

# ALMA Observing Tool User Manual

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

## 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.

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## Contributors

The ALMA OT Team, and the many Testers.

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# 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	The Java Web Start Installation . . . . .	8
2.2.1	Verifying Java Web Start . . . . .	8
2.2.2	Starting the OT . . . . .	9
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
<b>3</b>	<b>Basic Concepts</b>	<b>11</b>
3.1	Phase-1 Proposals . . . . .	11
3.2	Phase-2 Programs . . . . .	11
3.3	Science Goals . . . . .	11
3.4	Observing Unit Sets . . . . .	12
3.5	Scheduling Blocks . . . . .	12
3.6	Project Submission . . . . .	13
3.7	Project Validation . . . . .	13
3.8	AOT files . . . . .	14
3.9	Project Conversion . . . . .	14
<b>4</b>	<b>Overview of the Observing Tool</b>	<b>15</b>
4.1	Help . . . . .	15
4.2	The OT Main Graphical Interface . . . . .	15
4.2.1	GUI Parameter Fields . . . . .	15
4.2.2	GUI Features . . . . .	16
4.2.3	Menu and Toolbar . . . . .	17
4.2.4	The OT Panes . . . . .	17
4.2.4.1	The Project Structure Pane . . . . .	17
4.2.4.2	The Editors Pane . . . . .	18
4.2.4.3	The Feedback Pane . . . . .	19
4.2.4.4	The Overview Pane . . . . .	19
4.3	OT Configuration . . . . .	19

<b>5</b>	<b>Phase 1 – Observing Proposal</b>	<b>21</b>
5.1	Open a Phase-1 Proposal . . . . .	21
5.2	The Proposal Form . . . . .	22
5.2.1	Adding Investigators . . . . .	22
5.2.2	Scientific Case . . . . .	23
5.3	Adding Phase-1 Science Goals . . . . .	23
5.3.1	General . . . . .	24
5.3.2	Field Setup . . . . .	24
5.3.2.1	Source properties . . . . .	24
5.3.2.2	Resolving source information . . . . .	25
5.3.2.3	Field definitions . . . . .	26
5.3.3	Spectral Setup . . . . .	27
5.3.3.1	Spectral Line . . . . .	27
5.3.3.2	Single Continuum . . . . .	29
5.3.3.3	Spectral Scan . . . . .	30
5.3.3.4	Multiple velocities and tuning solutions . . . . .	30
5.3.4	Calibration Setup . . . . .	31
5.3.5	Control and Performance . . . . .	31
5.3.5.1	Imaging considerations: arrays and configurations . . . . .	32
5.3.5.2	Sensitivity considerations . . . . .	32
5.3.5.3	Time Estimation . . . . .	33
5.3.5.4	More time required due to $u, v$ coverage issues . . . . .	34
5.3.5.5	Time-constrained observing . . . . .	34
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 . . . . .	50
7.3	Spectral Line Selection Tool . . . . .	51
7.4	Archive Search Tool . . . . .	52
7.5	Calibrator Selection Tool . . . . .	52
7.6	LO Configuration Tool . . . . .	53
7.7	Calibration Time Estimate Tool . . . . .	53
7.7.1	Bandpass calibration . . . . .	54
7.7.2	Gain calibration . . . . .	54
7.7.3	Flux calibration . . . . .	55
7.7.4	Atmospheric calibration . . . . .	55

7.7.5	Pointing calibration . . . . .	56
7.7.6	Antenna movement . . . . .	56
<b>8</b>	<b>The Visual Spatial Editor</b>	<b>57</b>
8.1	Overview of the Graphical Interface . . . . .	57
8.2	Creating a Field Definition . . . . .	58
8.2.1	Single Pointings . . . . .	59
8.2.2	Rectangular Areas . . . . .	59
	8.2.2.1 Science Goal . . . . .	59
	8.2.2.2 Scheduling Block . . . . .	60
8.2.3	Offset Versus Absolute Coordinates . . . . .	60
<b>9</b>	<b>The Visual Spectral Editor</b>	<b>61</b>
9.1	Overview of the Graphical Interface . . . . .	61
9.2	Viewing a Spectral Setup . . . . .	62
	9.2.1 Science Goal . . . . .	62
	9.2.2 Scheduling Block . . . . .	62
<b>A</b>	<b>Create an External Ephemeris</b>	<b>65</b>
A.1	NASA resources for HORIZONS . . . . .	65
A.2	Instructions and Settings . . . . .	65
A.3	Example Ephemeris . . . . .	66
<b>B</b>	<b>Acronym List</b>	<b>69</b>

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# Chapter 1

## Introduction

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

### 1.1 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. Complimentary 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 2, 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 1.

## 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 is available in two flavours: Web Start and tarball. The Web Start method is recommended as it is much simpler. Provided a network connection is available, it will ensure that you are running the latest available version of the OT. The tarball method is a more classical installation involving the downloading and unpacking of a tarfile containing the OT application and other files required to run the OT. 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 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 version 6 of Java (also known as JAVA SE 6) be installed, although Java 7 also seems to work without any problems. 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_13"  
Java(TM) SE Runtime Environment (build 1.7.0_13-b20)  
Java HotSpot(TM) 64-Bit Server VM (build 23.7-b01, mixed mode)
```

The `_13` in this particular example refers to the patch release of the installation and should increment every time the Java installation is updated. Patch releases do appear intermittently and should usually be installed. When reporting a problem with the OT, the full version number including the patch release should be reported.

### 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 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 to install the OT, 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 The Java Web Start Installation

The Web Start application has the advantage that the OT is downloaded and installed on your computer with a single click in a browser, and because any updates to the OT will be automatically detected and installed. However, OpenJDK versions of Java such as IcedTea that are common on many modern Linux installations have proved to be problematic and thus we recommend that the distribution from Sun (now Oracle) be used instead. In the event that Web Start cannot be used, a tarball version is also provided.

### 2.2.1 Verifying Java Web Start

Java Web Start is part of Java 6 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 should be changed. On Firefox, this is done via the Applications tab of the Preferences menu (Figure 2.1).

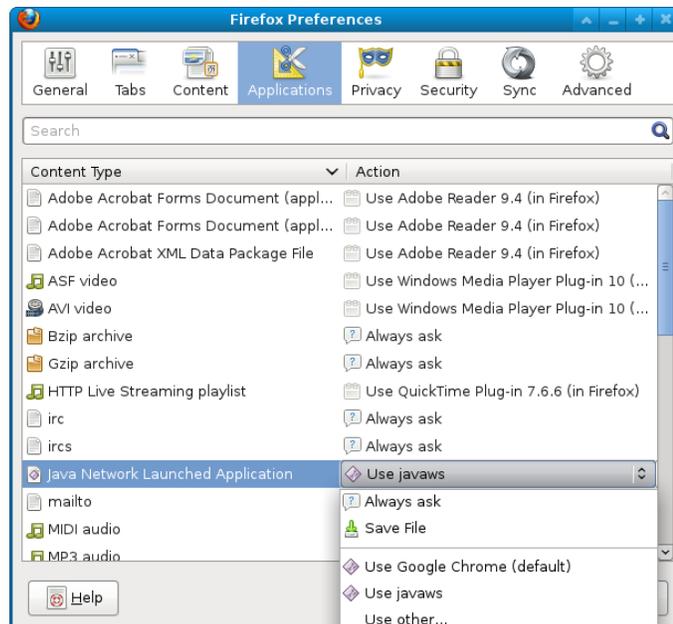


Figure 2.1: An example of the Applications menu in Firefox that can be used to change the version of Web Start used by the browser. This is for a Linux version of Firefox.

To verify that Web Start is correctly working, the following link should be followed and one or more of the demos launched:

<http://java.sun.com/javase/technologies/desktop/javawebstart/demos.html>

## 2.2.2 Starting the OT

To download and run the OT with Java Web Start please go to the ALMA Science Portal and follow the links to the Web Start version of the OT. Clicking on the link should start the download process or, if you already have an up-to-date installation, start the OT. Once the download is complete it is quite likely, but not certain, that a shortcut will be created. This will enable the OT to be started in the future without going back to the Science Portal. If prompted for a location, as usually happens on Macs, it is recommended that the Desktop be chosen. The actual OT software will be automatically placed into a specific subdirectory on your machine.

As part of the download process, a dialogue should appear that states that “The application’s digital signature has been verified.” This confirms that the OT has been downloaded from a trusted source and should cause no security concerns. The screenshot should look very similar to that in Figure 2.2. “Always trust content from this publisher” should be ticked, if this has not been done so automatically, and the installation continued.

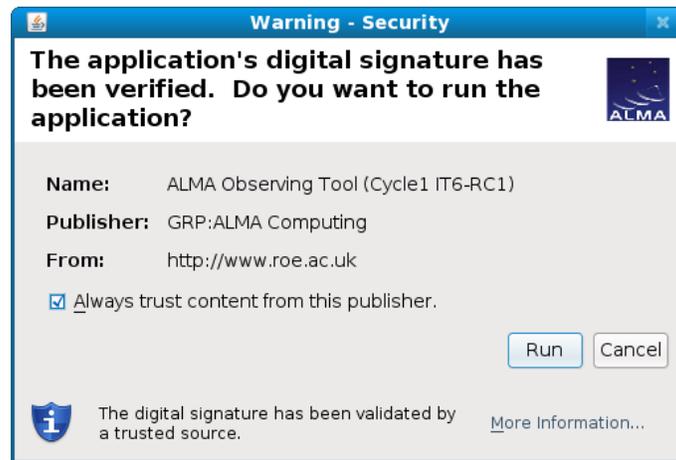


Figure 2.2: The dialogue that confirms that the OT is a trusted piece of software.

## 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 during download. 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 is complete with a recommended version of Java. 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 follow the steps given below.

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.

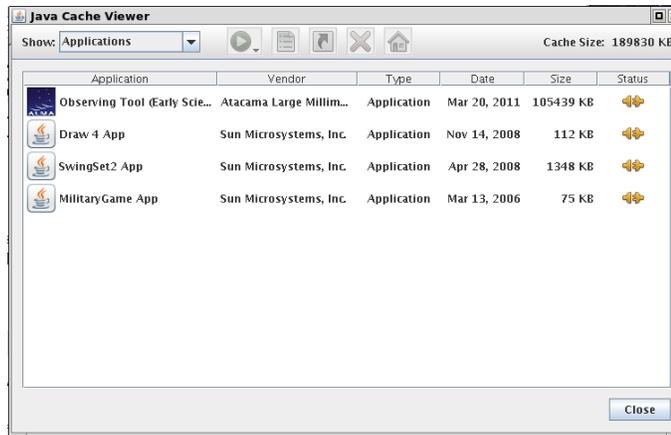


Figure 2.3: An example of the Java Application Cache Viewer. The viewer displays the Java applications that are available locally. If a network connection is available, a more recent version of an application (provided it exists) can be downloaded and run.

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 MacOS is as follows:

```
> cd ALMAOT-Cycle2/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.

