

# Preliminaries

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- Verify that your computer (`> hostname`) is a GIPSY client.  
If not, add your computer name to the file `$gip_loc/clients`
- Verify that you run the tc-shell (`> echo $SHELL`)
- In your home directory, add these lines to the `.tcshrc` file:  
`setenv gip_root <path to gipsy installation>`  
`source $gip_root/sys/gipenv.csh`
- Verify that the GIPSY environment is set (`> printenv | grep gip`)
- If you do not have a proper installation of GIPSY,  
work together with your neighbour

# T8 : Analysis of spectral line data cubes

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Goal : Extract scientifically meaningful information from a 'dirty' HI data cube obtained with a standard 12<sup>hr</sup> WSRT observation.

Object : NGC 4088 and its companion galaxy.

N4088 : 12<sup>h</sup>03<sup>m</sup>01.97<sup>s</sup> +50<sup>d</sup>49<sup>m</sup>02.3<sup>s</sup>     $V_{\text{hel}} = 757 \text{ km/s}$

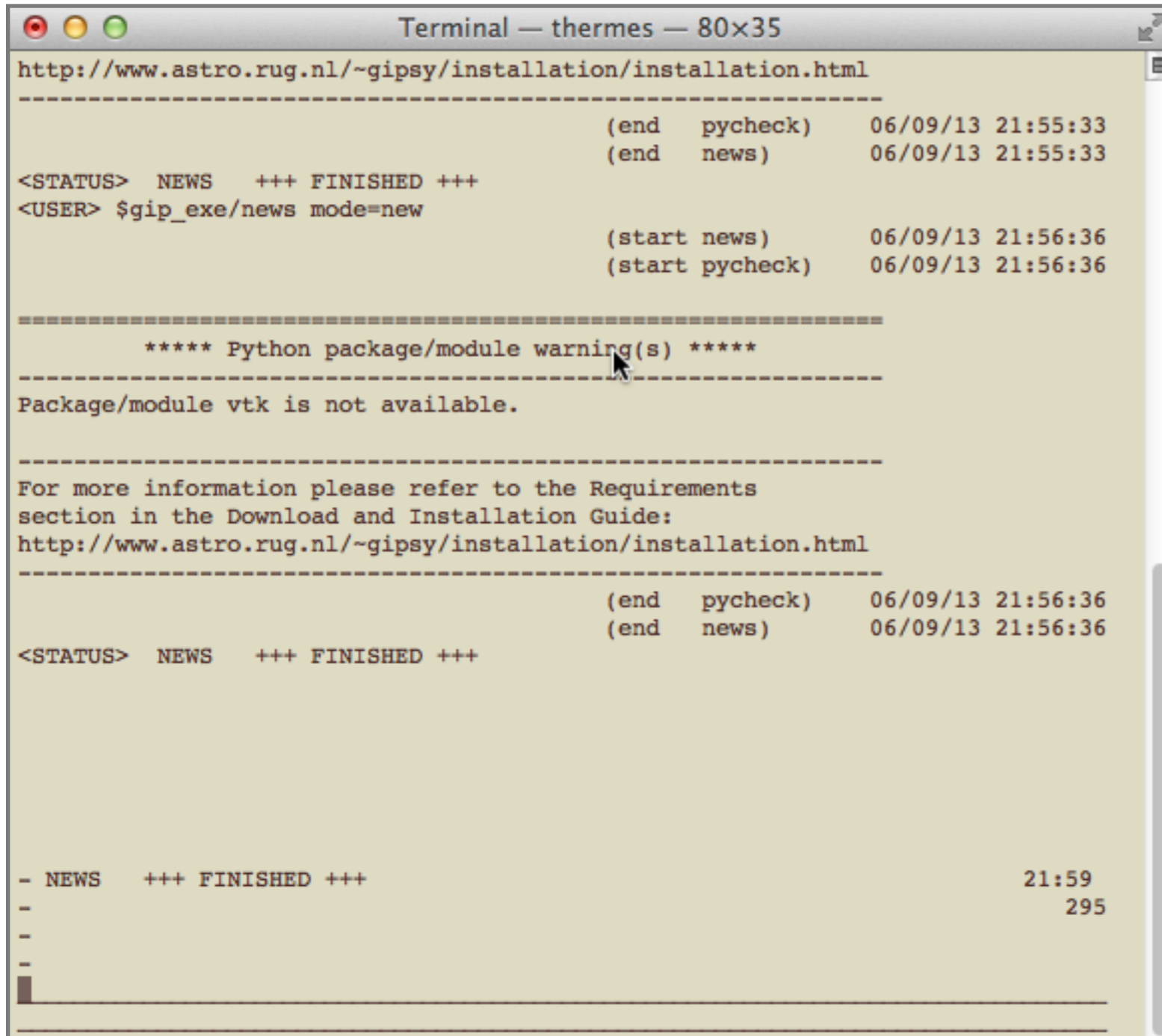
N4085 : 12<sup>h</sup>02<sup>m</sup>50.41<sup>s</sup> +50<sup>d</sup>37<sup>m</sup>52.4<sup>s</sup>     $V_{\text{hel}} = 746 \text{ km/s}$

Tool : Groningen Image Processing SYstem (gipsy)  
[www.astro.rug.nl/~gipsy](http://www.astro.rug.nl/~gipsy)

We take the most elementary approach.

# Introduction to Gipsy interface

## Hermes : the terminal-based interface



```
Terminal — thermes — 80x35
http://www.astro.rug.nl/~gipsy/installation/installation.html
-----
                                (end  pycheck)  06/09/13 21:55:33
                                (end  news)     06/09/13 21:55:33
<STATUS> NEWS    +++ FINISHED +++
<USER> $gip_exe/news mode=new
                                (start news)   06/09/13 21:56:36
                                (start pycheck) 06/09/13 21:56:36
-----
***** Python package/module warning(s) *****
-----
Package/module vtk is not available.
-----
For more information please refer to the Requirements
section in the Download and Installation Guide:
http://www.astro.rug.nl/~gipsy/installation/installation.html
-----
                                (end  pycheck)  06/09/13 21:56:36
                                (end  news)     06/09/13 21:56:36
<STATUS> NEWS    +++ FINISHED +++

- NEWS    +++ FINISHED +++                                21:59
-
-
-
-
-
```

### Common Output Area

toggle *Tab*: hermes help on/off

With task-name on command line,  
*Tab* provides help on task inputs

Ctrl+V/Z : page forward/backward

Ctrl+P : switch page mode on/off

Ctrl+Q : quit Hermes

Esc > / < : go to last/first page

Ctrl-X S : switch scrolling on/off

Esc B : switch bell on/off

**=** active task slots

**=** Ctrl-C : abort an active task

**=** command line editor

↑↓ : scroll input history

# Read FITS files into Gipsy GDS database

## ► Read cubes

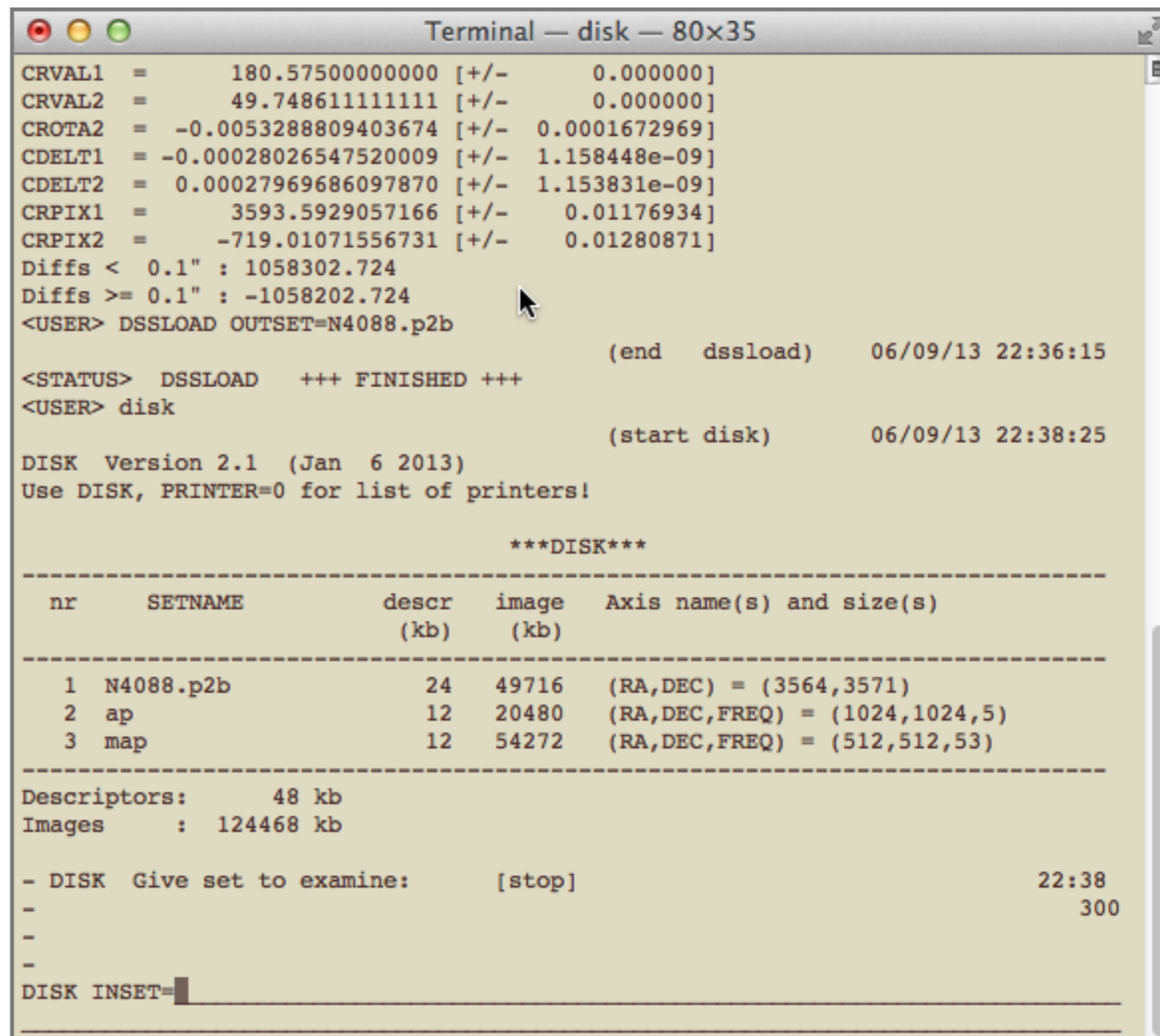
```
rfits
FITSFILE = map.fits
OUTSET = map
FREQ0 = ↵
FITSFILE = ↵
```

