ALMA Imaging

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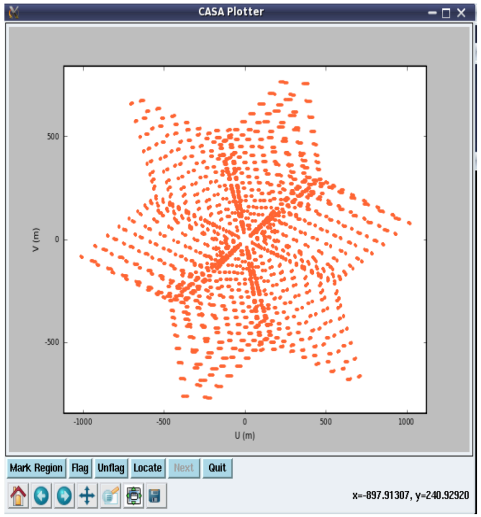
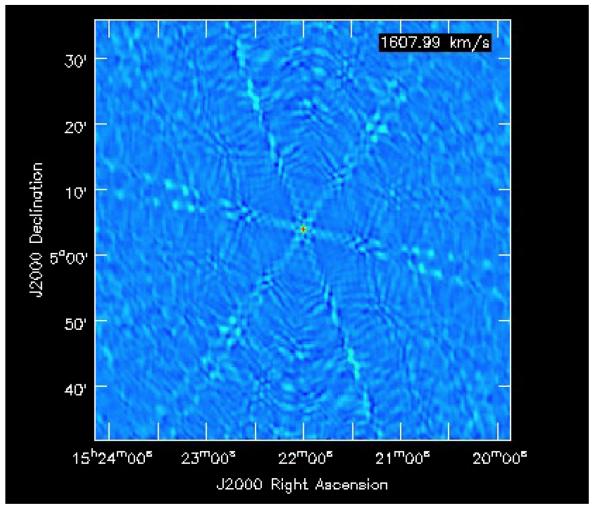
Allegro

ALMA CASA Tutorial day – 3 March 2017

What do we do with the calibrated visibilities?

$$V_{obs}(u,v) \xrightarrow{FT^{-1}} I_{dirty\_model}(x,y)$$





CLEAN: Replace the dirty psf by a 'cleaned' psf without sidelobes

$$I_{dirty\_model}(x,y) \rightarrow I_{clean\_model}(x,y) \sim I_{true}(x,y)$$

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Data Inspection

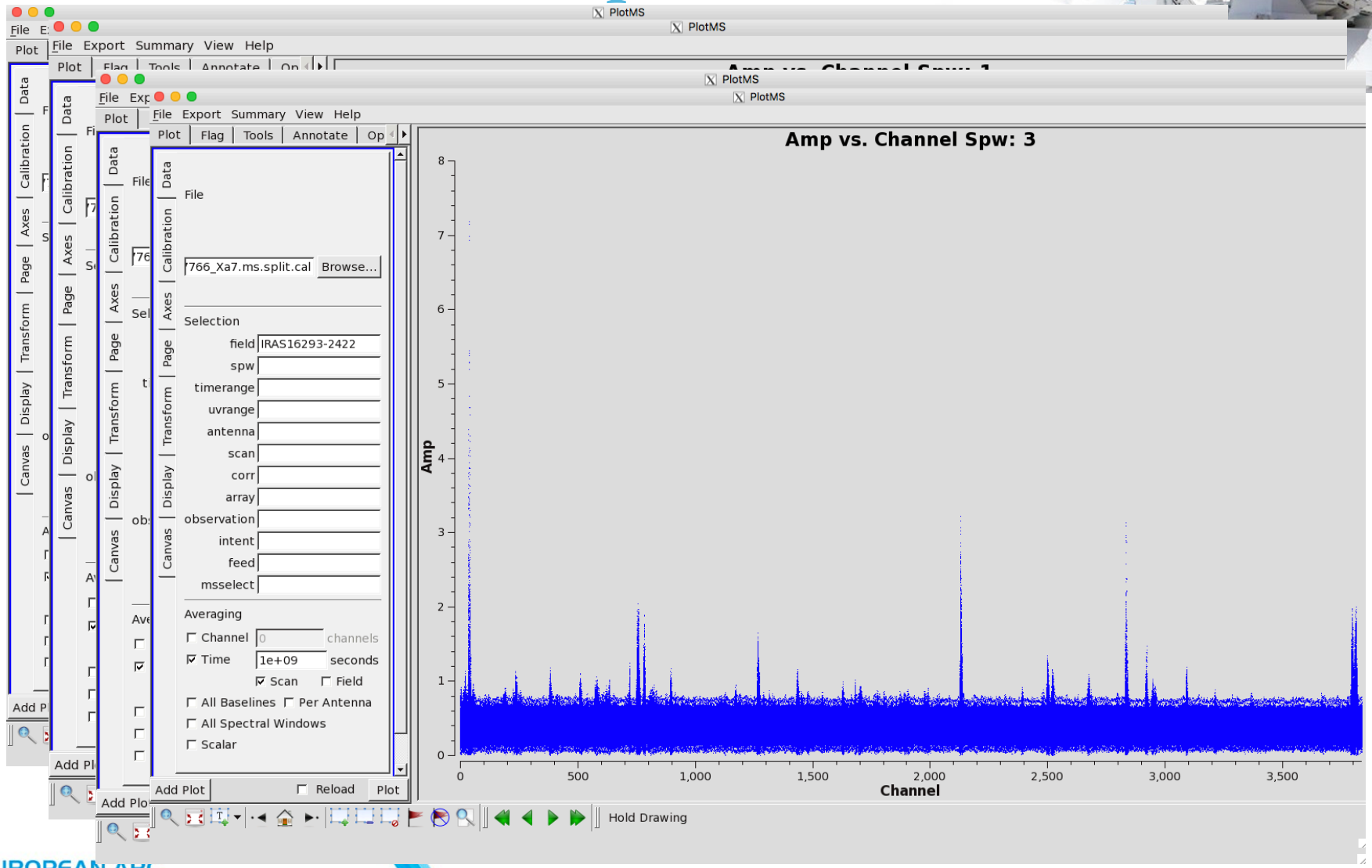
- Input: calibrated ms
  - data=calibrated.ms
- Listobs
  - listobs(data, listfile='calibrated.listobs')
- Plotms
  - plotms(vis=data, spw='', xaxis='frequency', yaxis='amp', avgtime='1e8', avgscan=T, iteraxis='spw', xselfscale=T)

