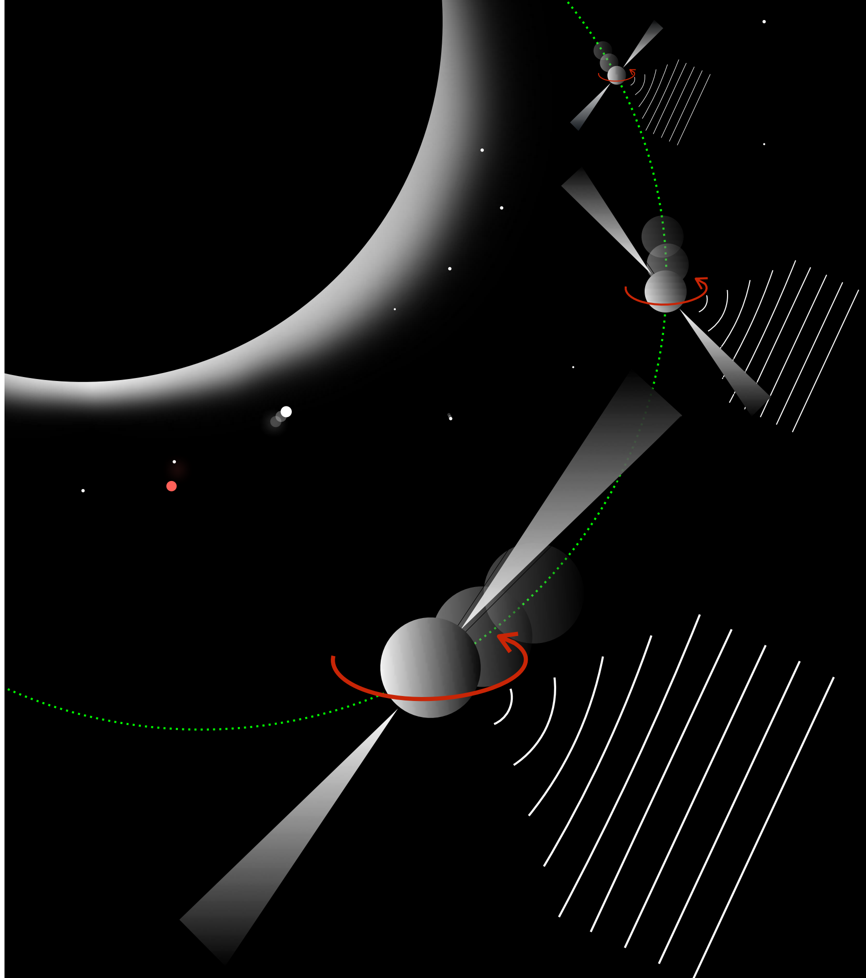
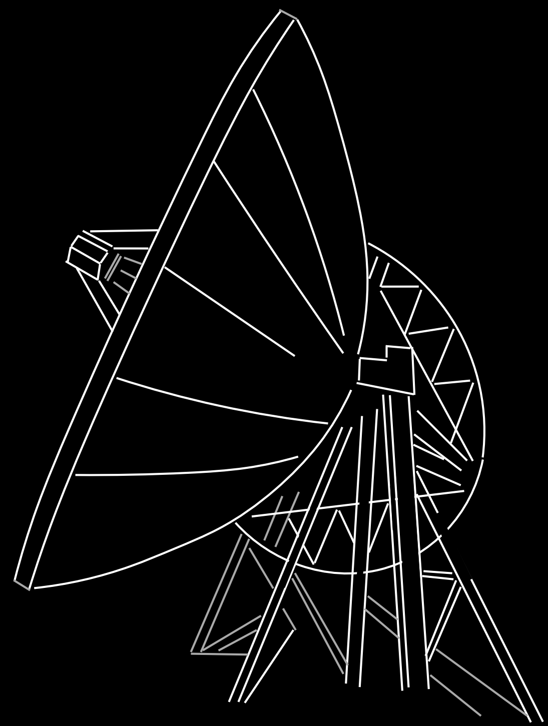


A magnetar at the heart of the Milky Way

Ralph Eatough

Max Planck Institute for Radio Astronomy,

IAUS 337 Pulsar Astrophysics - The Next 50 Years,
Jodrell Bank Observatory, 4-8th Sep. 2017



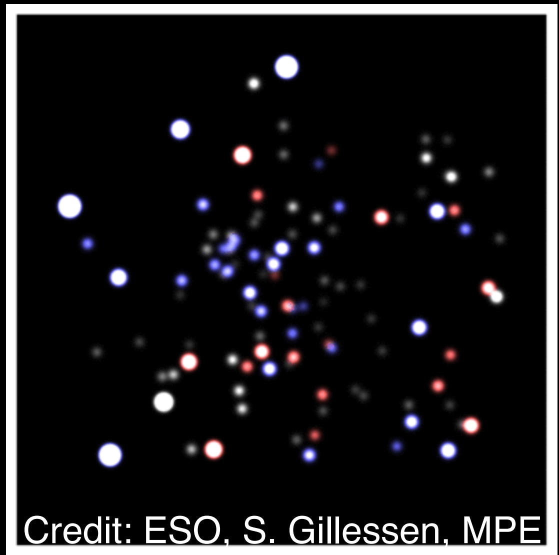
Gregory Desvignes,
Ue-Li Pen, Geoff Bower, Heino Falcke, Pablo Torne,
KJ Lee, Dominic Schnitzeler, Michael Kramer,
Ramesh Karuppusamy, Laura Spitler, Andrew Lyne,
Ben Stappers, Kuo Liu, Evan Keane.

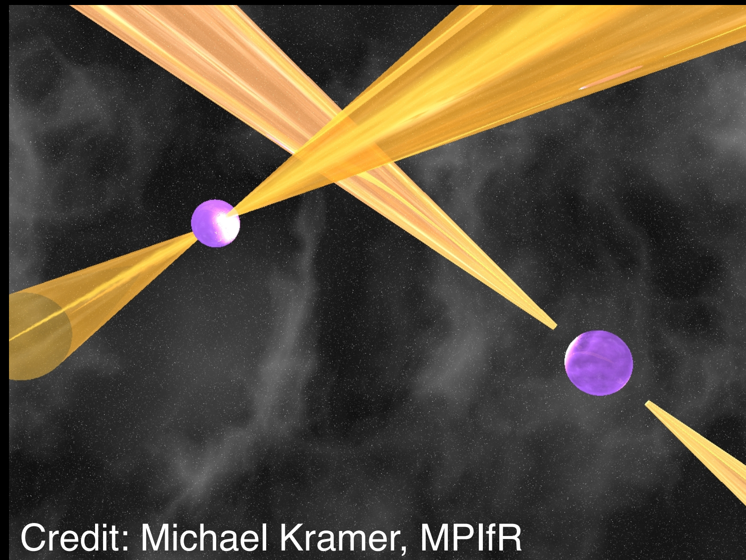
Telescope outline from a photo of the Effelsberg telescope by Enno Middelberg (Liu & Eatough, Nature Astronomy, 2017).

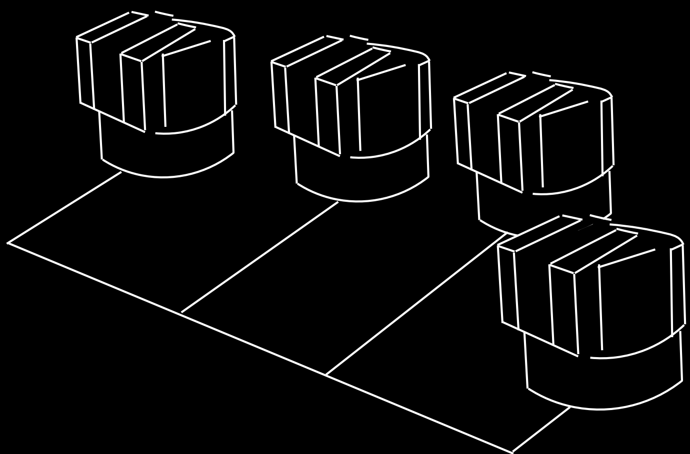
Outline

- Pulsars in the Galactic Centre.
- The Galactic Centre - a magnetic environment.
- PSR J1745-2900 - A magnetar at the heart of the Milky Way.
- Latest results from PSR J1745-2900.

