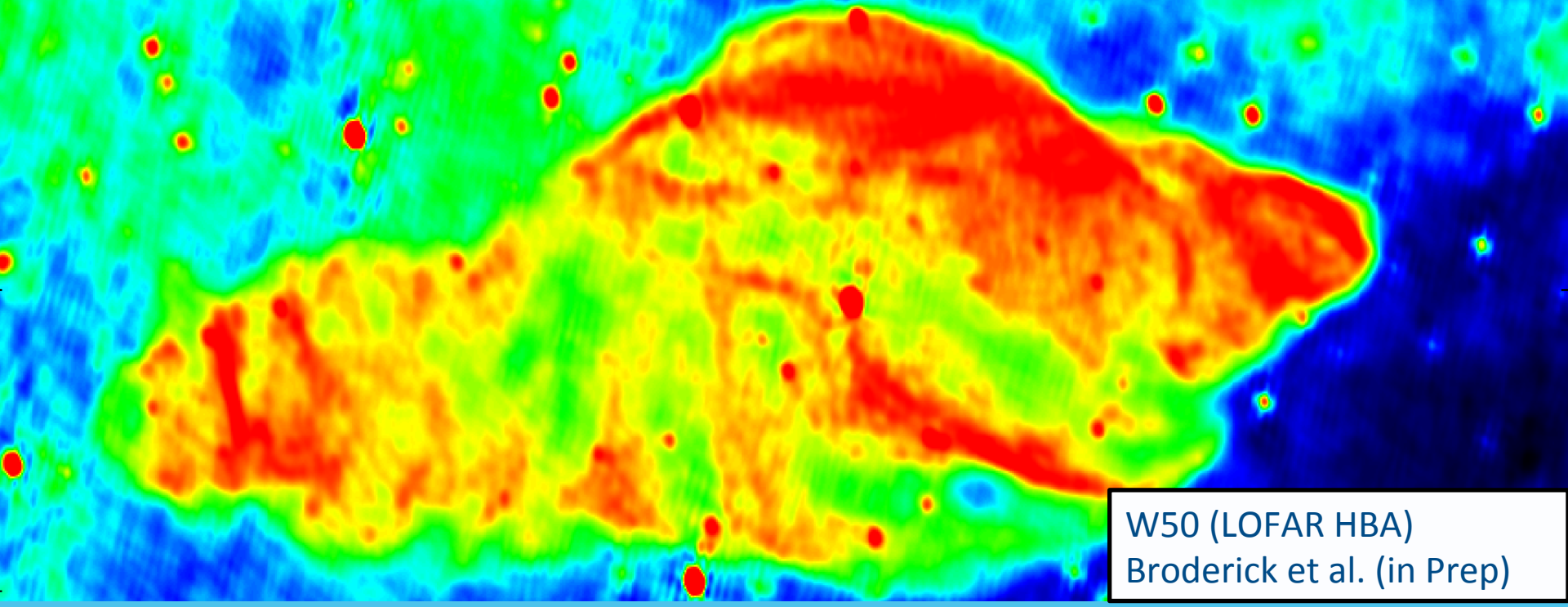


W50 (LOFAR HBA)
Broderick et al. (in Prep)

Image Analysis

Antonia Rowlinson

2 October 2014

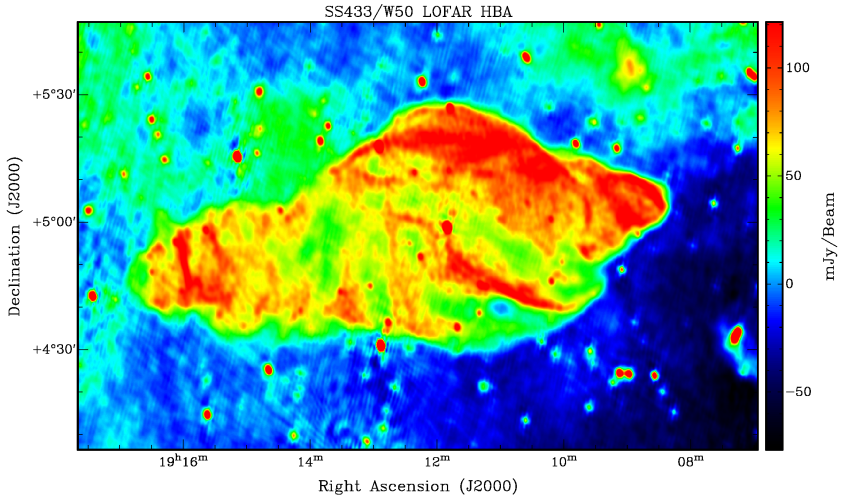
CSIRO ASTRONOMY AND SPACE SCIENCE
www.csiro.au

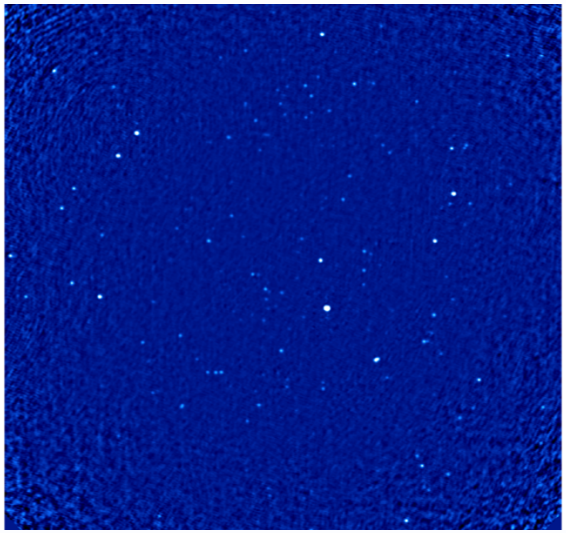
Overview:

1. Imaging strategies
2. Quality control
3. Source finders

Images fit for purpose:

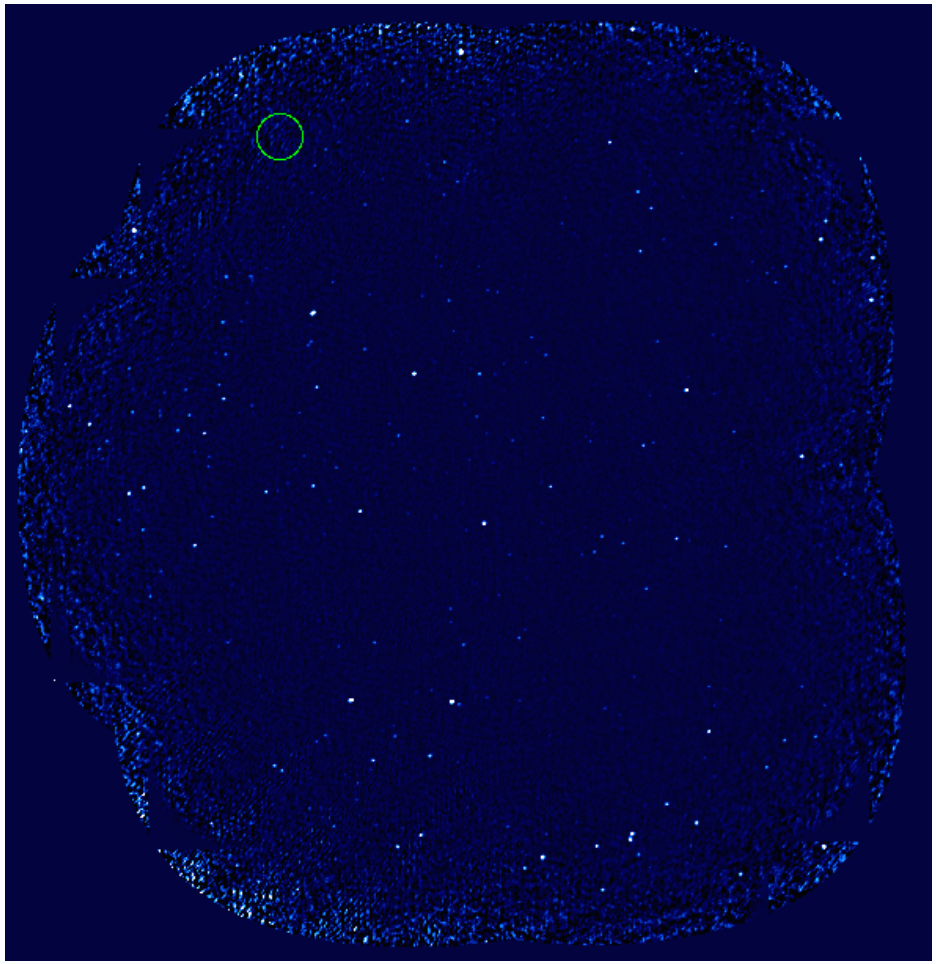
- First make sure your observations meet your requirements
  - UV coverage
  - Integration time
  - Field of view
  - Expected sensitivity
  - Frequency
  - Bandwidth
  - …
- Before making and analysing your images, make sure your images will be able to do what you want!
- Different imaging strategies for mapping extended emission versus point source surveys





LOFAR dataset – Radio Sky Monitor:

- Zenith monitoring survey
- ~5100 images
- 4 observing frequencies (124, 156, 164 and 185 MHz)
- 180 different fields (6 beams and 30 pointing directions)
- Fields observed 7 times separated by ~1 month
- 0.1 – 6 km baselines
- ~3 degree image radius



Need reasonable quality images with good positions and fluxes

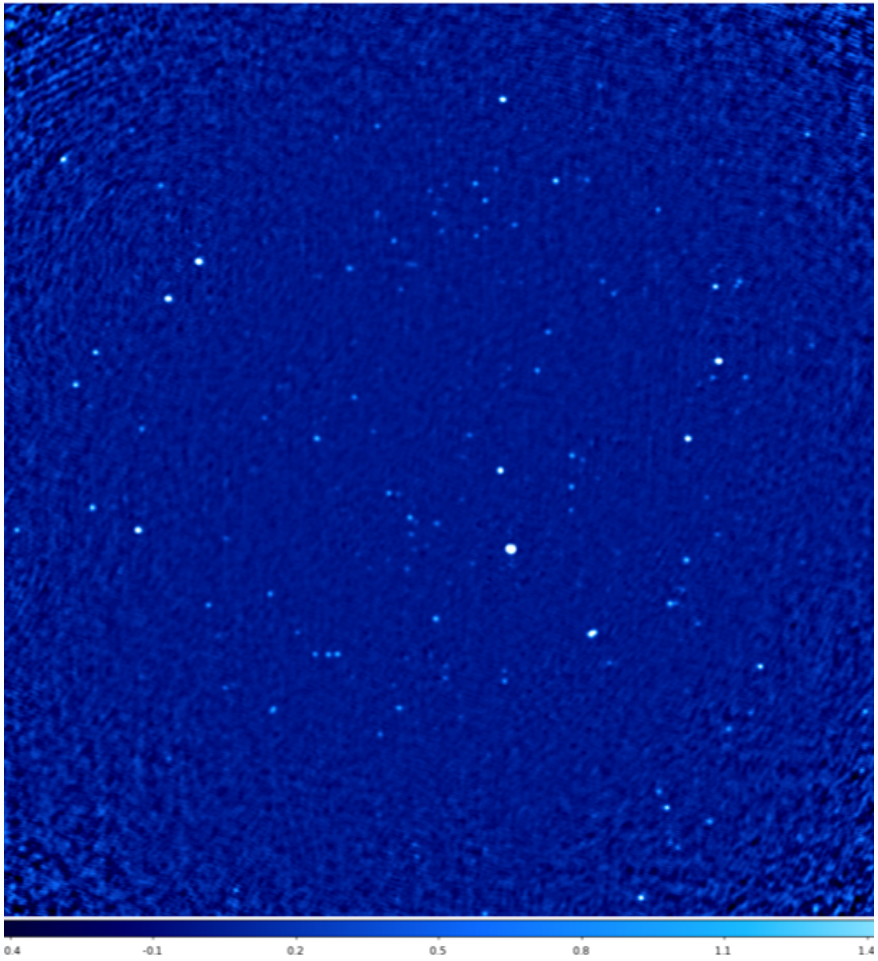
Quality Control:

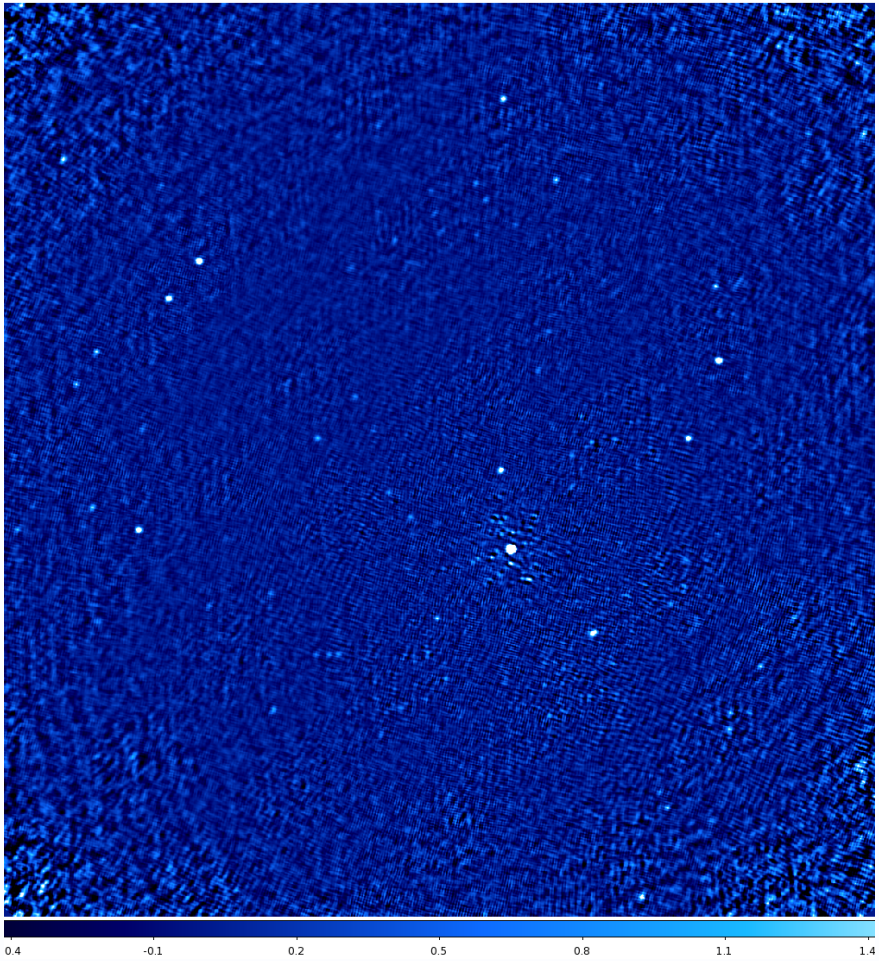
Before pulling out your science results and submitting that Nature/ Science paper - do you trust your data?

How can you test the quality of your image?

How do you deal with bad images?