# 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.

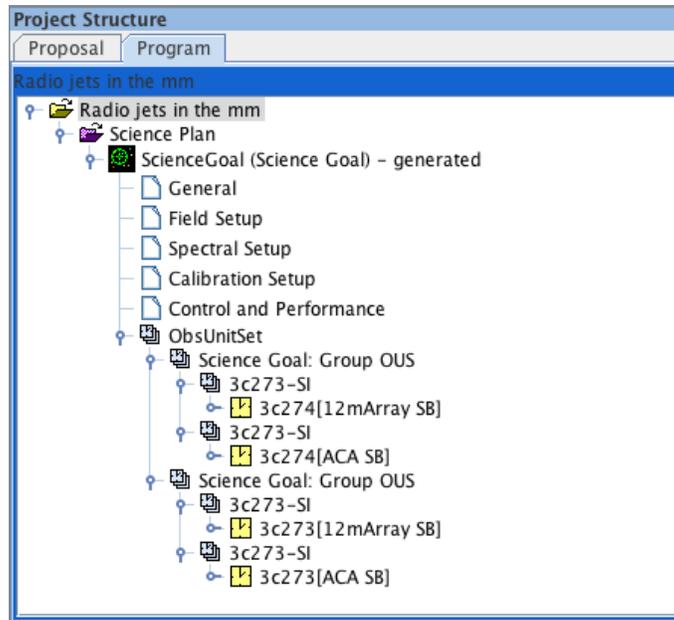


Figure 3.1: The Project Structure pane for a project involving two sources, each of which requires the 12-m array and the ACA. For each source, the SBs for each array live in their own Member OUS, and these are contained within a Group OUS. The two Group OUSs are contained within their common Science 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

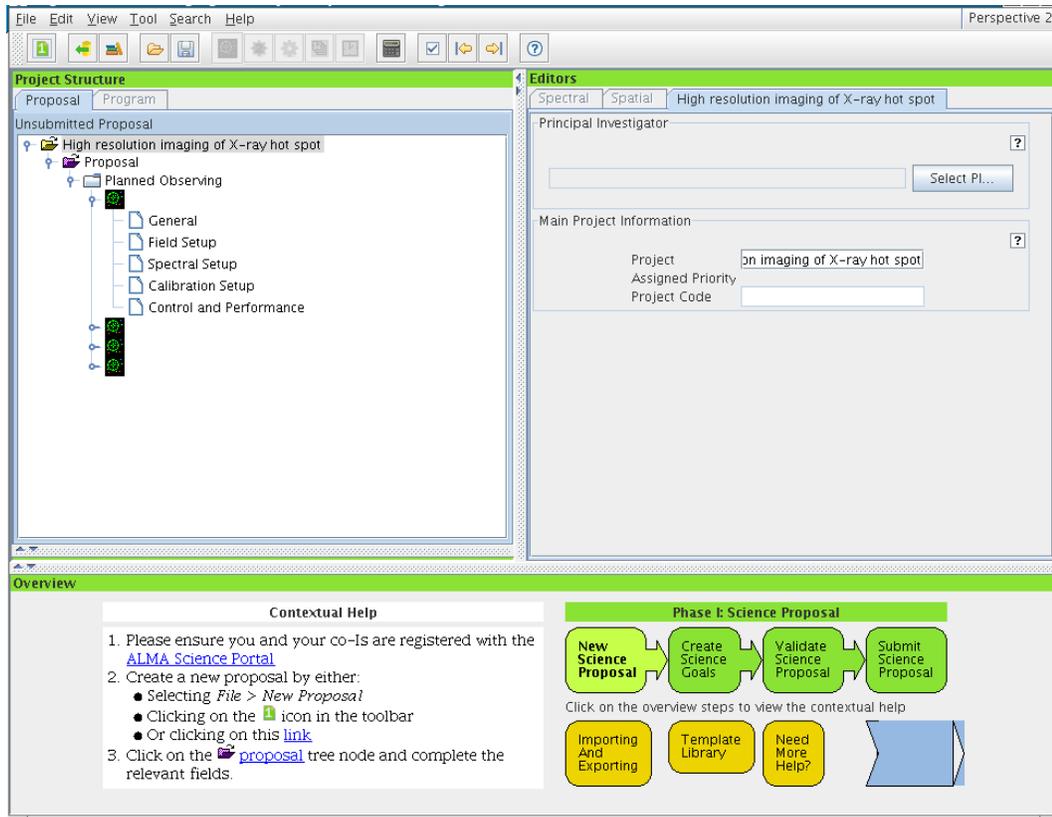


Figure 4.1: The Observing Tool main GUI.

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

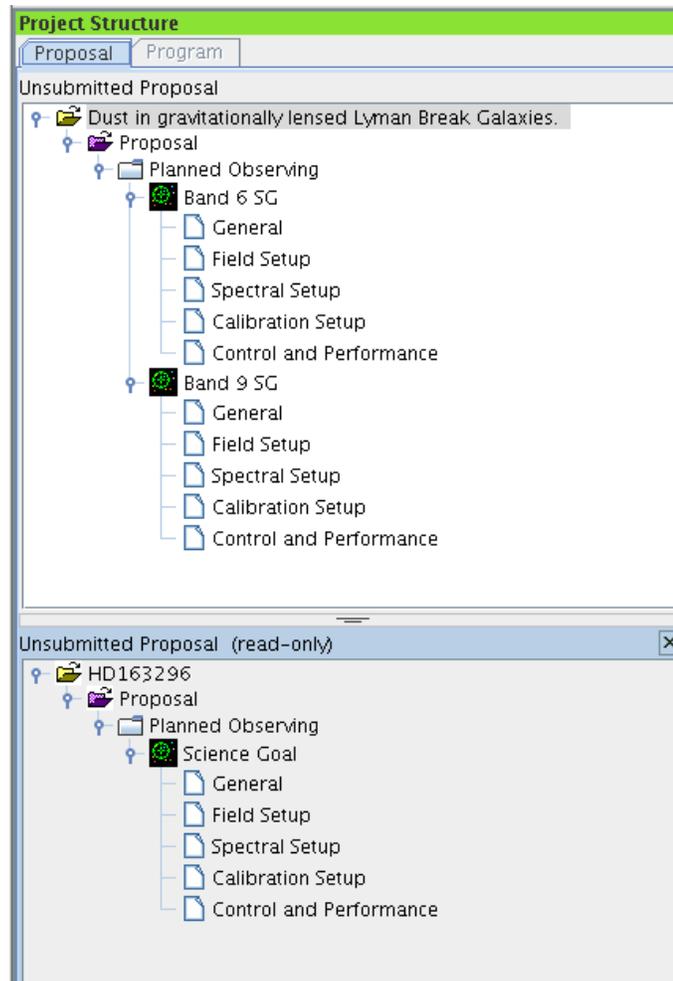


Figure 4.3: The Project Structure Pane. Visible is the structure of a Phase-1 proposal with two Science Goals (top) and a project that has been loaded as a template (bottom).

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

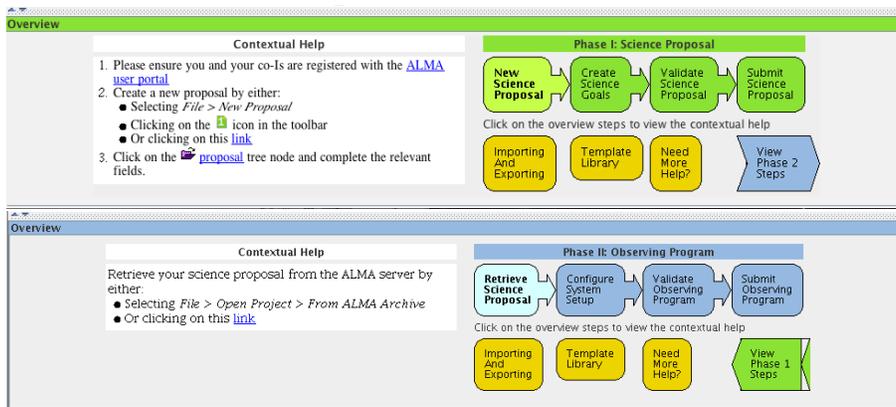


Figure 4.4: The Overview panes for Phase 1 (top) and Phase 2 (bottom). The text on the left reflects the project phase that is selected on the right.

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:

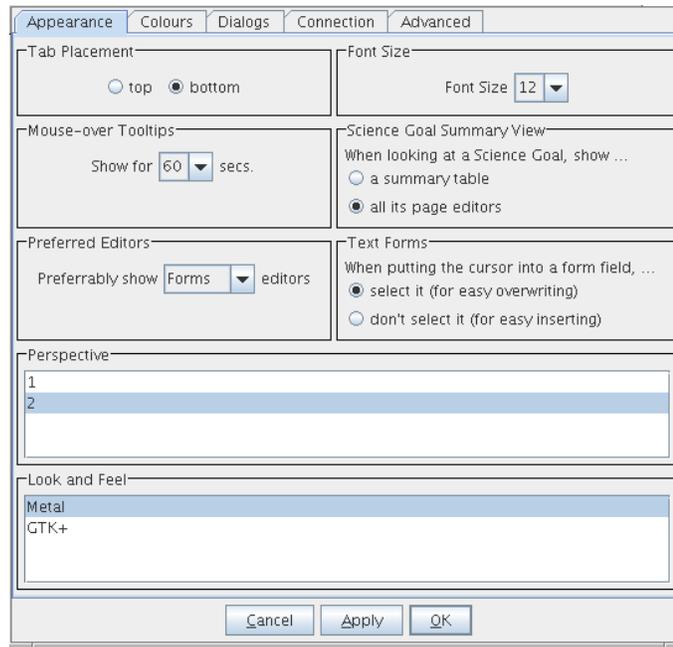


Figure 4.5: The GUI of the OT for setting the user preferences. The Appearance tab has been selected.

- 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 the “New Proposal” menu item 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. The Project form is visible in Figure 5.1.

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.



The screenshot shows a GUI window with two main sections. The top section is titled "Principal Investigator" and contains a text input field with the value "Rein Warmels (rwarmels@eso.org)" and a "Select Pl..." button. The bottom section is titled "Main Project Information" and contains three text input fields: "Project", "Assigned Priority", and "Project Code". Both sections have a question mark icon in the top right corner.

