VLBA Imaging of ICRF 3 Sources

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(for Lucas Hunt)

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ICRF Source Requirements

Radio Loud Quasars

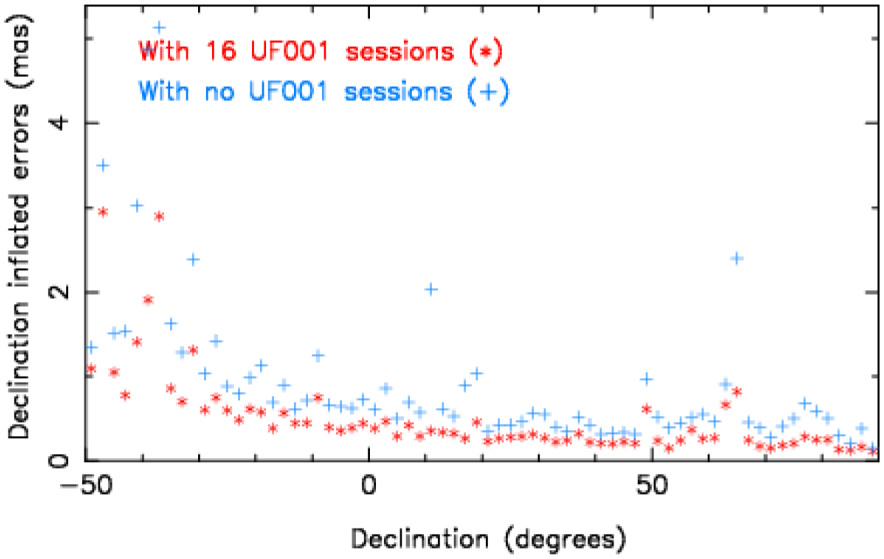
- Compact, high redshift, radio bright AGN objects
  - Point-like on the sky = Precise position on sky with little confusion
  - Relative position on the sky should not change (far away)
- Bright and stable in the radio spectrum
  - If source has high intensity we can observe them quickly
  - Can then observe many sources in a short time
  - Allows us to quickly create a grid of the sources on the sky
  - Sample a large range of elevations for better ionosphere and troposphere calibration
- Ability to continuously monitor these sources
  - Can observe same source numerous times to reduce effects of error

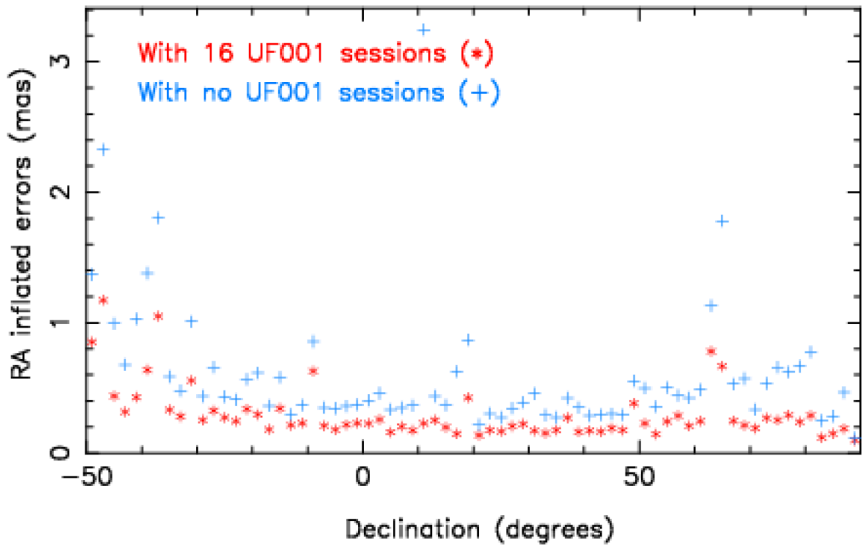
Astrometric positions derived from accurate measurement of group delay

- Can observe in short bursts to get good measurement of delay
  - Short observations may not be optimal for imaging. So why am I talking about it?

UF/UG Series on the VLBA

Motivation: To maintain, monitor, and improve the ICRF source positions and to make images of >3000 sources

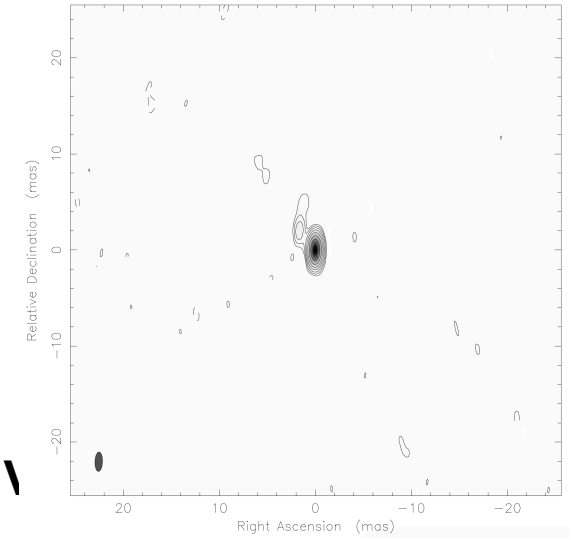


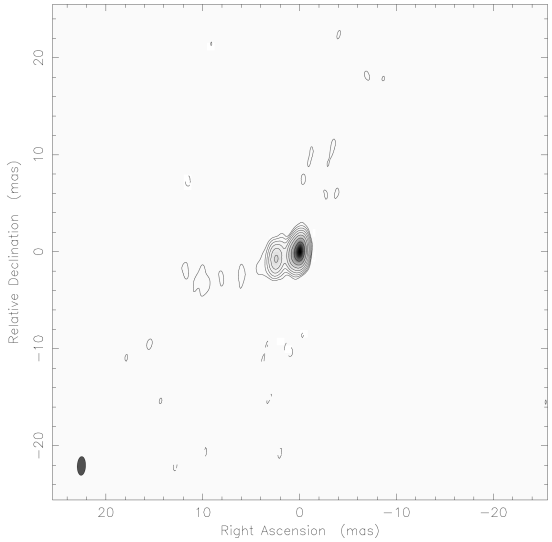


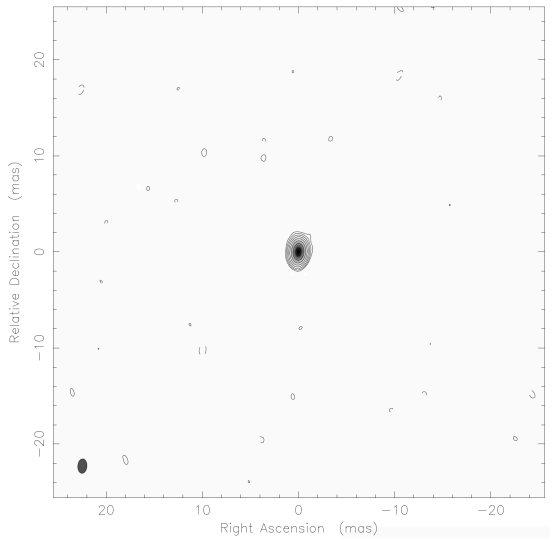
16 sessions from UF001
Improvement in inflated errors:
0.56 and 0.90 → 0.27 and 0.48
in RA and DEC, respectively

ICRF Imaging with VLBA

- Tells us important information:
  - **Source compactness**
    - Determine suitability as astrometric source
    - Determine suitability as a calibrator
    - Compare images over time
  - **Other Utility**
    - Make data products publicly available to astronomical community
  - \







Observing set-up/Calibration

Simultaneous S/X Band

- 2.3 (S)/8.7 (X) GHz
- 2 Gbps data rate
- 16 sub-bands
  - 4 at S-band, 12 at X-band
- 32 MHz bandwidth per sub-band
  - 64 channels/sub-band
- Right Circular Polarization

24 hour observations

- ~2 observations a month for 20 session per year
- ~300 objects observed per session per frequency
- Over 11,000 images