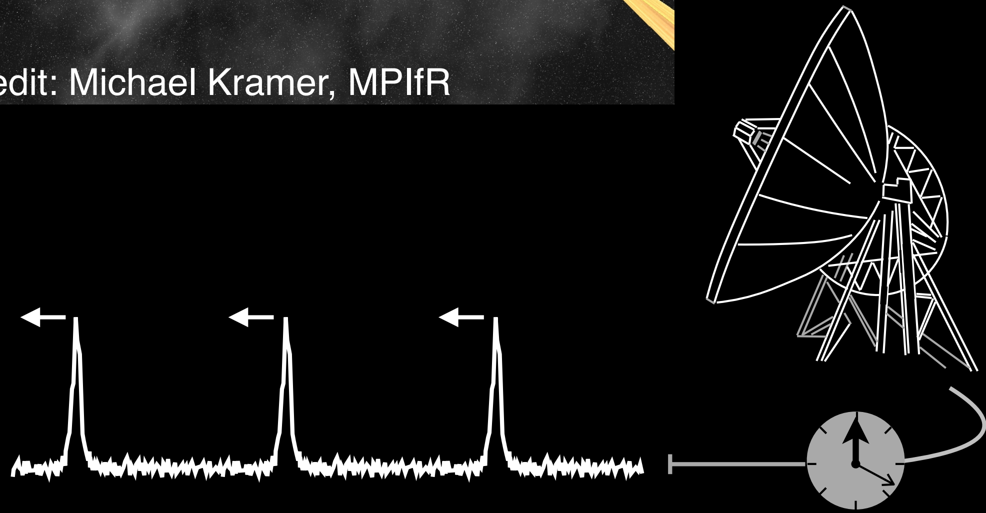
Pulsars in the Galactic Centre


Credit: ESO, S. Gillessen, MPE


Credit: Michael Kramer, MPIfR

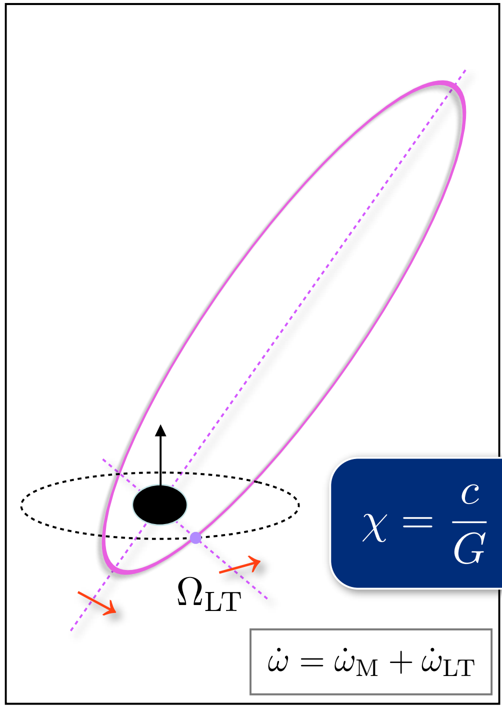


0.1 AU VLTI astrometry, GRAVITY.



Typical 100 μs timing residuals can give sensitivity to positional changes on spatial scales of the order of tens of kilometres.

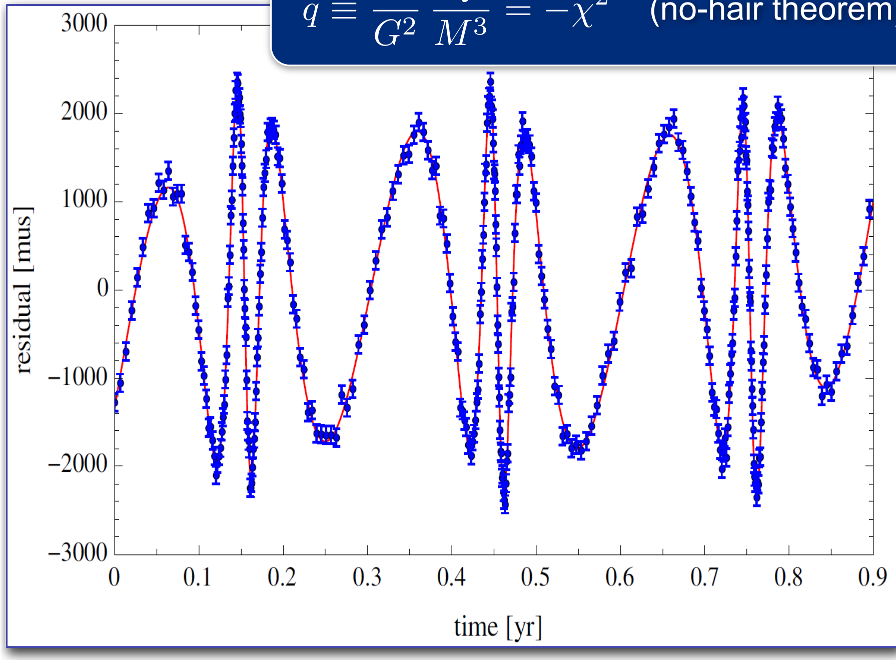
Pulsars in the Galactic Centre



$$\chi = \frac{c}{G}\frac{S}{M^2} \leq 1 \quad \text{(CCC)}$$

Lense-Thirring orbital precession will be used to extract spin of black hole. Fig. courtesy of Wex.

$$q \equiv \frac{c^4}{G^2}\frac{Q}{M^3} = -\chi^2 \quad \text{(no-hair theorem)}$$



Simulated quadrupole moment signature in Sgr A* PSR timing residuals. Fig. courtesy of Liu & Wex.

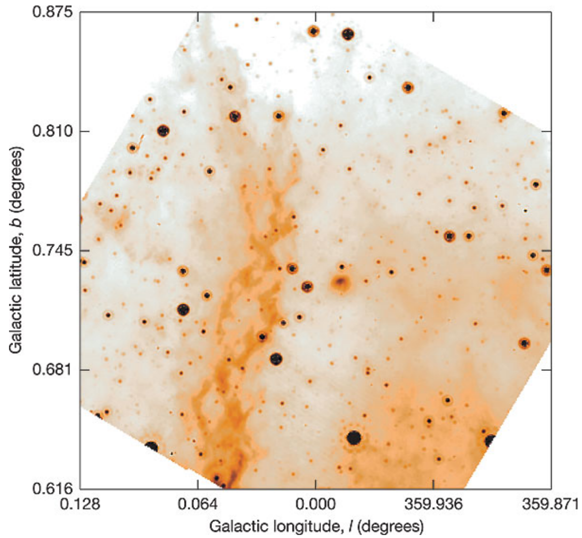
SMBH mass (±1 $M_\odot$),

Spin (***Cosmic Censorship Conjecture***),

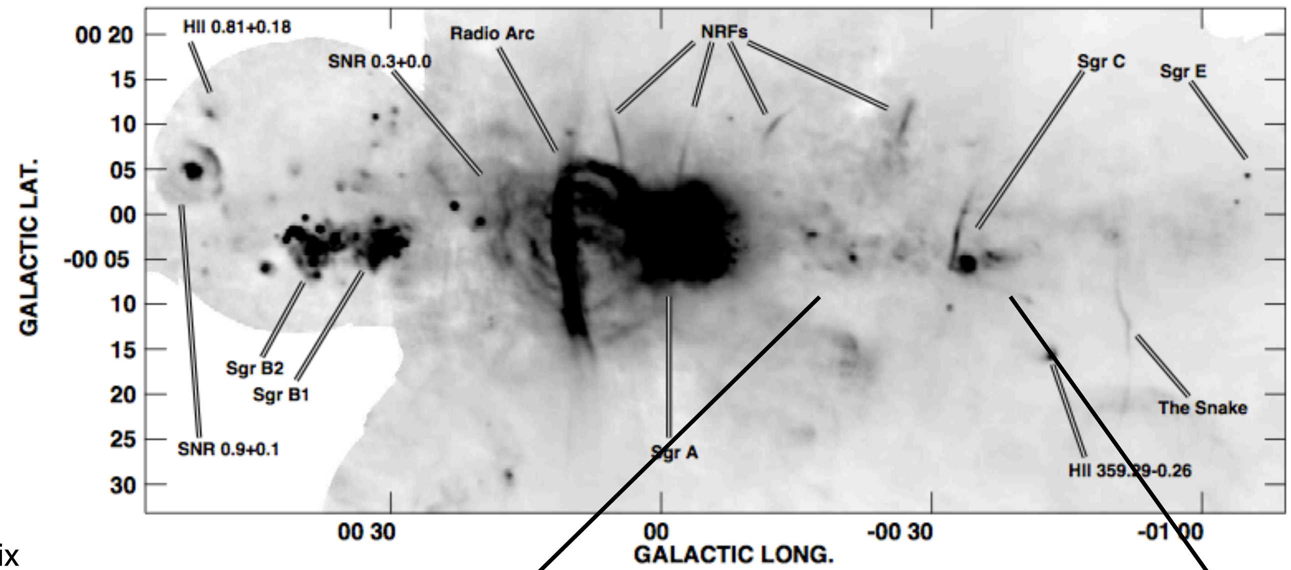
Quadrupole moment (***No-hair Theorem***),

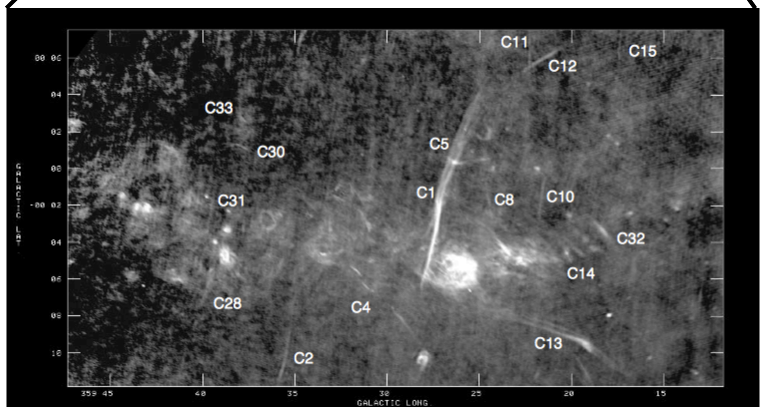
Distance (±1 pc - in conjunction with optical astrometry).

The Galactic Centre - a magnetic environment



Spitzer 24 μm IR image of a "Double Helix Nebula" toward GC. Morris et al. 2006, Nature





VLA 20 cm continuum survey of the GC showing "vertical" and randomly oriented NTFs. Yusef-Zadeh et al. 2004, ApJ Sup.

