The objective of this tutorial is to become familiar with the process of setting up the ALMA OT for a proposal, from defining key observational parameters to configuring the OT. Please note that many modes are not described in this basic tutorial, the OT User Manual (<https://almascience.nrao.edu/documents-and-tools/cycle6/alma-ot-usermanual>) provides further reference.

For this tutorial, you may either use the ***Minor Mergers*** example provided, or use your own preferred source or set of sources.

**Step 1: Estimate Source Characteristics**

Before starting to craft a proposal, you should have an estimate of some characteristics of your source. These include:

* The coordinates of the source(s), its velocity towards the observer (in km/s or redshift).
* The extent or size of the emission/absorption regions (which will inform your necessary spatial resolution, as well as your largest angular scale).
* A list of transitions (lines) of interest observable with ALMA, and their estimated brightness (in Jy/beam). You can use *Splatalogue* (<https://www.cv.nrao.edu/php/splat/>) to determine which lines are encompassed within the ALMA bands. Be careful to include the source’s redshift/velocity.
* If it is an emission/absorption line experiment, the width of the frequency structure that you want to detect (in km/s or kHz/MHz/GHz).
* The continuum emission flux, based on your own models or previous observations (in Jy/beam at a given frequency).

**Step 2: Define Measurement Goals**

Once your source(s) is/are defined, you must decide what scientific goals you want to achieve, and what measurements would allow you to meet your scientific goals.

You should in particular decide:

* The spatial resolution do you want to reach.
* The maximal spatial scale that you want to be able to retrieve.
* The signal-to-noise you want to achieve (on a line detection or on the continuum detection).
* The frequency range(s) which you want to observe.
  + For continuum observations, the choice of frequency is usually driven by compromise between signal-to-noise and spatial resolution. Play with the reference frequency in the OT to determine the best option.
  + For line observations, this choice is driven by the sky frequencies of the lines most suited for your scientific goal (based on your own models, previous publications, or line parameters from Splatalogue).

It is very likely that you will need to go back and forth and modify your original goals while preparing the proposal, to satisfy constraints on ALMA observational setups, or optimize the signal to noise.

**Step 3: Start Proposal in the OT**

* Open the OT and choose “Create a new proposal” from the pop-up window. . You will see a tree structure on the left panel of the OT display, which describes the structure of the proposal.
* Click on 'Proposal' in the tree structure.
* On the main panel, add a title and select Proposal Type/Scientific Category/Keywords.

**Step 4: Determine ALMA Science Goals (SGs)**

Next, we must translate our measurement goals into ALMA science goals (SG). Each SG corresponds to observations obtained with a single receiver and correlator/receiver setup (except for spectral scan mode) of sources that are sufficiently nearby in the sky (~<10 degrees apart) to use the same phase calibrator. A single science goal can be used with several arrays or configurations.

* Create your scientific goals by clicking on the 'target' button on the task bar of the OT ('New phase 1 science goal').
* In the project tree, click on the newly created SG. You will see that the SG is divided in 6 panels (General, Field, Spectral, Calibration, Control, Justification).
* In the 'General' panel of the SG, give a distinctive name to each science goal.

**Step 5: Field Setup** *(repeat for each SG)*

* In the tree structure click on the 'Field Setup' section of a SG.
* In the 'Field Setup' tab, define the name, coordinates and velocity (in km/s or z) of a source, as well as some expected properties.
  + Note that fluxes densities are defined 'per beam'. This corresponds to the flux encompassed in a resolution unit of the size of your requested angular resolution. For example, if your source has a 4"-wide circular disk shape on the plane-of sky, emitting 1 Jy of continuum emission total, the peak flux density per beam of 0.4" will be 10 mJy.
* If your source size may extend beyond half of the primary beam of the telescope (which depends on the observing frequency), or if it is composed of several regions of interest that are more than half of the primary beam away from each other, you will need to observe multiple pointings within your source. In that case:
  + You may define yourself the coordinate of each pointing. Select ‘individual pointings’ on the ‘target type’ line. Add as many pointings as desired by clicking on 'Add' at the bottom of the 'Field Center coordinates' panel. You can define the coordinates of each pointing in RA/Dec or offsets from the coordinates defined above. By clicking 'custom mosaic', these pointings will be imaged as a single mosaic
  + Or, you may set up a regular pattern of pointings so as to ideally cover a given area around the source center. Select 'Rectangular field' on the 'target type' line. You will need to define the size of the area in two directions (p and q), and the spacing between pointings. The OT will suggest a number of pointings with the 12-m array (and with the 7m array if necessary).
* In the 'Spatial' tab (top of the panel), you can obtain a graphic view of the chosen pointing pattern. You will need to upload a fits file of the source or make an image query.
* If you want to add additional sources to the SG, click on 'Add Source' at the bottom of the panel.

**Step 6: Spectral Setup** *(repeat for each SG)*

* Click on the 'Spectral Setup' section of a SG.
* On the 'Spectral type' line, define if this is a line project (spectral line or spectral scan) or a continuum project.