Calibration done in AIPS

- Follow standard procedure

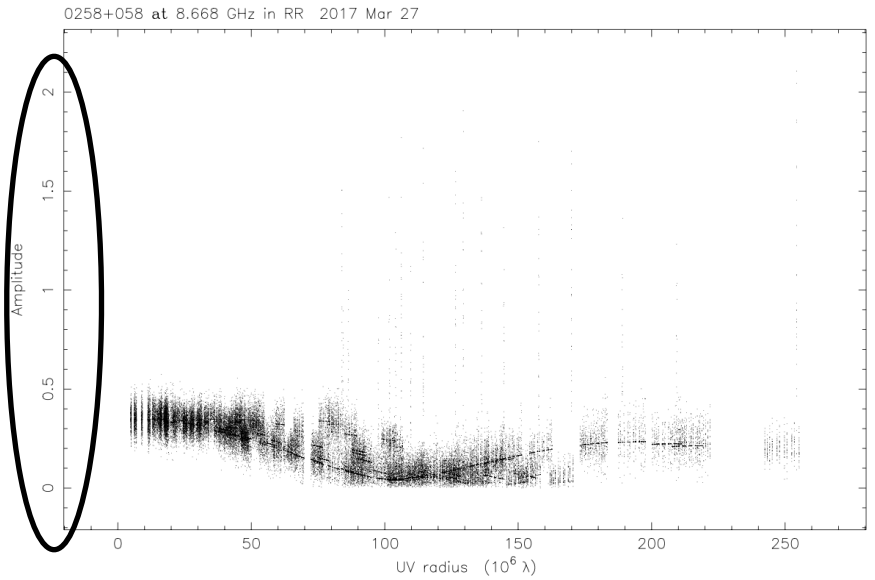
Imaging done in program called Difmap

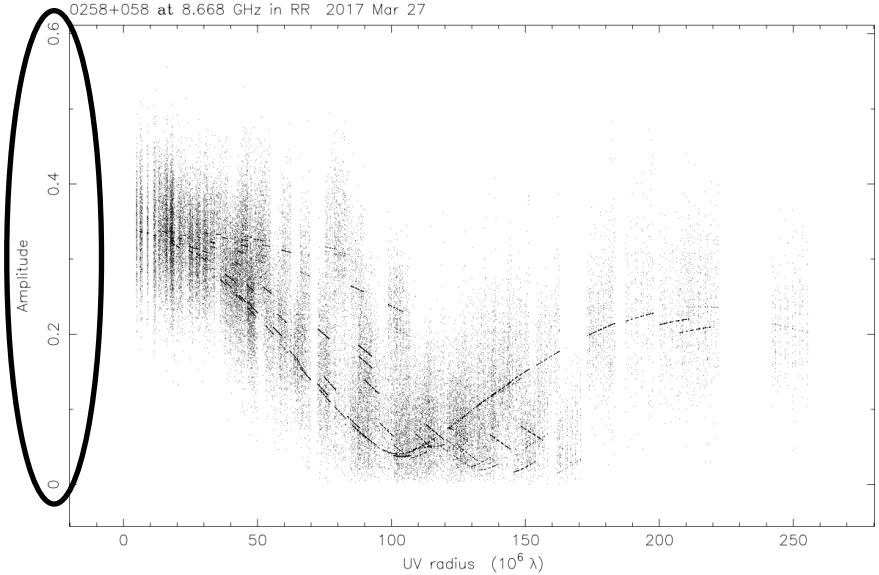
- Automated imaging

Imaging

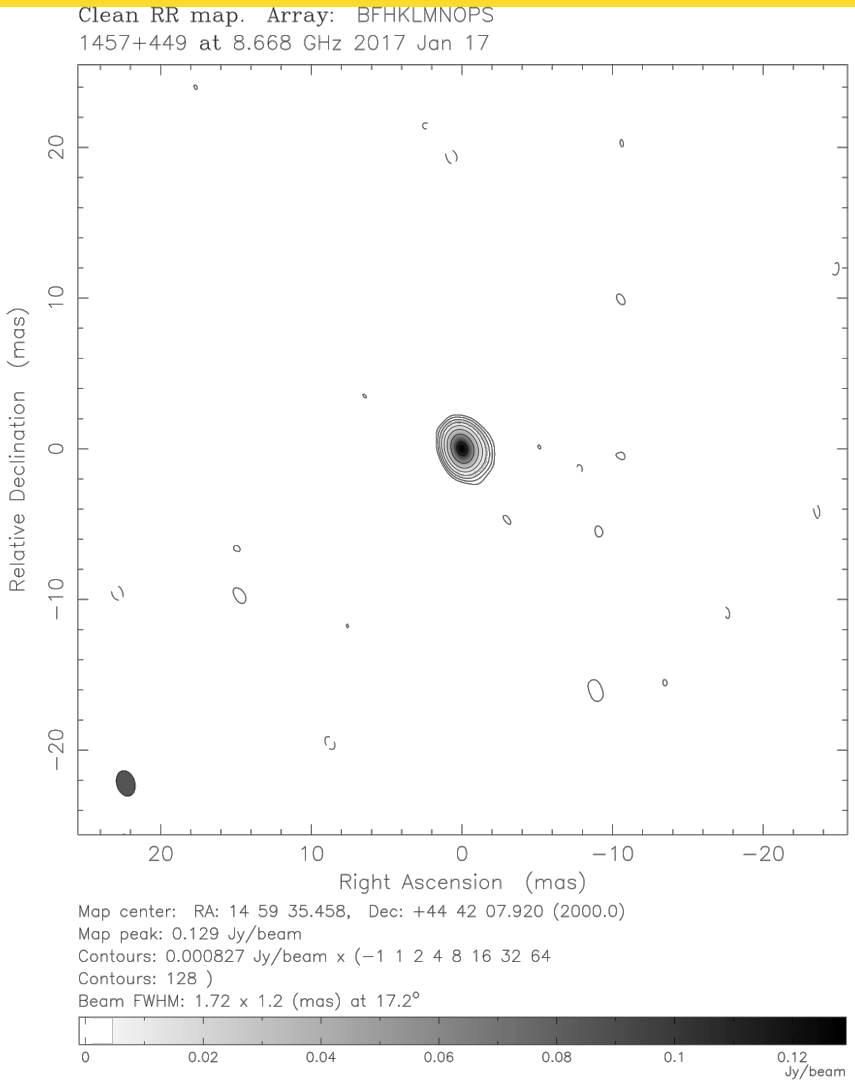
Difmap Scripts

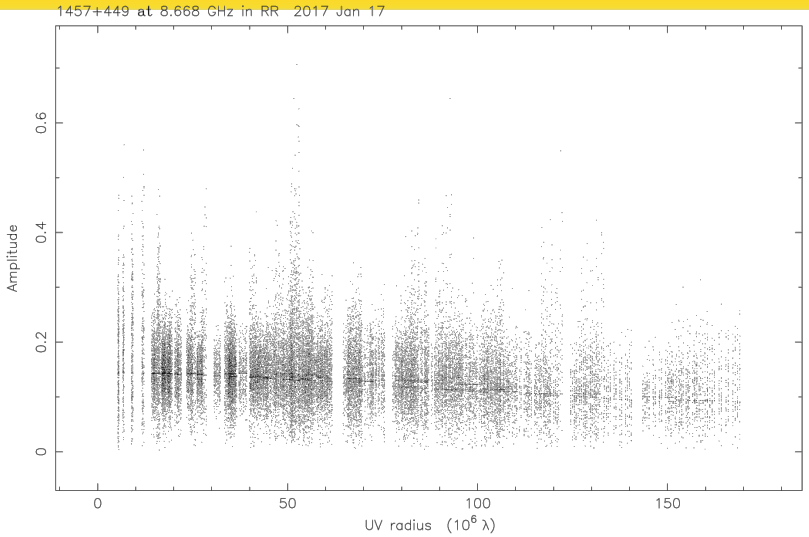
- Data split from aips, run through difmap using script
  - Script was used for previous RDV imaging, therefore outputs products similar to those available on RRFID
    - .fits, model, log, par, image, uv plot
- Data with bad points manually flagged in difmap
  - Large PDF file created showing image and amp/uv plot. Manually inspect to find number of successful sources and sources that need more editing
  - Manually inspecting images and flagging data takes a lot of time
  - Bottleneck! Find ways to automate

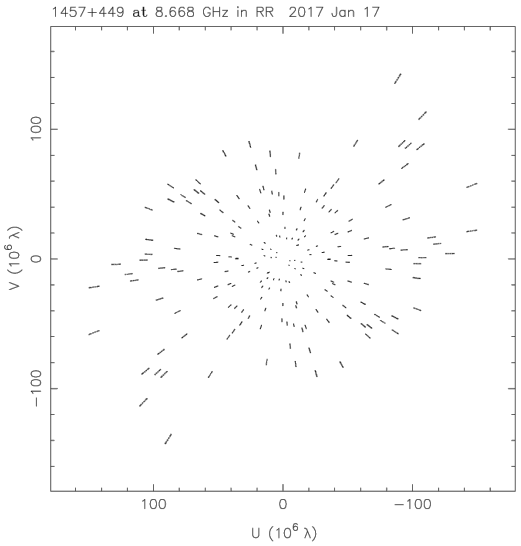




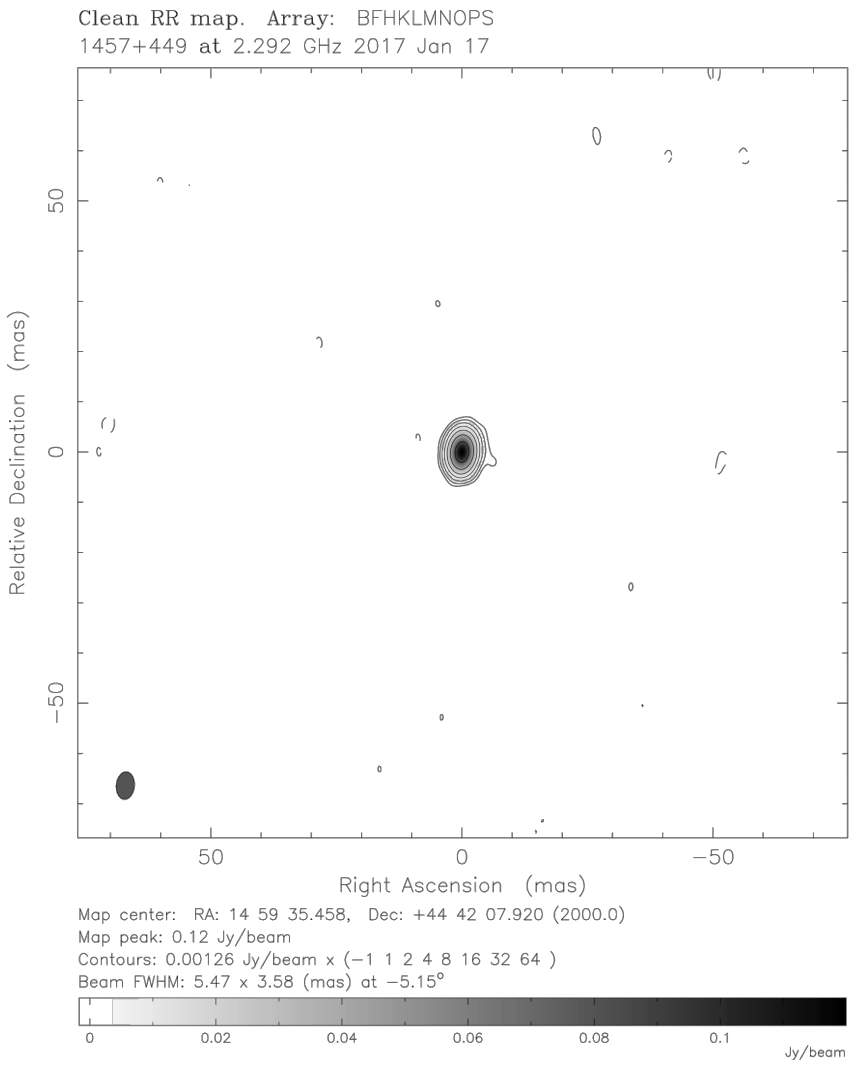
Images (X-band)

