ERROR RECOGNITION & IMAGE ANALYSIS

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Eleventh Synthesis Imaging Workshop

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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 during and after the 'best' calibration, editing, etc.
  -- Image analysis describes the almost infinite ways in which
  useful insight, 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.

OBVIOUS IMAGE PROBLEMS

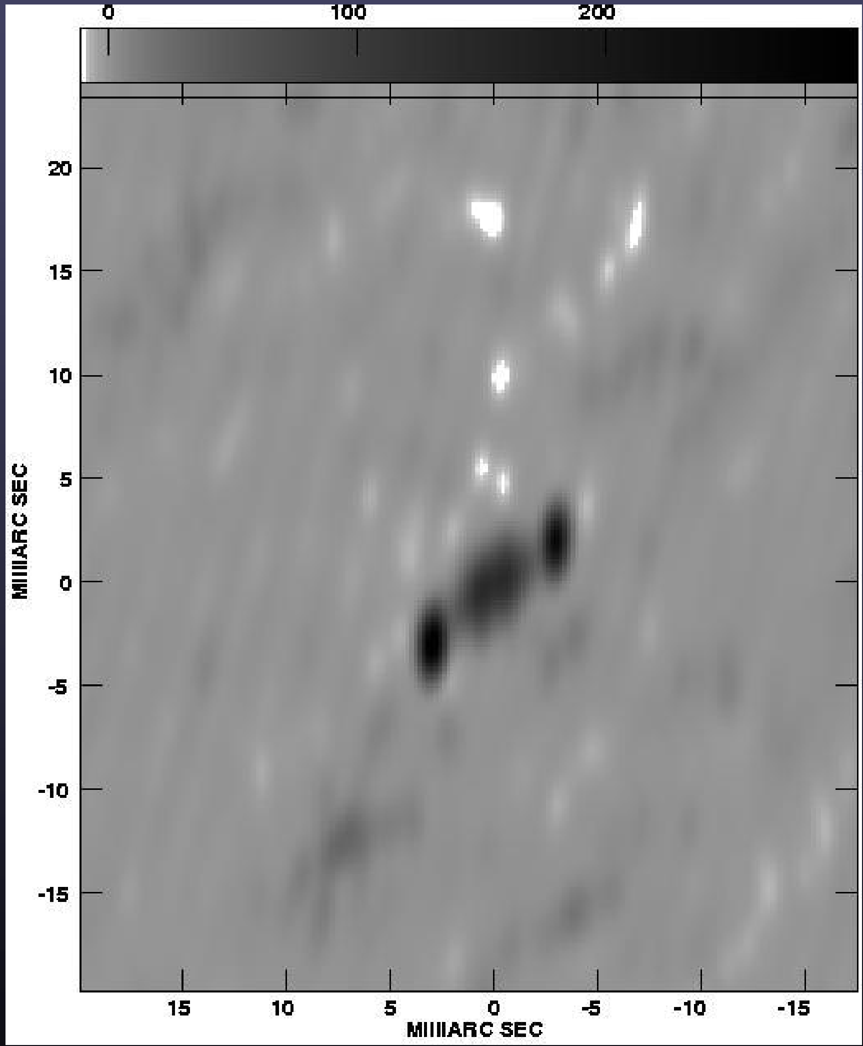
Rats!!

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!!

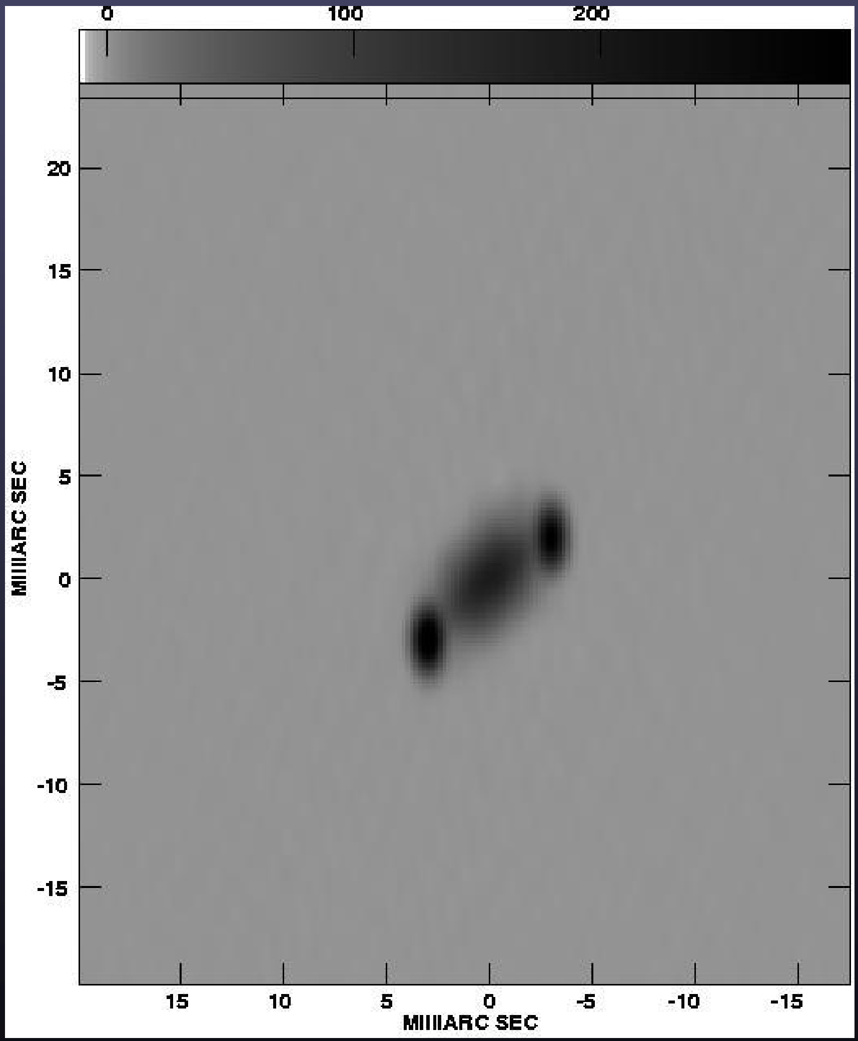
After lots of work, I can finally analyze this image and get some interesting scientific results.

What were defects?

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

This part of the lecture.

How to find the errors and remove



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

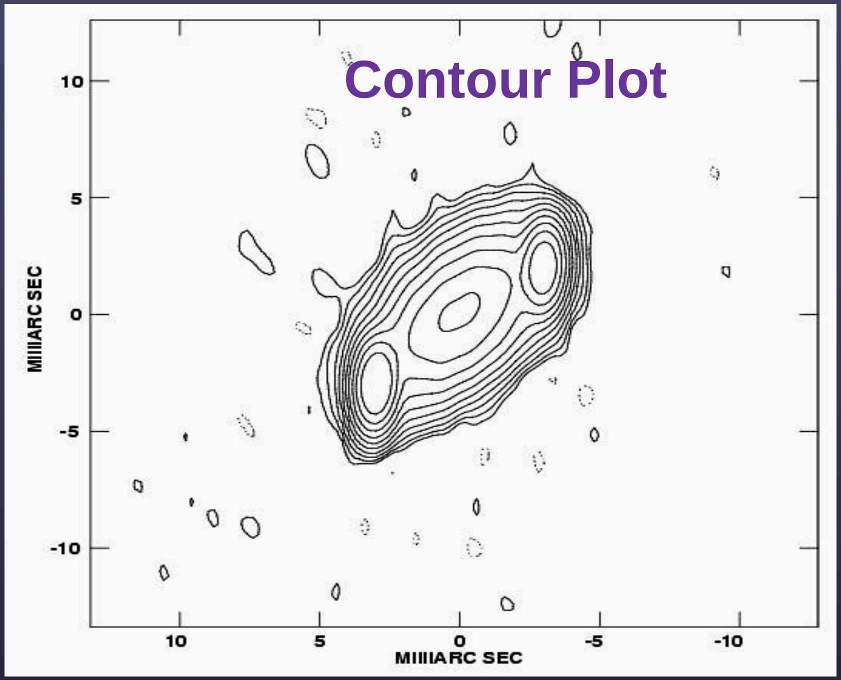
					235					245					255					265					275				
287	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
283	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0
281	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	3	3	4	3	1	0	0	0	0
279	0	0	0	0	0	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	48	61	173	288	168	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	59	86	108	130	137	123	106	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	18	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	8	3	1	0	0	0	0	0	0	0	0
243	0	0	0	1	4	42	222	402	242	65	36	37	38	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	18	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

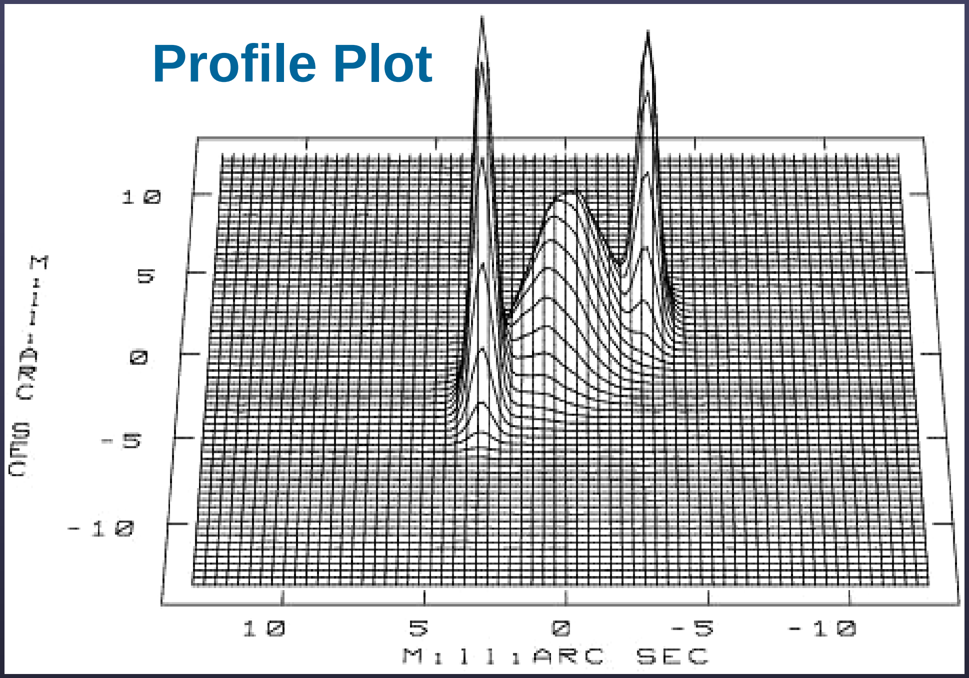
Digital imag

Numbers are
proportional
the intensit

Good for slo
links, ie. F
the Gobi des
to Socorro

IMAGE DISPLAYS (2)



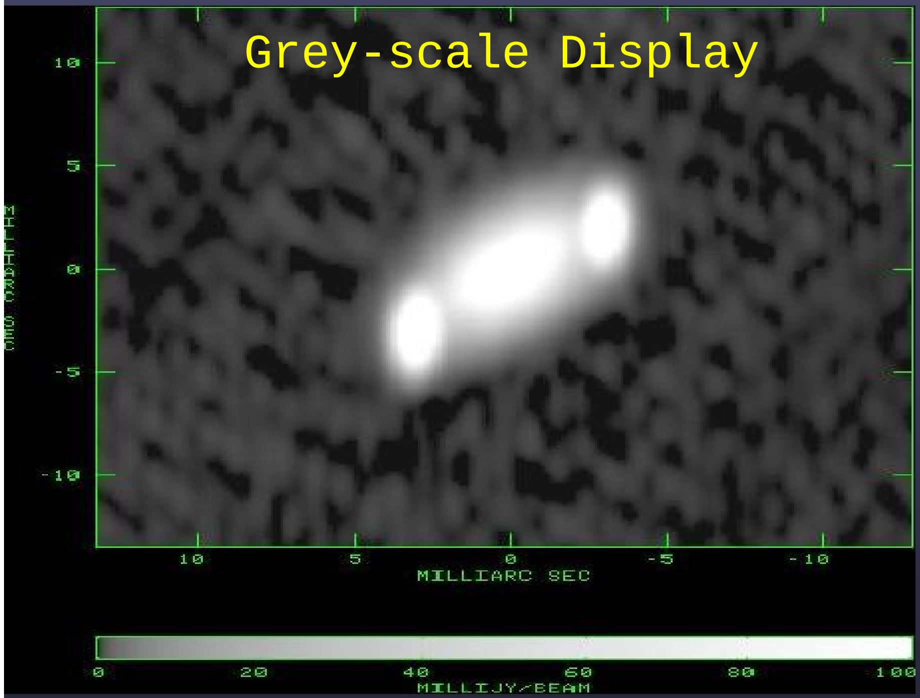


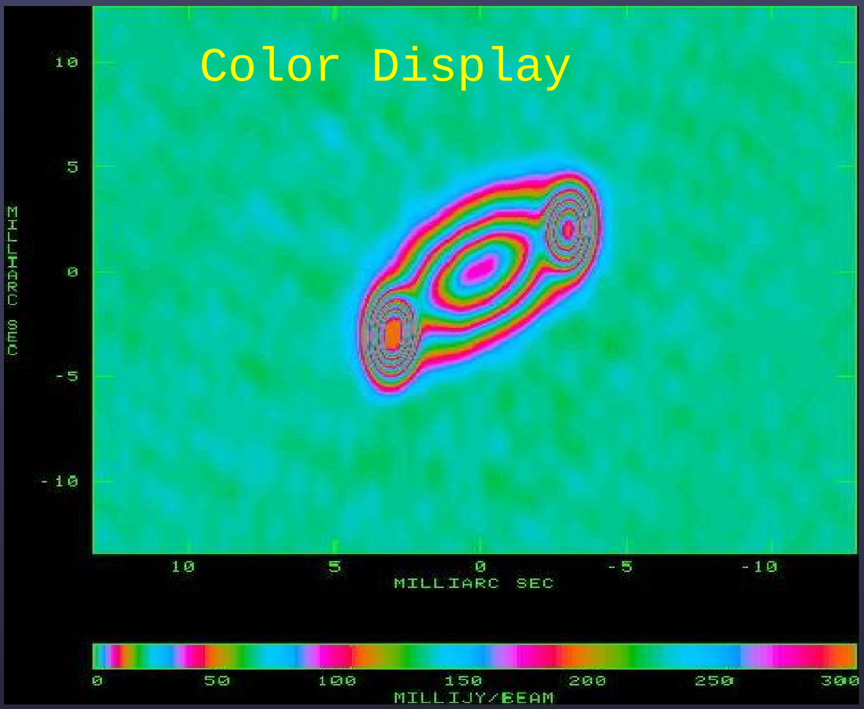
These plots are easy to reproduce and printed

Contour plots give good representation of faint emission.

Profile plots give a good representation of the 'mosque-like'

IMAGE DISPLAYS (3)





TV-based displays are most useful and interactive:

Grey-scale shows faint structure, but not good for high dynamic range and somewhat unbiased view of source

DATA DISPLAYS(1)

List of u-v Data

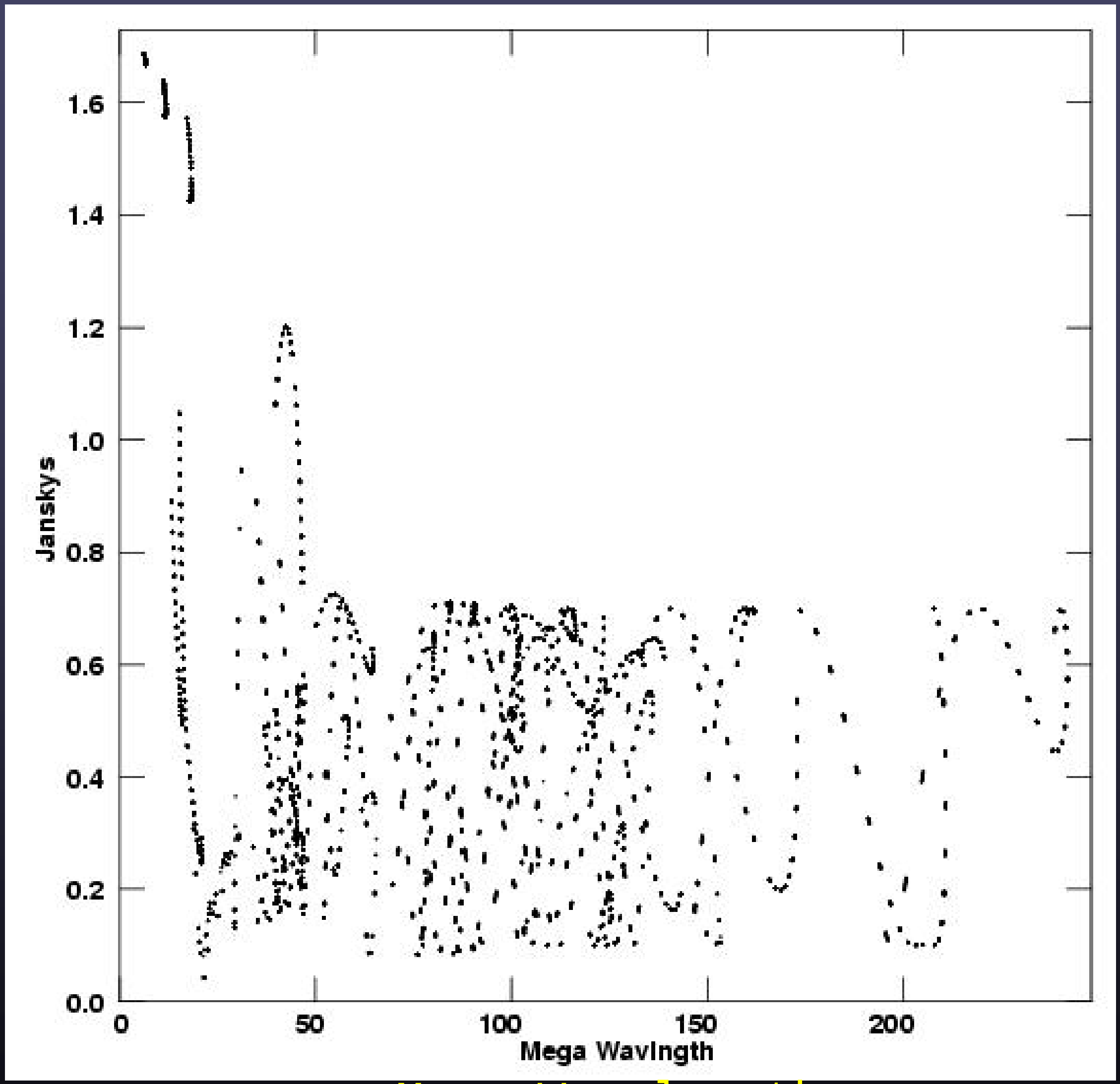
Source= J0121+11 Freq= 8.434858511 Sort= TB 1 RR

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. Often need precise times in order to flag the data appropriately.