Figure 5.1: The Forms editor for the Project node, as seen by an unprivileged user.

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 (Figure 5.2). 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.

The screenshot shows a web form titled "Proposal Information". It contains several input fields and a list of options:

- Proposal Title:** Gas and dust at high redshift
- Proposal Cycle:** TEST\_6
- Abstract (max. 4000 characters):** Your abstract here.
- Proposal Type:** Radio buttons for "Standard" (selected) and "Target Of Opportunity".
- Scientific Category:** Radio buttons for "Cosmology and the High Redshift Universe" (selected), "Galaxies and Galactic Nuclei", "ISM, star formation and astrochemistry", "Circumstellar disks, exoplanets and the solar system", and "Stellar Evolution and the Sun".
- Keywords (max. 2 keywords):** A list box containing "Lyman Alpha Emitters/Blobs (LAE/LAB)", "Lyman Break Galaxies (LBG)", "Starburst galaxies" (highlighted), "Sub-mm Galaxies (SMG)", and "High-z Active Galactic Nuclei (AGN)".

Figure 5.2: An example of the Proposal form. A single scientific keyword has been chosen.

### 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 (Figure 5.3) 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 a single row is a handy shortcut to enter this user into the table of investigators (Figure 5.4). 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, adding them all can be very irksome. Fortunately, if you have a previous proposal that contains all or some of the desired investigators, these can be imported 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.

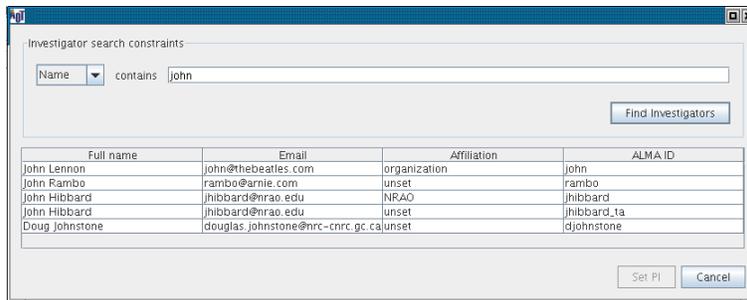


Figure 5.3: The investigator search dialog to select a proposal’s investigators from the ALMA user database.

### 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.

**In contrast to previous cycles, 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

Once the administrative information has been added, 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 (Figure 5.5). Note that a Science Goal can only be added if either the Proposal or Planned Observing nodes are currently active.

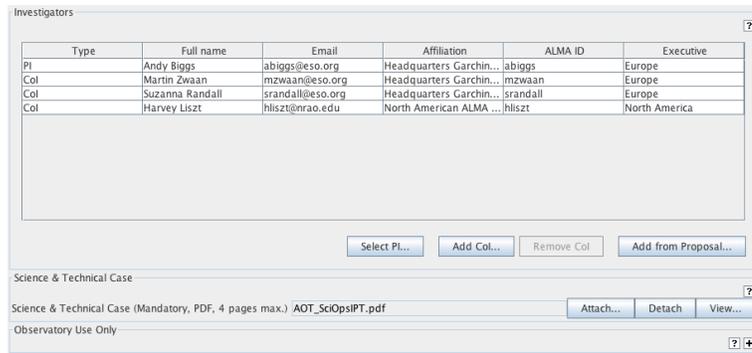


Figure 5.4: The lower part of the Proposal form with investigator details and attached scientific justification.

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.

The six sections of a Science Goal are: General, Field Setup, Spectral Setup, Calibration Setup, Control and Performance and Technical Justification. These will now be discussed in detail.

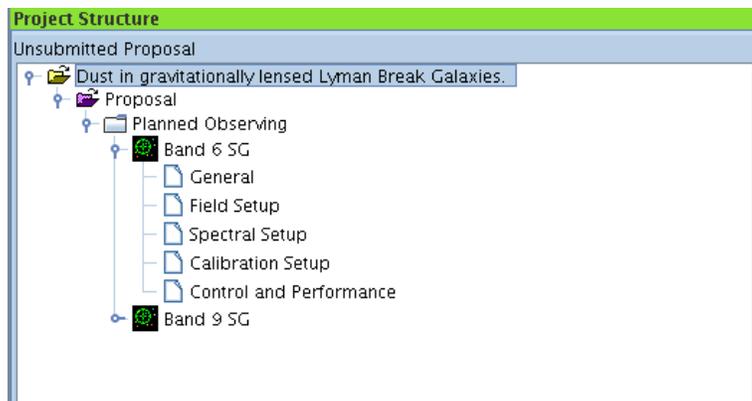


Figure 5.5: Project Structure tree for a Phase-1 proposal with two Science Goals.

### 5.3.1 General

The Science Goal name and a description of the Science Goal can optionally be completed using the text fields in the General form. To edit the description, it is most convenient to type directly into the text field, although it is also possible to launch a sophisticated text editor (jEdit).

### 5.3.2 Field Setup

#### 5.3.2.1 Source properties

In the Field Setup page, the user is asked for source parameters, such as a name, coordinates (which must be specified in the J2000 system), velocity and proper motion. 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. Regarding proper motions, the components in the Dec. and R.A. (cross declination)

directions 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 2000.

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 (default radio). 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.

Finally, the middle panel contains three fields that can be used during the technical review of the Phase-1 proposal. Although it is sometimes hard to be sure of the values before the source has actually been observed, 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 if full polarization has been requested. 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.

The above-described information (except Solar System objects) can be added to a Science Goal from an ASCII file using “Load from File...”. This can be used to either load a set of additional pointings or to completely replace the list of currently-defined pointings. The format of the ASCII source list is shown below; it should be possible to cut and paste this into a text editor:

```
Source Name, RA(sexagesimal) , Dec(sexagesimal), PMRA (mas/yr), PMDec(mas/yr),  
Velocity (km/s), velocity reference frame, peak continuum (mJy), peak line flux (mJy),  
expected continuum polarization (%), expected line polarization, expected linewidth (kHz)  
-- This signals end of the header  
ngc 253, 00:47:33.129, -25:17:17.808, 0.0, 0.0, 244.0, lsrk, 200, 1000, 2, 0, 1500  
ngc1068, 23:59:59.266, -00:02:02.774, 0.0, 0.0, 1133.0, topo, 1100.0, 30, 0, 0, 20
```

### 5.3.2.2 Resolving source information

The querying (or “resolving” in OT parlance) will work once a source name has been entered. The OT will first try SIMBAD and then, if no result is forthcoming, NED. It is not possible to select which server is queried although the OT will state which one gave the displayed result. In the case of SIMBAD, the OT performs a so-called “basic query”. The safest method is to enter a non-ambiguous catalogue/survey name such as Cen A, NGC 5128, Arp 153, etc. Catalogue/survey names that include coordinates are okay as well e.g. PKS J1325-4303. Note that searches based on coordinates alone e.g. 1325-4303 are totally disallowed as they hardly ever return the right source.

It is possible to search for a source using the so-called IAU format i.e. a source name based on the source coordinates and an equinox indicator e.g. J1325-430. This type of search is entered as “iau J1325-430”, but should usually be avoided as it will usually return the wrong source (SIMBAD returns several sources around the implied position and the OT simply takes the first one). Inserting an “object type” can though make this a fairly useful search option e.g. “iau J1325-430=QSO”. The name should though be changed to something more sensible once the correct source has been found.

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.

Although an extremely useful tool resolving source information should be used with care and all details should be checked very carefully. The OT will present a table containing the source information that has been resolved, before this is entered into the Field Setup form. This will warn the user if proper motions or a velocity have not been found and will also give the actual name of the source contained within the database (as opposed to the one that was used for the search). 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.

**Please note that the user has ultimate responsibility to ensure that the source details are correct!**

### 5.3.2.3 Field definitions

Figure 5.6: The Science Goal Field Setup form for a rectangular field definition.

There are two kinds of field definition in a Phase-1 Science Goal, one or more individual pointings around a source position, or a single rectangular area. Depending on which of these is chosen, the contents of the third panel at the bottom of the page will change. Rectangles will ultimately either be observed as a collection of individual pointings i.e. a mosaic (12- and 7-m arrays) or scanned continuously in multiple rows (Total Power antennas). As the response of the antenna to the astronomical signal drops off with increasing distance from the pointing centre, the effective noise in a single pointing is position-dependent. This is compensated for by overlapping the pointings and the row scans. It is not currently possible to define more than one source per Science Goal if this uses a rectangular field definition.

For multiple pointings, a list of positions can be entered in a table in the Forms editor (Fig. 5.6) or can be placed onto an image using the Visual Spatial Editor (Chapter 8). As with the sources within a Science Goal, the individual pointings within a single source cannot be more than 10 degrees apart. If these pointings are ultimately to be pipeline processed as a mosaic, this should be indicated by checking the “Custom Mosaic” box – in this case all fields should be overlapping. Otherwise, each pointing will produce a single image.

For a rectangular field, the size and orientation can be entered manually at the bottom of the Forms editor, or it can be drawn by hand using the Visual Spatial Editor (Chapter 8). Once a rectangle has been defined, the OT will automatically calculate a mosaic pattern of evenly-spaced single pointings that will cover the defined area, both for the 12-m and 7-m arrays. The number of pointings for each array will be displayed in the Forms Editor and displayed in the Visual Spatial Editor. The latter will also display the area that will be scanned by the TP array if the ACA has been selected. If you would like to use the mosaic pointings in your own software, or as input to CASA’s `simdata` task, their positions can be exported to file.

The spacing parameter can be specified in either angular units or as a fraction of the antenna beam (“main” beam), but defaults to the Nyquist value in both cases. This is the value,  $\lambda/(\sqrt{3}D)$ , that is appropriate for a hexagonal/triangular mosaic pattern, the OT’s default. As the antenna beam size is  $1.2\lambda/D$ , the actual value reported in beam units is  $1/(1.2\sqrt{3})$  i.e. 0.48. Particularly for projects that are mapping large structures, this should not be changed as it ensures maximum coverage of short  $u, v$  spacings. Projects which simply aim to cover a large area can use larger spacings, but non-uniform sensitivity will eventually result. Non-Nyquist spacings must be discussed in the Technical Justification node.

Regardless of the how the various pointings have been defined, it is not currently possible to submit a proposal with more than 150 12-m array pointings.

### 5.3.3 Spectral Setup

The Spectral Setup page contains fields to specify spectral windows, each of which samples a sources’s spectrum over a particular range of frequencies. The Forms editor basically consist of panels for the spectral specification, a feedback area that gives messages when the spectral specs are in error, and a panel that contains the sources that have been defined in the Field Setup page. An example is provided in Figure 5.7. An extremely useful accompaniment to the Forms editor is the Visual Spectral Editor that is described in full detail in Chapter 9.

