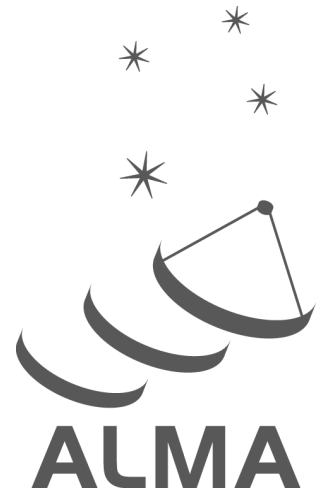


# ALMA Observing Tool User Manual

Andy Biggs, Rein H. Warmels



[www.almascience.org](http://www.almascience.org)

---

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

## User Support:

For further information or to comment on this document, please contact your regional Helpdesk through the ALMA User Portal at [www.almascience.org](http://www.almascience.org). Helpdesk tickets will be directed to the appropriate ALMA Regional Centre at ESO, NAOJ or NRAO.

## Revision History:

---

Version	Date	Editors
0.5, Ver. 1.0	March 2011	Rein Warmels
0.5, Ver. 1.1	August 2011	Rein Warmels
1.5, Ver. 1.0	May 2012	Rein Warmels
1.5, Ver. 1.1	October 2012	Andy Biggs
1.5, Ver. 1.2	February 2013	Andy Biggs
1.5, Ver. 1.3	February 2013	Andy Biggs
2.5, Ver. 1.0	October 2013	Andy Biggs
3.5, Ver. 1.0	March 2015	Andy Biggs

---

## Contributors

The ALMA OT Team, and the many Testers.

In publications, please refer to this document as:

**OT User Manual 3.5, Version 1.0**

---

# Contents

<b>1</b>	<b>Introduction</b>	<b>5</b>
1.1	How to Use this Manual . . . . .	5
1.2	User Support . . . . .	6
1.3	Release Information . . . . .	6
1.4	Credits and Acknowledgements . . . . .	6
<b>2</b>	<b>Install and Run the Observing Tool</b>	<b>7</b>
2.1	Hardware and Software Prerequisites . . . . .	7
2.1.1	Java Software . . . . .	7
2.1.2	Supported Platforms . . . . .	7
2.1.3	Disk Space Required . . . . .	8
2.2	Using the OT with Java Web Start . . . . .	8
2.2.1	Verifying Java Web Start . . . . .	8
2.2.2	Starting the OT with Web Start . . . . .	8
2.2.3	Running the OT offline . . . . .	9
2.3	Tarball Installation . . . . .	9
2.3.1	Installation . . . . .	9
2.3.2	Starting the OT . . . . .	10
2.4	Connecting Through a Proxy Server . . . . .	10
<b>3</b>	<b>Basic Concepts</b>	<b>13</b>
3.1	Phase-1 Proposals . . . . .	13
3.2	Phase-2 Programs . . . . .	13
3.3	Science Goals . . . . .	13
3.4	Observing Unit Sets . . . . .	14
3.5	Scheduling Blocks . . . . .	14
3.6	Project Submission . . . . .	15
3.7	Project Validation . . . . .	15
3.8	AOT files . . . . .	16
3.9	Project Conversion . . . . .	16
<b>4</b>	<b>Overview of the Observing Tool</b>	<b>17</b>
4.1	Help . . . . .	17
4.2	The OT Main Graphical Interface . . . . .	17
4.2.1	GUI Parameter Fields . . . . .	17
4.2.2	GUI Features . . . . .	18
4.2.3	Menu and Toolbar . . . . .	19
4.2.4	The OT Panes . . . . .	19
4.2.4.1	The Project Structure Pane . . . . .	19
4.2.4.2	The Editors Pane . . . . .	20
4.2.4.3	The Feedback Pane . . . . .	21
4.2.4.4	The Overview Pane . . . . .	21
4.3	OT Configuration . . . . .	21

<b>5</b>	<b>Phase 1 – Observing Proposal</b>	<b>23</b>
5.1	Open a Phase-1 Proposal	23
5.2	The Proposal Form	23
5.2.1	Adding Investigators	24
5.2.2	Scientific Case	24
5.3	Adding Phase-1 Science Goals	25
5.3.1	General	25
5.3.2	Field Setup	25
5.3.2.1	Sources	25
5.3.2.2	Resolving source information	26
5.3.2.3	Expected Source Properties	26
5.3.2.4	Field definitions	26
5.3.2.5	Import/Export of Source Information	27
5.3.3	Spectral Setup	27
5.3.3.1	Spectral Type	28
5.3.3.2	Polarization Products	28
5.3.3.3	Spectral Line – one spectral window per baseband	28
5.3.3.4	Spectral Line – more than one spectral window per baseband	29
5.3.3.5	Representative Frequency	30
5.3.3.6	Single Continuum	30
5.3.3.7	Spectral Scan	30
5.3.3.8	Multiple velocities and tuning solutions	31
5.3.4	Calibration Setup	31
5.3.5	Control and Performance	32
5.3.5.1	Imaging considerations: arrays and configurations	32
5.3.5.2	Sensitivity considerations	33
5.3.5.3	Time Estimation	33
5.3.5.4	Overriding the OT's time estimate	34
5.3.5.5	Time-constrained observing	35
5.3.6	Technical Justification	35
5.4	Summary Information	36
5.5	Proposal Validation	36
5.6	Proposal Submission	37
<b>6</b>	<b>Phase 2 – Observing Program</b>	<b>39</b>
6.1	Generation from Science Goals	39
6.1.1	Phase-2 Science Goals	39
6.1.2	Scheduling Block Generation	39
6.1.3	Manual creation	40
6.2	Observing Program Structure	40
6.2.1	Observing Unit Sets	40
6.2.2	Scheduling Blocks	40
6.2.3	Targets	42
6.2.4	Resources	42
6.2.4.1	Field Source	42
6.2.4.2	Instrument Setup	44
6.2.4.3	Observing Parameters	45
6.2.5	Observing Groups	46
6.3	Submit the Observing Program	47
<b>7</b>	<b>Tools</b>	<b>49</b>
7.1	The ALMA Template Library	49
7.2	Sensitivity Calculator	49
7.3	Spectral Line Selection Tool	50
7.4	Archive Search Tool	51
7.5	Calibrator Selection Tool	52

7.6	LO Configuration Tool . . . . .	53
<b>8</b>	<b>The Visual Spatial Editor</b>	<b>55</b>
8.1	Overview of the Graphical Interface . . . . .	55
8.2	Creating a Field Definition . . . . .	56
8.2.1	Single Pointings . . . . .	57
8.2.2	Rectangular Areas . . . . .	57
8.2.2.1	Science Goal . . . . .	57
8.2.2.2	Scheduling Block . . . . .	58
8.2.3	Offset Versus Absolute Coordinates . . . . .	58
<b>9</b>	<b>The Visual Spectral Editor</b>	<b>59</b>
9.1	Overview of the Graphical Interface . . . . .	59
9.2	Viewing a Spectral Setup . . . . .	60
9.2.1	Science Goal . . . . .	60
9.2.2	Scheduling Block . . . . .	60
<b>A</b>	<b>Create an External Ephemeris</b>	<b>63</b>
A.1	NASA resources for HORIZONS . . . . .	63
A.2	Instructions and Settings . . . . .	63
A.3	Example Ephemeris . . . . .	64
<b>B</b>	<b>Acronym List</b>	<b>67</b>

This page was intentionally left almost blank

# 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 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 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.

Instead, this manual attempts to give an overview of what is possible with the OT, 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, although the chapters that cover the tools and visual editors remain relevant. As normal users do not create Phase-2 programs themselves, Chapter 6 is more intended for expert users and observatory staff. The same applies to the Appendices that also cover special topics.

## 1.2 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:** <http://alma.mtk.nao.ac.jp/e/>

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>

## 1.3 Release Information

This version of the manual is intended to be used with the OT that will be used to create Phase-1 proposals for ALMA Cycle 3, either a one submitted at the standard deadline, or a Director's Discretionary Time (DDT) proposal that can usually be submitted once observing has begun. A completely separate version of the OT is currently available for the preparation of Phase-2 programs and DDT proposals for Cycle 2.

## 1.4 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.



## Chapter 2

# Install and Run the Observing Tool

The ALMA OT is written in Java and can be installed in two different ways, using Java Web Start and with a traditional tarball distribution. We strongly recommend the Web Start as it will ensure that you are running the latest available version of the OT by automatically downloading a new version if this is available. The tarball method involves more steps on the part of the user and any updates will need to be installed manually. In this chapter, both installation procedures will be discussed.

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<sup>1</sup> may also contain useful information via its Knowledgebase system. If a solution to a problem cannot be found, a user should then file a Helpdesk ticket.

## 2.1 Hardware and Software Prerequisites

### 2.1.1 Java Software

In order to use the OT, it should only be necessary that the computer in question has Java installed. Most computers have Java pre-installed, but if this is not the case, the latest version of Java (also known as the Java Runtime Environment or JRE) should be downloaded from <http://java.com/>. Regarding the version of Java, it is absolutely essential that Java 7 be installed, although Java 8 probably works okay. The currently installed version can be checked by typing `java -version` on the command line, the output of which should look something like this:

```
java version "1.7.0_71"  
Java(TM) SE Runtime Environment (build 1.7.0_71-b14)  
Java HotSpot(TM) 64-Bit Server VM (build 24.71-b01, mixed mode)
```

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

OpenJDK versions of Java such as IcedTea that are common on many modern Linux installations have proved problematic in the past and thus we recommend that the official release from Oracle be used wherever possible.

### 2.1.2 Supported Platforms

The OT should run on any machine that has an appropriate version of Java installed. This is because the JRE includes a Java Virtual Machine (JVM) which actually executes the platform-dependent OT code. Regular

---

<sup>1</sup><https://help.almascience.org/>

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.

### 2.1.3 Disk Space Required

To install the ALMA Observing Tool via Java Web Start or by unpacking the tarball requires approximately 100 MBytes – including Java makes the distribution somewhat larger. If Web Start is used, this space must be available in the location where your Java Web Start is configured to install downloaded applications. The default for this will be a subdirectory of your home space (Unix/MacOS/Linux) or in the profile area (Windows). In case of a tarball installation the disk space must be available in the location where the OT will be installed.

## 2.2 Using the OT with Java Web Start

Using Java Web Start is the recommended way of running the OT. This is because the first installation of the OT is usually easier and updates to the OT are automatically detected and installed.

### 2.2.1 Verifying Java Web Start

A Java installation should include Web Start by default and so does not need to be installed separately. The very first download of the Web Start version must take place through a browser and, although this will usually be correctly configured to launch Web Start when the OT is selected in the ALMA Science Portal, this may not always be the case. Linux users will often find that IcedTea is the default version of Java and this ideally should be changed. On Firefox, this is done via the Applications tab of the Preferences menu (Figure 2.1).

