CASA – the science data analysis package for ALMA

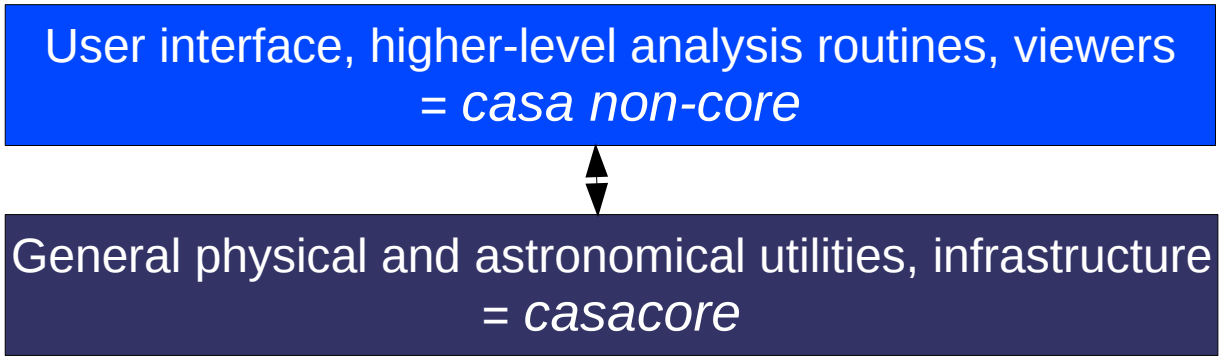
Dirk Petry (ESO), April 2010

Outline

→ What is *CASA?*	- main features of *CASA*
→ Who develops *CASA*?	- development team
→ What are the main requirements and how does *CASA* meet them?	- design and implementation
→ How does CASA look and feel?	- the CASA user interface
→ CASA status and release plans	

CASA main features

- ***CASA* = Common Astronomy Software Applications**
- **Development started in the 90s as the next generation of AIPS**
- **Refocussed in 2003 to be *the ALMA/EVLA analysis package***
- **Has the intention to be a *general software package to reduce both interferometer and single-dish data***
- **Internally consists of two parts:**



- **Implements the "Measurement Equation" (Hamaker, Bregman & Sault 1996)**
- **Internal data format is the "Measurement Set" (Kemball & Wieringa 2000)**
- **1.5 Million lines of code (mostly C++)**
- **In public release under GNU Public License since December 2009**

CASA – development team

CASA Developers Meeting, VLA site, February 2008

CASA – development team

Since mid 2008, two CASA developers at ESO, since Sept. 2009 three

CASA – development team

Originally only developed at NRAO (Socorro, NM), now

approx. 17 FTE developers are at work at

NRAO Socorro (7)
NRAO Charlottesville (2)
University of Maryland (1)
NAOJ (3)
University of Virginia (0.5)
Observatoire de Paris (0.5)
ESO Garching (3)

+ 1 CASA manager (NRAO Socorro) = Nick Elias

+ 1 Project Scientist (NRAO Socorro) = Jürgen Ott

+ a few 5% FTEs at ASTRON, ATNF, and other places
Also involved:
ALMA Computing Managers = B. Glendenning (NRAO), G. Raffi, P. Ballester (ESO)

CASA design and implementation

Overall architecture:

1) A data structure

2) A set of data import/export facilities

3) A set of tools for data access, display, and editing

4) A set of tools for science analysis

5) A set of high-level analysis procedures (“tasks”)

6) A programmable command line interface with scripting

7) Documentation

CASA design and implementation

Overall architecture:

1) A data structure
   Tables: Images, Caltables, and the *Measurement Set* (MS)
2) A set of data import/export facilities
   the so-called *fillers*: ASDM → MS, FITS → Image, UVFITS → MS, VLA → MS, etc.
3) A set of tools for data access, display, and editing
   tools to load/write data into/from casacore data types,
   Qt-based table browser, viewer, and (beta) x/y plotter, *matplotlib*-based x/y plotter
4) A set of tools for science analysis
   built around the *Measurement Equation* (developed in 1996) = a set of C++ classes
   for radio astronomical calibration and imaging
5) A set of high-level analysis procedures ("tasks")
   special procedures for each required task such as CLEAN etc.
6) A programmable command line interface with scripting
   Python (augmented by *IPython*) gives a MATLAB-like interactive language
7) Documentation
   an extensive cookbook (500 pages) + documentation through help commands
   (help, ?, pdoc) + online help pages for users and developers

CASA design and implementation

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special procedures for each required task such as CLEAN etc.

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c) → *Python* (augmented by *IPython*) gives a MATLAB-like interactive language

7) Documentation

an extensive cookbook (500 pages) + documentation through help commands (help, ?, pdoc) + online help pages for users and developers

CASA design and implementation

CASA special features:

a) the *Measurement Set* (MS)

- developed by Cornwell, Kemball, & Wieringa between 1996 and 2000

- designed to store both interferometry (multi-dish) and single-dish data

- supports (in principle) any setup of radio telescopes

- supports description and processing of the data via the Measurement Equation

- fundamental storage mechanism: *CASA Tables* (inspired by *MIRIAD*)

- *MS = table for radio telescope data (visibilities) + auxiliary sub-tables*

CASA design and implementation

The Measurement Set

MAIN	none	-	-	ANTENNA_ID FEED_ID DATA_DESC_ID PROCESSOR_ID (PHASE_ID) FIELD_ID (PULSAR_GATE_ID) ARRAY_ID OBSERVATION_ID STATE_ID
(FREQ_OFFSET)	none	-	-	ANTENNA_ID FEED_ID SPW_ID
(SYSCAL)	none	-	-	ANTENNA_ID FEED_ID SPW_ID
POINTING	none	-	-	ANTENNA_ID POINTING_MODEL_ID
(WEATHER)	none	-	-	ANTENNA_ID
HISTORY	none	-	-	OBSERVATION_ID OBJECT_ID
FLAG_CMD	none	-	-	none

ANTENNA	ANTENNA_ID	row number	MAIN FEED FREQ_OFFSET POINTING SYSCAL WEATHER	(ORBIT_ID) (PHASED_ARRAY_ID)
FEED	FEED_ID	explicit	MAIN FREQ_OFFSET SYSCAL	ANTENNA_ID SPW_ID BEAM_ID (PHASED_FEED_ID)
DATA_DESCRIPTION	DATA_DESC_ID	row number	MAIN	SPW_ID POLARIZATION_ID (LAG_ID)
PROCESSOR	PROCESSOR_ID	row number	MAIN	TYPE_ID MODE_ID (PASS_ID)
FIELD	FIELD_ID	row number	MAIN	SOURCE_ID (EPHEMERIS_ID)
OBSERVATION	OBSERVATION_ID	row number	MAIN HISTORY	none
STATE	STATE_ID	row number	MAIN	none
SPW	SPW_ID	row number	DATA_DESCRIPTION FEED FREQ_OFFSET SOURCE SYSCAL	(RECEIVER_ID) (DOPPLER_ID) (ASSOC_SPW_ID)

POLARIZATION	POLARIZATION_ID	row number	DATA_DESCRIPTION	none
(SOURCE)	SOURCE_ID	explicit	(DOPPLER) FIELD	SPW_ID (PULSAR_ID)
(DOPPLER)	DOPPLER_ID	explicit	SPW_ID	SOURCE_ID TRANSITION_ID

Legend:

[Table Name] [Key defined in this table] [key definition method] [referenced by] [referenced keys] (optional) reference to table outside the MS definition

