ERROR RECOGNITION & IMAGE ANALYSIS

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Tenth Summer Synthesis Imaging Workshop

University of New Mexico, June 13-20, 2006

PREMABLE TO ERROR RECOGNITION and IMAGE ANALYSIS

- Why are these two topics in the same lecture?

  - - Error recognition is used to determine defects in the data and image after the ‘best’ calibration, editing, etc.
  - - Image analysis describes the almost infinite ways in which useful information and parameters can be extracted from the image.

- Perhaps the two topics are related to the reaction one has when looking at an image after ‘good’ calibration, editing, self- calibration, etc.

- If the reaction is:

POSSIBLE IMAGE PROBLEMS

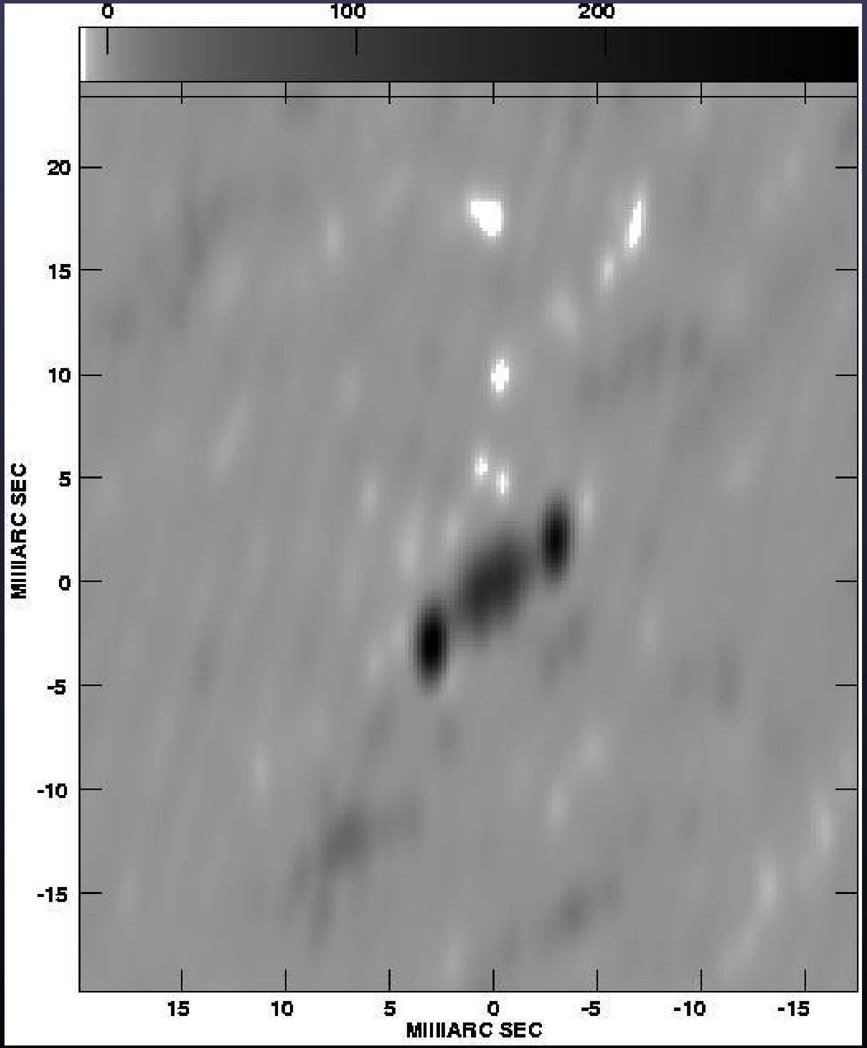
Rats!!

This can't be right. This is either the most remarkable radio source ever, or I have made an error in making the image.

Image rms, compared to the expected rms, unnatural features in the image, etc are clear signs of problems.

How can the problems be found and corrected?

mJy scale



milliarcsec

HIGH QUALITY IMAGE

Great!!

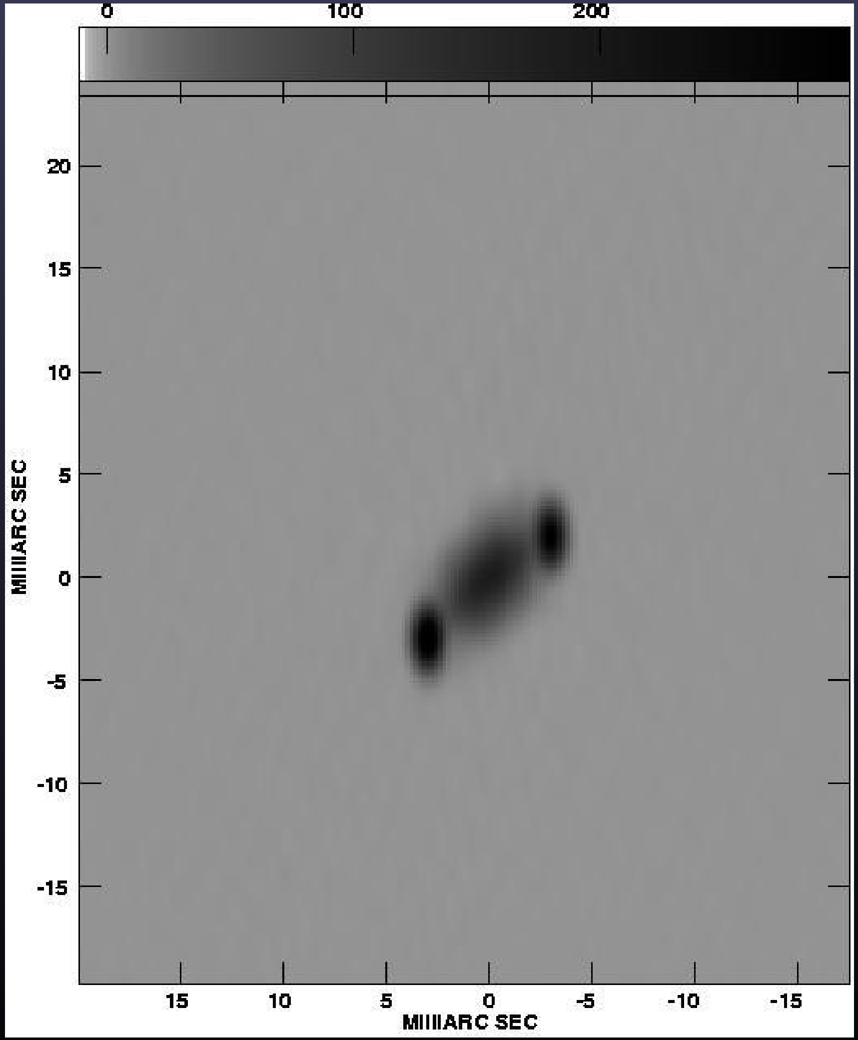
After lots of work, I can finally analyze this image and get some interesting scientific results.

What were defects?

Two antennas had 10% calibration errors, and one with a 5 deg error, plus a few outlier points.

This Lecture.

How to find the errors and fix them.



milliarcsec

GENERAL PROCEDURE

Assuming that the data have been edited and calibrated reasonably successfully (earlier lectures). Self- calibration is usually necessary.

So, the first serious display of an image leads one- -

to inspect again and clean- up the data with repetition of some or all of the previous reduction steps.

to image analysis and obtaining scientific results from the image.

But, first a digression on data and image display.

IMAGE DISPLAYS (1)

Pixel values

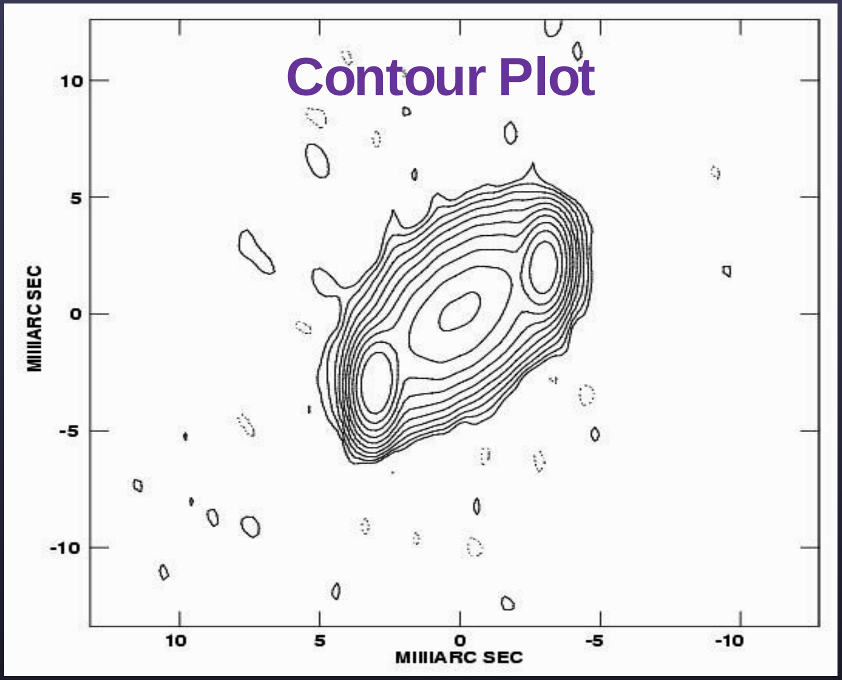
					235					245					255					265					275				
287	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
283	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0
281	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	3	3	4	3	1	0	0	0	0
279	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	4	5	5	9	12	8	3	1	0	0	0
277	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	5	7	7	8	9	9	19	32	22	6	1	0	0	0
275	0	0	0	0	0	0	0	0	0	0	0	1	2	4	6	9	13	14	15	14	16	40	72	47	12	2	0	0	0
273	0	0	0	0	0	0	0	0	1	1	1	2	4	8	12	17	22	23	24	22	27	77	136	87	19	2	0	0	0
271	0	0	0	0	0	0	0	0	1	1	2	4	8	15	21	28	35	36	37	33	43	126	217	132	28	3	0	0	0
269	0	0	0	0	0	0	0	0	1	3	4	8	15	25	34	44	54	54	53	49	61	173	298	169	34	3	0	0	0
267	0	0	0	0	0	0	0	1	2	4	8	14	25	40	52	67	79	77	74	63	75	199	316	177	34	3	0	0	0
265	0	0	0	0	0	0	0	1	3	7	14	24	40	60	77	97	109	102	93	74	79	191	289	155	29	3	0	0	0
263	0	0	0	0	0	0	1	2	5	11	22	37	58	86	108	130	137	123	105	79	73	154	220	113	20	2	0	0	0
261	0	0	0	0	0	1	1	3	8	17	33	54	81	116	139	156	156	133	107	75	61	106	140	69	12	2	0	0	0
259	0	0	0	0	0	1	2	5	12	24	45	72	105	143	162	170	161	131	99	66	47	64	75	36	6	1	0	0	0
257	0	0	0	0	0	2	4	8	19	32	58	88	124	160	171	169	152	118	86	55	36	36	36	16	3	1	0	0	0
255	0	0	0	0	1	2	7	16	27	42	70	101	135	162	164	156	134	100	71	44	27	20	16	7	1	0	0	0	0
253	0	0	0	0	1	4	15	34	43	51	77	105	133	150	146	135	112	81	56	34	19	11	7	3	1	0	0	0	0
251	0	0	0	0	1	8	34	73	70	59	79	100	120	130	122	110	88	61	41	24	12	6	3	1	0	0	0	0	0
249	0	0	0	1	2	14	69	141	112	65	73	87	100	106	96	83	64	43	27	14	7	3	1	1	0	0	0	0	0
247	0	0	0	1	3	23	121	238	167	69	62	69	77	81	70	59	42	26	16	8	3	1	0	0	0	0	0	0	0
245	0	0	0	1	3	34	180	338	217	69	48	52	56	57	47	36	25	15	9	3	1	0	0	0	0	0	0	0	0
243	0	0	0	1	4	42	222	402	242	65	36	37	39	37	29	21	14	7	4	1	0	0	0	0	0	0	0	0	0
241	0	0	0	1	4	44	229	398	228	56	26	25	25	22	16	11	7	3	1	0	0	0	0	0	0	0	0	0	0
239	0	0	0	1	3	39	196	327	179	41	19	16	15	12	8	5	3	1	1	0	0	0	0	0	0	0	0	0	0
237	0	0	0	1	3	28	139	223	118	26	11	9	8	6	4	2	1	1	0	0	0	0	0	0	0	0	0	0	0
235	0	0	0	0	2	18	82	127	64	14	6	5	4	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
233	0	0	0	0	1	9	40	60	29	7	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
231	0	0	0	0	0	4	17	23	11	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
229	0	0	0	0	0	2	6	7	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
227	0	0	0	0	0	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

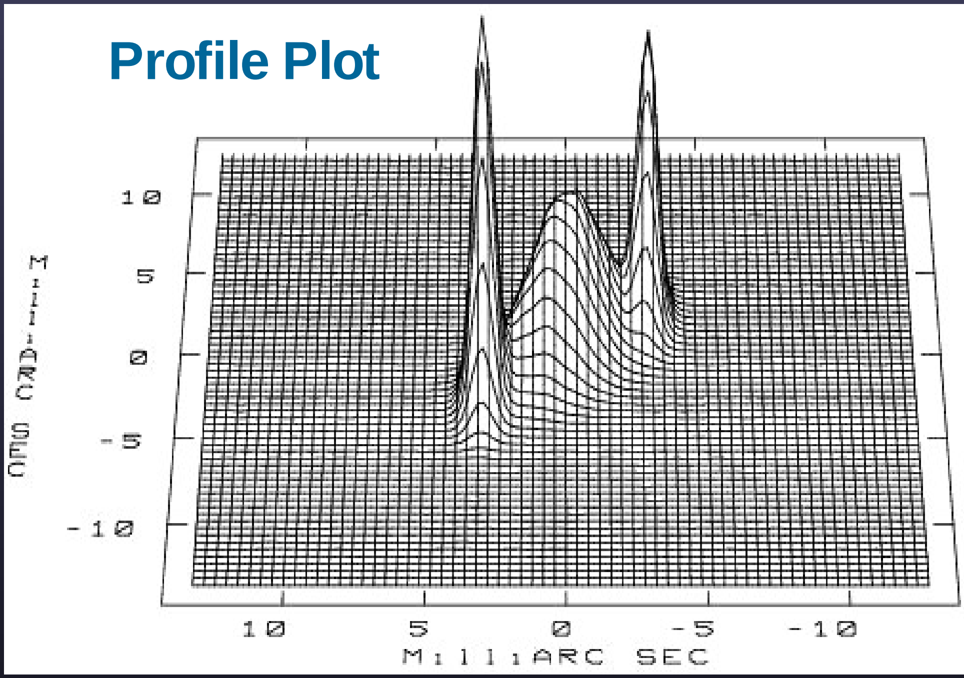
Digital image

Numbers are proportional to the intensity

Good for slow links

IMAGE DISPLAYS (2)



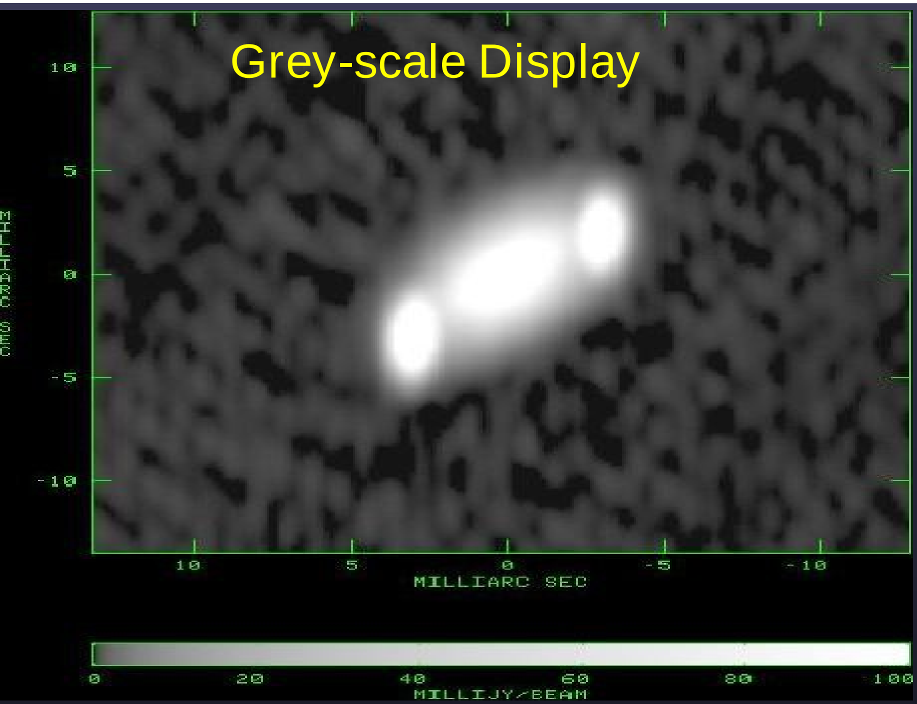


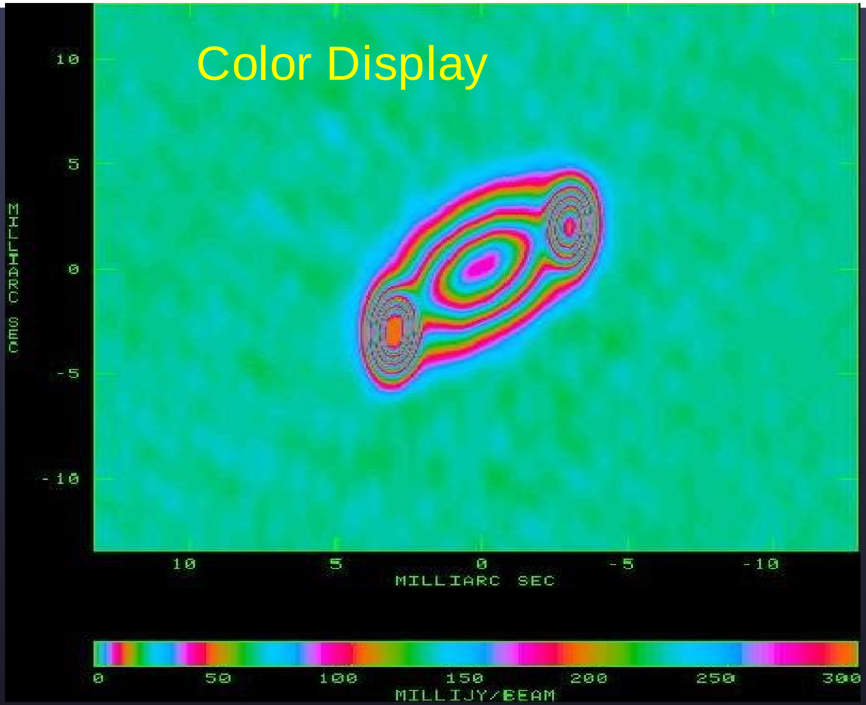
These plots are easy to reproduce in printed documents

Contour plots give good representation of faint emission.