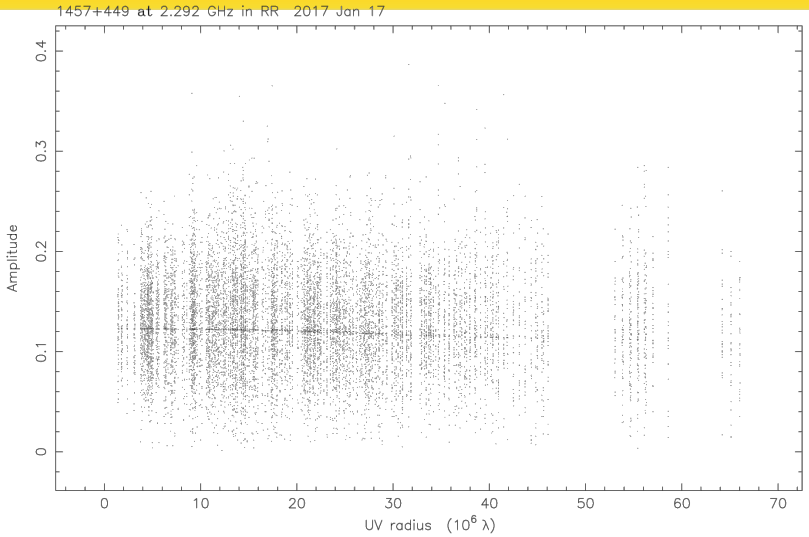


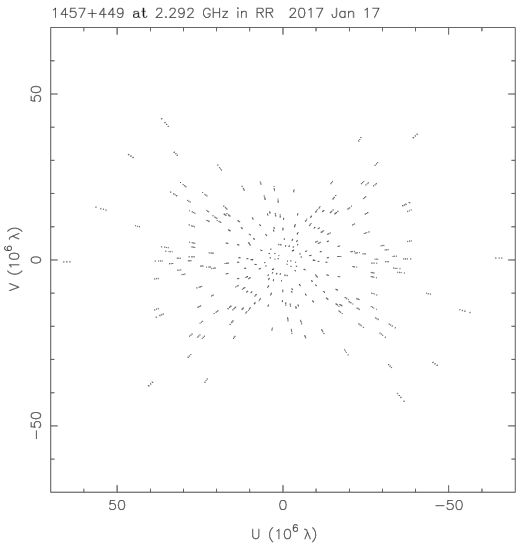




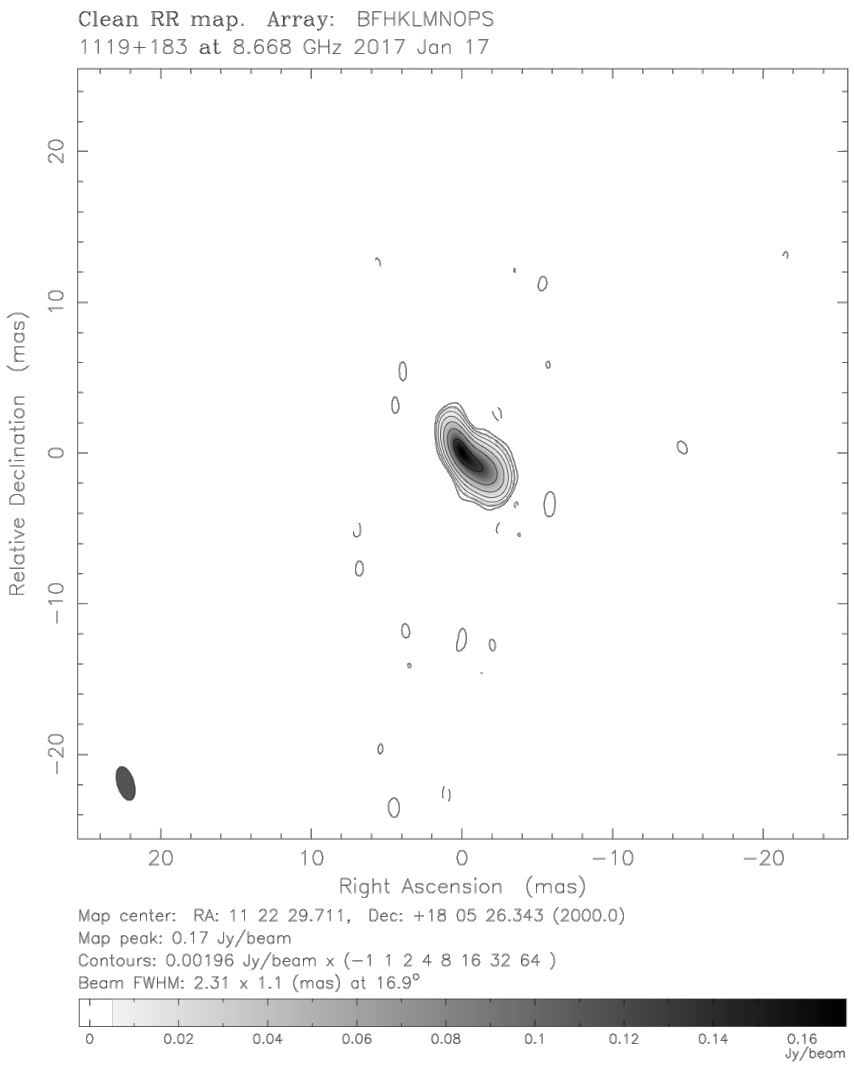
Images (S-band)

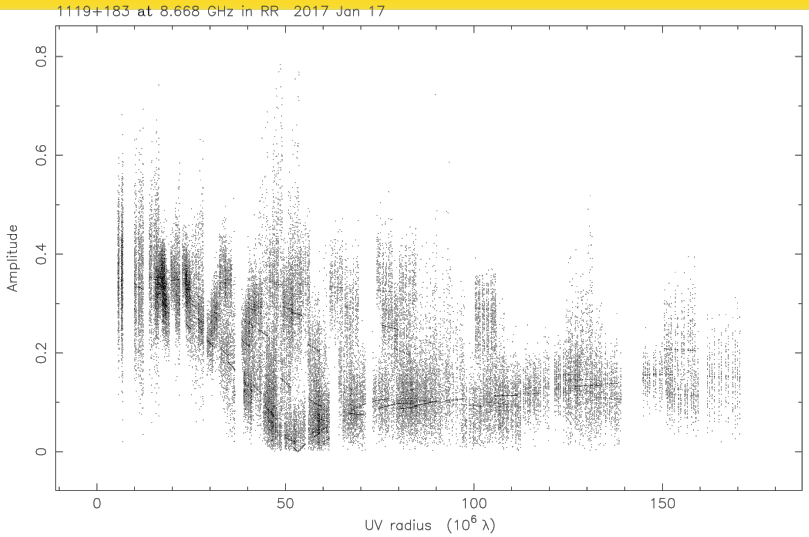


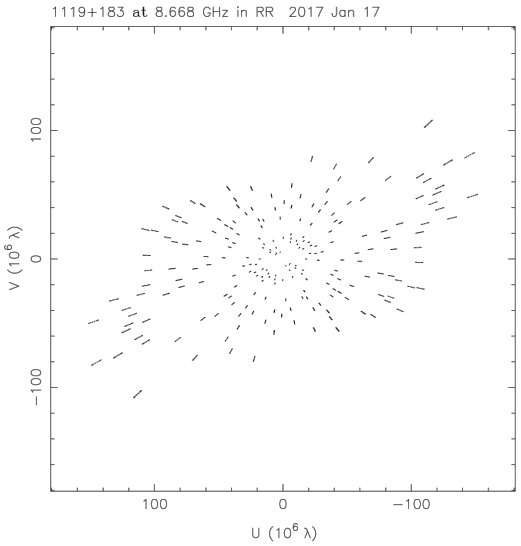




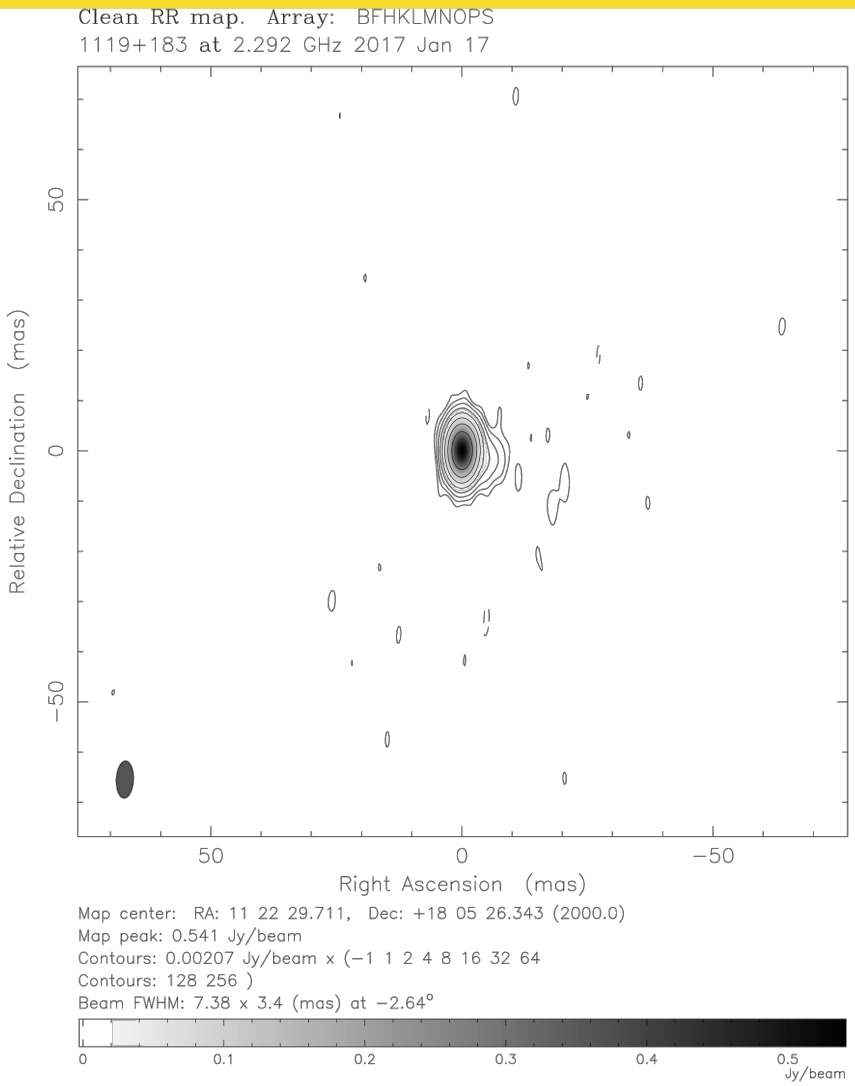
Images (X-band)