## ► Read POSS-2 image

```
dssload
FILENAME = N4088.p2b.fits
OUTSET = N4088.p2b
```

## ► Check GDS catalog

```
disk
INSET = ↵
```



Terminal — disk — 80x35

```
CRVAL1 = 180.5750000000 [+/- 0.000000]
CRVAL2 = 49.748611111111 [+/- 0.000000]
CROTA2 = -0.0053288809403674 [+/- 0.0001672969]
CDELTA1 = -0.00028026547520009 [+/- 1.158448e-09]
CDELTA2 = 0.00027969686097870 [+/- 1.153831e-09]
CRPIX1 = 3593.5929057166 [+/- 0.01176934]
CRPIX2 = -719.01071556731 [+/- 0.01280871]
Diffs < 0.1" : 1058302.724
Diffs >= 0.1" : -1058202.724
<USER> DSSLOAD OUTSET=N4088.p2b
                                (end dssload) 06/09/13 22:36:15
<STATUS> DSSLOAD +++ FINISHED +++
<USER> disk
                                (start disk) 06/09/13 22:38:25

DISK Version 2.1 (Jan 6 2013)
Use DISK, PRINTER=0 for list of printers!

***DISK***
-----
nr      SETNAME      descr      image      Axis name(s) and size(s)
      (kb)          (kb)
-----
  1  N4088.p2b      24      49716      (RA,DEC) = (3564,3571)
  2   ap           12      20480      (RA,DEC,FREQ) = (1024,1024,5)
  3   map           12      54272      (RA,DEC,FREQ) = (512,512,53)
-----
Descriptors:      48 kb
Images           : 124468 kb

- DISK Give set to examine:      [stop]      22:38
-
-
-
DISK INSET=
```



# Inspect image and cubes with visions

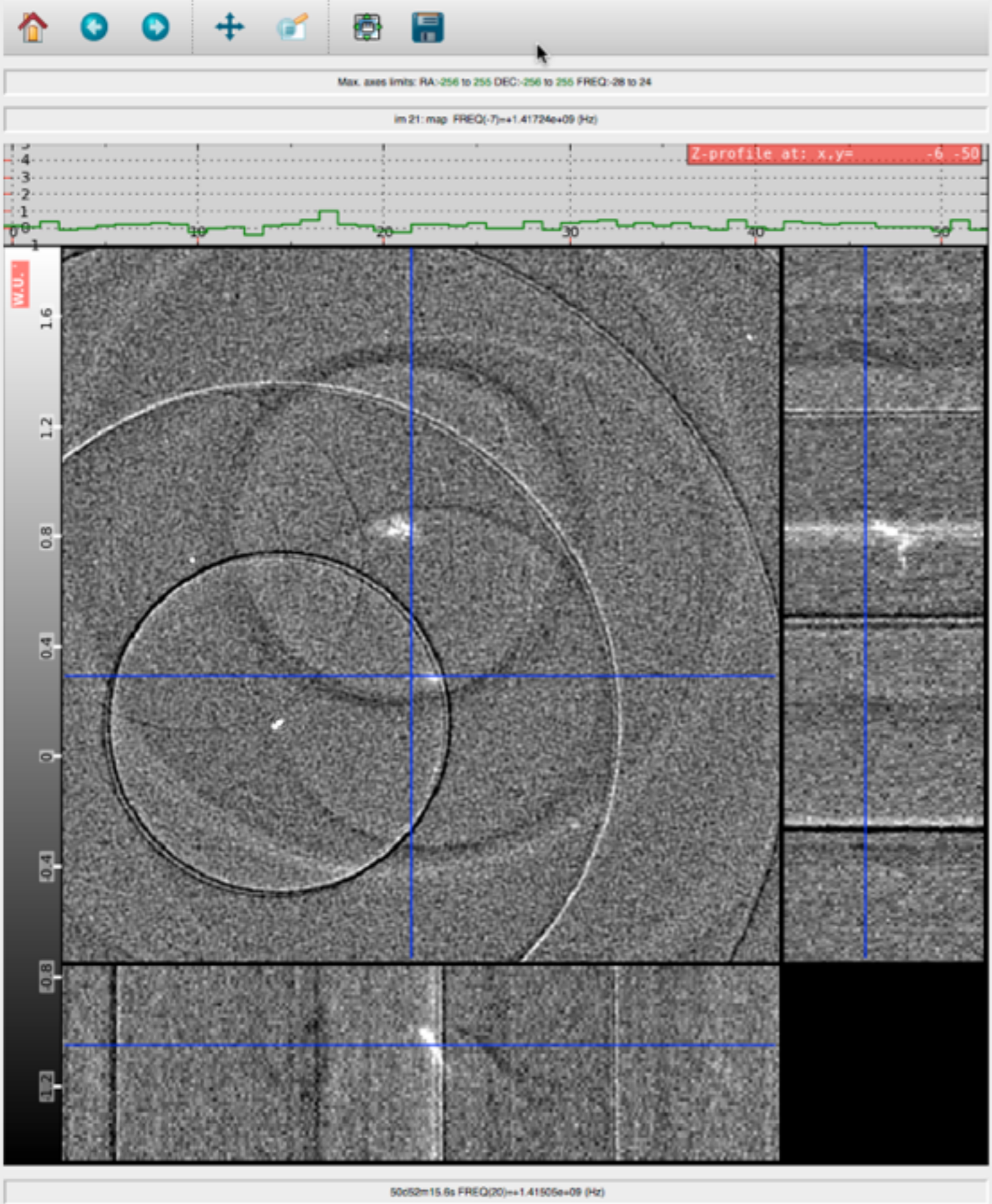
The screenshot displays the VISIONS (1.0.9) software interface. The main window shows an astronomical image with a circular region of interest. The image is titled "Data 0" and "AGAL/ERIS2013/Tutorial/map FREQ". The image has a vertical axis labeled "W.U." ranging from -1.2 to 1.6. The image is titled "Data 0" and "AGAL/ERIS2013/Tutorial/map FREQ". The image has a vertical axis labeled "W.U." ranging from -1.2 to 1.6. The image is titled "Data 0" and "AGAL/ERIS2013/Tutorial/map FREQ". The image has a vertical axis labeled "W.U." ranging from -1.2 to 1.6.

The control panel on the right is divided into several sections:

- Data 0**: Contains buttons for "Compose", "Draw", "No WCS", "Box", "Header", "Defaults", and "Help". The "Compose" button is circled in red, and an arrow points from it to the "Mean/rms" section.
- Origin clip levels**: Contains radio buttons for "Header" and "Data", and input fields for values: -3.99917, 20.674, -3.99917, and 20.674.
- Mean/rms**: Contains radio buttons for "Mean/rms" (selected) and "User", and input fields for "mean -", "4", "x rms =", "-1.48529", "mean +", "5", and "x rms =", "1.85859".
- Miscellaneous**: Contains buttons for "Spectral", "Native", "Sky", "Native", "Graticule", "Colorbar", "Swap axes", "Aspect", "Xpanel", "Ypanel", "Clevels", "Cont. on", "Fix backgr.", and "Colour".
- Reproject data to template**: Contains buttons for "Tab number with template", "Interpol. mode", "Cubic spline", and "Start transform".

