Pushing for higher precision VLBI astrometry of radio stars

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Stellar Radio Emission - Why VLBI?

- Study Emission Mechanism
  - Good sensitivity
    - EVN achieves 20 μJy in one hour at L-band
    - Still requires non-thermal emission
  - Polarization of the emission (H/V and L/R)
  - Lightcurve to study flares
  - Spectral propeprties
- High astrometric accuracy
  - Comparable to Gaia
    - Match optical against radio position
  - Resolve close binaries
  - Sensitive to face-on orbits
    - Complementary to RV and transit methods
    - Find companions through reflex motion

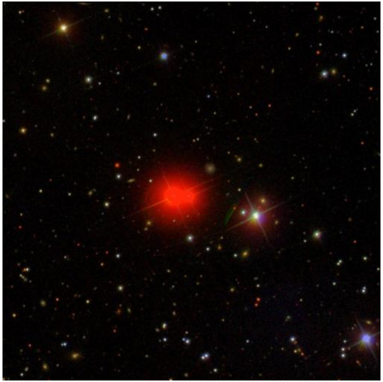
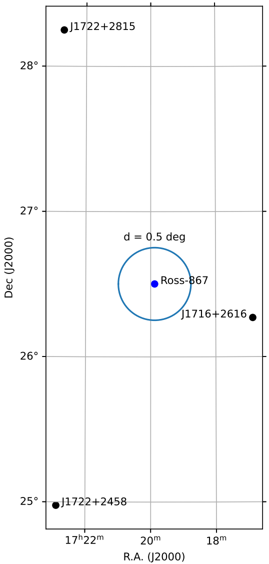
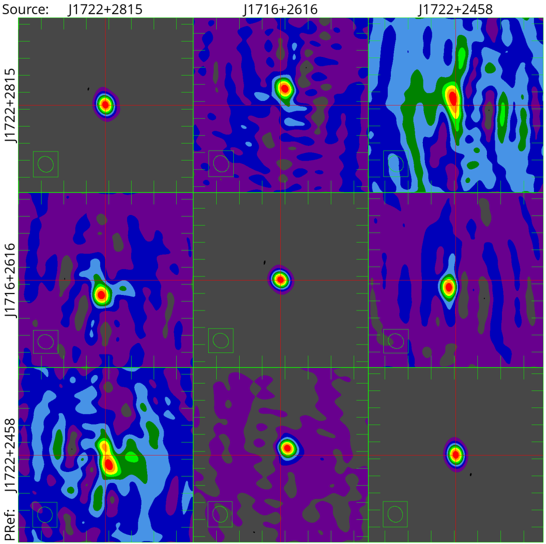