Level 1: Tables not referenced by other tables

Level 2: Tables referenced by level 1

Level 3: Tables referenced by level 2

V1, D.Petry, 13.2.09

CASA design and implementation

Example of a *Measurement Set*

```
$ tree AT352_A071103-K
AT352_A071103-K
|-- ANTENNA
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- DATA_DESCRIPTION
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- DOPPLER
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- FEED
|   |-- table.dat
|   |-- table.f0
|   |-- table.f0i
|   |-- table.info
|   `-- table.lock
|-- FIELD
|   |-- table.dat
|   |-- table.f0
|   |-- table.f0i
|   |-- table.info
|   `-- table.lock
|-- FLAG_CMD
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- HISTORY
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- OBSERVATION
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- POINTING
|   |-- table.dat
|   |-- table.f0
|   |-- table.f0i
|   |-- table.f1
|   |-- table.info
|   `-- table.lock
|-- POLARIZATION
|   |-- table.dat
|   |-- table.f0
|   |-- table.f0i
|   |-- table.info
|   `-- table.lock
|-- PROCESSOR
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- SORTED_TABLE
|   |-- table.dat
|   `-- table.info
|-- SPECTRAL_WINDOW
|   |-- table.dat
|   |-- table.f0
|   |-- table.f0i
|   |-- table.info
|   `-- table.lock
|-- STATE
|   |-- table.dat
|   |-- table.f0
|   |-- table.info
|   `-- table.lock
|-- table.dat
|-- table.f0
|-- table.f1
|-- table.f10
|-- table.f1_TSM1
|-- table.f2
|-- table.f2_TSM1
|-- table.f3
|-- table.f3_TSM1
|-- table.f4
|-- table.f4_TSM1
|-- table.f5
|-- table.f5_TSM1
|-- table.f6
|-- table.f6_TSM1
|-- table.f7
|-- table.f7_TSM1
|-- table.f8
|-- table.f8_TSM1
|-- table.f9
|-- table.f9_TSM0
|-- table.info
`-- table.lock

15 directories, 88 files
```

CASA design and implementation

CASA special features:

b) the *Measurement Equation* (Hamaker, Bregman, & Sault 1996 + Sault, Hamaker, & Bregman 1996) implemented as a set of C++ classes for radio astronomical calibration and imaging

$$\vec{V}_{ij} = \vec{\vec{M}}_{ij}\vec{\vec{B}}_{ij}\vec{\vec{G}}_{ij}\vec{\vec{D}}_{ij}\int \vec{\vec{E}}_{ij}\vec{\vec{P}}_{ij}\vec{\vec{T}}_{ij}\vec{\vec{F}}_{ij}\ \vec{SI}_{\nu}(l,m)\, e^{-i2\pi(u_{ij}l+v_{ij}m)}\, dl\, dm + \vec{A}_{ij}$$

where

the vectors are: V = visibility = $f(u, v)$, I = Image to be calculated,

A = additive baseline-based error component

the matrices are: M = multiplicative, baseline-based error component

B = bandpass response

G = generalised electronic gain

D = polarisation leakage

E = antenna voltage pattern

P = paralactic angle

T = tropospheric effects

F = ionospheric Faraday rotation

S = mapping of I to the polarization basis of the observation

other variables and indices are:

l, m = image plane coordinates, i, j = telescope ID pairs = baseline, u, v = Fourier plane coordinates

CASA design and implementation

***CASA* special features:**

b) the *Measurement Equation* (Hamaker, Bregman & Sault 1996)
implemented as a set of C++ classes for radio astronomical calibration and imaging
(continued)

Assuming, e.g., independence of the matrices from (l,m), the ME can be solved for individual calibration components.

$$\vec{V}_{ij}^{obs} = \vec{\vec{B}}_{ij}\vec{\vec{G}}_{ij}\vec{\vec{D}}_{ij}\vec{\vec{P}}_{ij}\vec{\vec{T}}_{ij}\vec{\vec{F}}_{ij}\,\vec{V}_{ij}^{ideal}$$

ideal visibility known from calibrator source

⇒ have set of linear equations.

The actual calculation of the component is then a χ^2 minimization.

The calibrater (cb) tool contains a set of ***solvers*** for the different calibration components.

CASA design and implementation

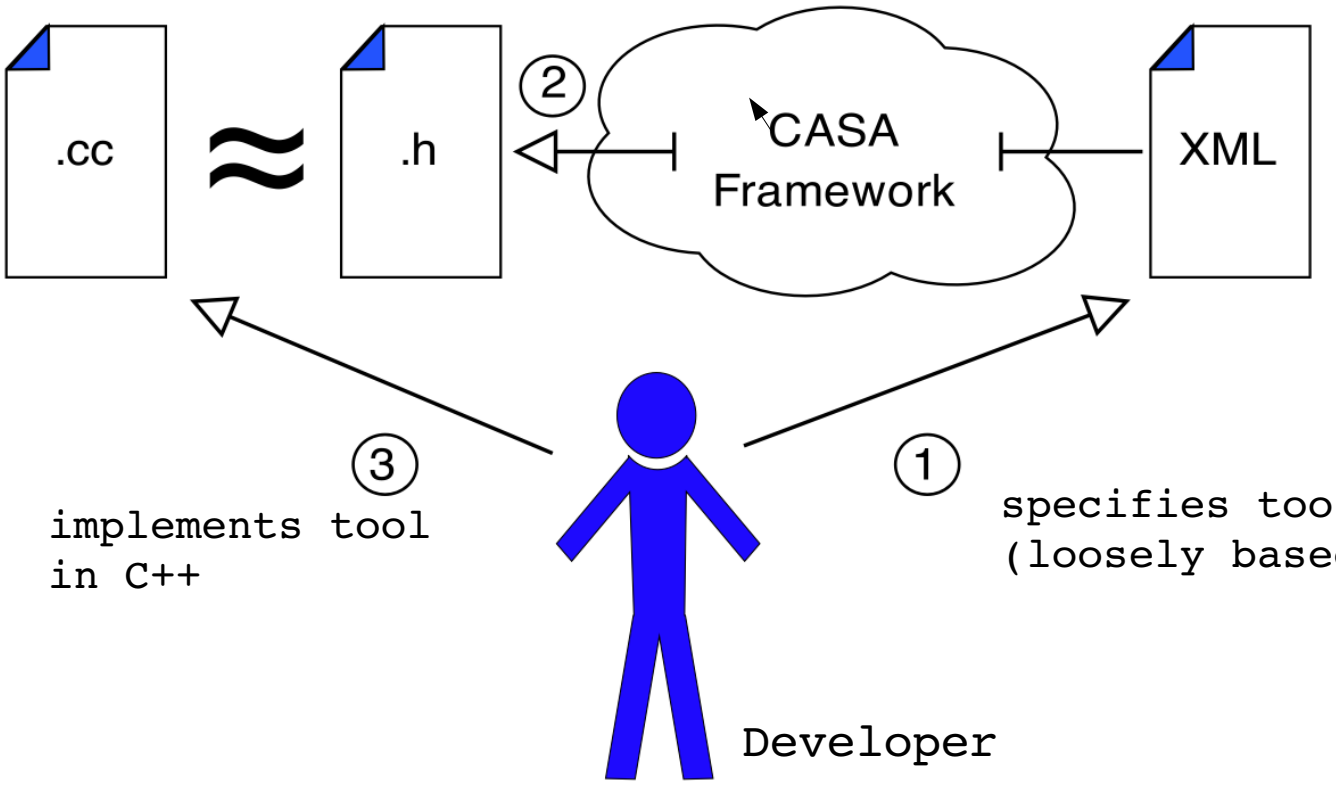
***CASA* special features:**

c) A programmable command line interface with scripting

Originally AIPS++/*CASA* had *GLISH*

Abandoned in 2006 for a ***Framework Architecture of tools***

Framework generates headers + bindings to scripting language + documentation



CASA design and implementation

***CASA* special features:**

c) A programmable command line interface with scripting (continued)

Framework Architecture of 17 tools can be bound to any scripting language, presently selected is ***Python (augmented by IPython)***

at – atmosphere library
ms – Measurement Set utilities
mp – Measurement Set Plotting, e.g. data (amp/phase) versus other quantities
cb – Calibration utilities
cp – Calibration solution plotting utilities
im – Imaging utilities
ia – Image analysis utilities
fg – flagging utilities
tb – Table utilities (selection, extraction, etc.)
me – Measures utilities
tp – table plot
vp – voltage patterns
qa – Quanta utilities
cs – Coordinate system utilities
pl – matplotlib functionality
sd - ASAP = ATNF Spectral Analysis Package (single-dish analysis imported from ATNF)
sm - simulation

