Radio Pulsar searches of the Galactic Centre

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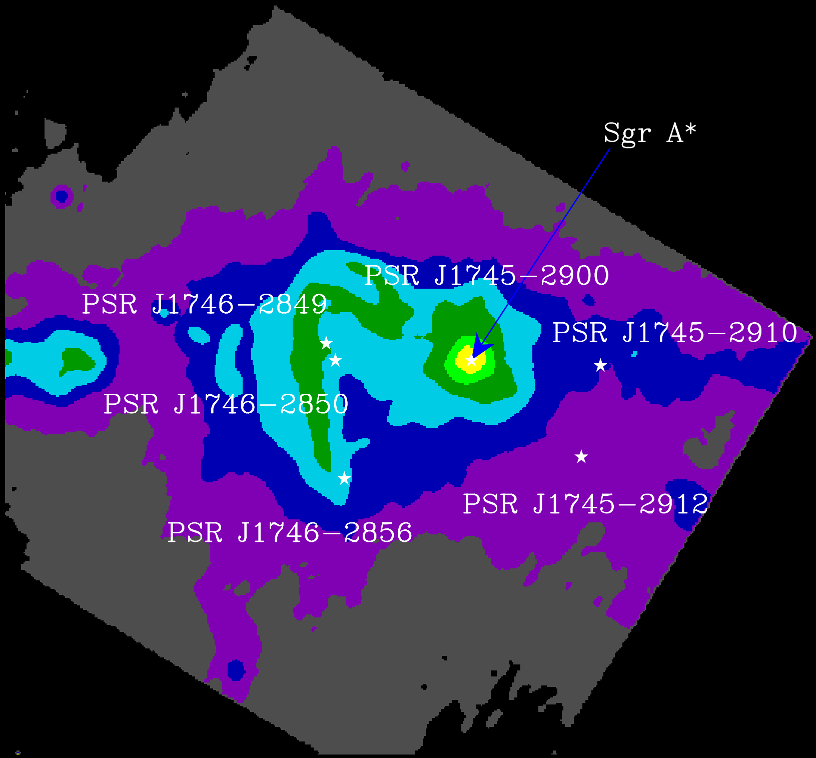
& members of the MPIfR group:

Fundamental Physics in Radio Astronomy



Gamma Rays & Dark Matter

Dec 9th, 2015, Obergurgl, Austria.

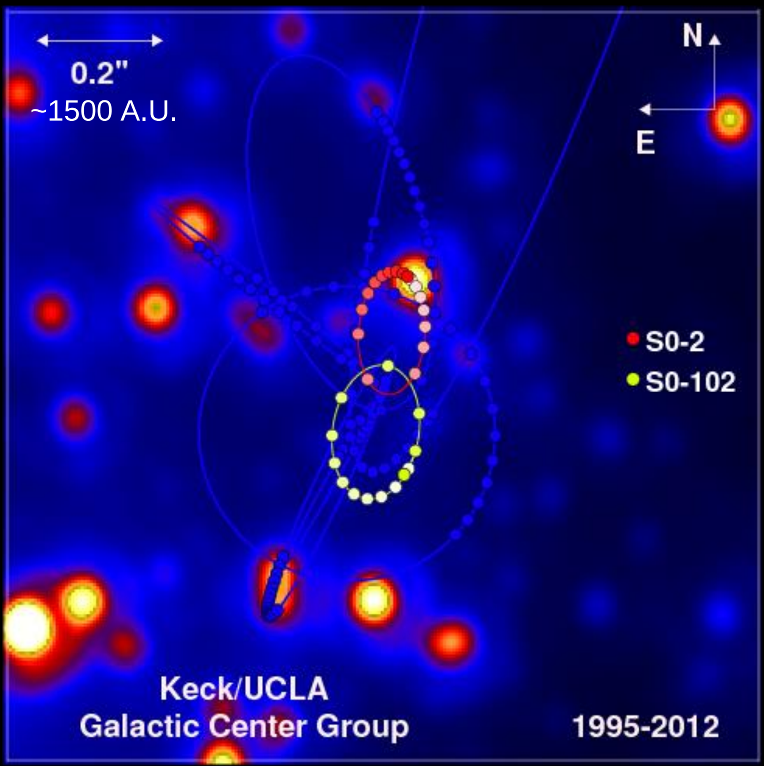
Overview

- Why do we want to find pulsars in the Galactic Centre?
- Current observational status of pulsars in the Galactic Centre
- Where are all the pulsars?
- On-going and future Galactic Centre radio pulsar searches

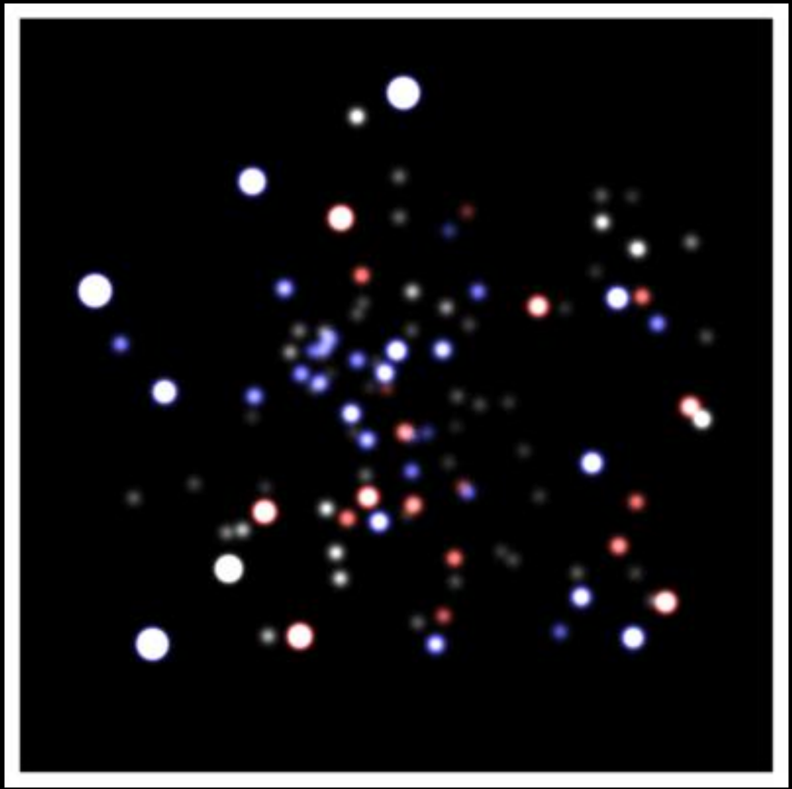
Why do we want to find pulsars in the Galactic Centre?

IR *speckle* and AO images of stars in the GC have inferred the presence of a dark ~4x10^6 $M_\odot$ compact object coincident with the Sgr A* radio source → **black hole** (Eckart & Genzel, MNRAS, 1997, Ghez et al. ApJ, 1998, Gillessen et al. ApJ, 2009A/B).

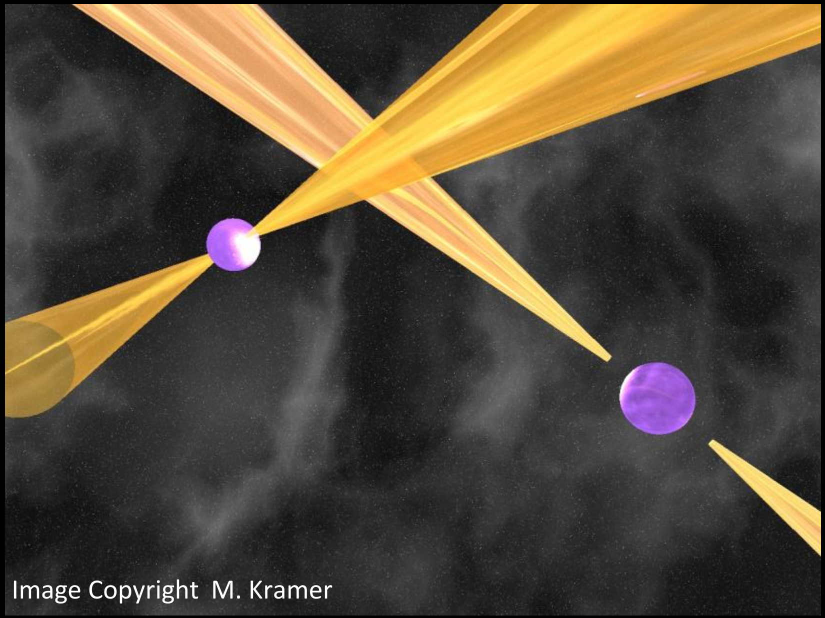
Future IR experiments (VLTI, GRAVITY, ELT) will have spatial localization down to 10 μas = **0.1 AU**. Will be used for tests of Einstein's General Relativity.



Meyer et al., Science, 2012



ESO / S. Gillessen MPE Garching



PSRs are **precision clocks!** Typical PSR timing precision (e.g. 100 μs) can give a sensitivity to positional changes on spatial scales of the order of **tens of kilometres** (c.f. **0.1 AU** VLTI astrometry).

Precision lies in phase connected timing solution

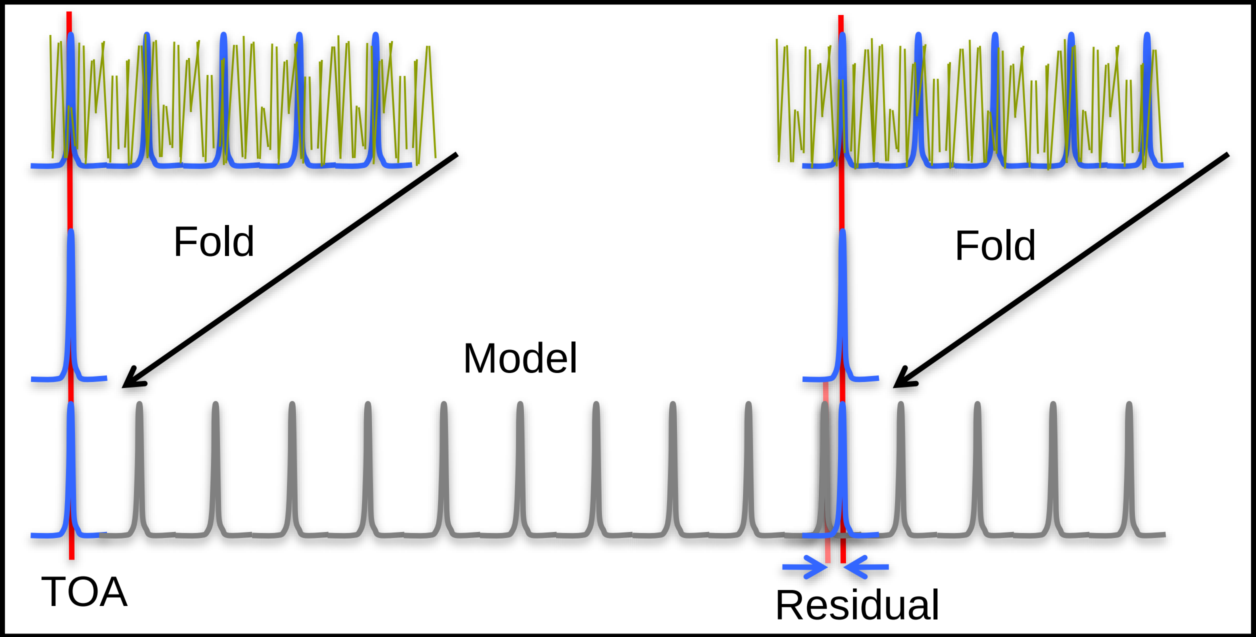


Image credit David Champion, MPIfR

CSIRO Parkes Observatory, NSW, Australia

e.g. spin period of PSR B1937+21

P = 0.0015578064688197945 ± 0.0000000000000000004 seconds

(Kaspi et al. 1994, ApJ.)

