CASA VLBI

WORKSHOP 2020

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Lecture #8: basic imaging of VLBI

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CASA
Common Astronomy Software Applications

JIVE
Joint Institute for VLBI ERIC

RadioNet

JUMPING JIVE
Joint Institute for VLBI ERIC

Basic imaging of VLBI

Lecture #8
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GOALS

- Make dirty and CLEANed images from a VLBI dataset
- Visualization of the CASA imaging products
- Analysis of the results in the image plane
- Export your images (also as FITS)

Basic imaging of VLBI

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B = Intrinsic source brightness distribution

An interferometer measures the visibilities V(u,v)

$$\mathrm{V}(u,v) \approx \iint_{lm} \mathrm{B}(l,m) e^{-2\pi i(ul+vm)} dldm$$

l,m = directional cosines
u,v = coordinates (defined as perpendicular to the source)

Key issue: the uv-plane is not continuously filled (**sparse arrays**) – so direct FT of V(u,v) is not possible.

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"coverage function" of Ivan's talk

S = sampling function
= 1 where there is a measurement in the uv plane
= 0 otherwise

B = Intrinsic source brightness distribution

D = dirty beam = point spread function (PSF)

Convolution

BUT Check Ivan's talk about the gain "corruption"

$$B(l,m) * D(l,m) \approx \iint_{uv} S(u,v)V(u,v)e^{2\pi i(ul+vm)}dudv$$

$$D(l,m) = \iint_{uv} S(u,v)e^{2\pi i(ul+vm)}dudv$$

We know this!
To recover B we have **"just" to deconvolve** the D(l,m) term

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Basics of a standard CLEANing process (e.g. Högbom/Clark algorithms):

1. Initialize a residual map to the dirty image
2. Start cleaning loop: identify strongest component in residual map as a delta component
3. Add this point source to the model = clean component list
4. Convolve the point source with the beam and subtract a fraction (the loop gain, typically 10%) of that from residual map
5. If stopping criteria are not reached, do next iteration

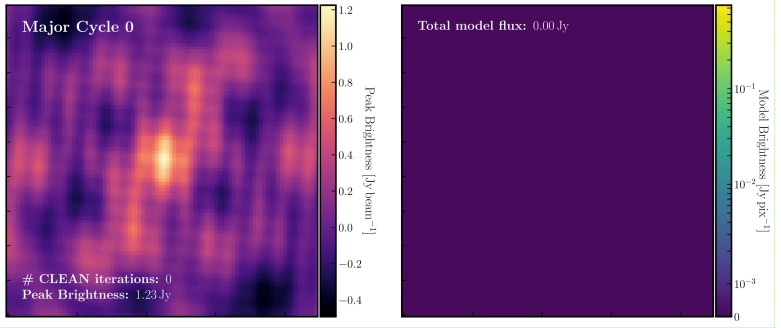

Image credits: DARA tutorials (A. Richards, J. Radcliffe, D. Small)
http://www.jb.man.ac.uk/DARA/unit4/Workshops/EVN_continuum_part_2.html

Finally = Convolve the model by an estimate of the main lobe of the dirty beam (the "CLEAN beam") and add residual map to make the final "restored" image -- what we call "CLEANed image"

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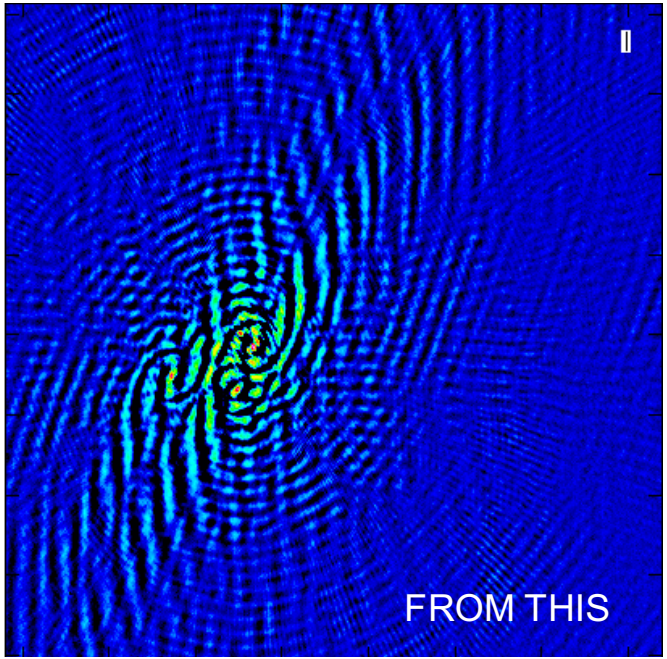
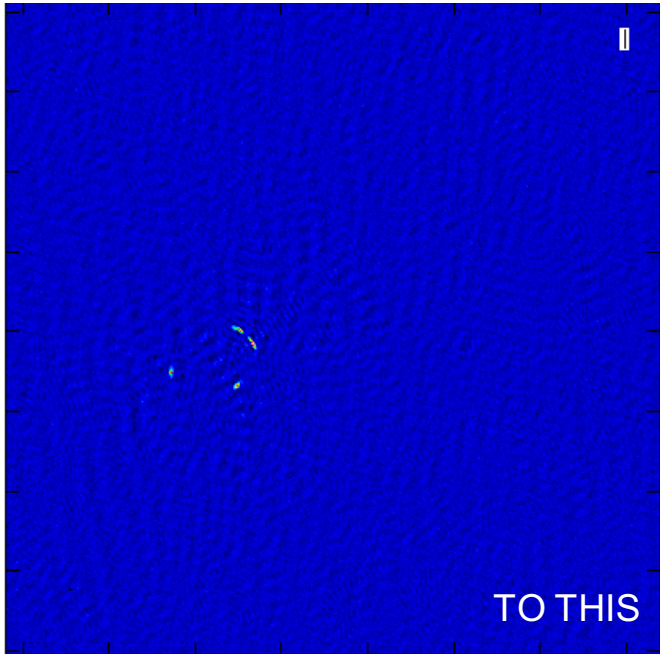


"**Undeconvolved**" image (dirty image)



Deconvolved image with Högbom CLEANing algorithm

TCLEAN

```
CASA <4>: default tclean
--------> default(tclean)
```

(it corresponds to IMAGR in AIPS)

```
CASA <4>: inp tclean
--------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''            #  Name of input visibility file(s)
selectdata          =       True            #  Enable data selection parameters
     field          =         ''            #  field(s) to select
     spw            =         ''            #  spw(s)/channels to select
     timerange      =         ''            #  Range of time to select from data
     uvrange        =         ''            #  Select data within uvrange
     antenna        =         ''            #  Select data based on antenna/baseline
     scan           =         ''            #  Scan number range
     observation    =         ''            #  Observation ID range
     intent         =         ''            #  Scan Intent(s)

datacolumn          = 'corrected'           #  Data column to image(data,corrected)
imagename           =         ''            #  Pre-name of output images
imsize              =      [100]            #  Number of pixels
cell                = ['1arcsec']           #  Cell size
phasecenter         =         ''            #  Phase center of the image
stokes              =        'I'            #  Stokes Planes to make
projection          =      'SIN'            #  Coordinate projection (SIN, HPX)
startmodel          =         ''            #  Name of starting model image
specmode            =      'mfs'            #  Spectral definition mode
                                            #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''            #  Reference frequency

gridder             = 'standard'            #  Gridding options (standard, wproject,
                                            #   widefield, mosaic, awproject)
     vptable        =         ''            #  Name of Voltage Pattern table
     pblimit        =        0.2            #  >PB gain level at which to cut off
                                            #   normalizations

deconvolver         =    'hogbom'           #  Minor cycle algorithm (hogbom,clark,multis
                                            #   cale,mtmfs,mem,clarkstokes)
restoration         =       True            #  Do restoration steps (or not)
     restoringbeam  =         []            #  Restoring beam shape to use. Default is
                                            #   the PSF main lobe
     pbcor          =      False            #  Apply PB correction on the output restored
                                            #   image

outlierfile         =         ''            #  Name of outlier-field image definitions
weighting           =  'natural'            #  Weighting scheme (natural,uniform,briggs)
     uvtaper        =         []            #  uv-taper on outer baselines in uv-plane

niter               =          0            #  Maximum number of iterations
usemask             =     'user'            #  Type of mask(s) for deconvolution:  user,
                                            #   pb, or auto-multithresh
     mask           =         ''            #  Mask (a list of image name(s) or region
                                            #   file(s) or region string(s) )
     pbmask         =        0.0            #  primary beam mask

restart             =       True            #  True : Re-use existing images. False :
                                            #   Increment imagename
savemodel           =     'none'            #  Options to save model visibilities (none,
                                            #   virtual, modelcolumn)
```

CASA VLBI TCLEAN

select measurement set (MS)

select field (if there are multiple in MS)

you can exclude the outer noisy channels (if not already flagged)

If you ran applycal, you have generated a CORRECTED column: that's the one you want to image!

If you split the target into a new MS using the CORRECTED column, then you have only the DATA column, which is the calibrated one

```
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vis                 =         ''            #  Name of input visibility file(s)
    field           =         ''            #  field(s) to select
    spw             =         ''            #  spw(s)/channels to select
    uvrange         =         ''            #  Select data within uvrange
    antenna         =         ''            #  Select data based on antenna/baseline
    scan            =         ''            #  Scan number range
    observation     =         ''            #  Observation ID range
    intent          =         ''            #  Scan Intent(s)

datacolumn          = 'corrected'           #  Data column to image(data,corrected)
imsize              =      [100]            #  Number of pixels
cell                = ['1arcsec']           #  Cell size
phasecenter         =         ''            #  Phase center of the image
stokes              =        'I'            #  Stokes Planes to make
projection          =      'SIN'            #  Coordinate projection (SIN, HPX)
startmodel          =         ''            #  Name of starting model image
specmode            =      'mfs'            #  Spectral definition mode
                                            #   (mfs,cube,cubedata, cubesource)
    reffreq         =         ''            #  Reference frequency

gridder             = 'standard'            #  Gridding options (standard, wproject,
                                            #   widefield, mosaic, awproject)
    vptable         =         ''            #  Name of Voltage Pattern table
    pblimit         =        0.2            #  >PB gain level at which to cut off
                                            #   normalizations

deconvolver         =    'hogbom'           #  Minor cycle algorithm (hogbom,clark,multis
                                            #   cale,mtmfs,mem,clarkstokes)
restoration         =       True            #  Do restoration steps (or not)
    restoringbeam   =         []            #  Restoring beam shape to use. Default is
                                            #   the PSF main lobe
    pbcor           =      False            #  Apply PB correction on the output restored
                                            #   image

outlierfile         =         ''            #  Name of outlier-field image definitions
weighting           =  'natural'            #  Weighting scheme (natural,uniform,briggs)
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niter               =          0            #  Maximum number of iterations
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                                            #   pb, or auto-multithresh
    mask            =         ''            #  Mask (a list of image name(s) or region
                                            #   file(s) or region string(s) )
    pbmask          =        0.0            #  primary beam mask

restart             =       True            #  True : Re-use existing images. Fals
                                            #   Increment imagename
savemodel           =     'none'            #  Options to save model visibilities (no
                                            #   virtual, modelcolumn)
```

CASA VLBI

TCLEAN

Select image size in pixel

Cell size in arcsec (see syntax!)

