Radio Data Archives

how to find, retrieve, and image radio data: a lay-person's primer

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By the end of this talk, you should know:

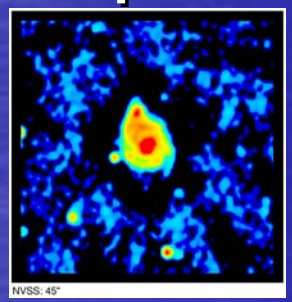
- The standard radio imaging surveys that provide FITS images
- How to find your source in the VLA/VLBA archives
- How to choose which data to download from those archives
- That there is an easy method to convert those data into preliminary images

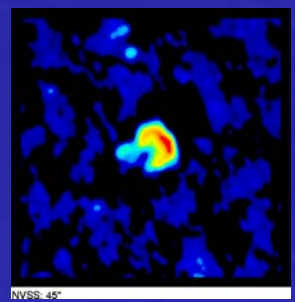
Limitations of this talk

- FITS, not JPEG → not image galleries
- Images → not catalogs or flux densities
- Emphasis on interferometers (vs. single dishes)
  - High-quality, high-resolution imaging
  - Much better archives (!)
- Primarily NRAO instruments
  - Much recent work (kudos to John Benson ☺)
  - Again, better archives (!!!)
  - Looking to ALMA/EVLA: the shape of things to come!
- Concentrate on existing, currently find-able data
- Aimed at intrepid explorers, *not* super-pundits

Sources of radio data: Surveys

- Will soon cover entire sky at <= 1.5 GHz
- Resolutions typically 45 arcsec
- RMS noise of 0.5 mJy (NVSS/1.4 GHz, >-40)
  to 2 mJy (SUMSS/0.84 GHz, <-30)
- Postage stamp servers → JPG/FITS images
- NVSS:





Sources of radio data: Surveys

- Several other sky surveys: WENSS, 4MASS/VLSS, FIRST, ...
- Many nifty targeted, special-interest surveys
  - Canadian Galactic Plane Survey (CGPS)
  - WHISP, BIMA-SONG
  - VLBI: MOJAVE, Radio Reference Frame Image Database, DRAGN, VLBA Calibrator Survey, ...
  - SIRTF/Spitzer First Look Survey

Survey	Area	Freq.	Res'n	Rms	sample
NVSS	Dec>-40	1.4 GHz	VLA/D 45asec	0.45 mJy	
FIRST	N/S Gal.caps	1.4 GHz	VLA/B 5asec	0.15 mJy	
VLSS/ 4MASS	Dec>-30	74 MHz	VLA/B 80asec	100 mJy	
WENSS	Dec> 30	326 MHz	WSRT 54asec	3.6 mJy	
SUMSS	Dec<-30	843 MHz	MOST 45asec	1.3-2 mJy	
CGPS	|b|<5 |=74,147	408, 1420			

Sources of radio data: Archives

- VLA: arcsec-arcmin resolution over few to 10s of arcminutes
- VLBA: milliarcsecond resolution over arcseconds
- GBT: arcminute resolution over degrees
  - One-year proprietary period
  - Returns raw data via ftp
- Australia Telescope Compact Array (ATCA): arcsecond resolution over arcminutes
  - 18-month proprietary period
  - E-mail to get raw data
- MERLIN: 10s of milliarcsecond resolution over arcminute
  - One-year proprietary period
  - ☺ Working on processing all data for public use!
- Others
  - do not exist (WSRT, OVRO, PdBI, GMRT)
  - painful to search (BIMA, EVN/JIVE)

Sources of radio data: Archives

- NRAO: dec > -40
  - Very Large Array (VLA): the workhorse, ~3 TB of data!
  - Very Long Baseline Array (VLBA)
  - Green Bank Telescope (GBT)
  - One-year proprietary period
  - Returns raw data via ftp
- Australia Telescope Compact Array (ATCA): dec < -30
  - 18-month proprietary period
  - E-mail to get raw data
- MERLIN: high-res'n for dec > 0-ish
  - One-year proprietary period

  ☺ Working on processing all data for public use!
- Others
  - do not exist (WSRT, OVRO, PdBI, GMRT)
  - painful to search (BIMA, EVN/JIVE)

Sources of radio data: Archives

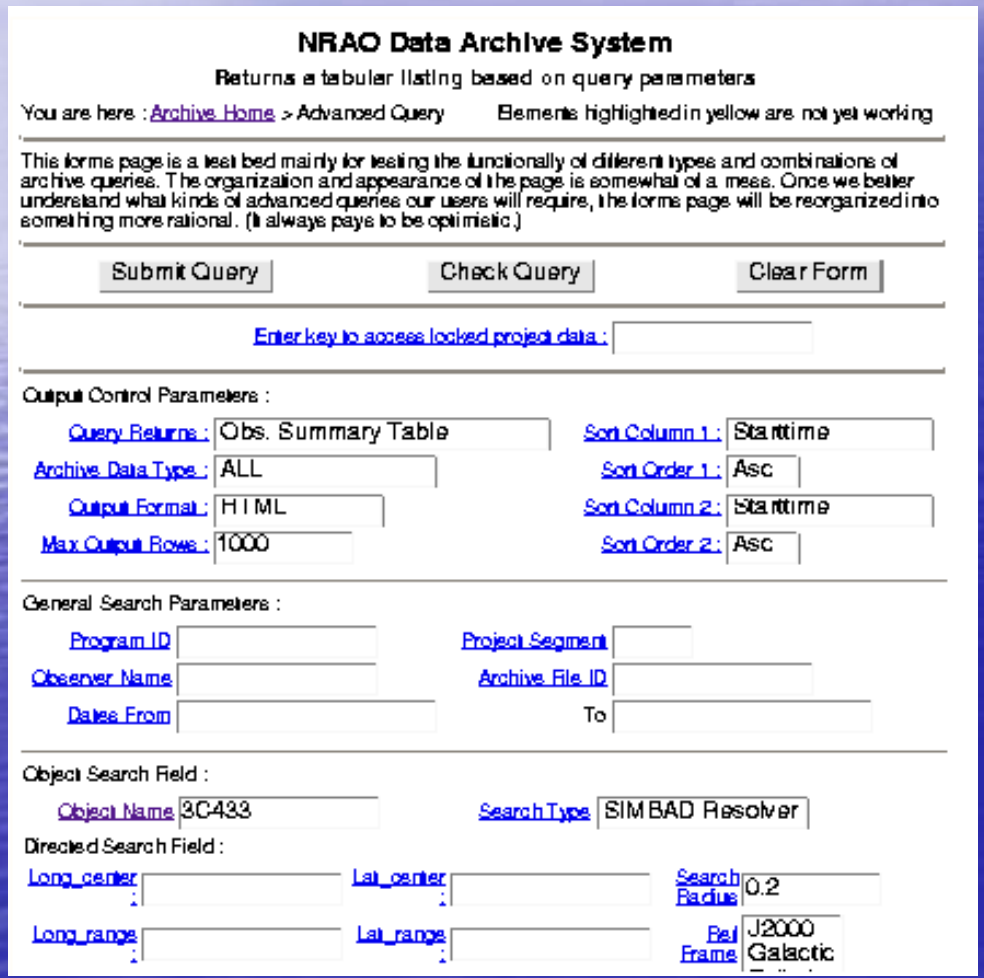
- NRAO
  - Very Large Array (VLA): the workhorse, ~3 TB of data!
  - Very Long Baseline Array (VLBA)
  - Green Bank Telescope (GBT)
  - Returns raw data via ftp
- Australia Telescope Compact Array (ATCA)
  - E-mail to get raw data
- MERLIN (England)

  ☺Working on processing all data for public use!
- Others
  - do not exist (WSRT, OVRO, PdBI, GMRT)
  - painful to search (BIMA, EVN/JIVE)

Finding radio data: choosing the telescope

- North or south?
  - Dec >-40 → VLA/VLBA
    - Dec> 0 → MERLIN
  - Dec <-30 → ATCA
- Desired resolution & source size?
  - VLA/ATCA: arcsecond to arcmin resolution over few to 10s of arcminutes
  - MERLIN: 10s of milliarcseconds res'n over arcmin
  - VLBA: milliarcsecond res'n over arcseconds

Finding radio data: checking the (VLA) archive



NRAO Data Archive System

Returns a tabular listing based on query parameters

You are here : Archive Home > Advanced Query Elements highlighted in yellow are not yet working

This forms page is a test bed mainly for testing the functionality of different types and combinations of archive queries. The organization and appearance of the page is somewhat of a mess. Once we better understand what kinds of advanced queries our users will require, the forms page will be reorganized into something more rational. (It always pays to be optimistic.)