Image Courtesy SDSS DR16

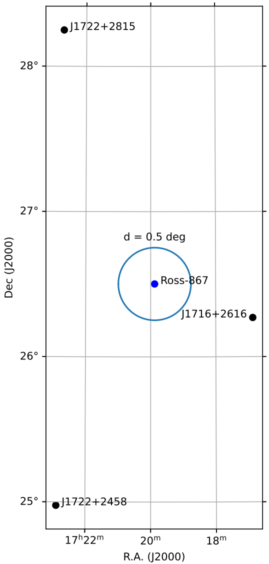
Ross 867/868



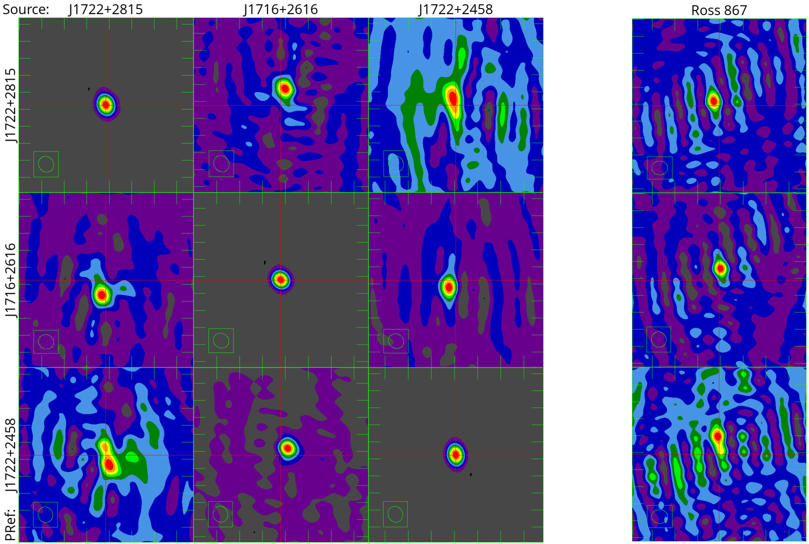


- A&P selfcal on phase reference targets
- Imaged against each other
- Scale:
  Dec. ticks: 5 mas
- Note the symmetries

Ross 867/868



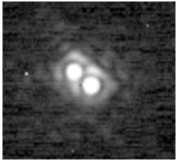
J1722+2815
28°
27°
d = 0.5 deg
Ross-867
J1716+2616
26°
25°
J1722+2458
Dec (J2000)
17^h22^m
20^m
18^m
R.A. (J2000)



Source:
J1722+2815
J1716+2616
J1722+2458
Ross 867
J1722+2815
J1716+2616
J1722+2458
PRef:

GJ3789A/B and RIPL

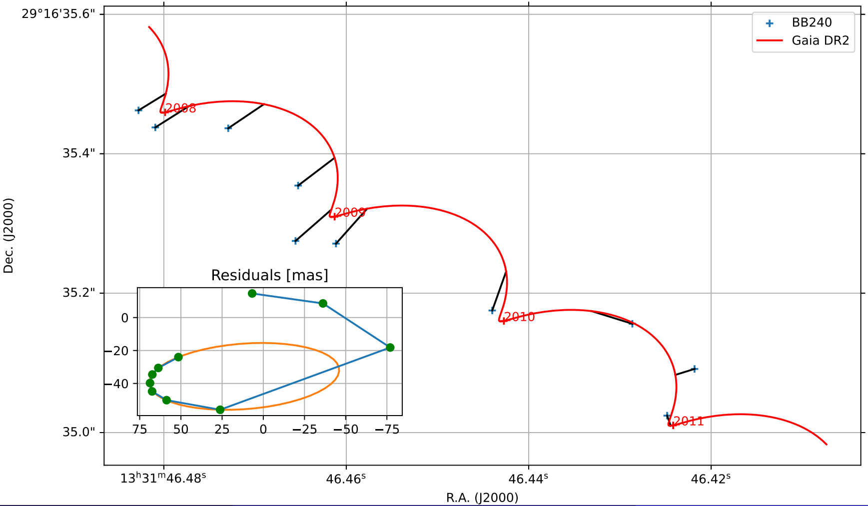
- Close M dwarf binary, V* DG CVn, 2x M4Ve
  - Only one is radio loud
  - Optical separation up to 0.2” (projected)
- Observed 2007 - 2010 in G. Bowers ‘RIPL’ project
  - Radio Interferometric Planet Search
  - VLBA X-band
  - Detected in 10 out of 12 epochs
  - RIPL only included stars closer than 10 pc (or did they?)
  - VLBI results remained unpublished due to puzzling astrometric residuals



Keck (AO + NIRC2) image courtesy of KOA

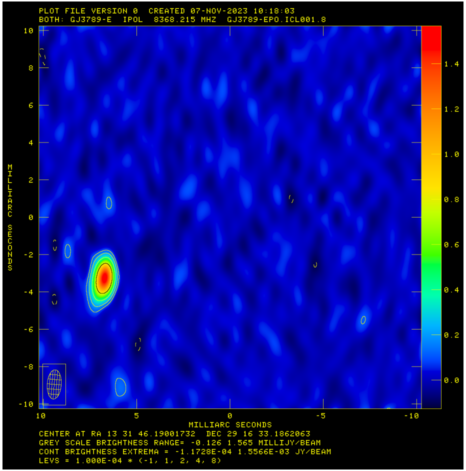
GJ3789 in Gaia

- DR2: $\varpi = 54.69 \pm 0.33\,\text{mas}$, $\text{PM}_{\alpha\cos\delta} = -232.8 \pm 0.5\,\frac{\text{mas}}{\text{year}}$, $\text{PM}_{\delta} = -149.8 \pm 0.3\,\frac{\text{mas}}{\text{year}}$
- DR3: only photometry remains...