Phase center in J2000 coords
(if the source is not at the center)

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     field          =         ''            #  field(s) to select
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     timerange      =         ''            #  Range of time to select from data
     uvrange        =         ''            #  Select data within uvrange
     antenna        =         ''            #  Select data based on antenna/baseline
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     intent         =         ''            #  Scan Intent(s)

datacolumn          = 'corrected'           #  Data column to image(data,corrected)
imagename           =         ''            #  Pre-name of output images
imsize              =      [100]            #  Number of pixels
cell                = ['1arcsec']           #  Cell size
phasecenter         =         ''            #  Phase center of the image
stokes              =        'I'            #  Stokes Planes to make
projection          =      'SIN'            #  Coordinate projection (SIN, HPX)
startmodel          =         ''            #  Name of starting model image
specmode            =      'mfs'            #  Spectral definition mode
                                            #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''            #  Reference frequency

gridder             = 'standard'            #  Gridding options (standard, wproject,
                                            #   widefield, mosaic, awproject)
     vptable        =         ''            #  Name of Voltage Pattern table
     pblimit        =        0.2            #  >PB gain level at which to cut off
                                            #   normalizations

deconvolver         =   'hogbom'            #  Minor cycle algorithm (hogbom,clark,multis
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weighting           =  'natural'            #  Weighting scheme (natural,uniform,briggs)
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niter               =          0            #  Maximum number of iterations
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                                            #   file(s) or region string(s) )
     pbmask         =        0.0            #  primary beam mask

restart             =       True            #  True : Re-use existing images. False :
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savemodel           =     'none'            #  Options to save model visibilities (none,
                                            #   virtual, modelcolumn)
```

Image parameters

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Pixel scale = cell size

$$\text{cell} \approx \frac{180}{\pi N_s} \times \frac{1}{D_{\max}[\lambda]} \text{ [deg]}$$

Field of view = image size

Check bandwidth and time smearing
for your specific dataset
+ primary beam
+ expected size of your source

Nyquist sampling = N_s = 3 o 5 pixels across the main lobe of the beam

Max baseline in lambda units (D_{max}) - you can find it using PLOTMS (amp vs uvwave) check Benito's Lecture (#2)

TCLEAN

Ok for standard MFS cleaning
of radio continuum observations

MFS = multi-frequency synthesis = gridding different freqs on same uv-grid (it takes spectral dependency of the source into account, see Ivan's talk)

Set max number of iterations
niter = 0 produces a DIRTY IMAGE
(= no deconvolution)

If you select niter >0 other parameters are unlocked for setting the minor cycles, threshold etc.

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vis                 =         ''            #  Name of input visibility file(s)
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     field          =         ''            #  field(s) to select
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     scan           =         ''            #  Scan number range
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     intent         =         ''            #  Scan Intent(s)

datacolumn          = 'corrected'           #  Data column to image(data,corrected)
imagename           =         ''            #  Pre-name of output images
imsize              =      [100]            #  Number of pixels
cell                = ['1arcsec']           #  Cell size
phasecenter         =         ''            #  Phase center of the image
stokes              =        'I'            #  Stokes Planes to make
projection          =      'SIN'            #  Coordinate projection (SIN, HPX)
startmodel          =         ''            #  Name of starting model image
specmode            =       'mfs'           #  Spectral definition mode
                                            #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''            #  Reference frequency

gridder             = 'standard'            #  Gridding options (standard, wproject,
                                            #   widefield, mosaic, awproject)
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     pblimit        =        0.2            #  >PB gain level at which to cut off
                                            #   normalizations

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     pbcor          =      False            #  Apply PB correction on the output restored
                                            #   image

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                                            #   pb, or auto-multithresh
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                                            #   file(s) or region string(s) )
     pbmask         =        0.0            #  primary beam mask

restart             =       True            #  True : Re-use existing images. Fals
                                            #   Increment imagename
savemodel           =     'none'            #  Options to save model visibilities (no
                                            #   virtual, modelcolumn)
```

TCLEAN

Natural = more weight to short baselines (→ larger beam)
Uniform = more weight to long baselins (→ smaller beam)

Briggs weighting: it uses the “robust” parameter, which is between -2 and 2
Note that robust = 0.5 in CASA corresponds to robust = 0 in AIPS

Here select **weighting scheme** (natural, uniform, briggs) and **uvtaper**

Check out these two!

Restart = remember to change the name of each image you create
Savemodel attaches a MODEL_COLUMN to your MS

```
CASA <4>: inp tclean
--------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''            #  Name of input visibility file(s)
selectdata          =       True            #  Enable data selection parameters
     field          =         ''            #  field(s) to select
     spw            =         ''            #  spw(s)/channels to select
     timerange      =         ''            #  Range of time to select from data
     uvrange        =         ''            #  Select data within uvrange
     antenna        =         ''            #  Select data based on antenna/baseline
     scan           =         ''            #  Scan number range
     observation    =         ''            #  Observation ID range
     intent         =         ''            #  Scan Intent(s)

datacolumn          = 'corrected'           #  Data column to image(data,corrected)
imagename           =         ''            #  Pre-name of output images
imsize              =      [100]            #  Number of pixels
cell                = ['1arcsec']           #  Cell size
phasecenter         =         ''            #  Phase center of the image
stokes              =        'I'            #  Stokes Planes to make
projection          =      'SIN'            #  Coordinate projection (SIN, HPX)
startmodel          =         ''            #  Name of starting model image
specmode            =      'mfs'            #  Spectral definition mode
                                            #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''            #  Reference frequency

gridder             = 'standard'            #  Gridding options (standard, wproject,
                                            #   widefield, mosaic, awproject)
     vptable        =         ''            #  Name of Voltage Pattern table
     pblimit        =        0.2            #  >PB gain level at which to cut off
                                            #   normalizations

deconvolver         =    'hogbom'           #  Minor cycle algorithm (hogbom,clark,multis
                                            #   cale,mtmfs,mem,clarkstokes)
restoration         =       True            #  Do restoration steps (or not)
     restoringbeam  =         []            #  Restoring beam shape to use. Default is
                                            #   the PSF main lobe
     pbcor          =      False            #  Apply PB correction on the output restored
                                            #   image

outlierfile         =         ''            #  Name of outlier-field image definitions
weighting           =  'natural'            #  Weighting scheme (natural,uniform,briggs)
     uvtaper        =         []            #  uv-taper on outer baselines in uv-plane

niter               =          0            #  Maximum number of iterations
usemask             =     'user'            #  Type of mask(s) for deconvolution:  user,
                                            #   pb, or auto-multithresh
     mask           =         ''            #  Mask (a list of image name(s) or region
                                            #   file(s) or region string(s) )
     pbmask         =        0.0            #  primary beam mask

restart             =       True            #  True : Re-use existing images. False :
                                            #   Increment imagename
savemodel           =     'none'            #  Options to save model visibilities (none,
                                            #   virtual, modelcolumn)
```

TCLEAN

```
CASA <18>: go tclean
---------> go(tclean)
Executing:  tclean()
```

In the Logger there is the info on what is going on

```
vis                 = 'b0128.calibrated.ms/' #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          =     'data'        #  Data column to image(data,corrected)
imagename           =    'dirty'        #  Pre-name of output images
imsize              =    [2048]         #  Number of pixels
cell                = ['0.002arcsec']   #  Cell size
stokes              =      'I'          #  Stokes Planes to make
projection          =     'SIN'         #  Coordinate projection (SIN, HPX)
startmodel          =         ''        #  Name of starting model image
specmode            =     'mfs'         #  Spectral definition mode
                                        #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''        #  Reference frequency

gridder             = 'standard'        #  Gridding options (standard, wproject,
                                        #   widefield, mosaic, awproject)
     vptable        =         ''        #  Name of Voltage Pattern table
     pblimit        =        0.2        #  >PB gain level at which to cut off
                                        #   normalizations

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                                        #   cale,mtmfs,mem,clarkstokes)
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     pbcor          =      False        #  Apply PB correction on the output restored
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outlierfile         =                   #  Name of outlier-field image definitions
weighting           =  'natural'        #  Weighting scheme (natural,uniform,briggs)

niter               =          0        #  Maximum number of iterations
usemask             =     'user'        #  Type of mask(s) for deconvolution:  user,
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                                        #   file(s) or region string(s) )
     pbmask         =        0.0        #  primary beam mask

restart             =       True        #  True : Re-use existing images. False :
                                        #   Increment imagename
savemodel           =     'none'        #  Options to save model visibilities (none,
                                        #   virtual, modelcolumn)
```

