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Proper motion of the radio pulsar B1727—47 and its association with the supernova remnant RCW 114

PSR B1727–47 (J1731–4744) discovered in 1968 with Molonglo

Pulsar parameters

Period $P = 0.83$ s

Spin-down energy $\dot{E} = 1.1 \times 10^{34}$ erg/s

Magnetic field $B = 1.18 \times 10^{13}$ G

Characteristic age $\tau = 80$ kyr

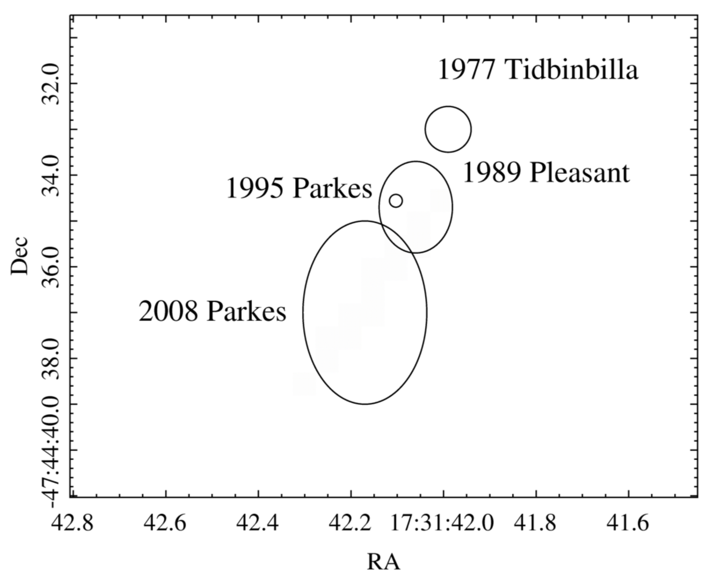
Radio brightness $S_{1400} = 12$ mJy

№1 for $B > 10^{13}$ G and №4 for $\tau < 100$ kyr

Dispersion measure $DM = 123$ pc/cm^3

Dispersion measure distance 2.7 kpc in the NE2001 model (Cordes&Lazio 2002) and 5.5 kpc in the YWM16 model (Yao et al. 2016)

Published positions

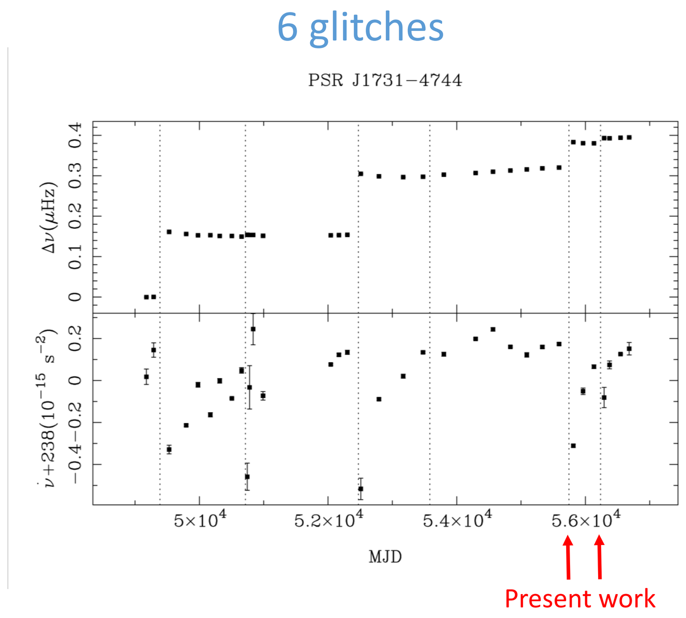


Published positions strongly suggest the prominent proper motion, but it has not been reported yet. The reason is a high level of timing noise and regular glitching behavior. We performed the timing analysis of more than 20 years of Parkes data and also analyzed archival ATCA data from 2005 and 2015. In addition, the pulsar was observed with ATCA in 2016. under our proposal.

Timing analysis

222 TOA between February, 1993 and March,2014 (MJD 49043—56740) were analyzed. We found two new (previously unpublished) glitches. We used the TEMPONEST package (Lentati et al. 2014) to model both the timing model and timing noise. The glitch paramters were first found by comparison of the timing solutions in the inter-glitch intervals (right). In this way the positions on the inter-glitch epoch were found. Then the full TEMPONEST solution was found taking into account proper motion, glitches, and timing noise. The timing solution residuals are shown below.