Submit Query | Check Query | Clear Form

Enter key to access locked project data :

Output Control Parameters :

Query Returns :	Obs. Summary Table	Sort Column 1 :	Starttime
Archive Data Type :	ALL	Sort Order 1 :	Asc
Output Format :	HTML	Sort Column 2 :	Starttime
Max Output Rows :	1000	Sort Order 2 :	Asc

General Search Parameters :

Program ID		Project Segment	
Observer Name		Archive File ID	
Dates From		To	

Object Search Field :

Object Name 3C433 Search Type SIMBAD Resolver

Directed Search Field :

Long_center :		Lat_center :	
Long_range :		Lat_range :	

Search Radius 0.2

Ref Frame J2000 Galactic

- Search by
  - source name (SIMBAD) or position + radius
  - VLA configuration
  - obs. Frequency

Actively evolving – feedback is very welcome!!!

Finding radio data: checking the (VLA) archive

NRAO Archive DB Query Results - OBSSUMMARY Table Listing

Data Selection Parameters :

Object Name = 3C433
SIMBAD Long. Center= 21h23m44.75s
SIMBAD Lat. Center = +25d04'17.8"
Search Radius = 0.2
Obs. Bands = X
Max Rows = 1000

Table Sort Order :

Sort By = Starttime
Sort Order = Asc

Displaying nrows : 12

Project	Source	IF Band	Ref Freq	First Time	Last Time	Exposure	Bandwidth	Config	chans
AB0534	3C433	X	8235.000	89-Apr-07 18:32:24	89-Jul-02 12:56:05	3110	50.000	B	1
AB0534	3C433	X	8465.000	89-Apr-07 18:32:24	89-Jul-02 12:56:05	3110	50.000	B	1
AB0568	21232503	X	8414.900	90-May-04 13:05:14	90-May-04 13:07:25	130	100.000	A	1
AB0568	21232503	X	8464.900	90-May-04 13:05:14	90-May-04 13:07:25	130	100.000	A	1
AB0534	3C433	X	8235.000	90-May-25 08:33:04	90-May-26 13:46:44	7700	50.000	A	1
AB0534	3C433	X	8465.000	90-May-25 08:33:04	90-May-26 13:46:44	7700	50.000	A	1
AB0534	3C433	X	8414.900	91-May-23 16:03:14	91-May-23 16:06:14	180	100.000	D	1
AB0534	3C433	X	8464.900	91-May-23 16:03:14	91-May-23 16:06:14	180	100.000	D	1
AB0667	21232504	X	8414.900	93-Jan-03 22:00:45	93-Jan-03 22:02:45	120	100.000	A	1
AB0667	21232504	X	8464.900	93-Jan-03 22:00:45	93-Jan-03 22:02:45	120	100.000	A	1
AK0403	3C433	X	8414.900	95-Jul-27 09:35:45	95-Jul-27 14:27:45	360	100.000	A	1
AK0403	3C433	X	8464.900	95-Jul-27 09:35:45	95-Jul-27 14:27:45	360	100.000	A	1

Returns:

- Observing frequency
- Configuration
- Exposure time
- Bandwidth
- Number of channels

Umm...

- what's an array configuration?
- why does the frequency matter?
- what's up with this %&%* column listing the number of channels?!?

How do I choose which data to look at???

Finding radio data: checking the (VLA) archive

- Search by position, array configuration, frequency
  - Umm...what's an array configuration?
  - ...and why does the frequency matter?
  - ...and what's up with this %&%* column listing the number of channels?!?
- How do I choose which data to look at???

First, have a stiff drink...

Choosing your data: field-of-view

- Antenna response (primary beam): $\Theta \propto \lambda/D$
  - VLA/ATCA/VLBA:
    - 30 arcmin @ 20cm (1.4 GHz)
    - 9 arcmin @ 6cm (4.9 GHz)
    - 3 arcmin @ 2cm (15 GHz)
    - 1 arcmin @ 0.7cm (45 GHz)
- Chromatic aberration (beam smearing)
  - can't focus wide bandwidths all at once, over the entire primary beam
  - leads to radial smearing towards edges of field at higher resolutions (e.g., VLA/A config.)

→ If you have a nice high-res'n image with lots of dots in the middle and radial smears further out, *talk to someone!*

Choosing your data: resolution

$\Theta \propto \lambda/B$

The four VLA configurations:

A: 36km
0.3” @ 6cm

B: 11km
1.2” @ 6cm

C: 3.4km
4” @ 6cm

D: 1.0 km
14” @ 6cm

Choosing your data: resolution

$\Theta \propto \lambda/B$

"So it's easy: you always use A configuration!"

Well...no...:

- Surface brightness sensitivity: you want to match the resolution to the source size, for maximum sensitivity
- Chromatic aberration
- Interferometers act as **spatial filters**...and you're quite likely to high-pass filter your source away

Choosing your data: missing structure

- Interferometers have the resolution of a telescope the size of the antenna separation (e.g. kilometers)
- Unfortunately that size scale's the only one they measure!
  - hence the need for >> 2 antennas ☺
- If you have lots of telescopes widely separated from one another, you learn lots about the fine-scale source structure...and nothing at all about the source as a whole.
  - *For math types: we measure only the high-frequency Fourier components*

