Atacama Large Millimeter Array	ALMA-SW-666 Revision:3.1 2001-08-08 *Requirements* Steven T. Myers

ALMA Offline Data Processing Requirements

Requirements

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1 Introduction

The history of this document and correspondence can be found at:

`http://www.aoc.nrao.edu/ smyers/alma/offline-req/`

This document is `myers-report-3.1.tex`.

This document describes the requirements for offline data processing software packages in order to be able to handle the ALMA data output. It is assumed that there will be (at least) one software package available for users to reduce their own data and/or data from the archive offline at their home institution, at an ALMA regional center, or remotely using ALMA center computing. This suite of tools must fulfill the Offline Data Processing Requirements (Section 2). We refer to the ensemble that fulfills these as the "Package". Again this might be an assortment of different programs from different software packages (e.g. AIPS, GILDAS, MIRIAD, aips++) but in this case it is highly desirable that there be at least one single package that fulfills the Offline requirements or that there be an installation that integrated the necessary parts. Note, however, that is is highly unlikely that disparate applications from different packages will fulfill the requirements on similar "look and feel" and inter-connectivity, and thus it is likely as well as desirable that this will be a single homogeneous suite.

This document assumes requirements already delineated in ALMA-SW MEMO 11 "ALMA Software Science Requirements and Use Cases" at:

`http://www.alma.nrao.edu/development/computing/docs/joint/0011/ssranduc.pdf`

Much of the content of this document is based on the AIPS++ User specifications Memo 115 found at:

`http://aips2.nrao.edu/stable/docs/specs/specs.html`

Although it was intended to be the basis for AIPS++, these are an excellent starting point for our requirements to build upon. We do not think this makes this too specific to AIPS++, as our document is intended to be package-independent.

1.1 Nomenclature

The subject of Section 2 on Offline Data Processing Requirements is referred to as the *Package* or *Offline Package*. This is intended as a set of tools or programs, believed adequate for ALMA reductions, and used by observers for science and by ALMA staff for reductions upon which the behavior of the system will be judged. It may consist of packages provided by different groups, with transitions provided to integrate them into a single suite. It may be that more than one Package fulfills the requirements of Section 2 and thus can be considered as suitable for ALMA processing. The requirements will state that the Package will be available for installation on the observer's own computer systems as well as present at ALMA centers.

There is another set of requirements, given in ALMA-SW MEMO 11, for the software that forms the ALMA Online Data Processing Pipeline, or simply the *Pipeline*. Note that the Pipeline may or may not be based on the offline Package(s), depending on implementation. However, the functionality of the Pipeline must be available in the offline Package for users.

The user of the package may be referred to as *user* or *observer*, and may be the actual proposer or a staff member. In automated modes, the user may actually be another tool or program.

The *Archive* refers to the totality of the ALMA data storage and consists of possible different physical archives.

The definitions of various terms, such as *scans*, are given in ALMA-SW MEMO 11.

1.2 General Considerations

A. Two fundamentally new aspects of ALMA are the integrated Archive and the Pipeline, therefore the impact of requirements on these two areas should be considered. We have included topics "Relation to the Pipeline" (§2.1.1) and "Interaction with Archive" (§2.3.8).

B. There is a operational difference between running the ALMA array in interferometric and single-dish modes. However, this difference may not be so fundamental for many types of data processing. For example, if several single dishes observe together, much of the calibration will be done interferometrically (pointing, focus, beam shape); for interferometric observations, temperature scale is derived from single-dish measurements. Moreover, the inclusion of single-dish capability in ALMA is primarily intended to aid in the mosaicing of targets larger than a primary beam, and thus array and total-power data are likely to be combined in these instances. Therefore, these two paths are split or combined as is appropriate for the context, with special sections on "Mosaicing Considerations" also included to clarify these issues.

C. There is no fundamental difference between spectral-line and continuum observations, merely number of channels and bandwidths coming out of the correlator. Due to the nature of the ALMA correlator, most of the special calibration needs of traditional spectral line observations (e.g. bandpass calibration) are also applicable to continuum observations (continuum is built up through summation of spectral channels taken at low resolution). We will assume that all data will be effectively taken in spectral line mode.

D. There is no fundamental distinction needed for polarization data, merely consideration of the number of polarization products or polarization states needed for processing. The model we consider here is the processing of one or more Stokes parameters and thus polarization is integrated into all the topics. One complication that must be considered is the combination of the array (products) and single-dish data (states).

E. We use a system of prioritizing with codes:

1 = essential
2 = highly desirable
3 = desirable, but not critical

These codes are enclosed in brackets [] at the end of the items they qualify.

It is intended that Priority 1 items must be present in the Package and work with high efficiency. Priority 2 items should be in the package, though there may have to be sacrifices in performance or availability may be delayed. Fulfilling Priority 2 items well should give a boost to a given Package's rating. We expect that the Package will fulfill all Priority 1 and 90% or more of Priority 2 requirements. Priority 3 items should be considered for upgrades or development.

F. The requirements in this document are prefixed with **FL**. Specific requirements are broken into subcases or instances (e.g. R1 R1.1, R1.2) for clarity. These sub-requirements are either special cases of the main requirement (often with different priority) or itemized instances or examples related to the requirement.

G. There are a number of instances where certain specifications, such as data formats supported, are designated as being in a list maintained by the ALMA project. There are other points in the requirements that refer to "standard modes", which implies a detailed list (tbd) also maintained by the project. These cases are indicated in **boldface** to aid in determining which lists will need to be constructed.

H. At the time this document was written, the ACA has not been officially scoped as part of ALMA. However, some placeholder ACA-related requirements are included in the main requirements section, and are clearly labeled as such.

2 Offline Data Processing Requirements

2.1 General Requirements and Interaction with Other ALMA Elements

2.1.1 Goals of the Offline Package and Relation to the Pipeline

Note: An ALMA Offline Data Processing Package (or "the Package") is primarily intended to enable end-users of ALMA (e.g. observers or Archive users) to produce scientifically viable results that involve ALMA data products. The secondary use is to enable ALMA staff to assess the state of the array and derive calibration parameters for the system, although it is anticipated that the Pipeline will be the primary engine for Online Data Processing and system monitoring.