Profile plots give a good representation of the ' mosque-like' bright emission and faint ripples.

IMAGE DISPLAYS (3)





TV-based displays are most useful and interactive:

Grey-scale shows faint structure, but not good for high dynamic range.

Color displays more flexible; pseudo contours

DATA DISPLAYS(1)

List of u- v Data

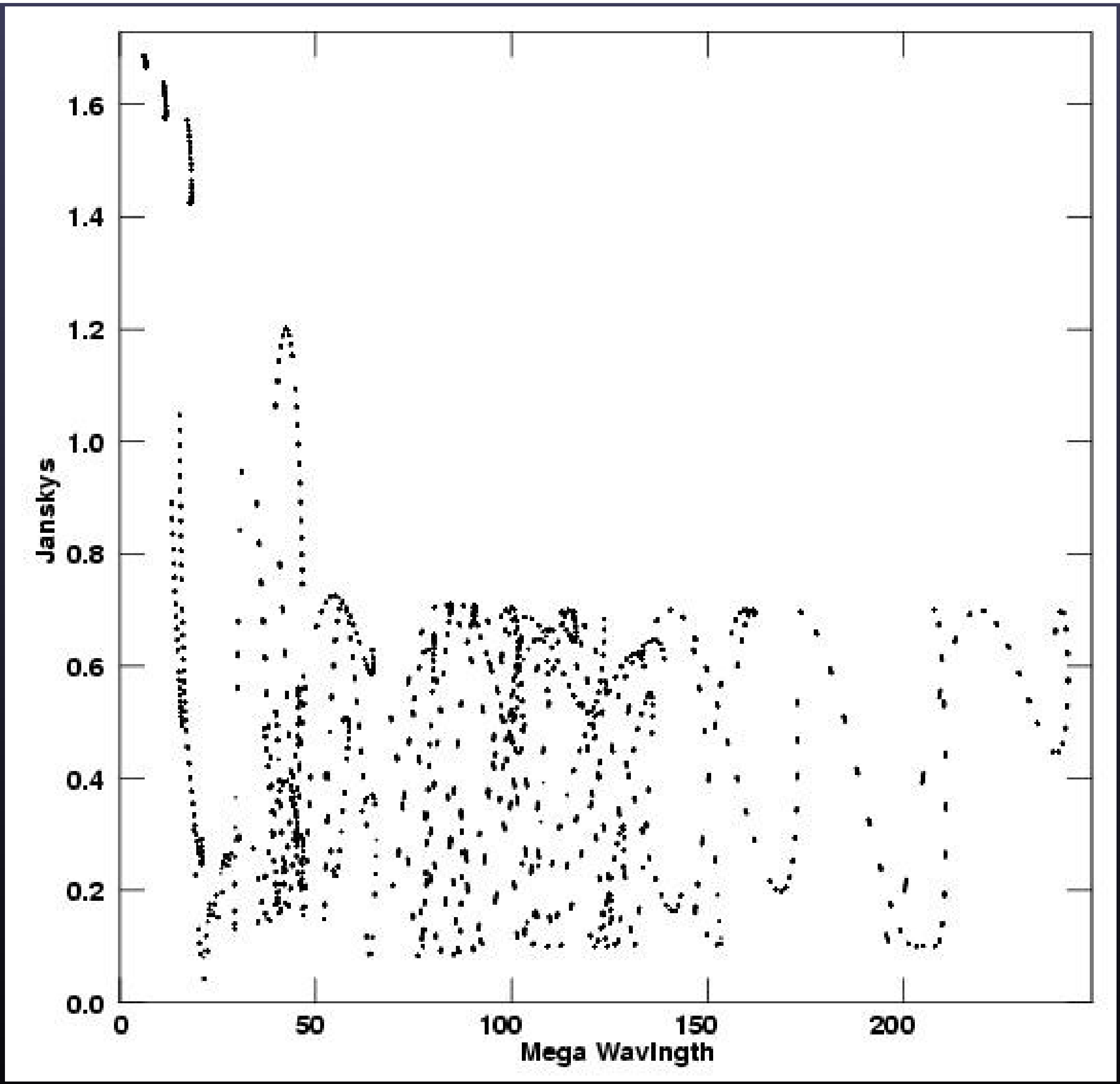
Source= J0121+11   Freq= 8.434858511   Sort= TB   1   RR

Vis #	IAT	Ant	Su	Fq	U(klam)	V(klam)	W(klam)	Amp	Phas	Wt
2191	0/22:35:08.22	5- 6	1	0	94220	23776	100371	0.614	-16	1.0000
3971	0/22:43:43.34	5- 6	1	0	97659	24517	96844	0.508	-13	1.0000
6431	0/23:07:05.15	5- 6	1	0	106307	26661	86632	0.154	17	1.0000
6611	0/23:07:14.98	5- 6	1	0	106364	26677	86557	0.152	17	1.0000
6791	0/23:07:24.81	5- 6	1	0	106421	26692	86483	0.150	18	1.0000
6971	0/23:07:34.64	5- 6	1	0	106477	26708	86408	0.148	19	1.0000
7151	0/23:07:44.47	5- 6	1	0	106534	26724	86333	0.146	19	1.0000
7331	0/23:07:54.30	5- 6	1	0	106591	26739	86259	0.144	20	1.0000
7511	0/23:15:06.84	5- 6	1	0	109027	27438	82930	0.101	74	1.0000
7691	0/23:15:16.67	5- 6	1	0	109081	27454	82854	0.101	75	1.0000
7871	0/23:15:26.50	5- 6	1	0	109135	27470	82777	0.102	77	1.0000
8051	0/23:15:36.33	5- 6	1	0	109189	27486	82701	0.102	78	1.0000
8231	0/23:15:46.16	5- 6	1	0	109243	27502	82624	0.103	79	1.0000
8411	0/23:15:55.99	5- 6	1	0	109297	27518	82547	0.104	81	1.0000
9701	0/23:31:02.36	5- 6	1	0	114020	29035	75322	0.260	134	1.0000
9791	0/23:31:06.29	5- 6	1	0	114040	29042	75290	0.261	134	1.0000
10301	0/23:31:29.88	5- 6	1	0	114156	29082	75098	0.266	134	1.0000
10861	0/23:39:02.08	5- 6	1	0	116320	29863	71379	0.348	139	1.0000
10951	0/23:39:06.01	5- 6	1	0	116339	29870	71346	0.348	139	1.0000
11171	0/23:39:15.84	5- 6	1	0	116384	29887	71264	0.350	139	1.0000

Very primitive display, but sometimes worth-while: egs, can search on Amp > 1.0, for example, or large Wt.

DATA DISPLAYS(2)

Jy



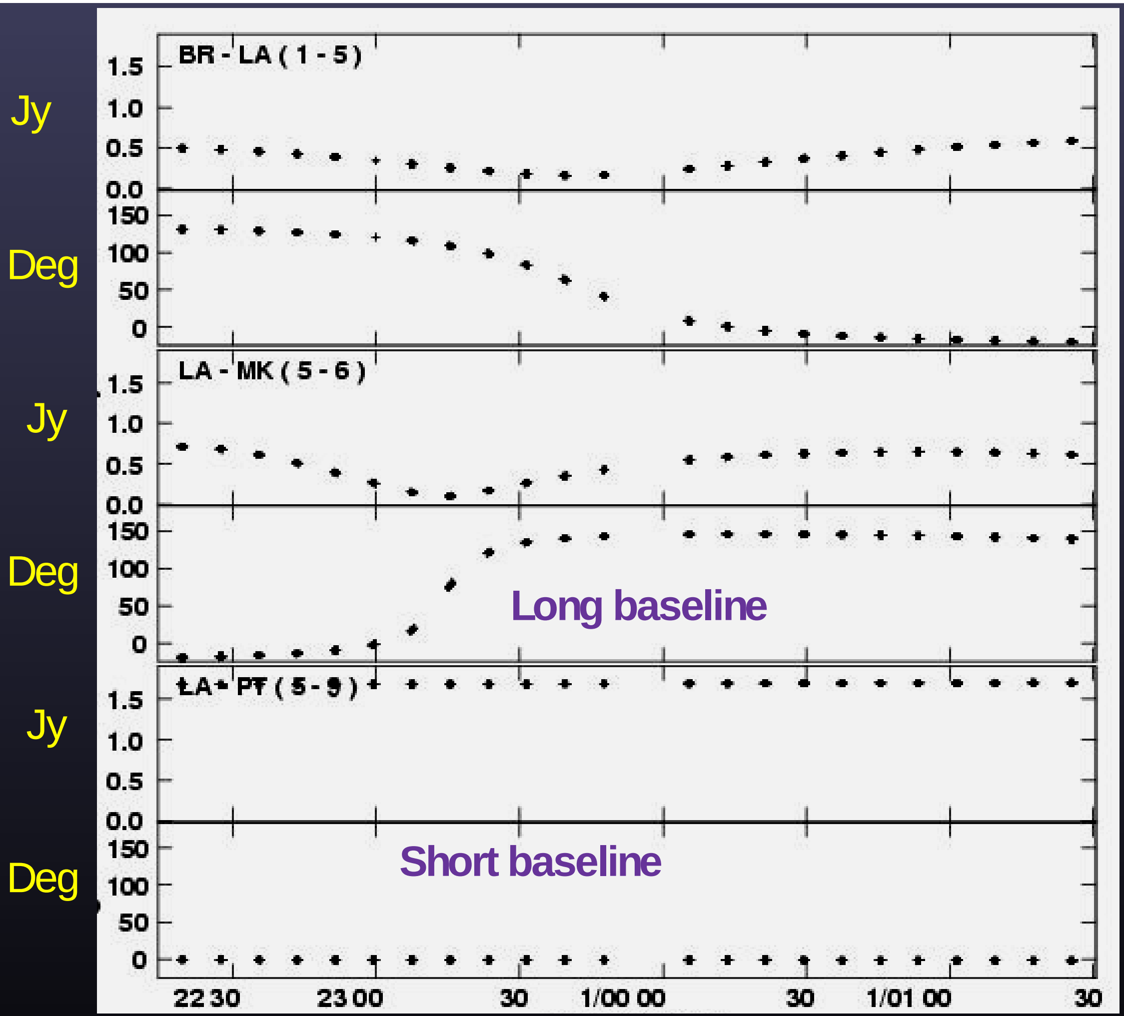
Mega Wavelength

Visibility Amplitude versus
Projected uv spacing

General trend of data.
Useful for relatively strong
Sources.

(Triple source model with
large component in middle,
see Non-imaging lecture)

DATA DISPLAYS(3)

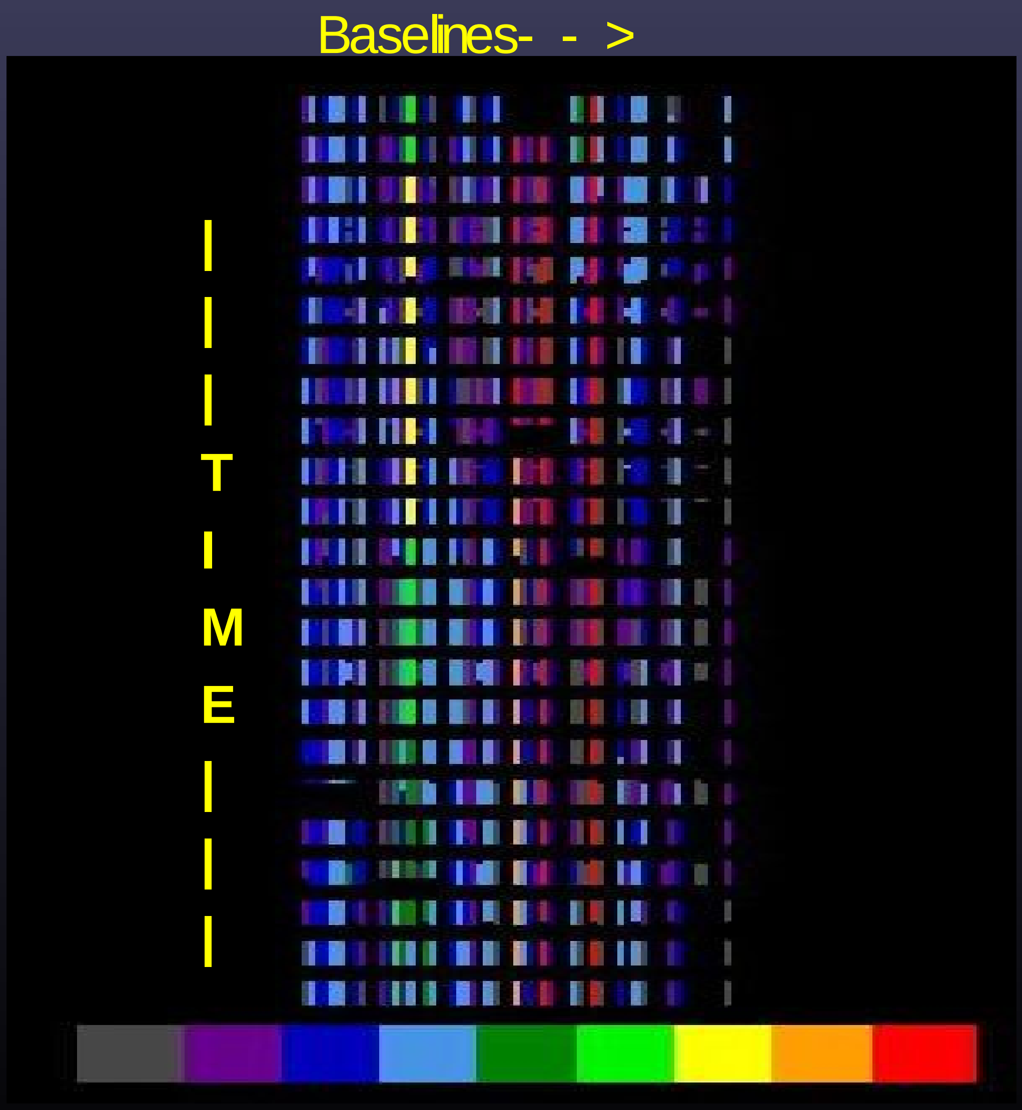


Time in d/ hh mm

Plot of Visbility amplitude and Phase versus time for various baselines

Good for determining the continuity of the data. should be relatively smooth with time

DATA DISPLAYS(4)



Color Display of Visibility amplitude of each baseline with time.

Usually interactive editing is possible. Example later.

IMAGE PLANE OR DATA (U- V) PLANE?

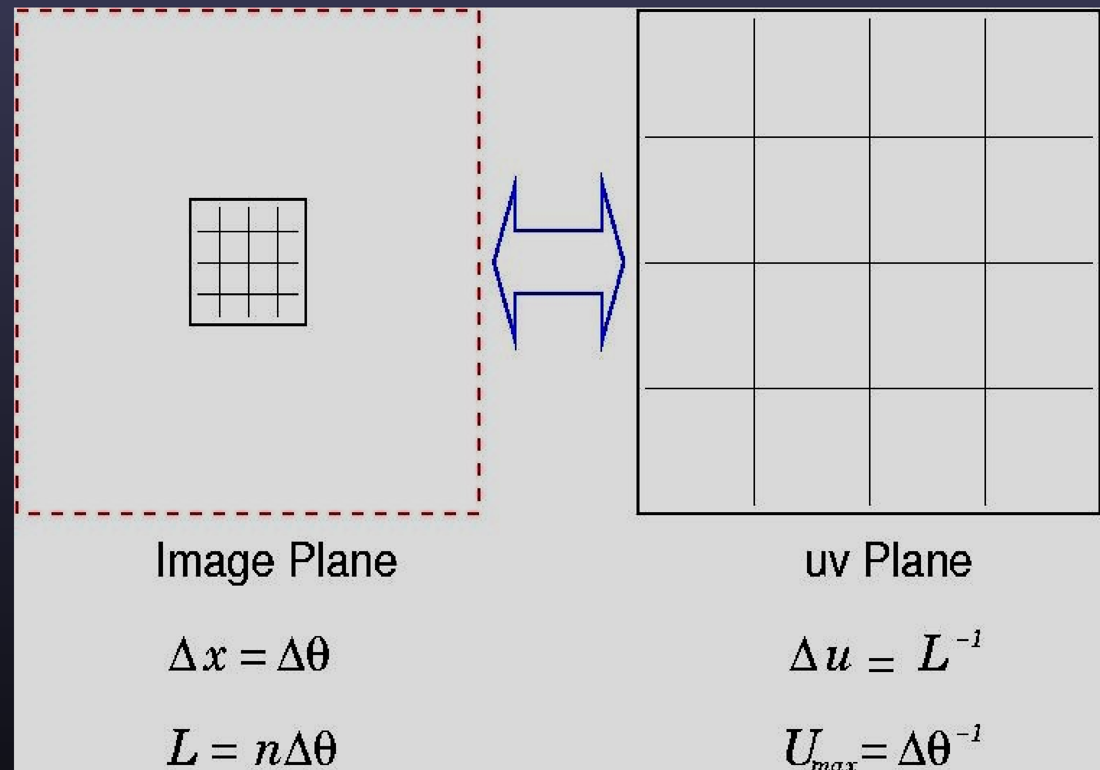
Errors obey Fourier relationship

Narrow features <-->
Wide features
(easier to find narrow features)

Orientations are orthogonal

Data amplitude errors <->
symmetric image features

Data phase error -->
asymmetric image features



GOLDEN RULE OF FINDING ERRORS

- - - Obvious outlier data (u- v) points:

100 bad points in 100,000 data points gives an 0.1% image error (unless the bad data points are 1 million Jy)

USE DATA to find problem (but don' t go overboard)

- - - Persistent small data errors:

egs a 5% antenna gain calibration error is difficult to see in (u- v) data (not an obvious outlier), but will produce a 1% effect in image with specific characteristics (more later).

USE IMAGE to discover problem

- - - Non- Data Problems:

Perfect data but unstable algorithms. Very common.