Choosing your data: missing structure

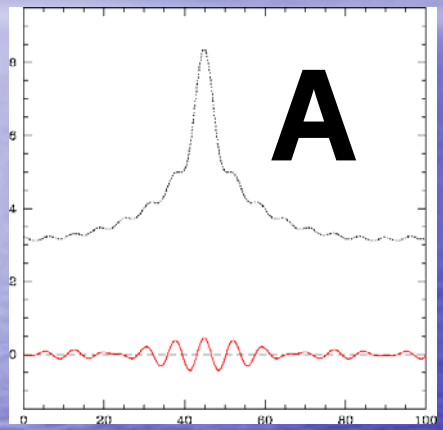
A: 36km
0.3” @ 6cm

B: 11km
1.2” @ 6cm

C: 3.4km
4” @ 6cm

D: 1.0 km
14” @ 6cm

Choosing your data: missing structure

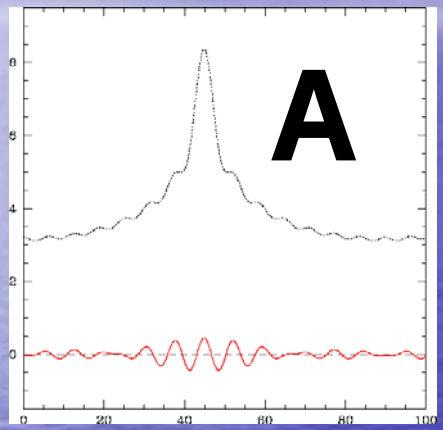


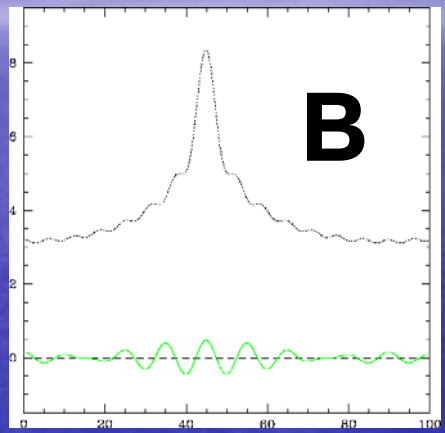
B: 11km
1.2” @ 6cm

C: 3.4km
4” @ 6cm

D: 1.0 km
14” @ 6cm

Choosing your data: missing structure

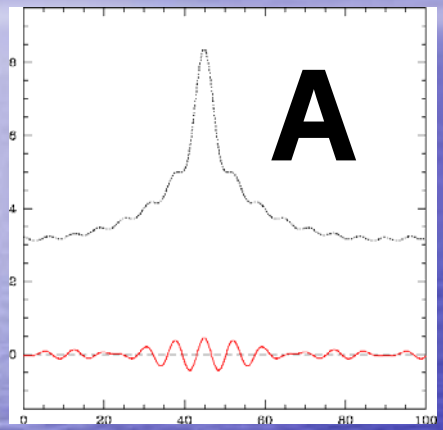


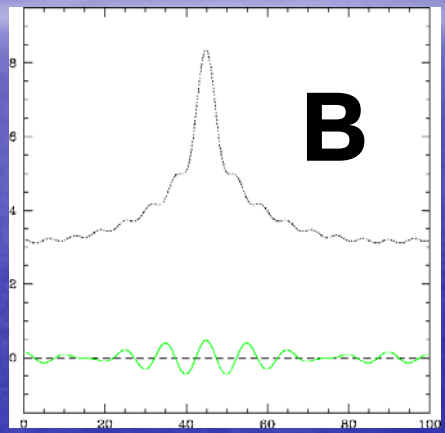


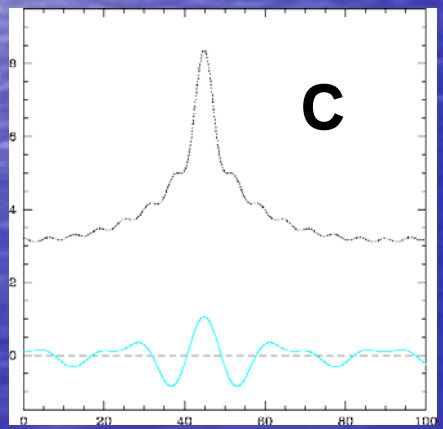
C: 3.4km
4” @ 6cm

D: 1.0 km
14” @ 6cm

Choosing your data: missing structure

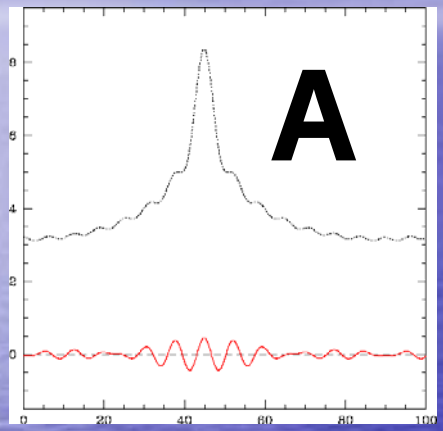


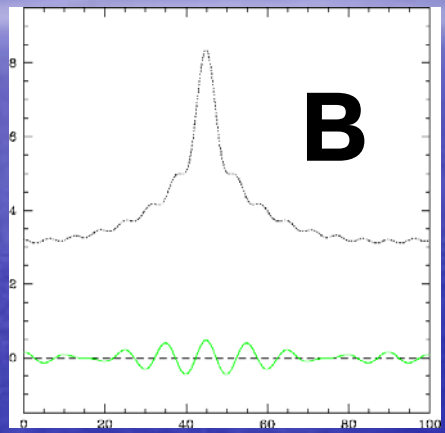


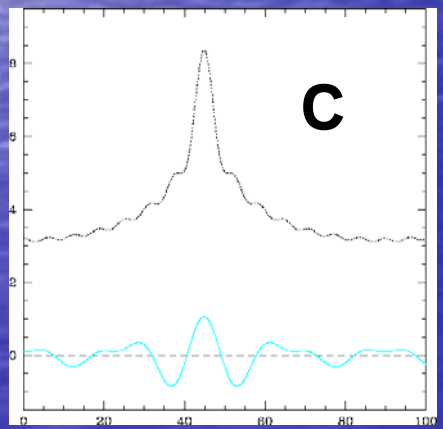


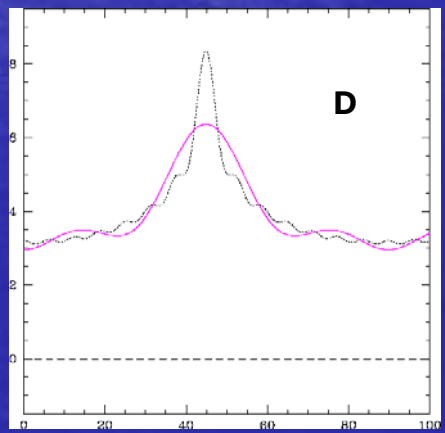
D: 1.0 km
14” @ 6cm

Choosing your data: missing structure

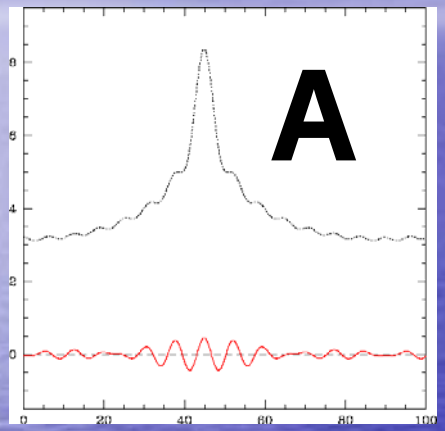


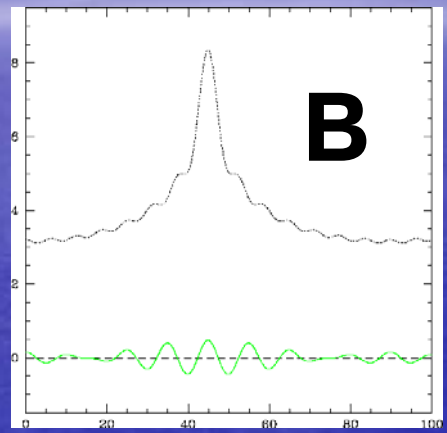


