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ALMA Observing Tool User Manual

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www.almascience.org

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Contents

1 Introduction **5**
1.1 What's new in Cycle 12? . . . 5
1.2 How to Use this Manual . . . 5
1.3 User Support . . . 6
1.4 Release Information . . . 6
1.5 Credits and Acknowledgements . . . 7

2 Install and Run the Observing Tool **9**
2.1 System Requirements . . . 9
2.1.1 Java . . . 9
2.1.2 Supported Platforms . . . 9
2.1.3 Disk Space and Memory . . . 10
2.1.4 Mac Issues . . . 10
2.2 Tarball Installation . . . 10
2.2.1 Installing and starting the OT on MacOS . . . 10
2.2.2 Installing and starting the OT on Linux . . . 11
2.2.3 Installing and starting the OT on Windows . . . 11
2.3 Connecting Through a Proxy Server . . . 12

3 Basic Concepts **13**
3.1 Phase 1 Proposals . . . 13
3.2 DDT Proposals . . . 13
3.3 Stand-alone ACA . . . 14
3.4 Phase 2 Programs . . . 14
3.5 Science Goals . . . 14
3.6 Observing Unit Sets . . . 14
3.7 Scheduling Blocks . . . 15
3.8 Project Submission . . . 16
3.9 Project Validation . . . 16
3.10 AOT files . . . 16
3.11 Project Conversion . . . 17

4 Overview of the Observing Tool **19**
4.1 Help . . . 19
4.2 The OT Main Graphical Interface . . . 19
4.2.1 GUI Parameter Fields . . . 19
4.2.2 GUI Features . . . 20
4.2.3 Menu and Toolbar . . . 21
4.2.4 The OT Panes . . . 21
4.2.4.1 The Project Structure Pane . . . 21
4.2.4.2 The Editors Pane . . . 22
4.2.4.3 The Feedback Pane . . . 23
4.2.4.4 The Overview Pane . . . 23
4.3 OT Configuration . . . 23

5 Phase 1 – Observing Proposal **25**
5.1 Open a Phase 1 Proposal . . . 25
5.2 The Proposal Form . . . 26
5.2.1 Joint Proposals . . . 26
5.2.2 Adding Investigators . . . 26
5.2.3 Reviewer Information . . . 27
5.2.4 Scientific Case . . . 27
5.2.5 Team Expertise . . . 28
5.2.6 Scheduling Feasibility . . . 28
5.2.7 Duplicate Observations . . . 28
5.3 Adding Phase 1 Science Goals . . . 28
5.3.1 General . . . 28
5.3.2 Field Setup . . . 28
5.3.2.1 Sources . . . 28
5.3.2.2 Source clustering/Psuedo-Science Goals . . . 29
5.3.2.3 Resolving source information . . . 30
5.3.2.4 Expected Source Properties . . . 30
5.3.2.5 Field definitions . . . 31
5.3.2.6 Solar total-power observing . . . 31
5.3.2.7 Import/Export of Source Information . . . 32
5.3.3 Spectral Setup . . . 32
5.3.3.1 Spectral Type . . . 32
5.3.3.2 Recovering image sidebands at Bands 9 and 10 (90-Degree Walsh Switching) . . . 33
5.3.3.3 Polarization Products . . . 33
5.3.3.4 Spectral-window placement . . . 34
5.3.3.5 Spectral Line – one spectral window per baseband . . . 34
5.3.3.6 Spectral Line – more than one spectral window per baseband . . . 35
5.3.3.7 Spectral Line – VLBI . . . 36
5.3.3.8 Representative Frequency . . . 36
5.3.3.9 Single Continuum . . . 36
5.3.3.10 Spectral Scan . . . 37
5.3.3.11 Multiple velocities and tuning solutions . . . 37
5.3.3.12 Rest Frequencies . . . 38
5.3.4 Calibration Setup . . . 38
5.3.4.1 User-defined calibration . . . 38
5.3.4.2 Astrometry . . . 39
5.3.5 Control and Performance . . . 39
5.3.5.1 Imaging considerations: arrays and configurations . . . 39
5.3.5.2 Sensitivity considerations . . . 40
5.3.5.3 Time Estimation . . . 41
5.3.5.4 Differential Gain Calibration . . . 42
5.3.5.5 Solar and VLBI . . . 43
5.3.5.6 Overriding the OT's time estimate . . . 43
5.3.5.7 Simultaneous observing . . . 43
5.3.5.8 Time-constrained observing . . . 43
5.3.6 Technical Justification . . . 44
5.4 Summary Information . . . 45
5.5 Proposal Validation . . . 45
5.6 Proposal Submission . . . 45

6 Phase 2 – Observing Program **49**
6.1 Generation from Science Goals . . . 49
6.1.1 Phase 2 Science Goals . . . 49
6.1.2 Scheduling Block Generation . . . 49
6.2 Observing Program Structure . . . 50
6.2.1 Observing Unit Sets . . . 50
6.2.2 Scheduling Blocks . . . 50
6.2.3 Targets . . . 50
6.2.4 Resources . . . 52
6.2.4.1 Field Source . . . 52
6.2.4.2 Instrument Setup . . . 53
6.2.4.3 Observing Parameters . . . 55
6.2.5 Observing Groups . . . 56

7 Tools **59**
7.1 The ALMA Template Library . . . 59
7.2 Sensitivity Calculator . . . 59
7.3 Spectral Line Picker . . . 60
7.4 Archive Search Tool . . . 62
7.5 Calibrator Selection Tool . . . 62
7.6 LO Configuration Tool . . . 63

8 The Visual Spatial Editor **65**
8.1 Overview of the Graphical Interface . . . 65
8.2 Creating a Field Definition . . . 66
8.2.1 Single Pointings . . . 67
8.2.2 Rectangular Areas . . . 67
8.2.3 Offset Versus Absolute Coordinates . . . 68

9 The Visual Spectral Editor **69**
9.1 Overview of the Graphical Interface . . . 69
9.2 Viewing a Spectral Setup . . . 70
9.2.1 Science Goal . . . 70
9.2.2 Scheduling Block . . . 71

A Create an External Ephemeris **73**
A.1 NASA resources for HORIZONS . . . 73
A.2 Instructions and Settings . . . 73
A.3 Example Ephemeris . . . 74

B Acronym List **79**

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Chapter 1

Introduction

The OT User Manual describes the ALMA Observing Tool (OT) that is used to prepare observing proposals (Phase 1) and to schedule approved observations (Phase 2) for the Atacama Large Millimeter/submillimeter Array (ALMA). The OT is a Java-based application consisting of a set of user interfaces that are needed to prepare an ALMA observing project. This consists of a valid observing proposal and/or an observing program containing one or more Scheduling Blocks that are executed at the telescope.

1.1 What's new in Cycle 12?

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

- **New capabilities:**
  - Full-polarization single-field interferometry in Band 1 on the 7-m Array (Stand-alone ACA) with the same polarization capability and accuracy as in Band 3 - 7.
- Band-to-Band (B2B) is allowed in Large Programs starting from Cycle 12. The OT will allow the submission of a Large Program if any science target requires B2B observing.
- The shadowing tables used by the OT have been updated. For multi-configuration Science Goals, shadowing is applied also to secondary configurations (TM2, 7M) and their time estimates are corrected according to their corresponding shadowing factors.

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 and/or observing program. Especially for inexperienced users, such a step-by-step guide to proposal creation is available in the form of the OT Quick Start Guide, which can be obtained either through the OT's internal help system or through the ALMA Science Portal. Observing programs are not intended to be created by normal users and therefore a Phase 2 counterpart to this does not exist.
- This manual is also not designed to describe everything that can be 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.

- Finally, this manual does not cover advanced use by the ALMA commissioning teams performing "Extension and Optimization of Capabilities" (EOC) in Chile. Starting the OT in its CSVALMA mode makes available more capabilities than are provided to normal users so that these can be tested. There are also fewer validation checks. Once a mode has been tested by EOC it is then usually transfered to the main OT for use by PIs.

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, Phase 1 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 provides information about how to install, configure and run the Observing Tool, Chapter 3 describes the main components of an observing proposal and program, and Chapter 4 provides a general overview of the OT.

In order to create a Phase 1 proposal, all the essential information is covered in Chapter 5 – this describes the process in some detail and should be read by all users. Complementary to this is Chapter 7 which describes various OT tools and Chapters 8 and 9 that give detailed information on how to use the visual spatial and spectral editors.

Phase 2 programs are covered in Chapter 6 where this essentially means Scheduling Blocks. It is not envisaged that PIs will ever be involved with editing the contents of SBs, let alone create them manually, and this chapter therefore remains only or practical interest to observatory staff.

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 (Phase 1), observation program preparation (Phase 2) 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. For simple projects, experienced users may only need to submit their Phase 1 and Phase 2 programs without any need for further support and they will receive their data package from the ARCs. Inexperienced users and more complex programs may require active ARC support during all phases of the observing program.

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 to be used with the OT that will be used to submit normal (non-DDT) proposals for Cycle 12.

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.

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Chapter 2

Install and Run the Observing Tool

The ALMA OT is written in Java and for Cycle 12 can only be installed using the traditional tarball distribution. Users are given the option to increase the amount of heap space (memory) made available to the OT – this can be very helpful when processing large proposals.

If problems are encountered during installation and/or operation of the OT, users are recommended to examine the Science Portal, especially the OT Troubleshooting and Known Issues pages, for solutions. The Helpdesk[1] may also contain useful information via its Knowledgebase system. If a solution to a problem cannot be found, a user should then open a Helpdesk ticket.

2.1 System Requirements

2.1.1 Java

If a version of Java has been installed by the user, its version number can be checked by typing `java -version` on the command line, the output of which should look something like this:

```
java version "1.8.0_271"
Java(TM) SE Runtime Environment (build 1.8.0_271-b09)
Java HotSpot(TM) 64-Bit Server VM (build 25.271-b09, mixed mode)
```

The number that follows the underscore refers to the update of the Java version that has been installed. When reporting a problem with the OT, the full version number including the update should be reported.

It may be possible to work with two different user-installed versions of Java (i.e. 8 and 11) and switching between these.

Note for MacOS Users: Apple has introduced a security measure which makes it difficult to install unsigned software. Therefore we recommend the some steps in Sec. 2.2.1 to ensure that the correct version of Java is installed.

2.1.2 Supported Platforms

The OT should run on any machine so long as a version of Java is available. This is because the JRE includes a Java Virtual Machine (JVM) which actually executes the platform-dependent OT code. Regular testing of the OT has found that it works using all common Linux distributions, Mac OS X and Windows. When reporting bugs, the platform on which the OT is installed should be included.

[1] https://help.almascience.org/

2.1.3 Disk Space and Memory

The basic OT release (tarball) takes up about 100 MB of disk space, but is significantly larger (∼200 MB) if Java is included. The default memory allocation for the OT is 8 GB, but this can be changed during the installation (see Sec. 2.2) .

2.1.4 Mac Issues

Macs contain a security application called "Gatekeeper" that can cause problems when installing the OT, especially on machines running Mac OS versions more recent than and including Catalina. Here we include some information that might prove helpful,.

Starting the OT may bring up a dialogue box saying that the application cannot be opened due to Java being from an unidentified developer. In order to overcome this one must open the "Security & Privacy" section of "System Preferences" and enable the installer there ("Allow Anyway"). This might need to be done even if the dialogue box does not mention the reason for the failure. It is also probably necessary that the settings allow applications to run from "identified developers". More information can be found at the following url:

https://support.apple.com/en-us/HT202491

2.2 Tarball Installation

To install the OT using the tarball distribution please the follow the steps given in the ALMA Science Portal and reported below.

2.2.1 Installing and starting the OT on MacOS

1. Install the Java runtime environment (JRE) from the eclipse foundation. They provide JRE for both modern (Apple aarch64 CPU) and older (Intel x64 CPU) generation hardware. It is advisable to download the '.pkg' package because it is easier to install on your system. You can find the latest JRE 17 release at the following Eclipse JRE web page.

2. After downloading the JRE software package. Double click on the file and it will open an installer application. Follow the instructions in the installer to complete the installation of JRE.

3. Download the ALMA OT

4. Open a terminal and extract the ALMA OT tarball

```
> tar xf alma-ot-c12.tgz
```

5. Change directory into the setup directory and execute the setup-unix.sh shell script

```
> cd alma-ot-c12/setup
> bash ./setup-unix.sh
> cd ..
```

6. Launch the ALMA OT application from the command line

```
> bash ./ALMA-OT.command
```

7. Or launch the ALMA OT application from finder by opening the application directory and double clicking on the ALMA-OT.command icon

Please note: if you are planning to work on large proposals (e.g. including many sources and/or science goals) or on a Large Program you may consider increasing the maximum heap space memory size. This will improve the performance and usability of the ALMA OT application. The default value is typically 8 G but you can increase the maximum heap size by using the –max-heap-size command line option. In this example we increase the maximum heap space memory size to 16 G. You can set it to higher values, but please keep in mind the maximum memory available on your computer:

```
> bash ./ALMA-OT.command --max-heap-size 16
```

Similar issues may affect tarball installation on a Mac as apply to the OT Installer (Section 2.1.4) e.g. the selection of "Allow Anyway" in "Security & Privacy". After this, running the setup script again should work correctly.

2.2.2 Installing and starting the OT on Linux

1. Download the ALMA OT for Linux including JRE (x64).
2. Open a terminal and extract the ALMA OT tarball

   ```
   > tar xf alma-ot-c12-linux-jre-x64.tgz
   ```

3. Change directory into the setup directory and execute the setup-unix.sh shell script

   ```
   > cd alma-ot-c12/setup
   > ./setup-unix.sh
   > cd ..
   ```

4. Launch the ALMA OT application from the command line

   ```
   > ./alma-ot.sh
   ```

Please note: if you are planning to work on large proposals (e.g. including many sources and/or science goals) or on a Large Program you may consider increasing the maximum heap space memory size. This will improve the performance and usability of the ALMA OT application. The default value is typically 8 G but you can increase the maximum heap size by using the –max-heap-size command line option. In this example we increase the maximum heap space memory size to 16 G. You can set it to higher values, but please keep in mind the maximum memory available on your computer:

```
> ./alma-ot.sh --max-heap-size 16
```

2.2.3 Installing and starting the OT on Windows

1. Download the ALMA OT for Windows including JRE (x64).
2. Right click on the alma-ot-c12-windows-jre-x64.zip file and select "Extract All..." to extract the contents
3. Go to the alma-ot-c12/setup directory
4. Double click setup-windows (may read setup-windows.cmd)
5. Go to the alma-ot-c12 directory
6. Double click ALMA-OT (may read ALMA-OT.cmd)

Please note: If you have windows defender running on your windows OS you may see a pop-up window warning you that "Microsoft Defender SmartScreen prevented an unrecognised app from starting." Click on the "More info" link and then click on "Run anyway" button to run the ALMA OT application.

2.3 Connecting Through a Proxy Server

If you are using the OT at a location where the internet is accessed through a proxy server, the OT will attempt to automatically discover your existing proxy server settings.

