REDUCTION OF ALMA DATA USING CASA SOFTWARE

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CONTENS

Introduction

- ALMA - Atacama Large Millimeter/submillimeter Array:
  - is an astronomical interferometer of radio telescopes located in the Atacama Desert of northern Chile
  - 5000 meters above sea level
  - 66 12-meters and 7-meters antennas
  - Comparable with 14,000-meter dish
- Single antenna
  - weight 100 tons
  - ultra-stable CFRP (Carbon Fiber Reinforced Plastic) , reflecting panels of rhodium-coated nickel
  - electronic detector is kept at 4 K

Cost $1.3 billions

international partnership: Europe, the United States, Canada, Japan, South Korea, Taiwan, and the Republic of Chile.

Introduction

- Interferometry Resolution $=\theta \sim \lambda/D$

  (D=aperture and λ=wavelength)

A single dish sees the convolution of the sky brightness B by the PSF:

$$I=B*PSF$$

A pair of antennas *(each having a pencil PSF)*

$V(1)= A\exp(i\omega[t+\delta/2])$

$V(2)= A\exp(i\omega[t-\delta/2])$

Summing: $V=2A\exp(i\omega t)\cos(\omega\delta/2)$

The first factor oscillates very fast

The detected power is

$$\tfrac{1}{2}|V|^2=2A^2\cos^2(\omega\delta/2)=J(1+\cos(\omega\delta))$$

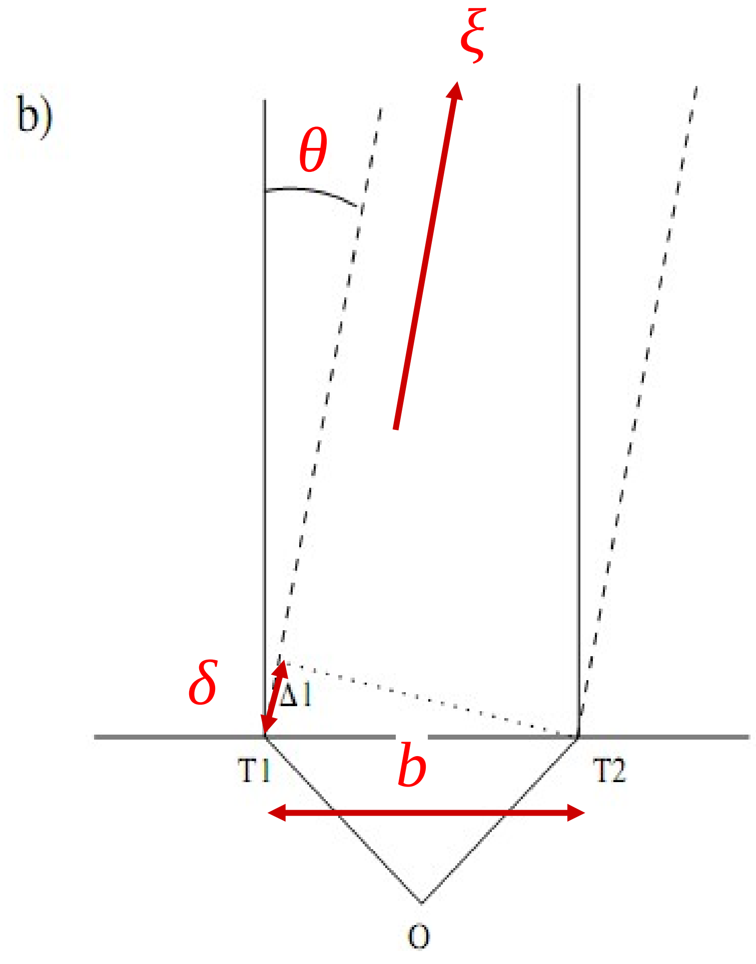
where $\delta \sim \lambda b\theta \sim \lambda \mathbf{b}.\boldsymbol{\xi}$ and $\omega=2\pi/T$

with λ the wave length,

$\mathbf{b}$ the baseline and

$\boldsymbol{\xi}$ the sky coordinates of the source

$$V=V_1+iV_2=\exp(i\omega\delta)=\exp(2i\pi\mathbf{b}.\boldsymbol{\xi})$$



Introduction

From a point source to an extended source with brightness *B(ξ)*

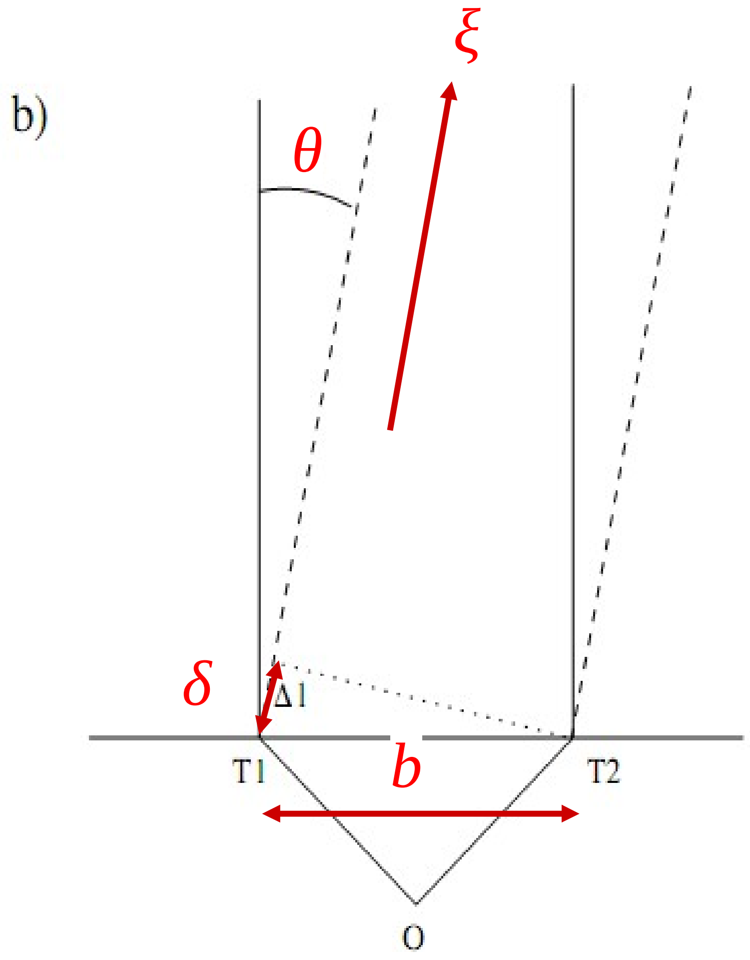
$$V(\mathbf{b})=\iint B(\boldsymbol{\xi})\exp(2i\pi\mathbf{b}.\boldsymbol{\xi})d\boldsymbol{\xi}$$

$$=V_1+iV_2$$

ξ are the sky coordinates

Baseline vectors ***b*** form the Fourier plane or *uv* plane

All the information about the source is contained in the visibility.



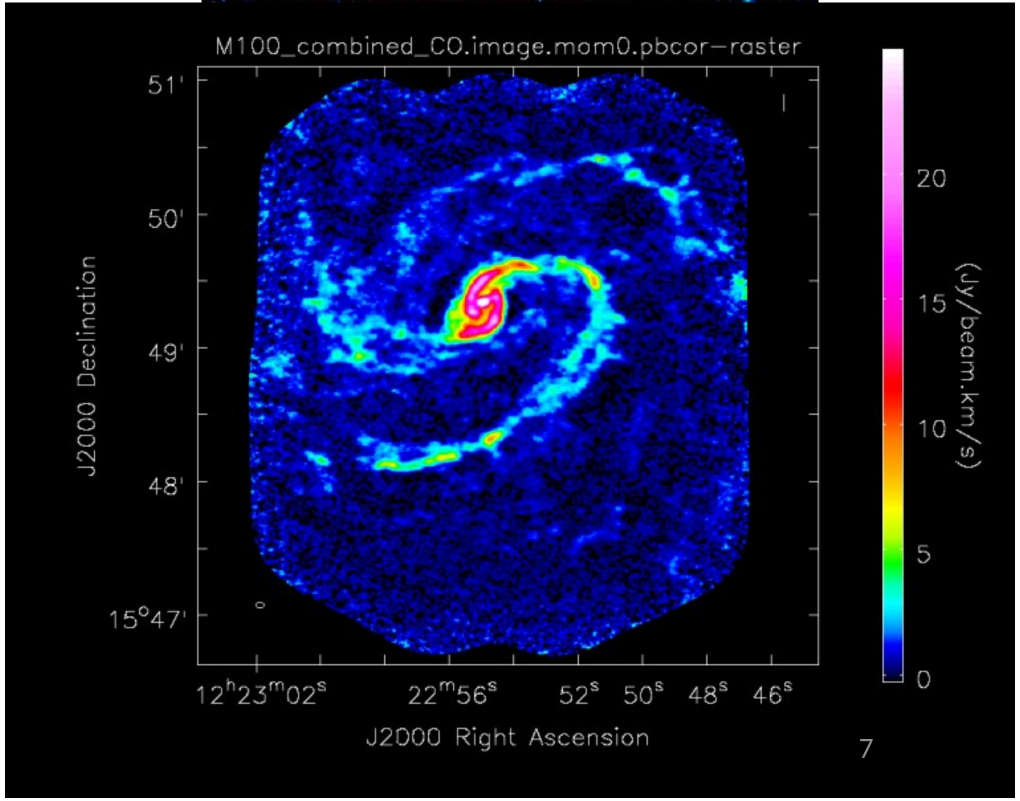
Introduction

Casa: *Common Astronomy Software Applications*

- supporting the data post-processing the new generation of radio astronomical telescopes such: ALMA, VLA
- international consortium of scientists based at NRAO, ESO,NAOJ, ASIAA, CASSASTRON
- CASA infrastructure consists of a set of C++ tools bundled together under an iPython interface as a set of data reduction tasks

