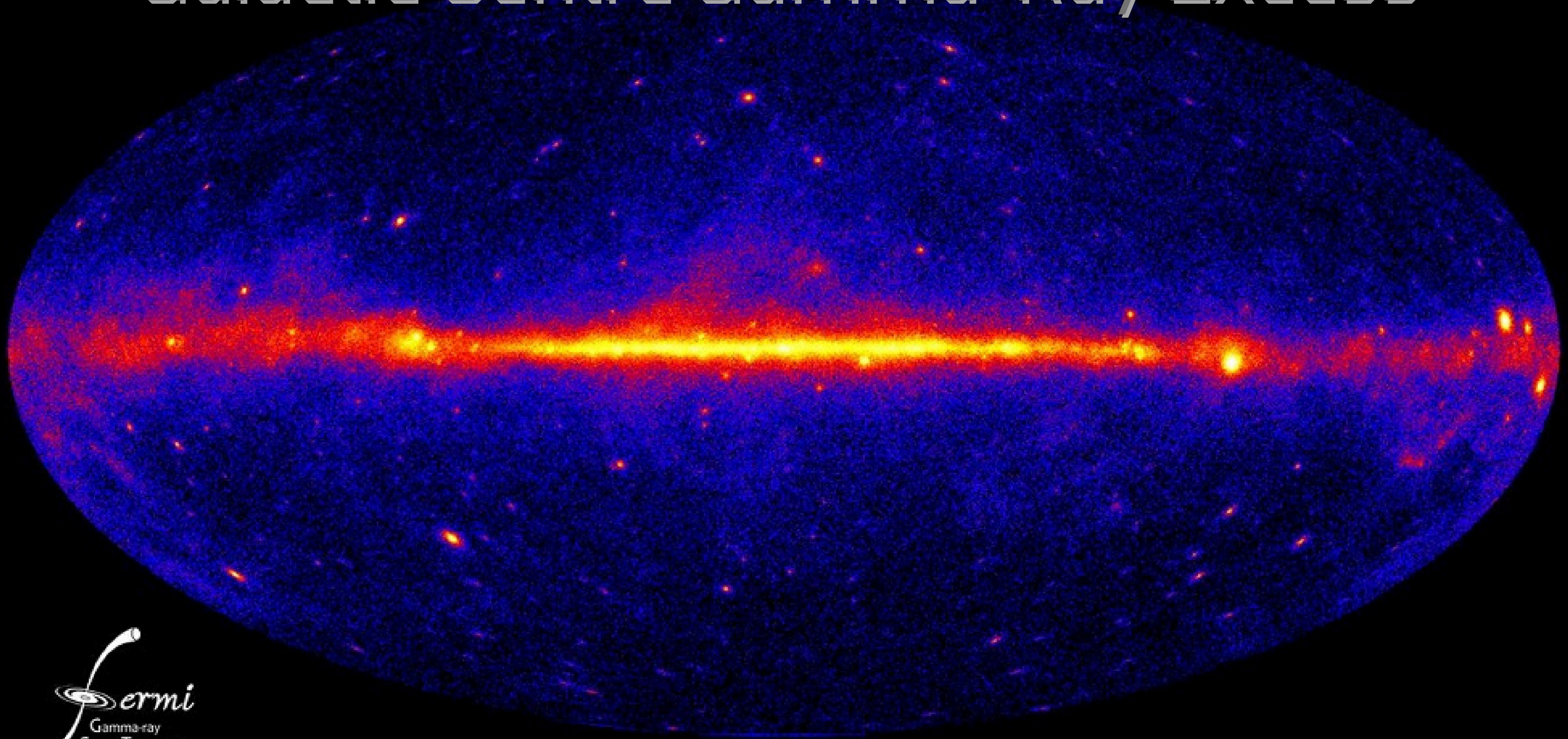
MAX-PLANCK-INSTITUT
FÜR RADIOASTRONOMIE

Probing the Galactic Centre with Pulsars

Isabella Rammala

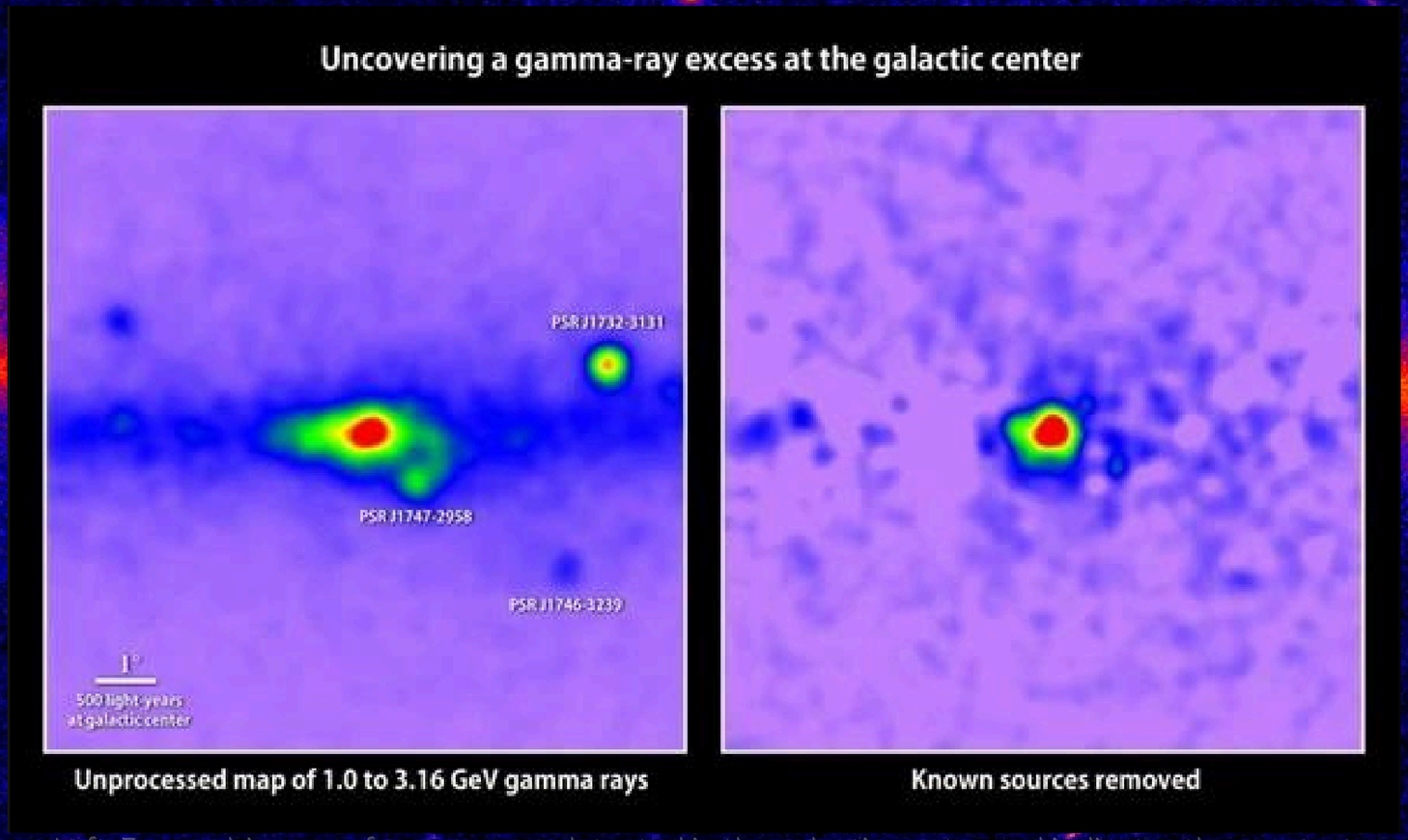
On behalf of the MeerKAT-MPIfR Galactic Plane Survey working group

Galactic Centre Gamma-Ray Excess



Fermi
Gamma-ray
Space Telescope

Galactic Centre Gamma-Ray Excess



Left: Zoomed-in map of gamma rays detected in the galactic centre; red indicates the greatest number. Prominent pulsars are labeled. Right: Residual map after all known gamma-ray sources are removed, revealing the excess emission.
Credit: T. Linden, Univ. of Chicago

Fermi Gamma-ray Space Telescope

Due to Dark Matter self-annihilation?