If yours is a pure continuum project, you will probably want to maximize the observed bandwidth and use the low resolution-large bandwidth mode of the correlator (Time Division Mode or TDM).

* Define the receiver band corresponding to your chosen frequency, and you'll be given a default suggested frequency and a correlator setup (4 2-GHz wide spectral windows). You can change the average sky frequency (the corresponding rest frequency is shown below).

For a line project, you will need to manually define each desired spectral window within the four basebands. Each baseband encompasses at most 2 continuous GHz of the sky spectrum, and can be split in up to 4 spectral windows. There are several rules restricting how basebands and spectral windows within basebands can be setup with respect to each other.

* To add spectral windows in each baseband, you can either:
  + Click on the 'add' button below the baseband panel. An additional line appears above, in which you write the desired central frequency directly in either the 'rest' frequency' or 'sky' box. Or,
  + Click on the 'Select Lines to Observe' button below the baseband panel. A *Splatalogue* line selection window pops up. Once you have identified the line you want, highlight it and click on 'Add to selected transitions'. You can select up to 4 transitions. When you click 'ok' (bottom right), a spectral window will be created for each selected transition. Any unacceptable selection will be highlighted in red in the 'Spectral Setup Errors' box.
* Define the spectral resolution/bandwidth and spectral smoothing of each spectral window. This is mainly driven by the expected width of the observed spectral lines, and how well you need to resolve them.
* Select which one of the spectral windows will define the representative frequency for which noise, signal-to-noise and resolution are calculated.

At any time you can have a graphic view of your spectral setup plotted over the atmospheric absorption spectrum on the top of the “Spectral” panel.

**Step 7: Control and Performance** *(repeat for each SG)*

* In the tree structure on the left panel in the display, click on 'Control and Performance'

Now you can define the imaging performance parameters for your project:

* Enter the desired angular resolution.
* Enter the largest angular structure (LAS).

The desired signal-to-noise drives the required sensitivity, which typically sets the required observing time. The sensitivity corresponds to the flux density per beam divided by the S/N ratio. For a line detection, S is the peak flux density averaged over the lowest spectral resolution unit on which you want to achieve a detection (usually, the expected FWHM of the linez0. If the SG includes different lines and continuum detections, the desired sensitivity for the SG will be the most stringent sensitivity requirement.

* Fill in your desired sensitivity (in Jy).
* Specify the corresponding bandwidth. For a continuum project, this is the aggregate bandwidth over all spectral windows. For a line project, this is the lowest spectral resolution unit on which you want to achieve the detection.

**Step 8: Check Observing Time and Arrays** *(repeat for each SG)*

* Click on 'Time Estimate'. You will obtain a breakdown of the estimated time to be spent on source and on calibrators, as well as which arrays and configurations are needed to perform the proposed measurement.

Depending on your desired angular resolution and LAS, the time estimator may indicate that a combination observation from different arrays or array configurations is needed. An extended configuration of the main array may provide an excellent spatial resolution, but filter out large scales. This would be compensated by adding observations, not necessarily simultaneous, in a more compact configuration of the 12-m array, or observations by the ACA. You will find more information to understand the concept of largest recoverable scale at <https://science.nrao.edu/science/videos/largest-angular-scale-and-maximum-recoverable-scale>.

If you think that the final time estimate is too high, there are many ways to drive it down. Remember that the observing time varies as the square of the sensitivity, so a small change in requested sensitivity can significantly change the time request.

* Increase the requested angular resolution. With a larger synthesized beam, the (resolved) sources' expected flux per beam increases. For a constant desired S/N ratio, the corresponding desired sensitivity will be increased.
* Decrease the size of the area to be mapped - hence decreasing the number of necessary pointings.
* Increase the spectral resolution unit for line detection.
* If possible, change the frequency for a frequency offering a better S/N ratio (often at the expense of spatial resolution).
* Eliminate scientific objectives which are too time-expensive.

*Additional Steps for a Real Submission*

While in practice you may need several iterations to hone the most optimal observation parameters, in principle you have now defined your observational setup. To verify if all parameters are set in a correct way, run a proposal validation (check mark icon on the main task bar). This will indicate if there are errors in the proposal and parameters that need to be changed.

There are additional steps to undertake to transform a mock-up proposal into a real one:

* Add yourself as PI and collaborators as co-Is. You can only add people who are registered in the ALMA userbase. You can register at almascience.org ('Register' link at the top-right corner).
* Justify your choices of observational parameters in the 'Technical Justification' tab.
* Attach a pdf of your scientific justification.
* Other front-page things: justify duplications, identify related proposals from this cycle (“Related Proposals”) or previous cycles (“Previous Proposals”), share if the proposal will make up part of a student PhD project, …
* Generate a pdf file of your proposal. In the Tool section at the top of the window, click on 'Generate a pdf'.
* Submit it: In the File section at the top of the window, click on 'Submit'. **Don’t forget to submit well before the deadline!**