Data Inspection: Listobs

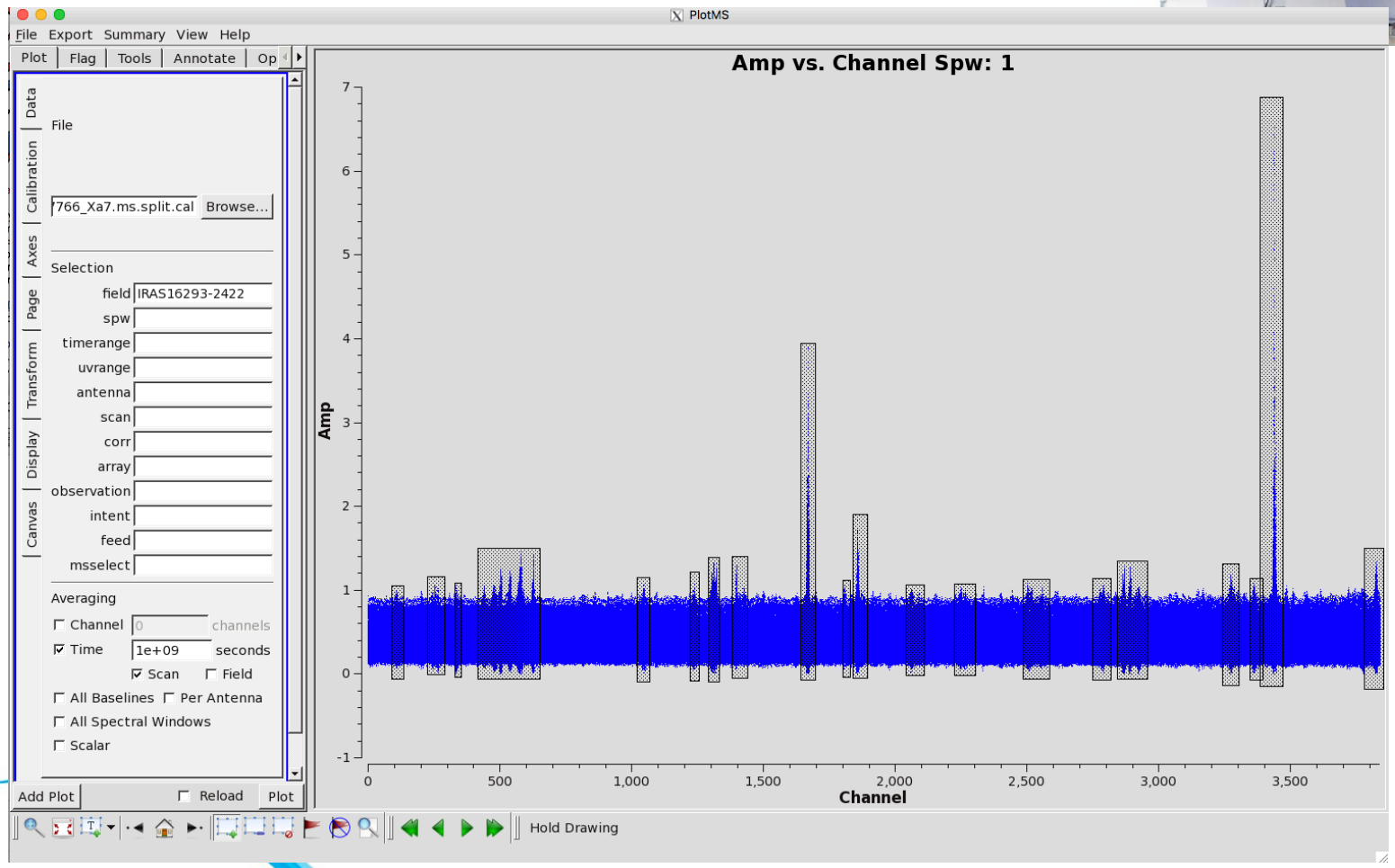
```
================================================================================
           MeasurementSet Name:  /lustre/allegro/data/projects/BAXM80vX/analysis/ycontreras/20XX.1.0XXXX.S/sg_ouss_id/group_ouss_id/member_ouss_id/calibrated/uid___A002_X867766_Xa7.ms.split.cal      MS Version 2
================================================================================
   Observer: satoko     Project: uid://A002/X8666bf/Xc
Observation: ALMA
Data records: 816960       Total elapsed time = 5192.88 seconds
   Observed from   11-Jul-2014/04:01:40.1   to   11-Jul-2014/05:28:13.0 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  11-Jul-2014/04:01:40.1 - 04:06:56.8     4      0 J1700-2610              55200  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:07:35.6 - 04:10:13.4     6      1 J1517-243               27600  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_FLUX#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:10:31.3 - 04:11:01.6     7      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:11:36.5 - 04:17:56.8     9      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:18:10.1 - 04:18:40.4    10      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:18:56.3 - 04:25:16.6    11      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:25:33.0 - 04:26:03.3    12      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:26:37.0 - 04:32:57.2    14      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:33:17.5 - 04:33:47.8    15      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:34:03.9 - 04:40:24.2    16      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:40:37.2 - 04:41:07.5    17      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:41:46.9 - 04:48:07.2    19      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:48:20.3 - 04:48:50.5    20      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:49:06.5 - 04:55:26.7    21      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              04:55:40.0 - 04:56:10.3    22      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              04:56:45.0 - 05:03:05.3    24      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              05:03:25.3 - 05:03:55.6    25      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              05:04:12.9 - 05:10:33.2    26      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              05:10:46.4 - 05:11:16.6    27      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              05:11:57.0 - 05:18:17.2    29      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              05:18:30.8 - 05:19:01.0    30      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              05:19:17.2 - 05:25:37.4    31      3 IRAS16293-2422          66240  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              05:25:50.7 - 05:26:20.9    32      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              05:26:57.3 - 05:27:27.5    34      3 IRAS16293-2422           5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              05:27:42.8 - 05:28:13.0    35      2 J1625-2527               5520  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
           (nRows = Total number of rows per scan)
Fields: 4
  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
  0    none J1700-2610          17:00:53.154060 -26.10.51.72530 J2000   0          55200
  1    none J1517-243           15:17:41.813132 -24.22.19.47608 J2000   1          27600
  2    none J1625-2527          16:25:46.891640 -25.27.38.32690 J2000   2          66240
  3    none IRAS16293-2422      16:32:22.735600 -24.28.32.50000 J2000   3         667920
Spectral Windows:  (4 unique spectral windows and 1 unique polarization setups)
  SpwID  Name                          #Chans   Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
  0      ALMA_RB_04#BB_1#SW-01#FULL_RES   3840   TOPO  156833.170       122.070    468750.0 157067.4843        1  XX  YY
  1      ALMA_RB_04#BB_2#SW-01#FULL_RES   3840   TOPO  157286.899       488.281   1875000.0 158224.1547        2  XX  YY
  2      ALMA_RB_04#BB_3#SW-01#FULL_RES   3840   TOPO  147236.910       -61.035    234375.0 147119.7531        3  XX  YY
  3      ALMA_RB_04#BB_4#SW-01#FULL_RES   3840   TOPO  146981.861      -488.281   1875000.0 146044.6047        4  XX  YY
Sources: 16
  ID   Name                SpwId RestFreq(MHz)  SysVel(km/s)
  0    J1700-2610          0     157052.295     0
  0    J1700-2610          1     158230         0
  0    J1700-2610          2     147103.902     0
  0    J1700-2610          3     146050         0
  1    J1517-243           0     157052.295     0
  1    J1517-243           1     158230         0
  1    J1517-243           2     147103.902     0
  1    J1517-243           3     146050         0
  2    J1625-2527          0     157052.295     0
  2    J1625-2527          1     158230         0
  2    J1625-2527          2     147103.902     0
  2    J1625-2527          3     146050         0
  3    IRAS16293-2422      0     157052.295     3
  3    IRAS16293-2422      1     158230         3
  3    IRAS16293-2422      2     147103.902     3
  3    IRAS16293-2422      3     146050         3
```