M100

M100 - NGC 4321
- RA 12h 22m 54.8s, Dec +15 49’ 19"
- Distance 16Mpc
- Long spiral arms dominating its optical disk and an abundance of molecular gas in its centre.
- Seen nearly face-on with an inclination of only 30^o



Data examination

```
   Observer: Unknown     Project: uid://A002/X259150/X129
Observation: ALMA
Data records: 897793       Total elapsed time = 5460.05 seconds
   Observed from   10-Sep-2011/18:08:40.1   to   10-Sep-2011/19:39:40.2 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  10-Sep-2011/18:08:40.1 - 18:09:38.5     1      0 3c273 - Pointing          7618  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_POINTING#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:10:27.3 - 18:11:14.3     2      1 Titan                     4563  [0,9,10,11,12,13,14,15,16]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_ATMOSPHERE#OFF_SOURCE,CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#OFF_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:11:46.8 - 18:15:24.0     3      1 Titan                    45721  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:15:52.1 - 18:16:39.6     4      2 3c273 - Bandpass          4576  [0,9,10,11,12,13,14,15,16]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_ATMOSPHERE#OFF_SOURCE,CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#OFF_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:17:12.8 - 18:20:49.9     5      2 3c273 - Bandpass         45734  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:21:18.1 - 18:22:06.3     6      3 1224+213 Phase            4576  [0,9,10,11,12,13,14,15,16]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_ATMOSPHERE#OFF_SOURCE,CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#OFF_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:22:38.8 - 18:24:23.9     7      3 1224+213 Phase           22867  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:24:53.6 - 18:25:40.7     8      4 3c273 - Phase             4563  [0,9,10,11,12,13,14,15,16]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_ATMOSPHERE#OFF_SOURCE,CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#OFF_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:26:14.2 - 18:26:44.6     9      4 3c273 - Phase             7618  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:27:14.1 - 18:28:01.8    10      5 M100                      4576  [0,9,10,11,12,13,14,15,16]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
[CALIBRATE_ATMOSPHERE#OFF_SOURCE,CALIBRATE_ATMOSPHERE#ON_SOURCE,CALIBRATE_WVR#OFF_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              18:28:42.8 - 18:41:00.4    11      6 M100                      7618  [0,1,2,3,4,5,6,7,8]  [1.15, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02, 6.05, 2.02]
```

Target

Intens for each scan

Spectral windows

- 3 Measurement set
- Spectral windows 0 – 16
- Scientific target : M100
- Calibrators: 3c273, Titan, 1224+213
- 13 antennas

Calibration

Flagging data
- Shadowing
- Autocorrelation data
- Pointing scans and T_{sys}
- CM01 antenna

Prior calibration
- Water Vapour Radiometer (WVR), phase delay due to atmosphere: We generate the WVR calibration table (so-called caltable) for each EB using wvrgcal(). The WVR of each antenna measures the rapid fluctuation of the 183 GHz water line and corrects short-timescale phase variations (seconds timescale)
- System temperature – *Tsys* by task *gencal()*

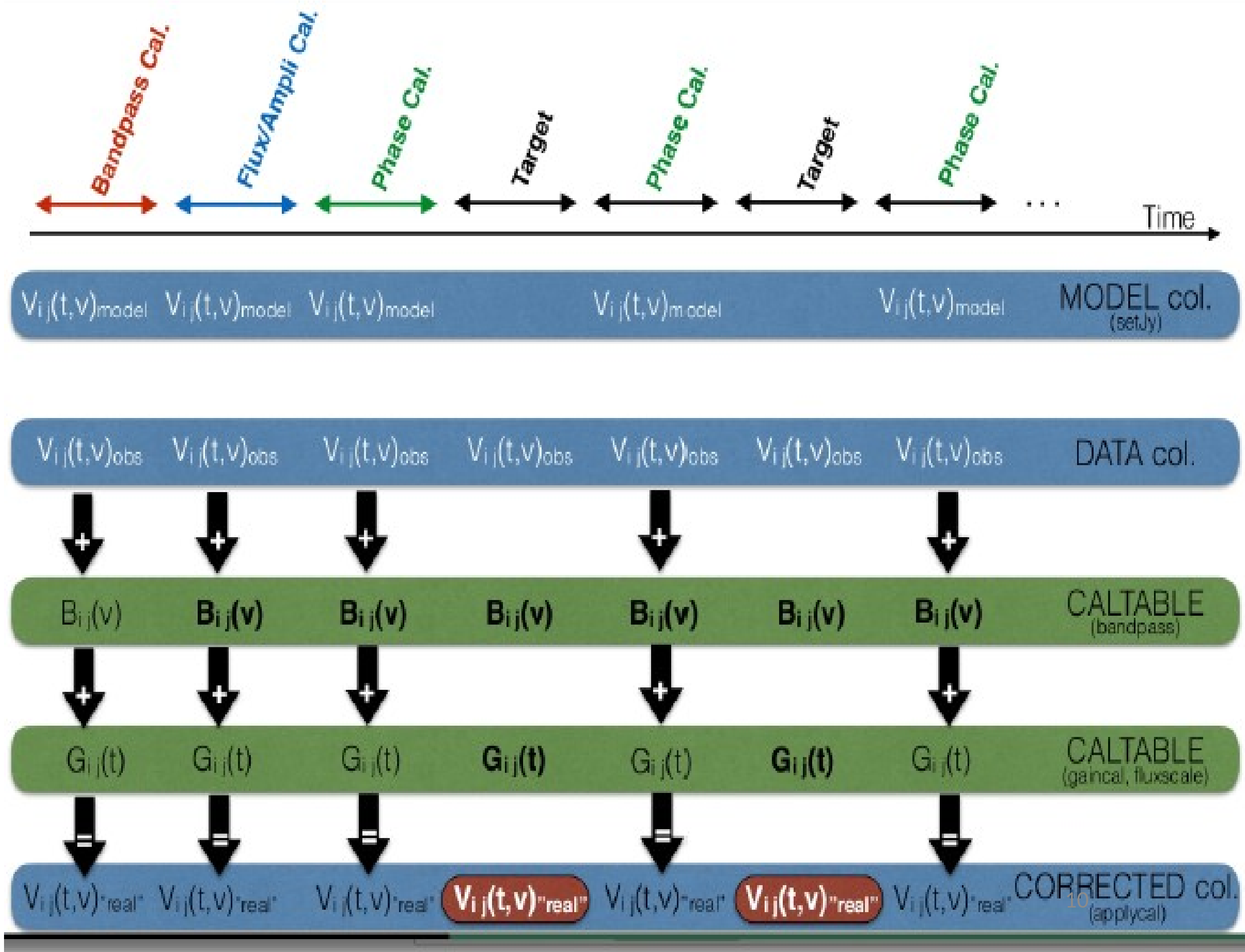
Calibration

- Calibration flow

$$V_{ij}(t,v)_{obs}=V_{ij}(t,v)G_{ij}(t)B_{ij}(v)$$

t is time, v is frequency
i and j refer to a pair of antennas (i,j)

B is the complex frequency-dependent gain
G is the complex time-dependent continuum gain.