Graphic interface: Viewer

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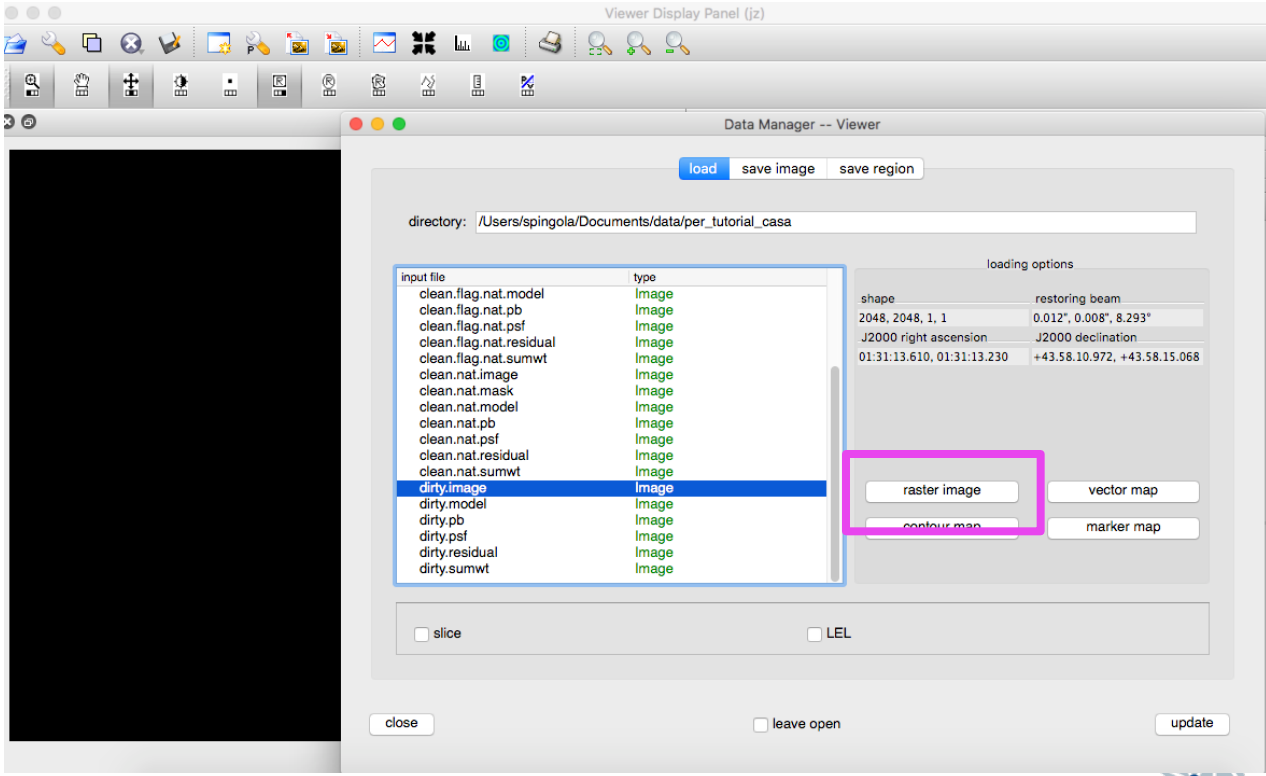
```
CASA <19>: viewer
---------> viewer()
```

Select the image that you want to inspect:

dirty.image

(select `raster image`)



Graphic interface: Viewer

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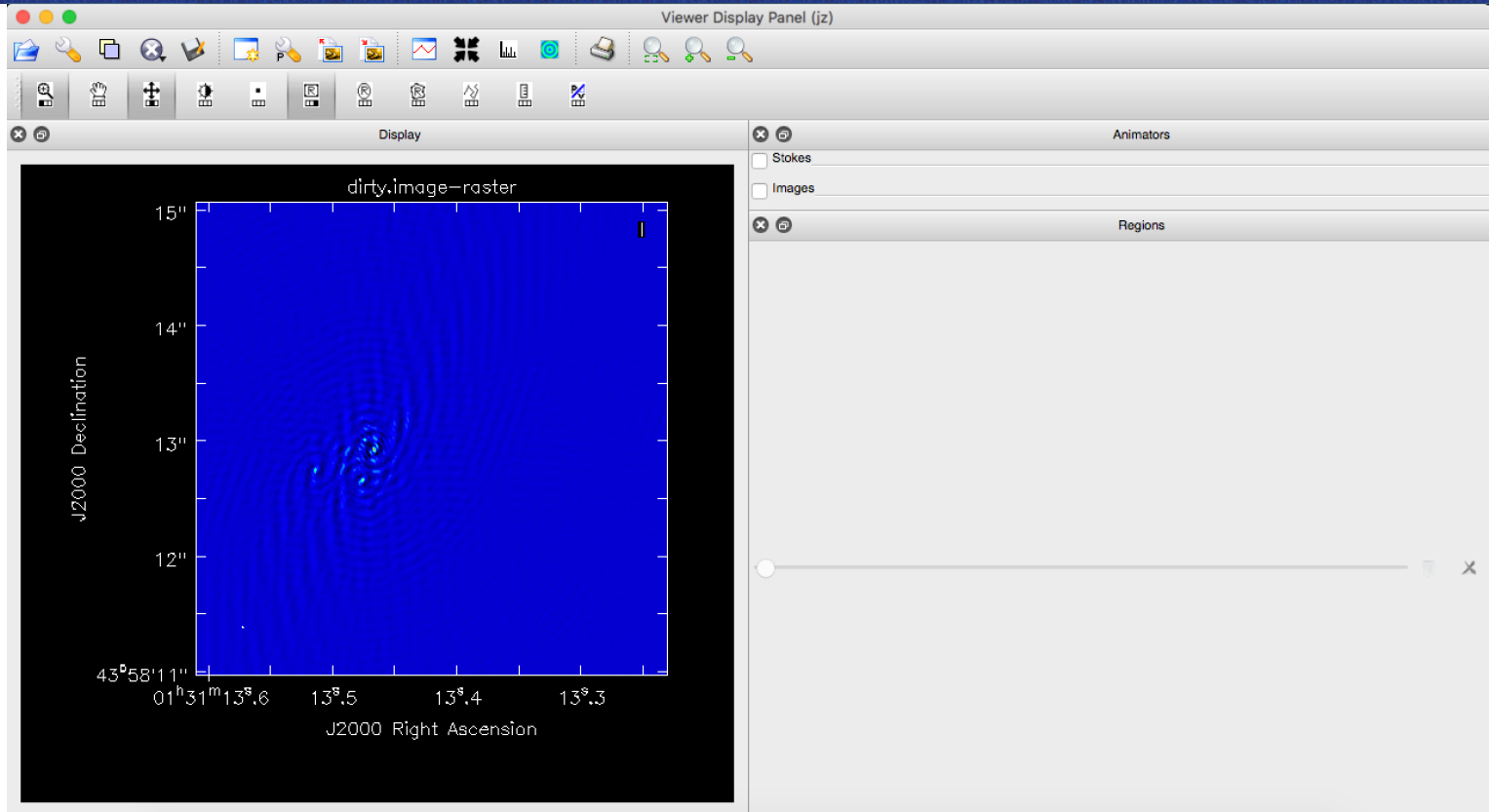
This is the **dirty image**

This target is a jetted AGN that is gravitationally lensed into 4 images



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Graphic interface: Viewer

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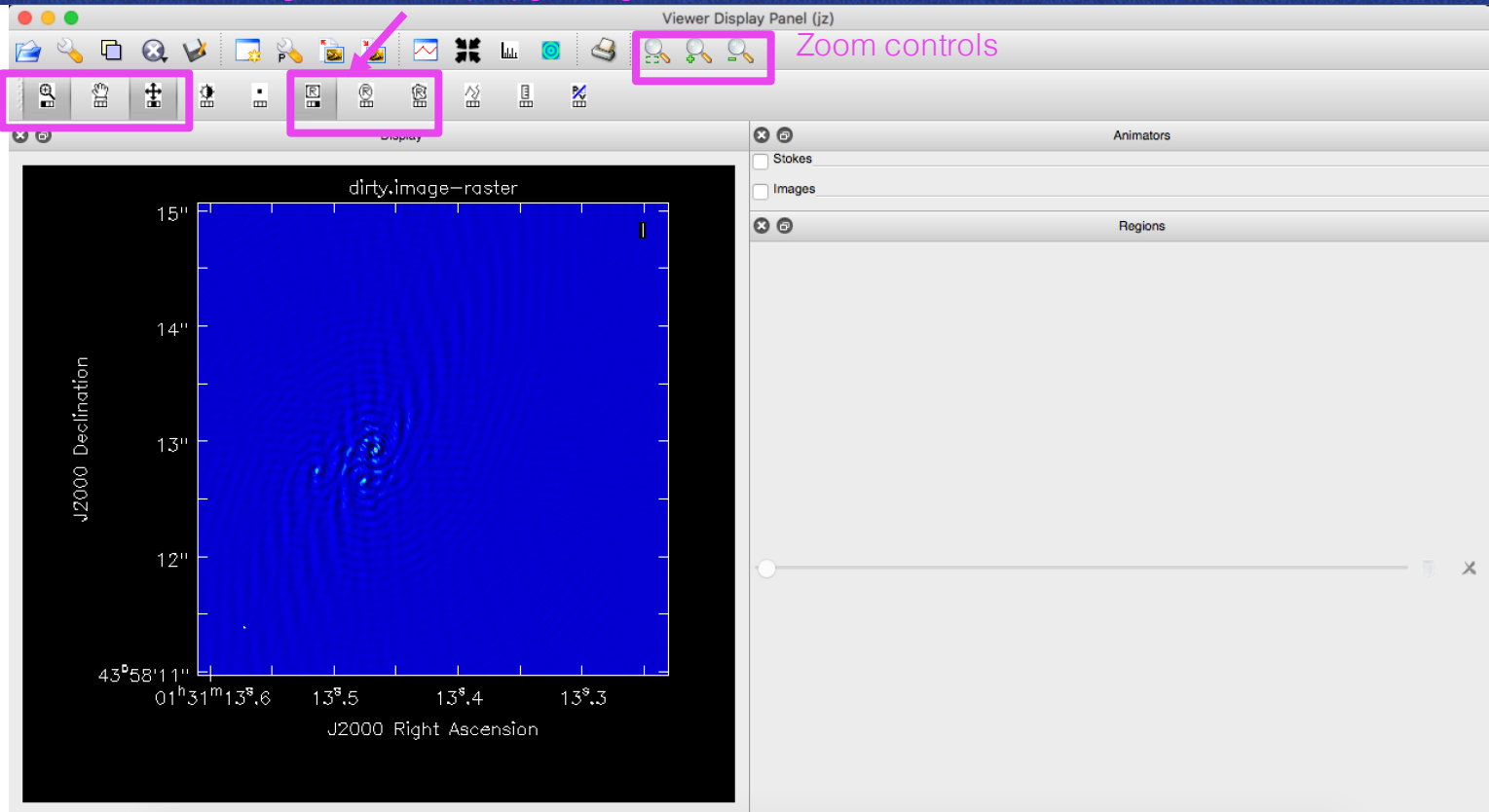
Draw rectangular, oval or polygon regions

Zoom controls

Zoom/move the image



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Graphic interface: Viewer

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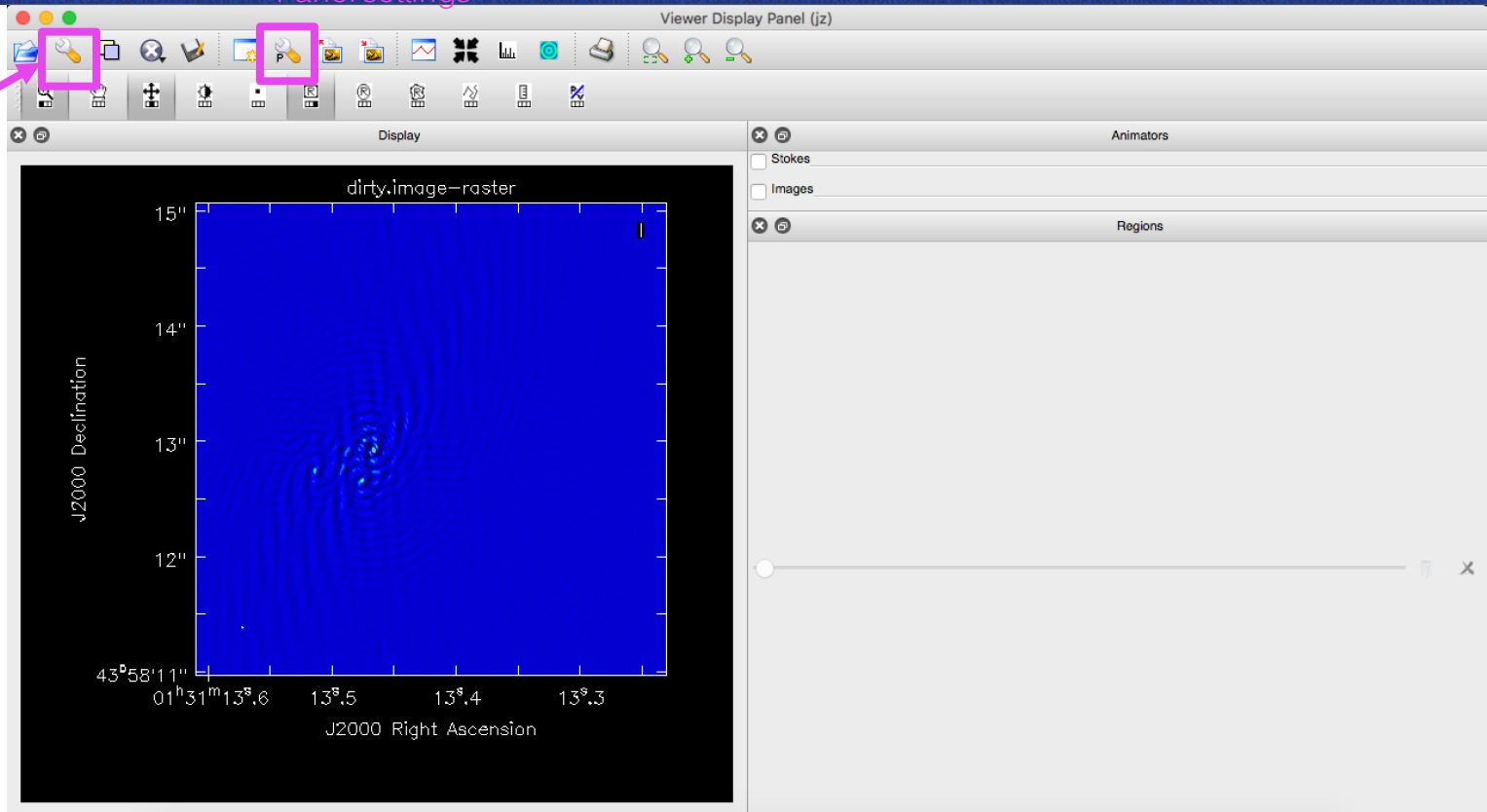
Panel settings

Image settings!!



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Graphic interface: Viewer

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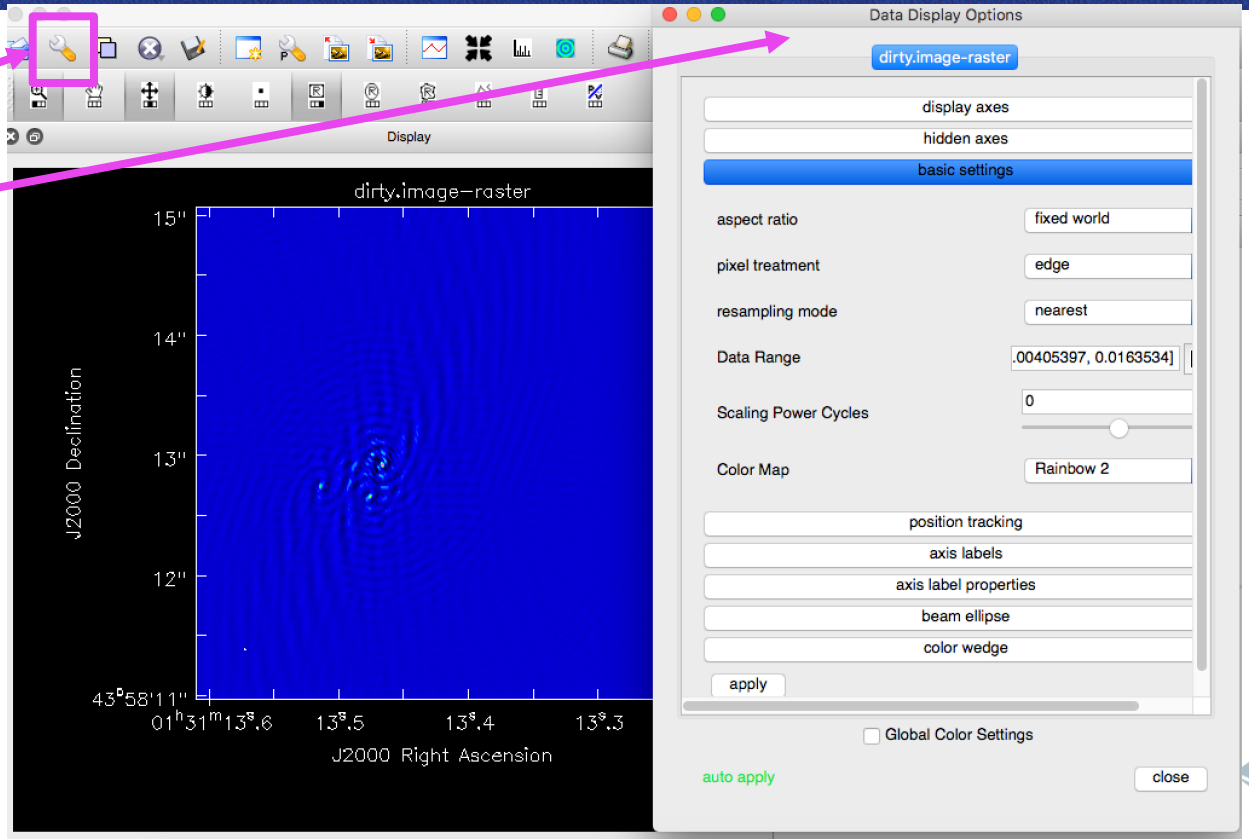
Image settings!!



Graphic interface: Viewer

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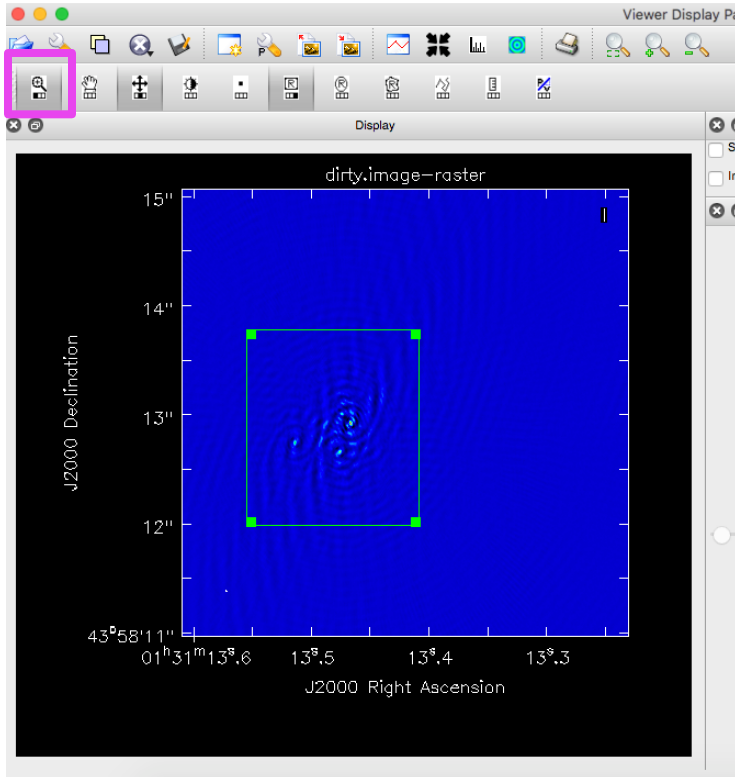
The source is not at the phase center:
Let's zoom on the source