ERROR RECOGNITION IN THE U- V PLANE

Editing obvious errors in the u- v plane

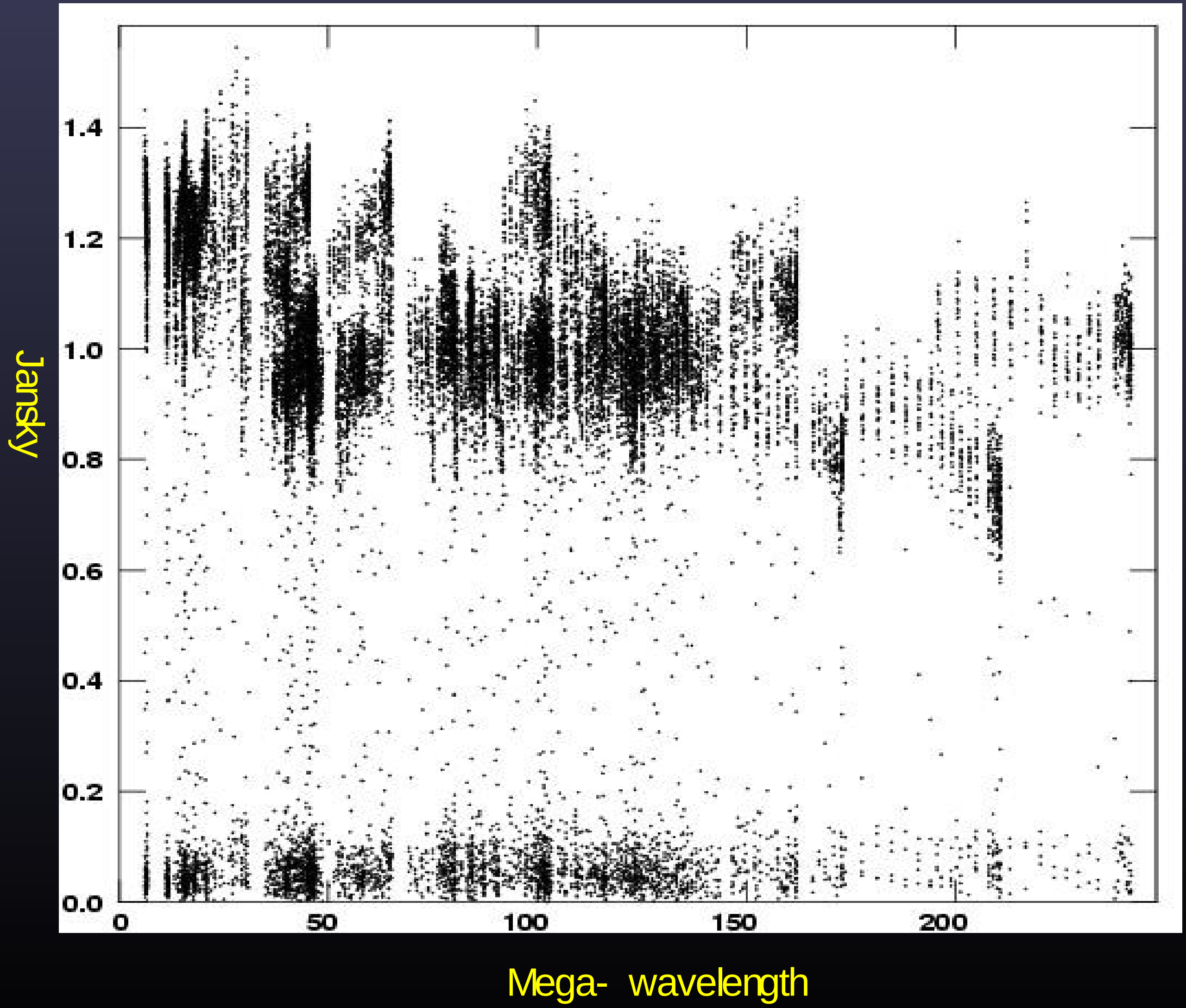
- - - Mostly consistency checks assuming that the visibility cannot change much over a small change in u- v spacing

- - - Also, double check gains and phases from calibration processes. These values should be relatively stable.

See Summer school lecture notes in 2002 by Myers

See ASP Vol 180, Ekers, Lecture 15, p321

Editing using Visibility Amplitude versus uv spacing



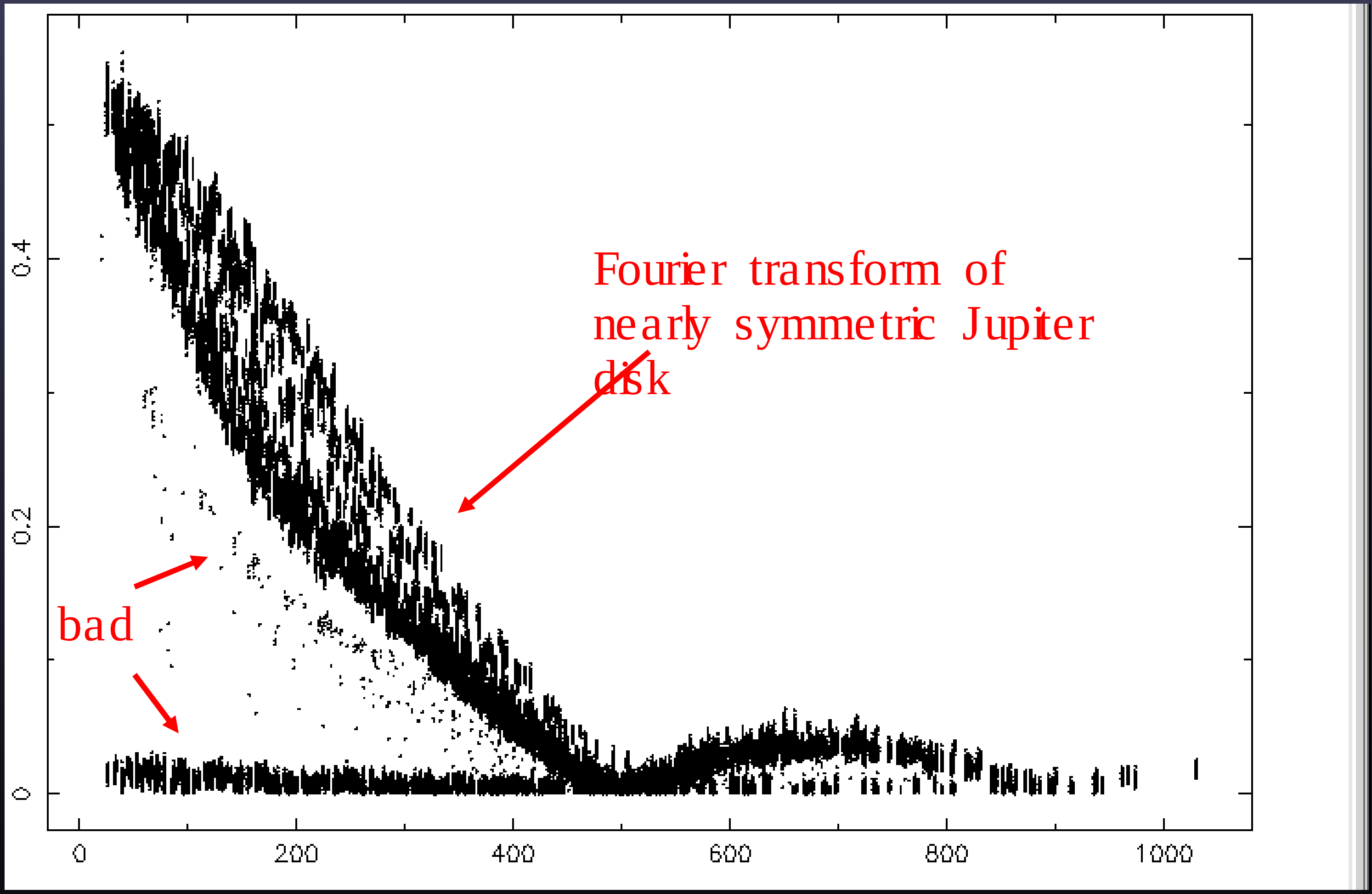
Nearly point source

Lots of drop- outs
Some lowish points

Could remove all data less than 0.6 Jy, but Need more inform- ation.

A baseline- time plot is more instructive.

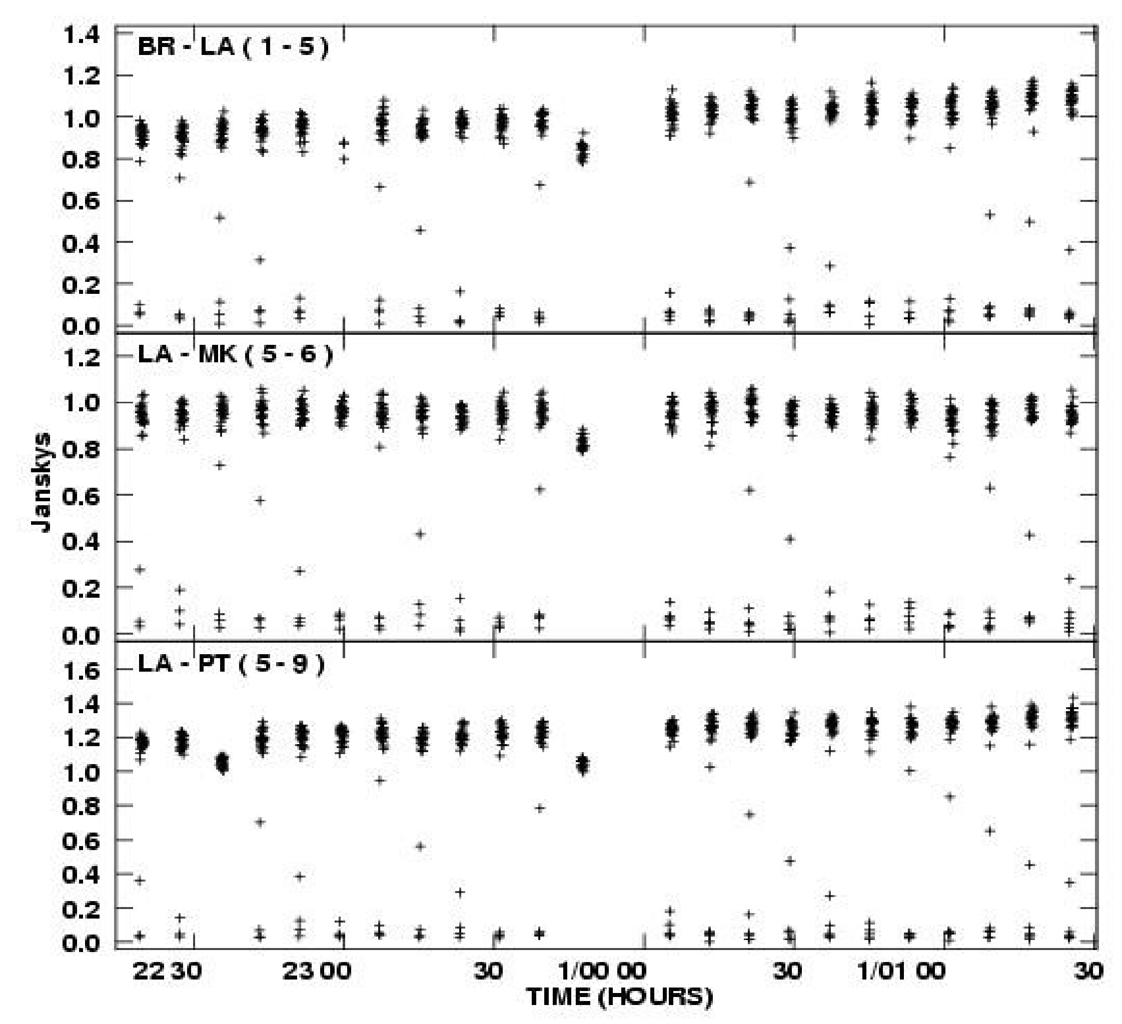
Example Edit – msplot (2)



Jansky

Kilo- wavength

Editing using Time Series Plots

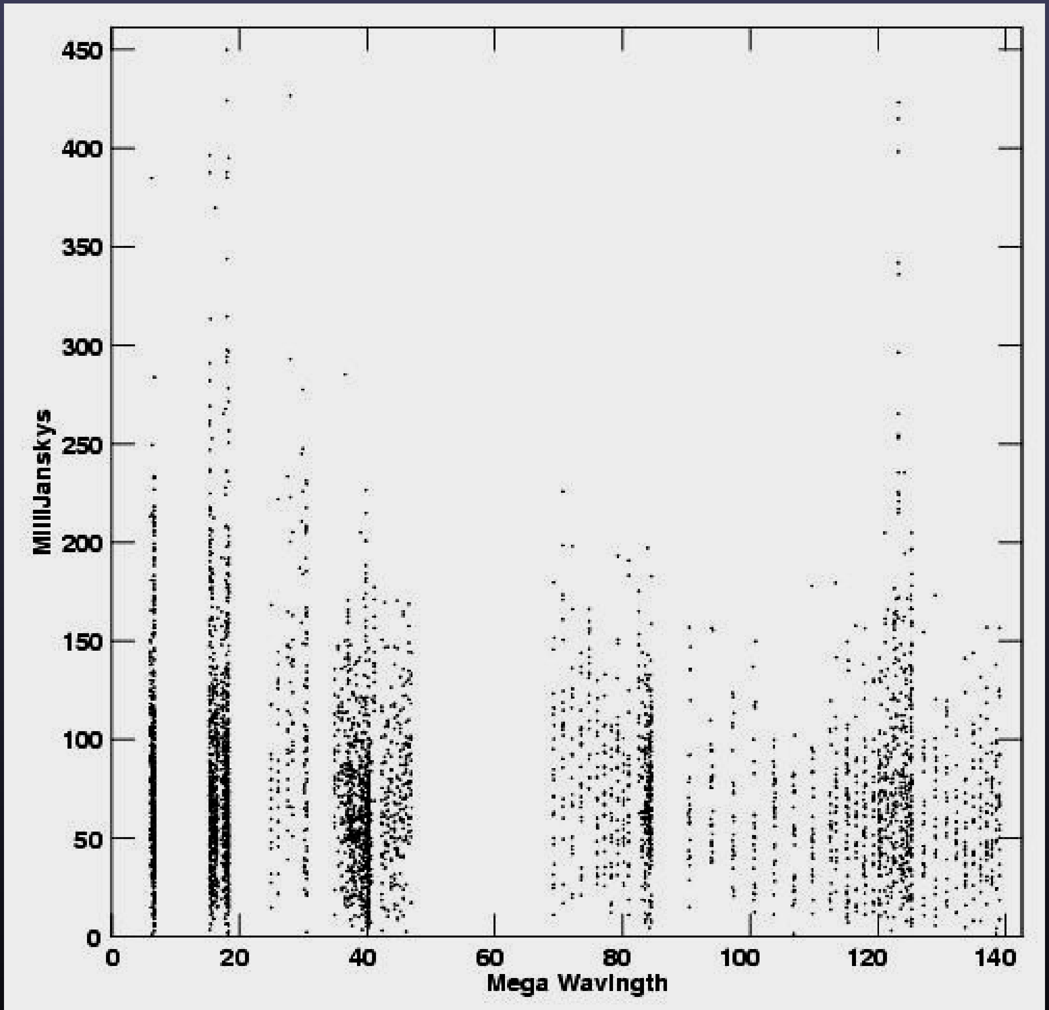


Mostly occasional drop-outs

Hard to see, but drop outs and lower points at the beginning of each scan. (aips, aips++ task QUACK)

Should apply same editing to all sources, even if too weak to see signal.

Editing noise- dominated Sources

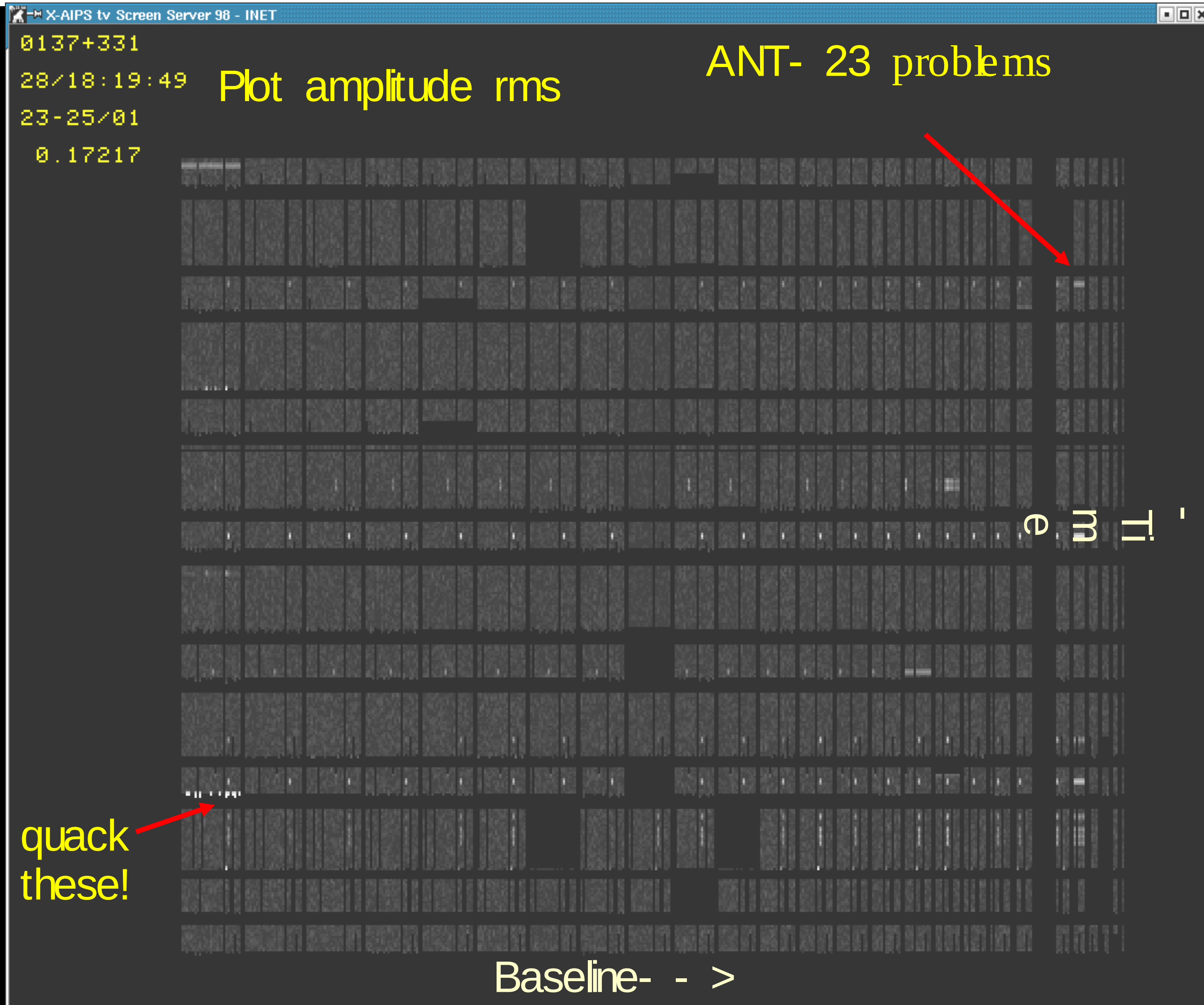


No source structure information available.

