# The *CASA* software package

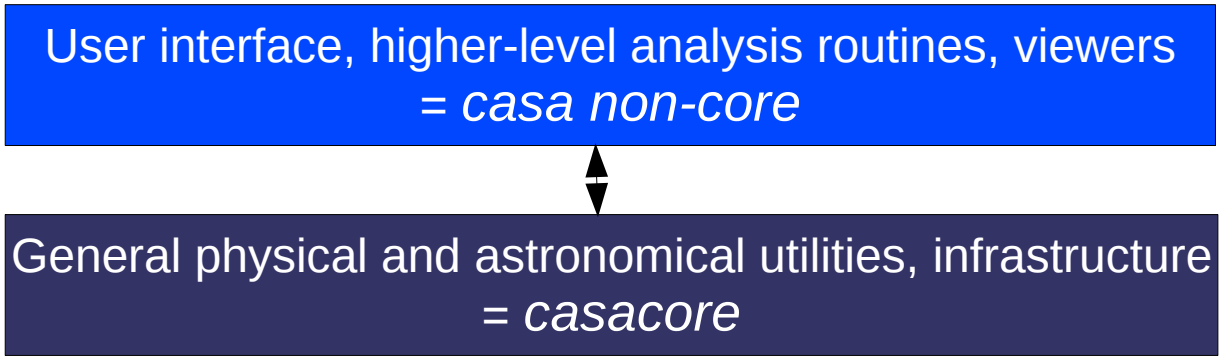
Dirk Petry (ESO), October 2010

**Outline**

| | |
|---|---|
| → What is *CASA?* | - main features |
| → Who develops *CASA*? | - development team |
| → What are the main requirements and how does *CASA* meet them? | - design and implementation |
| → CASA status and release plans | |
| → How does CASA look and feel? | - installation and the typical analysis session |

# *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, NRAO, Socorro, May 2010

# *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. 19 FTE developers are at work at**

**US (NRAO and others): 12**
**Japan (NAOJ): 3**
**Europe (ESO and others): 4**

+ 1 CASA manager (NRAO Socorro) = Jeff Kern

+ 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, UVFITS, FITS-IDI, VLA archive) → MS,  FITS → Image
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 toolkit for radio astronomical calibration, imaging, and simulation
5) A set of high-level analysis procedures (“tasks”)
   user-friendly implementations of the solutions for all common analysis problems
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, See **http://casa.nrao.edu/**

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# *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<br>FEED_ID<br>DATA_DESC_ID<br>PROCESSOR_ID<br>(PHASE_ID)<br>FIELD_ID<br>(PULSAR_GATE_ID)<br>ARRAY_ID<br>OBSERVATION_ID<br>STATE_ID |
| (FREQ_OFFSET) | none | - | - | ANTENNA_ID<br>FEED_ID<br>SPW_ID |
| (SYSCAL) | none | - | - | ANTENNA_ID<br>FEED_ID<br>SPW_ID |
| POINTING | none | - | - | ANTENNA_ID<br>POINTING_MODEL_ID |
| (WEATHER) | none | - | - | ANTENNA_ID |
| HISTORY | none | - | - | OBSERVATION_ID<br>OBJECT_ID |
| FLAG_CMD | none | - | - | none |

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

| | | | | |
|---|---|---|---|---|
| POLARIZATION | POLARIZATION_ID | row number | DATA_DESCRIPTION | none |
| (SOURCE) | SOURCE_ID | explicit | (DOPPLER)<br>FIELD | SPW_ID<br>(PULSAR_ID) |
| (DOPPLER) | DOPPLER_ID | explicit | SPW_ID | SOURCE_ID<br>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

**_CASA_ special features:**

b) A toolkit for radio astronomical calibration, imaging, and simulation built around the *Measurement Equation* (Hamaker, Bregman, & Sault 1996 + Sault, Hamaker, & Bregman 1996)

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

where

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

$A$ = 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, i.e. primary beam effects

$P$ = parallactic angle dependence

$T$ = 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) A toolkit for radio astronomical calibration, imaging, and simulation built around the *Measurement Equation* (Hamaker, Bregman, & Sault 1996 + Sault, Hamaker, & Bregman 1996) (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 $\chi^2$ minimization.

(For wide-field imaging the above assumption doesn't hold and the solution is more complex but still possible.)

CASA contains a set of ***solvers*** for the different calibration components.

# *CASA* design and implementation

***CASA* special features:**

b) A toolkit for radio astronomical calibration, imaging, and simulation (continued)

**Imaging in CASA: Combinations of Major and Minor Cycle Algorithms**

*Imaging (Major Cycle):*

1) Standard (no dir.-dep. effects, uv-grid sampling uses convolutional regridding)
2) with dir.-dep. effects:
   a) W-term (image domain faceting, uv domain faceting, W projection)
   b) PB correction (image domain, A projection)
   c) Pointing Offset correction by phase gradient
   d) Mosaicing (linear (separate) deconvolution,
      joined deconv. of combined dirty images,
      mosaicing by regridding all uv data onto one grid)

*Deconvolution (Minor Cycle):*

1) CLEAN (delta function model)
2) MS-CLEAN (blob model)
3) MSMFS CLEAN (model of blobs with polynomial spectrum)
4) MEM (maximum entropy method using prior image and delta function model)

see nice overview compiled by Urvashi Rau: https://safe.nrao.edu/wiki/bin/view/Software/AlgorithmList

# *CASA* design and implementation

***CASA* special features:**

b) A toolkit for radio astronomical calibration, imaging, and simulation (continued)

A sophisticated radio-astronomical data simulator: ***simdata***

**- Create Measurement Sets of simulated data**
(and for convenience: analyse the simulated MS to create simulated image)

**- Input:**

**a) FITS image**

**b) "antenna list" file describing your interferometer (incl. site name)**
sites: *browsetable(os.getenv("CASAPATH").split(' ')[0]+"/data/geodetic/Observatories")*
arrays: *ls os.getenv("CASAPATH").split(' ')[0]+"/data/alma/simmos/"*

**c) observation setup parameters**
(central direction, time, mosaicing, spectral, integration time, etc.)

**d) corrupting effect parameters**
(thermal noise from atmosphere and receiver)

- *uses realistic site-dependent troposphere model*
- *knows about ALMA and EVLA receiver parameters*
- *phase noise and gain drift can be applied to the MS later via CASA tools*

**e) for convenience: clean task parameters for output image creation**

# *CASA* design and implementation

**_CASA_ special features:**

c) A programmable command line interface with scripting

*Framework Architecture of 18 tools bound to* ***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
- sl - spectral line tool (new in CASA 3.1!)