Calibration

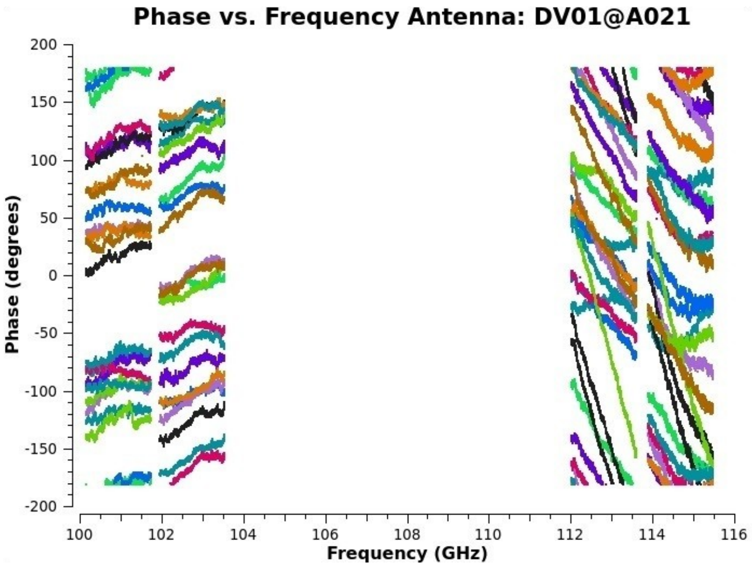
Bandpass calibration

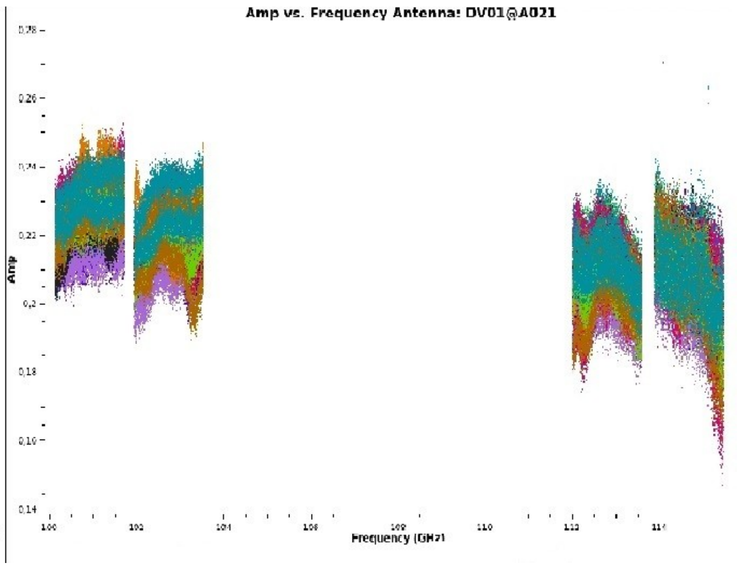
- Process of measuring and correcting the frequency-dependent part of the gains,

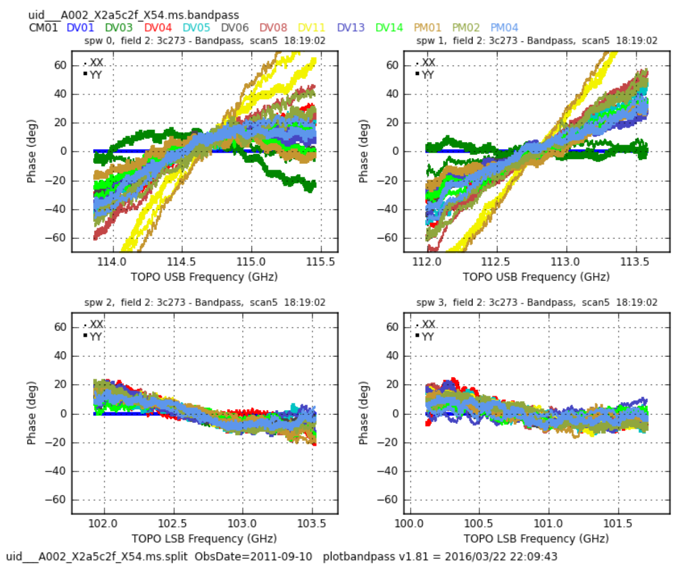
$B_{i,j}(\nu)$ – the variation of phase and amplitude corresponding to frequencies.

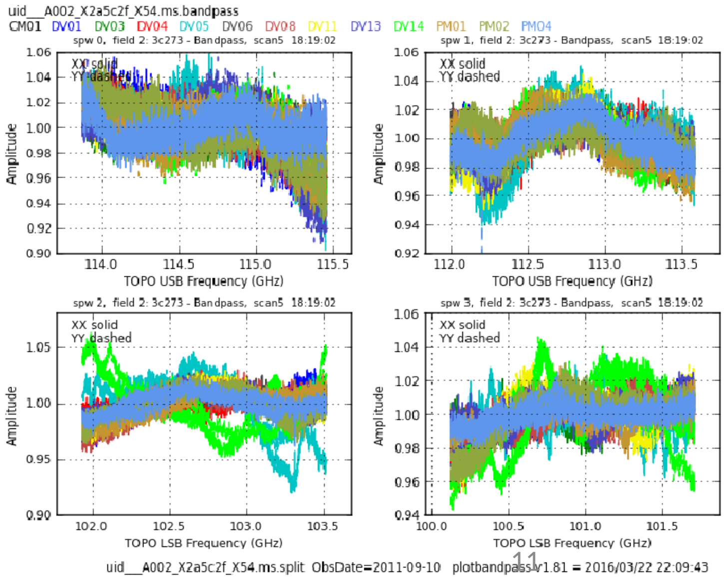
- The purpose is to track the variation of the instrumental response at different frequencies

Calibrators : bright sources having a flat and featureless spectrum.







