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GLOSTAR

A GLObal view on STAR formation:

VLBI Survey of compact sources in the Galactic Plane

A. Brunthaler, A. Pushkarev, Y. Kovalev, T. Koryukova, A. Plavin,

K. Menten, S. Dzib, S. Medina, H. Nguyen, M. Rugel, Y. Gong, A. Yang, G. Ortiz-León, R. Dokara, S. Khan, F. Wyrowski, B. Winkel, W. Reich, P. Müller (MPIfR); P. Atri (Astron); J. Urquhart (Kent); B. Cotton (NRAO); J. Pandian (Hawaii); N. Roy (IIoS); C. Carrasco-Gonzales (UNAM); H.Beuther (MPA); T. Csengeri (CNRS); C. Murugeshan (Swinburne); M. Reid (CfA)

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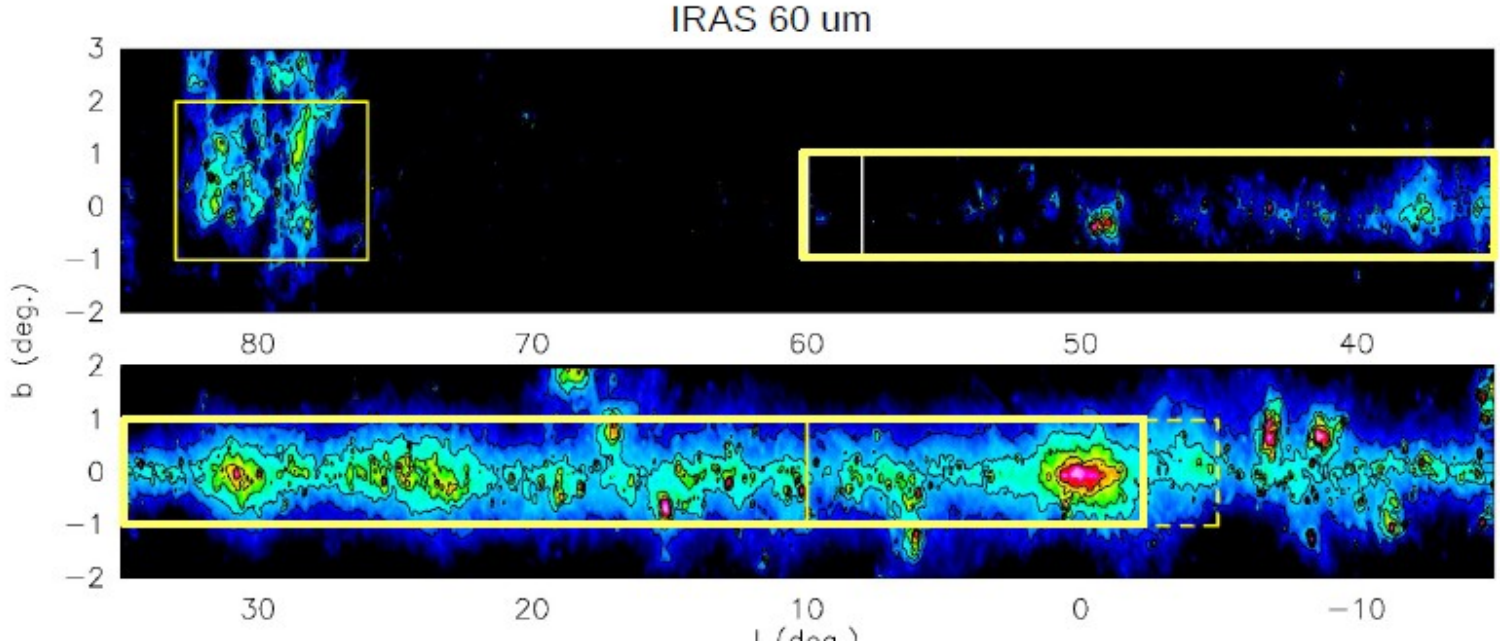
GLOSTAR Galactic Plane Survey

Details of GLOSTAR observations:

- C-band (4-8 GHz), 2x1 GHz continuum (full pol.), 6.7 GHz methanol masers, 4.8 GHz formaldehyde, and 7 Radio Recombination Lines
- coverage from **l = -2º to +60º |b|<1º** and **l=+76º to +83º b=-1º to +2º**
- in D-configuration (**18" resolution**) and B-configuration (**1.0" resolution**)
- Effelsberg 100-m observations for zero spacings



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- in D-configuration (**18" resolution**) and B-configuration (**1.0" resolution**)
- Effelsberg 100-m observations for zero spacings
- 49,463 individual pointings in total, 800.5 hours observing time, ~ 42 TB raw data
- Calibration and Imaging:

  - **Continuum:** Obit (Cotton 2008), image pointings separately

  - **Spectral lines:** CASA, first only dirty images for methanol and formaldehyde

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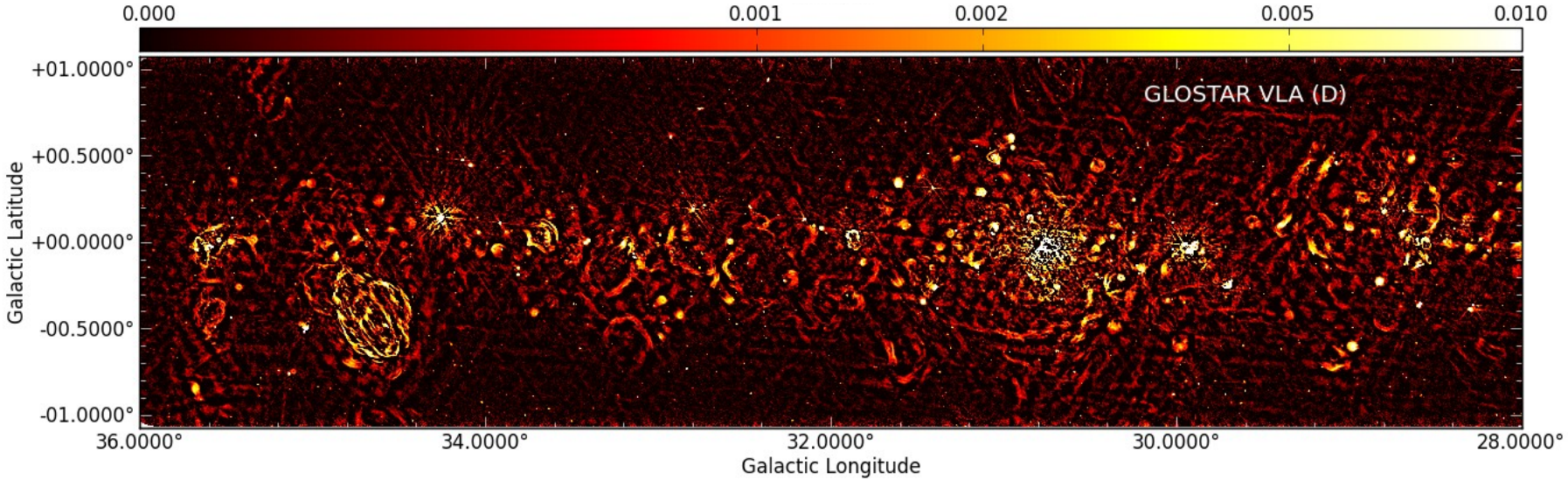
GLOSTAR Galactic Plane Survey