- Conditions in the inner few hundred pc (CMZ) unlike elsewhere in Galaxy.

Morris 2014, arXiv:1406.78.59:

- B-field in dense clouds ***parallel*** to plane.

- Strong ***poloidal*** field in intra-cloud regions visible as non-thermal filaments.

The Galactic Centre - a magnetic environment

GC pulsars would also be excellent probes of the ionized & magnetized environment; through measurements of dispersion measure (*DM*), rotation measure (*RM*) and scatter broadening (angular and temporal).

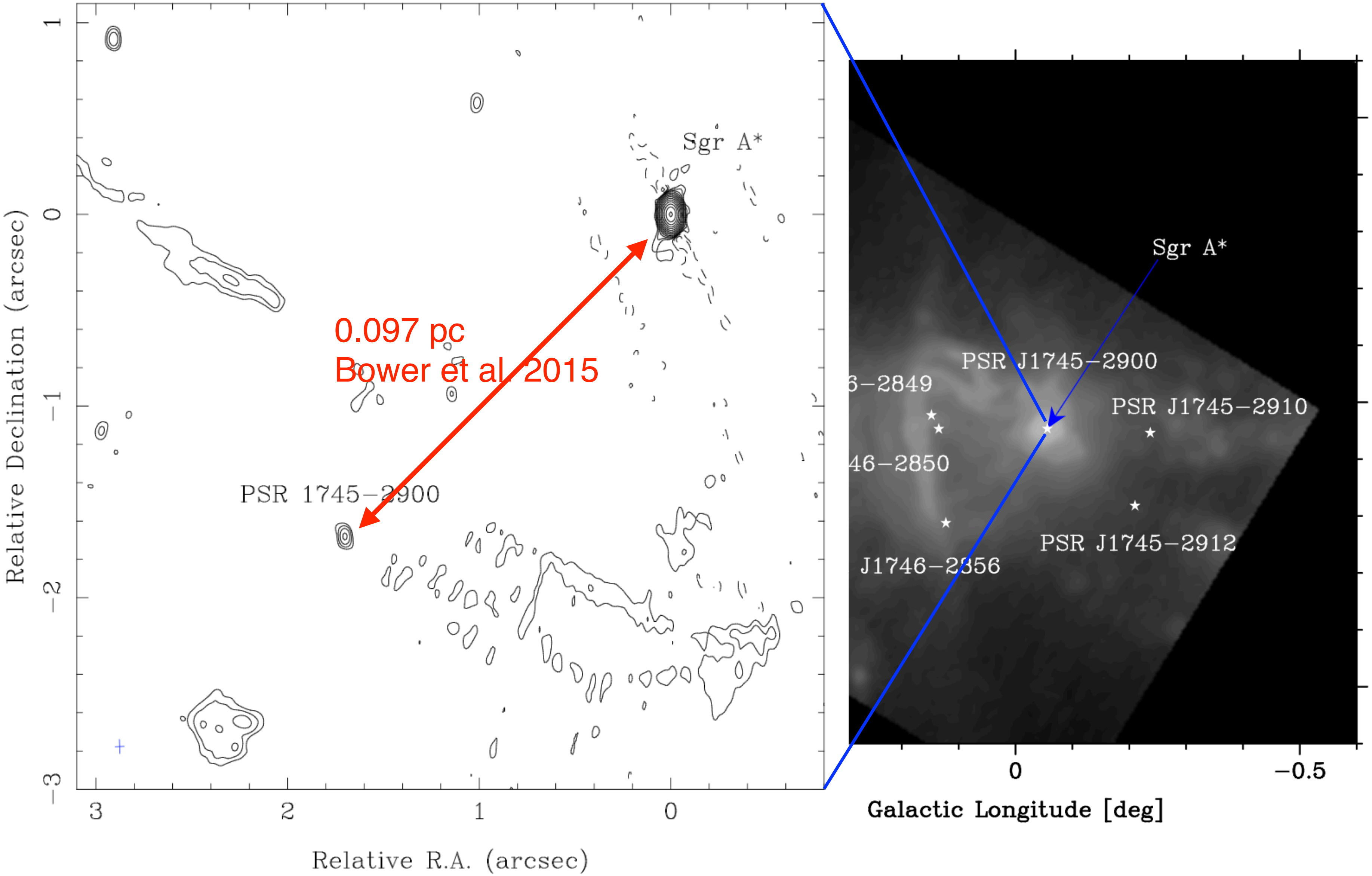
$$DM = \int n(l)\,dl$$

$$RM = e^3 / (2\pi m_e^2 c^4) \int B(l)n(l)\,dl$$

$$\Delta\phi = RM\,\lambda^2$$

$$B_{=} \geq \frac{RM}{0.81DM}\,\mu G$$

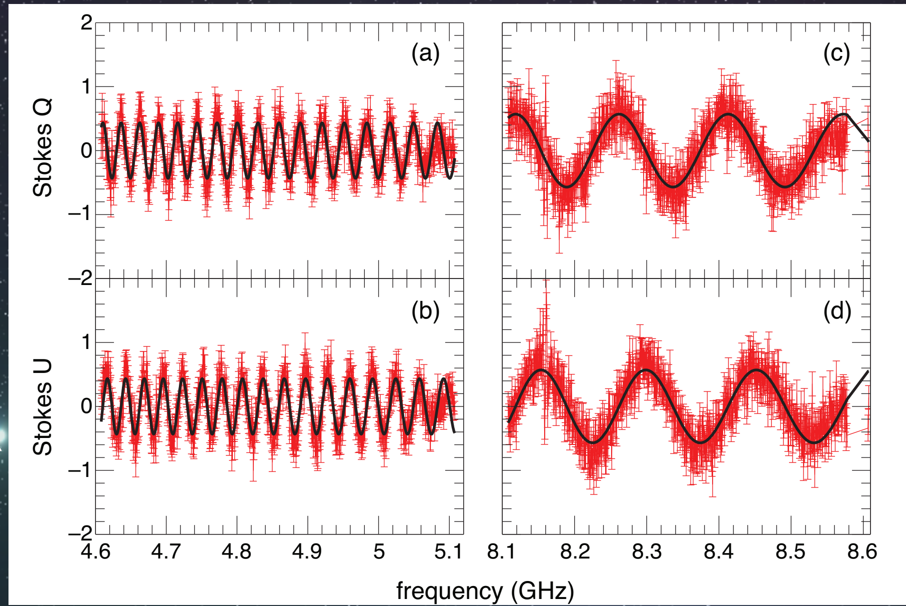
PSR J1745-2900 - A magnetar at the heart of the Milky Way

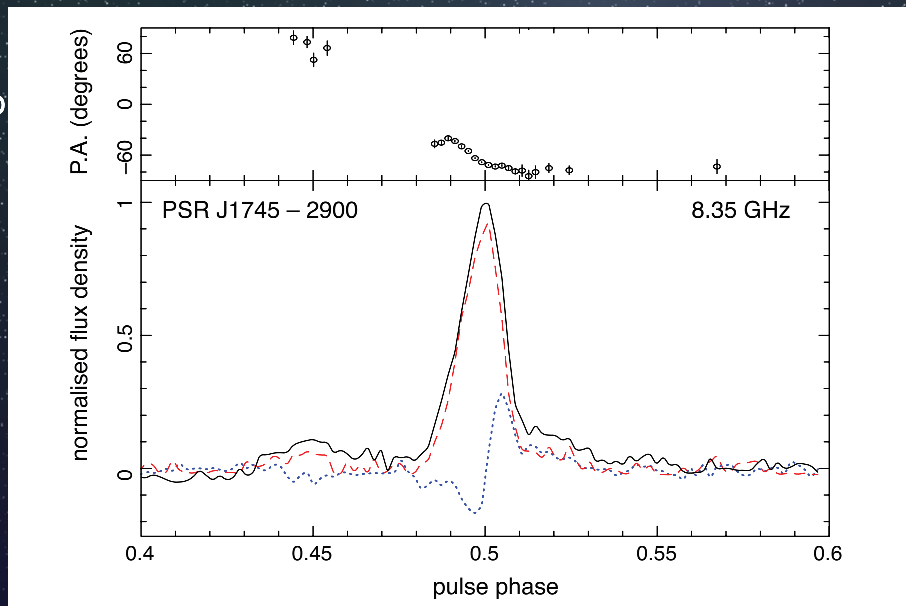


Kravchenko et al. 2014, VLA


PSR J1745-2900 - A magnetar at the heart of the Milky Way
RM = -440’000 rad m-2
(1st)
RM = -66’960 rad m-2
(2nd)