All you can do is remove outlier points above 0.3 Jy. Precise level not important as long as large outliers removed.

Other points consistent with noise.

USING TVFLG DISPLAY on noisy source



ERROR RECOGNITION IN THE IMAGE PLANE

Some Questions to ask?

Noise properties of image:

- Is the rms noise about that expected from integrtion time?
- Is the rms noise much larger near bright sources?
- Are there non- random noise components (faint waves and ripples)?

Funny looking Structure:

- Non- physical features; stripes, rings, symmetric or anti- symmetric
- Negative features well- below 4xrms noise
- Does the image have characteristics in the dirty beam?

Image- making parameters:

- Is the image big enough to cover all significant emission?
- Is cell size too large or too small? > 4 points per beam
- Is the resolution too high to detect most of the emission?

EXAMPLE 1

All data bad over a short period of time

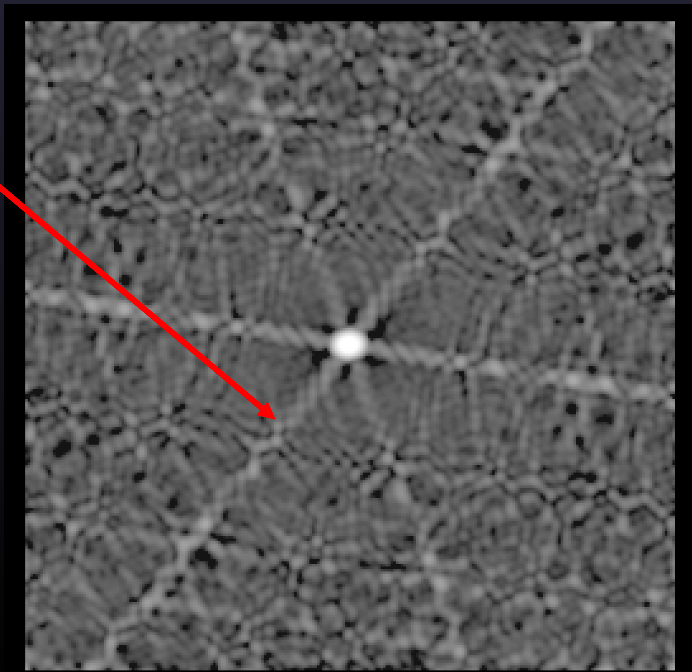
Results for a point source using VLA. 13- 5min observation over 10 hr.

Images shown after editing, calibration and deconvolution.

no errors:
max 3.24 Jy
rms 0.11 mJy

10% amp error for all antennas for 1 time period
rms 2.0 mJy

6-fold symmetric pattern due to VLA “ Y” .
Image has properties of dirty beam.

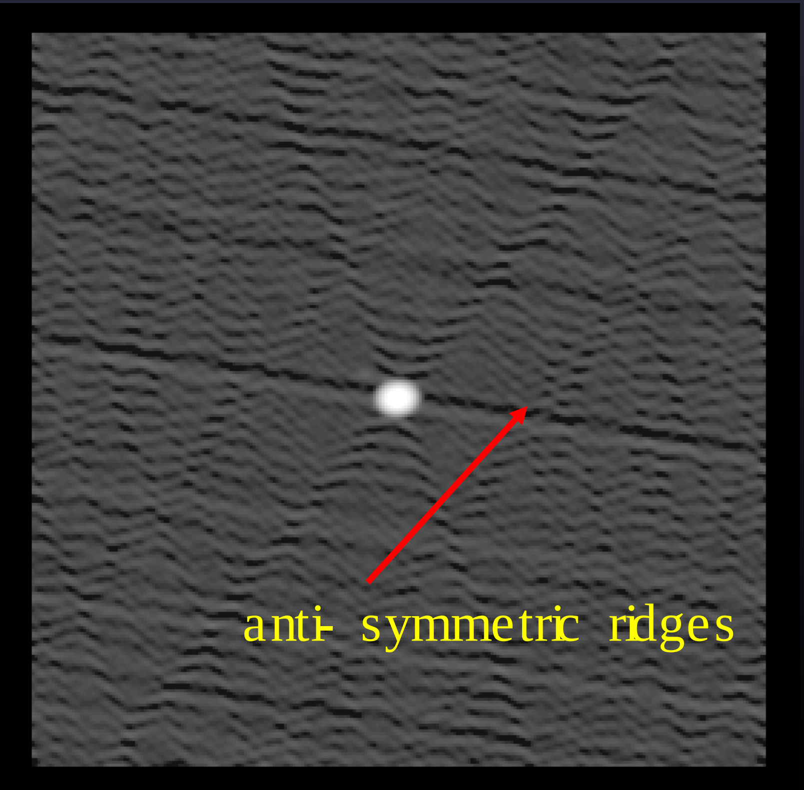


EXAMPLE 2

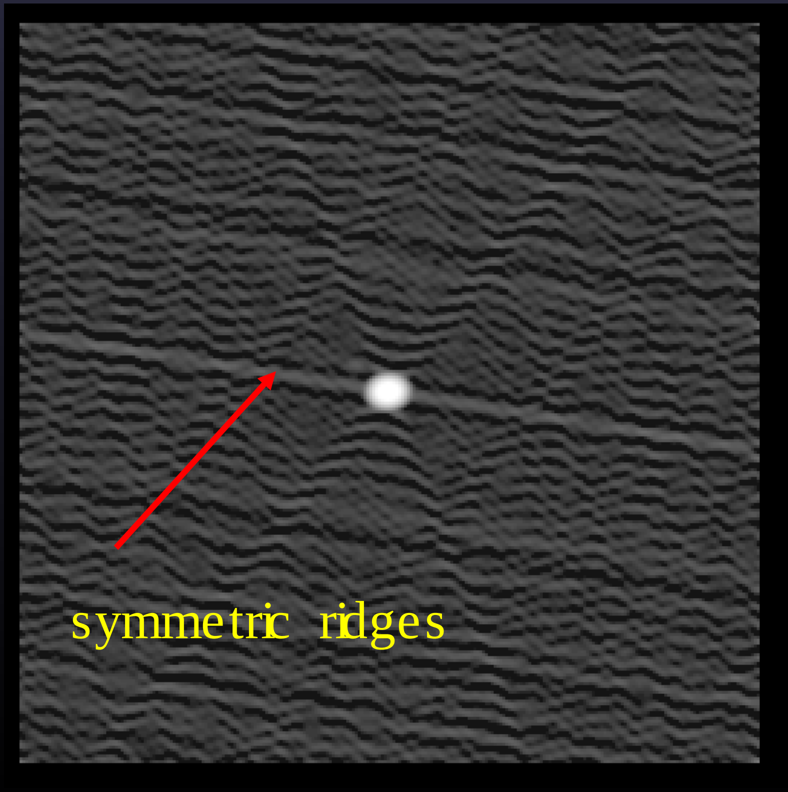
Short burst of bad data

Typical effect from one bad u-v points: Data or weight

10 deg phase error for
one antenna at one time
rms 0.49 mJy



20% amplitude error for
one antenna at 1 time
rms 0.56 mJy (self-cal)

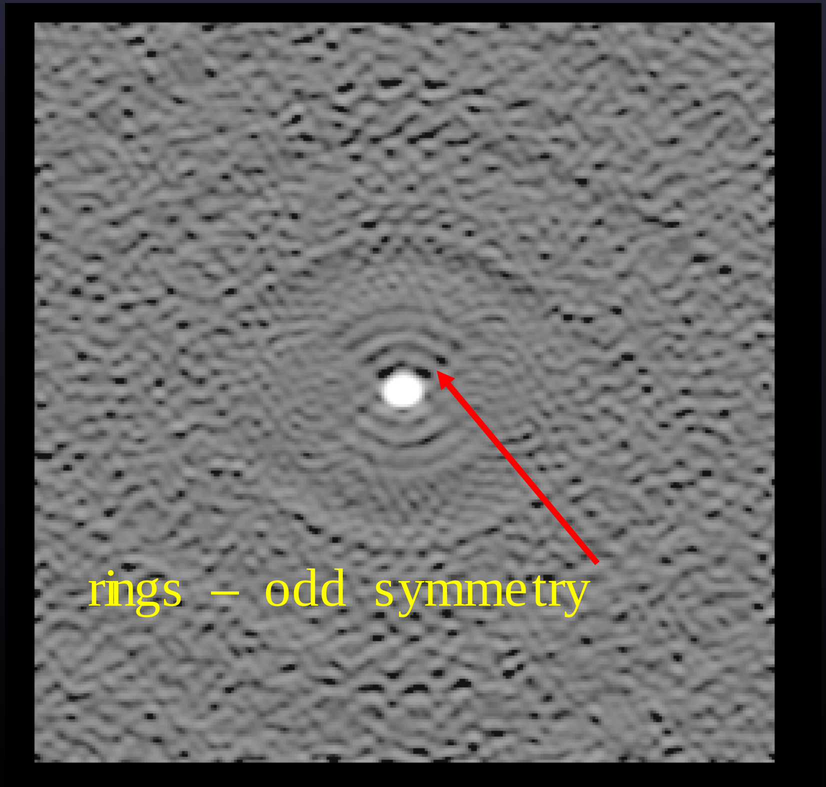


EXAMPLE 3

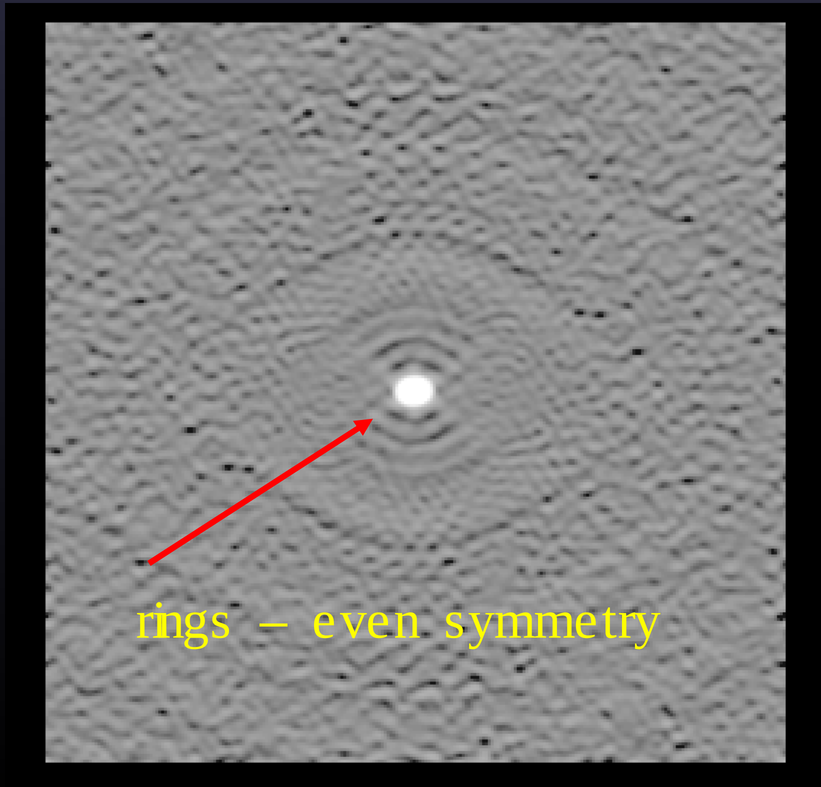
Persistent errors over most of observations

NOTE: 10 deg error equivalent to 20% error. That is why phase variations are generally more serious

10 deg phase error for one antenna all times
rms 2.0 mJy



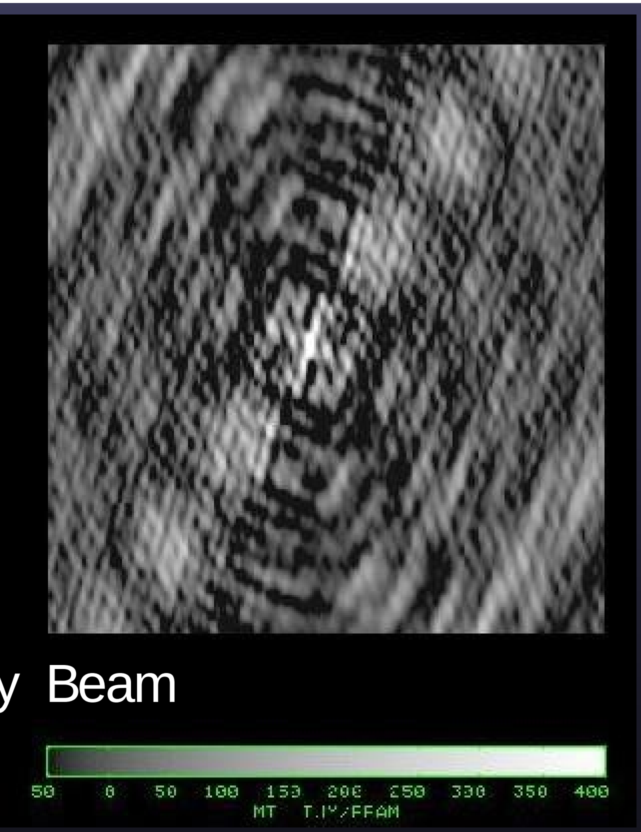
20% amp error for one antenna all times
rms 2.3 mJy



DECONVOLUTION ERRORS

- Even if data is perfect, image errors will occur because of incomplete or poor deconvolution.
- This is often image distortions serious associated with extended sources or those with limited (u- v) coverage.
- The problems can usually be recognized, if not always fixed. Get better (u- v) coverage if you can.
- Also, 3- D sky distortion, chromatic aberration and time- smearing distort the image (other lectures).

DIRTY IMAGE and BEAM (point spread function)



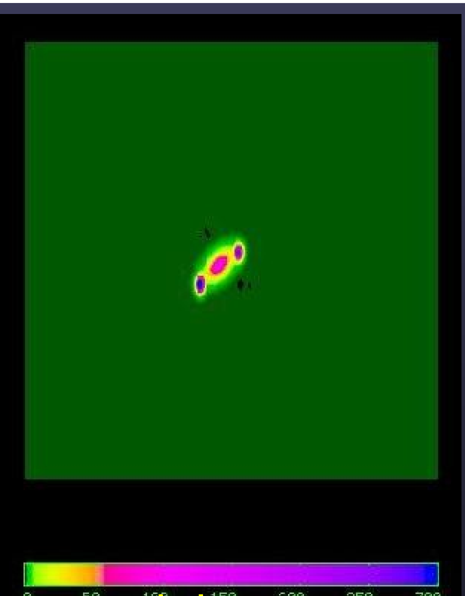
The dirty beam has large, complicated side-lobe structure.

It is often difficult to recognize any details on the dirty image.

An extended source exaggerates the side-lobes.

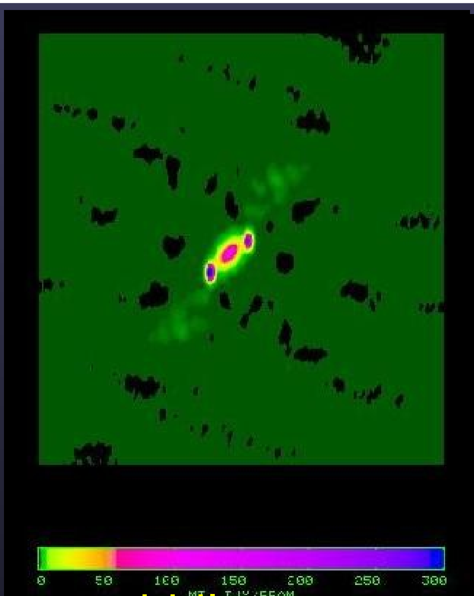
5% in dirty beam becomes 20% for extended source

CLEANING WINDOW SENSITIVITY



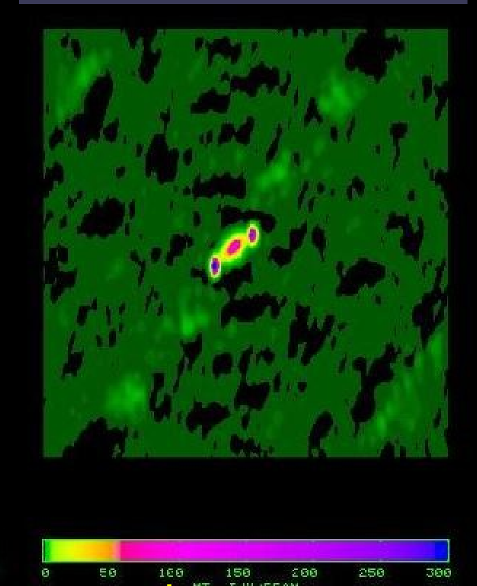
Tight Box

Three small clean boxes (interactive clean shown next)