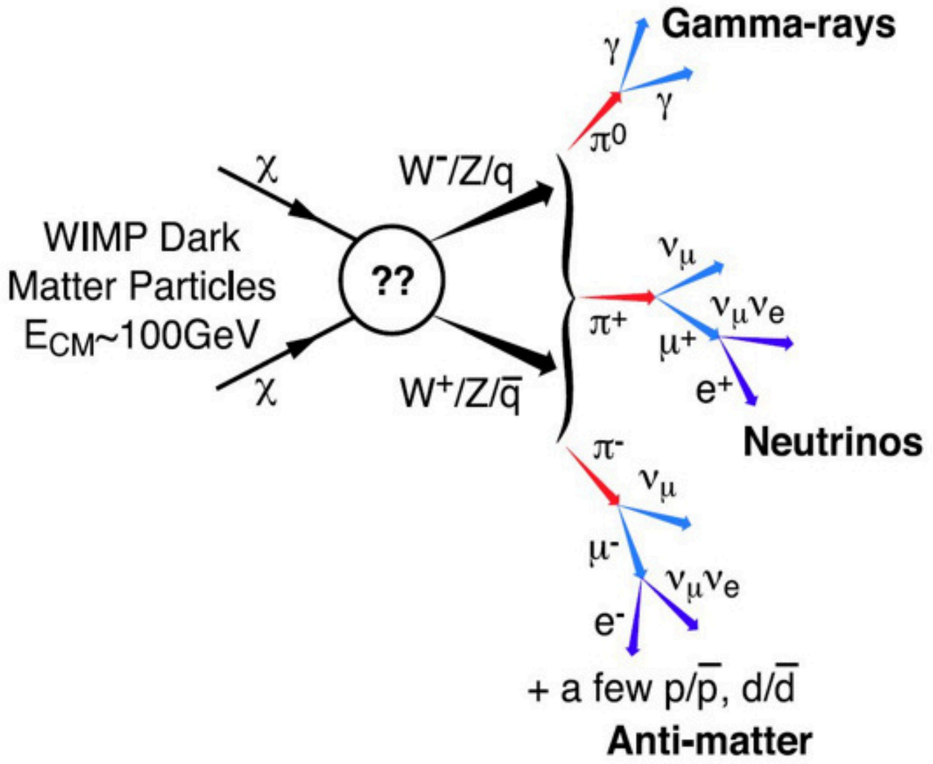
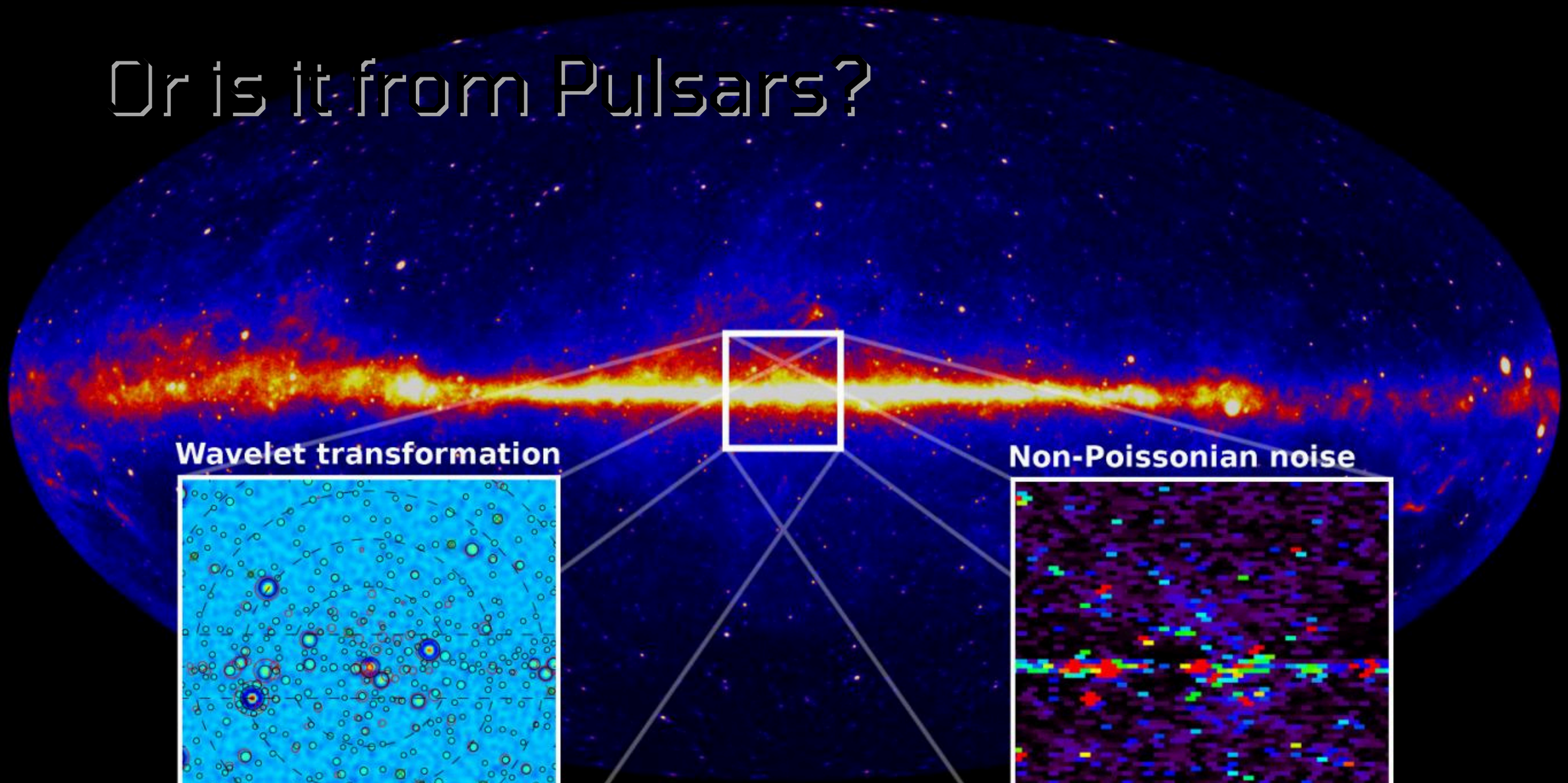


Diagram showing the annilation of Weakly Interacting Massive Particles (WIMPs) of dark matter, forming a shower of Gammarays, Neutrinos, and anti-matter. Credit: Fermi/NASA

Or is it from Pulsars?



Filtering & Statistical re-analysis of the Fermi data show a non-smooth distribution of photons (as expected from dark matter particle annihilation). Credit: Christoph Weniger

In this talk:

- Why search for Galactic Center pulsars
  - Pulsars as tools for fundamental physics.
- Why it’s difficult to find Pulsars in the Galactic Centre
  - the “Missing Pulsar” problem.
- Candidate search selection (image domain)
  - & targeted search for pulsations (time-domain).

Pulsars in the Galactic Center: What we can do with them!

Pulsars in the Galactic Center: The Fundamental Physics

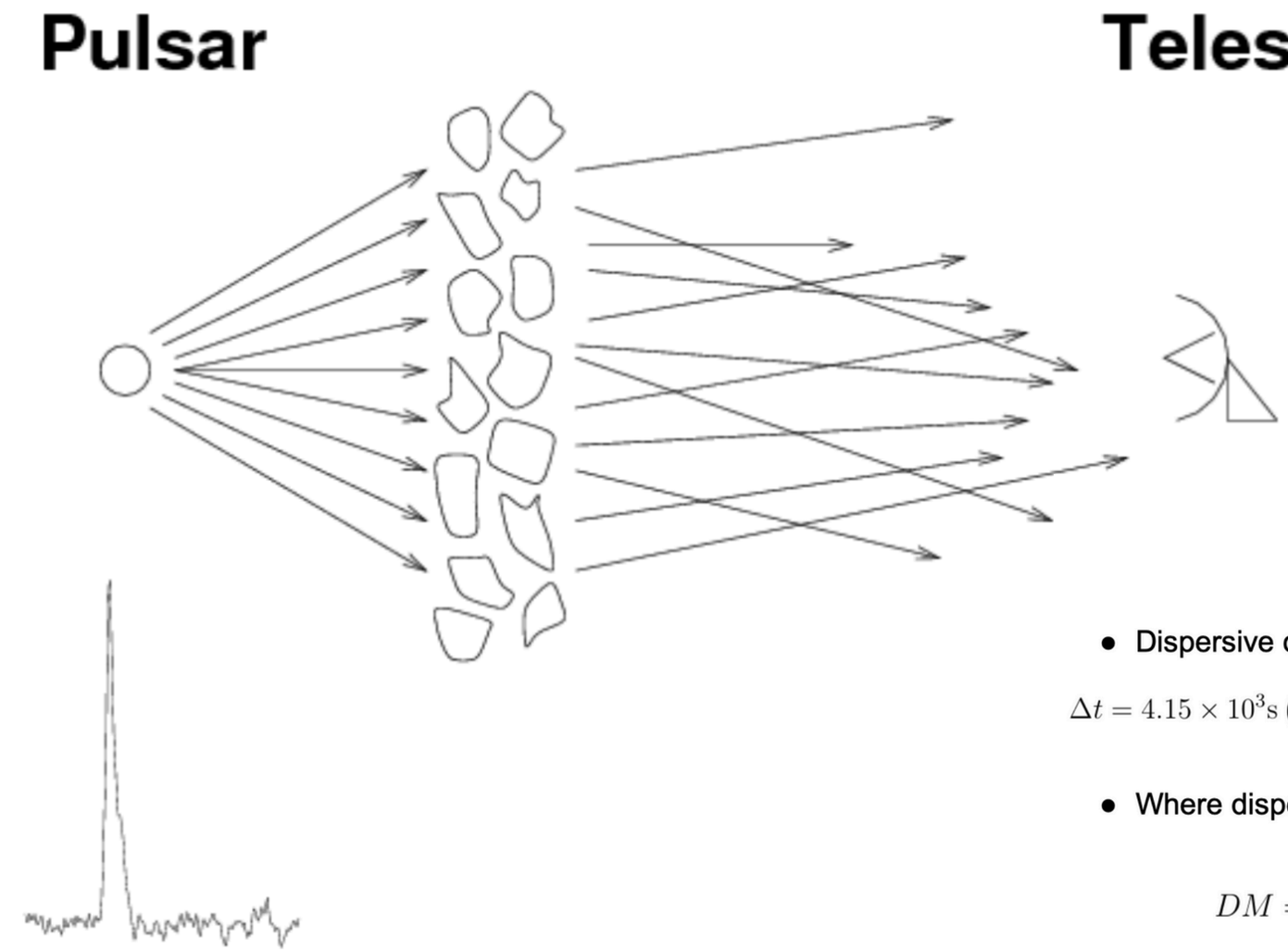
- Their Characteristic ages >> star formation history
- Pulsars as accelerator-meters >> Local gravitational potential
- Distribution and properties of central Interstellar Medium
- Faraday rotation >> Properties and strength of central magnetic field