The first thing to select is the type of spectral observation: Spectral Line, Single Continuum or Spectral Scan. The main difference between Spectral Line and Single Continuum is that the latter is basically a shortcut to defining a maximum-bandwidth, low-resolution spectral setup that will almost certainly be used for observing a continuum only. Spectral Line gives you full flexibility in defining spectral window positions, bandwidths and spectral resolutions. Spectral Scan is also a shortcut, in this case to a collection of multiple tunings that cover a continuous array of frequency space.

In addition, the polarization products must be specified. All ALMA receivers detect linearly-polarized radiation and the two orthogonal senses of this are referred to as X and Y. In order to maximise sensitivity, dual-polarization observations correlate both the X and Y signals from each antenna, leading to both XX and YY being delivered for each spectral window. It is usually only necessary to observe in single polarization (XX) if the maximum spectral resolution is required. Full polarization observations (XX, YY, XY and YX) should be selected if the source polarization properties (magnitude and position angle of linear polarization) need to be determined. For the moment, full polarization can only be selected for sources that are no larger than one third the size of the antenna beamsizes i.e. mosaics and the ACA are not available.

#### 5.3.3.1 Spectral Line

As said above, the spectral line interface gives maximum flexibility in what can be defined. It will in fact generally be used to observe spectral lines, usually using high spectral-resolution correlator modes (FDM) although low spectral-resolution modes (TDM) are also available, either for wide spectral lines or continuum determination. A mixture of these can be observed in the same spectral setup (Figure 5.7). A line peak flux density and a line width must be entered into the expected source properties section of the Field Setup form.

Spectral Type

Spectral Type  Spectral Line  
 Single Continuum  
 Spectral Scan

Polarization Products desired  XX  DUAL

Spectral Line

Baseband-0

Fraction	Center Freq (Rest)	Center Freq (Sky)	Transition	Bandwidth, Resolution (Hanning smoothed)	Representative Window
1(Full)	115.27120 G...	114.83638 G...	CO v=0 1-0	58.594 MHz( 153 km/s), 30.518 kHz( 0.080 km/s)	<input checked="" type="radio"/>

Select Lines to Observe in Baseband-0... Add Delete

Baseband-1

1(Full)	113.26726 G...	112.84000 G...	Manual window	58.594 MHz( 156 km/s), 30.518 kHz( 0.081 km/s)	<input type="radio"/>
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Select Lines to Observe in Baseband-1... Add Delete

Baseband-2

1(Full)	103.22940 G...	102.84000 G...	Manual window	58.594 MHz( 171 km/s), 30.518 kHz( 0.089 km/s)	<input type="radio"/>
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Select Lines to Observe in Baseband-2... Add Delete

Baseband-3

1(Full)	101.22183 G...	100.84000 G...	Manual window	58.594 MHz( 174 km/s), 30.518 kHz( 0.091 km/s)	<input type="radio"/>
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Select Lines to Observe in Baseband-3... Add Delete

Representative Frequency

The representative frequency is used in conjunction with the sensitivity entered on the 'Control and Performance' page to estimate the required observing time and to set the size of the antenna beam shown in the 'Spatial Visual' editor. If the transition you are most interested in does not fall in the centre of the chosen spectral window, its frequency can be changed here. The sky equivalents of the representative frequency are shown in the targets table below.

115.2712 GHz

Figure 5.7: Example of a Science Goal Spectral Setup Form. In this setup, four spectral windows have been defined. The first baseband contains an observation of CO in a narrow, high-resolution, spectral window and was created using the Spectral Line Picker. The other three basebands all contain a single, low-resolution, spectral window in order to determine the source continuum. They were entered manually and are automatically described as such by the OT. The CO spectral window has been selected to set the Representative Frequency.

Within each of the four available basebands, a single correlator mode can currently be used, and the bandwidth of this can either be observed as a single or multiple spectral windows. These can either be entered manually or via the Spectral Line Selection tool which will set the frequency automatically (see Section 7.3). Once a row in the spectral line table has been entered, it is possible to choose the bandwidth and spectral resolution of the spectral window and, for FDM, a meaningful name (e.g. spectral transition) must be entered. The single TDM spectral window is shown in bold font in order to distinguish it and, although its bandwidth is stated as 2000 MHz, its effective bandwidth is actually only 1875 MHz (the correlator outputs the full 2000 MHz though).

As Hanning smoothing is enabled by default in the ALMA correlator, the displayed frequency resolution will always be at least twice that of the channel spacing. Further smoothing is possible by averaging channels in the correlator. This has the advantage of reducing the data rate and volume and therefore making data transport and reduction much easier. Spectral averaging of the relevant spectral windows is done by selecting a power of two (up to a maximum of 16) from the drop-down list. This is done on a per spectral window basis and the displayed spectral resolution will be updated to reflect the choice of averaging.

Note that, because of the Hanning smoothing, averaging channels does not simply cause the spectral resolution to increase by the averaging factor. However, a rule of thumb is that as the averaging factor is increased, the spectral resolution tends towards the channel spacing multiplied by the averaging factor. It is not possible to average TDM spectral windows as these already have very low spectral resolution.

Multiple spectral windows per baseband (known as Multi-Region Mode) are created in the correlator by moving the individual 62.5 MHz-wide tunable filters within the confines of the baseband – this therefore only makes sense for modes with a bandwidth of 1 GHz or less. The splitting up of modes is done using the “Fraction” column in the spectral window table. This changes the modes available in the drop-down list by e.g. halving

the bandwidths, and different fractions therefore allow spectral windows with a variety of bandwidths. Note that the spectral resolution (before spectral averaging) of each must be identical, or else they cannot be said to correspond to the same correlator mode. The sum of the fractions must (obviously) not exceed unity, although (less obviously) they do not have to add up unity i.e. it is not compulsory to use the full mode. Multi-region mode is not possible using TDM where it will always only be possible to select one maximum-bandwidth spectral window per baseband.

If the entered frequencies are not able to be observed simultaneously e.g. they do not all lie within the receiver sidebands, an error message will appear in red below the spectral window table and the proposal will also not validate. Using the Visual Spectral Editor is an excellent way of diagnosing spectral setup errors as it displays the lines and their bandwidths as well as the ALMA bands and sidebands. When choosing lines with the Selection Tool, its unobservable line filter will ensure that lines cannot be picked if they can't be observed simultaneously with lines that have already been defined.

The final column of the spectral window table selects which is to be used to set the Representative Frequency. This is a very important parameter as it, in conjunction with the sensitivity entered in the Control and Performance page, sets the total observation time (by setting the opacity and aperture efficiency that is used in the sensitivity calculation). It also sets the antenna beamsize in the Visual Spatial Editor. If the transition you are most interested in does not fall in the centre of the chosen spectral window, the Representative Frequency can be changed to the appropriate value, with the restriction that the edited frequency must lie within the spectral window. The Representative Frequency interface is also shown in Figure 5.7.

At the bottom of the page is a list of all the sources that have been defined in the Field Setup page and which are listed together with their velocity specifications and Representative Frequencies. The latter are given in the sky (observed) frame as this is relevant quantity for determining the observing time for each source. Clicking on a source will use that source's velocity for the rest-to-observed frame and velocity conversions in both the spectral window table and the Spectral Visual Editor (Chapter 9).

The Spectral Visual Editor is very useful as it provides a clear, graphical overview of the spectral setup including the spectral windows and their location within the sideband. At Band 9, the "image" versions of the user-defined "signal" spectral windows are also shown. Astronomical emission and atmospheric noise from the image spectral windows find their way into their signal equivalents, although the correlator is able to reject the astronomical component. The noise, however, will remain and therefore regions of low atmospheric transmission should also be avoided in the image spectral windows.

### 5.3.3.2 Single Continuum

The Single Continuum interface essentially provides a shortcut to producing a spectral setup that covers the maximum possible bandwidth with the lowest possible spectral resolution. It is not expected that this interface will be used to observe spectral lines. For the expected source properties, only a continuum flux must be entered.

After selection of a receiver band each baseband receives a 2 GHz-wide TDM spectral window, each of which has an effective bandwidth of 1875 MHz. For bands that have 2SB receivers e.g. bands 3, 4, 6, 7 and 8, two will be placed in each sideband. For band 9, which is a DSB receiver, all four are placed in the same sideband and the same discussion about avoiding the image-sideband equivalents mentioned in Section 5.3.3.1 applies.

The default spectral window frequencies have been chosen such that the continuum sensitivity is maximised and prominent atmospheric absorption features avoided. For most projects these defaults should be chosen. It is possible to choose a different set of spectral windows by entering a central (average) frequency (in the observed/sky frame) although this cannot be done if full polarization has been selected.

The Representative Frequency will default to being the central (sky) frequency of the first spectral window. As with the spectral line interface, this can be changed, both by changing the spectral window and the frequency within this window. However, it is not possible to change the other parameters of the individual spectral windows. These can only be changed by editing the single value of the sky frequency.

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

Table 5.1: Default single continuum frequencies for the available receiver bands.

Band	Spectral window frequencies (GHz)	Central frequency (GHz)
3	90.5, 92.5, 102.5, 104.5	97.5
4	138, 140, 150, 152	145
6	224, 226, 240, 242	233
7	336.5, 338.5, 348.5, 350.5	343.5
8	398, 400, 410, 412	405
9	676, 678, 680, 682	679

### 5.3.3.3 Spectral Scan

For projects which require more frequency coverage than a single tuning can provide, a short-cut to a multiple-tuning, continuous frequency coverage setup is provided by the Spectral Scan interface. Examples of such a project include the search for multiple CO lines for redshift measurement reasons, or a survey of multiple species in the dense line forest of a molecular cloud. Spectral scans can only be used for observations of a single offset pointing per source and the ACA is not allowed.

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. It is only possible to select spectral windows with a width greater than or equal to 500 MHz. Using these parameters the OT will then attempt to cover the requested frequency range using a maximum of five tunings. This maximum results in it not always being possible to cover the requested range and additional Science Goals should perhaps be created if significantly more coverage is required. The OT will issue a *warning* if this is the case. Also, the algorithm used to calculate the tunings usually assumes that all spectral windows of a tuning must be used – this leads to the actual range being observed usually differing from that requested. Spectral averaging is available, but will be the same for each spectral window of each tuning.