DATA DISPLAYS(2)

Jy



Mega Wavelength

Visibility Amplitude versus
Projected uv spacing

General trend of data.

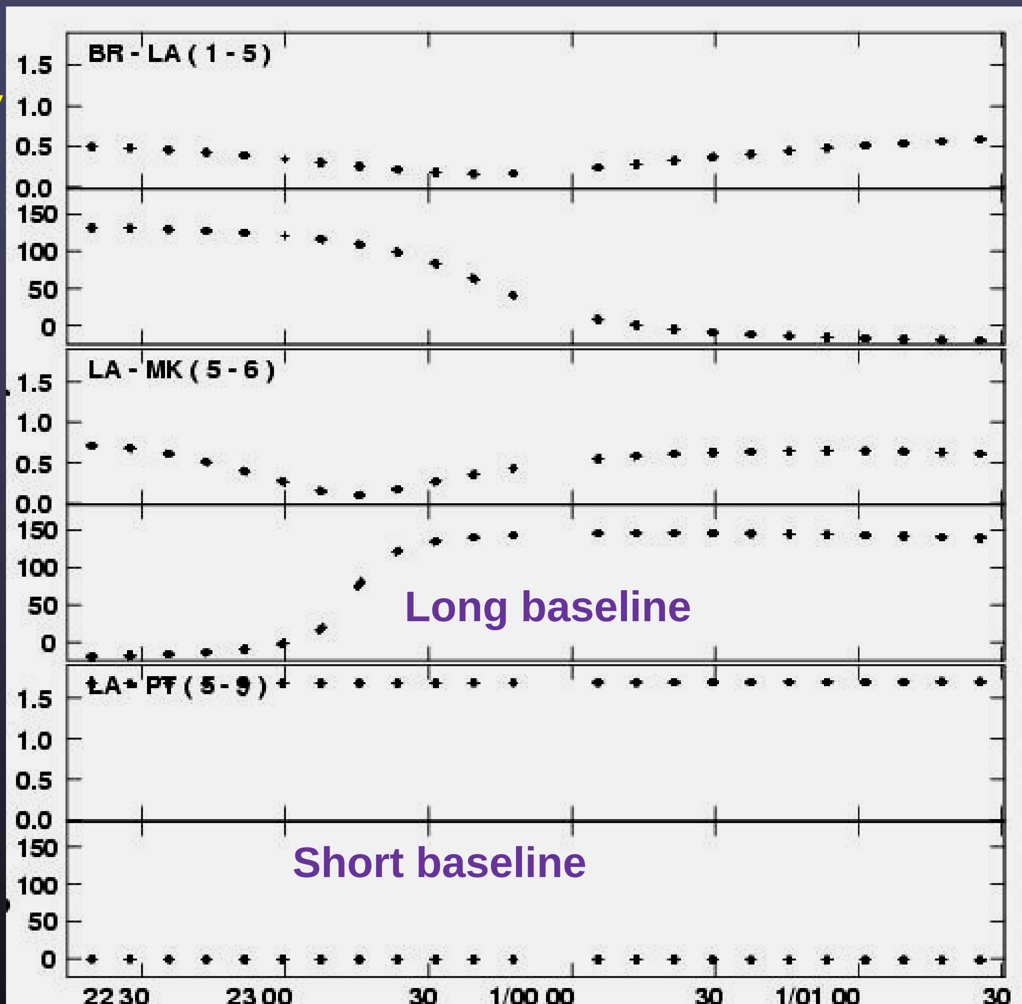
Useful for relatively strong Sources.

Triple source model. Large
component cause rise at
short spacings.

Oscillation at longer

DATA DISPLAYS(3)

Jy
Deg
Jy
Deg
Jy
Deg



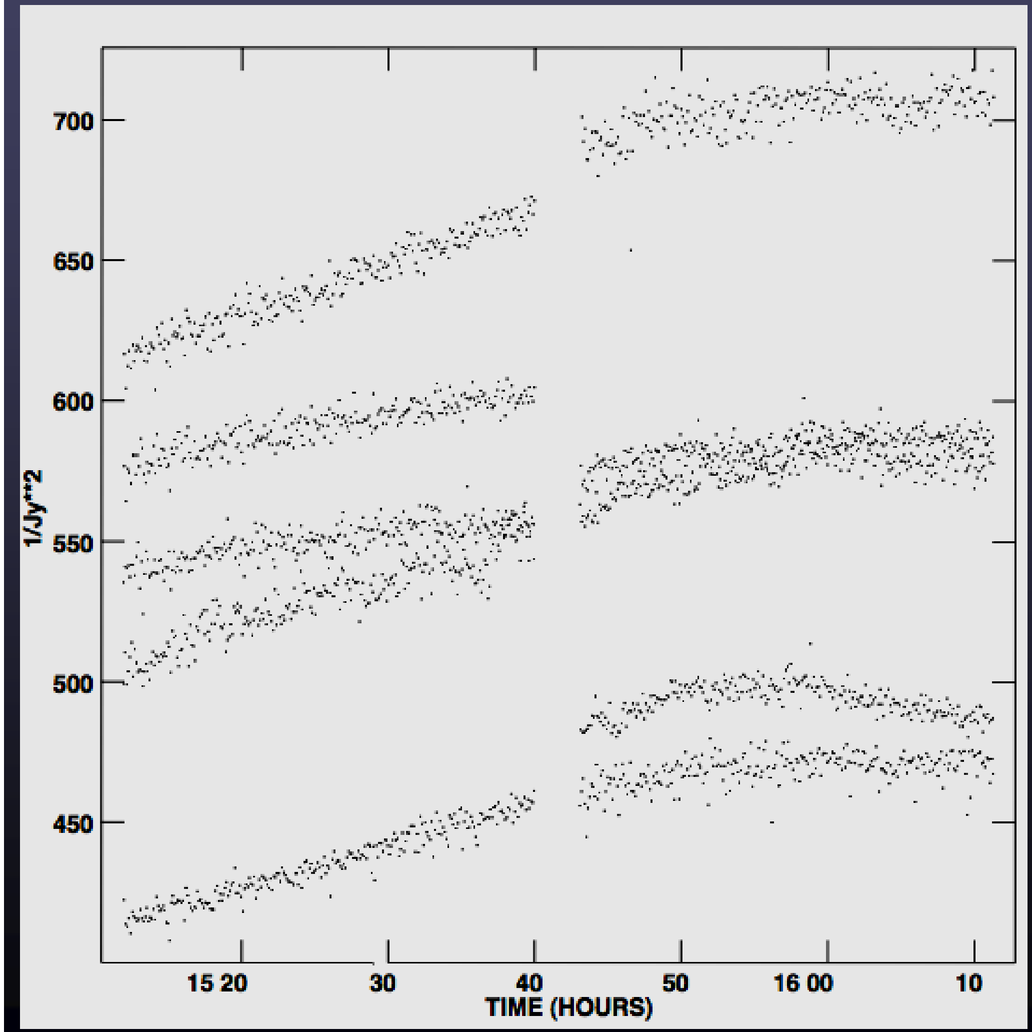
Time in d/hh mm

Visibility amplitude
and phase versus time
for various baselines

Good for determining t
continuity of the d
Should be relatively s
with time.
Outliers are obvious.

DATA DISPLAYS(4)

Weights of antennas 4 with 5,6,7,8,9



All u-v data points have a weight.
The weight depends on the antenna sensitivity, measured during the observations.
The amplitude calibration values also modify the weights.

Occasionally the weight of the points become very large, often caused by subtle software bugs.

A large discrepant weight causes the same image artifacts as a large discrepant visibility value.

Please check weights to make sure they are reasonable.

IMAGE PLANE OR DATA (U-V) PLANE INSPECTION?

Errors obey Fourier relationship

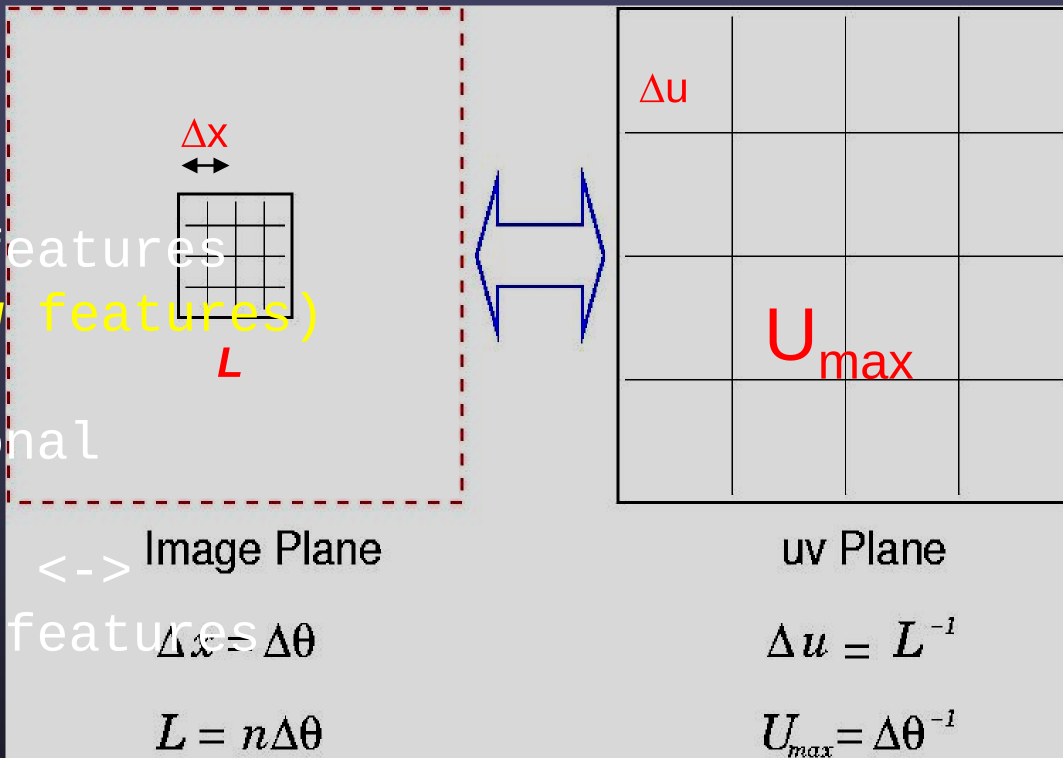
Narrow features <--> Wide features

(easier to find narrow features)

Orientations are orthogonal

Data uv amplitude errors <-> symmetric image features

Data uv phase errors --> 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)

LOOK at DATA to find gross problem (but don't go overboard)

FURTHER OPPORTUNITIES TO FIND BAD DATA!

---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

ERROR RECOGNITION IN THE U-V PLANE

Editing obvious errors in the u-v plane

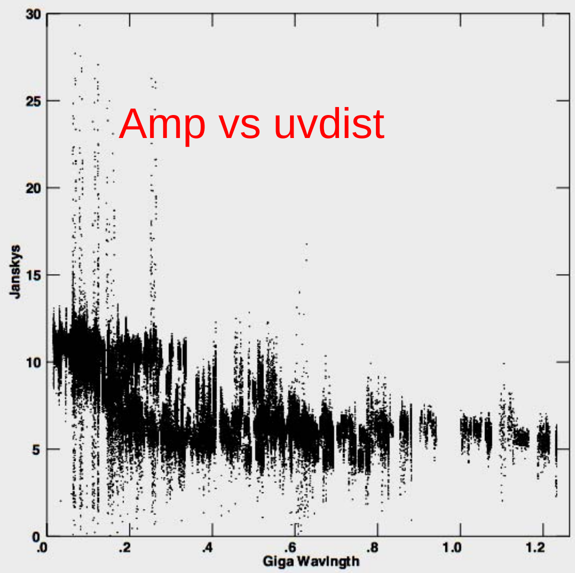
---Mostly consistency checks assume that the visibility cannot change much over a small change in u-v spacing

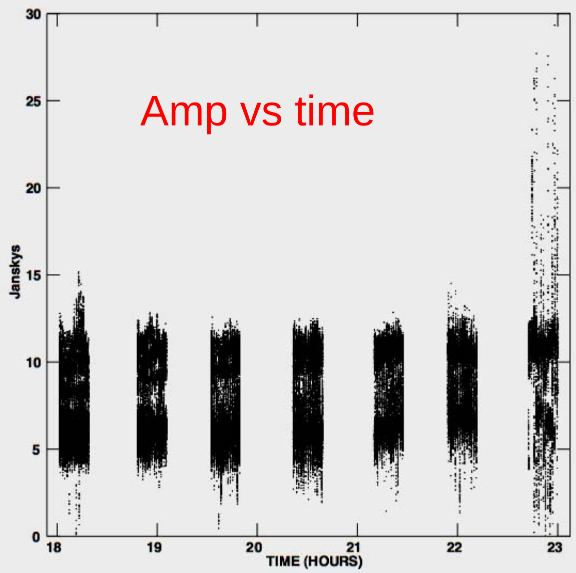
---Also, double check gains and phases from calibration processes. These values should be relatively stable.

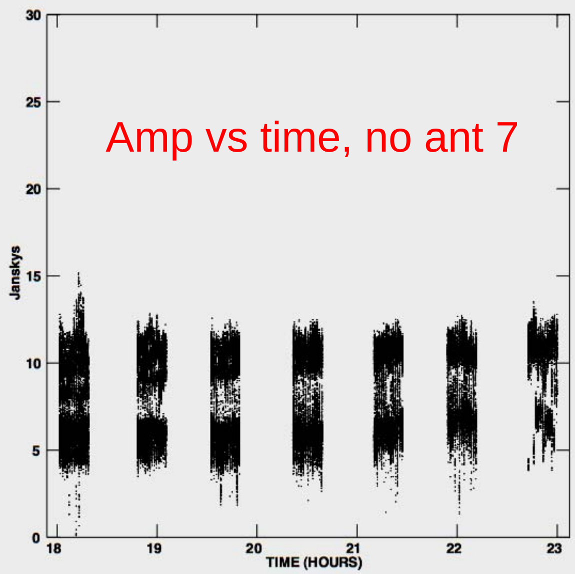
See Summer school lecture notes in 2002 by Myers

See ASP Vol 180, Ekers, Lecture 15, p321

VISIBILITY AMPLITUDE PLOTS







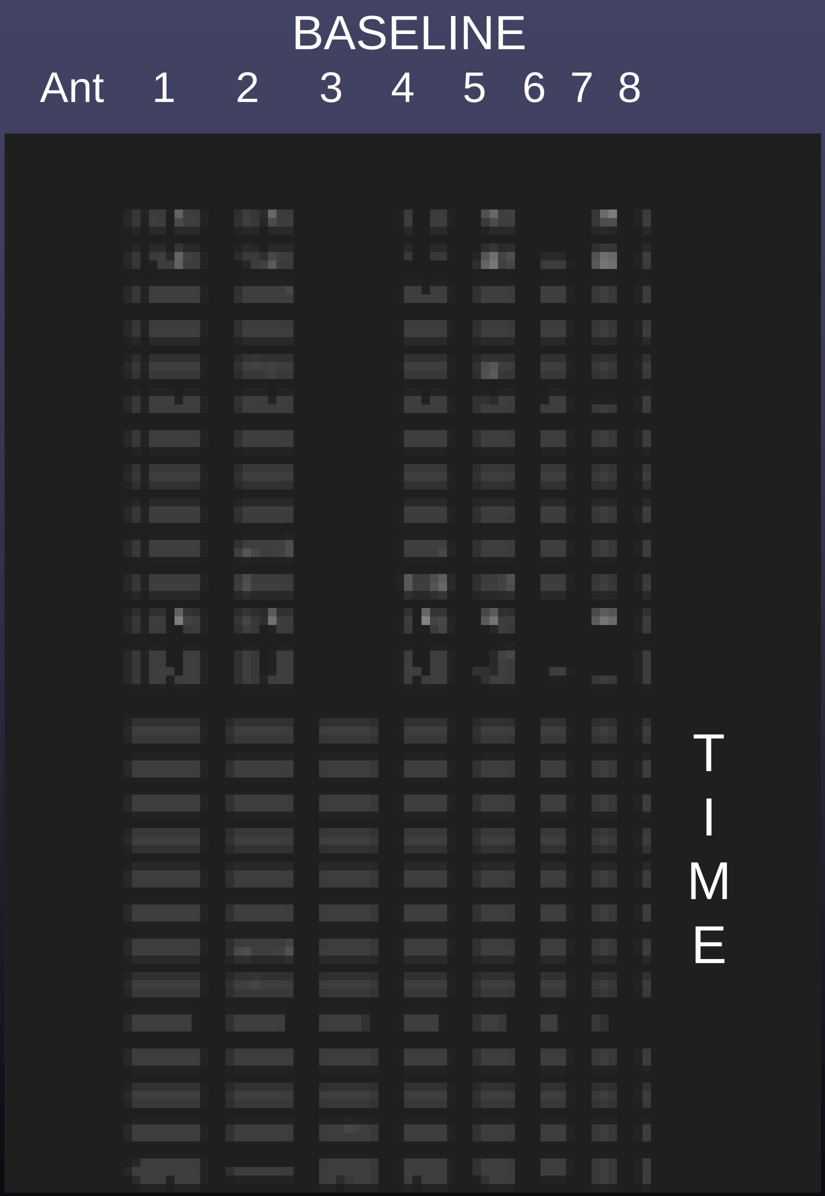
Amp vs uvdist shows outlliers

Amp vs time shows outliers in last scan

Amp vs time without ant 7 should good data

(3C279 VLBA data at 43 GHz)

VISIBILITY AMPLITUDE RASTERS



(Last two scans from previous slide)

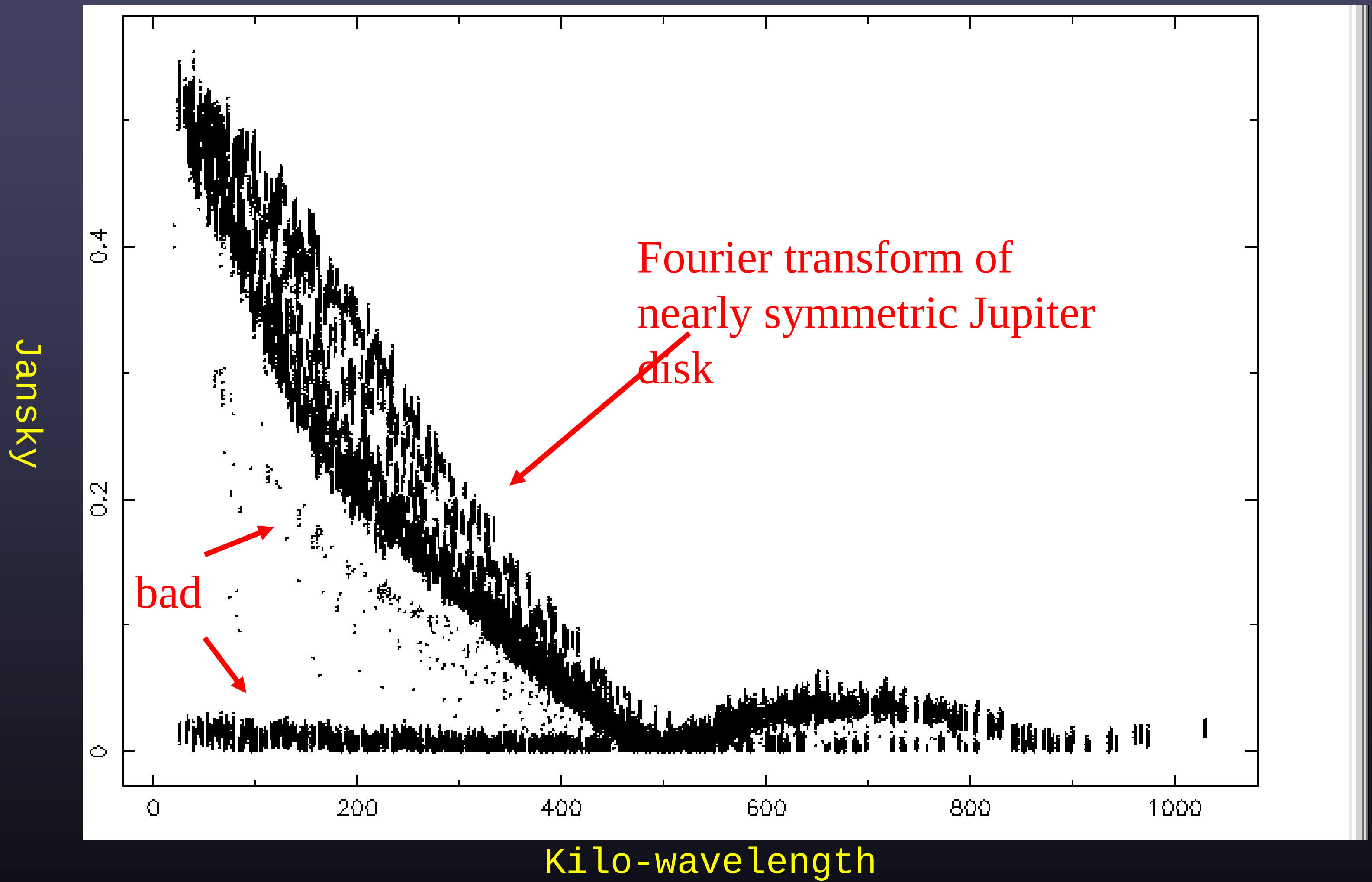
Use AIPS task TVFLG, CASA viewer

Raster scan of baseline versus time immediately shows where the bad data are

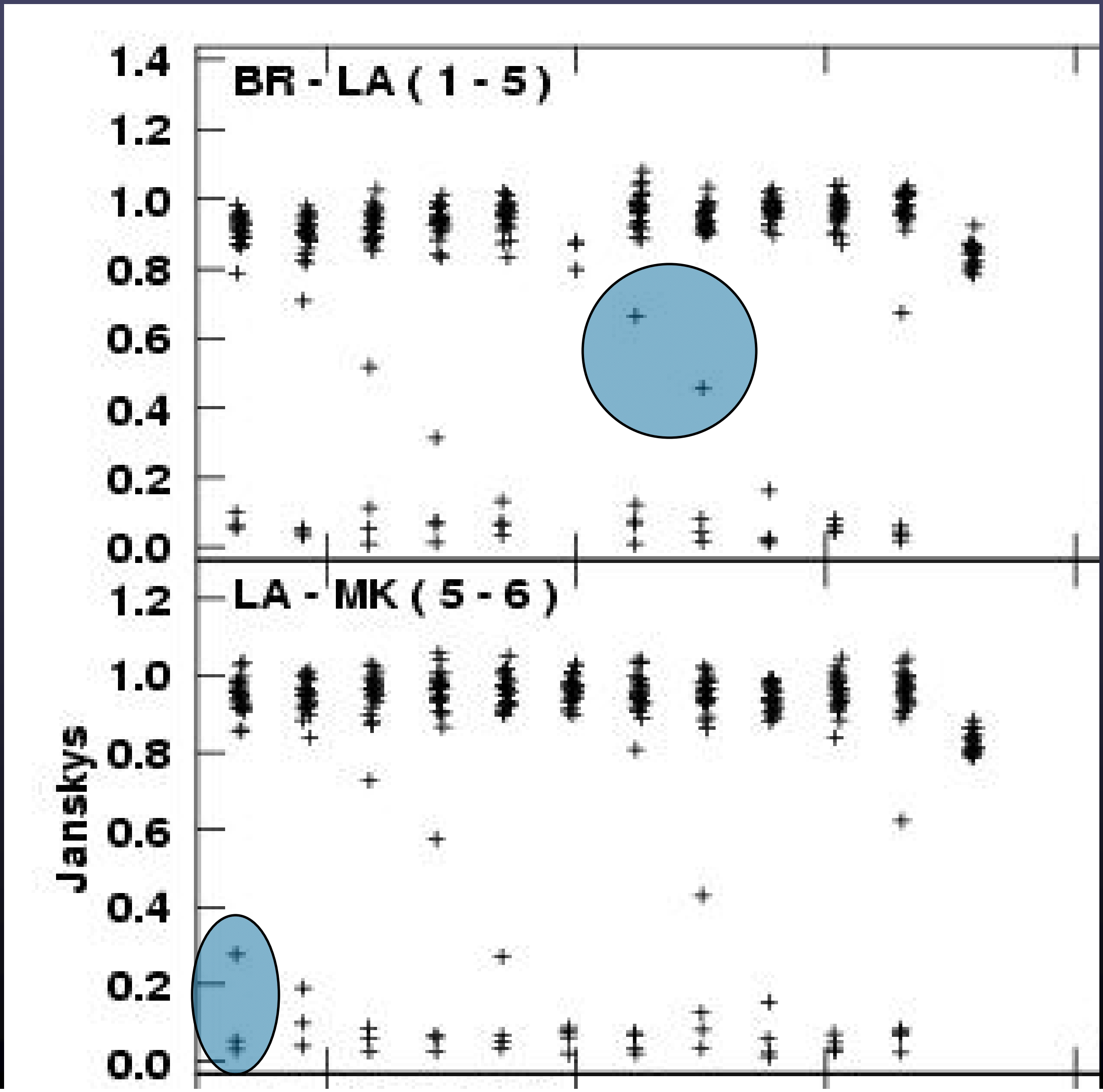
Pixel range is 5 to 20 Jy

Bad data can be flagged with an interactive clipping control

Example Edit – msplot (2)



Drop-outs at Scan Beginnings



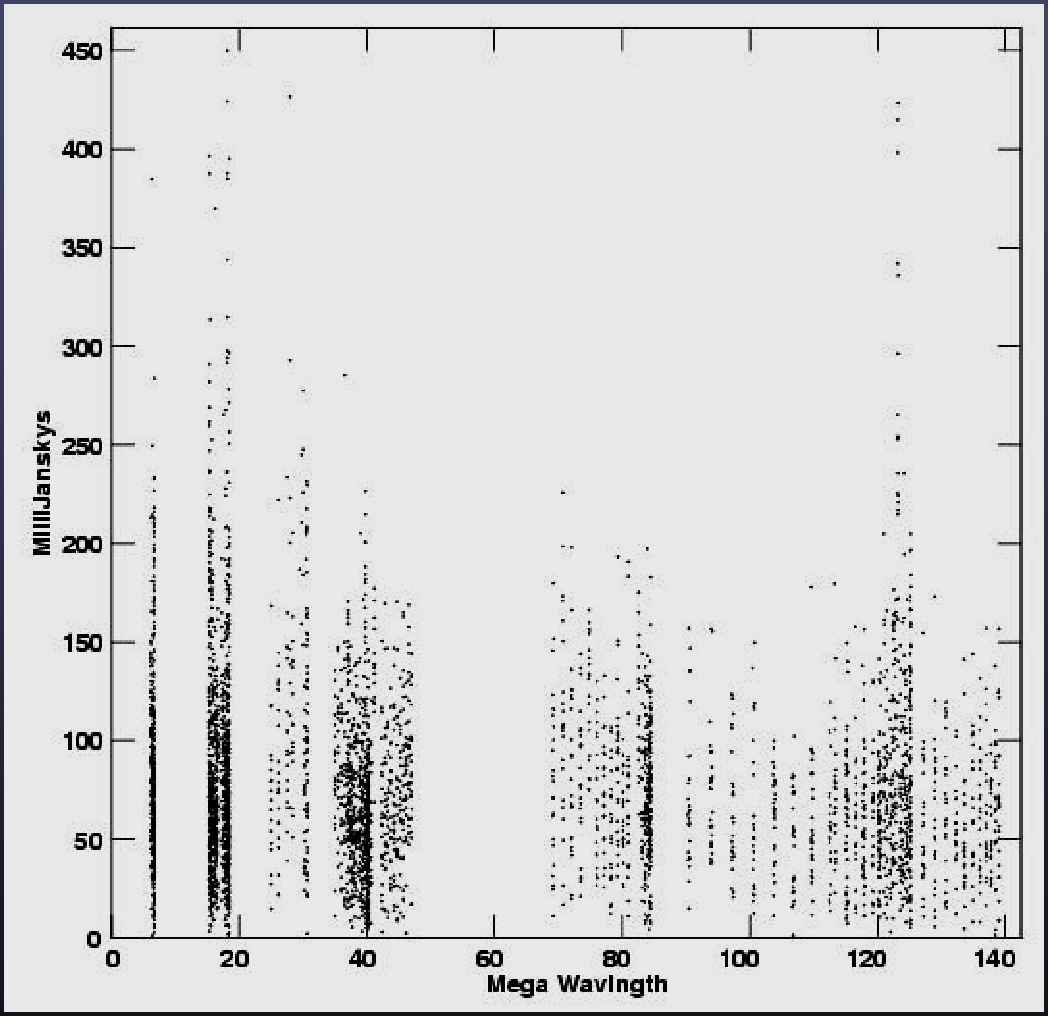
Often the first few points of a scan are low. Egs. antenna not on source.

Software can remove these points (aips,casa 'quack')

Flag extension:

Should flag all sources in the same manner even though you cannot see dropout for weak sources

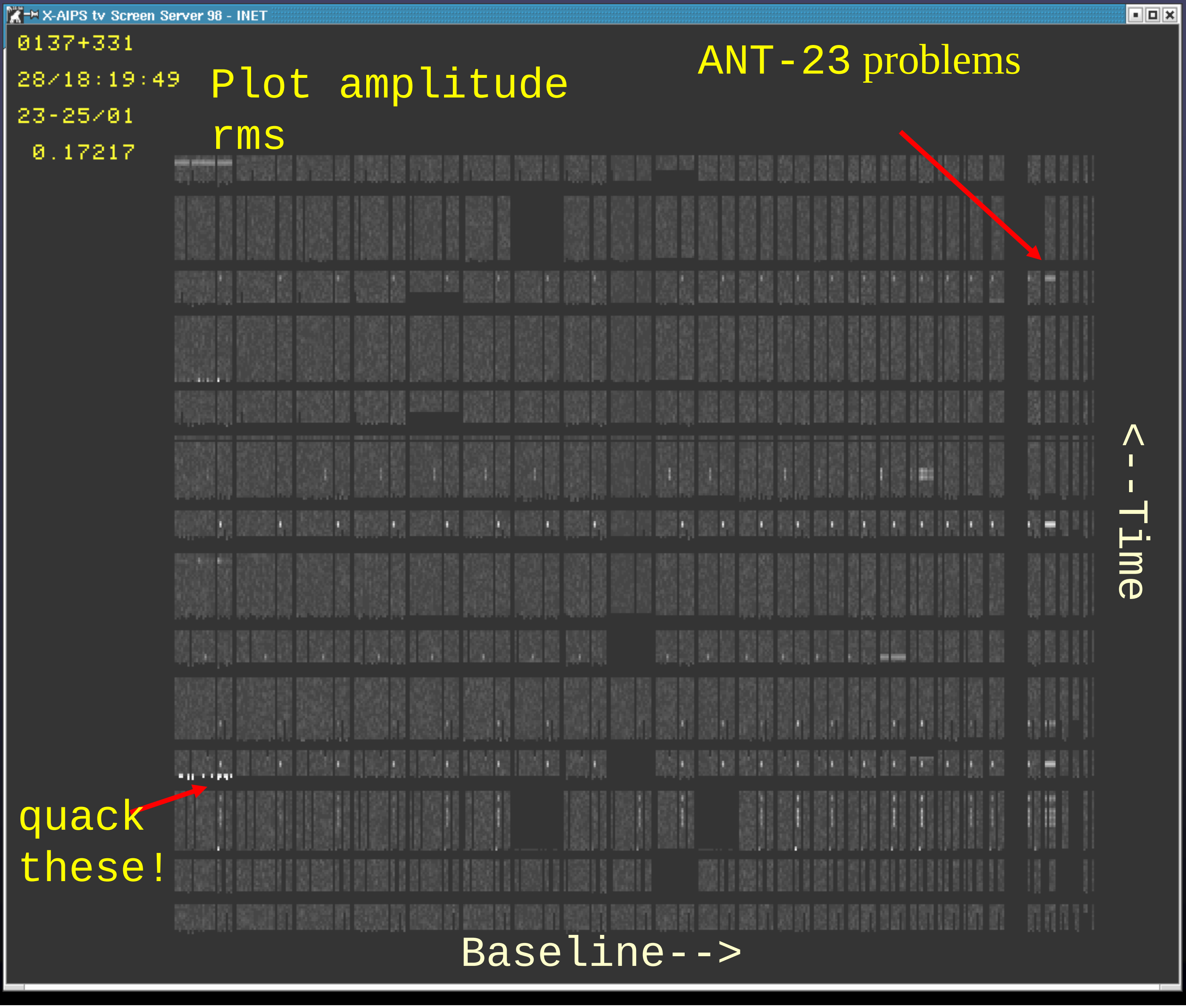
Editing Noise-dominated Sources



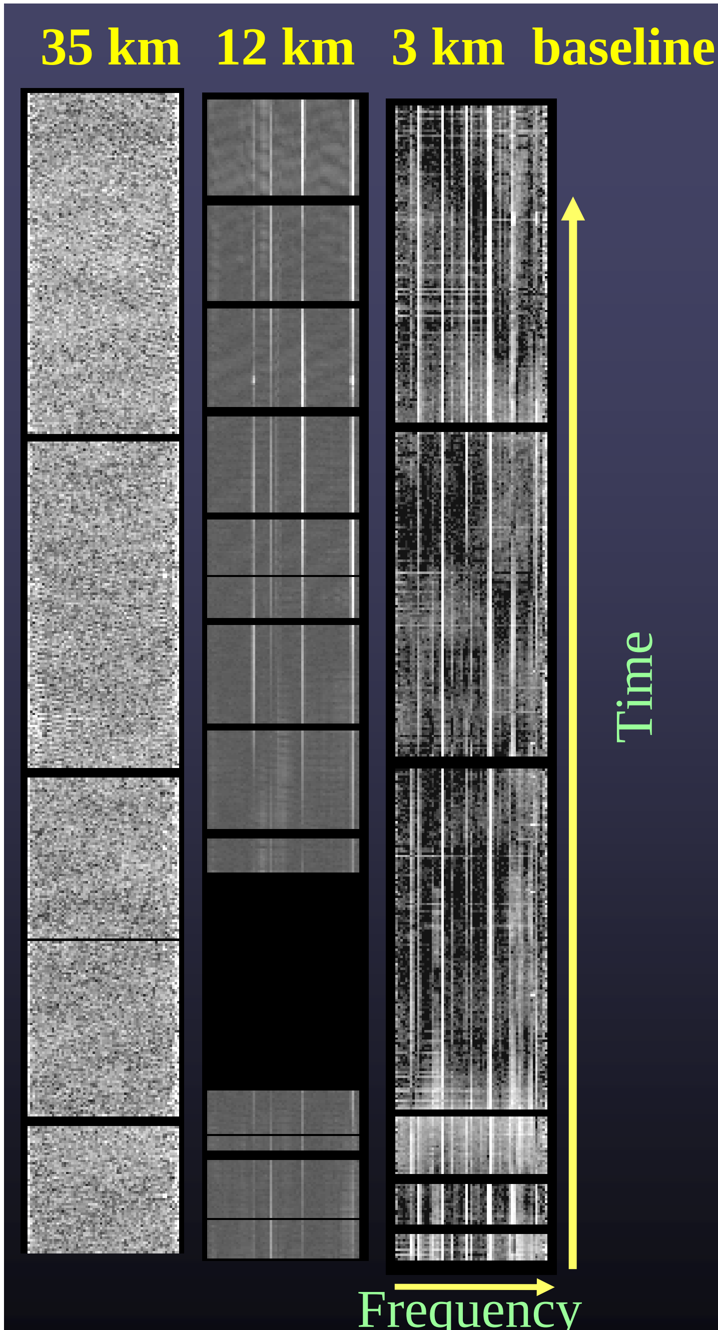
No source structure
information is detected.
Noise dominated.

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

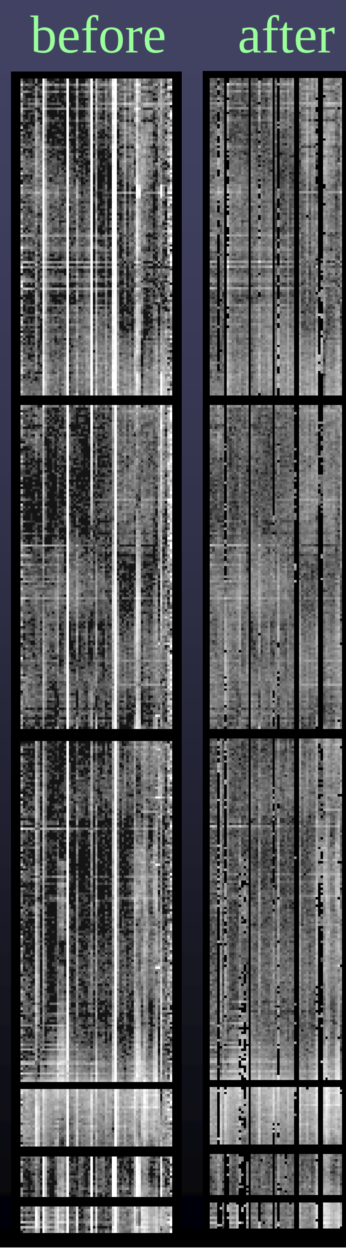
USING TVFLG (VIEWER) DISPLAY on a source



RFI Excision



AIPS: SPFLG



RFI environment worse on short baselines

Several 'types': narrow band, wandering, wideband, ...