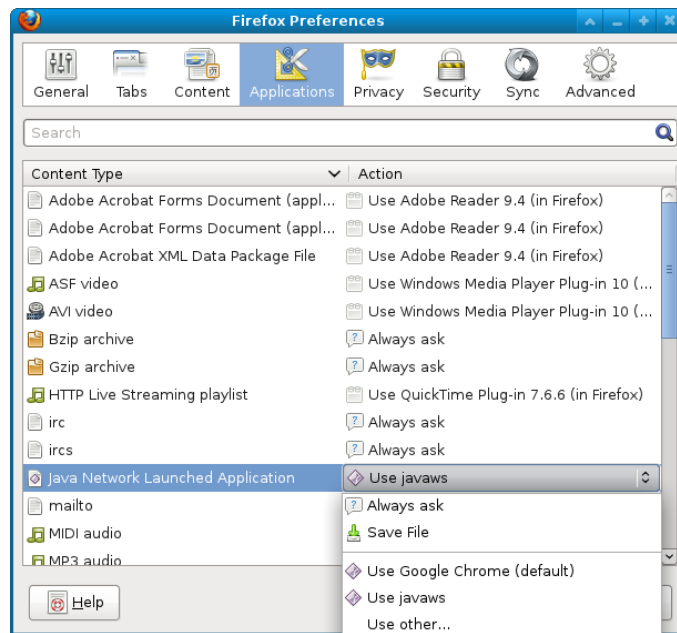


Figure 2.1: An example of the Applications menu in Firefox that can be used to change the version of Web Start used by the browser. This is for a Linux version of Firefox.

### 2.2.2 Starting the OT with Web Start

To download and run the OT with Java Web Start, please go to the ALMA Science Portal and navigate to the Web Start version of the OT. When the link is clicked, a `ObservingTool1.jnlp` file is downloaded by the browser

and opened by the Web Start executable `javaws` that lives in the Java distribution's `bin/` directory. At least, this is what will happen with a Linux distribution – the OT will start automatically, with the user only needing to confirm in a security dialogue that the OT should indeed be run (Figure 2.2).

On a Mac the situation is somewhat more complicated due to “Gatekeeper”, a feature introduced in OS X Lion which prevents malware from being installed. In its default setting the OT will not start as it is from an “unidentified developer”. The recommended solution is to view the `.jnlp` file in Finder (this can be done directly from the download menu in Firefox or Safari) and to launch the OT manually by right-clicking on the file and selecting Web Start from the “Open With” menu item. Alternatively, Gatekeeper can be switched off via the Security & Privacy section of System Preferences (allow applications from “Anywhere”) but this is not recommended.

The first time that the OT is run, it is quite likely that a shortcut will be created. This usually appears on your machine's Desktop, but Mac's often prompt for a location (choose Desktop!). Future sessions should be started by clicking on this.

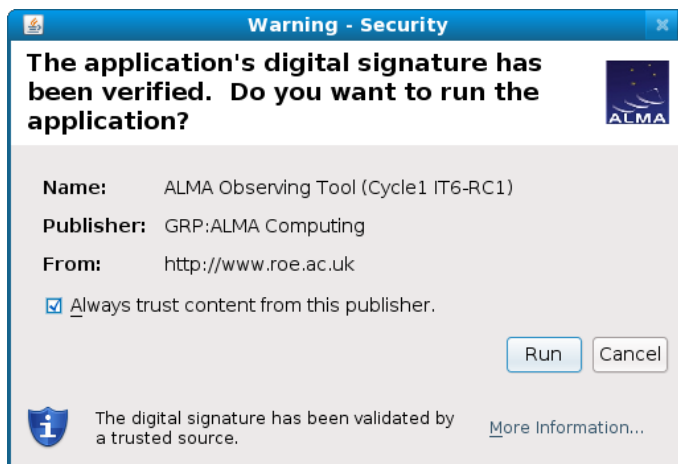


Figure 2.2: The dialogue that confirms that the OT is a trusted piece of software.

### 2.2.3 Running the OT offline

If you have downloaded the OT and wish to run the software later when not on the network or not from a browser, the easiest way is to use the shortcut that was probably created the first time the OT was run. An alternative method is to use the Java Application Cache Viewer, which can be started by typing `javaws -viewer` on the command line. The resulting dialogue displays the Java applications that are locally available and gives the opportunity to start one of them, in online or offline mode. An example of what the Java Application Cache Viewer looks like is provided in Figure 2.3.

## 2.3 Tarball Installation

### 2.3.1 Installation

The tarball version of the OT must be installed manually and does not automatically update itself when a new version is released. However, if there are problems with Web Start, it provides a backup installation method that should always work. In addition, a download of the OT is provided for Linux users that comes together with a recommended version of Java (32- and 64-bit systems are now supported). Please use this if you have any problems running the OT tarball install with your default Java.

To install the OT using the tarball distribution please the follow the steps given below.

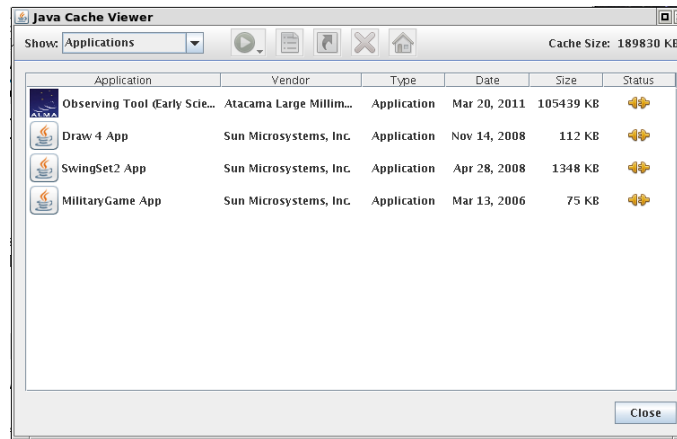


Figure 2.3: An example of the Java Application Cache Viewer. The viewer displays the Java applications that are available locally. If a network connection is available, a more recent version of an application (provided it exists) can be downloaded and run.

1. Download the OT tarball via the Science Portal and store the tarball in the directory of your choice. Note that the tarball is available in `.zip` and in `.tgz` format. Choose the one that is most convenient for you.
2. Unpack the tarball in the installation directory you have chosen in Step 1.
3. Read the `README.txt` available in the installation directory and follow the post-installation setup instructions contained therein for your platform.

The post-installation setup for Linux and Mac OS is as follows:

```
> cd ALMAOT-Cycle3/setup
> ./Setup-Linux.sh
> cd ..
```

The setup is very similar for Windows except that the file that must be run will be named `Setup-Windows`, or `Setup-Windows.cmd`.

### 2.3.2 Starting the OT

For both Linux and MacOS, the OT can be started using the script that is in the directory in which you unpacked the tarball distribution:

```
> ./ALMA-OT.sh &
```

Note, that you can also add the OT installation directory to your path and run the `ALMA-OT.sh` script from anywhere. If you're on MS Windows, double-click `ALMA-OT` (might read `ALMA-OT.cmd`).

Performing the above will issue a number of messages in your terminal window and finally start the OT. The script will also create a `.almaot` folder in your home directory, containing the user's preferences and a log file (`ot.log`). The latter contains useful debugging information, but is overwritten each time the OT is started and therefore should be saved before sending an error report.

## 2.4 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. The Web Start version acquires these from the

default internet browser, whilst the tarball release retrieves them from the operating system.

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](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.

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 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 (SBs) 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 SB generation is the standard way of producing the SBs in this case.

### 3.3 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 definitely recommended.

## 3.4 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 it has been decided that only a fixed number of OUS levels will be allowed and that each level will always appear, even if all are in theory not necessary. It has been decided that for all observations the same OUS/SB structure will be used.

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

- Member OUS – this level, and only this level, will contain the SBs. Once an SB within a Member OUS has been fully observed, the OUS will trigger the data reduction of the resulting ASDMs.
- Group OUS – this OUS contains one or more Member ObsUnitSets. If there is more than one Member OUS, 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 Group OUS once reduction of all the individual Member ObsUnitSets is complete. Even if the Group OUS only contains a single Member OUS, 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 pipeline processing happens at this level.

As can be 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.

## 3.5 Scheduling Blocks

Scheduling Blocks are the key executable units of a project and contain all information necessary to execute a “single” observation i.e. the SB is the quanta of the ALMA scheduling system. It is expected that SBs will 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.

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.



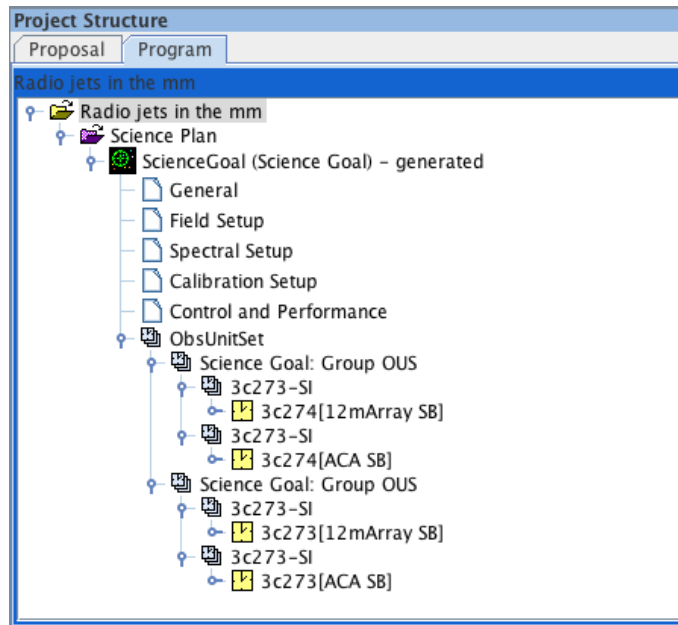


Figure 3.1: The Project Structure pane for a project involving two sources, each of which requires the 12-m array and the ACA. For each source, the SBs for each array live in their own Member OUS, and these are contained within a Group OUS. The two Group OUSs are contained within their common Science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

### 3.6 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 co-Is. Multiple submissions are possible, including overwriting a project in the archive with an older version that was saved to disk after a previous submission. Note that each submission causes a timestamp to be written into a project and, if the archive notices that the timestamp in the current submission is older than that of the version stored in the archive, a warning will be issued. Once submitted, projects can be retrieved from the archive using a search interface.

### 3.7 Project Validation

In order to ensure that the user's specifications for an observation are indeed possible, in particular that they satisfy the capabilities for the current cycle, the OT provides a number of validation checks. Part of the validation is performed automatically when observing parameters are entered and invalid input will be immediately 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 both 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.