# *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***

**tasks** (implemented in Python) ⟶ **tools** (implemented in C++)

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 3.1 comes with 106 implemented tasks.*

# *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
- The first public release was CASA 3.0.0 (Dec 2009), release 3.1.0 coming before Dec. 2010

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

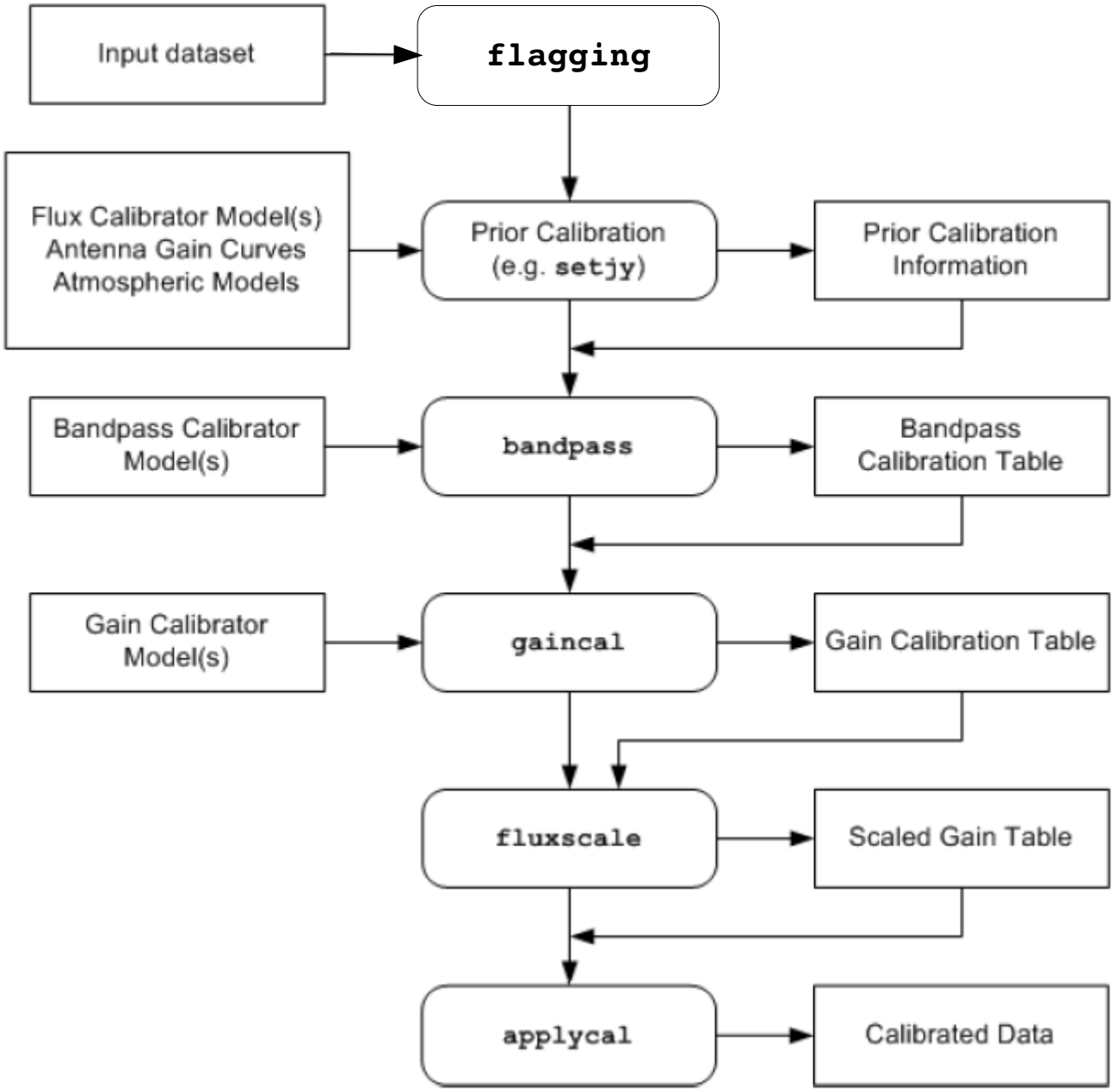
- Code kept in *svn* repository at NRAO, Socorro
- Have approx. 4300 modules, 1.5E6 lines of code, 1E6 lines of comments
- The core functionality (*casacore,* also available at http://code.google.com/p/casacore/ )
  is also used by other projects

- *Hot topics*:
  - Support for High Performace Computing and Parallelisation
  - Advanced Imaging: wide fields, continuum imaging over wide spectral ranges
  - Interoperability: using CASA for other observatories and VLBI