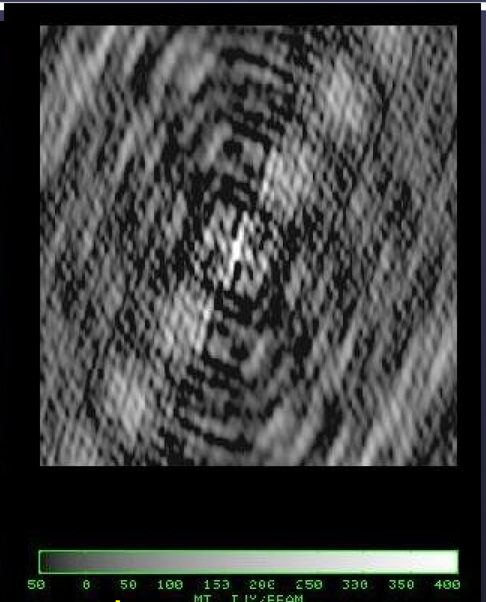
Middle Box

One clean box around all emission



Big Box

Clean entire inner map quarter



Dirty Beam

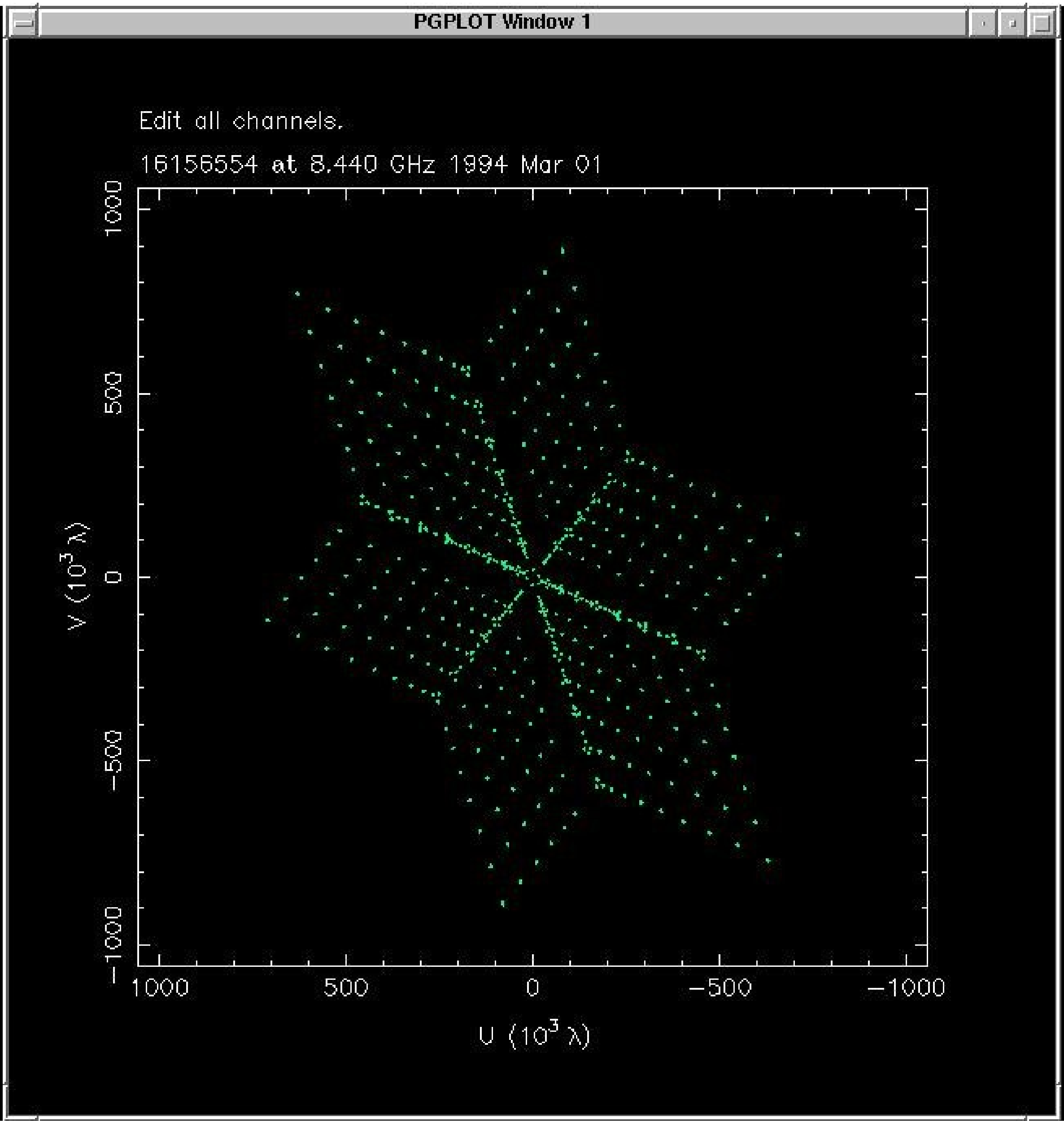
Spurious emission is always associated with higher sidelobes in dirty-beam .

A SEQUENCE ABOUT CLEANING

Snapshot 1

Using Caltech
Difmap Software

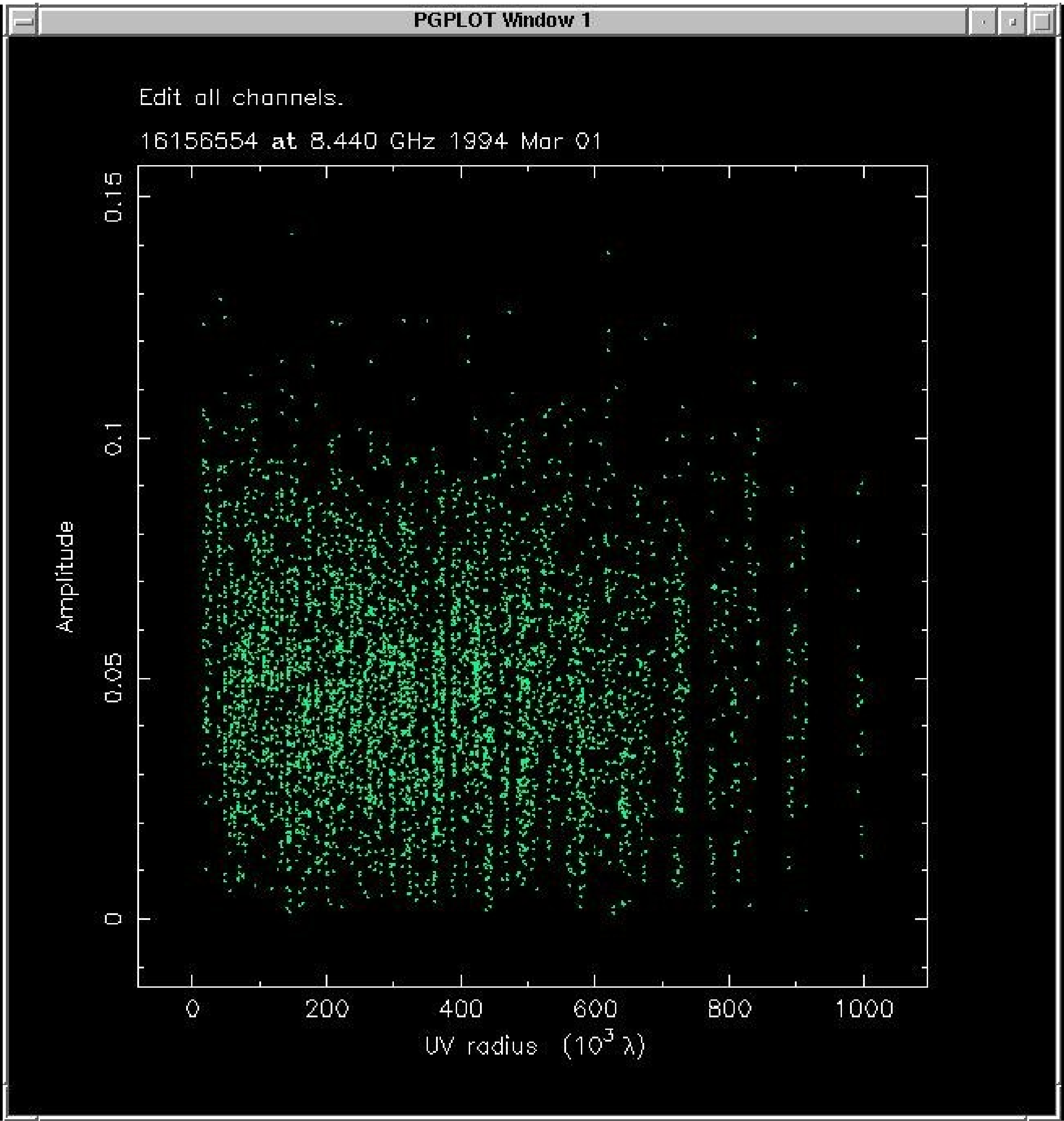
uv coverage



Snapshot 2

amplitude vs. uv radius

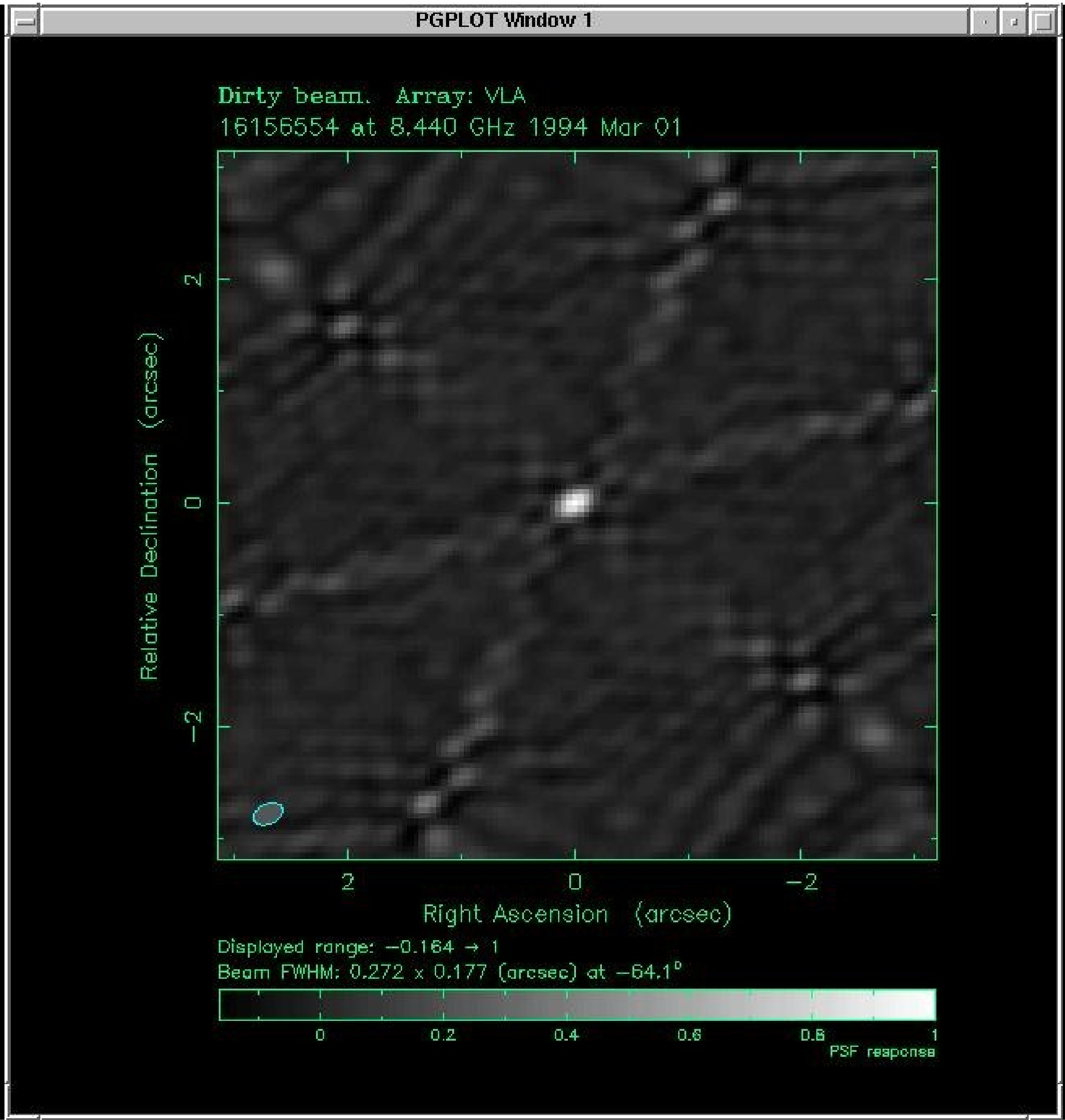
Somewhat noisy with about 50 mJy in emission