PSR J1745-2900 - A magnetar at the heart of the Milky Way



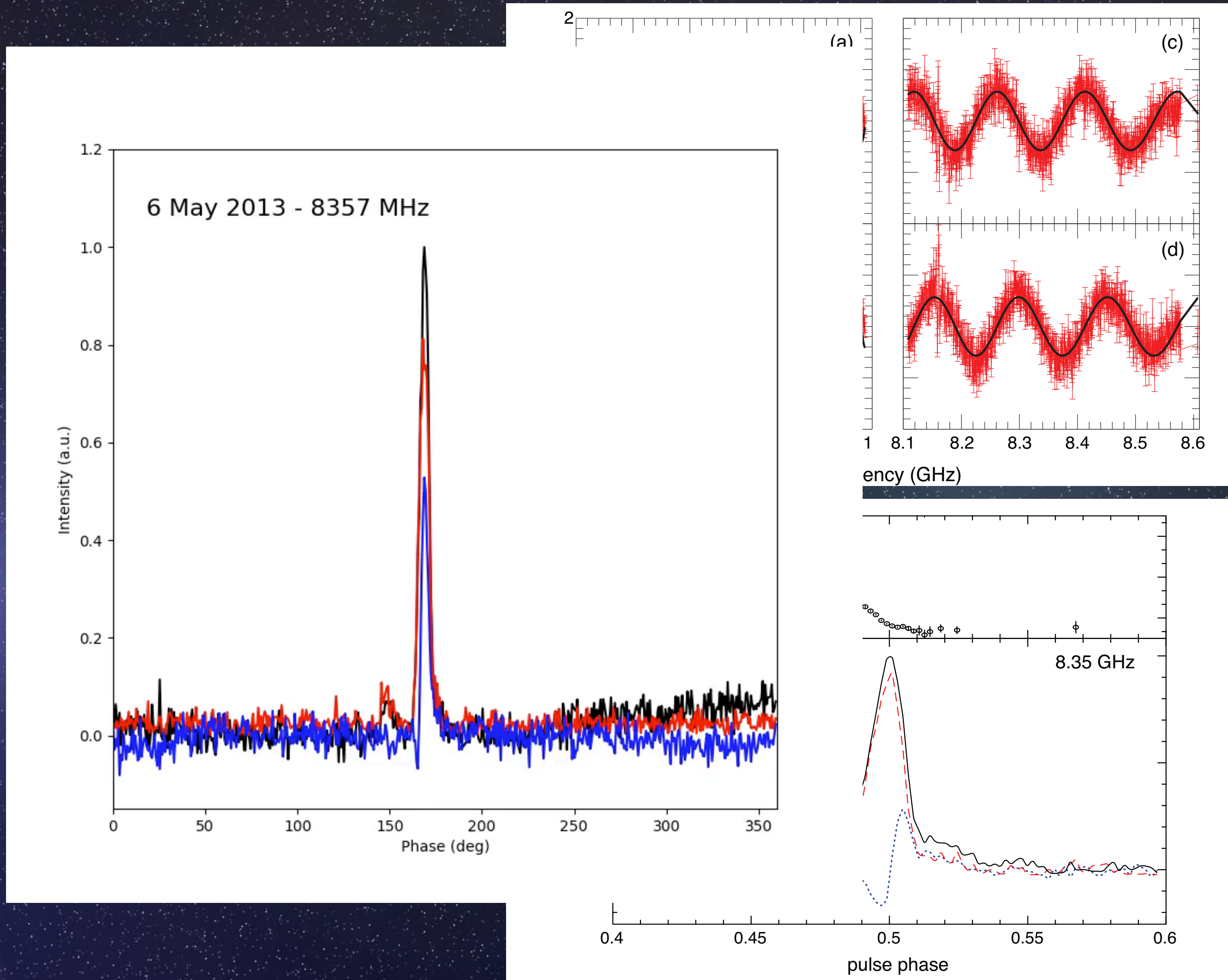


Eatough et al. 2013, Nature

RM = -66’960 rad m^{-2}

(2nd)

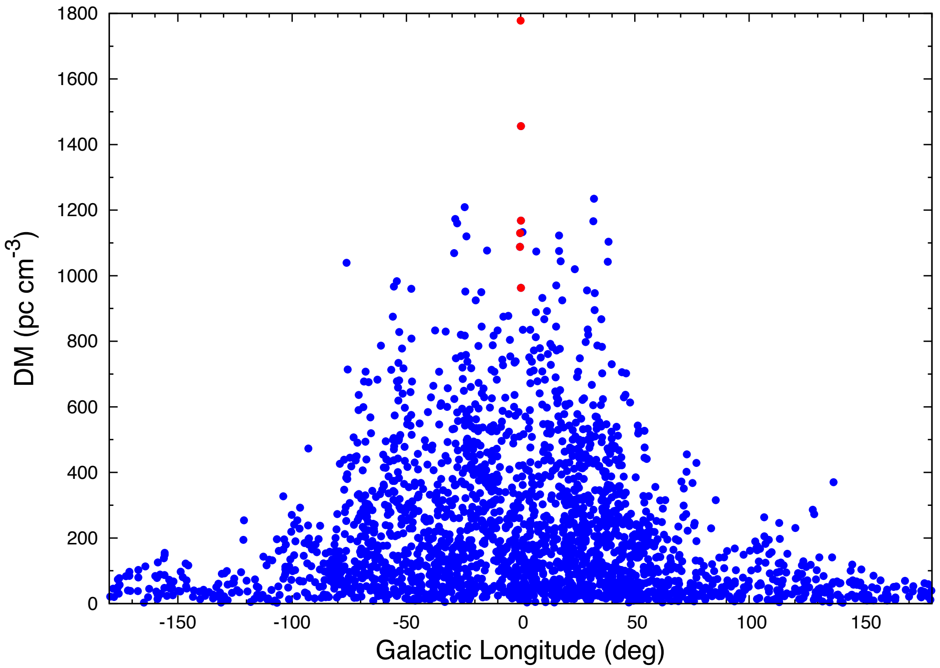
PSR J1745-2900 - A magnetar at the heart of the Milky Way



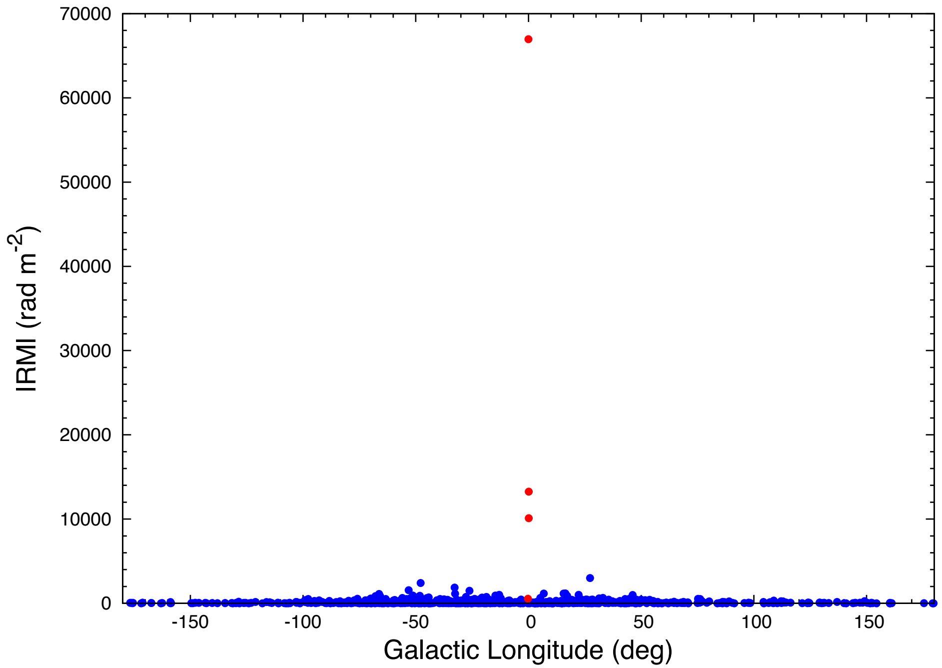
RM =

PSR J1745-2900 - A magnetar at the heart of the Milky Way

DM



RM

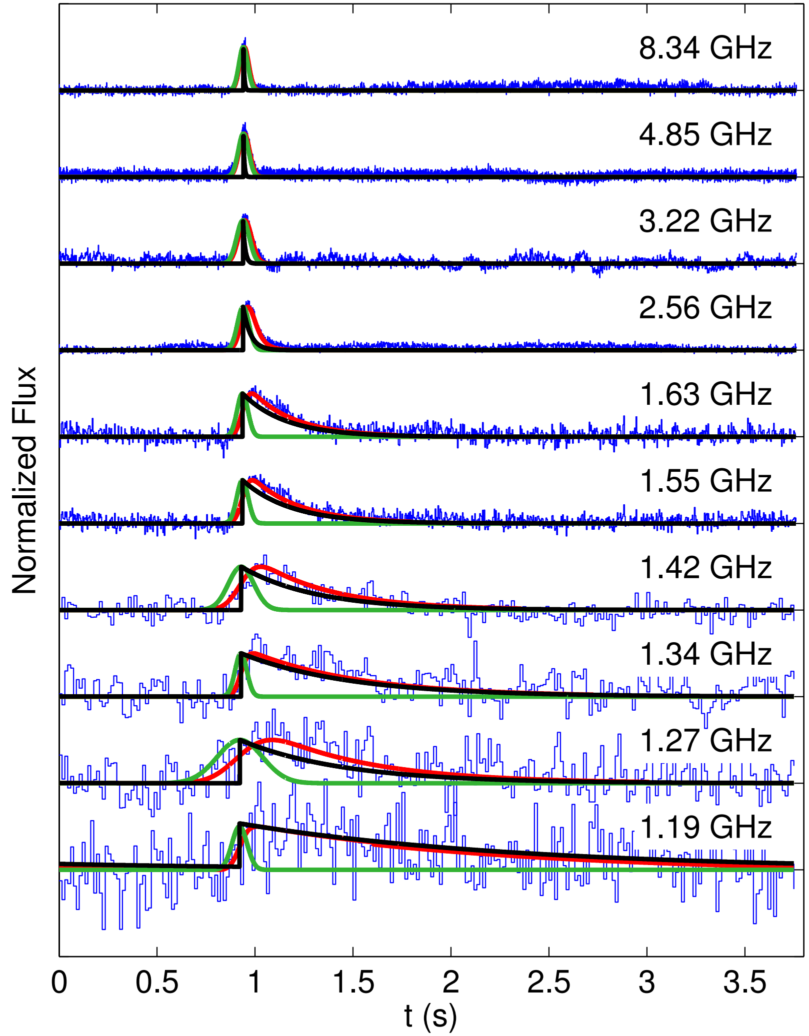


A Strong Magnetic Field around the Black Hole?