Sgr A* is the ultimate gravitational laboratory

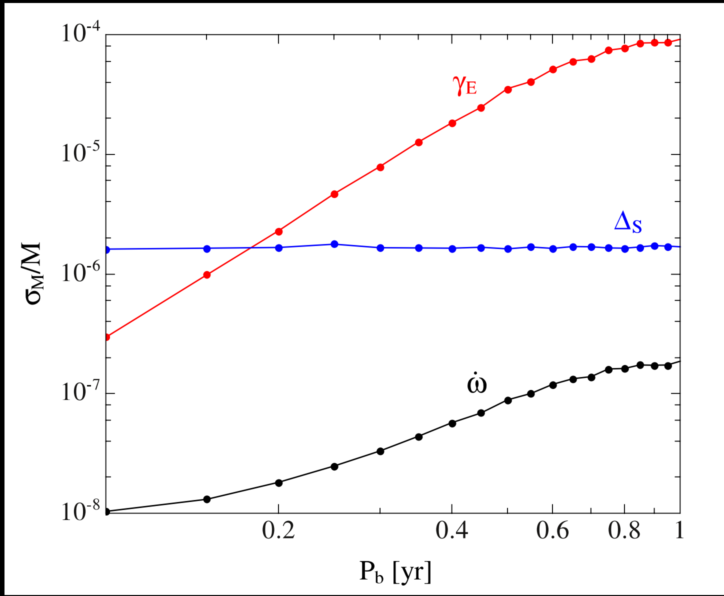
- **BH Mass.** $M_{BH} >> M_{PSR}$ only one Post Keplerian parameter needed to get BH mass to a fractional uncertainty of 10^{-6} ($1\ M_{\odot}$)

- **BH Spin.** Lense-Thirring contribution to advance of pericenter. Dimensionless spin parameter better be less than one!

  Cosmic Censorship Conjecture

- **BH Quadrupole moment:** With mass and spin…

  No-Hair Theorem



Simulations: 5 years of timing, one 100 μs TOA per week (Liu et al. 2012).

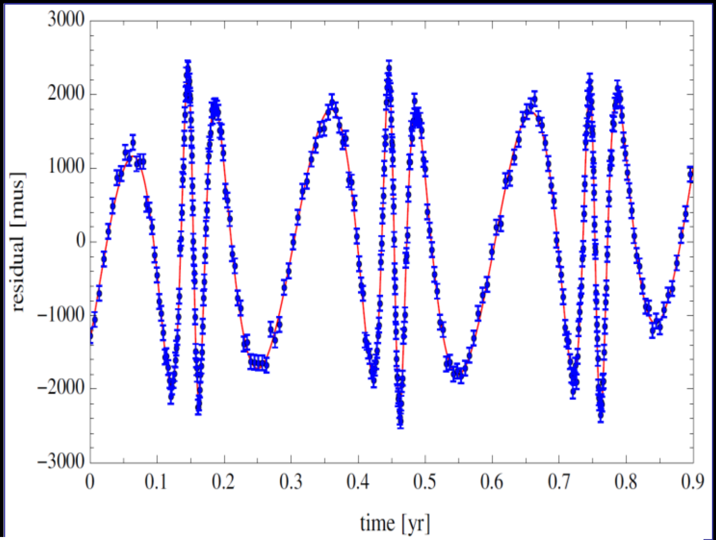
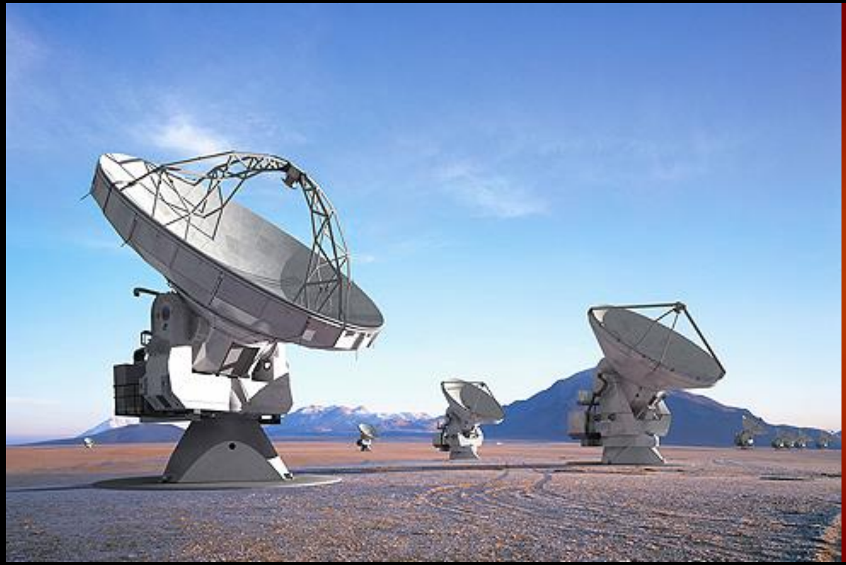
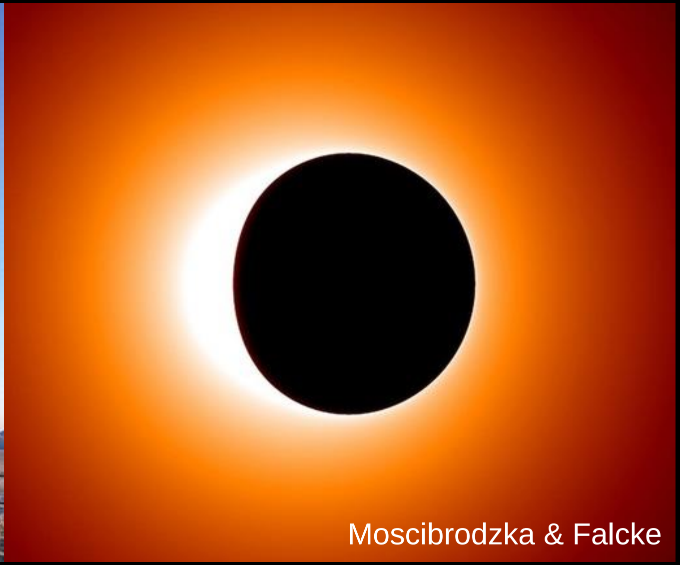


Figure provided by N. Wex & K. Liu

Synergies and probing the GC environment

- Mass measurement from PSRs unaffected by distance uncertainty. In combination with 10 μas optical astrometry, **Sgr A* distance to within ~1 pc** (Psaltis et al. 2015).
- BH spin will tell us how the shadow will appear. See Event Horizon Telescope (EHT) and the BlackHoleCam - (14 M€ ERC Synergy Grant - H. Falcke, M. Kramer, L. Rezzolla).





Moscibrodzka & Falcke

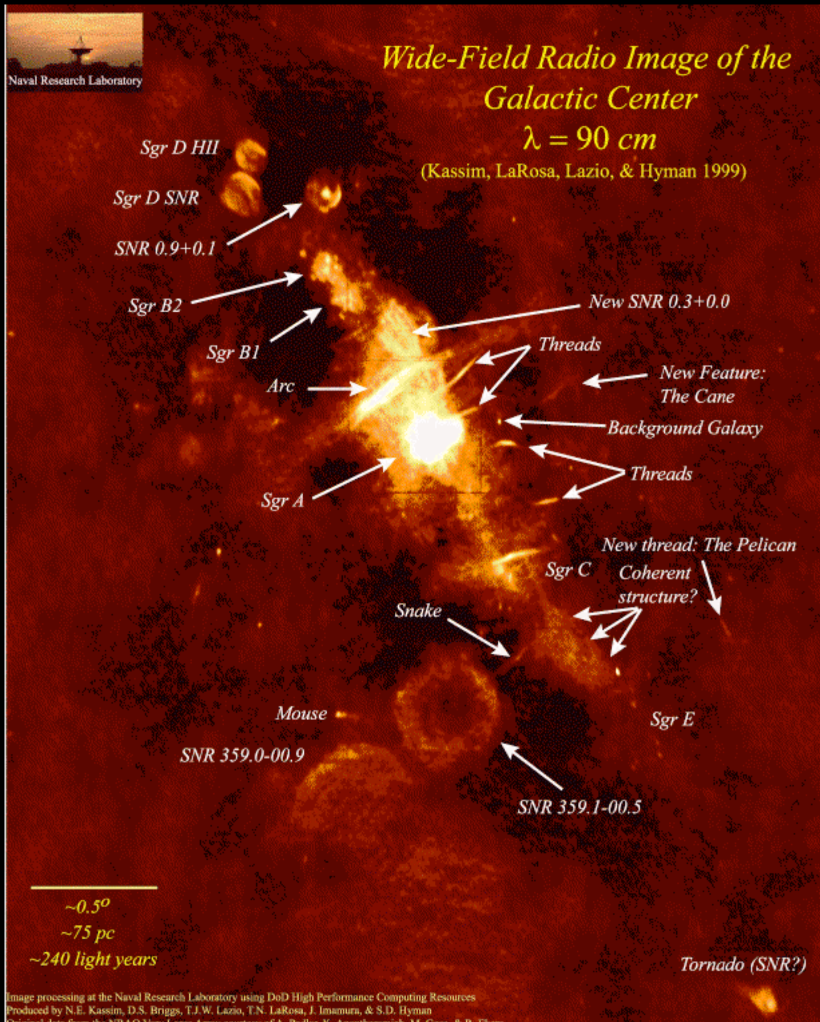
- **PSRs are "GC weather stations":** give measurements of extreme environment in GC (free electron density, magnetic fields, scattering regions).