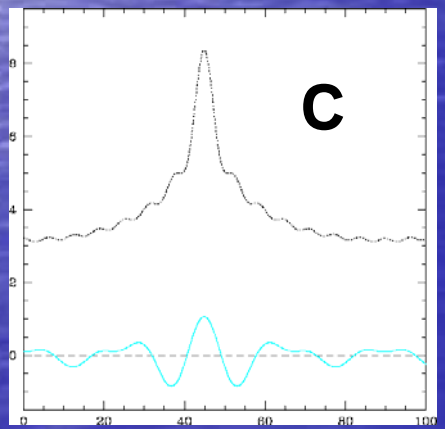


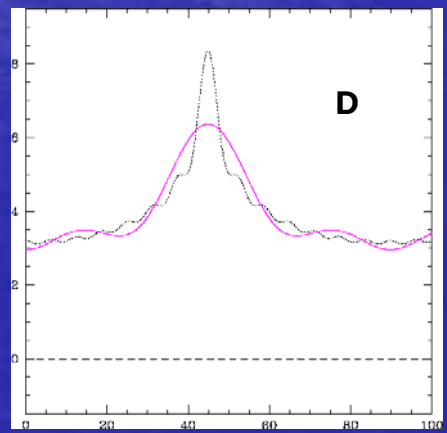


Choosing your data: missing structure

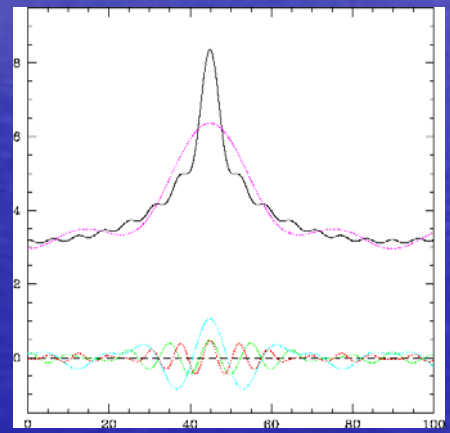








→



$A + B + C + D$

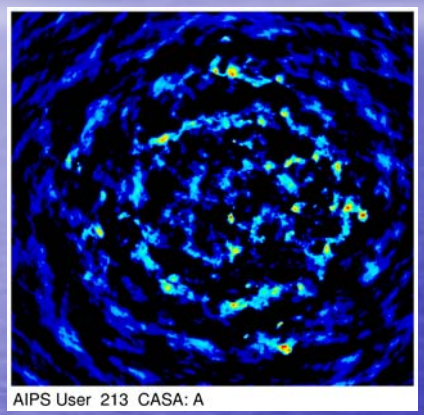
A real-life example

C
4”

D
15”

A real-life example

A
0.3”

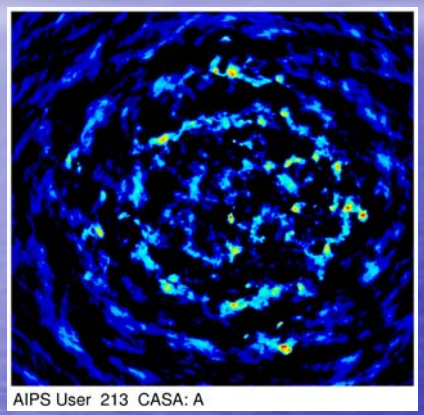


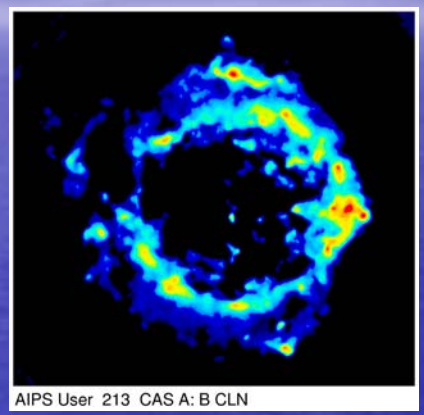
C
4”

D
15”

A real-life example

A
0.3”





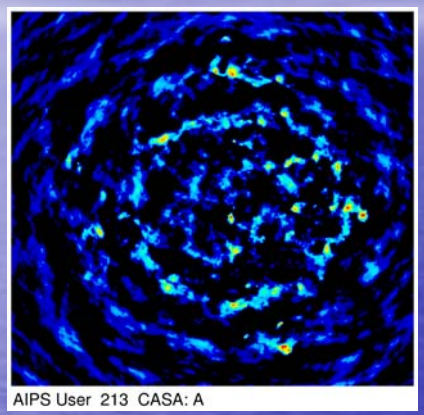
B
1.3”

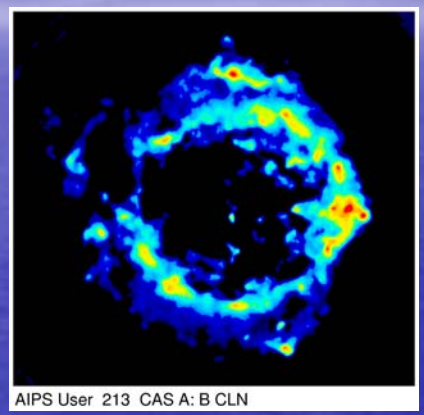
C
4”

D
15”

A real-life example

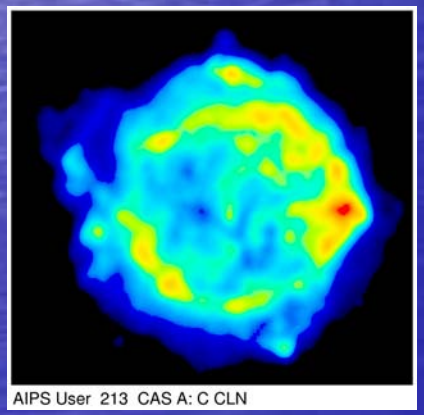
A
0.3”


AIPS User 213 CASA: A


AIPS User 213 CAS A: B CLN

B
1.3”

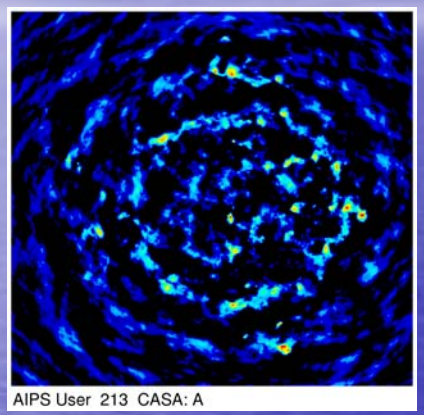
C
4”

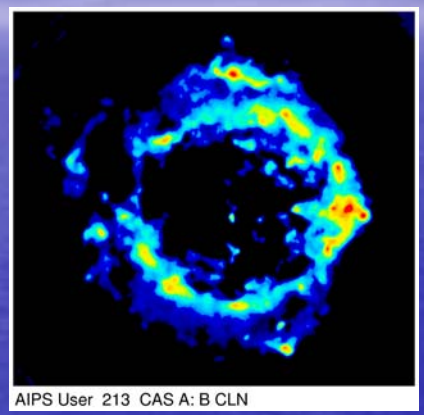

AIPS User 213 CAS A: C CLN

D
15”

Cas A: four VLA configurations

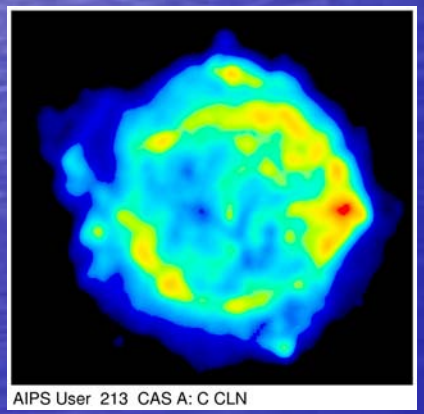
A
0.3”

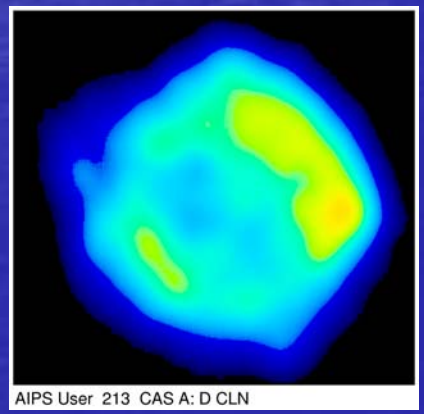




B
1.3”