If your system does not support automatic discovery of proxy server settings, then these will have to be configured manually, either for the OT only, or for your Java installation. The former is only possible with the tarball version and you will be guided through the necessary steps during the setup stage.

The Java proxy settings are set via the Java Control Panel. The executable for this lives in the `bin/` directory of the Java installation and, if this in your path, can be started by typing `ControlPanel` (or `jcontrol`) at the command line. On a Mac it can also be launched from System Preferences. Once launched, the steps necessary to set up a proxy can be followed: http://www.java.com/en/download/help/proxy_setup.xml.

Chapter 3

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.

3.1 Phase 1 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 a Phase 1 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 pages, each of which covers a different aspect of the proposed observations, including the source list and the spectral setup.

3.2 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. 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.

DDT proposals look different to normal proposals in that the colour bars at the top of each panel in the OT GUI have a different colour (red by default). The OT also tries to include at various places (the GUI's titlebar, various submission dialogue boxes, etc.) that a DDT proposal is currently being viewed/worked on. Proposal codes use letters for the subcycle field i.e. the first DDT proposal of Cycle 7 had the code 2019.A.00001.S.

It is now possible to open a normal proposal as a DDT proposal (and vice versa) via the options contained in the File menu.

3.3 Stand-alone ACA

In its early cycles, it was only possible to obtain time on the ACA as part of observations conducted on the 12-m Array i.e. the shorter baselines of the ACA were required to image the largest angular scales in the source. However, this restriction was dropped in Cycle 4 and since then it has been possible to request time for the ACA only. 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 time can also be requested with the SACA.

3.4 Phase 2 Programs

After the successful submission of a Phase 1 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 the creation of these is the heart of the Phase 2 process.

The OT provides two methods for creating Scheduling Blocks: they can either be created by allowing the OT to automatically generate them from a Phase 2 Science Goal (essentially identical to a Phase 1 Science Goal), or this can be done manually. The latter is not for the faint-hearted and is usually only carried out by observatory staff. Successful proposals will have had their Phase 1 Science Goals automatically copied to their Phase 2 counterparts and batch generation of SBs by observatory staff is the standard way of producing the SBs in this case i.e. PIs do not create SBs themselves.

3.5 Science Goals

Science Goals are integral to the definition of a Phase 1 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.

As already said, Science Goals come in two varieties, Phase 1 and Phase 2. Both look, and to all intents and purposes are, identical. The main difference is that, if the SBs used to perform the observations are automatically generated, this is done using the Phase 2 versions only. For expert users, Phase 2 Science Goals aren't necessary to produce SBs, but their use is *highly* recommended. Even if the required SB cannot be created with all details correct, it should be possible to generate an SB from a Science Goal and then edit it.

3.6 Observing Unit Sets

Depending on the user inputs in a Science Goal, multiple Scheduling Blocks might result e.g. both the 12-m Array and the ACA might be required and these cannot be observed with the same SB. SBs are contained within folders called Observing Unit Sets (usually abbreviated to ObsUnitSet or OUS) which can in turn be contained within other ObsUnitSets. In principle, an arbitrarily complicated nested OUS/SB structure could be created, but ALMA uses a fixed number of OUS for all observations.

The OUS levels in a project are shown in Figure 3.1 and comprise the following (from bottom to top):

- Member OUS (MOUS) – this level, and only this level, can contain SBs. Currently, only one SB per MOUS is allowed, although this restriction is lifted for commissioning projects. Once an SB within a MOUS has been fully observed, the OUS will trigger the data reduction of the resulting ASDMs.

- Group OUS (GOUS) – this OUS contains one or more Member ObsUnitSets. If there is more than one MOUS, usually when both ALMA and the ACA are required, this indicates that these should be combined during subsequent data processing. This will be triggered by the GOUS once reduction of all the individual Member ObsUnitSets is complete. Even if the GOUS only contains a single MOUS, it will still be present, even though it strictly speaking isn't necessary
- Science Goal OUS – all Group OUSs for a given Science Goal are contained in the corresponding Science Goal OUS. No ALMA Data Reduction Pipeline processing happens at this level.

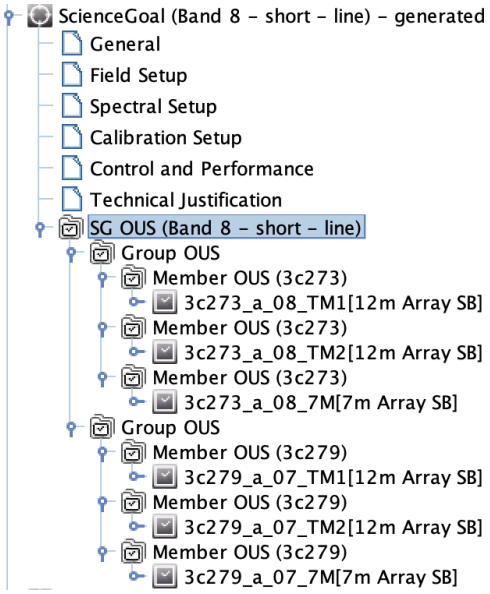

Figure 3.1: The Project Structure pane for a project involving two sources, each of which requires the 12-m Array and the ACA. For each source, the SBs for each array live in their own Member OUS, and these are contained within a Group OUS. The two Group OUSs are contained within their common Science Goal OUS. The two sources are in separate Group OUSs because the data will not be combined.

As can been seen, one of the main purposes of an OUS is to define relationships between different SBs for data processing purposes. The data processing pipeline is only triggered when all of the SBs inside an individual OUS are marked as completed, unless other conditions apply to finish the observation.

3.7 Scheduling Blocks

Scheduling Blocks are the key executable units of a project and contain all information necessary to execute a "single" observation i.e. SBs are the quanta of the ALMA scheduling system. SBs typically last one hour, this relatively short time required to take advantage of rapidly changing atmospheric conditions at the ALMA site. Therefore, SBs will often be repeated several times in order to achieve the desired sensitivity and will in general not be executed consecutively. Each SB execution is referred to as an Execution Block (EB).

The SB contains a huge amount of information, including detailed information about e.g. the receiver and correlator setup that have usually been automatically generated from the scientific constraints entered in the Science Goals. Calibration information will also have been created, usually in the form of "calibrator queries" that prompt the telescope control system to search for a suitable calibrator at execution time based on a set of constraints.

If an SB has been automatically generated, it is still possible to edit the various parameters if required, although this may not be possible for general users of the telescope. Manual creation is a particularly laborious process and is intended for experienced observers and for observatory staff for developing and testing new observing modes.

3.8 Project Submission

Phase 1 proposals and Phase 2 programs 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. Note that each submission causes a timestamp to be written into a project and if this is older than the one attached to the archive copy, a warning will be issued. Because of this, it is often easier to just work with the version of the proposal stored in the archive, although it is not currently possible to share this with Co-Is.

Projects from previous cycles can be used to create new proposals. For example, if an old project has been stored on disk, it can be read into the OT and submitted as a new proposal (using the usual "Submit Project" option in the File menu) so long as it is in the Phase 1 state i.e. the Proposal tab of the Project Structure pane is active. The Project Cycle shown in the Proposal editor will initially show the original value, but this will be updated during submission, as will the previous proposal code if this had originally been set. When the project is submitted, the OT will bring up a pop-up warning that a new proposal is being created, in case this is not what was intended.

No proposals from previous cycles that are stored in the archive should be in the Phase 1 state. Many will have 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 from the File menu should be used instead. 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 proposal (Main Call, DDT) can be created in this way.

3.9 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 coloured red. Other warnings will also appear without any intervention by the user, particularly to do with the spectral setup.

A complete validation is only possible by requesting this manually, most conveniently by using the icon in the toolbar. ALMA proposals and programs 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 make it into the server.

Validation is available at Phase 1 and Phase 2, although it is only run on one of these at any one time. For example, SBs are generated whilst working in the Phase 2 tab of the Project Tree. Even if the Phase 1 Science Goals are present in the other tab, any validation check will only work on the currently-selected (Phase 2) tab.

3.10 AOT files

When saving a project to disk, the file that is written will have an `aot` extension (the prefix must contain at least three characters!) and is usually referred to as an "AOT file". AOT files can be emailed to other people for viewing in the OT, but once a project has been submitted, a Co-I can also retrieve it from the ALMA archive and view it in read-only mode.

There have been reports of users encountering problems with saving to disk and, upon reading the file back in, get a "ZLIB input stream" error due to the file being empty. The reason for this has never been tracked down, mainly due to this error occurring very rarely. In response to this, the `$HOME/.almaot` directory contains a subdirectory in which backups of projects are regularly made. This may allow the recovery of a corrupted

project.

3.11 Project Conversion

When importing a project from disk it is scanned to see if it is a project created with the current version of the ALMA Project Data Model (APDM). This is a protocol that describes every piece of information contained within an ALMA project and is usually different for different versions of the OT. If the imported project was created using a different version of the APDM compared to that used by the OT that is trying to read it, an attempt will be made to convert it to the current version. If the upgrade is successful, the project will import successfully and future saves will also conform to the new model. However, the imported project is unlikely to successfully validate, usually because the new model requires information that was not present in the previous.

In case this was not what was desired, the OT will ask the user to confirm during a submission or when saving to disk. It is usually not desirable to submit a project being *observed* during Cycle N with the OT used to submit proposals for Cycle N+1. This is mainly an issue for ALMA staff.

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Chapter 4

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.

4.1 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, including its main constituents, Science Goals and Scheduling Blocks.
- OT Quickstart Guide – provides a description of how create a Phase 1 proposal in 10 easy steps.
- Reference Manual – gives a brief description of every button and input field.
- Contextual Help – the "question mark" symbols scattered throughout the OT take you to the relevant section of the Reference Manual.
- Tooltips – placing the mouse over an input field will reveal a short description of its purpose. The length of time that each is visible is viewable from the Preferences menu.

At the top of the OT GUI, at the right, you will find the Help button. This provides access to the User Manual, the Reference Manual, the OT Quickstart Guide and general information about the OT. In the OT Help, the User and Reference Manuals provide a table of contents, are fully indexed and have search a facility. Also, a list of favourites can be created.

4.2 The OT Main Graphical Interface

Once you have successfully started the ALMA OT, it should look similar to Figure 4.1. It contains three major components: a menu bar at the top, a toolbar just below this containing the most frequently used functions, and finally a number of panes, the most important of which allow access to, and the construction of, an ALMA project.

4.2.1 GUI 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 parameters fields can be selected from a drop-down list located to the

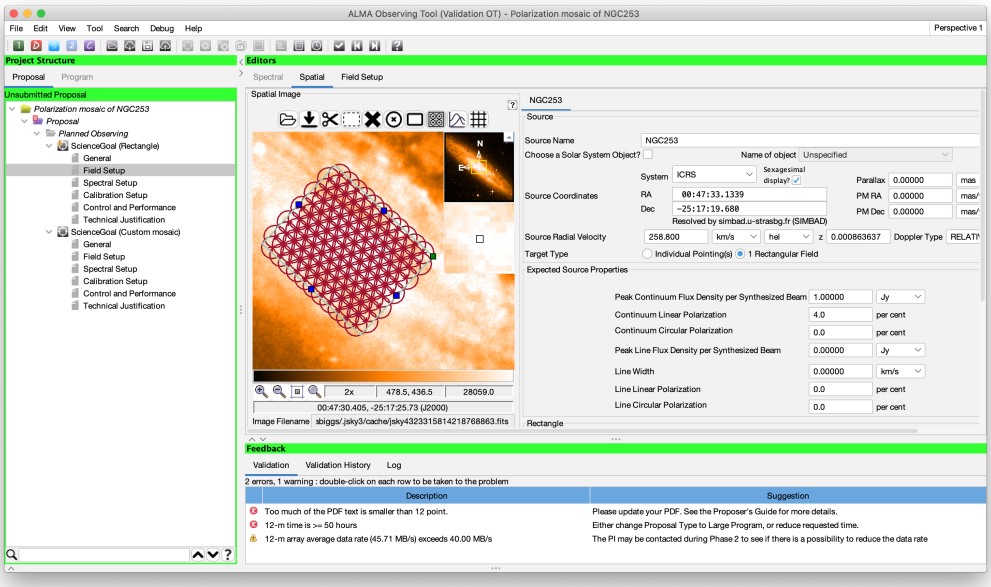

Figure 4.1: The Observing Tool main GUI. This shows the OT as configured for use by a normal PI (i.e. without special privileges) during the Main Call. This illustrates one of the "flat" look-and-feel themes that are now available.

right of the input field. When changing the units with the mouse combined with holding down the Alt key, the quantity will be converted to that unit. Changing the unit without pressing the Alt key will change the unit only. For example, if you have an angle of 1 arcmin, changing the unit to arcsec in the drop-down list without the Alt key will result in an angle of 1 arcsec. If instead the Alt key is pressed, an angle of 60 arcsec will result. The drop-down menu can be opened without the Alt key – this only needs to be depressed at the moment that the new unit is selected. Note that the appropriate key modifier is system dependent and on Linux systems it may be necessary to use Ctrl-Alt instead.

When a text field is selected (with the cursor or by tabbing into it), then by default the text in the field will now be selected. Typing anything will replace the value in the field. Changing this, so that new text is initially inserted into fields rather than replacing a field, can be done via the Preferences menu.

Another handy feature of the OT pertains to the entering of sexagesimal numbers i.e. source positions, in that it is not necessary to use colons as separators. For example, entering `12` and hitting return will cause `12:00:00` to be automatically entered and `124050.5` will be formatted as `12:40:50.5`.

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 coloured red. For a currently limited number of fields, the OT will in fact flash the entire entry field red and then reinsert the value that had originally been entered. Finally, validation will capture the remaining instances of where a value doesn't make sense.

4.2.2 GUI Features

Use of the OT relies heavily on selecting and manipulating items by means of standard GUI conventions such as mouse-driven positioning of the cursor or mouse-button clicking to select elements. Standard operations such as cut, copy, and paste, as well as drag-and-drop and other operations are all implemented and work basically in the same way as on most windows-based platforms.

Cut, copy and paste can be used on practically any item within the OT, including textual fields and nodes within the Project Structure tree. The usual modifier buttons will work i.e. on a Linux system Ctrl-C will copy

a Science Goal and Ctrl-V will paste it. For Mac, the Cmd key should be used. Copied nodes will change colour (probably to pink) as a visual reminder that they currently reside in the copy buffer. The copy of an object will usually have the text "Copy of" prefixed to its name. Dragging and dropping is also supported and will usually work where it makes sense – a very useful application is copying pages from a Science Goal into another Science Goal, replacing what was previously there. It is not possible, for example, to drop an OUS into a SB.

On a Mac, if the OT is being viewed in X11 over a remote connection, in order to see the Paste option after copying it may be necessary to disable the option "Update Pasteboard when CLIPBOARD changes" in the X11 Preferences menu.