New VLBA observations: BB451

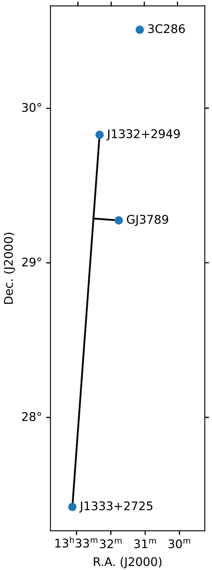
- Astrometric follow-up on GJ3789 A/B / DG CVn
- Awarded 4x7 hours 4Gb/s X-band
- Full polarization to measure circular polarization



GJ3789 detection in BB451A

MultiView Interpolation

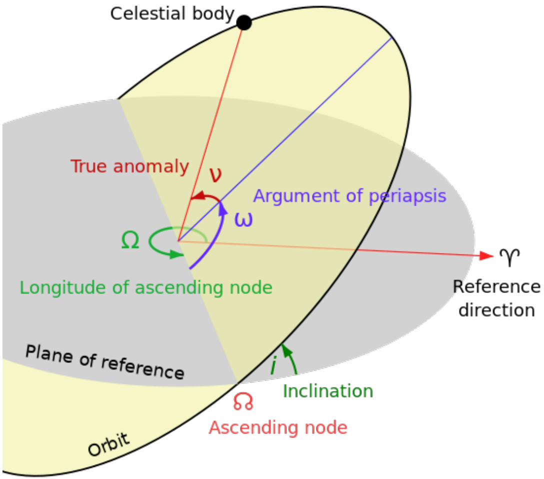
- Calibrate on J1333+2725 (435 mJy)
- From there, calibrate on J1332+2949 (18 mJy)
- Interpolate solutions to GJ3789 intersection
    - Factor 0.775
    - Scale phase and gain separately
    - Implemented in ParselTongue
- Result: Better flux and SNR on GJ3789, scaled position shift
    - SNR: PR1: 44, PR2: 48, Interpolated: 50.
- To Do: Verify astrometric scatter decreases in multiple MV epochs



Fitting a binary orbit - MCMC

12 Parameter model

- Position (R.A. and Dec.)
- Proper motion (μ_α, μ_δ)
- Parallax (ϖ)
- Binary Period (P)
- Semi-Major Axis (a) [mas]
- Ellipticity (e)
- Inclination (i)
- Argument of Periapsis (ω)
- Longtitude of ascending node (Ω)
- Periapsis epoch (T0)