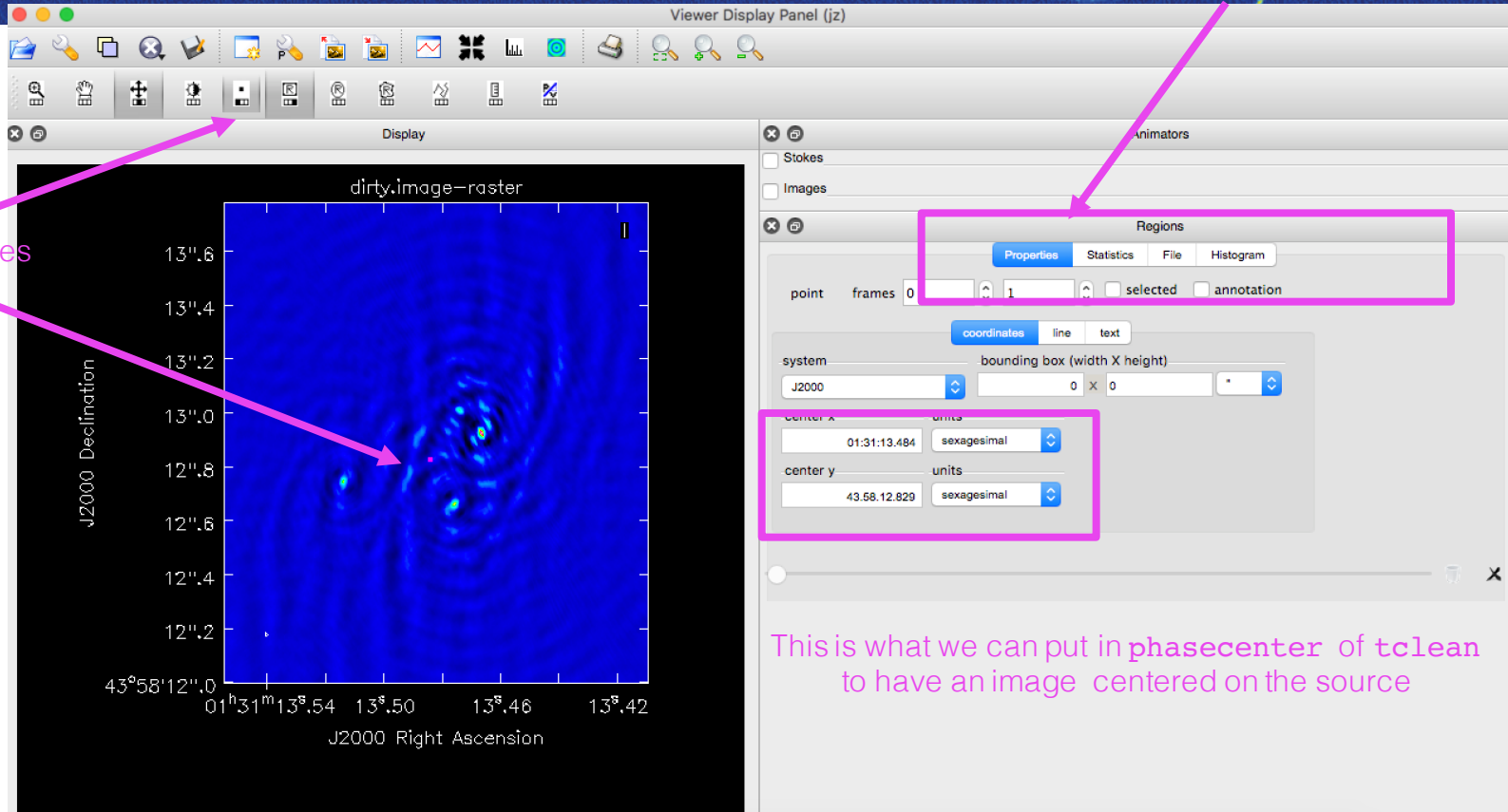


CASA VLBI

Graphic interface: Viewer

Select PROPERTIES
(if there isn't, go to the top menu and select **view → regions**)

Point button
To get the coordinates at the centre of the lensed images



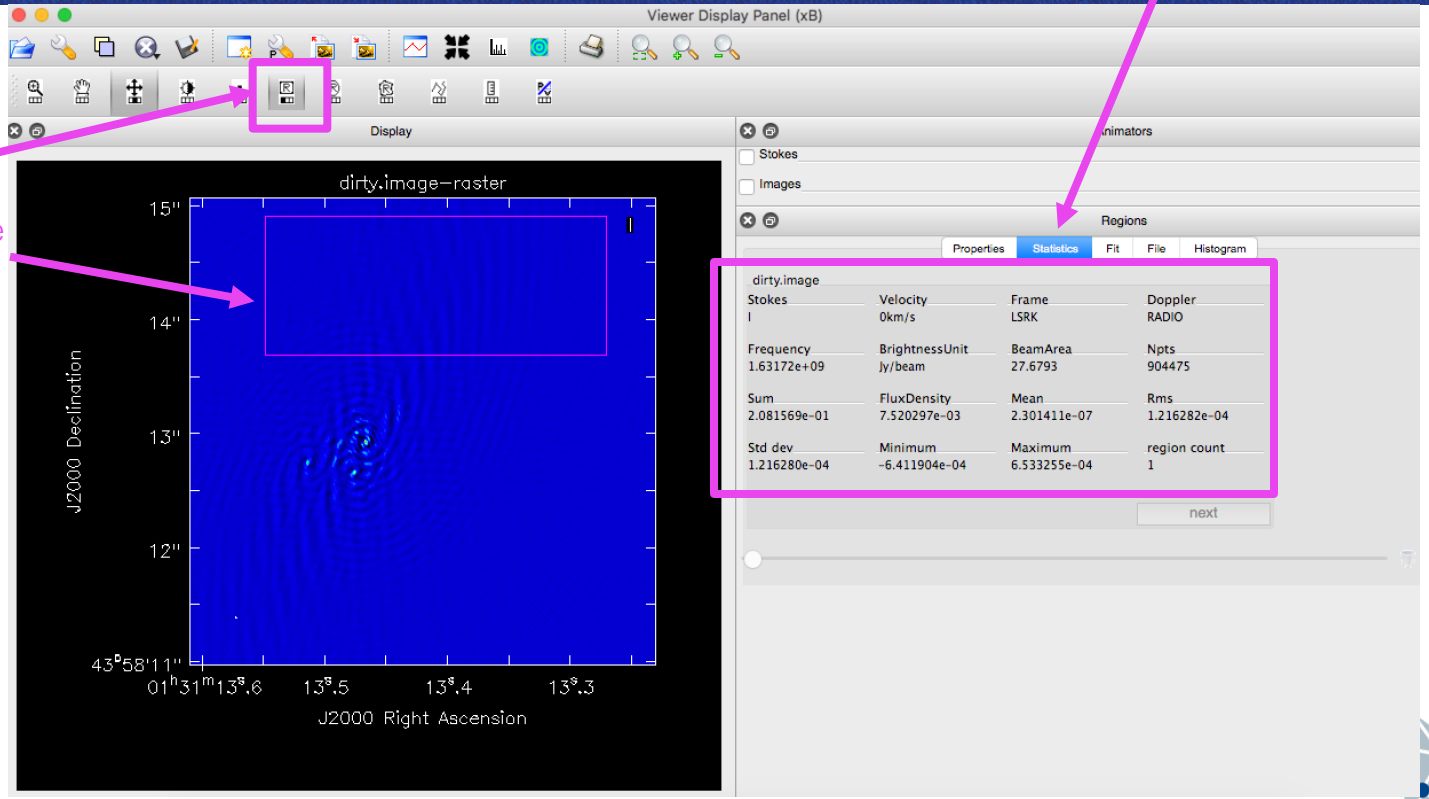
This is what we can put in `phasecenter` of `tclean` to have an image centered on the source

CASA VLBI

Graphic interface: Viewer

STATISTICAL PROPERTIES OF THAT REGION
Click on “statistics” in the “Regions” box

Draw a region in the image and check its properties



CASA VLBI

Make a cleaned image

Lecture #8
Cristiana Spingola
@spingola in mattermost

```
vis                 = 'b0128.calibrated.ms/' #  Name of input visibility file(s
)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

     datacolumn     =     'data'        #  Data column to image(data,corrected)
     imagename      = 'clean.nat'       #  Pre-name of output images
     imsize         =     [2048]        #  Number of pixels
     cell           = ['0.002arcsec']   #  Cell size
                                        #  Phase center of the image
     stokes         =        'I'        #  Stokes Planes to make
     projection     =      'SIN'        #  Coordinate projection (SIN, HPX)
     startmodel     =         ''        #  Name of starting model image
     specmode       =      'mfs'        #  Spectral definition mode
                                        #   (mfs,cube,cubedata, cubesource)
     reffreq        =         ''        #  Reference frequency

     gridder        = 'standard'        #  Gridding options (standard, wproject,
                                        #   widefield, mosaic, awproject)
     vptable        =         ''        #  Name of Voltage Pattern table
     pblimit        =        0.2        #  >PB gain level at which to cut off
                                        #   normalizations

     deconvolver    =   'hogbom'        #  Minor cycle algorithm (hogbom,clark,m
                                        #   ultiscale,mtmfs,mem,clarkstokes)
     restoration    =       True        #  Do restoration steps (or not)
     restoringbeam  =         []        #  Restoring beam shape to use. Default
                                        #   is the PSF main lobe
     pbcor          =      False        #  Apply PB correction on the output
                                        #   restored image

     outlierfile    =         ''        #  Name of outlier-field image
                                        #   definitions
     weighting      =  'natural'        #  Weighting scheme
                                        #   (natural,uniform,briggs)
     uvtaper        =         []        #  uv-taper on outer baselines in uv-
```

```
niter               =     100000        #  Maximum number of iterations
     gain           =        0.1        #  Loop gain
     threshold      =        0.0        #  Stopping threshold
     nsigma         =        0.0        #  Multiplicative factor for rms-based
                                        #   threshold stopping
     cycleniter     =         -1        #  Maximum number of minor-cycle
                                        #   iterations
     cyclefactor    =        1.0        #  Scaling on PSF sidelobe level to
                                        #   compute the minor-cycle stopping
                                        #   threshold.
     minpsffraction =       0.05        #  PSF fraction that marks the max depth
                                        #   of cleaning in the minor cycle
     maxpsffraction =        0.8        #  PSF fraction that marks the minimum
                                        #  depth of cleaning in the minor cycle
     interactive    =       True        #  Modify masks and parameters at
                                        #  runtime

usemask             =     'user'        #  Type of mask(s) for deconvolution:
                                        #   user, pb, or auto-multithresh
     mask           =         ''        #  Mask (a list of image name(s) or
                                        #   region file(s) or region string(s) )
     pbmask         =        0.0        #  primary beam mask

restart             =       True        #  True : Re-use existing images. False
                                        #   : Increment imagename
savemodel           =     'none'        #  Options to save model visibilities
                                        #   (none, virtual, modelcolumn)
calcres             =       True        #  Calculate initial residual image
calcpsf             =       True        #  Calculate PSF
parallel            =      False        #  Run major cycles in parallel
```

Make a cleaned image

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Check the logger!

