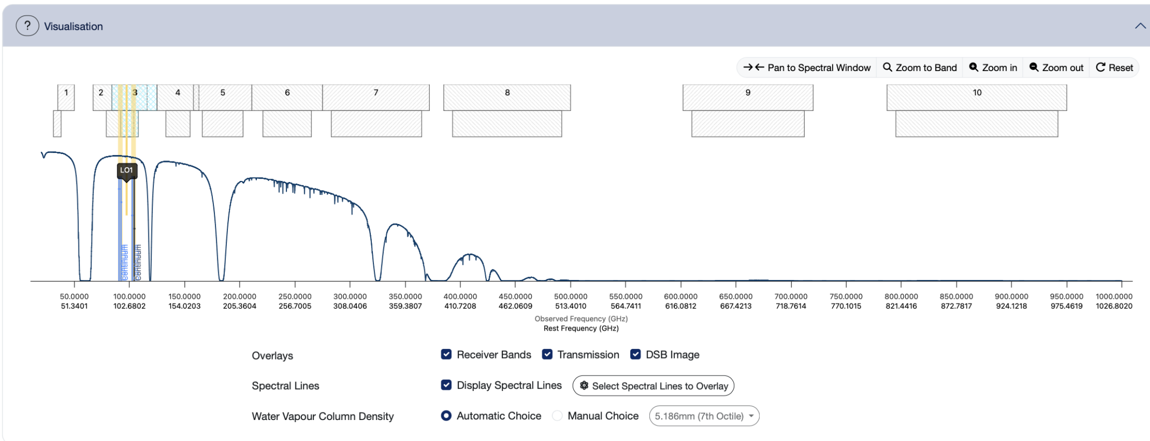

Figure 5.5: The spectral visualizer, showing a continuum setup in Band 3.

The Spectral Visualizer (Fig. 5.5) allows the spectral windows that are defined by the user to be viewed in a graphical environment that contains a number of aids to their placement, particularly the atmospheric transmission and the receiver/correlator configuration (receiver bands, sidebands, etc.). It is strongly recommended that a spectral setup is always checked in the Spectral Visualizer which can be found in the Spectral Setup panel in each Science Goal.

5.5.1 Overview of the Graphical Interface

The Spectral Visualizer's graphical interface consists of two frequency axes, one above the other, for the observed and rest frequencies, depending on the source velocity. The display can be zoomed using different buttons (Pan to Spectral Window, Zoom to Band, Zoom in, Zoom out).

Hatched areas at the top show the available receiver bands. These are displayed in grey, apart from the currently-selected receiver band which is coloured bright blue (and doubly, compared to singly, hatched). The upper, wider part of the hatched area shows the full range of frequencies that can be observed using a band whilst a narrower rectangle below this shows the allowed range where the first local oscillator (LO1) frequency can be placed.

A prominent feature of the graphical interface is the transmission curve. This shows how much of the radiation from the source is actually received at the telescope and is calculated using the Atmospheric Transmission at Microwaves (ATM) code[2] that is also used in the ALMA Sensitivity Calculator and for the OT time estimates. Years of monitoring have been used to determine the characteristic octiles of precipitable water vapour (PWV) at the ALMA site and the transmission curve corresponding to each can be selected manually, or the OT can automatically display the appropriate one. The latter is recommended as it is this value of PWV (or a very similar one) that will be used to trigger the observation of a project, based upon the spectral windows that have been defined in the Spectral Setup panel, specifically by the Representative Frequency. Changing the displayed transmission curve is for experimentation only as it will *not* affect the conditions assumed for the observations and hence the OT's time estimates!

It is also possible to display spectral lines using the Spectral Line Picker which is described in detail in Section 5.2.