Current observational status of pulsars in the Galactic Centre

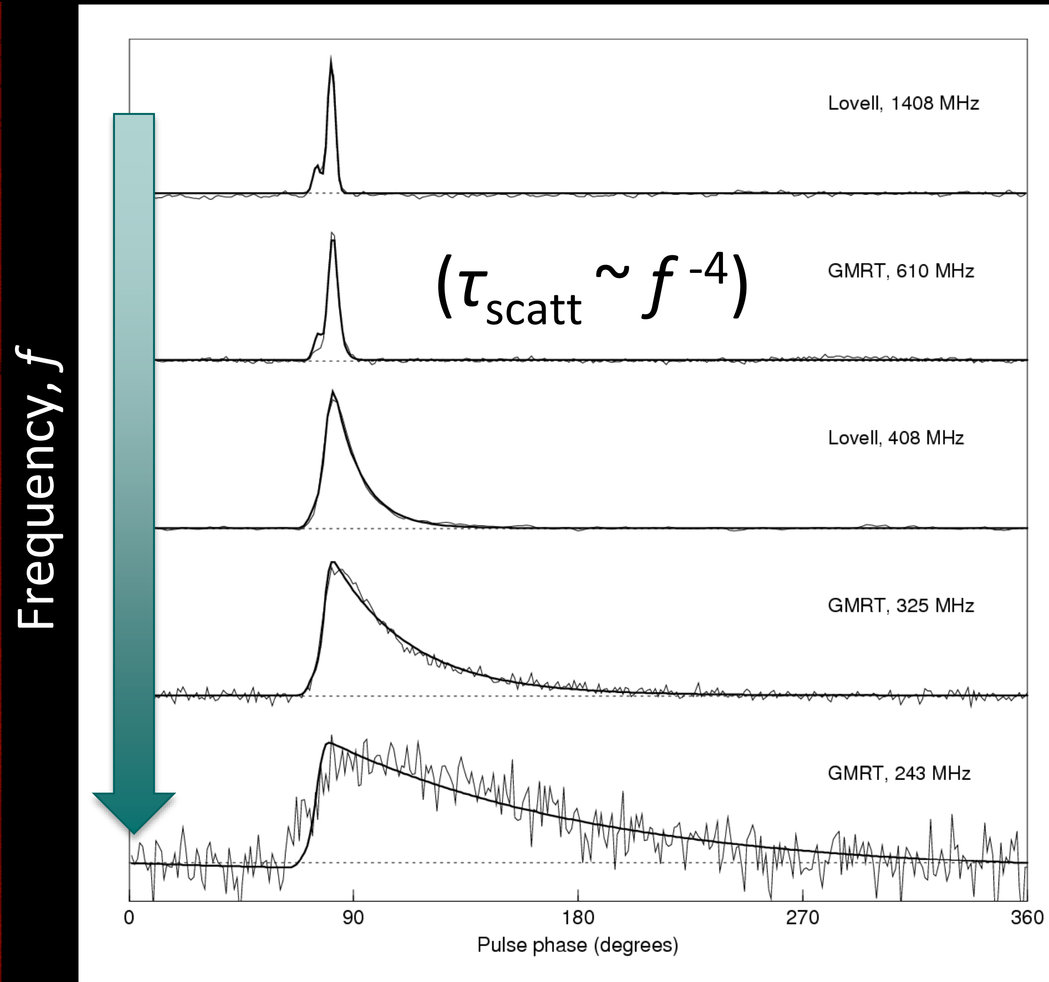
There's lots of evidence for neutron stars in the GC…

- Sustained star formation (e.g. Serabyn & Morris, Nature,1996. Ott et al., ApJ, 1999).
- Wolf Rayet and other massive stars (NS progenitors) (e.g. Figer et al., ApJ, 1999).
- Dense stellar disks of young massive stars within in central pc (Paumard et al., ApJ, 2006).
- NS perhaps already identified as ''overabundance'' of X-ray binary systems with *Chandra* (Muno et al., ApJ, 2005). → 4 within 1 pc of Sgr A*.
- At least one ''PSR like'' point source in the GC identified by *Fermi* (Lee et al. 2012).
- Pulsar wind nebula (Wang et al., MNRAS, 2006).
- Theoretical predictions for large NS population in the GC (e.g. Pfhal & Loeb, ApJ, 2004).
- Large MSP population in central stellar cluster to explain GeV γ-ray emission excess (e.g. Bednarek & Sobczak., MNRAS letters, 2013).
- **Recent estimate based on multi wavelength observations is ~1000 pulsars in inner pc! (Wharton et al. ApJ, 2012).**

A turbulent environment: pulse scattering



Kassim, LaRosa, Lazio & Hyman 1999



PSR B1831-03, Loehmer et al. 2001. Figure from The Handbook of Pulsar Astronomy, Lorimer and Kramer 2005.

A turbulent environment: pulse scattering

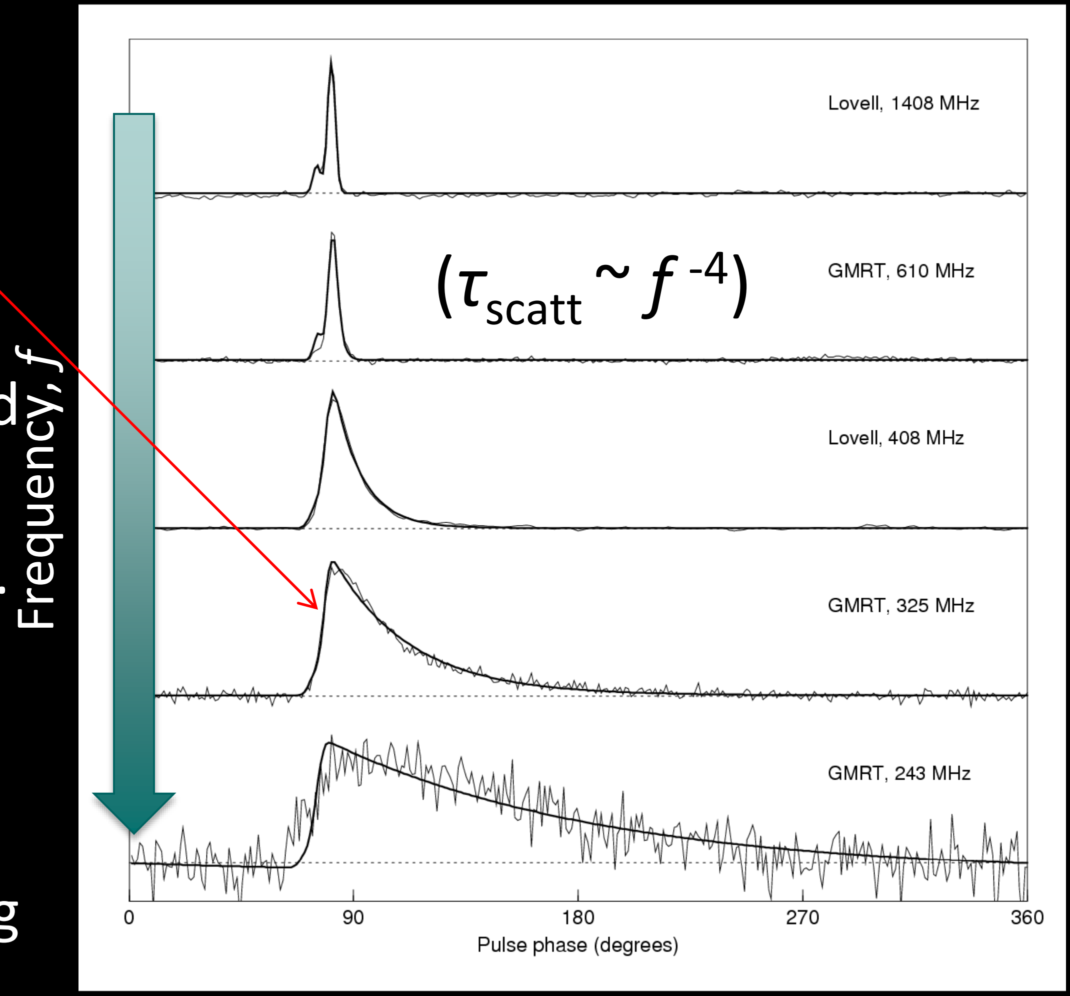
Scattering causes angular broadening & temporal broadening.

From the angular broadening of radio images of background sources ➔

τ_{scatt}~2000 seconds in the GC. (Lazio & Cordes 1998, ApJ)

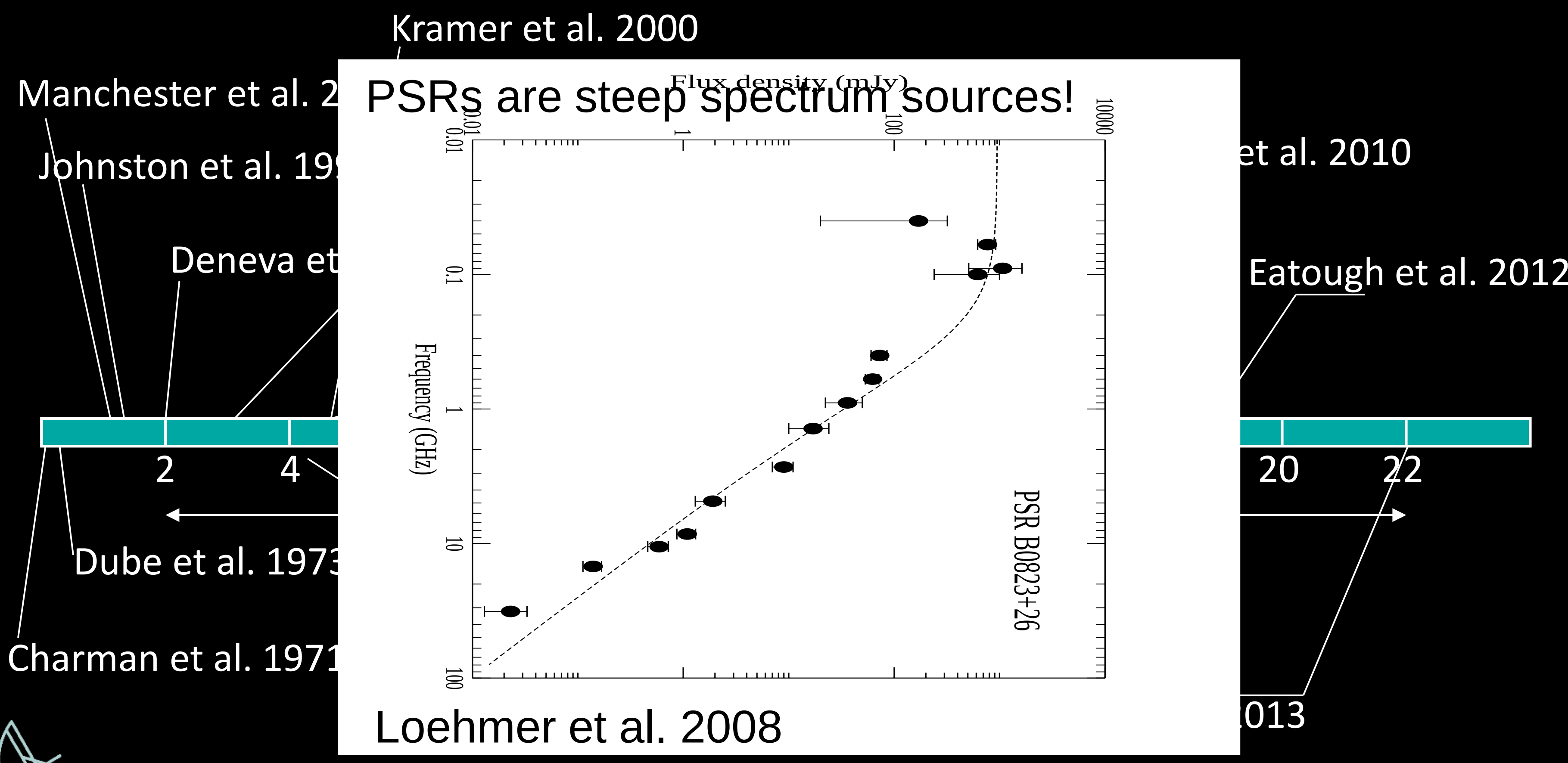
Pulsars in the GC don't pulse!