Data Inspection: plotms



Data Inspection: Identifying Line-Free channels



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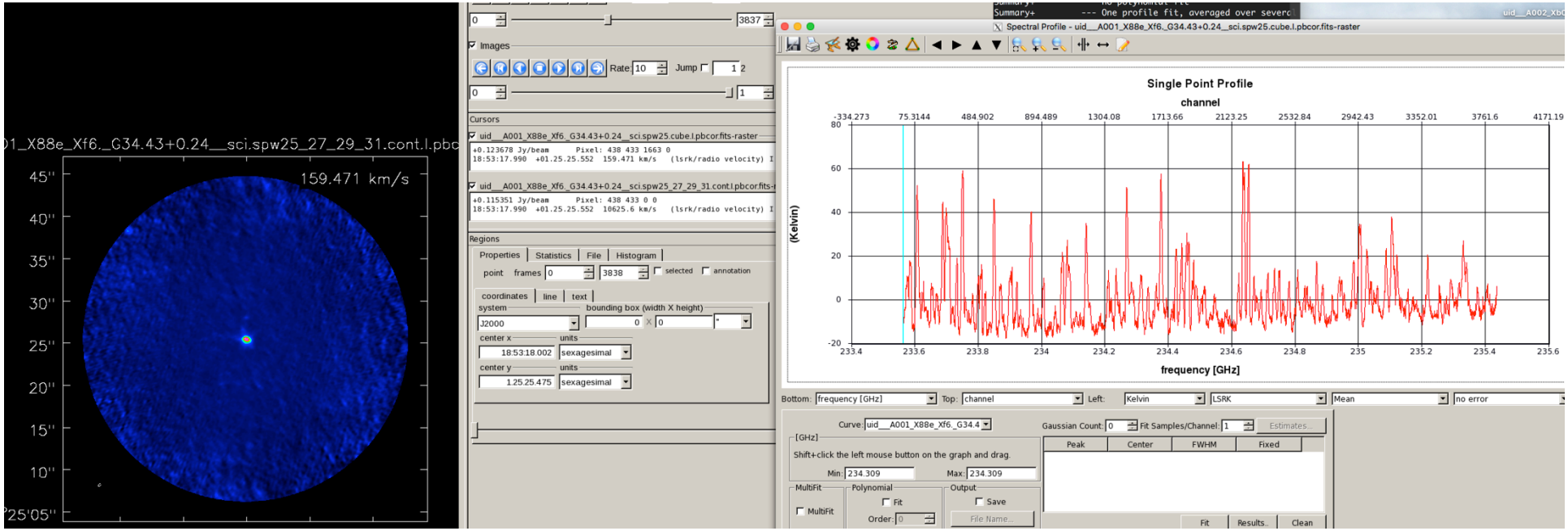
Data Inspection: Identifying Line-Free channels



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ScriptForImaging.py

- This script does not always provides science quality imaging, but it a good start for the data imaging.
  - Continuum imaging
  - UV Continuum subtraction
  - Line Imaging
  - PB correction
  - Export to fits files

ScriptForImaging.py

- CLEAN
  - Normal clean used widely on other interferometer data analysis packages
- TCLEAN
  - CASA own clean algorithm, it is faster and it is more robust than CLEAN for ALMA data
  - NOT FULLY DOCUMENTED
  - SOME FUNCTIONS ARE NOT FULLY TESTED
  - CASA 4.7.1 HAVE AN ISSUE WITH TCLEAN