Wideband interference hard for automated routines

Example using AIPS tasks FLGIT, FLAGR

Unfortunately, still best done by hand!

ERROR RECOGNITION IN THE IMAGE PLANE

Some Questions to ask?

Noise properties of image:

Is the rms noise about that expected from integra

Is the rms noise much larger near bright sources?

Are there non-random noise components (faint wave

Funny looking Structure:

Non-physical features; stripes, rings, symmetric

Negative features well-below 4xrms noise

Does the image have characteristics in the dirty

Image-making parameters:

Is the image big enough to cover all significant

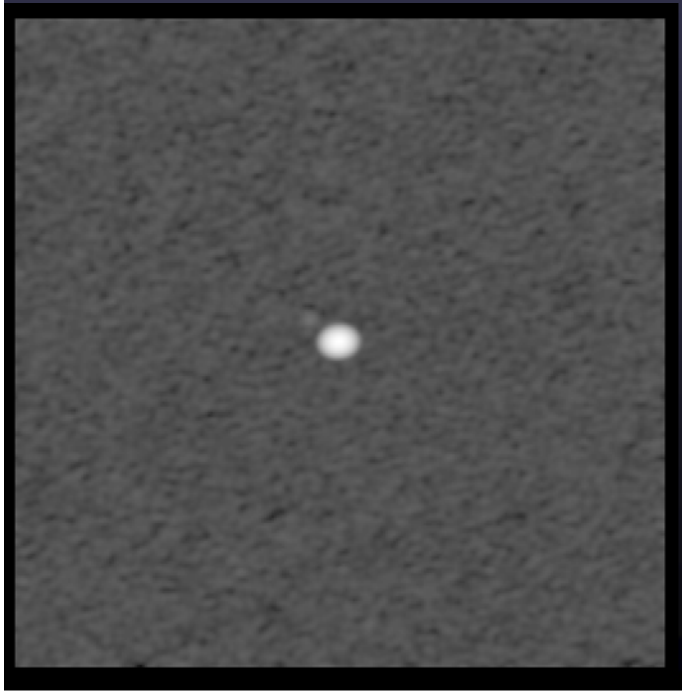
Is cell size too large or too small? ~4 points p

Is the resolution too high to detect most of the

Data bad over a short period of time

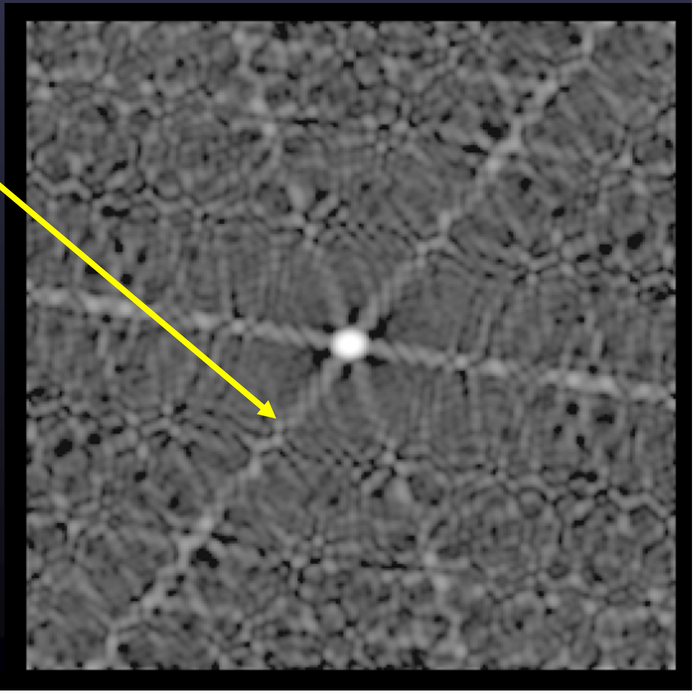
Results for a point source using VLA. 13-5min observation over 10 hr.
Images shown after editing, calibration and deconvolution.

no errors:
max 3.24 Jy
rms 0.11 mJy



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

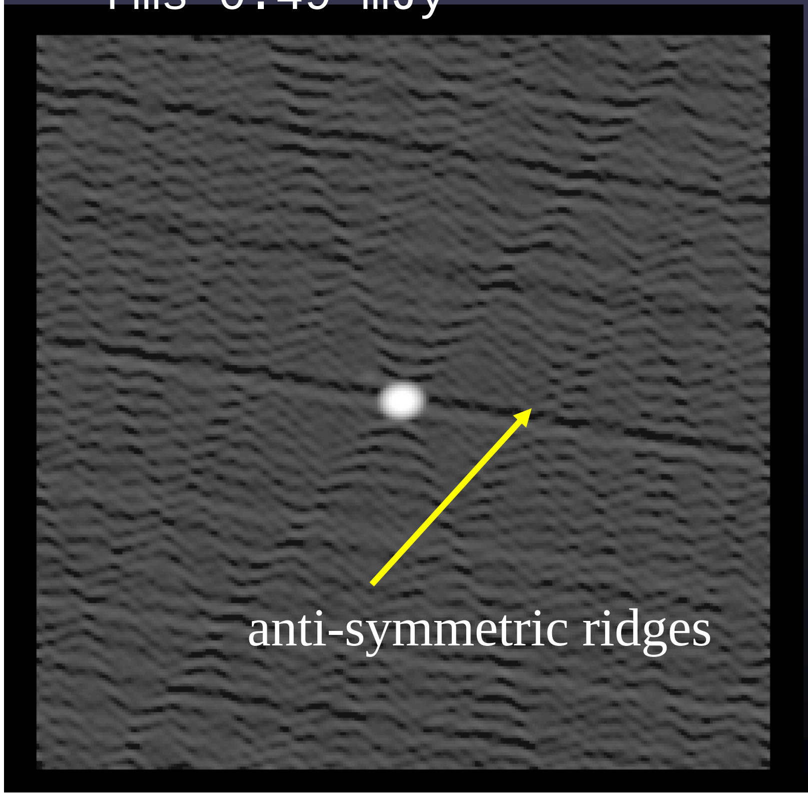
6-fold symmetric pattern due to VLA “Y”. Image has properties of dirty beam.



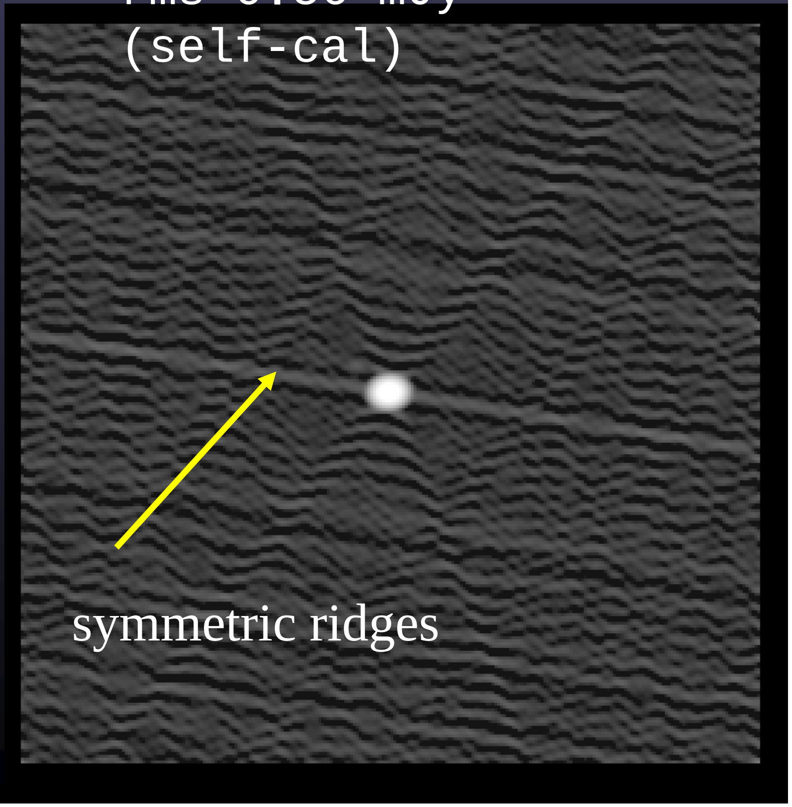
EXAMPLE 2
Short burst of bad data

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

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



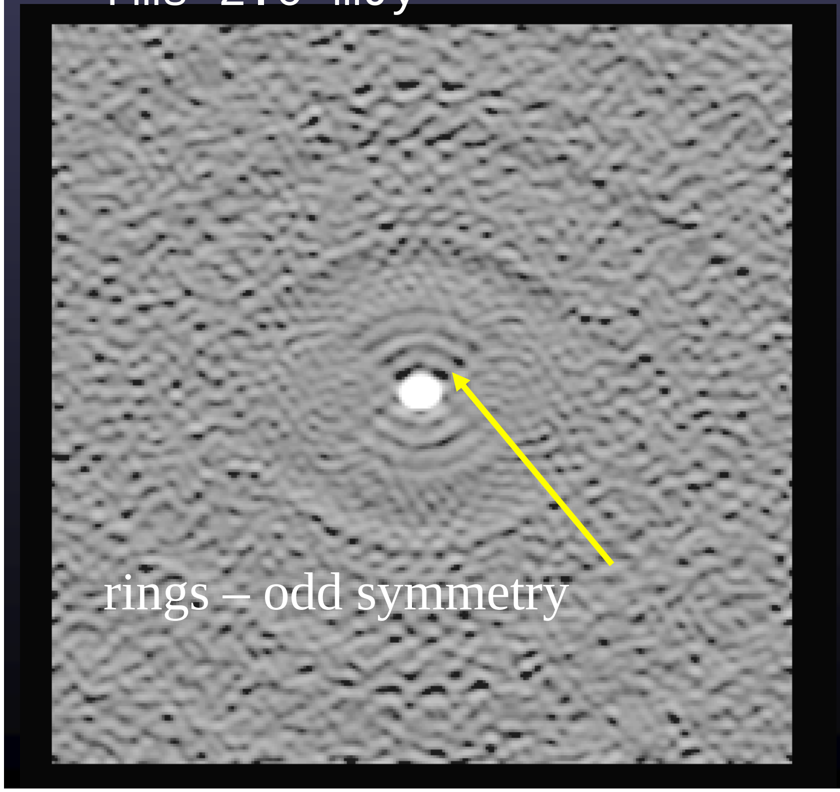
20% amplitude error
for one antenna at
1 time
rms 0.56 mJy
(self-cal)



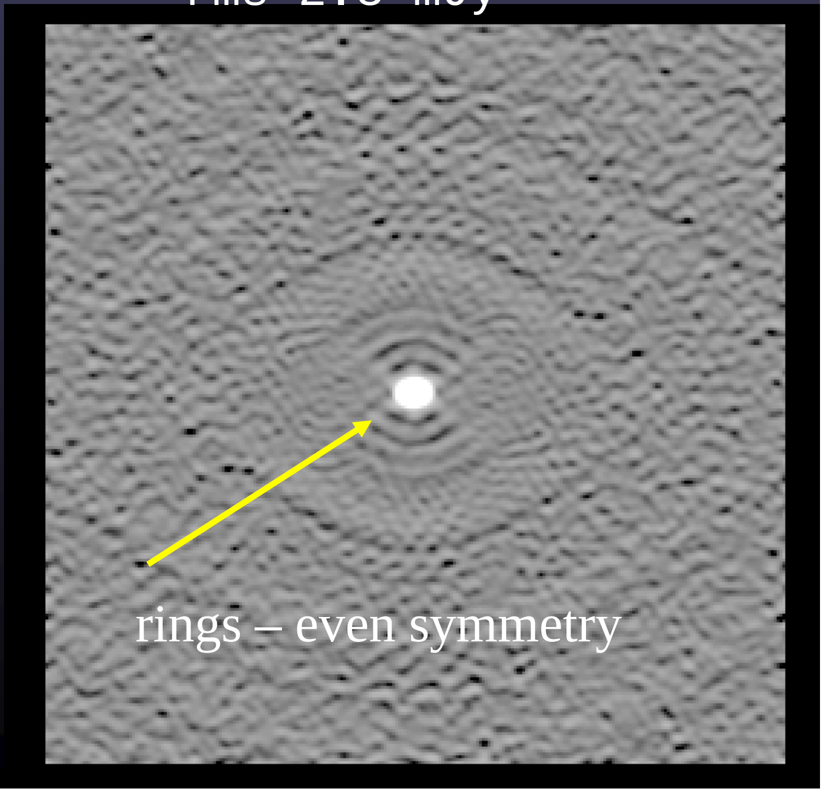
EXAMPLE 3
Persistent errors over most of observations

NOTE: 10 deg phase error to 20% amplitude error
cause similar sized artifacts

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



EXAMPLE 4
Spurious Correlator Offset Signals

Occasionally correlators produce ghost signals or cross talk signals
Occurred last year during change over from VLA to EVLA system

Symptom: Garbage near phase center, dribbling out into image

Image with correlator offsets

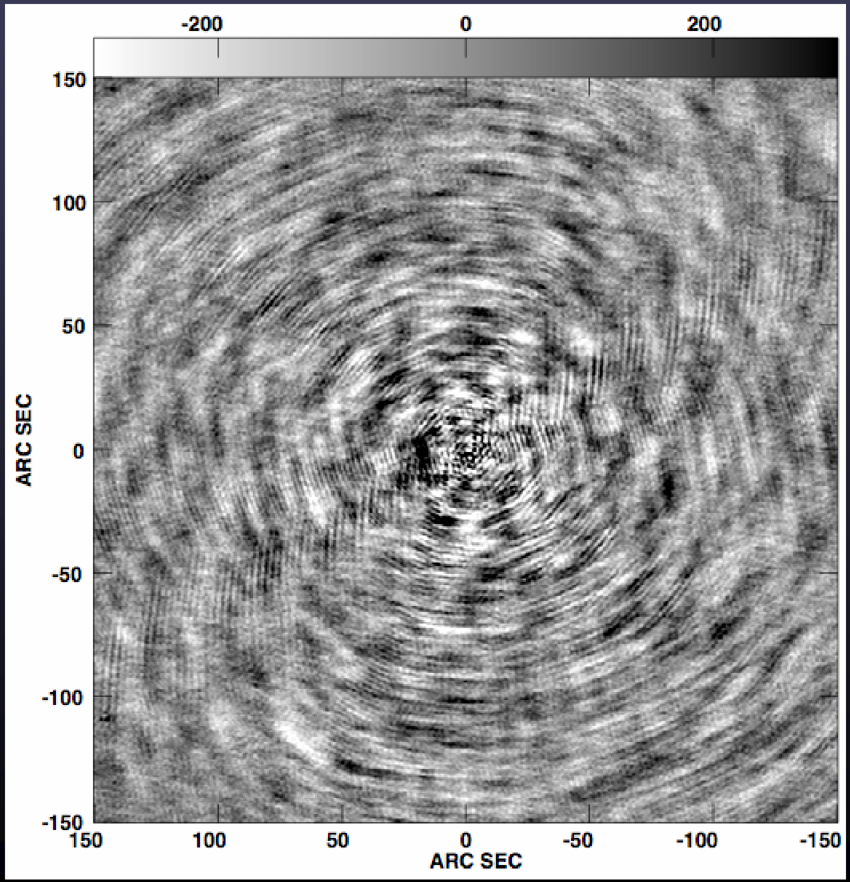
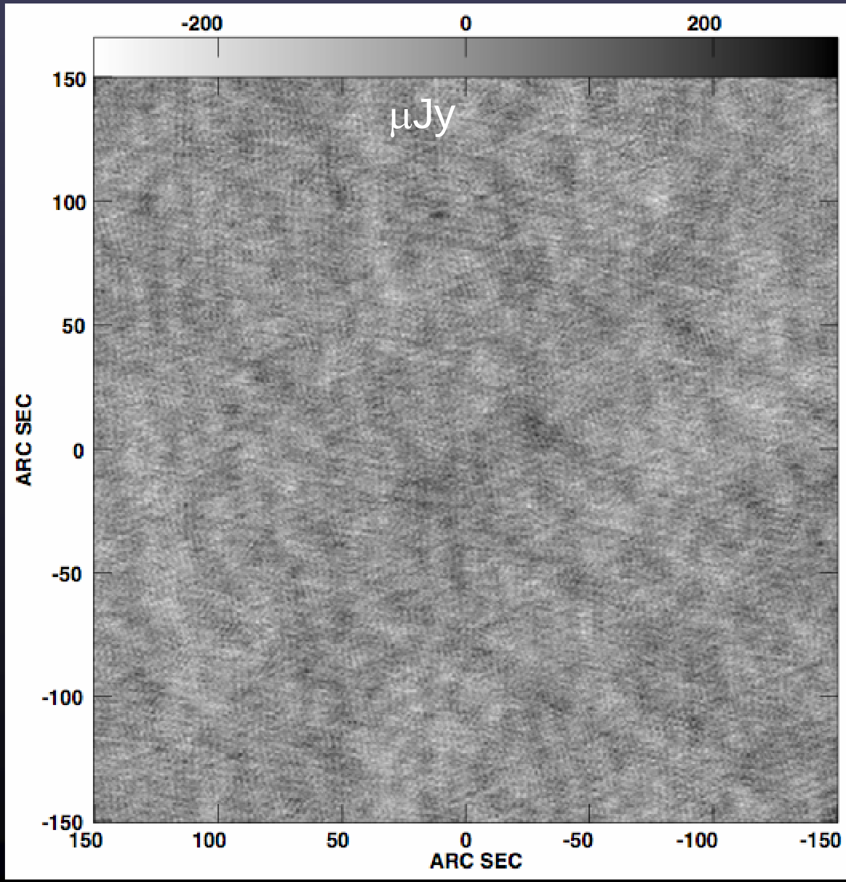
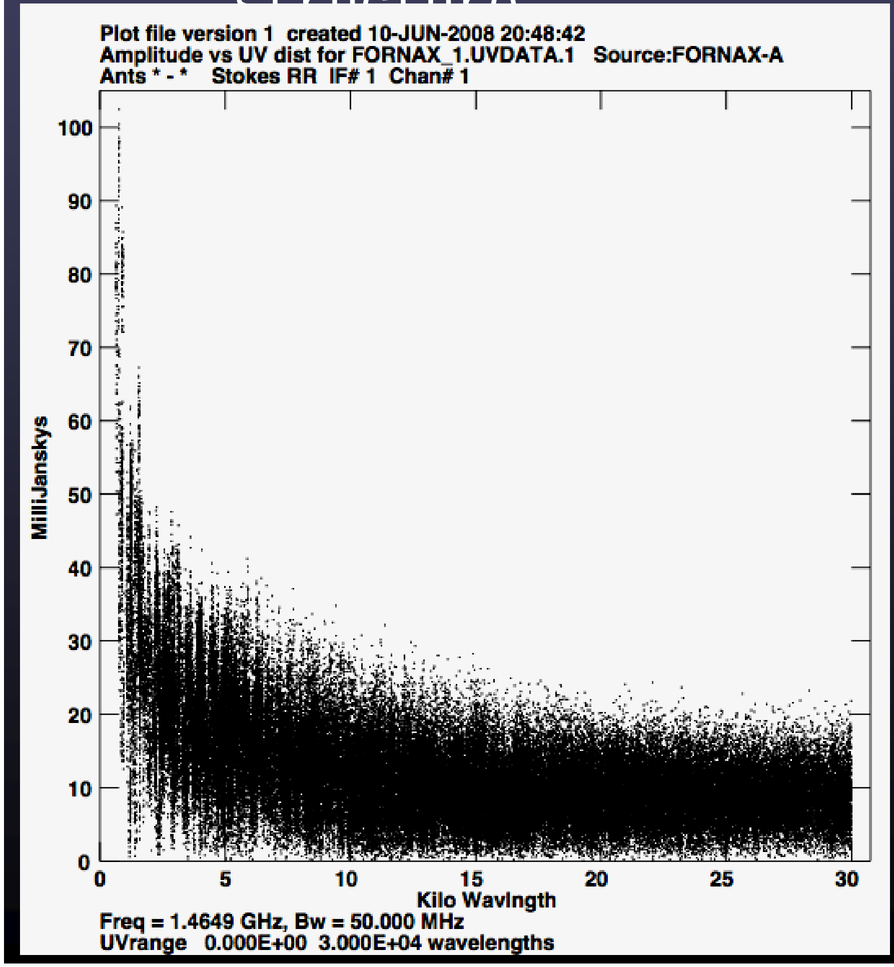