- *DM* and *RM* governed by different scales!
- Looks like GC region is magnetically dominated.
- Using a simple density profile from X-ray observations of the hot gas phase, we find ***B* > 8 mG** at scales of projected distance of ~0.1 pc.

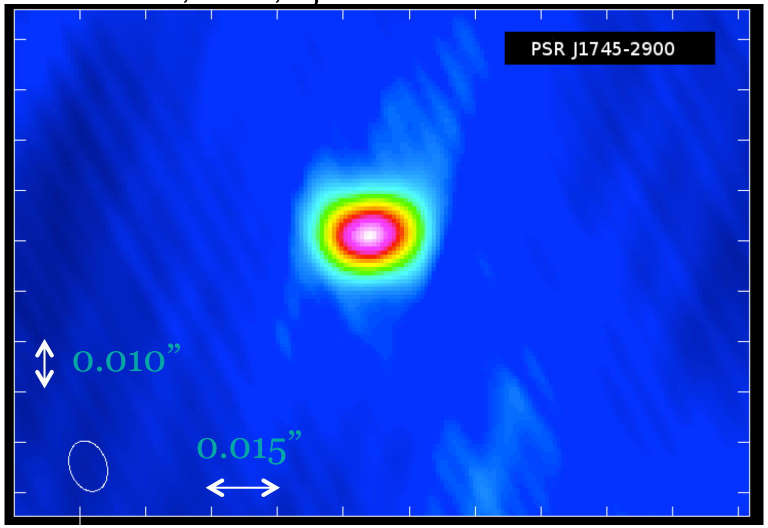
Galactic Centre scattering

Spitler et al., 2014, *ApJ letters*



Pulse scattering ~1.3 sec @ 1GHz

Bower et al., 2014, *ApJ letters*

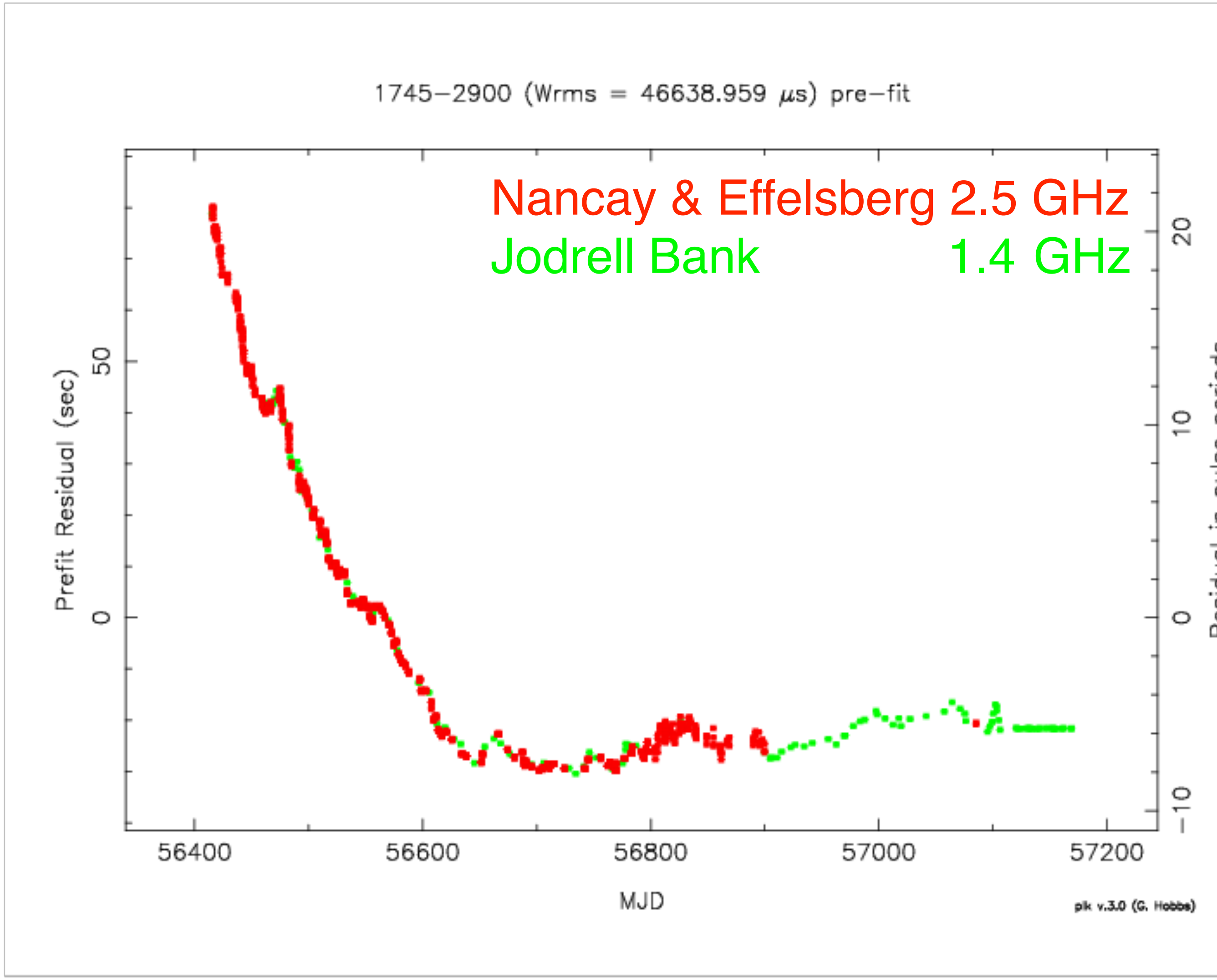


$$\tau = 6.3\sec\left(\frac{D}{8.5kpc}\right)\left(\frac{\theta_1}{1.3arc\sec}\right)^2\left(\frac{D}{\Delta}-1\right)\nu^{-4}$$

Cordes & Lazio, 1997, *ApJ*.

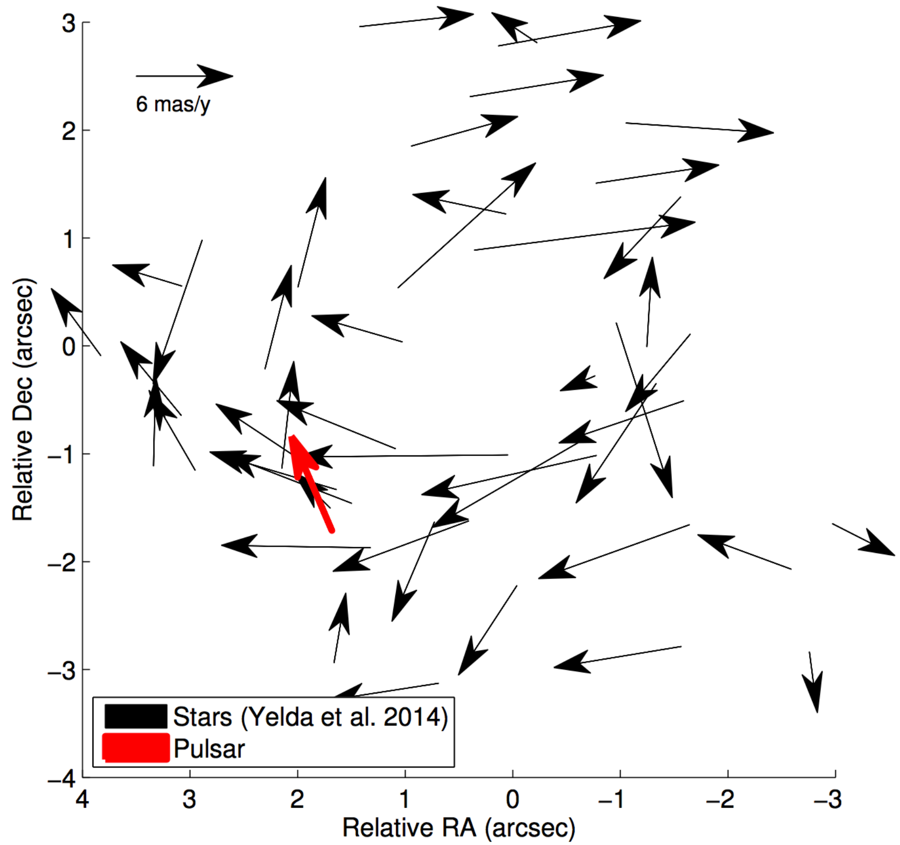
Using both angular and temporal scattering, screen is found to be 5.9 ± 0.3 kpc from GC.

Timing at Jodrell, Nancay and Effelsberg



VLBA observations

- VLBA @ 8 and 15 GHz.
- Proper motion, 234 km/s consistent wth motion in clockwise stellar disk.
- Magnetar is likely bound to Sgr A* with a period of ~700 years.
- VLBA also used to measure scattering properties.
- PSR J1745-2900 also acts as a reference for freq. dependent measurements of core-shift in Sgr A* - limits on evidence for jet.

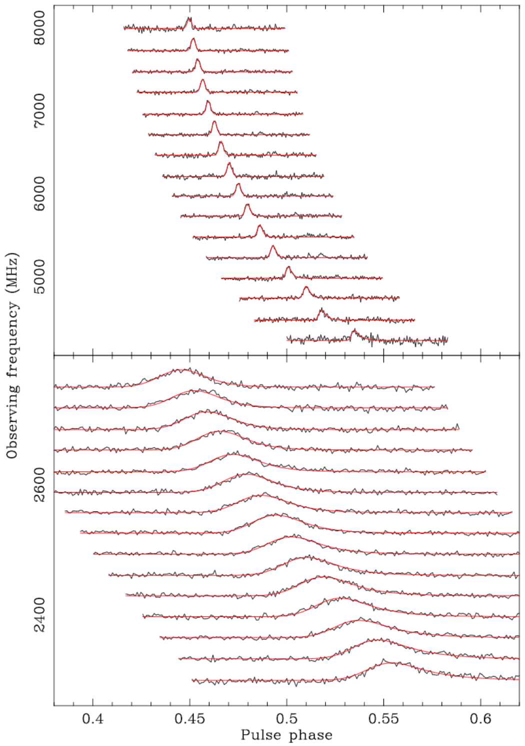


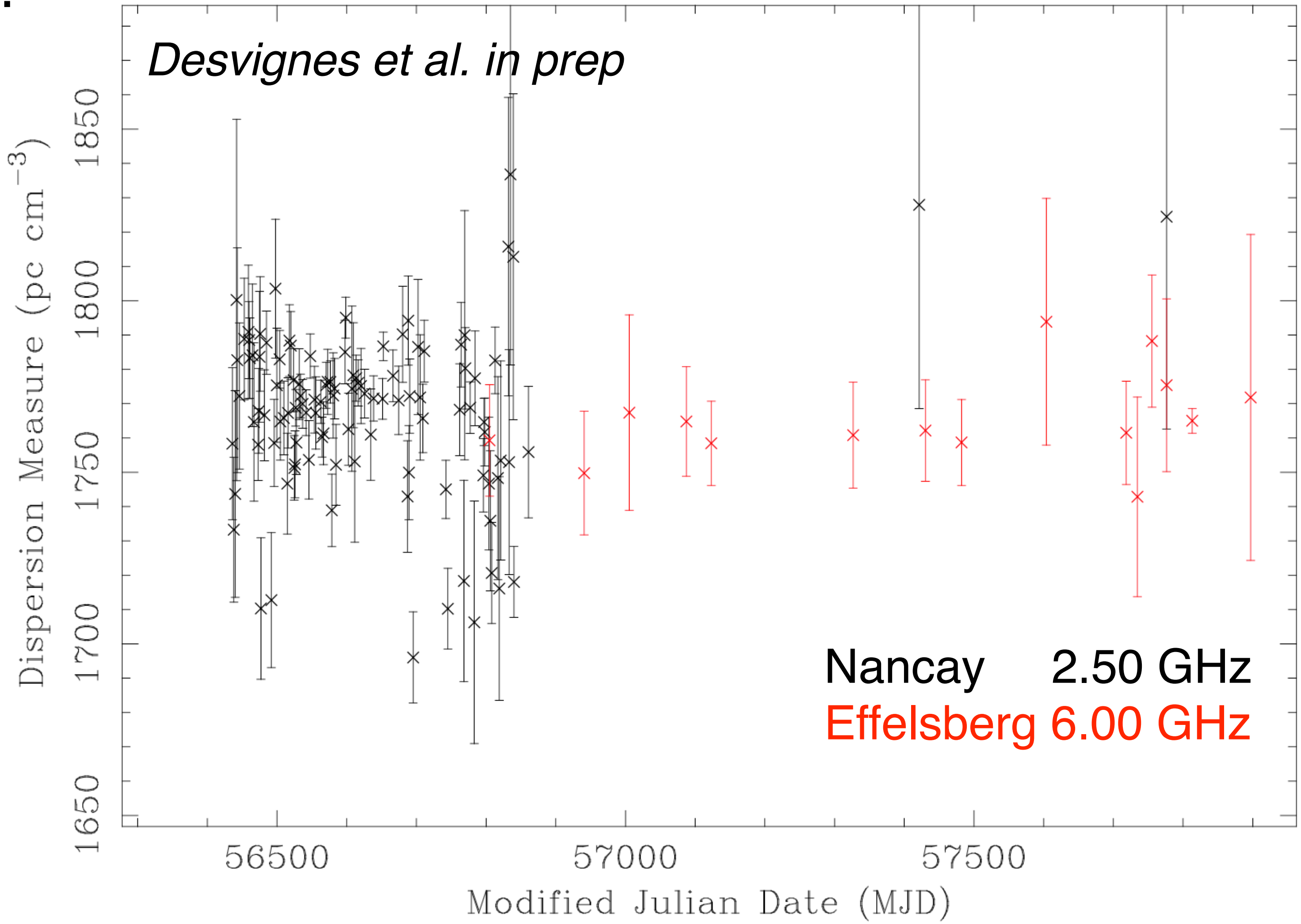
Bower et al., *ApJ*, 2015.

Latest results

Properties of the black hole reservoir

Dispersion measure looks pretty constant (once scattering is accounted for):

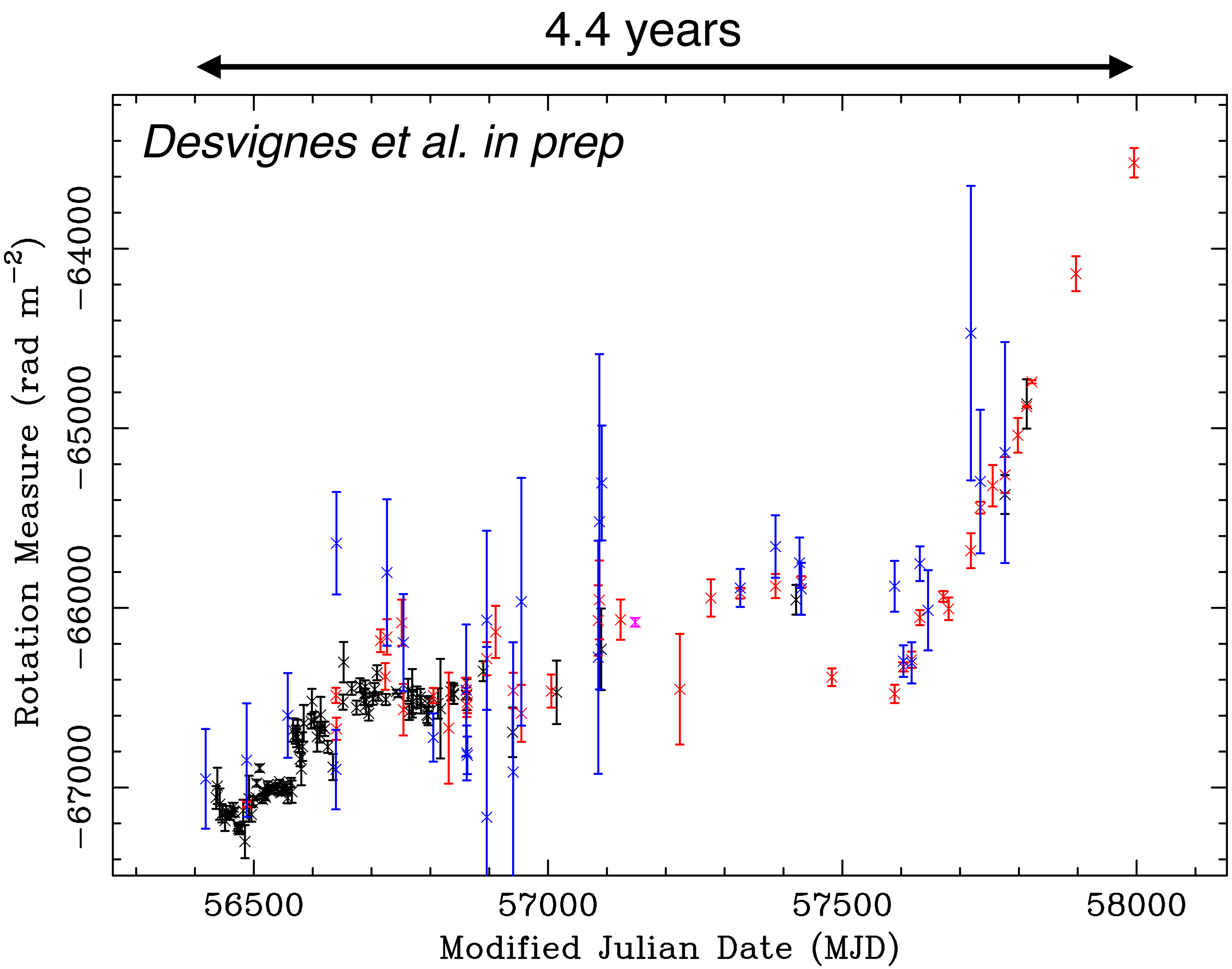




Properties of the black hole reservoir

Extreme rotation measure variations:

Nancay 2.50 GHz
Effelsberg 4.85 GHz
ATCA 5.50 GHz
Effelsberg 8.35 GHz



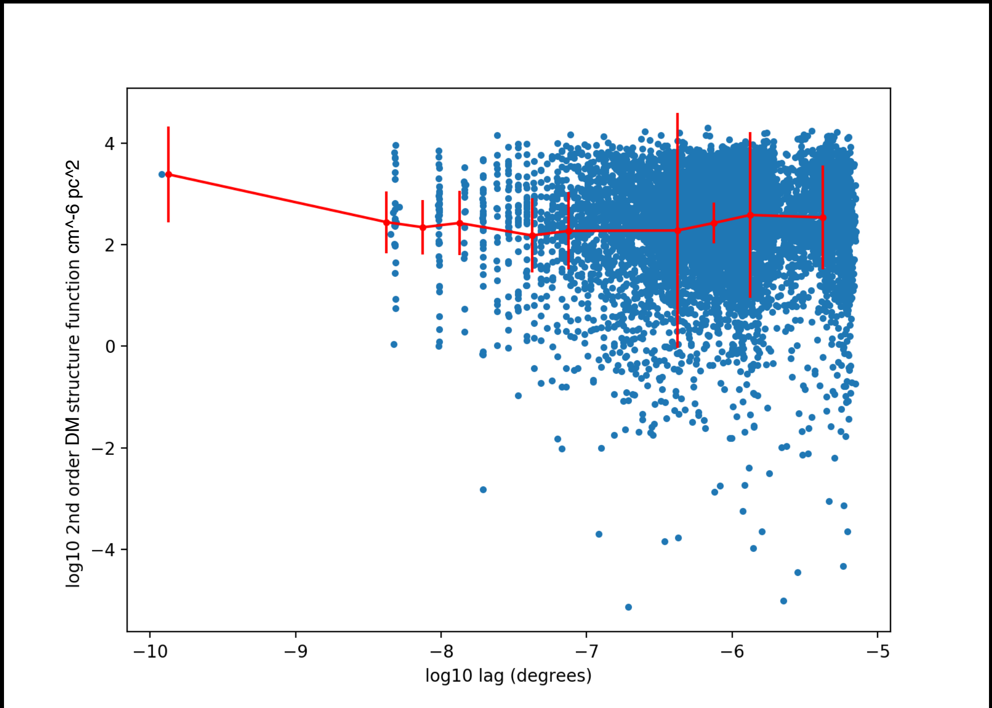
Since *DM* is constant, these must be magnetic in nature.

c.f. PSR-Be star binary PSR B1259-63

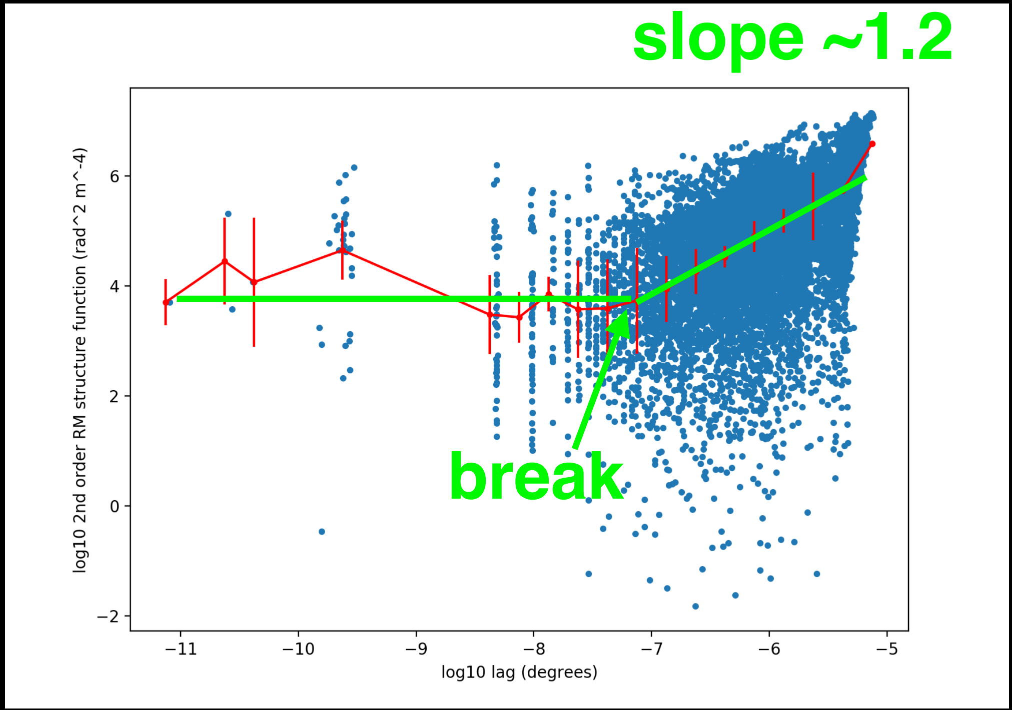
DM and *RM* structure function analysis

Using proper motion of 276 km/s can convert changes in position to a physical scales.

DM



RM



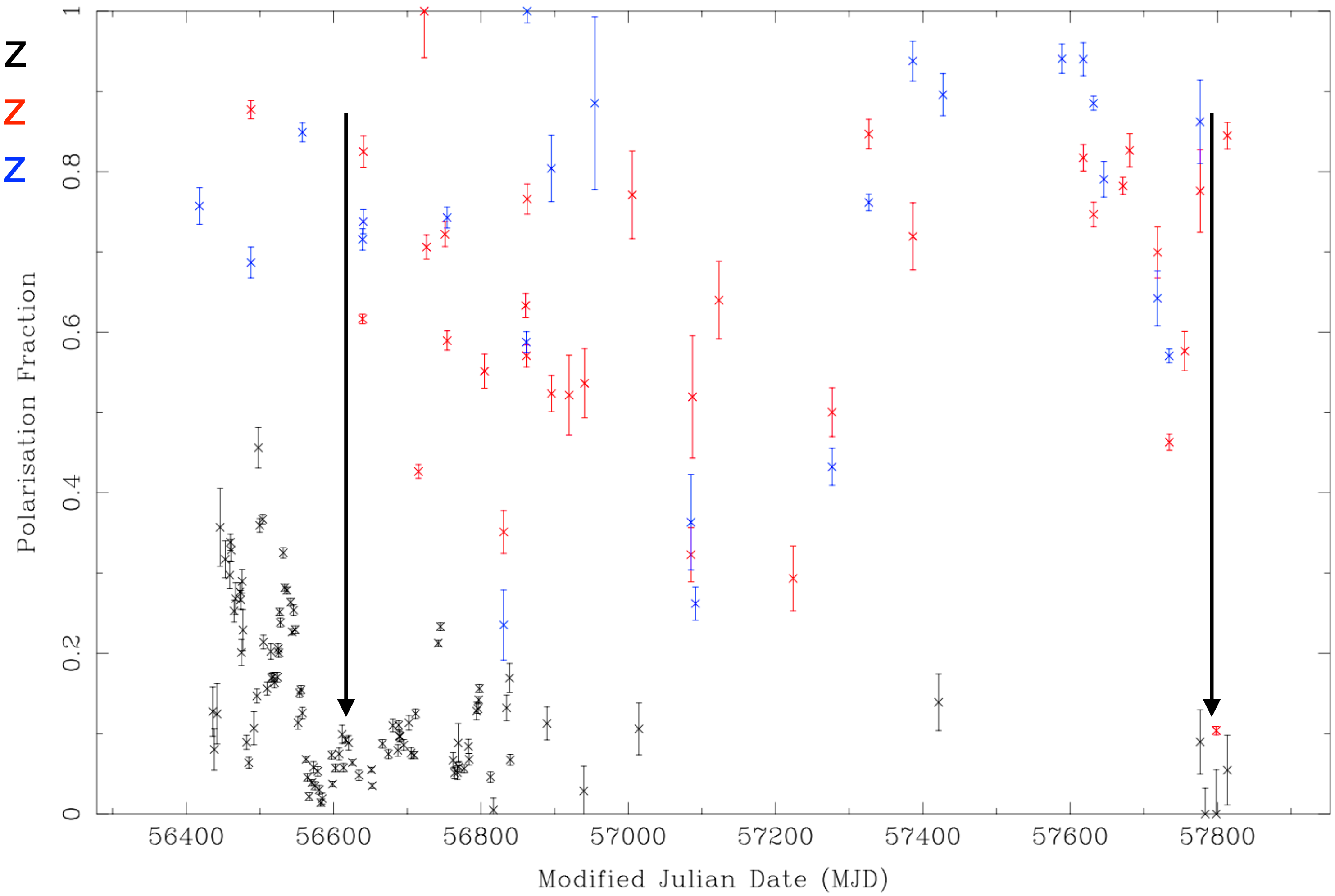
Little evidence for structure in *DM on* any scale.

Inner-scale in *RM starting at* scales 10^{-7} deg = 3 a.u. at GC distance of 8.3 kpc.

Properties of the black hole reservoir

Depolarisation at 2.5 GHz **likely propagation induced**.