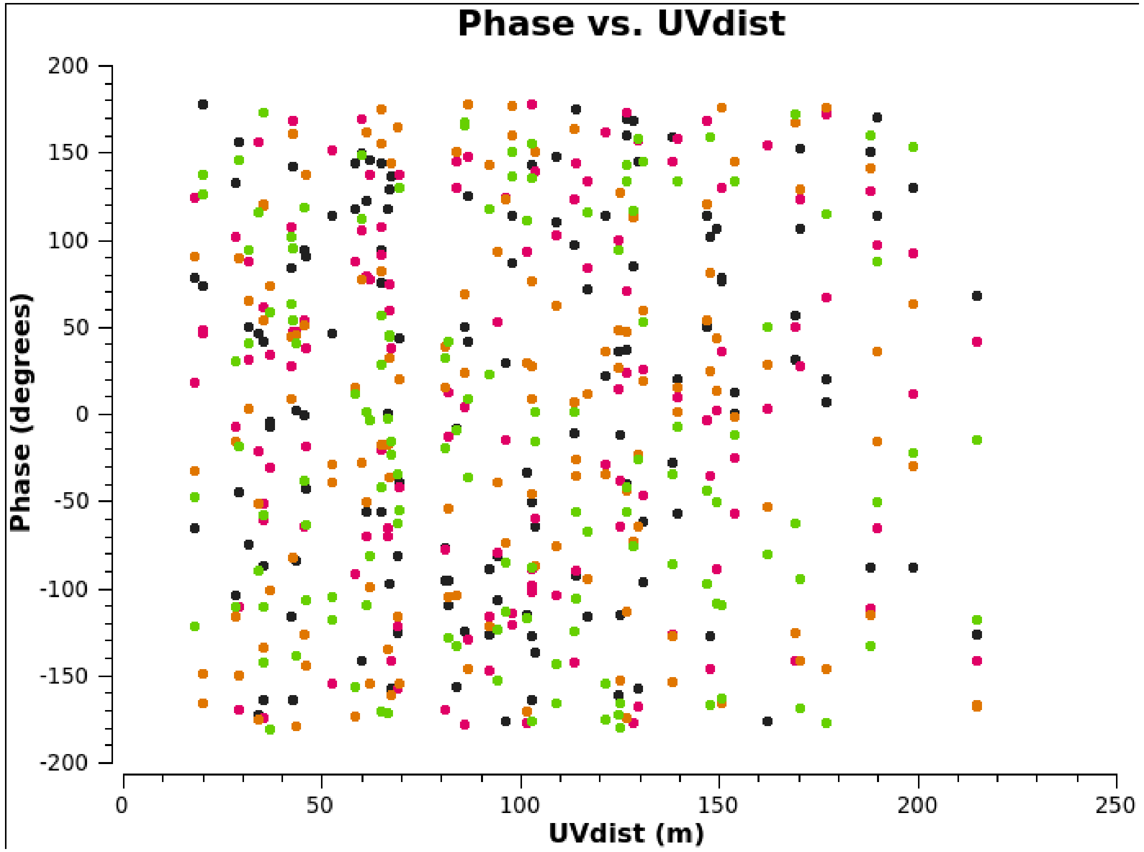


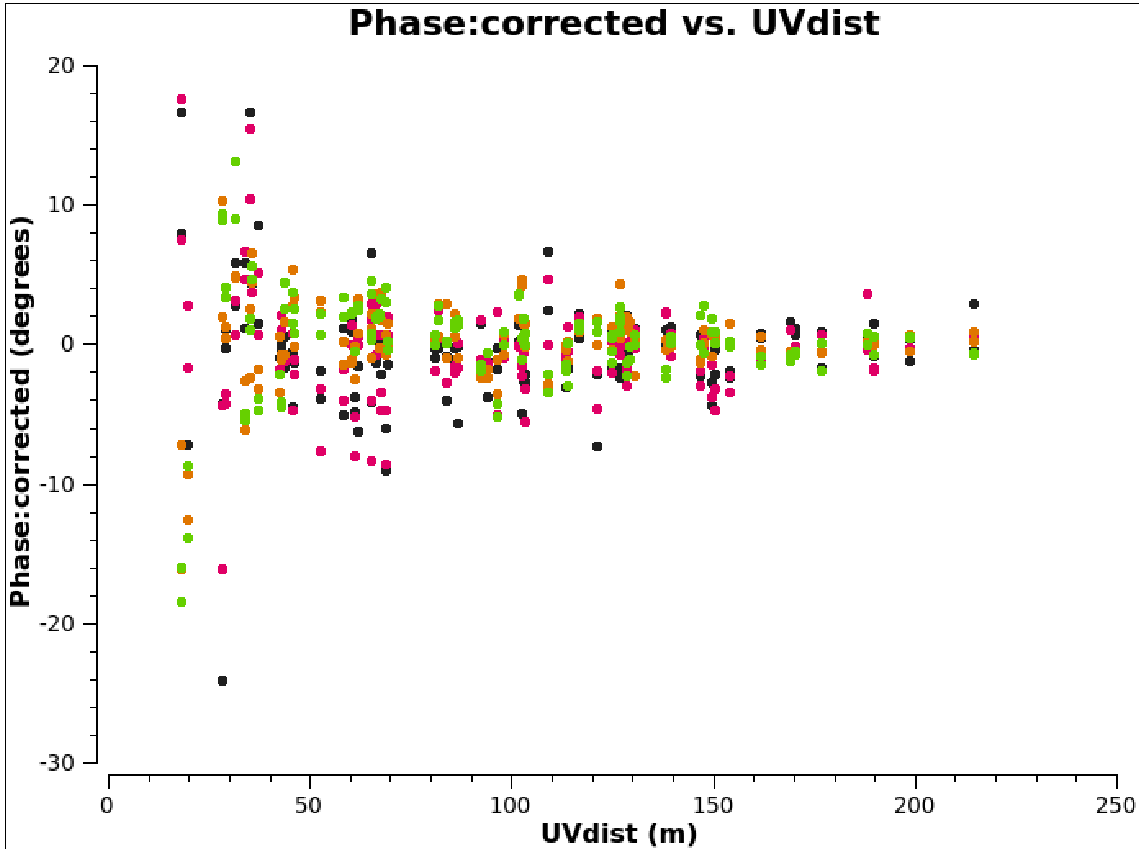
Flux and phase calibration

- Flux calibration is an iterative process in which the known flux of one or more calibrators is fixed to determine the efficiencies (Jy/K) of the antennas.
- A good flux calibrator is essential to obtain reliable absolute flux measurements. A good flux calibrator is: a bright source with known shape/flux (few sources available) not necessarily near the science target on the sky.
- A good phase calibration is key for image fidelity and good noise level.
- A good phase calibrator is a relative bright point source at well known position and need to be close to the scientific target in sky

Calibration

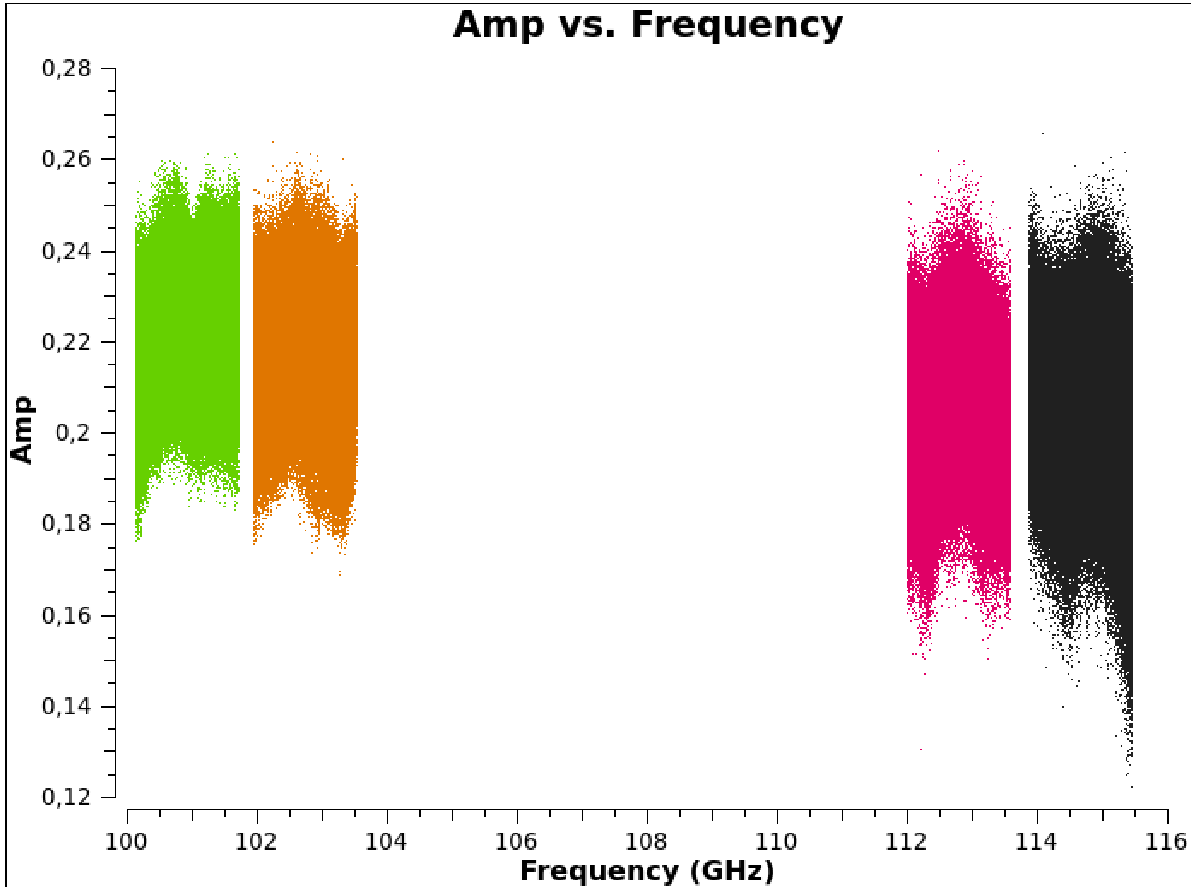
- Apply caltable: bandpass, Flux, Phase.

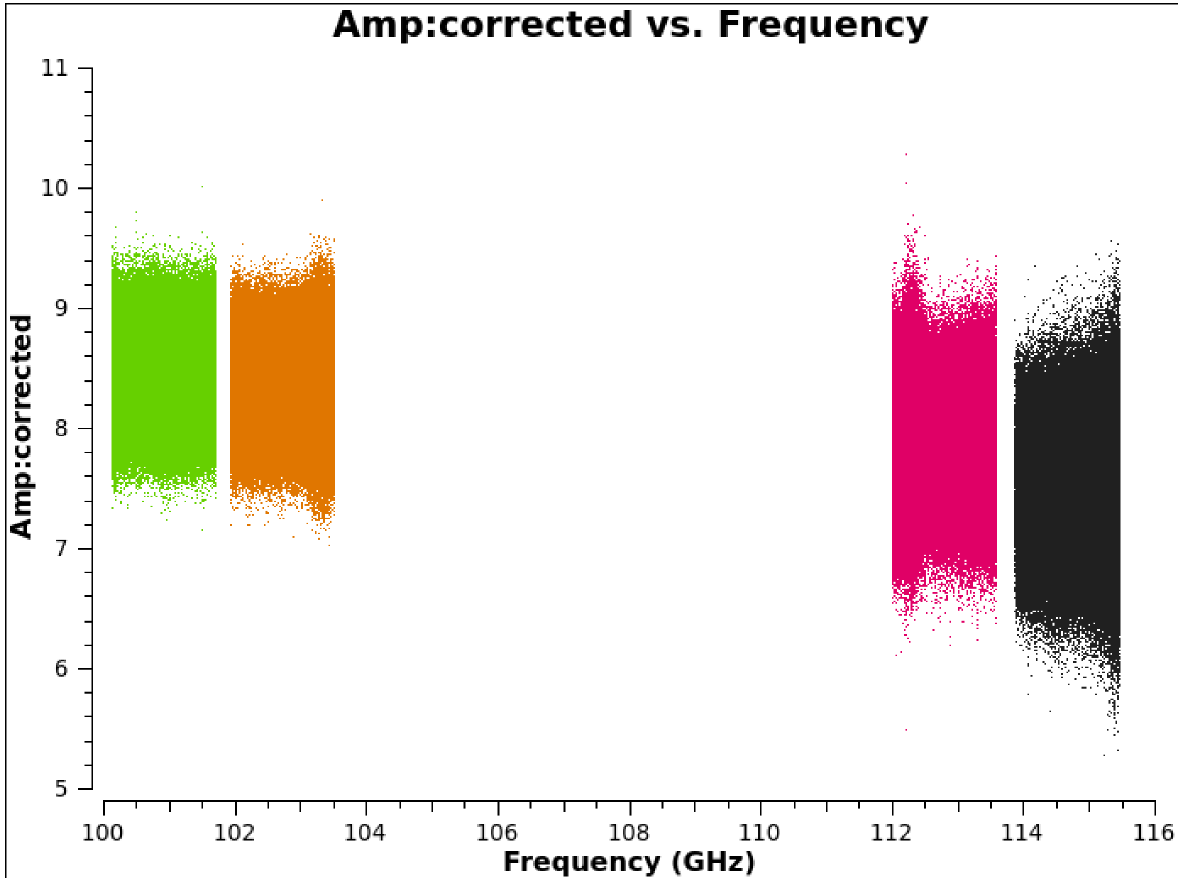




Calibration

- Apply caltable: bandpass, Flux, Phase.





Imaging

Computing the dirty image and the dirty beam from the measured visibilities and the sampling function.

1. Replace measured visibilities (real and imaginary parts) by a grid of numbers in the (u,v) plane of baseline coordinates
2. Fourier transform the visibilities sample to get i (l,m) dirty

The result is called the “dirty map”

the dirty map of a point source is called the "dirty beam"

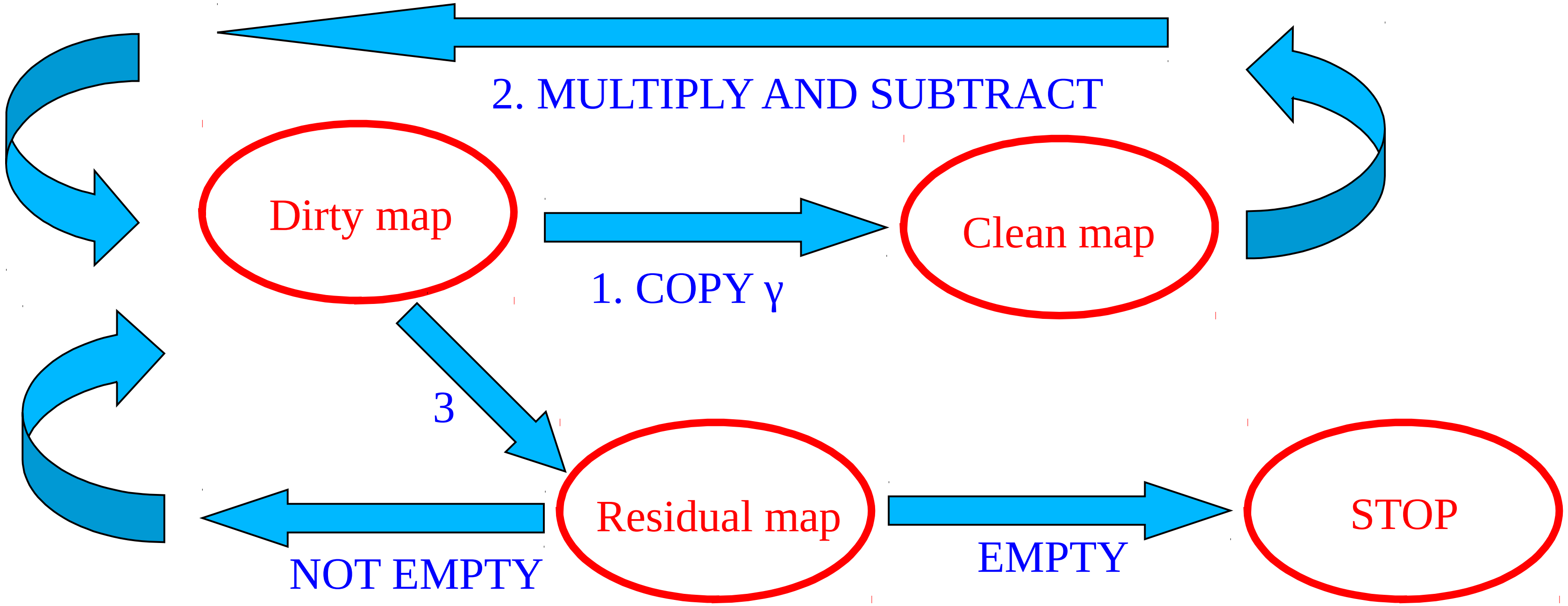
Deconvolution

Obtain the “real images” of the sky

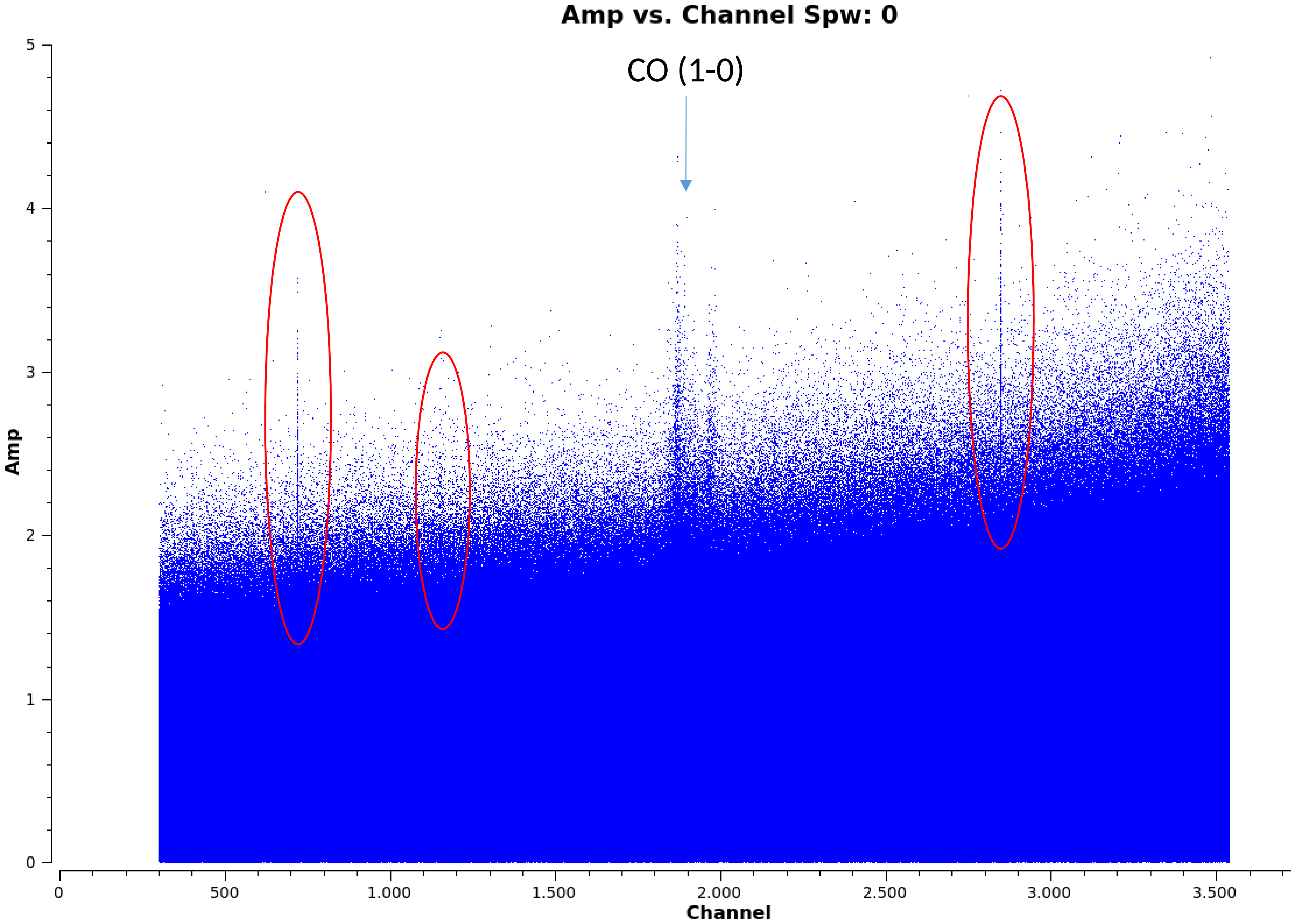
Clean algorithm

- Identify the highest peak of dirty map and copy a fraction (γ) in clean map
- Multiply this fraction by the dirty beam and subtract it from the dirty map
- If the resulting “residual map” reaches threshold, then stop!

(stopping criteria = n x rms (if noise limited), or imax/n (if dynamic range limited), where n is some arbitrarily chosen value)

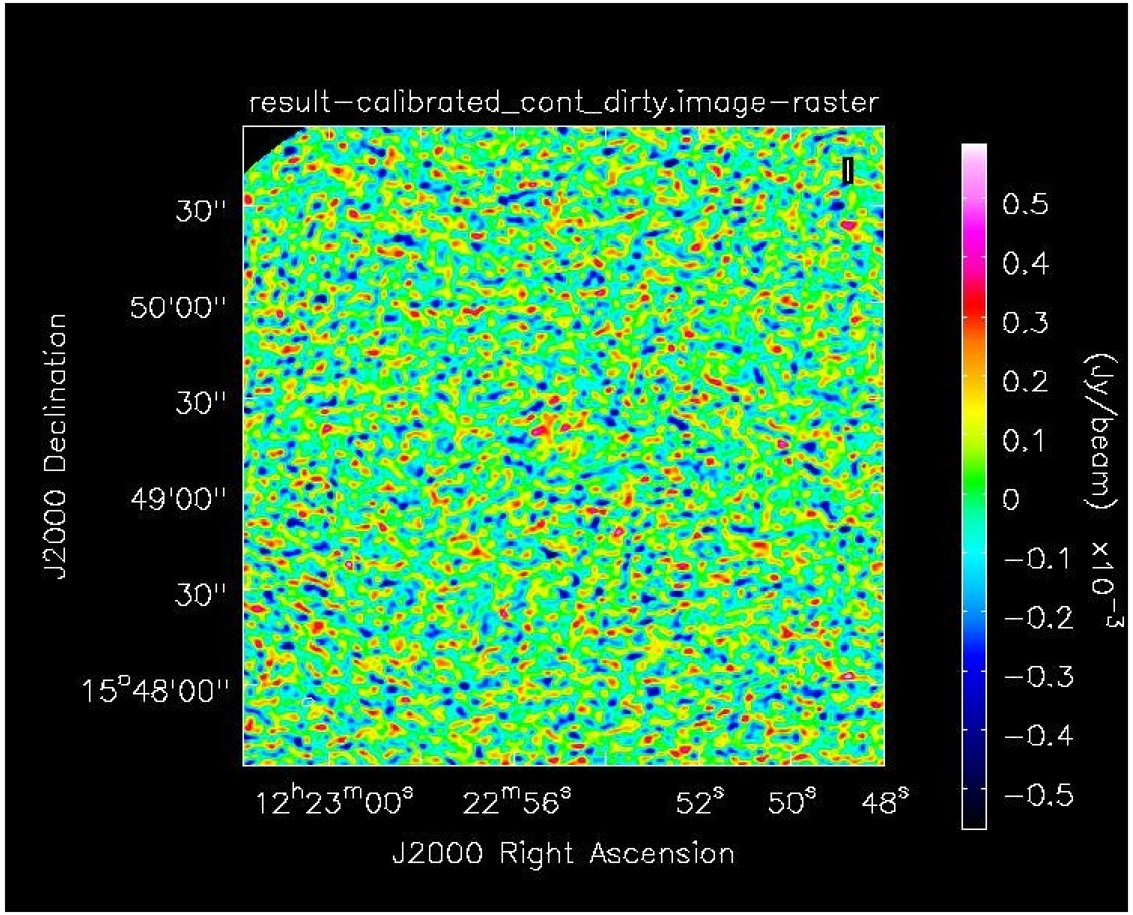


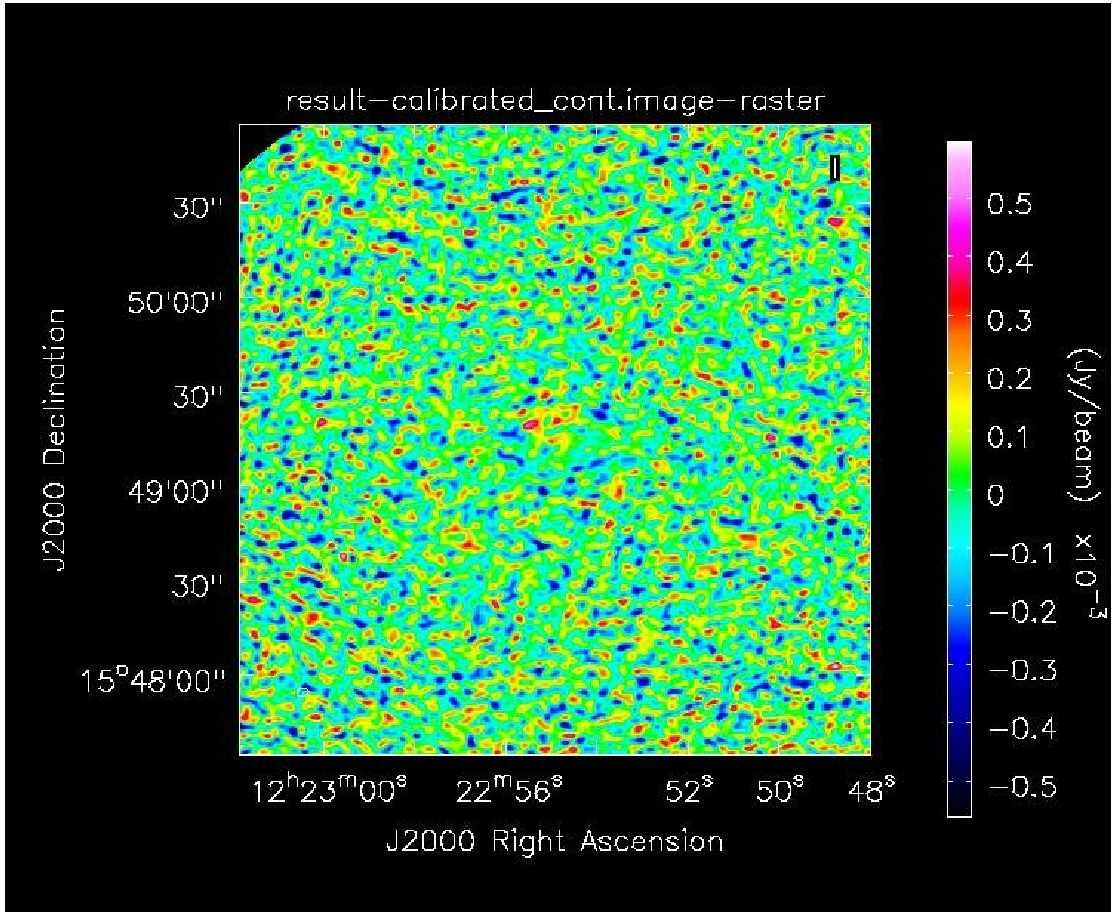
Imaging



Amp vs. Channel Spw: 0
CO (1-0)
Amp
Channel
0
1
2
3
4
5
0
500
1.000
1.500
2.000
2.500
3.000
3.500

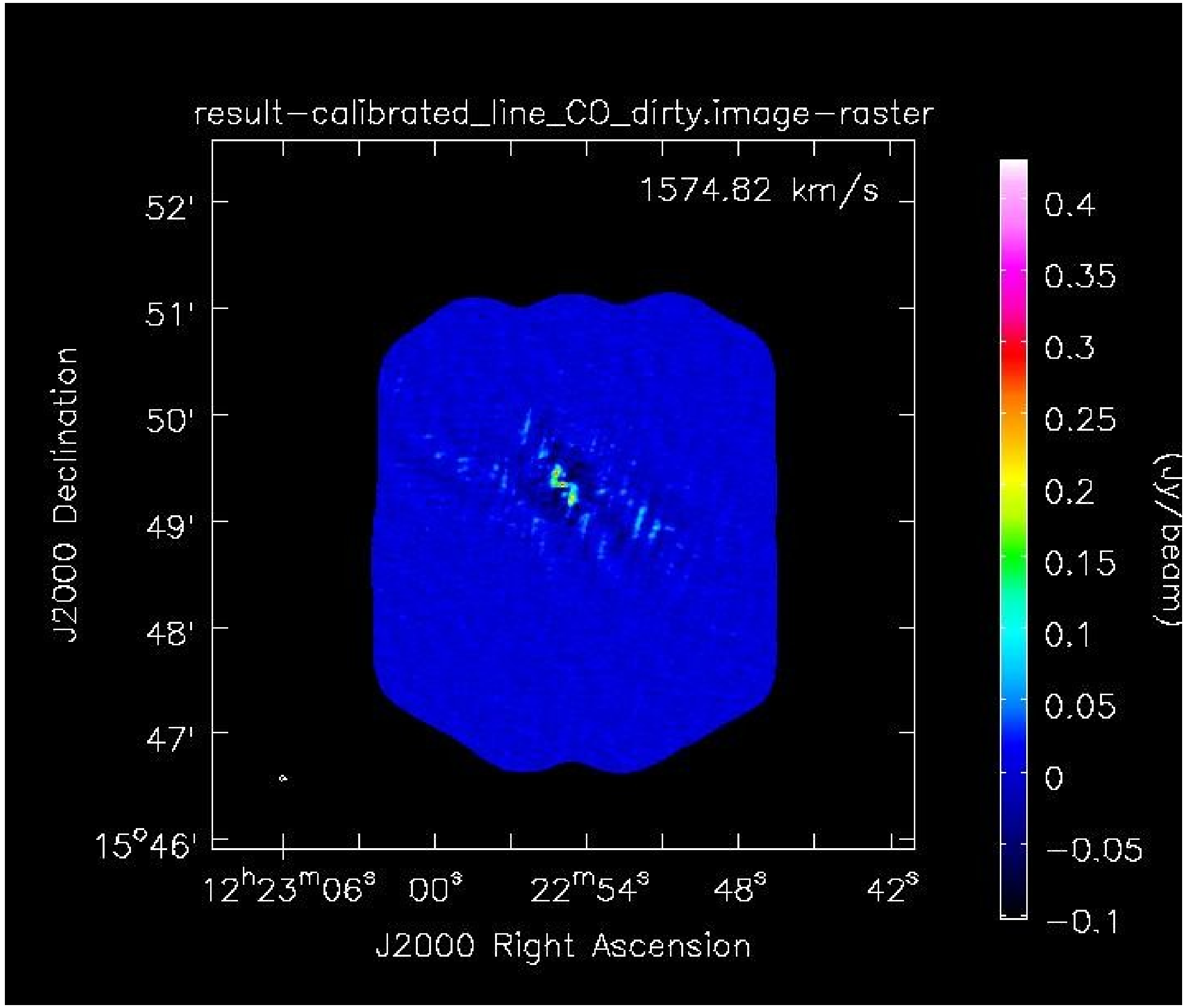
Imaging - Continuum map

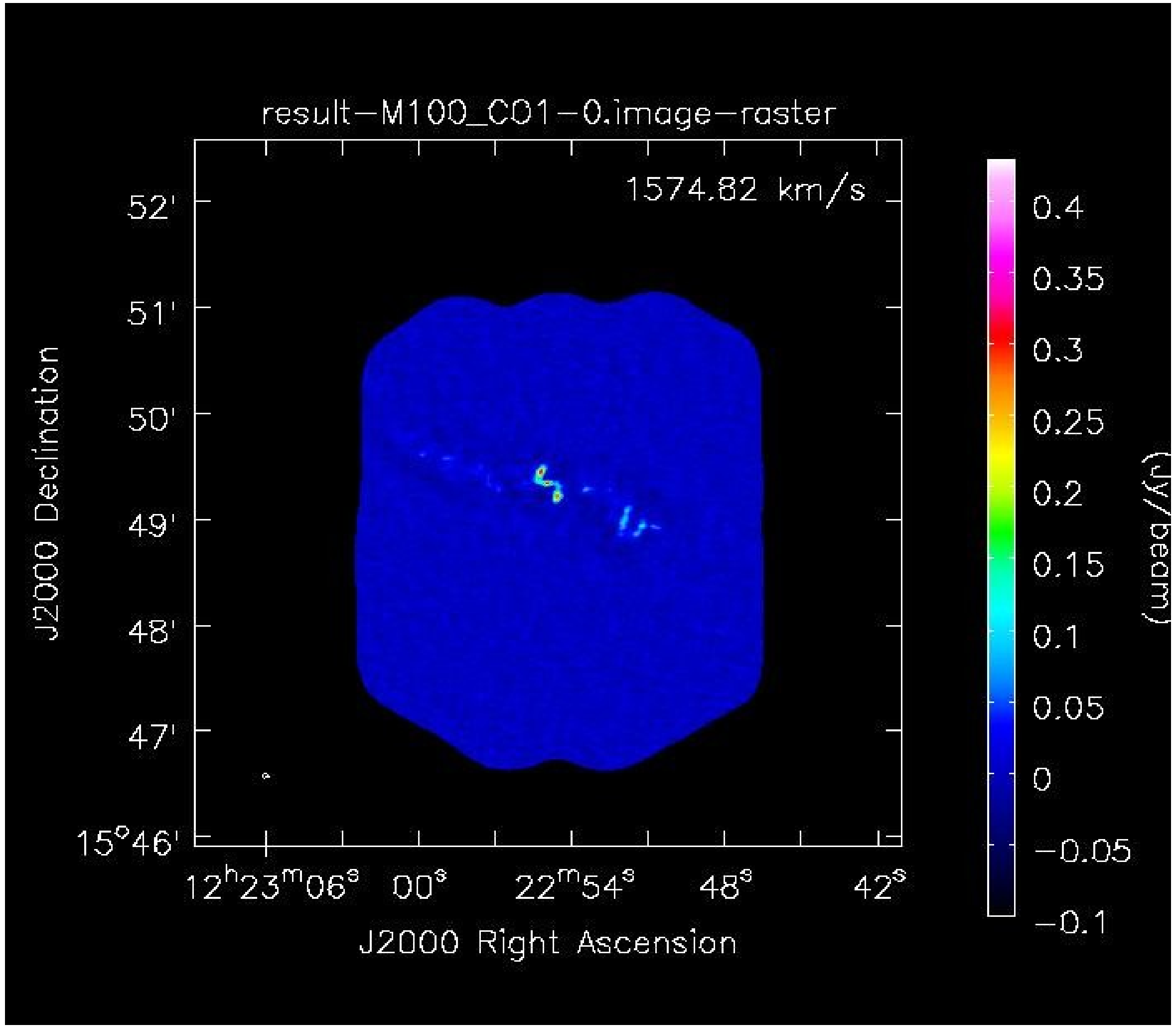




No source is seen. The reason is that the peak of the continuum detection is less than the rms in a single line channel

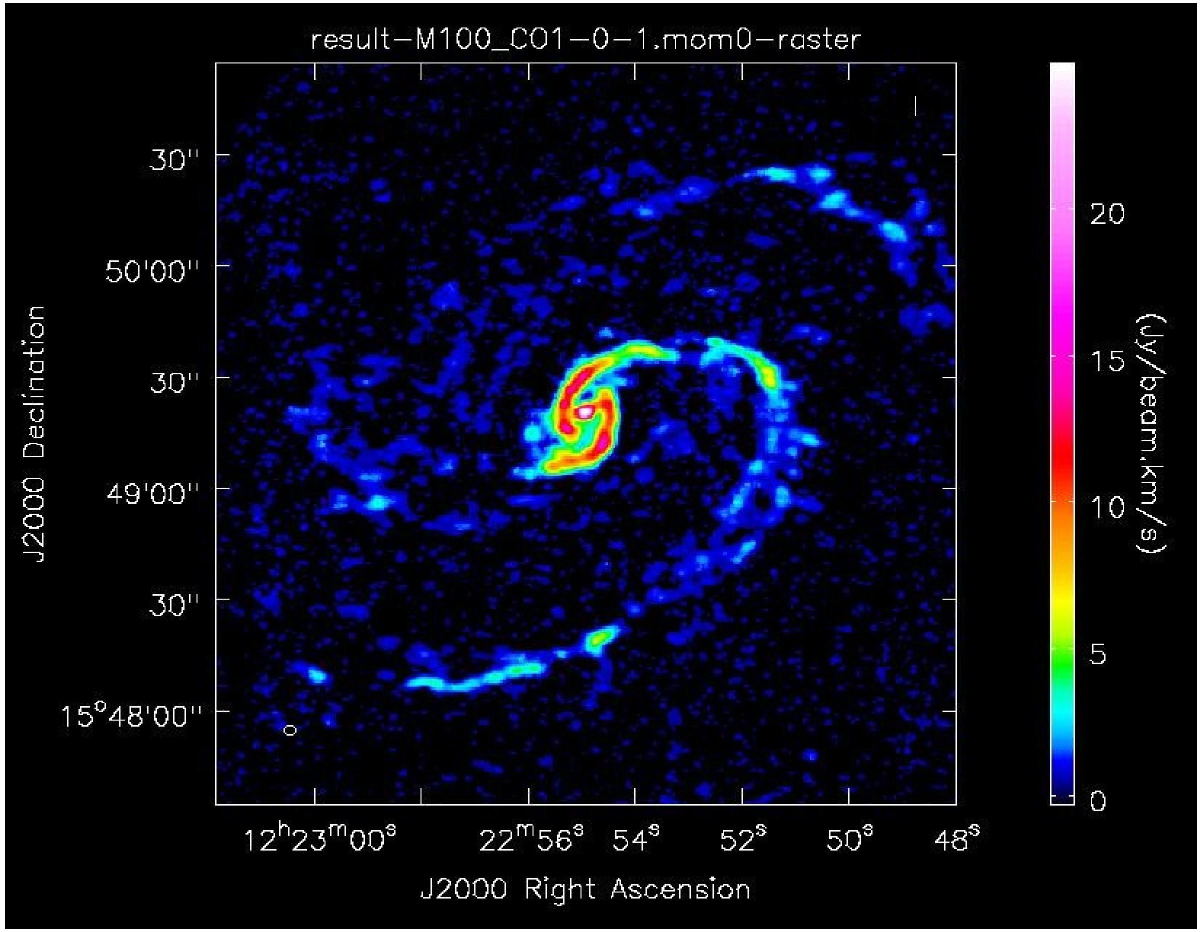
Imaging – CO(1-0) map



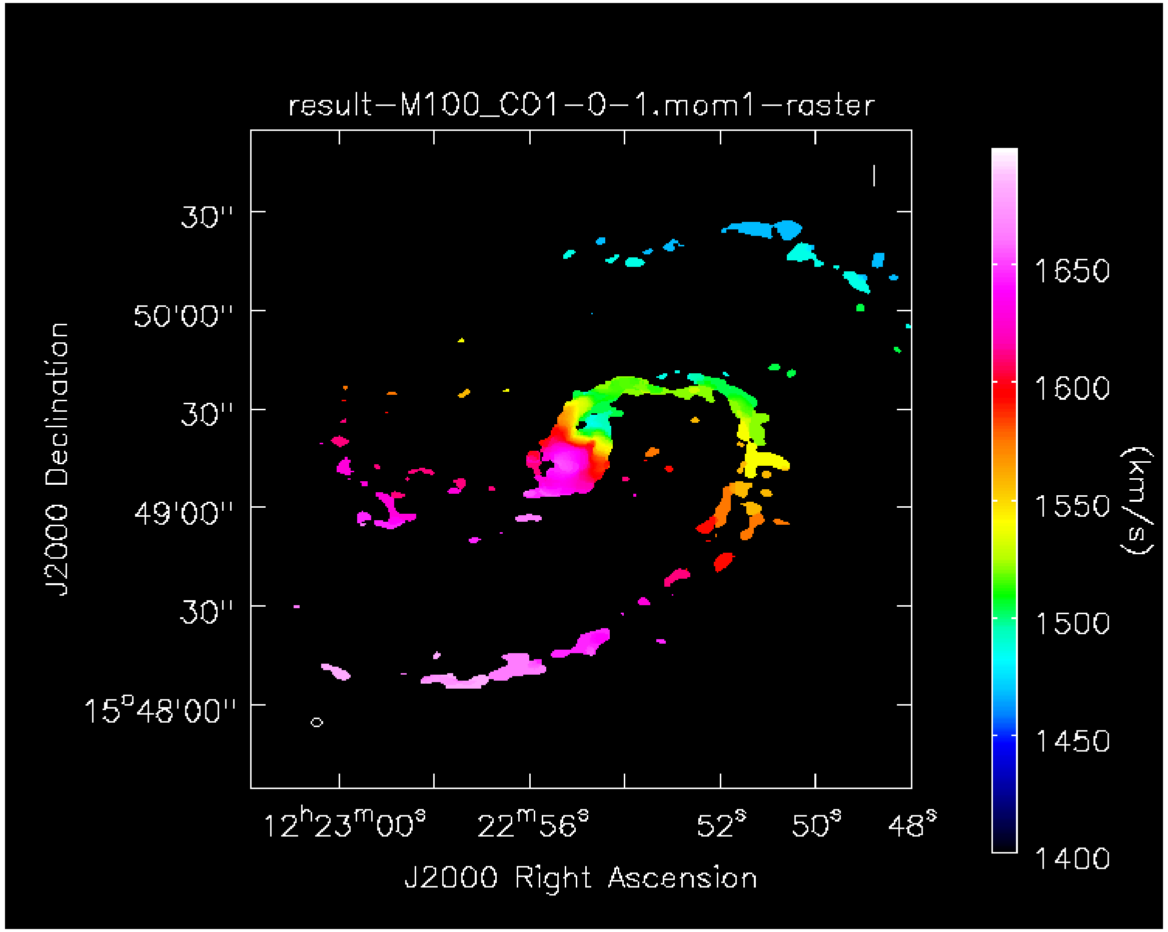


CO(1-0) map at v =1574.82 km/s (channel 29)
Clean threshold = 1.5 time average channel rms

Imaging - CO(1-0) emission

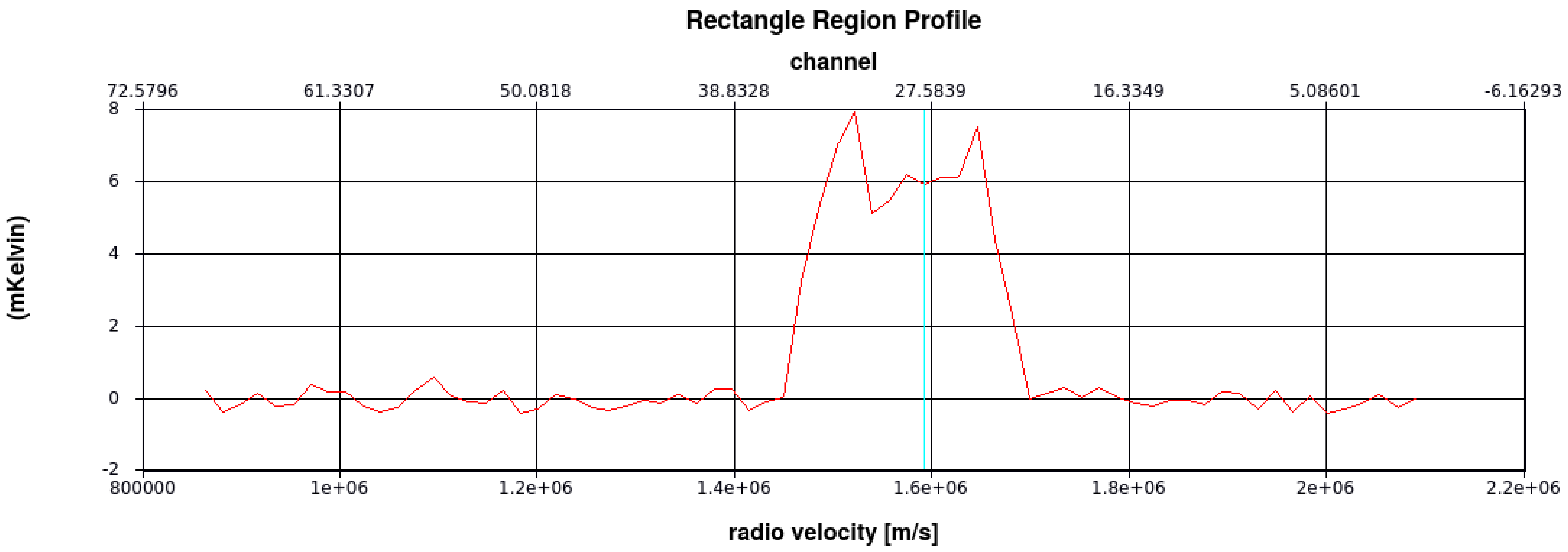


Integrated flux maps



Mean velocity maps

Imaging



Rectangle Region Profile
channel
72.5796
61.3307
50.0818
38.8328
27.5839
16.3349
5.08601
-6.16293
8
6
4
2
0
-2
(mKelvin)
800000
1e+06
1.2e+06
1.4e+06
1.6e+06
1.8e+06
2e+06
2.2e+06
radio velocity [m/s]

Summary

- Having studied about the principle of interferometry technique.

- Using the CASA software to reduce data of the CO(1-0) emission of M100, which were observed in band 3 by ALMA.

- The data reduction process proceeds from data examination and editing, calibration to imaging. Finally, I obtained a clean image of M100 and a data cube ready for further investigation.

- M1 internship has been a good opportunity for me to work with top quality data recorded by the world best radio interferometer

- Learning how to work with others as well as by myself, to acquire new knowledge and new skills.

- Having a clearer view of both technical and scientific aspects of radio astronomy.

Thank you for your attention !

This Report Makes Use Of The Following Alma Data: Ads/Jao.Alma#2011.0.00004.Sv. Alma Is A Partnership Of Eso (Representing Its Member States), Nsf (Usa) And Nins (Japan), Together With Nrc (Canada) And Nsc And Asiaa (Taiwan), And Kasi (Republic Of Korea), In Cooperation With The Republic Of Chile. The Joint Alma Observatory Is Operated By Eso, Aui/Nrao And Naoj.