ScriptForImaging.py

- Continuum Imaging

```
import re

if re.search('^4.7.0', casadef.casa_version) == None:
    sys.exit('ERROR: PLEASE USE THE SAME VERSION OF CASA THAT YOU USED FOR GENERATING THE SCRIPT: 4.7.0')

print "# Running clean."

visdata='uid___A002_X867766_Xa7.ms.split.cal'
fieldname='3'
phasecenter=3
cellsize='0.15arcsec'
imagesize=[640, 640]

spwcont='1:0~89;131~224;288~328;350~415;649~1019;1065~1221;1253~1290;1324~1380;1431~1650;1698~1790;1880~2020;2100~2200;2300~2450;2550~2750;2950~3250;3300~3350;
    3380~3420;3520~3800'


tclean(vis = visdata,
       imagename = 'IRAS.continuum',
       field = fieldname,
       spw = spwcont,
       specmode = 'mfs',
       deconvolver='hogbom',
       nterms=1,
       chanchunks=-1,
       gridder = 'mosaic',
       interactive = F,
       imsize = imagesize,
       cell = cellsize,
       phasecenter = phasecenter,
       weighting = 'briggs',
       robust = 0.5,
       pbcor=True,
       outframe='LSRK',
       niter=100)
```

ScriptForImaging.py

- UV Continuum subtraction

```
###Continuum subtraction for Line Imaging
fitspw = '0:0~200;300~350;500~800;1250~1600,1800~2100;2500~2700,2900~3200'
linespw = '0' # line spectral windows. You can subtract the continuum from multiple spectral line windows at once.

uvcontsub(vis=visdata,
          spw=linespw, # spw to do continuum subtraction on
          fitspw=fitspw, # select spws to fit continuum. exclude regions with strong lines.
          combine='spw',
          solint='int',
          fitorder=1,
          want_cont=False) # This value should not be changed.
```

```
uvcontsub(vis=visname,
          field='4',
          fitspw=spwcont,
          want_cont=False)
```

ScriptForImaging.py

- Imaging of the Lines

```
##############################################
# Image line emission [REPEAT AS NECESSARY]

linevis = visdata + '.contsub'

##############################################
# Image CH3OH line emission

sourcename ='IRAS16293' # name of source
linename = 'Methanol' # name of transition (see science goals in OT for name)
lineimagename = sourcename+'_'+linename+'_image' # name of line image

restfreq='157.17902GHz' # Typically the rest frequency of the line of
                        # interest. If the source has a significant
                        # redshift (z>0.2), use the observed sky
                        # frequency (nu_rest/(1+z)) instead of the
                        # rest frequency of the
                        # line.

#start='-90km/s' # start velocity. See science goals for appropriate value.
#width='0.1km/s' # velocity width. See science goals.
#nchan = 1800  # number of channels. See science goals for appropriate value.
spwline='0' # uncomment and replace with appropriate spw if necessary.

tclean(vis=linevis,
       imagename=lineimagename,
       field=fieldname,
       spw=spwline,
       specmode='cube',
       deconvolver='hogbom',
       nterms=1,
       chanchunks=-1,
       phasecenter=phasecenter,
       #start=start,
       #width=width,
       #nchan=nchan,
       outframe='LSRK',
       veltype='radio',
       restfreq=restfreq,
       niter=100,
       #threshold=threshold,
       interactive=False,
       imsize = imagesize,
       cell = cellsize,
       weighting='briggs',
       robust=0.5,
       pbcor=True,
       gridder='mosaic')
```

ScriptForImaging.py

- PB Correction, and conversion to fits.

```
##Make pb correction, export fits.
for myimagebase in ['IRAS.continuum',lineimage]:
    print myimagebase
    # export the corrected image and the PB image
    exportfits(imagename=myimagebase+'.image.pbcor', fitsimage=myimagebase+'.image.pbcor.fits')
    exportfits(imagename=myimagebase+'.pb', fitsimage=myimagebase+'.flux.fits')
```

If you use clean, ALWAYS put “pbcor=False”.
For tclean you have to use “pbcor=True”