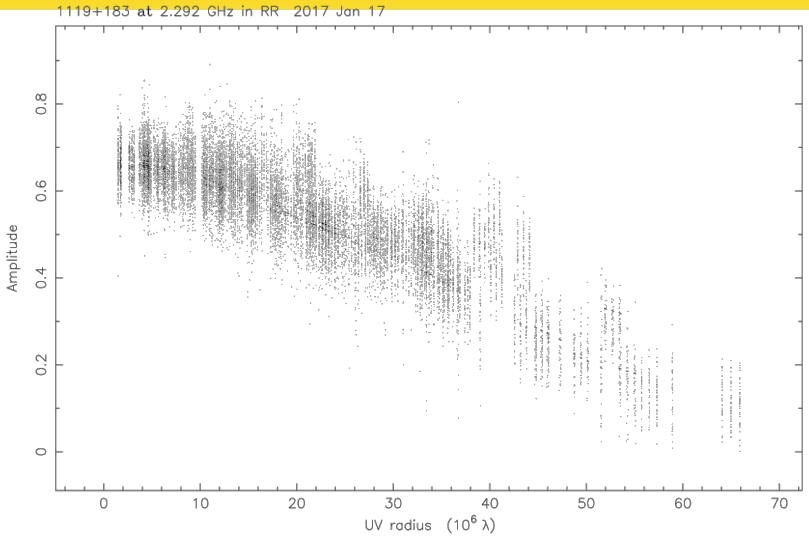


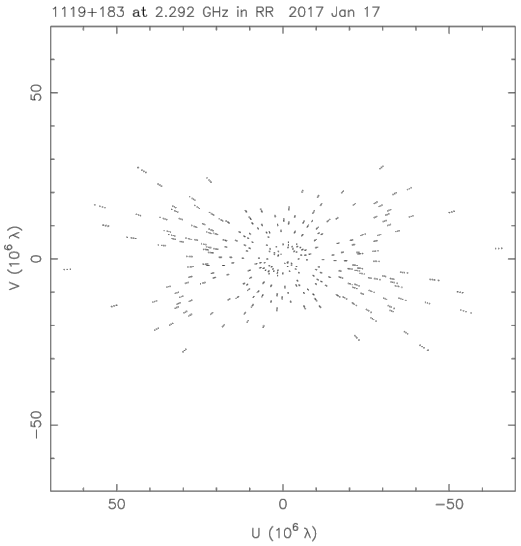




Images (S-band)







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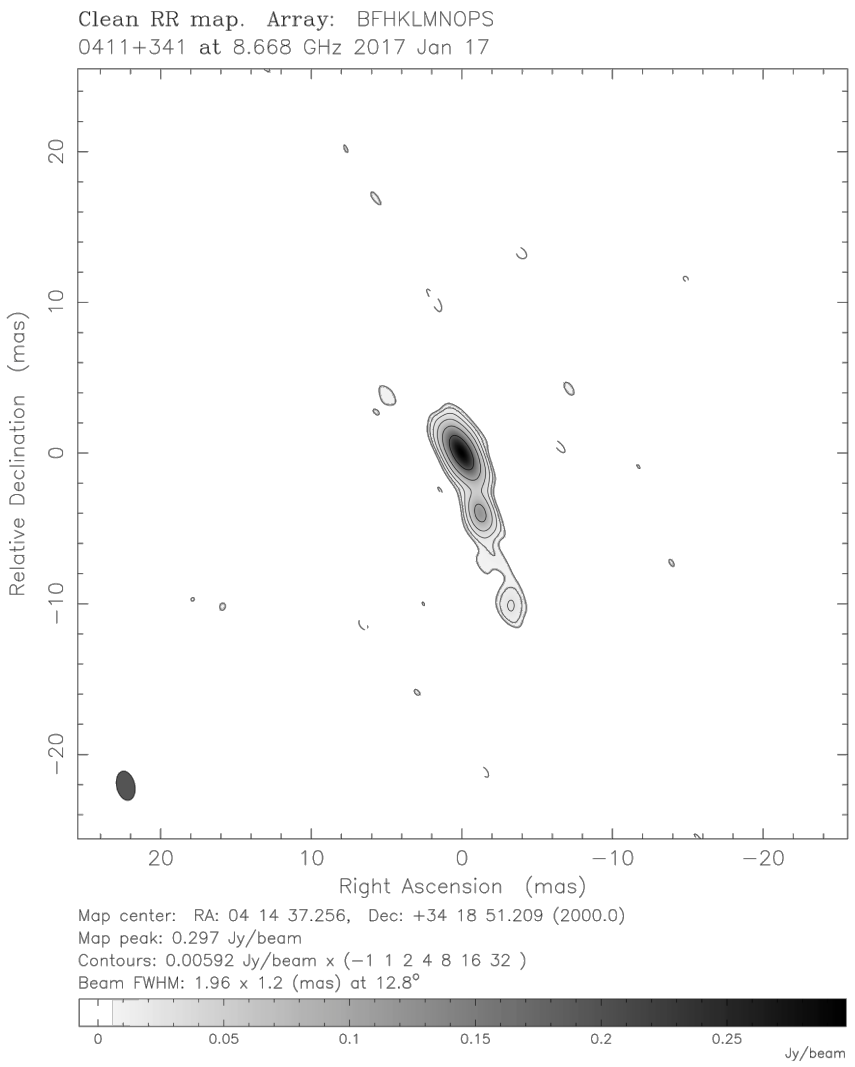
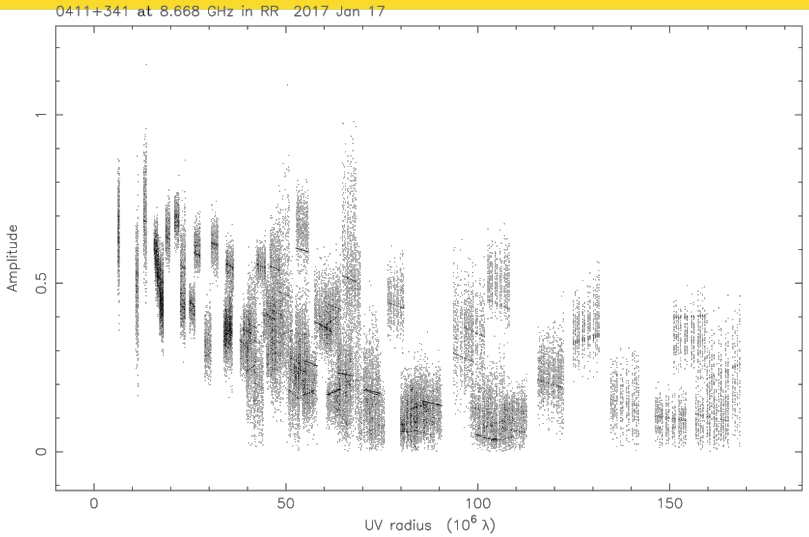
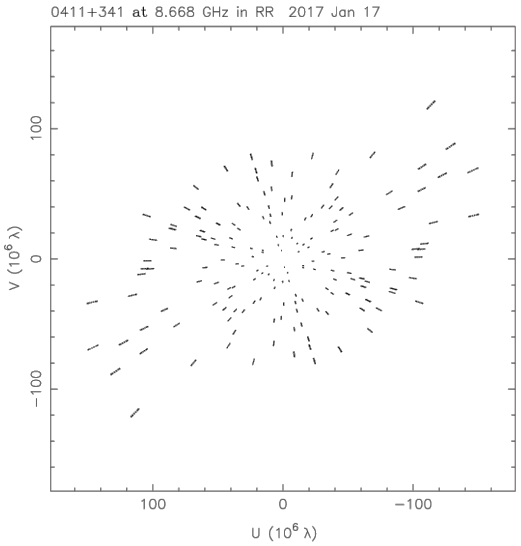
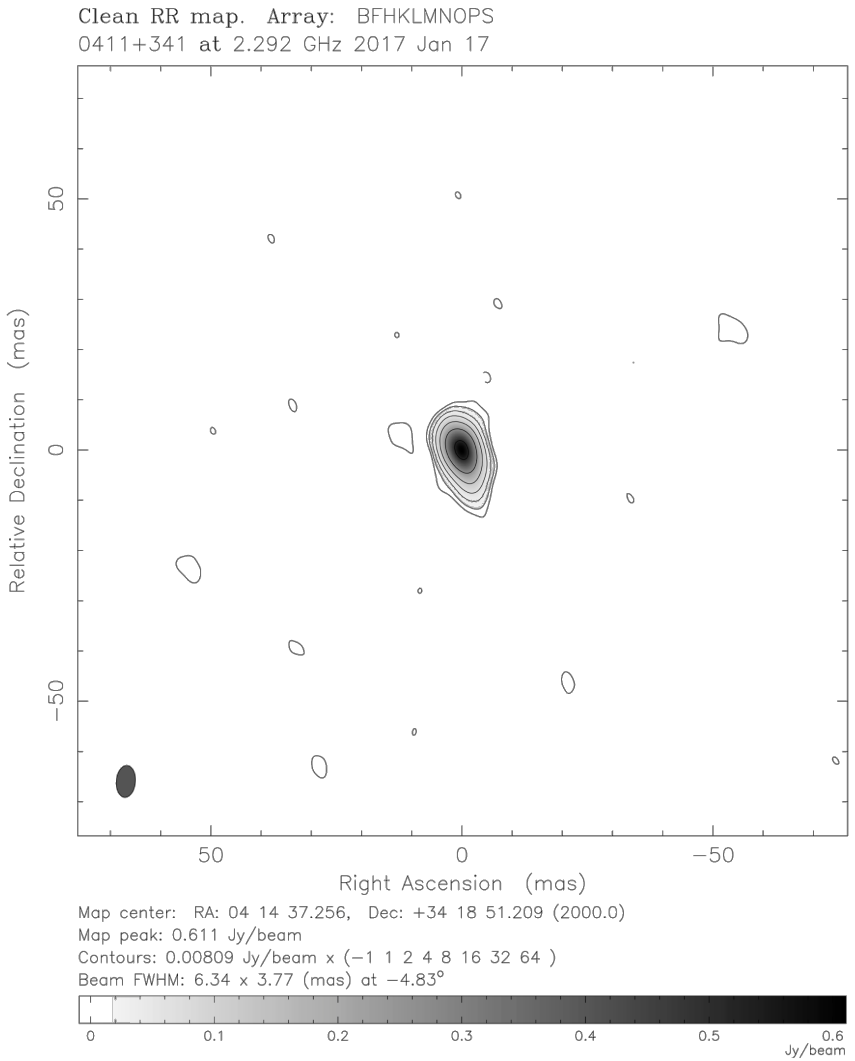
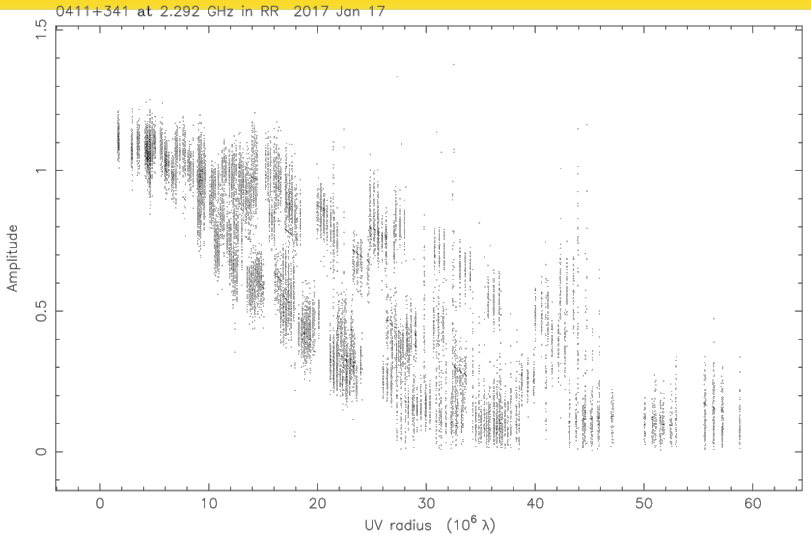


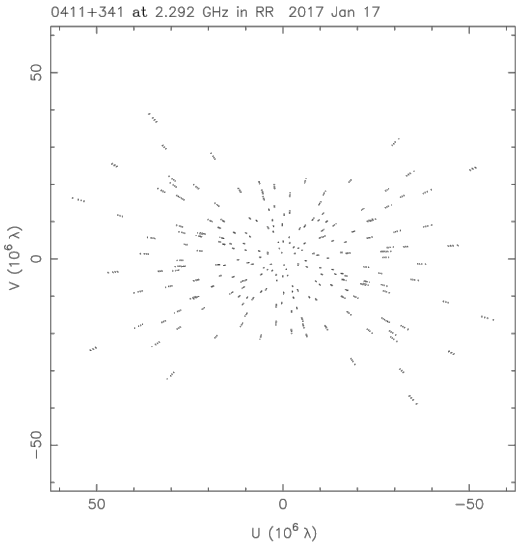




Images (S-band)







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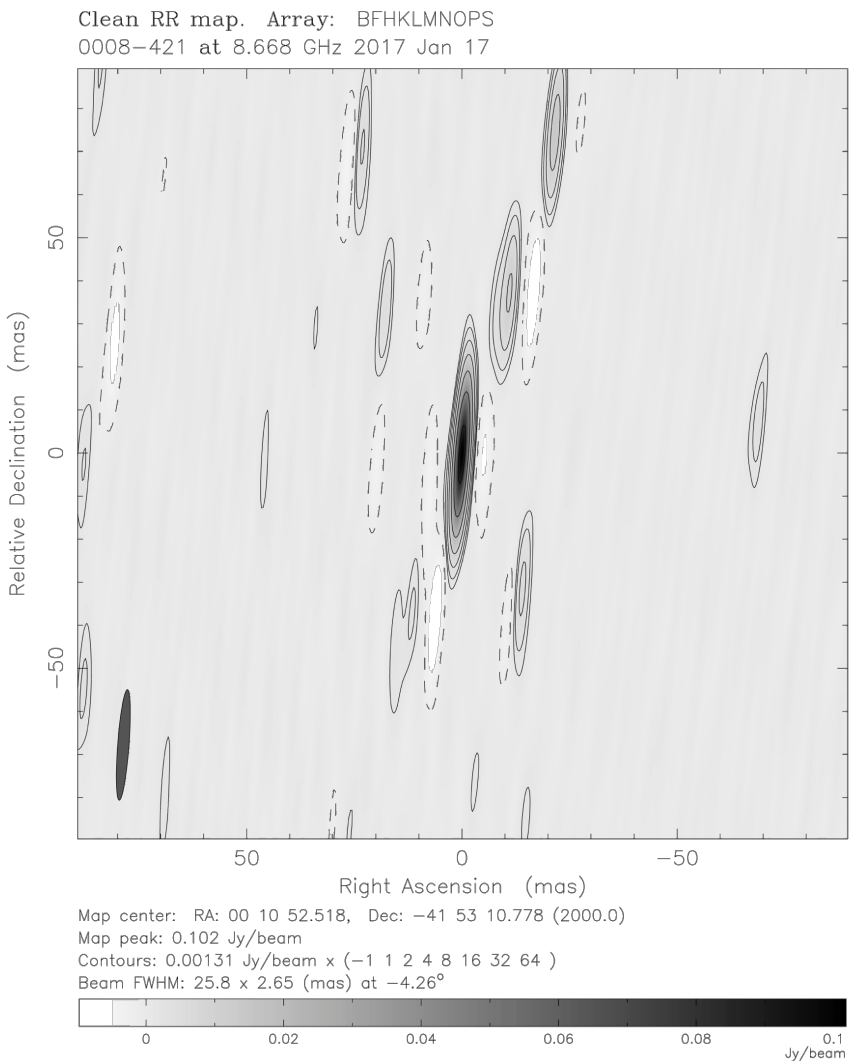

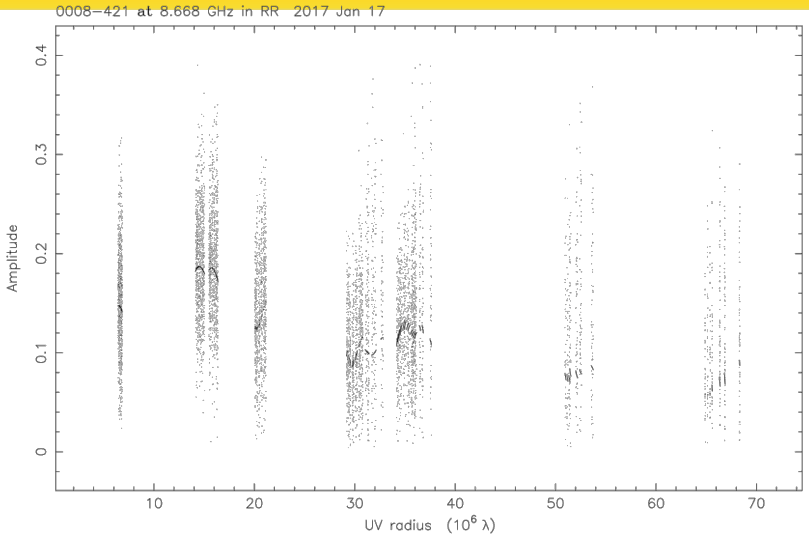

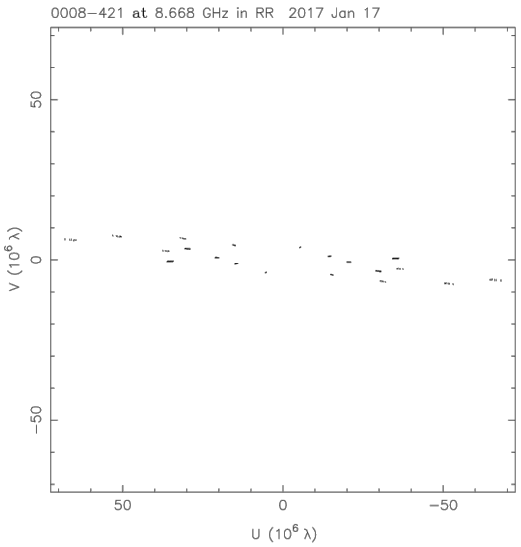

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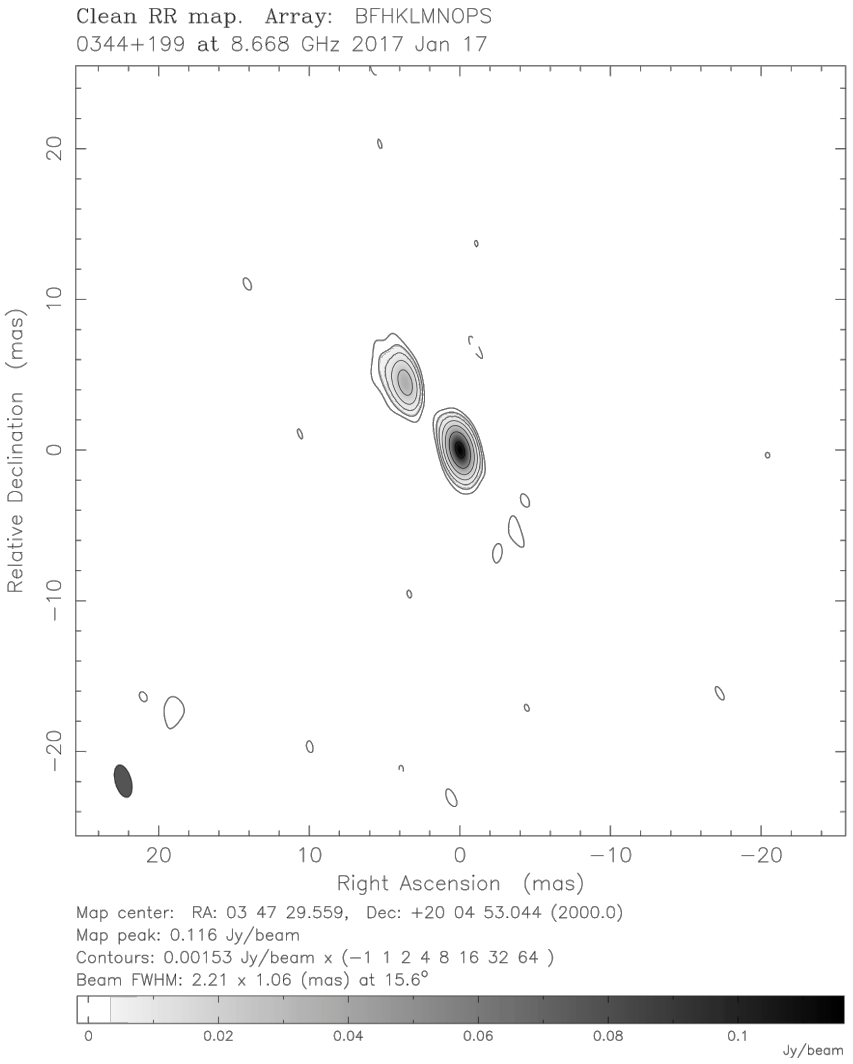
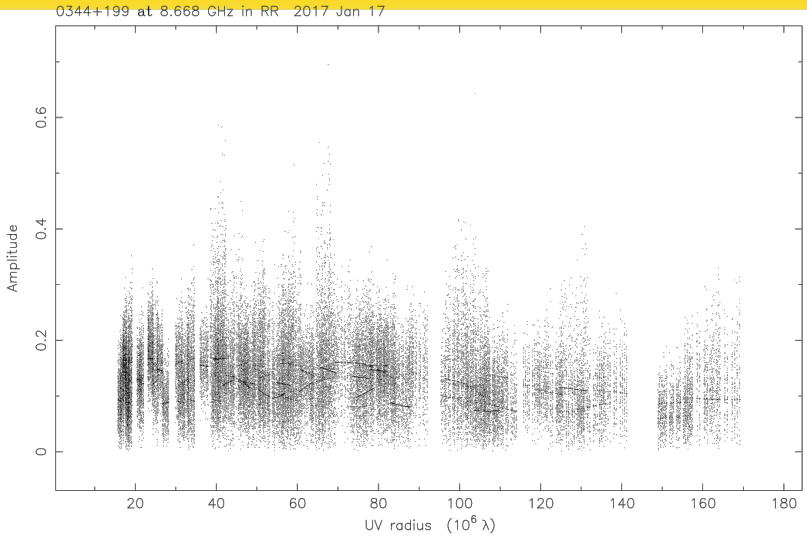
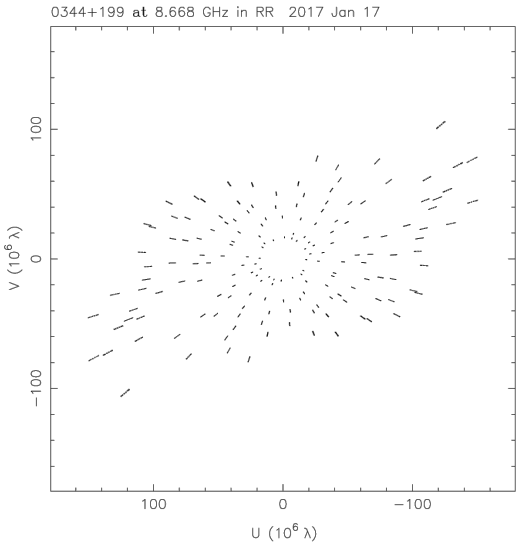






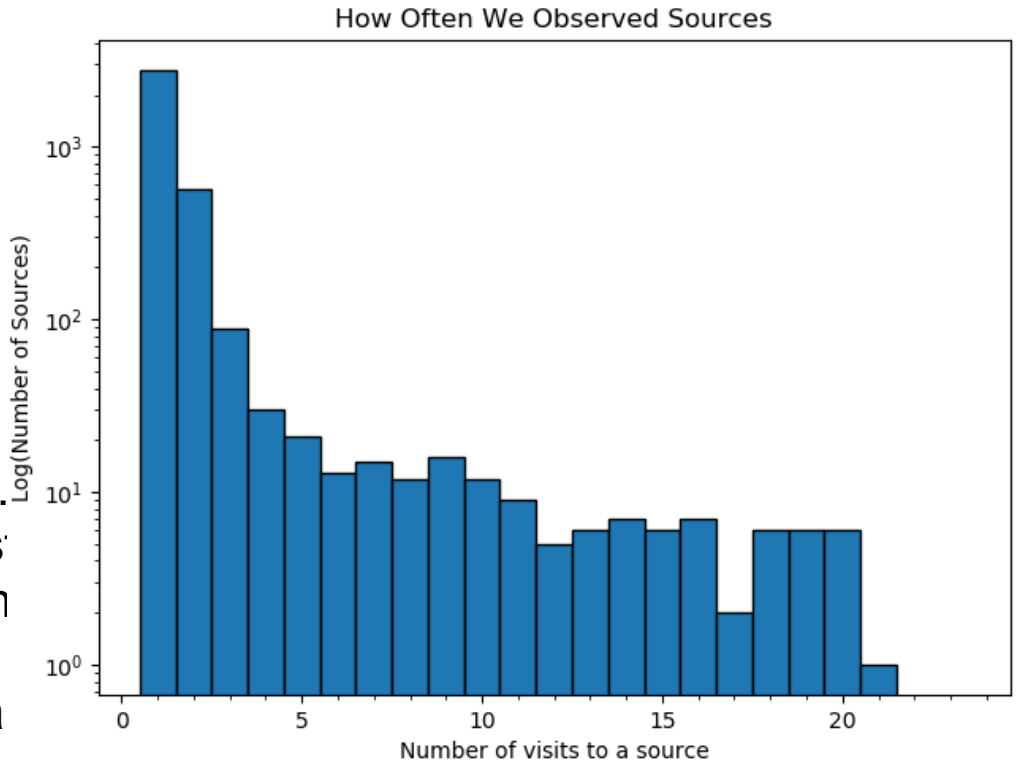
Statistics

All 20 Observations complete

- X-Band
  - 5228/5897 images created
    - ~90% success rate
- S-Band
  - 5664/5897
    - ~96% success rate

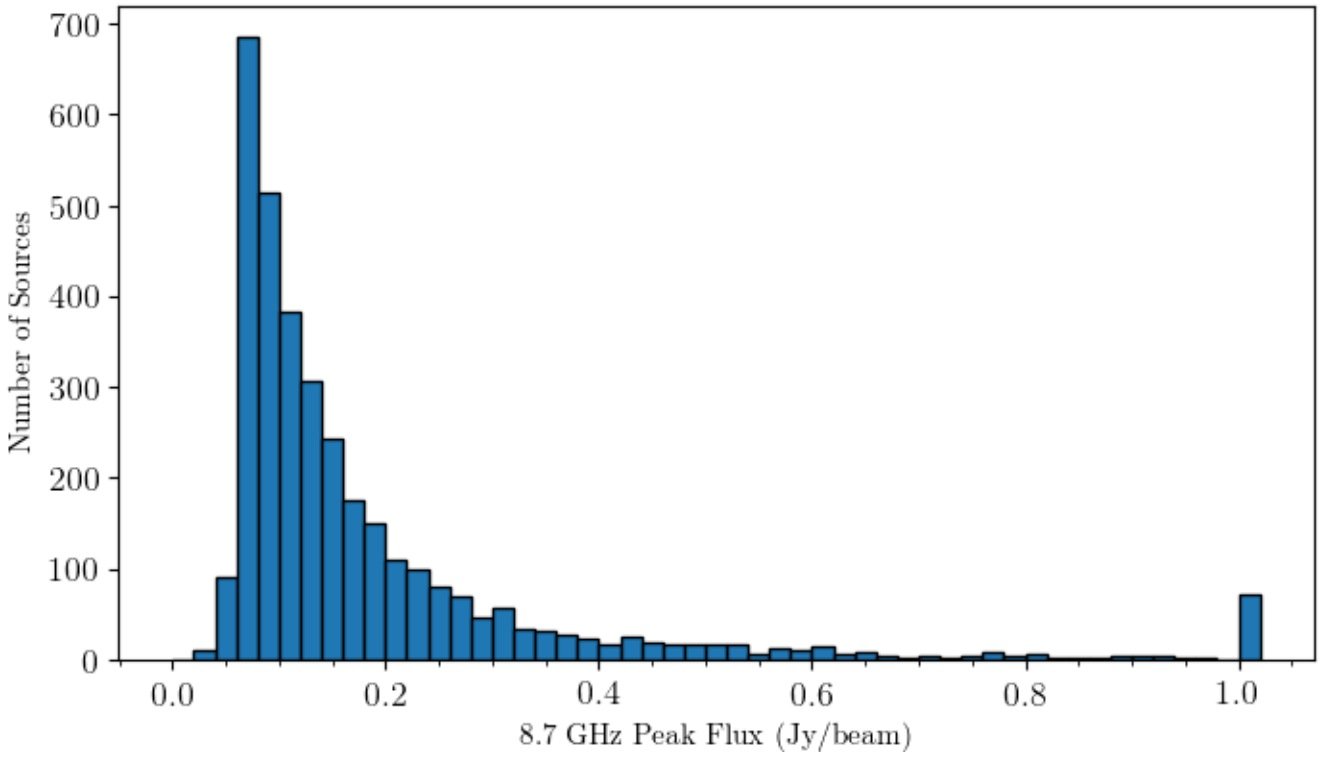
Reasons for failure

- Not observed long enough
- Failed calibration?
  - Assume most objects are point like. not, calibration may not be success
  - Observing some failed sources with longer integration time and phase referencing to determine intensity a structure



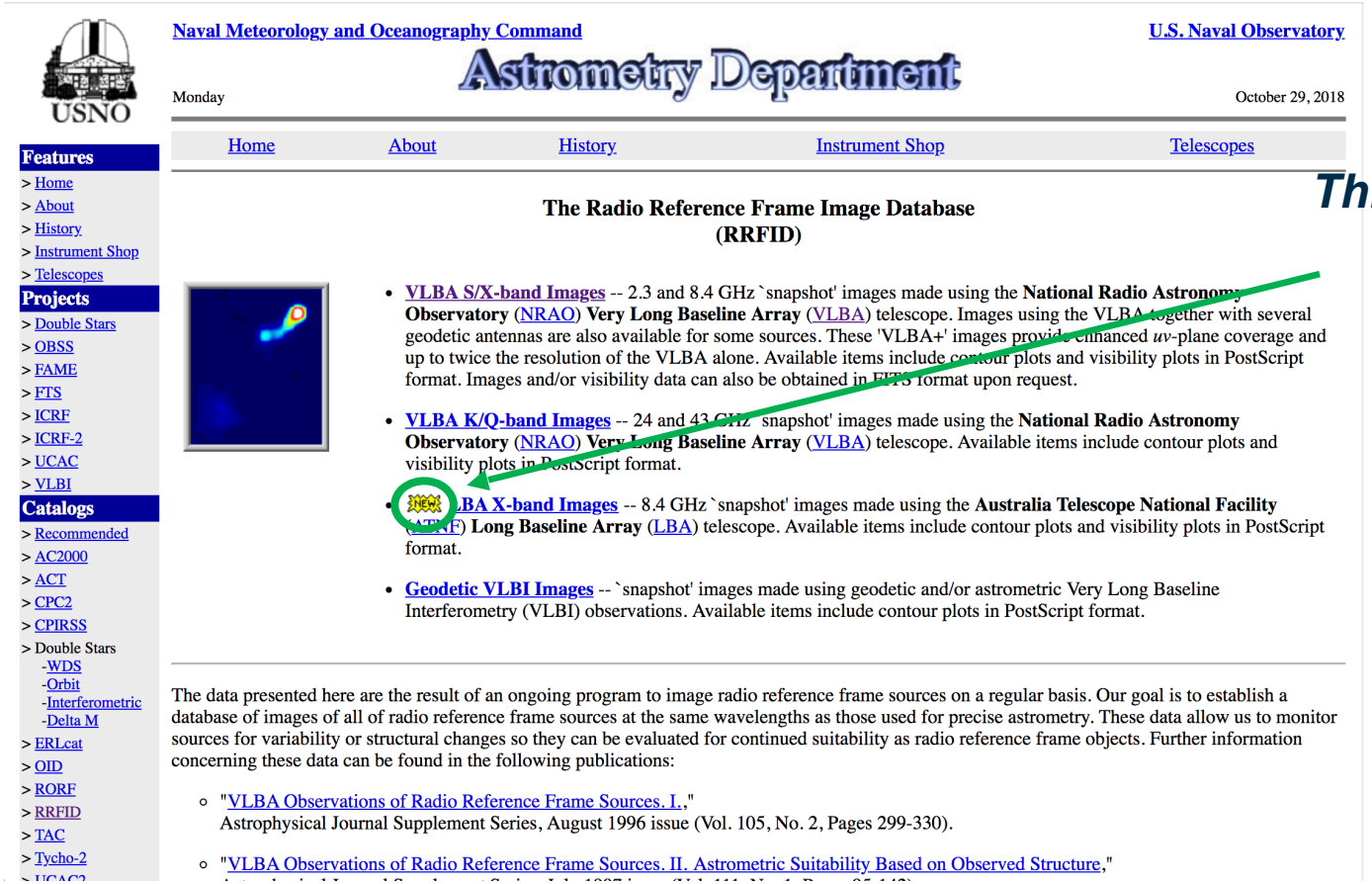
Statistics

Peak of distribution ~ 75 mJy/bm



Radio Reference Frame Image Database

Images of all sources in ICRF (685 available at S/X)



USNO

Naval Meteorology and Oceanography Command — U.S. Naval Observatory

Astrometry Department

Monday — October 29, 2018

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The Radio Reference Frame Image Database (RRFID)

- **VLBA S/X-band Images** -- 2.3 and 8.4 GHz `snapshot' images made using the **National Radio Astronomy Observatory** (NRAO) **Very Long Baseline Array** (VLBA) telescope. Images using the VLBA together with several geodetic antennas are also available for some sources. These 'VLBA+' images provide enhanced *uv*-plane coverage and up to twice the resolution of the VLBA alone. Available items include contour plots and visibility plots in PostScript format. Images and/or visibility data can also be obtained in FITS format upon request.
- **VLBA K/Q-band Images** -- 24 and 43 GHz `snapshot' images made using the **National Radio Astronomy Observatory** (NRAO) **Very Long Baseline Array** (VLBA) telescope. Available items include contour plots and visibility plots in PostScript format.
- NEW! **VLBA X-band Images** -- 8.4 GHz `snapshot' images made using the **Australia Telescope National Facility** (ATNF) **Long Baseline Array** (LBA) telescope. Available items include contour plots and visibility plots in PostScript format.
- **Geodetic VLBI Images** -- `snapshot' images made using geodetic and/or astrometric Very Long Baseline Interferometry (VLBI) observations. Available items include contour plots in PostScript format.

The data presented here are the result of an ongoing program to image radio reference frame sources on a regular basis. Our goal is to establish a database of images of all of radio reference frame sources at the same wavelengths as those used for precise astrometry. These data allow us to monitor sources for variability or structural changes so they can be evaluated for continued suitability as radio reference frame objects. Further information concerning these data can be found in the following publications:

- "VLBA Observations of Radio Reference Frame Sources. I.,"
Astrophysical Journal Supplement Series, August 1996 issue (Vol. 105, No. 2, Pages 299-330).
- "VLBA Observations of Radio Reference Frame Sources. II. Astrometric Suitability Based on Observed Structure,"

This is from 2004

Radio Reference Frame Image Database

Images of all sources in ICRF (685 available at S/X)

U.S. Naval Observatory — Astrometry Department

The Radio Reference Frame Image Database
S/X Band VLBA and VLBA+ Images

(This document is available with and without frames.)

Available items include PostScript format contour plots of Radio Reference Frame source images at frequencies of **2 GHz**, **8 GHz**, and **15 GHz**. Plots of visibility data in PostScript format are also available. Calibration, data analysis, and other information can be obtained by retrieving the files 0000CALIB.ps and 0000README (one for each observation epoch). Visibility data and images are available in FITS format upon request to afey@usno.navy.mil.

Animated GIF format images as well as estimates of the astrometric suitability for many of these sources, based on the images presented here, are also available.

If you make use of these data in any publication, please refer to the citation instructions.

Available Sources

0003+380, 0003-066, 0007+106, 0007+171, 0007-325, 0009+081, 0010+405, 0013-005, 0014+813, 0016+731, 0017+200, 0019+058, 0025+197, 0026+346, 0035+413, 0035-024, 0035-252, 0039+230, 0043-268, 0043-392, 0046+316, 0047+023, 0048-097, 0048-427, 0054+161, 0055+300, 0055-059, 0056-001, 0059+581, 0102+511, 0103+127, 0104-408, 0106+013, 0108+388, 0109+224, 0110-361, 0111+021, 0111+131, 0112-017, 0113-118, 0114-211, 0115-214, 0116+319, 0118-272, 0119+041, 0119+115, 0123+257, 0130-171, 0131-367, 0131-450, 0133+476, 0134+311, 0134+329, 0135-247, 0137+012, 0137+467, 0138-097, 0146+056, 0148+274, 0149+218, 0149-175, 0151+474, 0153+744, 0159+723, 0201+113, 0202+149, 0202+319, 0202-172, 0208-512, 0209+168, 0211+171, 0212+735, 0215+015, 0219+428, 0220-349, 0221+067, 0224+671, 0227-369, 0229+131, 0234+285,

2000JUL06	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2000OCT23	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2001JAN29	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2001MAY09	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2002JAN16	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2004FEB15	2 GHz , 8 GHz	2 GHz , 8 GHz
2004JUL14	2 GHz , 8 GHz	2 GHz , 8 GHz
2006JUL11	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2006SEP13	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2007JAN24	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2007JUN26	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2008JAN23	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2008MAY14	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+
2008SEP03	2 GHz+ , 8 GHz+	2 GHz+ , 8 GHz+

Newest image from 2008

Snapshot Images come from RDV sessions
Only image and UV plots available
(Other products available by request)

Fundamental Reference Image Data Archive (FRIDA)

ICRF images from all available sources

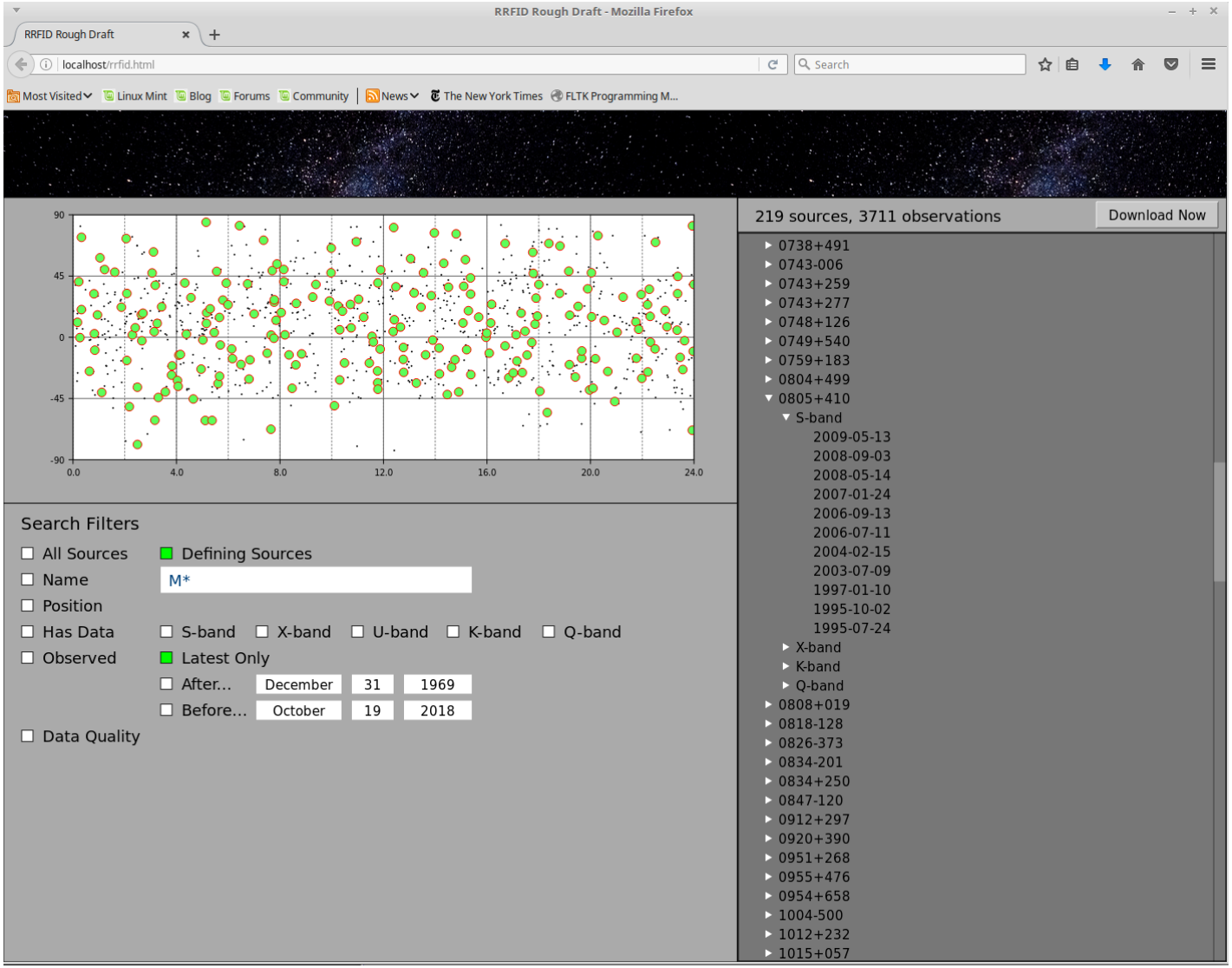
- Images from RDV experiments
- Images from USNO VLBA survey
- Cover S-band through Ka-Band

Other information

- .fits, model, log, par, contour plot, amplitude/uv distance plot

Easier Search

Fundamental Reference Image Data Archive (FRIDA)



Ongoing Work

Determine Source Structure Index/Correction Maps

- Suitability of source for astrometry

Explore Automated Flagging options!

- Some automated flagging algorithms available
  - Pieflag, AOFLAGGER, RFLAG, TFCROP

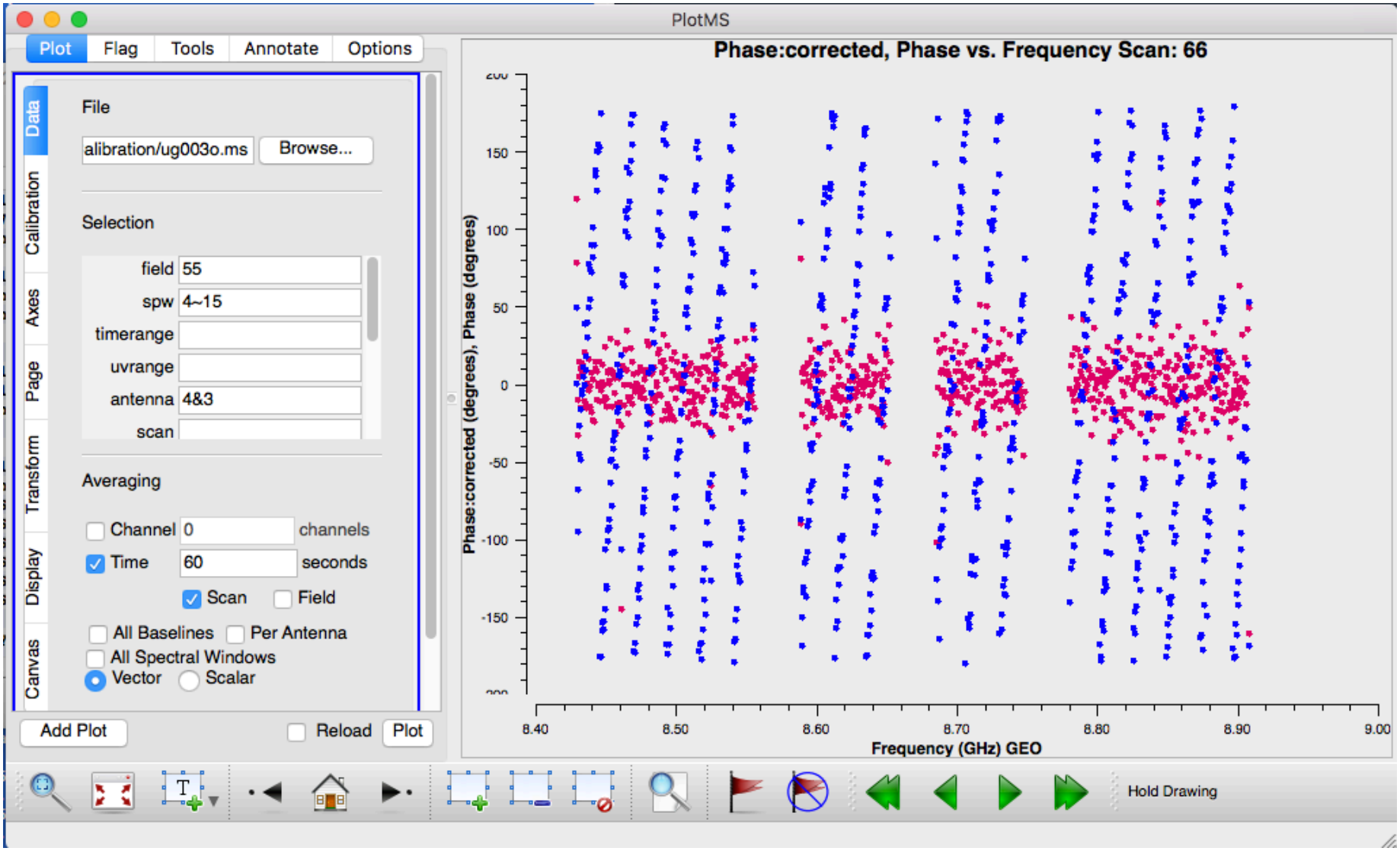
Continue imaging

- VLBA observations ongoing

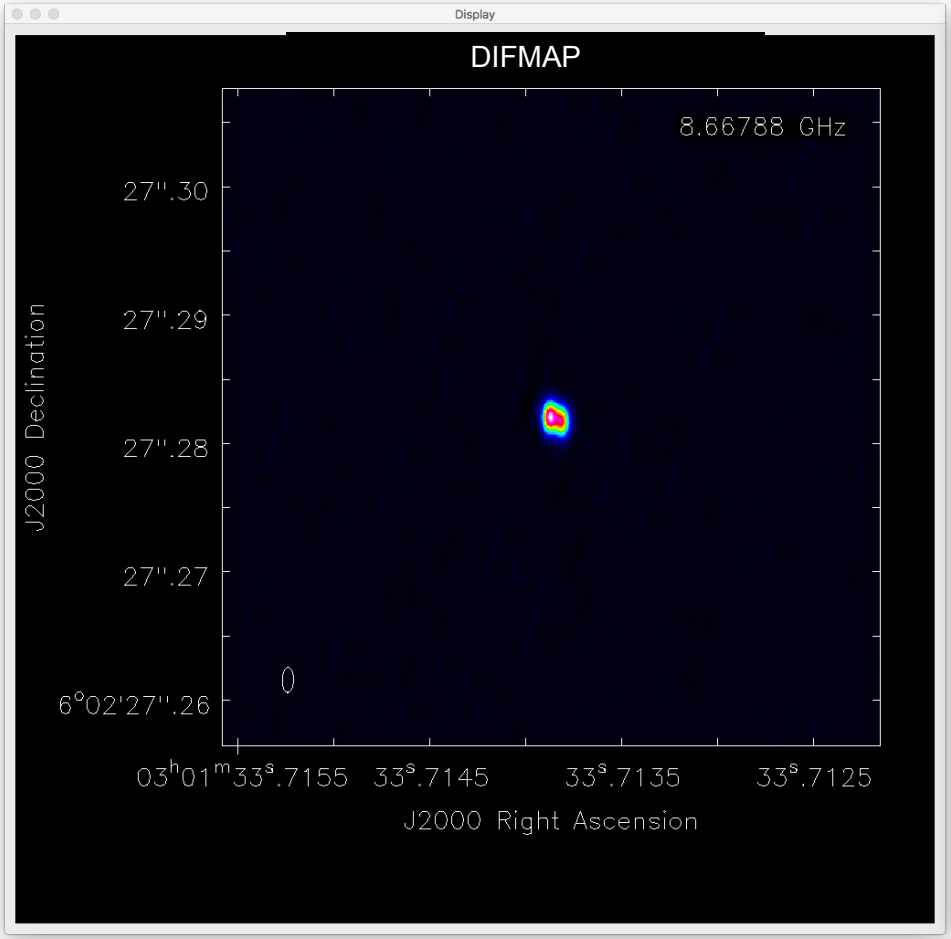
Explore Calibration and Imaging Options

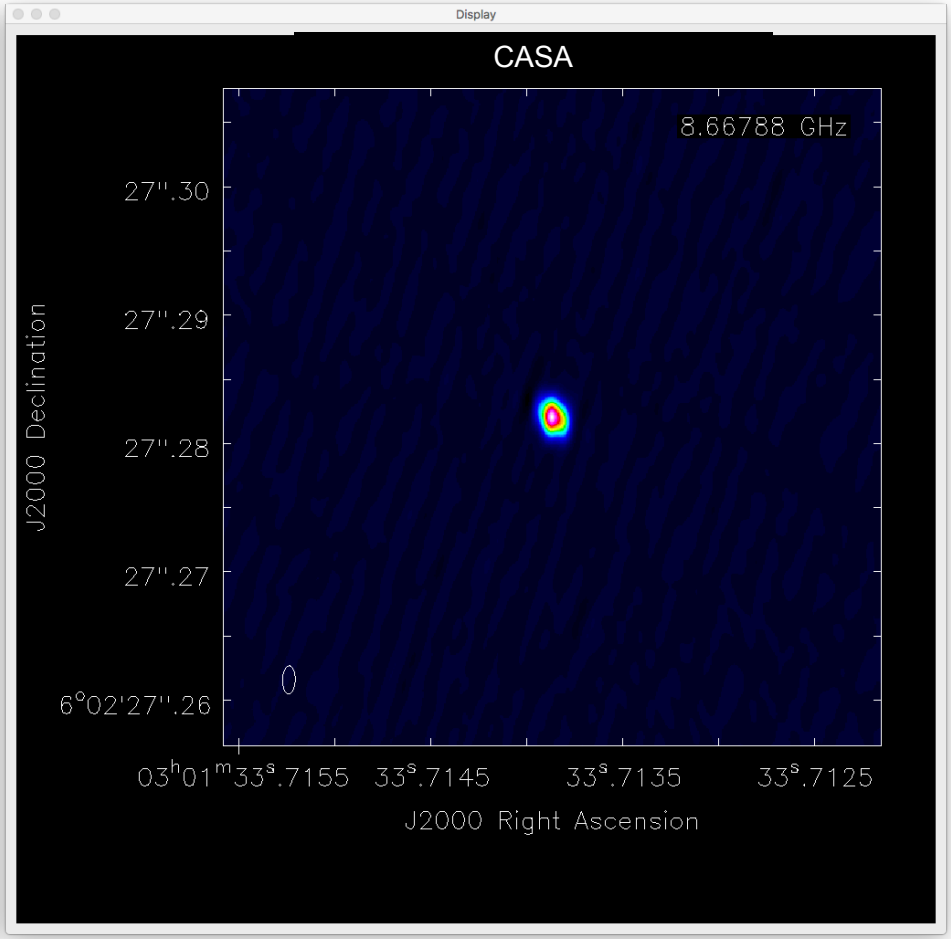
- AIPS
  - Requires too much interaction=Too much time for large survey
- CASA
  - Has automated imaging routine (tclean)
  - Self-Calibration automatically removes visibilities that don't fit with calibration model
  - ***New FRINGEFIT task implemented***; makes end-to-end calibration in CASA feasible

FRINGEFIT in CASA



Current Work





RMS=3.9x10^{-4} Flux Density=0.35 Jy

RMS=8.7x10^{-4} Flux Density=0.34 Jy

Conclusion

Using USNO VLBA time to observe ICRF sources

- More observations improve astrometric precision
- Images will tell us about source compactness/suitability as calibrator and variability
- Cover >3000 objects included in ICRF3
- S-/X-band Observations ongoing

All data will be publicly available

- Searchable database
- Include contour and amplitude/uv-distance plots
- Information to reproduce images
- Updated database coming soon

References

Thompson, A.R., Moran, J.M. & Swensen, G.W. 2004, "Interferometry and Synthesis in Radio Astronomy" 2nd edition (Wiley-VCH)

Synthesis Imaging workshop proceedings

- Perley, R.A., Schwab, F.R., Bridle, A.H., eds. 1989, ASP Conf. Series 6, "Synthesis Imaging in Radio Astronomy" (San Francisco: ASP)
  - Ch. 6: Imaging (Sramek & Schwab), Ch. 8: Deconvolution (Cornwell)
- http://www.aoc.nrao.edu/events/synthesis
  - Imaging and Deconvolution lectures by Cornwell 2002, Bhatnagar 2004, 2006

For more information see Synthesis Imaging Workshop Lectures (NRAO)