Image after correlation of offsets



DECONVOLUTION ERRORS

Even if the data are perfect, image errors and uncertainties will occur because the (u-v) coverage is not adequate to map the source structure

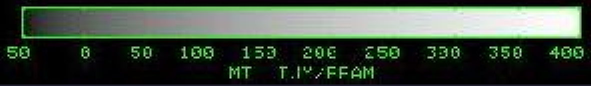


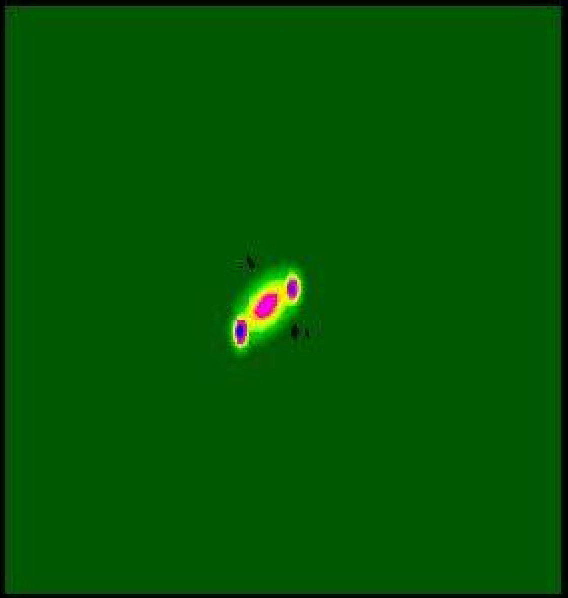
The extreme rise of visibility at the short spacings makes it impossible to image the extended structure. You are better of imaging the source with a cutoff below about 2 kilo-wavelengths

Get shorter spacing or single-dish data

DIRTY IMAGE and BEAM (point spread function)

Dirty Beam





Dirty Image

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-

CLEANING WINDOW SENSITIVITY

Tight Box
Big Box

Middle Box
Dirty Beam

One small clean box
(interactive clean shown next)

One clean box around all emission

Clean entire inner map

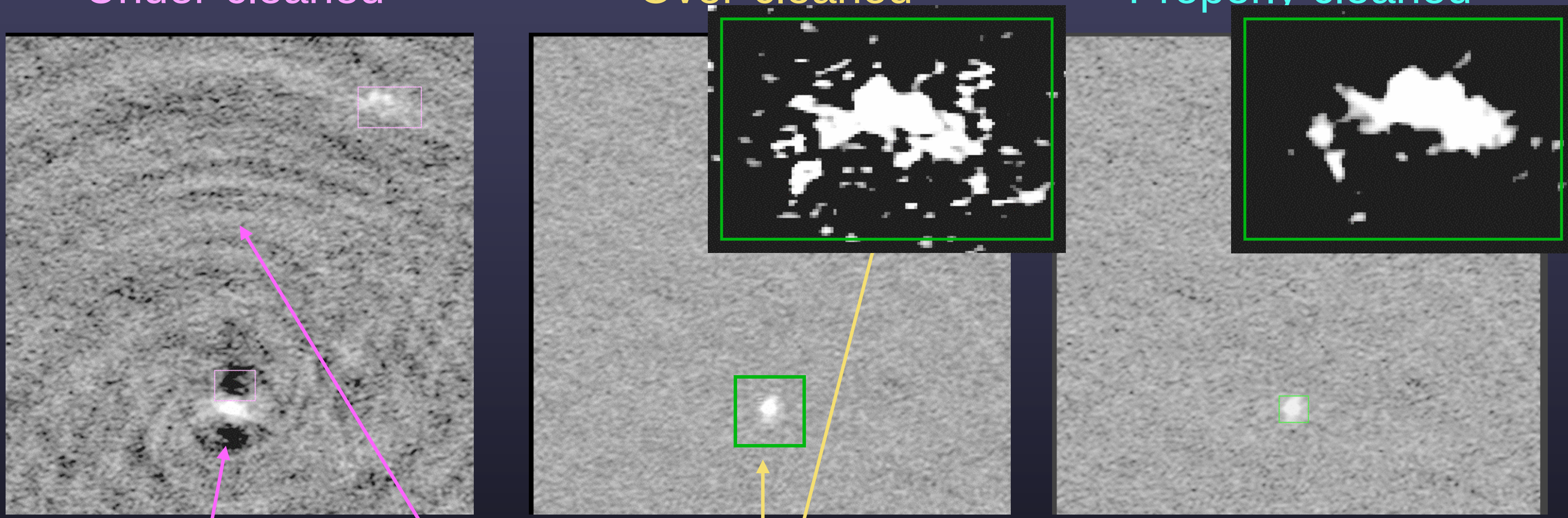
Spurious emission is always associated with higher sidelobes in dirty-beam.

How Deep to Clean?

Under-cleaned

Over-cleaned

Properly cleaned



Residual sidelobes dominate the noise

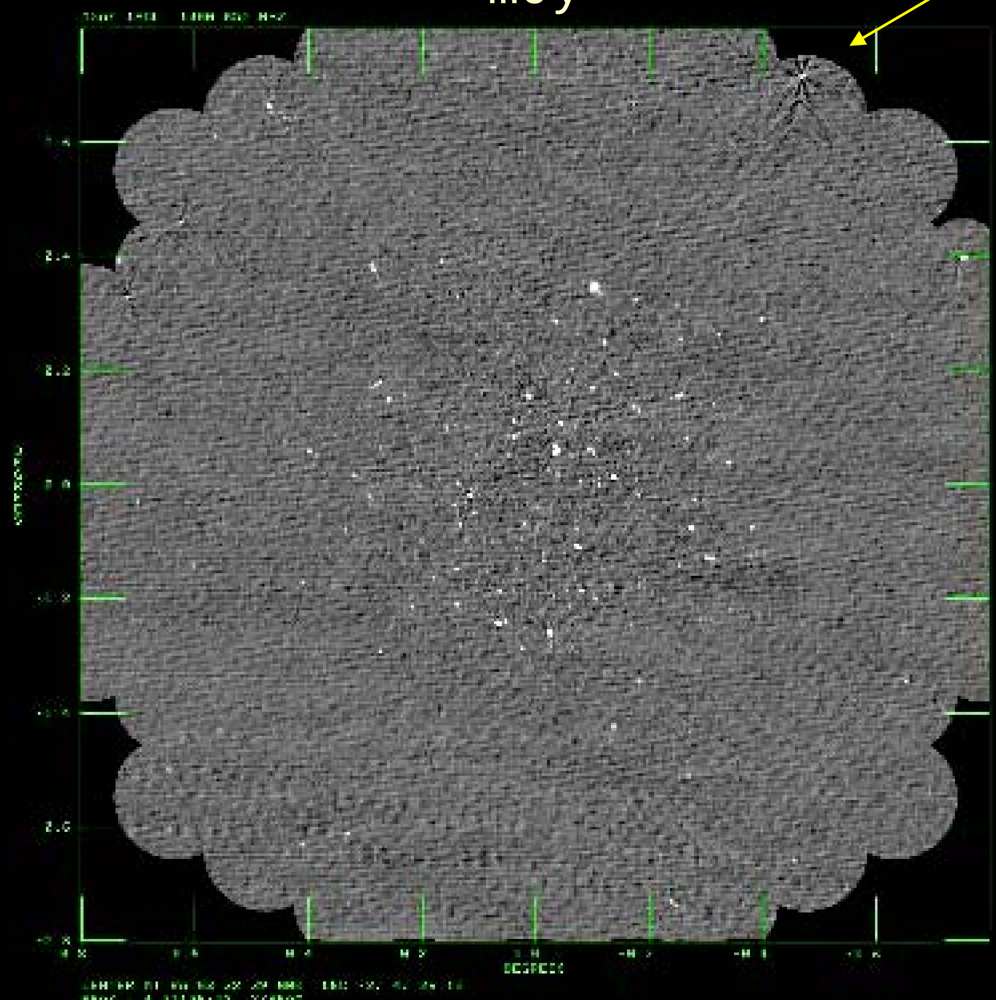
Emission from second source sits atop a negative "bowl"

Regions within clean boxes appear "mottled"

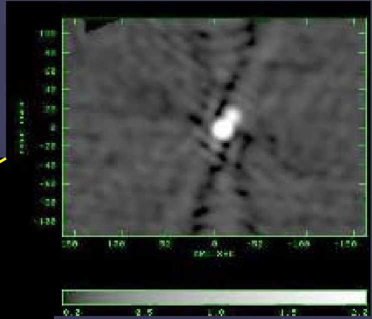
Background is thermal noise-dominated; no "bowls" around sources.

FINDING HIDDEN BAD DATA

Chandra Deep Field South
Peak = 45 mJy, rms = 0.02 mJy

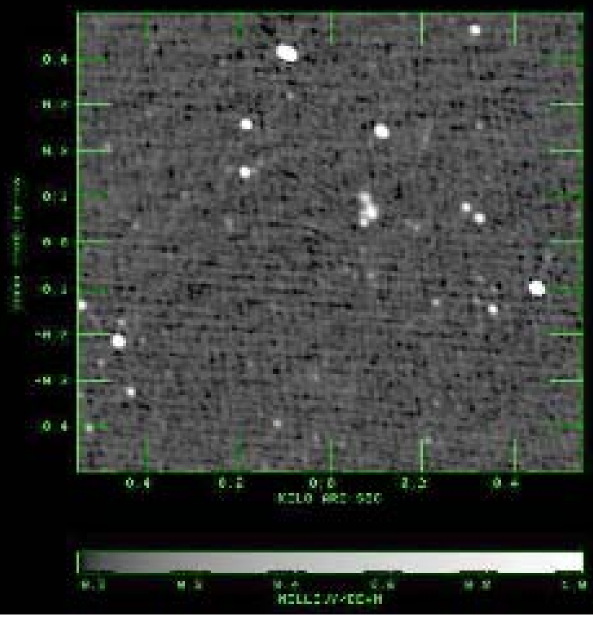


Source to NE in first Primary beam sidelobe

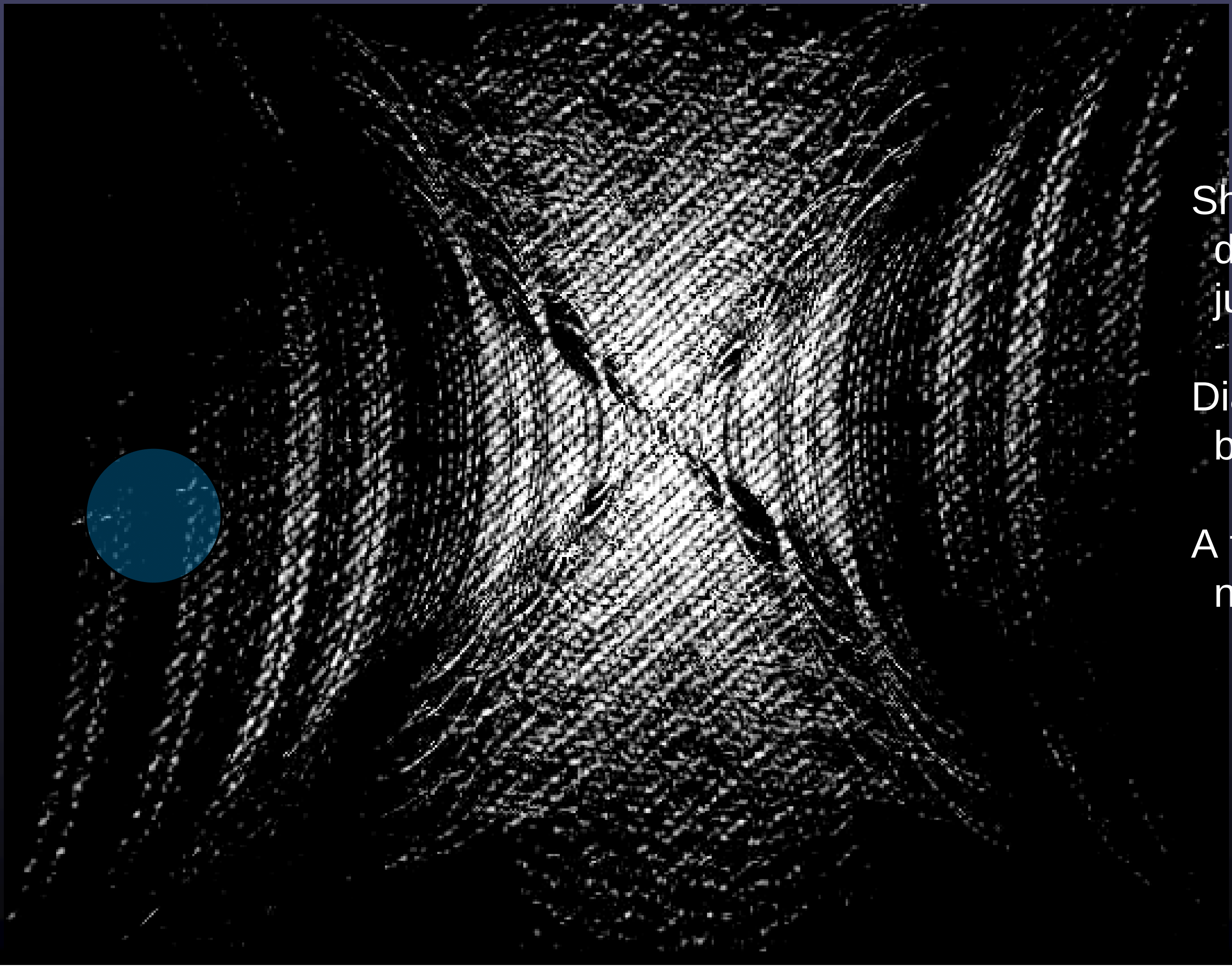


See Lectures Perley on Wide-field Imagiing, and Uson on High dynamic Range Imaging

Center of Field

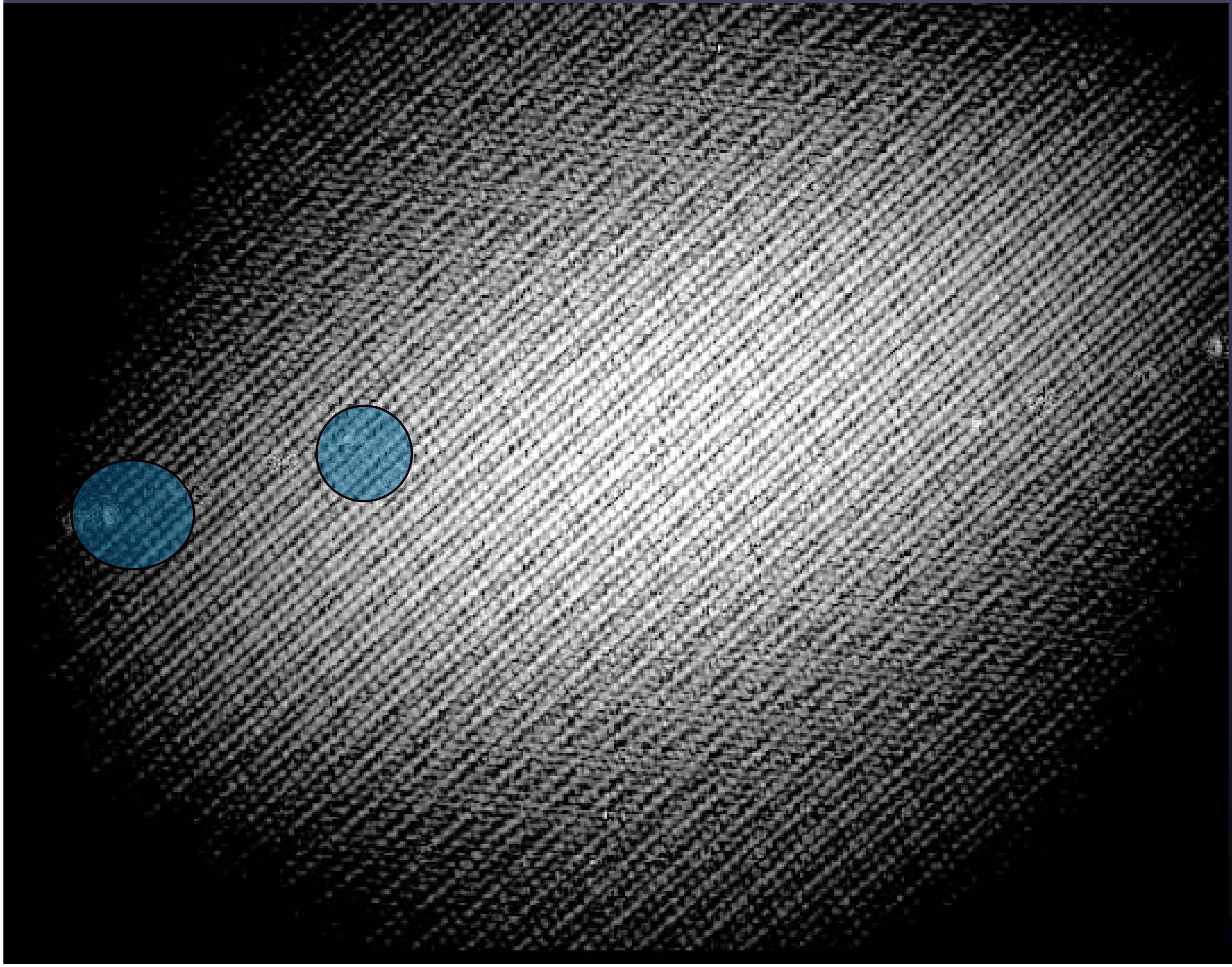


Fourier Transform Dirty Image



- Shows the u-v data as gridded just before imaging
- Diagonal lines caused by structure in field
- A few odd points are not very noticeable