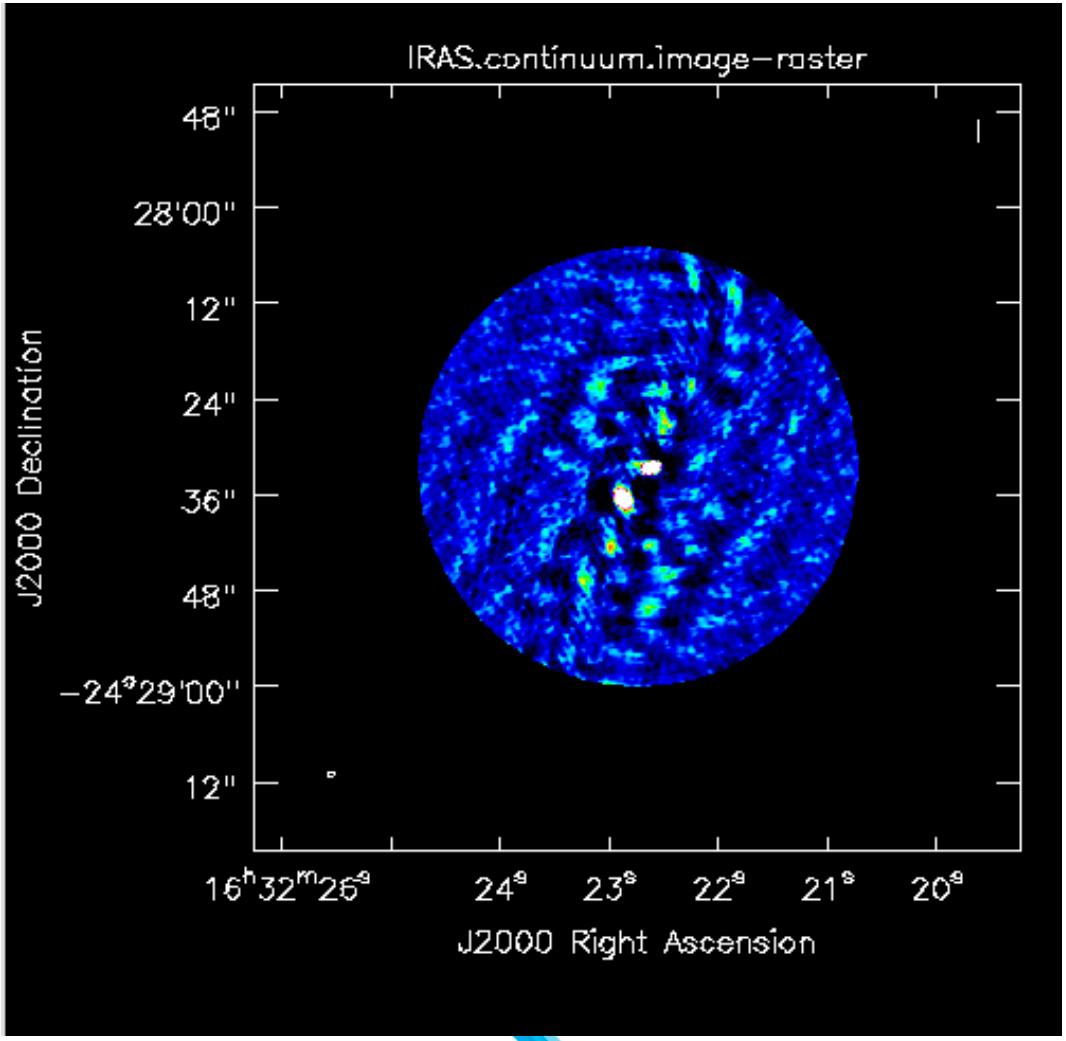
Continuum

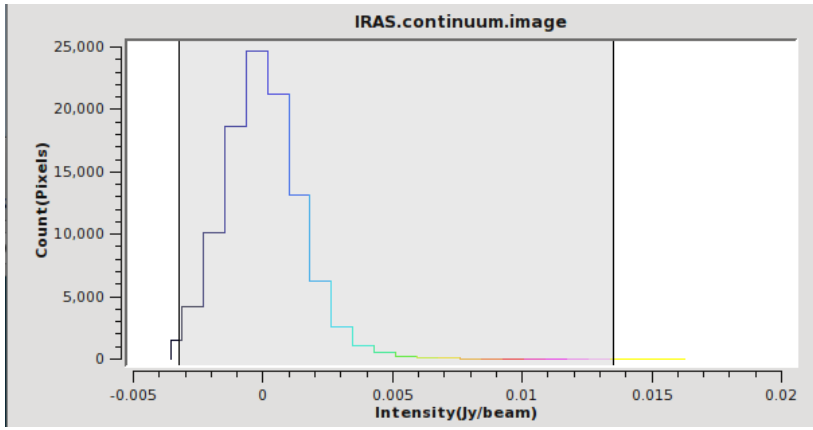
- Select only line-free data!

```
clean(vis=msfile,
      imagename='continuum',
      field=thetarget,
      phasecenter=thephasecenter,
      spw=spwcont,
      mode='mfs',
      nterms=1,
      weighting='briggs',
      robust=0.5,
      threshold='2mJy',
      pbcor=False,
      imsize=[128,128],
      cell=['0.1arcsec'],
      psfmode='clark'
      imagermode='mosaic'
      interactive=True)
```

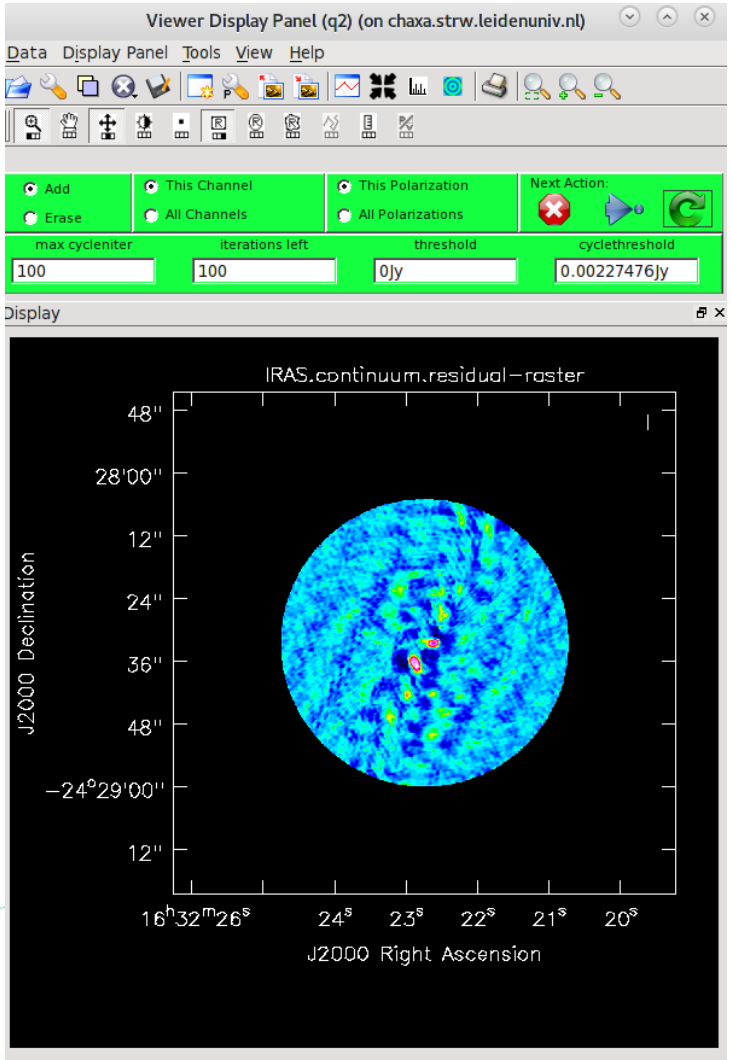
```
tclean(vis=ms1,
      imagename='continuum',
      field=thetarget,
      phasecenter=thephasecenter,
      spw=spwcont,
      specmode='mfs',
      nterms=1,
      weighting='briggs',
      robust=0.5,
      threshold='2mJy',
      pbcor=True,
      imsize=themosaicimsize,
      cell=thecellsize,
      deconvolver='hogbom',
      chanchunks=-1,
      gridder='mosaic',
      interactive=True)
```