Snapshot 3

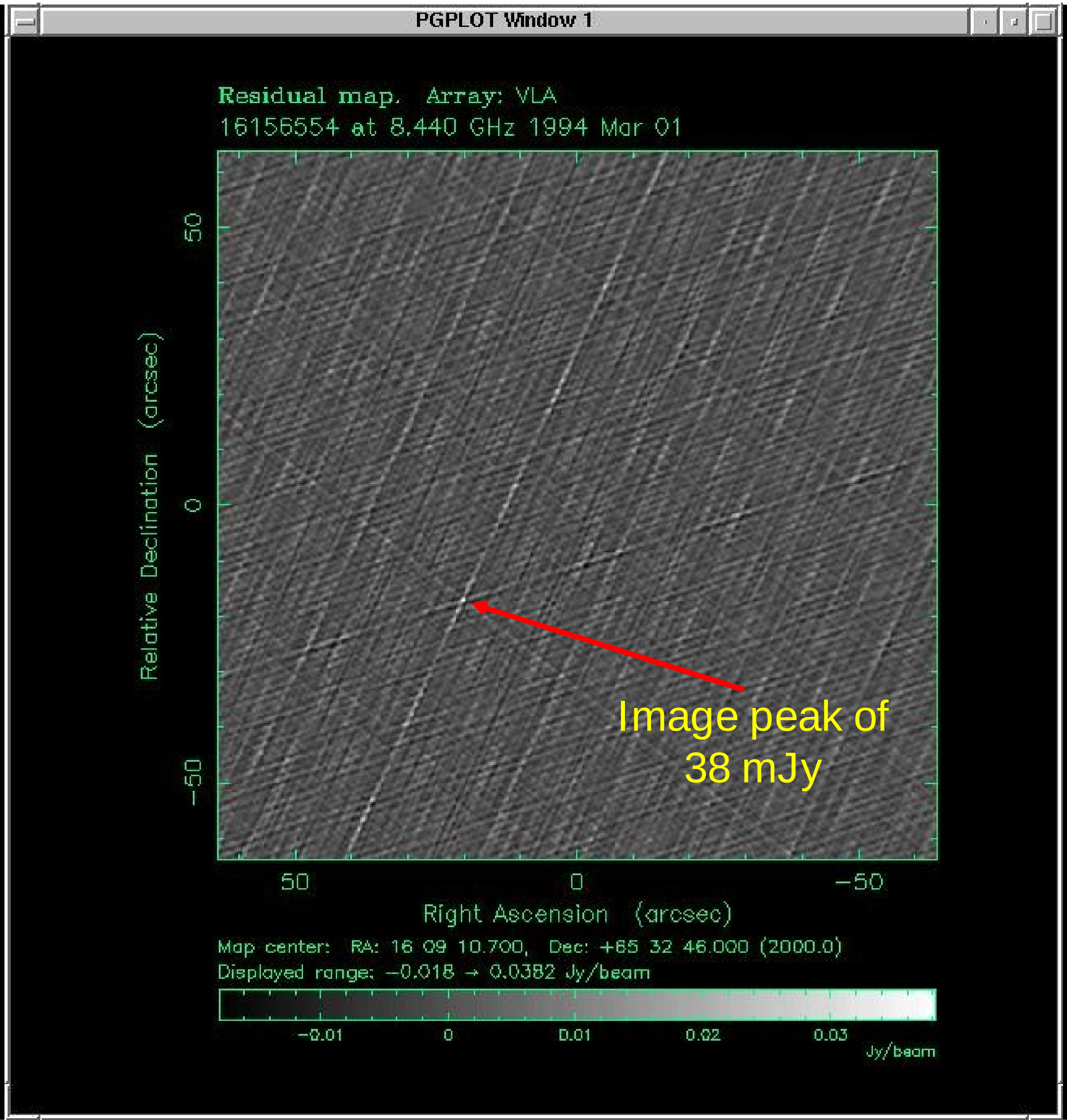
dirty beam

20% sidelobes



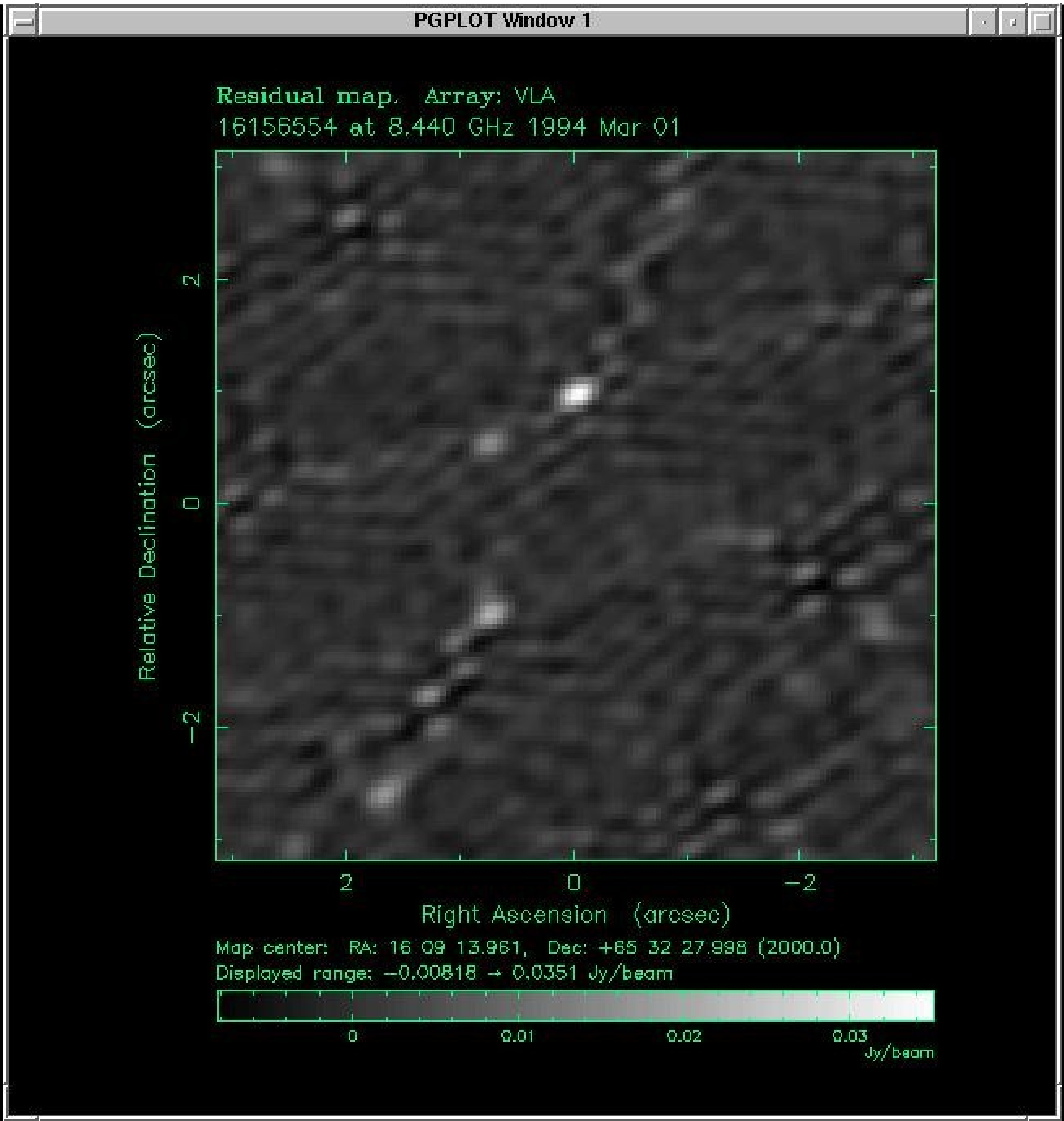
Snapshot 4

dirty image - wide field view



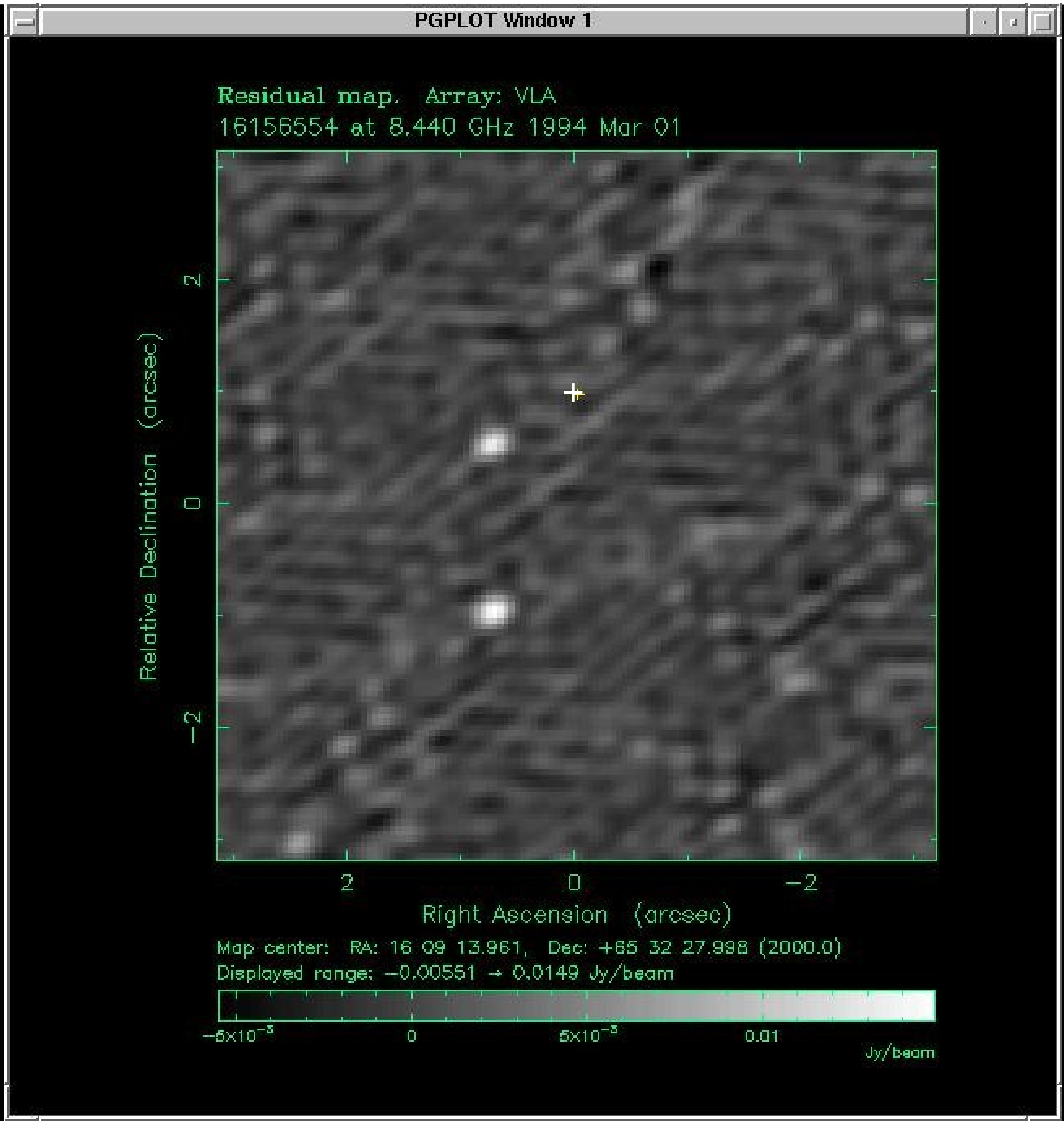
Snapshot 5

dirty image - full resolution around peak



Any thing that is not symmetric may be real (phase errors)

Snapshot 6



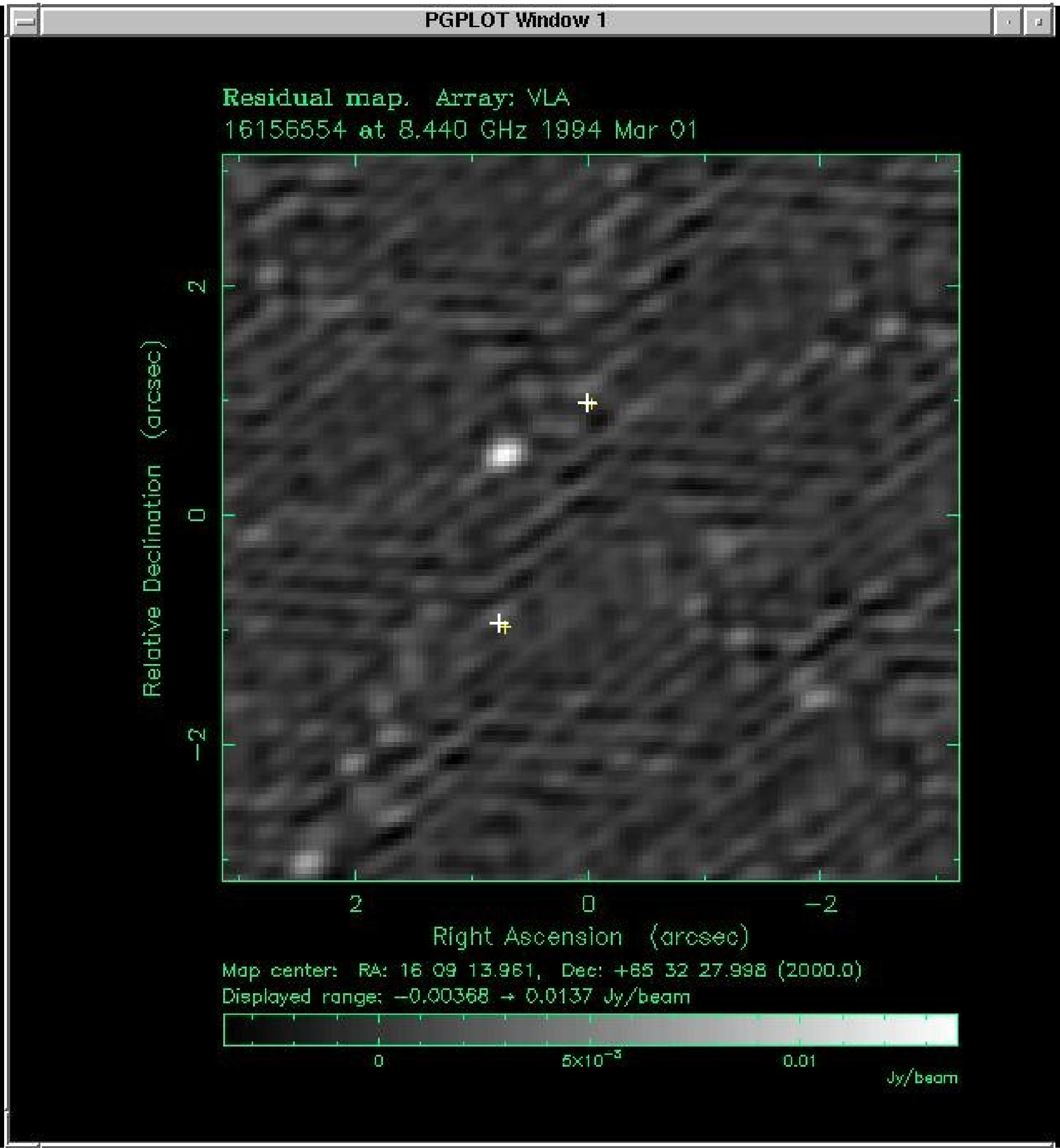
residual image - 1st source removed

Fit in u- v plane for a small- diameter comp near + location, and remove it from data and make new image

Cleaning does almost the same thing.

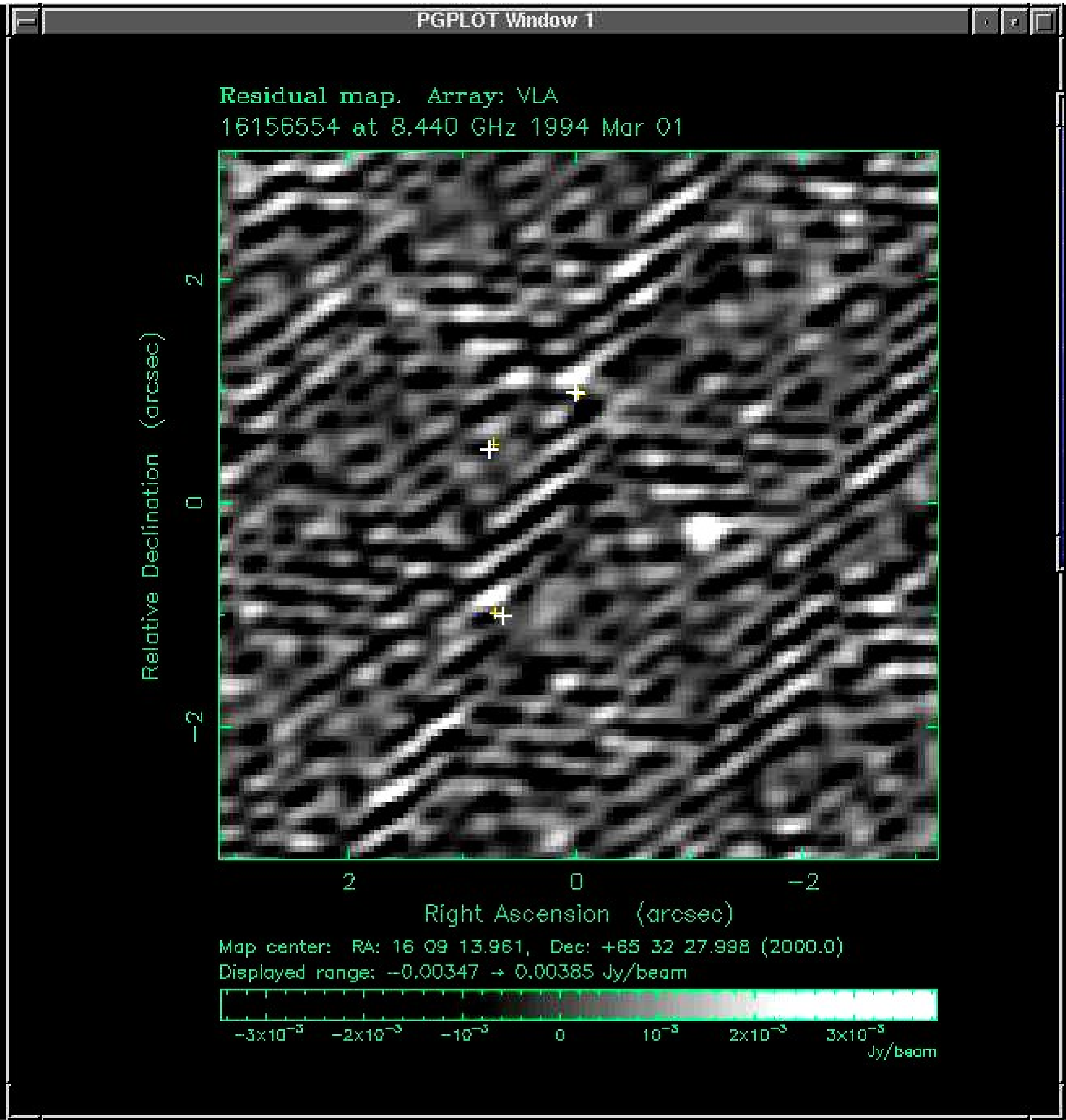
Snapshot 7

residual image - 2nd source removed



Snapshot 8

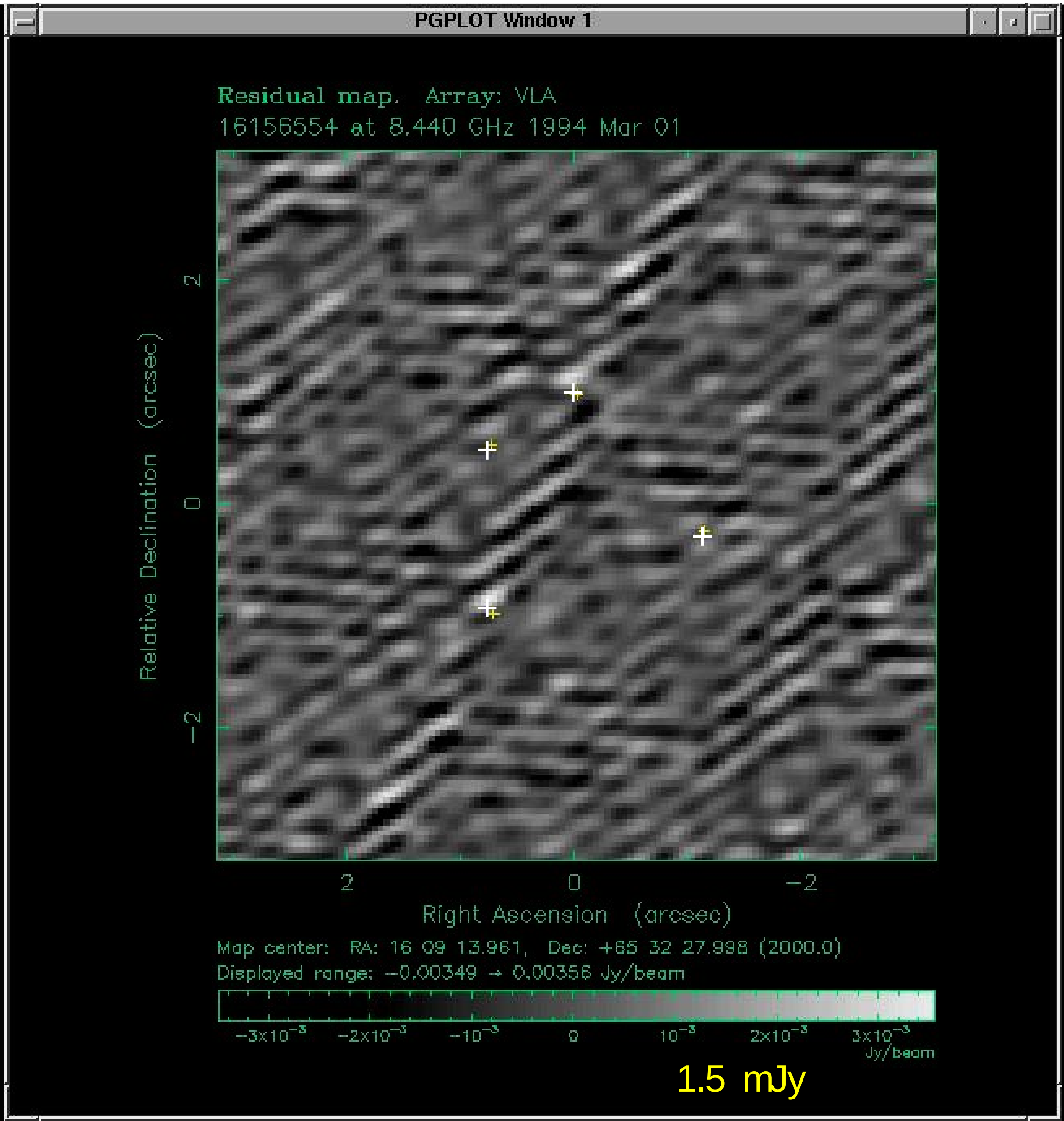
residual image - 3rd source removed



Snapshot 9

residual image - 4th source removed

Notice noise structure is left. Need further self- calibration?

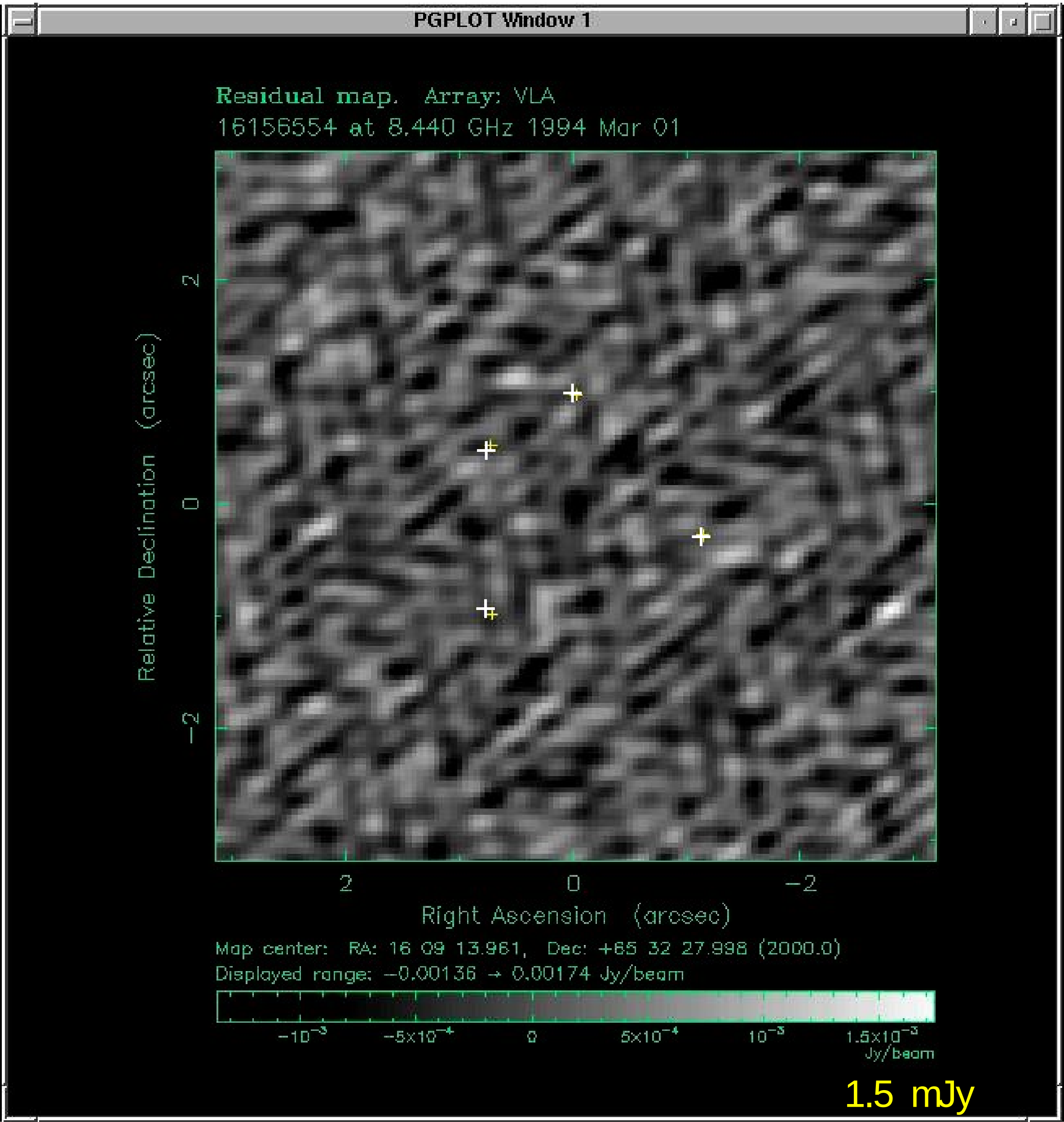


Snapshot 10

New residual image

After phase self- cal with the four component model

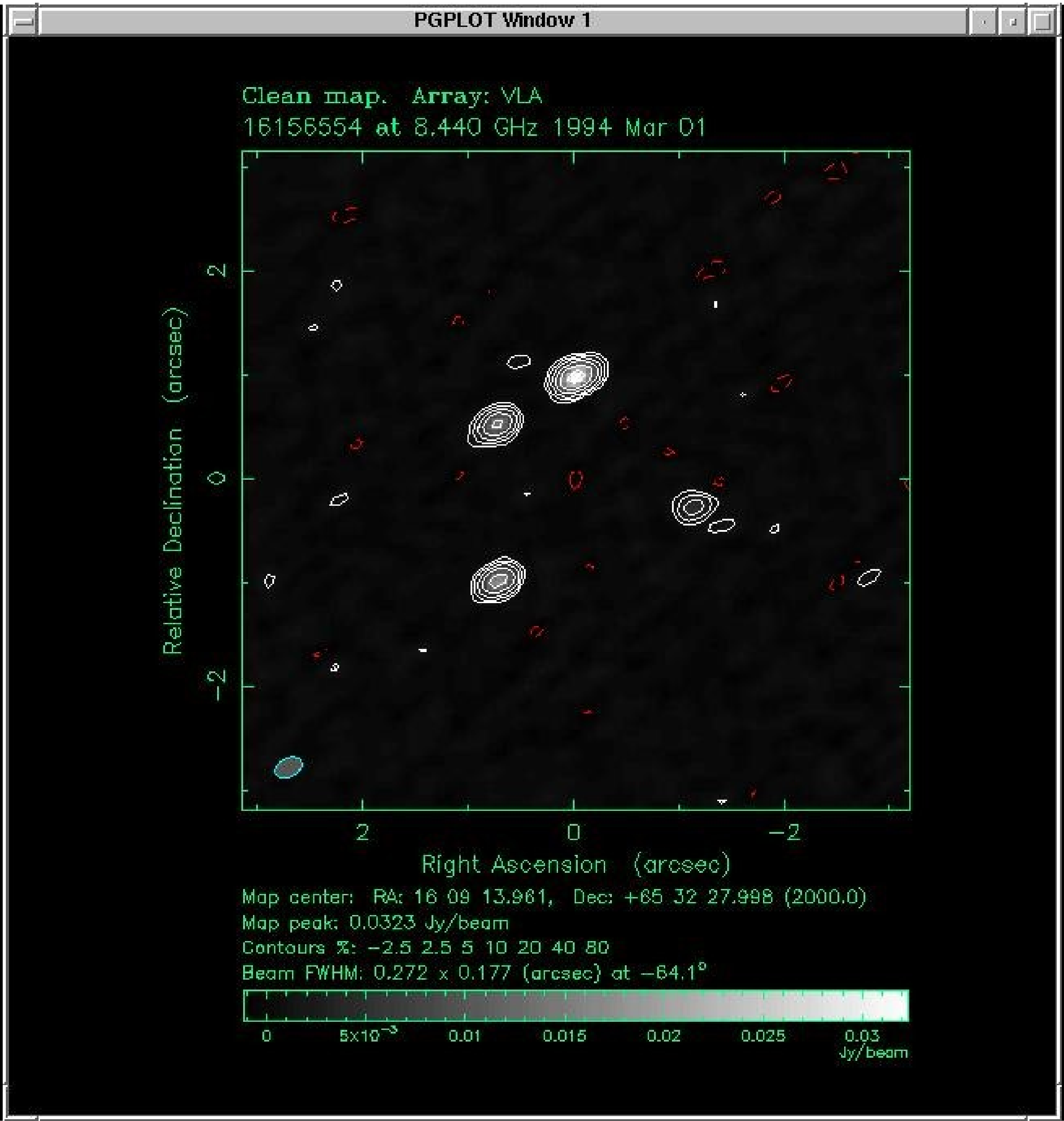
Note: Change of brightness scale by a factor of 2.



1.5 mJy

Snapshot 11

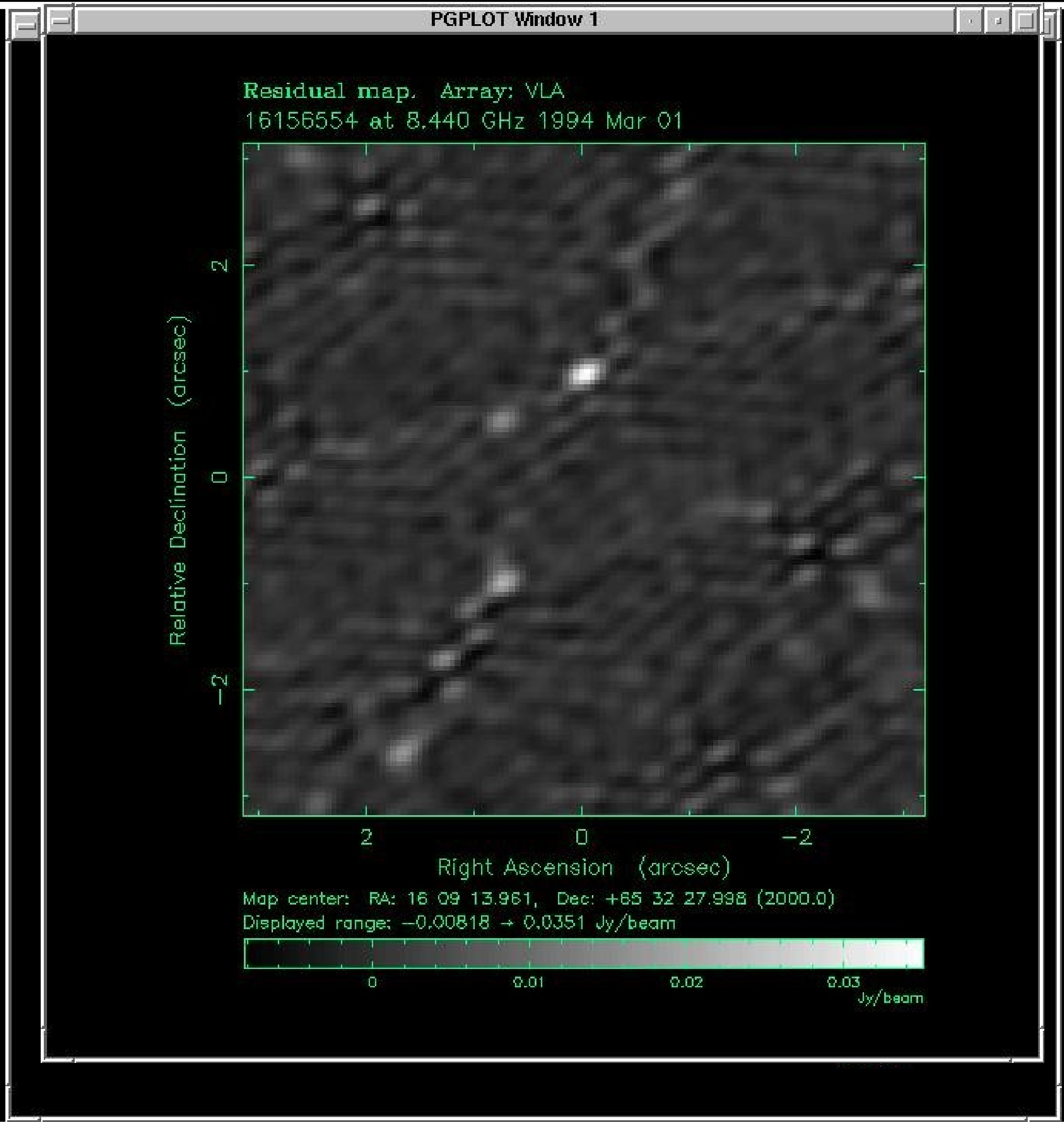
Final restored image



Gravitational lens:
four radio blobs
from one true source
near middle.

Snapshot 11

Final image (contour) overlayed on original dirty image



It's amazing how well deconvolution and self-cal work if you are careful!

SUMMARY OF ERROR RECOGNITION

Source structure should be 'reasonable', the rms image noise as expected, and the background featureless. If not,

UV data

Look for outliers in u-v data using several plotting methods.

Check calibration gains and phases for instabilities.

Look at residual data (uv-data - clean component)

IMAGE plane

Do defects resemble the dirty beam?

Are defects related to possible data errors?

Are defects related to possible deconvolution problems?

IMAGE ANALYSIS

Ed Fomalont

Tenth Summer Synthesis Imaging Workshop

University of New Mexico, June 13-20, 2006

IMAGE ANALYSIS

- Input: Well-calibrated data-base producing a
  high quality image
- Output: Parameterization and interpretation
  of image or a set of images

This is very open-ended

Depends on source emission complexity

Depends on the scientific goals

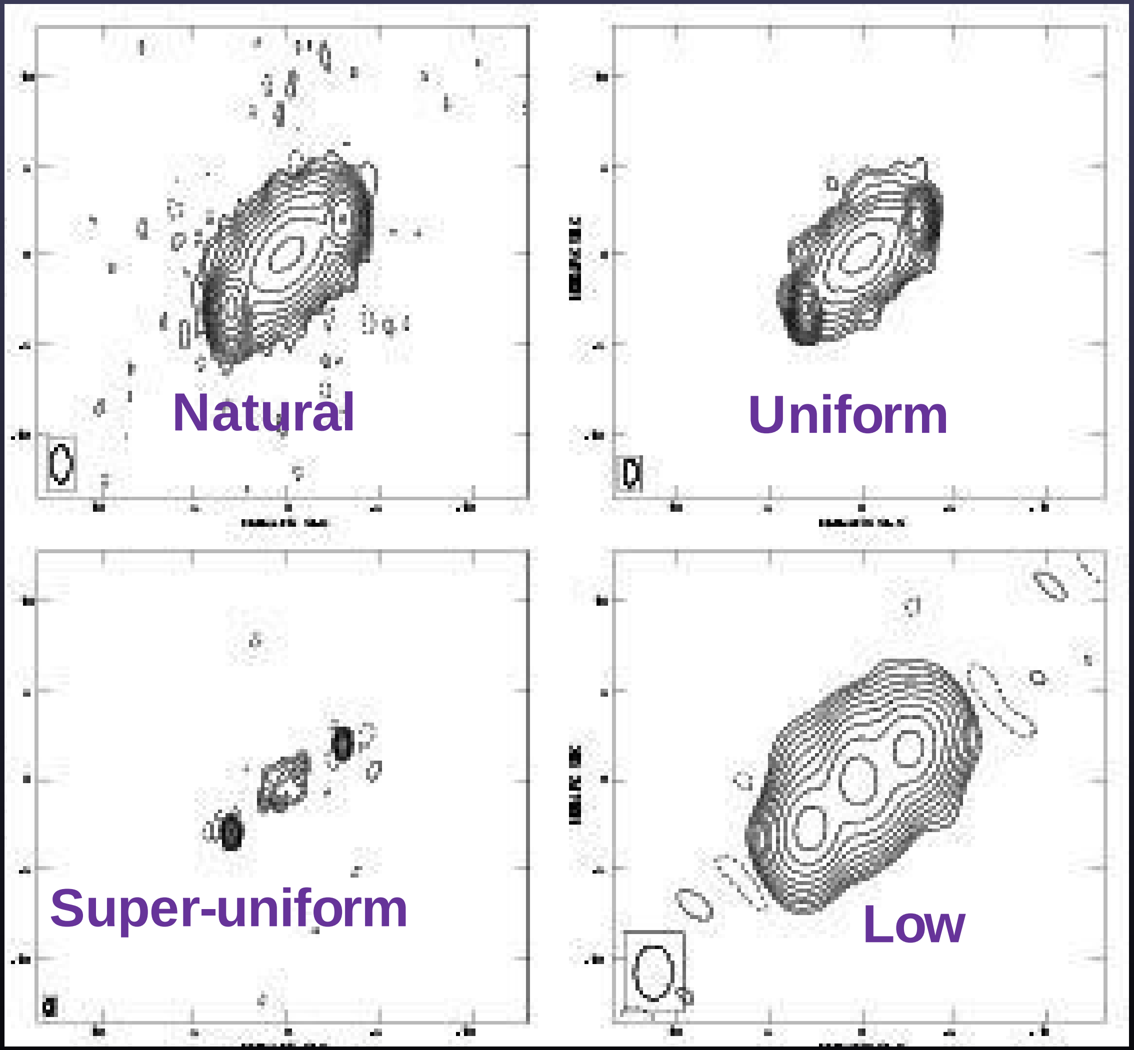
Examples and ideas are given.

Many software packages, besides AIPS and Casa (eg. IDL, DS-9) are available.

IMAGE ANALYSIS OUTLINE

- Multi- Resolution of radio source.
- Parameter Estimation of Discrete Components
- Polarization Data
- Image Comparisons
- Positional Registration

IMAGE AT SEVERAL RESOLUTIONS



Milli- arcsec

Different aspects of source can be seen at the different resolutions, shown by the ellipse at the lower left.

SAME DATA USED FOR ALL IMAGES

For example, the outer components are very small.

There is no extended emission beyond the three main components.

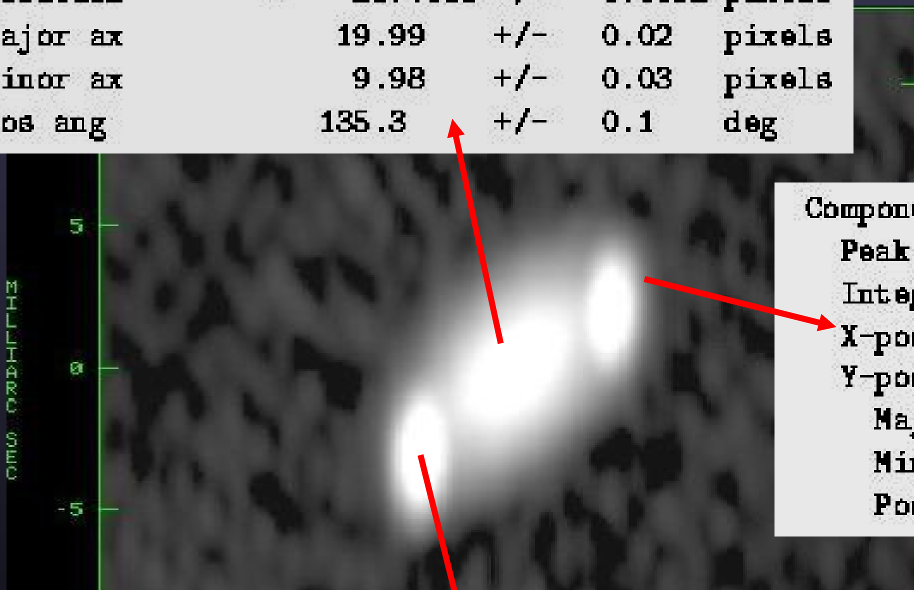
PARAMETER ESTIMATION

Parameters associated with discrete components

- Fitting in the image
  - Assume source components are Gaussian-shaped
  - Deep cleaning restores image intensity with Gaussian-beam
  - True size * Beam size = Image size, if Gaussian-shaped. Hence, estimate of true size is relatively simple.
- Fitting in (u- v) plane
  - Better estimates for small-diameter sources
  - Can fit to any source model (egs ring, disk)
- Error estimates of parameters
  - Simple ad-hoc error estimates
  - Estimates from fitting programs

IMAGE FITTING

```
Component   2-Gaussian
  Peak intensity     = 0.104 +/- 0.005 JY/BEAM
  Integral intensity= 0.998 +/- 9,47   JANSKYS
  X-position         =    255.986 +/-   0.0029 pixels
  Y-position         =    257.033 +/-   0.0032 pixels
    Major ax             19.99    +/-   0.02   pixels
    Minor ax              9.98    +/-   0.03   pixels
    Pos ang             135.3     +/-   0.1    deg
```




```
Component   1-Gaussian
  Peak intensity     = 0.300 +/- 0.005 JY/BEAM
  Integral intensity= 0.302 +/- 0.008 JANSKYS
  X-position         =    270.991 +/-   0.001 pixels
  Y-position         =    267.018 +/-   0.001 pixels
    Major ax              0.53    +/-   0.01  pixels
    Minor ax              0.00    +/-   0.05  pixels
    Pos ang              21.6     +/-   1.1   deg
```