4.2.3 Menu and Toolbar

The menu bar gives access to a variety of OT functions and tools that are more-or-less self-explanatory. One that all users should be aware of though is the Preferences menu that is accessed through the File menu. This gives access to a large number of configuration options, including the ability to turn user privileges on or off. This requires a password and will cause a number of the options within the OT, including menu and toolbar items, to change. A recent addition is the ability to display the operations that are allowed to be performed by the currently logged-in user.

The toolbar contains buttons for executing frequently-used OT functions and tools. Only those buttons are enabled that can be applied for the selected node in the Project tree. Unfortunately, not all of the icons are necessarily self-explanatory although each has an associated tooltip. The validate button is a particularly useful shortcut as this should be pressed at regular intervals.

4.2.4 The OT Panes

The area below the menu bar and toolbar is divided into a number of panes. Each of these has a couple of tabs that determine which information is displayed and the position of these (bottom or top) can be controlled via the Preferences menu. The panes can be collapsed and expanded by the small arrows on the boundaries of the panes.

4.2.4.1 The Project Structure Pane

Each ALMA project consists of a number of different items, including Science Goals, ObsUnitSets and Scheduling Blocks, that are arranged in a hierarchical tree structure which can be viewed in the Project Structure pane (also known as the Project tree). Each item in the tree is known as a node and, when selected, will allow different information to be viewed and edited in the main Editors pane. It is possible for the Project tree to become very crowded and it is often advantageous to restrict it to only show down as far as a particular node. Nodes are opened and closed using the "key" symbols and whole trees below a particular node can be collapsed and expanded via the right-click menu. The Project Structure pane is shown in Figure 4.2.

The two phases of ALMA projects, Phase 1 proposals and Phase 2 programs, are viewable by clicking the tabs at the top (or bottom if you've changed this in the Preferences menu) of the Project tree pane. The Program tab is only clickable for approved proposals or for privileged users. When the Proposal tab is enabled, all panes have a green (or red for DDT) header bar (the same colour is used for the Phase 1 steps in the Overview pane) and a different colour, blue, is used for Phase 2. A separate option for privileged users allows a commissioning project to be created, this using a purple colour.

The Project Structure pane can be split into a number of sections. The top section always contains the project that is being worked on (either the Phase 1 or the Phase 2 tree). In the sections below, templates can be loaded, either from the ALMA Template Library, or from an existing project on disk. You can display several projects in parallel. Note the grey background of the template sections, indicating that the content is read-only and cannot be changed. With the OT, you can copy parts of the templates into the project that you are working on. The project that is being worked on is visually highlighted and its title displayed in the title bar of the Observing Tool main window.

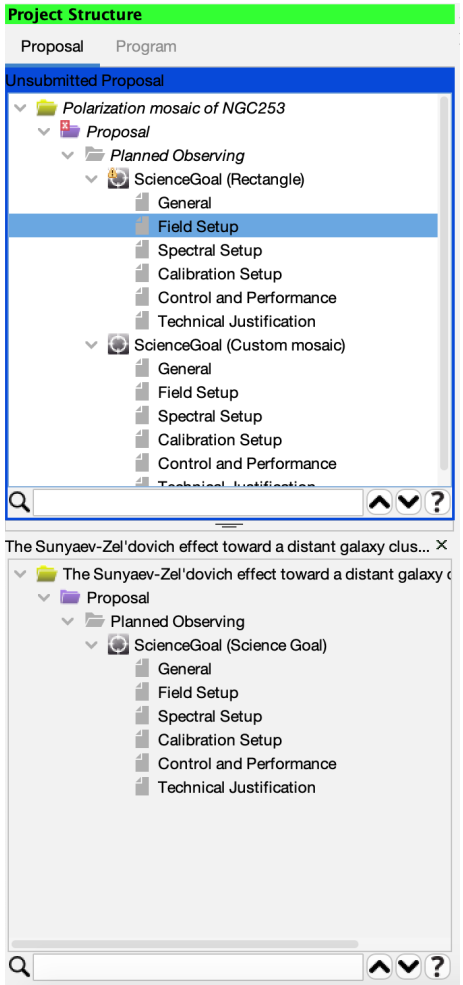

Figure 4.2: The Project Structure Pane. Visible is the structure of a Phase 1 proposal with two Science Goals (top) and a project that has been loaded as a template (bottom). Note the search interface at the bottom of the proposal's Project Tree. The pink colour of the first Science Goal signifies that it was copied and pasted, before being edited to create the second SG.

At the bottom of this pane there is now a search interface. This is particularly useful at Phase 2 after SBs have been generated as a fully expanded Project Tree can be extremely long. Extensive help is available via the contextual help button.

4.2.4.2 The Editors Pane

The Editors pane is the main interface that is used to specify a project. It actually contains three separate editors: Spectral, Spatial and another which is usually referred to as the Forms editor. These are selectable via the tabs although the Spectral and Spatial editors are only viewable when it is appropriate to do so e.g. when a Science Goal's Spectral Setup or Field Setup page is active. The Forms editor is always available to receive input and is also visible when using the Spatial or Spectral Editors. The name of the tab changes to reflect the currently chosen node in the Project tree.

Both the Spectral and Spatial tabs give access to graphical interfaces that are extremely useful for viewing a spectral setup, as well as for viewing and defining a field setup. It is highly recommended that these always be viewed when creating an ALMA project.

4.2.4.3 The Feedback Pane

The Feedback pane 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 pane appears automatically when the validation command is executed, even if it has previously been hidden.

Upon validation, the feedback can be inspected in three tabs: Validation, Validation History and Log. The former is the one that is usually used and gives a row listing of the errors and warnings found during the most recent validation. The location of each problem is indicated by a cross on a red background in the Project tree and double-clicking on the row will cause the location to be displayed in the Editors pane.

4.2.4.4 The Overview Pane

The Overview pane at the bottom of the OT window outlines the steps for preparing a new Phase 1 proposal or Phase 2 program. Clicking on the arrows will bring up a help listing which may also include clickable links to perform the necessary steps. It is recommended that this panel be minimised unless you are a novice user.

4.3 OT Configuration

The OT supports a number of layout and display configurations that can be selected by the user. The most basic configuration option is that you may collapse the various panes in the main GUI window and/or change their size. Collapsing can be done via the small arrows next to the pane borders; the border themselves can be moved using the left cursor button. These changes are automatically maintained the next time you run the tool.

Additionally, using the Preferences menu a large number of OT settings can be specified, mostly to do with the OT's appearance and behaviour. Particularly useful options include the time that each tooltip is displayed for, whether a Science Goal is displayed as a summary table or a collection of all its editors, and whether the OT should display Spatial, Spectral or Forms editors by default. Options for the OT's appearance have recently been made expanded via the addition of various "flat" options for the "look and feel" of the GUI.

Other features of the Preferences menu include:

- Dialog behaviour – the OT displays many dialogue boxes during its operation, often to confirm if a particular operation is really required. At the risk of making mistakes, it can be advantageous to switch some of these off using the Dialogs tab. This is particularly useful for people who do a lot of work with SBs.
- User credentials – if they have already been entered, e.g. to submit a project to the ALMA archive, or to enable user privileges, the username and password will be displayed here. These details are remembered by the OT and will persist across OT sessions.
- User privileges – if a user has an account with special privileges, these must be activated using the Advanced tab. Once this is done, the OT will prompt for the username and password each time it is started. Note that this means it is not possible to use the OT with user privileges without a network connection!

All user preferences are stored by the OT in the `$HOME/.almaot` directory and will be used when starting the OT.

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Chapter 5

Phase 1 – Observing Proposal

This chapter guides you through the steps needed to produce a Phase 1 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). DDT proposals look identical to normal proposals except for the colour used to highlight the title of each pane in the OT's GUI (Project Structure, Editor and Feedback). This is green for normal proposals and reddish-pink for DDT. A recent addition has been ACA Supplemental Call proposals which use cyan as the distinguishing colour by default.

5.1 Open a Phase 1 Proposal

A proposal is often created from scratch using the File menu or toolbar, but it is also possible to read in an existing project from disk or from the archive. Previously-submitted proposals that have been retrieved from the archive will be in Phase 2 and cannot be used to create a new proposal as is. However, they can be read in and converted to new (unsubmitted) Phase 1 Proposals using an option in the File menu. There is also now an option to open a previously submitted project as a DDT or an ACA Supplemental Call proposal.

The first task is to provide some generic information about the project. Selecting the Project node in the Project Structure tree will enable both the PI to be chosen, by querying the ALMA User Database, and a title for the project to be entered, although both can in fact be entered in the subsequent Proposal node. Once the project title has been entered, this will be reflected in various places in the OT: the main GUI titlebar, the Project node and the Forms tab of the Editors pane. A non-editable project code will initially be blank and only be completed once a proposal has been submitted for the first time.

Note that privileged users will also see panels entitled Project Notes and Advanced Options. Amongst other things, these enable observatory staff to gain access to restricted information about a project (including the outcome of its scientific and technical review) and to note useful information.

To continue with proposal creation, the Proposal node in the Project tree should now be selected. A number of information fields should be visible in the Editors pane and double-clicking on the node will reveal an empty node named Planned Observing; the Phase 1 Science Goals are kept here. Also note that on top of the Project tree, in the blue banner, the status of the proposal is visible. For newly created proposals it will say "Unsubmitted Proposal" whilst proposals that have already been submitted will show "Submitted Proposal". If this message is visible, submission of the proposal will overwrite the previous submission!

5.2 The Proposal Form

When the Proposal node is selected, the Proposal form is loaded in the Editor pane. The form contains roughly a dozen fields for describing the proposal, including an abstract, proposal type, scientific keywords and investigator information. Completing the information should be straightforward and the meaning of the fields, and whether they need to 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 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. The resultant signal has previously only been used for VLBI observations, but is now available in a stand-alone mode. 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 starting from Cycle 10.
- 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).

Once a Science Category has been provided, a list of keywords appears, the content of which depends on which category has been picked. At least one, and up to two, can be chosen and the Shift and Control/Command keys can be used to select multiple entries in the usual manner.

5.2.1 Joint Proposals

Starting from Cycle 10 Joint Proposals with other observing facilities – including JWST, VLA, and VLT – are possible. A new panel is presented in the OT to allow the PIs to select if their proposal is a Joint Proposal. If Joint Proposal 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.

5.2.2 Adding Investigators

Further down the page is a panel for adding the details of the 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 and VLBI proposals (not Phased Array) can in addition have multiple Co-PIs. Clicking on e.g. "Select PI..." 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, email address or ALMA ID (username). To find matching users, select which attribute should be searched from the drop-down list, enter a valid constraint into the text field and click "Find Investigators". If the entered constraint is invalid, it will be highlighted in red and searching will be disabled. A valid constraint consists of:

- Name: at least 3 characters (partial matches are reported)
- ALMA ID: at least 3 characters (only exact matches are reported)
- Email: a valid email address (only exact matches are reported)

All searches are case-insensitive and multiple queries can be performed in one go by entering search terms separated by commas. In case only one result is returned, it will be automatically highlighted for convenience and 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 – removing them works in the same way.

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 or European 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 any 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.

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 Proposal..." button. The project in question must exist on the local disk and once selected, its investigators will be *added* to any that have already been selected.

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'.

5.2.3 Reviewer Information

A reviewer must be nominated for a subset of proposals submitted as part of the Main Call. This is to enable the reviewer to participate in distributed proposal review. The OT will request that reviewer information be added - if the proposal is not a Large Program - as they will ultimately be asked to participate in the distributed review. All Large Programs will instead be reviewed by panels. More information can be found in the Proposer's Guide.

If the reviewer doesn't have a PhD then it is possible to nominated a suitably qualified mentor who will provide support.

5.2.4 Scientific Case

Below the list of investigators, the PDF document to support the science case must be attached. 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, provided that your computer contains appropriate software.

The minimum font size for the PDF is 12 point. A check is made of the fraction of text smaller than this which, if >15 per cent, will cause a validation **error** to be issued (this was previously just a warning). 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 being placed into a dedicated node of each Science Goal.

5.2.5 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. The font-size restrictions also apply here.

5.2.6 Scheduling Feasibility

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. As long as "No" is selected, the proposal does not validate.

5.2.7 Duplicate 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 panel. A failure to do so may result in the proposal being rejected. More information on what constitutes a duplication can be found in the Science Portal.

5.3 Adding Phase 1 Science Goals

Phase 1 Science Goals are added in a number of ways, but the most convenient is by using the toolbar icon. Each time this is clicked, an empty Science Goal will appear underneath the Planned Observing node and by default each will show its six sections. Note that a Science Goal can only be added if either the Proposal or Planned Observing nodes are currently active. There is no limit to the number of SGs that can be added.

A number of summary views of the defined Science Goals are available. The first is a table that is visible when the Planned Observing node is active – each row gives a brief description of each SG. If the top node of a Science Goal is selected, what is displayed depends on the user's preferences. The choices are a similar table to that displayed in Planned Observing or a view of all six sections of a Science Goal simultaneously.

5.3.1 General

The Science Goal name and a description of the Science Goal can be placed here if desired.

5.3.2 Field Setup

5.3.2.1 Sources

In the Field Setup page, the user is asked for source parameters, the most important of which are the name, coordinates and velocity. 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.

Apart from Galactic coordinates, the only system that should be used is ICRS. FK5 can be entered, but the observations will be performed as if the coordinates were ICRS. This has very little impact as the difference is small, amounting to a maximum of some tens of mas. 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 must 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. The OT will issue an error if this is the case. This issue is explained more in Section 5.3.3.11.

5.3.2.2 Source clustering/Psuedo-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 dialogue box 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 node 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.

[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.

5.3.2.3 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.

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.

If the OT is unable to resolve a source and the details of a source had previously been entered, it will bring up a dialogue box asking whether the name should be reset to the previous source or whether the failed search term should be left for editing.

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

5.3.2.4 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. 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 node (Section 5.3.6).

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. It was initially only possible to use the science target as the phasing calibrator and thus VLBI was restricted to relatively bright sources (>0.35 Jy for Band 1, >0.5 Jy for Band 3 and Band 6, and >0.7 Jy for Band 7). For spectral line observing the flux thresholds are calculated using the formula reported in the Proposer's Guide. However, it is now possible to request that another source be used for this purpose i.e. the phasing solutions found on the calibrator are used during the scan on the science target – VLBI users of the VLA will be familiar with this mode. If the appropriate checkbox is ticked, a nearby (phase) calibrator should be defined in the Calibration Setup node and justified in the Technical Justification node. Note that passive

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

phasing must be used in Phased Array mode. 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.

5.3.2.5 Field definitions

The observing patterns that are used to observe a source fall into two categories:

- 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 approximated 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 5.3.3.8).

Both rectangles and individual pointings can be defined using the Visual Spatial Editor (Chapter 8) 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.

5.3.2.6 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 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.

For early cycles of solar observing it was only possible to produce TP maps of the full solar disc, even though the interferometric data only covers a small region on the Sun's surface. From Cycle 9 though it has been possible to also request TP observations of this region, in addition to the full solar disc. 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. More options will be added in the future.