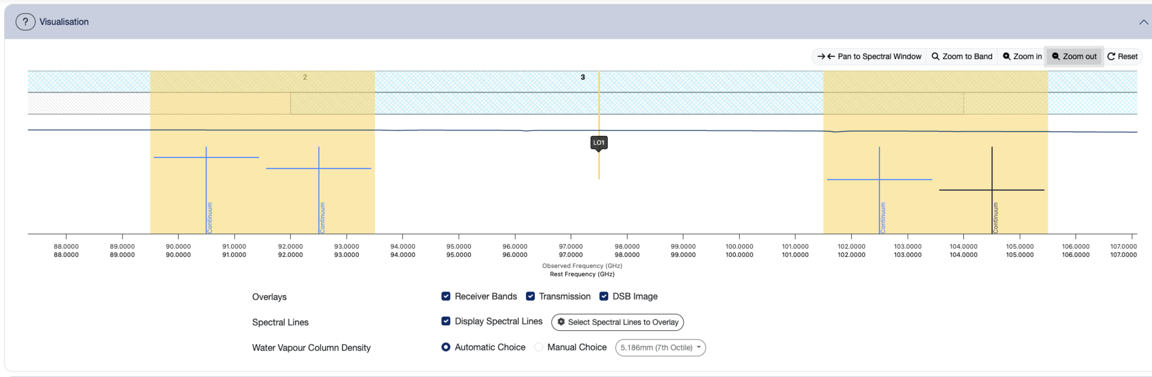

Figure 5.6: Zoom in on the B3 spectral setup in the Spectral Visualizer.

5.5.2 Viewing a Spectral Setup

The main purpose of the Spectral Visualizer is to allow the spectral setup to be viewed against the background of the transmission curve and available spectral lines (Fig. 5.6). The spectral windows themselves must be defined in the Spectral Setup panel as it is not possible to do this using the graphical interface. These in turn are used by the OT to calculate a tuning solution that sets the positions of the basebands and sidebands. Together with the spectral windows, these can be viewed in the Spectral Visualizer.The representative window is shown in black and the other windows in dark blue, except if a window is selected, then its color changes to bright blue.

5.5.2.1 Science Goal

After defining spectral windows in the Spectral Setup panel, these will appear in the Spectral Visualizer (Figure 5.5) as vertical blue lines marking the central frequency and a horizontal bar to indicate the bandwidth. For Band 9 and 10 setups, the "image" spectral windows will also be shown in the opposite sideband – these are indicated in order to bring the user's attention to other lines or atmospheric absorption features that may affect the quality of the data in the "signal" spectral window.

If no warnings have been issued by the OT, a tuning solution will have been found and the sidebands and LO1 indicator will be coloured yellow. For a tuning solution to be found, it should be the case that all of the spectral windows fit within the sidebands. However, it is possible that small portions of the spectral windows do lie outside the sidebands, but as long as these are coloured yellow, there is nothing to worry about. If no solution is found then the sidebands are coloured grey.

The Sources subpanel contains a table with an overview of relevant source properties, including their velocity and Representative Frequency. If multiple sources have been defined, this table allows the user to display the spectral windows according to this source's velocity. Only one source at a time can be selected.

As part of the tuning solution, the OT will also have calculated the positions of the basebands, but these are not currently displayed in the Science Goal Spectral Editor.

[2] e.g. Pardo, J. R., Cernicharo, J., Serabyn, E., 2001, ITAP, 49, 1683.

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Appendix A

Create an External Ephemeris

This Appendix explains in detail how to use the JPL HORIZONS system to create an ephemeris file for solar-system bodies. Only ephemerides generated by HORIZONS will work with the ALMA Control System and the OT will reject the ephemeris if this is not the case.

A.1 NASA resources for HORIZONS

The following internet links can be useful for ALMA users requiring an ephemeris.

- `https://ssd.jpl.nasa.gov/horizons/app.html`: Direct link to the HORIZONS web interface. This is a very useful link as, if an ephemeris has previously been generated using the web browser, it will bring up the inputs that were last used.
- `https://ssd.jpl.nasa.gov/horizons`: HORIZONS web page (web interface link can be found here, in addition to multiple formats for documentation).
- `https://ssd.jpl.nasa.gov/horizons/manual.html`: On-line user manual. This is the ultimate reference, is extremely detailed and should not be required for most users.

A.2 Instructions and Settings

Go to `https://ssd.jpl.nasa.gov/horizons/app.html`. The HORIZONS web interface shows the current settings, all of which can be modified using the "Edit" buttons. Previously-used settings seem to be remembered, so we first recommend that all inputs should be set to their default using the "custom" settings. The inputs should then be set as follows:

- Ephemeris Type should be `Observer Table` (default).
- Set Target Body to the relevant solar-system body.
- The Observer Location is most easily set to ALMA using the "Lookup the Specified location" option. Entering "ALMA" will enable a search and the entry that should be chosen is `Atacama Large mm/sub-mm Array (ALMA, Center)@399`. Note that geocentric locations should no longer be used.
- The Time Specification should be set as needed. The ephemeris should contain at least one row for every hour and, except for fast objects, one row every 20 minutes is sufficient. The online system will linearly interpolate between rows in an ephemeris when determining the antenna pointing and propagation delay.

- Of the many possible Custom settings, only `Astrometric RA & DEC` and `Obsrv range & rng rate` are required – there are options 1 and 20. It is also recommended that "Extra precision" be selected from the additional settings. Do not select the `elevation cutoff` option as this is likely to fail.

Once the inputs have been checked and found to be okay, the ephemeris can be generated. This will take the form of text in the browser window which can be downloaded as a text file and then read into the Science Goal.

A.3 Example Ephemeris

The text below shows what a typical ephemeris generated by HORIZONS should look like – it was copied and pasted directly out of a browser window. Ephemerides that do not conform to the HORIZONS format will be rejected by the OT.

```
*******************************************************************************
JPL/HORIZONS                2 Pallas (A802 FA)           2025-Feb-03 01:21:41
Rec #:       2 (+COV) Soln.date: 2024-Dec-12_17:11:23   # obs: 9741 (1804-2024)

IAU76/J2000 helio. ecliptic osc. elements (au, days, deg., period=Julian yrs):

  EPOCH=  2457870.5 ! 2017-Apr-27.00 (TDB)         Residual RMS= .27459
   EC= .230654532309575    QR= 2.133412766192127   TP= 2458320.726491679
   OM= 173.0883296761345   W=  309.9974922206295   IN= 34.83970333808084
   A= 2.773023116125753    MA= 263.9040942238881   ADIST= 3.412633466059379
   PER= 4.61784            N= .21343903            ANGMOM= .027873209
   DAN= 2.28651            DDN= 3.08249            L= 128.7190393
   B= -25.9536438          MOID= 1.23221004        TP= 2018-Jul-21.2264916790

Asteroid physical parameters (km, seconds, rotational period in hours):
   GM= 13.63               RAD= 256.5              ROTPER= 7.813221
   H= 4.11                 G= .110                 B-V= .635
                           ALBEDO= .155            STYP= B

ASTEROID comments:
1: soln ref.= JPL#67, OCC=0
2: source=ORB
*******************************************************************************


*******************************************************************************
Ephemeris / WWW_USER Mon Feb  3 01:21:42 2025 Pasadena, USA      / Horizons
*******************************************************************************
Target body name: 2 Pallas (A802 FA)             {source: JPL#67}
Center body name: Earth (399)                    {source: DE441}
Center-site name: Atacama Large mm/sub-mm Array (ALMA, center)
*******************************************************************************
Start time      : A.D. 2025-Jan-13 20:00:00.0000 UT
Stop  time      : A.D. 2025-Jul-18 20:20:00.0000 UT
Step-size       : 14400 minutes
*******************************************************************************
Target pole/equ : IAU                            {East-longitude positive}
Target radii    : 275.0, 258.0, 238.0 km         {Equator_a, b, pole_c}
Center geodetic : 292.2452521,-23.029211,5.07489  {E-lon(deg),Lat(deg),Alt(km)}
Center cylindric: 292.2452521,5877.5143,-2481.68209 {E-lon(deg),Dxy(km),Dz(km)}
Center pole/equ : ITRF93                         {East-longitude positive}
Center radii    : 6378.137, 6378.137, 6356.752 km {Equator_a, b, pole_c}
Target primary  : Sun
Vis. interferer : MOON (R_eq= 1737.400) km       {source: DE441}
Rel. light bend : Sun                            {source: DE441}
```

```
Rel. lght bnd GM: 1.3271E+11 km^3/s^2
Small-body perts: Yes                            {source: SB441-N16}
Atmos refraction: NO (AIRLESS)
RA format       : HMS
Time format     : CAL
Calendar mode   : Mixed Julian/Gregorian
EOP file        : eop.250131.p250429
EOP coverage    : DATA-BASED 1962-JAN-20 TO 2025-JAN-31. PREDICTS-> 2025-APR-28
Units conversion: 1 au= 149597870.700 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO ),Airmass (>38.000=NO), Daylight (NO )
Table cut-offs 2: Solar elongation (  0.0,180.0=NO ),Local Hour Angle( 0.0=NO )
Table cut-offs 3: RA/DEC angular rate (     0.0=NO )
*******************************************************************************
Initial IAU76/J2000 heliocentric ecliptic osculating elements (au, days, deg.):
  EPOCH=  2457870.5 ! 2017-Apr-27.00 (TDB)         Residual RMS= .27459
   EC= .230654532309575    QR= 2.133412766192127   TP= 2458320.726491679
   OM= 173.0883296761345   W=  309.9974922206295   IN= 34.83970333808084
  Equivalent ICRF heliocentric cartesian coordinates (au, au/d):
   X= 2.964644625717728E+00  Y= 1.388006437987008E-01  Z=-2.357603579788067E-01
  VX=-2.665042982037095E-03 VY= 9.076070445626725E-03 VZ=-1.610668574682083E-03
Asteroid physical parameters (km, seconds, rotational period in hours):
   GM= 13.63               RAD= 256.5              ROTPER= 7.813221
   H= 4.11                 G= .110                 B-V= .635
                           ALBEDO= .155            STYP= B
************************************************************************************
 Date__(UT)__HR:MN     R.A.__________(ICRF)__________DEC             delta      deldot
************************************************************************************
$$SOE
 2025-Jan-13 20:00 *   19 00 58.372486 +03 08 11.73781  4.18225356024991  -0.1541259
 2025-Jan-23 20:00 *   19 14 46.828789 +03 29 31.38065  4.17201448056080  -2.6351448
 2025-Feb-02 20:00 *m  19 28 15.531752 +03 59 47.74279  4.14726944504919  -5.1276510
 2025-Feb-12 20:00 *   19 41 18.401465 +04 38 18.98651  4.10825588188254  -7.5392037
 2025-Feb-22 20:00 *   19 53 50.424648 +05 24 19.12791  4.05547625315058  -9.8836675
 2025-Mar-04 20:00 *m  20 05 45.952890 +06 17 03.16163  3.98937506353445 -12.1307522
 2025-Mar-14 20:00 *   20 16 58.704449 +07 15 31.32735  3.91084045549975 -14.1944862
 2025-Mar-24 20:00 *   20 27 23.138926 +08 18 44.64039  3.82091426745452 -16.0982566
 2025-Apr-03 20:00 *m  20 36 52.328924 +09 25 39.42601  3.72066348611142 -17.7843491
 2025-Apr-13 20:00 *   20 45 18.833700 +10 34 54.26679  3.61166242268931 -19.1818592
 2025-Apr-23 20:00 *   20 52 35.386074 +11 45 07.63016  3.49555382837809 -20.3071324
 2025-May-03 20:00 *m  20 58 32.855878 +12 54 40.18577  3.37416266802182 -21.0692009
 2025-May-13 20:00 *   21 03 02.312376 +14 01 27.85639  3.24986550501436 -21.4150656
 2025-May-23 20:00 *   21 05 55.123471 +15 03 16.57244  3.12508906406692 -21.3351502
 2025-Jun-02 20:00 *m  21 07 02.201635 +15 57 15.27401  3.00265338340735 -20.7097185
 2025-Jun-12 20:00 *   21 06 17.998686 +16 40 04.93125  2.88588891399198 -19.5132333
 2025-Jun-22 20:00 *   21 03 40.707808 +17 08 14.37217  2.77814556955834 -17.7163573
 2025-Jul-02 20:00 *m  20 59 14.350305 +17 17 47.95792  2.68319920225201 -15.2301197
 2025-Jul-12 20:00 *   20 53 13.705068 +17 05 20.48551  2.60489079989877 -12.1199417
$$EOE
************************************************************************************
Column meaning:

TIME

  Times PRIOR to 1962 are UT1, a mean-solar time closely related to the
prior but now-deprecated GMT. Times AFTER 1962 are in UTC, the current
civil or "wall-clock" time-scale. UTC is kept within 0.9 seconds of UT1
using integer leap-seconds for 1972 and later years.

  Conversion from the internal Barycentric Dynamical Time (TDB) of solar
system dynamics to the non-uniform civil UT time-scale requested for output
```

has not been determined for UTC times after the next July or January 1st. Therefore, the last known leap-second is used as a constant over future intervals.

Time tags refer to the UT time-scale conversion from TDB on Earth regardless of observer location within the solar system, although clock rates may differ due to the local gravity field and no analog to "UT" may be defined for that location.

Any 'b' symbol in the 1st-column denotes a B.C. date. First-column blank (" ") denotes an A.D. date.