C
4”

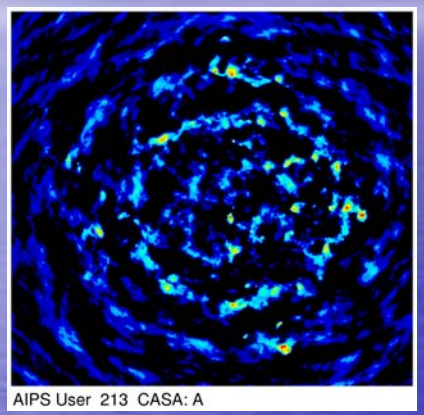


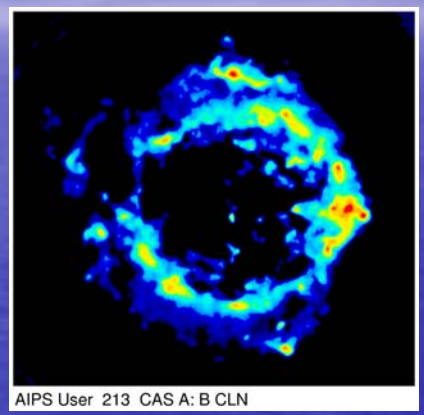


D
15”

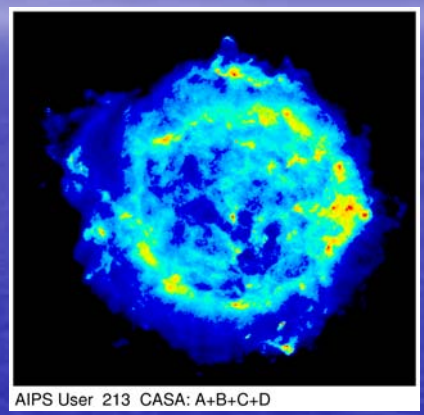
Cas A: four VLA configurations

A
0.3”

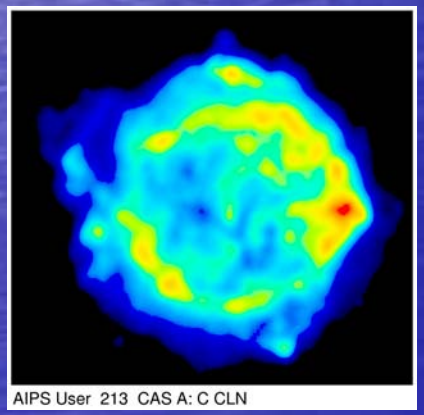


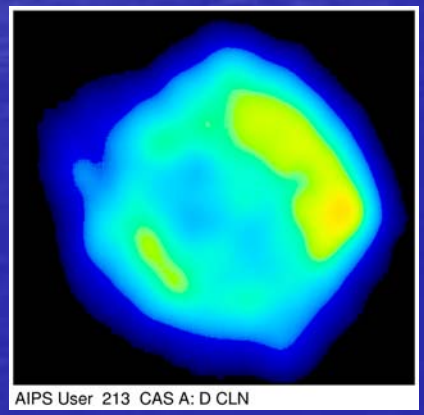


B
1.3”



C
4”





D
15”

A+B+C+D
0.3” +
total flux

The Obs. Status Summary

Table 3: **Configuration Properties**

Configuration	A	B	C	D
$B_{\max}(\mathrm{km}^1)$	36.4	11.4	3.4	1.03
$B_{\min}(\mathrm{km}^1)$	0.68	0.21	0.035^5	0.035
	Synthesized Beamwidth θ_{HPBW}(arcsec)^{1,2,3}			
400 cm	24.0	80.0	260.0	850.0
90 cm	6.0	17.0	56.0	200.0
20 cm	1.4	3.9	12.5	44.0
6 cm	0.4	1.2	3.9	14.0
3.6 cm	0.24	0.7	2.3	8.4
2 cm	0.14	0.4	1.2	3.9
1.3 cm	0.08	0.3	0.9	2.8
0.7 cm	0.05	0.15	0.47	1.5
	Largest Angular Scale θ_{LAS} (arcsec)^{1,4}			
400 cm	800.0	2200.0	20000.0	20000.0
90 cm	170.0	540.0	4200.0	4200.0
20 cm	38.0	120.0	900.0	900.0
6 cm	10.0	36.0	300.0	300.0
3.6 cm	7.0	20.0	180.0	180.0
2 cm	4.0	12.0	90.0	90.0
1.3 cm	2.0	7.0	60.0	60.0
0.7 cm	1.3	4.3	43.0	43.0

Resolution

Largest visible structure

Finding radio data: checking the (VLA) archive

NRAO Archive DB Query Results - OBSSUMMARY Table Listing

Data Selection Parameters :

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SIMBAD Lat. Center = +25d04'17.8"
Search Radius = 0.2
Obs. Bands = X
Max Rows = 1000

Table Sort Order :

Sort By = Starttime
Sort Order = Asc

Displaying nrows : 12

Project	Source	IF Band	Ref Freq	First Time	Last Time	Exposure	Bandwidth	Config	chans
AB0534	3C433	X	8235.000	89-Apr-07 18:32:24	89-Jul-02 12:56:05	3110	50.000	B	1
AB0534	3C433	X	8465.000	89-Apr-07 18:32:24	89-Jul-02 12:56:05	3110	50.000	B	1
AB0568	21232503	X	8414.900	90-May-04 13:05:14	90-May-04 13:07:25	130	100.000	A	1
AB0568	21232503	X	8464.900	90-May-04 13:05:14	90-May-04 13:07:25	130	100.000	A	1
AB0534	3C433	X	8235.000	90-May-25 08:33:04	90-May-26 13:46:44	7700	50.000	A	1
AB0534	3C433	X	8465.000	90-May-25 08:33:04	90-May-26 13:46:44	7700	50.000	A	1
AB0534	3C433	X	8414.900	91-May-23 16:03:14	91-May-23 16:06:14	180	100.000	D	1
AB0534	3C433	X	8464.900	91-May-23 16:03:14	91-May-23 16:06:14	180	100.000	D	1
AB0667	21232504	X	8414.900	93-Jan-03 22:00:45	93-Jan-03 22:02:45	120	100.000	A	1
AB0667	21232504	X	8464.900	93-Jan-03 22:00:45	93-Jan-03 22:02:45	120	100.000	A	1
AK0403	3C433	X	8414.900	95-Jul-27 09:35:45	95-Jul-27 14:27:45	360	100.000	A	1
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Returns:

- ✓ Obs. frequency
- ✓ Configuration
- Exposure time
- Bandwidth
- Number of channels

Choosing your data: sensitivity

$$\sigma \propto 1/(\tau \, \Delta\nu)^{1/2}$$

- Longer observations are better
  - even more true for interferometers
- More bandwidth is good
  - apart from spectroscopy, chromatic aberration, etc.
- Some frequency bands are more sensitive than others
  - depends on the instrument
  - 5 or 8 GHz probably a good bet

The Obs. Status Summary

Table 4: **VLA Sensitivity**

Frequency (GHz)	Band Name: approximate wavelength	Band Name: letter code	System Temperature[1] (K)	Antenna Efficiency[2] (%)	RMS (10 min) Sensitivity (mJy)
0.073 - 0.0745	400 cm	4	1000-10000	15	150[(3)]
0.3 - 0.34	90 cm	P	150-180	40	1.4[(3)]
1.24 - 1.70	20 cm	L	35	55	0.056
4.5 - 5.0	6 cm	C	45	69	0.054
8.1 - 8.8	3.6 cm	X	35	63	0.045
14.6 - 15.3	2 cm	U	120	58	0.19
22.0 - 24.0	1.3 cm	K	50 - 80	40	0.10[(4)]
40.0 - 50.0	0.7 cm	Q	80	35	0.25[(5)]