- **Pilot Region: 28° < l < 36°; |b| < 1°**: ~ 5500 pointings



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GLOSTAR Galactic Plane Survey

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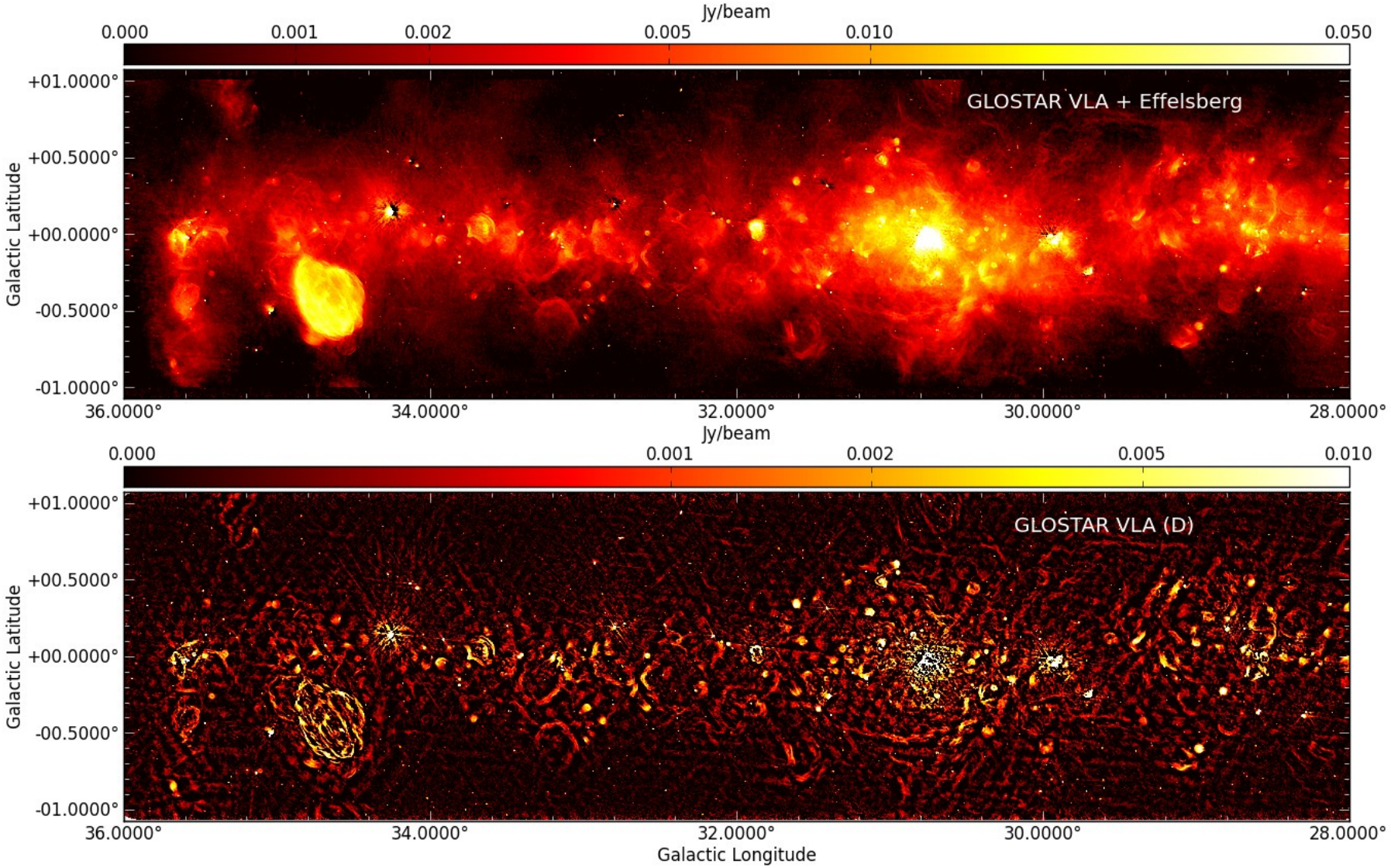

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GLOSTAR Galactic Plane Survey

First 12 papers published!

1 2019A&A...627A.175M 2019/07 cited: 34
GLOSTAR: Radio Source Catalog I. 28° < ℓ < 36° and |b| < 1°
Medina, S. -N. X.; Urquhart, J. S.; Dzib, S. A. *and 18 more*

2 2021A&A...651A..85B 2021/07 cited: 41
A global view on star formation: The GLOSTAR Galactic plane survey. I. Overview and first results for the Galactic longitude range 28° < l < 36°
Brunthaler, A.; Menten, K. M.; Dzib, S. A. *and 20 more*

3 2021A&A...651A..86D 2021/07 cited: 31
A global view on star formation: The GLOSTAR Galactic plane survey. II. Supernova remnants in the first quadrant of the Milky Way
Dokara, R.; Brunthaler, A.; Menten, K. M. *and 17 more*

4 2021A&A...651A..87O 2021/07 cited: 17
A global view on star formation: the GLOSTAR Galactic plane survey. III. 6.7 GHz methanol maser survey in Cygnus X
Ortiz-León, Gisela N.; Menten, Karl M.; Brunthaler, Andreas *and 16 more*

5 2021A&A...651A..88N 2021/07 cited: 17
A global view on star formation: The GLOSTAR Galactic plane survey. IV. Radio continuum detections of young stellar objects in the Galactic Centre region
Nguyen, H.; Rugel, M. R.; Menten, K. M. *and 19 more*

6 2022A&A...666A..59N 2022/10 cited: 17
A global view on star formation: The GLOSTAR Galactic plane survey. V. 6.7 GHz methanol maser catalogue
Nguyen, H.; Rugel, M. R.; Murugeshan, C. *and 15 more*