Pulsars in the Galactic Center: The Fundamental Physics

- Finding compact binary pulsars (ideally with stellar BH)
- Probe spacetime around and properties of SGR A*

The “Missing Pulsars” Problem: Why haven’t we found them?

ISM effect: Dispersive Delay



- Dispersive delay defined by

$$\Delta t = 4.15 \times 10^3 \mathrm{s} \left(\nu_2^{-2} - \nu_1^{-2}\right) \int_0^d n_e dl$$

- Where dispersion measure

$$DM = \int_0^d n_e dl$$

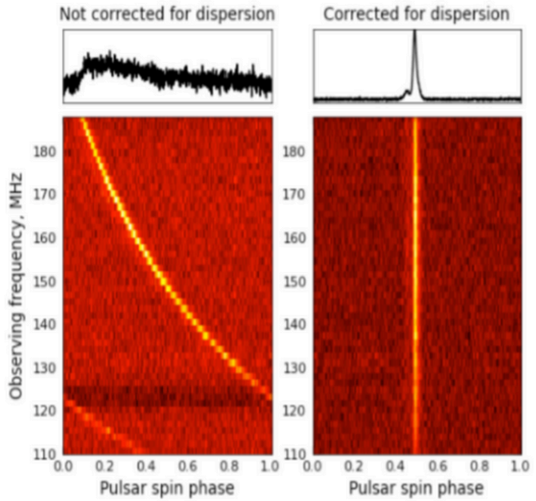
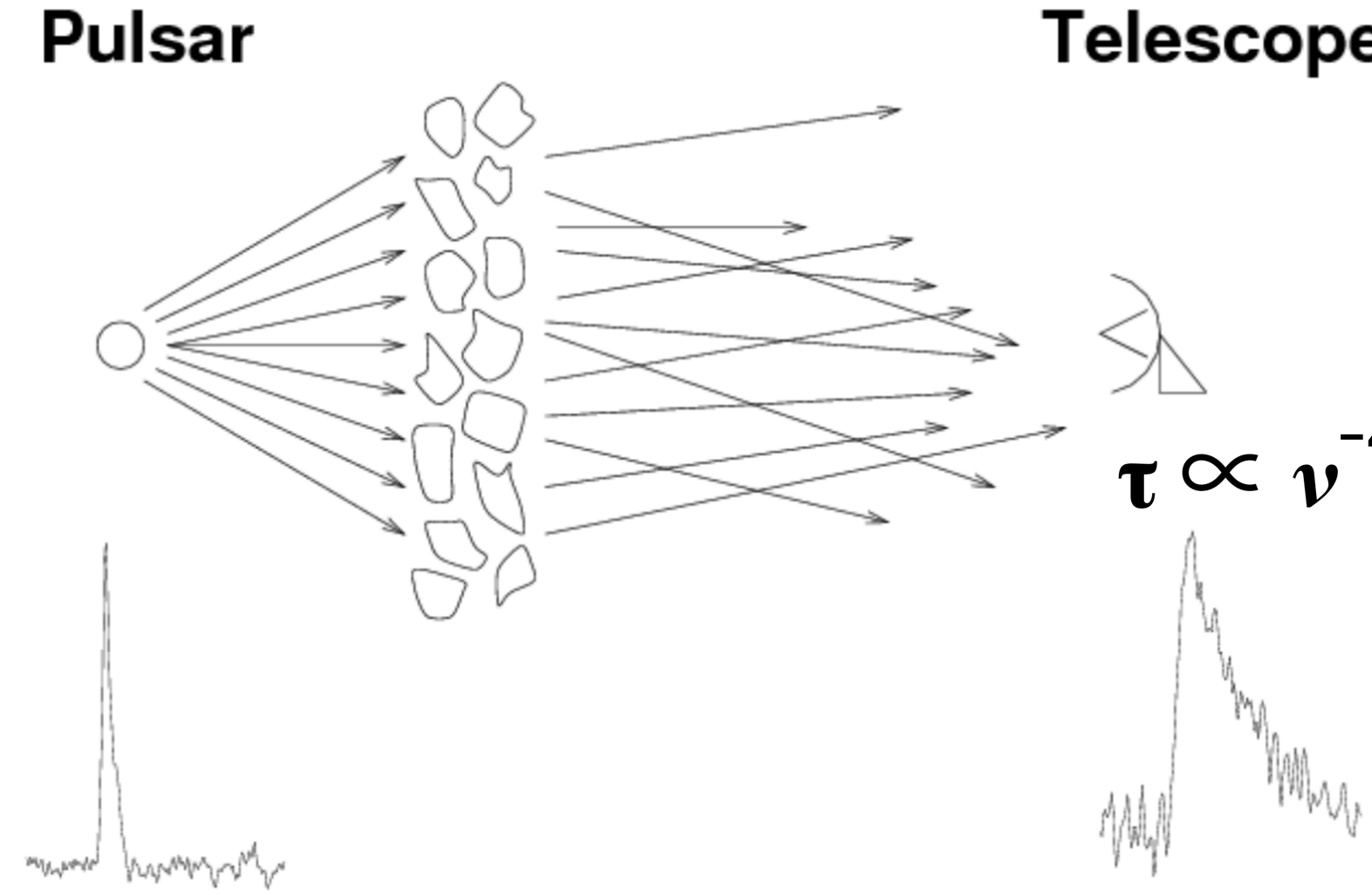


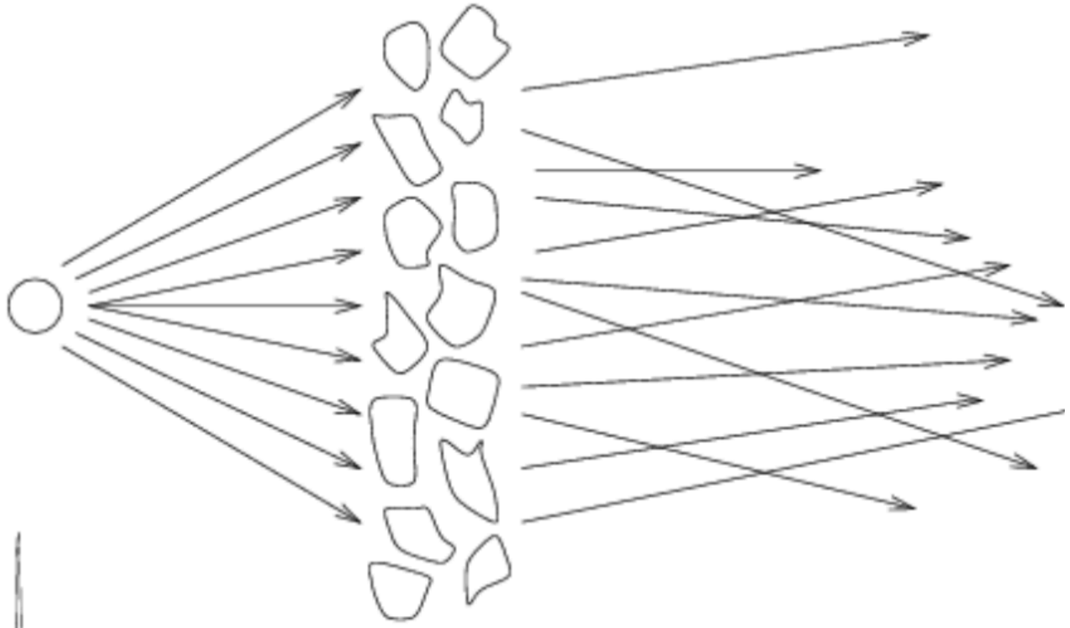
Image credit: Anya Bilous (LOFAR)

ISM effect: Interstellar Scattering



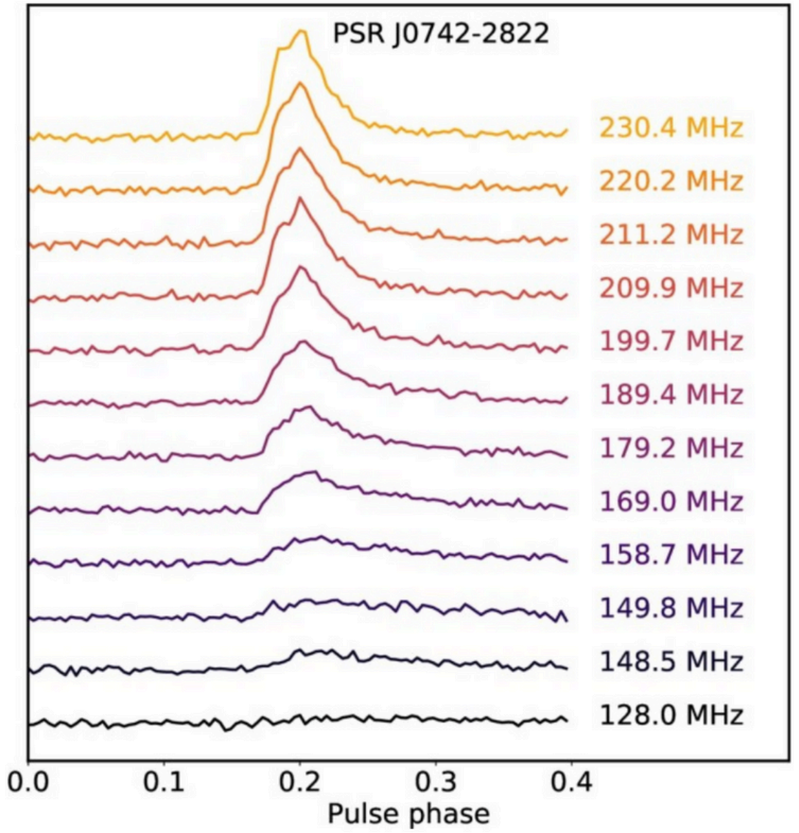
ISM effect: Interstellar Scattering

Pulsar



Emitted Pulse

Telescope



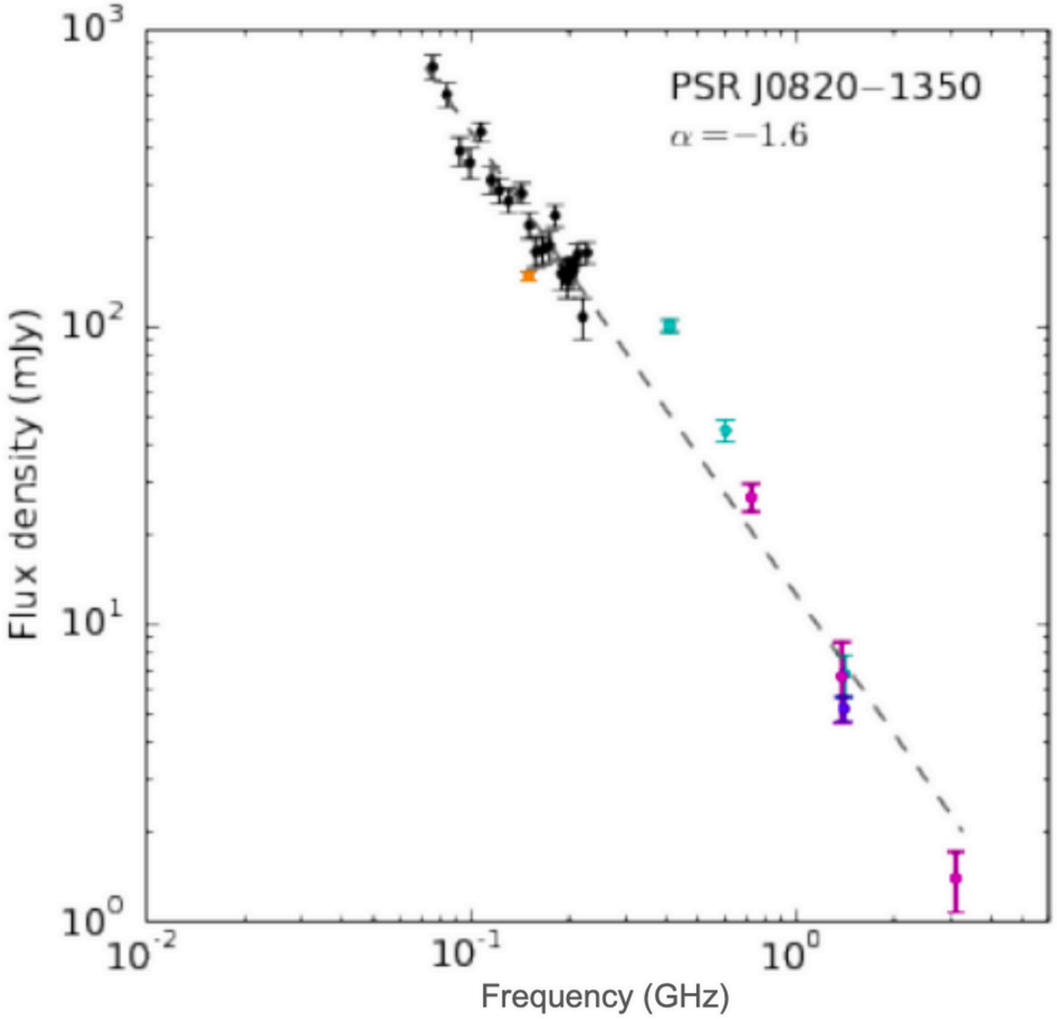
Detected Pulse

Kirsten et al., 2019 (Scattering of the Pulses of Pulsar PSRJ J0742-2822 across the frequency band).

Radio Spectrum

- Radio emission weak at high frequency
- Steep negative spectral index

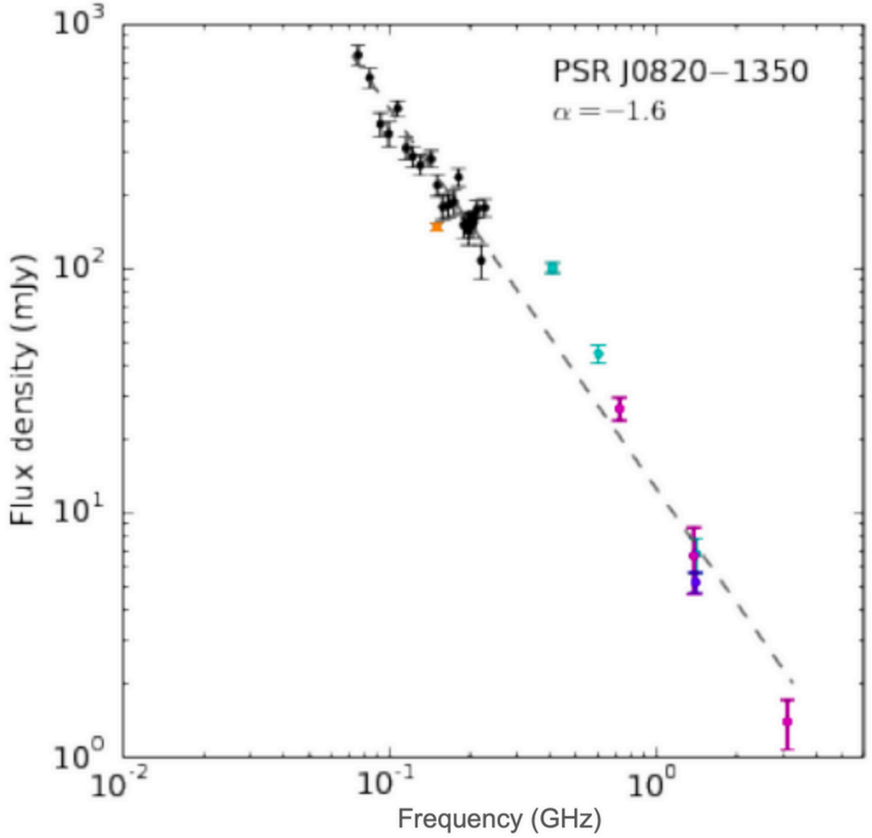
$$S(\nu) \propto \nu^{\alpha}$$



Murphy et. al, 2017 (Low frequency spectral energy distributions of radio pulsar PSR J0820-1350 detected with the Murchison Widefield Array)