## 3.8 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”. This is actually a zip file that contains the various components of a project, including the XML descriptions of the proposal, project and SBs, as well as the PDF file that will have been attached to provide a scientific and technical justification. Therefore, it is possible to “unzip” an aot file to get at these individual components, but this should only ever be necessary for expert users. 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. **Under no circumstances should a project be altered by editing the XML directly!**

## 3.9 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.

# 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

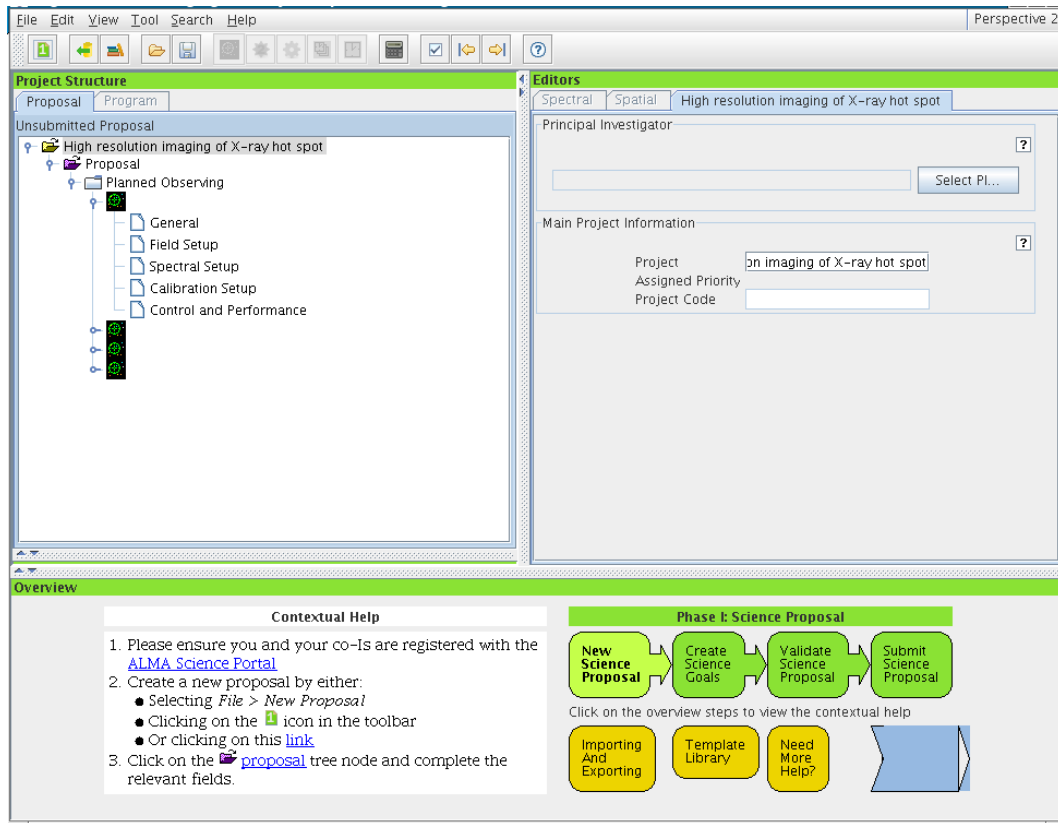


Figure 4.1: The Observing Tool main GUI.

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. 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.

A number of Mac-specific complications exist. When copying and pasting, the Control and Command keys will probably work when dealing with Project tree nodes, but for textual fields, Control must be used. Also, 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 (Figure 4.2) 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.



Figure 4.2: The menu bar and toolbar are displayed at the top of the OT window. This example is for someone who has user privileges turned on.

The toolbar (also Figure 4.2) 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 4.3.

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

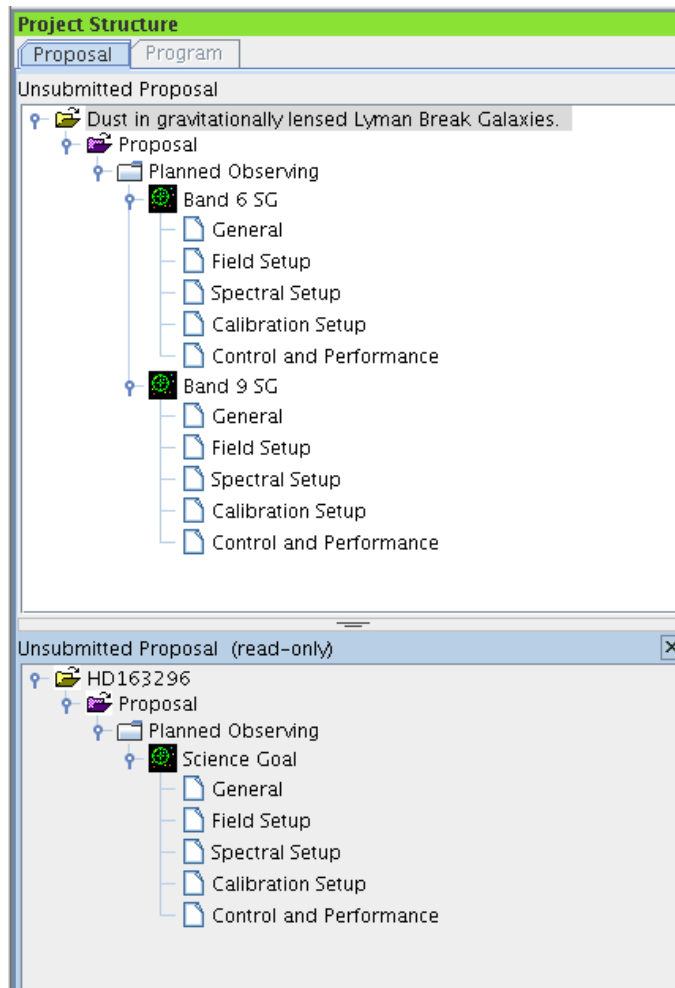


Figure 4.3: The Project Structure Pane. Visible is the structure of a Phase-1 proposal with two Science Goals (top) and a project that has been loaded as a template (bottom).

tab is only clickable for approved proposals or for privileged users. When the Proposal tab is enabled, all panes have a green 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.

#### 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

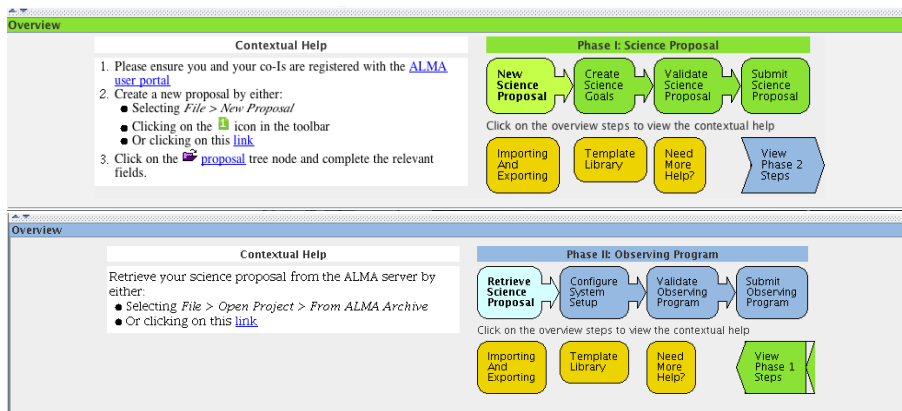


Figure 4.4: The Overview panes for Phase 1 (top) and Phase 2 (bottom). The text on the left reflects the project phase that is selected on the right.

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. The dialogue is shown in Figure 4.5. 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.

Other features of the Preferences menu include:

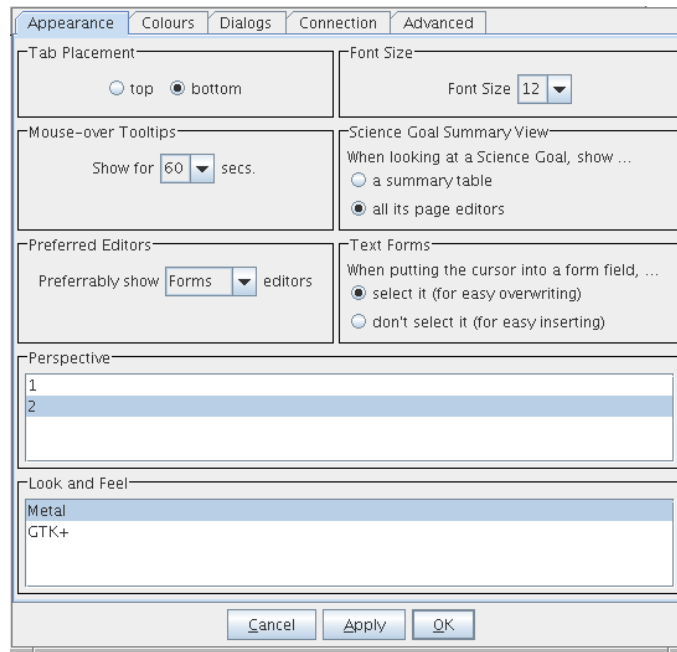


Figure 4.5: The GUI of the OT for setting the user preferences. The Appearance tab has been selected.

- Dialog behaviour – the OT displays many dialogues 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.



# 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.

### 5.1 Open a Phase-1 Proposal

Firstly, a proposal must be loaded into the OT. Often, this will be done by starting completely from scratch using “New Proposal” from the File menu or toolbar icon (number “1” on a green background). There is also the possibility to open a Director’s Discretionary Time (DDT) proposal using the corresponding menu or toolbar item i.e. the letter “D” on a reddish-pink background. The rest of this chapter is essentially identical for each, the only obvious difference being the bars in the GUI that have the same colour as the icon backgrounds. It is also possible to read in an existing project from disk or from the archive. In each case, dialogue boxes will warn about possible overwriting of the current project if it has unsaved changes.

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 be filled in, self-explanatory. Note though that the proposal type can only be edited for proposals

before their first submission – after this, no further edits are possible. The available proposal types are:

- Standard: for proposals that require < 100 hours of observing time
- Target Of Opportunity: For proposing the observation of an unpredictable sudden astronomical event, such as a Gamma-ray burst.

Once the 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. Related proposals should be listed in the two boxes below the keywords. One box is for proposals from this cycle and the other from previous cycles. In each case the project code, title and PI name should be given.

### 5.2.1 Adding Investigators

Further down the page is a panel for adding the details of the 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. 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.

The last column 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.

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.

### 5.2.2 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 4 pages and must not exceed a total size of 20 Mbytes. 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.

**Since Cycle 2, the PDF should no longer contain the technical case, this instead being captured by a dedicated node inside the Science Goal. Figures that might be referred to as part of the technical justification should though be included in the PDF.**

## 5.3 Adding Phase-1 Science Goals

It is now possible to insert the Phase-1 Science Goals. These can be added in a number of ways, but perhaps 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 Science Goal. If the top node of a Science Goal is selected, what is displayed depends on what has been set in the Preferences menu. 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.

The source coordinates **must** be entered in the FK5 system i.e. the reference frame based on the Fifth Fundamental (star) Catalogue with equinox and epoch both equal to J2000.0 (this system is often simply referred to as “J2000”). This *dynamical* reference system has been superseded by the International Celestial Reference System (ICRS), a frame based on the positions of extragalactic radio sources and which, therefore, is fixed in space (does not rotate with time). This, however, is not yet supported by the telescope control system. 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.