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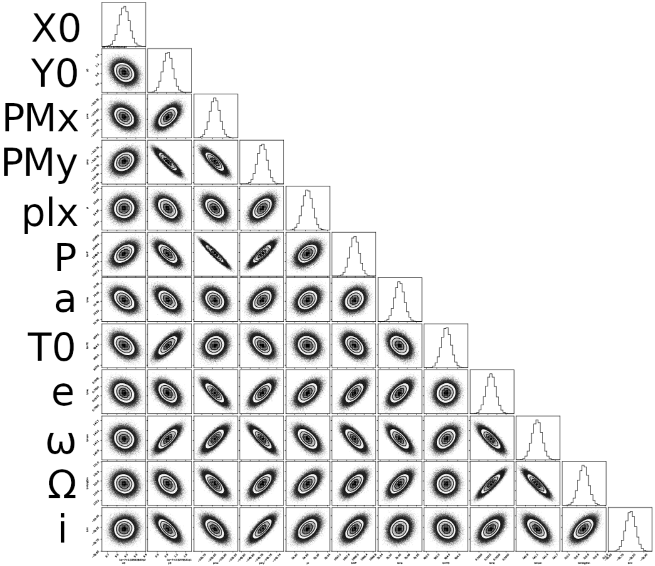
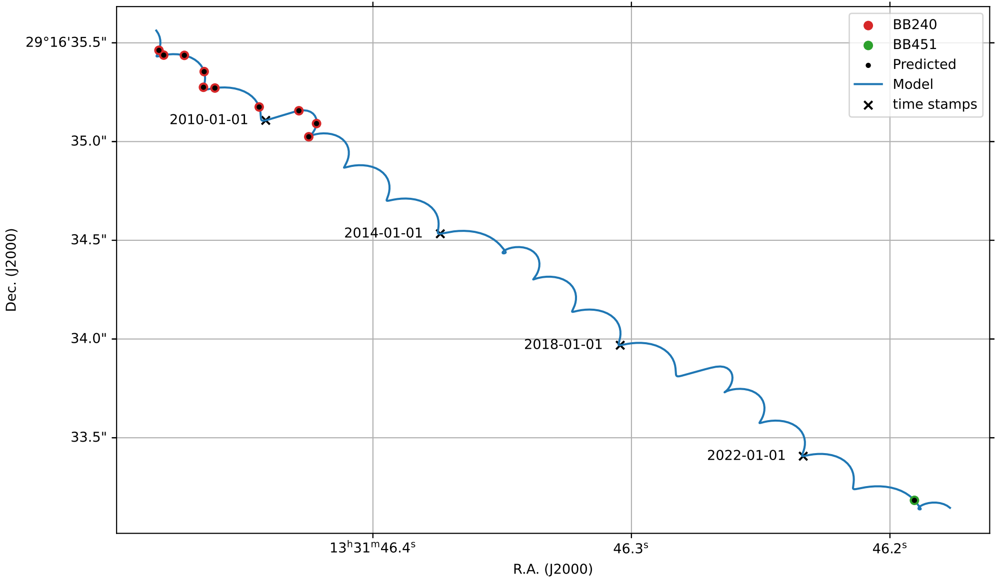


Updated Orbital Model



Orbital Model - Preliminary Data

Par.	Value	Uncert.	Unit	
R.A.	202.9436479	1e-8	deg	
Dec.	29.27652107	1e-8	deg	
$PM_{\alpha \cos \delta}$	-233.63	0.02	mas/year	
PM_{δ}	-143.77	0.01	mas/year	
ϖ	54.97	0.02	mas	(18.193 pc)
a	70.411	0.04	mas	
ω	141.2	0.15	deg	
Ω	110.5	0.1	deg	
i	-50.57	0.06	deg	
e	0.7619	8e-4		
P	1648.0	0.2	days	(4.5 years)
T0	903.9	0.2	days	