In more detail, spectral scans involving only a single sideband (either because the 500 or 1000 MHz-wide spectral windows are being used, or because the requested frequency coverage is relatively small) are calculated by placing the lowest frequency of tuning  $n + 1$  directly next to the highest frequency of tuning  $n$ . No overlap is assumed, either between the spectral windows of a tuning, or between tunings. This ensures maximum frequency coverage and should still ensure a seamless join between the tunings as, when placing the tunings, the OT assumes the effective bandwidth for the FDM spectral windows i.e. edge channels are already flagged. For TDM, the OT also uses the effective bandwidth although the edge channels are not flagged in the output data.

A two-sideband tuning solution is used when the 1875 and 2000 MHz-wide spectral windows are requested and the frequency coverage is greater than can be provided by a single-sideband solution. In this case, only the lower sidebands are used to arrange the different tunings i.e. the highest frequency in the lower sideband of tuning  $n$  abuts against the lowest frequency in the lower sideband of tuning  $n + 1$ . No overlap is assumed between these, but significant overlap will result elsewhere in the scan due to the presence of two sidebands. The effective bandwidth of 1875 MHz is assumed when arranging the 2000 MHz-wide TDM spectral windows.

The OT reports the frequencies of each spectral window and also displays them in the Visual Spectral Editor. Spectral windows corresponding to the same tuning are plotted with the same  $y$ -offset and displayed with the same colour, this being different for each tuning. Also shown is the requested frequency range for easy comparison with the actual frequency coverage.

### 5.3.3.4 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 usually irrelevant as the setup is usually defined in the sky frame and 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 OT automatically calculates how many tunings are required by calculating a solution separately for each velocity and then seeing which of the other sources could be observed using this tuning. The result is a minimum list of tunings required to observe all the spectral lines. The number of tunings is reported in the Time Estimate dialogue (Section 5.3.5.3).

### 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.

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. There are three pointing observations and these are associated with the calibration that appears below them i.e. the first pointing is for the amplitude calibrator.

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

The screenshot shows the 'Control and Performance' configuration window. It is organized into several sections:

- Configuration Information:**
  - Antenna Beamsize ( $1.2 * \lambda / D$ ): 12m 54.181 arcsec, 7m 92.882 arcsec
  - Number of Antennas: 12m 34, 7m 9, TP 2
  - Longest baseline ( $L_{max}$ ): Most extended 12m configuration 1.508 km, Most compact 12m configuration 0.166 km
  - Synthesized beamsize ( $\lambda / L_{max}$ ): 0.359 arcsec, 3.271 arcsec
  - Shortest baseline ( $L_{min}$ ): 0.041 km, 0.014 km
  - Maximum recoverable scale ( $0.6 \lambda / L_{min}$ ): 8.005 arcsec, 22.911 arcsec
- Desired Performance:**
  - Desired Angular Resolution: 3.00000 arcsec
  - Largest Angular Structure in source:  Point Source,  Extended Source 100.00000 arcsec
  - Desired mosaic sensitivity: 100.00000 mJy equivalent to 1.04300 K
  - Bandwidth used for Sensitivity: RepresentativeWindowResolution, Frequency Width 0.060577 MHz
  - Do you request complementary ACA Observations?:  Yes,  No
- Science goal integration time estimate:**
  - Is more time required due to u,v coverage issues? (must be justified):  Yes,  No
  - Are the observations time-constrained?:  Yes,  No

Buttons: 'Suggest', 'Time Estimate'.

Figure 5.8: Example of the Control and Performance parameters.

The final 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. It also includes how long these will observe for which, unlike most other radio/mm/submm telescopes, is calculated from a desired sensitivity. An example of the Control and Performance parameters is shown in Fig. 5.8, including the ACA interface.

### 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 and the maximum and minimum baseline lengths of the most compact and most extended configurations and the angular resolution ( $\lambda/L_{\max}$ ) and maximum recoverable angular scale ( $0.6\lambda/L_{\min}$ ) corresponding to each. Note that the source declination is not taken into account when calculating these quantities. Also shown is the beamsize of both the 12-m and 7-m antennas ( $1.2\lambda/D$ ) 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  $\lambda$ .

Based on these displayed values, it should be possible to enter the requirements for the proposed observations. The angular resolution, for example, 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. For the largest angular structure (LAS), point source should only be chosen if the source will be unresolved by any of the available configurations. Otherwise, an estimate of the LAS should be entered.

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. If point source is indicated then only one configuration will be used.
- If point source has not been selected, the OT then checks to see whether the selected array has baselines that are short enough that the largest angular structure is less than the max recoverable scale. If not, and if the existing 12-m configuration is fairly extended, then a more compact 12-m configuration will be added.
- It remains possible that the source contains structures large enough that the ACA might also be required. This can be set automatically using the “Suggest” button. This choice 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. As the ACA TP array is not available for continuum observations or at band 9 during Cycle 2, the OT will issue a warning if the 7-m array is unable to provide short-enough baselines to map the largest structures in the source.

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 give the names of the configurations that 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 5.9) 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 (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). 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.

Every observation 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 “control” 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. This is listed in the dialogue as a delay calibrator. Full polarization observations also include a dedicated polarization calibrator.

In deriving its time estimates, the OT usually assumes that the observations in a Science Goal will go into a single SB (that might be executed more than once). The exception is for SGs that include sources whose velocities are different enough that they cannot be observed using the same spectral setup (Section 5.3.3.4). The OT assumes that these will be split into separate SBs and therefore that these incur additional overheads e.g. due to the time required to start up and stop each SB.

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 – it should normally be the case that all the pointings in a mosaic are observed together i.e. an integer number of complete mosaics should be scheduled per SB. The OT does in fact assume this for

mosaics that are created from a rectangular definition, in order to calculate how many SB executions are required and the resulting calibration and other overheads.

- Time-constrained observing – if multiple visits have been requested, this will be taken into account in the time estimates.

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 More time required due to $u, v$ coverage issues

Even the instantaneous  $u, v$  coverage of ALMA is excellent and thus it is not expected that many projects will have issues reaching the requested sensitivity due to dynamic range issues. This is most likely to be a problem for complicated sources with large structures for which the sensitivity requirement is not that demanding, leading to small on-source integration times. If it is felt that more time is required than implied by the sensitivity alone, then it is possible to override the sensitivity-based time with a user-entered estimate. This should be 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 current interface allows three 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.
- Continuous monitoring – if the time required for your project is not sensitivity-based, but rather a certain fixed amount of time needs to be observed instead (for example, in order to get sufficient sampling of source variability) then that time should be entered here. Note that the time entered must be the total time for the single 12-m configuration i.e. including calibration and overheads.

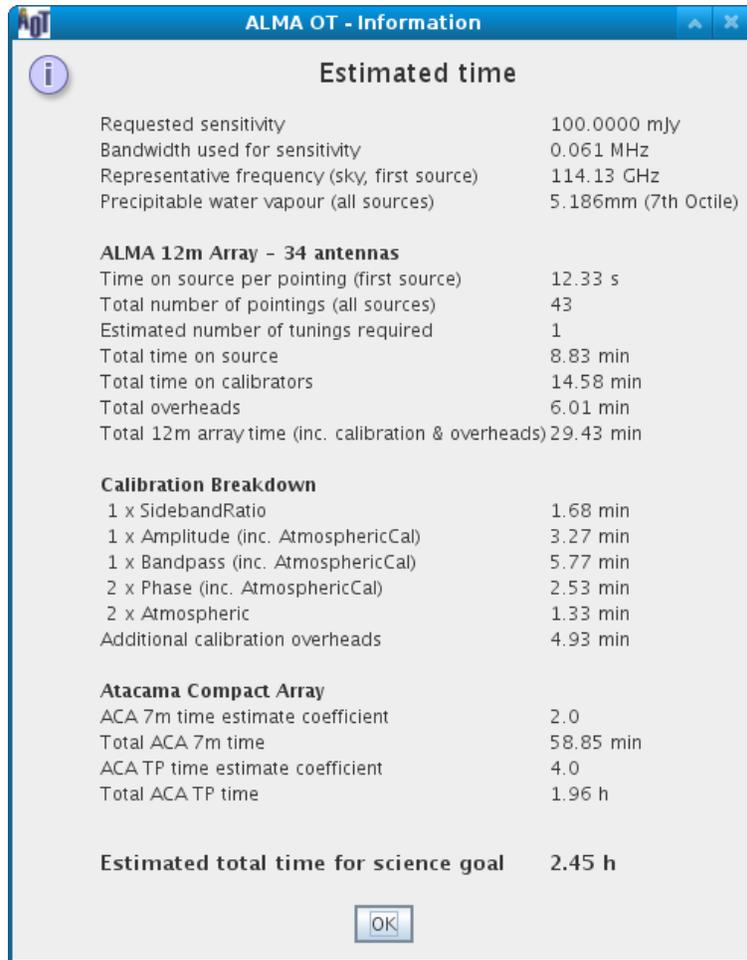


Figure 5.9: Example of the Time Estimate dialogue. This is for a mosaic project and the time per pointing has been calculated assuming antenna beam overlap. Two 12-m configurations are required as is the ACA. Their times are calculated as multiplication factors of the largest 12-m configuration time, 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.

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 for Cycle 2 is 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 should no longer be submitted as part of the PDF that contains the scientific case, but instead using a node in the Science Goal. This has been designed to help non-expert users in particular in the writing of technical justifications and does this by presenting the relevant parameters that need justifying, including “non-standard” choices, in one location in the OT. The user should read the information presented in this node carefully and use and refer to it in the textual justification, which

is also entered in this node. Please note that any figures which the user would like to refer to should go into the Scientific Justification PDF.

The following information is presented:

- Relevant science parameters – shown here are parameters that mainly affect the achieved sensitivity and the configurations and arrays that will be required.
- Expected source properties – this is mainly a repeat of the parameters that were entered in the Field Setup node, but are accompanied by their SNR equivalents and a dynamic range, if applicable. The number of resolution elements across the line width is also shown and includes the effects of Hanning smoothing and spectral averaging. A note on SNR and dynamic range calculations:
  - If the SG contains multiple sources, the SNR calculations will use the **lowest** flux density that was entered. SNR values should be no lower than 5, although exceptions are possible.
  - The dynamic range is only calculated if a continuum and line flux have been entered and is defined as the ratio of the continuum flux and line rms. The higher this parameter, the more challenging the observation will be as detecting weak lines against a strong continuum requires a very good bandpass calibration. Unlike the SNR value, the dynamic range is calculated using the **largest** source flux density.
  - For spectral line projects where a continuum flux has also been entered, the OT will calculate a continuum SNR using a continuum rms calculated from the maximum non-overlapping bandwidth of the defined spectral windows and the on-source time calculated to achieve the line rms.
- Non-standard choices – 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, briefly mention this.

