Neutron Stars and Pulsars: Challenges and Opportunities after 80 years
Proceedings IAU Symposium No. 291, 2012
J. van Leeuwen, ed.

doi:10.1017/S1743921312024209

Can we see pulsars around Sgr A*? The latest searches with the Effelsberg telescope.

R. P. Eatough, M. Kramer, B. Klein, R. Karuppusamy, D. J. Champion, P. C. C. Freire, N. Wex and K. Liu.

Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany
email: reatough@mpifr-bonn.mpg.de

Abstract. Radio pulsars in relativistic binary systems are unique tools to study the curved space-time around massive compact objects. The discovery of a pulsar closely orbiting the super-massive black hole at the centre of our Galaxy, Sgr A*, would provide a superb test-bed for gravitational physics. To date, the absence of any radio pulsar discoveries within a few arc minutes of Sgr A* has been explained by one principal factor: extreme scattering of radio waves caused by inhomogeneities in the ionized component of the interstellar medium in the central 100 pc around Sgr A*. Scattering, which causes temporal broadening of pulses, can only be mitigated by observing at higher frequencies. Here we describe recent searches of the Galactic centre region performed at a frequency of 18.95 GHz with the Effelsberg radio telescope†.

Keywords. Pulsars, Sgr A*.

1. Introduction

Both theoretical predictions and observational evidence have shown that a large population of pulsars should exist in the Galactic centre (GC) (e.g. Pfahl & Loeb 2004, Deneva *et al.* 2009, Wharton *et al.* 2012). The discovery of a pulsar closely orbiting (orbital period $\lesssim$ 1 yr) the supermassive black hole at the centre of our Galaxy, Sgr A*, would supersede all previous strong field tests of General Relativity (e.g. Wex & Kopeikin 1999, Liu *et al.* 2012). Despite many radio pulsar searches that have covered the GC region, a remarkable lack of pulsars have been discovered within the central 100 pc. The lack of pulsar detections is thought to be caused by extreme scattering of radio waves due to inhomogeneities in the ionized component of the interstellar medium within 100 pc of Sgr A* (Lazio & Cordes 1998). Scattering causes temporal broadening of pulses that has a strong dependence on observing frequency, ν ($\propto \nu^{-4}$), rendering pulsar periodicity searches at typical observing frequencies ineffective e.g. the broadening time is expected to be $\sim$ 500 seconds at 1.4 GHz; 1000 times the length of a typical pulsar period! Unlike pulse dispersion, which can be corrected for by the use of filterbanks, scatter broadening cannot be compensated by instrumental means. As such, pulsar searches covering the GC have been performed at increasingly high frequencies (e.g. Johnston *et al.* 1995, Kramer *et al.* 2000, Manchester *et al.* 2001, Klein *et al.* 2004, Johnston *et al.* 2006, Deneva *et al.* 2009, Deneva 2010, Macquart *et al.* 2010, Bates *et al.* 2011).

† This work was based on observations with the 100-m telescope of the MPIfR (Max-Planck--Institut für Radioastronomie) at Effelsberg. http://www.mpifr-bonn.mpg.de/effelsberg

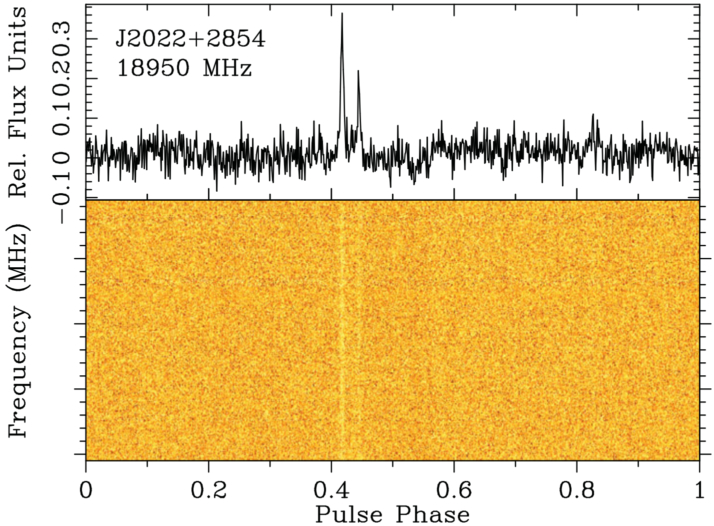

Figure 1. 15 minute test observation of PSR B2020+28 at a frequency of 18.95 GHz using the XFFTS system. The top panel displays the integrated profile, and the bottom panel shows phase folded subbands across the 2 GHz bandpass.

2. Observations and data analysis

From Effelsberg the Sgr A⋆ region is visible at low elevation for approximately 2 hours and 25 minutes everyday. For this reason we have opted to make repeated observations and incoherently combine the data to improve sensitivity. Observations are made using the Effelsberg K-band (18-26 GHz) primary focus receiver and the new XFFTS digital spectrometer operating in pulsar search mode. Using XFFTS we record dual polarizations for 256 spectral channels across a bandwidth of 2 GHz. A test observation of PSR B2020+28 using our observing system can be seen in Figure 1.