Here you can read your inputs

Creating the beam: here you can see your beam size

```
##########################################
##### Begin Task: tclean              #####
tclean(vis="b0128.calibrated.ms/",selectdata=True,field="",spw="",timerange="",
       uvrange="",antenna="",scan="",observation="",intent="",
       datacolumn="data",imagename="clean.nat",imsize=[2048],cell=['0.002arcsec'],phasecenter="",
       stokes="I",projection="SIN",startmodel="",specmode="mfs",reffreq="",
       nchan=-1,start="",width="",outframe="LSRK",veltype="radio",
       restfreq=[],interpolation="linear",gridder="standard",facets=1,chanchunks=1,
       wprojplanes=1,vptable="",usepointing=False,mosweight=True,aterm=True,
       psterm=False,wbawp=True,conjbeams=True,cfcache="",computepastep=360.0,
       rotatepastep=360.0,pblimit=0.2,normtype="flatnoise",deconvolver="hogbom",scales=[],
       nterms=2,smallscalebias=0.6,restoration=True,restoringbeam=[],pbcor=False,
       outlierfile="",weighting="natural",robust=0.5,npixels=0,uvtaper=[],
       niter=100000,gain=0.1,threshold=0.0,nsigma=0.0,cycleniter=-1,
       cyclefactor=1.0,minpsffraction=0.05,maxpsffraction=0.8,interactive=True,usemask="user",
       mask="",pbmask=0.0,sidelobethreshold=3.0,noisethreshold=5.0,lownoisethreshold=1.5,
       negativethreshold=0.0,smoothfactor=1.0,minbeamfrac=0.3,cutthreshold=0.01,growiterations=75,
       dogrowprune=True,minpercentchange=-1.0,verbose=False,restart=True,savemodel="none",
       calcres=True,calcpsf=True,parallel=False)
Verifying Input Parameters
MS : b0128.calibrated.ms/ | [Opened in readonly mode]
  NRows selected : 256096
Leap second table TAI_UTC seems out-of-date.
Until the table is updated (see the CASA documentation or your system admin),
times and coordinates derived from UTC could be wrong by 1s or more.
Define image coordinates for [clean.nat] :
Impars : start
Shape : [2048, 2048, 1, 1]Spectral : [1.63172e+09] at [0] with increment [2.55996e+08]
Set Gridding options for [clean.nat] with ftmachine : gridft
Set imaging weights : Natural weighting
Set Deconvolution Options for [clean.nat] : hogbom
Set Iteration Control Options
------------------------------------------------------------ Make PSF ------------------------------
[clean.nat] Theoretical sensitivity (Jy/bm):0.0311187
Beam : 0.0121181 arcsec, 0.00806336 arcsec, 8.29284 deg
PBMath init to Airy scaled to diameter = 25
vi2 : Evaluating Primary Beam model onto image grid(s)
------------------------------------------------------------ Run Major Cycle 1 ---------------------
```

Make a cleaned image

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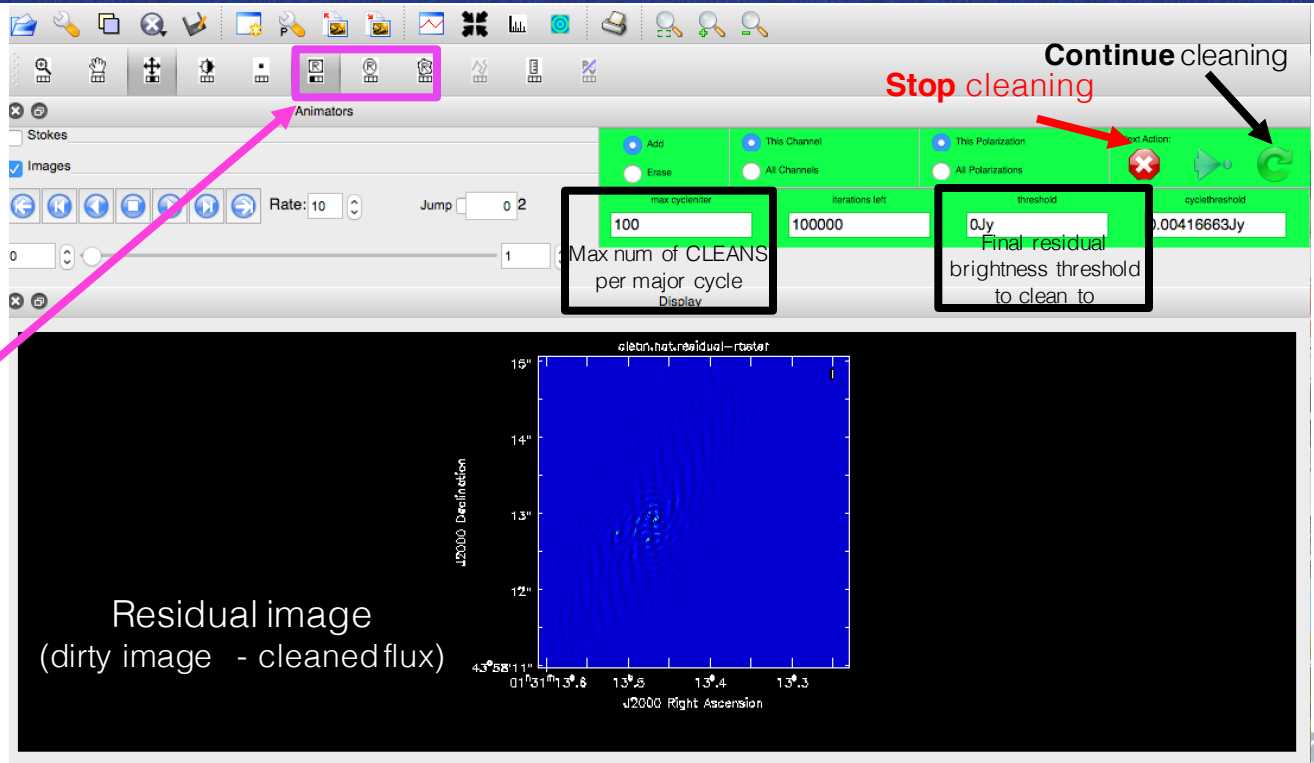
@spingola in mattermost

A viewer window opens

As this is the first step of cleaning, therefore this corresponds to the dirty image

Use the regions to create the mask (double click in the image to create the region)

Note: we create a mask to help and speed up the deconvolution process



CASA VLBI

CLEANing stopping criteria

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- Number of iterations (not the best criterion as you may end up doing too much or too little cleaning)
- Negative peak identified
- Smallest peak identified below a threshold – which can be noise-based (e.g. 3 x rms)
- Visually = when your residuals contain only noise – this means that you cleaned all the flux density of the source

Make a cleaned image

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Check the logger!

```
---------------------------------------------------------- Make PSF ----------------------------------------------
[clean.nat] Theoretical sensitivity (Jy/bm):0.0311187
Beam : 0.0121181 arcsec, 0.00806336 arcsec, 8.29284 deg
PBMath init to Airy scaled to diameter = 25
vi2 : Evaluating Primary Beam model onto imag
---------------------------------------------------------- Run Major Cycle 1 ----------------------------------------
[clean.nat] Peak residual (max,min) over full
[clean.nat] Total Model Flux : 0
[clean.nat] Initializing new mask to 0.0 for interactive drawing
[clean.nat] Number of pixels in the clean mask : 0 out of a total of 4.1943e+06 pixels. [ 0 % ]
[clean.nat.mask] Mask modified from 0 pixels to 737 pixels
[clean.nat] Mask changed interactively.
[clean.nat] Peak residual (max,min) within mask : (0.0163534,0) over full image : (0.0163534,-0.00405397)
[clean.nat] Total Model Flux : 0
---------------------------------------------------------- Run Minor Cycle Iterations ---------------------------------
[clean.nat] Run Hogbom minor-cycle | CycleThreshold=0.00416663, CycleNiter=100, Gain=0.1
[clean.nat] iters=0->39 [39], model=0->0.0282109, peakres=0.0163534->0.00416491, Reached cyclethreshold.
Completed 39 iterations.
---------------------------------------------------------- Run Major Cycle 2 ----------------------------------------
[clean.nat.mask] Mask modified from 737 pixels
[clean.nat] Mask changed interactively.
[clean.nat] Peak residual (max,min) within mask : (0.0041649,0) over full image : (0.0041649,-0.00234448)
[clean.nat] Total Model Flux : 0.0282109
---------------------------------------------------------- Run Minor Cycle Iterations ---------------------------------
[clean.nat] Run Hogbom minor-cycle | CycleThreshold=0.00106116, CycleNiter=100, Gain=0.1
[clean.nat] iters=0->100 [100], model=0.0282109->0.0526445, peakres=0.0041649->0.00147647, Reached cycleniter.
Completed 139 iterations.
---------------------------------------------------------- Run Major Cycle 3 ----------------------------------------
[clean.nat.mask] Mask modified from 1281 pixels
[clean.nat] Mask changed interactively.
[clean.nat] Peak residual (max,min) within mask : (0.00147648,-2.16617e-05) over full image : (0.00147648,-0.0012918
[clean.nat] Total Model Flux : 0.0526445
---------------------------------------------------------- Run Minor Cycle Iterations ---------------------------------
[clean.nat] Run Hogbom minor-cycle | CycleThreshold=0.000376187, CycleNiter=100, Gain=0.1
[clean.nat] iters=0->100 [100] model=0.0526445->0.0635712, peakres=0.00147648->0.000804764, Reached cycleniter.
Completed 239 iterations.
---------------------------------------------------------- Run Major Cycle 4 ----------------------------------------
```

Make a cleaned image

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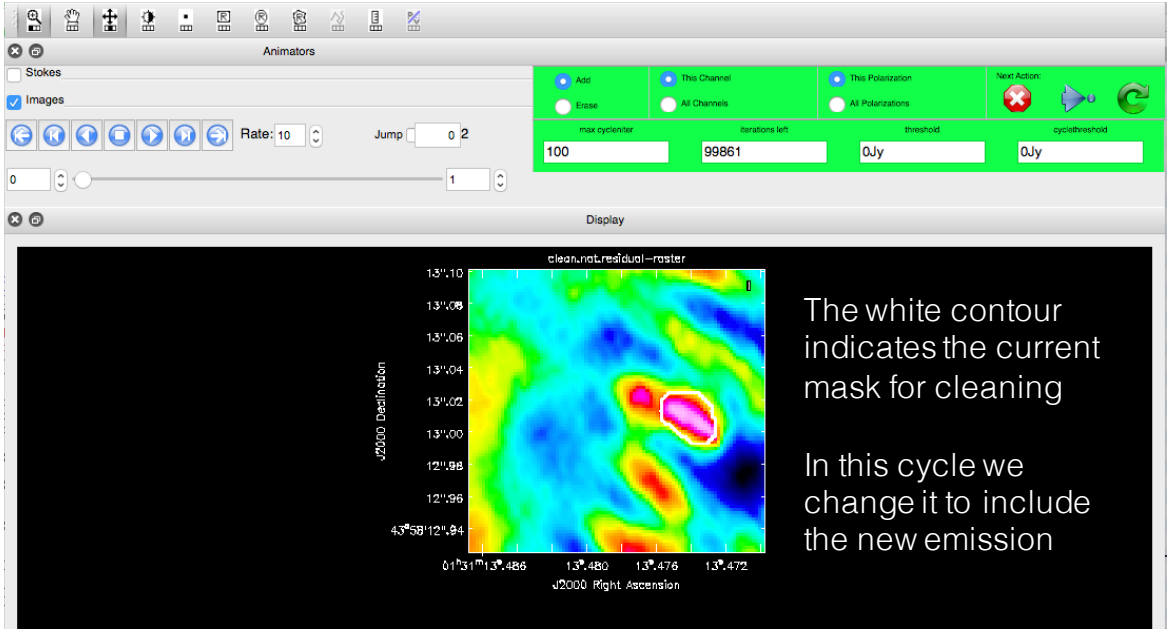
Example
new emission at lower surface brightness comes out while doing interactive cleaning:

add a box on the new emission and continue cleaning



The white contour indicates the current mask for cleaning

In this cycle we change it to include the new emission

TIPS
The flux density in the logger should be always increase (as shown in a previous slide)
Change the mask if you are cleaning a negative region of the image (no boxes on negative areas!!)