epoch = JD 2454382.2757

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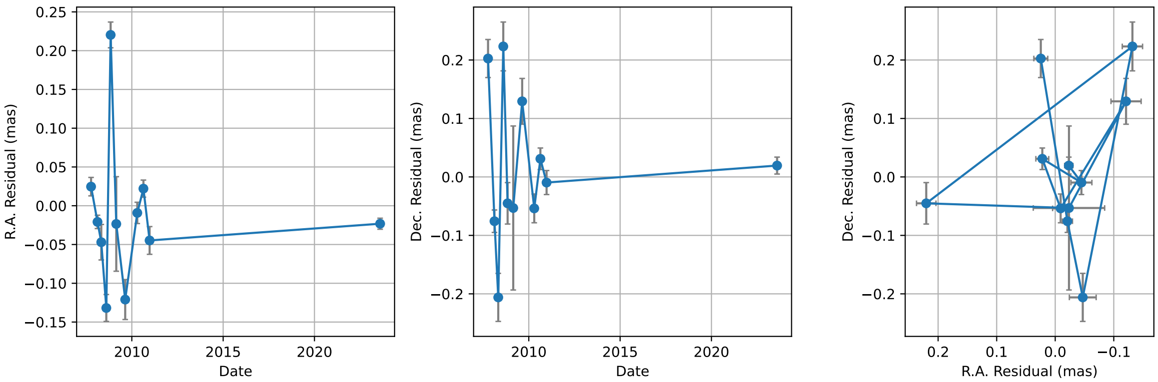
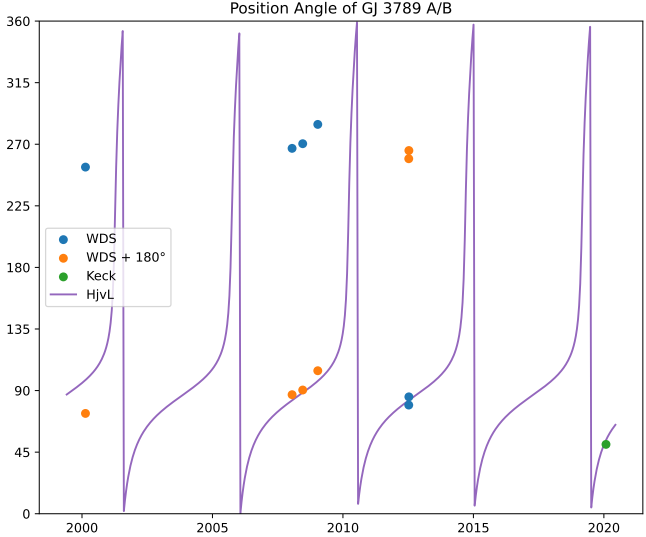
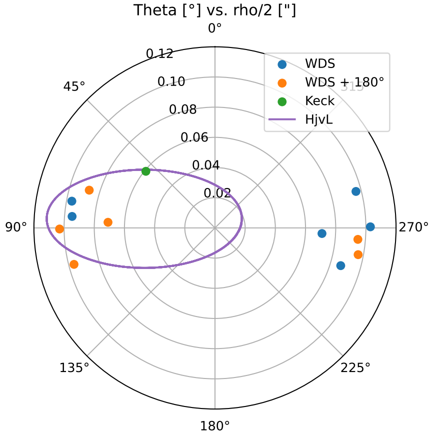
All values to at least 4 significant digits

Astrometric Residuals - Preliminary



The Optical Picture

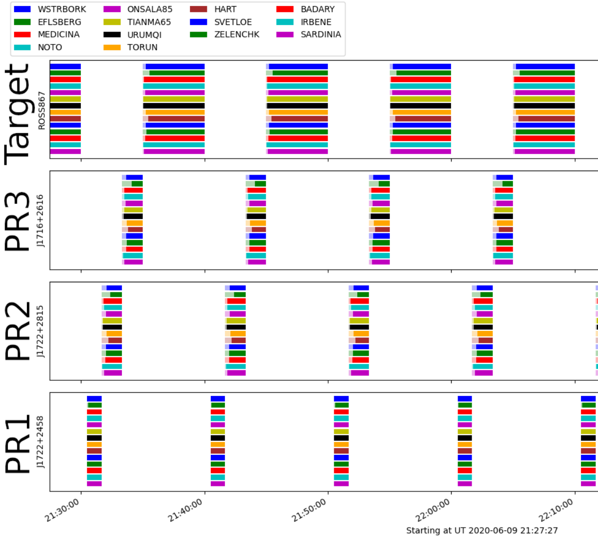




Optical relative astrometry data courtesy of the Washington Double Star Catalog, maintained by the USNO
Keck data (AO + NIRC2) courtesy of KOA

VLBI with next gen arrays

- Chasing phaserefs = loss in sensitivity
  - Target + 3 phaserefs = 50% loss
  - Additional loss due to slewing
  - Cycle time may not match ionospheric turbulence
- More phaserefs is preferable
  - Consistency check
  - Higher order solutions
- Ideal: in-beam phaserefs
  - Smaller dishes
  - Beamform N local small dishes to improve sensitivity
  - Beams for target + at least 3 PR
  - Cheaper than a single large dish
  - High bandwidth



Conclusions, and a puzzle

- VLBI astrometry can be a useful tool to study stellar systems
- MultiView to mitigate ionospheric turbulence
  and increase astrometric accuracy
- Full and accurate 5D astrometry solution for GJ3789 A/B

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