# How does *CASA* look and feel?

**A typical analysis session**

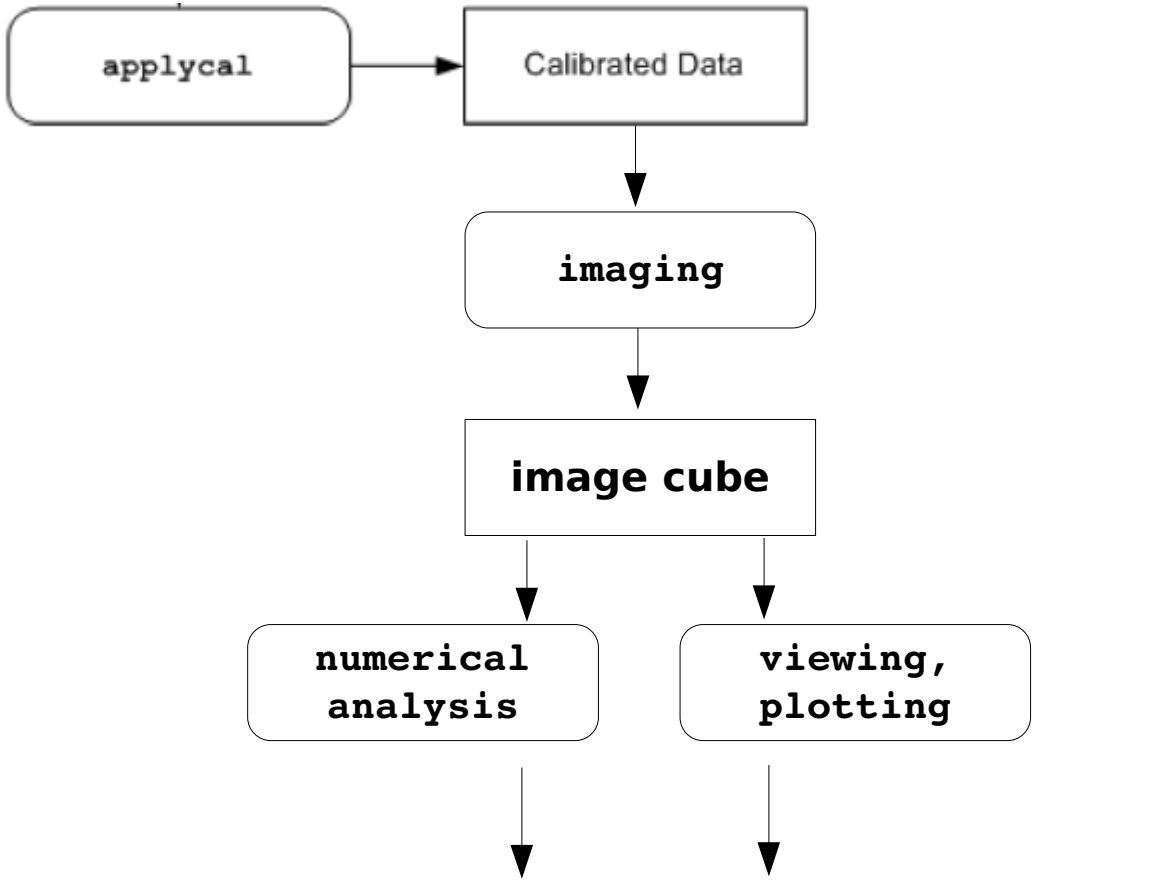
Part 1: flagging and calibration



# How does *CASA* look and feel?

**A typical analysis session**

Part 2: imaging and
image analysis



# How does *CASA* look and feel?

**Installation - CASA comes as a tgz-file for Linux or a dmg-file for Mac OS-X**

Download latest version at

https://svn.cv.nrao.edu/casa/linux_distro

or

https://svn.cv.nrao.edu/casa/osx_distro

Linux:

Unpack tgz file in a location of your choice.
cd into the created casapy directory.

```
export PATH=$PWD:$PATH
```

Mac OS-X:

Open the CASA disk image file (if your browser does not do so automatically).
Drag the CASA application to the Applications folder of your hard disk.
Eject the CASA disk image.
Double-click the CASA application to run it for the first time.

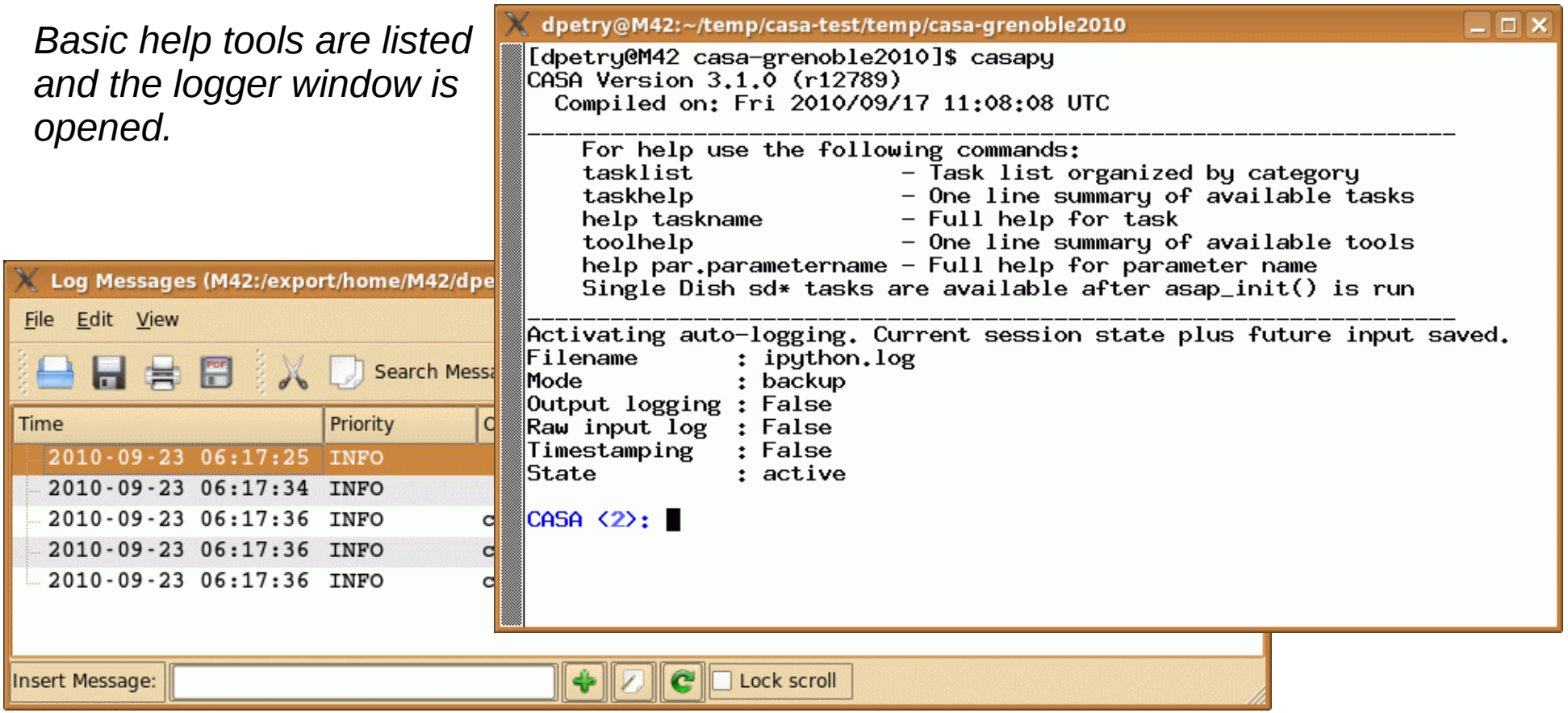
Distribution contains all necessary libraries and Python. No external packages needed.