Fourier Transform Clean Image

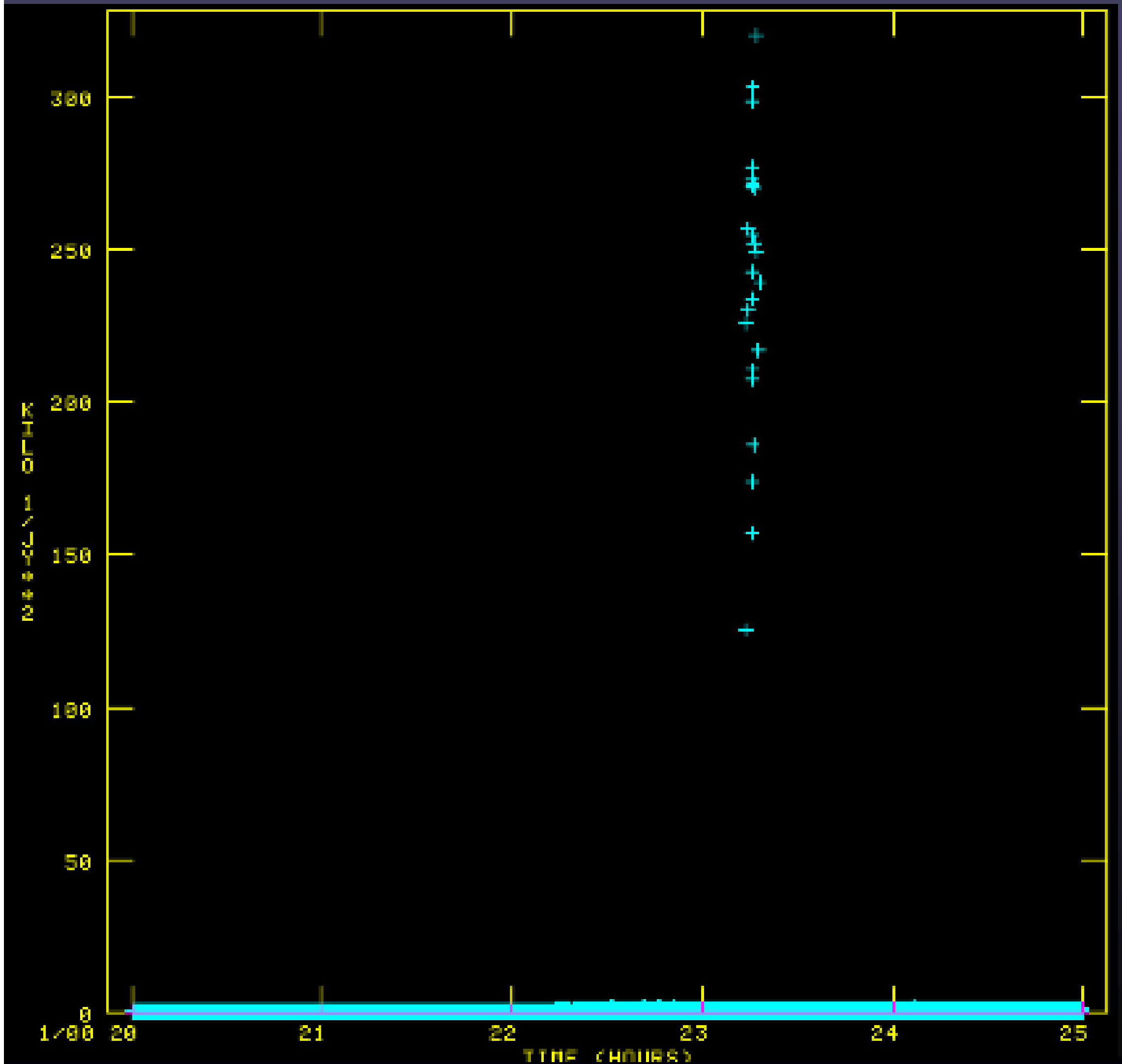


Shows the u-v data from clean image.

Diagonal lines still present. Notice that clean does an interpolation in the u-v plane between u-v tracks.

The odd points are smeared, but still present. These produce the low level ripples.

Bad weighting of a few u-v points



After a long search through the data, about 30 points out of 300,000 points were found to have too high of a weight by a factor of 100.
Effect is <1% in image.

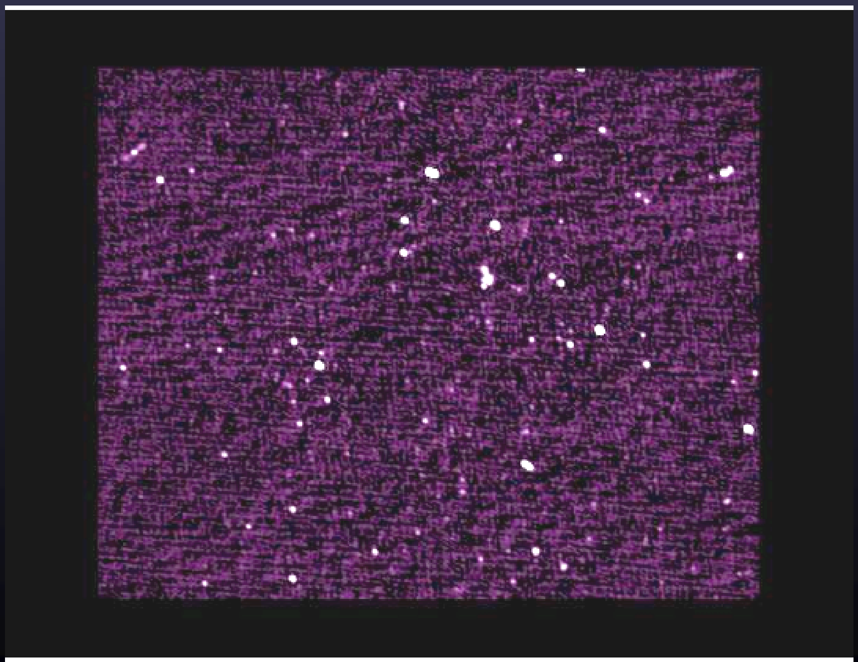
Cause??
Sometimes in applying calibration produced an incorrect weight in the data. Not present in the original data.

These problems can sneak up on you. Beware.

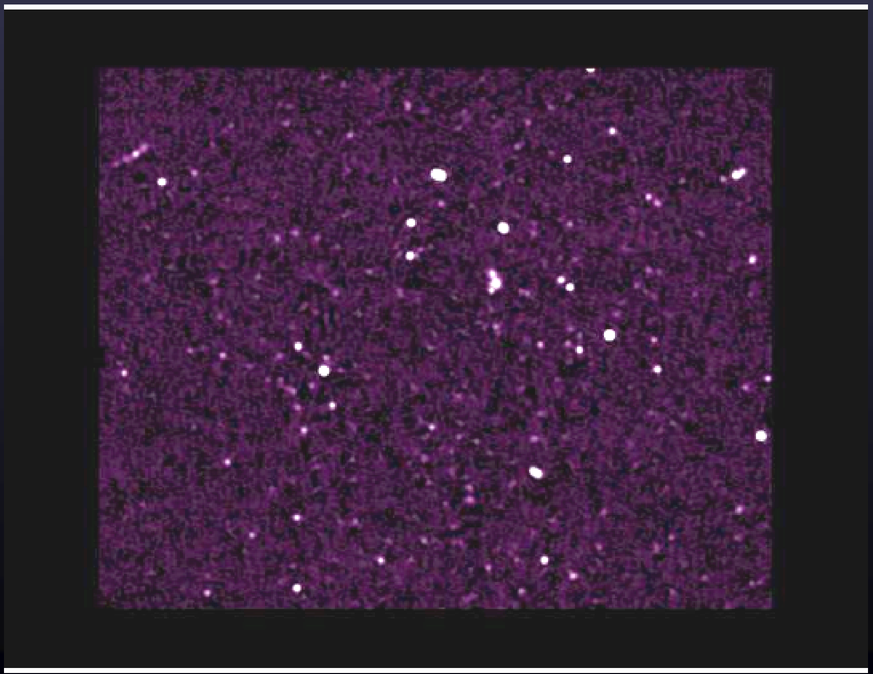
Improvement of Image

Removal of low level ripple improves detectability of faint sources

Before editing



After editing



SUMMARY OF ERROR RECOGNITION

Source structure should be 'reasonable', the rms im
as expected, and the background featureless.

UV data

Look for outliers in u-v data using several plotti

Check calibration gains and phases for instabili

Look at residual data (uv-data - clean component

IMAGE plane

Do defects resemble the dirty beam?

Are defect properties related to possible data e

Are defects related to possible deconvolution pr

IMAGE ANALYSIS

Ed Fomalont

Eleventh Synthesis Imaging Workshop

Socorro, June 10-17, 2008

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

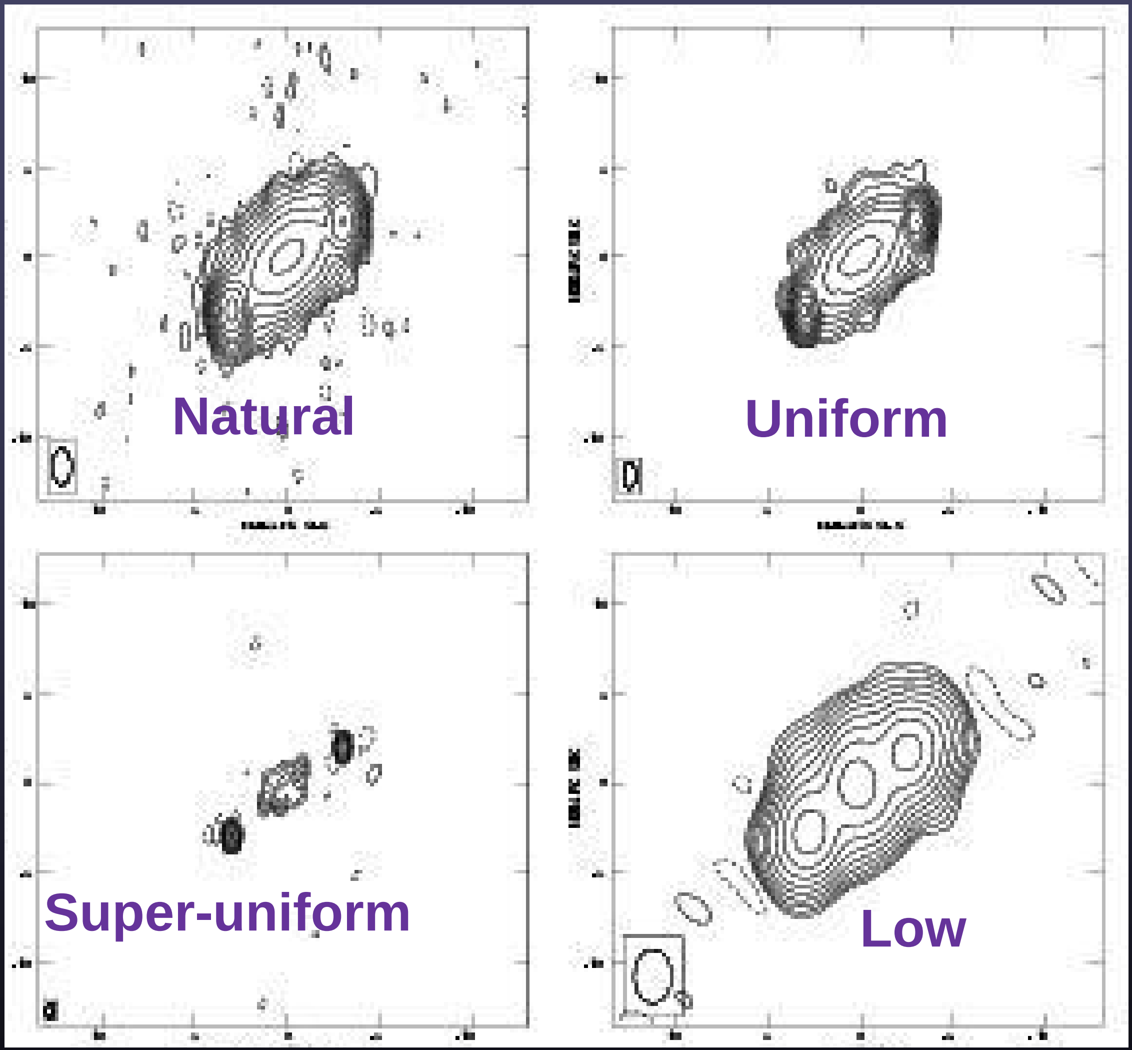
Depends on source emission complexity

Depends on the scientific goals

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

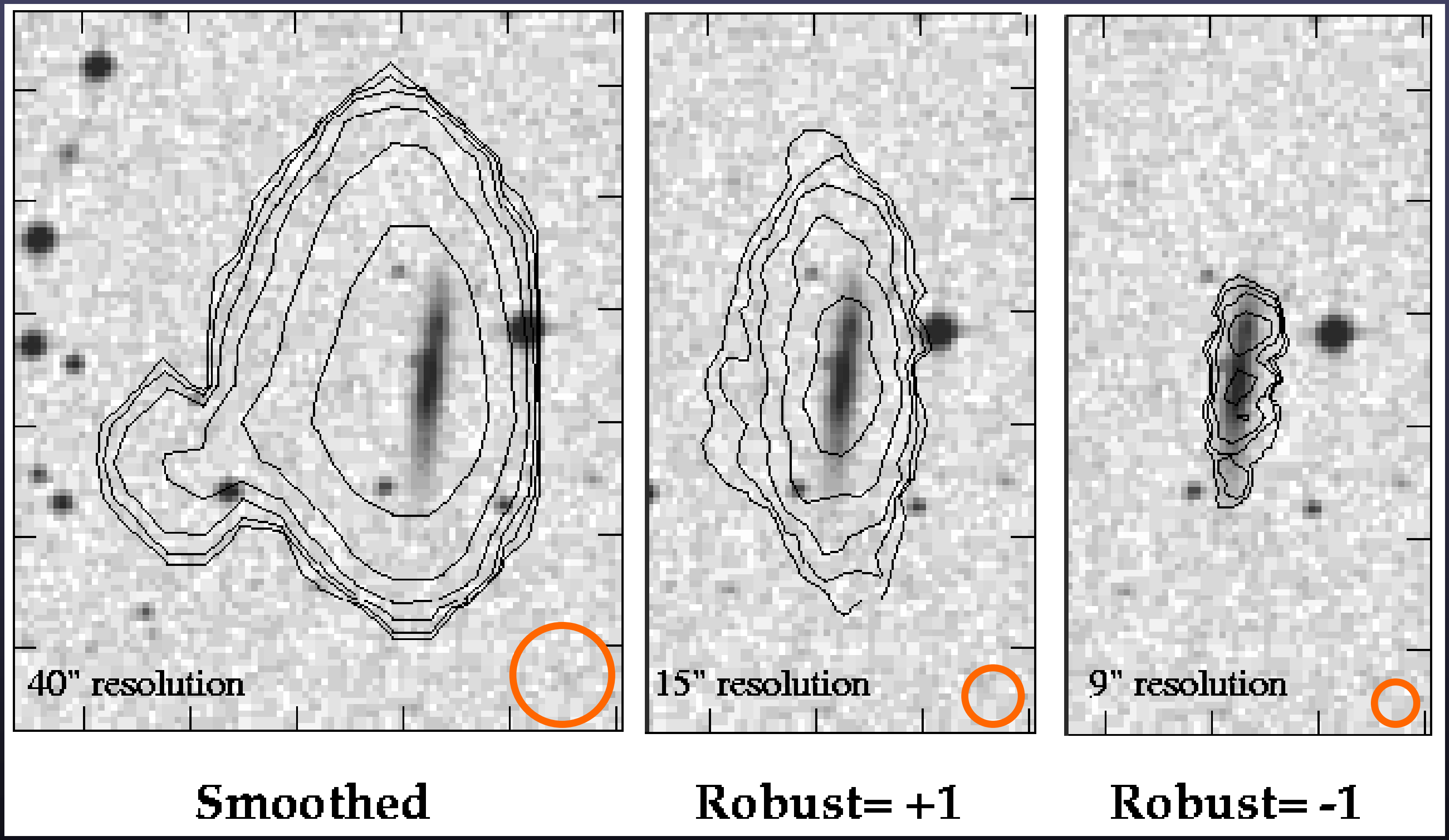
Different aspect of source structure can be see af various resolutions, shown by the ellipse in the lower left corner of each box.