7 2023A&A...670A...9D 2023/02 cited: 13
A global view on star formation: The GLOSTAR Galactic plane survey. VI. Radio Source Catalog II: 28° < ℓ < 36° and |b| < 1°, VLA B-configuration
Dzib, S. A.; Yang, A. Y.; Urquhart, J. S. *and 20 more*

8 2023A&A...671A.145D 2023/03 cited: 12
A global view on star formation: The GLOSTAR Galactic plane survey. VII. Supernova remnants in the Galactic longitude range 28° < l < 36°
Dokara, R.; Gong, Y.; Reich, W. *and 19 more*

9 2023A&A...678A.130G 2023/10 cited: 9
A global view on star formation: The GLOSTAR Galactic plane survey. VIII. Formaldehyde absorption in Cygnus X
Gong, Y.; Ortiz-León, G. N.; Rugel, M. R. *and 21 more*

10 2023A&A...680A..92Y 2023/12 cited: 5
A global view on star formation: The GLOSTAR Galactic plane survey. IX. Radio Source Catalog III: 2° < ℓ < 28°, 36° < ℓ < 40°, 56° < ℓ < 60° and |b| < 1°, VLA B-configuration
Yang, A. Y.; Dzib, S. A.; Urquhart, J. S. *and 20 more*

11 2024arXiv240705770K 2024/07 cited: 2
A global view on star formation: The GLOSTAR Galactic plane survey X. Galactic HII region catalog using radio recombination lines
Khan, S.; Rugel, M. R.; Brunthaler, A. *and 17 more*

12 2024arXiv240712585M 2024/07 cited: 1
A global view on star formation: The GLOSTAR Galactic plane survey. XI. Radio source catalog IV: $2^\circ < \ell < 28^\circ$, $36^\circ < \ell < 60^\circ$ and $|b| < 1^\circ$
Medina, S. -N. X.; Dzib, S. A.; Urquhart, J. S. *and 17 more*


Rohit Dokara


G. Ortiz-León


Yan Gong


Michael Rugel


Sac Medina


Sergio Dzib


Aiyuan Yang


Hans Nguyen


Sarwar Khan

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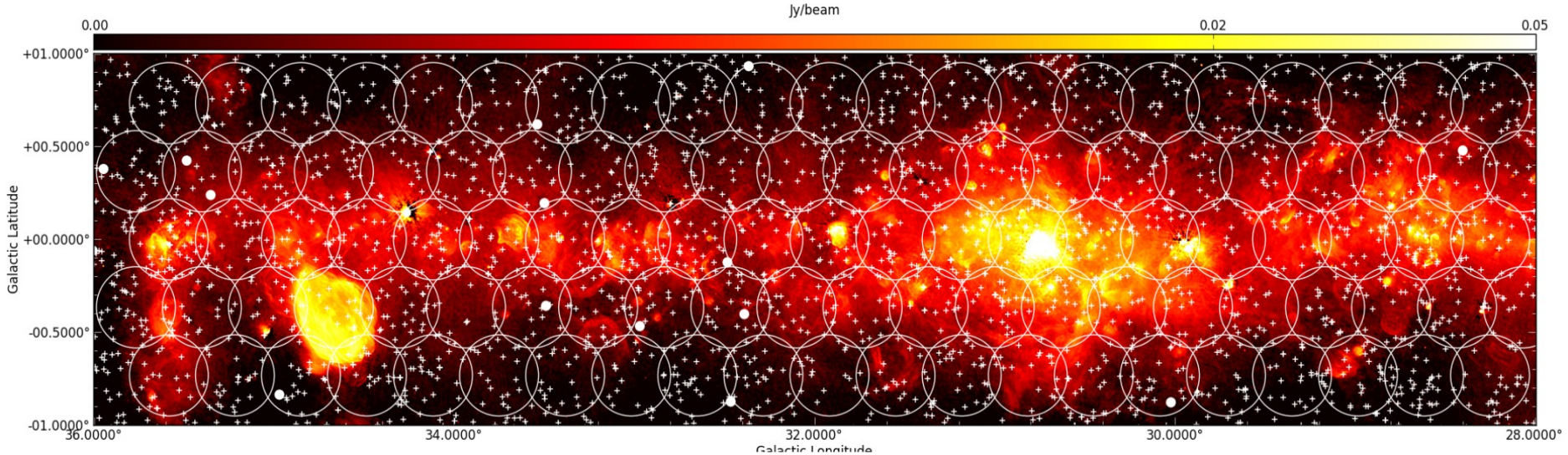
VLBA observations of compact sources

An unbiased VLBI survey of compact sources in the Galactic Plane

Goals:

- Search for proper motions to find Galactic sources
  - in particular black hole X-ray binaries (see talk by P. Atri yesterday)
- Find radio stars with non-thermal radio emission for Gaia link (see poster by S. Dzib)
- Find denser grid of background calibrators for astrometry
- Investigate the scattering properties of the Milky Way



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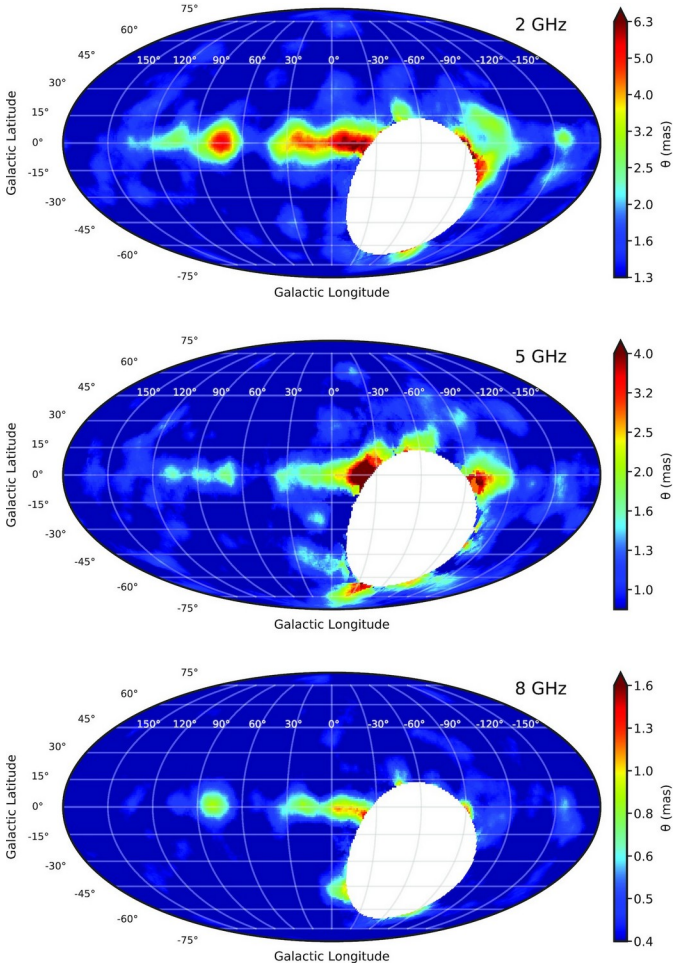
VLBA observations of compact sources