# How does *CASA* look and feel?

**Pictures from a typical analysis session**

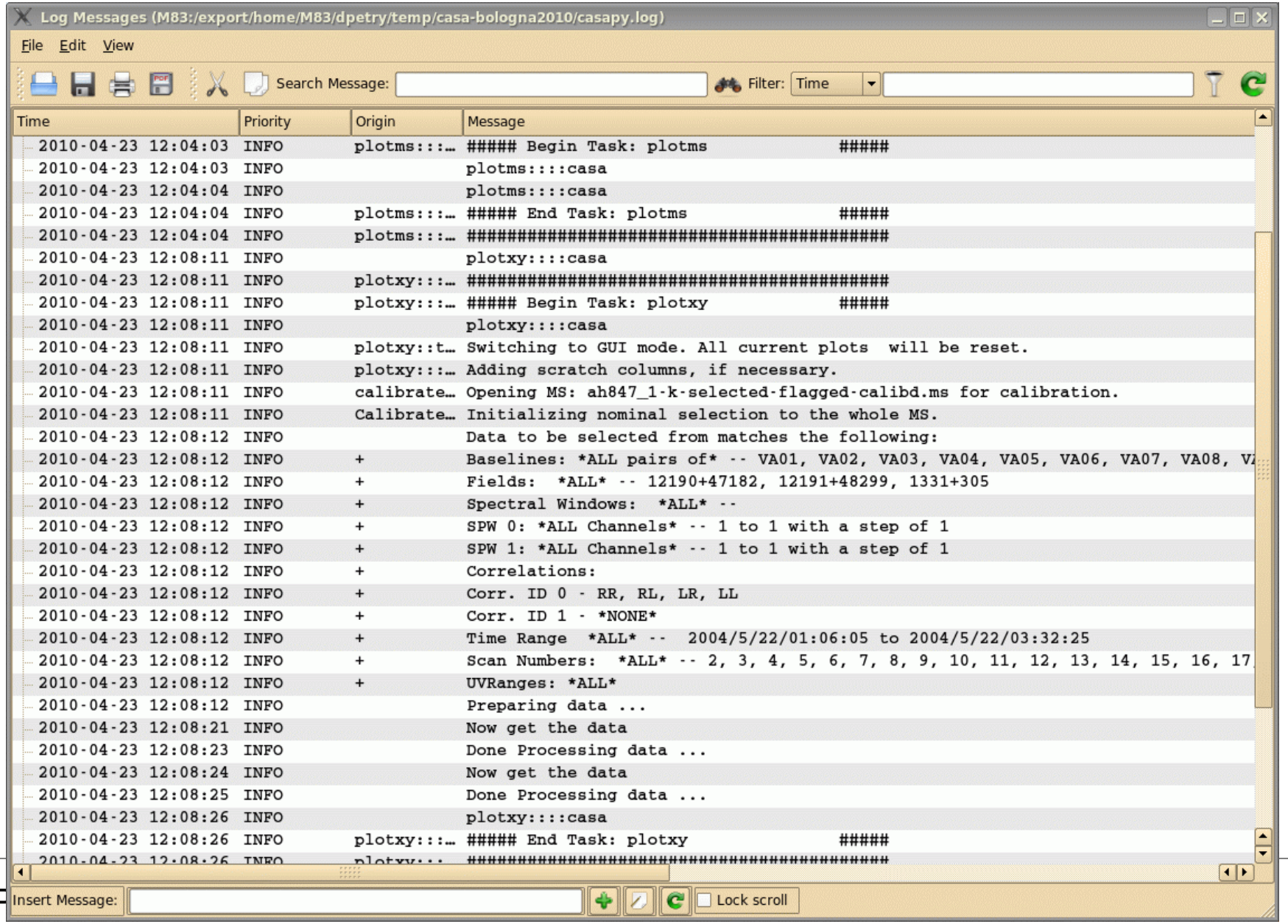
1) Startup:
open terminal and start *casapy*

*Basic help tools are listed and the logger window is opened.*



# The *CASA* user interface

*The logger provides functionality for monitoring and debugging command execution.*