The bottom of the window shows the text "GIPSY/Kapteyn Package data viewer v1.0.9" and "Mem. pages: 181824".





Data Utils Movie Colors **Slices** Cursor Zoom Log

Slice panels from frames defined in data tabs

**Draw X** → **Draw Y**

Remove X Remove Y

Slice panels frame selection by user

X slice

Y slice

Draw

Z-profile

Z-profile Manual position 10 -51

Min, max -1 5

Note 'scaling' of grating rings

# Inspect the headers

## ► Check data structure

header

INSET = map

map : RA : 512 [-256, 255]  
DEC : 512 [-256, 255]  
FREQ : 53 [-28, 24]

ap : RA : 1024 [-512, 511]  
DEC : 1024 [-512, 511]  
FREQ : 5 [-2, 2]

Center of cube at (0,0,0)

N4088.p2b RA : 3564 [-3592, -29]  
DEC : 3571 [721, 4291]

## ► Full header listing:

fixhed

INSET = map

ITEM = ↶

```
Terminal — thermes — 80x35
                                (start header) 06/09/13 23:20:59
HEADER Version 1.0 (Jun 14 2013)
<USER> HEADER INSET=map
*****
Set: map top level                                06-Sep-2013
Observer: ****                      Obs. date: ****          Object: UGC7081/75
Obs. type: ****                     Instrument: WSRT         Polarization: ****
Projection centre:                    (Epoch: 1950.0)
RA : 180.73750000 DEGREE = 12h 2m56.999s (at grid: 0.00)
DEC : 50.72500000 DEGREE = 50d43m30.00s (at grid: 0.00)
FREQ : 1416692137.34699988 HZ = 800.00 KM/S = 800000.00 M/S (at grid)
Axis length and range:
RA : 512 [-256, 255]
DEC : 512 [-256, 255]
FREQ : 53 [-28, 24]
Grid spacing:
RA : -0.001389 DEGREE = -5.000004 arcsec
DEC : +0.001801 DEGREE = +6.482304 arcsec
FREQ : -78125.000000 HZ
Data range = [-3.99917,20.674 ] (W.U. ') Number of blanks not in header
*****
Fringe stopping center RA = ****
                        DEC = ****
Pointing center        RA = 180.74 = 12h 2m56.999s
                        DEC = 50.73 = 50d43m30.00s
Rest frequency         1420.406 MHZ      Interferometers 40
Total bandwidth        4921875.00000 MHZ  Polarizations   ****
- HEADER   +++ FINISHED +++
-
-
-
                                23:21
                                325 326
```

# Determine beam size and assign to channel maps

## ► measure FWHM of dirty beam

```
antpat box =-5 -5 5 5
APSET = ap 0
UPSET = map f -6:6
FITAGAIN = no
```

Do the same for the other  
4 antenna patterns:

```
APSET = ap -2
UPSET = map f -28:-20
```

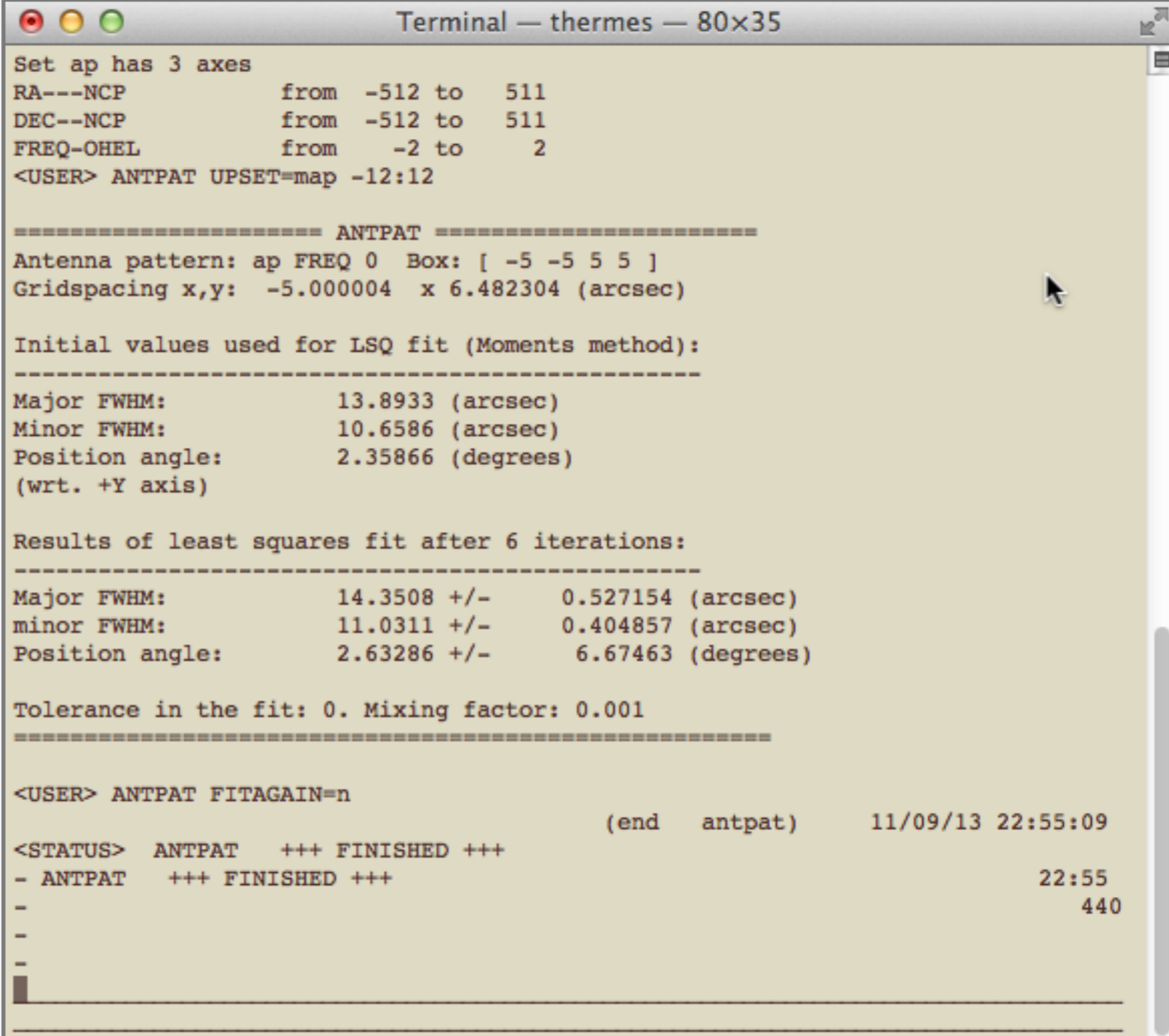
```
APSET = ap -1
UPSET = map f -19:-7
```

```
APSET = ap 1
UPSET = map f 7:19
```

```
APSET = ap 2
UPSET = map f 20:24
```

Check updated header:

```
header
INSET = map f 9
```



```
Terminal — thermes — 80x35
Set ap has 3 axes
RA---NCP          from -512 to 511
DEC--NCP          from -512 to 511
FREQ-OHEL         from -2 to 2
<USER> ANTPAT UPSET=map -12:12

===== ANTPAT =====
Antenna pattern: ap FREQ 0 Box: [ -5 -5 5 5 ]
Gridspacing x,y: -5.000004 x 6.482304 (arcsec)

Initial values used for LSQ fit (Moments method):
-----
Major FWHM:      13.8933 (arcsec)
Minor FWHM:     10.6586 (arcsec)
Position angle:  2.35866 (degrees)
(wrt. +Y axis)

Results of least squares fit after 6 iterations:
-----
Major FWHM:      14.3508 +/- 0.527154 (arcsec)
minor FWHM:     11.0311 +/- 0.404857 (arcsec)
Position angle:  2.63286 +/- 6.67463 (degrees)

Tolerance in the fit: 0. Mixing factor: 0.001
=====

<USER> ANTPAT FITAGAIN=n
                                (end antpat) 11/09/13 22:55:09
<STATUS> ANTPAT  +++ FINISHED +++
- ANTPAT  +++ FINISHED +++                                22:55
-                                                            440
```

What is your  $m\text{Jy} \rightarrow \text{K}$  conversion factor?