CASA design and implementation

CASA special features:

c) A programmable command line interface with scripting
(continued)
Python (augmented by IPython)

Gives features such as

- tab completion
- autoparenthesis
- command line numbering
- access to OS, e.g.
  Lines starting with '!' go to the OS.
  `a = !ls *.py` to capture the output of '`ls *.py`'.
  `!cmd $myvar` expands Python var `myvar` for the shell.
- history
- execfile()
- comfortable help

CASA design and implementation

***CASA* special features:**

c) A programmable command line interface with scripting
(continued)

In addition to toolkit: high-level tasks for the standard user

toolkit (implemented in C++) ⟶ tasks (implemented in Python)

e.g. the task *importfits* is based on the tool *ia* (image analysis):

```
#Python script
casalog.origin('importfits')
ia.fromfits(imagename,fitsimage,whichrep,whichhdu,zeroblanks,overwrite)
ia.close()
```

CASA status

- Since Dec 2009 in public release under GPL = anybody can download,
  no warranty (see http://casa.nrao.edu),
  limited support (help desk, needs registration)
- Tutorials for the user community regularly given
- Naming scheme:
  - release X.Y.0 - “major release” (once or twice per year)
  - release X.Y.Z, Z≠0, denotes “patch release” = major release with urgent improvements
- The first public release was CASA 3.0.0 (Dec 2009)
- Release 3.0.1 has been published this month.
- *At this tutorial you are going to use release 3.0.1*

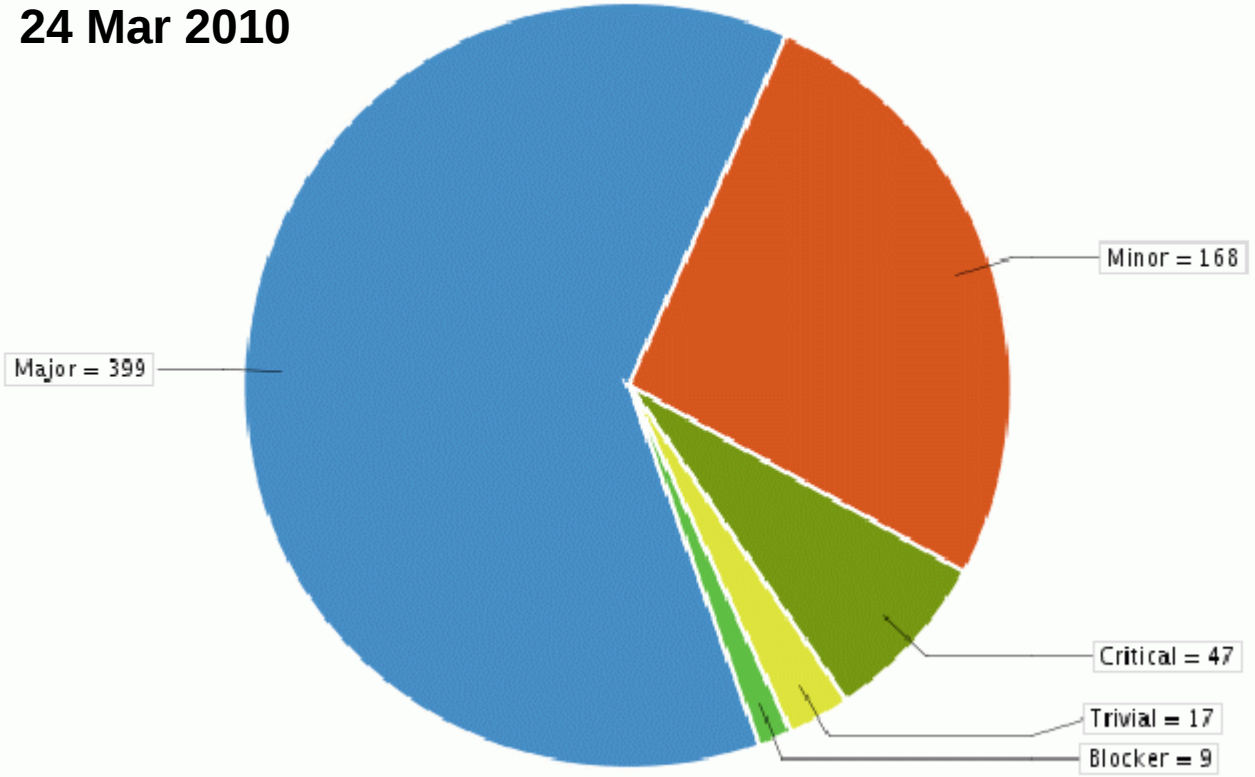
- Development platforms: Linux (RHEL) + Mac OS X
- Supported platforms (binary distribution): RHEL, Fedora, openSuSE, Ubuntu, Max OS X

- Code kept in *svn* repository at NRAO, Socorro
- Presently have approx. 4200 modules, 1.5E6 lines of code, 1E6 lines of comments
- The core functionality (mostly derived from AIPS++) was split off into *casacore* for use by other projects
  (also available at http://code.google.com/p/casacore/)

CASA status

- **Status in terms of JIRA tickets (bug reports and requests for new features)**

24 Mar 2010

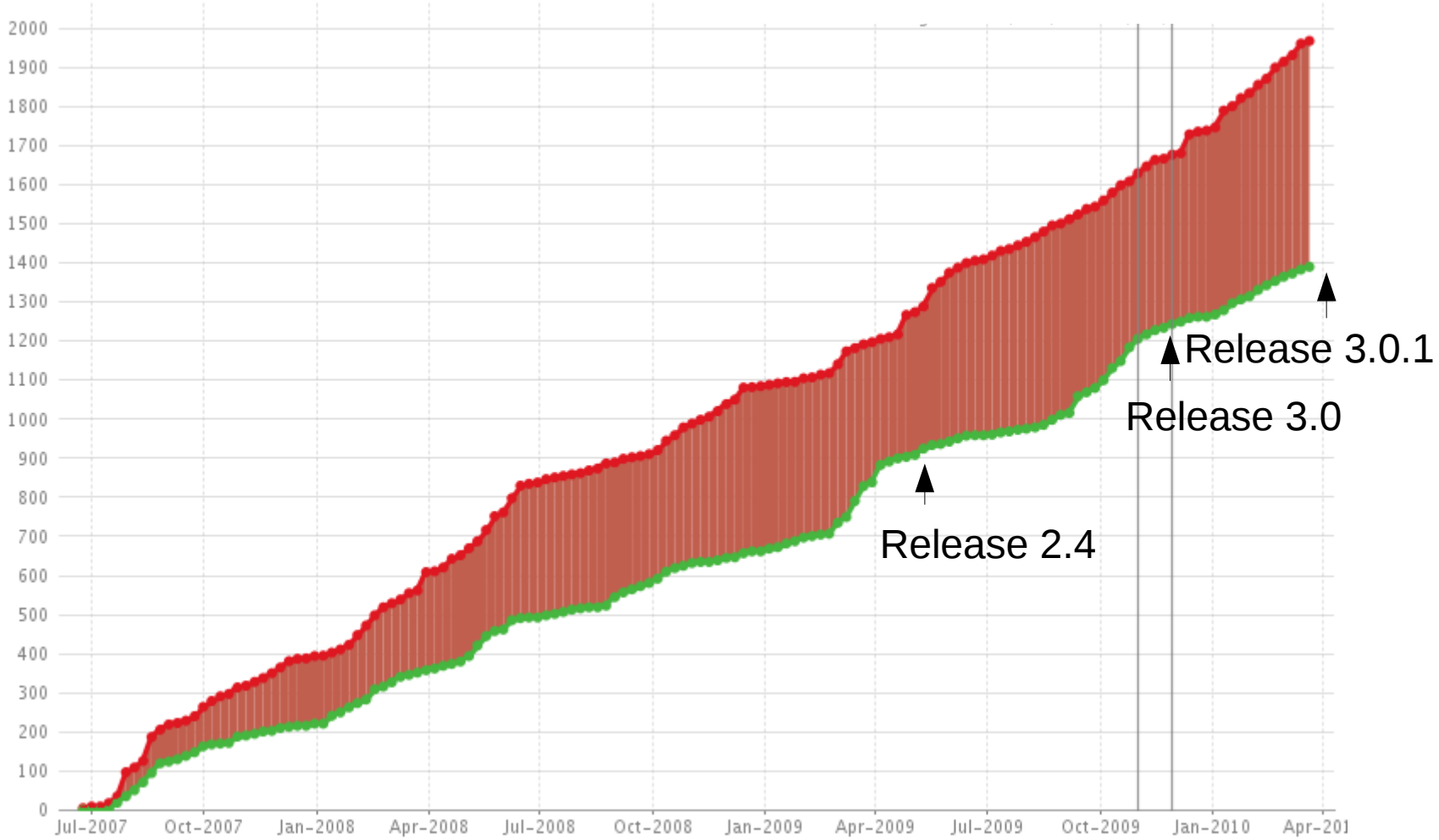


	Issues	%
Major	399	62%
Minor	168	26%
Critical	47	7%
Trivial	17	2%
Blocker	9	1%

(there has been a certain inflation in the priority classification of tickets)