Also note that not all offline analysis tools will necessarily be in the Pipeline package. For example, one of the important differences between Pipeline and Offline reduction path is that Offline one should have extensive interactive capabilities to merge and compare data with different resolution, coordinate system, data grid, and so on.

OL–1.1–R1 There must be an Offline Data Processing Package that fulfills the requirements laid forth in this document.

Priority: 1

OL–1.1–R2 All standard observing modes supported by ALMA must be processable by the Package.

Priority: 1

OL–1.1–R3 The package should be able to function (be installed) at the users home institution and at ALMA regional centers (both locally and remotely). It should be portable to a reasonable number of supported platforms, including systems without network connections and laptops.

Priority: 1

OL–1.1–R4 The performance of the package should be quantifiable and commensurate with the data processing requirements of ALMA output at a given time. This should be benchmarked (e.g. "AIPS-marks") and reproduce accurately results for a fiducial set of reduction tasks on specified test data.

Priority: 1

OL–1.1–R5 All standard processing functionality available in the Pipeline must be available in the Package also as an offline analysis option.

Priority: 2

2.1.2 Operational Issues

OL–1.2–R1 Installation of package must be flexible, and able to be installed on non-specialized hardware by end user, preferably without root user permission (on Unix).

Priority: 1

OL–1.2–R2 User-understandable and non-destructive error handling at all levels is highly desirable. There must be provision for job control such as interrupt and abort.

Priority: 1

OL–1.2–R3 The Package providers must provide support for the package, with bug-fixing on timescales appropriate to the severity level of the defect (e.g. 1 week or less for catastrophic bugs with no work-around). **These defect levels and timescales should be delineated by the ALMA project**.

Priority: 1

OL–1.2–R4 Updates and new versions of the package should be backward compatible where possible, such that user-built and observatory provided scripts and tools should be executable with only minor changes.

Priority: 1

OL–1.2–R5 Source code for the astronomical routines in the Package should be available to the user.

Priority: 1

Notes: This does allow for the use of some proprietary data handling, output formatting, and special processing (e.g. Pixon) routines.

OL–1.2–R6 User installation of the package should not be restricted by other issues such as expensive or unduly restrictive licenses. The Package license should convey all other necessary licenses (such as GNU) or they should be available to the user for only an nominal fee.

Priority: 2

Comment: This allows for the use of commercial components. Although it may be attractive to build upon a commercial package such as IDL, this is likely to be prohibitive unless a blanket license would be bought by the project and distributable free of charge to users.

OL–1.2–R7 There should be the provision for the development and incorporation of user-supplied routines.

Priority: 2

OL–1.2–R8 The application of successive stages of calibration, correction, flagging and editing should not be destructive to the data. The package should be able to recover and revert to earlier stages without resorting to saving of the entire dataset at intermediate states.

Priority: 2

2.2 Interface

2.2.1 General User Interface Requirements

OL–2.1–R1 User must be able to choose from a variety of interface styles, including:

- **OL–2.1–R1.1** A Command Line Interface (CLI) must be provided, with access via both an interactive input and via script.
  Priority: 1
- **OL–2.1–R1.2** A Graphical User Interface (GUI) must be provided for interactive processing. Actions taken under the GUI must be loggable, editable, and executable by the CLI.
  Priority: 1

OL–2.1–R2 The user should be able to interact with the host operating system with command sequences invoked from the UI.

Priority: 1

OL–2.1–R3 Multitasking for all interfaces should be available where appropriate. It must be possible to run one or more long-running calculations in the background. While background tasks are running normal interactive activities must be possible.

Priority: 1

2.2.2 Graphical User Interface (GUI)

Note: The GUI is intended to be the primary interactive mode for users, especially neophyte users, and thus should be tailored for clarity and ease of use. Use of the Package GUIs should be a pleasurable, not a frustrating, experience!

OL–2.2–R1 The GUI should provide real-time feedback via standard compact displays:

- **OL–2.2–R1.1** Window updating should be fast (¡0.1s on same host).
  Priority: 1
- **OL–2.2–R1.2** Windows should not take up excessive screen space, with full GUI controls visible on a window one-third the size of a standard view surface (or approximately 800x800).
  Priority: 1
- **OL–2.2–R1.3** Users should have the choice of cascading windows or re-use of single window for new operations.
  Priority: 2
- **OL–2.2–R1.4** It is desirable that there be a master control GUI for process control which keeps track of sub-windows and tools.
  Priority: 3

OL–2.2–R2 It must be easy to run GUIs remotely from the host machine (e.g. via X displays).

Priority: 1

OL–2.2–R3 GUI-based tools should be available for reduction of data taken in all standard ALMA observing modes.

Priority: 2

OL–2.2–R4 The default look and feel of the GUI should be uniform and familiar through the entire package.

Priority: 2

OL–2.2–R5 The look and feel of the GUI must be customizable to accommodate both the expert specialist and the novice user, with ability to hide complexity when prudent and the ability to access deeper levels when desired. The default look to the novice should not be overly busy, with functionality easily apparent through labeling and built-in help facility.

Priority: 2

OL–2.2–R6 It is desirable that it be easy for users to develop and include their own custom GUIs in the Package.

Priority: 3

2.2.3 Command Line Interface (CLI)

Note: the CLI is the primary mode for automatic reduction for ALMA, and it is anticipated that there will be a suite of "standard" scripts developed to help users in data reduction tasks. Thus it is important that the Package support all of its critical modes in the CLI.

OL–2.3–R1 The interface must have the facility to read in command files for batch processing of a sequence of CLI commands.

Priority: 1

OL–2.3–R2 The CLI should have command-line recall and editing, and name completion where appropriate.

Priority: 1

OL–2.3–R3 All functionality of the GUI must also be available in CLI mode (although possibly with loss of simplicity in instances where the graphical selection is important).

Priority: 1

OL–2.3–R4 The CLI should be usable remotely over low-speed modem lines or network connections, with ASCII terminal emulation.

Priority: 2

OL–2.3–R5 A CLI mode menu for display and editing of input parameters and execution of tasks is desirable.