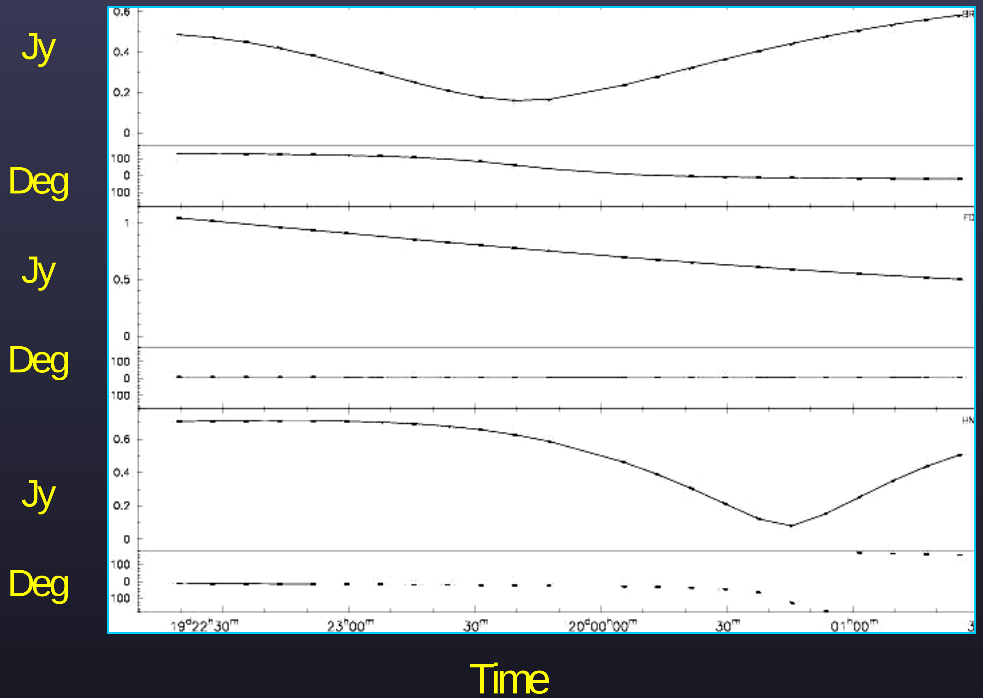
```
Component   3-Gaussian
  Peak intensity     = 0.393 +/- 0.004 JY/BEAM
  Integral intensity= 0.403 +/- 0.008 JANSKYS
  X-position         =    241.007 +/-   0.001 pixels
  Y-position         =    241.988 +/-   0.001 pixels
    Major ax              1.54    +/-   0.01  pixels
    Minor ax              0.21    +/-   0.01  pixels
    Pos ang               3.6     +/-   0.2   deg
```

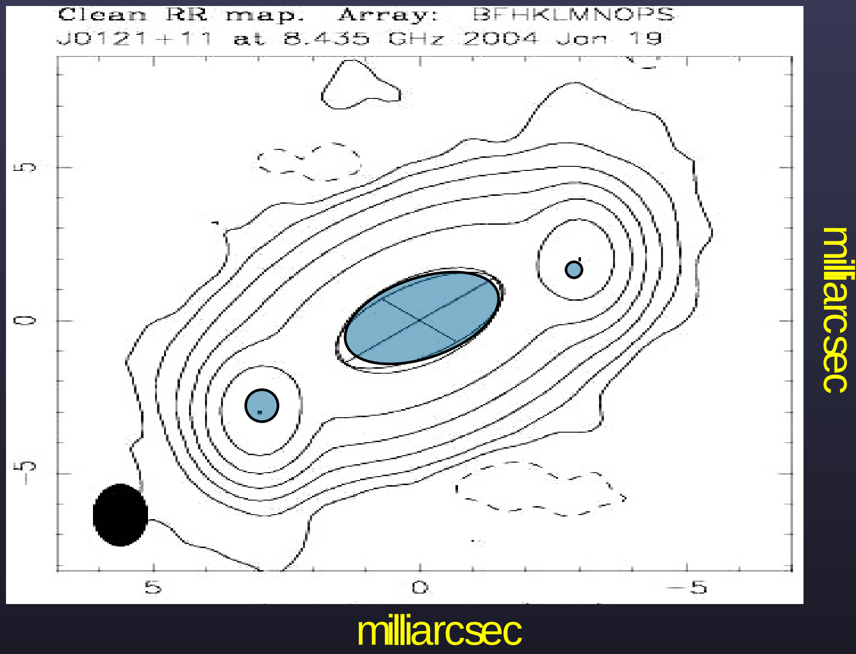
AIPS task: JMFIT

Casa tool

imagefitter

(U- V) DATA FITTING





DIFMAP has best algorithm

Fit model directly to (u-v) data

Look at fit to model

Contour display of image

Ellipses show true component size. (super-resolution?)

COMPONENT ERROR ESTIMATES

P = Component Peak Flux Density

σ = Image rms noise P/σ = signal to noise = S

B = Synthesized beam size

θ_i = Component image size

ΔP = Peak error = σ

ΔX = Position error = $B / 2S$

$\Delta\theta_i$ = Component image size error = $B / 2S$

θ_t = True component size = $(\theta_i^2 - B^2)^{1/2}$

$\Delta\theta_t$ = Minimum component size = $B / S^{1/2}$

most interesting

Comparison and Combination of Images of Many Types

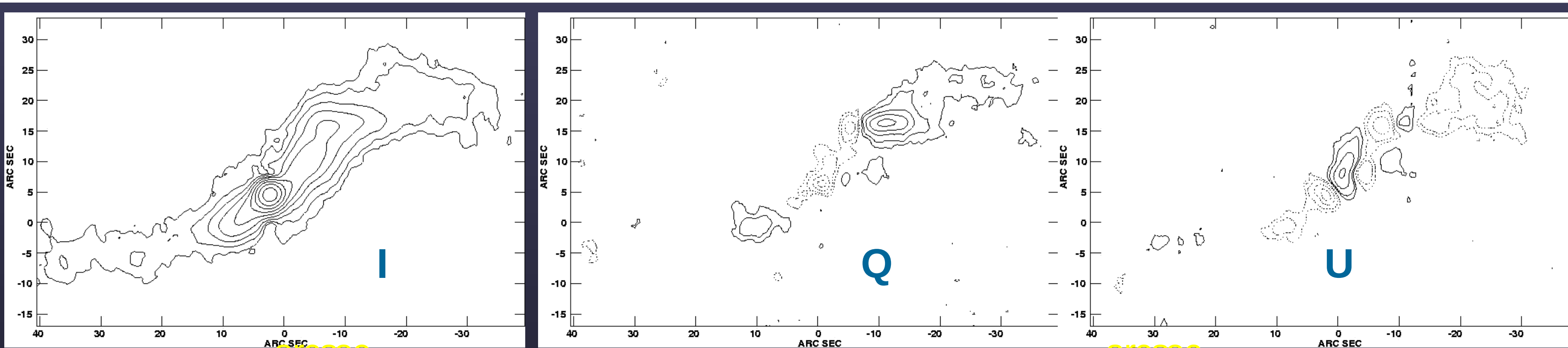
FORNAX- A Radio/ Optical field

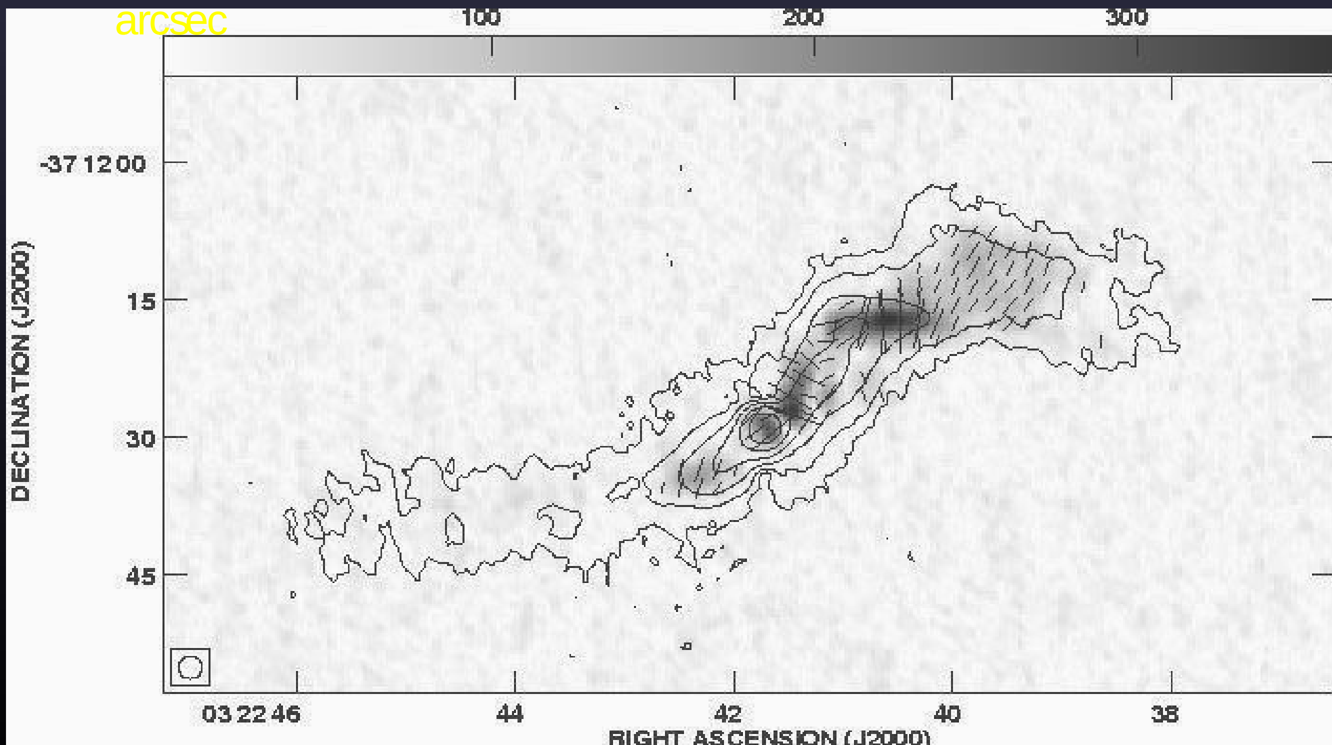
Radio is red
Faint radio core
in center of
NGC1316

Optical in
blue-white

Frame size is
60’ x 40’

LINEAR POLARIZATION





Multi- purpose plot

Contour – I,Q,U Pol

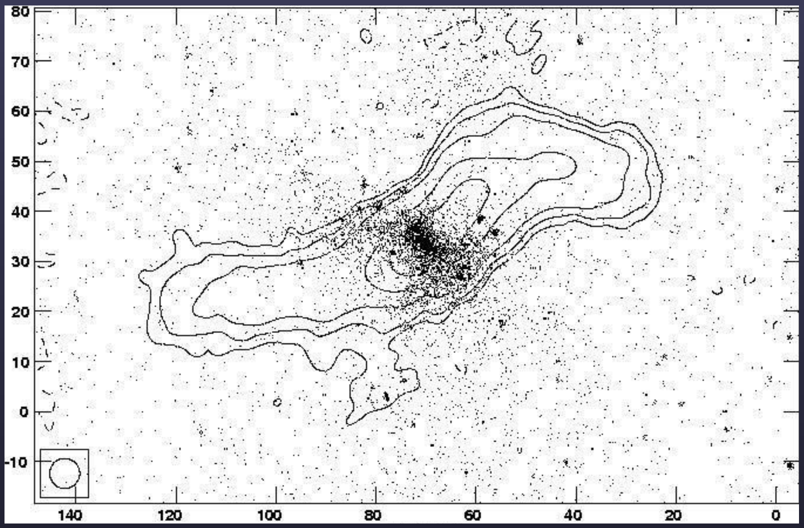
Grey scale – P Pol

  sqrt (Q^2+U^2) - noise

Line segments – P angle

  atan2(0.5*Q/U)

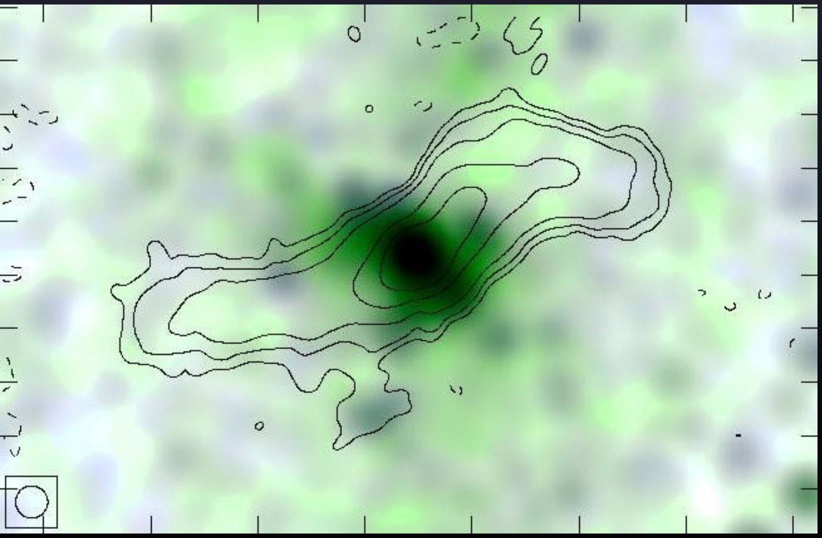
COMPARISON OF RADIO/ X- RAY IMAGES



arcsec

Contours of radio intensity at 5 GHz

Dots represent X-ray Intensity (photons) between 0.7 and 11.0 KeV



Contours of radio intensity at 5 GHz

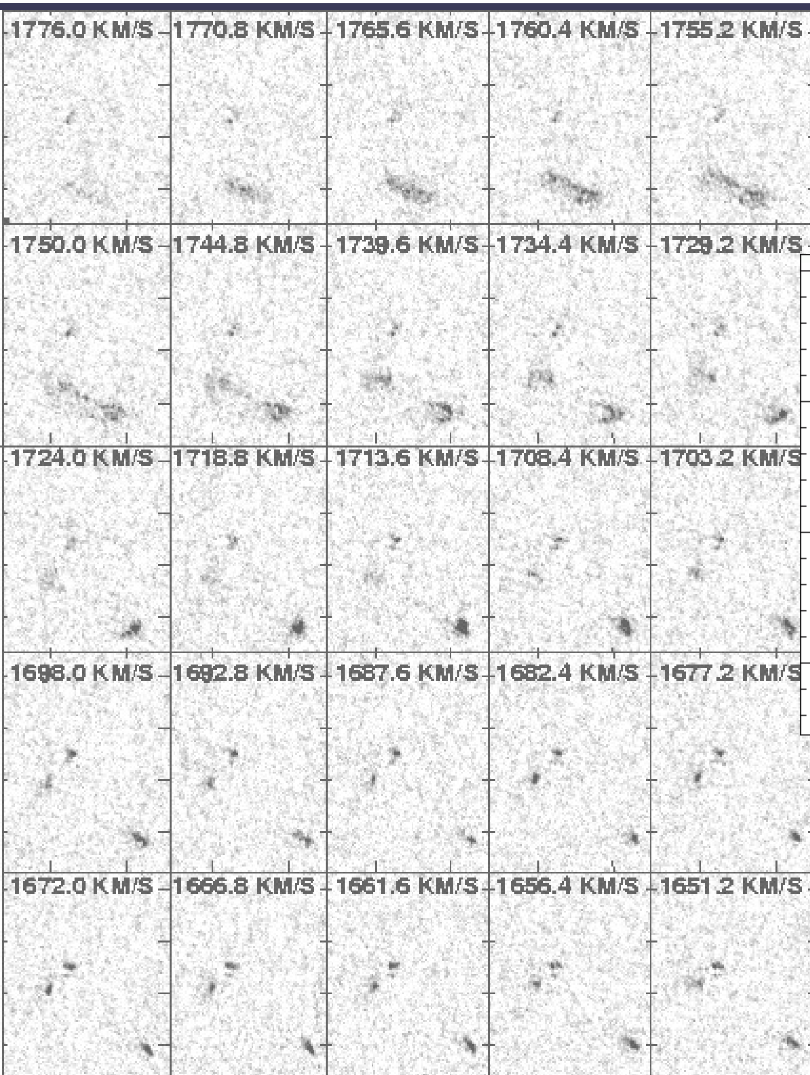
Color intensity represents X-ray intensity smooth to radio resolution

Color represents hardness of X-ray (average weighted frequency)

Blue - soft (thermal)

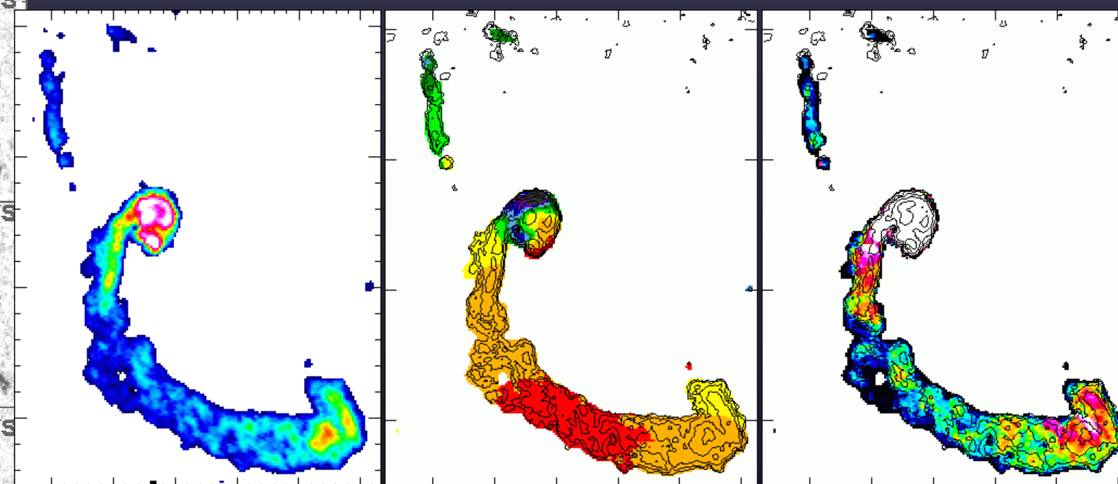
Green - hard (non-thermal)

SPECTRAL LINE REPRESENTATIONS



False color intensity

Low = Blue; High = Red



Integrated Mean

Velocity

Flux Velocity

Dispersion

amount of rotational

turbulence?

IMAGE REGISTRATION AND ACCURACY

- Separation Accuracy of Components on One Image:

  Limited by signal to noise to 1% of resolution.

  Errors of 1:10000 for wide fields.

- Images at Different Frequencies:

  Multi-frequency. Use same calibrator for all frequencies.

  Watch out at frequencies < 2 GHz when ionosphere can produce displacement. Minimize calibrator-target separation

- Images at Different Times (different configuration):

  Use same calibrator for all observations. Differences can occur up to 25% of resolution. Minimize calibrator-target separation.

- Radio versus non- Radio Images:

  Header-information of non-radio images often much less accurate than that for radio. For accuracy <1”, often have to align using coincident objects.

DEEP RADIO / OPTICAL COMPARISON

Grey-Scale:
- Optical emission faintest is 26-mag

Contours:
- Radio Emission faintest is 10 μJy