CASA status

JIRA tickets

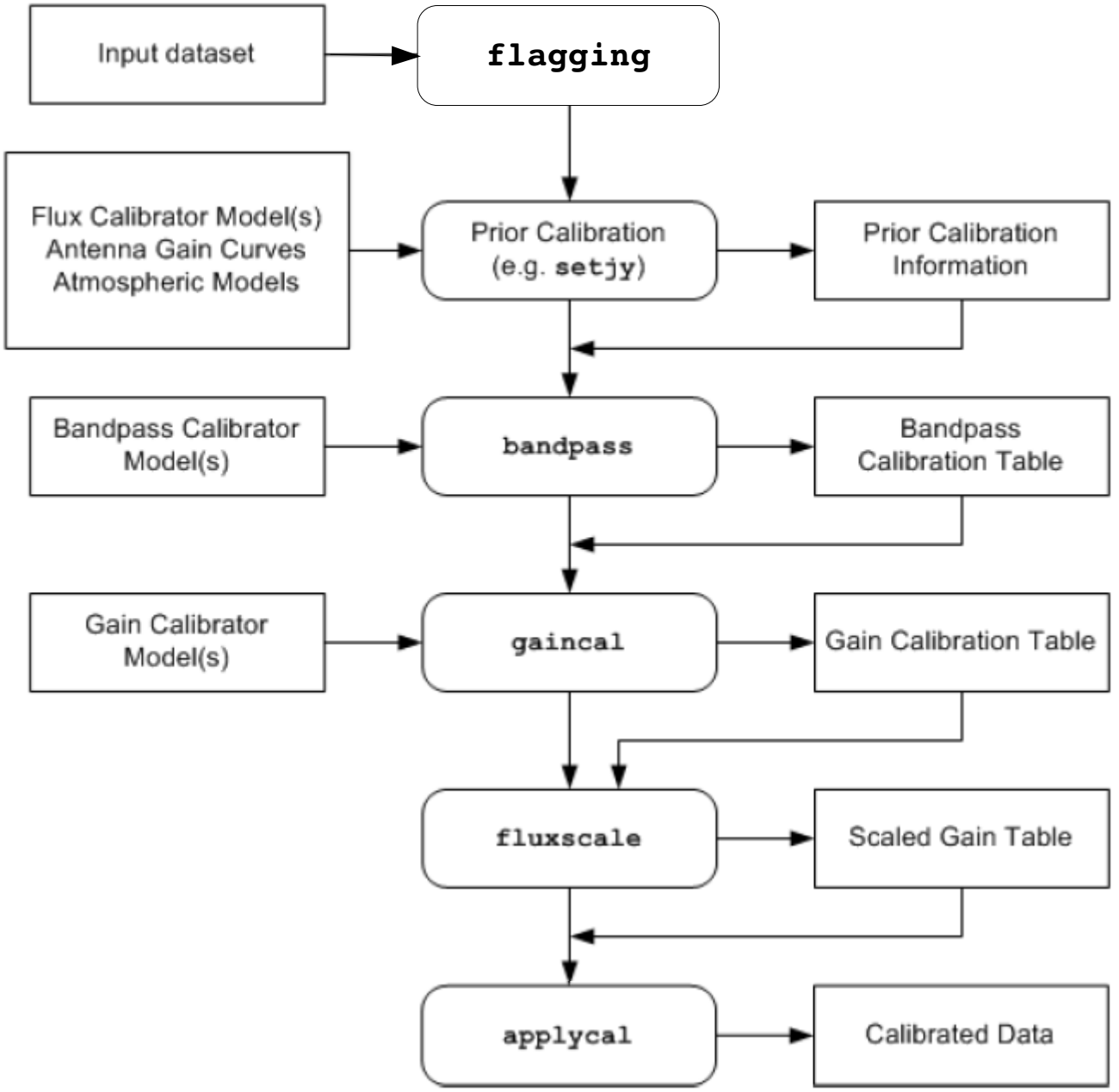


For release 3.0 approx. 225 issues were resolved/closed, another 180 for 3.0.1.
These include not only bug fixes but also new features and improvements.
Testing has intensified leading presently to an increased rate of issue reports.

How does *CASA* look and feel?

A typical analysis session

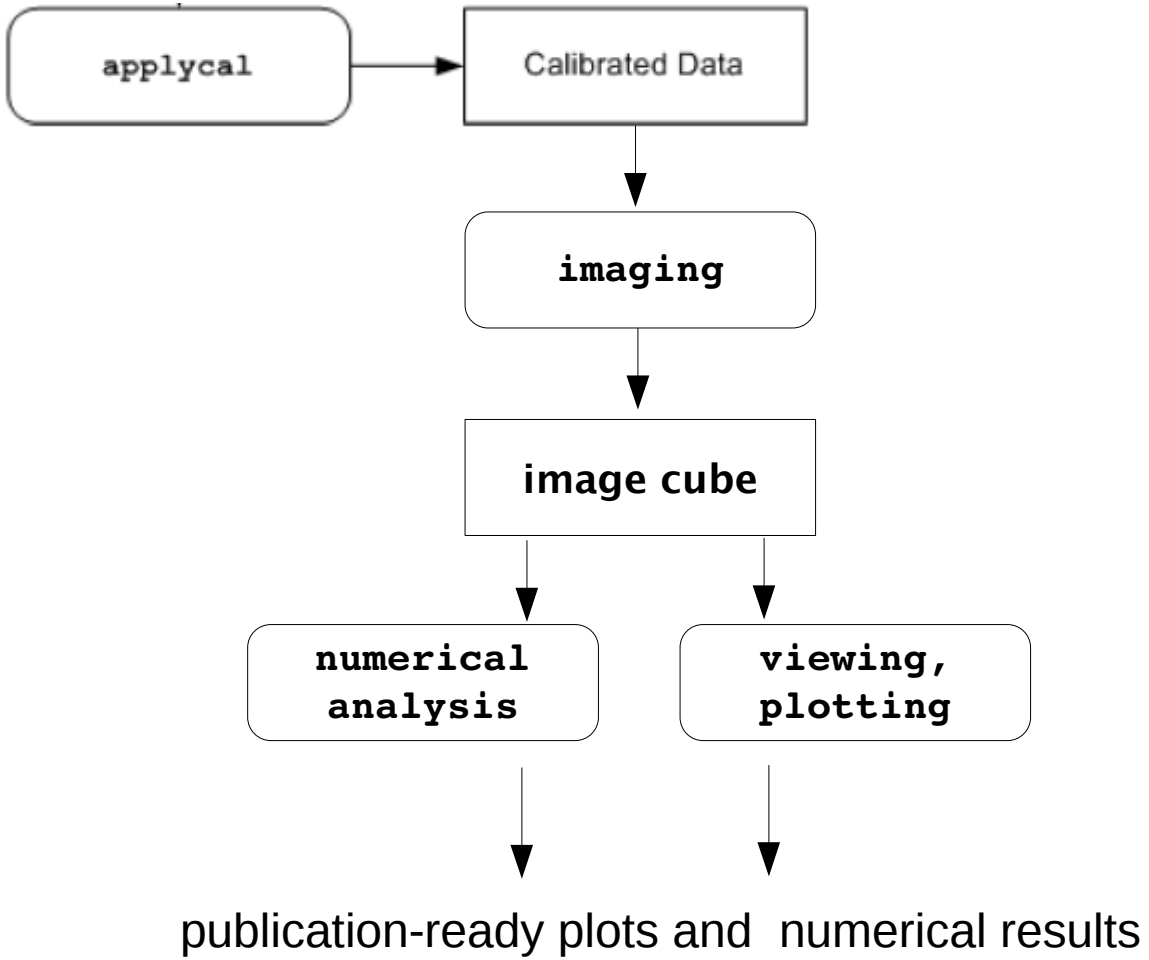
Part 1: flagging and calibration



How does *CASA* look and feel?

A typical analysis session

Part 2: imaging and
image analysis

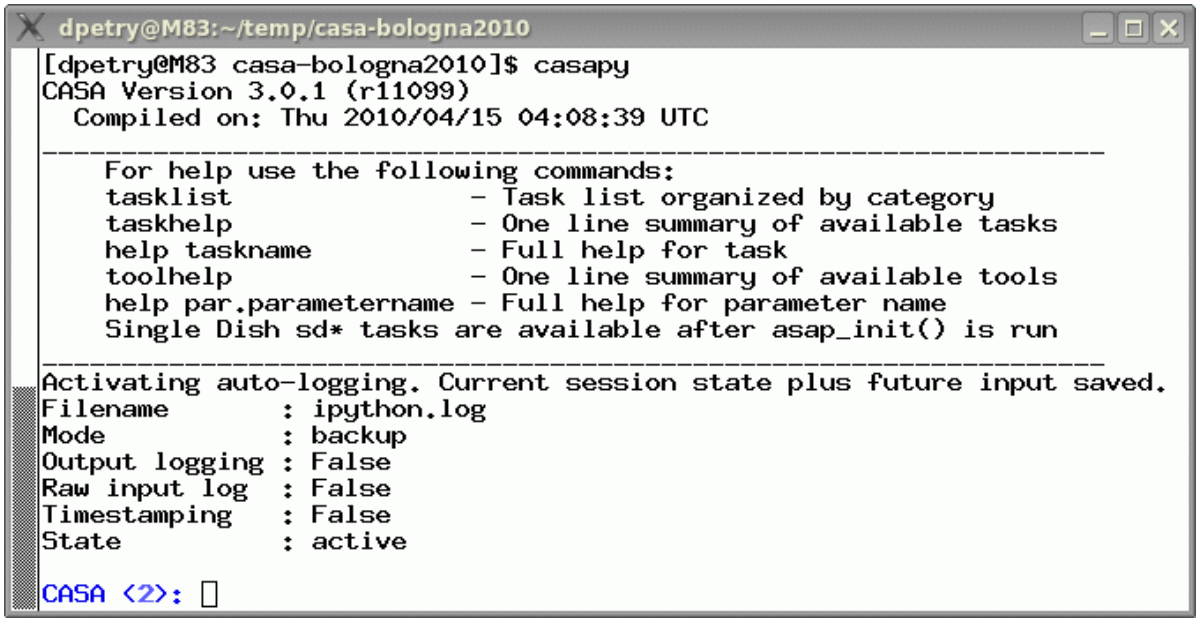


How does *CASA* look and feel?

Pictures from a typical analysis session

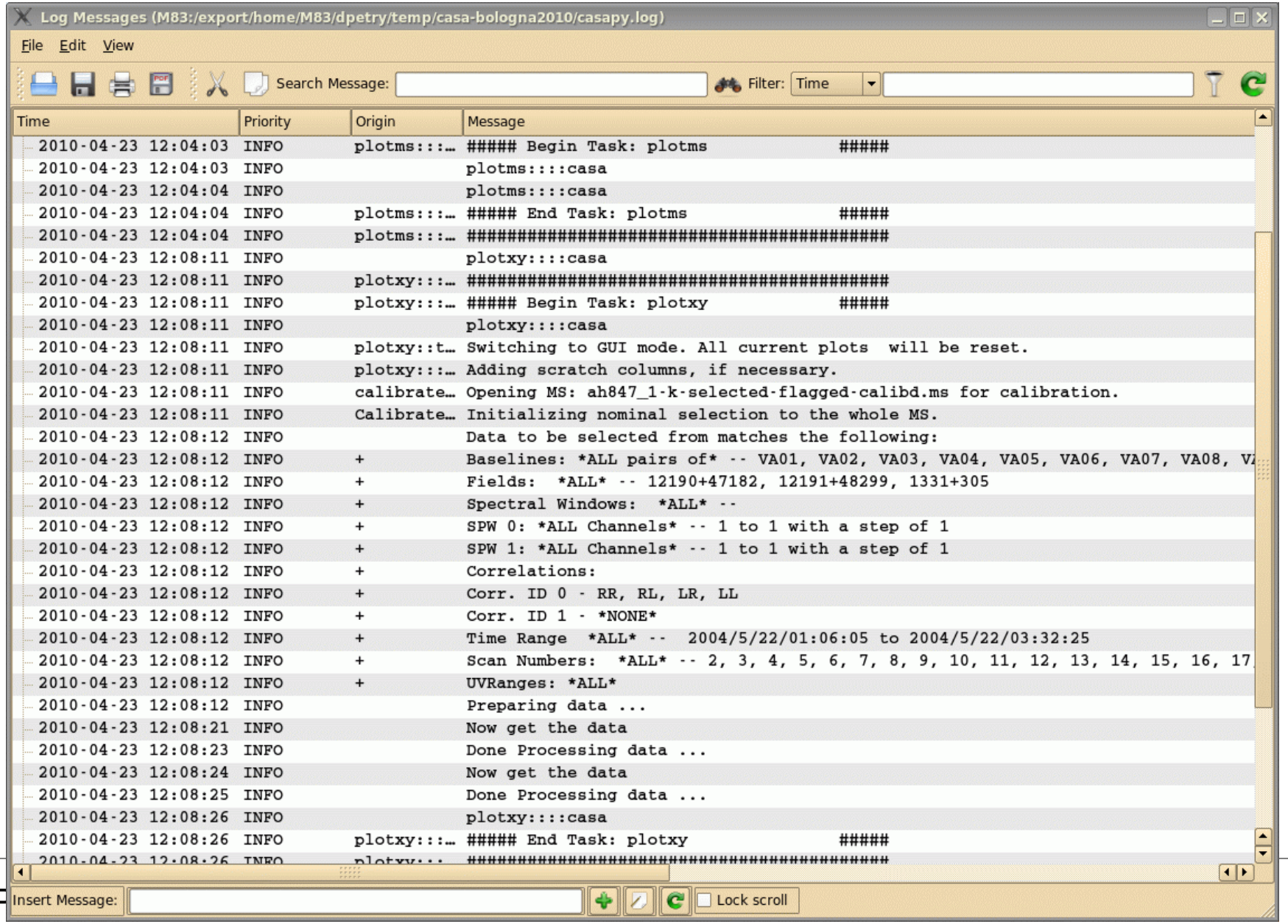
1) Startup:
open terminal and start *casapy*

Available tasks and tools are listed and the logger window is opened.



The *CASA* user interface

The logger provides functionality for monitoring and debugging command execution.



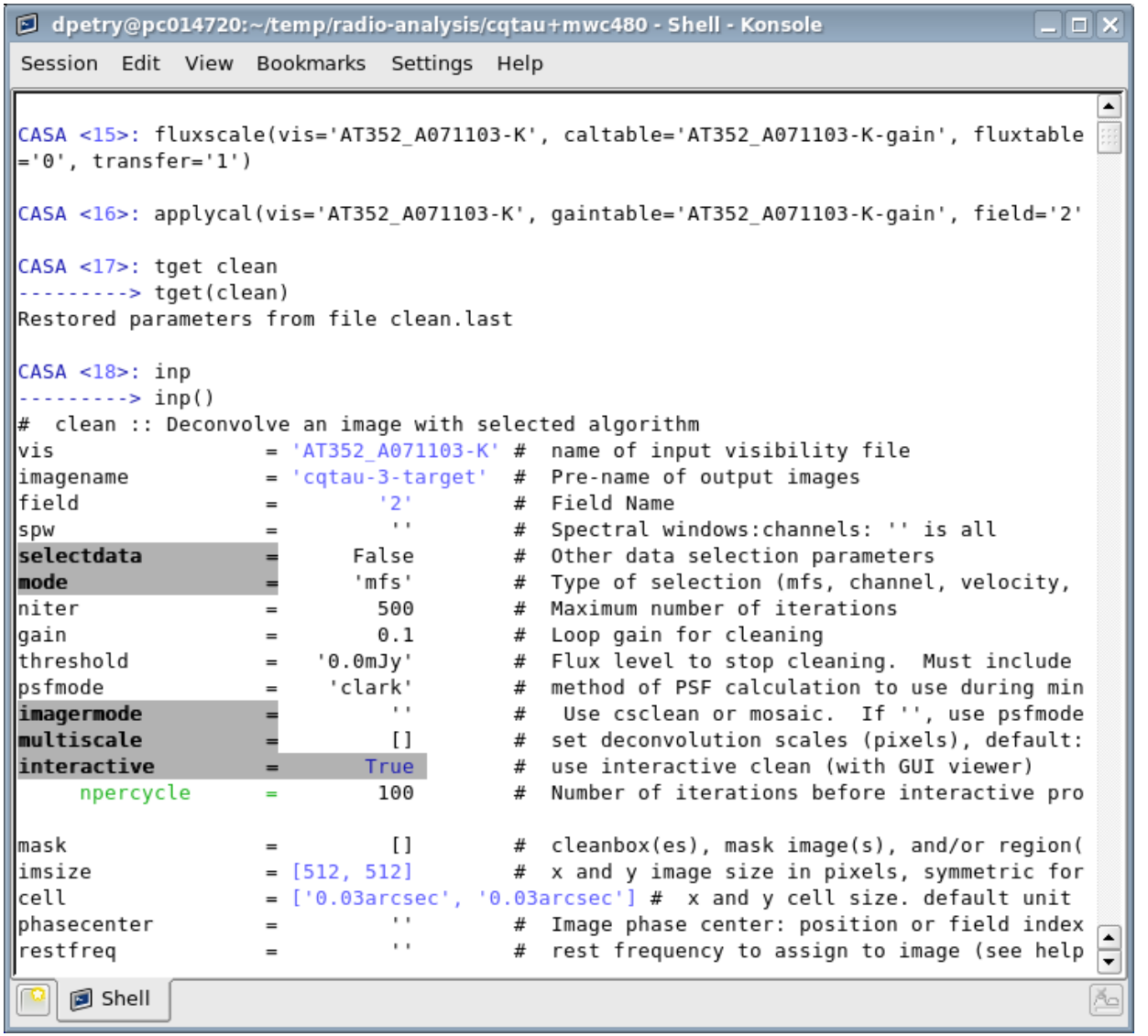
The *CASA* user interface

Pictures from a typical analysis session

2) enter commands in a MATLAB-like environment

`recall previous settings`

`list present settings for given task (includes parameter verification)`



The *CASA* user interface

Pictures from a typical analysis session

3) where needed, tools have GUIs:

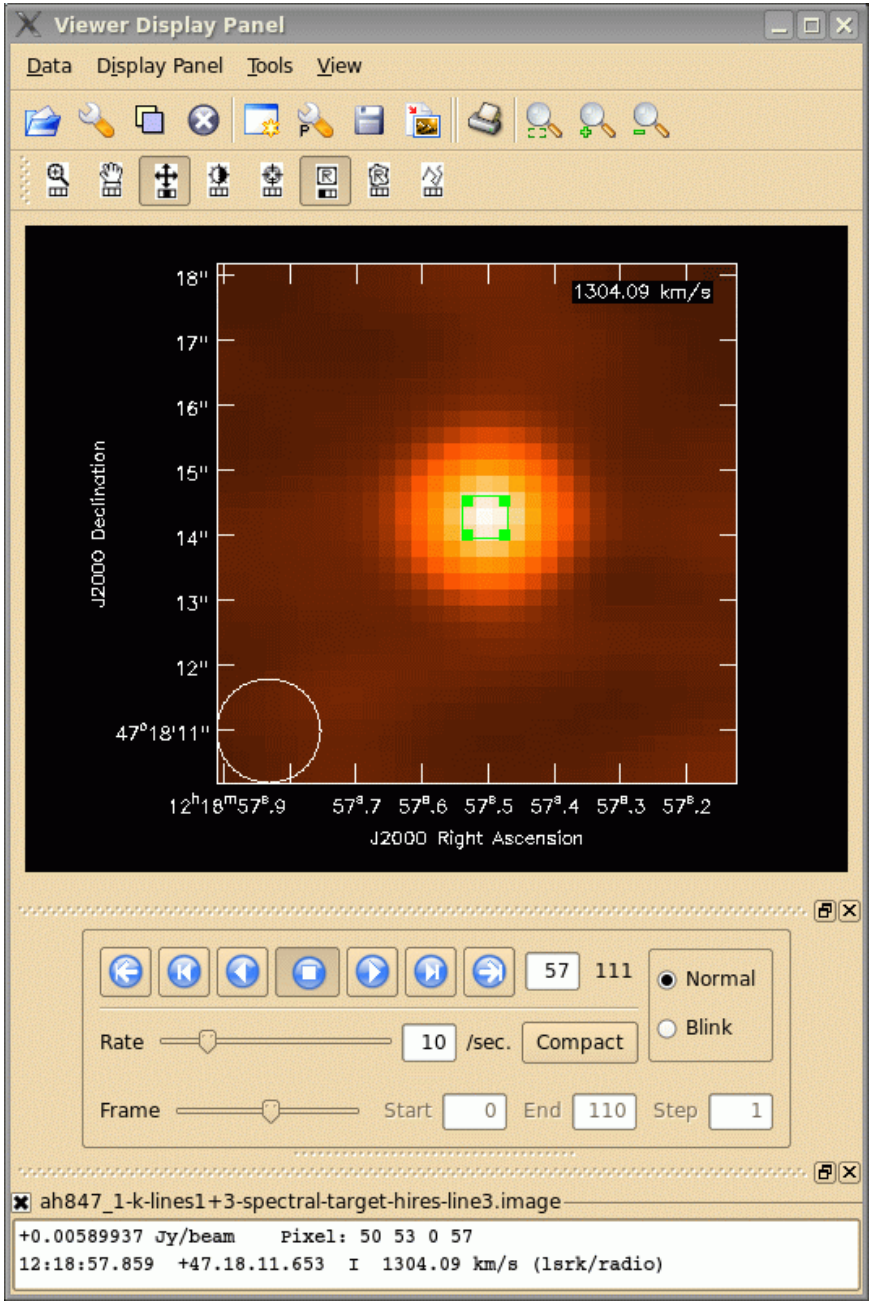
plotxy, plotcal, browsetable, viewer, clean

(started in separate threads)

The ***viewer*** is a powerful multi-function tool for data selection and visualization.