The justification text itself cannot exceed 4000 characters. If no text is entered than the project will not validate.

## 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. These come in three 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 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.
- Whole proposal summary – this is a combination of the previous two summaries.

## 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 performed using the OT, it will be performed by the server in Chile. 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.



# 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.

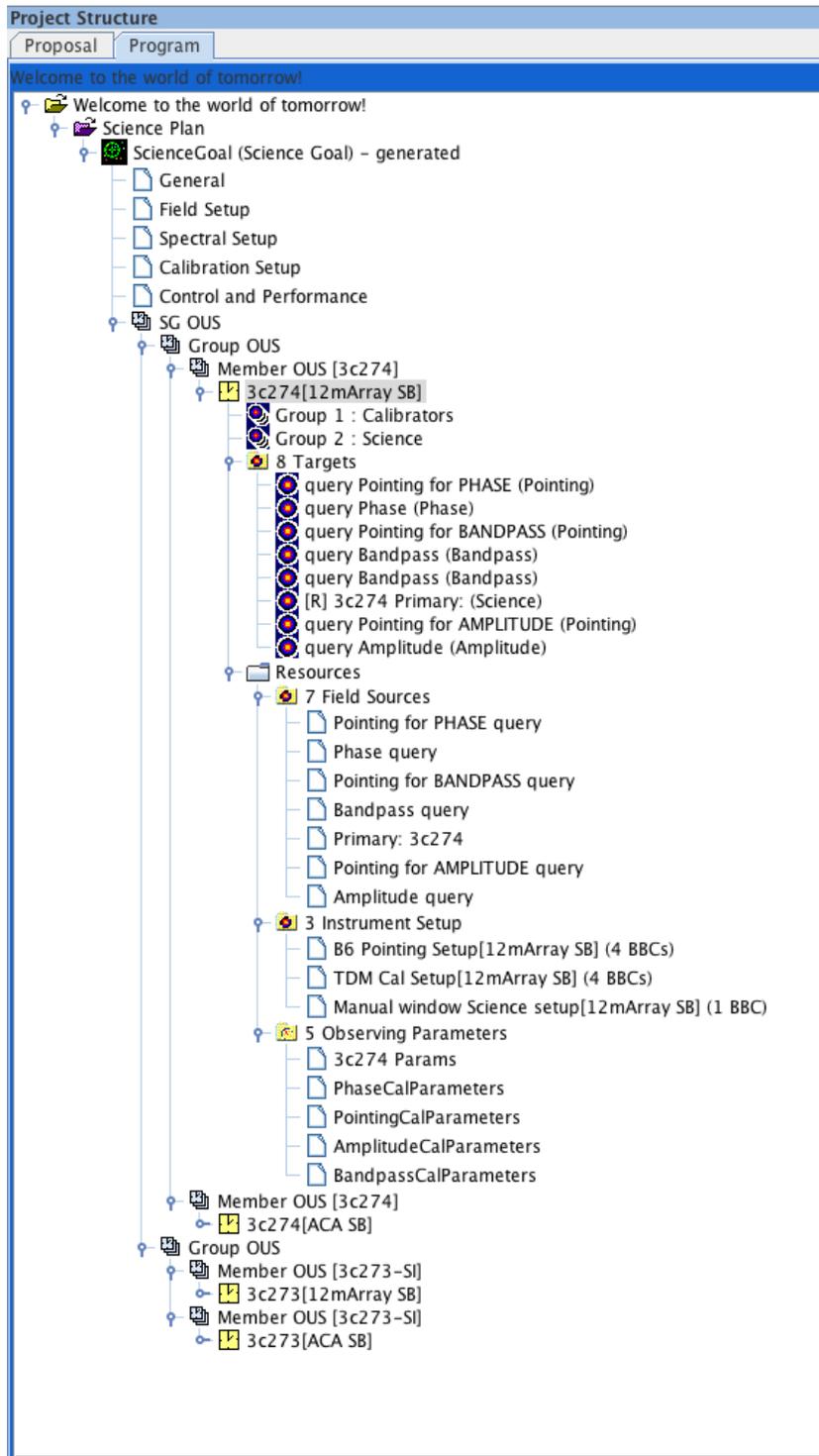


Figure 6.1: An example of a typical project structure. For this FDM project, two sources have been split into separate Group OUSs, each of which requires two Member OUSs, one for the ALMA 12-m array and one for the ACA. For only the first SB is its internal structure shown.

## 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.

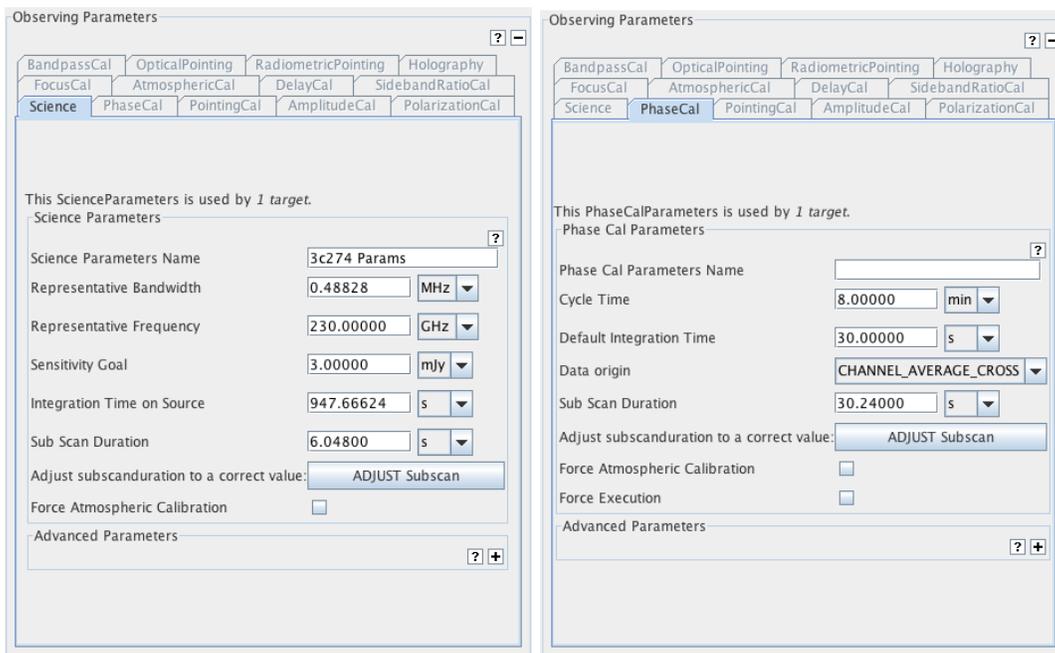


Figure 6.4: Examples of the Observing Parameters form for a science target (left) and a phase calibrator (right). The tabs at the top show all the observing intents that could be created.

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.

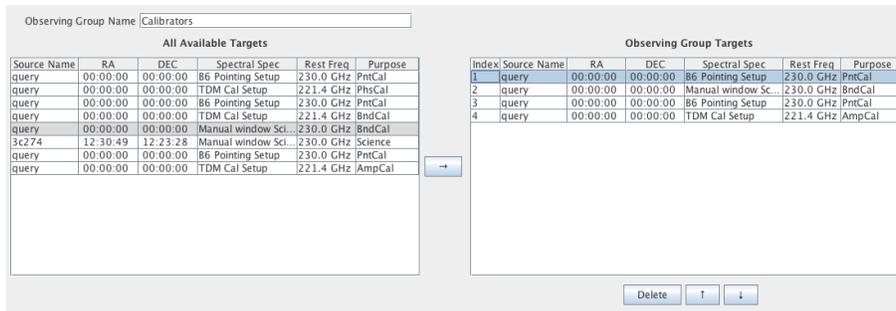


Figure 6.5: The Observing Group editor. The table on the left lists the already-defined Targets that could be placed into this Observing Group, this being done by moving them into the table on the right. The order of the chosen Targets can be changed using the up and down arrows and are removed from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

The OT has a number of tools to help users plan observations. In particular, they facilitate: calibrator selection, LO configuration, calibrator time estimation and spectral line selection. The OT also includes the ALMA Sensitivity Calculator and a template library.

### 7.1 The ALMA Template Library

The purpose of the ALMA Template Library (Figure 7.1) is to provide a set of Science Goals that cover different proposal types. Once the Template Library is opened (via the File or View menus), the Science Goals within can be inspected in situ and items within it individually copied and pasted (or dragged and dropped) into an existing Science Goal in a proposal that is being worked on. Alternatively, a complete Science Goal can be copied into an active proposal and then edited as normal.

The Science Goals within the Template Library are based on the projects contained within the ALMA Primer. A user's own projects can also be used as templates and are opened as such (in read-only mode) from the File menu.

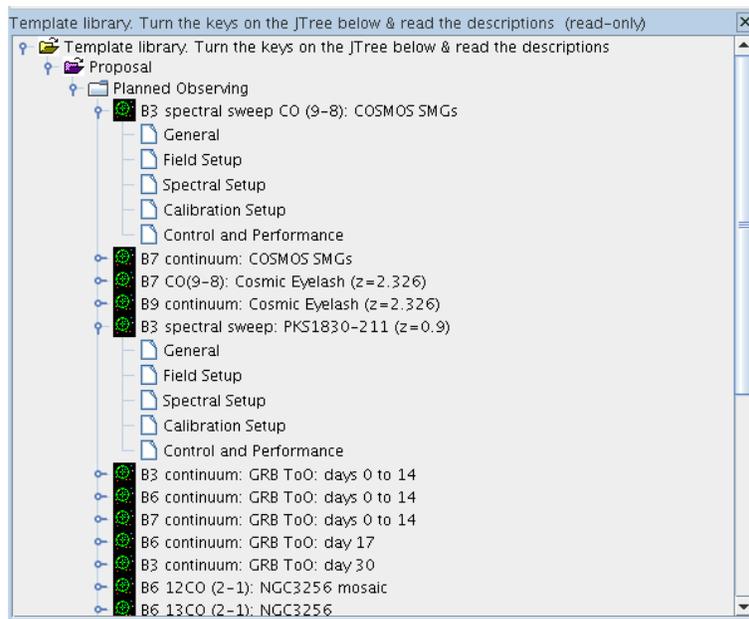


Figure 7.1: The ALMA Template Library.