Make a cleaned image

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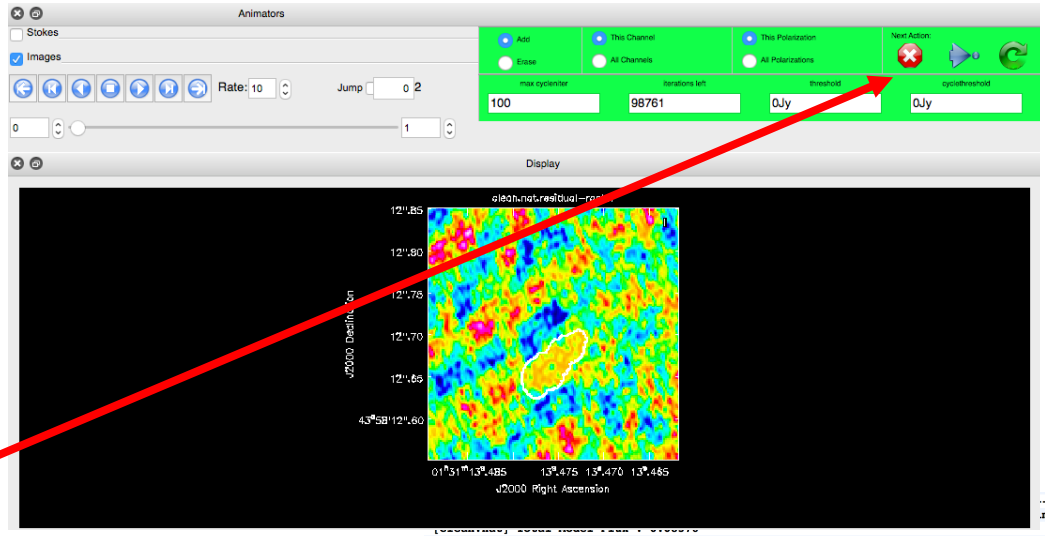
Example

The surface brightness within the mask (white contours) is lower than that outside the mask:

this can be a good moment to **stop** cleaning




```
                                                                    mage : (0.000194478,-0.000208889)
[clean.nat] Run Hogbom minor-cycle | CycleThreshold=2.12191e-05, CycleNiter=100, Gain=0.1
[clean.nat] iters=0->100 [100], model=0.08376->0.0843901, peakres=8.32817e-05->7.25854e-05, Reached cycleniter.
Completed 1139 iterations.
[clean.nat] Peak residual (max,min) within mask : (7.23531e-05,-7.25853e-05) over full image : (0.000191027,-0.000203992)
[clean.nat] Total Model Flux : 0.0843901
[clean.nat] Run Hogbom minor-cycle | CycleThreshold=1.84938e-05, CycleNiter=100, Gain=0.1
[clean.nat] iters=0->100 [100], model=0.0843901->0.0849047, peakres=7.25853e-05->6.40383e-05, Reached cycleniter.
Completed 1239 iterations.
[clean.nat] Peak residual (max,min) within mask : (6.40383e-05,-6.32947e-05) over full image : (0.000188163,-0.000200224)
[clean.nat] Total Model Flux : 0.0849047
Reached global stopping criterion : force stop
[clean.nat] : Restoring model image.
Beam for chan : 0 : 0.0121181 arcsec, 0.00806336 arcsec, 8.29284 deg
##### End Task: tclean                  #####
########################################
```

CASA VLBI

Inspect CLEANed image &co.

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.image	restored (CLEANed) image
.mask	mask used during cleaning (your regions)
.model	model = clean components
.pb	primary beam
.psf	point spread function (dirty beam)
.residual	residual image (data-model)
.sumwt	single px image containing sum of the weights

We can take a look at them using the task VIEWER

(Select the image → Raster image → Use the arrows in the box "Animators" to see each of them)

Inspect CLEANed image &co.

Lecture #8
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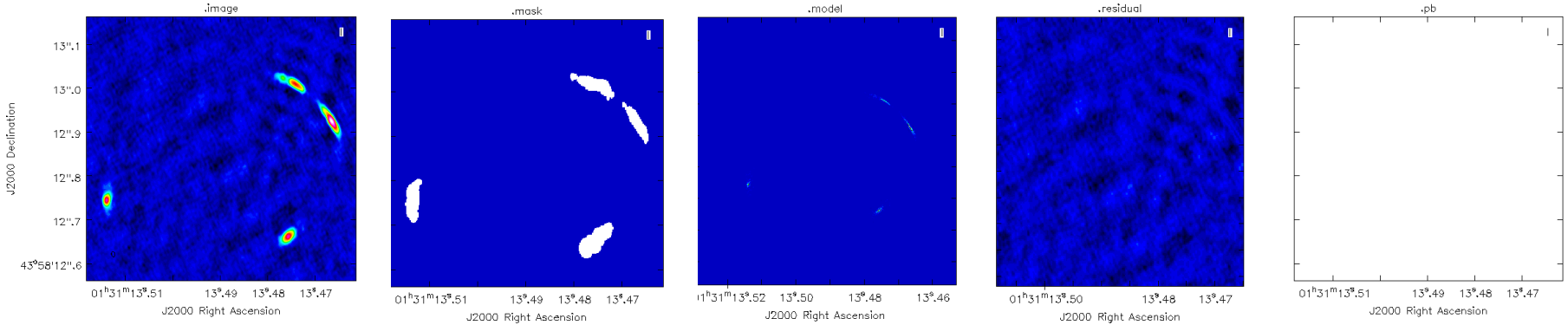
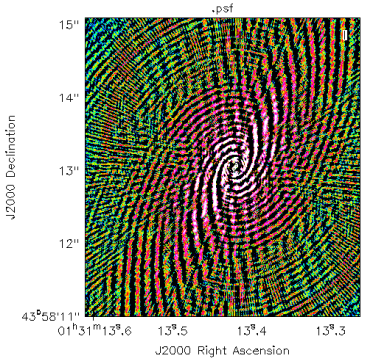


.image	restored (CLEANed) image
.mask	mask used during cleaning (your regions)
.model	model = clean components
.pb	primary beam (empty because no PB correction has been applied)
.psf	point spread function (dirty beam)
.residual	residual image (data-model)
.sumwt	single px image containing sum of the weights



Inspect CLEANed image &co.

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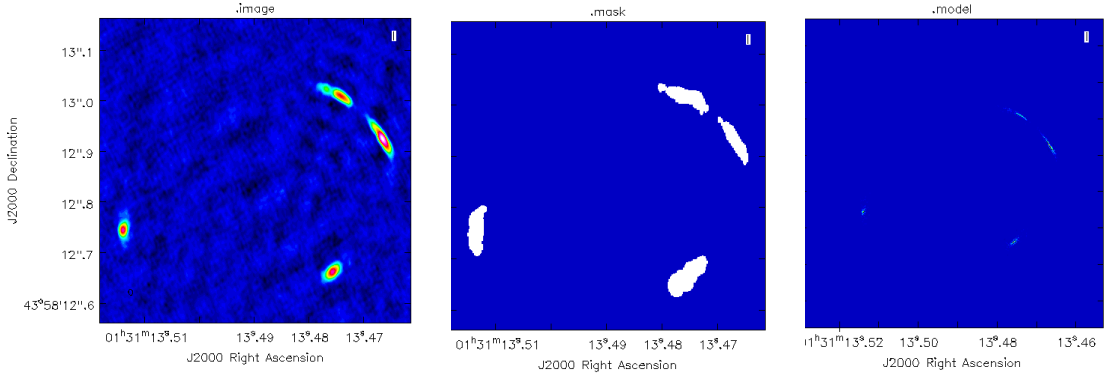
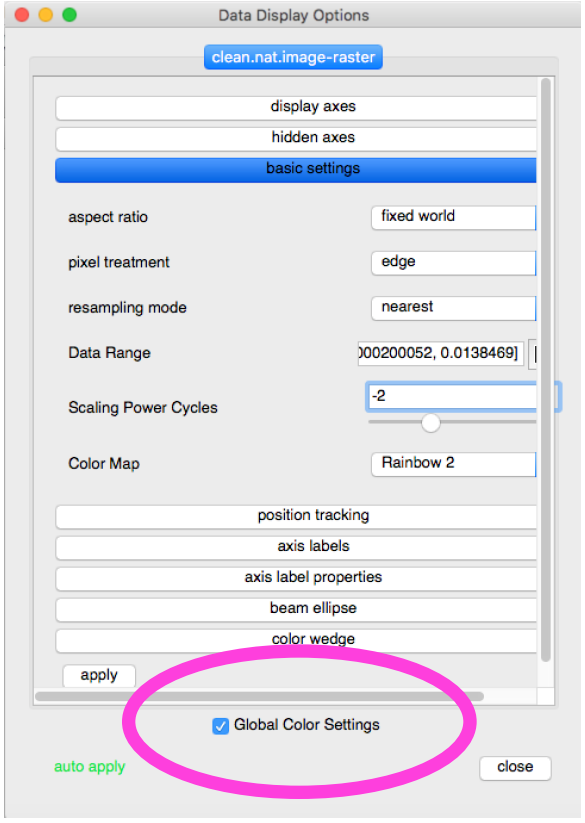


Put all images on the same scale
(e.g. that of the clean.image)
to make a proper comparison
selecting "**Global Color Settings**"
in the "Data display options



CASA VLBI

Inspect CLEANed image &co.