An unbiased VLBI survey of compact sources in the Galactic Plane



(Koryukova et al. 2022, MNRAS 515, 1736)

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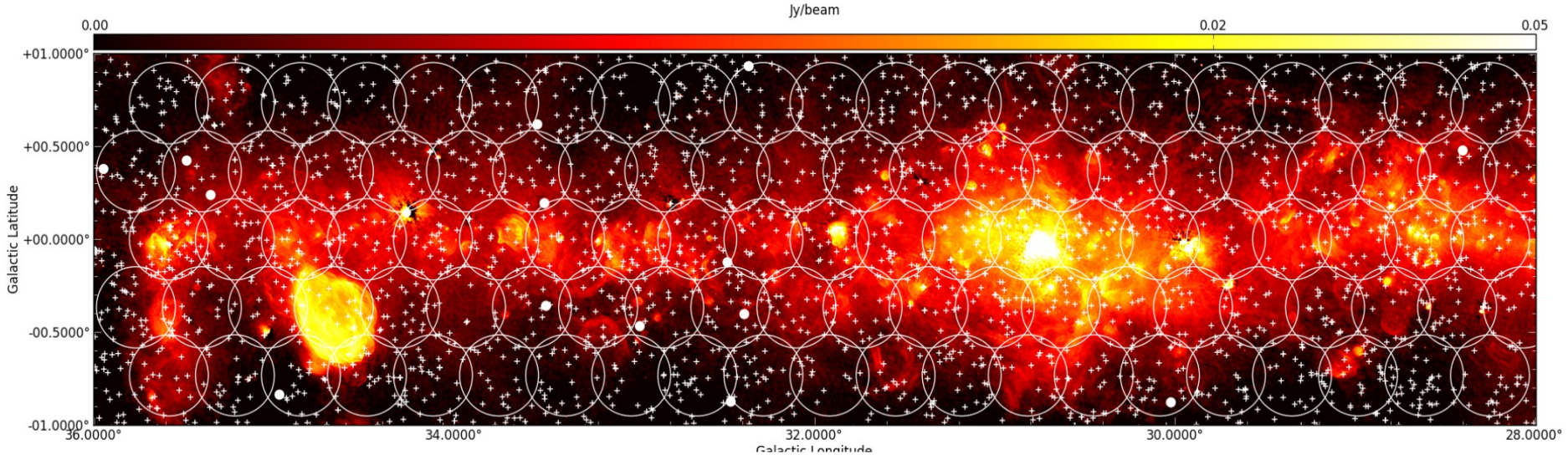
VLBA observations of compact sources

An unbiased VLBI survey of compact sources in the Galactic Plane

Observations:

- VLBA L-band (1.4-1.8 GHz), 2 Gbps, 13 min on source, ~75-100 μJy/beam
- 107 pointings with multiple phase centers with ~12 sources each
- 16 sq. deg = 8° x 2°; 28° < l < 36°; |b| < 1°
- 2 epochs separated by one year



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VLBA observations of compact sources

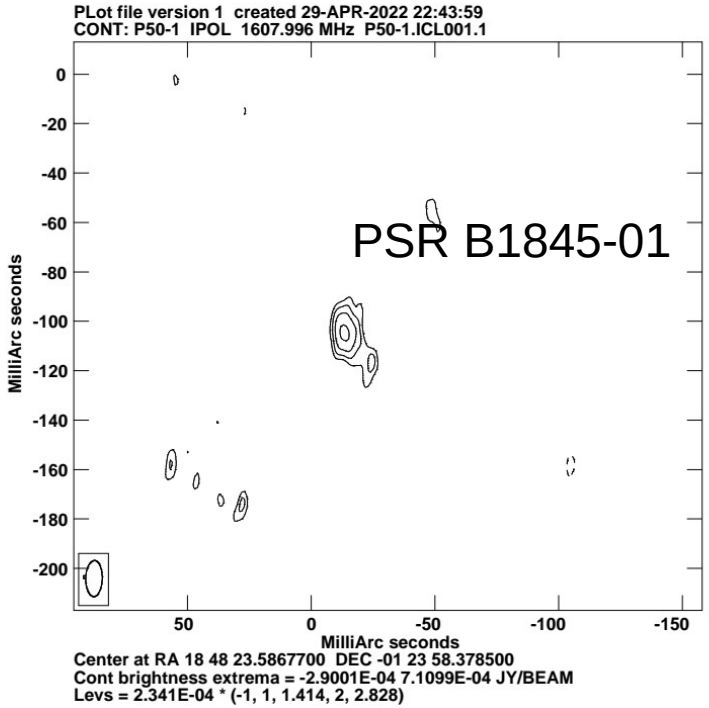
Imaging:

- Imaging 1211 unique sources

VLBA observations of compact sources

Imaging:

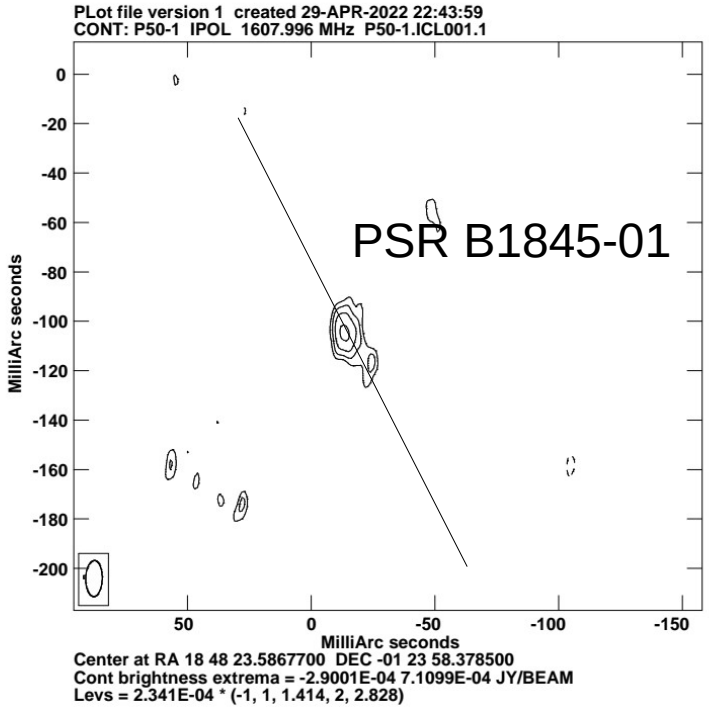
- Imaging 1211 unique sources resulted in only one detection
- turned out to be a pulsar at distance of 3.5 - 4.4 kpc



VLBA observations of compact sources

Imaging:

- Imaging 1211 unique sources resulted in only one detection
- turned out to be a pulsar at distance of 3.5 - 4.4 kpc
- much lower detection rate than away from plane (Deller & Middelberg 2014)
- several sources with higher noise.
- Is very strong scattering the reason?