## 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 a web applet in the Science Portal.

Common Parameters	
Dec	-13:00:00.000
Polarization	Dual
Observing Frequency	345.00000 GHz
Bandwidth per Polarization	10.0 GHz
Water Vapour	<input type="radio"/> Automatic Choice <input checked="" type="radio"/> Manual Choice
Column Density	2.748mm (6th Octile)
tau/Tsky	tau=0.446, Tsky=99.067 K
Tsys	288.881 K

Individual Parameters			
	12m Array	7m Array	Total Power Array
Number of Antennas	32	6	1
Resolution	2.0 arcsec	5.974554 arcsec	17.923662 arcsec
Sensitivity(rms)	.1 mJy	Infinity Jy	Infinity Jy
(equivalent to)	0.00026 K	Infinity K	Infinity K
Integration Time	13.50695 min	0.00000 s	0.00000 s

Integration Time Unit Option: Automatic

Buttons: Calculate Integration Time, Calculate Sensitivity, Close

Figure 7.2: The ALMA Sensitivity Calculator.

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

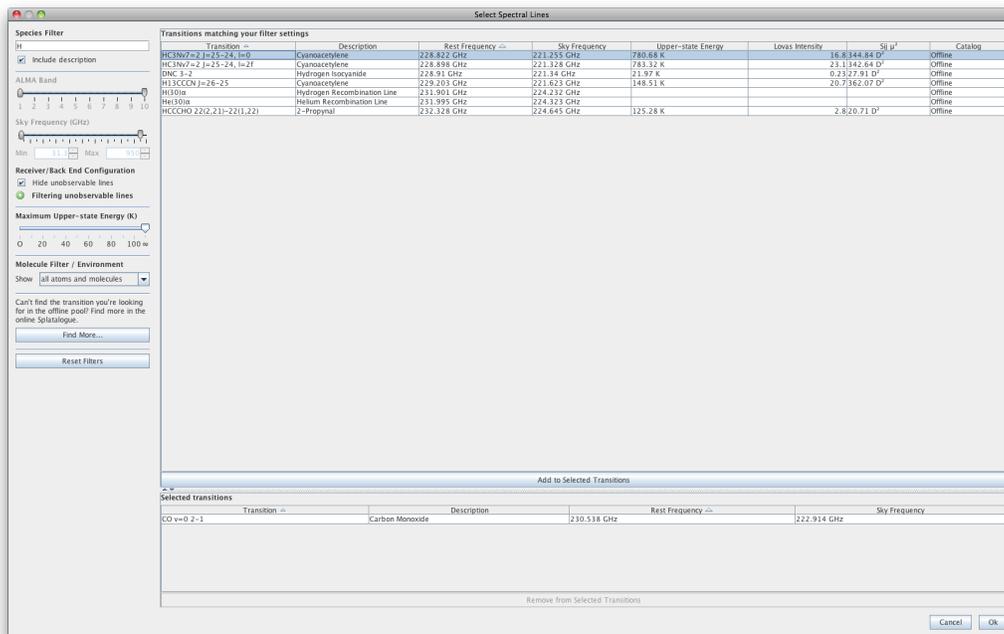


Figure 7.3: The ALMA Spectral Line Selection Tool.

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 at: [http://www.astrochymist.org/astrochymist\\_mole.html](http://www.astrochymist.org/astrochymist_mole.html). 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 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.

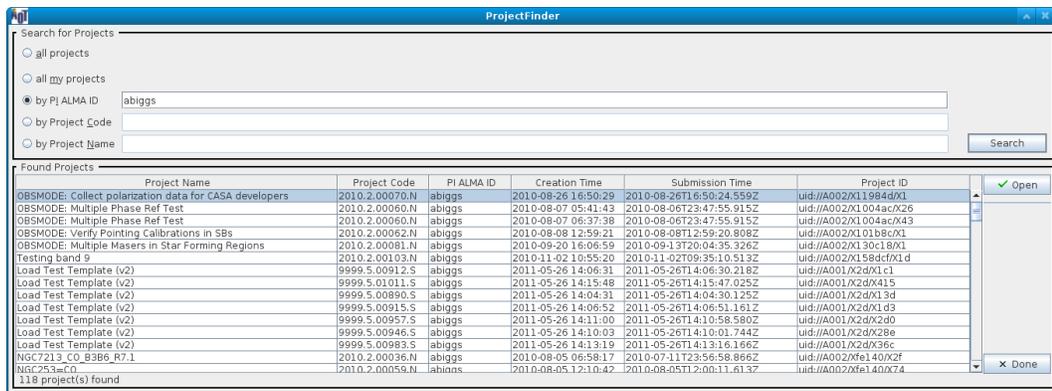


Figure 7.4: The Project Finder dialogue for searching for projects in the ALMA archive.

## 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.

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

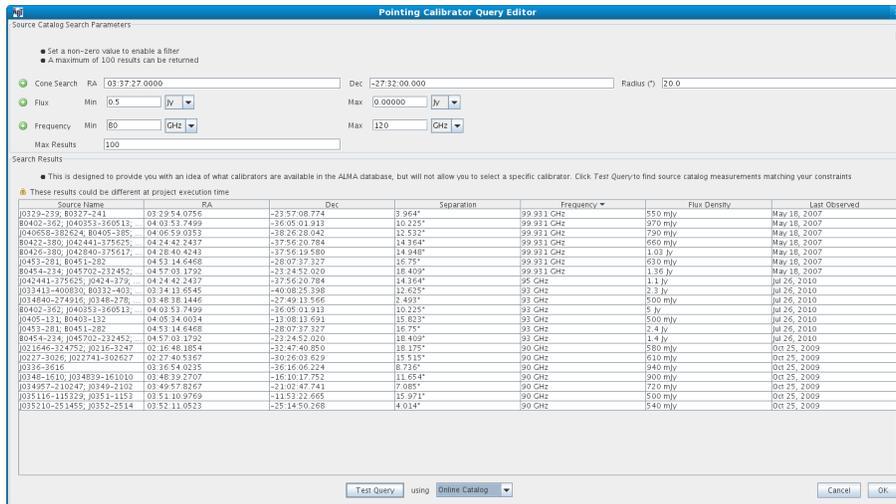


Figure 7.5: The Calibrator Selection Tool as used in the Calibration Setup of Science Goal. A search has been made for all calibrators within a 10-degree radius of a source position, that have a flux greater than 500 mJy in ALMA Band 3.

the 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

**For expert users only.** Available from the Tools menu, the LO Configuration tool 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.

## 7.7 Calibration Time Estimate Tool

The OT calculates the calibration overheads as part of its time estimate and the calibration time estimate tool was built to help in the implementation of this feature. It allows various parameters to be entered and the required dwell and cycle times for a variety of calibrators to be displayed. This tool can be seen in Figure 7.7. It is sensitive to the current choice of node in the Project Tree and will show the appropriate parameters already filled in for e.g. the currently-selected Science Goal.

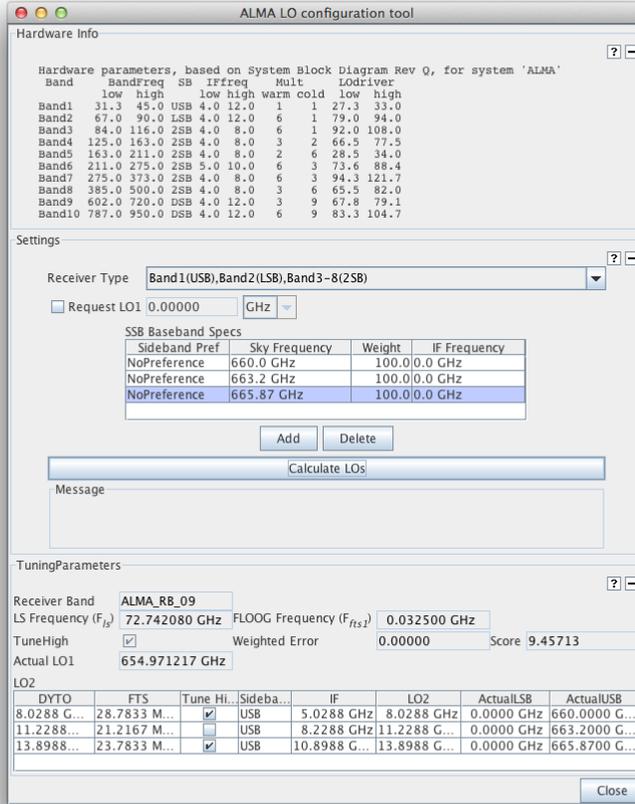


Figure 7.6: The LO Configuration Tool. Three Band-9 basebands have been requested with the tuning results shown at the bottom.

### 7.7.1 Bandpass calibration

The bandpass calculation uses a standard sensitivity equation where the time required to achieve a particular **antenna-based** SNR for a source flux of  $S_\nu$  can be written as

$$t = \left( \frac{2}{\Delta\nu(N-1)} \right) \left( \frac{\text{SNR} k T_{\text{sys}}}{\eta_q A_{\text{eff}} S_\nu} \right)^2 \quad (7.1)$$

where the remaining parameters have their usual meanings (see ALMA Sensitivity Calculator chapter of the ALMA Technical Handbook). The OT currently assumes that a SNR of 100 is required and that the typical source fluxes will be 10 Jy at bands 6 and below, and 100 Jy for bands 7 and above. It is also assumed that the bandpass created during data reduction will be smoothed by 20 channels i.e. 20 times the native correlator channel width is used.

### 7.7.2 Gain calibration

The time required per scan on the gain calibrator (also referred to as the phase calibrator) is also given by Equation 7.1, except that a minimum time of 2 seconds is enforced. The phase calibrator flux is always assumed to be 1 Jy and the required antenna-based SNR is 20 over a bandwidth of 2 GHz.