CALENDAR SYSTEM

Mixed calendar mode was active such that calendar dates after AD 1582-Oct-15 (if any) are in the modern Gregorian system. Dates prior to 1582-Oct-5 (if any) are in the Julian calendar system, which is automatically extended for dates prior to its adoption on 45-Jan-1 BC. The Julian calendar is useful for matching historical dates. The Gregorian calendar more accurately corresponds to the Earth's orbital motion and seasons. A "Gregorian-only" calendar mode is available if such physical events are the primary interest.

NOTE: "n.a." in output means quantity "not available" at the print-time.

SOLAR PRESENCE (OBSERVING SITE)
Time tag is followed by a blank, then a solar-presence symbol:

```
'*'  Daylight (refracted solar upper-limb on or above apparent horizon)
'C'  Civil twilight/dawn
'N'  Nautical twilight/dawn
'A'  Astronomical twilight/dawn
' '  Night OR geocentric ephemeris
```

LUNAR PRESENCE (OBSERVING SITE)
The solar-presence symbol is immediately followed by a lunar-presence symbol:

```
'm'  Refracted upper-limb of Moon on or above apparent horizon
' '  Refracted upper-limb of Moon below apparent horizon OR geocentric
     ephemeris
```

'R.A._________(ICRF)_________DEC' =
Astrometric right ascension and declination of the target center with respect to the observing site (coordinate origin) in the reference frame of the planetary ephemeris (ICRF). Compensated for down-leg light-time delay aberration.

```
Units: RA  in hours-minutes-seconds of time,    HH MM SS.ff{ffff}
       DEC in degrees-minutes-seconds of arc,  sDD MN SC.f{ffff}
```

'delta   deldot' =
Apparent range ("delta", light-time aberrated) and range-rate ("delta-dot") of the target center relative to the observer. A positive "deldot" means the target center is moving away from the observer, negative indicates movement toward the observer. Units: AU and KM/S

Computations by ...

Solar System Dynamics Group, Horizons On-Line Ephemeris System
4800 Oak Grove Drive, Jet Propulsion Laboratory
Pasadena, CA 91109 USA

```
    General site: https://ssd.jpl.nasa.gov/
    Mailing list: https://ssd.jpl.nasa.gov/email_list.html
    System news : https://ssd.jpl.nasa.gov/horizons/news.html
    User Guide  : https://ssd.jpl.nasa.gov/horizons/manual.html
    Connect     : browser        https://ssd.jpl.nasa.gov/horizons/app.html#/x
                  API            https://ssd-api.jpl.nasa.gov/doc/horizons.html
                  command-line   telnet ssd.jpl.nasa.gov 6775
                  e-mail/batch   https://ssd.jpl.nasa.gov/ftp/ssd/hrzn_batch.txt
                  scripts        https://ssd.jpl.nasa.gov/ftp/ssd/SCRIPTS
    Author      : Jon.D.Giorgini@jpl.nasa.gov

*******************************************************************************
```

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Appendix B

Acronym List

2SB: Two sideband (receiver)
ACA: Atacama Compact Array (also known as the Morita Array)
ALMA: Atacama Large Millimeter/submillimeter Array
APDM: ALMA Project Data Model
ASA: ALMA Science Archive
ASDM: ALMA Science Data Model
ARC: ALMA Regional Centre
ASC: ALMA Sensitivity Calculator
BWSW: Baseband Switching
B2B: Band-To-Band
DGC: Differential Gain Calibration
DDT: Director's Discretionary Time
DSB: Double Sideband (receiver)
EB: Execution Block
EOC: Extension and Optimization of Capabilities
FOV: Field Of View
GOUS: Group Observing Unit Set
LAS: Largest Angular Scale
LO: Local Oscillator
LSB: Lower Side Band
MOUS: Member Observing Unit Set
MRS: Maximum Recoverable Scale
OG: Observing Group
OT: Observing Tool
OTF: On The Fly
OUS: Observing Unit Set
PI: Principal Investigator
PWV: Precipitable Water Vapour
SACA: Stand-alone ACA
SB: Scheduling Block
SG: Science Goal
SSB: Single Sideband (receiver)
SFI: Single Field Interferometry
SLP: Spectral Line Picker
spw: Spectral Window
TFB: Tunable Filter Bank
TP: Total Power
USB: Upper Side Band

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 National Science and Technology Council (NSTC) in Taiwan and by NINS in cooperation with the Academia Sinica (AS) in Taiwan and the Korea Astronomy and Space Science Institute (KASI).

ALMA construction and 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 construction, commissioning and operation of ALMA.