Priority: 3

2.2.4 Interface Programming, Parameter Passing and Feedback

OL–2.4–R1 The UI must have basic programming facilities such as:

OL–2.4–R1.1 variable assignment and evaluation
Priority: 1

OL–2.4–R1.2 conditional statements
Priority: 1

OL–2.4–R1.3 control loops
Priority: 1

OL–2.4–R1.4 string manipulation
Priority: 1

OL–2.4–R1.5 user-defined functions and procedures
Priority: 1

OL–2.4–R1.6 standard mathematical operations and functions
Priority: 1

OL–2.4–R1.7 efficient vector and matrix operations
Priority: 2

OL–2.4–R1.8 user-defined data structures
Priority: 2

OL–2.4–R2 Commands executed should be logged, with provision to re-execute the session.

Priority: 1

OL–2.4–R3 Input parameter and syntax checking should be effected upon function calling or parsing with reporting of incorrect, suspicious or dangerous choices before execution where possible.

Priority: 1

OL–2.4–R4 Parameters should be passable between applications in as transparent a manner as possible. However, global variables should not be the default, unless designated specifically by the user-programmer.

Priority: 1

OL–2.4–R5 Application variables should be named consistently and as clearly as possible indicating their intended use using astronomical terms where appropriate.

Priority: 2

2.2.5 Documentation and Help Facility

OL–2.5–R1 The package creators must provide up-to-date, comprehensive and user comprehensible documentation for all parts of the package.

Priority: 1

OL–2.5–R2 There should be a variety of help levels and documentation formats accessible from the UI and over the Internet, applicable to novices, experts, and technical users. These would include:

OL–2.5–R2.1 user cookbooks with extensive examples
Priority: 1

OL–2.5–R2.2 application descriptions and reference manual (with all inputs to functions and tools)
Priority: 1

OL–2.5–R2.3 online help, FAQ, email contacts
Priority: 1

OL–2.5–R2.4 release history, bug reports and tracking, patch descriptions
Priority: 1

OL–2.5–R2.5 programmer references and guides
Priority: 2

OL–2.5–R2.6 data format descriptions
Priority: 2

OL–2.5–R2.7 algorithm descriptions
Priority: 2

OL–2.5–R2.8 newsletters, email exploders, notes series
Priority: 3
Note: these would be maintained by the package providers, with help from the ALMA project.

OL–2.5–R3 Help materials should also be available in printable formats (such as pdf and printer-friendly versions of HTML pages).

Priority: 1

OL–2.5–R4 Help should be context-sensitive where relevant. In GUI mode, fly-over banners should indicate use of buttons and fields, and clickable help buttons should be available on all pages.

Priority: 1

OL–2.5–R5 In GUI mode, help functions may direct user to Web page. In CLI mode, must support in-line text based help also.

Priority: 1

OL–2.5–R6 Full search capability must be built into documentation library.

Priority: 2

2.3 Data Handling

2.3.1 General Data Requirements

OL–3.1–R1 The package must support data taken in any of the standard ALMA hardware modes.

Priority: 1

OL–3.1–R2 Must be able to handle the integrated data objects corresponding to the observational programs carried out by ALMA. These objects may be implemented in any manner appropriate, though relations between the components of the object must be maintained through some mechanism. These include:

OL–3.1–R2.1 Program header information
OL–3.1–R2.2 Observation status information (and schedules themselves)
OL–3.1–R2.3 Field information
OL–3.1–R2.4 Coherence function (visibility) data from interferometer in all available polarization products, spectral channels, frequency bands, IFs, including auto-correlations, in uncorrected and/or corrected form (online WVR correction)
OL–3.1–R2.5 Auto-correlations in single-dish total power modes
OL–3.1–R2.6 Weights and/or data uncertainties
OL–3.1–R2.7 Frequency switching mode
OL–3.1–R2.8 Flagging data or masks
OL–3.1–R2.9 Diagnostic data and errors
OL–3.1–R2.10 A-Priori calibration data (bandpasses, flux densities, polarization leakages, etc.)
OL–3.1–R2.11 Derived calibration data (gain tables, flux bootstraps, etc.).
OL–3.1–R2.12 Images and/or models produced from data
OL–3.1–R2.13 Processing history

Priority: 1

OL–3.1–R3 There must be a selection mechanism integrated within tools to choose between the various available data subsets such as:

OL–3.1–R3.1 polarization products or channels
OL–3.1–R3.2 bands (frequency bands, IFs)
OL–3.1–R3.3 spectral channels
OL–3.1–R3.4 frequency-switched data
OL–3.1–R3.5 interferometer: subarrays
OL–3.1–R3.6 interferometer: WVR-corrected or uncorrected baselines

Priority: 1

OL–3.1–R4 Multiple pointing centers for mosaics must be supported.

Priority: 1

OL–3.1–R5 For polarization products, transformation must be provided to the desired Stokes output parameter(s).

Priority: 1

OL–3.1–R6 Averaging of bands and spectral channels (compression) should be possible.

Priority: 1

OL–3.1–R7 Data taken in arbitrary (but parameterized) scanning patterns must be dealt with.

Priority: 1

OL–3.1–R8 The flagging mask must be maintained and associated with the data it refers to during any subsequent operations (such as splitting of data sets).

Priority: 1

OL–3.1–R9 Calibration and ancillary monitoring data must be preserved, if requested.

Priority: 1

OL–3.1–R10 Comprehensive and understandable processing history information for the data must be maintained and be exportable (both as tables and as plain text).

Priority: 1

OL–3.1–R11 Users should have access (at the manipulation level) to all aspects of the data including the header.

Priority: 1

OL–3.1–R12 The Package must support locking data files so that there is no possibility of one process corrupting a file that is also being written to by another process in the Package. The default model should be: "one writer, multiple readers."

Priority: 1

OL–3.1–R13 Distinctions between "single-source", "multi-source", single-dish, and interferometer datasets should be avoided with context built into the dataset or header.

Priority: 2

OL–3.1–R14 Concatenation of datasets should be straightforward and robust. Extraction and reinsertion of data subsets should be supported.

Priority: 2

OL–3.1–R15 When sorting or indexing is desirable for performance enhancement, it is desirable that this be carried out in a manner transparent to the user.

Priority: 3

2.3.2 Data Import and Export

OL–3.2–R1 ALMA standard data formats (e.g. ALMA raw data format, FITS) must be supported for both input and output without loss of functionality or information.