5.3.2.7 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 from File..." located at the bottom of the node. This can be used to either load a set of additional sources, or to completely replace the list of currently-defined 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 to File..." option can be used to create a template.

```
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.

5.3.3 Spectral Setup

The Spectral Setup page contains fields to specify spectral windows, each of which samples a sources's spectrum over a particular range of frequencies. These are defined either manually or with the Spectral Line Picker (SLP, Section 7.3). All setups should be inspected using the Visual Spectral Editor (Chapter 9).

As mentioned in Section 5.3.2.1, 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 peform 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 topocentric, regardless of the frame specified in the Field Source definition.

5.3.3.1 Spectral Type

The OT offers three kinds of spectral observation:

- Spectral Line – offers maximum flexibility as almost any number of spectral windows can be defined, 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.

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

ALMA uses two types of receiver, "two-sideband" (Bands 3 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. In Cycles 0 to 4 this wasn't available and one sideband (known as the "image") was instead rejected i.e. the astronomical signal removed such that it didn't appear superimposed on the spectrum from the other (known therefore as the "signal"). Since Cycle 5 it has been possible to recover both sidebands and this is selected in the OT using a checkbox for Band 9 and 10 setups.

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 (not written into the ASDM) by unchecking the "Store Image" checkbox. Additionally, every spw is now by default spectrally averaged by a factor of two. This halves the data rate but, due to the fact that each spectrum is also Hanning smoothed, the spectral resolution is only degraded by $\sim$15 per cent. Science Goals for which the average data rate exceeds a maximum value will not validate.

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.

5.3.3.3 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.

Starting from Cycle 10, Band 3 full polarization is allowed for Solar observing. This is only allowed in single continuum.

5.3.3.4 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 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.

5.3.3.5 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. Starting from Cycle 10, for dual polarisaiton, not only 2x2-bit but also 4x4-bit correlator modes can be selected. Compared with their 2X2-bit equivalent, modes 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. For large numbers of channels the spectral resolution tends towards the channel width multiplied by the spectral averaging factor. 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.

Table 5.1: 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	

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 Visual Editor (Chapter 9) 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 Visual Editor 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.

5.3.3.6 Spectral Line – more than one spectral window per baseband

It is possible to have more than one spectral window per baseband 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 5.1 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, before spectral averaging, must have the same spectral resolution. If required, each spectral window can subsequently be spectrally averaged, but the "native" (unaveraged) spectral resolution must be the same for each spectral window.

Fraction	Center Freq	Center Freq	Transition	Bandwidth, Resolution (smoothed)	Spec. Avg.	Representative Window
1/4	460.00...	342.00...	Interesting non-CO line	468.750 MHz(411 km/s), 976.563 kHz(0.856 km/s)	1	○
1/4	459.00...	341.26...	Interesting non-CO line	468.750 MHz(412 km/s), 976.563 kHz(0.858 km/s)	1	○
1/2	459.34...	341.52...	CO v=0 4-3	937.500 MHz(823 km/s), 976.563 kHz(0.857 km/s)	1	◉

Figure 5.1: Example of a multi-region mode setup. A spectral window with a width of 1875 MHz has been split into three smaller windows using the fraction parameter and each placed at a different frequency.

An example of a multi-region mode is shown in Fig. 5.1 where a 1875 MHz-wide mode has been split up into three spectral windows. In addition to the restrictions on spectral window placement mentioned in Section 5.3.3.5,

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.

5.3.3.7 Spectral Line – VLBI

Spectral-line observing with VLBI is significantly different. 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.

5.3.3.8 Representative Frequency

A very important parameter that should be carefully set is the Representative Frequency (RF). 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 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 5.3.2.5). 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.

5.3.3.9 Single Continuum

The Single Continuum interface 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 3-8) 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 5.3.3.8) 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.

As the same suggests, Single Continuum setups are intended for continuum observations and thus were previously only allowed using low spectral-resolution spws i.e. the TDM correlator mode. It is now possible to instead select FDM mode – this covers the same bandwidth but has significantly higher spectral resolution. This 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.

5.3.3.10 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 $\geq$ 500 MHz). 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 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 500 or 1000-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 Visual Editor. 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.

Starting from Cycle 10, spectral scans are allowed for use also with the Total Power Array.

5.3.3.11 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 5.3.2.2, 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 5.3.5.3). As already stated, no more than five are allowed per SB and the user may have to split the sources into multiple SGs.

5.3.3.12 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 targetted transitions.

Many spectral windows are created by searching the Splatalogue using the Spectral Line Picker (Section 7.3) 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 Visual Spectral Editor (Chapter 9). 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 Setup page.

5.3.4 Calibration Setup

5.3.4.1 User-defined calibration

The Calibration Setup page 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 node (Section 5.3.6).

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 Phase 1, but the database is likely to change between proposal submission and program execution.

5.3.4.2 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. 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 node.

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

5.3.5 Control and Performance

This page of the Science Goal 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 and VLBI observations are different as the user requests a time and does not enter a desired sensitivity.

5.3.5.1 Imaging considerations: arrays and configurations

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 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 node, the OT displays various information regarding the configurations that are available in the advertised cycle. As it is not possible to show all the configurations, information is only displayed 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 requested frequency band (the largest configurations are not available at the highest frequencies). 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.

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. 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 5.3.2.2) 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 dialogue box when selecting a range of angular resolutions.

ALMA has for some years now offered a fixed set of 10 12-m configurations which are used in the OT to reflect the likely angular resolutions and LAS values that can be achieved. While not all have been available for each observing mode (e.g. the largest configurations have not been allowed for use with the highest-frequency bands) each of the 10 configurations was always visited at least once during a cycle. That has now changed and it is no longer the case that every cycle will include a vist to every 12-m configuration. This will be reflected in the angular resolutions and LAS values shown in the table at the top of the Control & Performance page and therefore the range of angular resolutions that can be requested.

5.3.5.2 Sensitivity considerations

The time required to achieve the requested sensitivity depends crucially on the spectral setup, particularly the Representative Frequency (this sets, amongst 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.

5.3.5.3 Time Estimation

When a Science Goal time estimate is requested, a dialogue box is displayed (Figure 5.2) that attempts to indicate 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 5.3.2.2) the time-estimate dialogue box 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. 5.2). 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. In future cycles, a new observing mode will be commissioned for use at the telescope and the OT will almost certainly change the way that these types of observation are created.

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.

5.3.5.4 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), although not all of these are currently commissioned e.g. Band 10 with C-9 or 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

[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.

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.

Bandwidth Switching is currently assumed by the OT for any "narrow-bandwidth" setup i.e. those where the aggregate non-overlapping bandwidth is less than 937.5 MHz. This is somewhat crude as DGC might not actually be required where there is a very bright calibrator near the science target. It is likely though that a similar procedure to that used in the B2B case (calibrator search) will be used in the future.

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

5.3.5.5 Solar and VLBI

Solar and VLBI projects are special as a sensitivity cannot be entered i.e. the user must enter a time request. 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 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.

Neither of these project types are available during the ACA Supplemental Call and an attempt to open a previous solar or VLBI proposal as a Supplemental Call proposal will fail.

5.3.5.6 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. 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 node and a detailed description of the user-defined time estimate given.

5.3.5.7 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, 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.

5.3.5.8 Time-constrained observing

It is possible to define various timing constraints for the observations that form a Science Goal. 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 abritrary 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.

5.3.6 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 node 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 node 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 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. This can either be done via the Edit menu, or one can simply drag and drop the node into the destination SG. Alternatively, the contents of individual text boxes can be copied and pasted.

5.4 Summary Information

Once the proposal is complete, various pieces of summary information can be obtained by right-clicking on the relevant node in the Project Tree. Of particular interest to most PIs is the amount of time required for the entire project and that can be seen in all of the following summaries.

The summaries come in four varieties:

- Science Goal summaries: These consist of a single page and show a lot of technical detail. These are, in fact, mainly to be used by the technical assessors when reviewing the submitted proposal, but may also be useful for the PI. They also include the contents of the Technical Justification node. Right-clicking on a Science Goal will provide access to its summary whilst the same on the Planned Observing node can show all Science Goal summaries together.
- Proposal summary: This single page (effectively a "Cover Sheet") consists of information entered in the Proposal node (title, abstract, etc.) plus a very brief summary of the Science Goals. It also gives the total time calculated for the proposal, separately for the 12-m Array (all configurations) and the ACA. The names of the investigators are no longer shown.
- Whole proposal summary: This is a combination of the previous two summaries, plus the scientific justification PDF.
- Project time summary: Information of the total amount (and different types) of time, as well as data rates and volumes can be viewed in the OT itself (as opposed to in a generated PDF) using this feature. This is available from the Toolbar, the Tool menu or by right-clicking on the project tree.

5.5 Proposal Validation

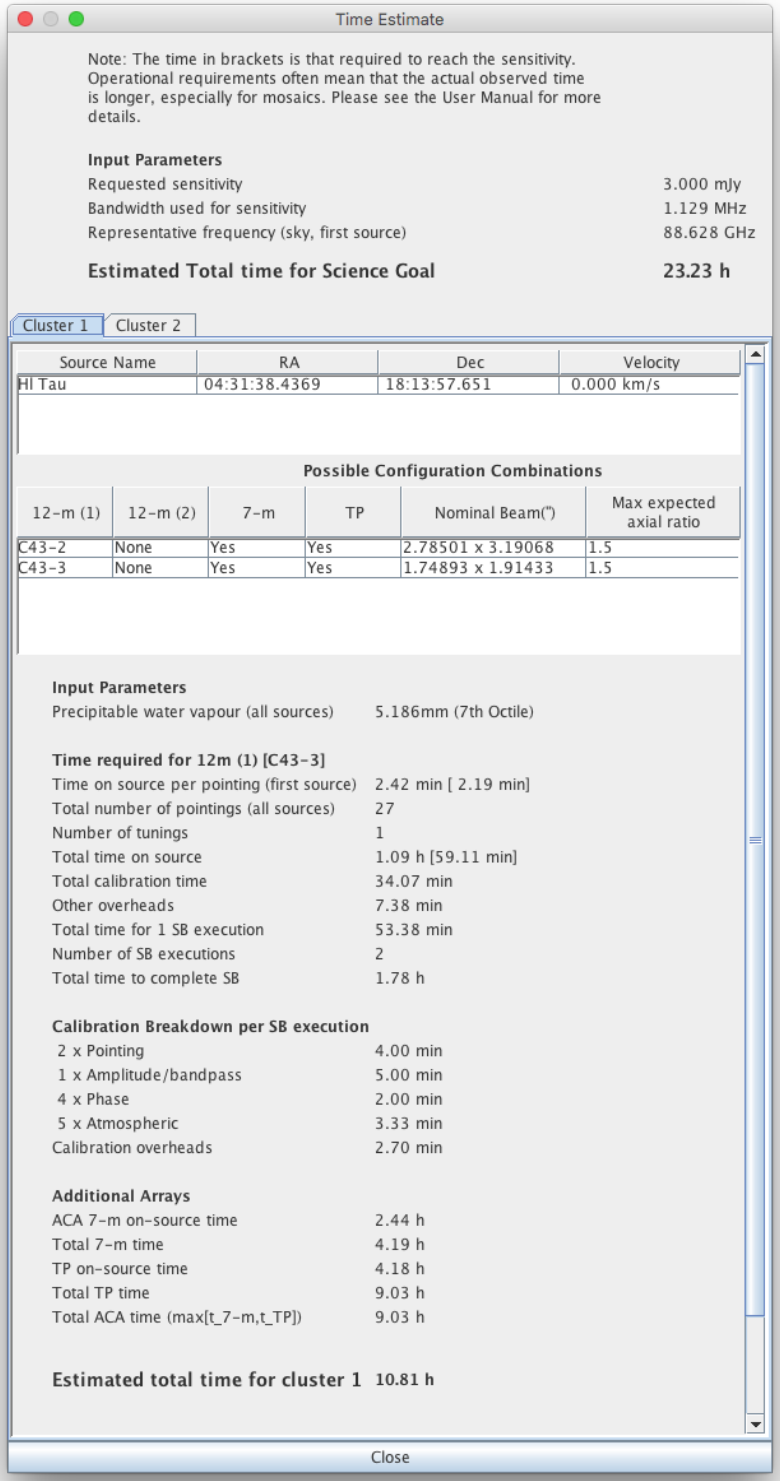
Before submitting the proposal to the ALMA archive, it is highly recommended that the validation procedure be run in order to make sure that the proposal contains no errors. In fact, it is even more highly recommended to validate regularly during proposal creation so as to spot mistakes as soon as possible. After a successful validation and, optionally, having saved the work locally, the proposal can be submitted. Even if validation is not validated 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. In our tests, an OT with 3 GB of heap memory took approximately five minutes to validate the most complicated proposal we've ever encountered. This is a significant improvement over the situation at Cycle 4 where it could take up to an hour, or not complete at all.

5.6 Proposal Submission

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, an email will be sent to all investigators and the PI will be asked to save the project to a local disk. Although it is possible to only work on the archive copy, each submission overwrites the previous one. Therefore, maintaining

local copies can be useful in the event that reverting to a previous version becomes desirable. The OT will give a warning if submission of an older version of a project is attempted, just in case this was not the intention.



Time Estimate

Note: The time in brackets is that required to reach the sensitivity. Operational requirements often mean that the actual observed time is longer, especially for mosaics. Please see the User Manual for more details.

Input Parameters

Requested sensitivity	3.000 mJy
Bandwidth used for sensitivity	1.129 MHz
Representative frequency (sky, first source)	88.628 GHz
Estimated Total time for Science Goal	**23.23 h**

Cluster 1 | Cluster 2

Source Name	RA	Dec	Velocity
HI Tau	04:31:38.4369	18:13:57.651	0.000 km/s

Possible Configuration Combinations

12-m (1)	12-m (2)	7-m	TP	Nominal Beam(")	Max expected axial ratio
C43-2	None	Yes	Yes	2.78501 x 3.19068	1.5
C43-3	None	Yes	Yes	1.74893 x 1.91433	1.5

Input Parameters

Precipitable water vapour (all sources)	5.186mm (7th Octile)

Time required for 12m (1) [C43-3]

Time on source per pointing (first source)	2.42 min [2.19 min]
Total number of pointings (all sources)	27
Number of tunings	1
Total time on source	1.09 h [59.11 min]
Total calibration time	34.07 min
Other overheads	7.38 min
Total time for 1 SB execution	53.38 min
Number of SB executions	2
Total time to complete SB	1.78 h

Calibration Breakdown per SB execution

2 x Pointing	4.00 min
1 x Amplitude/bandpass	5.00 min
4 x Phase	2.00 min
5 x Atmospheric	3.33 min
Calibration overheads	2.70 min

Additional Arrays

ACA 7-m on-source time	2.44 h
Total 7-m time	4.19 h
TP on-source time	4.18 h
Total TP time	9.03 h
Total ACA time (max[t_7-m,t_TP])	9.03 h

Estimated total time for cluster 1 **10.81 h**

Close

Figure 5.2: Example of the Time Estimate dialogue box. 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. There are also two clusters.

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Chapter 6

Phase 2 – Observing Program

Once a proposal has been approved, it is necessary to create the Scheduling Blocks that will be used to run the observations at the telescope. The SBs are automatically generated from the information contained in the Science Goals by observatory staff – this is no longer a task for the PI. Observatory staff can also build SBs from scratch, or edit what generation has produced. SB generation continues to be improved and in most cases can be relied upon, but special observing modes often require manual intervention.

6.1 Generation from Science Goals

6.1.1 Phase 2 Science Goals

Downloading an approved project from the archive will cause the Phase 1 Science Goals to be automatically copied over to the Program tab of the Project Tree and the project will open here. Technically speaking, the copied Science Goals are Phase 2 Science Goals, but their visible content is absolutely identical to that of their Phase 1 counterparts.

Note that PIs will no longer submit (or be able to edit) their Phase 2 SGs after they have been informed that their project has been approved. The conversion from Phase 1 to Phase 2 is now undertaken by the observatory. Any required changes to the contents of the SG will need to be communicated via a Helpdesk ticket.

Observatory staff can also create Phase 2 Science Goals from scratch, or create copies of existing ones. It is even possible to copy a Phase 1 SG into Phase 2.

6.1.2 Scheduling Block Generation

All approved projects have their SBs generated by the observatory. Note that it is possible that one or more SGs might be descoped by the proposal review process. If this is the case, SBs will not be generated from the descoped SGs. Whether an SG has been descoped or not is shown in the General node of an SG.

The generated SBs (including the Observing Unit Sets in which they are contained) are attached below each SG and cannot be edited by PIs, although the whole directory structure can be freely navigated and inspected. Only observatory staff can edit any content below the Science Goal and indeed, no PI should greatly concern themselves with the contents of the SBs. These contain a lot of technical information that the observatory will ensure is set correctly before the observations are executed. Most vital is that the scientific aims encapsulated in the SG are correct.

Observatory staff can generate SBs manually using the appropriate menu or toolbar options. Details of the contents of the SBs can be found in Section 6.2.

6.2 Observing Program Structure

As has already been said, it is not recommended that SBs ever be created from scratch. However, observatory staff can edit them without restriction and here we give here an overview of the their contents, in fact, the whole structure of an Observing Program.

The structure of a typical Phase 2 project is shown in Figure 6.1 and shows each of the required entities: Observing Unit Sets, Sheduling Blocks, Targets, Resources and Observing Groups.

6.2.1 Observing Unit Sets

The OUS is a fundamental part of the construction of an SB and, as explained in Section 3.6, a fixed OUS nested structure has been agreed. This is automatically produced during SB generation and should also always be followed when creating SBs manually. If desired, the entire contents of all OUSs (and their associated SBs) can be protected from editing by activating OUS Write Protection from the Advanced tab of the Preferences menu.

If a Phase 2 program is being constructed manually i.e. without a pre-defined Science Goal, the first step is to create a top-level OUS (usually refered to as the Science Goal OUS) in the Program tab of the Project Tree. This is done via the Science Plan folder, either by using the right-mouse menu or the toolbar icon. A new Special Observing Program folder will be created, and within this, the top-level OUS. Group and Member OUSs should then follow.

Clicking on an OUS will reveal its Form editor which contains a number of panels, very few of which are actually used at this time. Probably the only real option at the moment is to set the OUS name to something useful.

6.2.2 Scheduling Blocks

Scheduling Blocks contain most of the information that is required to run the observations and are therefore very complicated. The remainder of this chapter will describe in detail the contents of an SB and how the various components fit together to produce a valid observation. Indeed, the OT's validation function is also available at Phase 2 and should be routinely checked to ensure that the project will submit without problems to the ALMA archive. As usual, submission will not be possible for any project that does not pass validation.

When clicking on the Scheduling Block node in the Project tree, the SB's Form editor will appear in the Editors pane. It consists of eight panels, the first three of which are very similar to those in the OUS, but again, very little of this information is currently used. A number of panels will eventually influence the automatic scheduling of the observations, but ALMA does not yet have a mature scheduling system and so these fields are also not currently read.

Of the remaining panels, the most relevant ones are SchedBlock and Advanced Parameters. SchedBlock gives the name of the observing mode and states which observing script e.g. StandardInterferometery.py, will be used to actually run the observations. It also gives the number of executions that are allowed for this SB, which is often set to a large number as executions above this number are not allowed. Advanced Parameters is particularly relevant as a number of parameters can be defined here which will be read by the observing script e.g. to tell the script that more than one phase calibrator has been defined and both should be observed.

6.2.3 Targets

Within the SB, a series of observations (the ultimate order of which will be determined by the observing script) are actually constructed out of Targets. These define an observation of a given source and are close to the concept of a scan, each of which might be repeated multiple times, most obviously for the science target and phase calibrator. A Target is constructed out of a Field Source, an Instrument Setup and an Observing Parameter – these are in turn refered to as Resources and are stored in a Resources folder.

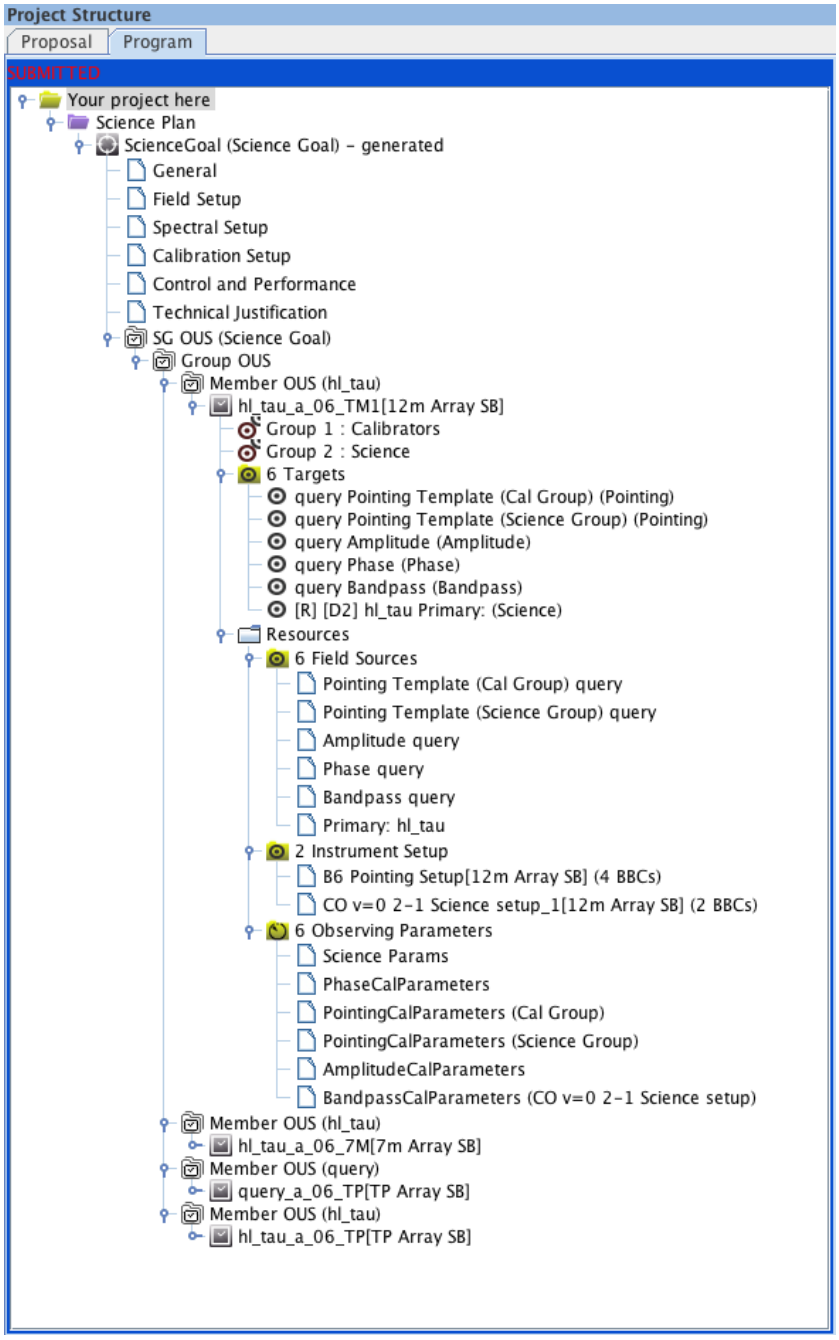

Figure 6.1: An example of a typical project structure. This contains a single Group OUS, but multiple Memeber OUSs for 12-m, 7-m and TP SBs. All but the first SB have had their structure hidden.

The Targets themselves reside in their own folder and clicking on this will reveal a table listing various properties of each (Figure 6.2). Clicking on a Target will highlight the Resources that have been used to create it and will also show the Forms editors for each Resource together in the Editors panel. This takes up a lot of space and the OT should normally have its size maximised. A Target is created by either right-clicking on the SB or Targets folder and selecting the appropriate option, or via the Edit menu.

Editors

SourceName	RA	Dec	PatternType	Transition	RestFrequency	ReceiverBand	#BBC	Sensitivity Goal	Calibrator
HD163296	17:56:21.287	-21:57:21.880	rectangle		231.276914131...	ALMA_RB_06	4	0.5 mJy	
J1820-254	18:20:57.850	-25:28:12.580	point		230.53798 GHz	ALMA_RB_06	1		Phs
NRAO530	17:33:02.710	-13:04:49.550	point		100.0 GHz	ALMA_RB_03	1		Pnt,Fcs
NRAO530	17:33:02.710	-13:04:49.550	point		230.0 GHz	ALMA_RB_06	1		Amp
NRAO530	17:33:02.710	-13:04:49.550	point		230.53798 GHz	ALMA_RB_06	2		Bnd
HD163296	17:56:21.287	-21:57:21.880	rectangle		230.53798 GHz	ALMA_RB_06	4	0.5 mJy	

Figure 6.2: Summary table shown when clicking on the Target folder. Each Target is shown along with some key properties.

Freshly-created Targets are initially empty and their Resources need to be added. This can be done in two different ways, the most convenient of which is to view the Target via the Editors window. This will show three panels, for each of which an already defined Resource can be reused, or a new Resource created. If the latter is chosen, the newly-created Resource will need to be opened and the necessary information filled in. The second method is to attach and detach the Resources via right-clicking on the Target. This brings up a dialogue box that shows all the pre-existing Resources in a column on the left, three of which need to be moved into the right column. Resources can also be independently created by clicking on the various Resource folders.

Each Target can only contain a single Field Source and Instrument Setup. It is technically possible to attach multiple Observing Parameters – some sources might be used for multiple calibrations for example – but this should not be done as the observing scripts cannot currently deal with this.

In order for a project to validate, it is necessary that one of the Targets be marked as the Representative Target – this is indicated with a `[R]` at the beginning of the Target's name. Note also that the names cannot be changed by the user as they follow a fixed format incorporating the source name and the observing intent (as set by the Observing Parameter). Targets without the three necessary Resources will cause a validation error.

6.2.4 Resources

A Resources folder contains three sub-folders, each of which contains the various instances of the individual Resources required to create a Target i.e. Field Sources, Instrument Setups and Observing Parameters. Clicking on each of these sub-folders will reveal a summary table of the currently-defined Resources and right-clicking will allow new Resources to be added.

6.2.4.1 Field Source

A Field Source form looks very similar to the Field Setup form of a Science Goal (Section 5.3.2), the source position, proper motions, etc., being displayed in the first panel. However, where in a Science Goal it is only possible to define a rectangular mapping area or a set of single pointings, more options exist within an SB. Reference (offset) positions can be defined e.g. for atmospheric calibrations, and a number of field patterns can be selected.