The velocity can be specified using the optical, radio, or relativistic convention. A number of different frames are available and the most useful of these are heliocentric, barycentric, 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, lsr and lsrk, the OT is not able to convert the velocity and you will be reminded of this via a pop-up dialogue.

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 Science Goal 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 5.3.3.8.

### 5.3.2.2 Resolving source information

Source details can be automatically filled in by “resolving” a recognized source name. The OT uses the Sesame<sup>1</sup> web service to first query SIMBAD<sup>2</sup> and then, if no source with that name is found, NED<sup>3</sup>. 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. Note that many sources have multiple names – at the time of writing SIMBAD contained 113 “identifiers” for 3C 273.

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 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!**

### 5.3.2.3 Expected Source Properties

Once the source position and velocity information has been completed, details of the source brightness, polarization 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 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.

### 5.3.2.4 Field definitions

The observing patterns that are used to observe a source fall into three 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
- Multiple individual pointings which are to be mosaiced together (“custom mosaic”) – 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 Pipeline will produce a single image of the field. If the ACA is required, the 7-m array will also observe the user-defined pointings, but the TP array will scan a rectangular area that is automatically calculated by the OT and displayed in light blue as for the rectangular definition

---

<sup>1</sup><http://cds.u-strasbg.fr/cgi-bin/Sesame>

<sup>2</sup><http://simbad.u-strasbg.fr/simbad/>

<sup>3</sup><http://ned.ipac.caltech.edu/>

- One or more individual pointings – the pointings do not have to overlap and Pipeline will produce a single image of each pointing. If the TP array is required, each source must only contain a single pointing.

All the sources in a Science Goal must use the same type of field definition i.e. all must either be a rectangle, a custom mosaic or a non-mosaiced collection of individual pointings. However, any number of sources can be created, so long as there are not more than 150 12-m array pointings. Also, all pointings must lie within a 10-degree radius.

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 the further away a source is 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  $\lambda$  is set from the Representative Frequency (Section 5.3.3.5).

Although the TP array is most commonly required for sources that are mosaiced using a rectangular definition, it can also be used with field patterns created using individual pointings e.g. custom mosaics or even single pointings. As no rectangle is entered by the user in this case, the OT calculates the area required for the ACA using an algorithm that calculates the smallest rectangle that encompasses all the pointings.

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.

### 5.3.2.5 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 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(sex), Dec(sex), 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)
-- This signals end of the header
ngc253, 00:47:33.134, -25:17:19.68, 0.0, 0.0, 258.688, lsrk, RADIO, 200, 1000, 2, 0, 1500
ngc1068, 02:42:40.771, -00:00:47.84, 0.0, 0.0, 1142.075, topo, OPTICAL, 1100.0, 30, 0, 0, 20
```

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
```

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 source’s spectrum over a particular range of frequencies. These are defined either manually or with the spectral line selection tool

(Section 7.3). All setups should be inspected using the Visual Spectral Editor (Chapter 9).

### 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 Polarization Products

For spectral type, the polarization products must be specified. 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 polarization (magnitude and position angle) is desired. This can only currently be selected for sources that are no larger than one third the size of the antenna beamsize i.e. mosaics and the ACA are not available. The detection of circular polarization is not yet officially supported.

### 5.3.3.3 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 (FDM) and one with much lower resolution (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.

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 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 equal twice 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.

Further degradation of the spectral resolution is possible for FDM spectral windows only. For these 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 spectral resolution is often higher than required and averaging can significantly reduce the data volume and speed up subsequent processing. As the averaging is done in addition to Hanning smoothing, the spectral resolution does not degrade linearly, but for large numbers of channels the spectral resolution tends towards the channel width multiplied by the spectral averaging factor.

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

Table 5.1: Available spectral windows in multi-region mode (dual polarization). 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	

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.

### 5.3.3.4 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. 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.

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 5.3.3.3, 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.



### 5.3.3.5 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, 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, 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 5.3.2.4). 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.

### 5.3.3.6 Single Continuum

The single continuum interface automatically creates four TDM spectral windows located such that they provide maximum sensitivity at low spectral resolution. For 2SB receivers (bands 3, 4, 6, 7 and 8) two spectral windows are placed in each sideband. For bands 9 and 10 (DSB) all four are placed in the same sideband. It is recommended that a receiver band be chosen, as this ensures maximum sensitivity by placing the windows in the centre of the band and avoiding atmospheric absorption features. 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 5.3.3.5) 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.

Spectral averaging is not available for Single Continuum as the spectral resolution is already relatively low.

### 5.3.3.7 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. In general, the OT will not be able to cover the exact requested frequency range, perhaps because this might require more than 5 tunings, but also because it always uses the maximum available four spectral windows per tuning. Spectral averaging is available for the high-resolution modes, but will be the same for each spectral window of each tuning.

As you would expect, the tunings are placed side-by-side, the only real complication being that for modes that require two sidebands, the lower sideband of tuning  $n + 1$  must be placed in the gap between the sidebands of tuning  $n$ . This is unavoidable and leads to non-uniform sensitivity in the final spectrum, but the requested sensitivity will be achieved everywhere. Since Cycle 3, small overlaps are assumed, both between the spectral windows of a tuning, and between tunings. This ensures that the edge channels that are most likely to be affected by technical problems are excluded.



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.

### 5.3.3.8 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 Science Goal 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.
- 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 (Section 5.3.5.3). As already said, no more than five are allowed and the user should split the sources into multiple SGs to avoid this limit.

## 5.3.4 Calibration Setup

The Calibration Setup page allows a user to choose between user-defined and system-defined calibrators. It is **STRONGLY** recommended to choose the system-defined option; 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).

When user-defined calibration is specified, a table appears in which the calibration sources can be added, deleted or edited. The initial list of calibrators describes the default calibration scheme for ALMA projects and appear in the approximate order in which they will be executed.

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.

The main use of user-defined calibration is probably to change some of the default dynamic queries to fixed calibrators. It is also possible to define additional calibrations, but removing the single-instance of the amplitude, bandpass or phase calibrator is not allowed – this will cause a validation error.

### 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 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.).

#### 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 (short baselines). It will often be the case that the required range of baselines cannot be achieved with a single 12-m array configuration alone and that additional 12-m array configurations and perhaps the ACA 7-m and Total Power arrays are needed. Based on the user input, the OT will automatically calculate how many 12-m configurations are required and will give a suggestion (which should usually be followed) as to whether the ACA should be requested.

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 most compact and extended. This includes their maximum and minimum baseline lengths, as well as the angular resolution ( $\lambda/L_{\max}$ ) and Maximum Recoverable Angular Scale (MRAS –  $0.6 \lambda/L_{\min}$ ). 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  $\lambda$ .

The angular resolution can lie anywhere between that corresponding to the most extended configuration, and twice that of the most compact configuration. The first limit simply states that it is impossible to achieve a higher angular resolution than that provided by the largest configuration, whilst the latter reflects the possibility that an image may ultimately be smoothed. 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 strive to enter a realistic, non-zero value.

The OT’s algorithm for selecting configurations can be summarised as follows:

- Based on the requested angular resolution, the smallest configuration is found that will achieve an angular resolution **at least as good** as that requested. This means that, if the user requests an angular resolution of 1 arcsec and the two nearest configurations correspond to, say, 0.5 and 1.1 arcsec, the OT will choose the larger of the two i.e. the one that delivers 0.5 arcsec.
- The OT then checks to see whether the selected array has baselines that are short enough that it is able to image the requested LAS i.e.  $\text{MRAS} > \text{LAS}$ . If not, the OT will then attempt to add a second 12-m configuration. This is not possible for the two largest Cycle-3 configurations (C36-7 and -8) as these cannot easily be combined with the other, much smaller, configurations (including the ACA) to form a reliable image. It will also not be possible to add another 12-m configuration if the first one is already quite small (C34-3 or smaller, to be precise). Adding the ACA in this situation is allowed though.
- If the source contains structures with a large angular scale, the ACA might also be required. The OT will first check to see if the 7-m array alone can image the large scales and, if not, the Total Power array will also be scheduled, unless this is forbidden (e.g. Bands 9 and 10 and single continuum). The choice of ACA can be set automatically using the “Suggest” button. This can be overridden, but doing so must be justified. If the ACA has been selected and parameters that affect the need for this subsequently change, the ACA will be automatically de-selected and its necessity should again be checked.

The configurations chosen will be used to set the time required for the Science Goal and a breakdown in the times is given in the Time Estimate dialogue. Note though that the actual 12-m array configurations can in practice differ from those chosen by the OT, partly because ALMA will be being constantly reconfigured and thus never conform exactly to one of the model array configurations, but also because the ultimate choice of what configuration will be used is ultimately a matter for the scheduling team. Therefore, the OT does not specify which configurations it assumed in its calculations.

### 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 temperature units, 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 (7.5 GHz) 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 “RepresentativeWindowResolution” (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 is displayed (Figure 5.2) that attempts to indicate how the total time, including calibration and overheads, was arrived at.

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 2 minutes.

One issue to be aware of is that 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.

Every SB will include an amplitude, bandpass 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 the observations in a Science Goal will go into a single SB. This is even the case for Science Goals that contain multiple tunings 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 be 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.

The above somewhat rigorous derivations are only carried out for the most-extended 12-m configuration. If any other configurations are required (a more compact 12-m configuration and perhaps the ACA 7-m and TP arrays) then their times are calculated as a multiple of the the total time (including calibration and overheads) required for the single 12-m configuration. The multiplicative factors were arrived at through extensive simulations and have been set as follows:

- 12-m extended configuration: 1
- 12-m compact configuration: 0.5
- ACA 7-m array: 2
- ACA TP array: 4

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 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  $u, v$  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.

#### 5.3.5.5 Time-constrained observing

For projects which have specific time constraints, an interface is available which will capture the various pieces of information required to schedule the observations. However, this is only available for those projects that require a single 12-m configuration as the time-constrained interface implies simultaneous observing and it is very difficult to guarantee this in practice. The interface allows two kinds of time-constrained observations:

- Specific dates – the SB will be observed during one of the specified dates. 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 needs to be repeated several times, these can be specified individually, both in terms of a specific date, or a time relative to a previous visit. A good example of this observing mode might be the observation of a Gamma-ray Burst at various times after its discovery.

Reasonable margins on the requested times should be entered. If these are too restrictive then it will be difficult to schedule the SB executions. The default margin since Cycle 2 has been 14 days i.e.  $\pm 7$  days. A text box is available if it is desired to give further information regarding the proposed time-constrained observing.

#### 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. 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, continua, or both. The discussion should convince the technical assessor that the line or continuum is being observed with sufficient signal to noise and that there are enough spectral bins across each spectral line to perform the scientific goals.
- Imaging: This should include an explanation of why the specific values of the angular resolution and largest angular scale were requested and discuss whether the arrays selected by the OT will produce a suitable image of the source. Images resulting from simulations that are relevant to this discussion should be attached to the PDF containing the scientific justification.
- Correlator configuration: The main thing to discuss here is the spectral resolution that has been selected and why. Spectral averaging should be mentioned if this has been requested.
- Choices to be justified: There are a number of setup options which, if selected, should be mentioned in the technical justification text. 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 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.

A new concept in ALMA is that of “non-standard” time. This is generally defined as time spent observing modes which cannot yet be properly pipelined, or which are simply harder to guarantee good results (e.g. long baselines and/or high frequencies). The project intends to only schedule 25 per cent of its time observing these types of Science Goal and so this is clearly of interest to all users. The modes that are considered “non-standard” are likely to evolve as Pipeline development continues and ALMA gains more operational experience.

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, PI, 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 amount of “non-standard time” is also reported.
- 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.

## 5.6 Proposal Submission

Proposal submission is only possible from the File menu and can only be performed by the PI. Once the submission is underway, a progress dialogue will be displayed and, depending on how big a proposal is, should lead to a successful submission in a matter of seconds. Upon submission, 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.

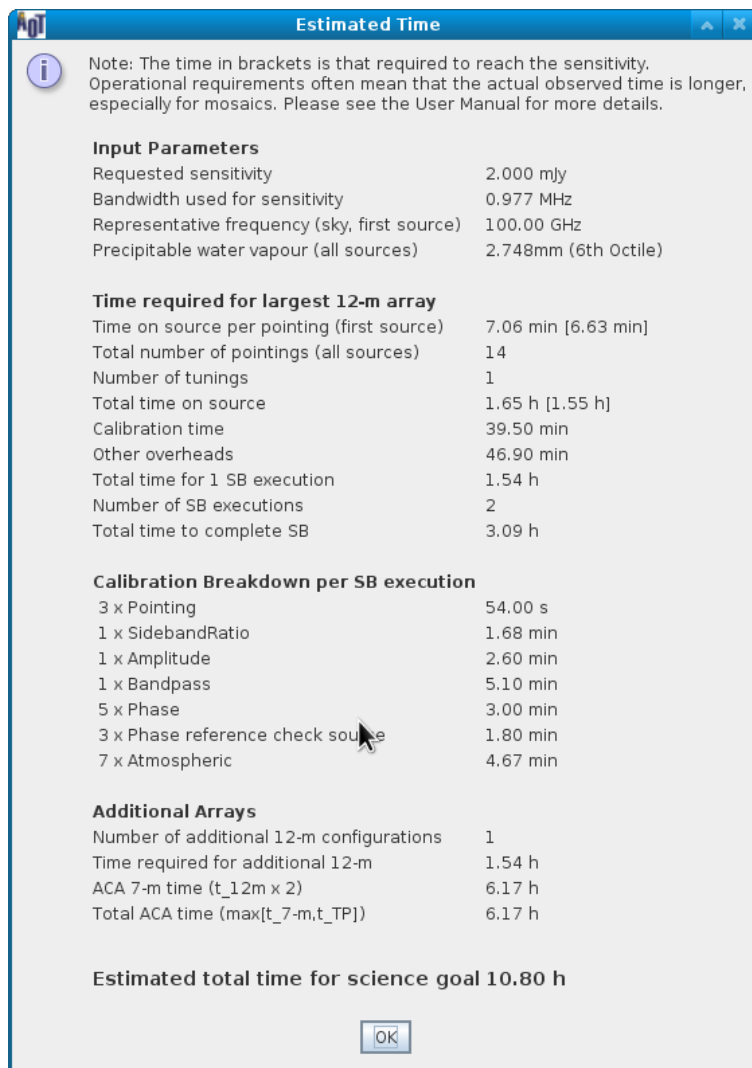


Figure 5.2: Example of the Time Estimate dialogue. This is for a mosaic project and the time per pointing has been calculated assuming antenna beam overlap. Two 12-m configurations are required as is the ACA. Their times are calculated as multiplication factors of the largest 12-m configuration time, but note that the total time is equal to the total 12-m time plus the TP array time only – the ACA arrays will run in parallel and thus only the TP array time counts in forming the total time estimate. As the time for the main 12-m array is greater than 50 min, two SB executions (EBs) are required. Note that the time per pointing is slightly longer than the time required to reach the sensitivity (in square brackets). This is typical for mosaics where each pointing must be observed the same number of times and the time for each is quantised



# Chapter 6

## Phase 2 – Observing Program

Once a proposal has been approved, or if a project is being created that hasn't had to go through the proposal system e.g. for observatory tests, it is then necessary to create the Scheduling Blocks that will be used to run the observations at the telescope. This can be done in one of two ways, either by generating a Phase-2 program via one or more Science Goals, or by constructing the SBs from scratch. The former is the route that will almost always be used, as an observing program is extremely complicated (described in Section 6.2) and the generation will get the structure and most (if not all) of the parameters correct with the click of a button. If necessary, the generated SBs can then be edited.

### 6.1 Generation from Science Goals

#### 6.1.1 Phase-2 Science Goals

If you have been awarded time as a result of submitting a proposal, the Phase-1 Science Goals will be automatically copied over to the Program tab of the Project Tree and the project will open here when retrieved from the ALMA archive (see Section 7.4). Technically speaking, the Science Goals that are shown in this tab are Phase-2 Science Goals, but their visible content is absolutely identical to that of their Phase-1 counterparts. If a Phase-2 Science Goal is instead being created from scratch, these are instead created in the same way as described in Section 5.3 for the Phase-1 variety. A Phase-2 Science Goal is most-easily created by clicking the icon in the Toolbar, but right-clicking on the Science Plan folder or opening the Edit menu will also work.

It is worth noting that, for those people with the necessary privileges, it is possible to copy a Phase-1 Science Goal (e.g. with Ctrl-C), to open a new Phase-2 Program (from the File menu) and then to paste the copied Science Goal into this.

#### 6.1.2 Scheduling Block Generation

Once a Science Goal has been completed, its SBs can be automatically generated by clicking the icon in the toolbar, although the Tool menu has the additional option of generating from multiple Science Goals simultaneously. The action of generation will, if SBs are being generated from the Science Goal for the first time, cause an ObsUnitSet to appear immediately below the Science Goal. The various sub-nodes of this can then be opened to reveal further ObsUnitSets and SBs in a nested structure. If these sub-nodes are already visible and the generation run again, the whole nested structure will be collapsed until only the uppermost OUS is visible. Details of the contents of the SBs can be found in Section 6.2.2.

For each ALMA cycle, the OT's SB generation algorithm is closely tied to the capabilities advertised in the most recent ALMA Call for Proposals and it should be possible to generate successfully from any Science Goal that has been copied from an accepted Phase-1 Proposal. More generally, what exactly is generated will depend on the observing mode.

### 6.1.3 Manual creation

If instead it is desired to build a Phase-2 program from scratch, there should usually be a really, really, really good reason for doing so. And even then you probably shouldn't do it. Even if generation from a Science Goal does not exactly produce the desired SB, it should usually be the case that an approximate version thereof can be produced and then edited. If this is for some reason not deemed possible, then a Phase-2 program should be created, either via the toolbar or the File menu and the various elements (described in the next section) added by hand.

## 6.2 Observing Program Structure

The structure of a typical Phase-2 project is shown in Figure 6.1 and shows each of the required entities: Observing Unit Sets, Scheduling Blocks, Targets, Resources and Observing Groups. These are now described in more detail.

### 6.2.1 Observing Unit Sets

The OUS is a fundamental part of the construction of an SB and, as explained in Section 3.4, 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 referred 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. StandardInterferometry.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.

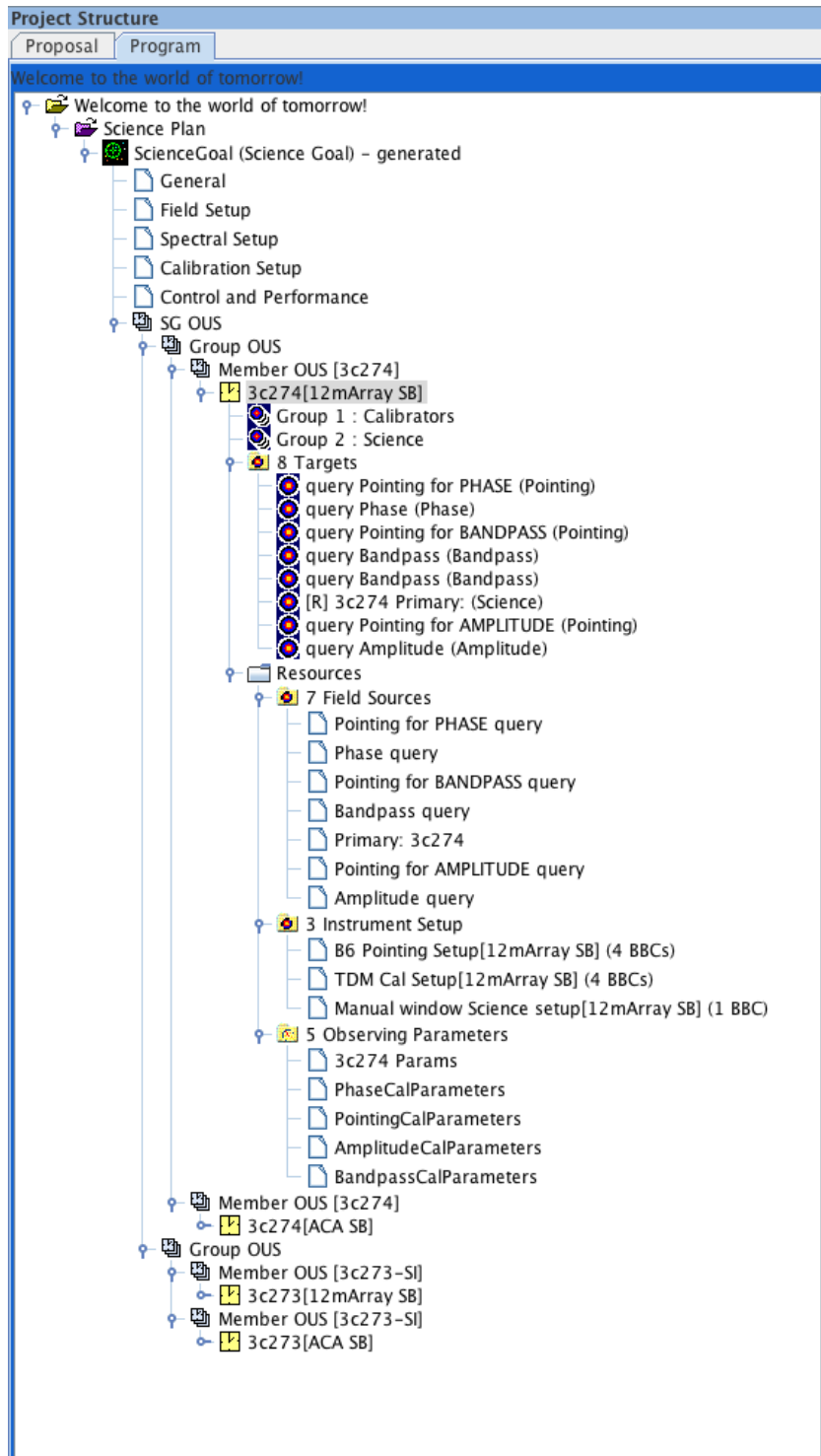


Figure 6.1: An example of a typical project structure. For this FDM project, two sources have been split into separate Group OUSs, each of which requires two Member OUSs, one for the ALMA 12-m array and one for the ACA. For only the first SB is its internal structure shown.

## 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 referred to as Resources and are stored in a Resources folder.

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.

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.

The created Target will initially be empty i.e. contain no Resources, so these 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 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.

For each Target it is only possible to add a single Field Source and Instrument Setup. It is technically possible to enter 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 by an [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

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.

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 of significant emission. When measuring  $T_{\text{sys}}$ , for example, a bright source will significantly add to the power detected by the antenna and increase the measured  $T_{\text{sys}}$ . 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 and only point and rectangle are usually used. The inputs for both 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 usually 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 particularly 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 (62.5 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. However, neither of these are yet available for science observing and therefore only one spectral window per baseband is currently allowed.

### 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.

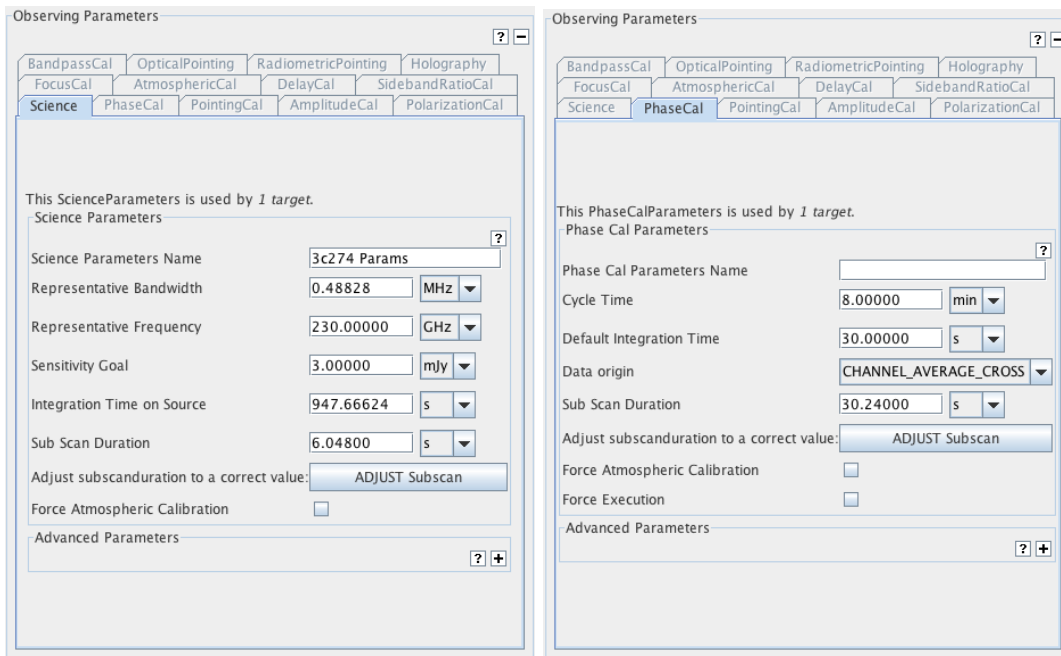


Figure 6.4: Examples of the Observing Parameters form for a science target (left) and a phase calibrator (right). The tabs at the top show all the observing intents that could be created.



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  $\sim 30$  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 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 SB.



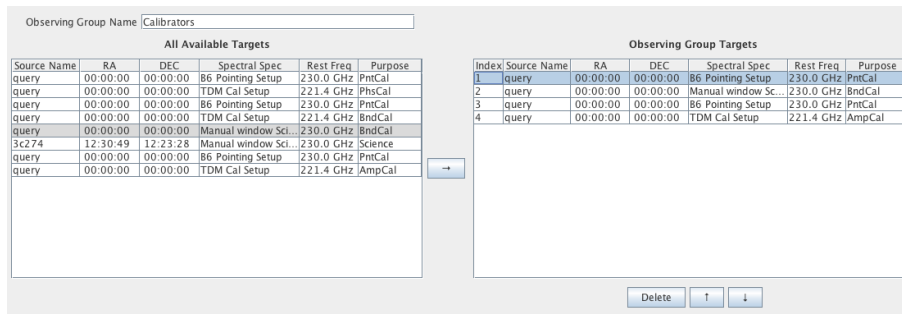


Figure 6.5: The Observing Group editor. The table on the left lists the already-defined Targets that could be placed into this Observing Group, this being done by moving them into the table on the right. The order of the chosen Targets can be changed using the up and down arrows and are removed from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

### 6.3 Submit the Observing Program

After having completed the Phase-2 program, the validation procedure should be run to make sure that it is technically correct. If no errors are found, submission should be successful and the project can then be retrieved from the archive at the telescope and executed. More information about validation and submission can be found in Sections 3.7 and 3.6.



# 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.

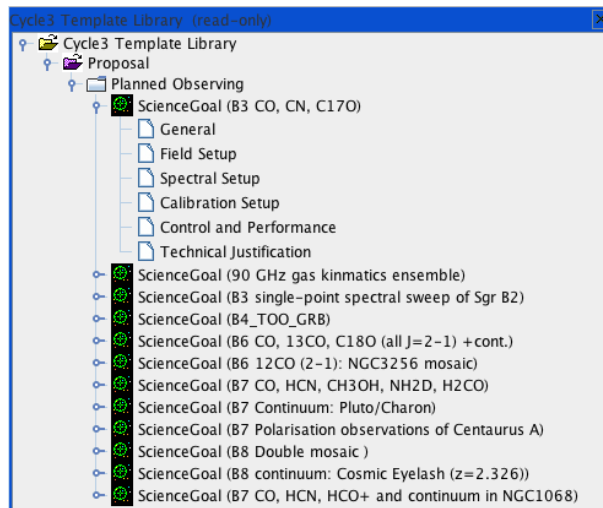


Figure 7.1: The ALMA Template Library.

### 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 array. Note that the numbers of antennas will be set to their default values for the present cycle. The tool also

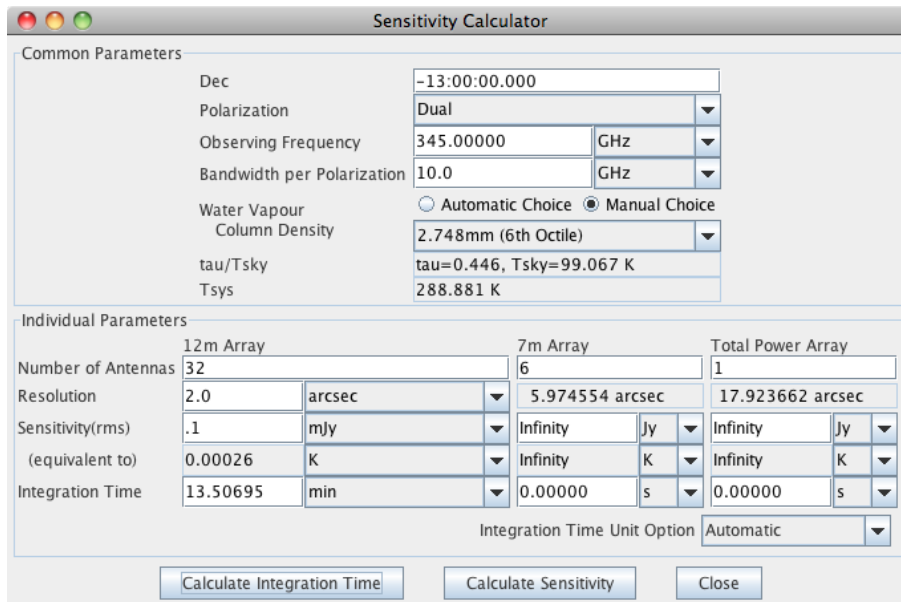


Figure 7.2: The ALMA Sensitivity Calculator.

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 Selection Tool

The ALMA spectral line catalogue contains the rest frequencies of millions of spectral line transitions. These transitions can be inspected and selected via the Spectral Line Selection tool. The initial list of molecules was first compiled using David Woon's website<sup>1</sup>. This list was followed up and information from the published literature added. A subset of the complete catalogue 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

<sup>1</sup>[http://www.astrochymist.org/astrochymist\\_mole.html](http://www.astrochymist.org/astrochymist_mole.html)

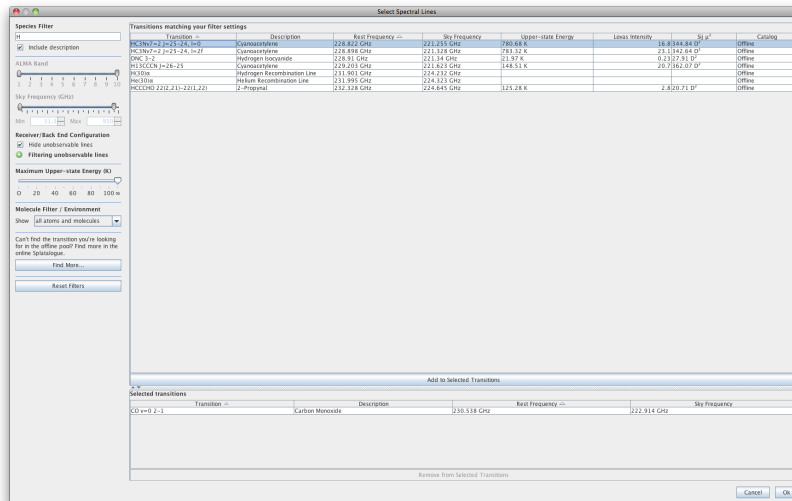


Figure 7.3: The ALMA Spectral Line Selection Tool.

define observed frequencies as well as being available to overlay on the Visual Spectral Editor.

When the transition selector dialogue 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.

A very important part of the Line Picker is its ability to only allow lines to be selected that can be observed together in a single tuning solution. This “unobservable lines” filter is enabled by default and calculates the range of frequencies for which a line could be entered to the currently defined list of spectral windows (even if they are in other basebands) and still result in a valid tuning. In overlaying mode, it instead restricts the list to those lines that could fit the current tuning solution. 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.