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VLBA observations of compact sources

Change in strategy:

- Second epoch at 2.3 GHz (87 sources) and 4.8 GHz (186 souces)
- Standard imaging still yields no new detections
- UV plots explain what is going on!

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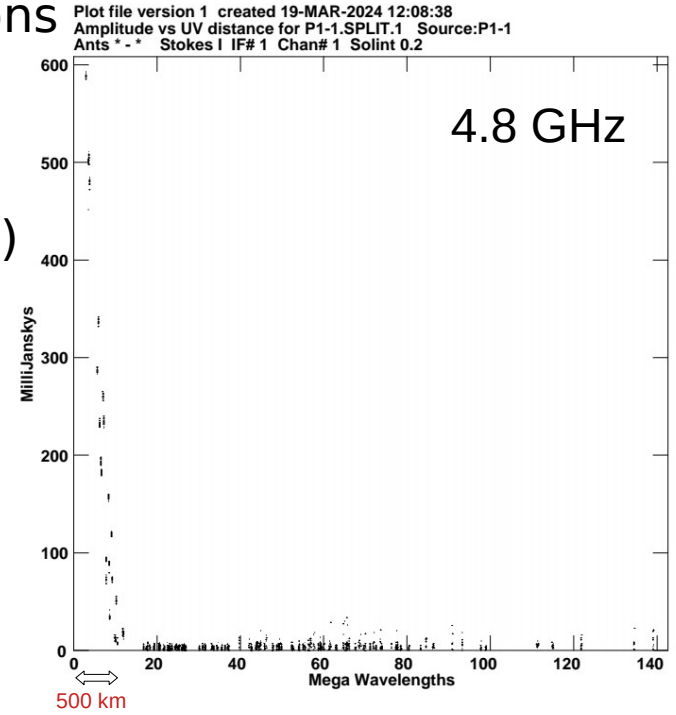
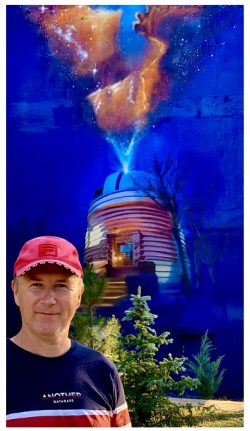
VLBA observations of compact sources

Change in strategy:

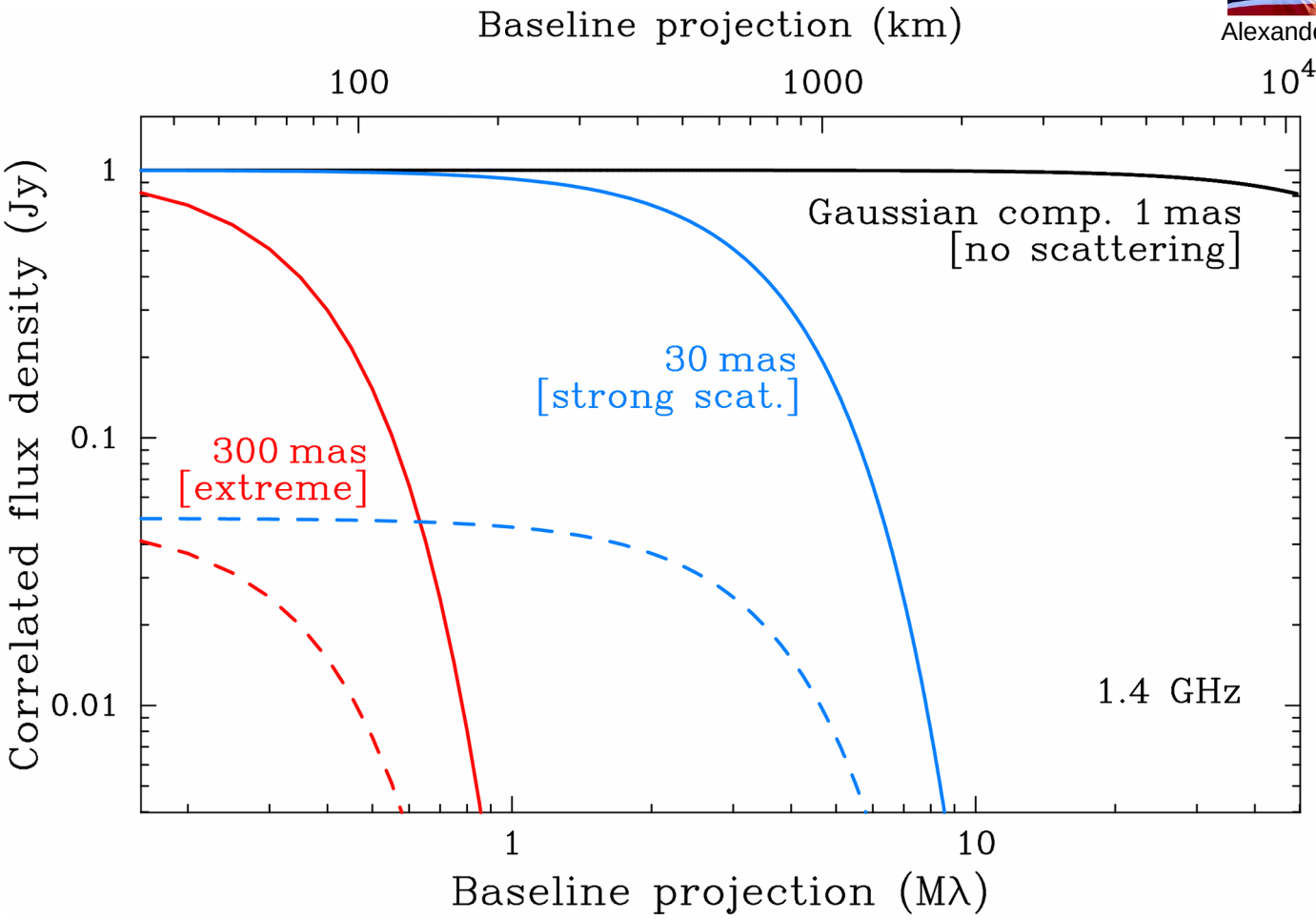
- Second epoch at 2.3 GHz (87 sources) and 4.8 GHz (186 souces)
- Standard imaging still yields no new detections
- UV plots explain what is going on!
- Amplitude drops to 0 within 10 Mλ (~500 km)
- VLBA has only 2 baselines below 500 km!