Only way to combat scattering is to observe at higher frequencies.



PSR B1831-03, Loehmer et al. 2001. Figure from The Handbook of Pulsar Astronomy, Lorimer and Kramer 2005.

In previous GC searches there has been a push to higher observing frequencies to combat effects of scattering.



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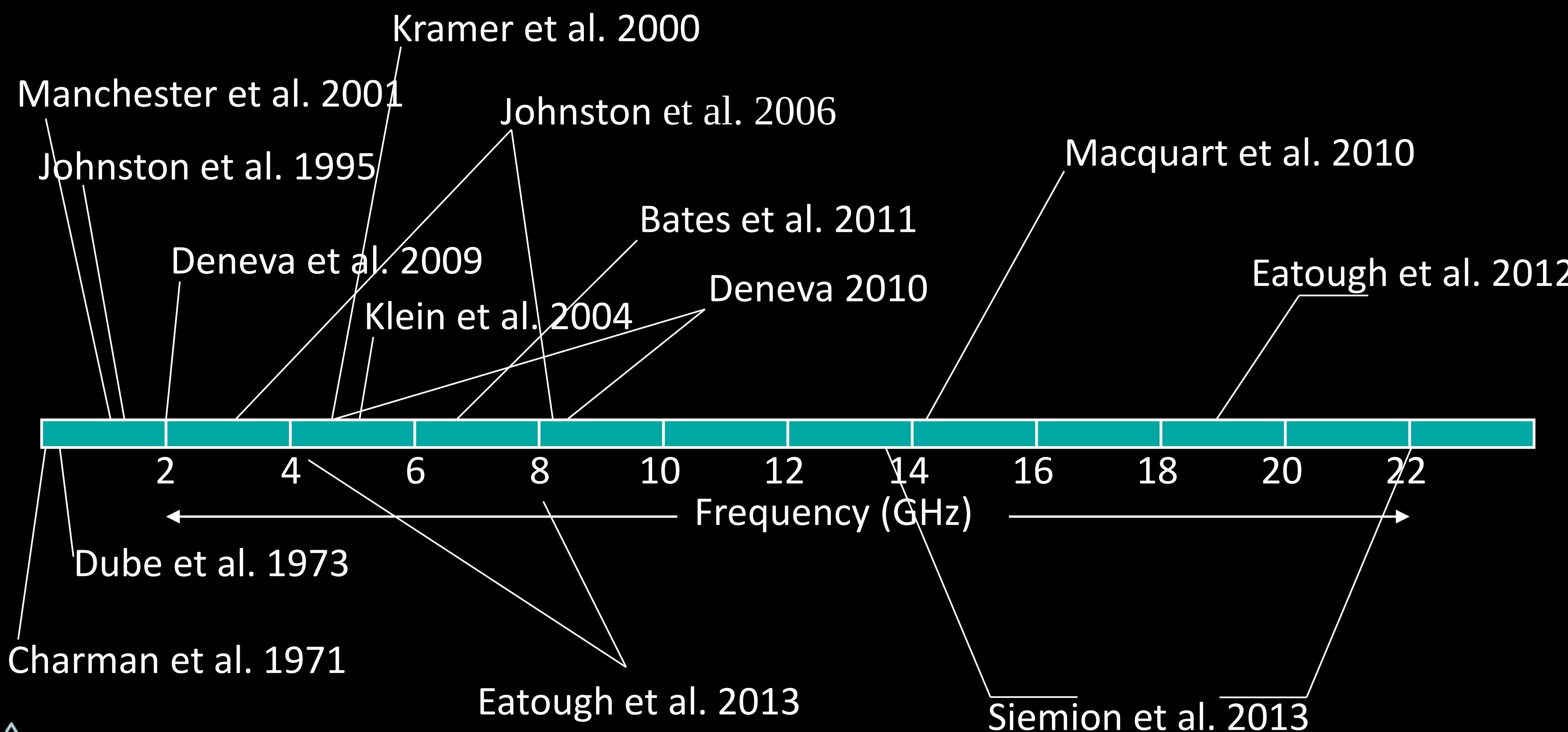
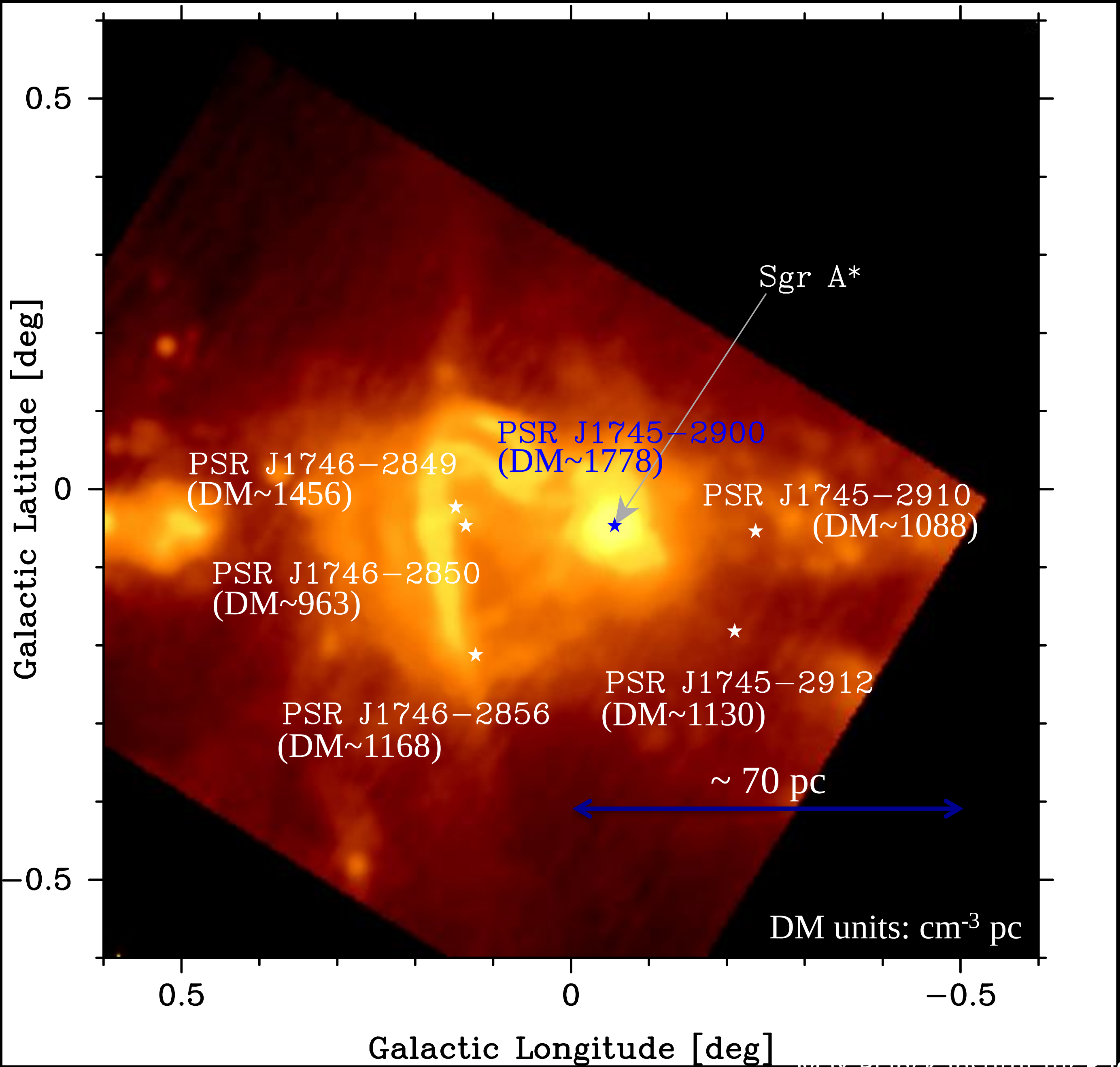


Effelsberg 10.55-GHz continuum map (Seiradakis et al. 1989). Image software provided by B. Klein.