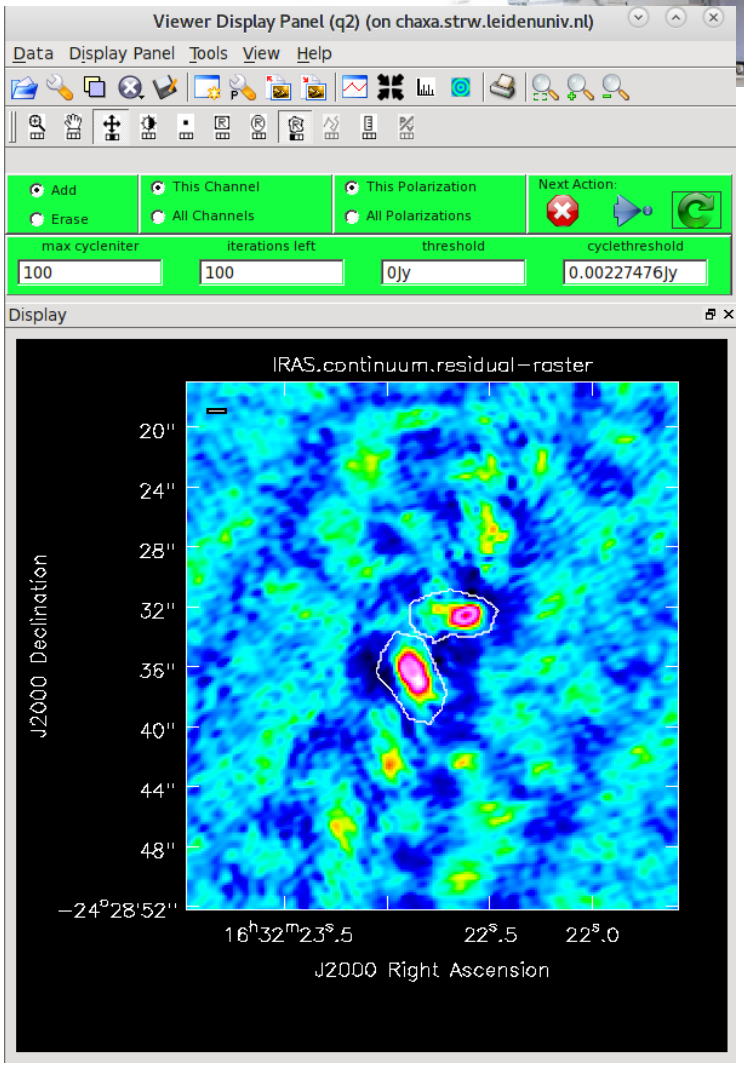
Cleaning..


IRAS.continuum.image-raster
48"
28'00"
12"
24"
36"
48"
−24°29'00"
12"
J2000 Declination
16h32m25s
24s
23s
22s
21s
20s
J2000 Right Ascension

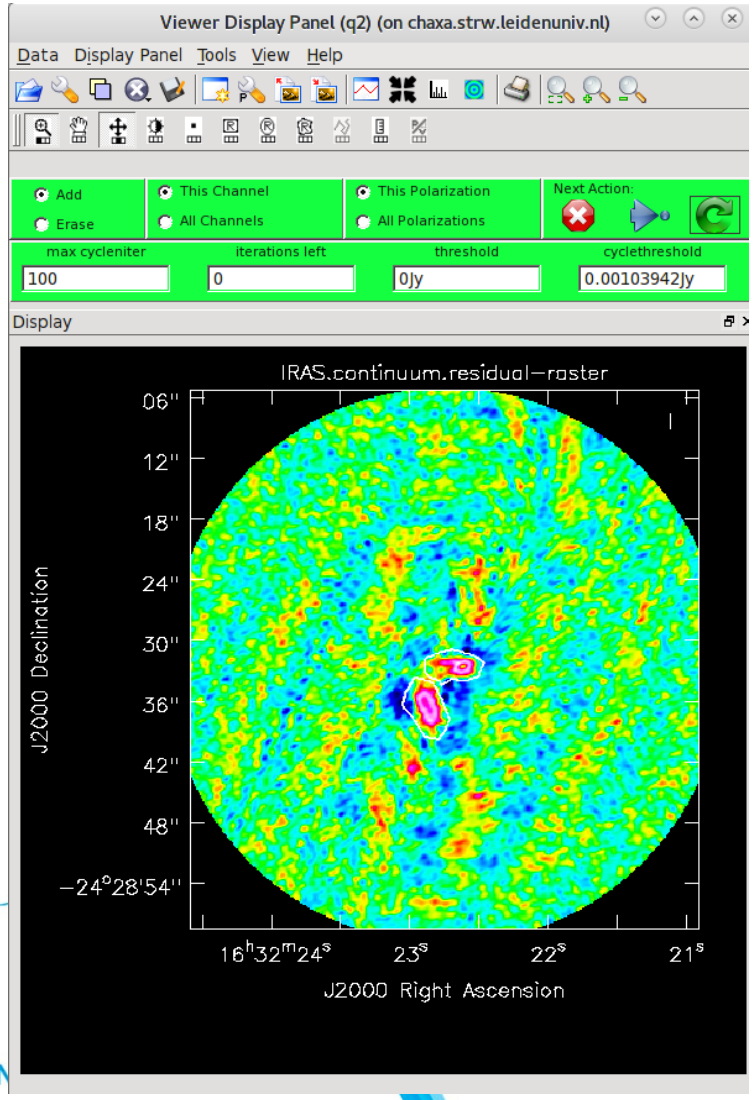

IRAS.continuum.image
25,000
20,000
15,000
10,000
5,000
0
Count(Pixels)
-0.005
0
0.005
0.01
0.015
0.02
Intensity(Jy/beam)