VLBA observations of compact sources


Alexander Pushkarev

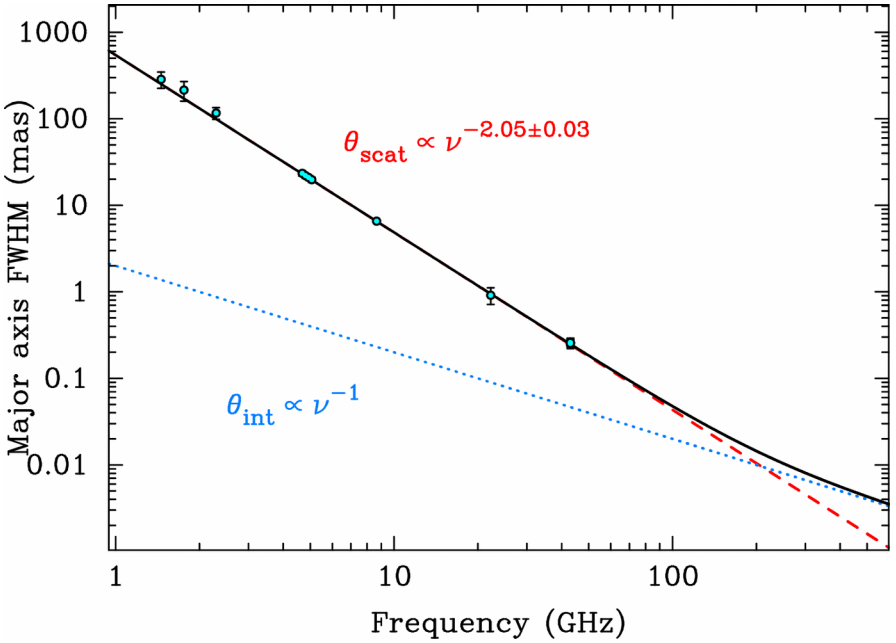
- Extreme scattering clearly responsible
- Even worse for weak sources (dashed lines)

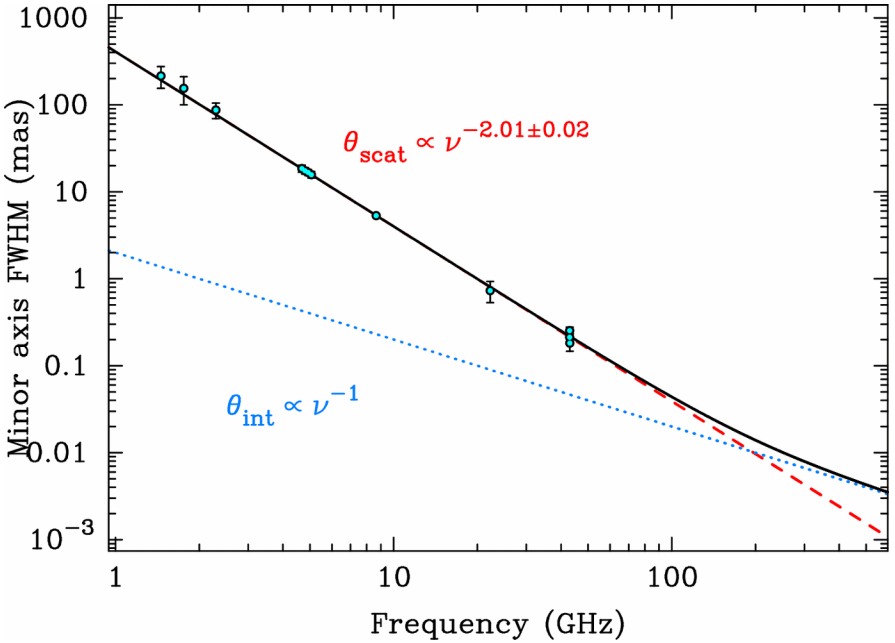


VLBA observations of compact sources

preliminary

- Size frequency relation for J1851+0035 at b=0.2° (incl. archival data)
- Already known to be strongly scattered (Lazio 2004, ApJ 613, 1023)





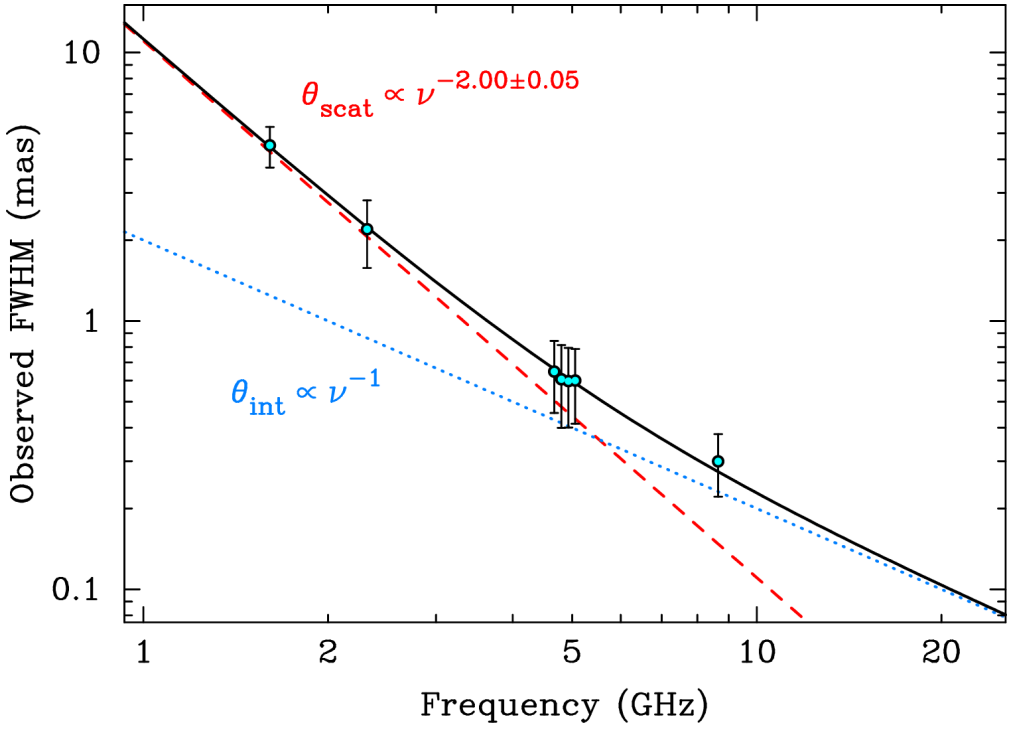
$$\theta^2_{\rm observed} = \left(\theta_{\rm scat}\nu^{k}\right)^2 + \left(\theta_{\rm int}\nu^{-1}\right)^2$$