Frequency (GHz)	RMS Point-Source Sensitivity (12 hours) (mJy)	Untapered Brightness Sensitivity[(6)] (D-config) (mKelvins)	Antenna Primary Beam Size (FWHP) θ_{PB}	Peak/Total Confusing Source in Beam (Jy)	RMS Confusion Level (D-config) (mJy)
0.073 - 0.0745	15[(3)]	300	700′	20/350	lots
0.3 - 0.34	0.17[(3)]	52.0	150′	1.8/15	500
1.24 - 1.70	0.0066	1.9	30′	0.11/0.35	30
4.5 - 5.0	0.0064	1.9	9′	0.002	1
8.1 - 8.8	0.0053	1.5	5.4′	0.001	0.4
14.6 - 15.3	0.020	6.0	3′	0.0001	0.05
22.0 - 24.0	0.025[(4)]	10.0	2′	0.00001	—
40.0 - 50.0	0.030[(5)]	20.0	1′	—	—

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Returns:

- ✓ Obs. frequency
- ✓ Configuration
- ✓ Exposure time
- ✓ Bandwidth
- Number of channels

Choosing your data: ease of reduction

- Continuum is easier than spectral line
  - single-channel data are simplest
- “Center” frequencies are easier than edges
  - 1-15 GHz is easier than <1 GHz or >15 GHz
- VLBI is trickier than VLA/ATCA
- New data are better than old

Finding radio data: checking the (VLA) archive

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22.0 - 24.0	0.025[(4)]	10.0	2′	0.00001	—
40.0 - 50.0	0.030[(5)]	20.0	1′	—	—

Dealing with data: a first look

- The archives send raw uv-data, not images
- Quick & dirty processing: VLARUN, VLBARUN
  (kudos to Loránt Sjouwerman ☺)
  - can get reasonable quick-look images in a few minutes, with no special punditry required
  - failures tend to be obvious
- Rules of thumb:
  - it is easier to destroy than to create!
  - the wackier the image, the easier it is to fix

Dealing with data: a first look

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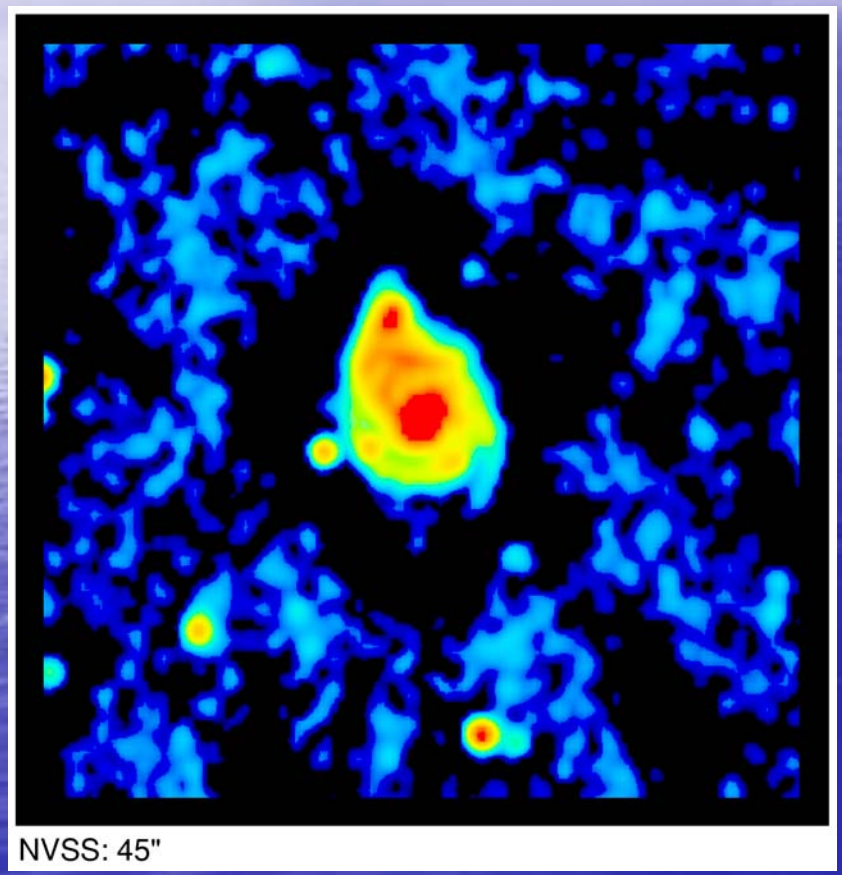
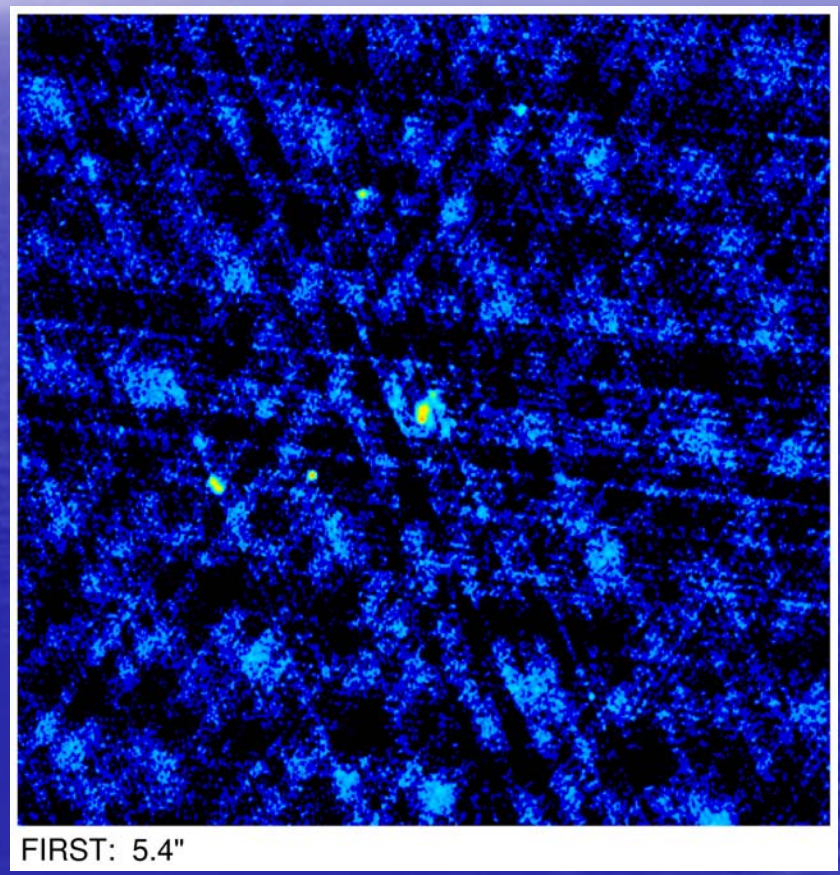
  - can get reasonable quick-look images in a few minutes, with no special punditry required
- Steps:
  - AIPS
  - Load in data (FILLM)
  - Set array configuration; image size; depth of deconvolution
  - VLARUN → calibrated data & images
  - Write them out (FITTP)