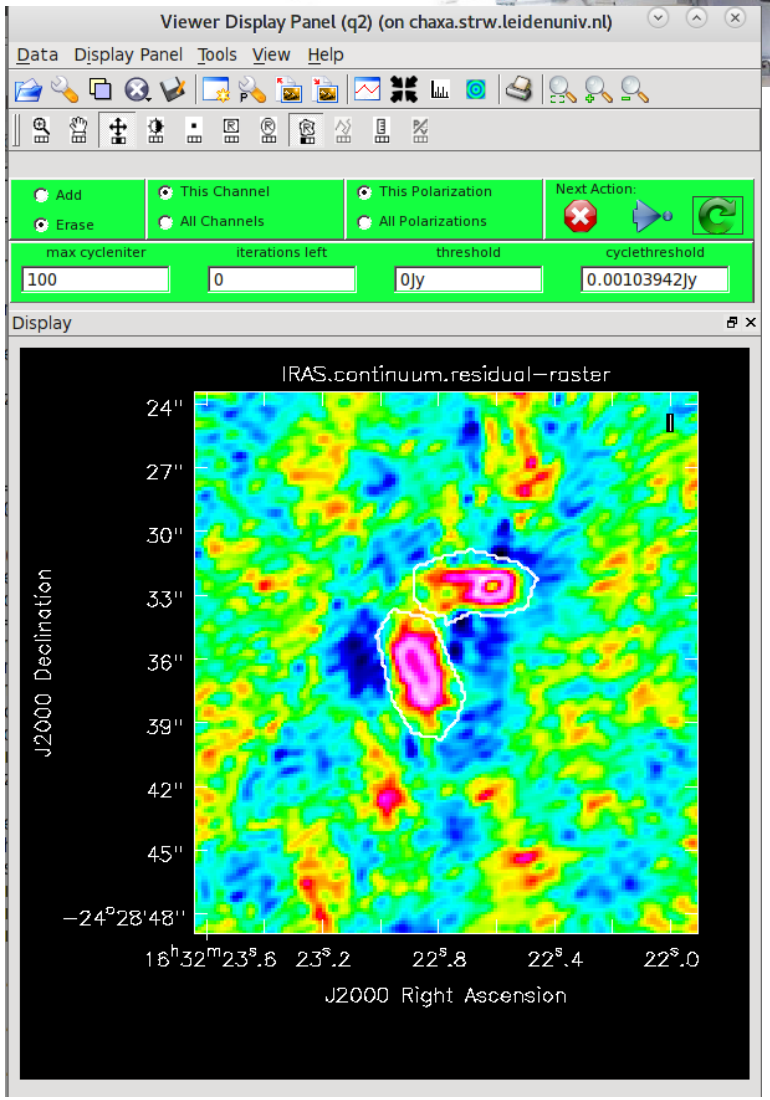
Cleaning..


Viewer Display Panel (q2) (on chaxa.strw.leidenuniv.nl)
Data Display Panel Tools View Help
Add
Erase
This Channel
All Channels
This Polarization
All Polarizations
Next Action:
max cycleniter
iterations left
threshold
cyclethreshold
100
100
0Jy
0.00227476Jy
Display
IRAS.continuum.residual−raster
J2000 Declination
J2000 Right Ascension

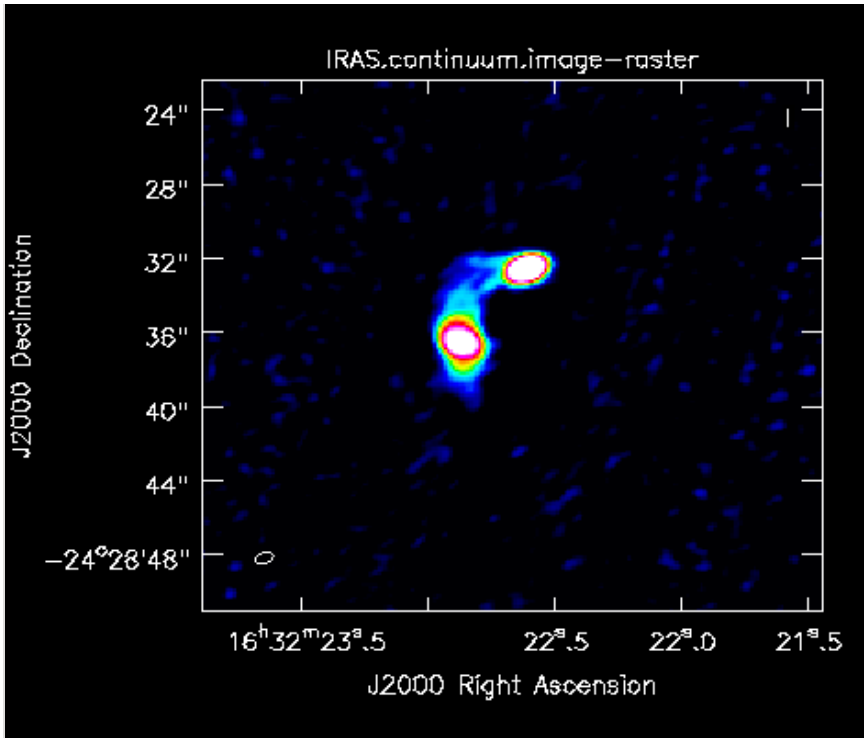

Viewer Display Panel (q2) (on chaxa.strw.leidenuniv.nl)
Data Display Panel Tools View Help
Add
Erase
This Channel
All Channels
This Polarization
All Polarizations
Next Action:
max cycleniter
iterations left
threshold
cyclethreshold
100
100
0Jy
0.00227476Jy
Display
IRAS.continuum.residual−raster
J2000 Declination
J2000 Right Ascension