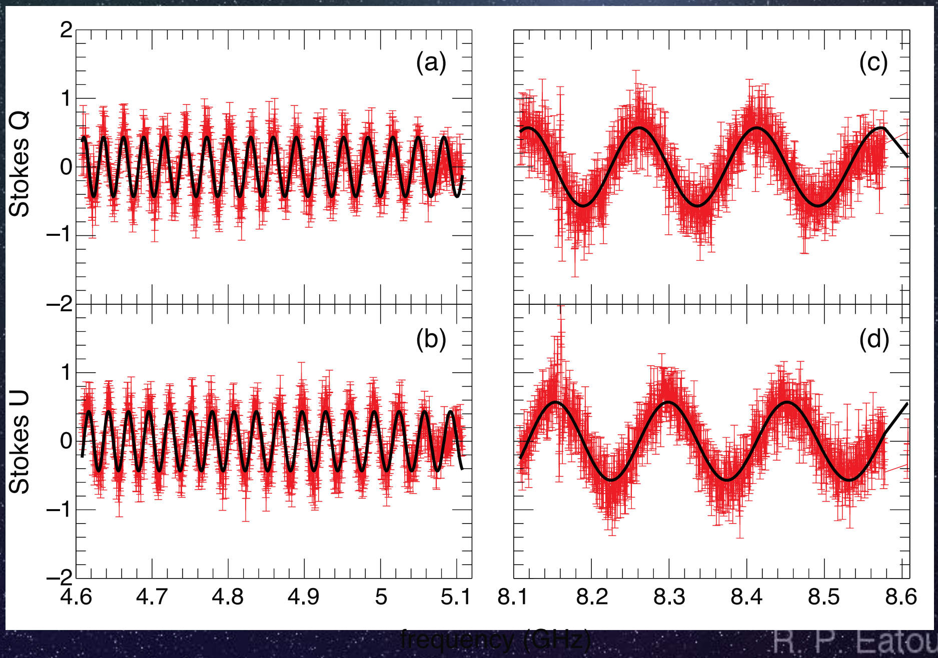


PSR/SGR J1745-2900 interesting facts & figures

- Power output from spin-down not enough to explain X-ray luminosity; likely a magnetar (Mori et al. 2013).
- Projected separation from Sgr A* ~20'000 AU (~0.1 pc).
- Bondi-Hoyle accretion zone of Sgr A* ~0.1 pc (Baganoff et al., ApJ, 2003).
- Circular orbit ~1400 year period.
- Eccentric orbit ~500 year period.
- Dispersion Measure 1778±3 cm^{-3} pc – **Highest DM known PSR.**
- Rotation Measure -66960±50 rad m^2 – **Second highest RM after Sgr A*.**

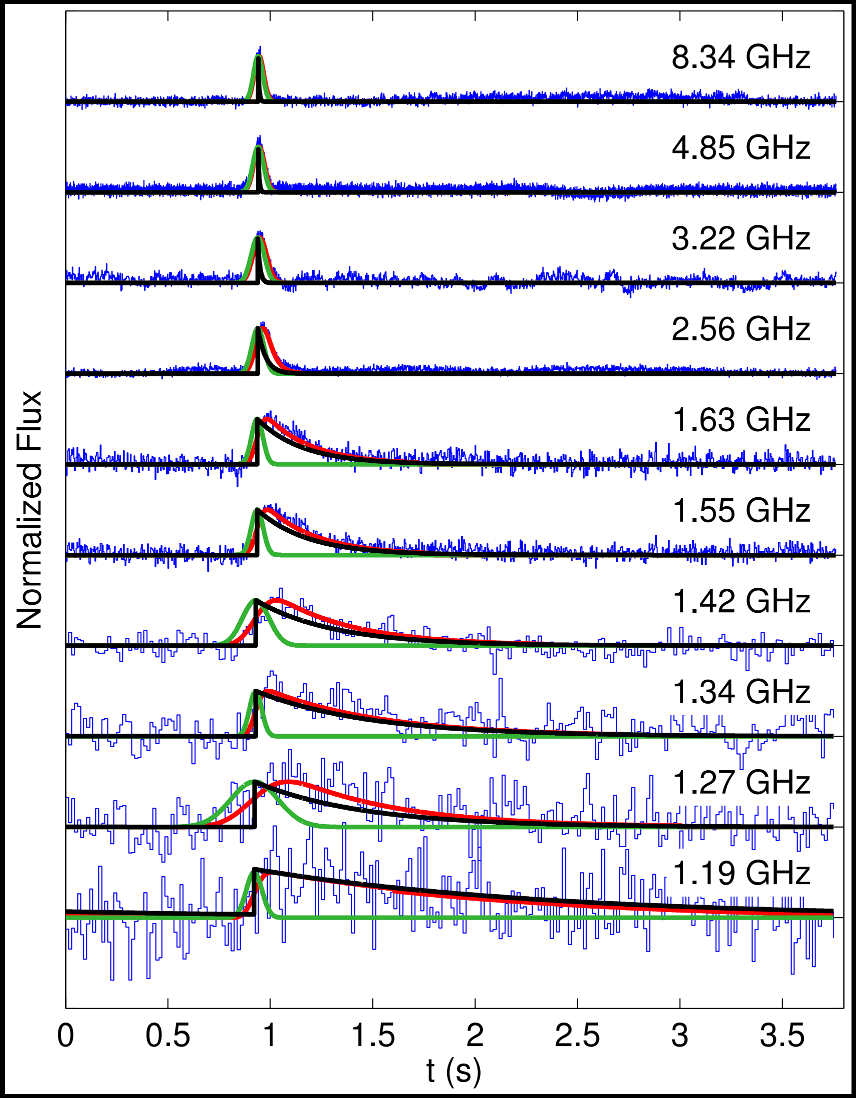
Suggests ≥8 mG magnetic field in the GC on scales of ~0.1 pc.

(Eatough et al. 2013 Nature)



R. P. Eatough

Re-evaluating pulse scattering towards the Galactic Centre



Scatter broadening time at 1 GHz

Previous prediction:

$t_{scatt} \gg 2000$ seconds

Measured value:

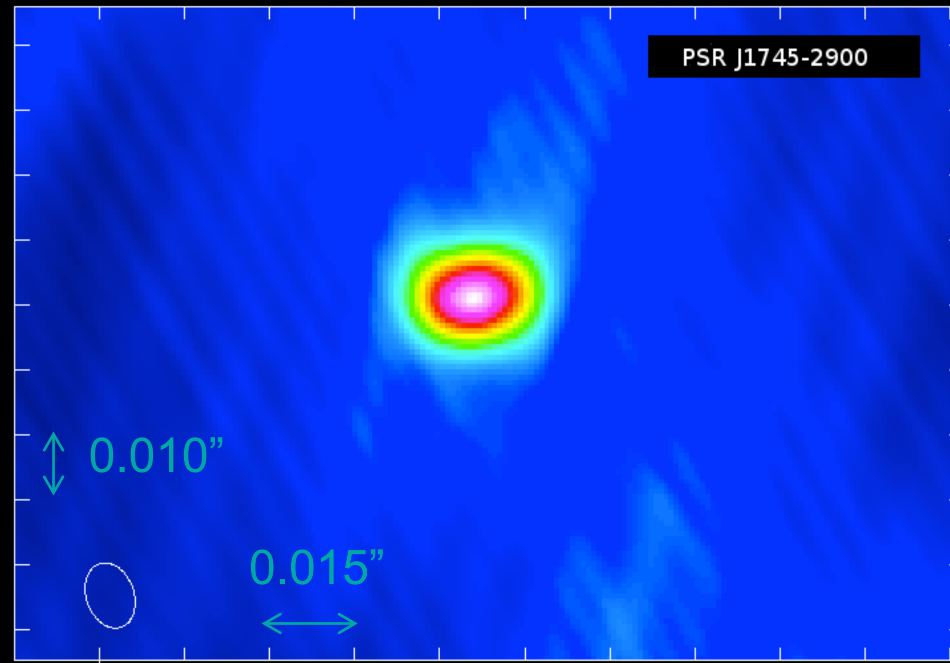
$t_{scatt} = 1.3 \pm 0.2$ seconds

Scattering spectral index of -3.8±0.2 consistent with previous measurements in the Galactic field.

Re-evaluating pulse scattering towards the Galactic Centre

- Angular size of Sgr A* and magnetar are the same. Suggests behind same scattering screen.
- From the pulse broadening measurements in combination with VLBA angular broadening, can also calculate the location **of a thin single scattering screen** (Bower et al. 2014 *ApJ Letters*).
- **Scattering screen 5.9 ± 0.3 kpc from the GC.** (c.f. 0.13 kpc Lazio & Cordes 1998 – if thin screen correct). Location of scattering material: Scutum-Centaurus spiral arm?

Bower et al., 2014, *ApJ Letters*



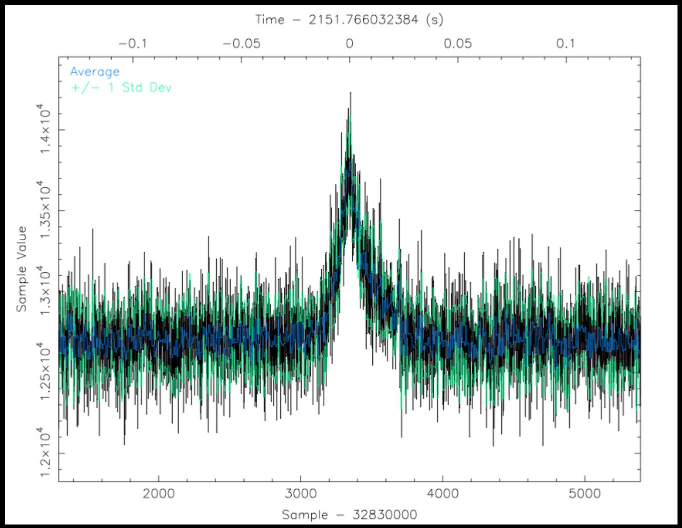
Cordes & Lazio 1997, *ApJ*

$$t = 6.3\sec\left(\frac{D}{8.5kpc}\right)\left(\frac{q_1}{1.3arc\sec}\right)^2\left(\frac{D}{\mathrm{D}} - 1\right)n^{-4}$$

So where are all the pulsars?

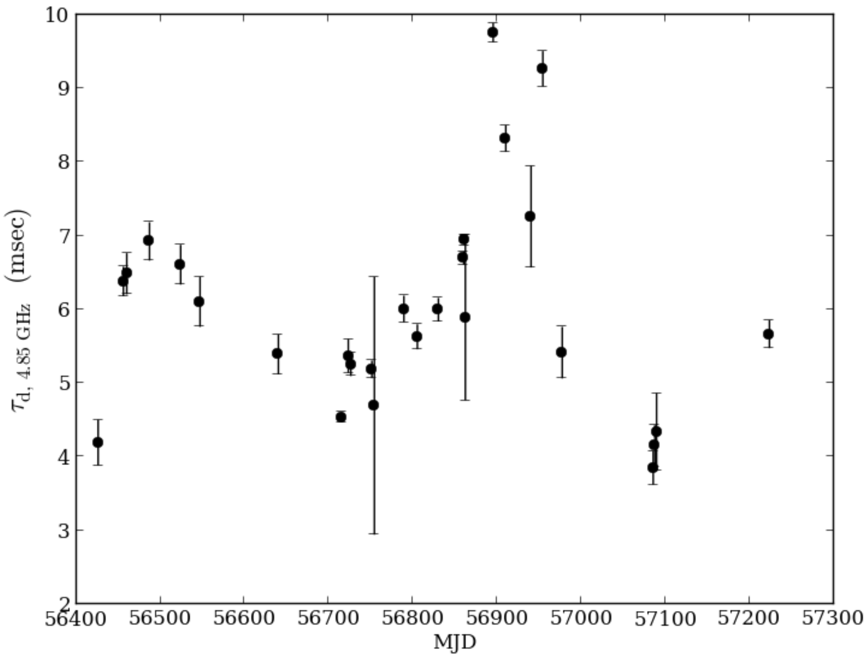
- While pulse scattering (toward Sgr A*) appears reduced, it is still enough to render pulsar searches below ~7 GHz unable to detect MSPs (c.f. 1.4 GHz where PSRs on ave. ~x20 brighter - integrate x400 longer!.) Not possible.