# Define the clean areas - I

## ► Clip the smoothed map at 2-sigma

```
clip
INSET = lmap.bs30 f
BOX = ↶
OUTSET = lmap.bs30.mask
RANGE = 2.0*0.41 inf
```

Check the resulting cube with  
visions

```
Terminal — python — 80x35
7: Plot number of blanks
8: Select another graphics device

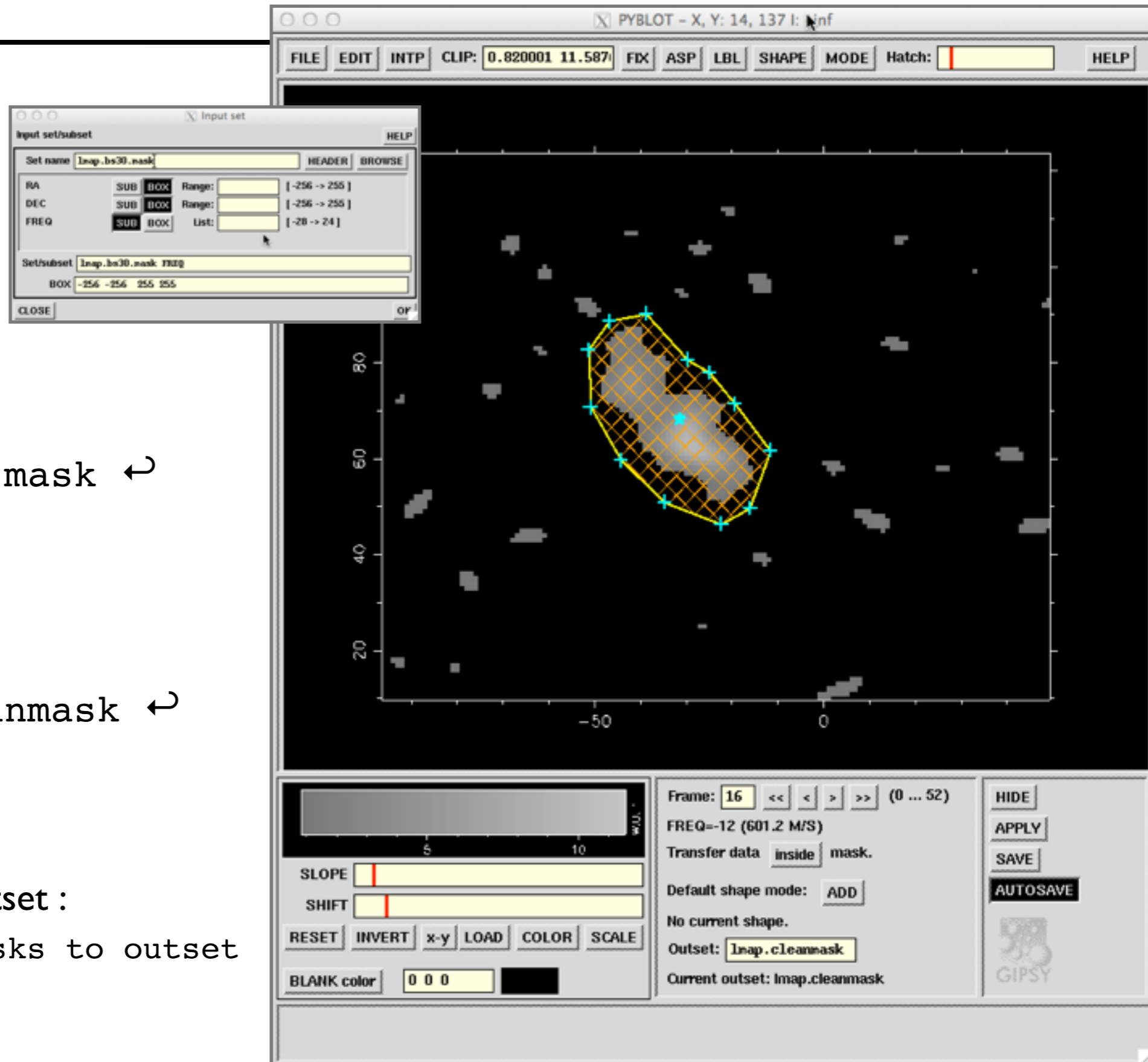
<USER> STAT PLOT=3
<USER> STAT GRDEVICE=screen
<USER> STAT PLOT=
(end stat) 12/09/13 09:33:24
<STATUS> STAT +++ FINISHED +++
<USER> clip
(start clip) 12/09/13 09:33:28
CLIP Version 1.0 (Jan 6 2013)
<USER> CLIP INSET=lmap.bs30 f
Set lmap.bs30 has 3 axes
RA---NCP from -256 to 255
DEC--NCP from -256 to 255
FREQ-OHEL from -28 to 24
<USER> CLIP BOX=
BOX range for set lmap.bs30 :
RA---NCP from -256 to 255
DEC--NCP from -256 to 255
<USER> CLIP OUTSET=lmap.bs30.mask
Set lmap.bs30.mask has 3 axes
RA---NCP from -256 to 255
DEC--NCP from -256 to 255
FREQ-OHEL from -28 to 24
<USER> CLIP RANGE=2.0*0.41
<USER> CLIP RANGE=2.0*0.41 inf
(end clip) 12/09/13 09:34:12
<STATUS> CLIP +++ FINISHED +++
- CLIP +++ FINISHED +++ 9:34
- PGVIEW RUNNING 474
-
-
```

# Define the clean areas - 2

## ► Isolate the areas with HI emission

pyblot

- Select the input set :  
FILE → Input set  
lmap.bs30.mask ↵  
→ OK
- Adjust the contrast :  
SLOPE / SHIFT
- Define the output set :  
Outset: lmap.cleanmask ↵
- Turn on AUTOSAVE
- Select a mask shape :  
SHAPE → Polygon
- Apply the masks to the outset :  
EDIT → Apply all masks to outset



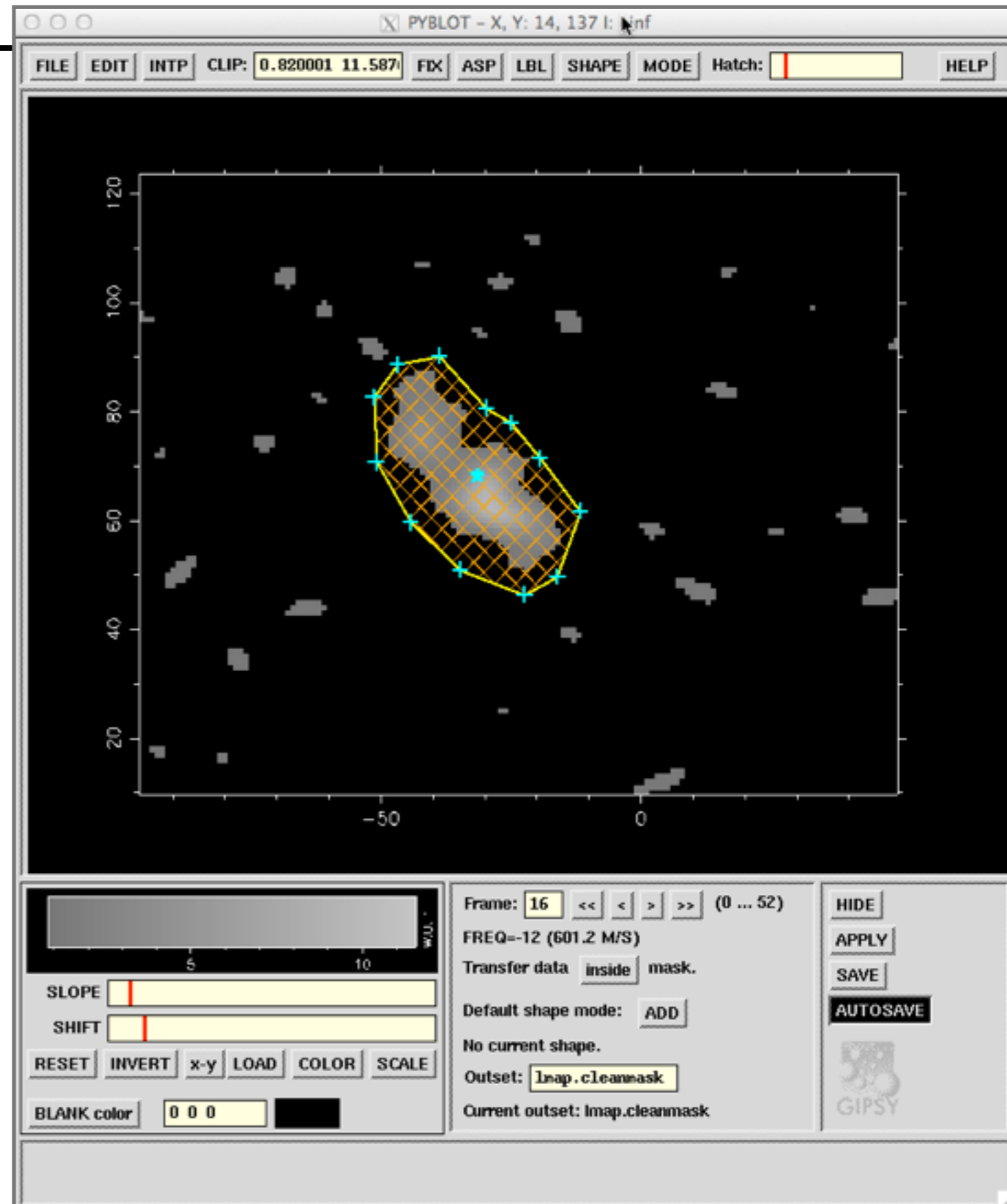
# Define the clean areas - 2

## ► Isolate the areas with HI emission

pyblot

- Zoom on area of interest:  
Shift + left mouse button
- Define a polygon:  
press **P** and use mouse  
(left: new point, right drag)
- Step through the channel maps  
with < and > buttons
- When ready, press APPLY  
The masks will be stored in the  
input set and applied to the  
output set.
- Exit pyblot:  
FILE → Exit

Check the resulting cube  
with *visions*





# Clean the channel maps

## ► Run clean

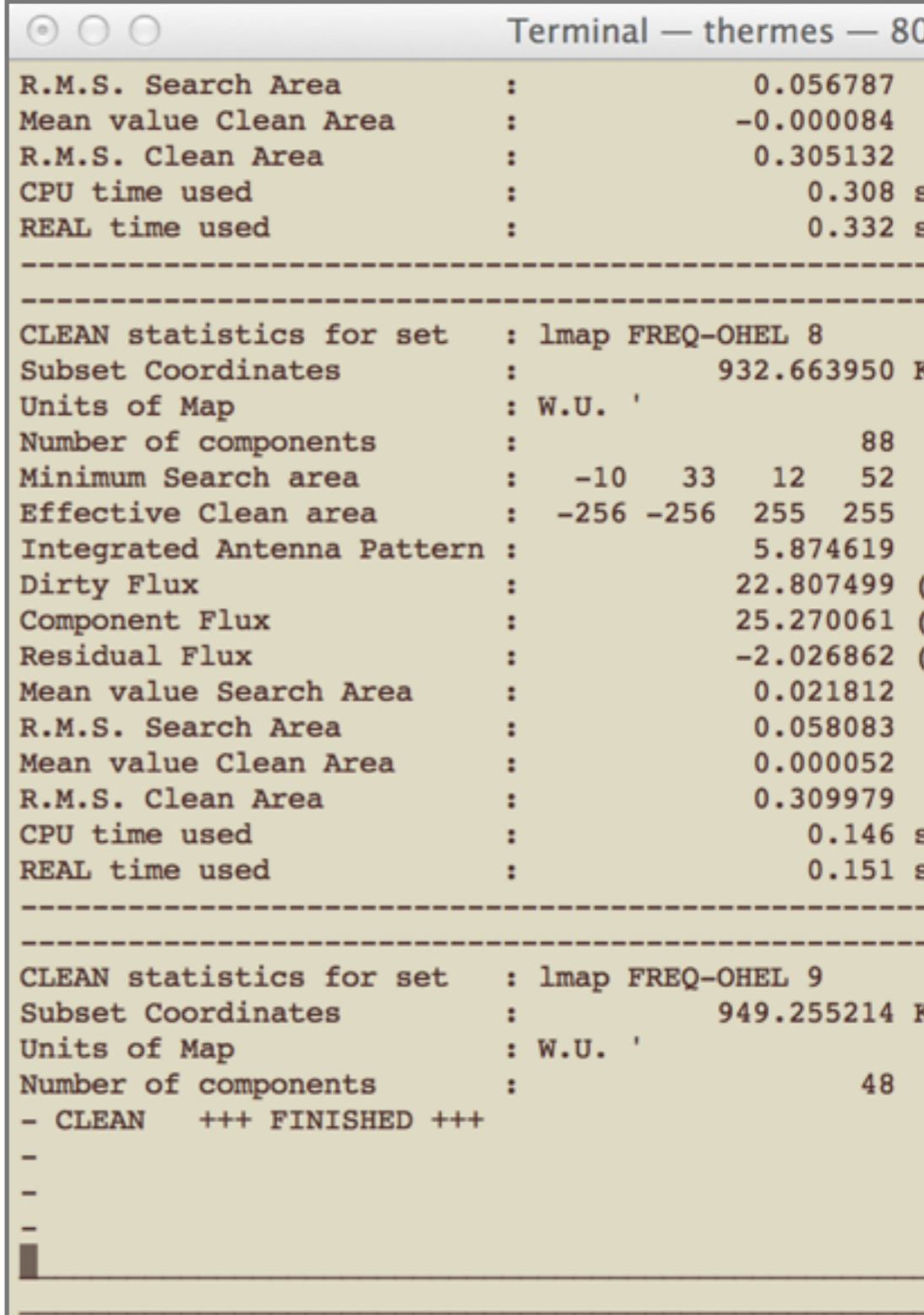
```
clean
INSET = lmap f -28:24
APSET = ap -2::9 -1::13 0::13 1::13 2::5
OUTSET = lmap.cl f -28:24
DEFSET = lmap.bs30.cleanmask f -28:24
CLEANBOX = ↶
NMAX = ↶
CUTOFF = 0.5*0.28
```

## ► Inspect the residual cube (visions)

## ► Restore the clean components

```
restore
INSET = lmap.cl f -28:24
BEAM = 14.0 11.0
BEAMPA = 0.0
```

## ► Inspect the residual cube (visions)



```
Terminal — thermes — 80
R.M.S. Search Area      :      0.056787
Mean value Clean Area  :     -0.000084
R.M.S. Clean Area      :      0.305132
CPU time used          :      0.308 s
REAL time used         :      0.332 s
-----
CLEAN statistics for set : lmap FREQ-OHEL 8
Subset Coordinates      :      932.663950 R
Units of Map            : W.U. '
Number of components    :      88
Minimum Search area    :     -10  33  12  52
Effective Clean area    :    -256 -256  255  255
Integrated Antenna Pattern :      5.874619
Dirty Flux              :     22.807499 (
Component Flux          :     25.270061 (
Residual Flux           :     -2.026862 (
Mean value Search Area :      0.021812
R.M.S. Search Area     :      0.058083
Mean value Clean Area  :      0.000052
R.M.S. Clean Area     :      0.309979
CPU time used          :      0.146 s
REAL time used         :      0.151 s
-----
CLEAN statistics for set : lmap FREQ-OHEL 9
Subset Coordinates      :      949.255214 R
Units of Map            : W.U. '
Number of components    :      48
- CLEAN   +++ FINISHED +++
-
-
-
█
```

# Cut out the areas with HI emission

- ▶ Conditionally transfer the data using the cleanmasks

```
condit
INSET = lmap.cl f -28:24
BOX = ↶
MASKSET = lmap.bs30.cleanmask f -28:24
OUTSET = N4088.HIcube
RGMODE = T
RANGE = -inf inf
BLMODE = B
BLOCKVAL = 0.0
```