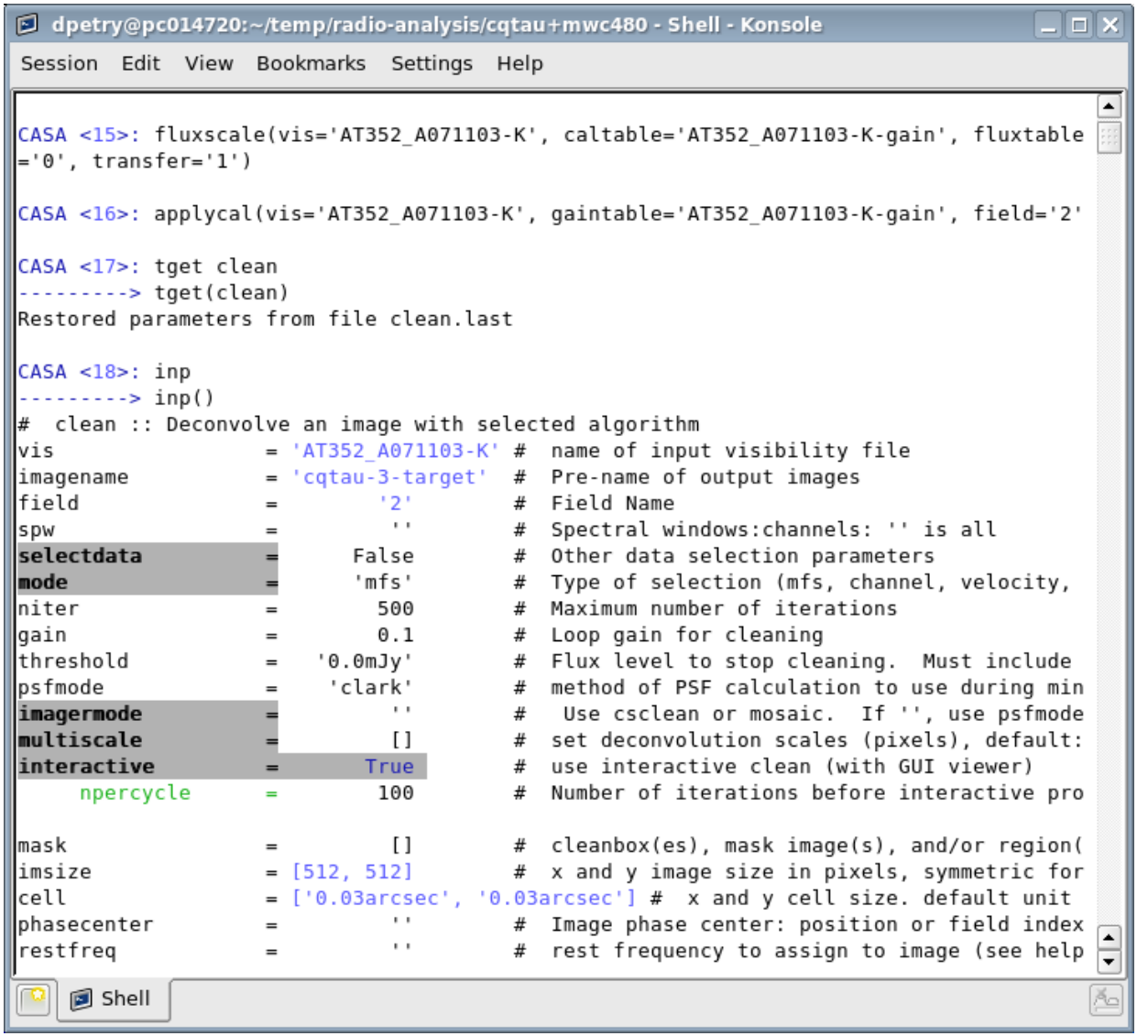
# The *CASA* user interface

**Pictures from a typical analysis session**

2) enter commands in a MATLAB-like environment

`recall previous settings`

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



# The *CASA* user interface

**Pictures from a typical analysis session**

3) where needed, tools have GUIs:

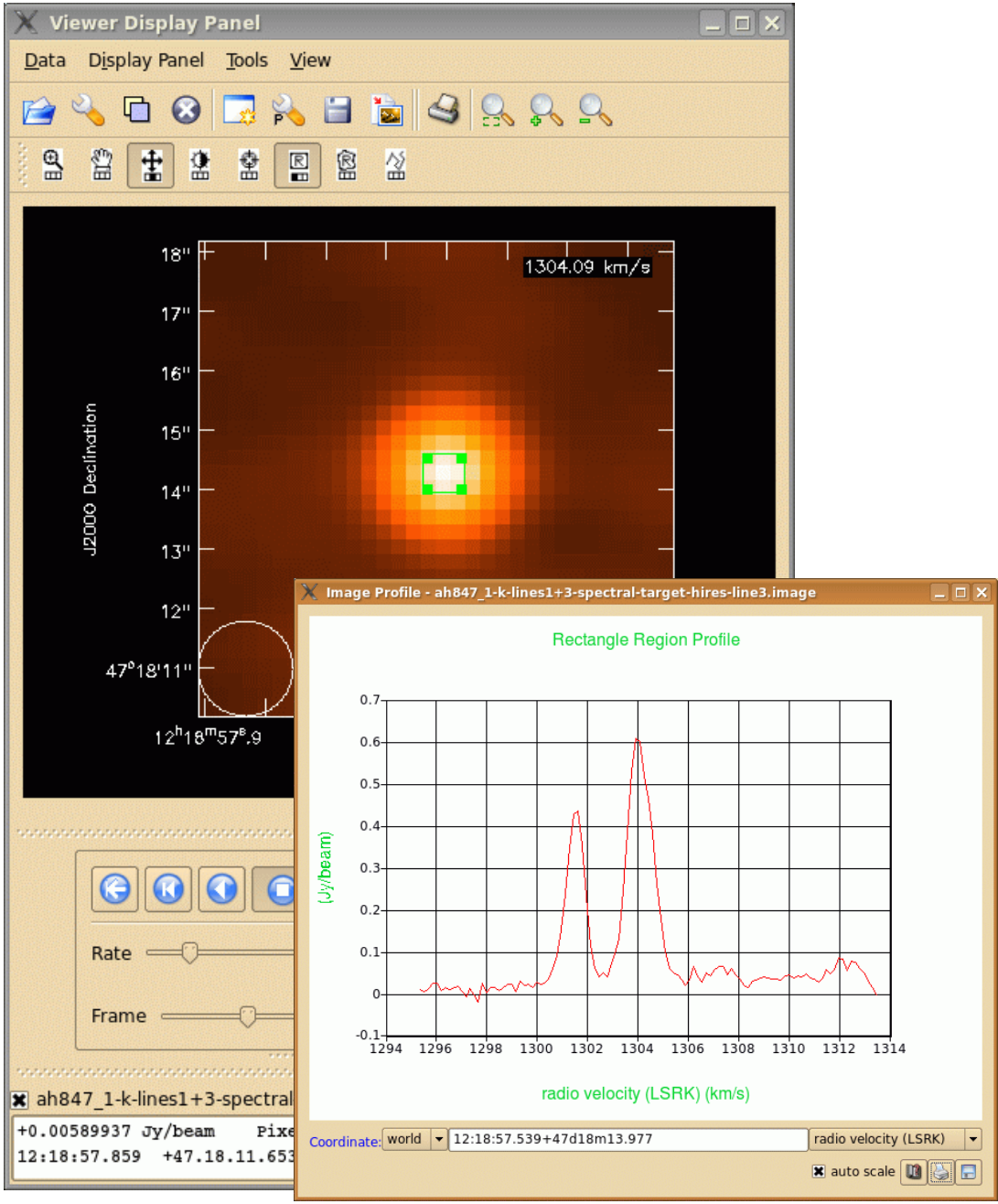
plotxy, plotcal, browsetable, viewer, clean, plotms