- PSR J1745-2900 shows scattering at similar observing frequencies appears to be variable in time. Fast moving clouds in the GC.



Example bright single pulse from PSR J1745-2900 measured at Effelsberg.

Spitler et al. in prep



- The GC preferentially produces magnetars (Dexter & O'Leary 2014)?

- Free-free thermal absorption in dense GC environment or ejecta surrounding newly born magnetars causes spectral turnover at high frequencies – PSRs never become bright (e.g. Lewandoski et al. 2015, Rajwade et al. 2016).

- Previous single dish searches are degraded by intense sky background, caused by e.g. Sgr A East and Sgr A West, in the telescope field of view (~arcmin). $S_{\mathrm{GC}} >> S_{\mathrm{receiver}}$

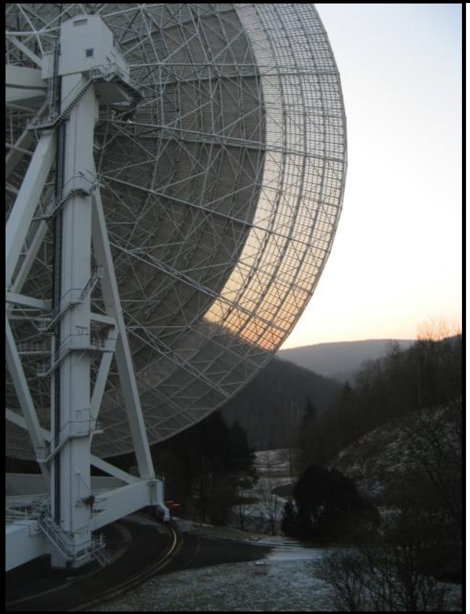
- Re-analysis of the implied pulsar population after previous surveys, and the discovery of PSR J1745-2900, are not inconsistent with ~200 PSRs in inner parsec (Chennamangalam & Lorimer 2014, MNRAS Let).

- Binary motion in deep searches smears PSR signal due to Doppler effect. Larger chance of binary companions when stelllar density two orders of magnitude higher than in Globular clusters (Macquart & Kanekar 2015, ApJ).

On-going and future Galactic Centre radio pulsar searches

Regular observations with Effelsberg at 5, 8, 15 and 19 GHz.

Repeated searches are warranted due to binary motion or transient phenomena.



Effelsberg 100 m, Bad Münstereifel, Germany.

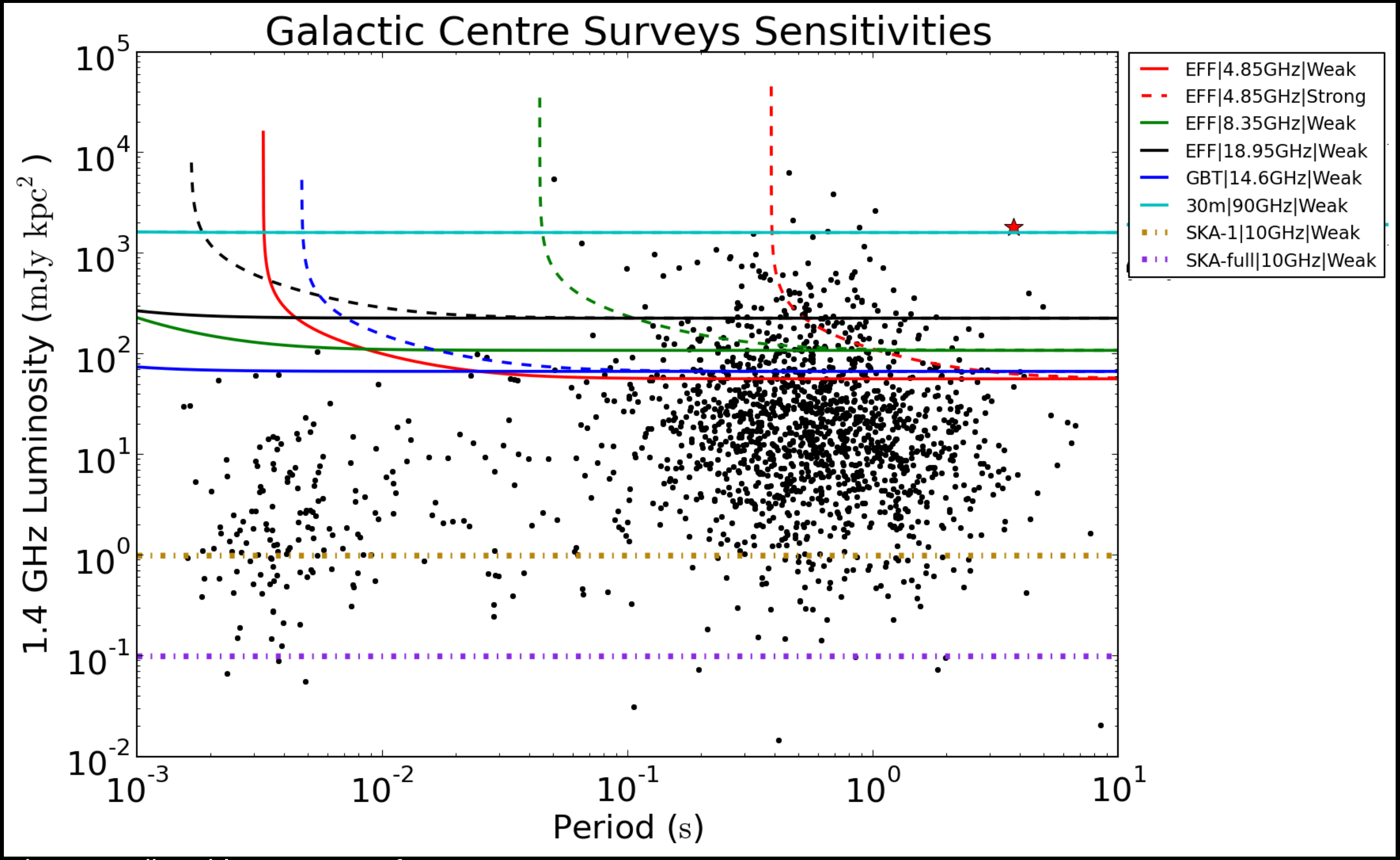
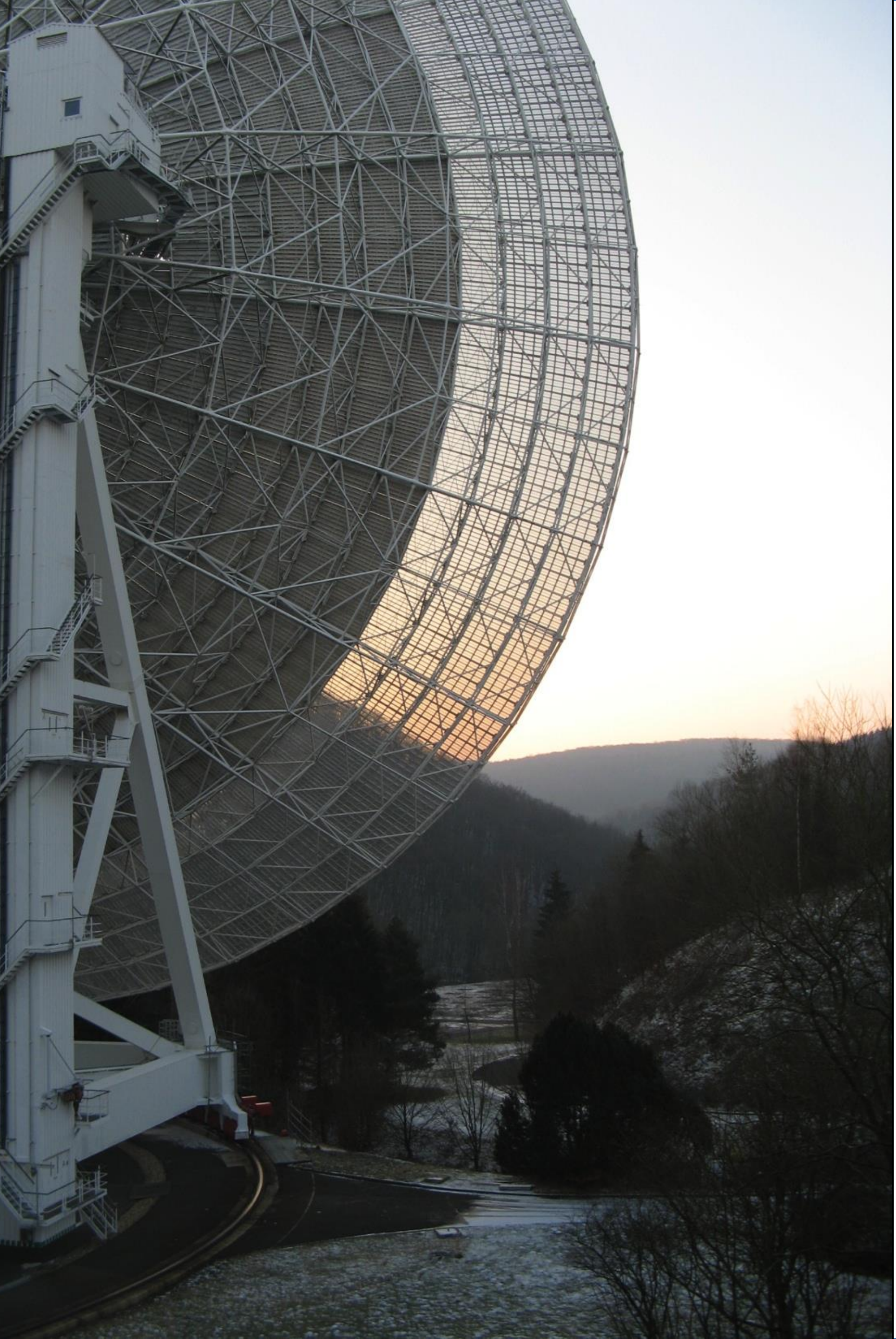
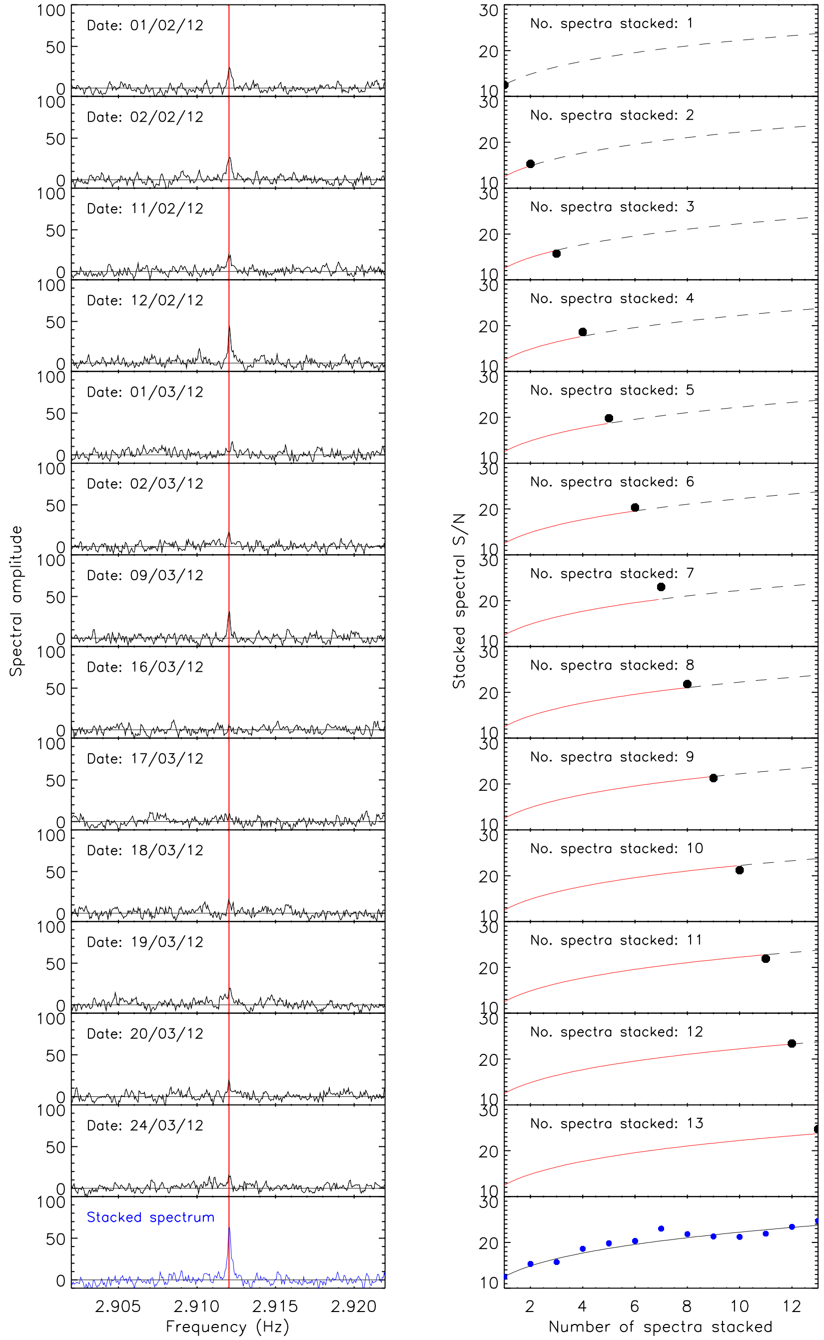


Figure credit Pablo Torne, MPIfR

Effelsberg 19 GHz GC pulsar stack search



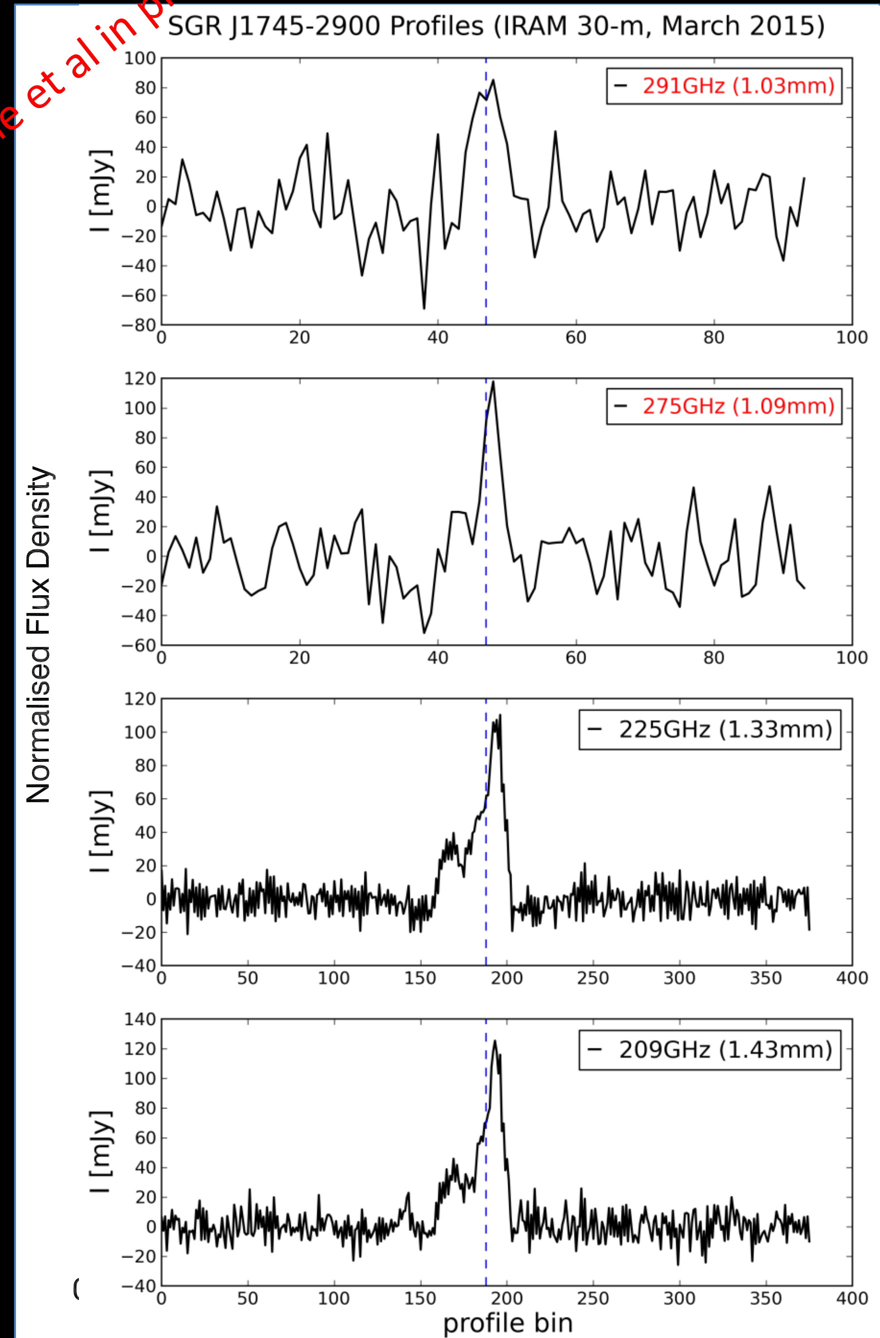


mm-wavelength searches

PSR J1745-2900 detected up to 225 GHz, (Torne et al. 2015).

Magnetars have flat spectra. Potentially a larger number of fainter objects could be detected with e.g. IRAM, TMT or ALMA (*BlackHoleCam*).

IRAM 30 m, Pico de Veleta, Spain.



JVLA "fast visibility search" at 3 GHz, P.I. Robert Wharton, Cornell.

New operational mode for imaging will be used to search central pc, and any interesting candidates flagged at high energy.

Image Copyright NRAO/AUI

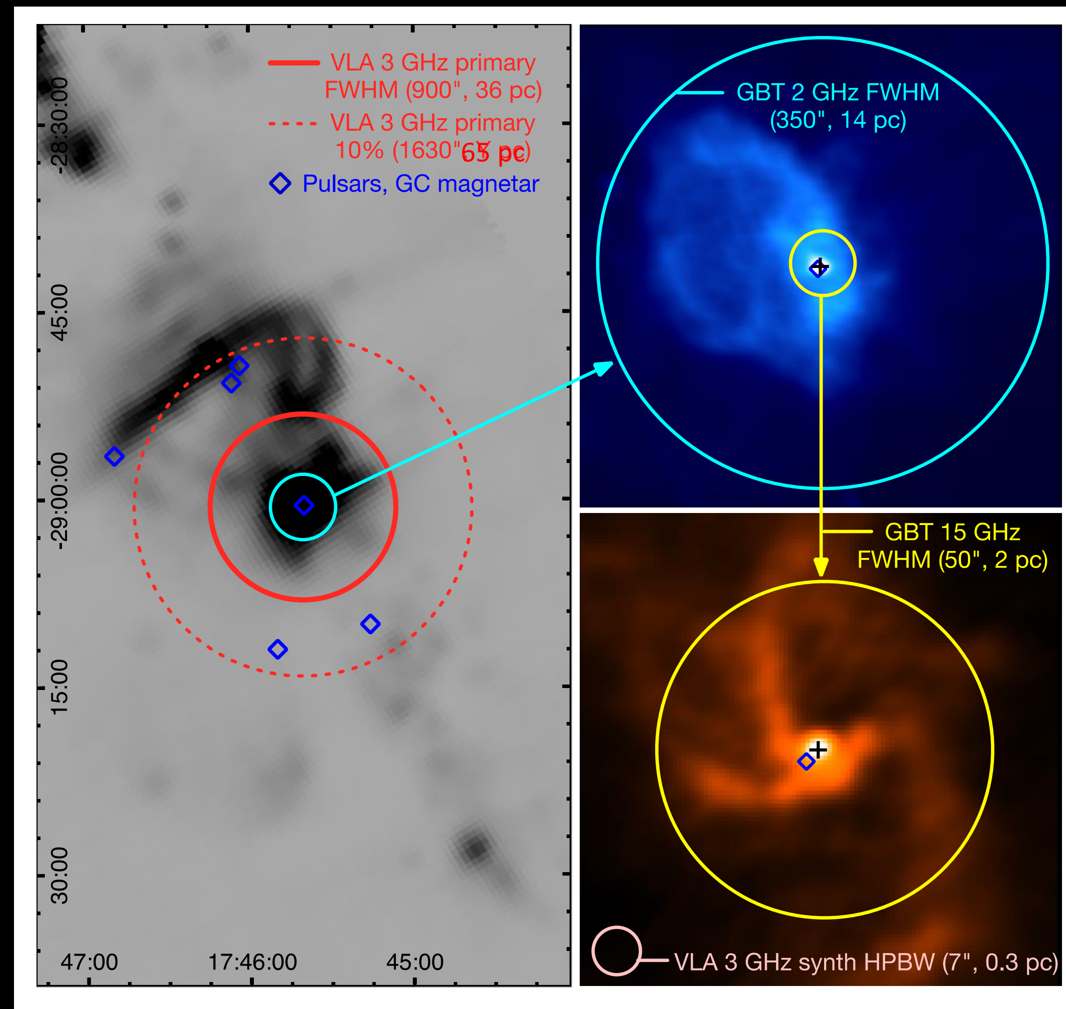


Image credit Robert Wharton

JVLA "fast visibility search" at 3 GHz, P.I. Robert Wharton, Cornell.

Survey will be x5 more sensitive than any previous. GC background can be neglected in small synthesized beam .

10 ms sample time, means no MSPs ☹

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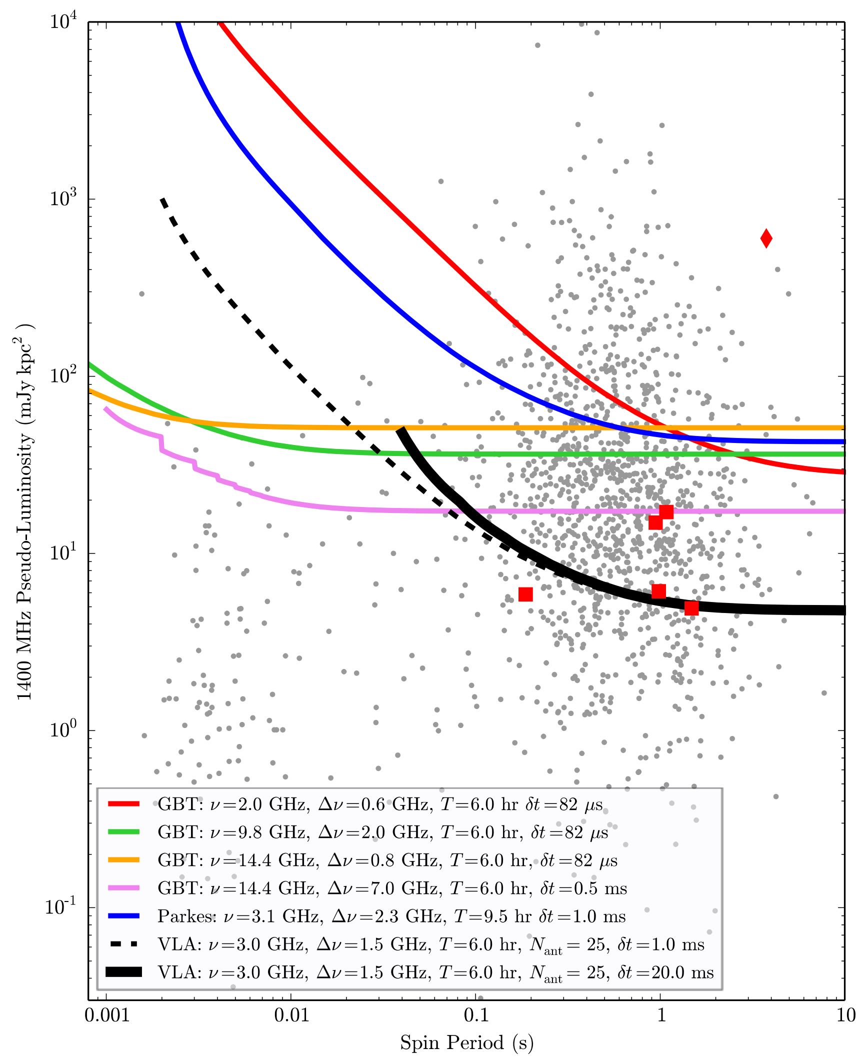
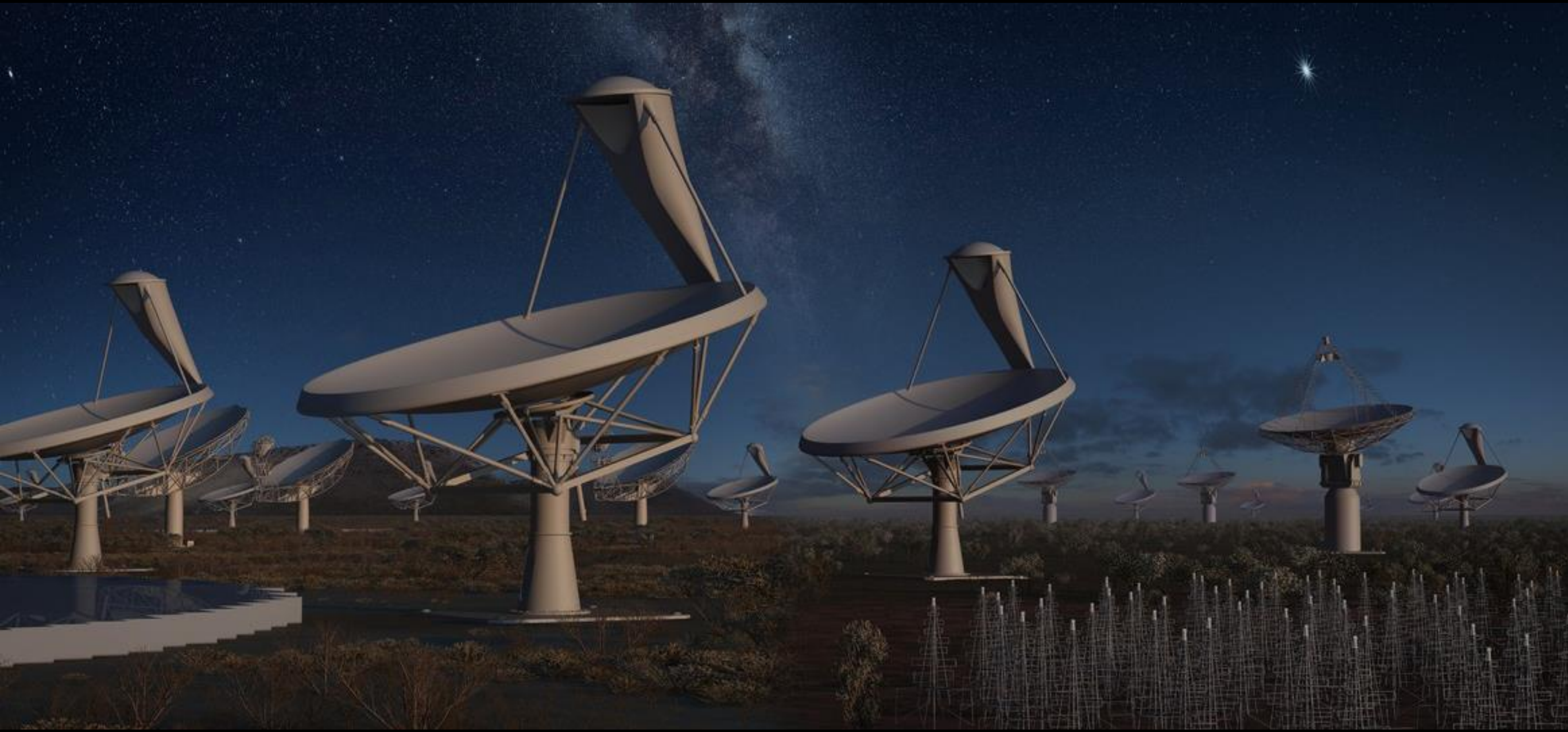


Image credit Robert Wharton

Future prospects with the SKA



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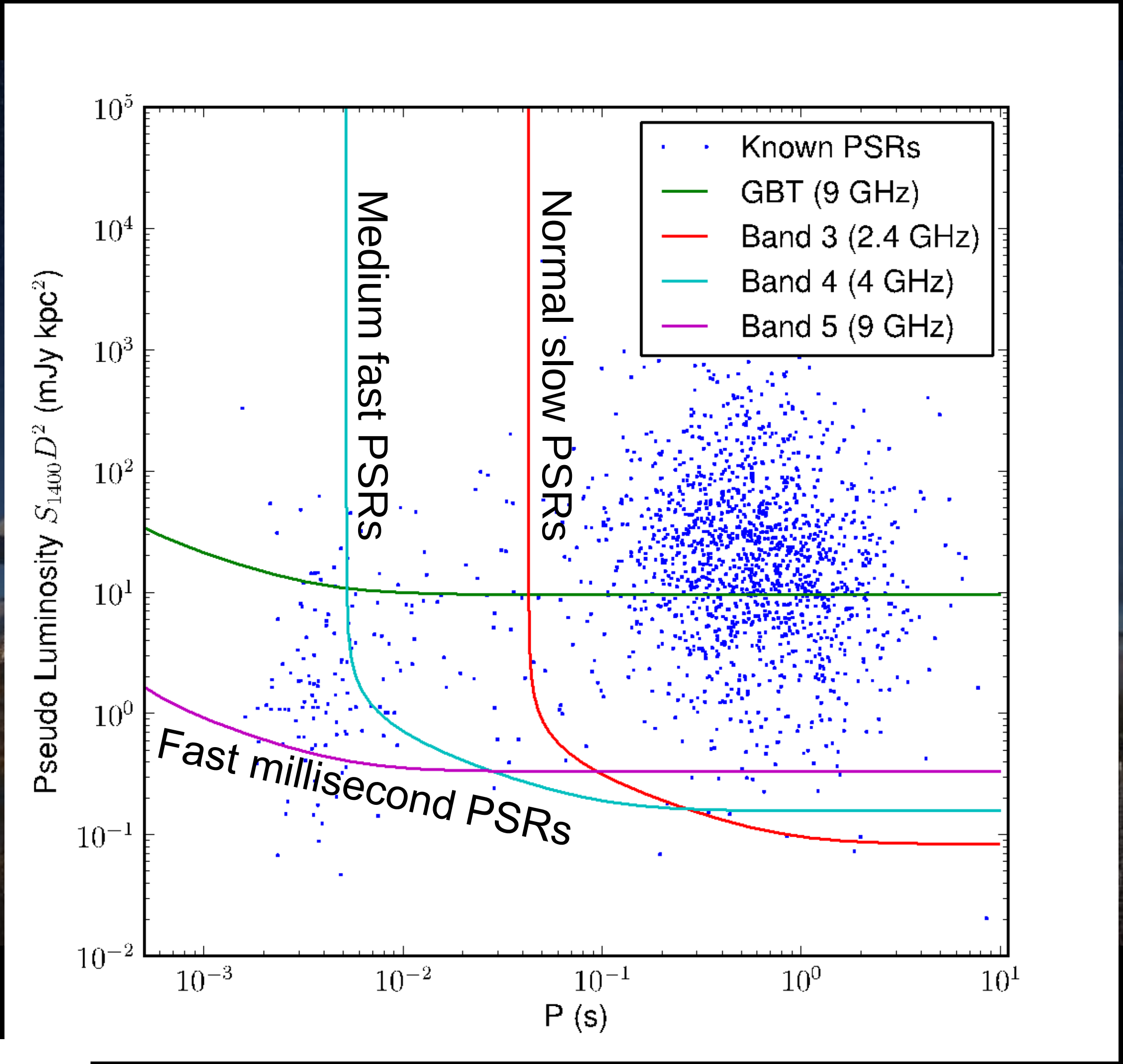

Figure provided by K. J. Lee

Thanks