How we'll search for them:
Our Approach

Properties of Radio Pulsars



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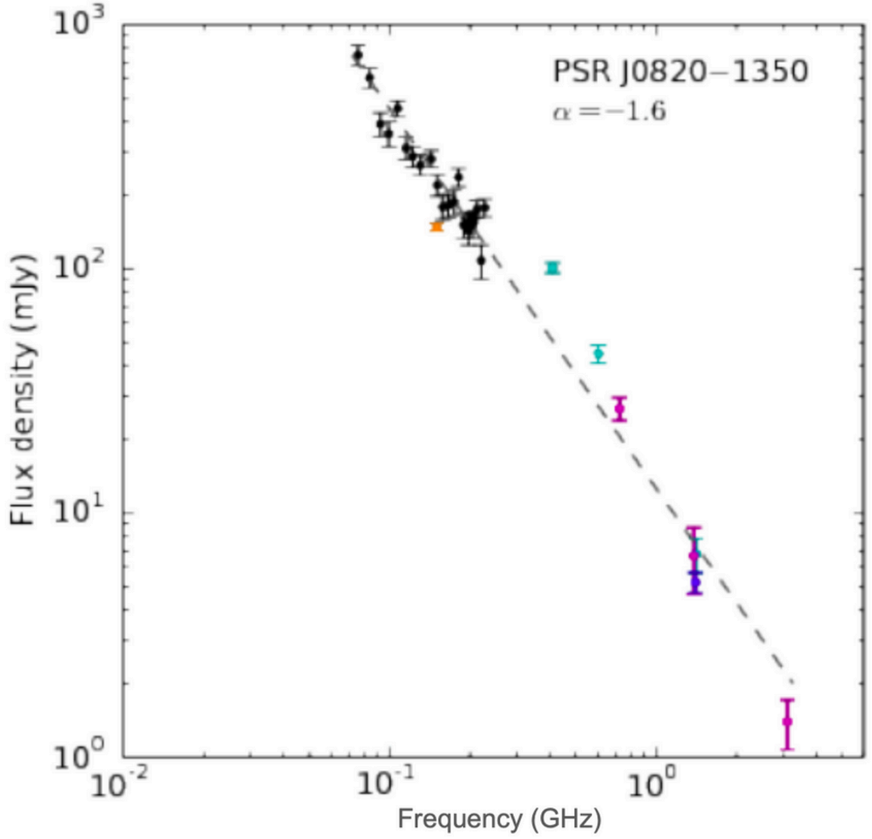
Properties of Radio Pulsars



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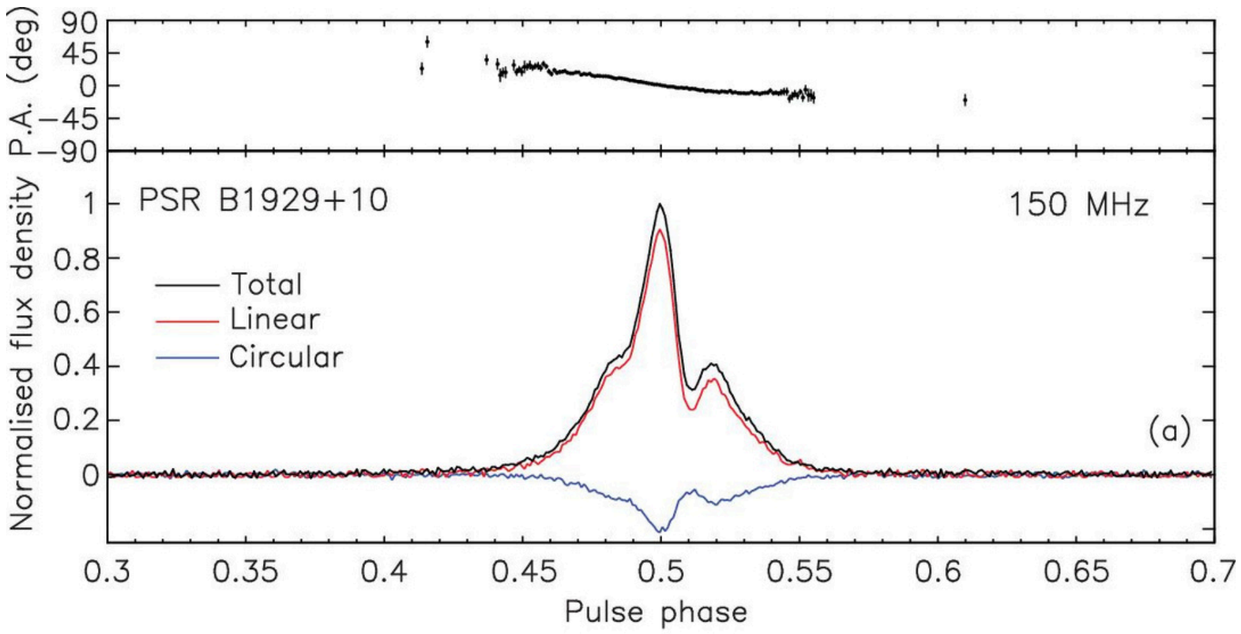
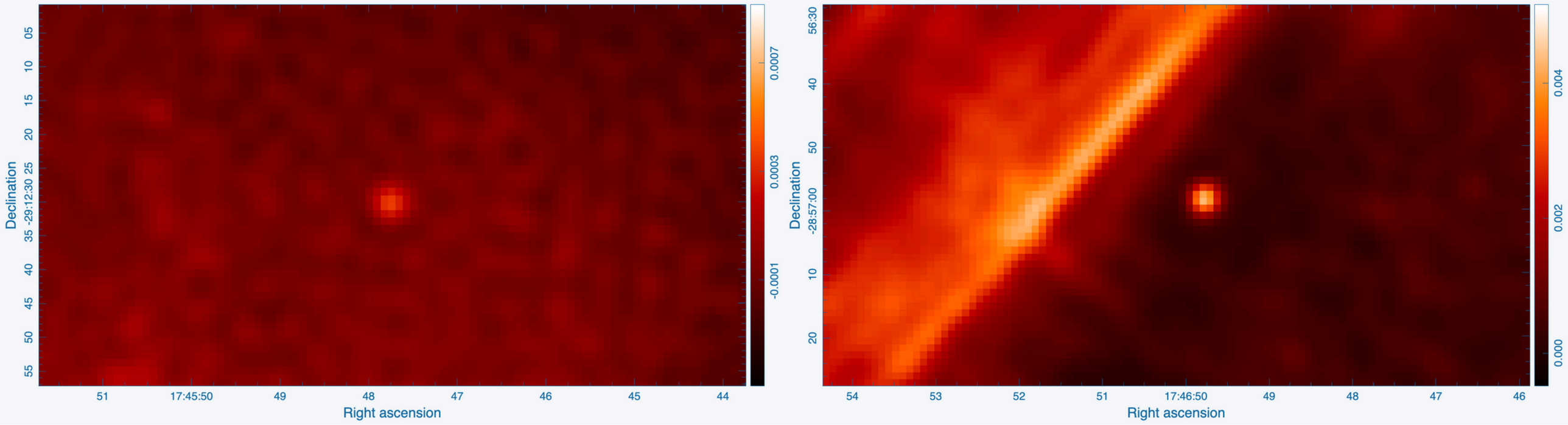


Average polarisation profile of PSR B1929+10 at 150 MHz. The black line shows the total intensity, the red line shows the linearly polarised intensity and the blue line, the circularly polarised intensity. The top panel shows the profile of the polarisation angle (Noutsos et al 2015)

Pulsars in the Galactic Center: What we expect them to look like

- Point Sources

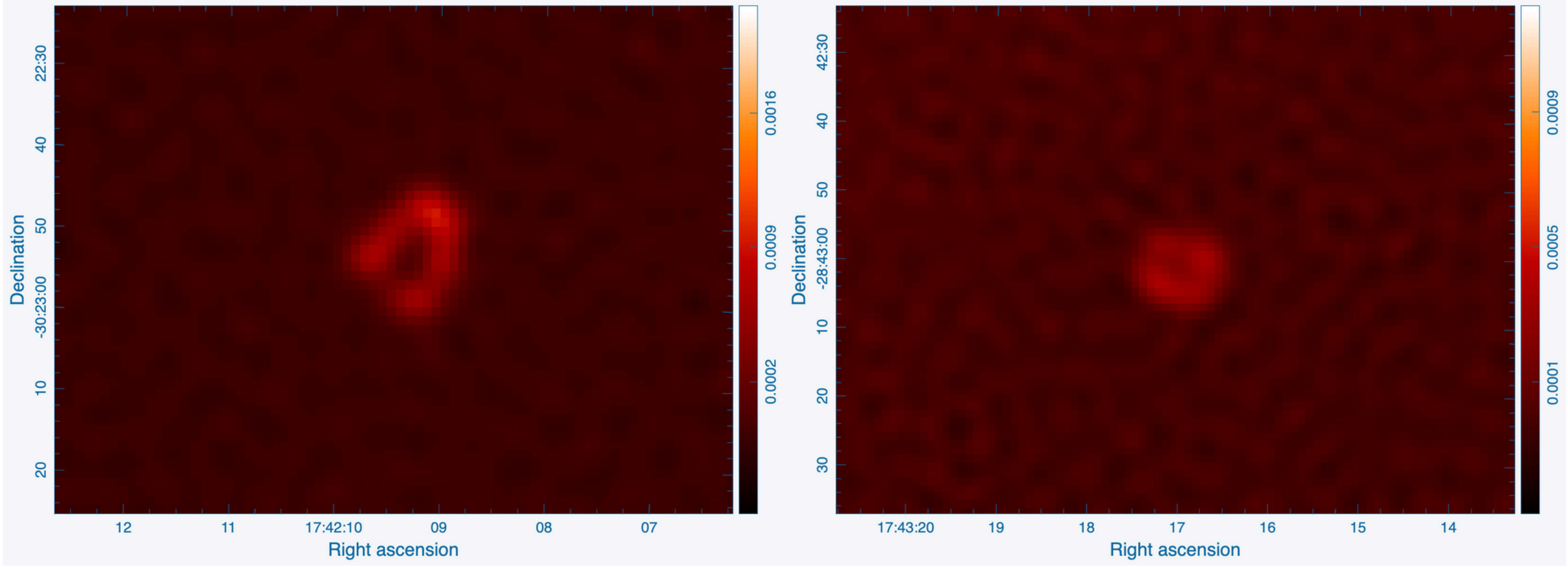
PSR J1745-2912 (left) & PSR J1746-2856 (right). Both pulsars are see as compact sources in the continuum data (Rammala et al: in prep).



Pulsars in the Galactic Center: What we expect them to look like

- May be associated with shell-like structures

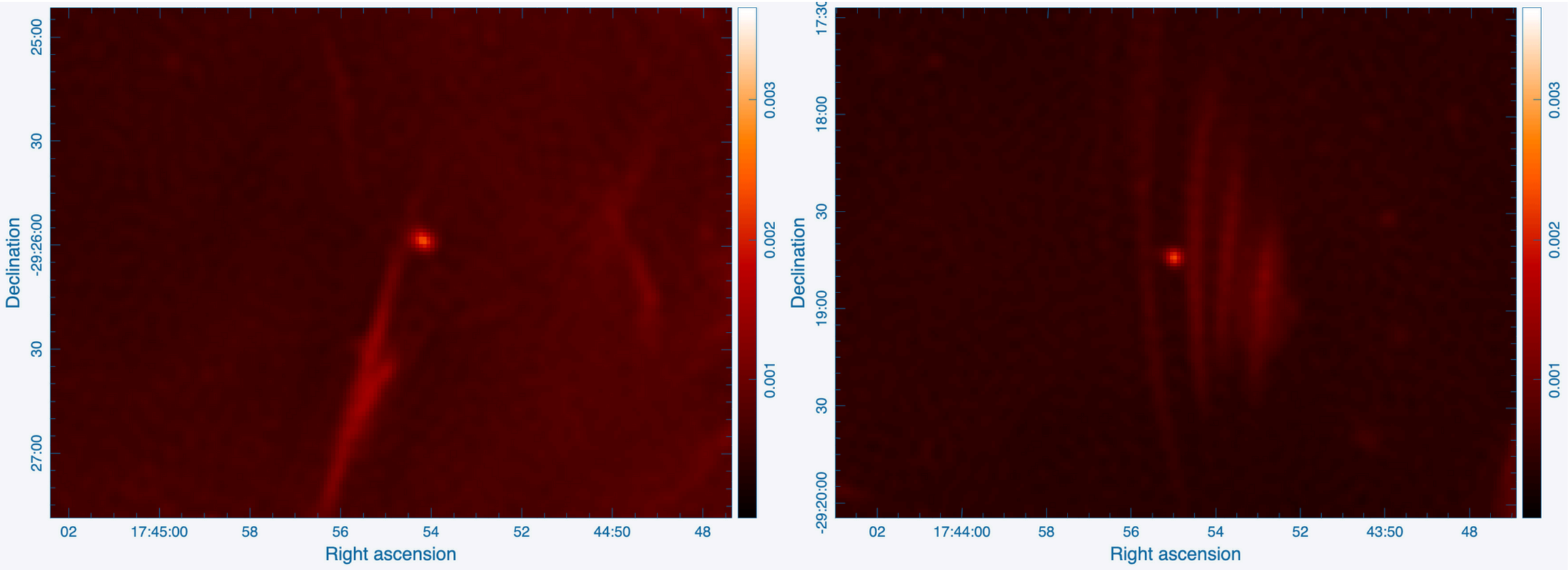
Examples of shell-type sources in the L-Band catalogue (Rammala et al, in prep)



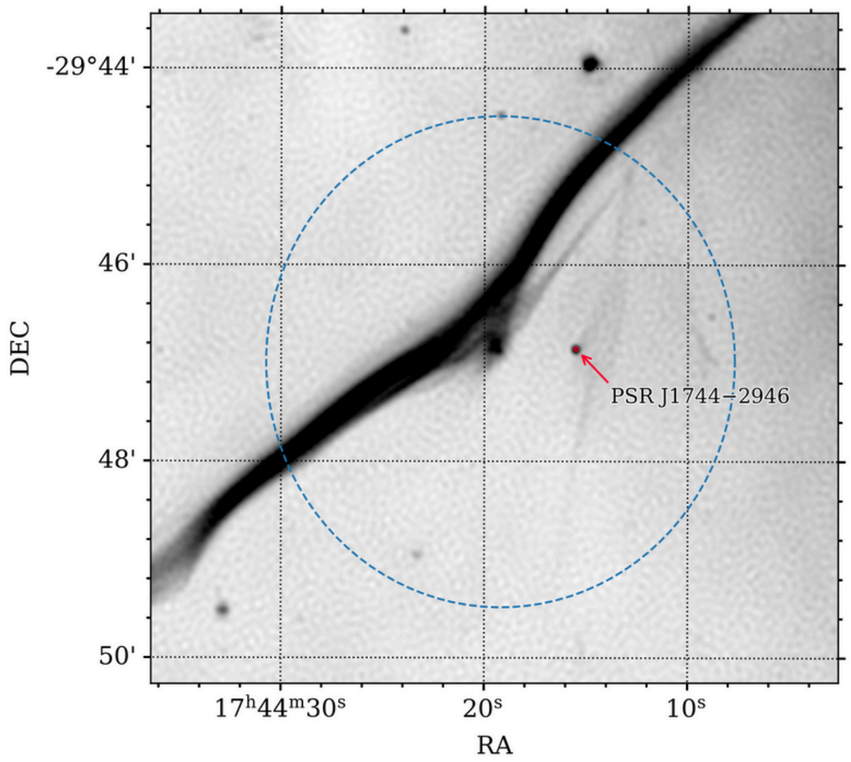
Pulsars in the Galactic Center: What we expect them to look like

- May be associated with filaments

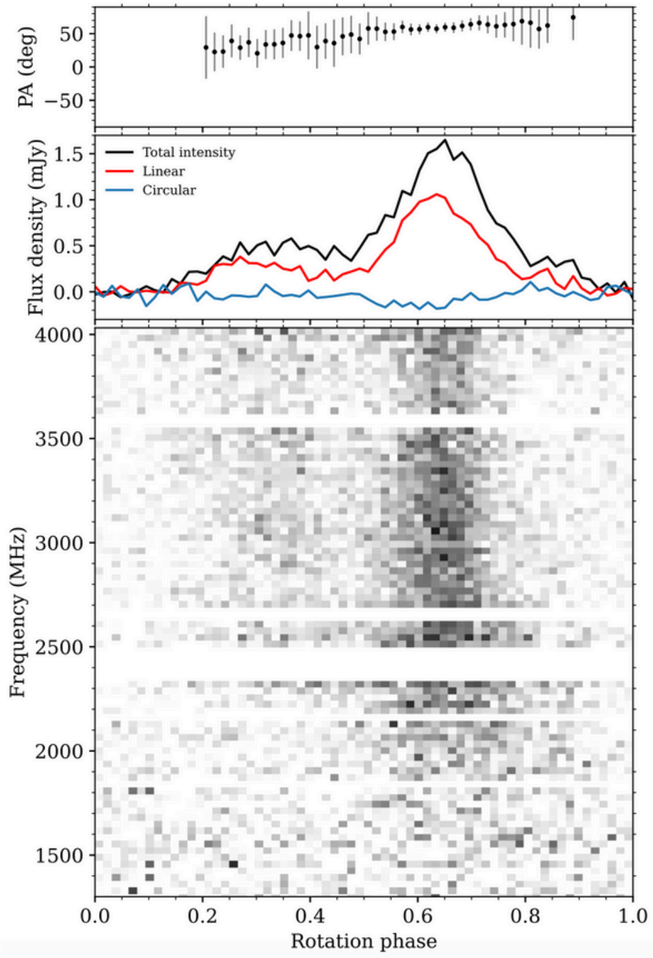
Examples of point sources associated with filaments in the L-Band catalogue (Rammala et al, in prep)



The Galactic Center Millisecond pulsar



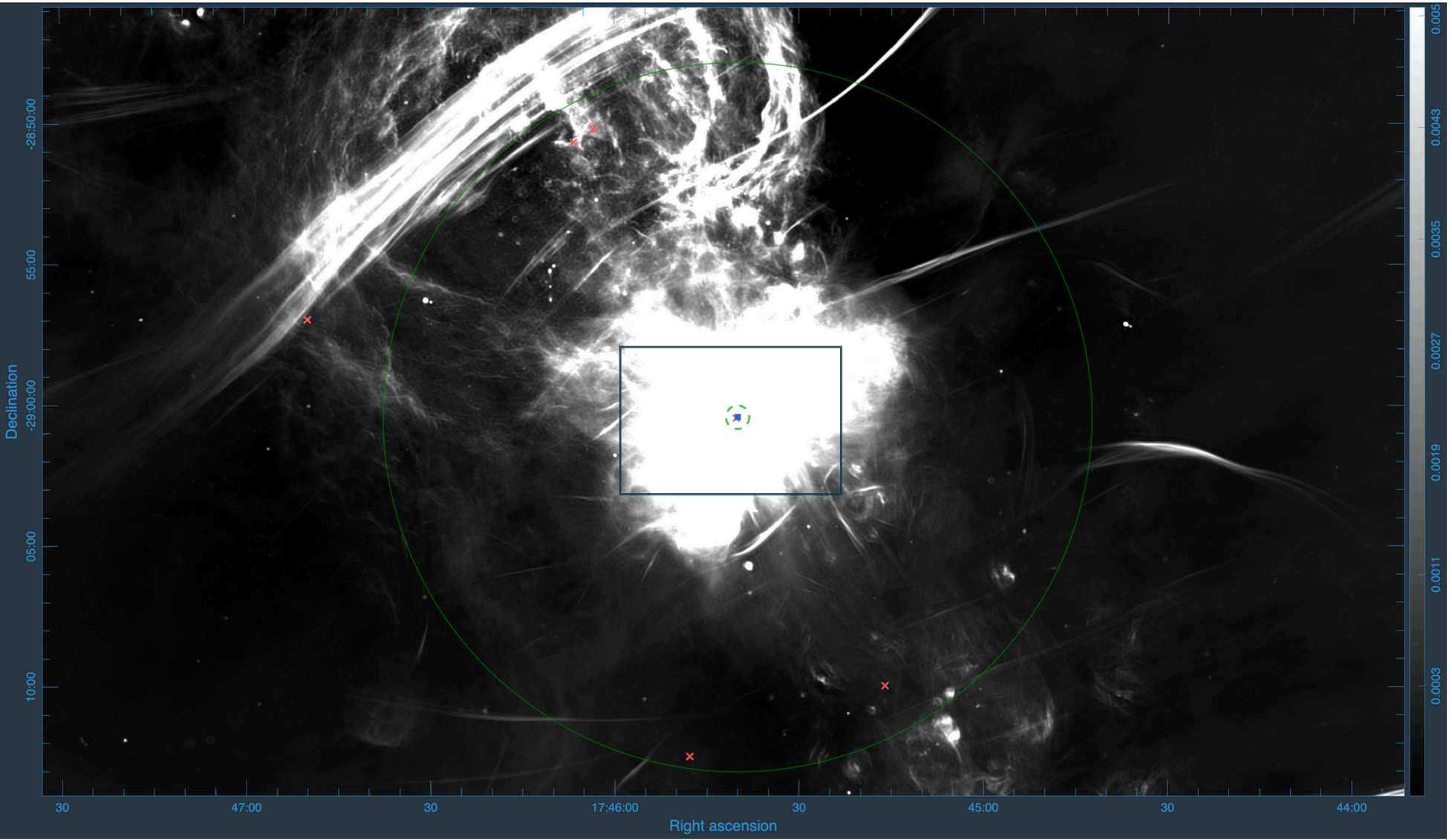
The 1.28 GHz radio image of the region around the major kink in the Snake (Heywood et al. 2022, Yusuf-Zadeh et al 2024). The 5 arcmin diameter beam of Murriyang at 4 GHz is shown by the large blue circle centered on G359.13142−0.20005. The red circle is centered on the MeerKAT S-band localization of PSR J1744−2946



Linear polarization position angle swing (top), time and frequency averaged polarization profile (middle) and the total in- tensity spectrum (bottom) of PSR J1744−2946. Note, the average profile in the middle panel excluded data below 1900 MHz (Lower et al 2024)

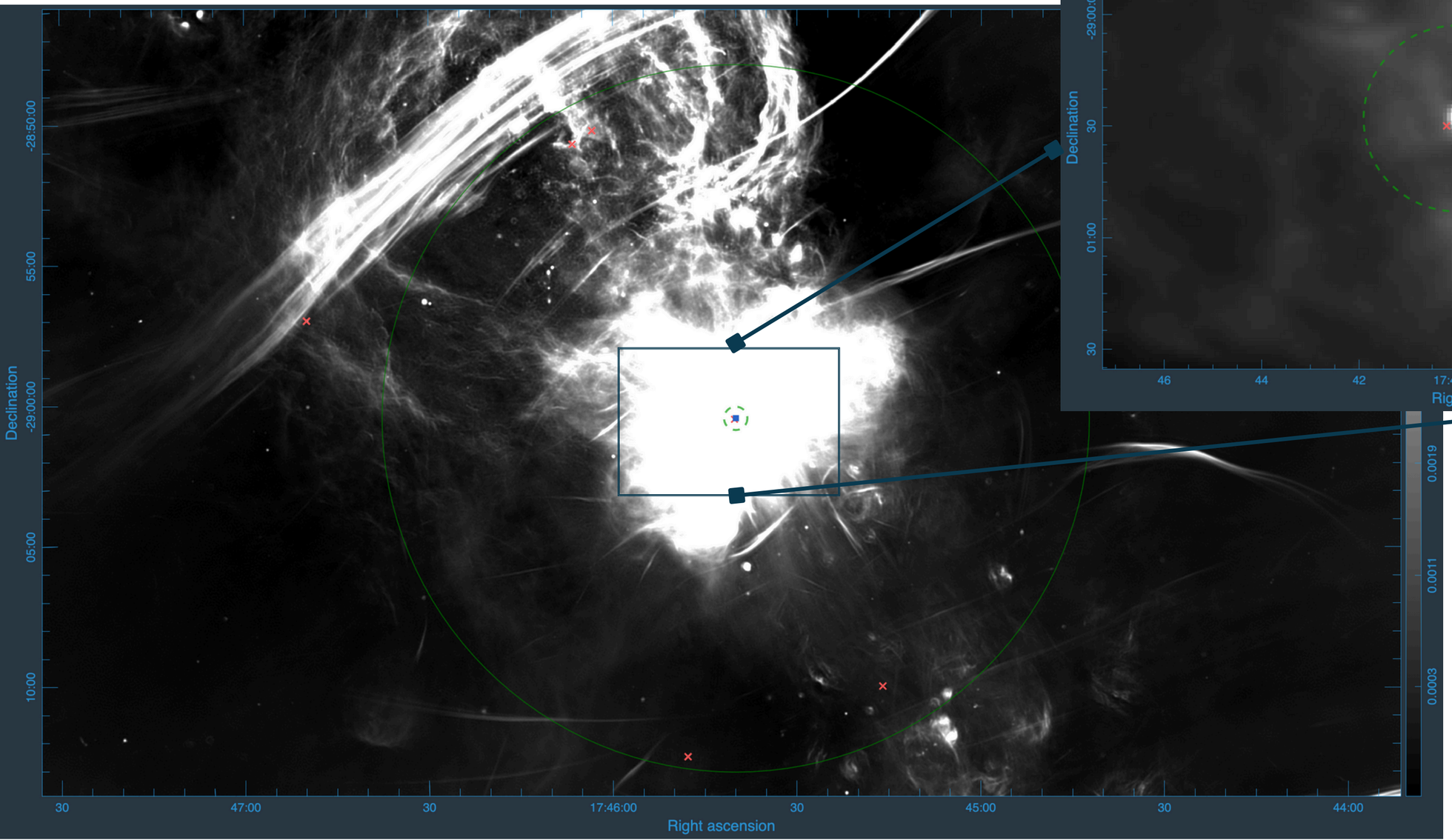
The Galactic Center @ S-Band: The Deep Sgr A* Survey