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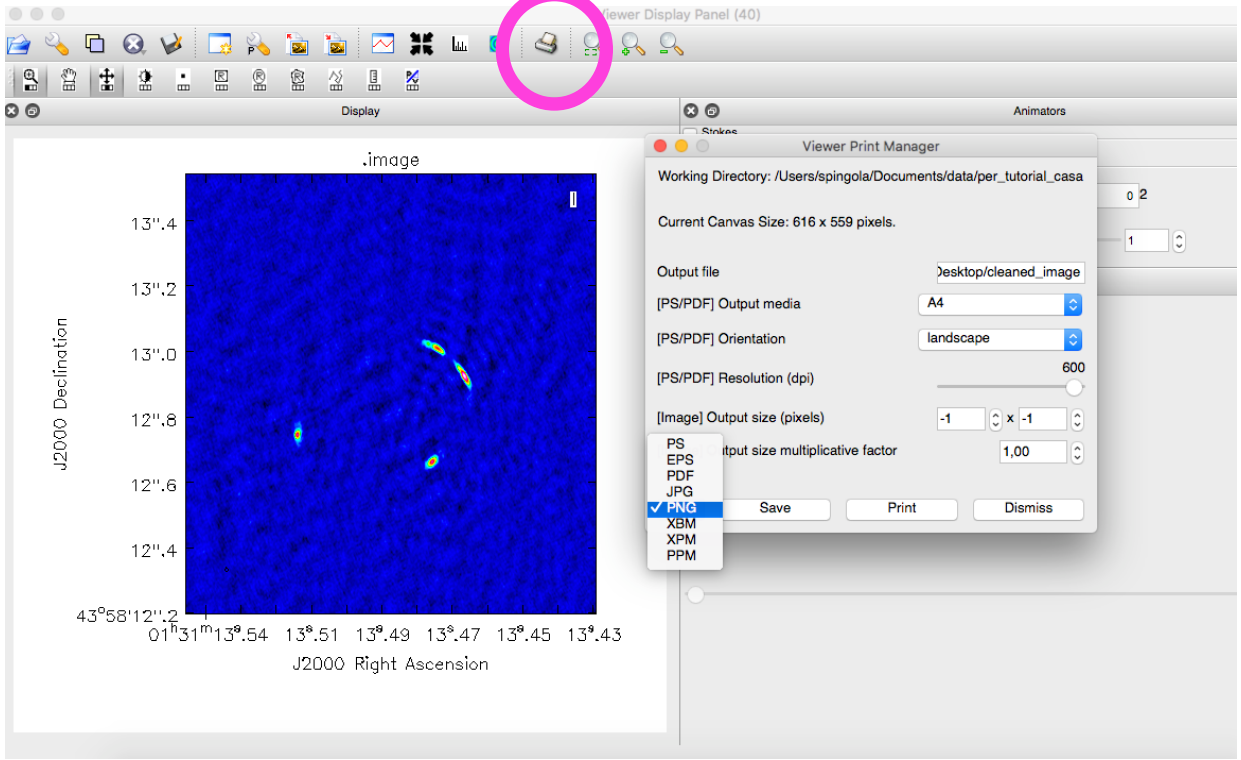
To save the image
you can use the button
“Print” and choose location and
format of your hard copy



CASA VLBI

Inspect CLEANed image &co.

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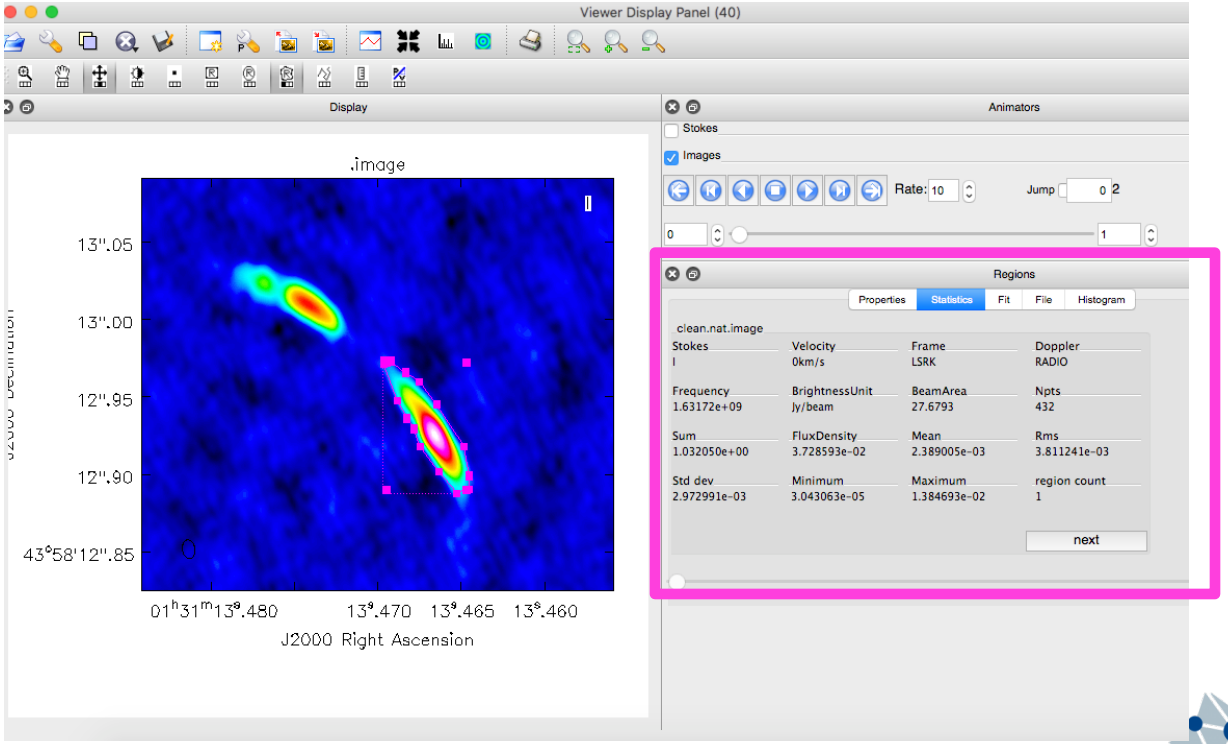
Draw a region in the image and check its properties

For example: we can draw a Polygon to inspect the properties of the brightest lensed image



Export your images as FITS files

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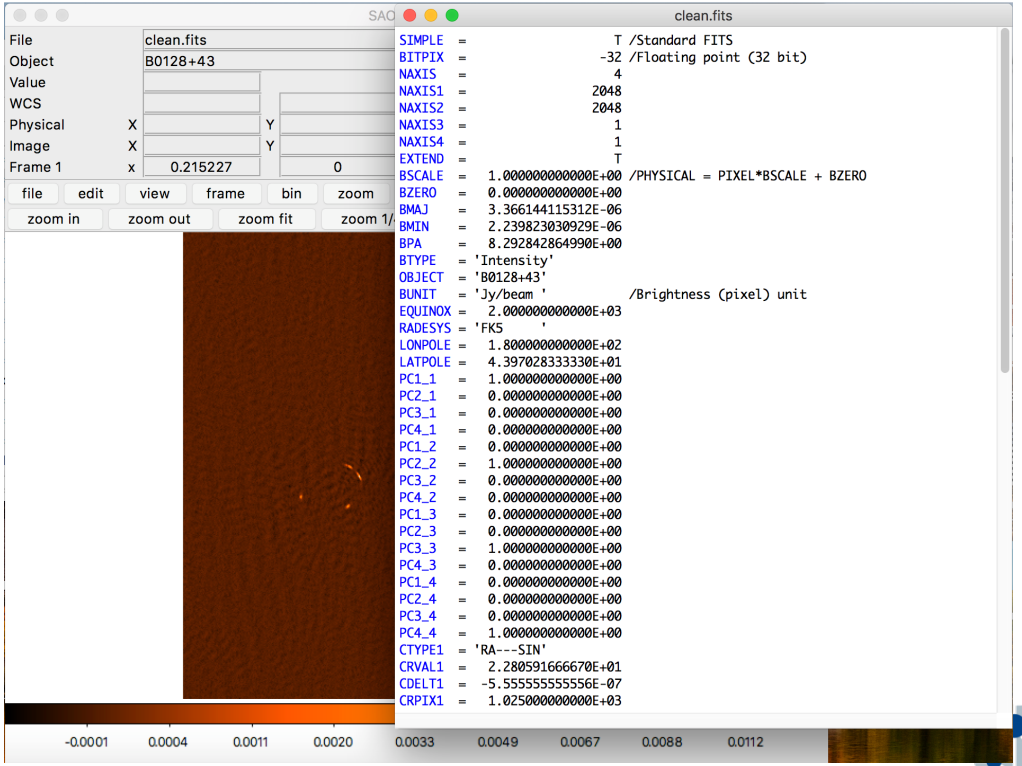
```
#  exportfits :: Convert a CASA image to a FITS file
imagename           =         ''         #  Name of input CASA image
fitsimage           =         ''         #  Name of output image FITS file
velocity            =      False         #  Use velocity (rather than frequency)
                                         #   as spectral axis
optical             =      False         #  Use the optical (rather than radio)
                                         #   velocity convention
bitpix              =        -32         #  Bits per pixel
minpix              =          0         #  Minimum pixel value (if minpix >
                                         #   maxpix, value is automatically
                                         #   determined)
maxpix              =         -1         #  Maximum pixel value (if minpix >
                                         #   maxpix, value is automatically
                                         #   determined)
overwrite           =      False         #  Overwrite pre-existing imagename
dropstokes          =      False         #  Drop the Stokes axis?
stokeslast          =       True         #  Put Stokes axis last in header?
history             =       True         #  Write history to the FITS image?
dropdeg             =      False         #  Drop all degenerate axes (e.g. Stokes
                                         #   and/or Frequency)?
```

If you prefer to visualize your images using other tools, you can export them as FITS files using the task **EXPORTFITS**

Note that the VLBI images can have the keyword NAXIS = 4, which is an issue for some plotting python modules. You can just drop the stoke axis using **dropstokes = True** (also **dropdeg = True)**



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JUMPING JIVE
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RadioNet

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