Imaging Tutorial

Z Canis Major (or Z CMa)

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Z CMa

- Pre-main sequence binary system
- Herbig Be star + FU Orionis object
- Distance: 1125 pc
- Separation: ~100 au (0.1”)
- Systemic velocity V_{LSR} ~ 14 km/s
- Both components drive molecular outflows

Nature paper about a flyby event

ALMA Data

- Project 2018.1.01131.S (March 14th, 2019)
- Band 6 (~ 218.2 – 232.5 GHz)
- Continuum and line (^{13}CS and CO)
- For the tutorial will use only 12m data (7m data also observed)

The Tutorial

- **uid___A002_Xd98580_X354.ms**: calibrated data, end-product of *scriptforPI.py*, 33 GB → 50 GB (step 0)

or

- **Z_Cma_TM2.split.cal**: science-only calibrated data, 5.8 GB → 13 GB (step 1)

and

- **scriptForImagingZCMa.py**: script to be used in the tutorial, with a “switch” for each step that you need to turn on (True) or off (False)

Let’s take a look to the script.

STEP 0

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’
Step 0 = True (all others to False)

STEP 1

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’

Step 1 = True (all others to False)

STEP 2

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’

contSPW = ‘0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10’
Step 2 = True (all others to False)

STEP 3: tclean parameters

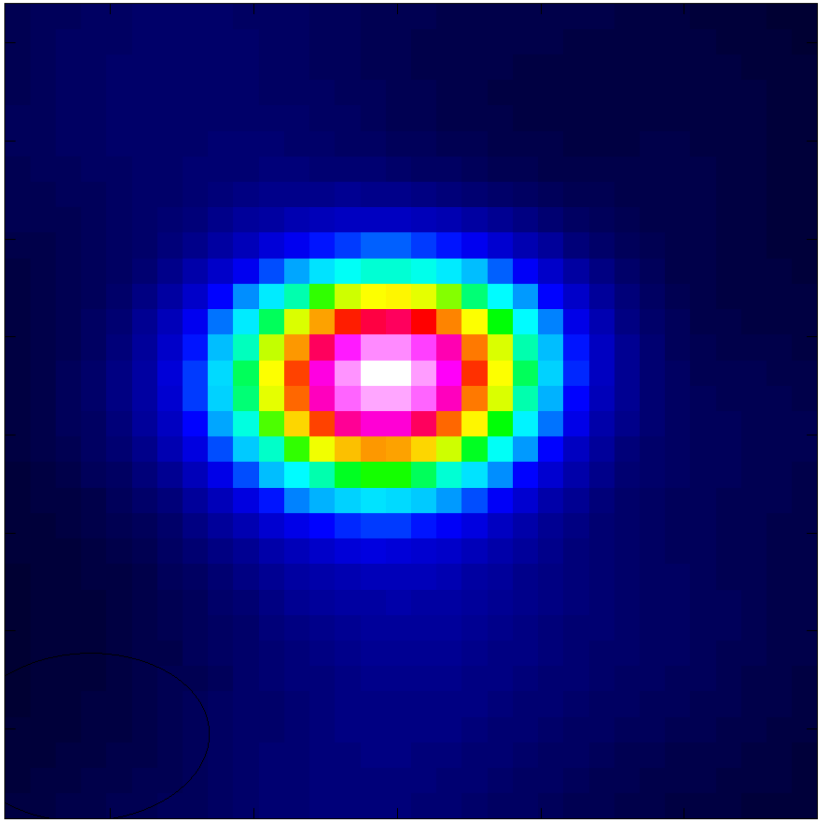

Image (N x N pixels)

STEP 3: tclean parameters

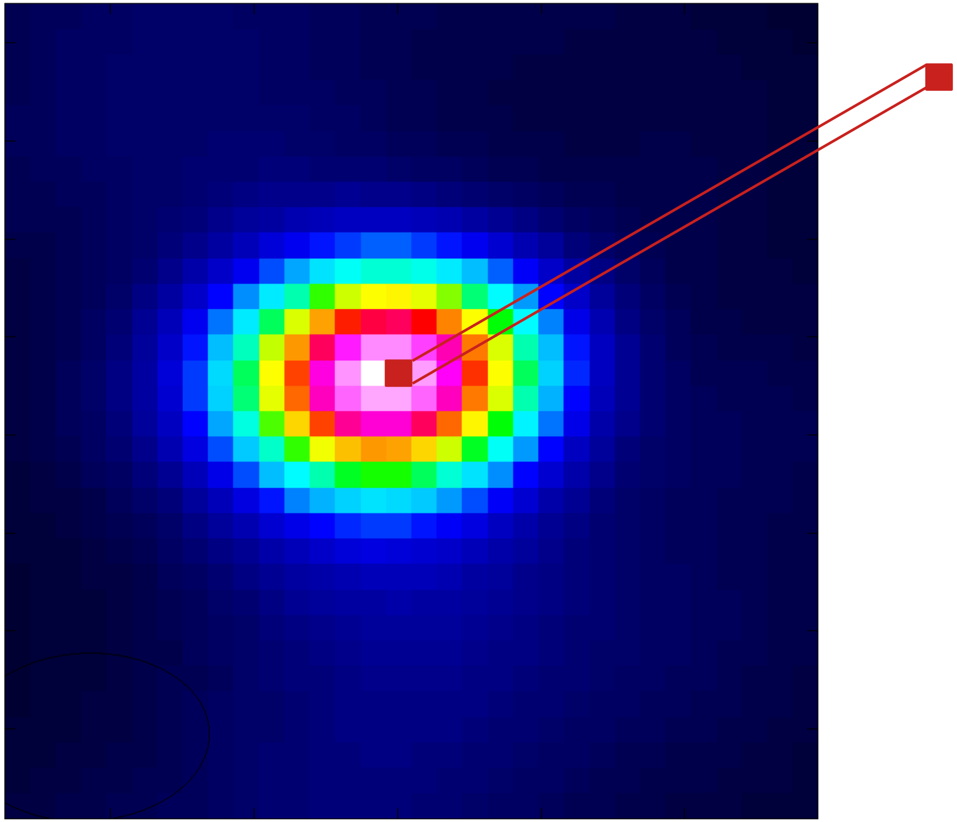

Image (N x N pixels)

- **cell**: angular size of your pixel, e.g.: 0.12”
  Depends on the angular resolution θ, i.e.: θ/6

STEP 3: tclean parameters

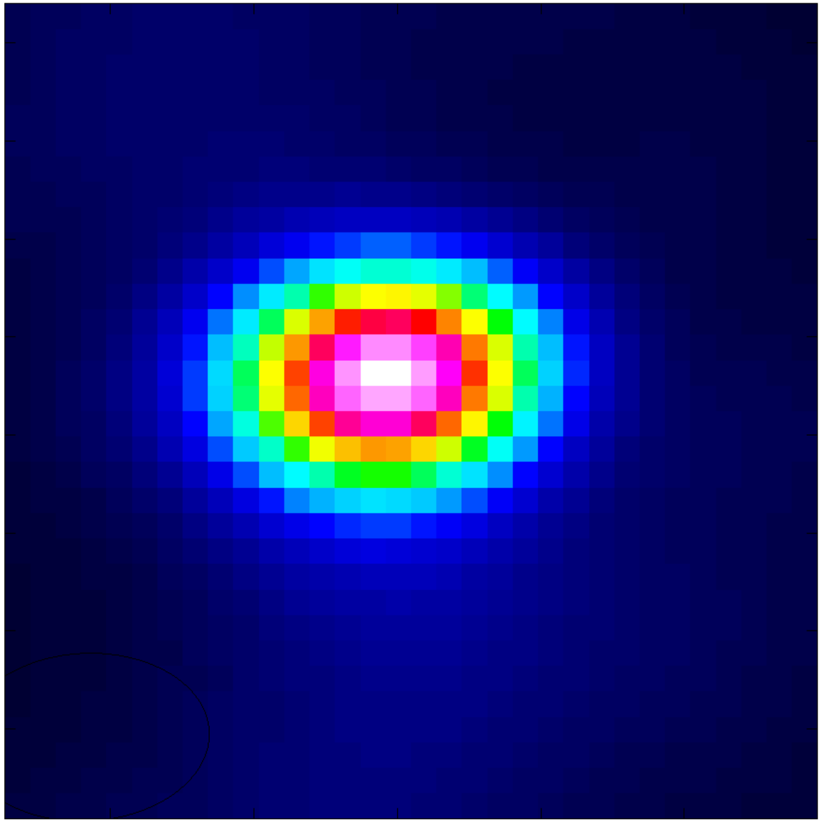

Image (N x N pixels)

cell: angular size of your pixel, e.g.: 0.12”
Depends on the angular resolution θ, i.e.: θ/6

imsize: pixel size of your image, e.g.: 500 x 500
Depends on the field of view FoV and cell, i.e.: 2*FoV/cell

STEP 3: tclean parameters

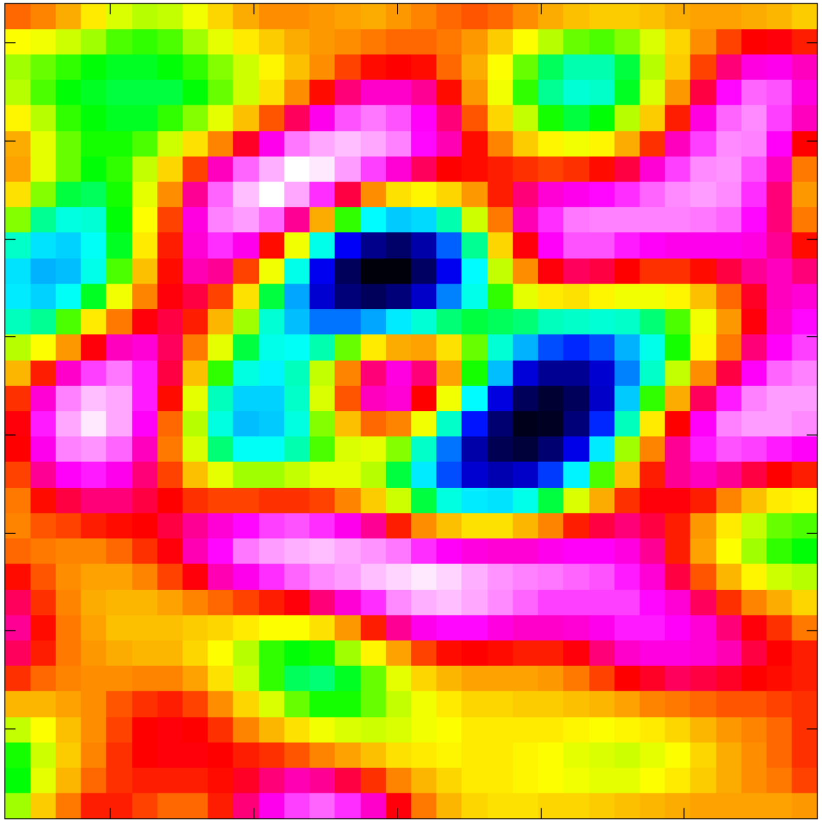

Image (N x N pixels)

cell: angular size of your pixel, e.g.: 0.12”
Depends on the angular resolution θ, i.e.: θ/6

imsize: pixel size of your image, e.g.: 500 x 500
Depends on the field of view FoV and cell, i.e.: 2*FoV/cell

threshold: how deep do you want to clean, e.g.: 10 μJy
Depends on the expected rms of your image, i.e.: 3xrms

STEP 3: tclean parameters

cell = **θ / 6**; **θ:** angular resolution

θ [rad] = **λ**[m] / $\mathbf{B}_{max}$[m]; **λ**: observing wavelength; $\mathbf{B}_{max}$: maximum baseline

STEP 3: tclean parameters

cell = **θ / 6**; **θ:** angular resolution

θ [rad] = **λ**[m] / **B_{max}**[m]; **λ**: observing wavelength; **B_{max}**: maximum baseline

Observed frequency range: 217.079 (spw5) – 233.443 (spw10) GHz
(**listobs**, weblog, plotms)

STEP 3: tclean parameters

cell = **θ / 6**; **θ:** angular resolution

θ [rad] = **λ**[m] / $\mathbf{B_{max}}$[m]; **λ**: observing wavelength; $\mathbf{B_{max}}$: maximum baseline

Observed frequency range: 217.079 (spw5) – 233.443 (spw10) GHz (**listobs**, weblog, plotms)

- ν = 225.261 GHz
- **λ** = c / ν = 1.33 mm = **0.00133 m**

STEP 3: tclean parameters

cell = **θ / 6**; **θ:** angular resolution

θ [rad] = **λ**[m] / $\mathbf{B_{max}}$[m]; **λ**: observing wavelength; $\mathbf{B_{max}}$: maximum baseline

Observed frequency range: 217.079 (spw5) – 233.443 (spw10) GHz (**listobs**, weblog, plotms)

- ➔ ν = 225.261 GHz
- ➔ **λ** = c / ν = 1.33 mm = **0.00133 m**

$\mathbf{B_{max}}$ **= 360.6 m** (**weblog,** plotms, aU.getBaselineLengths)

aU: analysisUtils python package (very handy tools!)

STEP 3: tclean parameters

cell = **θ / 6**; **θ:** angular resolution

θ [rad] = **λ**[m] / $\mathbf{B_{max}}$[m]; **λ**: observing wavelength; $\mathbf{B_{max}}$: maximum baseline

Observed frequency range: 217.079 (spw5) – 233.443 (spw10) GHz (**listobs**, weblog, plotms)

- ν = 225.261 GHz
- **λ** = c / ν = 1.33 mm = **0.00133 m**

$\mathbf{B_{max}}$ **= 360.6 m** (**weblog,** plotms, aU.getBaselineLengths)

θ [arcsec] = 0.00133 / 360.6 * 180 / π * 3600 ~ **0.76 arcsec**

cell = 0.76 / 6 ~ **0.13 arcsec**;

aU: analysisUtils python package (very handy tools!)

STEP 3: tclean parameters

imsize = 2* **FoV / cell**; **FoV**: field of view

FoV [rad] = **λ** [m] / **D**[m]; **λ**: observing wavelength; **D**: antenna diameter

STEP 3: tclean parameters

imsize = 2* **FoV / cell**; **FoV**: field of view

FoV [rad] = **λ** [m] / **D**[m]; **λ**: observing wavelength; **D**: antenna diameter

λ = **0.00133 m**

D = 12 m

cell = 0.13 arcsec

STEP 3: tclean parameters

imsize = 2* **FoV / cell**; **FoV**: field of view

FoV [rad] = **λ** [m] / **D**[m]; **λ**: observing wavelength; **D**: antenna diameter

λ = **0.00133 m**

D = 12 m

cell = 0.13 arcsec

FoV [arcsec] = 0.00133 / 12 * 180 / π * 3600 ~ **23 arcsec**

imsize = 2 * 23 / 0.13 ~ **354 pixels**

STEP 3: tclean parameters

imsize = 2* **FoV / cell**; **FoV**: field of view

FoV [rad] = **λ** [m] / **D**[m]; **λ**: observing wavelength; **D**: antenna diameter

λ = 0.00133 m

D = 12 m

cell = 0.13 arcsec

Hint: If imsize is even and factorizable by 2, 3, 5 only, tclean will work faster (i.e. **360**)

FoV [arcsec] = 0.00133 / 12 * 180 / π * 3600 ~ **23 arcsec**

imsize = 2 * 23 / 0.13 ~ **354 pixels**

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\,\Delta \nu)}};$$

k: Boltzmann constant;
$\mathbf{T_{sys}}$: antenna temperature;
$\mathbf{A_{eff}}$: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

STEP 3: tclean parameters

threshold = 3 * rms; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

STEP 3: tclean parameters

threshold = 3 * **rms**;   **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν =

Continuum selection: (0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10)

STEP 3: tclean parameters

threshold = 3 * **rms**;   **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν = 8 * 58593.8

Continuum selection: (**0, 1, 2, 3, 4, 5, 6, 7**, 8:300~959, 9:0~85;115~959, 10)

8 spw * bandwidth
(listobs)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\Delta\nu)}};$$

k: Boltzmann constant;
$\mathbf{T_{sys}}$: antenna temperature;
$\mathbf{A_{eff}}$: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν = 8 * 58593.8 + **660 * 122.070**

Continuum selection: (0, 1, 2, 3, 4, 5, 6, 7, **8:300~959**, 9:0~85;115~959, 10)

660 ch * chanwidth
(listobs)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν = 8 * 58593.8 + 660 * 122.070 + **931 * 122.070**

Continuum selection: (0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, **9:0~85;115~959**, 10)

931 ch * chanwidth
(listobs)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2]=\frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\Delta\nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν = 8 * 58593.8 + 660 * 122.070 + 931 * 122.070 + **1875000.0**

Continuum selection: (0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, **10**)

bandwidth
(listobs)

STEP 3: tclean parameters

threshold = 3 * **rms**;   **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
$\mathbf{T_{sys}}$: antenna temperature;
$\mathbf{A_{eff}}$: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)

Δν = (8 * 58593.8 + 660 * 122.070 + 931 * 122.070 + 1875000.0) * 10^{-6} = **2.54 GHz**

Continuum selection: (0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2\,k\,T_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\,\Delta\nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

$k = 1.38 \times 10^{-23}$ J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)
Δν = 2.54 GHz (listobs)

A_{eff} = efficiency * A_{12m} $= 0.7 * \pi * 6^2 =$ **$79.2\ m^2$**

(efficiency: Table 9.3 of ALMA Cycle 8 Handbook)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2\,k\,T_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\,\Delta\nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)
Δν = 2.54 GHz (listobs)
A_{eff} = 79.2 m^2 (ALMA documentation)

T_{sys} ~ 100 K (weblog)

STEP 3: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
$\mathbf{T_{sys}}$: antenna temperature;
$\mathbf{A_{eff}}$: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)
Δν = 2.54 GHz (listobs)
$\mathbf{A_{eff}}$ **= 79.2 m^2** (ALMA documentation)
$\mathbf{T_{sys}}$ **~ 100 K** (weblog)

rms = 8.37 x 10^{-31} J/m^2 = 8.37 x 10^{-31} x 10^{26} Jy = **83.7 µJy**

threshold = 3 * 83.7 = 251 uJy = **0.25 mJy**

STEP 3

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’

contSPW = ‘0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10’

mycell = ‘0.13 arcsec’
myimsize = 360
mythreshold = ‘0.25 mJy’
Step 3 = True (all others to False)

STEP 4: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image **per channel**

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t\,\Delta\nu)}};$$

k: Boltzmann constant;
$\mathbf{T_{sys}}$: antenna temperature;
$\mathbf{A_{eff}}$: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)
Δν = 122.070 kHz (listobs)
$\mathbf{A_{eff}}$ **= 79.2 m^2** (ALMA documentation)
$\mathbf{T_{sys}}$ **~ 100 K** (weblog)

STEP 4: tclean parameters

threshold = 3 * **rms**; **rms**: theoretical noise of the image **per channel**

$$rms[J/m^2] = \frac{2kT_{sys}}{A_{eff}\sqrt{(N(N-1)\Delta t \Delta \nu)}};$$

k: Boltzmann constant;
T_{sys}: antenna temperature;
A_{eff}: effective collecting area of a antenna;
N: number of antennas;
Δt: time on source;
Δν: total bandwidth

k = 1.38 × 10^{-23} J/K
N = 48 (weblog, listobs)
Δt = 302.4 s (weblog, listobs)
Δν = 122.070 kHz (listobs)
A_{eff} = 79.2 m^2 (ALMA documentation)
T_{sys} ~ 100 K (weblog)

rms_{ch} = rms_{cont} * sqrt($\Delta\nu_{cont}/\Delta\nu_{ch}$) = 83.7 * sqrt(2.54 * 10^6/122.070) **=** 12073 µJy **= 12 mJy**

threshold = 3 * 12 = **36 mJy**

STEP 4: tclean parameters

start: first channel to use for making the cube (plotms)
nChan: total of channels to use (plotms)
restfreq: rest frequency of the line (splatcatalogue)

CO cube (spw 8)

startCO = 50
nChanCO = 130
restfreq = 230.538 GHz

^{13}CS cube (spw 9)

startCS = 85
nChanCS = 30
restfreq = 231.2206 GHz

STEP 4

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’

contSPW = ‘0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10’

mycell = ‘0.13 arcsec’
myimsize = 360
mythreshold = ‘0.25 mJy’

startCO = 50
nChanCO = 130
myThreshCO = ‘36 mJy’
startCS = 85
nChanCS = 30
myThreshCS = ‘36 mJy’
Step 4 = True (all others to False)

STEP 5: immoments parameters

myLineChans: channel range of line emission (viewer, **CARTA**)

CO cube (spw 8)

V_{peak} ~ 14.5 km/s
myLineChans= 0 ~ 115

STEP 5

myMS = ‘uid___A002_Xd98580_X354.ms.calibrated’
target = ‘Z_CMa’

contSPW = ‘0, 1, 2, 3, 4, 5, 6, 7, 8:300~959, 9:0~85;115~959, 10’

mycell = ‘0.13 arcsec’
myimsize = 360
mythreshold = ‘0.25 mJy’

myLineChans = ‘0 ~ 115’
Step 5 = True (all others to False)

startCO = 50
nChanCO = 130
myThreshCO = ‘36 mJy’
startCS = 85
nChanCS = 30
myThreshCS = ‘36 mJy’