SAME DATA USED FOR ALL IMAGES

For example,
Outer components are small from SU resolution
There is no extended emission from low resolution

Imaging and Deconvolution of Spectral Line Data:

Type of weighting in imaging



HI contours overlaid on optical images of an edge-on galaxy

PARAMETER ESTIMATION

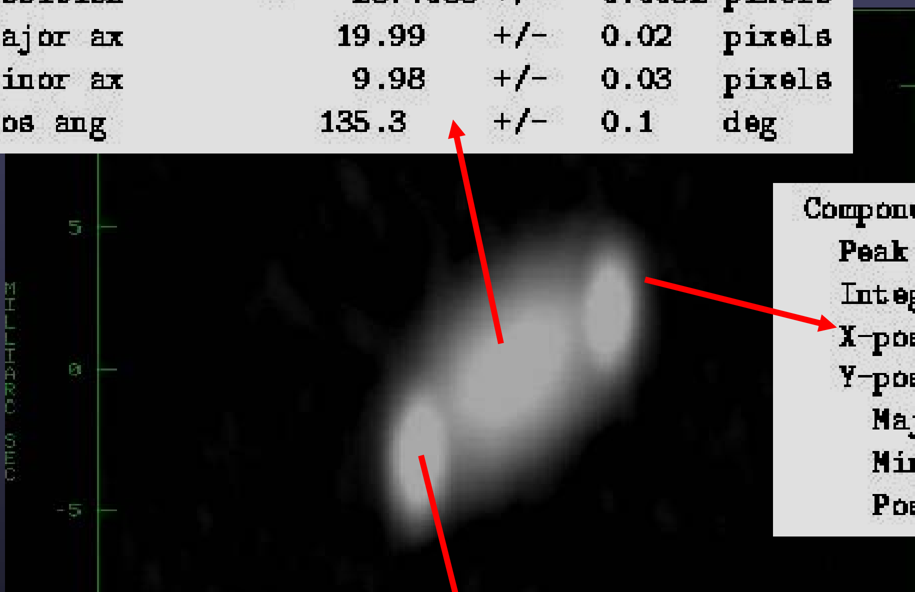
Parameters associated with discrete components

- 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) (see non-imaging analysis)
- 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

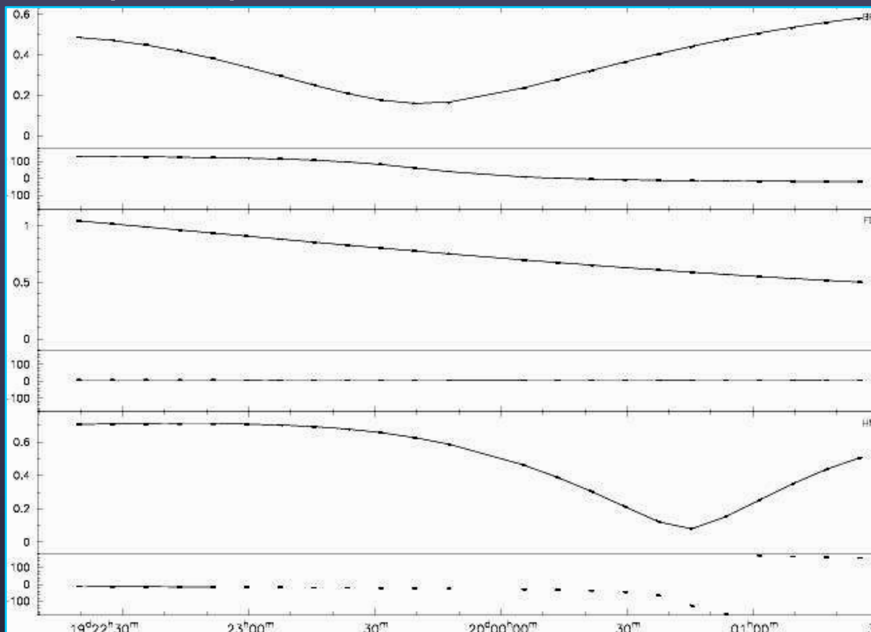
Casa tool

imfit

(U-V) DATA FITTING

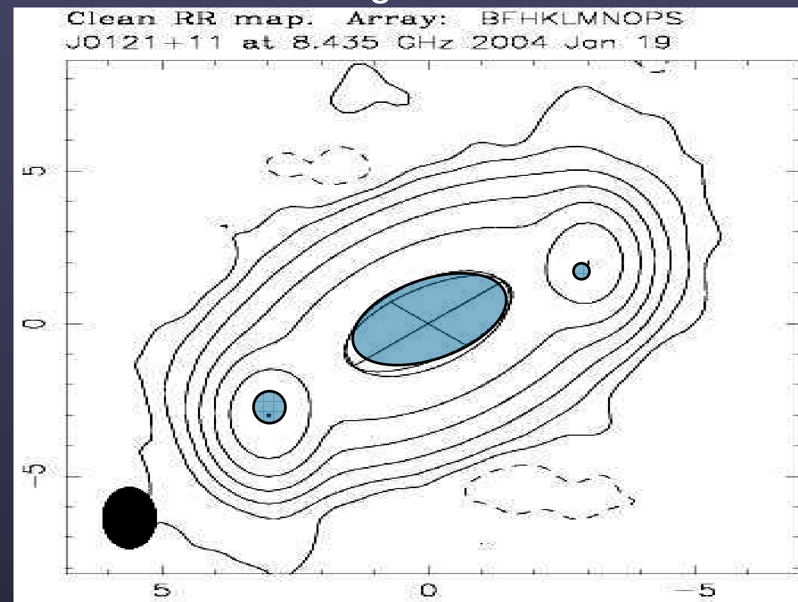
Amp and phase vs time for three baselines

Jy
Deg
Jy
Deg
Jy
Deg



Time

Contour image with model fits



milliarcsec

milliarcsec

DIFMAP has good u-v fitting algorithm

Fit model directly to (u-v) data
Contour display of image
Compare mode to data
Ellipses show true component size. (super-resolution?)

Greg Taylor, Tuesday June 17, “Non-image Data Analysis”

COMPONENT ERROR ESTIMATES

P = Component Peak Flux Density

σ = Image rms noise

P/σ = signal/noise = ***S***

B = Synthesized beam size

θ_i = Component image size

ΔP = Peak error = σ

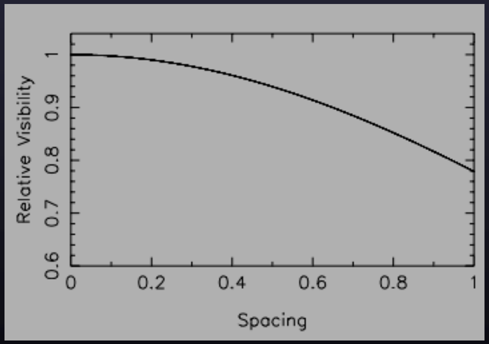
ΔX = Position error = ***B / 2S***

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

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

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

eg. S=100 means can determine size of B/10



Comparison and Combination of Images of Many Types

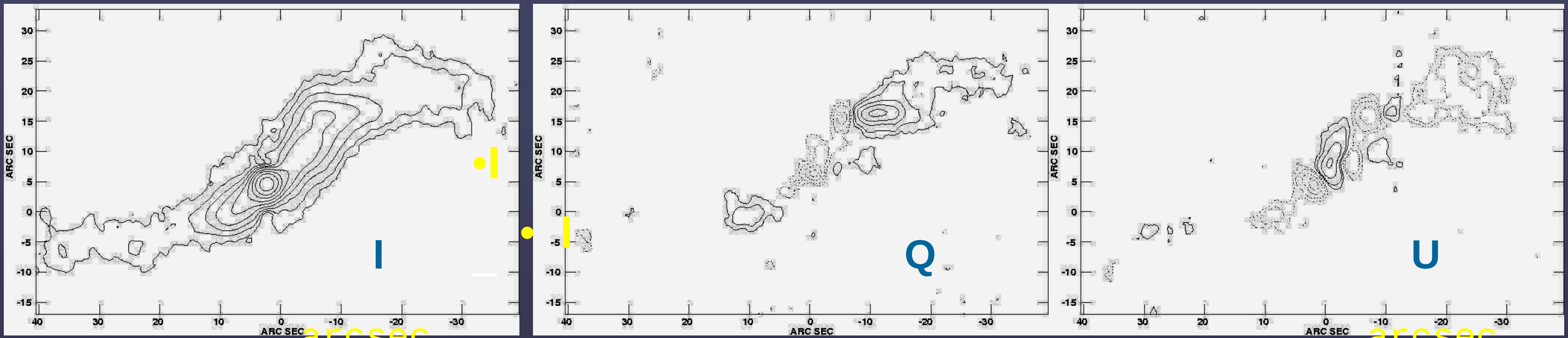
FORNAX-A Radio/Optical field

Radio is red
- Faint radio core in center of NGC1316

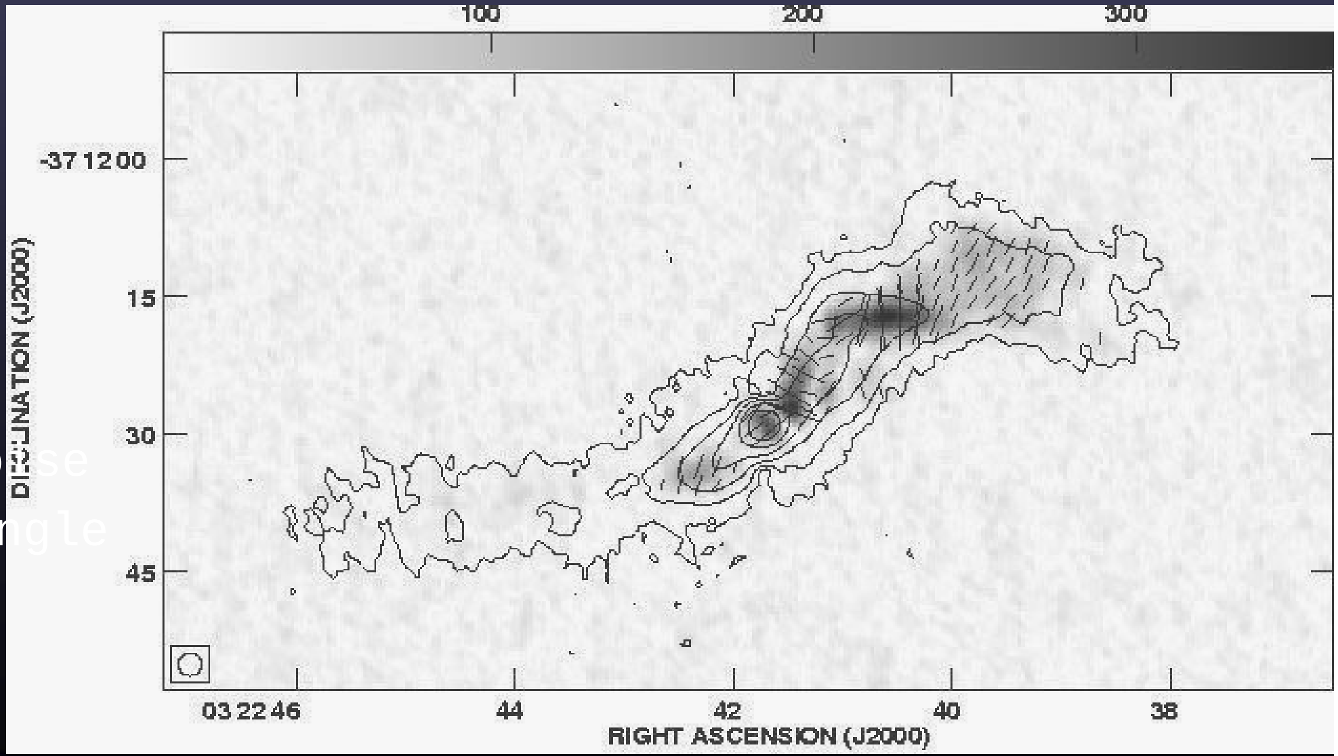
Optical in blue-white

Frame size is 60’ x 40’

LINEAR POLARIZATION



arcsec arcsec arcsec



Multi-purpose plot

Contour – I,Q,U Pol

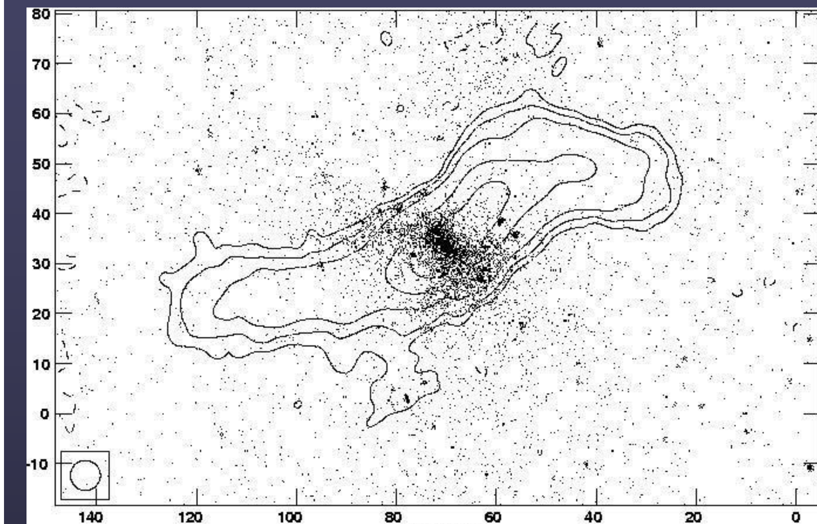
Grey scale – P Pol

$\mathrm{sqrt}\ (Q^2+U^2)$ - noise

Line segments – P angle

atan2(0.5*Q/U)

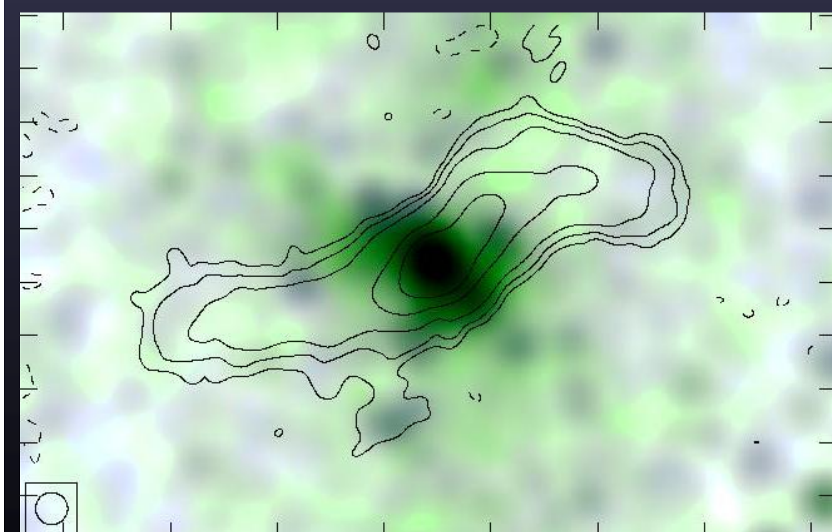
COMPARISON OF RADIO/X-RAY IMAGES



arcsec

Contours of radio intensity at 5 GHz

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



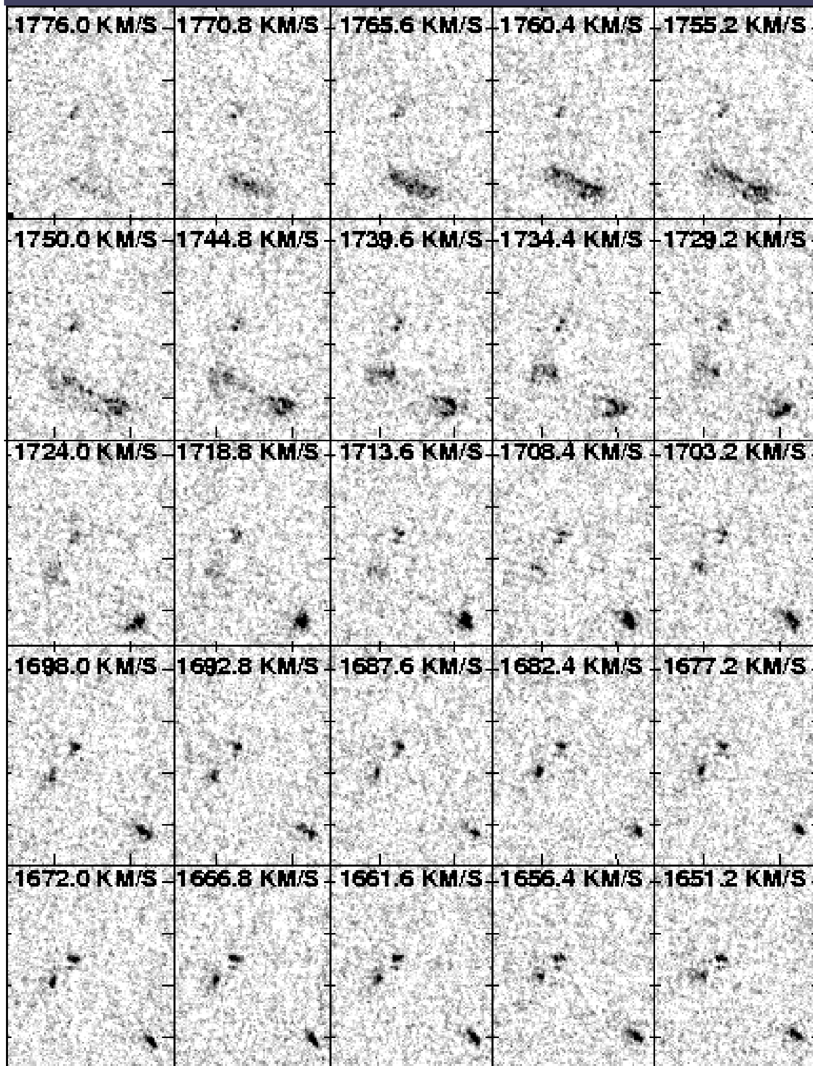
Contours of radio intensity at 5 GHz

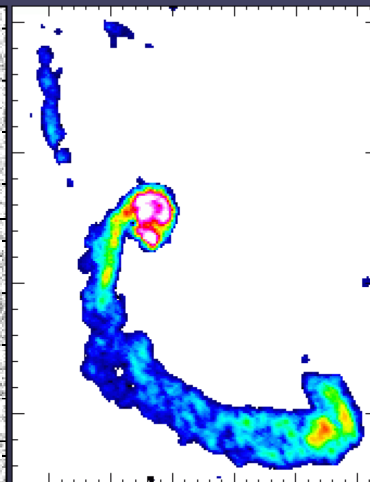
Color intensity represents X-ray intensity smooth to radio resolution

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

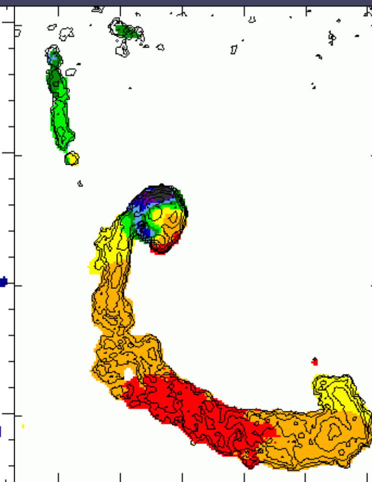
Blue - soft (thermal)

SPECTRAL LINE REPRESENTATIONS

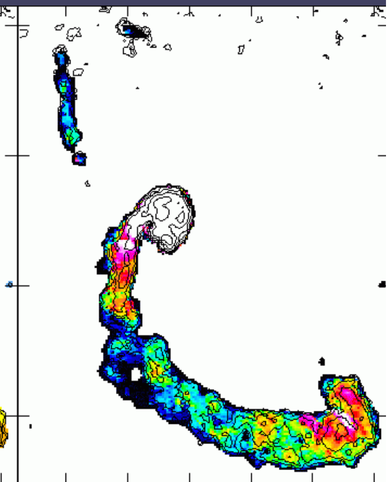




Intensity Image
Sum of velocity
Amount of HI
Red high,
Blue low



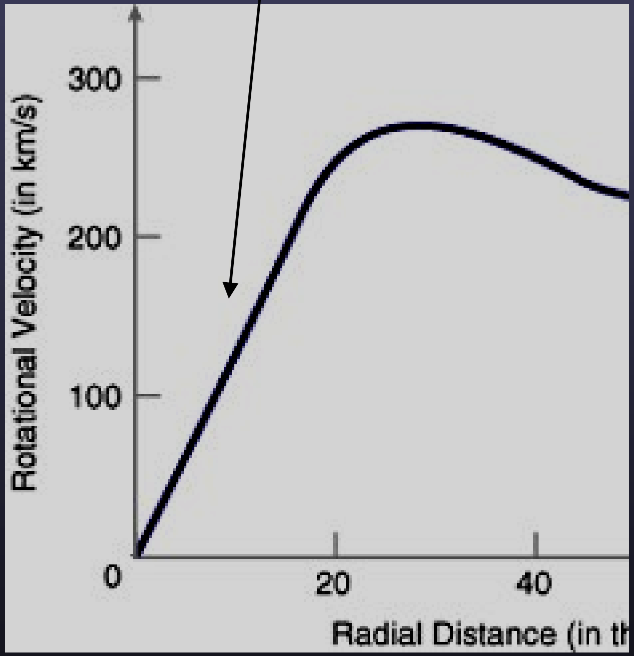
Average velocity
Red low vel
Blue high vel
Rotation



Second moment
Velocity width
Turbulence?