- ▶ Inspect the outset cube (visions)

```
Terminal — python — 80x
CONDIT Version 1.0 (Jan 6 2013)
<USER> CONDIT INSET=lmap.cl f -28:24
Set lmap.cl has 3 axes
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
FREQ-OHEL        from -28 to 24
<USER> CONDIT BOX=
BOX range for set lmap.cl :
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
<USER> CONDIT MASKSET=lmap.bs30.cleanmask f -28:24
Set lmap.bs30.cleanmask has 3 axes
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
FREQ-OHEL        from -28 to 24
BOX range for set lmap.bs30.cleanmask :
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
<USER> CONDIT OUTSET=N4088.HIcube
Set N4088.HIcube has 3 axes
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
FREQ-OHEL        from -28 to 24
<USER> CONDIT RGMODE=T
<USER> CONDIT RANGE=
<USER> CONDIT BLMODE=B
<USER> CONDIT BLOCKVAL=0.0
(end co

<STATUS> CONDIT +++ FINISHED +++
- CONDIT +++ FINISHED +++
- PGVIEW RUNNING
-
-

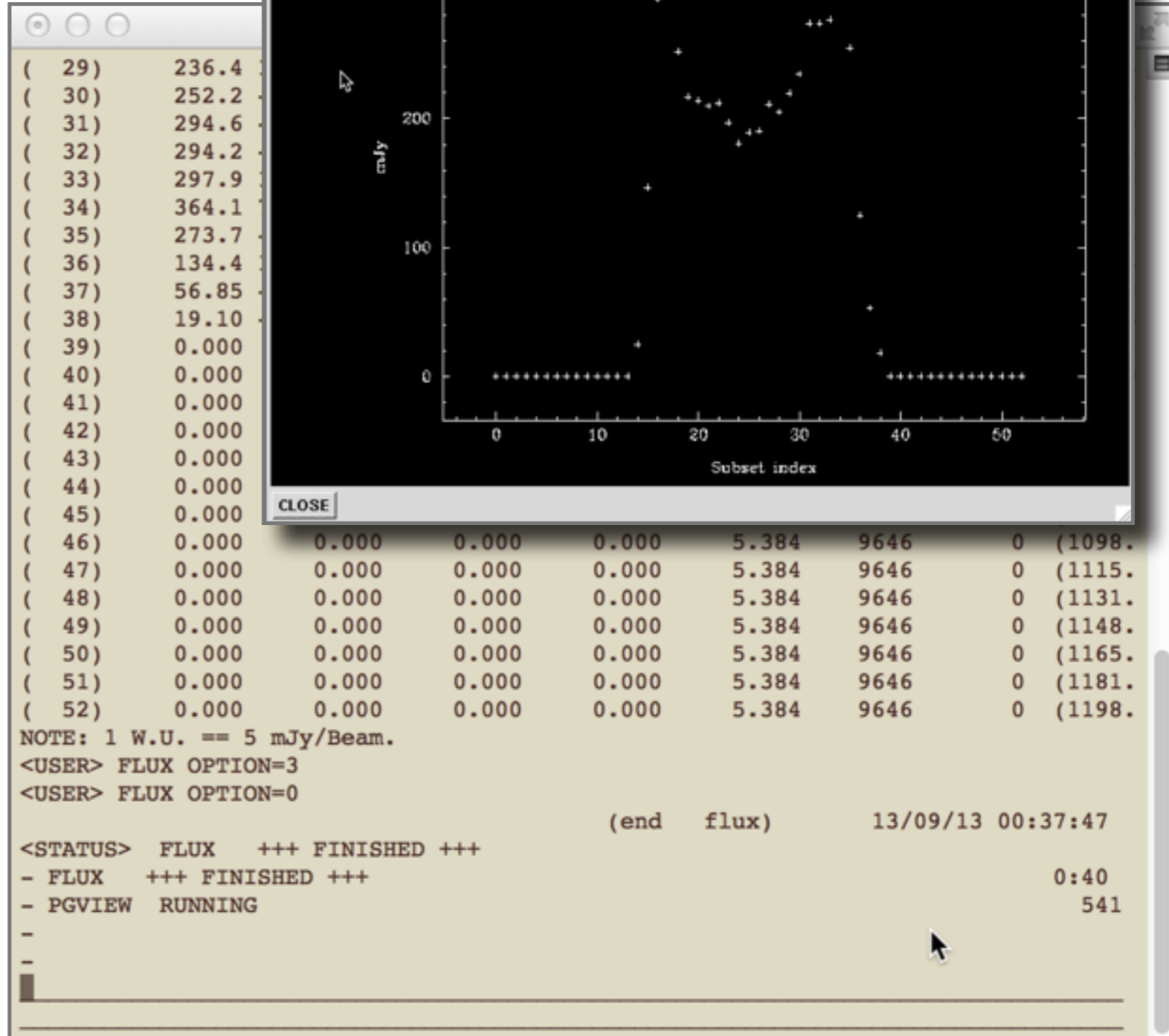
```

# Calculate the HI global profiles

- ▶ Calculate the flux of N4088 in each channel

```
flux
INSET = N4088.HIcube f
BOX1 = -60 0 45 90
BOX2 = ↶
CLEANBEAM = y
BEAM = 14.0 11.0
GRDEVICE = screen
FILENAME = N4088.gp.tbl
OPTION = 3
OPTION = 0
```

Repeat this for a box that encloses N4085.



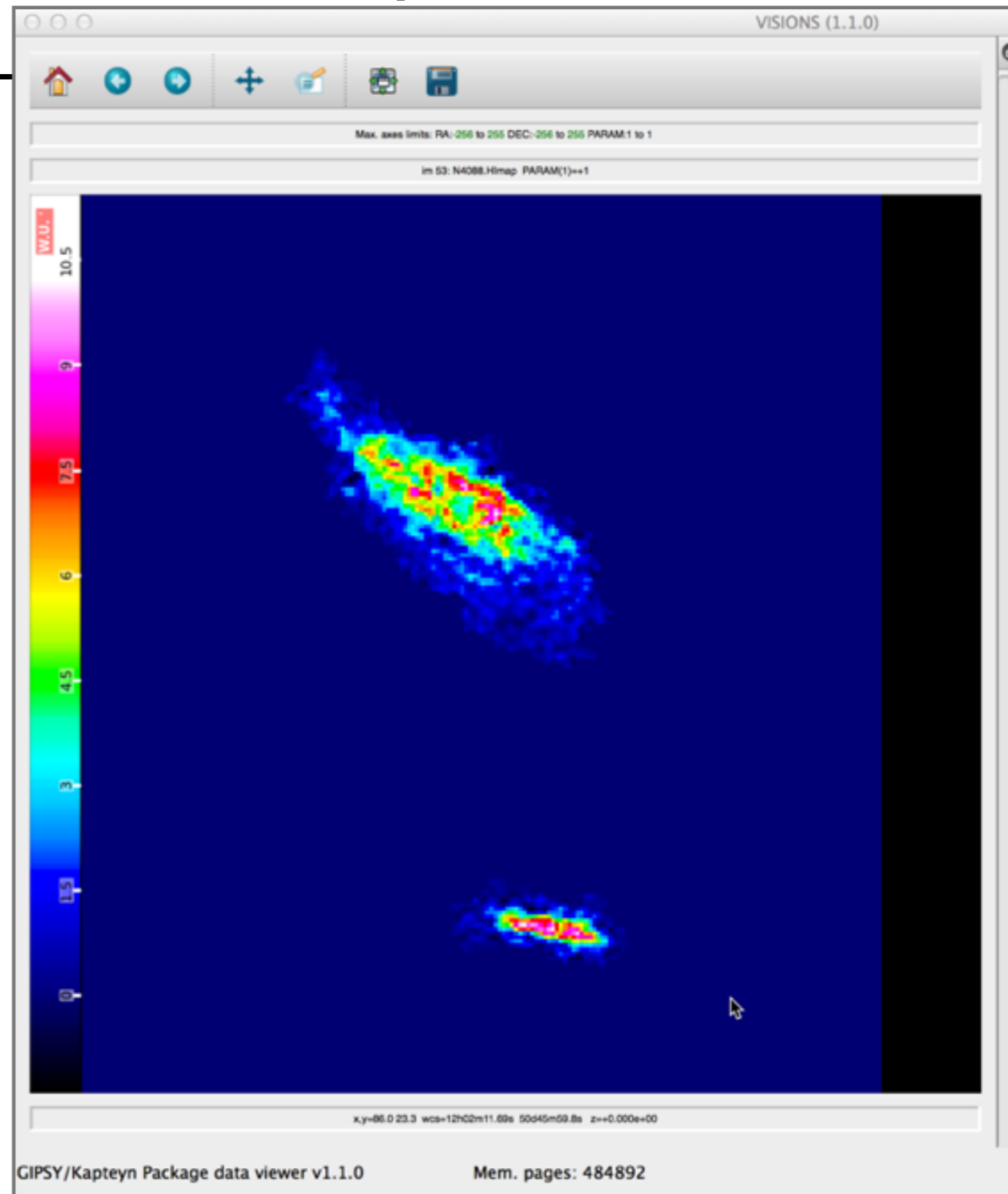


# Make the total HI map

- ▶ sum all the channels in the conditionally transferred cube

```
sum
INSET = N4088.HIcube f
BOX = ↶
CUT = ↶
OUTSET = N4088.HImap
```

- ▶ Inspect the HI map with `visions`



# Measure the total HI mass

- ▶ Calculate the total flux in the HI map

```
flux
INSET = N4088.HImap f 0
BOX1 = -60 0 45 90
BOX2 = ↶
CLEANBEAM = y
BEAM = 14.0 11.0
GRDEVICE = null
FILENAME = ↶
OPTION = 0
```

channel width [km/s]



$$\int S_\nu dv = 5.118 \times 15.0 = 76.8 \text{ [Jy km/s]}$$

$$D = 18.6 \text{ [Mpc]}$$

$$M_{\text{HI}} = 2.36 \times 10^5 \times D^2 \times \int S_\nu dv = 6.3 \times 10^9 \text{ [M}_{\text{sun}}\text{]}$$

```
Terminal — python — 80x35

-plots the results
-writes data to COLUMNS in a TABLE (TABNAME=)
-can use polygons instead of boxes (hidden keyword PO

=====
<USER> FLUX INSET=N4088.HImap p 1
Set N4088.HImap has 3 axes
RA---NCP          from -256 to  255
DEC--NCP          from -256 to  255
PARAM-SUM         from   1 to   1
PBC:  Used frequency:0.141669D+01 GHz
FLUX:  Data is identified as radio data
<USER> FLUX BOX1=-60 0 45 90
<USER> FLUX BOX2=
<USER> FLUX CLEANBEAM=y
<USER> FLUX BEAM=14.0 11.0
<USER> FLUX GRDEVICE=null
<USER> FLUX FILENAME=

SET: N4088.HImap  BOX 1: [ -60 0 45 90]
=====
subset      sum      sumPBC      flux      fluxPBC      sumAP
( # )      W.U. '   W.U. '   mJy       mJy         *
=====
( 0 )      5510. 2.933e+20  5118. 2.724e+20  5.384
NOTE: 1 W.U. == 5 mJy/Beam.
<USER> FLUX OPTION=0

                                (end flux)

<STATUS> FLUX   +++ FINISHED +++
- FLUX   +++ FINISHED +++
- PGVIEW RUNNING
-
```

# Construct a velocity field - I

- Use moments to make initial estimates

```

moments
INSET = N4088.HIcube f
BOX = ↵
OPTION = ↵
OPTION = 1 2 4
OUTSET = N4088.mom
RANGE = ↵
WINDOW = ↵

```

- re-order the subsets  
→ run copy 3 times:

```

copy
INSET = N4088.mom p 2 0 1
BOX = ↵
OUTSET = N4088.ini 1 2 3

```

```

Terminal — python — 80x35
DEC--NCP          from -256 to 255
<USER> MOMENTS OPTION=
          =====MOMENTS=====
0 Integrate subsets along operation axis
1 Intensity-weighted mean in profile
2 Intensity weighted dispersion in profile
3 Physical coordinate of maximum value on operating axis
4 Maximum values on operating axis
5 Dispersion in intensities
6 Number of subsets
7 Intensity weighted Mode (only with WINDOW=0)
<USER> MOMENTS OPTION=1 2 4
<USER> MOMENTS OUTSET=N4088.mom
Set N4088.mom has 3 axes
RA---NCP          from -256 to 255
DEC--NCP          from -256 to 255
PARAM-MOMENTS    from 0 to 2
<USER> MOMENTS RANGE=
<USER> MOMENTS WINDOW=
===== MOMENTS =====
Profiles examined from set [N4088.HIcube]
Results in output set [N4088.mom]
-subset 0: Intensity weighted mean of physical coords. (1 momen
-subset 1: Dispersion in intensity weighted physical coords. (2
-subset 2: Peak value in profile.
Units of operation axis: KM/S
Units of data: W.U. '
                                     (end moments) 13/09
<STATUS> MOMENTS +++ FINISHED +++
- MOMENTS +++ FINISHED +++
- PGMVIEW RUNNING
-

```



# Construct a velocity field - 2

## ► Make Gauss fits using the initial estimates

```
gaufit
STARTNEW = n
INSET = N4088.HIcube f
BOX = ↵
OPTION = ↵
OPTION = 0 1 2
NGAUSS = 1
OUTSET = N4088.velfi
ESTRMS = 0.28
NCORR = 1
Q = 2
CUTAMP = 3*0.28
CUTDISP = 5
TOLERANCE = ↵
```

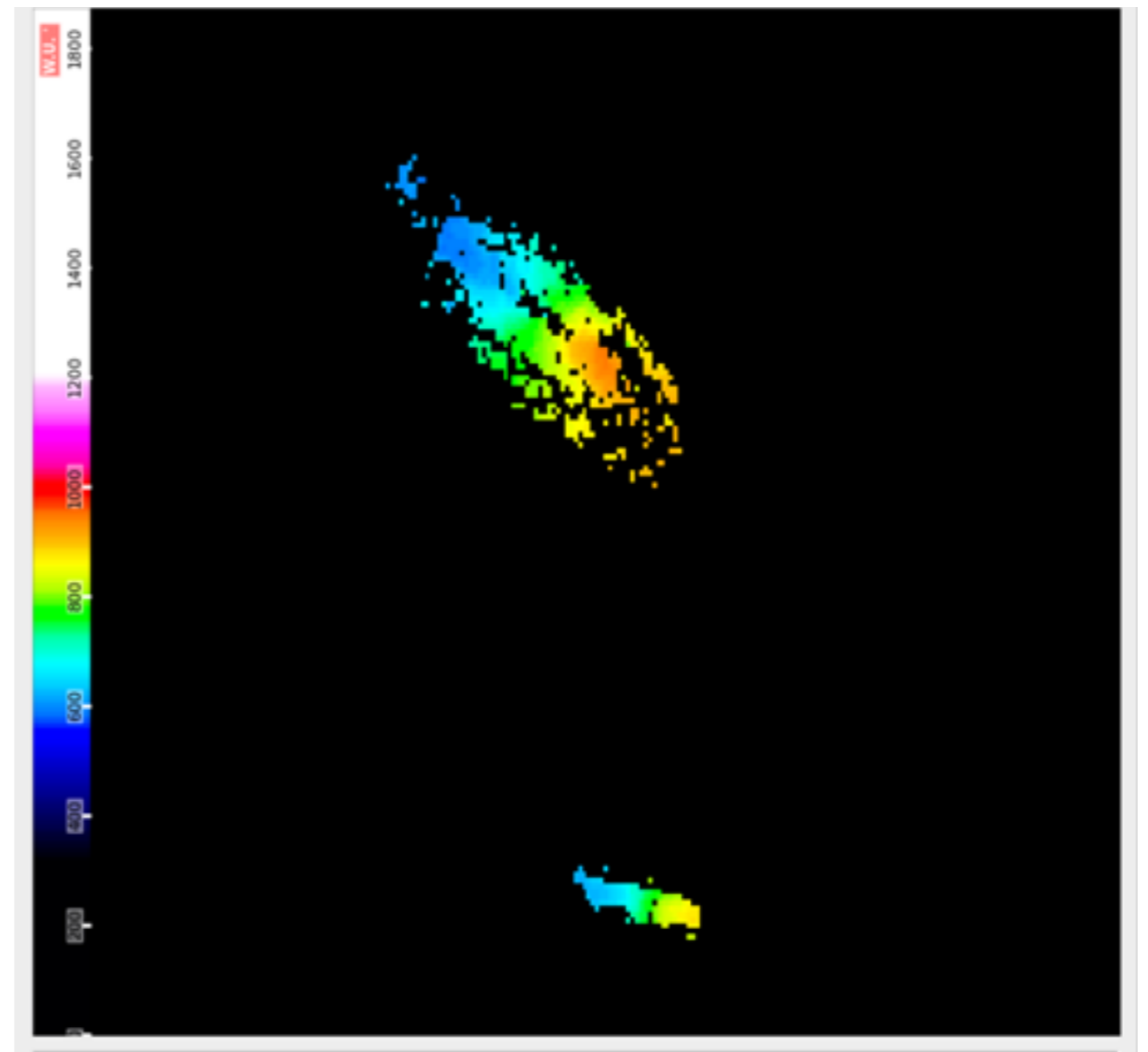
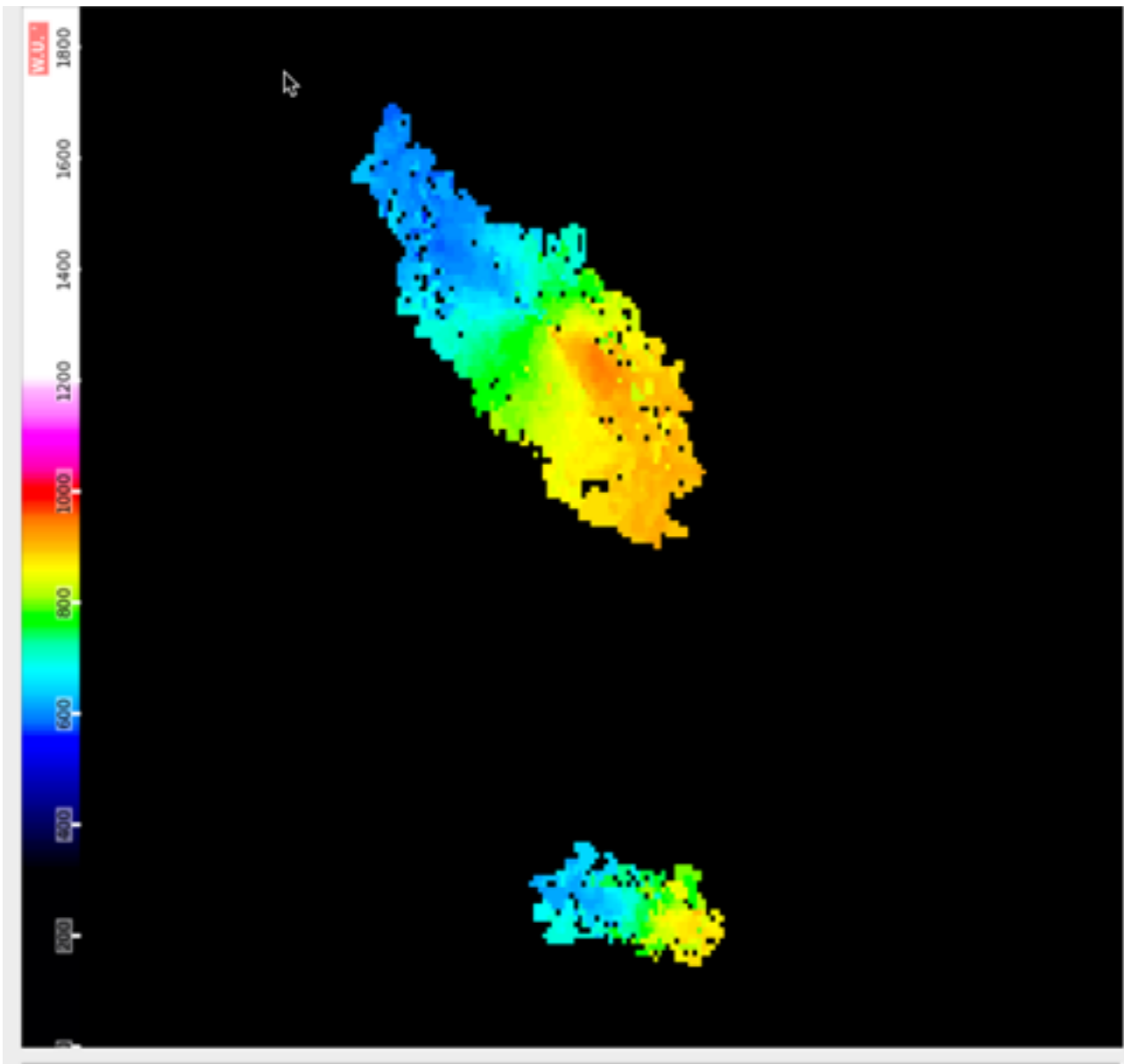
```
Terminal — python — 80x35
<USER> GAUFIT Q=2
<USER> GAUFIT CUTAMP=3*0.28
<USER> GAUFIT CUTDISP=5
<USER> GAUFIT TOLERANCE=

===== RESULTS =====
Profiles from set:  N4088.HIcube
Results in set:    N4088.velfi
param 1: Estimated amplitudes of component 1
param 2: Estimated centre of component 1
param 3: Estimated dispersion of component 1
param 4: fitted amplitudes of component 1
param 5: fitted centre of component 1
param 6: fitted dispersion of component 1
param 7: Error in fitted amplitudes of component 1
param 8: Error in fitted centre of component 1
param 9: Error in fitted dispersion of component 1
Max. number of gaussians in profile is 1
Range operation axis: [336.595,1198.34] KM/S
Fitted gaussians will have amplitude > 0.840000 W.U. '
Fitted gaussians will have dispersion > 5.000000 KM/S
One pixel on operation axis has (average) width 16.572090 KM/S
Processed 262144 profiles in 0.67 sec (0.65 cpu sec)
Number of profiles fitted with Q= 2:  2155
For 259124 profiles no estimate was found.
For 259989 profiles the fitting failed.
367 times the max. no. iterations was exceeded.
                                     (end  gaufit)      13/09/13 0
<STATUS> GAUFIT  +++ FINISHED +++
- GAUFIT  +++ FINISHED +++
- PGVIEW  RUNNING
-
-
█
```



# Construct a velocity field - 3

MOMENTS  $\xrightarrow{\text{initial estimate}}$  GAUFIT

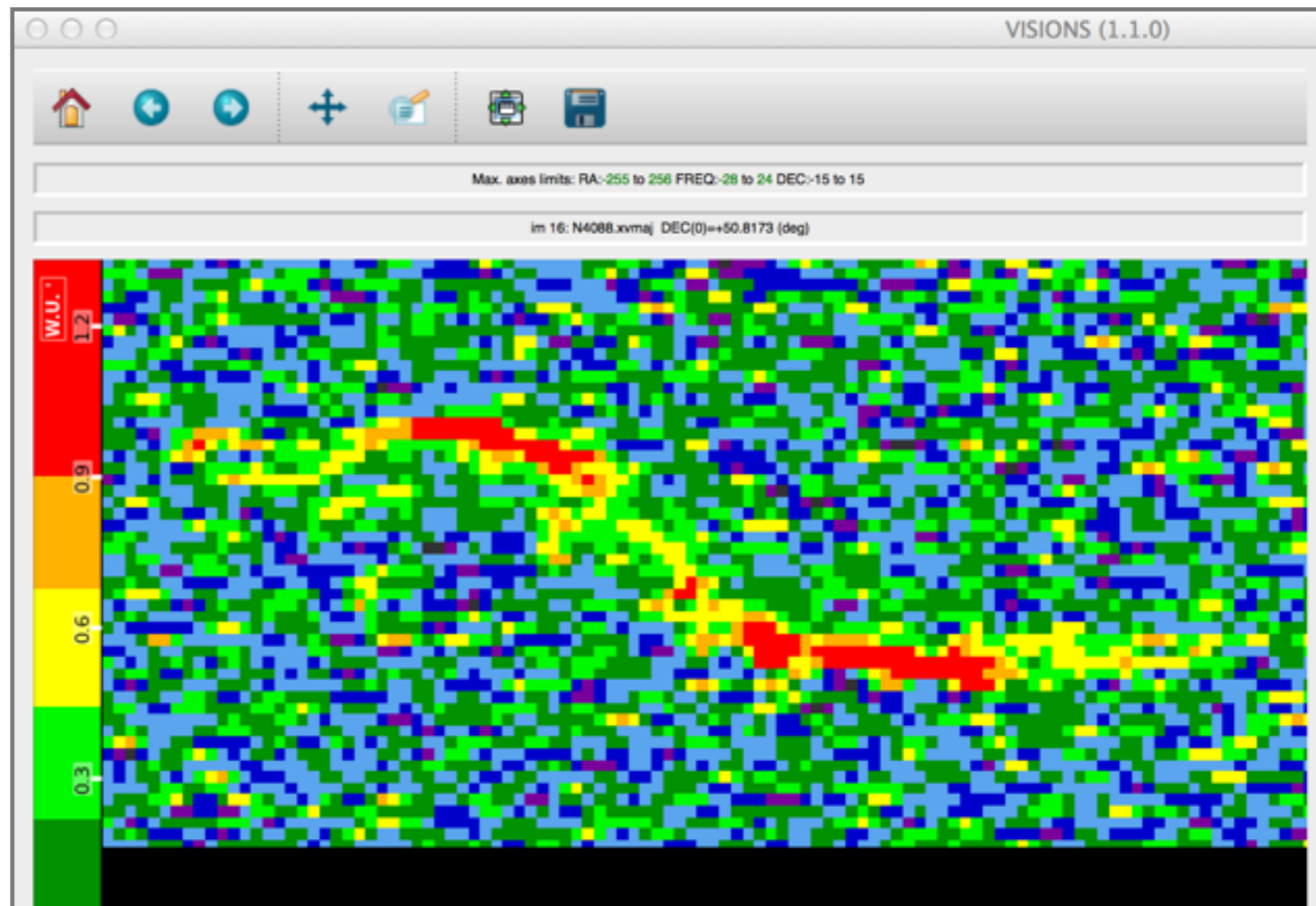


# Extract a Position-Velocity diagram

- ▶ Cut along the kinematic major axis

```
slice  
INSET = lmap.cl f  
POSITION = * 12 03 01.97 * 50 49 02.3  
ANGLE = 230  
GRIDOUT = ↶  
POINTS = ↶  
SLICES = 15,15  
SPACE = ↶  
OUTSET = N4088.xvmaj  
PLOT = n
```

Note that de 'DEC-axis'  
contains the 31 slices.



# Extract a rotation curve

## ► Example of `rotcur` parameters :

```
rotcur
INSET = N4088.velfi p 5
BOX = -60 0 45 90
RADII = 5:205:10
WIDTHS = 10.0 ;
VSYS = 757.0 ;
VROT = 200.0 ;
VEXP = 0.0 ;
PA = 230.0 ;
INCL = 65.0 ;
CENTRE = * 12 03 01.97 * 50 49 02.3
FREEANGLE = 0.0
SIDE = both
WEIGHT = uniform
FIXED = VSYS XPOS YPOS VEXP
FILENAME = N4088.rotcur.tbl
```

Note that `rotcur` can be run multiple times, keeping different sets of parameters fixed.

For example:

- Step 1 : fit `Vsys, Center`
- Step 2 : fit `PA, INC, VROT`
- Step 3 : fit `INC, VROT`
- Step 4 : fit `VROT`