Priority: 1

OL–3.2–R1.1 Other standard data formats must be supported, possibly with some loss in information content. **The project will maintain a list of formats which the package must support.**
Priority: 1

OL–3.2–R2 Disk and offline data storage (e.g. DAT, DDS, DLT) must be supported. **The project will maintain a list of media which the package must support.**

Priority: 1

OL–3.2–R3 The ability to drop flagged data on export should be included.

Priority: 2

OL–3.2–R4 The Package internal data format, which may be independent of other supported formats, must not be "bloated" and the required storage should not exceed by more than 1.5× the raw data format.

Priority: 2

2.3.3 I/O Speed and Efficiency

OL–3.3–R1 I/O of data must not be a bottleneck for processing. The total package performance must follow standards set by the Project (see 4).

Priority: 1

OL–3.3–R2 I/O failure (e.g. due to full disks, device offline) should not result in catastrophic failure of the Package. Error recovery should be as robust as possible.

Priority: 1

OL–3.3–R3 The Package must be able to handle, efficiently and gracefully, datasets larger than main memory of the host system.

Priority: 1

2.3.4 ALMA Interferometer Data

OL–3.4–R1 Correlation products accumulated at multiple bit depths (16-bit,32-bit) or compressed data must be supported transparently (see ALMA SW-11 3.2.3-R5).

Priority: 1

OL–3.4–R2 Total power detector data must be handled.

Priority: 2

OL–3.4–R3 Phased array data sequences must be handled.

Priority: 2

2.3.5 ALMA Single Dish Data

OL–3.5–R1 Data taken with nutating secondary must be supported, as a function of nutator position.

Priority: 1

OL–3.5–R2 Total power detector data must be handled.

Priority: 2

2.3.6 Images and Other Data Products

OL–3.6–R1 Standard multi-dimensional images must be supported, such as:

- **OL–3.6–R1.1** Spectra and image slices (1D)
  Priority: 1
- **OL–3.6–R1.2** Planar images (2D)
  Priority: 1
- **OL–3.6–R1.3** Spectral and Time Cubes (3D)
  Priority: 1
- **OL–3.6–R1.4** Higher-dimensional Arrays (4D+)
  Priority: 2

OL–3.6–R2 Other standard derived data products must be supported, such as:

- **OL–3.6–R2.1** Standard Models (e.g. CLEAN models, Gaussian models, disks)
  Priority: 1
- **OL–3.6–R2.2** Special Models (e.g. wavelets, Pixons)
  Priority: 3

OL–3.6–R3 Blanking of pixels must be maintained through the processing of images.

Priority: 1

2.3.7 Foreign Data

OL–3.7–R1 Data produced by other interferometers and single dishes in similar observing modes should be importable and processable if provided in a standard data exchange format.

Priority: 1

OL–3.7–R2 Imaging data in standard formats (e.g. FITS) from astronomical instruments at different wavelengths should be importable, with the ability to combine (coadd) these with ALMA data where appropriate. This should be through a set of widely used formats, with a **minimal list of supported standards established by the project**.

Priority: 1

2.3.8 Interaction with the Archive

OL–3.8–R1 Access from the archive (when such access is granted, e.g. when Package is run by ALMA staff) must be supported.

Priority: 1

OL–3.8–R2 The interface between the package and archive must be able to provide data access (when such access is granted) without interfering with other access to the archive.

Priority: 1

OL–3.8–R3 Security and integrity of the archive must be ensured during these operations.

Priority: 1

2.4 Calibration and Editing

2.4.1 General Calibration and Editing Requirements

OL–4.1–R1 The package must be able to reliably handle all *designated ALMA standard calibration modes* , possibly including but not exclusive to temperature controlled loads, semi-transparent vanes, apex calibration systems, WVR data, noise injection, fast-switching calibration transfer, planetary observations.

OL–4.1–R2 Calibration, editing, flagging, and correction of data should be easily reversible within the Package (ie. not requiring re-reading of the data from the archive).

Priority: 1

OL–4.1–R2.1 Logging of editing steps should be clearly marked in some sort of history table (possibly distinct from a more readable history).
Priority: 2

OL–4.1–R2.2 Individual edit undo is desirable.
Priority: 3

OL–4.1–R3 Data editing and flagging should be possible based upon array and environmental monitoring data.

Priority: 1

OL–4.1–R4 Data calibration, correction and flagging should be possible based upon standard or user-defined models in either functional or tabular form. Arbitrary user-specified scaling of data should be simple.

Priority: 1

OL–4.1–R5 Calibration should involve flexible averaging of data and calibration quantities with user-controllable interpolation, filtering, weighting, and application scope.

Priority: 1

OL–4.1–R6 Interactive data editing, calibration, and display of calibration quantities should be largely graphical and intuitive, with user-definable setups. Specialized editing display tools should include:

OL–4.1–R6.1 specification of data by selection of antenna, baseline, time range, uv range, pointing center, slice through data cube, etc.
OL–4.1–R6.2 displays of spectra and spectral cubes
OL–4.1–R6.3 the above with baseline, time, band and/or channel averaging
OL–4.1–R6.4 for interferometer data, amplitude (phase) vs. time on each baseline (Difmap vplot), vs. time-baseline (AIPS TVFLG) with interactive zoom and clipping
OL–4.1–R6.5 editing based on difference from a running mean or median, or rms in boxcar, or difference versus model, etc.
OL–4.1–R6.6 auto-scaling or fixed scaling of colormap, intensity or axes
OL–4.1–R6.7 inclusion and marking of flagged data in plots and in auto-scaling

Priority: 1

OL–4.1–R7 Automatic editing tools should be available in the package, including:

OL–4.1–R7.1 editing based on difference from a running mean or median, or rms in boxcar, or difference versus model, etc.
OL–4.1–R7.2 outlier editing
OL–4.1–R7.3 flagging based on strict selection (e.g. time, baseline, band, channel, etc.)
OL–4.1–R7.4 flagging based on ancillary data (e.g. wind speed, sun angle, temperature, etc.)

Priority: 1

OL–4.1–R8 Access to time history of calibration information such as source catalogs containing flux density histories, planetary ephemerides, noise tube values, etc. should be built into calibration engines. Output of calibration procedures should be exportable into similar structures.

Priority: 1

OL–4.1–R9 Data display and editing should be effected through generic tools applicable to both single-dish and interferometer modes. These should present should, as far as possible, present similar interfaces to the user and have the same look-and-feel.