- Strong anisotropic scattering
- Dominates up to 100-200 GHz

VLBA observations of compact sources

preliminary

- Phase calibrator at b=4.6° shows also scattering



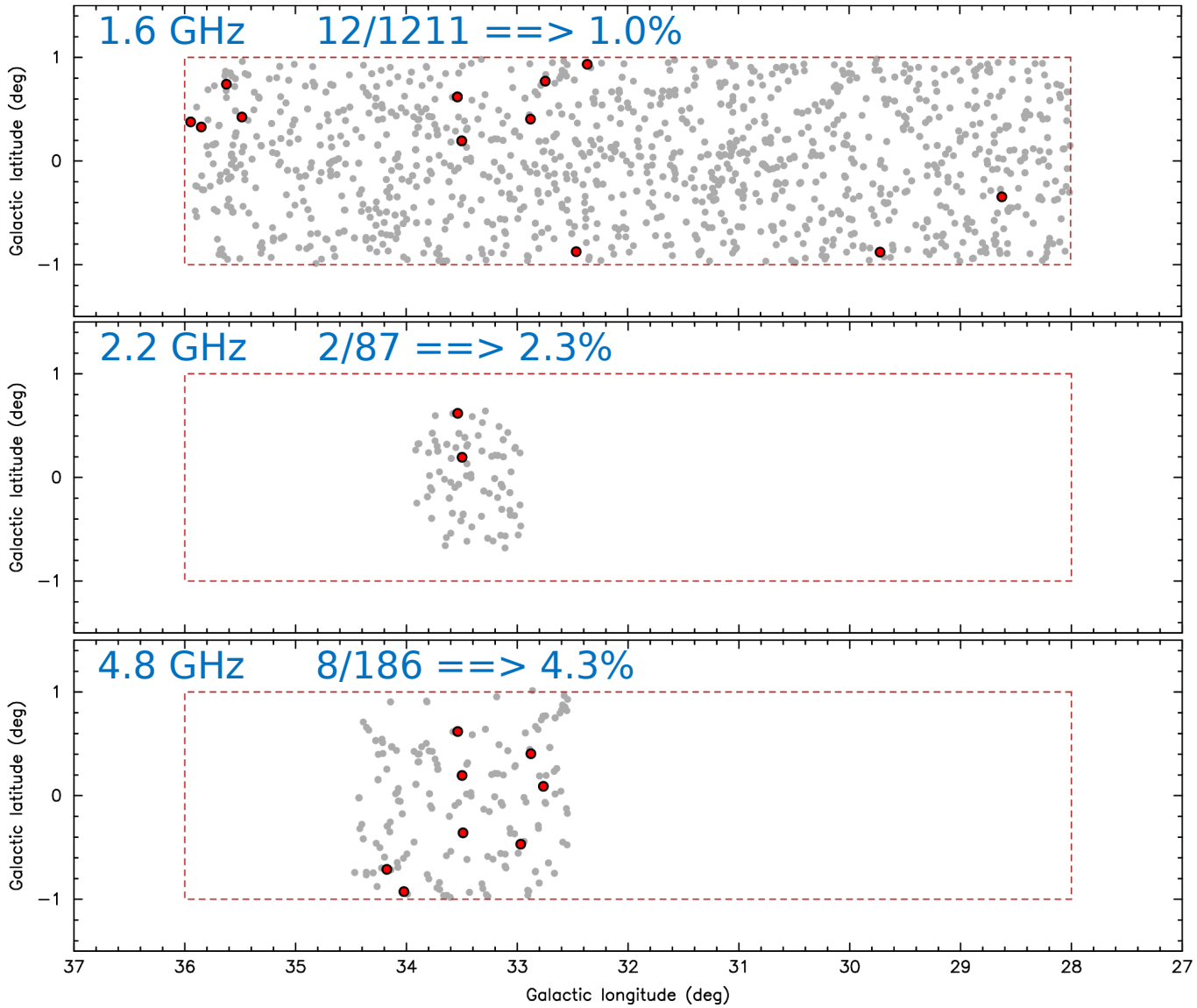
$$\theta^2_{\rm observed} = \left(\theta_{\rm scat}\nu^{k}\right)^2 + \left(\theta_{\rm int}\nu^{-1}\right)^2$$