## 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 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.

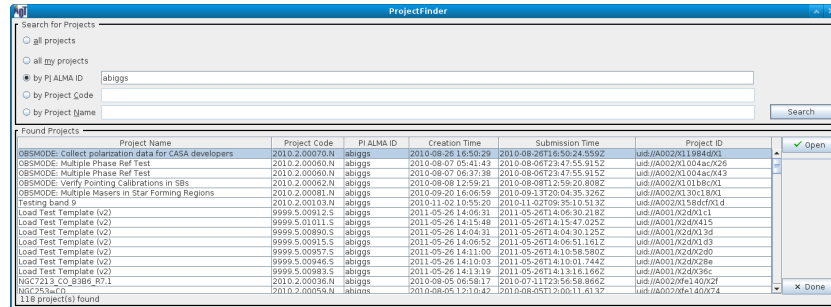


Figure 7.4: The Project Finder dialogue for searching for projects in the ALMA archive.

## 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.

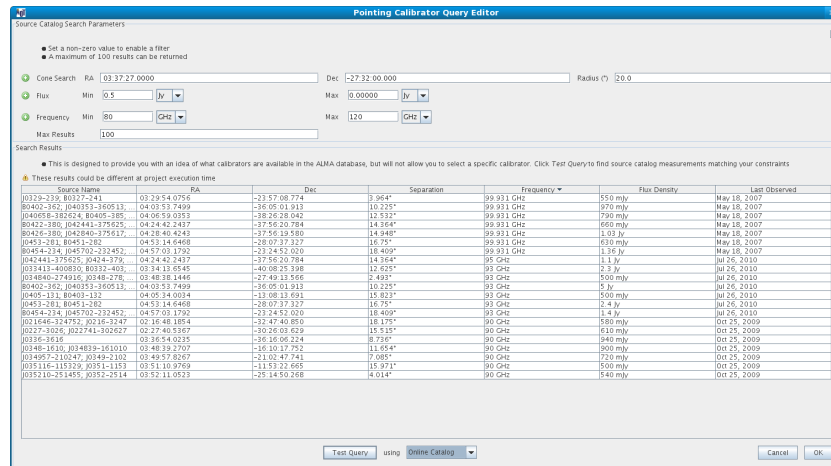


Figure 7.5: The Calibrator Selection Tool as used in the Calibration Setup of Science Goal. A search has been made for all calibrators within a 10-degree radius of a source position, that have a flux greater than 500 mJy in ALMA Band 3.

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 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

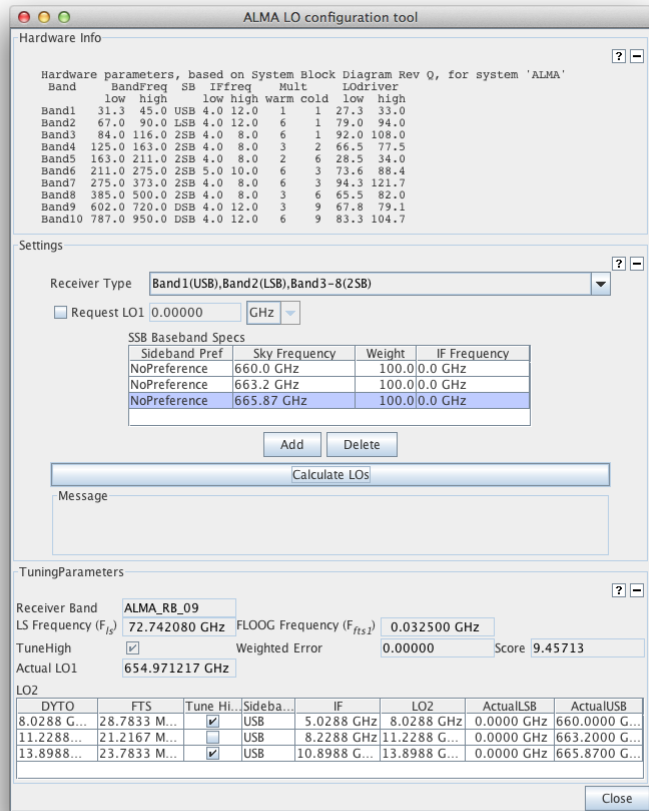


Figure 7.6: The LO Configuration Tool. Three Band-9 basebands have been requested with the tuning results shown at the bottom.

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.





# 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<sup>1</sup> 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 the antenna diameter that shall be used when displaying the antenna beams (field of view). 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.

---

<sup>1</sup><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).

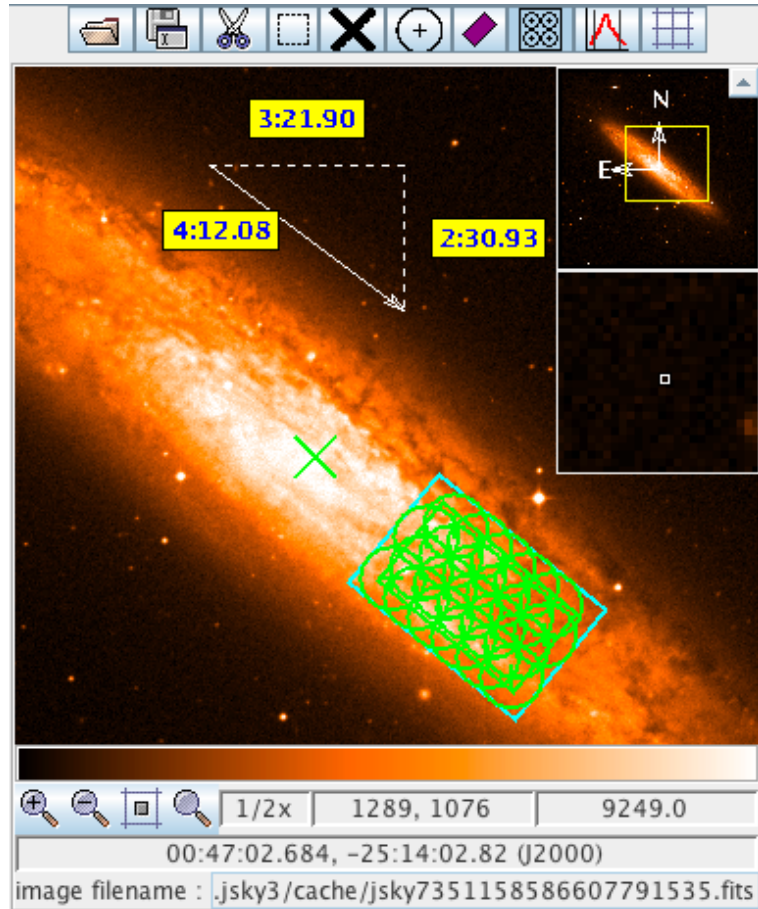


Figure 8.1: An example of the image display area on the Visual Spatial Editor. This shows a pointed mosaic observation of the outer reaches of NGC 253, the mosaic pointings having been automatically created based on a user-defined rectangle (green). The x-shaped cross at the centre marks the position 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.

At present, only FITS file with coordinates defined in the J2000 system are correctly handled. Therefore, you cannot use the Spatial Editor to set up pointings in Galactic coordinates. The OT will load the image, but the coordinates will not be displayed correctly. It is possible to use FITS files where the image is stored as a FITS extension, but the OT will only read the first, if multiple extensions exist.

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

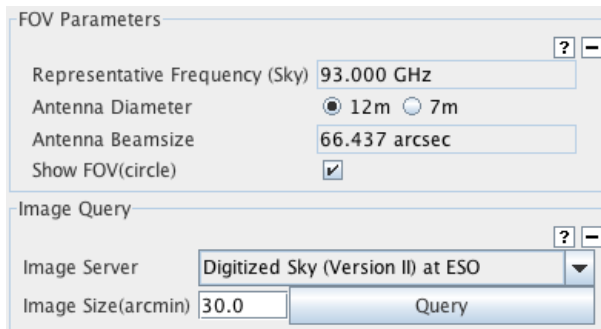


Figure 8.2: The FOV Parameters and Image Query panels in the Visual Spatial Editor.

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. 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 antenna beamsizes for each pointing, either for the 12- or 7-m antennas. 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

### 8.2.2.1 Science Goal

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.

#### **8.2.2.2 Scheduling Block**

Setting up a rectangular area using the Spatial Editor is essentially exactly the same in the Field Source of a Scheduling Block, except that it is possible to either convert it into a pointed mosaic or to have the telescopes scan it in strips.

#### **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<sup>1</sup> 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 Selection Tool 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 to do this using the graphical interface. These in turn are used by the OT to calculate a tuning solution that sets the positions of the basebands and sidebands. Together with the spectral windows, these can be viewed in the Spectral 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 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.

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).

---

<sup>1</sup>e.g. Pardo, J. R., Cernicharo, J., Serabyn, E., 2001, ITAP, 49, 1683.

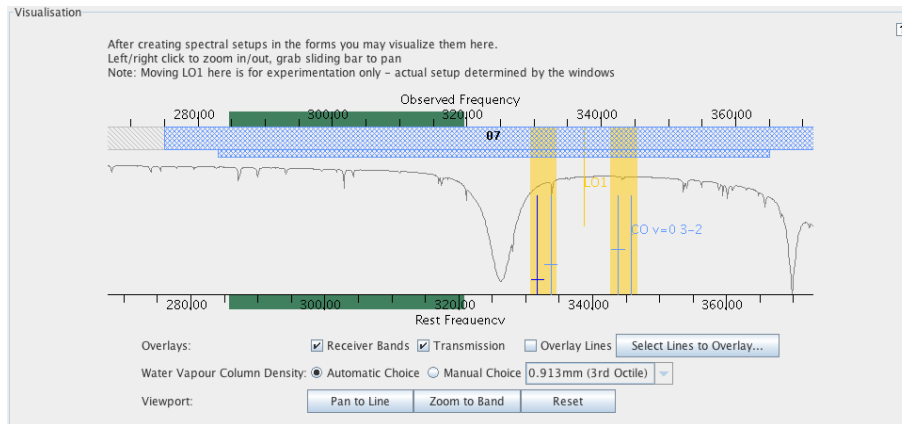


Figure 9.1: The graphical representation of the frequency information in a Science Goal. Four spectral windows are shown, a narrow one to observe the CO(3-2) transition and three other maximum-bandwidth ones for measuring a continuum. All four fit within the sidebands which are coloured yellow (as opposed 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.

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.

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.