(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



# The *CASA* user interface

**A typical analysis session**

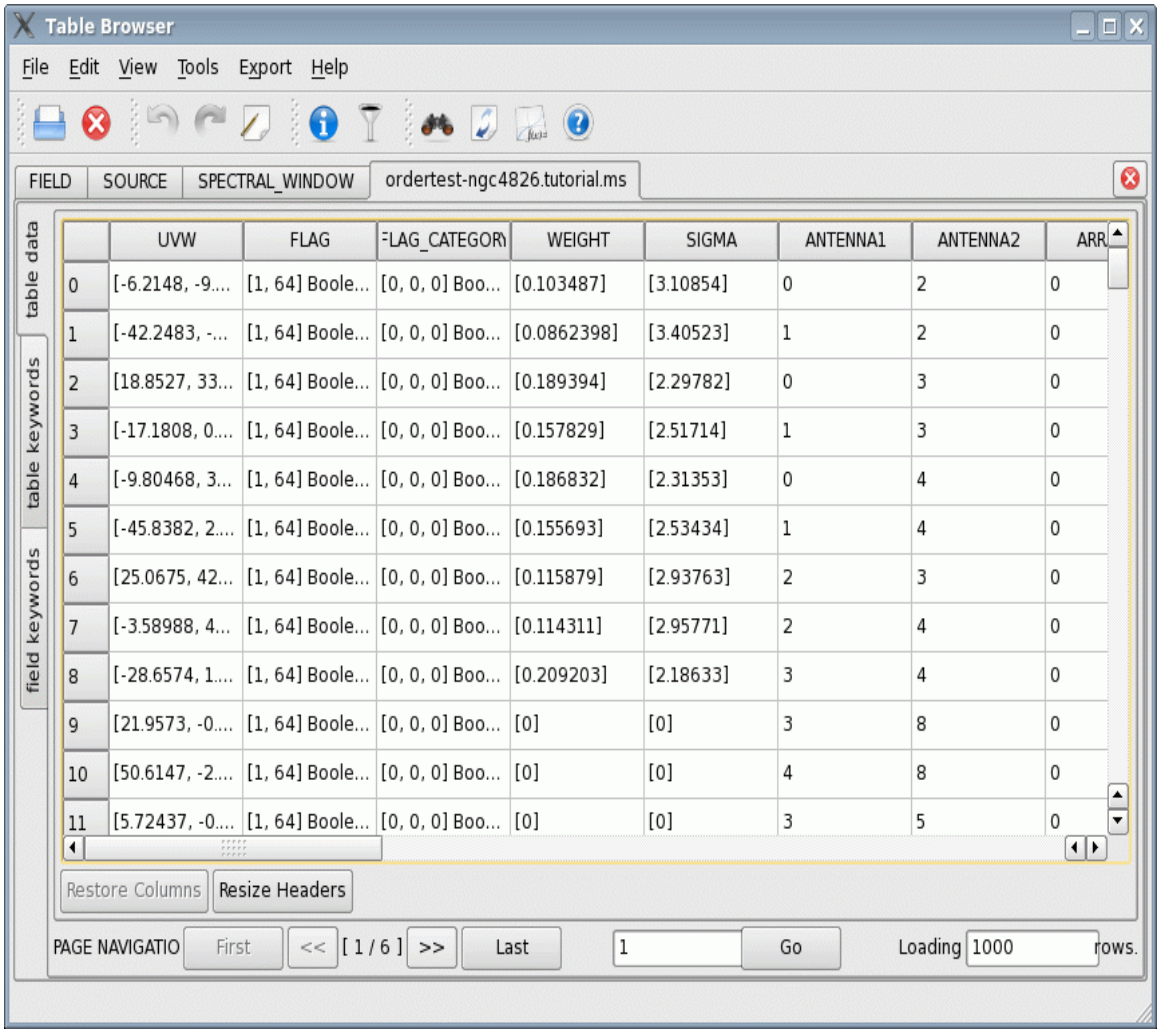
3) where needed, tools have GUIs:

plotxy, plotcal, browsetable, viewer, clean, plotms

(started in separate threads)

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

Also Qt-based.



# The *CASA* user interface

**A typical analysis session**

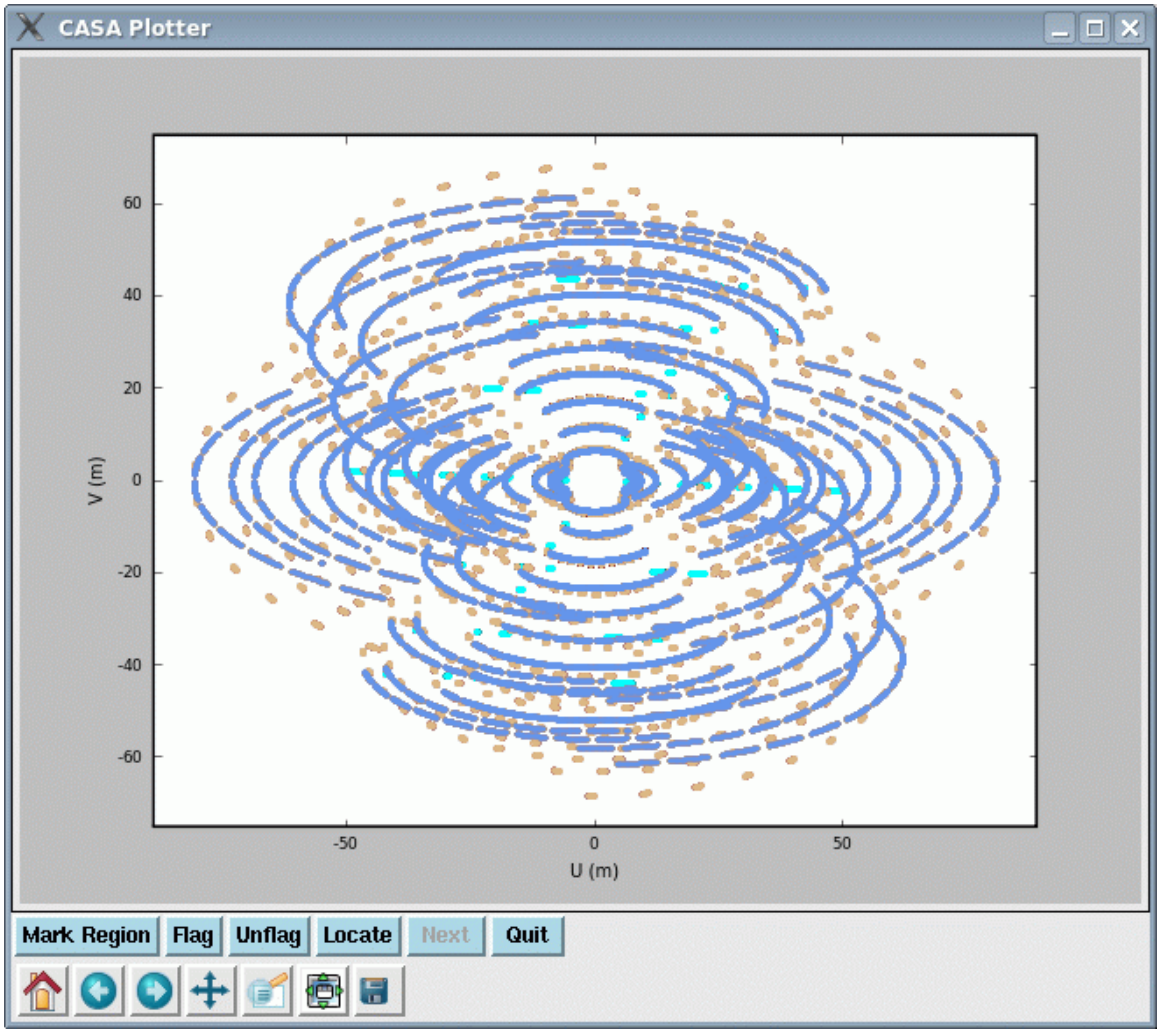
3) where needed, tools have GUIs:

plotxy, plotcal, browsetable, viewer, clean, plotms

(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:

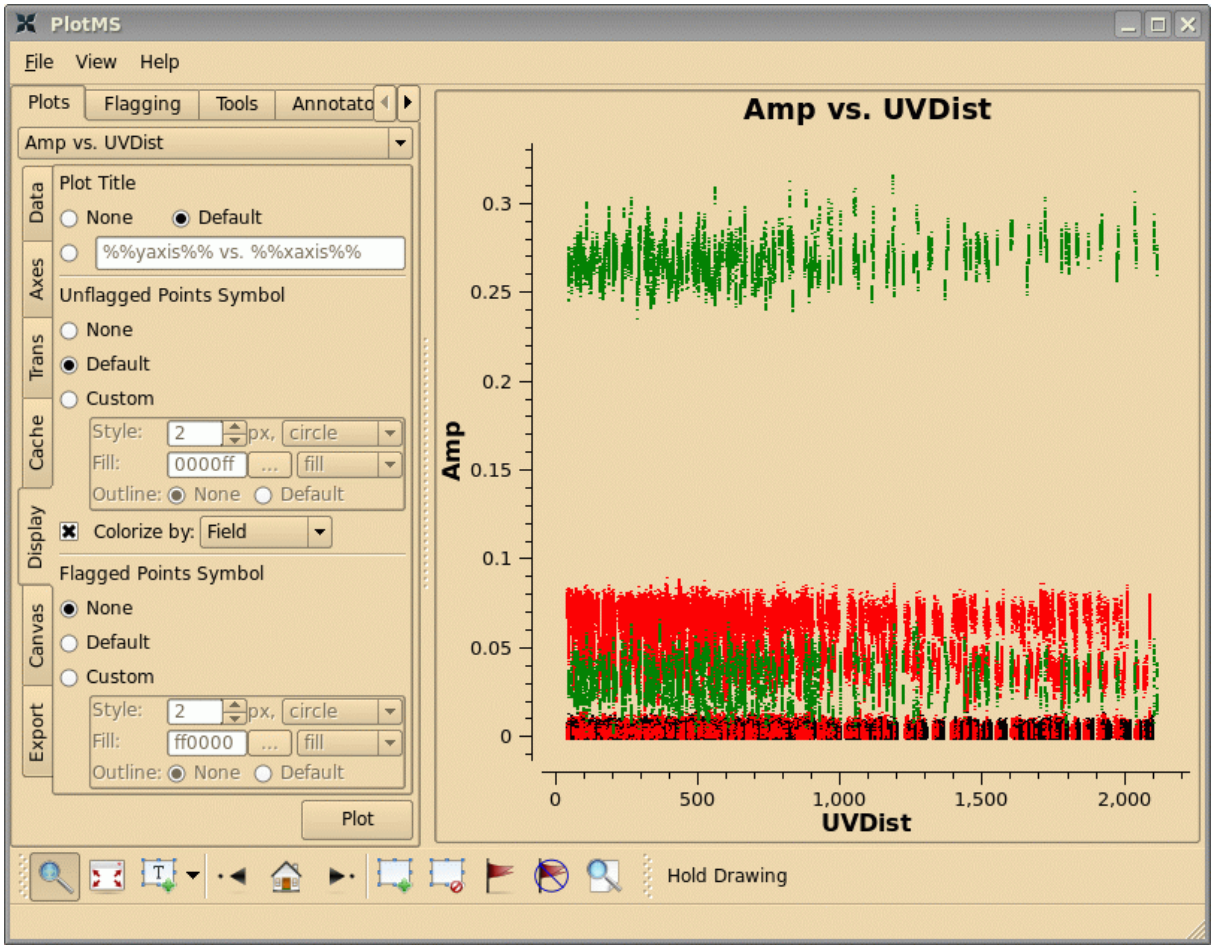
plotxy, plotcal, browsetable, viewer, clean, plotms

(started in separate threads)

***plotms*** is going to replace plotxy. Release 3.1 contains beta version.

plotms is Qt-based and much faster than plotxy.