M51: Surveys…





NVSS: 45” res’n

FIRST: 5.4” res’n

Finding radio data: checking the (VLA) archive

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Obs. Frequency

- 1.4 GHz for size

Configuration

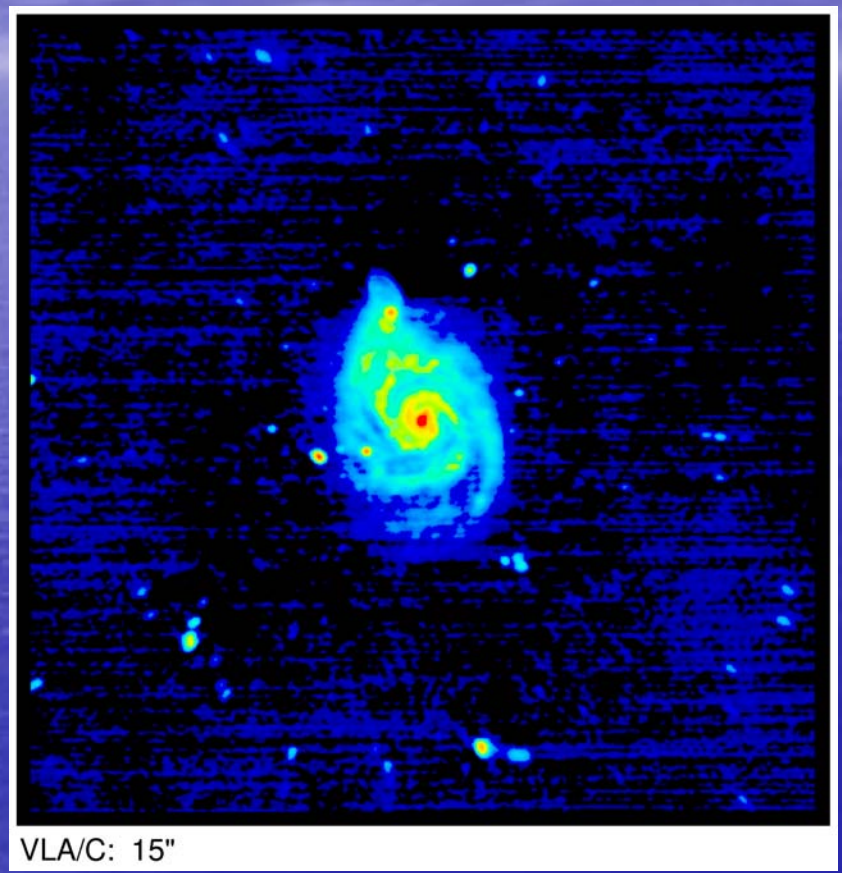
- C for res'n (15") + large structure

Exposure time

- Longest available

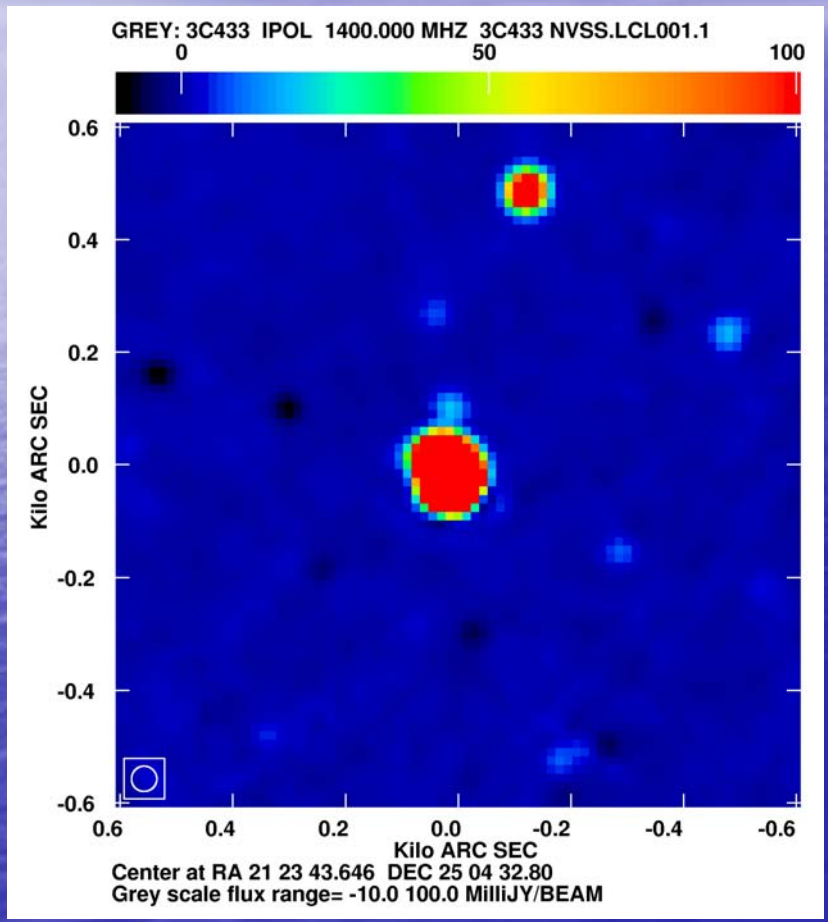
Continuum

...and the archive



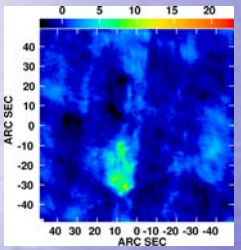
VLA/C @ 20cm:
15” res’n

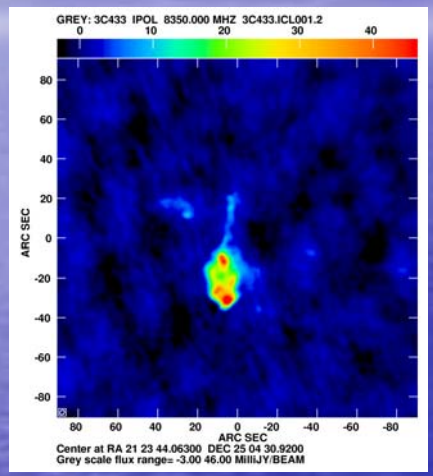
3C433: NVSS...

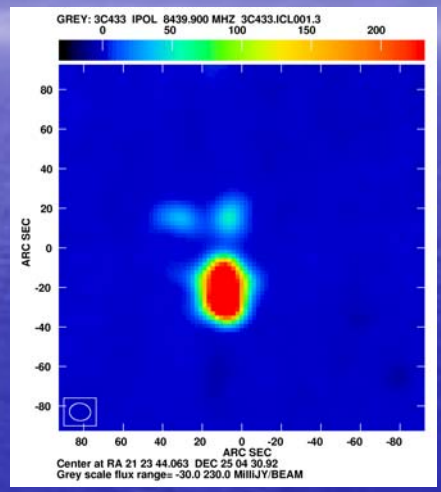


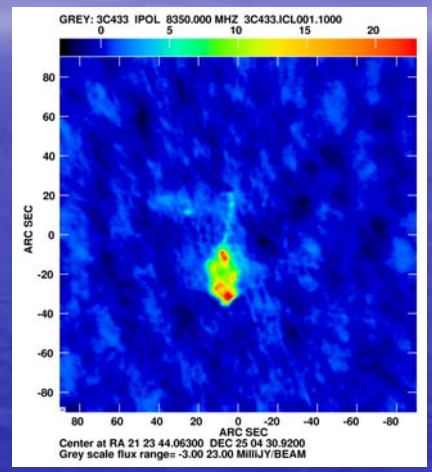
D @ 20cm:
45” res’n

...and the archive:









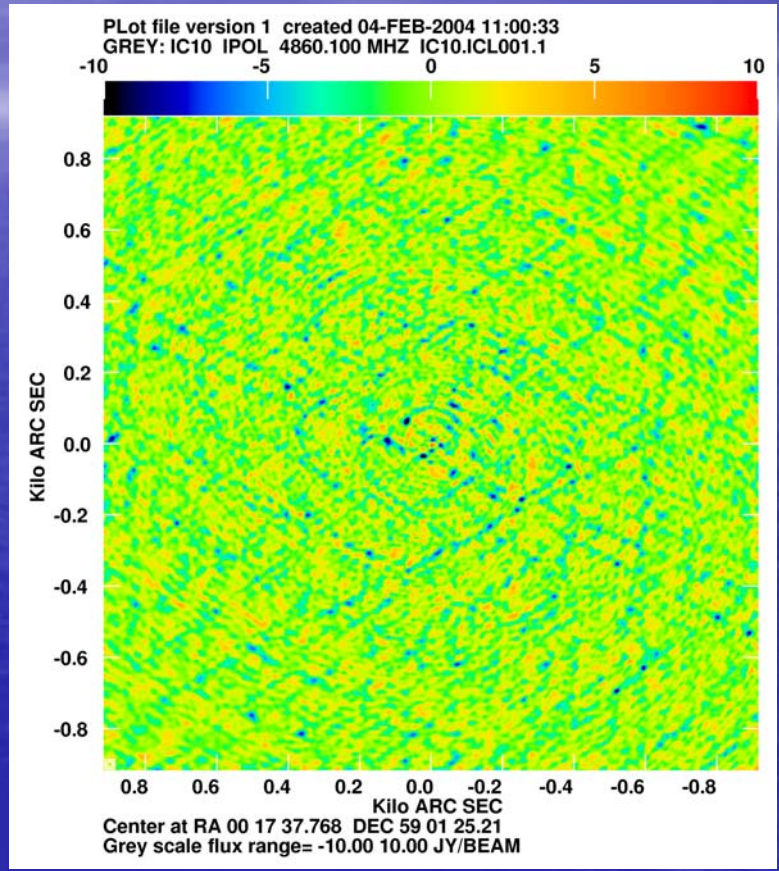
B **C** **D** **B+C+D**

VLA/B+C+D @ 4cm → 1.5” res’n

Elapsed time: ~1 hour

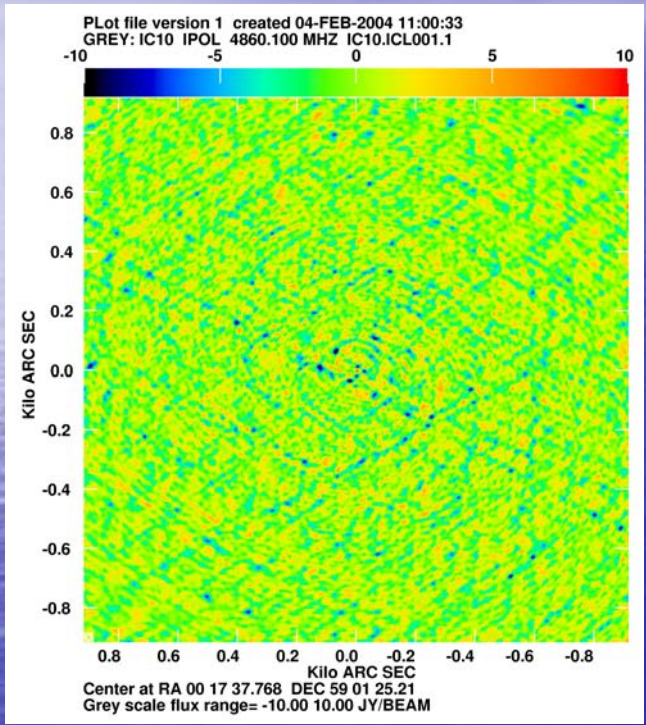
Dealing with data: a first look

- Failures tend to be obvious:
  - it is easier to destroy than to create!
  - the wackier the image, the easier it is to fix



IC10

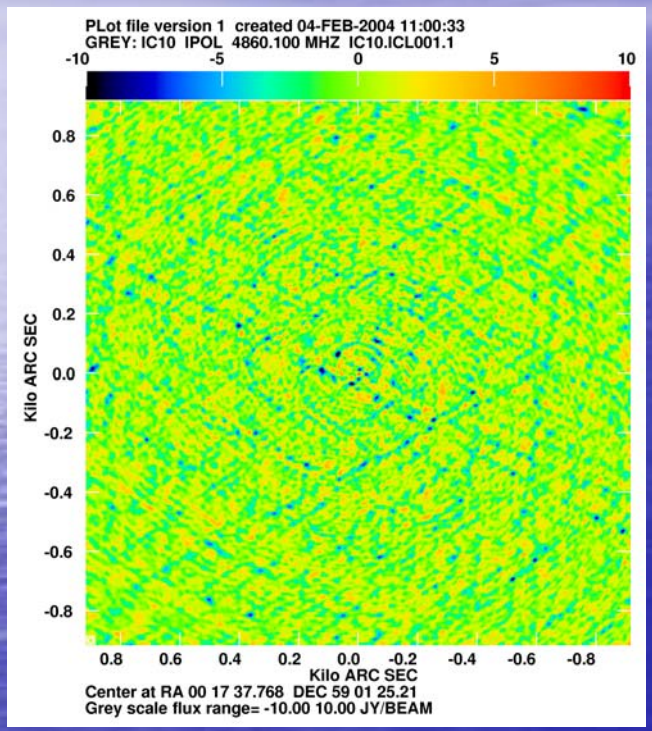
IC10

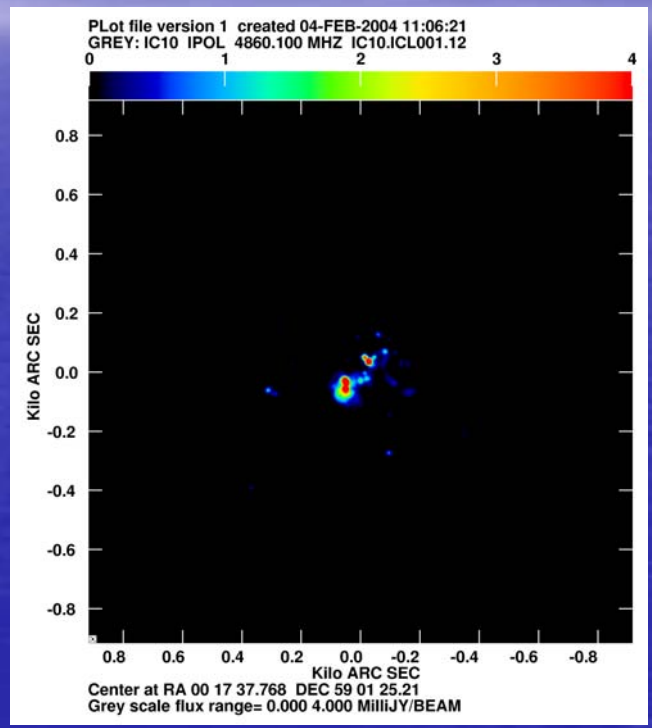


Note the flux density scale!

Flag two 10-second records...

IC10





Flag two 10-second records...

...et voilá!

Dealing with data: the next steps

- Lots of documentation
  - Observational Status Summary (VLA/VLBA)
  - Synthesis Imaging Schools & books
  - AIPS Cookbook
- We're here to help!
  - E-mail: analysts@nrao.edu
  - Auto-analysis of VLBI data
  - Short- or long-term visits to NRAO, with hands-on help at any level
- Travel & page charge support for some archival work

The future

- Actively working on improving the archive
  - already producing lots of good stuff: e.g., half the posters here!
- e2e is required for ALMA and the EVLA
- Lots of new radio telescopes coming this decade: SMA, EVLA, ALMA, eMERLIN, ...

  → a good time to learn!