An extremely important difference between the two is that within an SB it is possible to define a Field Source *query* (Figure 6.3). Here, instead of a specific source definition, this conducts a cone search around a position at the time of observation using the ALMA calibrator database. This is extremely useful as, at the time of SB creation, it is not normally known when the observations will be observed and therefore the positions of planets relative to the science target and the brightness of most calibrators are also highly uncertain. Any Field Source can be converted to a query by ticking the box in the Query Status (topmost) panel, and vice versa. In addition, this interface can be used to convert a dynamic calibrator (query) to a fixed calibrator by using a very similar interface to the Calibrator Selection Tool that is described in Section 7.5.

Reference positions are used during observations in order to integrate on a patch of sky that is usually devoid

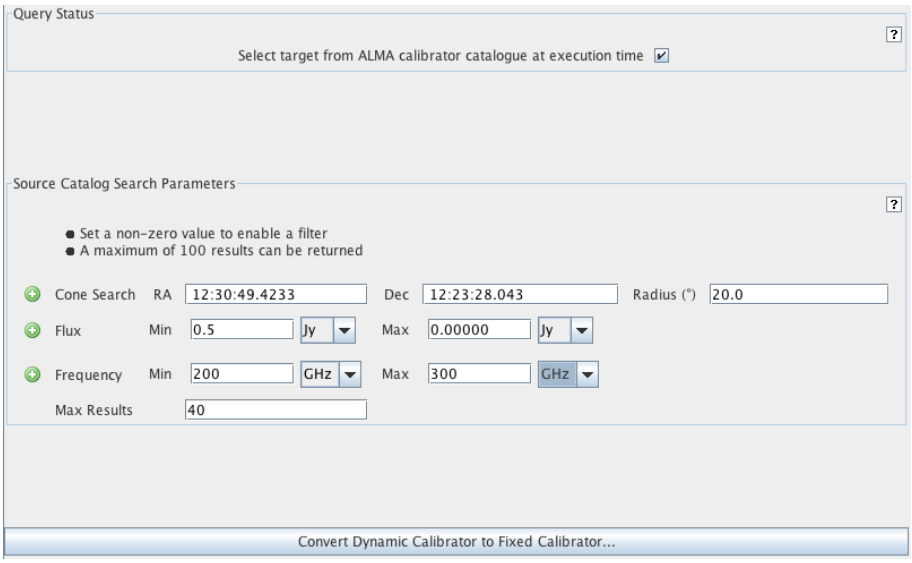

Figure 6.3: Example of the query interface for a Field Source. This is for the phase calibrator and the source coordinates have been entered automatically by the generation. Unticking the button at the top would return this form to the fixed source format used in a Science Goal. The bar at the bottom also allows a fixed source to be chosen from the ALMA calibrator database.

of significant emission. When measuring $T_{\rm sys}$, for example, a bright source will significantly add to the power detected by the antenna and increase the measured $T_{\rm sys}$. It is therefore usual to offset the antenna by a few arcmin in order to avoid the source. When observing Jovian or Saturnian satellites, the offset should be made bigger so as to ensure that the planet isn't observed by accident. Single-dish OTF mapping also requires an offset position so that the effects of changing atmospheric emission during the observations can be calibrated out. The ability to add a reference position to a Field Source is not possible for all observing intents e.g. pointing. The scanning used for the offset positions can currently only be done using equatorial i.e. J2000 and horizon coordinates. There are long-term plans to add Galactic to the list of supported systems. It does not appear that absolute offset coordinates are currently supported.

Of the various field patterns that it is possible to define, not all are currently supported. "Point" and "rectangle" are the most commonly used options and "fill" is now used for fast mapping of the Sun. The inputs for all options lie in the subsequent panel and change depending on which pattern is picked. Any observation that involves integrating when the telescope is not moving i.e. *not* OTF mapping, should use the point definitions. Each position in the table will be observed sequentially by the observing script, each for the subscan duration, before the total requested integration time for the source is reached. If necessary, the script will return to the first source in the list and continue. As it is usually the case that equal sensitivity is required per pointing, the total integration time should be set so as to ensure that each pointing is observed the same number of times. For SBs that have been generated from a Science Goal, the original rectangle definition will have been converted to a list of pointings for the ALMA 12-m and ACA 7-m antennas. Similarly, it is possible to convert a rectangle definition in the SB to multiple pointings.

6.2.4.2 Instrument Setup

By far the most complicated entity within an SB is the Instrument Setup. It defines a large number of parameters to do with the tuning and correlator configuration and must do this for both the 64-input and ACA Correlators, the parameters for which are not identical. As a consequence, it is beyond the scope of this document to describe all the entry fields in detail, although concise descriptions of each can be found in the ALMA OT Reference Manual. Help is also available from the ALMA Technical Handbook and the OT itself through its tooltips and validation. Finally, creating an Instrument Setup from scratch will set many of the parameters to reasonable defaults.

The ultimate task of the Instrument Setup is to define the spectral windows that actually constitute the scientific data product i.e. their central frequencies, bandwidths, spectral resolution, etc. There are a large number of restrictions in how spectral windows can be arranged and, as the OT is aware of these, automatic generation from a Science Goal should always produce a complete Instrument Setup that requires very little editing. The Visual Spectral Editor (Chapter 9 provides invaluable guidance when creating setups, as it shows the spectral windows, basebands and sidebands in a graphical format.

Starting at the top of the Instrument Setup form, the various components will now be briefly described. Fortunately, the ACA and 64-input Correlator inputs are similar enough that they can be dealt with together. The first panel of any real interest is the third one as it defines various time parameters – these are the integration duration (separation between data points in the science data) and the channel average duration (the same, but for the channel average regions – see below). Additionally, for the 64-input Correlator, a dump duration must also be defined. Of the Walsh function options, 180-deg switching is usually enabled, but 90-degree switching is only used when separating the sidebands at bands 9 and 10.

Next are the basebands, up to four of which can be created. Each defines a 2 GHz-wide signal that is subsequently sampled by the spectral windows that constitute the actual data. The main user inputs are the *desired* centre frequency of the baseband and the Doppler Reference. That the frequency is *desired* is, and apparently continues to be, emphasised because in general the actual observed frequency will differ from that requested, mainly because the value of the second local oscillator (LO2) is quantised. One notable exception is the creation of only one baseband as here the unquantised tuning ability of LO1 can be fully utilised. The actual frequencies are displayed after a tuning solution is requested using the "Calculate LOs 1 and 2" button (something that should always be done). It is possible to prioritise different basebands in the tuning solution using weights between 0 and 100, but these are probably always left at the default values of 100.

During the tuning process, the Doppler Reference tells the OT (and the telescope control system) how to interpret the baseband frequencies that are being passed to it and has three options: topo, rest and LSRK. Topocentric means that any source velocity relative to the telescope is ignored and therefore that the requested frequencies are those that will be observed, subject to any of the quantisation issues mentioned in the previous paragraph. This is commonly used for continuum and some calibration observations, such as pointing. Probably the most common choice will be to enter rest frequencies, the source velocity in this case being used to calculate the observed frequencies in the frame associated with the velocity e.g. LSRK, barycentric, heliocentric. However, as the OT does not know when the SB is going to be observed, it is not possible for it to make the final corrections for Earth motion relative to this frame. Similarly, the final choice (LSRK) assumes that the frequencies are already referenced to the local kinematic standard of rest, but that the final Earth Doppler corrections need to be made (the source velocity is therefore ignored, as with topo).

That the Earth Doppler corrections can only be made at run time therefore means that, if Doppler Reference has been set to rest or LSRK, the frequencies in the OT are generally not those that will be used during SB execution. Therefore, it is possible that, although the OT can find a valid tuning solution, this might not be the case when the SB is actually run, either because a baseband is very close to the edge of a band, or because basebands are close to the edges of their sideband (a negative velocity correction would push the basebands away from each other and possibly exceed the total width of the sideband, which is not allowed). As a check on this possibility, the OT will not only calculate a tuning for the requested source velocity, but also for this velocity plus and minus 32 km/s (unless the Doppler Reference is LSRK in which case the velocity is taken as zero). If the additional velocity component results in no valid tuning solution being found, the OT will issue a warning.

Lastly, spectral windows must be added to the basebands. A fundamental property of a baseband is the correlator mode that will be used to produce its spectral windows. A different mode can be chosen for each baseband by setting a bandwidth, number of channels, polarization products and, for the 64-input Correlator only, the number of bits and whether the data are sampled at Nyquist or twice-Nyquist rate. Currently, only 2-bit Nyquist sampling is allowed, but the other parameters are pretty flexible. The other parameters of a spectral window include the smoothing function to apply (Hanning is the default) and the correlator averaging factor. It is highly recommended to use the latter as this greatly reduces the data rate (which is reported for each baseband – the summed value is also given) and volume. ALMA is designed to operate with an average data rate of 6 MB/s and projects that require much more than this should be particuarly explored to see if spectral averaging is appropriate. As well as the average data rate limitation, there is also an absolute maximum that is allowed (70 MB/s) and this will cause a validation error if exceeded. Up to 10 spectral averaging regions can

also be defined – these define sub-windows that are averaged to a single channel and also appear in the ASDM.

The position of the spectral windows within the baseband is set by the Center Offset Frequency, where 3000 MHz refers to the centre of the baseband. This value is quantised and must be a multiple of 30.517578125 kHz for the 64-input Correlator and, for the ACA Correlator, a value which depends on the correlator mode that has been selected. Fortunately, the OT provides a button that will adjust an entry to the nearest legal value. Values that place any part of the spectral window outside of the 2 GHz-wide baseband are not allowed. As with basebands, the spectral windows are summarised in an editable table, but the complete parameter set can only be accessed from tabs below.

Both correlators are designed such that there can be multiple spectral windows per baseband – these use the so-called multi-region and multi-resolution modes. The latter is yet to be commissioned and therefore every spw in a baseband must currently have the same spectral resolution (before any spectral averaging is taken into account).

6.2.4.3 Observing Parameters

The final Resource essentially ascribes to the Target an "intent" i.e. it states the purpose of the Target in the observation. Most of the possible intents are for calibration and a large number are available (amplitude, bandpass, phase, etc.). Also available is the Resource for observing the science target. In general, each has a different set of parameters. All calibrators include a cycle time which instructs the observing script to repeat the scan after that much time has elapsed since the last observation of that Target. In this way it is not necessary to define a Target for e.g. each phase calibrator scan – the observing script will take care of this.

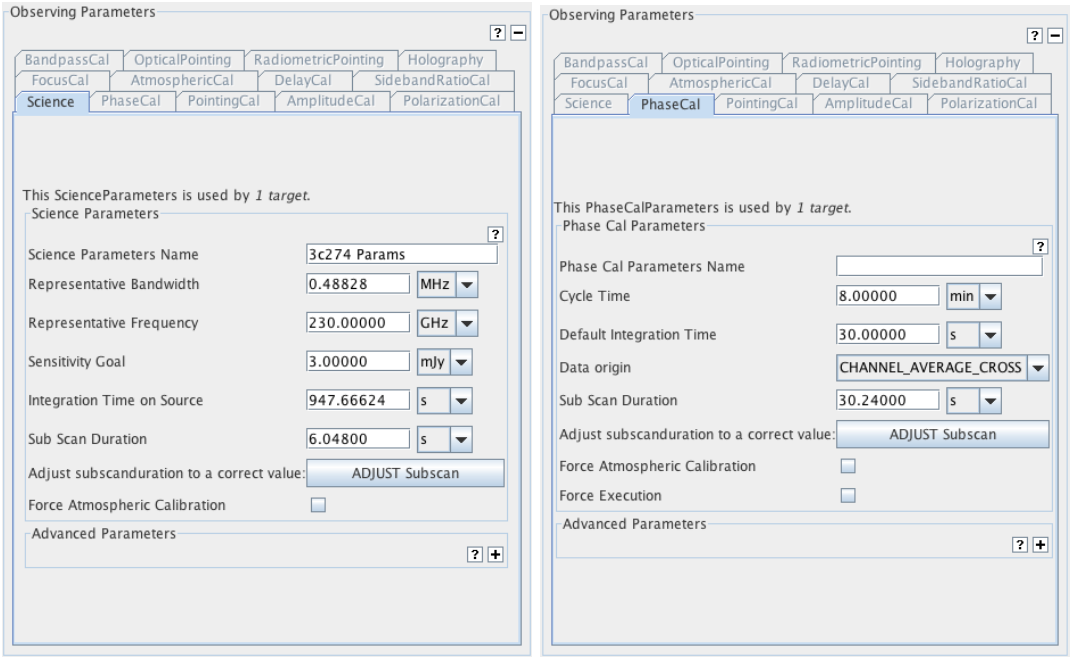

Figure 6.4: Examples of the Observing Parameters form for a science target (left) and a phase calibrator (right). The tabs at the top show all the observing intents that could be created.

The various integration times require some explanation. Most calibrators also define a default integration time which states how long an observation of a particular Target should last i.e. each scan of a phase calibrator Target will have this duration. The qualifier "default" recognises that there are other parameters (not currently used) that request a specific accuracy of calibration and that this might require more time depending on the conditions at the time of observation. Pointing calibrations are a little different in that the time spent is really set by the subscan duration – this defines how long is spent observing each position within the pointing pattern.

For other calibrators and the science target, the subscan duration sets the longest interval that the telescope

should continuously integrate for before writing to disk. Its maximum length is essentially set by memory issues and, for a commonly-used value of ∼30 seconds, a 1-min phase calibrator scan will contain two subscans. Unfortunately, the subscan must be a multiple of the correlator's dump duration and this is often an awkward number such as 1.008 sec. Fortunately, the OT provides a button that will convert a round number, such as 30 sec, to the nearest multiple e.g. for a dump duration of 1.008 sec, a subscan duration of 30.24 sec would result. There is a software overhead associated with each subscan so their number should be minimised. When setting integration times and subscan durations, it is important to realise that once a subscan has started, it will run to completion. Therefore, a subscan duration of 30.24 sec and an (admittedly unlikely) integration duration of 61 sec will cause three subscans to be executed and result in 50% more data than expected. For science observations the subscan duration also sets the amount of time spent observing each position within a mosaic pattern or each strip of an OTF raster scan.

For the science Observing Parameter, there is also an integration time parameter, but unlike the calibrator intents, this refers to the total time observed over the course of the SB's execution, and not to the length of individual visits to that source. Therefore, an SB will continue until each science target in an SB has been observed for the requested amount of time. Also contained within the science Observing Parameter are fields (desired sensitivity, Representative Frequency and Representative Bandwidth) that could potentially be used by the scheduling software to derive the time required at the time of observation. This is useful because the integration time requested will normally be an estimate based on a fixed value of the precipitable water vapour (PWV) – observations will rarely be carried out in these exact conditions, not least because the PWV can be extremely variable. However, these parameters are not yet used and so a definite time must currently be provided.

Whilst the OT provides a lot of control information regarding the execution of a SB, it is the observing script that ultimately decides what should be observed when. For example, the script may decide that, even though an amplitude calibration scan is included in the SB, this is not necessary due to one taken during a previous execution of the SB remaining valid. The Observing Parameters make it possible though to override this behaviour and force an execution of a calibrator. Similarly, an atmospheric calibration scan can be forced for every execution of a Target.

6.2.5 Observing Groups

In order for a Target to be observed, it must be placed into an Observing Group (OG). These give a user more control over how an observation will be conducted as each OG is observed once in the order that it appears. Within each OG there is also some ordering in that, if there are multiple versions of a particular calibration intent (and yet only one will be observed) the observing script will give precedence to the first instance of that calibrator type that it finds within the OG. The script though does set the order of each calibrator type, with bandpass preceding amplitude regardless of their order in the OG.

Group 1 is used for calibrators and should normally include Targets for bandpass and amplitude (flux) plus associated pointing observations. Group 2 should contain the science targets as well as the phase calibrators. Sources are placed into groups by clicking on the OG folder and copying the defined Targets listed in the left-hand column into that on the right (Figure 6.5). If the order of the OGs needs to be changed, this can be done using a panel in the top node of the SB.

Included in the table is a column for marking which science source should be used as the Doppler Target. This tells the telescope control system which source's velocity to use when calculating the observed frequencies and thus the tuning setup. Whichever source is selected is marked with a `[D]` in the Project Tree.

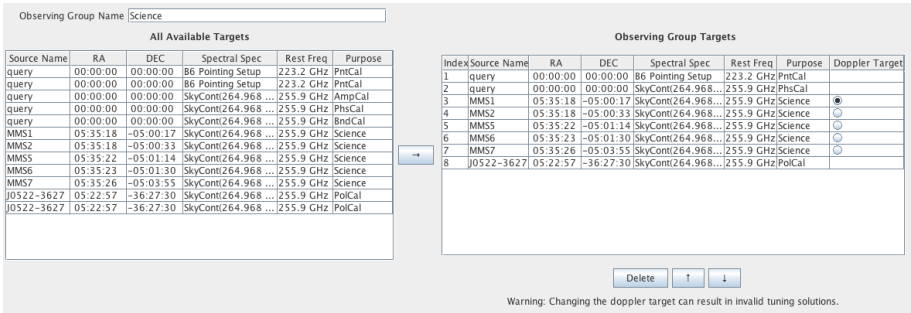

Figure 6.5: The Observing Group editor. The table on the left lists the already-defined Targets that could be placed into this Observing Group, this being done by moving them into the table on the right. The order of the chosen Targets can be changed using the up and down arrows and are removed from the Group via deletion.

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Chapter 7

Tools

7.1 The ALMA Template Library

The ALMA Template Library (Figure 7.1) provides a set of Science Goals that cover different proposal types. Once opened (via the File or View menus), the Science Goals within can be inspected and sections copied and pasted (or dragged and dropped) into a proposal's Science Goal. Alternatively, a complete Science Goal can be copied into a proposal and then edited as normal. A user's own projects can also be used as templates and are opened as such (in read-only mode) from the File menu.

The Template Library has not been updated since Cycle 5 and as such is currently disabled.

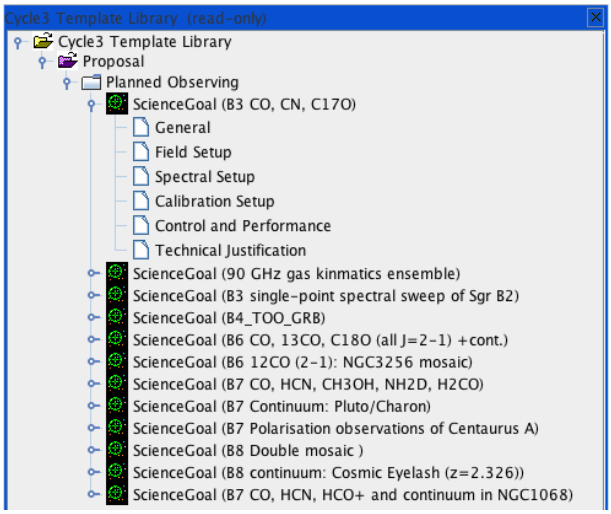

Figure 7.1: The ALMA Template Library.

7.2 Sensitivity Calculator

The ALMA Sensitivity Calculator is most easily accessed via the obvious icon in the toolbar. It 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. An identical version is available as an applet in the Science Portal.

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

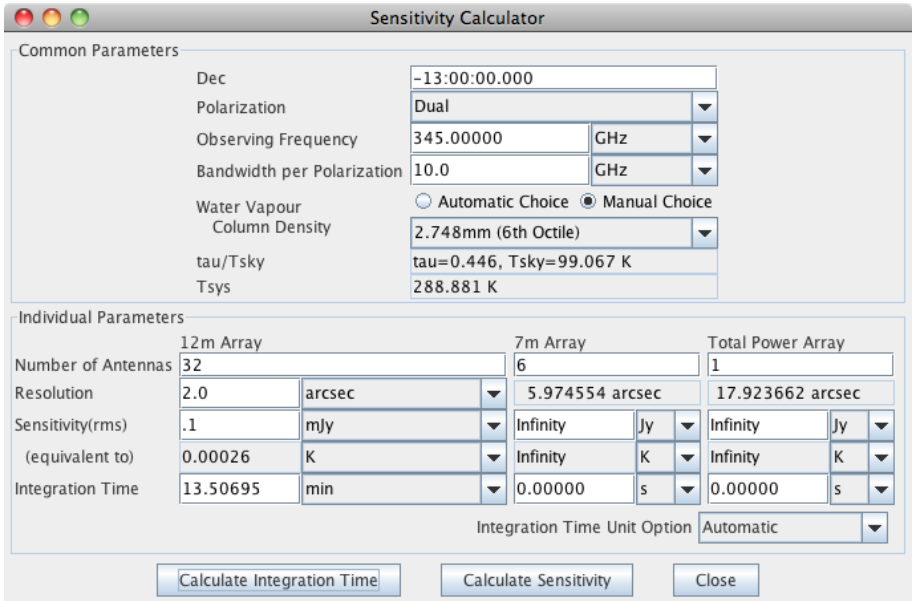

Figure 7.2: The ALMA Sensitivity Calculator.

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 7.2.

In the GUI, 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 7 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.

7.3 Spectral Line Picker

This tool allows a user to search the Splatalogue[1], a database containing millions of spectral-line transitions. A subset of the Splatalogue is packaged with the Observing Tool, which should be sufficient to select some of the most commonly targeted transitions, even when working offline. If network connectivity is available, access to the complete catalogue becomes possible using the online search functionality of the tool.

The tool is available either when creating a Spectral Setup in a Science Goal (see Section 5.3.3) or an Instrument Setup in a Scheduling Block (Section 6.2.4.2). In both cases, the selected transitions can be used to define observed frequencies as well as being available to overlay on the Visual Spectral Editor. In addition, a

[1] https://splatalogue.online

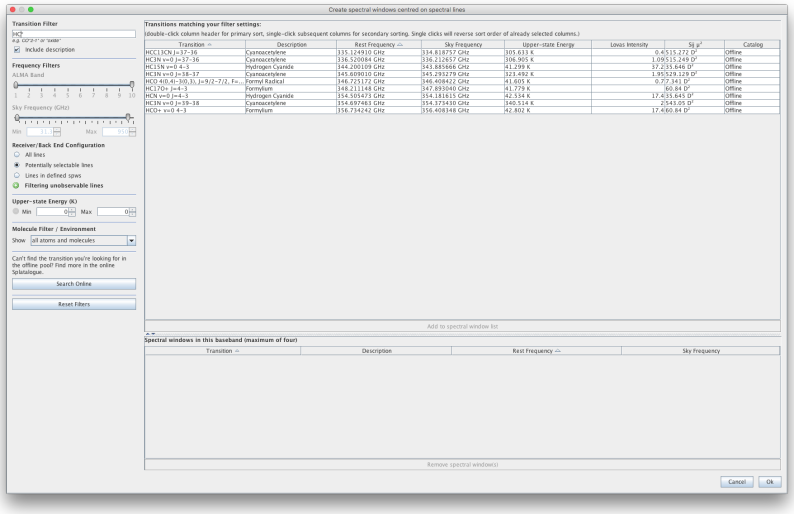

Figure 7.3: The ALMA Spectral Line Picker.

separate instance of the tool on the spectral-setup page of a Science Goal allows rest frequencies to be defined (Section 5.3.3.12).

When the transition selector dialogue box is launched, the offline spectral line catalogue is displayed and every transition in the catalogue is available for selection. Specific transitions can be located by using the controls in the left-hand 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 dragging the range sliders or 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). Note that the frequency slider refers to sky frequencies (these are calculated using the velocity of the first source in the Science Goal). Double-clicking on the column headings will cause the table to be sorted according to the values in that column (large triangle) and clicking a subsequent column will cause a secondary sort (small triangle). The triangles indicate the direction of the sort and subsequent single clicks will reverse this.

If a desired line cannot be found in the offline catalogue, it may exist in the more extensive online catalogue. The online catalogue can be queried by clicking the "Find More..." button; the query will use the species filter and the frequency limits only and wildcards are not allowed. **The results of the query will be added to the list of selectable transitions, and will persist as part of the offline database for the rest of the observing tool session.**

Having located a target transition, it can be copied into the table of selected transitions by selecting it and clicking the obvious button, or simply by double-clicking. When creating a spectral setup, only one line can be chosen at a time. However, when overlaying, multiple lines can be copied simultaneously into, and removed from, the table of selected transitions, by highlighting multiple rows. Closing the tool using the "OK" 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.

Absent is a filter to ensure that basebands for 2SB receivers (Bands 3–8) are only created in pairs. For these receivers both baseband pairs must either be in the same sideband or one can go in LSB and the other in USB. This may be added in the future.

7.4 Archive Search Tool

In order to retrieve a project from the ALMA archive, the OT provides an Archive Search Tool. This is started most conveniently from the toolbar, but can also be accessed from the File menu. This brings up a fairly straightforward dialogue box that is shown in Figure 7.4. Projects can be searched for in various ways, for example using the project code or the user's ALMA username. If a user's credentials have already been entered into the Preferences menu, there will also exist shortcuts to show all the projects belonging to the current user and, if the user has sufficient privileges, all users. Only one search field is active at any one time and all fields are case-insensitive and perform partial matches.

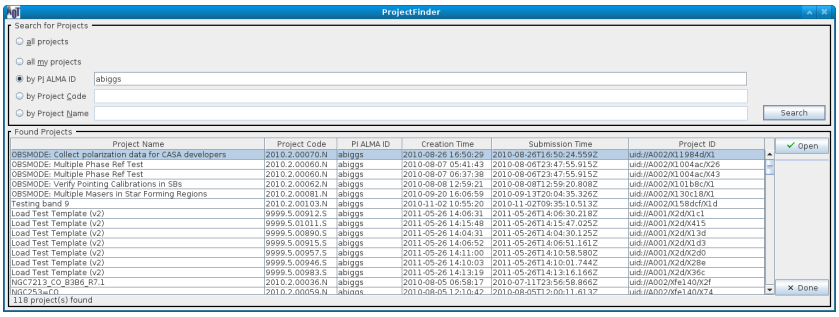

Figure 7.4: The Project Finder dialogue box for searching for projects in the ALMA archive.

7.5 Calibrator Selection Tool

Calibrators can be added to both Phase 1 proposals and Phase 2 programs using a standard calibrator search tool, although the details of how this works differs slightly in the two cases. Two catalogues can be searched: the full ALMA calibrator database that is searched online, or a much more limited version (smaller and not so up-to-date) that is contained within the OT and thus can be searched even in the absence of a network connection. The former is of course recommended and is the default. The internal catalogue is basically a snapshot of the SMA catalogue taken a few years ago and contains measurements at 3, 1 and 0.87 mm. The ALMA catalogue also contains these SMA data, but also VLA measurements at lower frequencies. Most importantly, new measurements taken with ALMA are now constantly being added.

The search interface is shown in Figure 7.5. 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, either the ALMA online catalogue or the internal OT catalogue

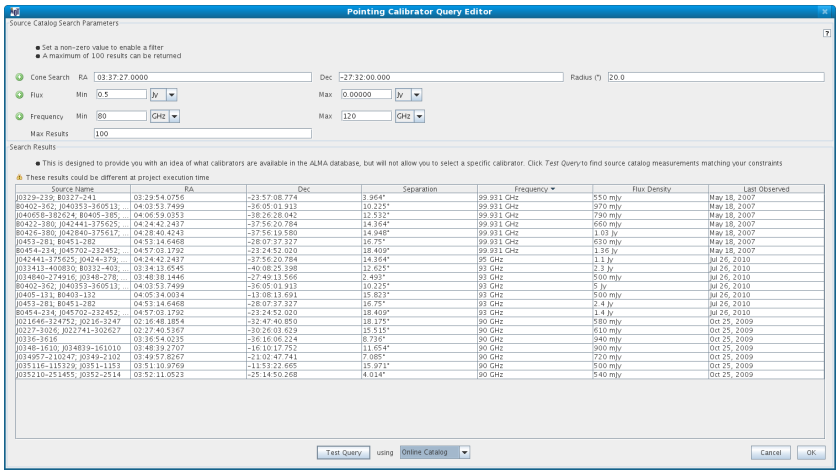

Figure 7.5: The Calibrator Selection Tool as used in the Calibration Setup of Science Goal. A search has been made for all calibrators within a 10-degree radius of a source position, that have a flux greater than 500 mJy in ALMA Band 3.

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.

The calibrator tool can be accessed in a number of ways. At Phase 1, it is only available when defining a user-defined calibration in a Science Goal. However, at Phase 2, it is also available from the Tool menu and from within a Field Source definition. In all cases, the search interface itself works identically, although the details of how a chosen source is used vary. Please consult the relevant sections of this manual for more information.

7.6 LO Configuration Tool

The LO Configuration tool is available from the Tools menu, but only if privileged operations are enabled. It is an interface to the algorithms used by the OT to generate tuning solutions. At its most basic, the centre frequencies of up to four basebands can be entered and a tuning solution (LO1 and LO2 frequencies) requested. Figure 7.6 demonstrates the use of this tool to derive a tuning solution for three basebands at Band 9. This tool only calculates the frequencies of basebands – the LO4 frequencies which determine where within the basebands the spectral windows lie must be separately calculated.

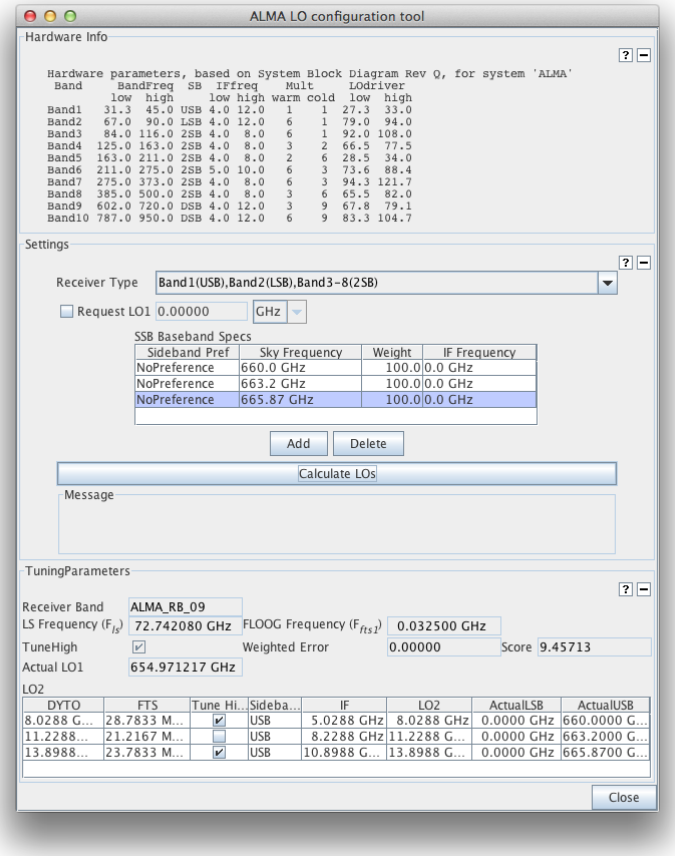

Figure 7.6: The LO Configuration Tool. Three Band-9 basebands have been requested with the tuning results shown at the bottom.

Chapter 8

The Visual Spatial Editor

The Visual Spatial Editor allows an image of the source that you wish to image to be loaded and can subsequently be used to determine where the telescopes should point, either by defining individual pointings or rectangular mapping areas. The information entered here will also appear in the Forms Editor that always accompanies the Spatial Editor i.e. it is not necessary to use the Spatial Editor to define any observation with ALMA, although it will greatly aid in setting up some observations.

The Spatial Editor is enabled by selecting the Spatial tab at the top of the Forms Editor when either of the following are selected:

- the Field Setup node of a Phase 1 or Phase 2 Science Goal (selecting the Science Goal summary view will also allow the Spatial Editor to be viewed)
- a Field Source in an SB (selecting a Field Source's Target will also allow the Spatial Editor to be viewed).

Whilst the Spatial Editor is identical in each case, the Forms Editor is somewhat different and is explained in detail in Section 5.3.2 (Science Goal) and Section 6.2.4.1 (Scheduling Block).

Note that use of the Spatial Editor can be enabled by default using the Preferences menu i.e. it will always be shown when a Field Setup or Field Source is selected.

8.1 Overview of the Graphical Interface

The Spatial Editor's graphical interface (Figure 8.1) uses libraries provided by the JSky project[1] and is dominated by a window for displaying images (in FITS format). In addition to this, there are also smaller windows for displaying the entire image (including a yellow square which indicates which portion of the entire image is displayed in the main window; this can be moved with the mouse) and another that shows the zoomed part of the image that is centred on the cursor position in the main window. Display of these is optional. The colourbar at the very bottom of the image can be used to change the image contrast by dragging the mouse within it – the contrast can be reset to the default with a right-click.

Above the image display there is a toolbar that can be used for various operations including loading and saving images, manipulating source and target positions and for setting the intensity cut level in the display. Zooming controls and positional information are located directly below the image window.

Below the image display and its menu and control buttons, the FOV Parameters and Image Query panels are visible (Figure 8.2). The former displays the value of the Representative Frequency (taking into account the source velocity) and allows the user to select which interferometric array's pointings to display, if there is a choice i.e. the 12- and 7-m arrays are required. Changing the source in the Forms Editor will change the Representative Frequency to the value appropriate to that source. The Image Query panel allows the image server and the size of the retrieved image to be specified.

[1] http://jsky.sourceforge.net/

A further feature of the graphical interface is the ability to measure the distance between two points within the image by right-clicking and dragging the mouse (Figure 8.1).

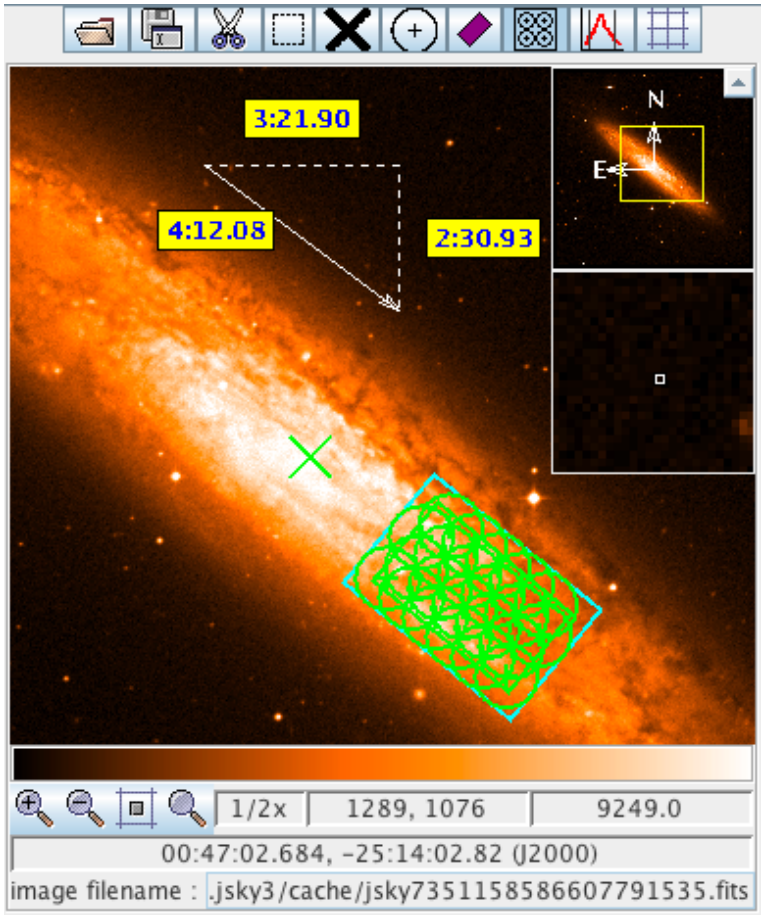

Figure 8.1: An example of the image display area on the Visual Spatial Editor. This shows a pointed mosaic observation of the outer reaches of NGC 253, the mosaic pointings having been automatically created based on a user-defined rectangle (green). The x-shaped cross at the centre marks the position of the coordinates given in the Forms Editor. As this is an observation that requires the ACA, also shown is the rectangular area (in blue) that will be mapped by the Total Power Array. Also shown is the ruler for measuring distances between points in the image.

8.2 Creating a Field Definition

An image can be loaded in one of two ways, either by loading a local one from disk using the image display's toolbar, 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 coordinates entered in the Forms Editor. These are indicated on the map by a green x-shaped cross which will move if the coordinates are changed. As of Cycle 6, Galactic coordinates are supported.

Once an image has been loaded, if any pointings or a rectangle were previously defined in the Forms Editor, they will appear on the image and can be edited with the mouse. 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). It is possible to change the definition using the Spatial Editor by clicking on the opposite definition on the toolbar i.e. by adding a single pointing when a rectangle has already been defined. A warning will be issued at this stage as the previous definition (size and orientation of rectangle, positions of all pointings) will be lost.

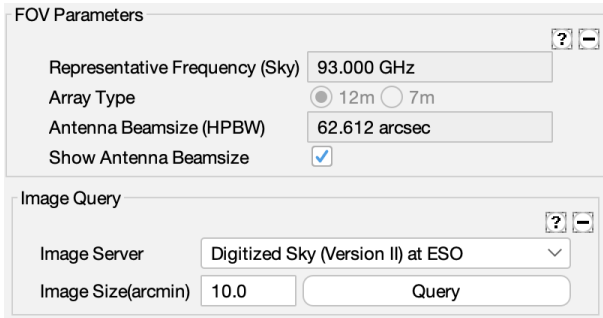

Figure 8.2: The FOV Parameters and Image Query panels in the Visual Spatial Editor.

As this implies, it is not possible to create a field definition that contains a mixture of single pointings and a rectangle.

An important part of the Spatial Editor 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 Editor.

8.2.1 Single Pointings

Multiple instances of single pointings can be added to the field definition by using the "Add a FOV" button on the toolbar 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. Once defined, pointings can be moved using the mouse or deleted. Clicking on a pointing will cause its background to become opaque - this indicates that this pointing has been selected and can, for example, be deleted using the scissors icon in the toolbar or moved by being dragged with the mouse. More than one pointing can be selected at any one time, either by using the rectangular selection button in the toolbar, or by holding down the Ctrl key whilst clicking on each pointing in turn. A subsequent dragging or delete operation will then apply to all pointings.

The pointings defined in the Spatial Editor are displayed in the Forms Editor where they can be edited or deleted.

8.2.2 Rectangular Areas

Instead of one or more single pointings, it is possible to define a **single** rectangular area. This is used to automatically calculate a mosaic of pointings based on the antenna spacing that is entered in the Forms Editor. This is usually set to some fraction of the antenna beamsize and Nyquist is the appropriate choice in nearly all cases and also the default. Once a rectangle has been defined, either with the mouse or with the fields in the Forms Editor, it can be manipulated further by clicking on the coloured boxes - the green box rotates and the blue boxes resize. Furthermore, the rectangle can be moved by clicking and dragging anywhere in its vicinity.

The mosaic pattern is not currently drawn by default and so the appropriate button in the toolbar 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 Forms Editor - as the spacing is usually a function of antenna beamsize, the mosaic patterns will therefore be different for the two arrays. For Phase-I proposals, it is probable that a limit on the number of pointings has been set for the current ALMA cycle and defining too many will result in a validation error that will prevent the project being submitted.

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.

8.2.3 Offset Versus Absolute Coordinates

When a pointing area is created using the Spatial Editor, 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 Forms Editor 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 Editor!

Chapter 9

The Visual Spectral Editor

The Visual Spectral Editor 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.). The spectral window information entered by the user is also visible as the Forms Editor always accompanies the Spectral Editor i.e. it is not necessary to use the Spectral Editor to define any observation with ALMA, although it will greatly aid in setting up some observations. It is strongly recommended that a spectral setup is always checked in the Visual Spectral Editor.

The Spectral Editor is enabled by selecting the Spectral tab at the top of the Forms Editor when either of the following are selected:

- the Spectral Setup node of a Phase 1 or Phase 2 Science Goal (selecting the Science Goal summary view will also allow the Spectral Editor to be viewed)
- an Instrument Setup in an SB (selecting a Instrument Setup's Target will also allow the Spectral Editor to be viewed).

The Forms Editor for spectral setups is explained in detail in Section 5.3.3 (Science Goal) and Section 6.2.4.2 (Scheduling Block).

Note that use of the Spectral Editor can be enabled by default using the Preferences menu i.e. it will always be shown when a Spectral Setup or an Instrument Setup is selected.

9.1 Overview of the Graphical Interface

The Spectral Editor's graphical interface consists of two frequency axes, one above the other, with the space in between used to display various features of interest. The two axes themselves show the features in observed and rest frequencies, depending on the source velocity. The display can be zoomed using mouse clicks (left-click: zoom in, right-click: zoom out) or the scroll wheel, the zoom being centred at the location of the mouse pointer (magnifying glass symbol). Once the display has been zoomed, it can be panned by grabbing one of the horizontal green bars that appear whenever the mouse is somewhere within the graphical area. Additional zooming and panning controls are located below the graph, as well as a number of other controls.

Just below the observed frequency axis are hatched areas that show the available receiver bands. These are displayed in grey, apart from the currently-selected receiver band which is coloured 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 of the first local oscillator (LO1).

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[1] 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 Forms Editor, 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 7.3.

9.2 Viewing a Spectral Setup

The main purpose of the Spectral Editor is to allow the spectral setup to be viewed against the background of the transmission curve and available spectral lines. The spectral windows themselves must be defined using the Forms Editor as it is not possible 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 Editor, the exact details of what can be displayed depending on whether a Science Goal or a Scheduling Block is being viewed.

9.2.1 Science Goal

After defining spectral windows in the Forms Editor, these will appear in the Spectral Editor (Figure 9.1) 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 have been 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.

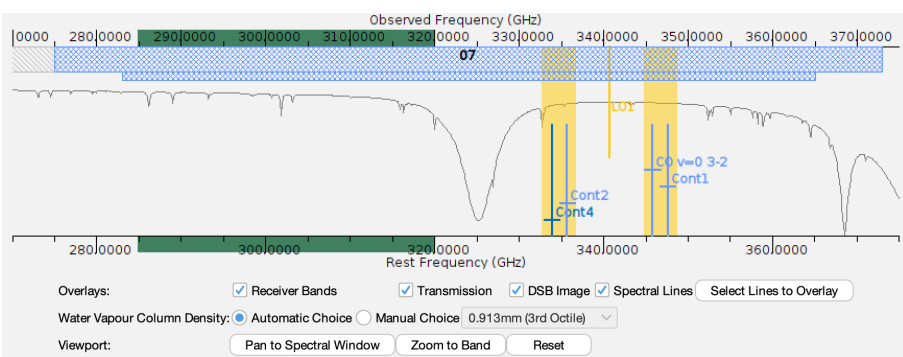

Figure 9.1: The graphical representation of the frequency information in a Science Goal. Four spectral windows are shown, a narrow one to observe the CO(3-2) transition and three other maximum-bandwidth ones for measuring a continuum. All four fit within the sidebands which are coloured yellow (as opposed to grey) to signify that a valid tuning solution has been found. The displayed transmission curve has been set to a value (3rd octile) appropriate for the frequency being observed. Also visible are the various controls as well as the green bars that must be grabbed to pan the display.

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

For experimentation purposes, it is possible to move the sidebands by dragging the LO1 marker, but as soon as the mouse is released, the sidebands will return to their original position. This is because the ALMA tuning solution is calculated by an algorithm that takes the spectral window frequencies and bandwidths as input i.e. the value of LO1 is not settable by the user. If no valid tuning solution exists, the sidebands will stay where they are when released, but remain coloured grey.

The Targets panel in the Forms Editor 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.

9.2.2 Scheduling Block

The graphical display in an SB is similar to that of the Science Goal, but shows more features of the spectral setup that is displayed/defined in the Forms Editor and allows more control over what is displayed (Figure 9.2).

The key features that are visible in an SB, but not in a Science Goal are the basebands and the spectral averaging regions. As this is a lot of information to display, what is shown depends on the level of zoom that is being used. At low levels of zoom, only the sidebands and the basebands are visible. Further zooming in will also show the spectral windows contained within each baseband, as well as the spectral averaging regions of each spectral window.

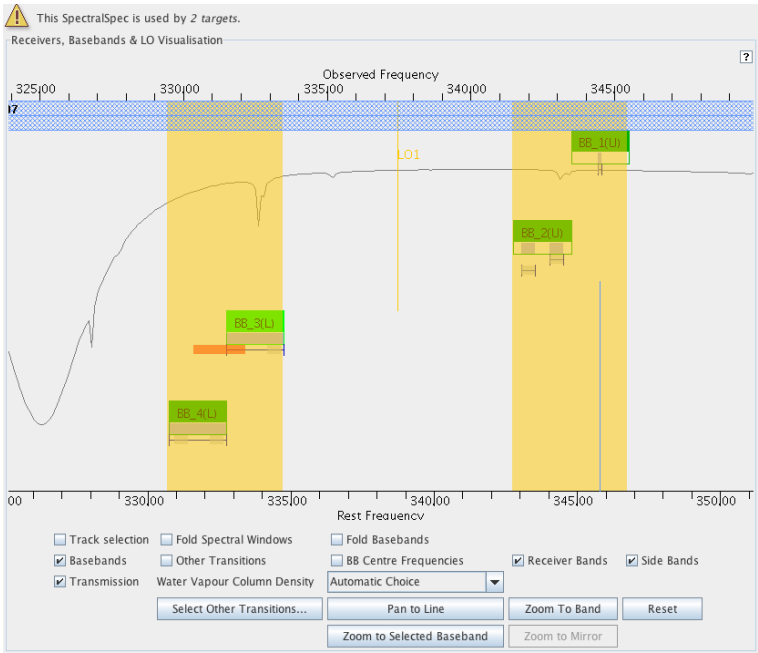

Figure 9.2: The graphical representation of the frequency information in a Scheduling Block. This is a zoomed view and hence the spectral windows and their spectral averaging regions can be seen. The basebands are shown as the green blocks and within these can be seen the spectral windows (horizontal bars). Below the basebands are the spectral averaging regions (also horizontal bars). Note that there are two spectral windows in Baseband 2, each with a single spectral averaging region. Baseband 3 contains a spectral averaging region which extends out of the spectral window and has thus been coloured orange to signify a problem.

Unlike in a Science Goal, it is possible to move the sidebands and LO1 using the mouse and this will even update the value of LO1 displayed in the Forms Editor. However, this will again be ignored when the observations are performed as the ALMA Control system will derive its own tuning solution using the spectral

window frequencies passed to it by the OT.

Whilst most of the controls are self-explanatory, the following are worth mentioning briefly. Checking `Fold Basebands` and `Fold Spectral Windows` allows the tool to use less vertical space, whilst `Track selection` results in which ever baseband is selected in the Forms Editor to be shown zoomed.

Source velocities are slightly tricky in the context of the Spectral Editor in a Scheduling Block. If the Spatial Editor is being viewed inside a Target, then things are simple and the velocity of that source will be used. However, if viewing the graphical display from within an Instrument Setup, this can potentially be attached to multiple Targets and therefore different sources. For calibrator Targets, these will use the velocity of the source contained in the Representative Target. For science Targets, the first source in the Field Sources folder which is attached to a Target will be used. However, regardless of which velocity is used, its value and the source it is taken from is displayed in the Forms Editor, just below the `Calculate LOs` button.

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. These can be used in either Science Goals (Section 5.3.2.1) or Scheduling Blocks (Section 6.2.4.1). 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 or SB.

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.