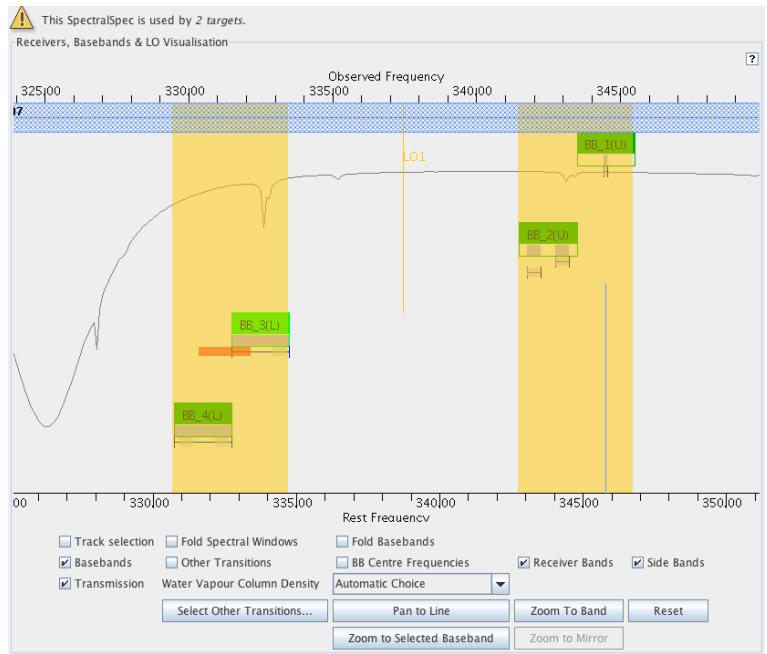


Figure 9.2: The graphical representation of the frequency information in a Scheduling Block. This is a zoomed view and hence the spectral windows and their spectral averaging regions can be seen. The basebands are shown as the green blocks and within these can be seen the spectral windows (horizontal 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.



# 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).

### A.1 NASA resources for HORIZONS

- <http://ssd.jpl.nasa.gov/horizons.cgi>: 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.
- <http://ssd.jpl.nasa.gov/?horizons>: HORIZONS web page (web interface link can be found here, in addition to multiple formats for documentation).
- [ftp://ssd.jpl.nasa.gov/pub/ssd/Horizons\\_doc.pdf](ftp://ssd.jpl.nasa.gov/pub/ssd/Horizons_doc.pdf): PDF user manual. Provided as a reference (very detailed, not required for following the steps outlined here).

### A.2 Instructions and Settings

Go to <http://ssd.jpl.nasa.gov/horizons.cgi>. The HORIZONS web interface shows the current settings, all of which can be modified using the “change” link. Previously-used settings seem to be remembered, so we first recommend that all inputs should be set to their default using the “Special Options” section. The inputs should then be set as follows:

- Ephemeris Type should be `OBSERVER` (default).
- Set Target Body to the relevant solar-system body.
- The Observer Location is most easily set to ALMA using the “Lookup named location” interface. Entering “ALMA” will enable a search and the entry that should be chosen is **Atacama Large mm/sub-mm Array (ALMA) Center of Array [-7]**. **These instructions have recently (Feb 2013) changed – geocentric locations should no longer be used!**
- Time Span 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 Table Settings, only `Astrometric RA & DEC` and `Obsrv range & rng rate` are required. If correctly chosen, the interface should read `QUANTITIES=1,20`. Do not select any of the optional settings as none have been tested with ALMA. It is known, however, that `extra precision` and `elevation cutoff` do not work.

- Display/Output should be set to plain text.

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 should be saved to a text file. This can then be 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. Ephemeris that do not conform to this format cannot be guaranteed to run correctly.

```
*****
Revised: Sep 28, 2012                Mars                499 / 4

GEOPHYSICAL DATA (updated 2009-May-26):
Mean radius (km)      = 3389.9(2+-4)   Density (g cm^-3)   = 3.933(5+-4)
Mass (10^23 kg)      = 6.4185         Flattening, f       = 1/154.409
Volume (x10^10 km^3) = 16.318          Semi-major axis     = 3397+-4
Sidereal rot. period = 24.622962 hr  Rot. Rate (x10^5 s) = 7.088218
Mean solar day       = 1.0274907 d   Polar gravity ms^-2 = 3.758
Mom. of Inertia      = 0.366          Equ. gravity ms^-2  = 3.71
Core radius (km)    = ~1700         Potential Love # k2 = 0.153 +- .017

Grav spectral fact u = 14 (x10^5)   Topo. spectral fact t = 96 (x10^5)
Fig. offset (Rcf-Rcm) = 2.50+-0.07 km  Offset (lat./long.) = 62d / 88d
GM (km^3 s^-2)       = 42828.3       Equatorial Radius, Re = 3394.0 km
GM 1-sigma (km^3 s^-2) = +- 0.1      Mass ratio (Sun/Mars) = 3098708+-9

Atmos. pressure (bar) = 0.0056       Max. angular diam.   = 17.9"
Mean Temperature (K)  = 210           Visual mag. V(1,0)   = -1.52
Geometric albedo     = 0.150         Obliquity to orbit   = 25.19 deg
Mean sidereal orb per = 1.88081578 y  Orbit vel. km/s      = 24.1309
Mean sidereal orb per = 686.98 d      Escape vel. km/s     = 5.027
Hill's sphere rad. Rp = 319.8         Mag. mom (gauss Rp^3) = < 1x10^-4
*****

*****
Ephemeris / WWW_USER Mon Feb 25 23:51:53 2013 Pasadena, USA / Horizons
*****
Target body name: Mars (499)           {source: MAR097}
Center body name: Earth (399)          {source: DE405}
Center-site name: Atacama Large mm/sub-mm Array (ALMA) Center of Array
*****
Start time      : A.D. 2012-Nov-20 00:00:00.0000 UT
Stop time      : A.D. 2012-Nov-20 01:00:00.0000 UT
Step-size      : 10 minutes
*****
Target pole/equ : IAU_MARS              {East-longitude -}
Target radii    : 3396.2 x 3396.2 x 3376.2 km {Equator, meridian, pole}
Center geodetic : 292.245252, -23.016211, 5.0748870 {E-lon(deg), Lat(deg), Alt(km)}
Center cylindric: 292.245252, 5878.07779, -2480.356 {E-lon(deg), Dxy(km), Dz(km)}
Center pole/equ : High-precision EOP model {East-longitude +}
```

Center radii : 6378.1 x 6378.1 x 6356.8 km {Equator, meridian, pole}  
 Target primary : Sun {source: DE405+DE406}  
 Vis. interferer : MOON (R\_eq= 1737.400) km {source: DE405}  
 Rel. light bend : Sun, EARTH {source: DE405}  
 Rel. lght bnd GM: 1.3271E+11, 3.9860E+05 km<sup>3</sup>/s<sup>2</sup>  
 Atmos refraction: NO (AIRLESS)  
 RA format : HMS  
 Time format : CAL  
 RTS-only print : NO  
 EOP file : eop.130225.p130519  
 EOP coverage : DATA-BASED 1962-JAN-20 TO 2013-FEB-25. PREDICTS-> 2013-MAY-18  
 Units conversion: 1 AU= 149597870.691 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 )

\*\*\*\*\*

Date__(UT)__HR:MN	R.A.__(ICRF/J2000.0)_DEC	delta	deldot
2012-Nov-20 00:00 Am	18 08 49.57 -24 32 45.2	2.11526724217947	5.4283109
2012-Nov-20 00:10 Am	18 08 50.96 -24 32 45.0	2.11528902003861	5.4308867
2012-Nov-20 00:20 m	18 08 52.35 -24 32 44.7	2.11531080675966	5.4327290
2012-Nov-20 00:30 m	18 08 53.73 -24 32 44.4	2.11533259939253	5.4338340
2012-Nov-20 00:40 m	18 08 55.12 -24 32 44.1	2.11535439497415	5.4341991
2012-Nov-20 00:50 m	18 08 56.51 -24 32 43.8	2.11537619053409	5.4338231
2012-Nov-20 01:00 m	18 08 57.90 -24 32 43.6	2.11539798310023	5.4327065

\$\$\$EOE

\*\*\*\*\*

Column meaning:

TIME

Prior to 1962, times are UT1. Dates thereafter are UTC. Any 'b' symbol in the 1st-column denotes a B.C. date. First-column blank (" ") denotes an A.D. date. Calendar dates prior to 1582-Oct-15 are in the Julian calendar system. Later calendar dates are in the Gregorian system.

Time tags refer to the same instant throughout the universe, regardless of where the observer is located.

The uniform Coordinate Time scale is used internally. It is equivalent to the current IAU definition of "TDB". Conversion between CT and the selected non-uniform UT output scale has not been determined for UTC times after the next July or January 1st. The last known leap-second is used over any future interval.

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 WITH TARGET RISE/TRANSIT/SET MARKER (OBSERVING SITE)

The solar-presence symbol is immediately followed by another marker symbol:

- 'm' Refracted upper-limb of Moon on or above apparent horizon
- ' ' Refracted upper-limb of Moon below apparent horizon OR geocentric
- 'r' Rise (target body on or above cut-off RTS elevation)
- 't' Transit (target body at or past local maximum RTS elevation)
- 's' Set (target body on or below cut-off RTS elevation)

RTS MARKERS (TVH)

Rise and set are with respect to the reference ellipsoid true visual horizon defined by the elevation cut-off angle. Horizon dip and yellow-light refraction (Earth only) are considered. Accuracy is  $<$  or  $=$  to twice the requested search step-size.

R.A.\_(ICRF/J2000.0)\_DEC =

J2000.0 astrometric right ascension and declination of target center.  
Corrected for light-time. Units: HMS (HH MM SS.ff) and DMS (DD MM SS.f)

delta deldot =

Range ("delta") and range-rate ("delta-dot") of target center with respect to the observer at the instant light seen by the observer at print-time would have left the target center (print-time minus down-leg light-time); the distance traveled by a light ray emanating from the center of the target and recorded by the observer at print-time. "deldot" is a projection of the velocity vector along this ray, the light-time-corrected line-of-sight from the coordinate center, and indicates relative motion. A positive "deldot" means the target center is moving away from the observer (coordinate center). A negative "deldot" means the target center is moving 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  
Information: <http://ssd.jpl.nasa.gov/>  
Connect : telnet://ssd.jpl.nasa.gov:6775 (via browser)  
          telnet ssd.jpl.nasa.gov 6775 (via command-line)  
Author : Jon.Giorgini@jpl.nasa.gov

\*\*\*\*\*

# Appendix B

## Acronym List

**2SB:** Two sideband (receiver)  
**ACA:** Atacama Compact Array  
**ALMA:** Atacama Large Millimeter/submillimeter Array  
**APDM:** ALMA Project Data Model  
**ASDM:** ALMA Science Data Model  
**ARC:** ALMA Regional Centre  
**ASC:** ALMA Sensitivity Calculator  
**BBC:** BaseBand Converter  
**DSB:** Double Sideband (receiver)  
**EB:** Execution Block  
**FOV:** Field Of View  
**LAS:** Largest Angular Scale  
**LO:** Local Oscillator  
**LSB:** Lower Side Band  
**MRAS:** Maximum Recoverable Angular Scale  
**OG:** Observing Group  
**OT:** Observing Tool  
**OTF:** On The Fly  
**OUS:** Observation Unit Set  
**PWV:** Precipitable Water Vapour  
**SB:** Scheduling Block  
**SSB:** Single Sideband (receiver)  
**SFI:** Single Field Interferometry  
**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 Organization 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 Council of Taiwan (NSC) 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.