Uses Qt widget set
(but 80% independent)

Rendering based on pgplot



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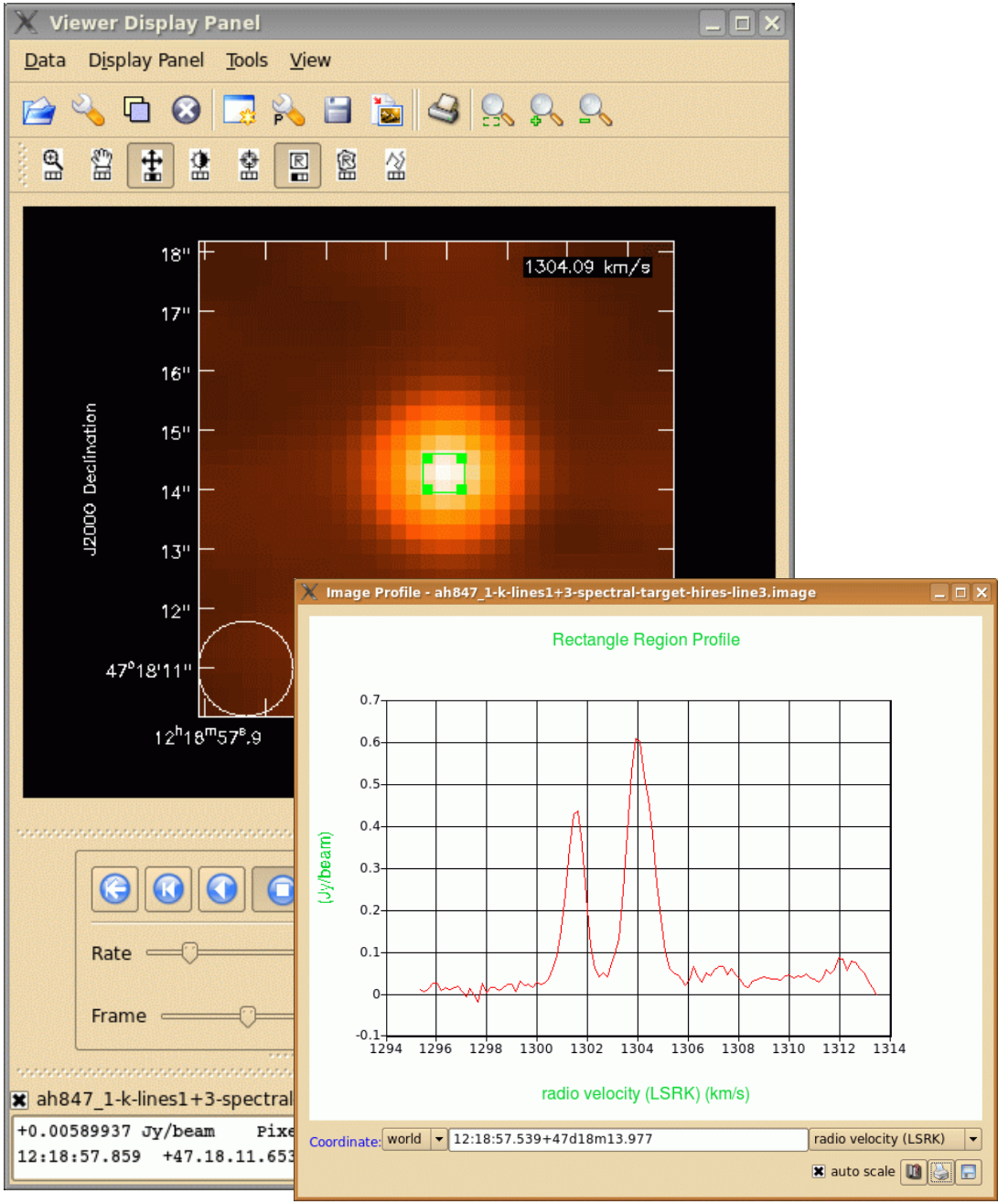

The *CASA* user interface

A typical analysis session

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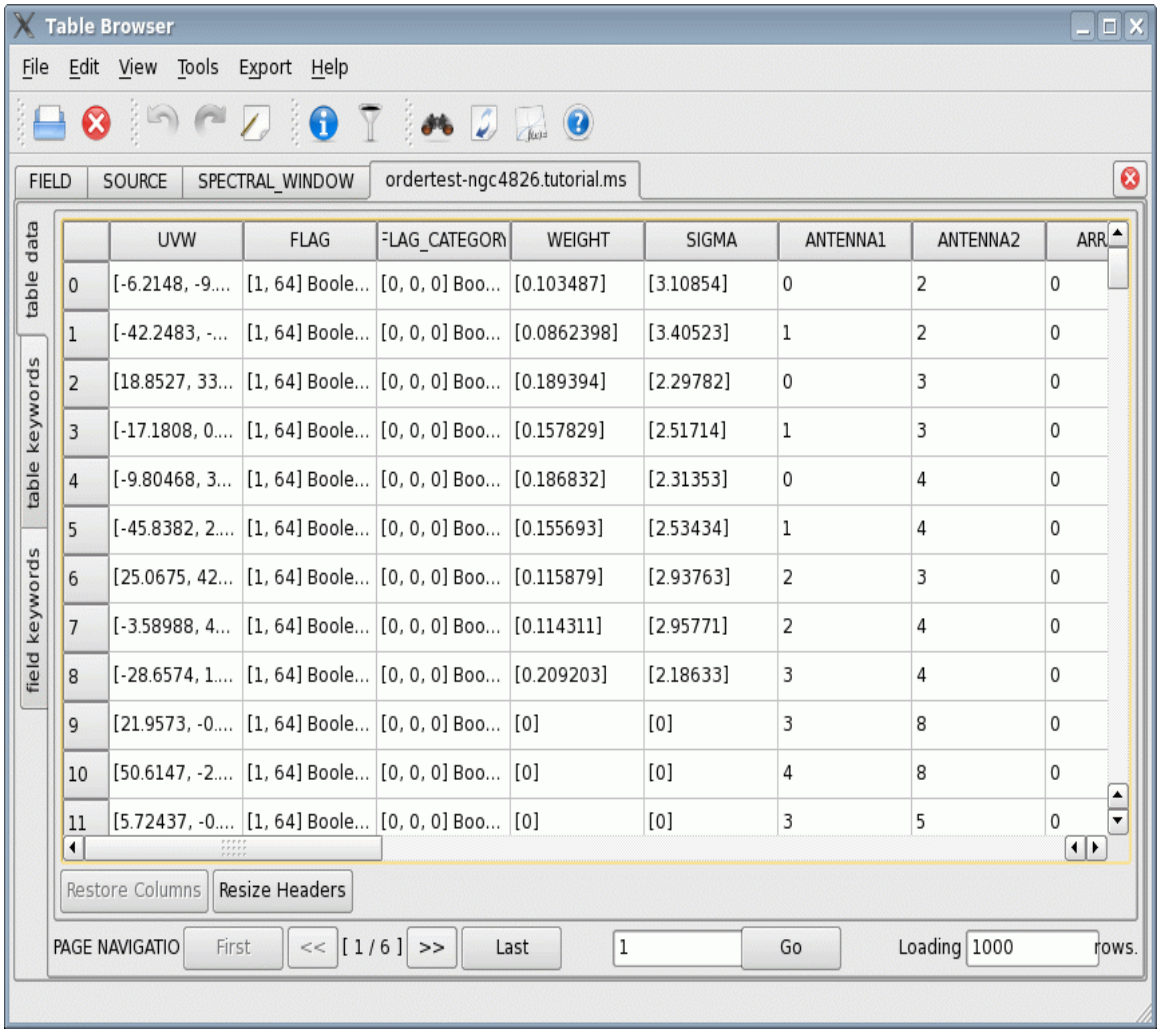
browsetable permits you to explore any CASA table, e.g. Measurement Sets

Also Qt-based.