Priority: 2

OL–4.1–R10 Editing should be incorporated into most visualization tools where data or data-derived quantities are plotted, such as from calibration solutions, amplitude vs. uv-distance plots, or any number of other plots. A "see-it, flag-it" capability should be the standard within the tools.

Priority: 2

2.4.2 Interferometer Data

OL–4.2–R1 Antenna-based determination of calibration quantities such as gains, polarization leakages, bandpasses, is the primary form of calibration where appropriate.

Priority: 1

OL–4.2–R2 In addition to antenna-based calibration, baseline dependent corrections will also be supported. For example, coherence loss due to atmospheric phase fluctuation depends on baseline length (this aspect will be more important at higher frequencies) and must be taken into account if some of the WVR corrections are discarded while others are applied. Also, in general, the bandpasses are baseline dependent and contain non-closing terms.

Priority: 1

OL–4.2–R3 Gain corrections will be made based on differences between observed and modeled data quantities, possibly with iteration (e.g. self-calibration and determination of gains using calibration sources). Where solutions are discrepant or poor, automatic editing should be possible.

Priority: 1

OL–4.2–R4 Calibration quantities (possibly stored in tables or data structures) should be transferable between sources and/or frequency bands, after any necessary interpolation, extrapolation or smoothing. This will be the primary method of phase calibration transfer using fast-switching between source and calibrator.

Priority: 1

OL–4.2–R5 Determination of, correction for, and examination of closure errors should be straightforward to carry out.

Priority: 1

OL–4.2–R6 Determination of the complex bandpass using calibration source observations, and transfer to target sources, should be simple and robust.

Priority: 1

OL–4.2–R7 Determination of polarization calibration quantities such as leakage (D-term or Jones matrix) and complex gain difference must be an integral part of the package, using both linearized and full matrix calculations.

Priority: 1

OL–4.2–R8 Incorporation of standard models (e.g. planetary disks, models for HII region structure, known source spectra) should be easy for calibration operations.

Priority: 1

OL–4.2–R9 Redundancy (e.g. same, similar, or crossing baselines) should be used wherever possible to increase accuracy of or check calibration solutions. Editing based on this comparison should be possible.

Priority: 2

OL–4.2–R10 Interferometric pointing, focus, baseline, and beam response fitting should be available in the Package as a supplement to the on-line calibration. These should work for single-scan calibration observations and also for multiple datasets.

Priority: 3

2.4.3 Single Dish Data

OL–4.3–R1 Straightforward and flexible fitting of spectral bandpass from calibration source observations is required.

Priority: 1

OL–4.3–R2 De-striping and adjustment of scan normalization factors must be available for single-dish OTF observations with overlapping and crossing scans.

Priority: 1

OL–4.3–R3 Calibration of system parameters such as temperature controlled loads and noise sources from observations of celestial sources should be supported.

Priority: 3

OL–4.3–R4 Processing for pointing, focus, tipping, or beam-fitting data must be available. These should work for single-scan calibration observations and also for multiple datasets.

Priority: 3

2.4.4 Mosaicing Considerations

OL–4.4–R1 Individual data points must be associated with pointing center information, as provided in the data object.

Priority: 1

OL–4.4–R1.1 The user should also be able to handle scanning strategies given a parameterized pattern or interpolated from a list of pointing centers versus time, in the absence of an internal data scan-descriptor object.
Priority: 3

OL–4.4–R2 Determination of and correction for pointing offsets and the polarized primary beam is critical to the ability to reliably mosaic using ALMA, and thus must be available in the Package, preferably in several algorithmic forms.

Priority: 1

OL–4.4–R3 Careful cross calibration of the flux scales between ALMA interferometric data and single dish data is required for high fidelity imaging. There must be tools to cross-check and correct the relative calibration between mosaics and different component observations. *Note: this is particularly important and more difficult for ACA data.*

Priority: 1

2.4.5 Ancillary and Diagnostic Data

OL–4.5–R1 Output from the atmospheric monitoring (e.g. WVR, FTS) instrumentation provided in ALMA format should be processed and used by calibration software.

Priority: 1

OL–4.5–R2 Pointing, focus and subreflector information must be processable and dealt with appropriately.

Priority: 1

OL–4.5–R3 Environmental data such as weather (e.g. wind speed, temperature, dew point) supplied in ALMA format, as FITS extension tables, or as ASCII tables should be importable for editing or calibration procedures, and easily incorporated into user-specified calibration models.

Priority: 2

OL–4.5–R4 Engineering monitoring information such as temperature sensor readings and tilt-meter outputs, included in ALMA format, as FITS extension tables, or as ASCII tables, should be readable and incorporated into the calibration and editing process.

Priority: 3

2.5 Imaging

2.5.1 General Imaging Requirements

Due to the high volume of data that can be produced by ALMA, it is imperative that the imaging and deconvolution tools in the Package be user-friendly, efficient, and flexible. This is the workhorse of the Package as far as most users will be concerned, and suitability and success of the Package will be judged with this in mind.

OL–5.1–R1 Imaging of data taken from any combination of ALMA exported data, the ALMA archive, or other instruments supporting common export formats must be provided.

Priority: 1

OL–5.1–R2 Imaging computations should work on combined multiple datasets.

Priority: 1

OL–5.1–R2.1 It is highly desirable that multiple input datasets be supported directly in the tools, rather than requiring previous concatenation of the data.
Priority: 2

OL–5.1–R3 Efficient selection of subsets of the imaging data must be provided.

Priority: 1

OL–5.1–R4 Provision must be made for the utilization and development of a variety of imaging, deconvolution, and analysis algorithms, including:

OL–5.1–R4.1 raw ("dirty") images with selectable weighting
Priority: 1
OL–5.1–R4.2 residual images after model subtraction
Priority: 1
OL–5.1–R4.3 single-scale CLEAN (various flavors)
Priority: 1
OL–5.1–R4.4 maximum entropy method (MEM)
Priority: 1
OL–5.1–R4.5 non-negative least-squares (NNLS)
Priority: 1
OL–5.1–R4.6 linear mosaics
Priority: 1
OL–5.1–R4.7 non-linear mosaics
Priority: 1
OL–5.1–R4.8 multi-scale CLEAN
Priority: 2
OL–5.1–R4.9 Gaussian or disk modelfitting
Priority: 2
OL–5.1–R4.10 multi-frequency synthesis with different spectral models
Priority: 2
OL–5.1–R4.11 special function deconvolution (e.g. Pixon, wavelet)
Priority: 3

OL–5.1–R5 A integrated deconvolution, self-calibration, and editing/filtering tool should be available, especially for novice users with data taken in commonly used modes. Because ALMA is inherently a multi-channel instrument, spectral cube mapping should be built in as the primary mode from the beginning.

Priority: 1

OL–5.1–R6 Image pixel blanking must be supported.

Priority: 1

OL–5.1–R7 Astrometric accuracy (10mas at 600GHz) must be preserved over phase-calibration distances of at least 5 degrees during imaging.

Priority: 1

Note: I am not sure what is intended by this requirement as far as the software is concerned.

OL–5.1–R8 Images made on different equinox (e.g. B1950 and J2000) or different coordinate (RA,DEC and l,b) systems or different projection (tangent, sinusoidal, ...) should be transformed, merged and compared appropriately.

Priority: 2

OL–5.1–R9 Data cubes using different velocity definition (optical or radio definition for Doppler velocity) should be transformed and merged appropriately.

Priority: 2

2.5.2 Interferometer Imaging

OL–5.2–R1 High-fidelity imaging of the entire primary beam in all Stokes parameters is the primary goal — therefore, incorporation of the polarized primary beam response of the array is required.

Priority: 1

OL–5.2–R2 Imaging of direct polarization products (e.g. RR, LL, RL, LR) or Stokes polarization states (e.g. I, Q, U, V) must be selectable and interchangeable where possible given the data.

Priority: 1

OL–5.2–R3 There must be straightforward and seamless integration of data from multiple epochs and configurations.

Priority: 1

OL–5.2–R4 Simultaneous multiple-field imaging and deconvolution with gridded and ungridded (FFT and DFT) computation of model subtraction must be supported.

Priority: 1

OL–5.2–R5 Subtraction of continuum level from spectral data is required, in both the Fourier and image domain. In the case of uv-plane subtraction, flexible setting of the frequency channel ranges for the calculation of the continuum level (graphically as well as CLI) should be available.

Priority: 1

OL–5.2–R6 There must be the ability to include "zero-spacing" values and short-spacing data taken in single-dish mode (both ALMA and non-ALMA data), with selectable weighting.

Priority: 1

OL–5.2–R7 Imaging must deal seamlessly with mosaiced data, with proper gridding in the uv-plane and compensation for primary beam effects and pointing in such a manner as to mitigate the effects of non-coplanar baselines and sky curvature.

Priority: 1

OL–5.2–R7.1 A variety of options for gridding and beam correction should be available at user request.
Priority: 2

OL–5.2–R8 Choice of FFT and DFT imaging (especially for small datasets).

Priority: 2

OL–5.2–R9 The creation of 3D images for rotating objects (e.g. planets) should be supported.

Priority: 3

2.5.3 Mosaicing and Single Dish Imaging Considerations

OL–5.3–R1 Combination of interferometer and single-dish data into mosaic imaging is essential.

Priority: 1

OL–5.3–R1.1 The ACA (should it be scoped as part of ALMA) must be integrally supported by the Package.
Priority: 1

OL–5.3–R2 Careful (polarized) primary beam correction and pointing correction is critical for high fidelity mosaic imaging and must be incorporated into the mosaicing algorithms.

Priority: 1

OL–5.3–R2.1 The primary beam calculation and correction must take into account the effect of on-the-fly scanning.
Priority: 1

OL–5.3–R2.2 The user should be able to specify the primary beam in a number of forms, both analytic and tabular, in addition to the ALMA provided primary beam.
Priority: 2

OL–5.3–R3 Handling of interferometer (polarization product) and single-dish (polarization channel) data together may not be straightforward, and must be deal with correctly by the Package.

Priority: 1

OL–5.3–R4 Scaling and de-striping of scans on image-plane combination is a necessary feature.

Priority: 1

OL–5.3–R5 The Package must be able to produce an image by combining data observed on different rasters, possibly taken with different (regular or irregular) spacings and image centers.

Priority: 1

OL–5.3–R6 The Package should have the capability to produce the stamp map (profile map) of spectra at a grid of positions.

Priority: 2

2.6 Data Analysis

2.6.1 General Analysis Requirements

OL–6.1–R1 The astronomer must have the capability to develop their own tools or tasks, with easy access to data and images, and straightforward interface with the package.

Priority: 1

OL–6.1–R2 Seamless transformation between image-plane and uv-plane analysis is necessary.

OL–6.1–R2.1 Analysis based on goodness-of-fit to models, in both uv-plane (for interferometry) and image plane, will be required.
Priority: 1

OL–6.1–R2.2 Fourier transform of images to a pseudo-uv plane image will be needed.
Priority: 2

OL–6.1–R3 Effective, robust and precise spectral baseline removal facility is required.

Priority: 1

OL–6.1–R3.1 Fourier analysis of standing waves and their removal is highly desirable.
Priority: 2

OL–6.1–R4 Automatic measurement of line parameters (line intensity, integrated intensity, Gaussian-fit line width, rms noise level, ...) for user specified velocity (frequency) window must be made, and to be stored in a text-format list file that can be output by the user if desired.

Priority: 1

OL–6.1–R5 Translation between various astronomical quantities and units (e.g. Jy and K, MHz and km/s) should be straightforward and user selectable.

Priority: 2

2.6.2 Image Cube Analysis and Manipulation

Because ALMA is inherently a multi-channel instrument, and due to the design of the ALMA correlator, spectral image cube can be considered to be the fundamental image structure. Single-channel or continuum images can be considered as subsets or instances of cubes. Note that ability to easily manipulate the dimensionality of the image cube is extremely important.

OL–6.2–R1 Basic cube rotation and transposition operations must be available.

Priority: 1

OL–6.2–R2 Identification and reporting of image features (e.g. positions of pixels or centroids, frequencies of pixels or line centers) should be easy, accurate, interactive (where appropriate) and exportable.

Priority: 1

OL–6.2–R3 The ability to extract same or lower-dimensional structures from higher-dimensional data cubes efficiently is required.

Priority: 1

OL–6.2–R3.1 Extraction of "cubical" sub-structures aligned with the original cube axes must be straightforward.
Priority: 1

OL–6.2–R3.2 User selection of extraction criteria must be possible through the GUI as well as scriptable.
Priority: 1

OL–6.2–R3.3 User-selectable sub-structures with arbitrary orientation within the parent cube, with appropriate transformation or interpolation, should be possible.
Priority: 2

OL–6.2–R3.4 Extraction of data structures based on standard SQL-like queries is desirable.
Priority: 3

OL–6.2–R4 The ability to collapse or integrate over sub-dimensions of data cubes in order to form "moments" is required.

Priority: 1

OL–6.2–R5 The Package must have the capability of assembling lower-dimensional data structures into higher-dimension cubes.

Priority: 1

OL–6.2–R6 Blanking of pixels must be maintained through the analysis process.

Priority: 1

OL–6.2–R6.1 It must be possible to turn on and off different blanking (mask) levels, when blanking is set within the Package.
Priority: 1

OL–6.2–R6.2 Blanking should not be destructive, and the original pixel value is retained (if defined).
Priority: 2

OL–6.2–R6.3 Interactive and automatic facilities for setting of blanking parameters (e.g. windowing, S/N based blanking) to avoid degrading S/N in the analysis should be provided.
Priority: 2

OL–6.2–R7 A variety of image processing and filtering operations on the cube should be available, including:

OL–6.2–R7.1 Smoothing and convolution using standard (e.g. Gaussian, top-hat) and user-definable kernels
Priority: 1

OL–6.2–R7.2 Clipping
Priority: 1

OL–6.2–R7.3 Windowing and boxing, with definitions of regions of interest recordable and passable for subsequent use
Priority: 1

OL–6.2–R7.4 Arithmetical operations (e.g. scale, logarithm)
Priority: 1

OL–6.2–R7.5 Statistical operations (e.g. mean, rms, median, mode, power spectrum, autocorrelation, structure function)
Priority: 1

OL–6.2–R7.6 Cube arithmetic (e.g. sum, mean, difference, products, cross correlation of multiple images)
Priority: 1

OL–6.2–R7.7 Vector images (e.g. polarization vector at each cube pixel)
Priority: 1

OL–6.2–R7.8 Interpolation across blanked or masked regions
Priority: 1

OL–6.2–R7.9 Fitting of models, shapes, profiles and functions (e.g. line profiles, Gaussian components)

Priority: 2

OL–6.2–R7.10 Filtering (e.g. Fourier, Sobel, unsharp mask)
Priority: 2

OL–6.2–R7.11 Deconvolution
Priority: 2

OL–6.2–R7.12 Differentiation (e.g. gradient, plus divergence, curl, Laplacian for vectors)
Priority: 3

OL–6.2–R7.13 It is desirable that there be the capability to manipulate data cubes as general data structures, so that arithmetical and logical operations can be applied as object methods.
Priority: 3

OL–6.2–R8 Astronomical and astrophysical processing operations should also be available, such as:

OL–6.2–R8.1 Astrometric facilities, i.e. based on comparing catalogs with the images it should be possible to calculate the coordinate system.
Priority: 2

OL–6.2–R8.2 The spectral display for should be linked to molecular data bases which make identification of the lines possible.
Priority: 2

OL–6.2–R8.3 It is desirable that astrophysical quantities be directly calculated from processed images, e.g. spectral index, rotation measure, etc.
Priority: 3

2.7 Visualization

This is intended as the purely graphical part of data analysis. There is by necessity some overlap with the functionality discussed under Data Analysis, particularly that for image cube manipulation, and it would in fact be ideal if visualization and analysis were so closely integrated that there were no effective difference. The intention here is that the user is not only able to display pre-calculated images (processed using tools from the Data Analysis suite), but also has the capability of doing some processing and display on-the-fly as an integral part of the visualization.

2.7.1 General Visualization and Plotting Requirements

OL–7.1–R1 Plotting and display capabilities should be integrated into the GUI tools throughout the package.

Priority: 1

OL–7.1–R2 Standard type of plots must be supported, such as

OL–7.1–R2.1 histograms
OL–7.1–R2.2 contour plots
OL–7.1–R2.3 vector plots
OL–7.1–R2.4 2D images
OL–7.1–R2.5 wireframe 3D surfaces

Priority: 1

OL–7.1–R3 An extra "axis" of information should be encodable on the standard plot types using color and/or intensity.

Priority: 1

OL–7.1–R4 "Blinking" between two different images at a user-selected rate (and with adjustable transfer functions) must be possible.

Priority: 1

OL–7.1–R5 Standard plotting formats should be supported, both displayed (e.g. X window) and hard-copy.

OL–7.1–R5.1 There must be at least one designated standard output format (e.g. fits) that can be converted by the user to a variety of formats using easily obtainable tools.
Priority: 1

OL–7.1–R5.2 It is desirable that the Package support the output of a variety of commonly used formats such as fits, postscript, pdf, gif and/or jpeg.
Priority: 3

OL–7.1–R6 Identification of cursor position should be available for interactive plots. Where appropriate, this information should be recordable and exportable. If you "see-it" you should be able to figure out where it came from.

Priority: 1

OL–7.1–R7 Where appropriate, edition and flagging capability should be incorporated into all plots. If you "see-it" you should be able to "flag-it".

Priority: 2

OL–7.1–R8 Where possible, the displays should have similar look and feel to reduce the plotting learning curve.

Priority: 2

2.7.2 Display Appearance and Interactivity

OL–7.2–R1 Plot selection parameters (axes, limits, colormap) should be conveniently controllable. For interactive displays, plot update should be immediate.

Priority: 1

OL–7.2–R2 Interactive display zooming and unzooming should be fast and intuitive.

Priority: 1

OL–7.2–R3 Different line styles, sizes, thicknesses and colors must be available. User should be able to manipulate intensity and color scales easily (and graphically for displays), with the setup saveable and reloadable. The default colors and line styles should be appropriate.

Priority: 1

OL–7.2–R4 Basic axis transformations should be built in to plotting, such as:

OL–7.2–R4.1 Logarithmic amplitude and intensity scale
Priority: 1

OL–7.2–R4.2 Different time and coordinate units and formats (e.g. hours, hhmmss, radians, ddmmss.s)
Priority: 1

OL–7.2–R5 User should be able to augment plots and produce overlays of different data sets of standard formats.

OL–7.2–R5.1 Images with same axes, size and orientation should be superposable directly, with basic control of colors and symbols.
Priority: 1

OL–7.2–R5.2 Overlay layer style should be selectable, e.g. contours, greyscale, colormapped (RGB or HSV), or single color (i.e. one layer gets assigned intensity scales of red, another one of green, and one of blue).
Priority: 1

OL–7.2–R5.3 Overlay of axis grids should be available.
Priority: 1

OL–7.2–R5.4 The user must be able to overlay functional fits (e.g. polynomials) or points read in from standard tabular files
Priority: 1

OL–7.2–R5.5 It is highly desirable that data sets be placed in "layers" be which can be interactively colormapped, and switched on and off.
Priority: 2

OL–7.2–R5.6 It should be possible to display and overlay data with different coordinate systems, i.e. the coordinate system of the display can be chosen independent of the system the data were observed in and the data transformed appropriately with pre-computation.
Priority: 3

OL–7.2–R5.7 The different images (layers) should be editable.
Priority: 3

OL–7.2–R5.8 It is desirable to shift, rotate and scale the images interactively.
Priority: 3

OL–7.2–R6 Hardcopy output quality should be suitable for publication.

Priority: 2

OL–7.2–R7 User should be able to add annotation, both interactively and through scripts, including text with various fonts (including Greek letters), symbols (e.g. all the symbols provided by the LaTeX package with AMSTeX extension), arrows, geometrical figures like boxes and circles, etc.

Priority: 2

OL–7.2–R8 It is desirable that displays be linked to appropriate image manipulation and analysis tools, such as astrometrical calculators, molecular line databases, etc.

Priority: 3

2.7.3 Visibility Data

OL–7.3–R1 Plotting of commonly used basic data and calibration quantities must be straightforward and easily accessible from all relevant tools. These include:

OL–7.3–R1.1 amplitude and phase versus time
OL–7.3–R1.2 amplitude and phase versus uv-radius
OL–7.3–R1.3 amplitude and phase versus channel (frequency)
OL–7.3–R1.4 amplitude and phase versus baseline and time
OL–7.3–R1.5 amplitude and phase versus time and channel
OL–7.3–R1.6 imaginary versus real
OL–7.3–R1.7 delay and rate versus time derived from spectra

Priority: 1

OL–7.3–R2 Data selection parameters should be understandable (e.g. by antenna name or number instead of antenna table entry number, polarization name RR or I) and straightforward, using graphical browsers (in GUI mode) and/or standard selection language (e.g. SQL queries) in script mode.

Priority: 1

OL–7.3–R3 It should be possible to switch between amplitude/phase and real/imaginary for any plotted visibilities or other complex values.

Priority: 2

2.7.4 Other ALMA Data

Although the Package will not likely be the primary vehicle for the ALMA staff to assess the state of the array, it is intended that users (as well as staff) have the full capability of using ancillary data provided by ALMA to aid in the processing and understanding of their data. Therefore, the Package should be able to deal with this data in as user-friendly a manner as possible.

OL–7.4–R1 The package should be able to plot standard ALMA-format ancillary data, including

OL–7.4–R1.1 amplitude or single-dish power versus AZ and EL
Priority: 1
OL–7.4–R1.2 focus data and curves
Priority: 2
OL–7.4–R1.3 pointing data and offset vectors
Priority: 2
OL–7.4–R1.4 WVR output data
Priority: 3
OL–7.4–R1.5 holography and beam map data
Priority: 3
OL–7.4–R1.6 monitor point values (e.g. temperatures)
Priority: 3

2.7.5 Image-cube Manipulation

OL–7.5–R1 Overlay of selectable coordinate grids (e.g. J2000, B1950, galactic, ecliptic, pixel number) must be available. It must also be possible to overlay multiple grids.

Priority: 1

OL–7.5–R2 Histograms of pixel values must be easily produced for selected regions of the cube.

Priority: 1

OL–7.5–R3 It must be possible to plot values of the same pixel in different cube layers, or in different images, against each other.

Priority: 1

OL–7.5–R4 Data cubes must be viewable as movies with selectable frame rates and layer step directions.

Priority: 1

OL–7.5–R5 Interactive display of spectra corresponding to a pixel or region in a displayed image should be supported.

Priority: 2

OL–7.5–R6 Interactive display of a 1D slice taken from a 2D image, such as dragging the line on the map to bring up a position-velocity diagram, should be available.

Priority: 2

OL–7.5–R7 Plotting of spectra on a pseudo-grid corresponding to position on a raster (e.g. a "stamp map" or "profile map", basically thumbnail spectra in panels corresponding to position) should be possible.

Priority: 2

OL–7.5–R8 It should be possible to view arbitrary subsets or slices of data cubes. These should be interactively selected in GUI mode.

Priority: 3

2.8 Special Features

2.8.1 Simulation

Note: Inclusion of at least moderate simulation capability in the Package will benefit the user who may not have access to the more comprehensive simulator built into the Pipeline and Online systems. In the spirit of providing the user with offline options equivalent to those available in the project, it is desirable that some simulation capability also makes it into the Package albeit at low priority. The main goals would be to allow the user to simulate basic ALMA modes based on input models or images and to replace existing data in ALMA format with simulated data.

OL–8.1–R1 The Package shall inherit the basic simulation capability of the ALMA Online Data Processing Pipeline (Levels 1 and 2) as outlined in ALMA Memo SW-11, as per (5).

Priority: 2

2.8.2 VLBI

Note: It is assumed that VLBI data will be reduced in whatever package supports general VLBI observations, as ALMA will not be a stand-alone VLBI instrument. There are no VLBI requirements on the ALMA Offline Data Processing Package, though it may end up being the case that the Package also supports VLBI processing. This would have some advantage to users of the ALMA Package, and thus it is worth including a low-priority requirement to this effect.

OL–8.2–R1 It is desirable that the Package also support general VLBI processing suitable for dealing with ALMA data, in order to allow general ALMA users access to VLBI science without having to learn a completely new software package.

Priority: 3

2.8.3 Solar Observing

Need author for this section

2.8.4 Pulsar Observing

Need author for this section