Data combination is performed by summing the fluctuation spectra of the dedispersed time series from successive GC observations. So called 'stack searches' have been used to find isolated millisecond pulsars in the globular cluster Terzan 5 (Sulman *et al.* 2006) and to perform efficient acceleration searches on the Parkes multi-beam pulsar survey data (Faulkner *et al.* 2004). We have investigated the sensitivity of a GC pulsar stack search at Effelsberg by considering the following: assuming the GC pulsars have the same properties as the current known population of disk pulsars we have derived their expected flux density at 18.95 GHz assuming an average spectral index of -1.8 and placed at the distance of the GC. From these values the expected detection signal-to-noise ratio (S/N) has been calculated for a single 2 hour 25 minute observation. Figure 2 shows the results of this analysis. From statistical considerations the detection threshold of this search corresponds to a S/N $\sim$ 10. It can be seen that a number of pulsars would already be possible to detect with a single observation at 18.95 GHz. The number of pulsars possible to detect increases as more observations are combined.

3. Results and future work

To date 14 successful observations of the GC region have been performed. Each observation has been independently searched for periodic and impulsive signals in addition to a search of the combination of all 14 observations. In the data taken so far no pulsars have been detected. Assuming minimal atmospheric contributions to the system temperature

https://doi.org/10.1017/S1743921312024209 Published online by Cambridge University Press

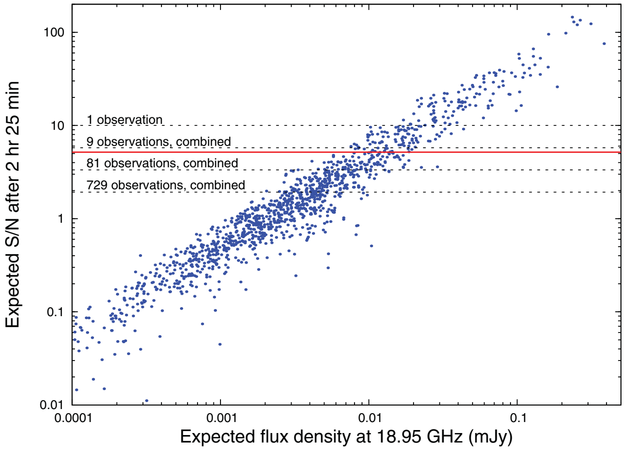

Figure 2. Expected detection S/N after a single 18.95 GHz observation at Effelsberg plotted against the predicted flux densities of the known pulsar population placed at the distance of the GC. The dotted horizontal lines indicate the minimum number of combined observations required to make a detection above our threshold of S/N $\sim$ 10. The red line shows our current sensitivity limit based on a combination of 14 GC observations.

we can place upper limits on the flux density of normal pulsars (10% duty cycle) within 1.7 pc of Sgr A* at the observing frequency of 18.95 GHz:

S/N $\sim$ 10 flux density limit of individual observations: $\sim 24\ \mu$Jy
S/N $\sim$ 10 flux density limit of 14 stacked observations: $\sim 12\ \mu$Jy

We will continue observations of the Sgr A* region since the emission beams of pulsars in close orbits could precess into the line-of-sight on the timescale of years (e.g. Macquart *et al.* 2010). For the target pulsars our stacking algorithm poses a problem. Such pulsars may have significant line-of-sight acceleration as they move in the gravitational potential of Sgr A* and thus would show Doppler changes in their pulse frequency. After data combination, Doppler shifts could smear the signal and reduce the spectral S/N. To counteract Doppler effects caused by orbital motion we are investigating 'stack-slide searches' where the spectra are added with different trial frequency offsets.

References

Bates, S. D., *et al.* 2011, *MNRAS*, 411, 1575
Deneva, J. S., *et al.* 2009, *ApJ*, 702, L177
Deneva, J. S. 2010, *Cornell Univ.*, PhD Thesis.
Faulkner, A. J., *et al.* 2004, *MNRAS*, 355, 147
Johnston, S., *et al.* 1995, *MNRAS*, 274, L43
Johnston, S., *et al.* 2006, *MNRAS*, 373, L6
Klein, M., *et al.* 2004, *IAUS*, 218, 133K
Kramer, M., *et al.* *ASPC*, 202, 37K
Lazio, T. J. W. & Cordes, J. M. 1998, *ApJ*, 505, 715
Liu, K., *et al.* 2012, *ApJ*, 747, 1
Macquart, J. P., *et al.* 2010, *ApJ*, 715, 939
Manchester, R. N., *et al.* 2001, *MNRAS*, 328, 17
Pfahl, E. & Loeb, A. 2004, *ApJ*, 615, 253
Sulman, B. 2006, *Oberlin College*, poster presentation.
Wharton, R. S., *et al.* 2012, *ApJ*, 753, 108W
Wex, N. & Kopeikin, S. 1999, *ApJ*, 513, 388