The *CASA* user interface

A typical analysis session

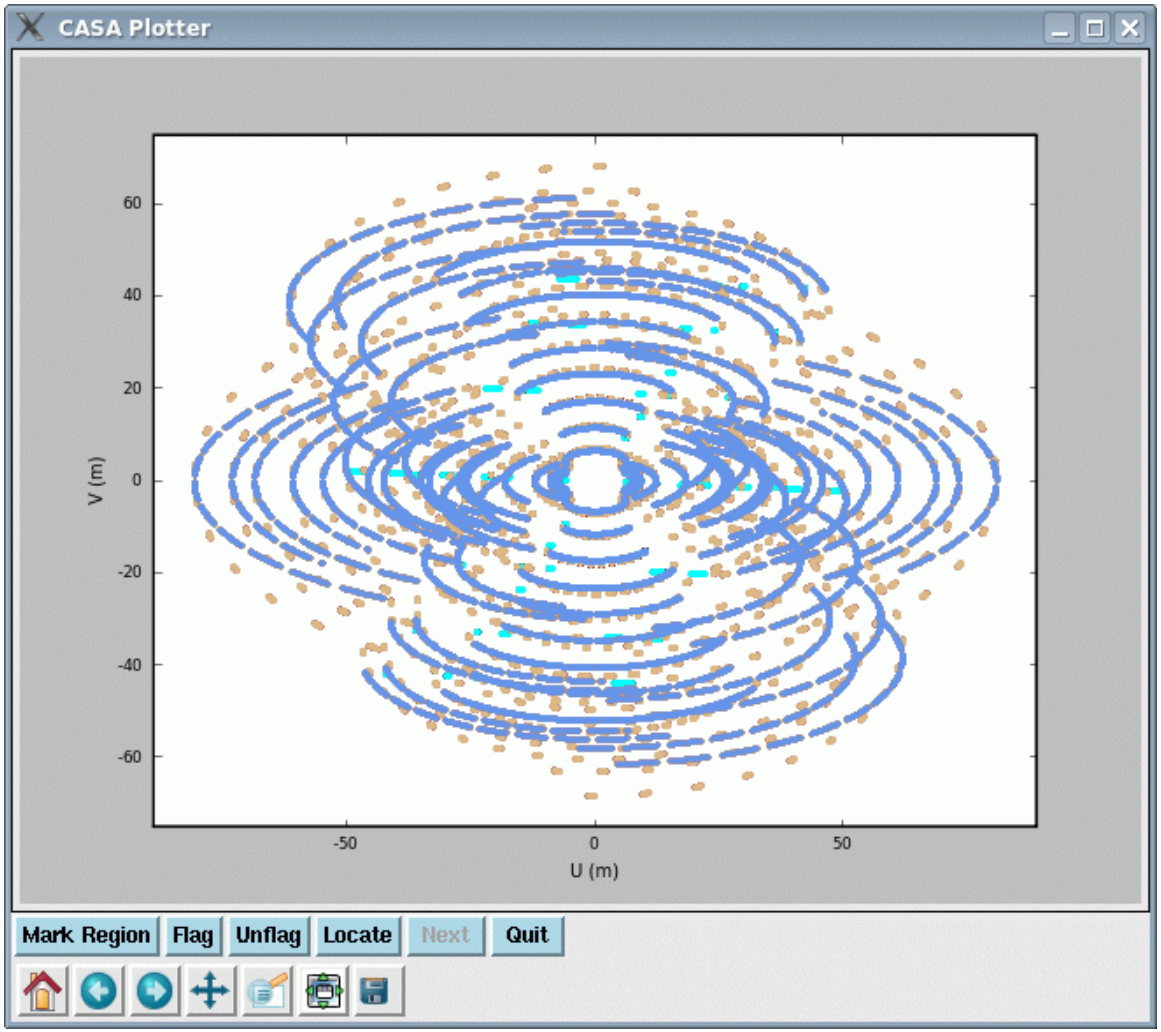
3) where needed, tools have GUIs:

plotxy, plotcal, browsetable, viewer, clean

(started in separate threads)

plotxy is a specialized tool for diagnostic plots and data selection

To be phased out.



The *CASA* user interface

A typical analysis session

3) where needed, tools have GUIs:

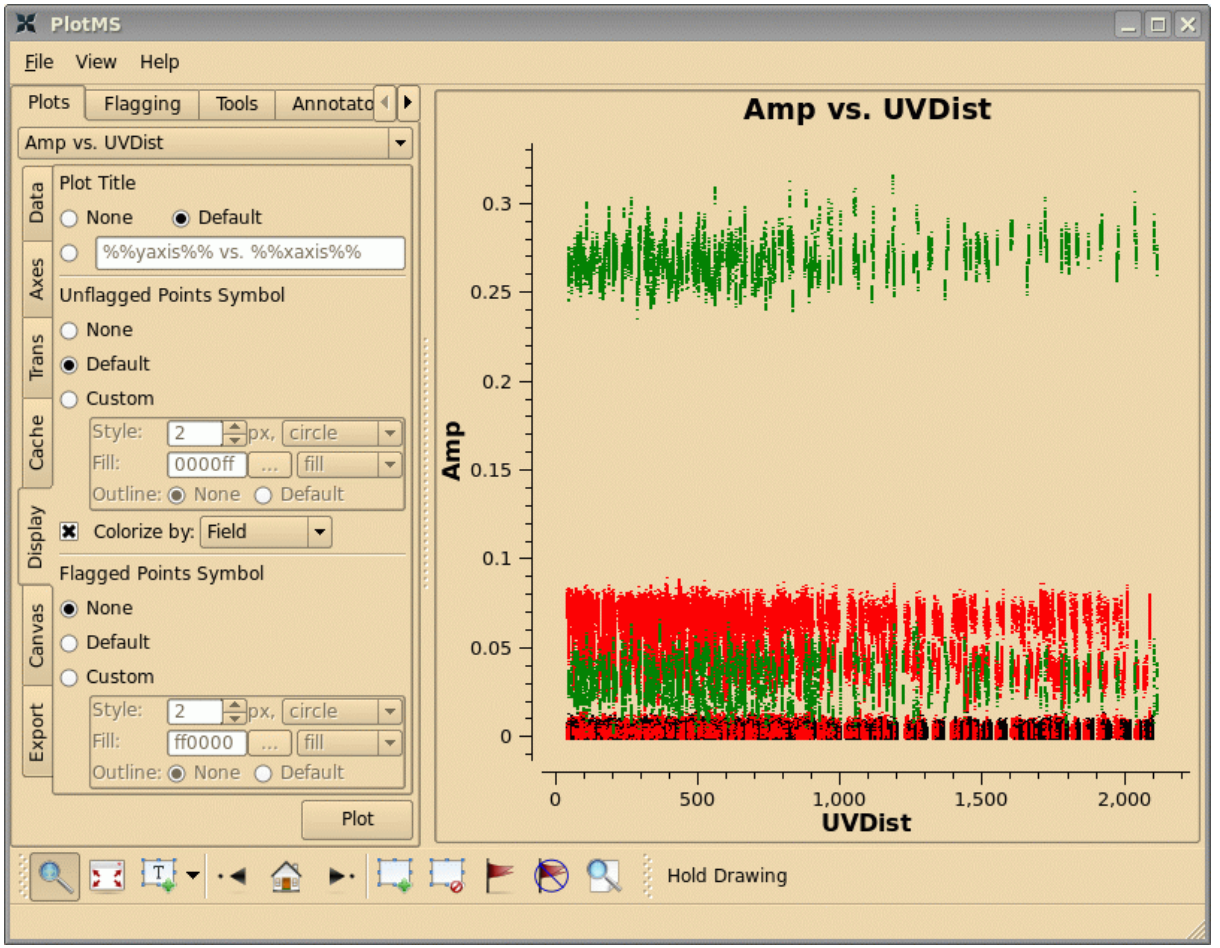
plotxy, plotcal, browsetable, viewer, clean

(started in separate threads)

plotms is going to replace plotxy. Release 3.0.0 contains beta version.

plotms is Qt-based and much faster than plotxy.

Uses generic plotting class which in turn uses **Qwt**.



Summary

- **The standard science data analysis package for ALMA and EVLA is *CASA***
- **Data from other observatories can also be processed, e.g. VLA, BIMA, ATCA, ...**
- ***CASA* derives from AIPS++ (partially survives in *casacore*)**
- **approx. 20 people are working on *CASA***
  in North America, Europe, and Japan
- ***CASA* is a toolbox with**
  - **MATLAB-like user interface**
  - **GUI tools for data selection, browsing, and image processing**
- **the heart of the science analysis code is the *Measurement Equation***
- **the internal data format are *CASA Tables***
- **the *Measurement Set* is the *CASA* data format for visibility data**
  (it is technically a Table with several well-defined sub-tables)
- ***CASA* is publicly available under GPL for Linux and Mac OS X**

- **The first public release of *CASA* (version 3.0.0) became available in December 2009**
- **The latest release is version 3.0.1**