- no anisotropy
- Dominates up 5 GHz

VLBA observations of compact sources

preliminary

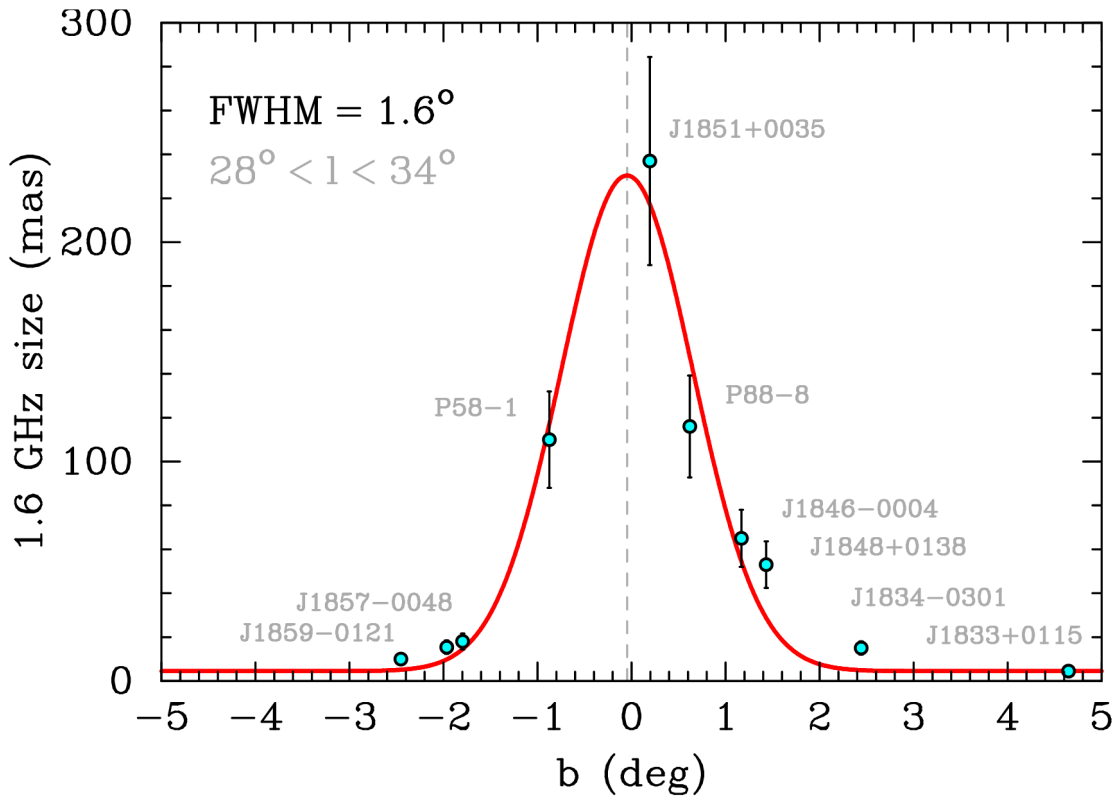
- Inspection of uv plots gives more detections (with more tentative)



VLBA observations of compact sources

preliminary

- Scattering sizes at different Galactic latitudes



- All sources scattered but with different power – increase to b = 0°
- Effective with of scattering band ~ 1.5° - 2°

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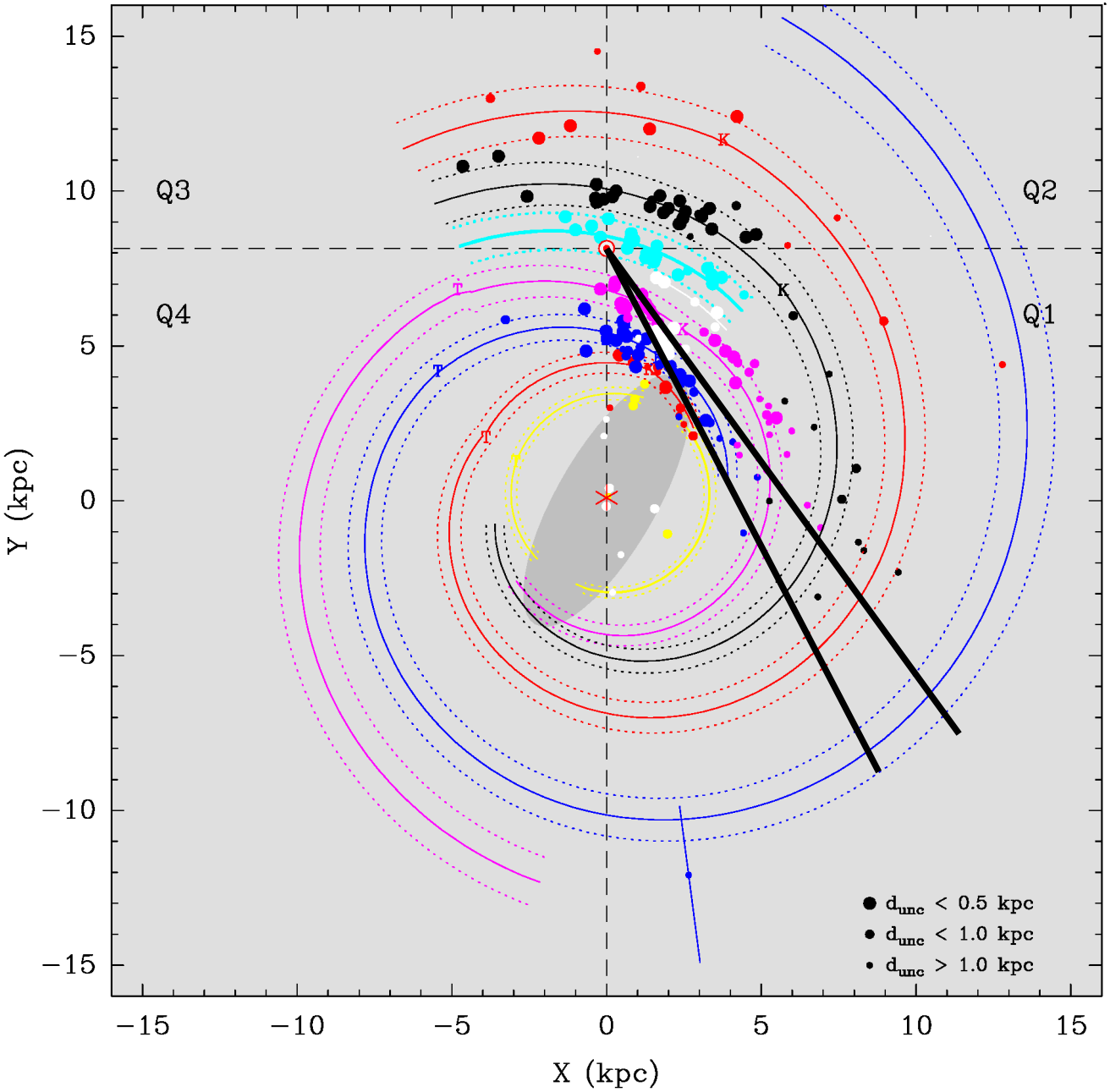
VLBA observations of compact sources

preliminary

- S



➢ A … to b = 0°

➢ I

Summary

preliminary

- VLBA observations of the pilot region in the Galactic plane ($28° < l < 36°$; $|b| < 1°$) showed very strong scattering
- Brightness distribution of J1851+0035 ($b = 0.2°$) within the frequency range from 1.4 to 43 GHz dominated by propagation effects, with a scattering index $k = 2.0$.
  - scattering is strong + present at each obs. epoch from 2005 to 2023
  - scattering is anisotropic (flat screen geometry) and symmetric along the b = const line
- The screen in inhomogeneous. Scattering power rapidly decrease with |b|. Effective width of the scattering band is ~1.6°
- Detection of PSR B1845-01 ($b=0.04°$) indicates that scattering screen is more than 3.5-4.4 kpc away, consistent with the end of the bar at 5 kpc.

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GLOSTAR Galactic Plane Survey

- **Cygnus X Region: 76° < l < 83°; -1°< b < 2°**: