Images: Error Recognition and Analysis

Robert Laing
ESO

ERIS, ASTRON, Sept 9 - 13 2013

Error recognition

Load the files

In the directory where you put the .tgz files

```
>tar xvfz T7images.tgz
T7images/
T7images/REFERENCE.IMAGE.FITS
T7images/ERROR3.IMAGE.FITS
T7images/ERROR4.IMAGE.FITS
T7images/ERROR1.IMAGE.FITS
T7images/ERROR2.IMAGE.FITS
>tar xvfz T7uv_AIPS.tgz
T7uv/
T7uv/ERROR2.UV.FITS
T7uv/REFERENCE.UV.FITS
T7uv/ERROR3.UV.FITS
T7uv/ERROR1.UV.FITS
T7uv/ERROR4.UV.FITS
T7uv/CBAND.BOXES

>cd T7images
>mv ../T7uv/* .
```

(to get everything in the same directory)

You should have
```
>ls -1
CBAND.BOXES
ERROR1.IMAGE.FITS
ERROR1.UV.FITS
ERROR2.IMAGE.FITS
ERROR2.UV.FITS
ERROR3.IMAGE.FITS
ERROR3.UV.FITS
ERROR4.IMAGE.FITS
ERROR4.UV.FITS
REFERENCE.IMAGE.FITS
REFERENCE.UV.FITS
```

The following assumes that you are starting AIPS in the same directory as you have stored all of the files. If not, set an environment variable (e.g. MYDATA) to point at the data directory, e.g.:

```
>setenv MYDATA /home/another/aipsdata (C shell)
```

or

```
>export MYDATA='/home/another/aipsdata' (bash shell)
```

Start up AIPS

```
>aips tv=local
AIPS 1: Enter user ID number
?6
```

>restore 0

to make a pristine AIPS environment

Load the images

```
>task 'fitld'
>defau fitld
>datain 'pwd:REFERENCE.IMAGE.FITS'
>go
>datain 'pwd:ERROR1.IMAGE.FITS'
>go
>datain 'pwd:ERROR2.IMAGE.FITS'
>go
>datain 'pwd:ERROR3.IMAGE.FITS'
>go
>datain 'pwd:ERROR4.IMAGE.FITS'
>go
```

Your catalogue should have:

```
>mc
AIPS 1: Catalog on disk  1
AIPS 1:  Cat Usid Mapname      Class   Seq  Pt     Last access      Stat
AIPS 1:    1    6 REFERENCE   .ICL001.    1 MA 11-SEP-2013 15:39:00
AIPS 1:    2    6 ERROR1      .ICL001.    1 MA 11-SEP-2013 15:40:09
AIPS 1:    3    6 ERROR2      .ICL001.    1 MA 11-SEP-2013 15:40:22
AIPS 1:    4    6 ERROR3      .ICL001.    1 MA 11-SEP-2013 15:40:27
AIPS 1:    5    6 ERROR4      .ICL001.    1 MA 11-SEP-2013 15:40:32
```

Now look at the images with two different intensity ranges, starting from the reference image

```
>getn 1
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   REFERENCE.ICL001.1
>pixr 0
>tvlo
>pixr 0 0.005
>tvlo
```

This is the "best" image I have managed to make of the famous microquasar SS433 (an observation with the VLA A configuration at 4.9 GHz, courtesy of Katherine Blundell).

To turn on colour

```
>tvps
```

then hit D with cursor in TV window

To change the transfer function:

```
>tvtra
```

then adjust by moving the cursor to the TV window, hold down the left mouse button and move around the frame. Press D to exit (the cursor must still be within the frame).

To reset the transfer function to the default value:

```
>offtra
```

To revert to grey-scale

```
>offps
```

Images ERROR1 - ERROR4 each have one, deliberate error introduced.

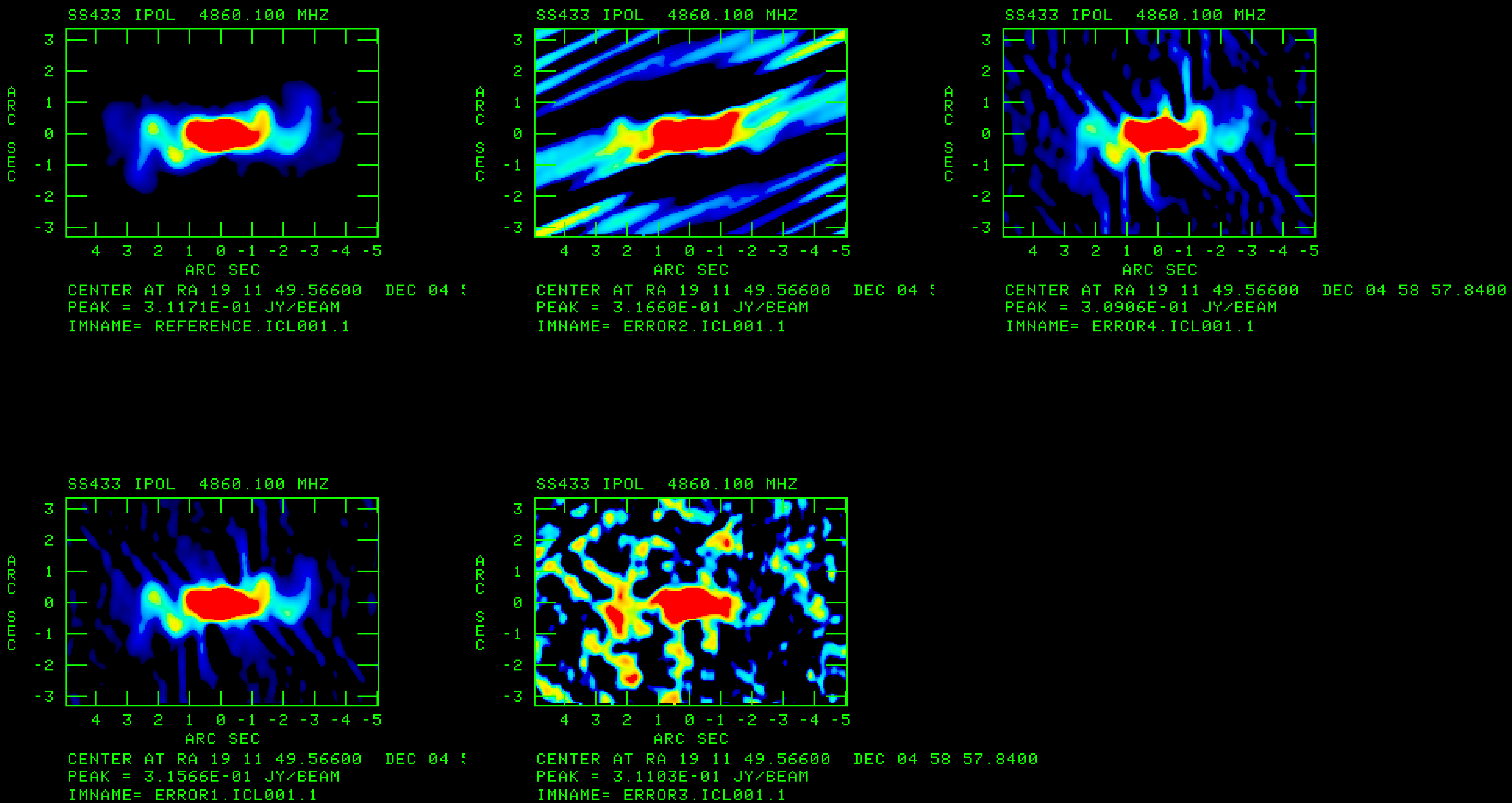
The aim of this part of the tutorial is to identify the type of error. Later on, we will work out how to localise and fix the errors.

For each of the images ERROR1 - ERROR4, look at the form of the error pattern. Using the guidelines from the Error recognition lecture, work out what sort of error has been applied to each dataset.

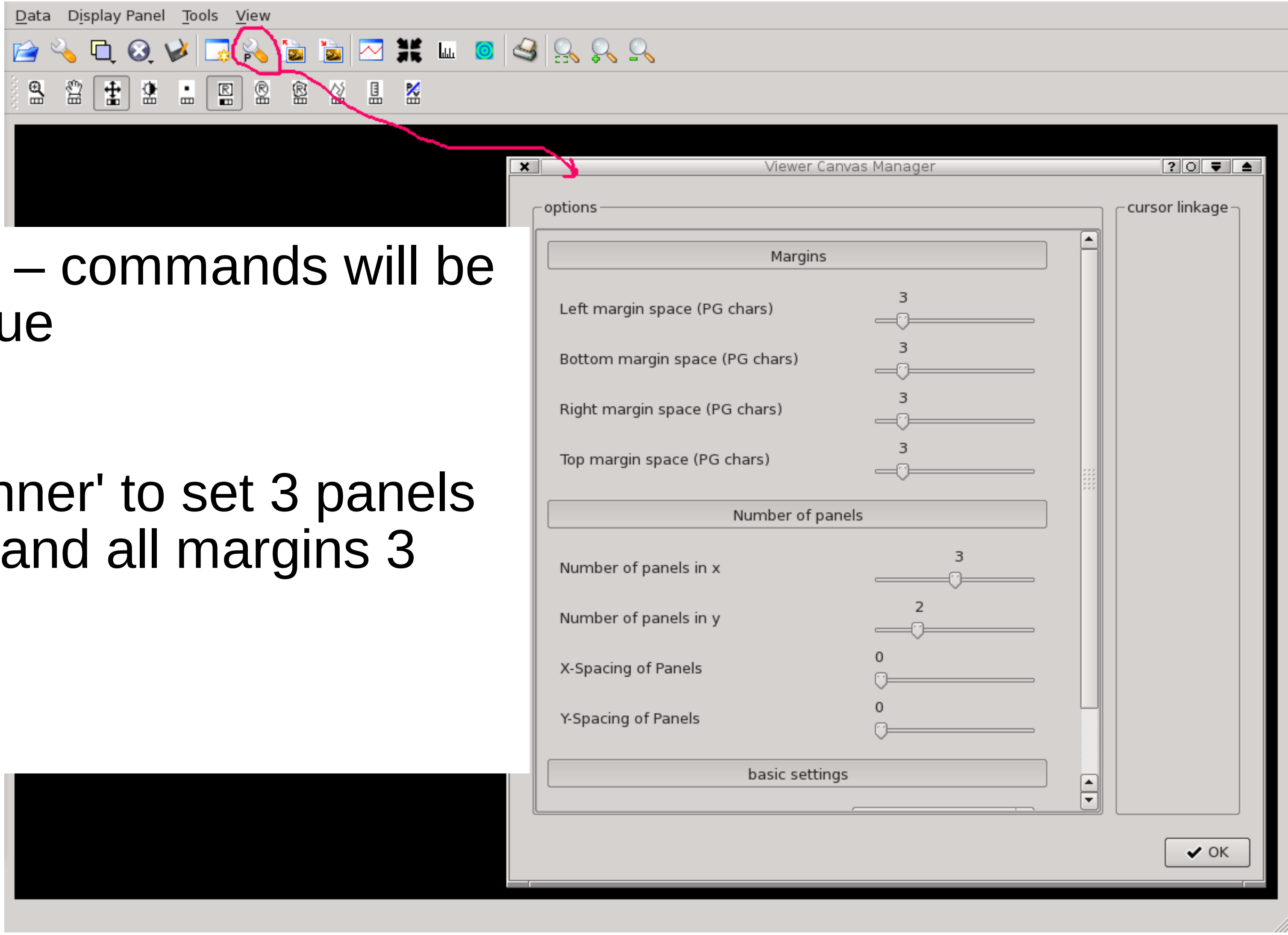
To look at them:

```
>getn 2
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   ERROR1.ICL001.1
>pixr 0
>tvlo
>pixr 0 0.005
>tvlo
```

and so on for ERROR2-4.


SS433 IPOL 4860.100 MHZ
ARC SEC
CENTER AT RA 19 11 49.56600 DEC 04 5
PEAK = 3.1171E-01 JY/BEAM
IMNAME= REFERENCE.ICL001.1
SS433 IPOL 4860.100 MHZ
ARC SEC
CENTER AT RA 19 11 49.56600 DEC 04 5
PEAK = 3.1660E-01 JY/BEAM
IMNAME= ERROR2.ICL001.1
SS433 IPOL 4860.100 MHZ
ARC SEC
CENTER AT RA 19 11 49.56600 DEC 04 58 57.8400
PEAK = 3.0906E-01 JY/BEAM
IMNAME= ERROR4.ICL001.1
SS433 IPOL 4860.100 MHZ
ARC SEC
CENTER AT RA 19 11 49.56600 DEC 04 5
PEAK = 3.1566E-01 JY/BEAM
IMNAME= ERROR1.ICL001.1
SS433 IPOL 4860.100 MHZ
ARC SEC
CENTER AT RA 19 11 49.56600 DEC 04 58 57.8400
PEAK = 3.1103E-01 JY/BEAM
IMNAME= ERROR3.ICL001.1

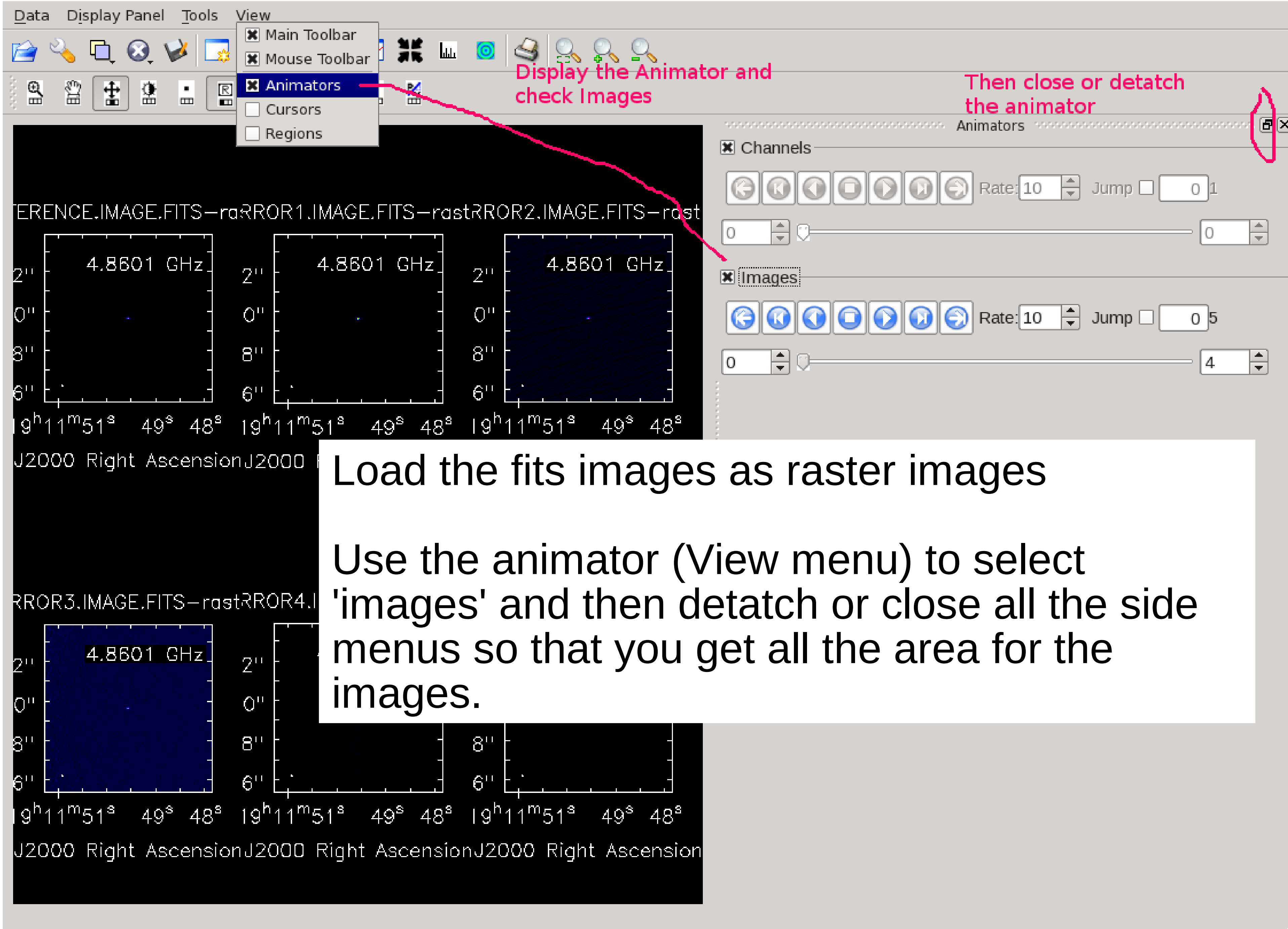
Finding errors in images: CASA approach



Start CASA – commands will be shown in blue

viewer()

Use 'P-spanner' to set 3 panels in X, 2 in Y and all margins 3 units

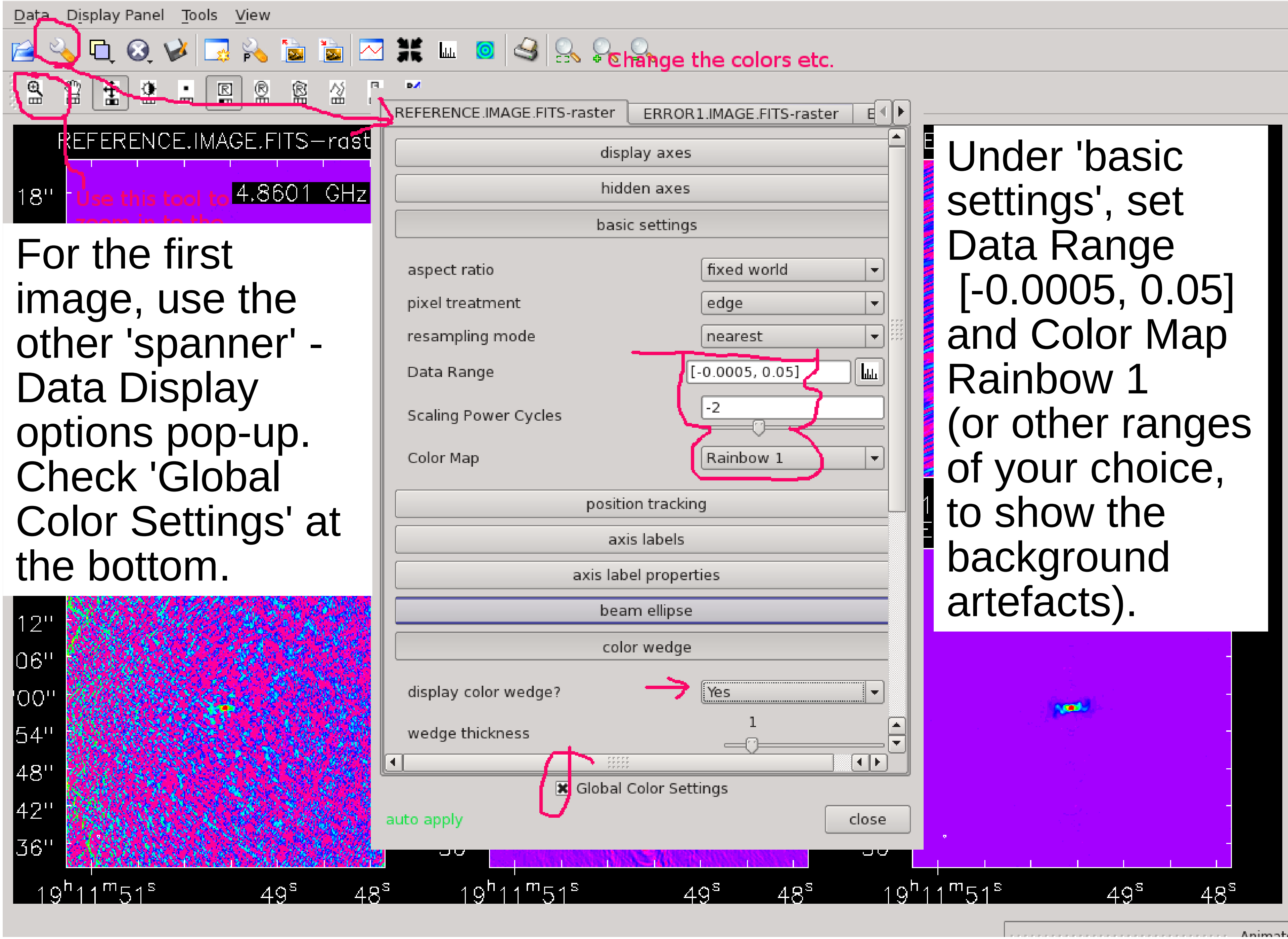


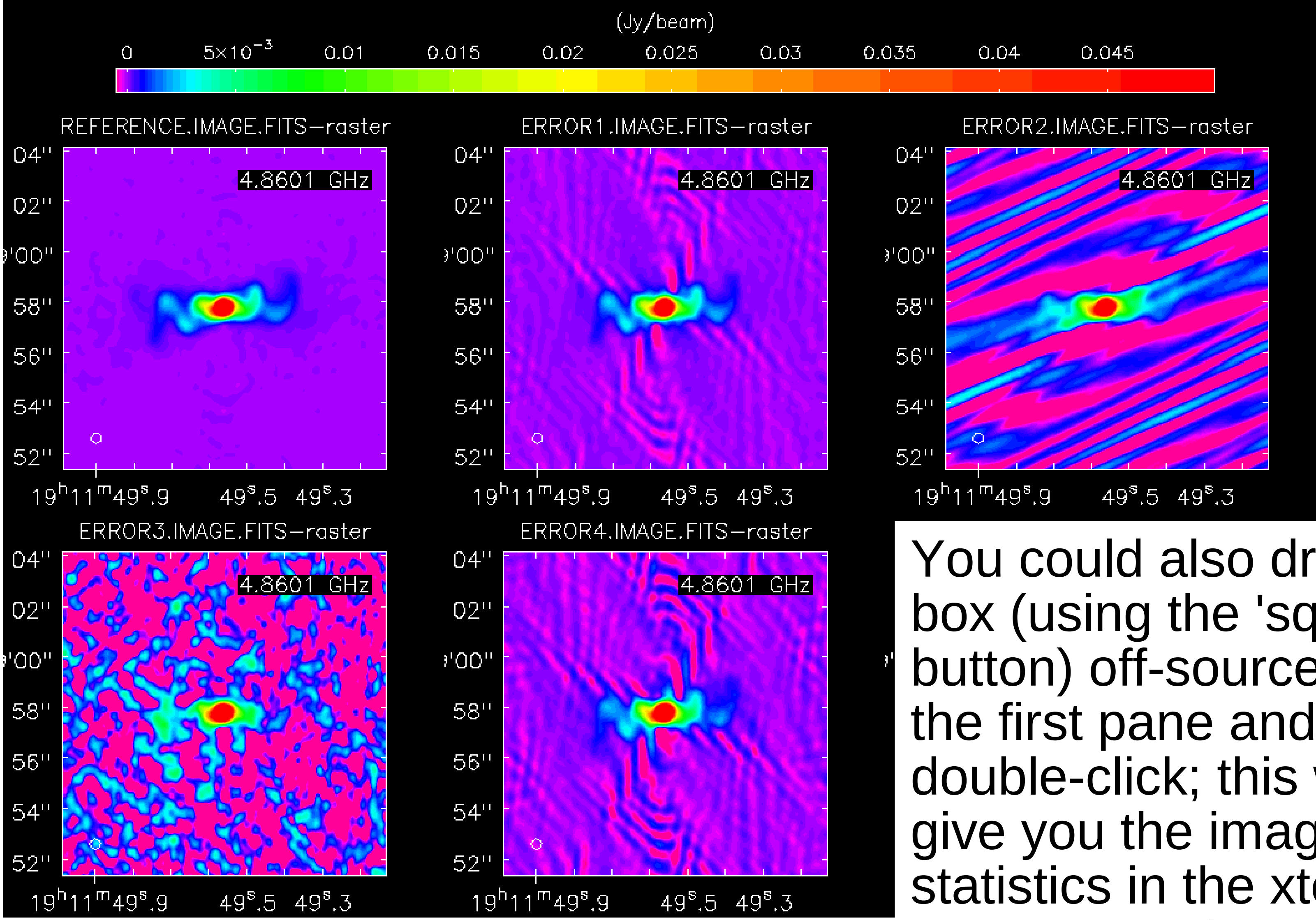
Load the fits images as raster images

Use the animator (View menu) to select 'images' and then detatch or close all the side menus so that you get all the area for the images.

For the first image, use the other 'spanner' - Data Display options pop-up. Check 'Global Color Settings' at the bottom.

Under 'basic settings', set Data Range [-0.0005, 0.05] and Color Map Rainbow 1 (or other ranges of your choice, to show the background artefacts).





You could also draw a box (using the 'square' button) off-source in the first pane and double-click; this will give you the image statistics in the xterm you are running CASA in, so you can see the increase in noise rms in the various images.

Error diagnosis: AIPS

First load all of the uv data

```
>tget fitld
>datain 'pwd:error1.uv.fits'
>go
```

and so on for the other three files

```
>uc
AIPS 1: Catalog on disk  1
AIPS 1:  Cat Usid Mapname      Class   Seq  Pt     Last access      Stat
AIPS 1:    6    6 ERROR1      .UV     .    1 UV 11-SEP-2013 17:25:06
AIPS 1:    7    6 ERROR2      .UV     .    1 UV 11-SEP-2013 17:26:50
AIPS 1:    8    6 ERROR3      .UV     .    1 UV 11-SEP-2013 17:27:00
AIPS 1:    9    6 ERROR4      .UV     .    1 UV 11-SEP-2013 17:27:08
```

A good way to find residual errors is to subtract the current model and look at the residuals.

```
>task 'uvsub'
>defau 'uvsub'
>getn 6
AIPS 1: Got(1)   disk= 1  user=   6   type=UV   ERROR1.UV.1
>get2n 2
>outn inn
>outc 'uvsub'
>go
```

This produces a uv file with the current CLEAN model subtracted:

AIPS 1: 8 6 ERROR1 .UVSUB . 1 UV 11-SEP-2013 17:02:08

Since we are looking for an amplitude error, it makes sense to display the residual amplitudes by antenna, baseline and time. To do this:

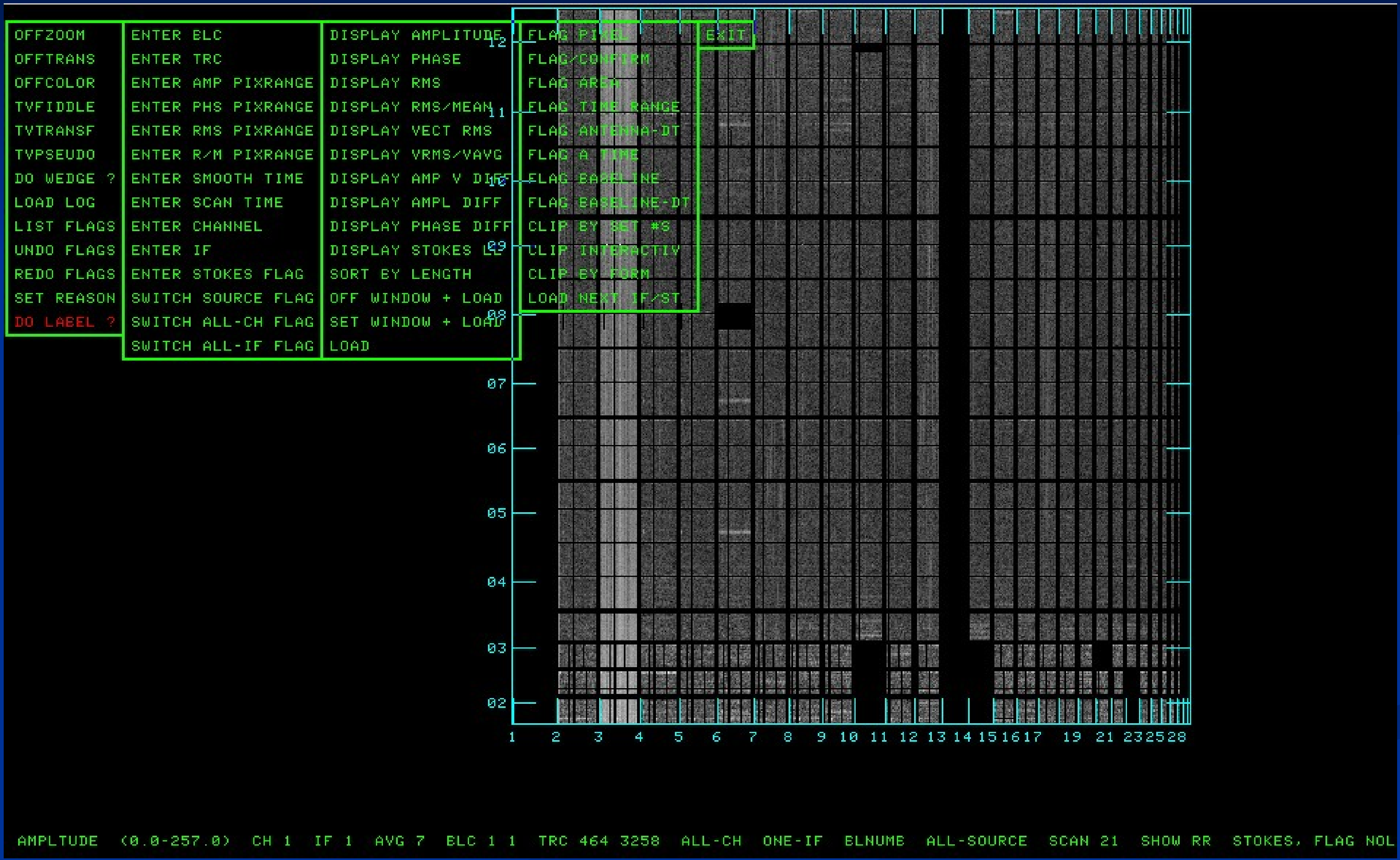
```
>task 'tvflg'
>defau 'tvflg
>getn 8
```

left click on DO LABEL? (bottom left hand corner of options) and press A. This labels the antennas and times. We aren't going to do any flagging at this point, so left click on EXIT and press A.

It is clear from this that antenna 3 has consistently high amplitudes. In fact, all of the amplitudes for that antenna were multiplied by 1.2 for the full timerange.

In fact, the error in this example is sufficiently large that you can see it on a plot of amplitude against uv distance even without doing the subtraction. This would not normally be the case at this stage in the reduction.

At this point, we could flag the offending data or otherwise fix the problem (in this particular case, it could be cured by 2 or 3 iterations of amplitude+phase selfcal).


OFFZOOM
OFFTRANS
OFFCOLOR
TVFIDDLE
TVTRANSF
TVPSEUDO
DO WEDGE ?
LOAD LOG
LIST FLAGS
UNDO FLAGS
REDO FLAGS
SET REASON
DO LABEL ?
ENTER BLC
ENTER TRC
ENTER AMP PIXRANGE
ENTER PHS PIXRANGE
ENTER RMS PIXRANGE
ENTER R/M PIXRANGE
ENTER SMOOTH TIME
ENTER SCAN TIME
ENTER CHANNEL
ENTER IF
ENTER STOKES FLAG
SWITCH SOURCE FLAG
SWITCH ALL-CH FLAG
SWITCH ALL-IF FLAG
DISPLAY AMPLITUDE
DISPLAY PHASE
DISPLAY RMS
DISPLAY RMS/MEAN
DISPLAY VECT RMS
DISPLAY VRMS/VAVG
DISPLAY AMP V DIFF
DISPLAY AMPL DIFF
DISPLAY PHASE DIFF
DISPLAY STOKES LL
SORT BY LENGTH
OFF WINDOW + LOAD
SET WINDOW + LOAD
LOAD
FLAG PIXEL
FLAG/CONFIRM
FLAG AREA
FLAG TIME RANGE
FLAG ANTENNA-DT
FLAG A TIME
FLAG BASELINE
FLAG BASELINE-DT
CLIP BY SET #S
CLIP INTERACTIV
CLIP BY FORM
LOAD NEXT IF/ST
EXIT
12
11
10
09
08
07
06
05
04
03
02
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 23 25 28
AMPLTUDE (0.0-257.0) CH 1 IF 1 AVG 7 BLC 1 1 TRC 464 3258 ALL-CH ONE-IF BLNUME ALL-SOURCE SCAN 21 SHOW RR STOKES, FLAG NOL

(b) ERROR2: Very high amplitudes over a short time period

This error is actually so bad that we could see it in the original data without subtraction, but in general this would not be the case, so follow the same procedure with UVSUB and TVFLG.

```
>tget uvsub
>inn 'error2'
>outn inn
>go
```

This makes

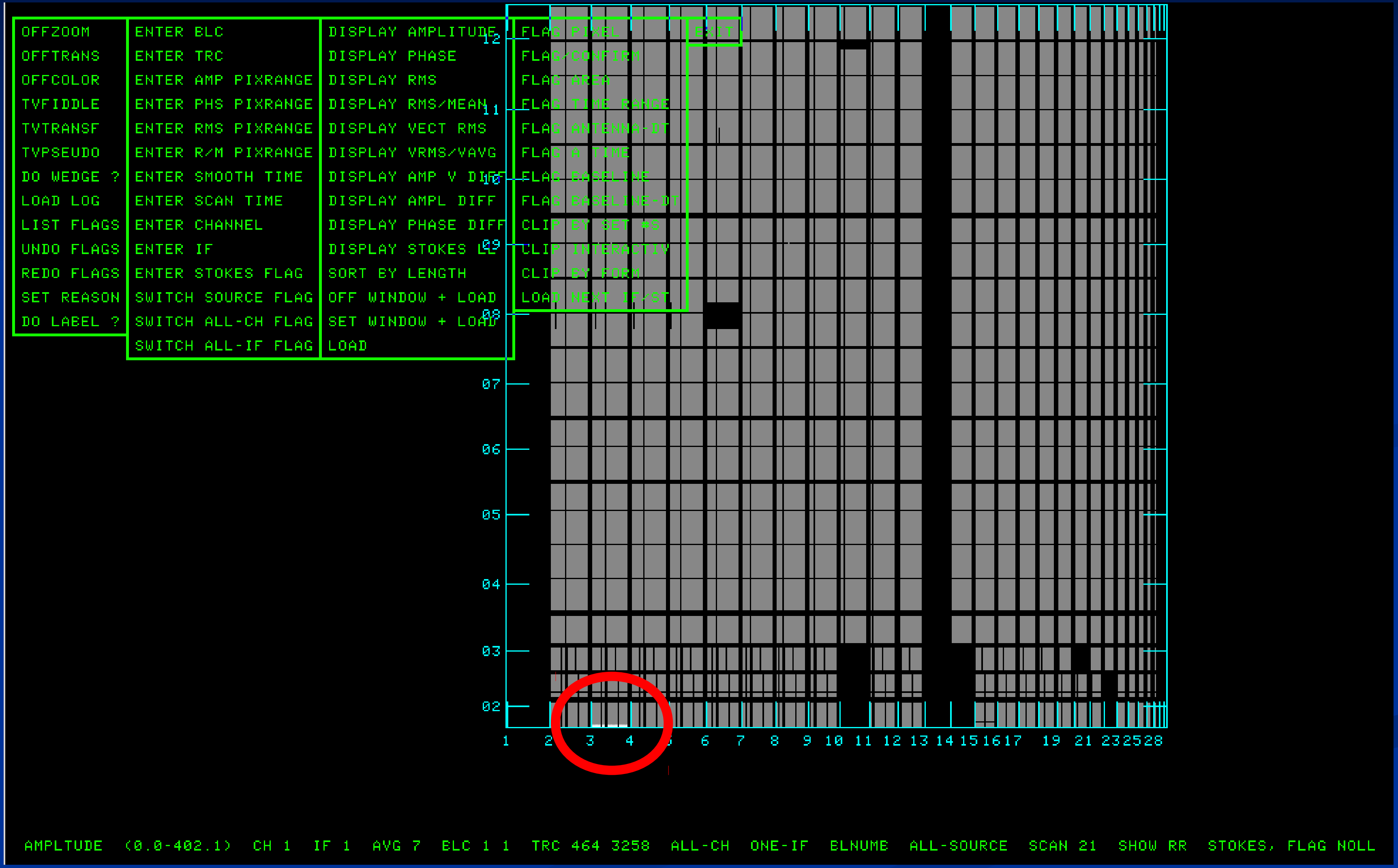
```
AIPS 1:   11    6 ERROR2      .UVSUB .    1 UV 11-SEP-2013 17:28:36
```

Display amplitudes using TVFLG

```
>tget tvflg
>getn 11
AIPS 1: Got(1)   disk= 1  user=   6   type=UV   ERROR2.UVSUB.1
>go
```

again, left click on DO LABEL? and press A; then left click on EXIT and press A.

The problem here is that antenna 3 (IF 1) has extremely high amplitudes for the first integration. Again, an error of this magnitude would normally have been found at an earlier stage in the processing, but low-level, persistent errors would not.


OFFZOOM
OFFTRANS
OFFCOLOR
TVFIDDLE
TVTRANSF
TVPSEUDO
DO WEDGE ?
LOAD LOG
LIST FLAGS
UNDO FLAGS
REDO FLAGS
SET REASON
DO LABEL ?
ENTER BLC
ENTER TRC
ENTER AMP PIXRANGE
ENTER PHS PIXRANGE
ENTER RMS PIXRANGE
ENTER R/M PIXRANGE
ENTER SMOOTH TIME
ENTER SCAN TIME
ENTER CHANNEL
ENTER IF
ENTER STOKES FLAG
SWITCH SOURCE FLAG
SWITCH ALL-CH FLAG
SWITCH ALL-IF FLAG
DISPLAY AMPLITUDE
DISPLAY PHASE
DISPLAY RMS
DISPLAY RMS/MEAN
DISPLAY VECT RMS
DISPLAY VRMS/VAVG
DISPLAY AMP V DIFF
DISPLAY AMPL DIFF
DISPLAY PHASE DIFF
DISPLAY STOKES LL
SORT BY LENGTH
OFF WINDOW + LOAD
SET WINDOW + LOAD
LOAD
FLAG PIXEL
FLAG/CONFIRM
FLAG AREA
FLAG TIME RANGE
FLAG ANTENNA-DT
FLAG A TIME
FLAG BASELINE
FLAG BASELINE-DT
CLIP BY SET #S
CLIP INTERACTIV
CLIP BY FORM
LOAD NEXT IF/ST
EXIT
12
11
10
09
08
07
06
05
04
03
02
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 23 25 28
AMPLTUDE (0.0-402.1) CH 1 IF 1 AVG 7 BLC 1 1 TRC 464 3258 ALL-CH ONE-IF BLNUMB ALL-SOURCE SCAN 21 SHOW RR STOKES, FLAG NOLL

(c) ERROR3: confusing source

Clues to the problem:
- characteristic sidelobe pattern
- far more amplitude than is present in the CLEAN model (even on the long baselines)

```
>task 'uvplt'
>default uvplt
>getn  8
AIPS 1: Got(1)   disk= 1  user=   6   type=UV   ERROR3.UV.1
>dotv 1
>stokes 'rr'
>bif 1
>eif 1
>xinc 100
```

plot every 100 points for speed

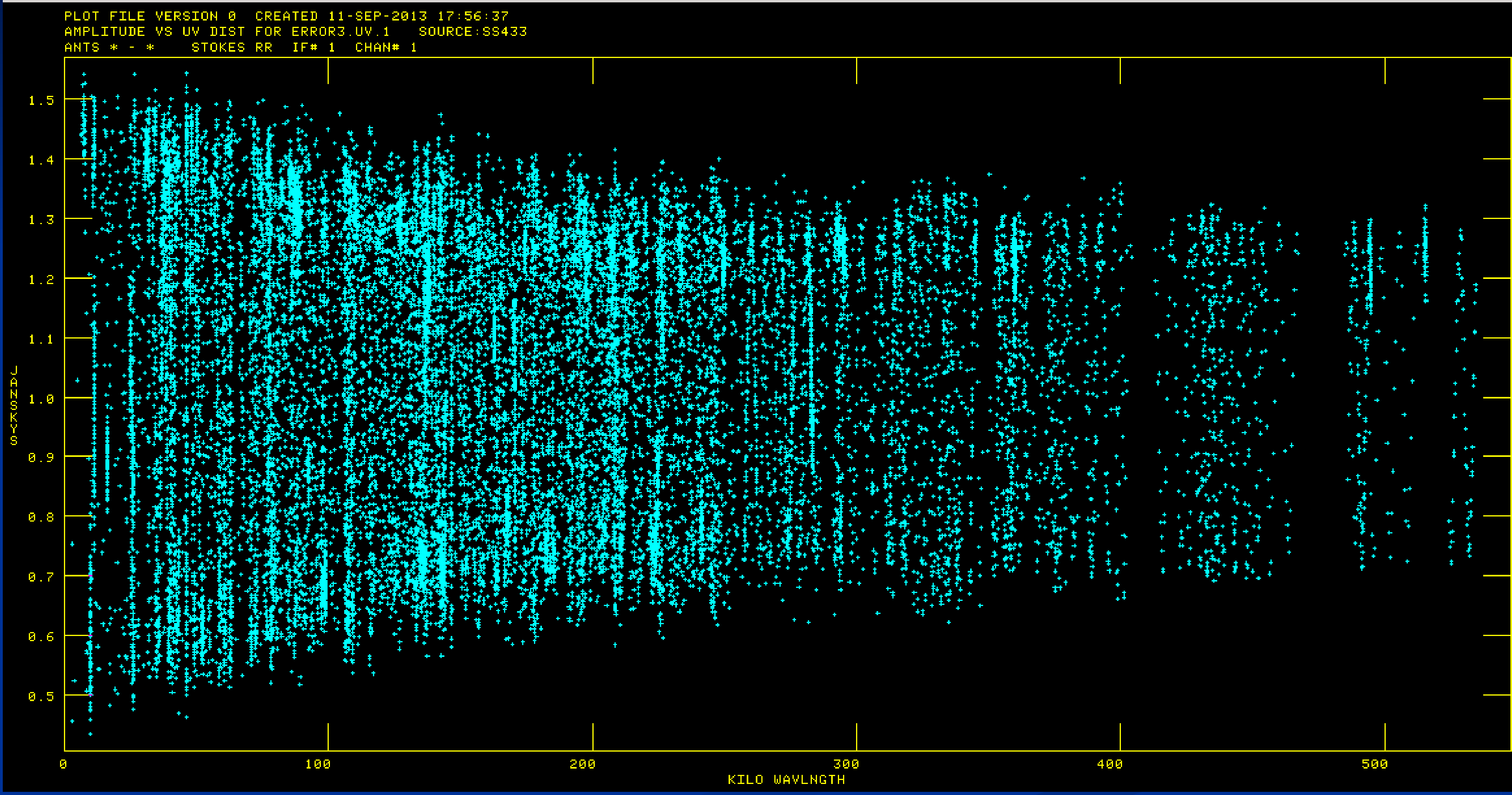
```
>tvinit
```

to clear the TV display

```
>go
```

Amplitude varies from 0.5 to 1.5 Jy, but there is only 0.46 Jy in the model!

Normally, you would make a larger map at ths point, tapering the data to allow a larger field to be imaged quickly. For this example, I have set things up to image two fields.


PLOT FILE VERSION 0 CREATED 11-SEP-2013 17:56:37
AMPLITUDE VS UV DIST FOR ERROR3.UV.1 SOURCE:SS433
ANTS * - * STOKES RR IF# 1 CHAN# 1
JANSKYS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
100
200
300
400
500
KILO WAVLNGTH

```
>task 'imagr'
>default imagr
>getn 8
AIPS 1: Got(1)   disk= 1  user=   6   type=UV   ERROR3.UV.1
>outn inn
>outse 2
>cells .05
>boxfile 'pwd:cband.boxes'
```

note that this file (which has details of the field centre positions and CLEAN boxes) must be in the directory from which AIPS was started;
if not, set an environment variable to point at it.

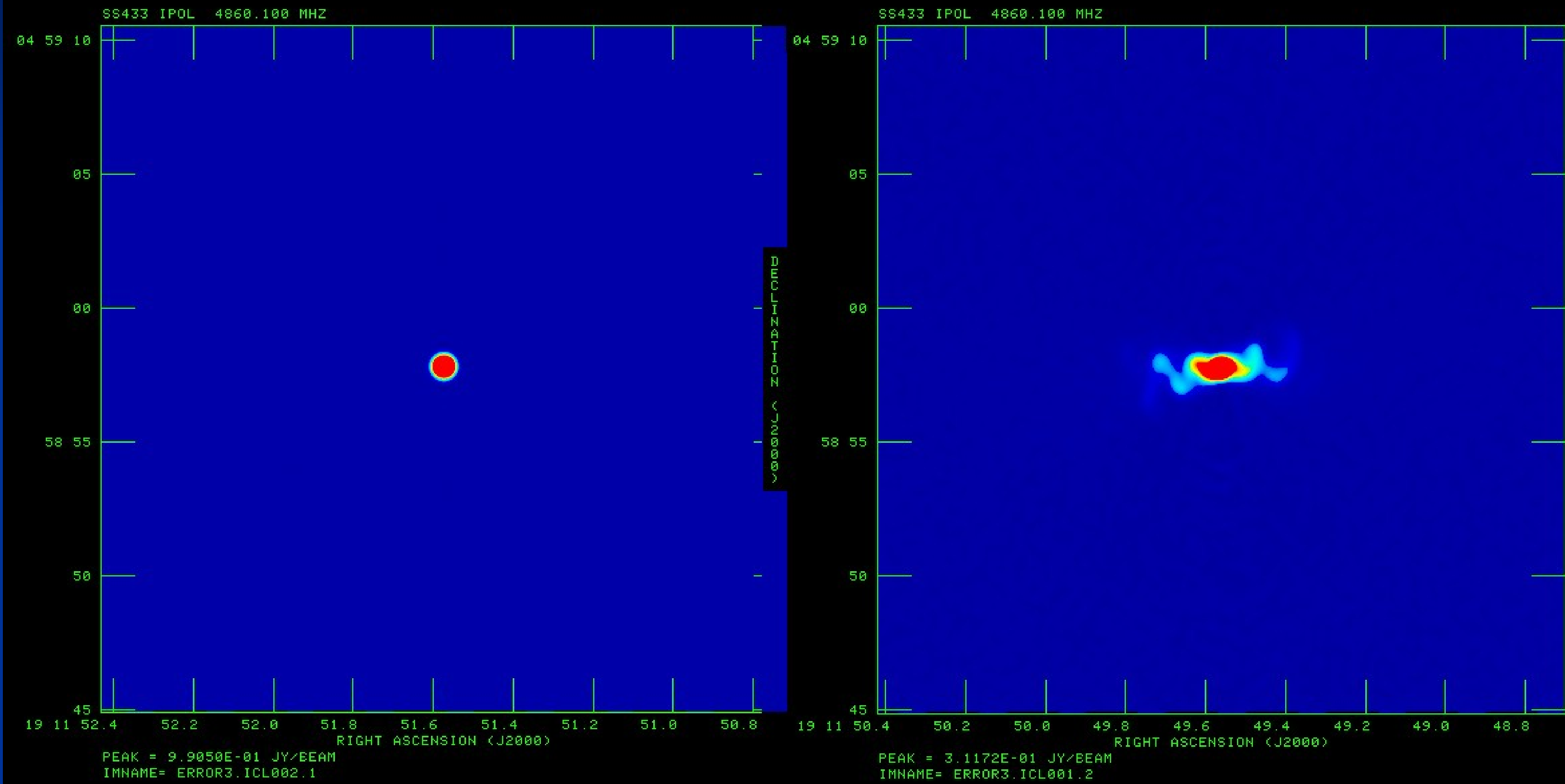
```
>nfield 2
>overlap 2
>bmaj 0.4
>bmin 0.4
>niter 3000
>go
```

This produces two image files:

```
AIPS 1:   17    6 ERROR3      .ICL001.    2 MA 11-SEP-2013 18:06:38
AIPS 1:   18    6 ERROR3      .ICL002.    2 MA 11-SEP-2013 18:06:38
```

The first is SS433. The second is a 1 Jy point source located 30 arcsec away.

```
>getn 17;tvlo
>getn 18;tvlo
```


SS433 IPOL 4860.100 MHZ
04 59 10
05
00
58 55
50
45
19 11 52.4
52.2
52.0
51.8
51.6
51.4
51.2
51.0
50.8
RIGHT ASCENSION (J2000)
DECLINATION (J2000)
PEAK = 9.9050E-01 JY/BEAM
IMNAME= ERROR3.ICL002.1
SS433 IPOL 4860.100 MHZ
19 11 50.4
50.2
50.0
49.8
49.6
49.4
49.2
49.0
48.8
RIGHT ASCENSION (J2000)
PEAK = 3.1172E-01 JY/BEAM
IMNAME= ERROR3.ICL001.2

>(d) ERROR4 - persistent phase error

Here (by design), there is no difference between the ampltiudes of the reference and error datasets (use UVPLT to compare). However, when you subtract the model, then the problem is easy to see.

```
>tget uvsub
>getn 9
>outn inn
>go
```

This makes

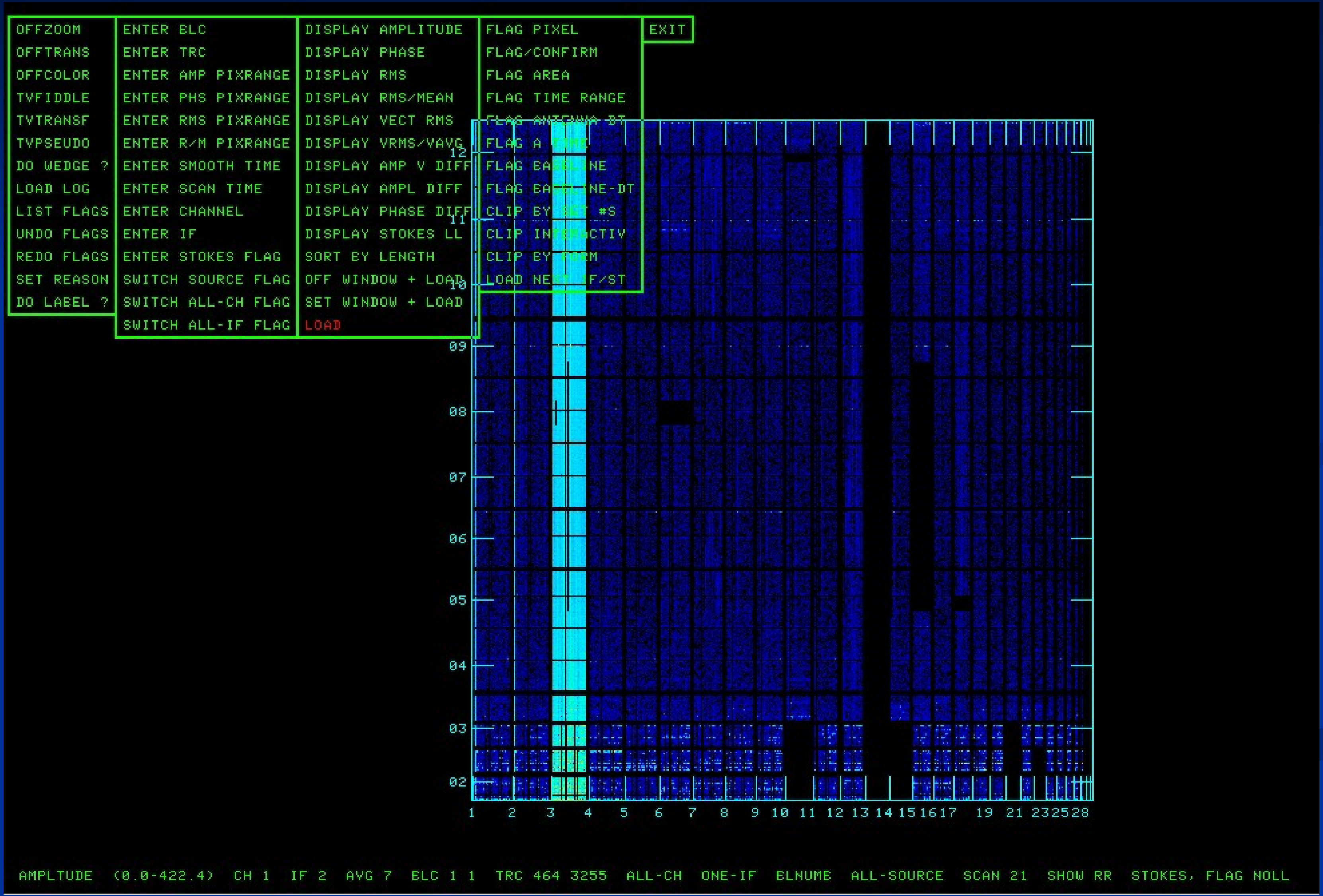
```
AIPS 1:   14    6 ERROR4      .UVSUB .    1 UV 11-SEP-2013 18:18:19
```

Display with TVFLG

```
>tget tvflg
>getn 14
AIPS 1: Got(1)   disk= 1  user=   6   type=UV   ERROR4.UVSUB.1
>go
```

left click on TVPSEUDO
A
D

(this gets a colour display of amplitude, which clearly shows a problem with antenna 3).



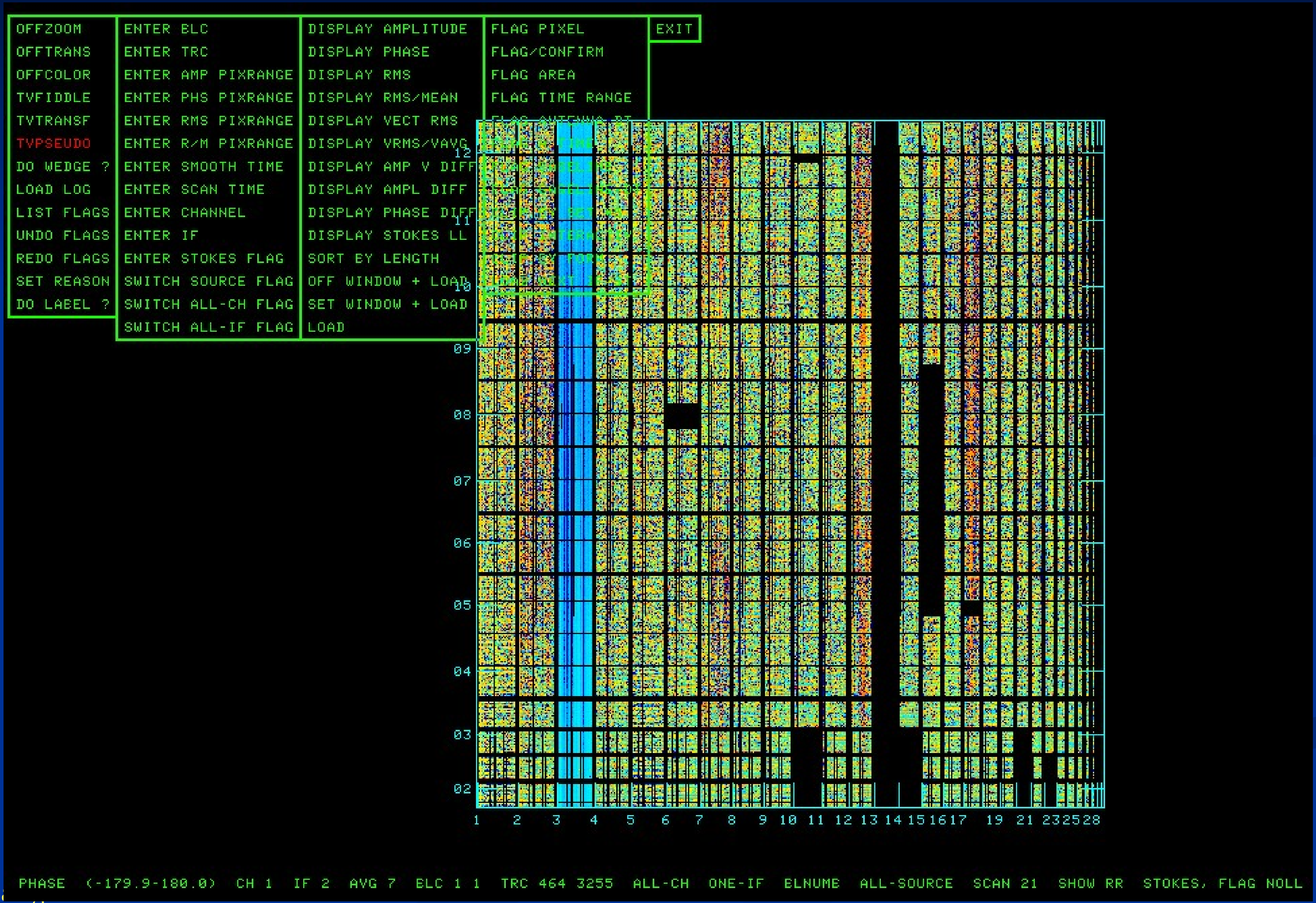
OFFZOOM
OFFTRANS
OFFCOLOR
TVFIDDLE
TVTRANSF
TVPSEUDO
DO WEDGE ?
LOAD LOG
LIST FLAGS
UNDO FLAGS
REDO FLAGS
SET REASON
DO LABEL ?
ENTER BLC
ENTER TRC
ENTER AMP PIXRANGE
ENTER PHS PIXRANGE
ENTER RMS PIXRANGE
ENTER R/M PIXRANGE
ENTER SMOOTH TIME
ENTER SCAN TIME
ENTER CHANNEL
ENTER IF
ENTER STOKES FLAG
SWITCH SOURCE FLAG
SWITCH ALL-CH FLAG
SWITCH ALL-IF FLAG
DISPLAY AMPLITUDE
DISPLAY PHASE
DISPLAY RMS
DISPLAY RMS/MEAN
DISPLAY VECT RMS
DISPLAY VRMS/VAVG
DISPLAY AMP V DIFF
DISPLAY AMPL DIFF
DISPLAY PHASE DIFF
DISPLAY STOKES LL
SORT BY LENGTH
OFF WINDOW + LOAD
SET WINDOW + LOAD
LOAD
FLAG PIXEL
FLAG/CONFIRM
FLAG AREA
FLAG TIME RANGE
EXIT
12
11
10
09
08
07
06
05
04
03
02
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 23 25 28
AMPLTUDE (0.0-422.4) CH 1 IF 2 AVG 7 BLC 1 1 TRC 464 3255 ALL-CH ONE-IF BLNUME ALL-SOURCE SCAN 21 SHOW RR STOKES, FLAG NOLL

To look at the phase directly:

left click on DISPLAY PHASE
A
left click on LOAD
A

left click on EXIT
A

to finish.


OFFZOOM
OFFTRANS
OFFCOLOR
TVFIDDLE
TVTRANSF
TVPSEUDO
DO WEDGE ?
LOAD LOG
LIST FLAGS
UNDO FLAGS
REDO FLAGS
SET REASON
DO LABEL ?
ENTER BLC
ENTER TRC
ENTER AMP PIXRANGE
ENTER PHS PIXRANGE
ENTER RMS PIXRANGE
ENTER R/M PIXRANGE
ENTER SMOOTH TIME
ENTER SCAN TIME
ENTER CHANNEL
ENTER IF
ENTER STOKES FLAG
SWITCH SOURCE FLAG
SWITCH ALL-CH FLAG
SWITCH ALL-IF FLAG
DISPLAY AMPLITUDE
DISPLAY PHASE
DISPLAY RMS
DISPLAY RMS/MEAN
DISPLAY VECT RMS
DISPLAY VRMS/VAVG
DISPLAY AMP V DIFF
DISPLAY AMPL DIFF
DISPLAY PHASE DIFF
DISPLAY STOKES LL
SORT BY LENGTH
OFF WINDOW + LOAD
SET WINDOW + LOAD
LOAD
FLAG PIXEL
FLAG/CONFIRM
FLAG AREA
FLAG TIME RANGE
EXIT
PHASE (-179.9-180.0) CH 1 IF 2 AVG 7 BLC 1 1 TRC 464 3255 ALL-CH ONE-IF BLNUMB ALL-SOURCE SCAN 21 SHOW RR STOKES, FLAG NOLL

Error diagnosis: CASA

The visibility data have already been converted to measurement sets

!tar -zxvf T7ms_CASA.tgz

!ls

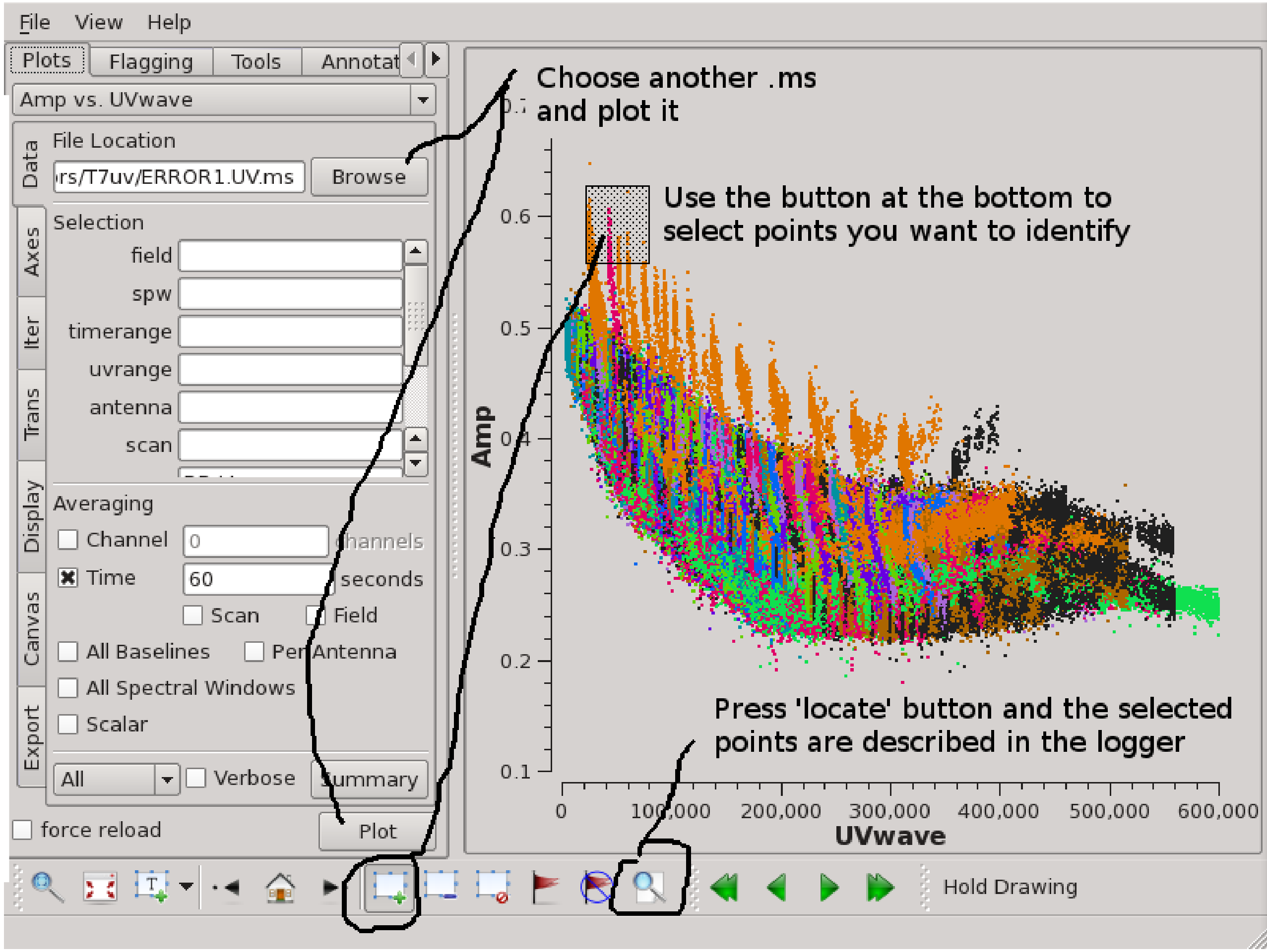
T7uv/REFERENCE.UV.ms/
T7uv/ERROR1.UV.ms/ T7uv/ERROR2.UV.ms/
T7uv/ERROR3.UV.ms/ T7uv/ERROR4.UV.ms/

Plot these:

plotms(vis='REFERENCE.UV.ms',xaxis='uvwave',yaxis='amp',
correlation='RR,LL',avgtime='60s',
coloraxis='antenna1',plotfile='Reference_uv-amp.png')

This makes a png of the reference image.
In plotms, use the Data tab to Browse, select ERROR1.UV.ms, and press Plot. Compare Reference_uv-amp.png

If you see any differences, use the 'Locate' facility in plotms



You can repeat with the other ERROR uv data, and also try plotting phase, or plotting against time - not necessarily every combination!

```
plotms(vis='T7uv/REFERENCE.UV.ms',
     xaxis='uvwave',  yaxis='phase',
      correlation='RR,LL',avgtime='60s',
      coloraxis='antenna1',plotfile='Reference_uv-phase.png')

plotms(vis='T7uv/REFERENCE.UV.ms', xaxis='uvwave', yaxis='time',
      correlation='RR,LL',avgtime='60s',
      coloraxis='antenna1',plotfile='Reference_time-amp.png')

plotms(vis='T7uv/REFERENCE.UV.ms',
     xaxis='uvwave', yaxis='phase',
      correlation='RR,LL',avgtime='60s',
      coloraxis='antenna1',plotfile='Reference_time-phase.png')
```

Image Analysis: AIPS

Copy T7images_analysis.tgz to the directory with the other data files.

```
>tar xvfz  T7images_analysis.tgz
NGC193C.I.FITS
NGC193C.Q.FITS
NGC193C.U.FITS
NGC193L.I.FITS
```

Load the files

```
>tget fitld
>datain 'pwd:ngc193c.i.fits';go
>datain 'pwd:ngc193c.q.fits';go
>datain 'pwd:ngc193c.u.fits';go
>datain 'pwd:ngc193l.i.fits';go
```

The images are all observations of the radio galaxy NGC193, at a resolution of 1.6 arcsec. I, Q and U at 4.9 GHz and I at 1.365 GHz.

```
AIPS 1:   20    6 NGC193C 1.6 .IMRCLP.    1 MA 11-SEP-2013 21:00:57
AIPS 1:   21    6 NGC193 T1.6 .QCL001.    1 MA 11-SEP-2013 21:01:20
AIPS 1:   22    6 NGC193 T1.6 .UCL001.    1 MA 11-SEP-2013 21:01:23
AIPS 1:   23    6 NGC193L 1.6 .IMRCLP.    1 MA 11-SEP-2013 21:01:28
```

(a) Measure noise levels

Set up a rectangular off-source region over which to measure the noise

>tvin

(to re-initialise TV display)

>getn 20
>pixr 0 0.001
>tvlo
>tvwin

left click and drag to bottom left-hand corner
A
left click and drag to top right-hand corner
D

Alternatively, set up manually

>blc 400 700
>trc 600 1350

To get the rms:

>imstat
AIPS 1: Mean=-9.448E-07 rms= 9.917E-06 JY/BEAM over 130851. pixels
AIPS 1: Maximum= 4.0768E-05 at 473 823 1 1 1 1 1
AIPS 1: Skypos: RA 00 39 29.62200 DEC 03 18 51.9870
AIPS 1: Skypos: IPOL 4860.100 MHZ
AIPS 1: Minimum=-4.2352E-05 at 485 850 1 1 1 1 1
AIPS 1: Skypos: RA 00 39 29.38162 DEC 03 19 00.0872
AIPS 1: Skypos: IPOL 4860.100 MHZ
AIPS 1: Flux density = -3.8360E-03 Jy. Beam area = 32.23 pixels

Repeat for the other 3 images

Results for this choice of window:

4.9GHz I: rms= 9.917E-06 JY/BEAM
Q: rms= 7.515E-06 JY/BEAM
U: rms= 7.475E-06 JY/BEAM
1.365GHz I: rms= 3.710E-05 JY/BEAM

(b) Spectral index

Calculate the spectral index between 1.365 and 4.9 GHz.

>task 'comb'
>defau comb

Important to reset various parameters which have been altered, such as BLC and TRC.

```
>getn 20
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193C 1.6.IMRCLP.1
>get2n 23
AIPS 1: Got(2)   disk= 1  user=   6   type=MA   NGC193L 1.6.IMRCLP.1
>outn 'ngc193 1.6lc'
>outc 'alpha'
>opco 'spix'
>aparm(1) = -1
```

sign convention

```
>aparm(9) 3*9.9e-6
>aparm(10) 3*3.71e-5
```

Blank output images at 3 x input rms

```
>doalign -2
```

Necessary because maps have been shifted to register accurately using the core position.

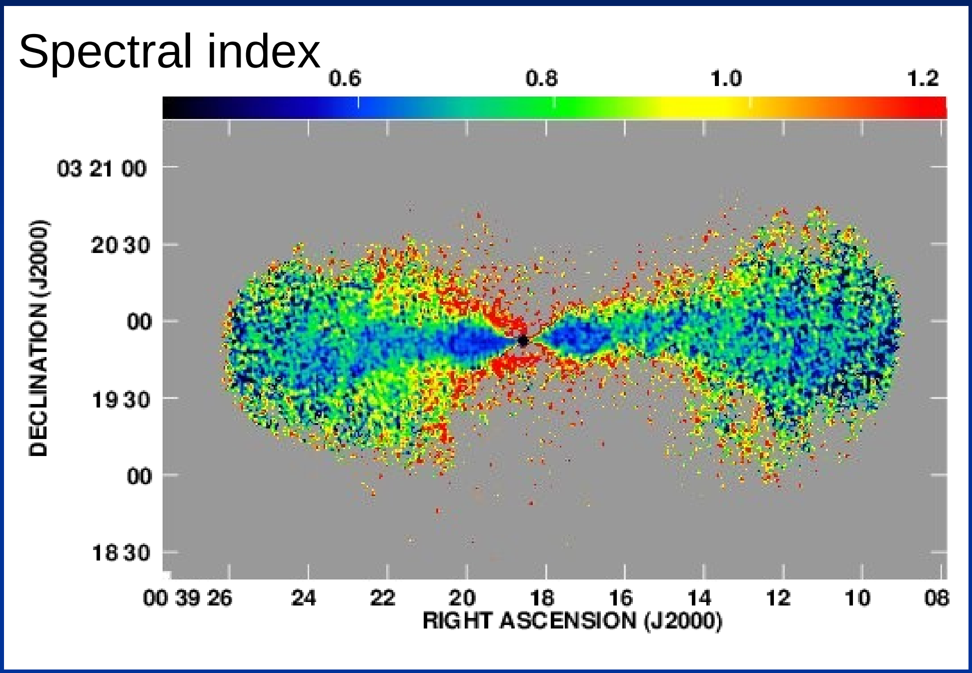
```
>bparm 9.9e-6 3.71e-5 1
```

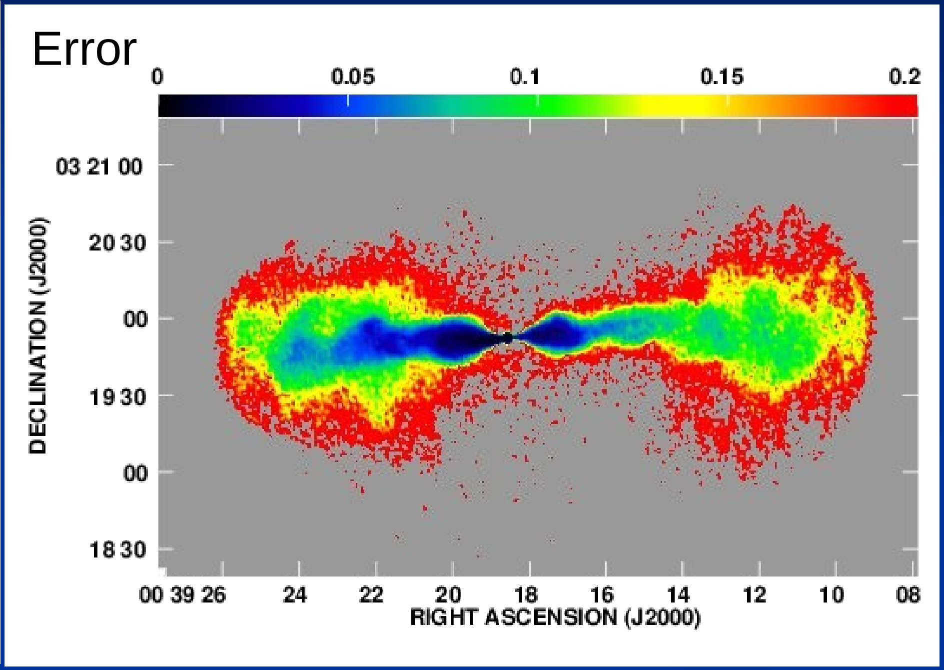
Noise levels for input maps in Jy/Beam; 1 tells it to output error map in addition.

```
>go
```

Typical spectral indices in the range 0.5 - 1.2; errors up to 0.2.

Spectral indices and errors





Sign convention $I \propto \nu^{-\alpha}$

(c) Derived polarization images

Position angle

```
>task comb
>default comb
>getn 21
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193 T1.6.QCL001.1
>get2n 22
AIPS 1: Got(2)   disk= 1  user=   6   type=MA   NGC193 T1.6.UCL001.1
>outn inn
>outc 'chi'
>bparm 7.5e-6 7.5e-6 1
```

Noise levels, also output error map

```
>go
```

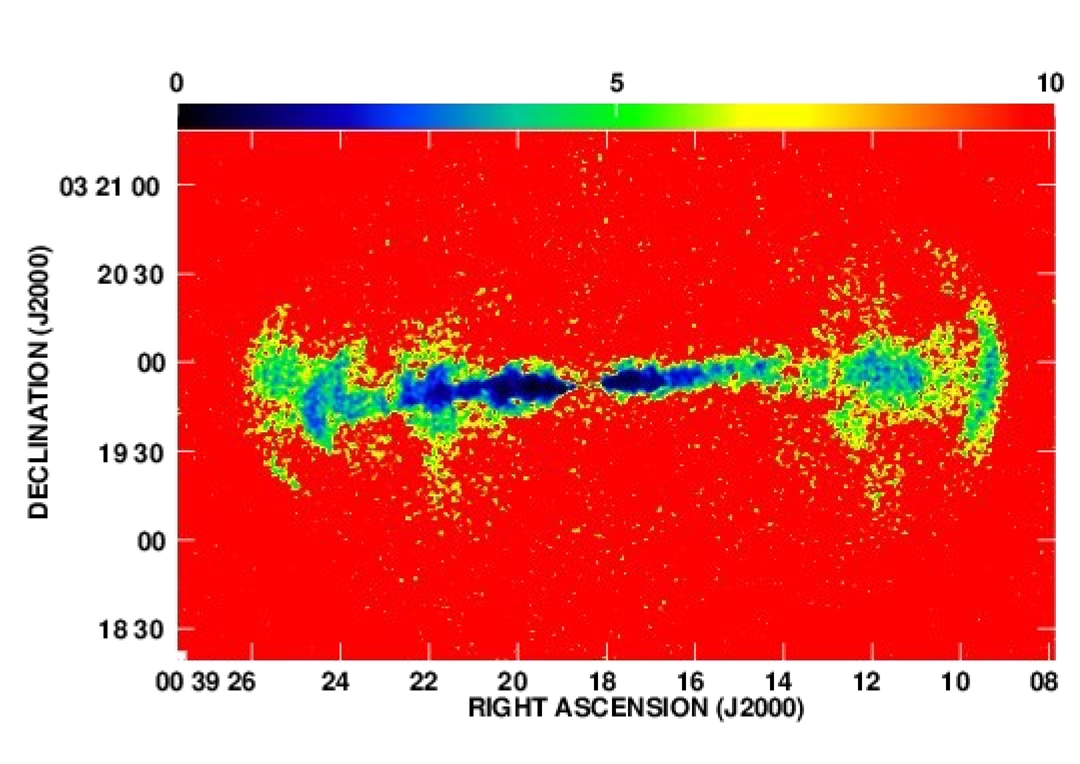
This produces an E-vector position-angle image and the associated error map,
both in degrees

```
AIPS 1:   27    6 NGC193 T1.6 .CHI   .    1 MA 11-SEP-2013 22:42:15
AIPS 1:   28    6 NGC193 T1.6 .CHI  N.    1 MA 11-SEP-2013 22:42:15
```

The error distribution is not Gaussian at low signal-to-noise; there are many instances of errors <20 deg where there is no signal in I.

Try looking at the image with pixrange = 1e-10 20

Position angle error



Polarized intensity

Polarized intensity has a positive bias (the noise distribution is Ricean, not Gaussian with zero mean). The standard packages make a first-order correction for this effect, which we use here.

```
>tget comb
>opco 'polc'
>outc 'p'
>go
```

(most of the inputs and noise levels are the same as for position angle).

Produces:

```
AIPS 1:   29    6 NGC193 T1.6 .P     .    1 MA 11-SEP-2013 22:56:02
AIPS 1:   30    6 NGC193 T1.6 .P    N.    1 MA 11-SEP-2013 22:56:01
```

Degree of polarization: divide P by I.

```
>tget comb
>getn 29
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193 T1.6.P.1
>get2n 20
AIPS 1: Got(2)   disk= 1  user=   6   type=MA   NGC193C 1.6.IMRCLP.1
>outc 'degp'
>opco 'div'
```

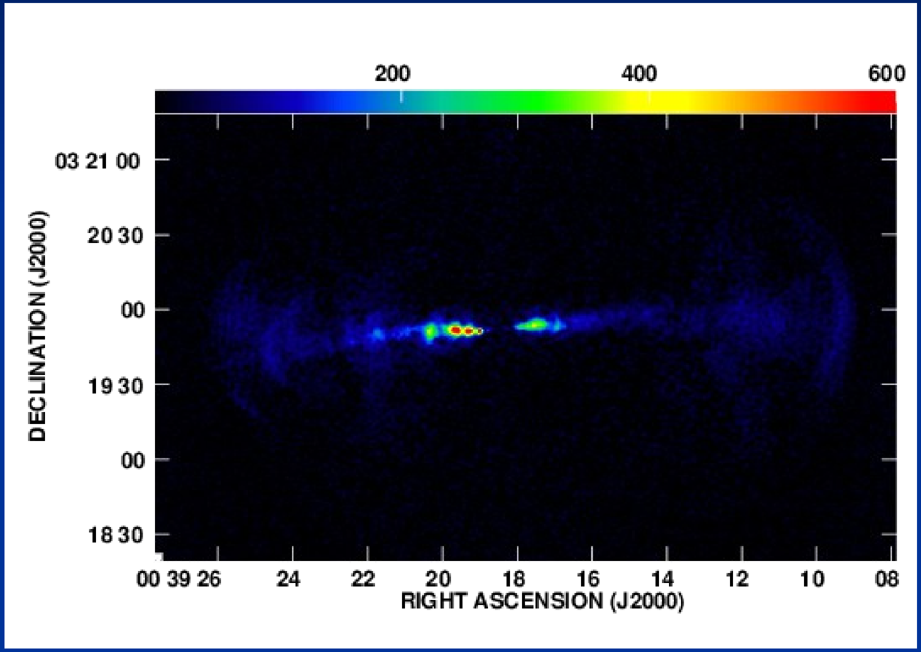
Blanked for P < 3rms and I < 5rms

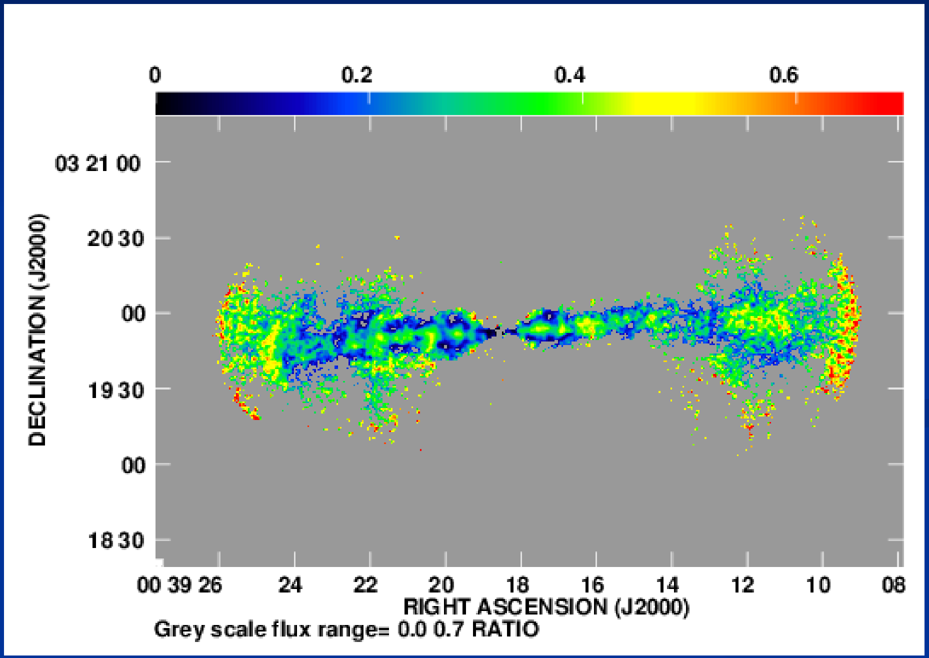
```
>bparm 0
>aparm(9) 3*7.5e-5
>aparm(10) 5*9.9e-5
>bparm 0
>go
```

It is also possible to propagate errors using error maps for P and I.

Try displaying p = P/I in the range 1e-10 to 0.7.

Polarized intensity and degree





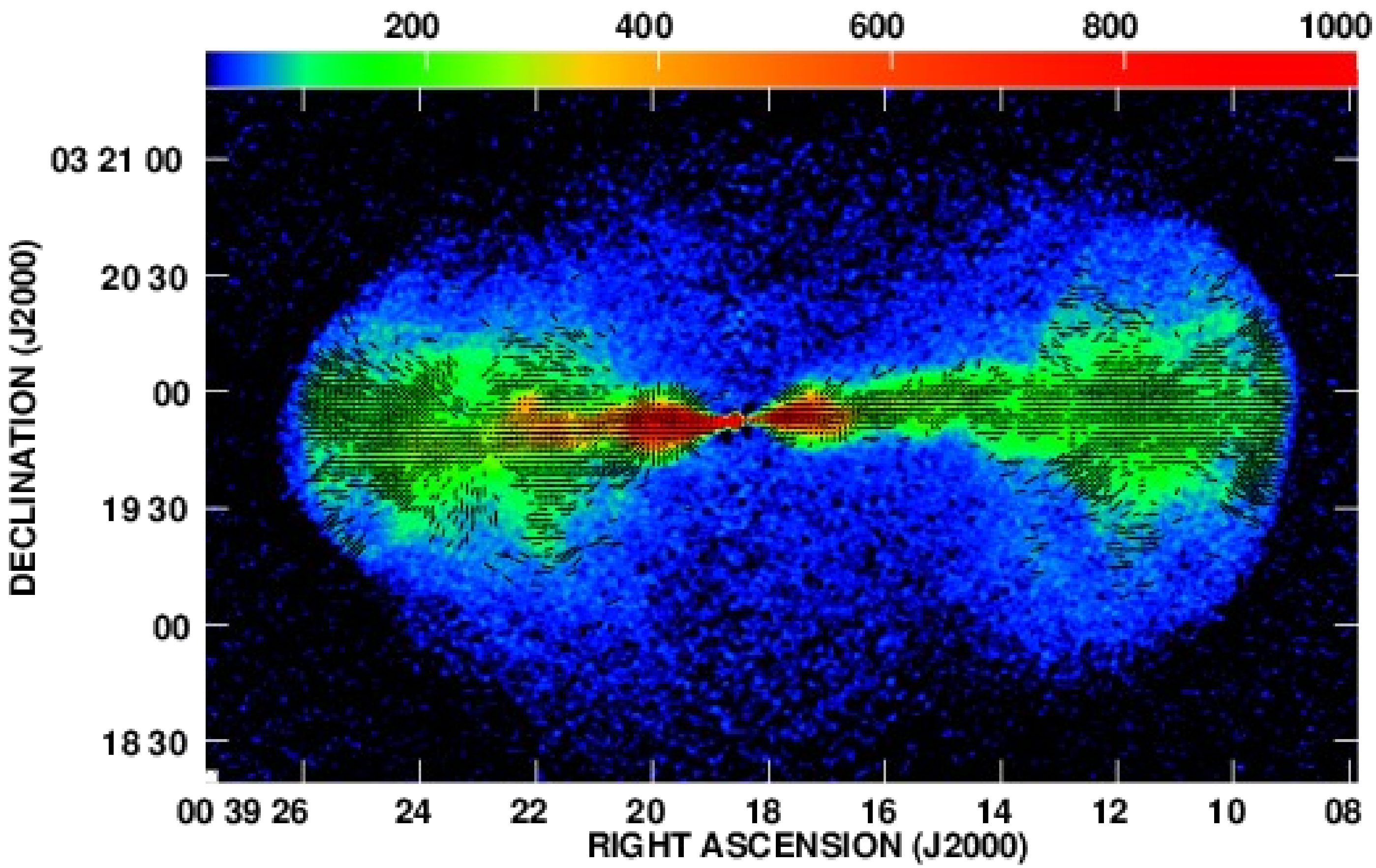
Polarized intensity P

Degree of polarization p = P/I

Making a vector plot (vectors with lengths proportional to the degree of polarization orientated along the E-vector direction on a false-colour image of total intensity).

```
>task 'kntr'
>defau 'kntr'
>docont -1
>dovec 1
>dogrey 1
>getn 20
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193C 1.6.IMRCLP.1
>get3n 31
AIPS 1: Got(3)   disk= 1  user=   6   type=MA   NGC193 T1.6.DEGP.1
>get4n 27
AIPS 1: Got(4)   disk= 1  user=   6   type=MA   NGC193 T1.6.CHI.1
>blc 605 780
>trc 1530 1316
>pixr 1e-5 0.001
>func 'sq'
>ofmfil 'rainbow'
>docol 1
>factor 10
>xinc 5
>yinc 5
>pcut 0
>icut 0
>dowedge 1
>dotv 1
>dodark 1
>darkline 1e-10
>go
```

Vector plot



200
400
600
800
1000
DECLINATION (J2000)
03 21 00
20 30
00
19 30
00
18 30
00 39 26
24
22
20
18
16
14
12
10
08
RIGHT ASCENSION (J2000)

Measuring the integrated flux density

Load the image on the TV display and adjust the transfer function so that you can see the low-level structure.

```
>tvinit
>tvlo
clears the vector plot and reloads the I image

>getn 20
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193C 1.6.IMRCLP.1
>pixr 0
>tvlo
>tvtra
AIPS 1: Cursor X position controls intercept
AIPS 1: Cursor Y position controls slope
AIPS 1: Hit buttons A or B to turn plot off or back on
AIPS 1: Hit button C to reverse sign of slope
AIPS 1: Hit button D to exit
>
```

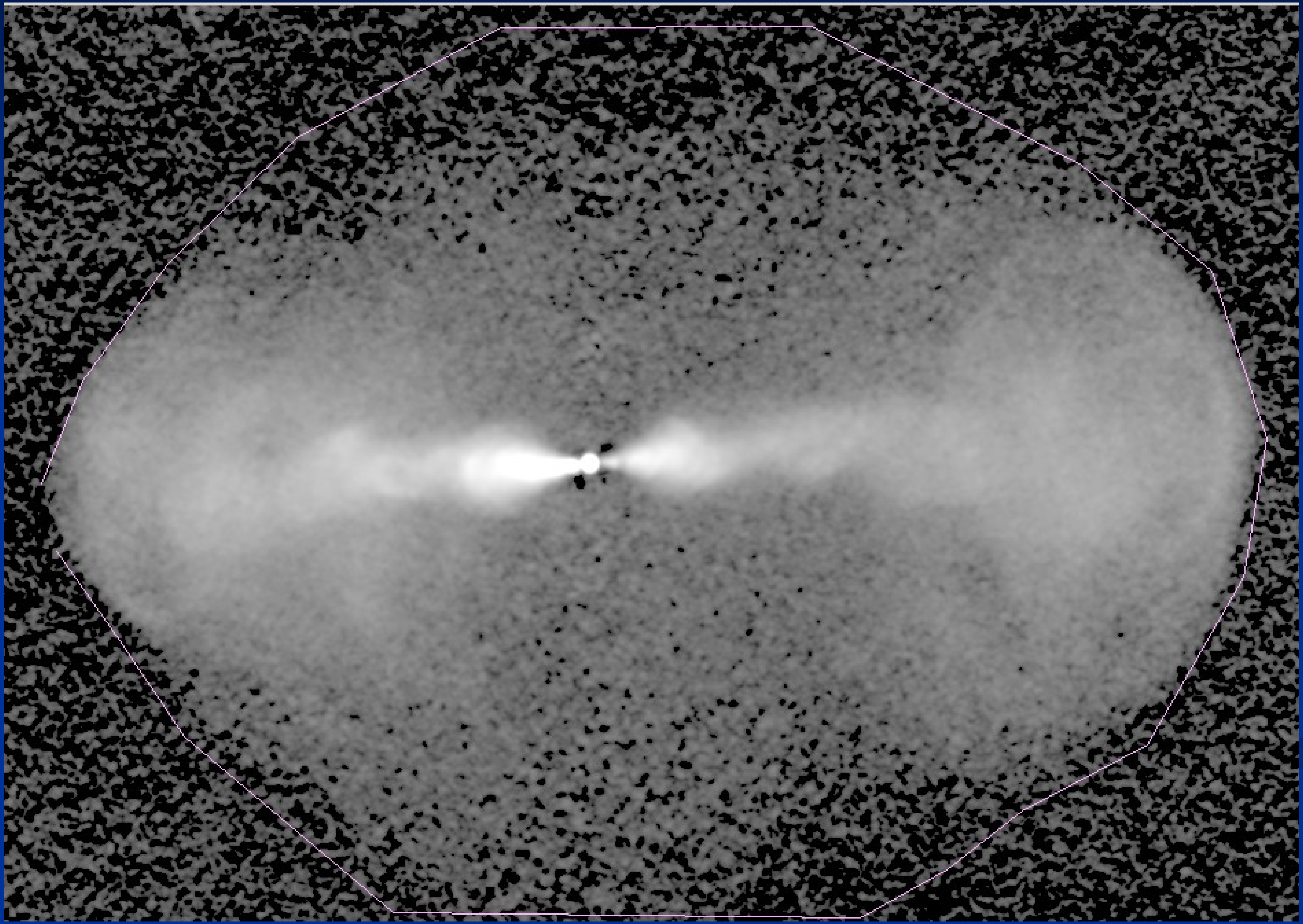
Draw a polygon around the structure, using left click followed by A to mark starting and intermediate points; D to finish.

```
>tvstat
```

AIPS 1: Begin setting region number 1
AIPS 1: Press button A to set intermediate vertex
AIPS 1: Press buttons B, C, or D to set final vertex
AIPS 1: C => then reset a vertex, D => then exit
AIPS 1: Mean= 5.758E-05 rms= 3.831E-04 JY/BEAM over 434286. pixels
AIPS 1: Maximum= 6.0346E-02 at 1024 1025 1 1 1 1 1
AIPS 1: Skypos: RA 00 39 18.58353 DEC 03 19 52.5909
AIPS 1: Skypos: IPOL 4860.100 MHZ
AIPS 1: Minimum=-3.8210E-05 at 1026 1274 1 1 1 1 1
AIPS 1: Skypos: RA 00 39 18.54346 DEC 03 21 07.2909
AIPS 1: Skypos: IPOL 4860.100 MHZ
AIPS 1: Flux density = 7.7586E-01 Jy. Beam area = 32.23 pixels

Compare with single-dish measurement at the same frequency to check for missing large-scale flux. This is 0.81 +/- 0.04 Jy, so consistent.

Measuring the integrated flux density



Robert Laing
ESO

Component fitting

```
>task 'jmfit'
>defau jmfit
>getn 20
AIPS 1: Got(1)   disk= 1  user=   6   type=MA   NGC193C 1.6.IMRCLP.1
>

>grcl
```

to get rid of the purple splodge

```
>tvwin
```

set a box around the core

left click and drag to set blc
A to switch corners
left click and drag to set trc
D to exit

```
>go
```

```
nb0174> JMFIT1: ********* Solution from JMFIT **********************
nb0174> JMFIT1:
nb0174> JMFIT1: Component   1-Gaussian
nb0174> JMFIT1:   Peak intensity    = 6.0182E-02 +/-  1.38E-05
JY/BEAM
nb0174> JMFIT1:   Integral intensity= 6.0676E-02 +/-  2.40E-05
JANSKYS
nb0174> JMFIT1:   X-position       =   1023.993 +/-   0.0005 pixels
nb0174> JMFIT1:   Y-position       =   1025.000 +/-   0.0005 pixels
nb0174> JMFIT1:                      RA 00 39 18.58367    +/-  0.0000104
nb0174> JMFIT1:                      DEC 03 19 52.5909    +/-   0.000155
nb0174> JMFIT1:   Major axis       =   5.376 +/-  0.0012 pixels
nb0174> JMFIT1:   Minor axis       =   5.335 +/-  0.0012 pixels
nb0174> JMFIT1:   Position angle    =  98.189 +/-  1.216 degrees
nb0174> JMFIT1:   Major axis       =  1.61263 +/-  0.00037 asec
nb0174> JMFIT1:   Minor axis       =  1.60043 +/-  0.00037 asec
nb0174> JMFIT1:   Position angle    =  98.188 +/-  1.216 degrees
nb0174> JMFIT1:   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
nb0174> JMFIT1:                Deconvolution of component in pixels
nb0174> JMFIT1:                     Nominal     minimum     maximum
nb0174> JMFIT1:     Major ax            0.673       0.663       0.682
nb0174> JMFIT1:     Minor ax            0.125       0.051       0.169
nb0174> JMFIT1:     Pos ang            98.189      96.973      99.405
nb0174> JMFIT1:                Deconvolution of component in asec
nb0174> JMFIT1:                     Nominal     minimum     maximum
nb0174> JMFIT1:     Major ax         0.201642    0.198789    0.204526
nb0174> JMFIT1:     Minor ax         0.037512    0.015348    0.050783
nb0174> JMFIT1:     Pos ang         98.181580   96.983627   99.411766
nb0174> JMFIT1:   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Image analysis: CASA

You can view images as fits files but for manipulation, import them as CASA format:

```
fitsims=['NGC193C.I','NGC193C.Q','NGC193C.U','NGC193L.I']

for f in fitsims:
   importfits(fitsimage=f+'.FITS',imagename=f+'.im')
```

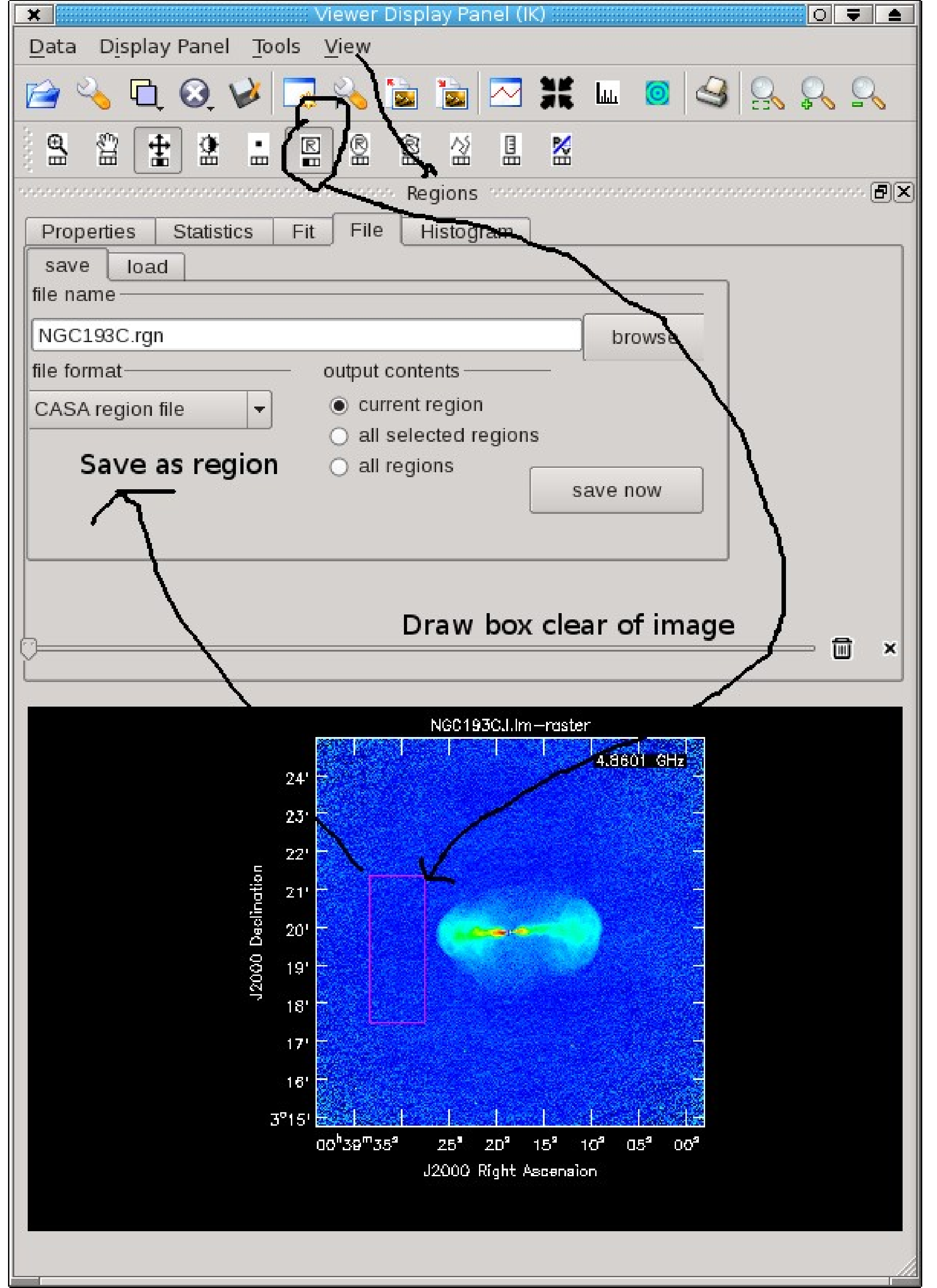
Measure the noise in the maps: Load the total intensity C-band map into the viewer and decide where to place a box avoiding the source (adjust the colour table etc. to see all the source).

```
viewer('NGC193C.I.im')
```

Select a box clear of the source
Open the Region pane (View menu) and go to File > Save and save the region as NGC193C.rgn

You can also make an ellipse or a polygon.

You can double-click on a region in the viewer and the statistics appear in the Xterm where you are running CASA, but it is easier to measure multiple images consistently with imstat.



Measuring images

Using the region you just saved from the viewer:
Cstats=imstat(imagename='NGC193C.I.im',region='NGC193C.rgn')

Type
Cstats
to see all the measurements. Set a variable for the rms
rmsC=Cstats['rms'][0]
Type
rmsC
(should be about 9 10^-6 Jy/bm)

Find the rms noise for NGC193L.I.im (write your own expressions for Lstats, and rmsL)

Do the same (use different region and variable names) around the peaks, to find the signal to noise ratio.

Spectral Index

Set a mask expression for a spectral index image

```
NGCmask='NGC193C.I.im>'+str(3.*rmsC) +' &&
NGC193L.I.im>' +str(3.*rmsL)

immath(imagename=['NGC193C.I.im','NGC193L.I.im'],
outfile='NGC193CL.spix', mode='spix',mask=NGCmask)

viewer('NGC193CL.spix')
```