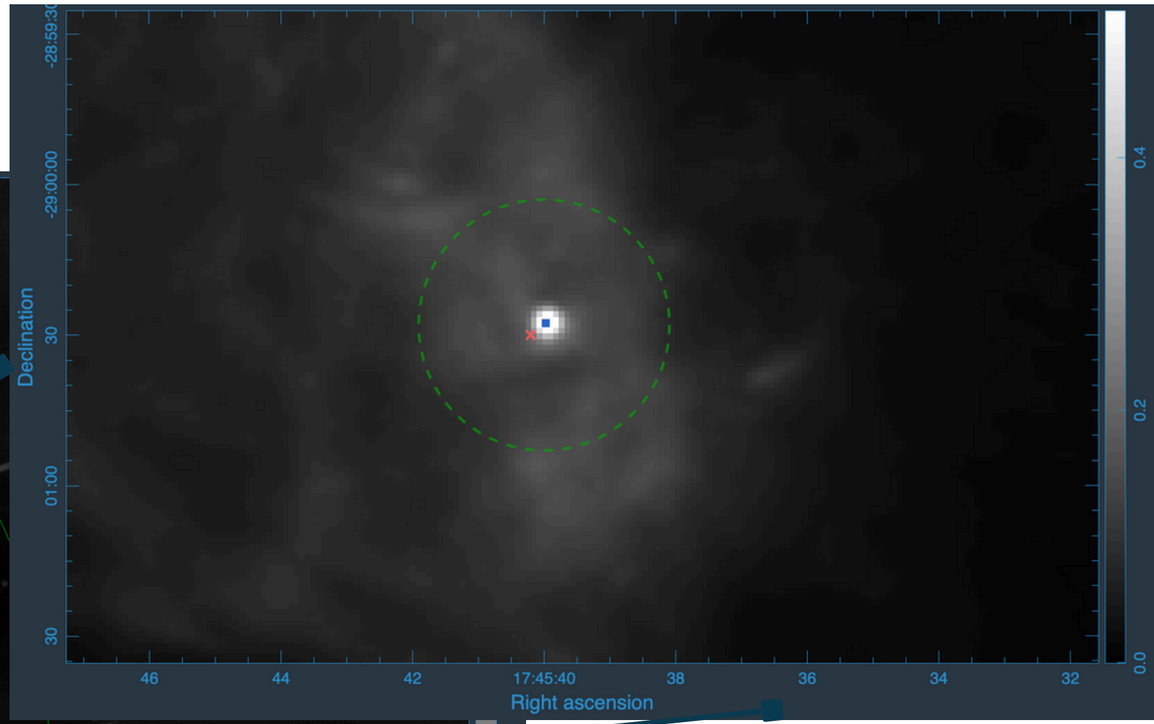
MMGPS - SgrA*:



- Goal: to search for a pulsar within 1 pc of Sgr A*

MMGPS - SgrA*:

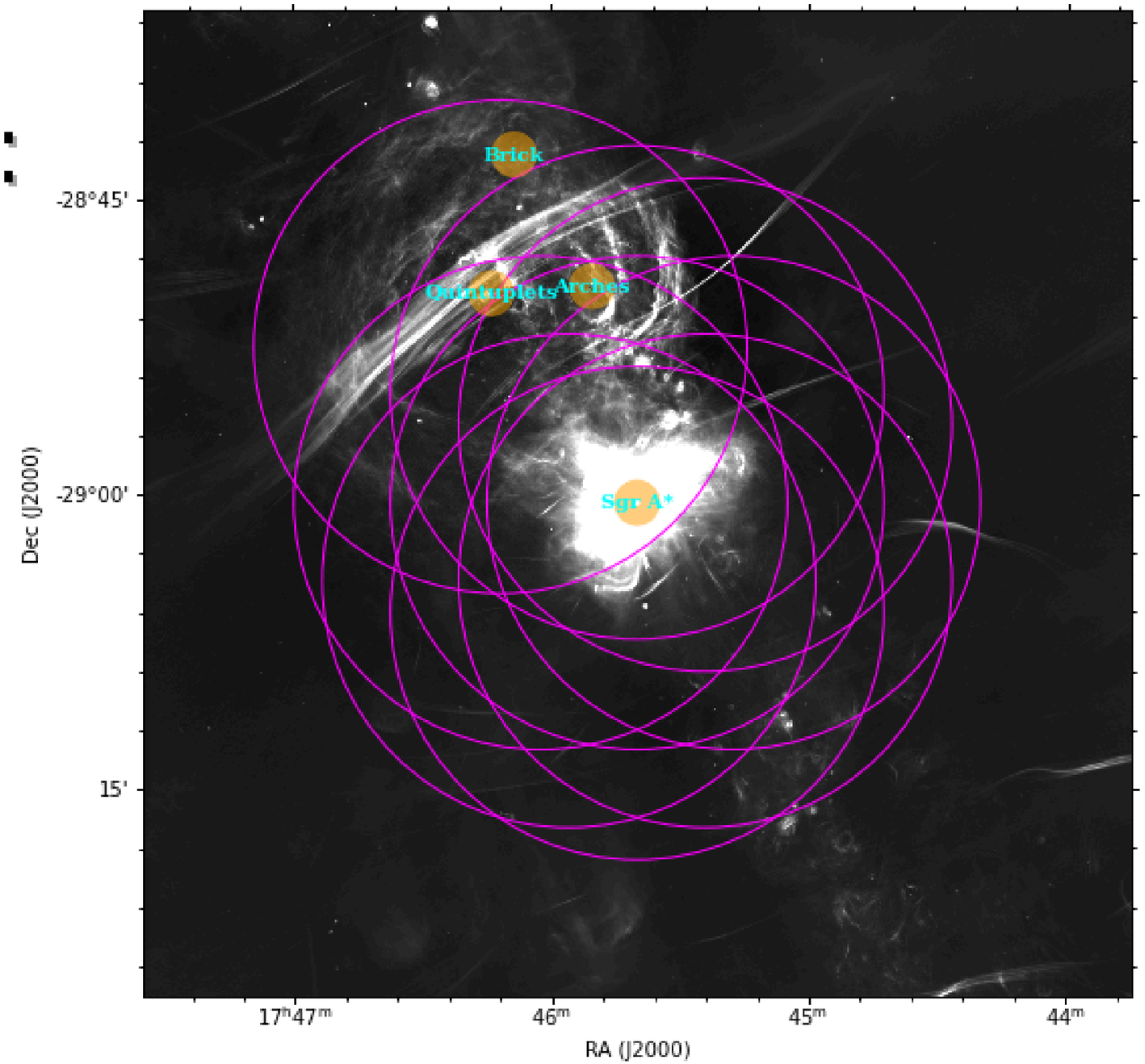




- Goal: to search for a pulsar within 1 pc of Sgr A*

MMGPS - SgrA*:

- 200 hours of time
- At S1 (2.4 GHz.), S3 (2.8 GHz) and S4 (3.1 GHz)
- 32 K channel mode
- 8 hours observing blocks
- Weekly observing cadence



Deep galactic centre survey pointing, showing the S4 beams centred on Srg A* , and the other 8 pointing dithering aroung the center beam

Summary

- Pulsars can be used as tools for fundamental physics.
- New detection likely limited by sensitivity and computational resources.
- Targeted searches may help focus our resources for extensive searches.