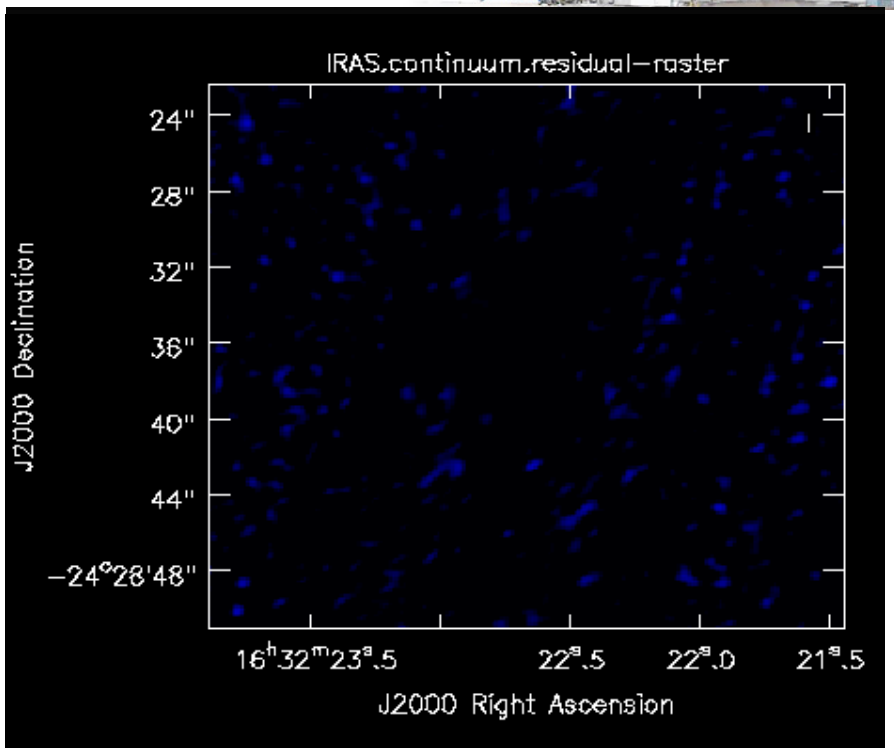
Cleaning…


Viewer Display Panel (q2) (on chaxa.strw.leidenuniv.nl)
Data Display Panel Tools View Help
Add
Erase
This Channel
All Channels
This Polarization
All Polarizations
Next Action:
max cycleniter
iterations left
threshold
cyclethreshold
100
0
0Jy
0.00103942Jy
Display
IRAS.continuum.residual−raster
06''
12''
18''
24''
30''
36''
42''
48''
−24°28'54''
J2000 Declination
16h32m24s
23s
22s
21s
J2000 Right Ascension


Viewer Display Panel (q2) (on chaxa.strw.leidenuniv.nl)
Data Display Panel Tools View Help
Add
Erase
This Channel
All Channels
This Polarization
All Polarizations
Next Action:
max cycleniter
iterations left
threshold
cyclethreshold
100
0
0Jy
0.00103942Jy
Display
IRAS.continuum.residual−raster
24''
27''
30''
33''
36''
39''
42''
45''
−24°28'48''
J2000 Declination
16h32m23s.6
23s.2
22s.8
22s.4
22s.0
J2000 Right Ascension

Cleaning


IRAS.continuum.image−raster
24"
28"
32"
36"
40"
44"
−24°28'48"
J2000 Declination
16h32m23s.5
22s.5
22s.0
21s.5
J2000 Right Ascension


IRAS.continuum.residual−raster
24"
28"
32"
36"
40"
44"
−24°28'48"
J2000 Declination
16h32m23s.5
22s.5
22s.0
21s.5
J2000 Right Ascension

Lines

```
clean(vis=ms1,
    imagename=thetarget+_C18O',
    field=thetarget,
    spw="2",
    mode="velocity",
    width="0.096km/s",
    start=-9.6km/s,
    nchan=200,
    outframe=theoutframe,
    veltype="radio",
    niter=1000,
    threshold="14mJy",
    psfmode="clark",
    imagermode="mosaic",
    interactive=True,
    imsize=themosaicimsize,
    cell=thecellsize,
    phasecenter=thephasecenter,
    restfreq="219.56035GHz",#C18O 2-1
    weighting="briggs",
    robust=0.5)
```

```
tclean(vis=ms1,
    imagename=thetarget+_C18O-tclean,
    field=thetarget,
    spw=[2],
    specmode=cube,
    width=0.096km/s,
    start=-9.6km/s,
    nchan=200,
    outframe=LSRK,
    niter=1000,
    threshold=14mJy,
    deconvolver=hogbom,
    gridder=mosaic,
    pbcor=True,
    chanchunks=-1,
    interactive=True
    imsize=themosaicimsize,
    cell=thecellsize,
    phasecenter=thephasecenter,
    restfreq="219.56035GHz",#C18O
    weighting=briggs,
    robust=0.5)
```

Weighting

- Natural:
  - Visibilities are weighted by the data weights, it will give the best signal-to-noise ratio and the worst angular resolution
- Uniform:
  - All cell have the same weigth
  - Makes the resolution finer, but this will increase the noise
- “briggs”:
  - Intermediate weighting, depending on the value of the robust. -2 more like the uniform, 2 more like natural
- Tapering:
  - Outer tapering only supported, which will reduce the weight of the longest baselines, thus increasing the sensitivity to the large-scale emission.
  - It will increase the noise

Creating Masks

- Manual: CASA in interactive mode
- Automatic: Using a threshold.
  - https://casaguides.nrao.edu/index.php/M100_Band3_Combine_4.3

```
immath(imagename = [myimage],outfile =
threshmask,expr = 'iif(IM0 > '+str(thresh) +',
1.0,0.0)')
```

Thing to consider

- The size of the image have to be at least twice the size of your primary beam
- To create the continuum do not flag the data, it is best to use the continuum channels as input into CLEAN (old scripts used to flag data instead)
- Look at the residuals and histograms!!

Thanks!

EUROPEAN ARC
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