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



# The *CASA* user interface

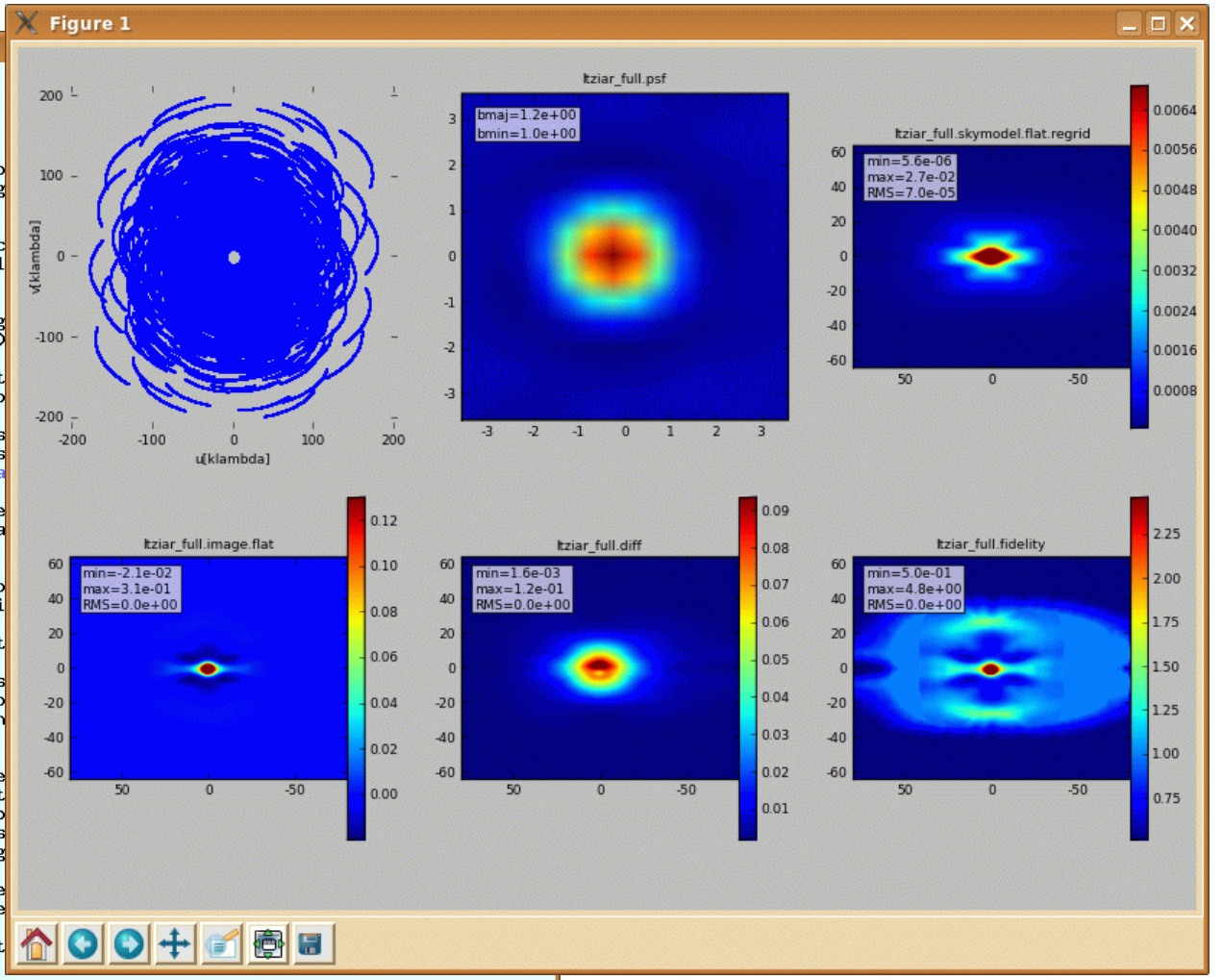
***A typical analysis session***

4) A sophisticated radio-astronomical data simulator: ***simdata***

IPy temp/simdata1

```
CASA <48>: inp
---------> inp()
#  simdata :: mosaic simulation task:
project             = 'Itziar_full'      #  root for output file
modifymodel         =       True         #  modify model image
     skymodel       = 'M1-mp1em9.a0p001.60d50r.c17o3.fits' #  mo
     inbright       = 'unchanged'        #  set peak surface brig
     indirection    = 'J2000 00h00m00.00 -30d00m00.0' #  "J2000
     incell         =       ''           #  cell/pixel size e.g.
     incenter       =    '200GHz'        #  frequency of center c
     inwidth        =    '0.2GHz'        #  channel width e.g. "1

setpointings        =       True
     integration    =      '10s'         #  integration (sampling
     direction      = ['J2000 00h00m00.00 -30d00m00.0'] #  "J200
     mapsize        = ['1arcmin', '1arcmin'] #  angular size of
     maptype        = 'hexagonal'        #  hexagonal, square, et
     pointingspacing =   '6arcsec'       #  spacing in between po

predict             =       True         #  calculate visibilites
     complist       =         ''         #  optional componentlis
     antennalist    = '/home/dpetry/temp/casa/data/alma/simmos/a
                                         #   interferometric MS
     refdate        = '2011/10/21/03:25:00' #  time/date of obse
     totaltime      =    '12000s'        #  total time of observa
     caldirection   =         ''         #  pt source calibrator
     calflux        =      '1Jy'
     sdantlist      =         ''         #  single dish antenna p
     sdant          =          0         #  single dish antenna i

thermalnoise        =         ''         #  add thermal noise: [t
leakage             =        0.0         #  cross polarization
image               =       True        #  (re)image $project.ms
     vis            = '$project.ms'      #  Measurement Set(s) to
     modelimage     =         ''         #  prior image to use in
     imsize         =          0         #  output image size in
     cell           =  '0.3arcsec'       #  cell size with units
     niter          =      10000         #  maximum number of ite
     threshold      =  '0.01 mJy'        #  flux level (+units) t
     weighting      =    'briggs'        #  weighting to apply to
     outertaper     =         []         #  uv-taper on outer bas
     stokes         =        'I'         #  Stokes params to imag

analyze             =      False         #  (only first 6 selecte
graphics            =   'screen'         #  display graphics at e
verbose             =       True
overwrite           =       True         #  overwrite files start
async               =      False         #  If true the taskname

CASA <49>:
```

Figure 1




# *Summary*

- **The standard science data analysis package for ALMA and EVLA is *CASA***
- **Data from other observatories can also be processed, e.g. BIMA, ATCA, CARMA, SMA**
- ***CASA* is mostly C++ code (libraries for general use available as *casacore*)**
- **approx. 20 people are working on *CASA* in North America, Europe, and Japan**
- ***CASA* is a *comprehensive toolbox* with**
  - **MATLAB-like, scriptable user interface using *Python/iPython***
  - **procedures for calibration, imaging, spectral and spatial analysis, simulation and more**
  - **GUI tools for data selection, browsing, plotting, and image processing**
- **The command-line interface has two levels:**
  - ***tasks* for the common analysis problems**
  - ***tools* for everything else including *your own tasks***
- **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**
- ***CASA* is publicly available under GPL for Linux and Mac OS X, installation is simple, see http://casa.nrao.edu/**
- **The latest release is version 3.1.0 (probably October 2010)**