LOFAR images – same field, different day…

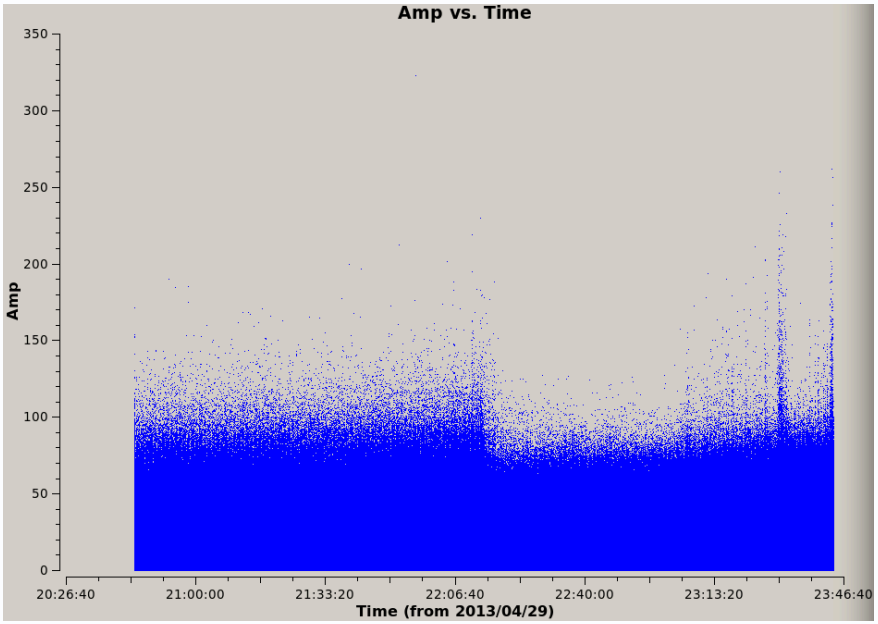




UV data first!

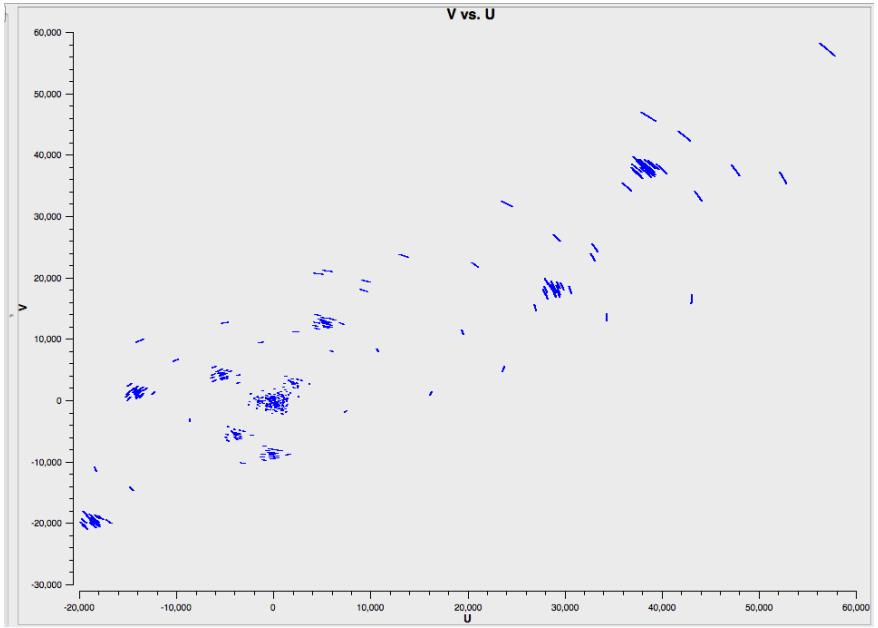
- Good initial quality control step
- Choose UV coverage to suit needs:
- Long baselines - narrow field of view and high spatial resolution
- Short baselines - wide field of view and extended emission clearer

For example: Transient searches - want field of view but not extended emission and good UV coverage in short snapshots

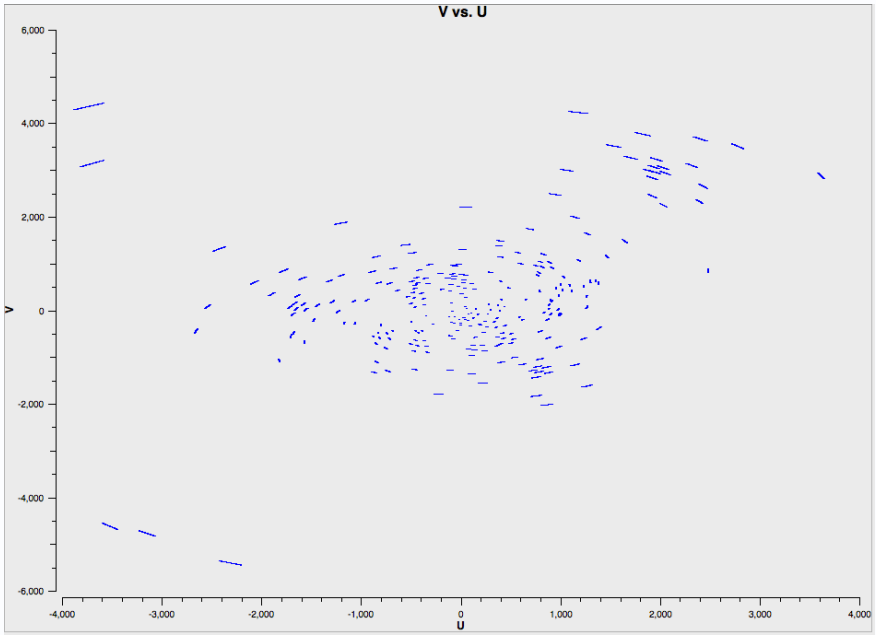


UV coverage in 11 min LOFAR snapshot

All baselines:



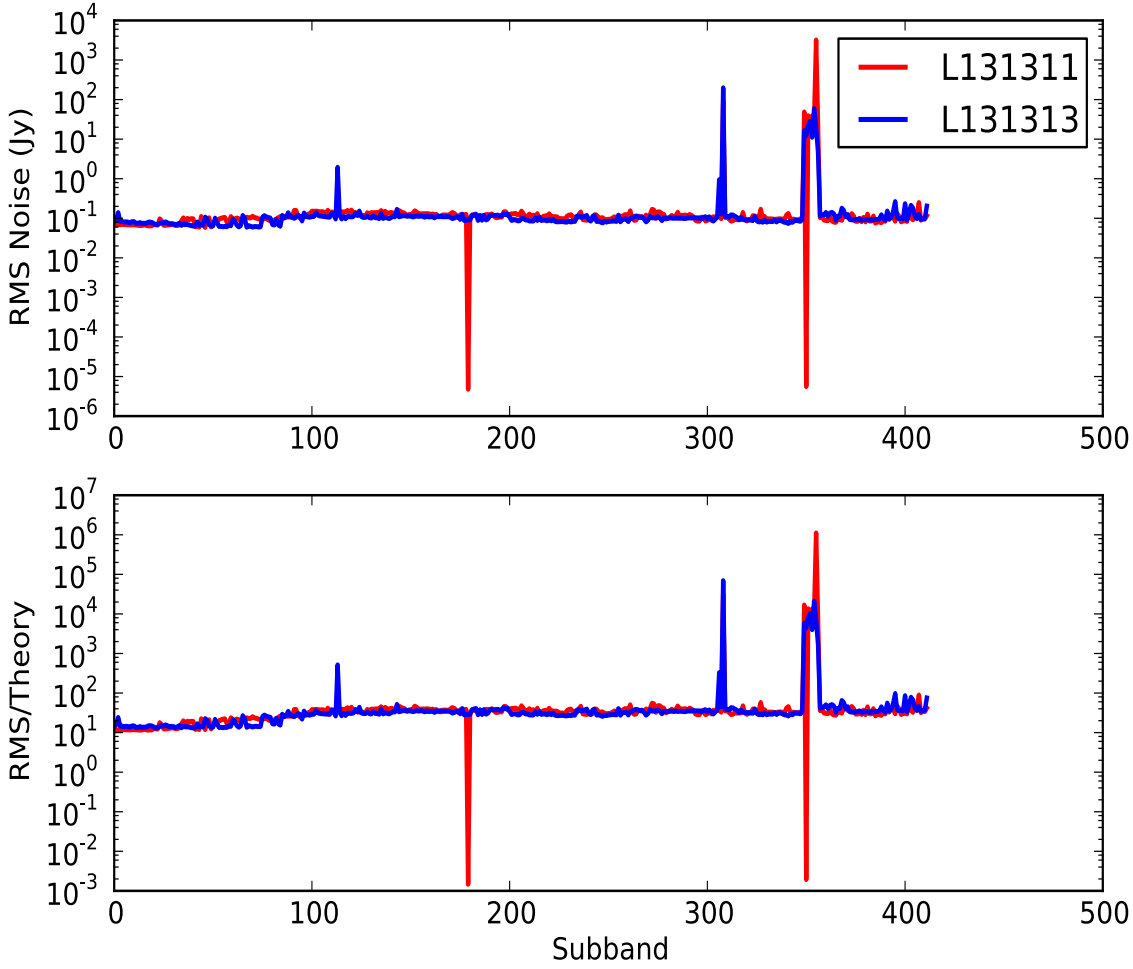
<6 km baselines:



Look at your calibrators!

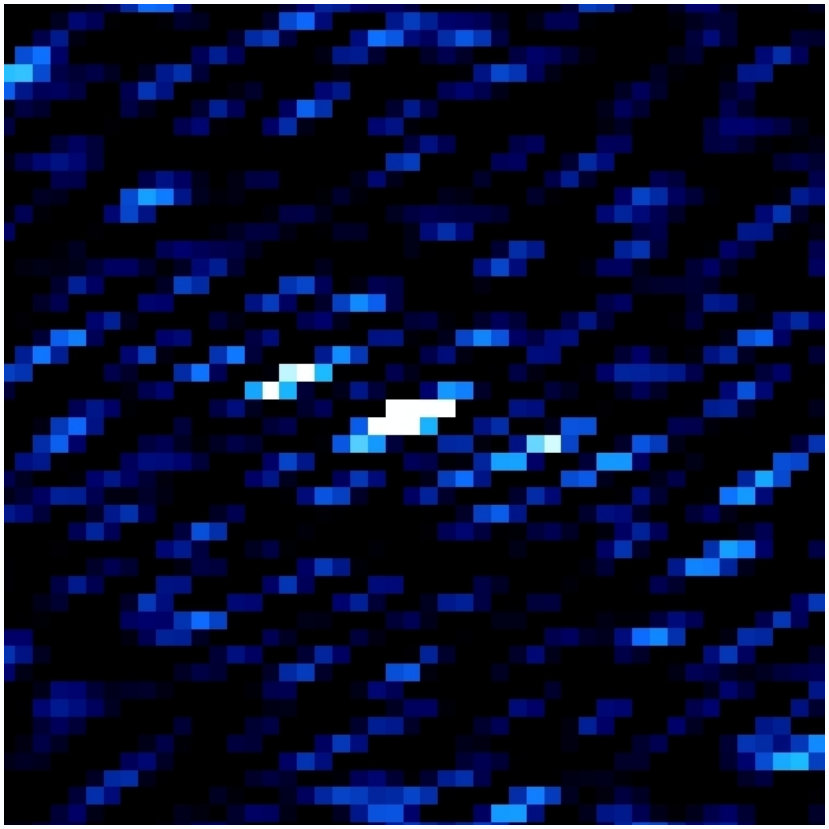
- UV data
- Try imaging
- Flux stability
- Position offset
- RMS noise
- …

Bad calibrator → Bad image!



Choose your imaging parameters carefully!

Poorly sampled restoring beam



Well sampled restoring beam

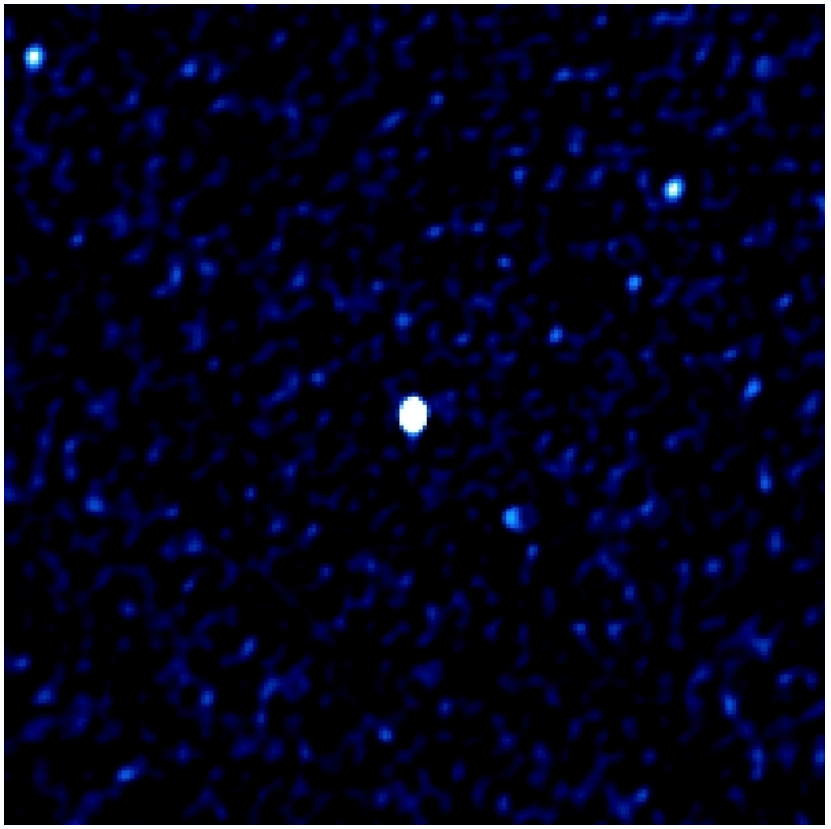
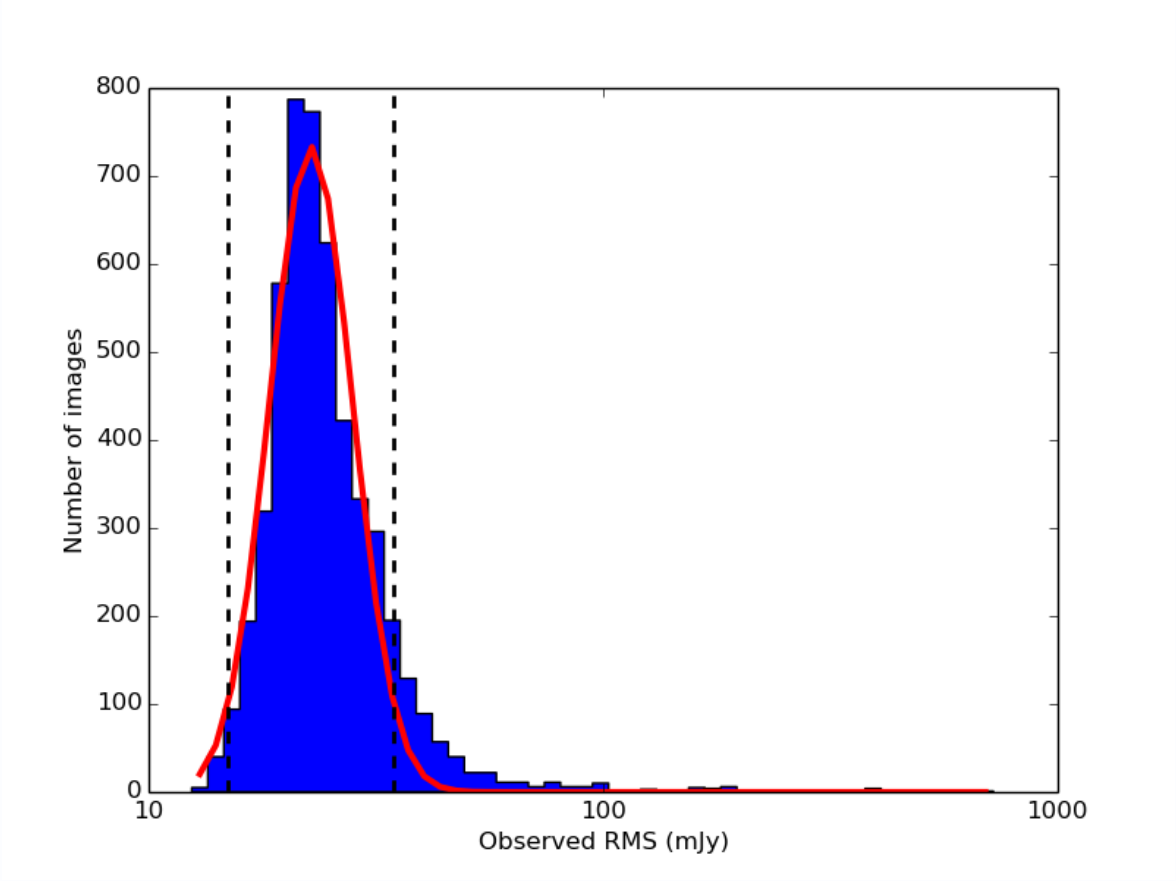