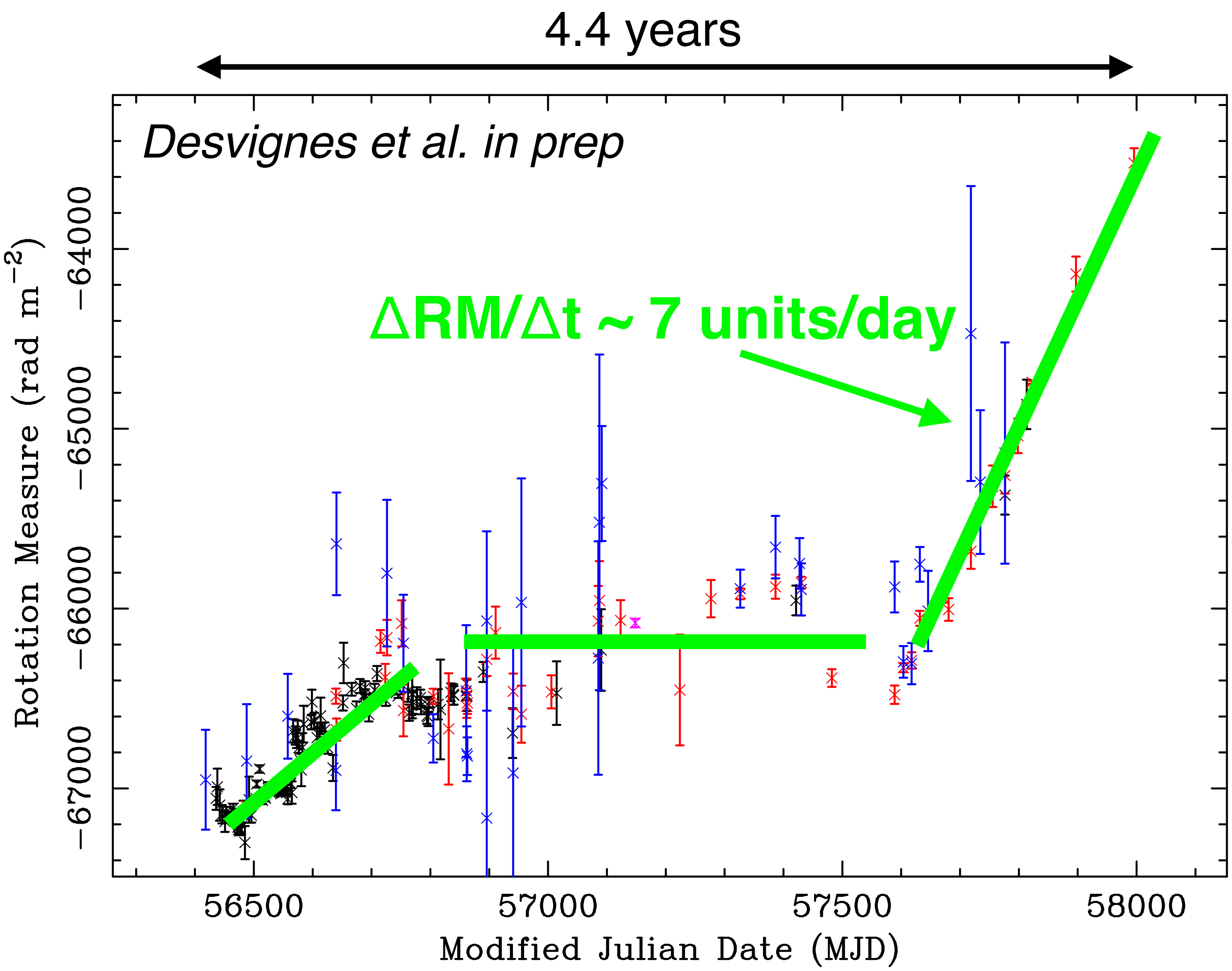
Nancay 2.50 GHz
Effelsberg 4.85 GHz
Effelsberg 8.35 GHz



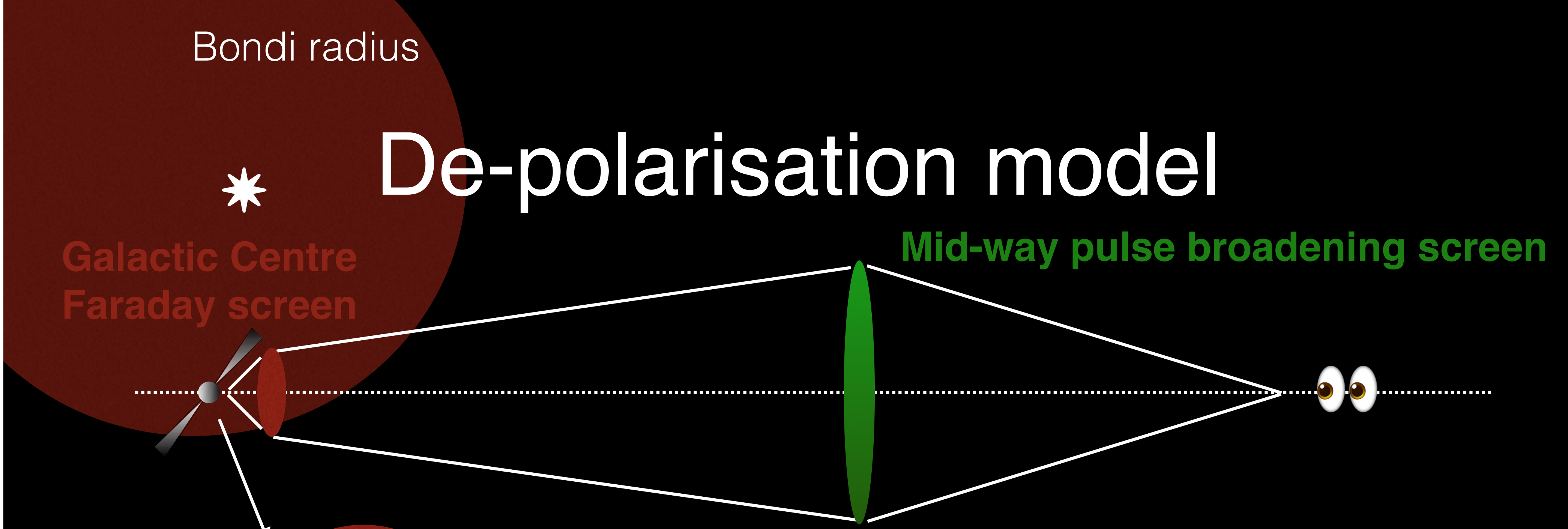
Properties of the black hole reservoir

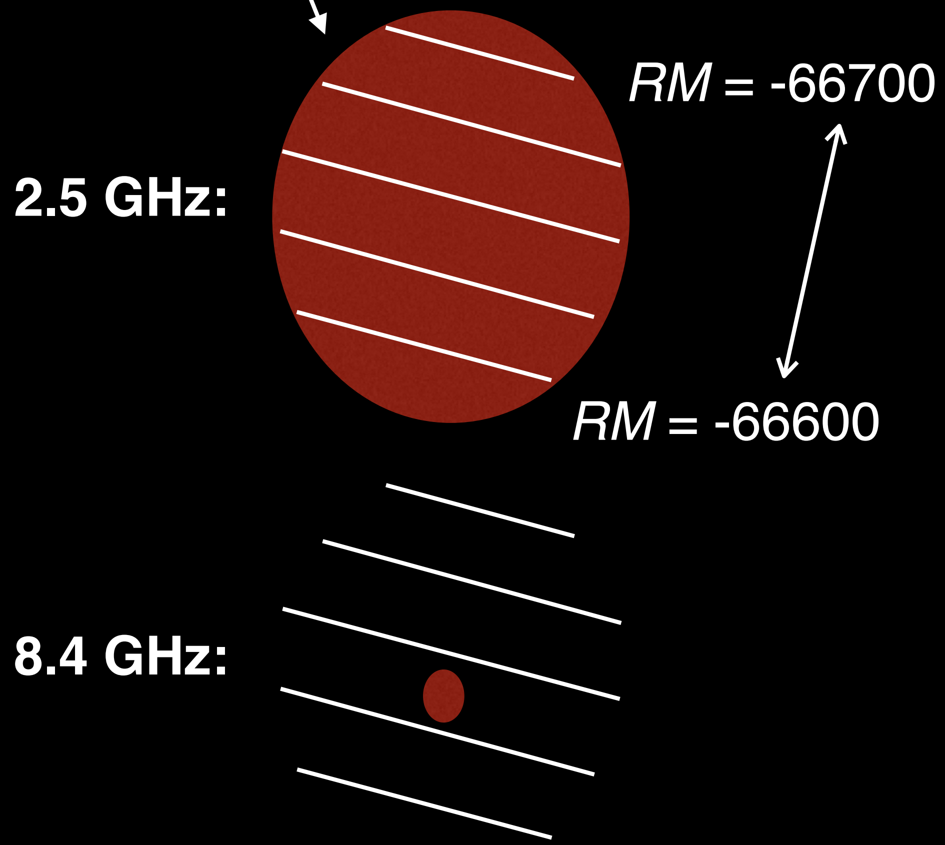
Depolarisation **roughly** correlated with epochs of high *RM* change.

Nancay 2.50 GHz
Effelsberg 4.85 GHz
ATCA 5.50 GHz
Effelsberg 8.35 GHz



De-polarisation model





- $\Delta RM \sim$ 100 units across GC screen needed to de-pol. *RM* changes of 100 seen on timescales of **weeks/months**, therefore physical size **few a.u. scale**.
- Using physical size and measured scattering time at 2.5 GHz, we would have to place magnetar at least ~0.1 **pc behind secondary scattering screen**, and likely Sgr A*. Unlikely PSR and screen in front of Sgr A* - *RM* too high. Stellar disk?? Outburst ejecta??

Summary

- PSRs in the GC would be very nice for testing gravity.
- The GC magnetar J1745-2900 has provided a new view of the GC pulsar arena.
- PSR J1745-2900 is a remarkable, and the first, tool for studying environment around black hole.
- There appears to be significant magnetic structure in the magnetar region (~Bondi radius) on scales of few a.u.
- PSR J1745-2900 might be ~0.1 pc behind a second scattering screen in the GC.