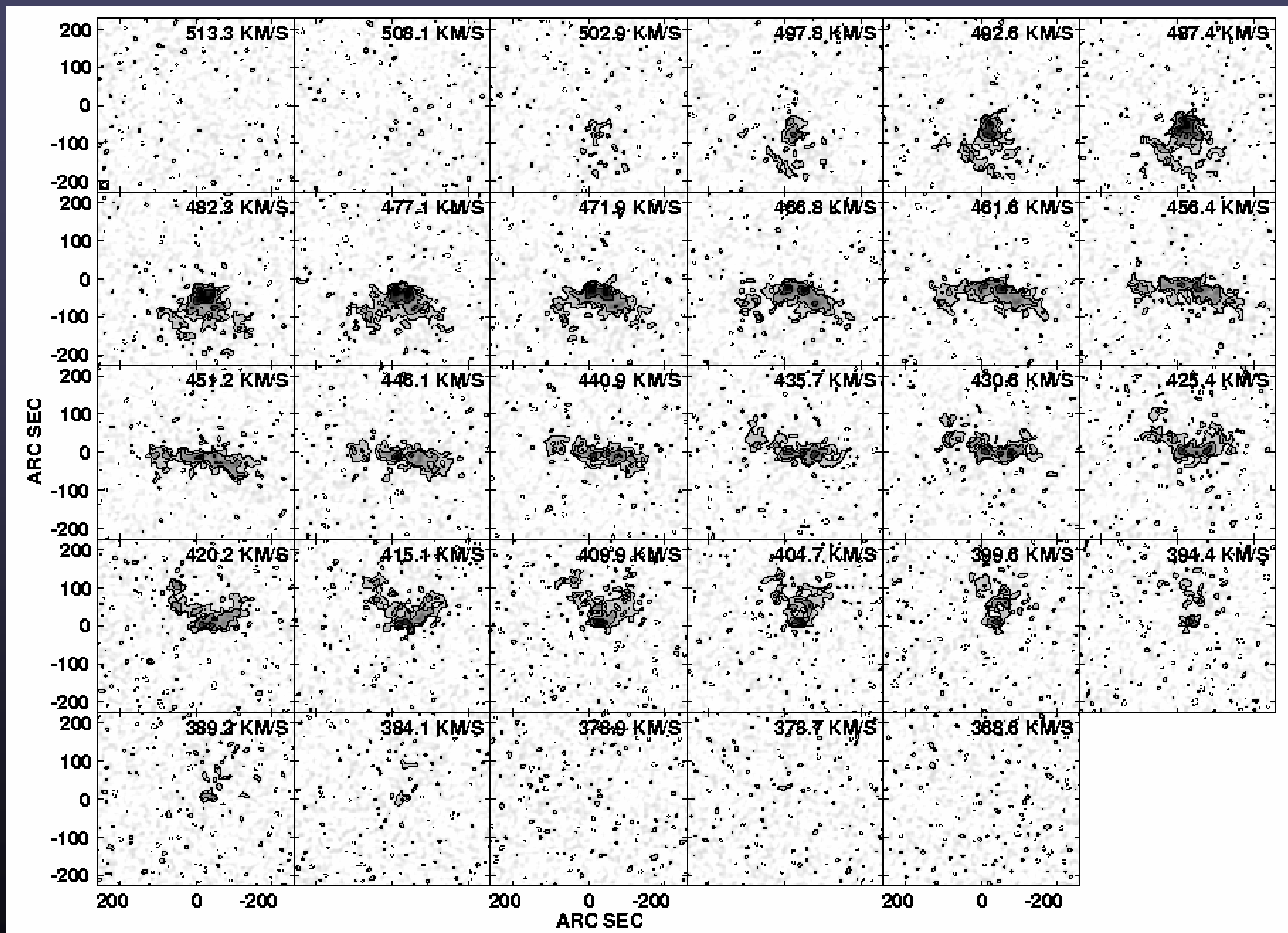
SPECTRAL LINE ROTATION MOVIES

Solid-body Rotation in
Inner parts of a galaxy



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Visualizing Spectral Line Data: Channel Images



Greyscale+contour representations of individual channel images

Visualizing Spectral Line Data: Channel Images

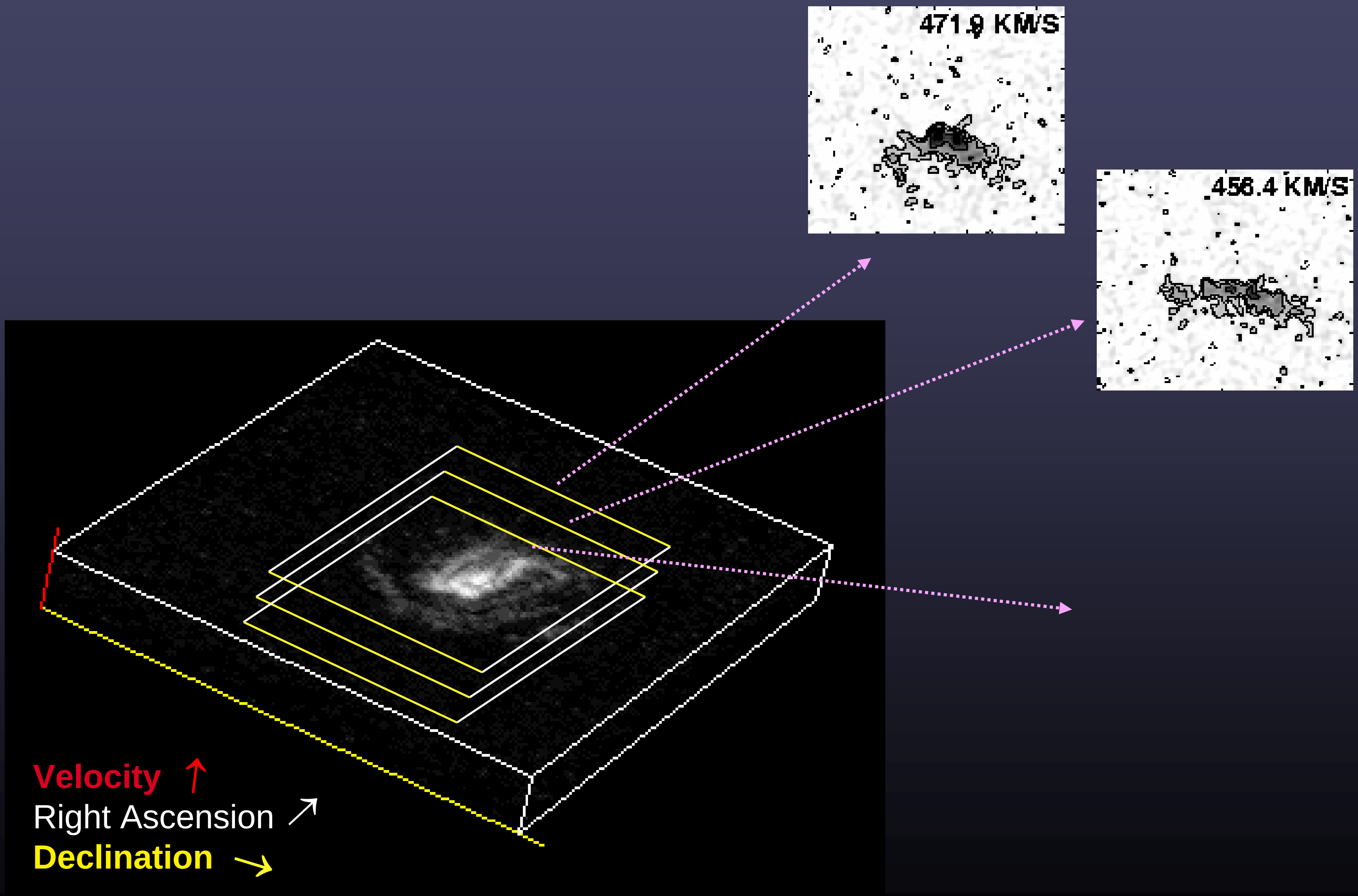


IMAGE REGISTRATION AND ACCURACY

- Separation Accuracy of Components on One Image:

  Limited by signal to noise to 1% of resolution.
  Position errors of 1:10000 for wide fields, i.e. 0.1” over 1.4 GHz PB

- 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. Daily troposphere changes
  can produce position changes up to 25% of the

DEEP RADIO / OPTICAL COMPARISON

Grey-Scale:

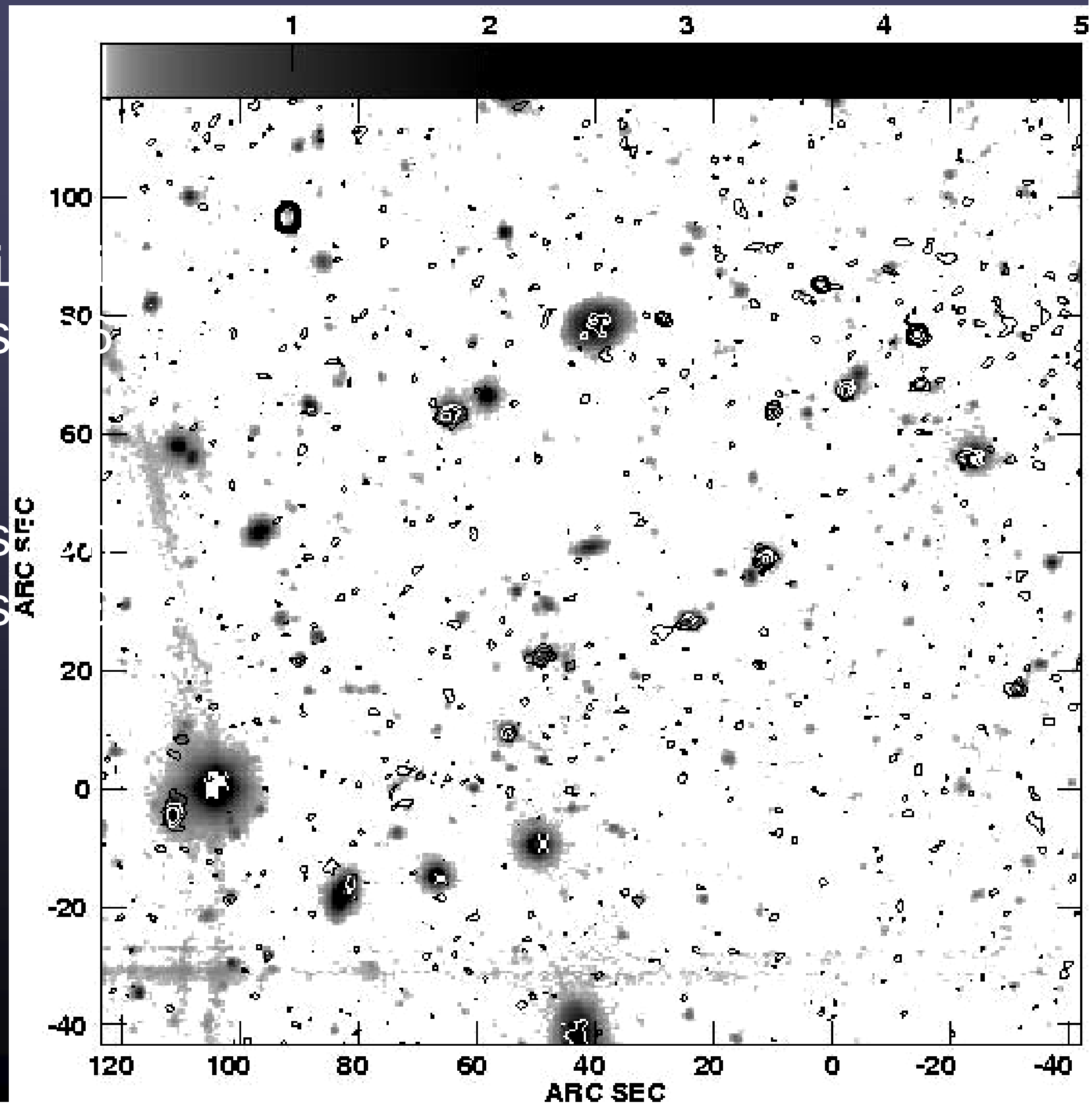
Optical emi

faintest is

Contours:

Radio Emiss

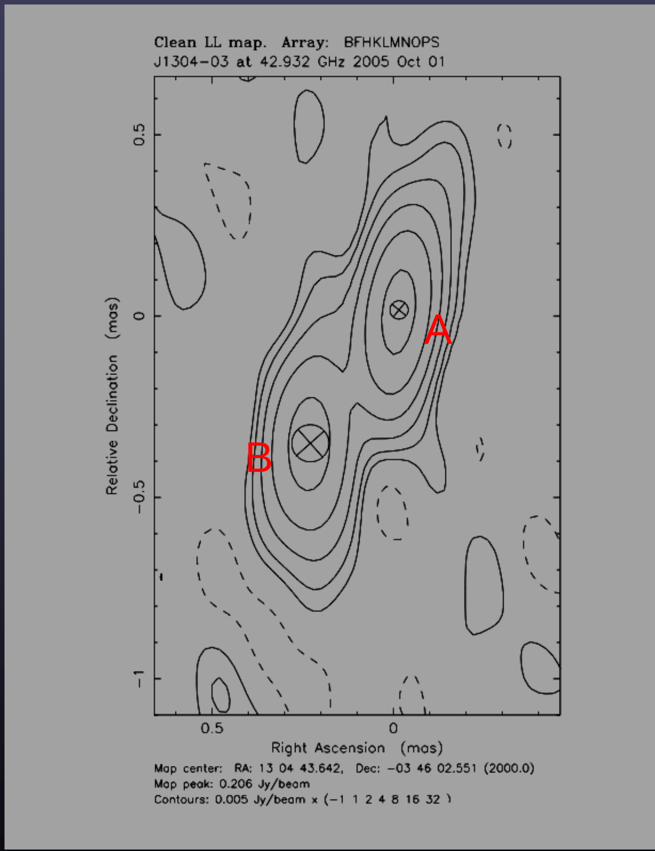
faintest is



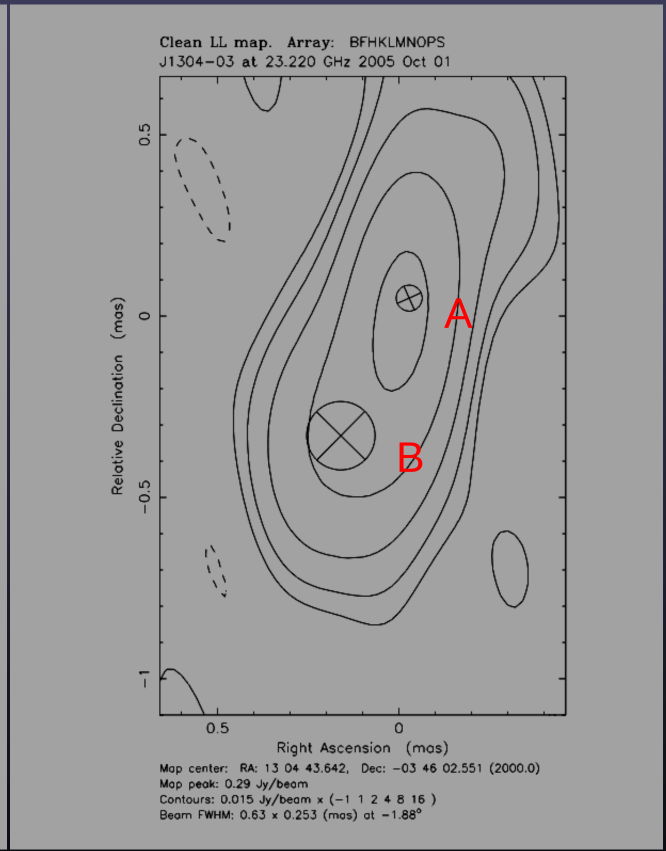
Radio Source Alignment at Different Frequencies

Self-calibration at each frequency aligns maximum at (0,0) point
Frequency-dependent structure causes relative position of maximum to change
Fitting of image with components can often lead to proper registration

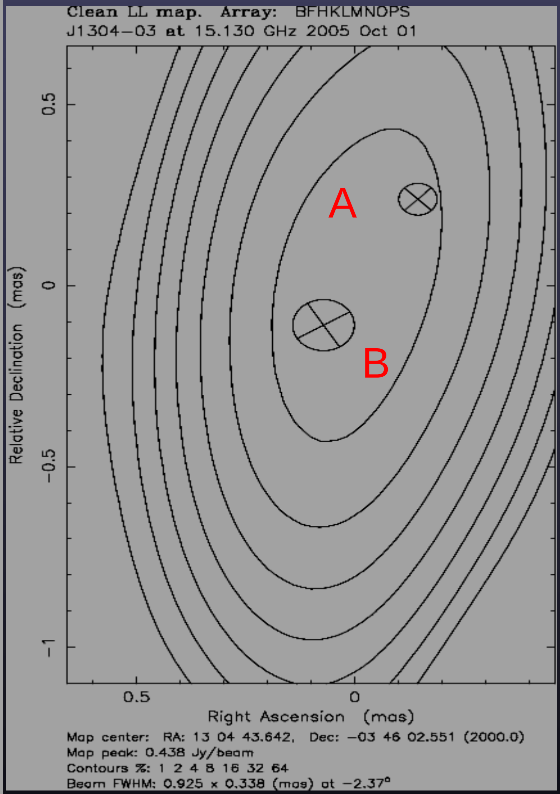
43 GHz: res = 0.3 mas



23 GHz: res = 0.6 mas



15 GHz: res = 0.8 mas



(Reid Lecture on Astrometry, Walker Lecture on VLBA Upgrade)

IMAGE ANALYSIS: SUMMARY

- Analyze and display data in several ways

  Adjust resolution to illuminate desired interpretation, analysis

- Parameter fitting useful, but try to obtain error estimate

  Fitting in u-v plane, image plane

- Comparison of multi-plane images tricky (Polarization and Spectral Line)

  Use different graphics packages, methods, analysis tools

- Registration of a field at different frequencies or wave-bands and be subtle.

  Often use adhoc methods by aligning ‘known’ counterparts