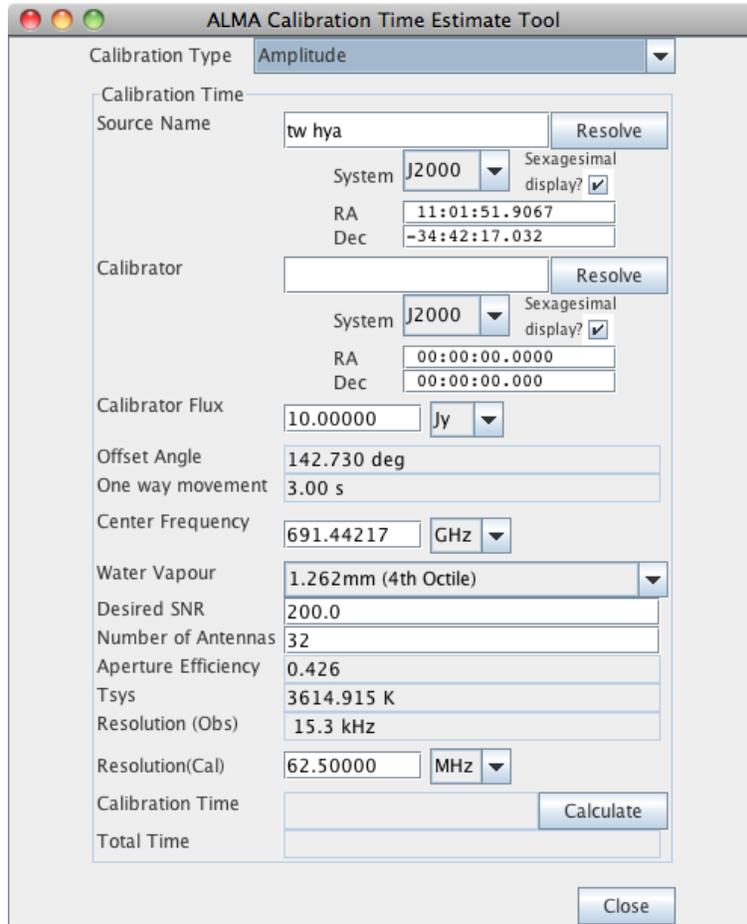


Figure 7.7: The Calibration Time Estimate as used to calculate the required time on source for an amplitude calibrator.

The phase calibration cycle time is calculated using

$$t = \max \left[ \left( \frac{2}{v_{\text{wind}}} \right) \left( \frac{\lambda}{2\pi\eta\sqrt{\sec Z}} \right)^{\frac{1}{\alpha}}, 15 \text{ sec} \right] \quad (7.2)$$

where  $Z$  is the zenith angle and  $\alpha$  the exponent of the phase fluctuation structure function (defined to be the median value at the AOS = 0.6). The phase fluctuations themselves are given by  $\eta$ , where this is equal to 2.9 for bands 6 and below, and to 6.1 for bands 7 and above. The wind speed is taken to be the site average of 10 m/s. As this formula is only valid up to 5 minutes, cycle times longer than this are set to this value.

### 7.7.3 Flux calibration

The times required to observe the flux calibrator (a process also referred to as amplitude calibration) also uses Equation 7.1 except that the source flux is always taken as 10 Jy and the required SNR as 200.

### 7.7.4 Atmospheric calibration

Use of the Amplitude Calibration Device to calibrate the temperature scale is assumed to happen every 4 min and last for 20 sec.

### 7.7.5 Pointing calibration

The integration time for each position in a standard 5-point calibration required to achieve a pointing error of  $\Delta x$  is given by

$$t_{\text{pt}} = \max \left[ \left( \frac{2}{N\Delta\nu} \right) \left( \frac{\theta}{\Delta x} \right)^2 \left( \frac{kT_{\text{sys}}}{\eta_{\text{q}}A_{\text{eff}}S_{\nu}} \right)^2, 2 \text{ sec} \right] \quad (7.3)$$

where  $\theta$  is the HPBW of the antenna. This calibration is assumed to be repeated every 15 min.

### 7.7.6 Antenna movement

The time reported for each calibration includes a contribution from the antenna movement required to get to a calibrator from the target and back again. As the OT does not know the source positions that will be observed for all calibrators, it assumes a one-way movement of 3 sec.

# 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.

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<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).

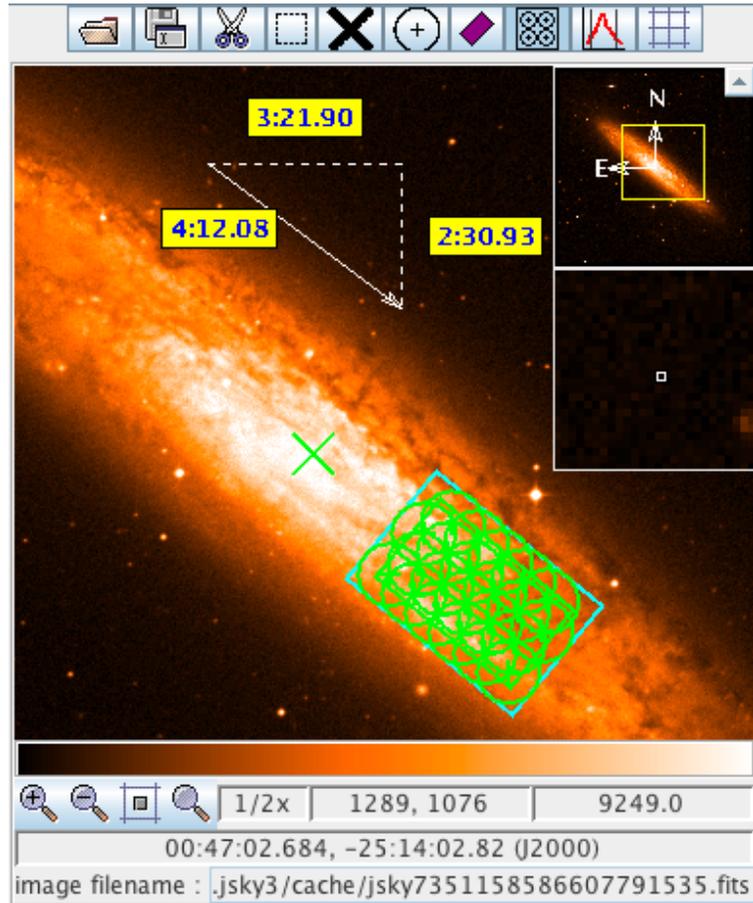


Figure 8.1: An example of the image display area on the Visual Spatial Editor. This shows a pointed mosaic observation of the outer reaches of NGC 253, the mosaic pointings having been automatically created based on a user-defined rectangle (green). The x-shaped cross at the centre marks the position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

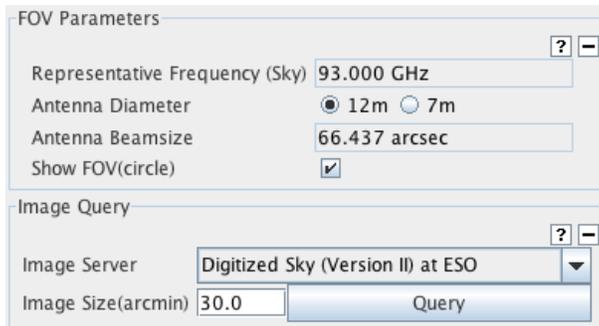


Figure 8.2: The FOV Parameters and Image Query panels in the Visual Spatial Editor.

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).

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

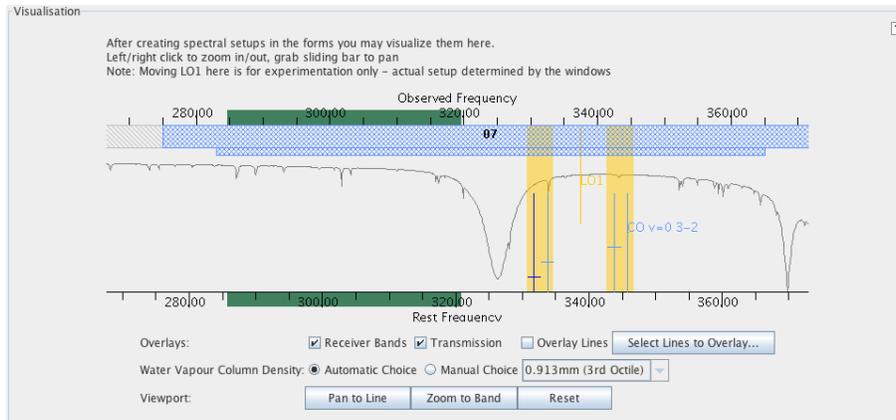


Figure 9.1: The graphical representation of the frequency information in a Science Goal. Four spectral windows are shown, a narrow one to observe the CO(3-2) transition and three other maximum-bandwidth ones for measuring a continuum. All four fit within the sidebands which are coloured yellow (as opposed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

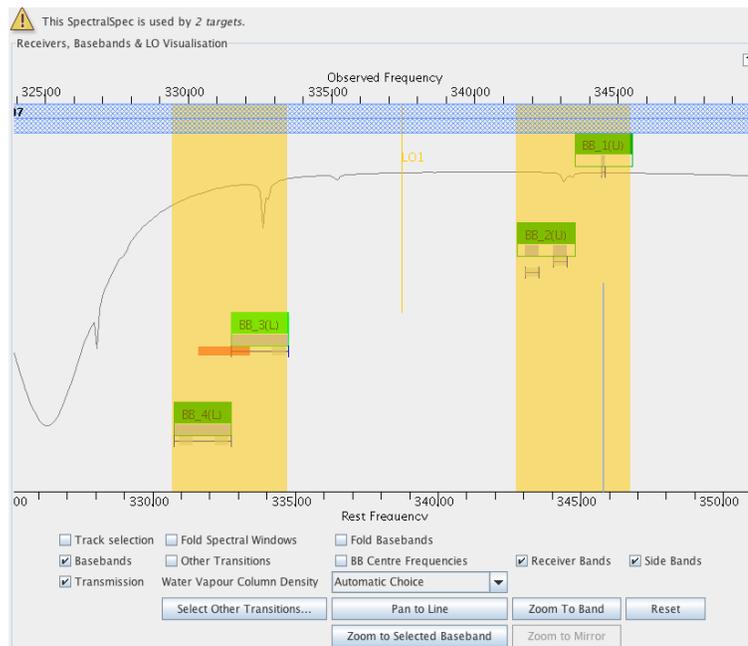


Figure 9.2: The graphical representation of the frequency information in a Scheduling Block. This is a zoomed view and hence the spectral windows and their spectral averaging regions can be seen. The basebands are shown as the green blocks and within these can be seen the spectral windows (horizontal 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. To ensure sufficient accuracy during the observations, sampling at 10-minute intervals is recommended. More frequent sampling should be avoided due to file size limits, although files with up to 90000 rows have been successfully tested.
- 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
-------------------	--------------------------	-------	--------

\*\*\*\*\*

\$\$SOE

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 ...

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          telnet ssd.jpl.nasa.gov 6775 (via command-line)  
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# Appendix B

## Acronym List

**2SB:** Two sideband  
**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  
**FOV:** Field Of View  
**LO:** Local Oscillator  
**LSB:** Lower Side Band  
**OG:** Observing Group  
**OT:** Observing Tool  
**OTF:** On The Fly  
**OUS:** Observation Unit Set  
**PWV:** Precipitable Water Vapour  
**SB:** Scheduling Block  
**SSB:** Single Sideband  
**SFI:** Single Field Interferometry  
**TFB:** Tunable Filter Bank  
**USB:** Upper Side Band



The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.