Image RMS noise

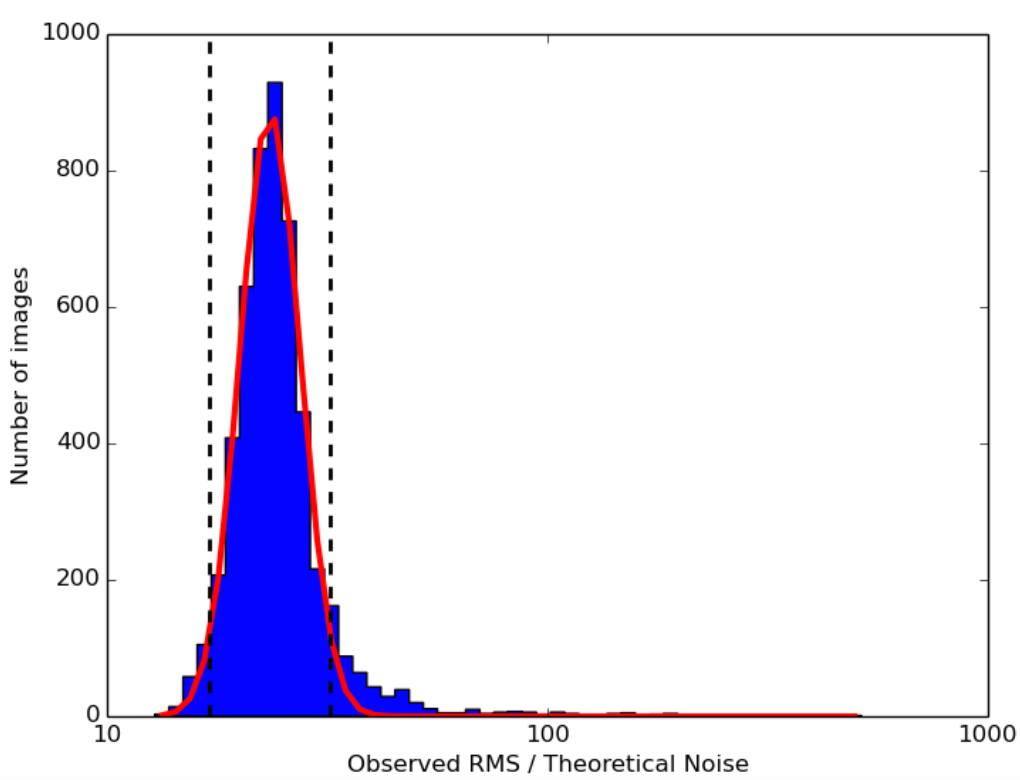
- Can give clear indication that an image is good or bad
- RFI and calibration issues can raise RMS
- Poor calibration can also lower RMS
- Look for outliers when using multiple images using identical settings (e.g. surveys and transient searches)



Theoretical Noise

- Better test is a comparison to the theoretical noise – the best noise you can achieve in the image
- Calculated using:
  - system flux (S_{sys}, related to the system temperature T_{sys})
  - Number of antennas (N)
  - Bandwidth (δv)
  - Integration time (δt)

$$\Delta S = \frac{S_{sys}}{\sqrt{N(N-1)2\delta\nu\delta t}}$$

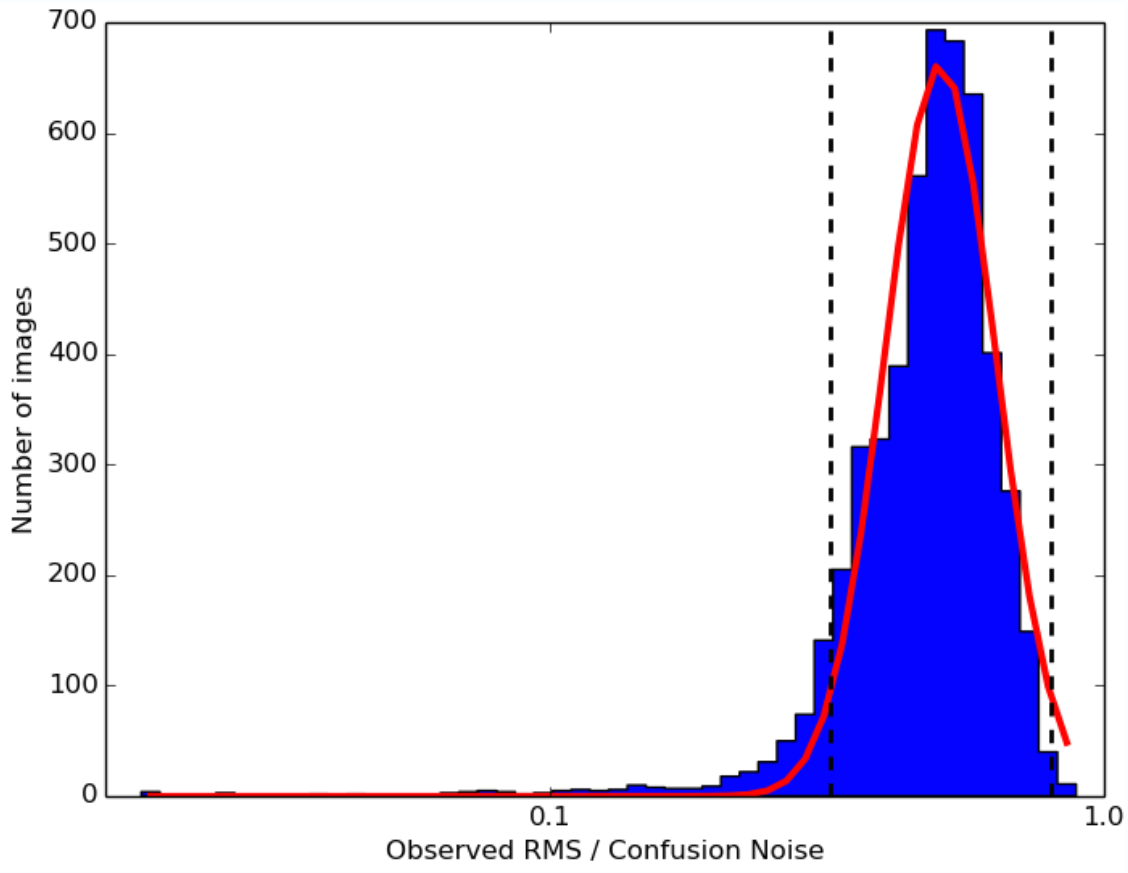


Confusion Noise

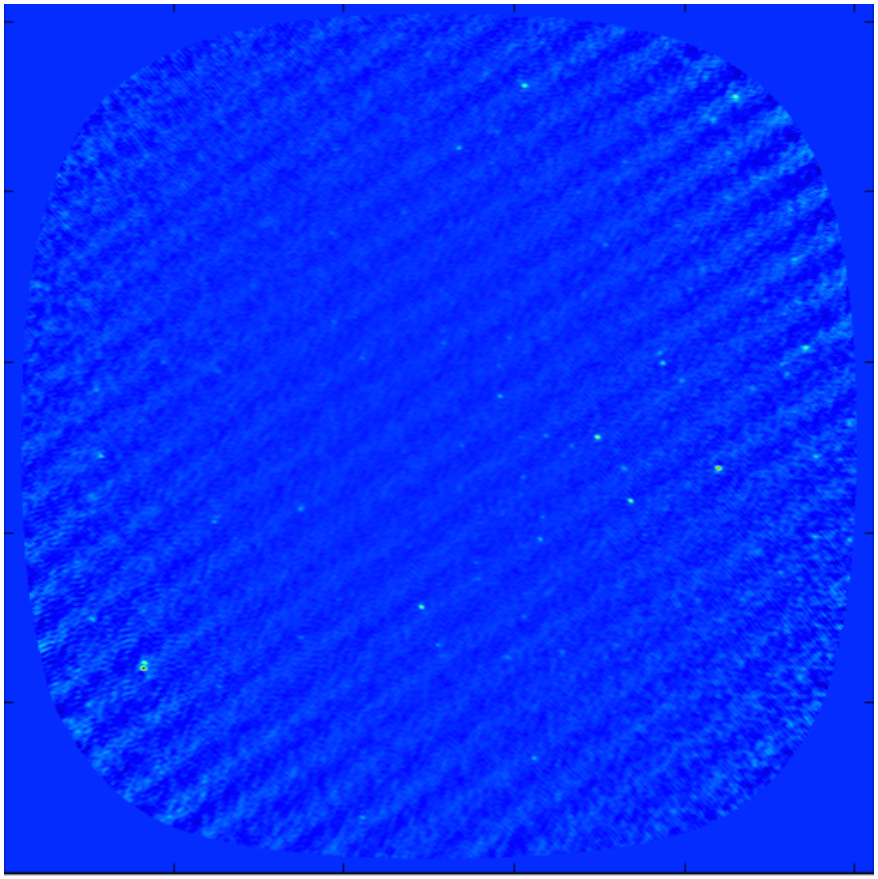
- Images become saturated with sources, individual sources cannot be resolved
- Confusion becomes a problem when source densities are more than 1/50-1/15 (Hogg 2001)
- Classical confusion limit:

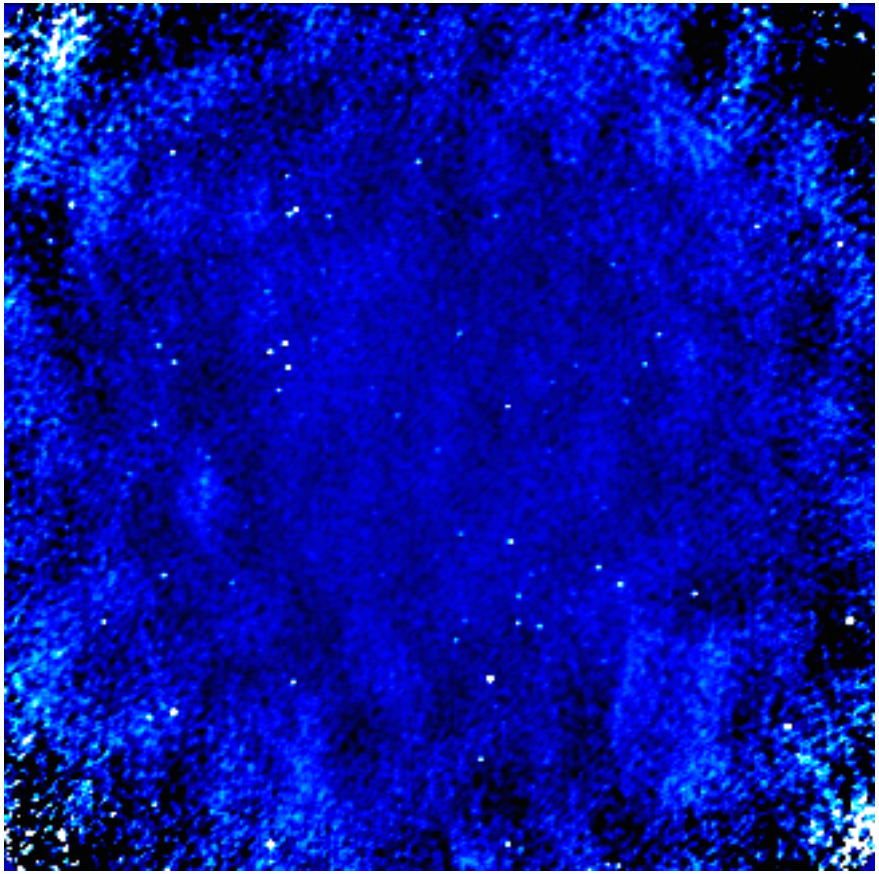
$$\langle N \rangle \frac{\pi \left(\theta_{\rm res}/2\right)^2}{\rm FoV} > \frac{1}{30}$$

- Where N is the predicted source count, θ_{res} is the angular resolution and FoV is the field of view



Structures in the noise:





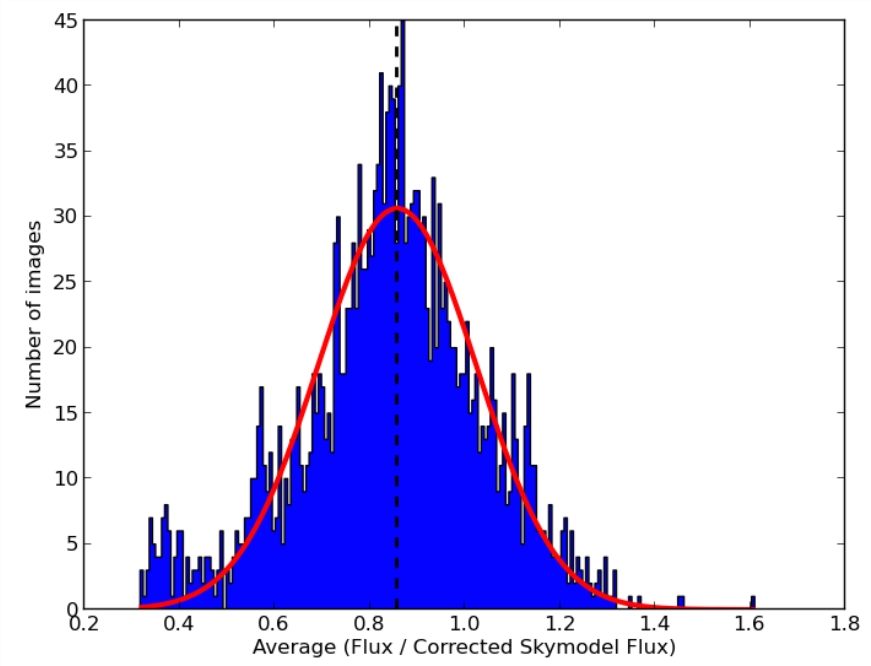
Flux scale in images:

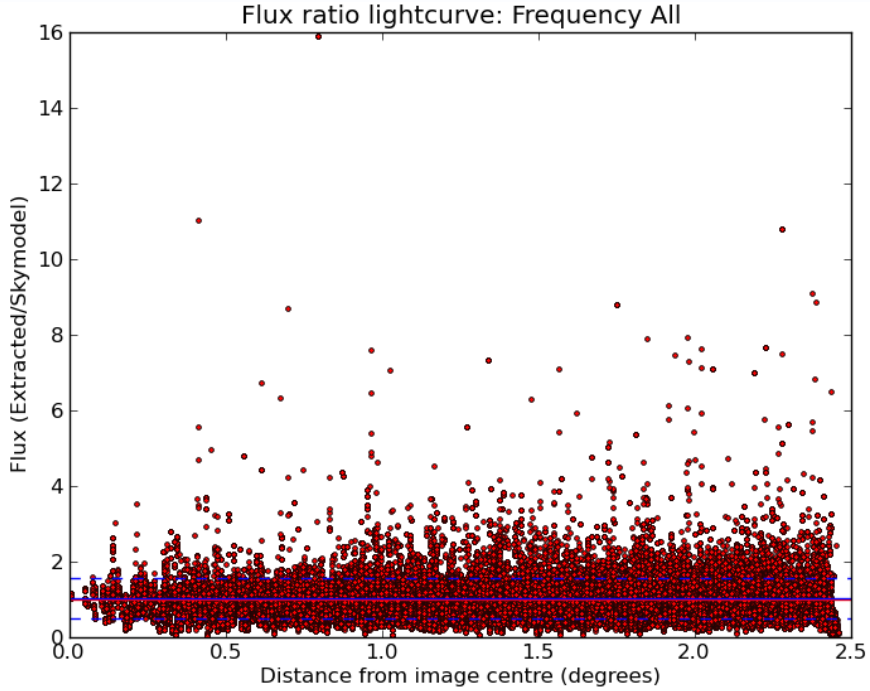
- Poor calibration is not always obvious
- Bad images can still look good with a low RMS
- Before trusting your fluxes check other sources in the field!

Vital for transients/variability searches and surveys

Important for any flux measurements

Compare the flux of your sources to the expected values or average values

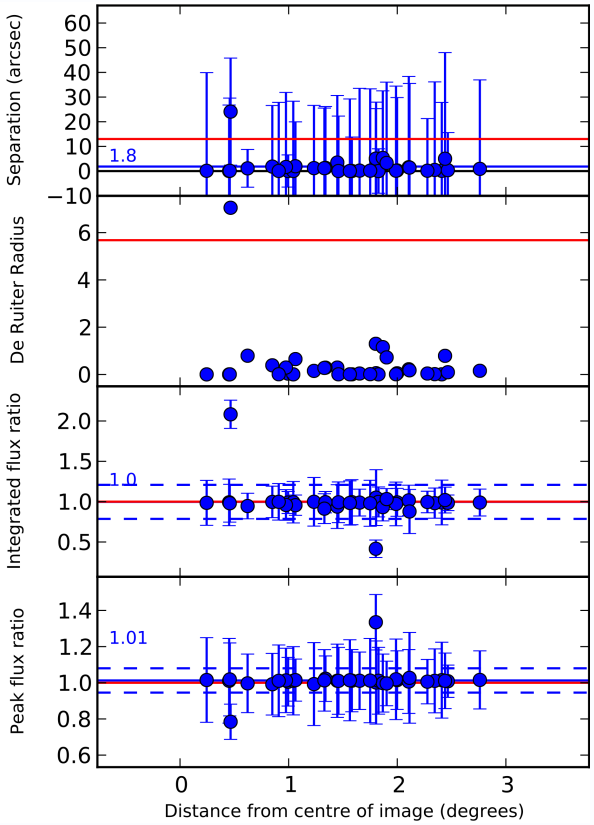




Failing to correct for the Primary Beam

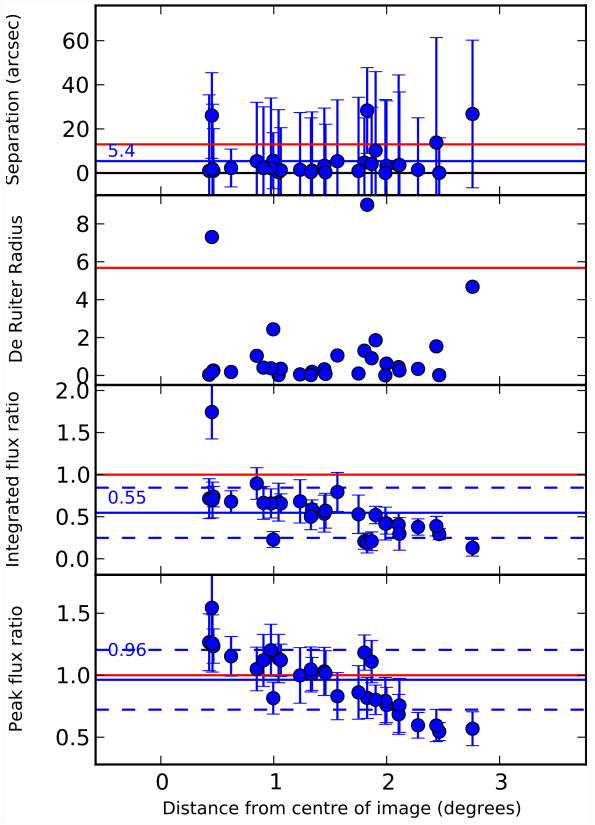
AWImager

(special for LOFAR)



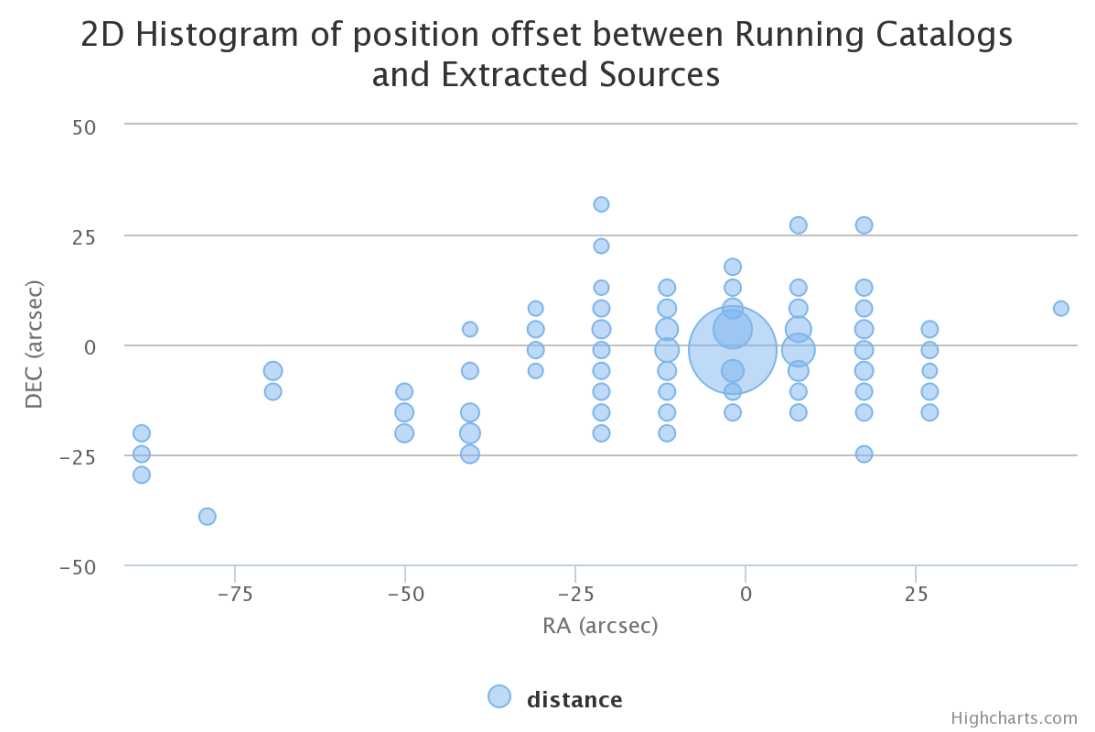
CASA

(no primary beam model for LOFAR)



Position offsets

- Important for source association across frequencies and observations
- Offsets can be caused by:
  - Poor calibration
  - RFI
  - Ionospheric effects
  - Source finder errors
  - …
- Understand cause and correct for it!

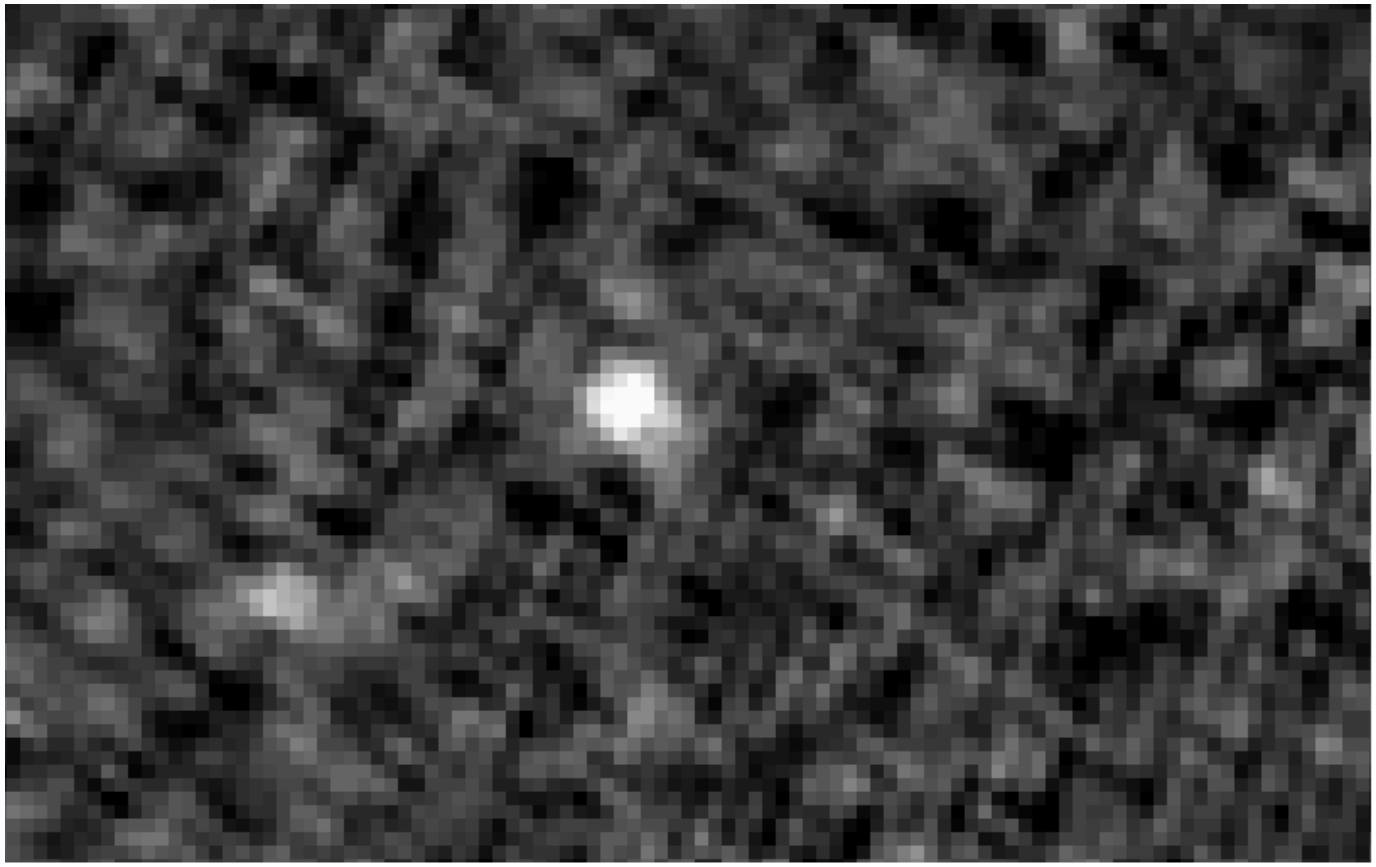


Principles of source finding

Basic source finding:

- Measure the RMS of different regions
- Find islands above the detection threshold
- Find all pixels around the islands that are above the analysis
- Fit a Gaussian to the pixels
- Source parameters are taken from the Gaussian fit

Great for point sources, not so good for extended emission…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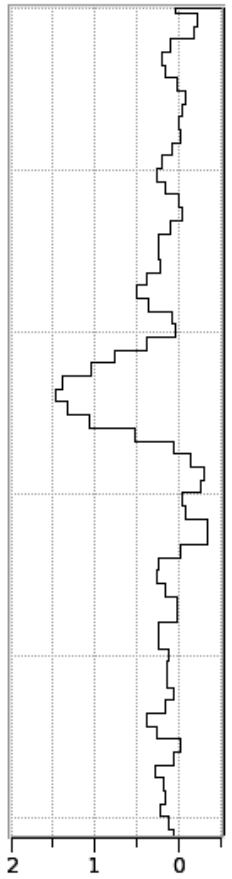
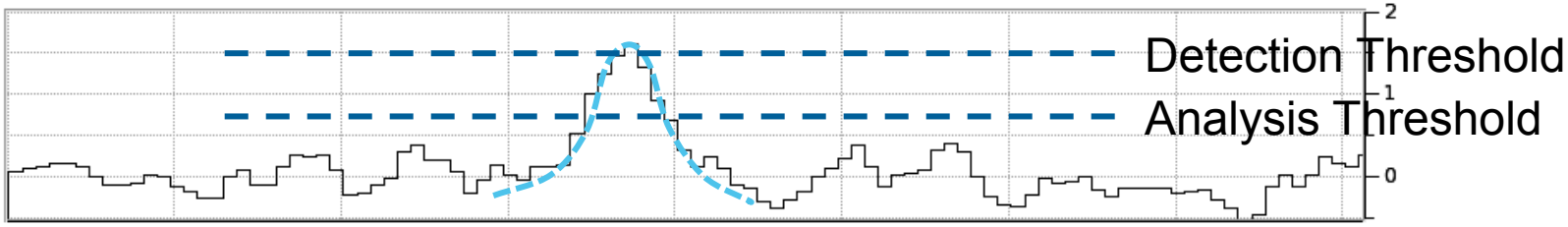
0.25
0.5
0.75
1
1.2
1.5
1.8

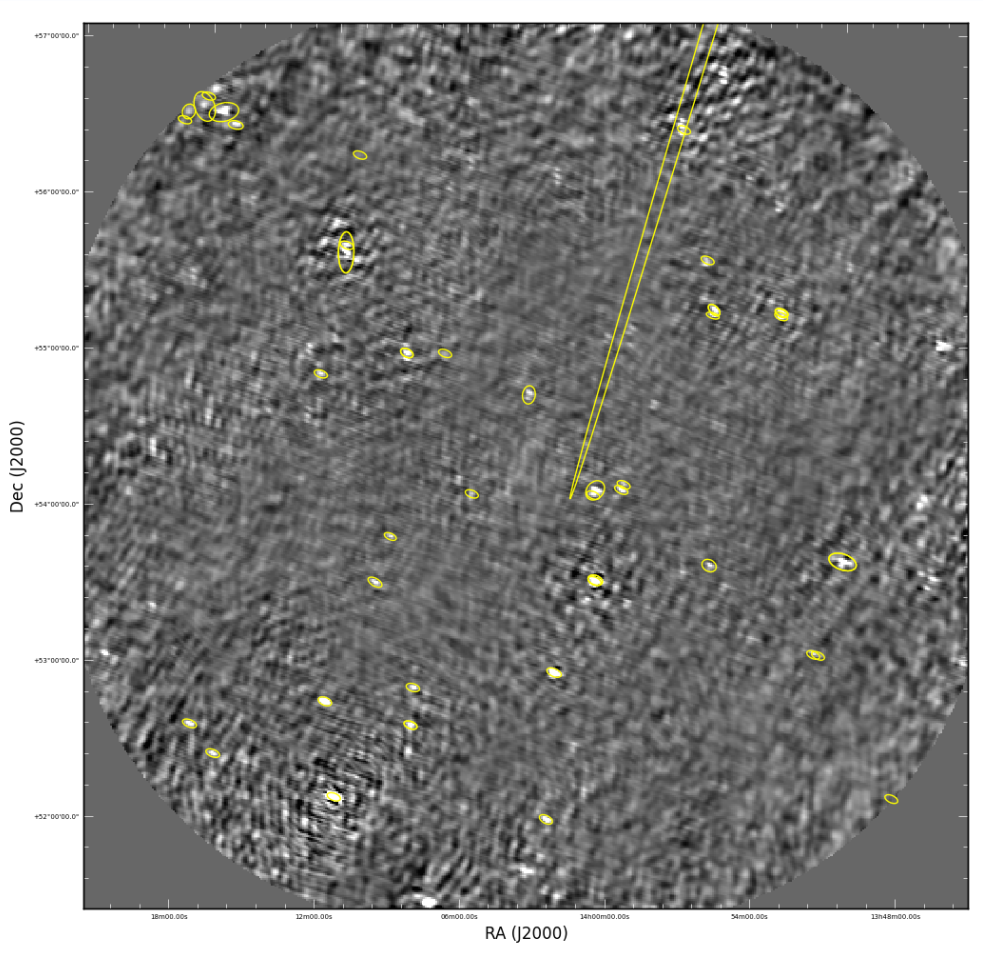

2
1
0

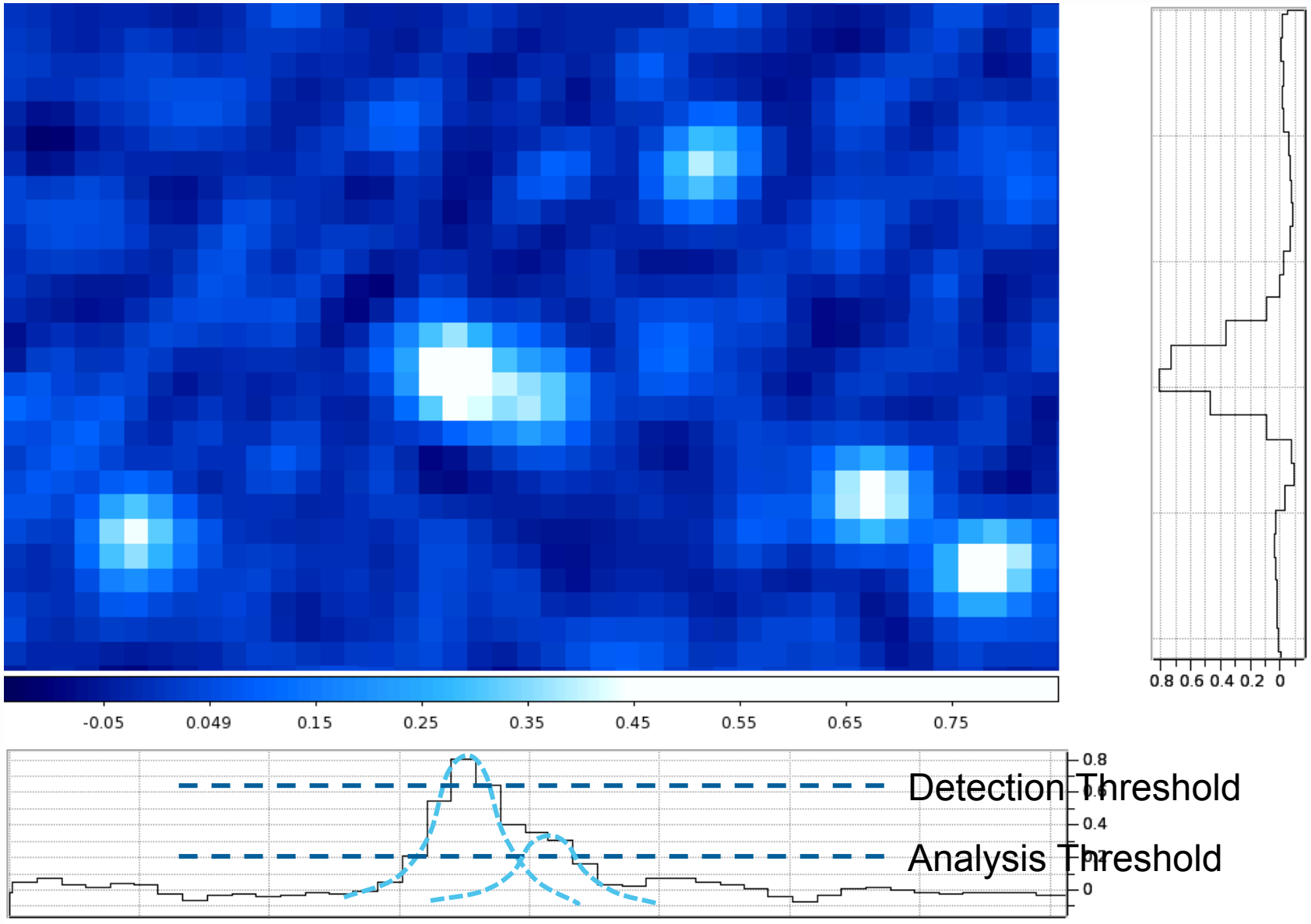

Detection Threshold
Analysis Threshold
2
1
0

Source finder issues

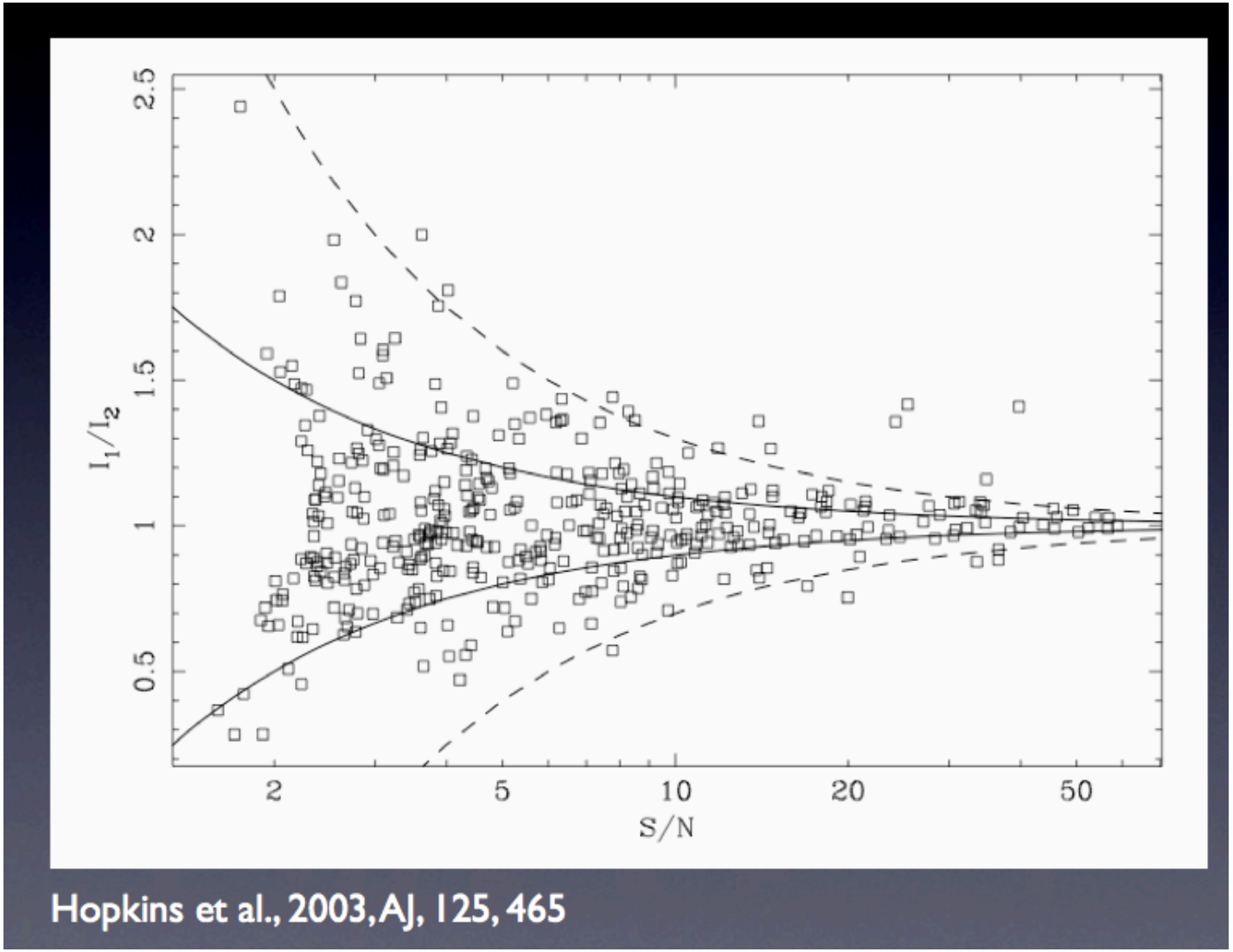
- Background estimation
- Completeness
- Threshold definitions
  - Fixed signal to noise
  - False detection rate
- Gaussian fits, moments analysis, wavelets, isophotal contours, etc…
- Complex or extended sources can be problematic!
- Deblending

Choose your source finder to match your needs!




-0.05
0.049
0.15
0.25
0.35
0.45
0.55
0.65
0.75
0.8 0.6 0.4 0.2 0
0.8
0.4
0
Detection Threshold
Analysis Threshold

Source finders – Flux Accuracy



Hopkins et al., 2003, AJ, 125, 465

Source finders and Transients

- Simple Gaussian fits of sources close to the detection thresholds are very sensitive to the RMS noise
- In each image the Gaussian has a slightly different shape or position angle → slight flux changes → false identification as a variable source ☹

- Transients/variables are point sources
- Should take shape of restoring beam
- Force fit the Gaussian to take shape of the beam → much better flux stability ☺

Source finders

- Miriad: imsad, sfind, imfit
- CASA: findsources, fitsky
- SExtractor – used a lot in optical astronomy

- Duchamp/Selavy – (ASKAP)
- Aegean – (ASKAP)
- PySE – specifically designed for point sources and to be fast (LOFAR transients)
- PyBDSM – (LOFAR)

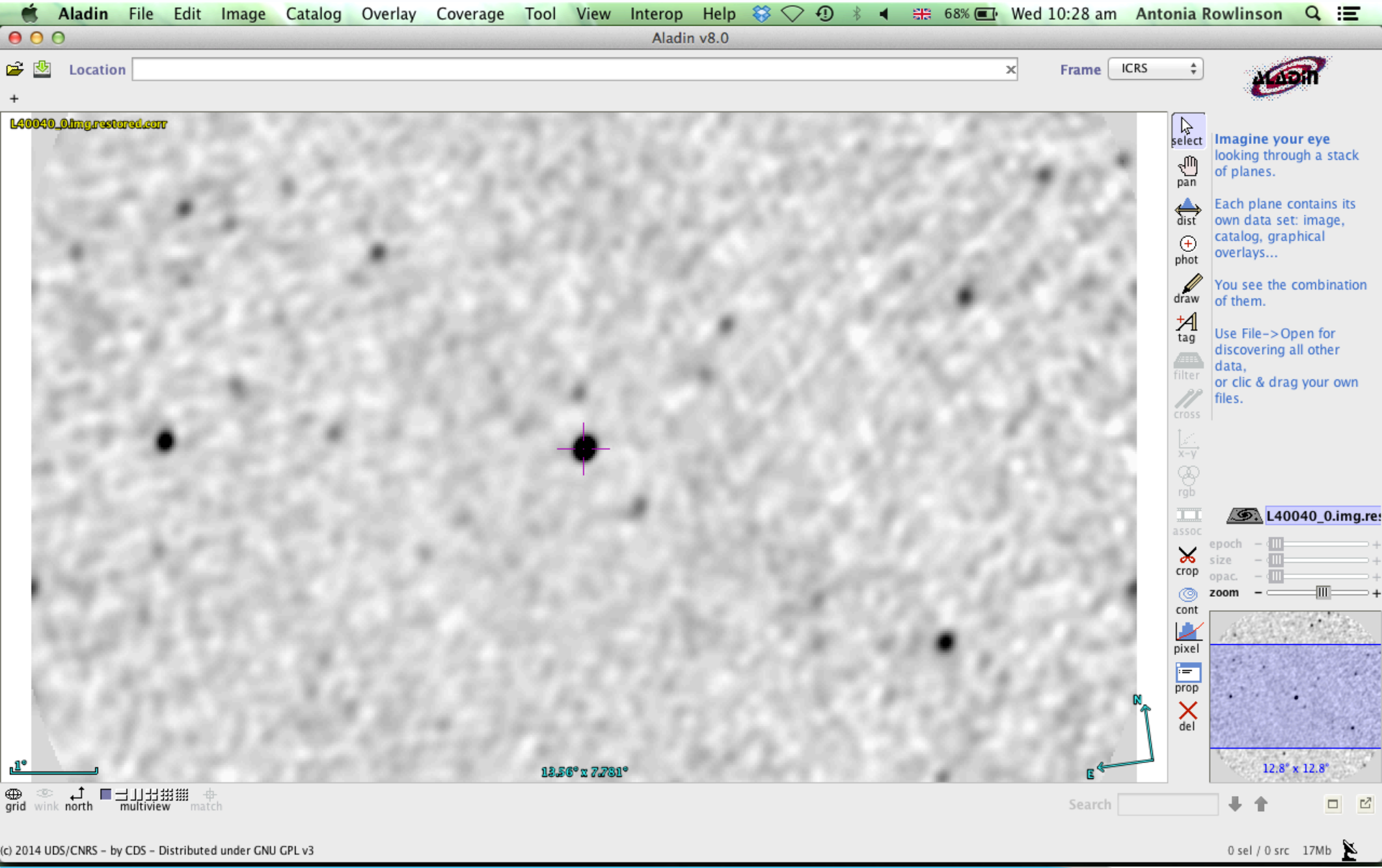
Source finders

- Miriad: imsad, sfind, imfit
- CASA: findsources, fitsky
- SExtractor – http://adsabs.harvard.edu/abs/1996A%26AS..117..393B http://sourceforge.net/projects/sextractor/
- Duchamp/Selavy – http://adsabs.harvard.edu/abs/2012MNRAS.421.3242W http://www.atnf.csiro.au/people/Matthew.Whiting/Duchamp/
- Aegean – http://adsabs.harvard.edu/abs/2012ascl.soft12009H https://github.com/PaulHancock/Aegean
- PySE – http://docs.transientskp.org/tkp/cycle0/tools/pyse.html (coming soon)
- PyBDSM – ftp://ftp.strw.leidenuniv.nl/pub/tasse/lofar_imaging_cookbook_v11.pdf (see section in LOFAR imaging cookbook)

Source Finder Challenge:
http://www.atnf.csiro.au/research/workshops/2013/astroinformatics/talks/EMU_ASKAP_datachallenge_AMH.pdf

Other useful tools

- Aladin and TopCat provide interactive link to Vizier, other catalogues and image servers
- Great for looking for source associations and multi-frequency information
- Downloads and tutorial here:
  - Aladin: http://aladin.u-strasbg.fr
  - TopCat: http://www.star.bris.ac.uk/~mbt/topcat/


Aladin File Edit Image Catalog Overlay Coverage Tool View Interop Help 68% Wed 10:28 am Antonia Rowlinson
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Imagine your eye looking through a stack of planes.
Each plane contains its own data set: image, catalog, graphical overlays...
You see the combination of them.
Use File->Open for discovering all other data,
or clic & drag your own files.
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multiview
match
Search
(c) 2014 UDS/CNRS - by CDS - Distributed under GNU GPL v3
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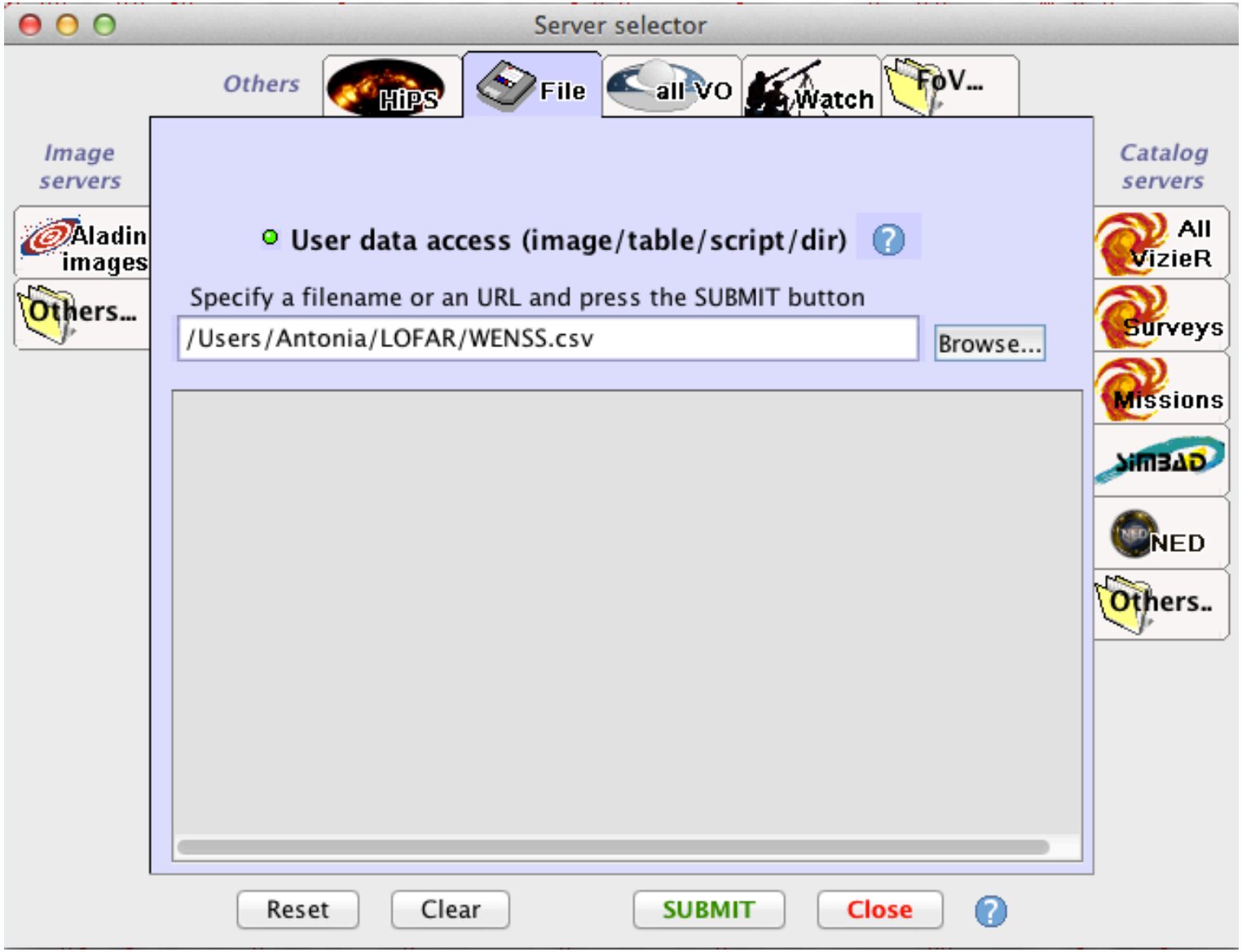
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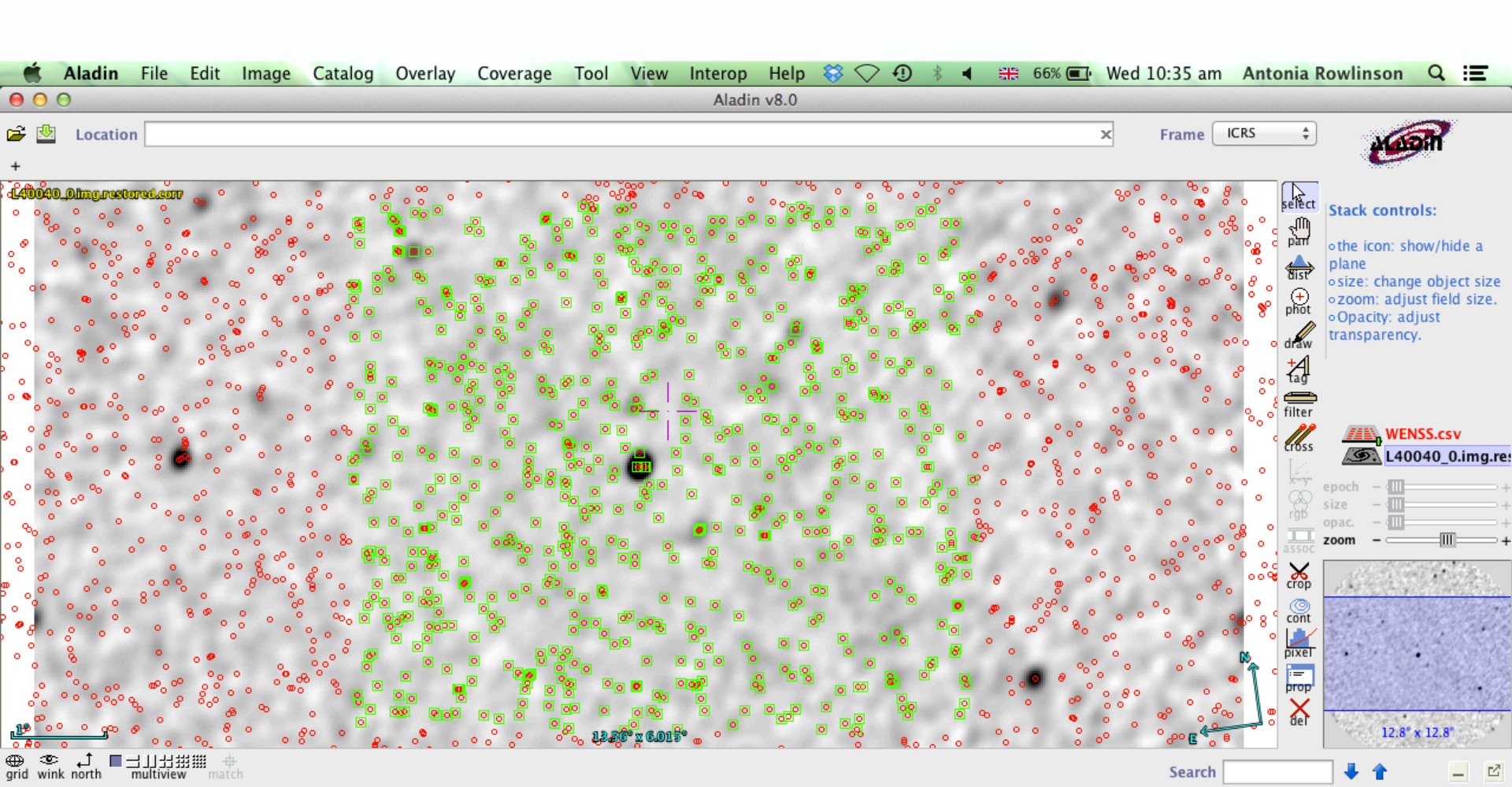
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Opacity: adjust transparency.
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Search
recno Name f_Name RAJ2000 DEJ2000 flg1 flg2 Speak Sint MajAxis MinAxis PA
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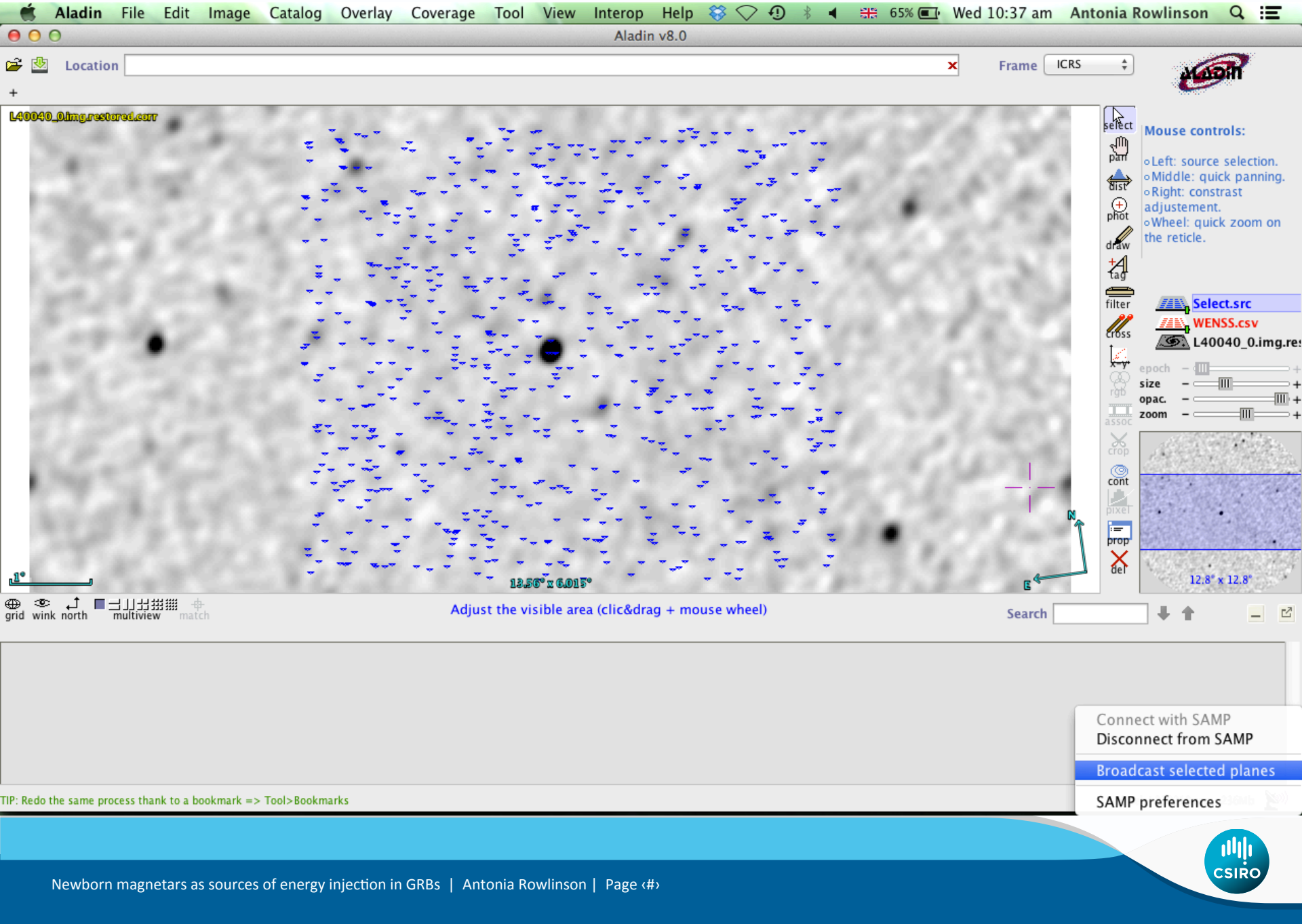
132320 B1430.3+... 14 31 56... +54 37 3... S 31 33 0 0 0
132325 B1430.3+... 14 31 57... +54 40 5... M 82 97 94 44 121
132326 B1430.3+... 14 31 55... +54 41 1... C 82 70 0 0 0
132327 B1430.3+... 14 32 05... +54 40 0... C 23 25 0 0 0
132332 B1430.3+... 14 32 00... +54 00 5... M 46 70 95 57 33
132333 B1430.3+... 14 31 54... +53 59 5... C 17 19 0 0 0
132334 B1430.3+... 14 32 01... +54 01 0... C 46 50 0 0 0
Click for sorting, click&drag on a border for resizing
TIP: Modify the default coordinate frame => Edit>Preferences
799 sel / 229420 src 231Mb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Middle: quick panning.
Right: constrast adjustement.
Wheel: quick zoom on the reticle.
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size
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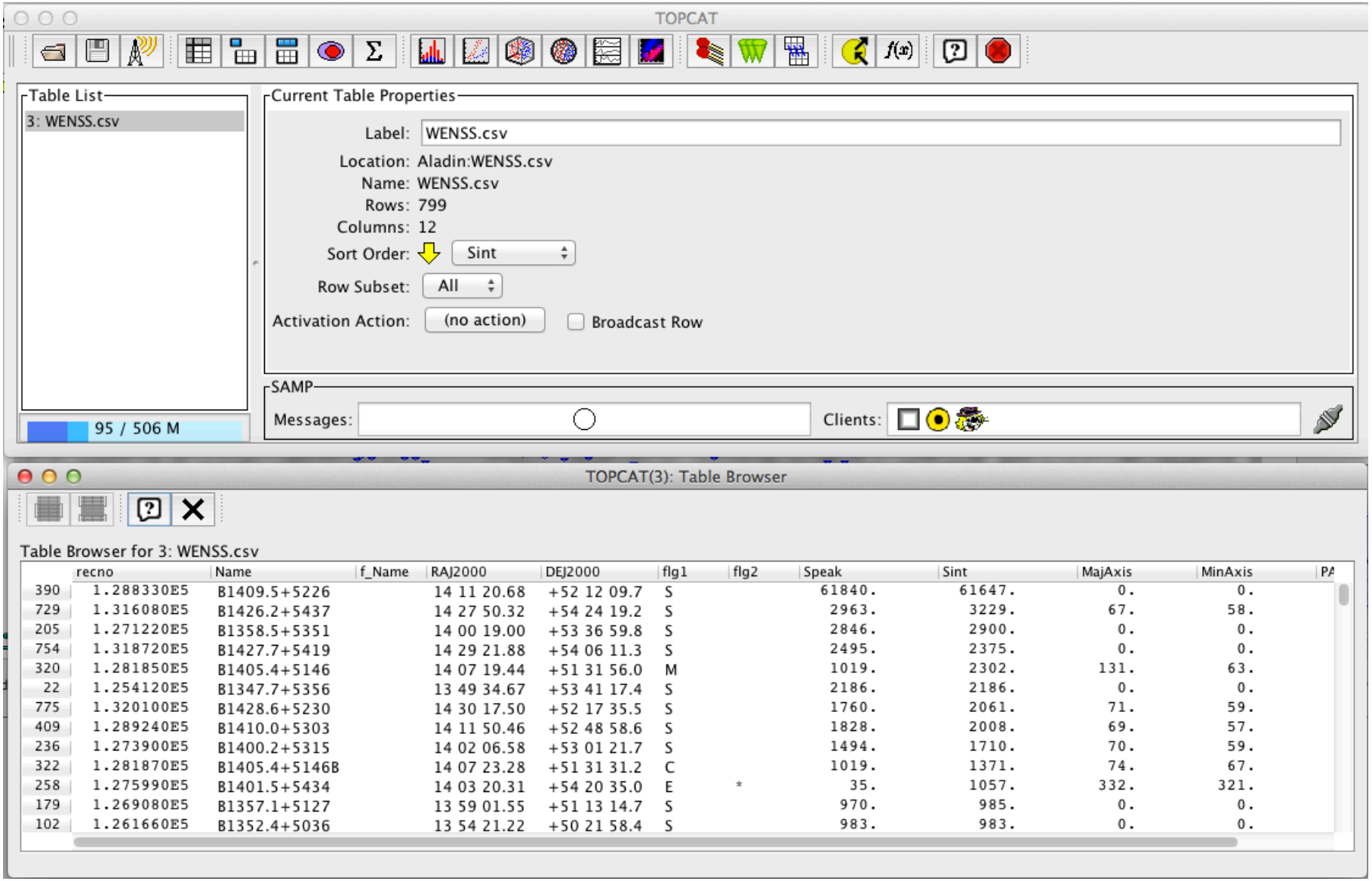
zoom
13.56° x 6.015°
12.8' x 12.8'
Adjust the visible area (clic&drag + mouse wheel)
Search
Connect with SAMP
Disconnect from SAMP
Broadcast selected planes
SAMP preferences
TIP: Redo the same process thank to a bookmark => Tool>Bookmarks



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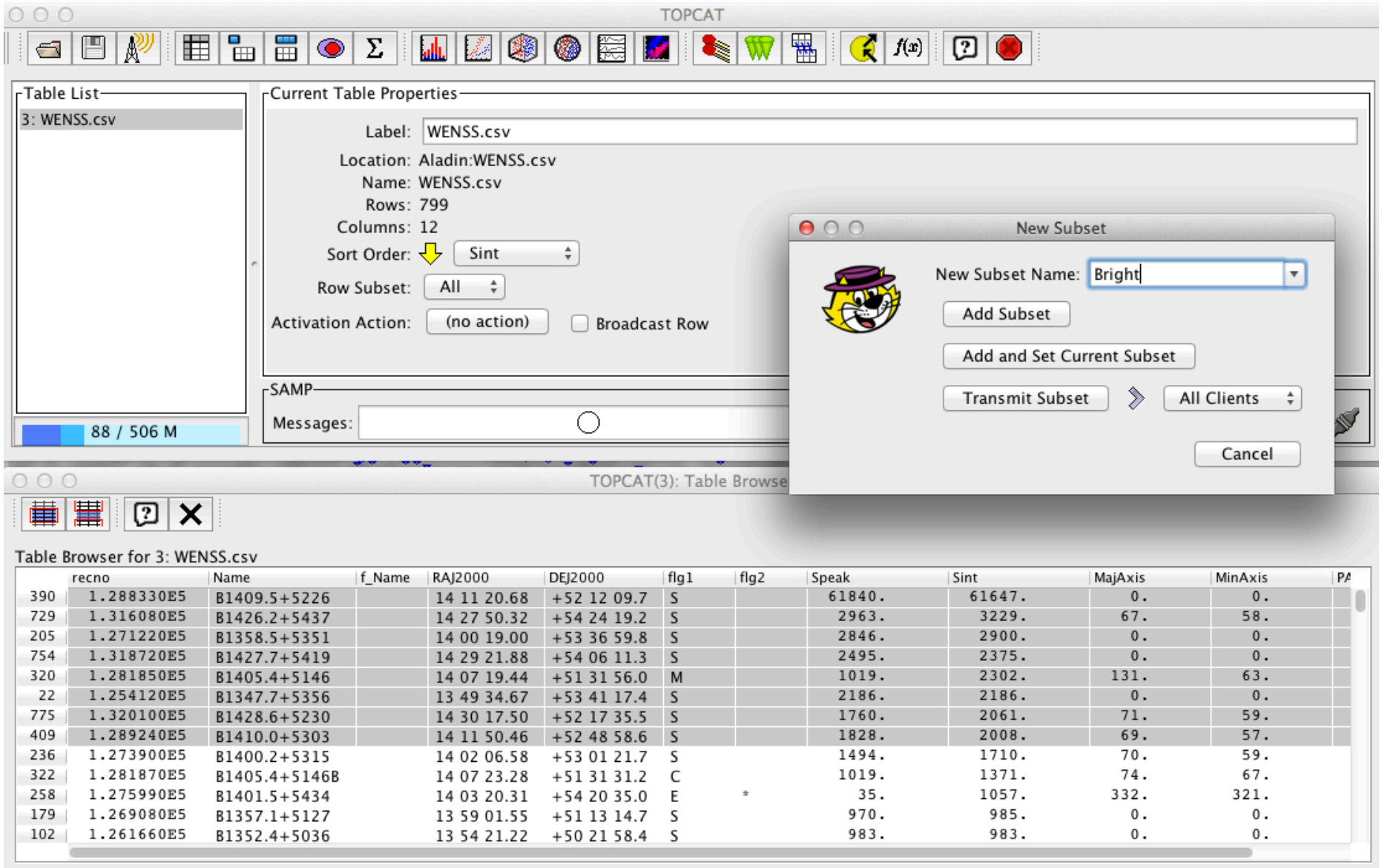
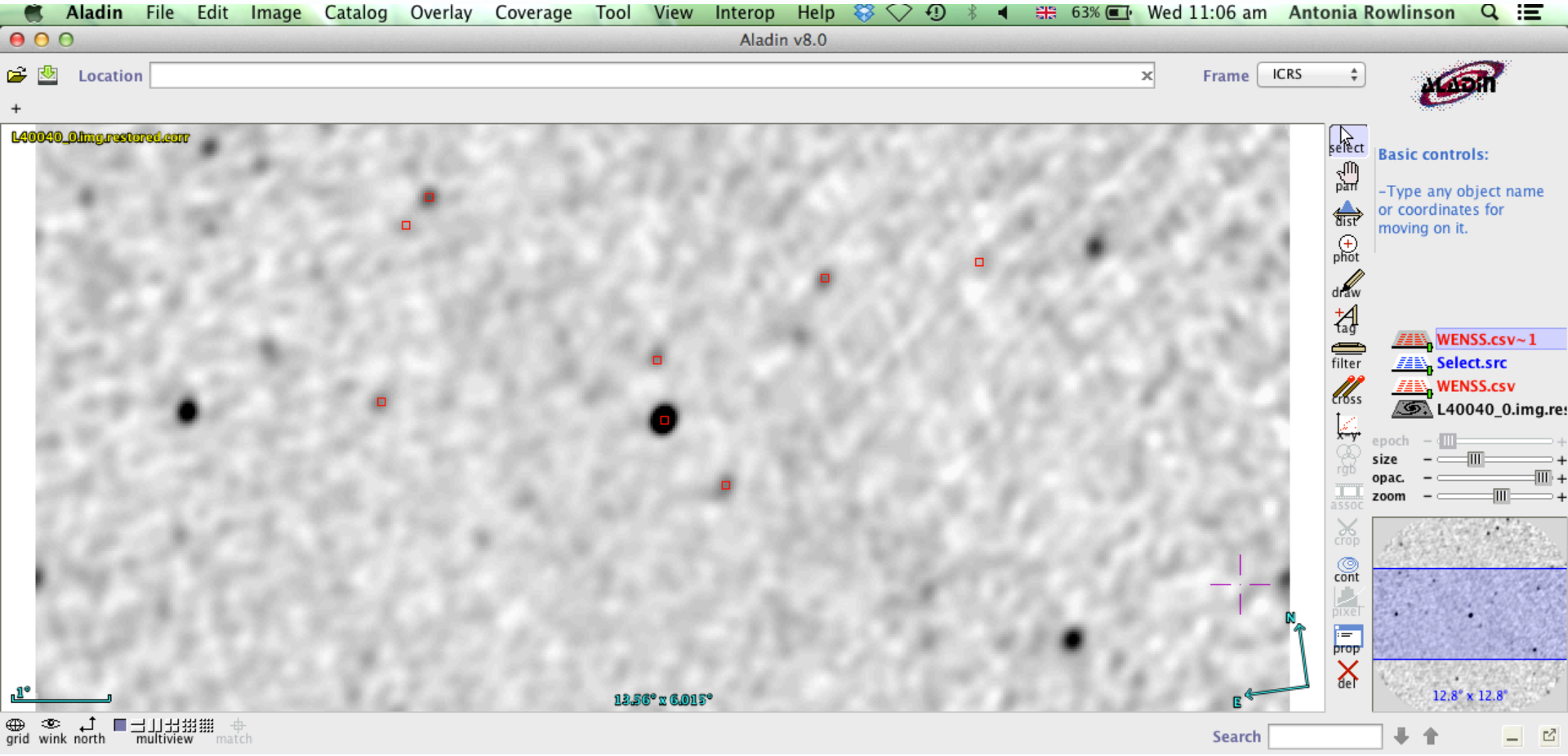
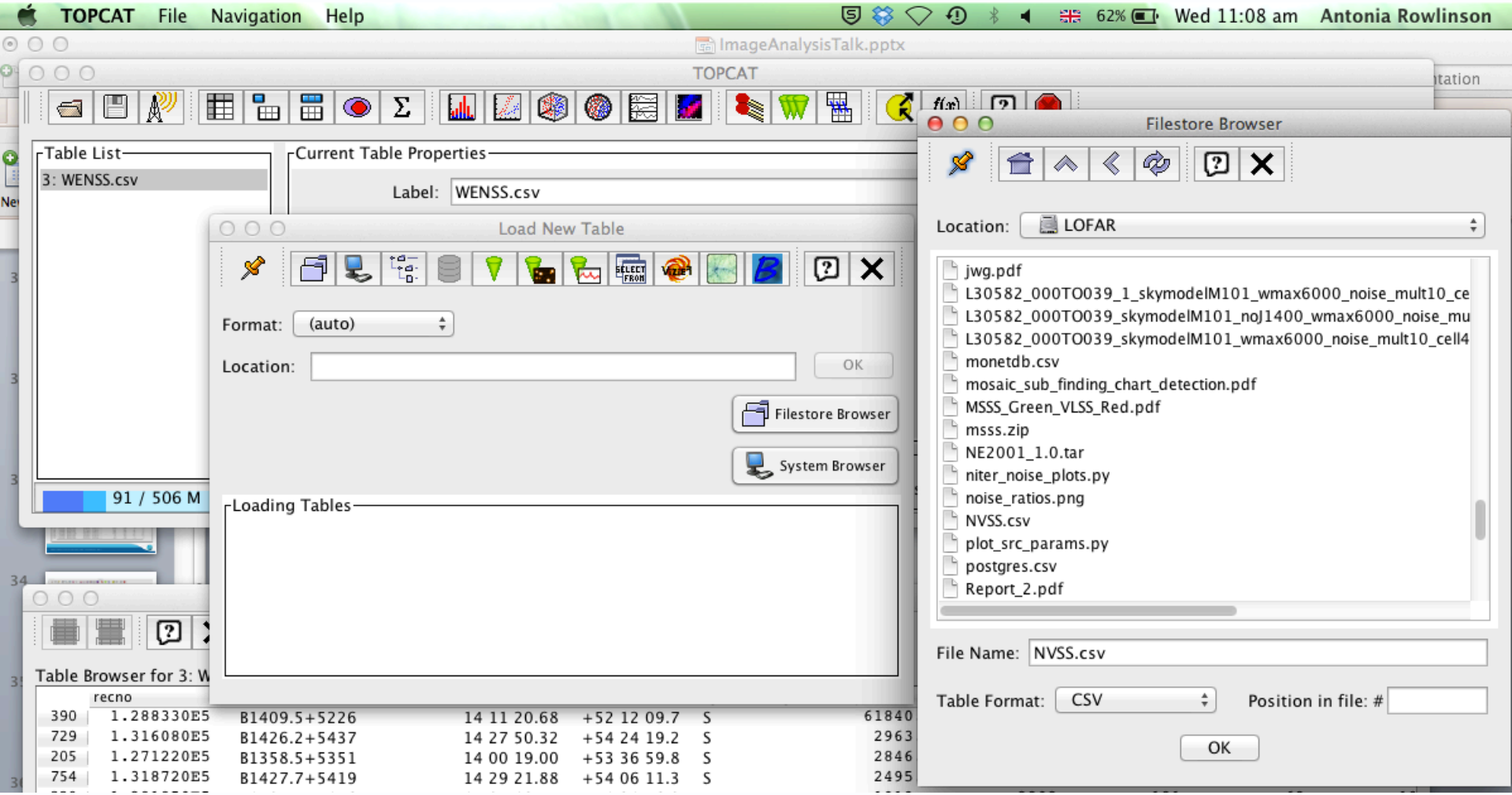
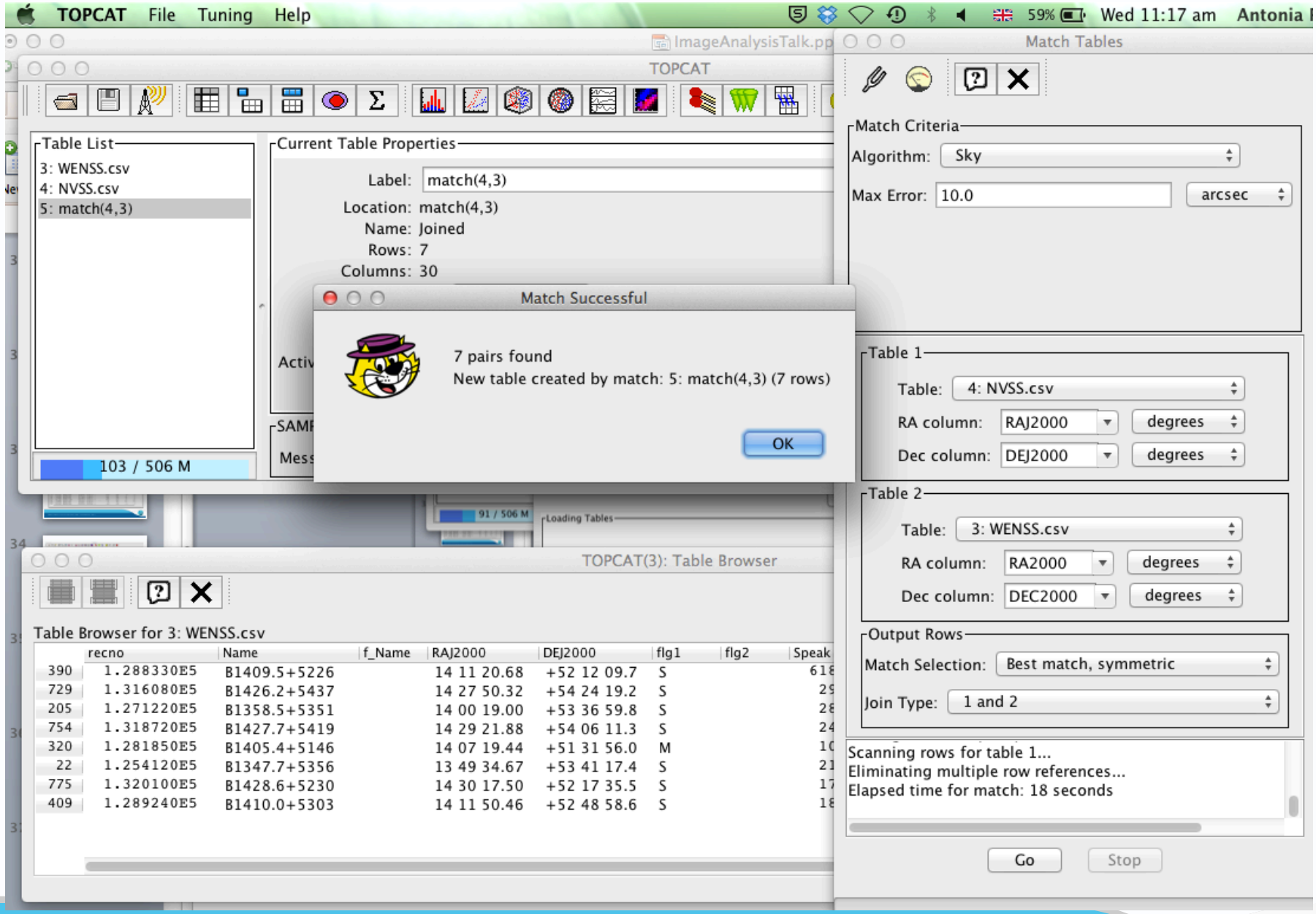
729	1.316080E5	B1426.2+5437		14 27 50.32	+54 24 19.2	S		2963.	3229.	67.	58.	
205	1.271220E5	B1358.5+5351		14 00 19.00	+53 36 59.8	S		2846.	2900.	0.	0.	
754	1.318720E5	B1427.7+5419		14 29 21.88	+54 06 11.3	S		2495.	2375.	0.	0.	
320	1.281850E5	B1405.4+5146		14 07 19.44	+51 31 56.0	M		1019.	2302.	131.	63.	
22	1.254120E5	B1347.7+5356		13 49 34.67	+53 41 17.4	S		2186.	2186.	0.	0.	
775	1.320100E5	B1428.6+5230		14 30 17.50	+52 17 35.5	S		1760.	2061.	71.	59.	
409	1.289240E5	B1410.0+5303		14 11 50.46	+52 48 58.6	S		1828.	2008.	69.	57.	
236	1.273900E5	B1400.2+5315		14 02 06.58	+53 01 21.7	S		1494.	1710.	70.	59.	
322	1.281870E5	B1405.4+5146B		14 07 23.28	+51 31 31.2	C		1019.	1371.	74.	67.	
258	1.275990E5	B1401.5+5434		14 03 20.31	+54 20 35.0	E	*	35.	1057.	332.	321.	
179	1.269080E5	B1357.1+5127		13 59 01.55	+51 13 14.7	S		970.	985.	0.	0.	
102	1.261660E5	B1352.4+5036		13 54 21.22	+50 21 58.4	S		983.	983.	0.	0.	

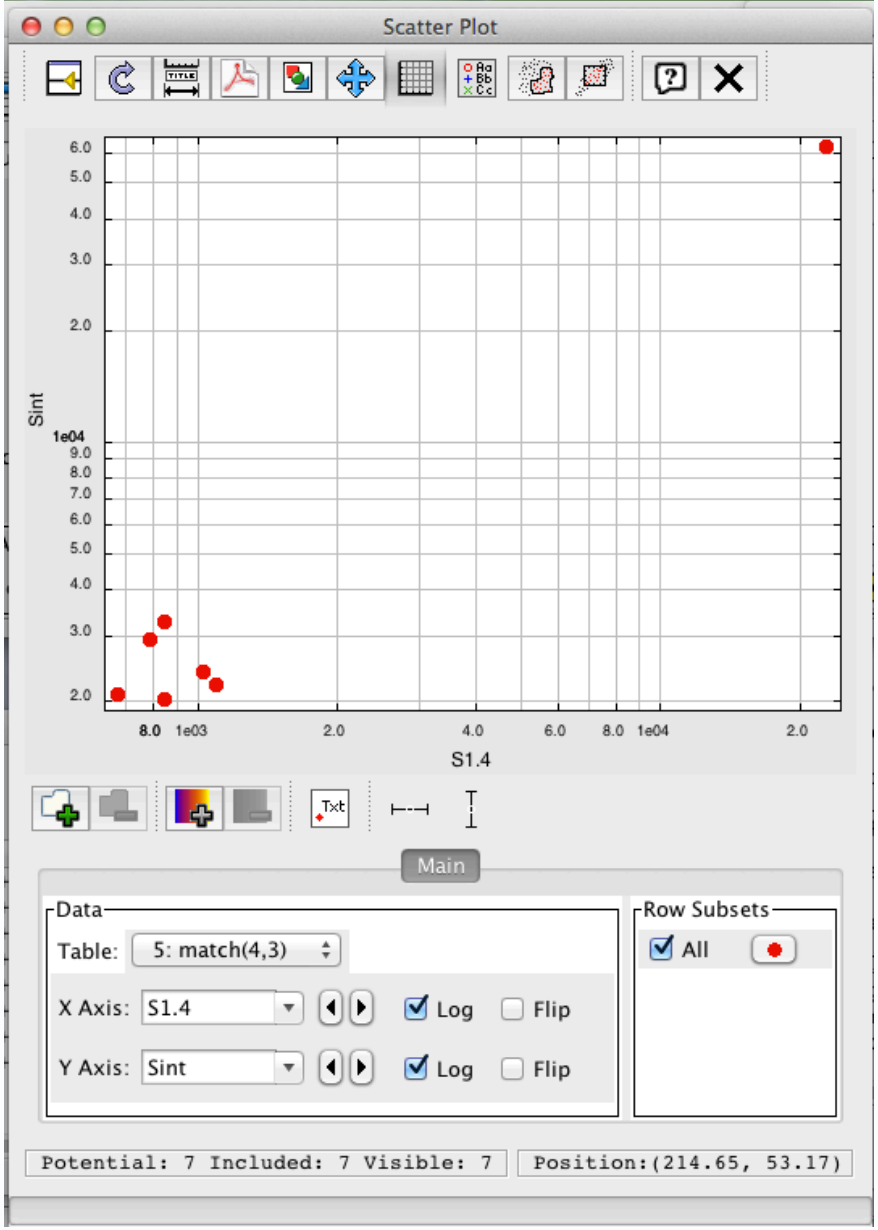


	recno	Name	f_Name	RAJ2000	DEJ2000	flg1	flg2	Speak	Sint	MajAxis	MinAxis	PA
390	1.288330E5	B1409.5+5226		14 11 20.68	+52 12 09.7	S		61840.	61647.	0.	0.	
729	1.316080E5	B1426.2+5437		14 27 50.32	+54 24 19.2	S		2963.	3229.	67.	58.	
205	1.271220E5	B1358.5+5351		14 00 19.00	+53 36 59.8	S		2846.	2900.	0.	0.	
754	1.318720E5	B1427.7+5419		14 29 21.88	+54 06 11.3	S		2495.	2375.	0.	0.	
320	1.281850E5	B1405.4+5146		14 07 19.44	+51 31 56.0	M		1019.	2302.	131.	63.	
22	1.254120E5	B1347.7+5356		13 49 34.67	+53 41 17.4	S		2186.	2186.	0.	0.	
775	1.320100E5	B1428.6+5230		14 30 17.50	+52 17 35.5	S		1760.	2061.	71.	59.	
409	1.289240E5	B1410.0+5303		14 11 50.46	+52 48 58.6	S		1828.	2008.	69.	57.	
236	1.273900E5	B1400.2+5315		14 02 06.58	+53 01 21.7	S		1494.	1710.	70.	59.	
322	1.281870E5	B1405.4+5146B		14 07 23.28	+51 31 31.2	C		1019.	1371.	74.	67.	
258	1.275990E5	B1401.5+5434		14 03 20.31	+54 20 35.0	E	*	35.	1057.	332.	321.	
179	1.269080E5	B1357.1+5127		13 59 01.55	+51 13 14.7	S		970.	985.	0.	0.	
102	1.261660E5	B1352.4+5036		13 54 21.22	+50 21 58.4	S		983.	983.	0.	0.	


Aladin File Edit Image Catalog Overlay Coverage Tool View Interop Help
Wed 11:06 am Antonia Rowlinson
Aladin v8.0
Location
Frame ICRS
L40040_0.img.restored.corr
Basic controls:
-Type any object name or coordinates for moving on it.
WENSS.csv~1
Select.src
WENSS.csv
L40040_0.img.res
epoch
size
opac.
zoom
13.56° x 6.015°
12.8° x 12.8°
grid wink north multiview match
Search


TOPCAT File Navigation Help
62% Wed 11:08 am Antonia Rowlinson
ImageAnalysisTalk.pptx
TOPCAT
Table List
3: WENSS.csv
Current Table Properties
Label: WENSS.csv
91 / 506 M
Load New Table
Format: (auto)
Location:
OK
Filestore Browser
System Browser
Loading Tables
Filestore Browser
Location: LOFAR
jwg.pdf
L30582_000TO039_1_skymodelM101_wmax6000_noise_mult10_ce
L30582_000TO039_skymodelM101_noJ1400_wmax6000_noise_mu
L30582_000TO039_skymodelM101_wmax6000_noise_mult10_cell4
monetdb.csv
mosaic_sub_finding_chart_detection.pdf
MSSS_Green_VLSS_Red.pdf
msss.zip
NE2001_1.0.tar
niter_noise_plots.py
noise_ratios.png
NVSS.csv
plot_src_params.py
postgres.csv
Report_2.pdf
File Name: NVSS.csv
Table Format: CSV
Position in file: #
OK
Table Browser for 3: W
recno
390 1.288330E5 B1409.5+5226 14 11 20.68 +52 12 09.7 S 61840
729 1.316080E5 B1426.2+5437 14 27 50.32 +54 24 19.2 S 2963
205 1.271220E5 B1358.5+5351 14 00 19.00 +53 36 59.8 S 2846
754 1.318720E5 B1427.7+5419 14 29 21.88 +54 06 11.3 S 2495


TOPCAT File Tuning Help
Wed 11:17 am
TOPCAT
Table List
3: WENSS.csv
4: NVSS.csv
5: match(4,3)
Current Table Properties
Label: match(4,3)
Location: match(4,3)
Name: Joined
Rows: 7
Columns: 30
103 / 506 M
Match Successful
7 pairs found
New table created by match: 5: match(4,3) (7 rows)
OK
Match Tables
Match Criteria
Algorithm: Sky
Max Error: 10.0
arcsec
Table 1
Table: 4: NVSS.csv
RA column: RAJ2000
Dec column: DEJ2000
degrees
Table 2
Table: 3: WENSS.csv
RA column: RA2000
Dec column: DEC2000
Output Rows
Match Selection: Best match, symmetric
Join Type: 1 and 2
Scanning rows for table 1...
Eliminating multiple row references...
Elapsed time for match: 18 seconds
Go
Stop
TOPCAT(3): Table Browser
Table Browser for 3: WENSS.csv
recno Name f_Name RAJ2000 DEJ2000 flg1 flg2 Speak
390 1.288330E5 B1409.5+5226 14 11 20.68 +52 12 09.7 S
729 1.316080E5 B1426.2+5437 14 27 50.32 +54 24 19.2 S
205 1.271220E5 B1358.5+5351 14 00 19.00 +53 36 59.8 S
754 1.318720E5 B1427.7+5419 14 29 21.88 +54 06 11.3 S
320 1.281850E5 B1405.4+5146 14 07 19.44 +51 31 56.0 M
22 1.254120E5 B1347.7+5356 13 49 34.67 +53 41 17.4 S
775 1.320100E5 B1428.6+5230 14 30 17.50 +52 17 35.5 S
409 1.289240E5 B1410.0+5303 14 11 50.46 +52 48 58.6 S


Scatter Plot
6.0
5.0
4.0
3.0
2.0
Sint
1e04
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
8.0 1e03
2.0
4.0
6.0
8.0 1e04
2.0
S1.4
Txt
Main
Data
Table: 5: match(4,3)
X Axis: S1.4
Log
Flip
Y Axis: Sint
Log
Flip
Row Subsets
All
Potential: 7 Included: 7 Visible: 7
Position:(214.65, 53.17)

Review:

1. Make observations and images fit for purpose
2. Confirm images are of sufficient quality for requirements
3. Choose your source finder and analysis tools carefully