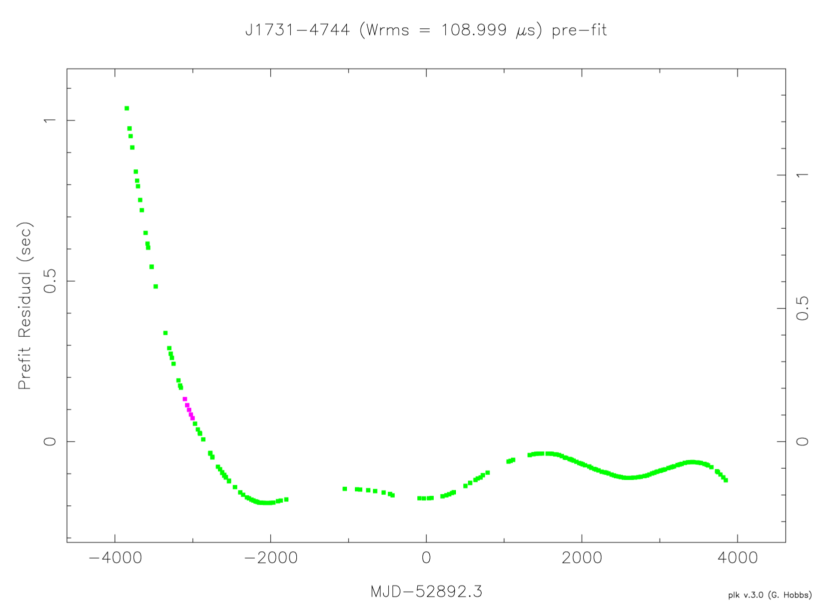
6 glitches



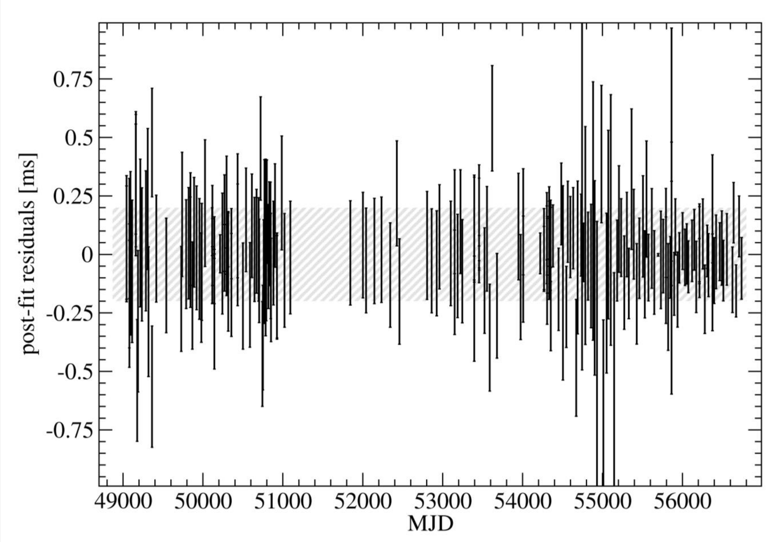
Epoch (MJD)	$\Delta\nu_g/\nu$ (10^{-9})	$\Delta\dot{\nu}_g/\dot{\nu}$ (10^{-3})	Q	τ_d (d)	No. of ToAs	Data span (MJD)
55735.18(14)	53(1)	3.4(7)	0.12(1)	141(25)	37	55272–56214
56239.86(77)	10(1)	1.6(2.5)	0.14(9)	70(96)	26	55897–56512

Timing solution residuals

With account for glitches; before timing noise removal



After removal of the timing noise
Hatched area shows the average level of 0.2 ms



Proper motion: linear regression of the interglitch positions. Each interglitch interval is too short (~3 years) to allow for the proper motion determination

$$\mu_\alpha^T = 65 \pm 13 \text{ mas yr}^{-1}$$
$$\mu_\delta^T = -223 \pm 27 \text{ mas yr}^{-1}$$
$$\mu^T = 232 \pm 27 \text{ mas yr}^{-1}$$

Proper motion: full data span analysis; timing noise removed

$$\mu_\alpha^{TN} = 47 \pm 14 \text{ mas yr}^{-1}$$
$$\mu_\delta^{TN} = -132 \pm 37 \text{ mas yr}^{-1}$$
$$\mu^{TN} = 141 \pm 36 \text{ mas yr}^{-1}$$

Radiointerferometric observations

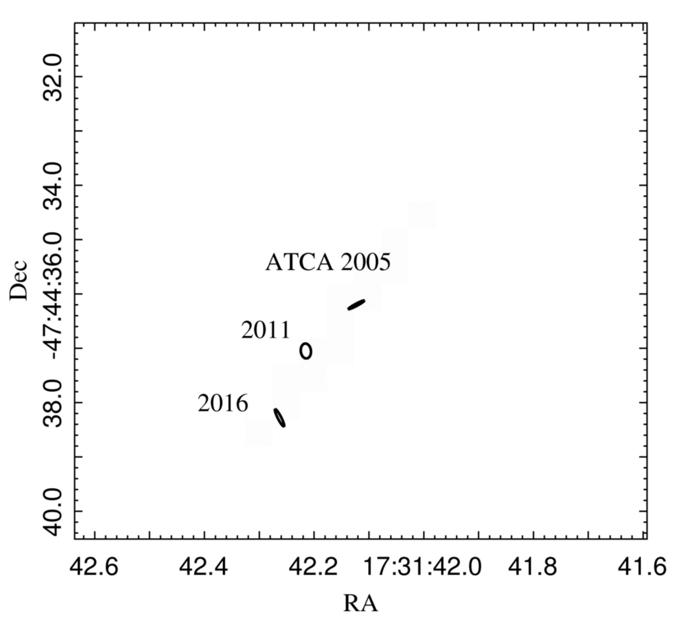
The ATCA radiointerferometry data were analysed

March 26, 2005:
frequency 1.38 GHz, BW 128 MHz; configuration 6A (0.4-6. km)
pulsar regime

November 19, 2011:
frequency 2.1 GHz, BW 1 GHz; configuration 1.5D (0.1-4.4 km)
pulsar regime

September 15, 2016:
Original director time observations
frquency 2.1 GHz, BW 1 GHz; configuration H168 (0.07-4.4 km)
standard regime

ATCA Positions

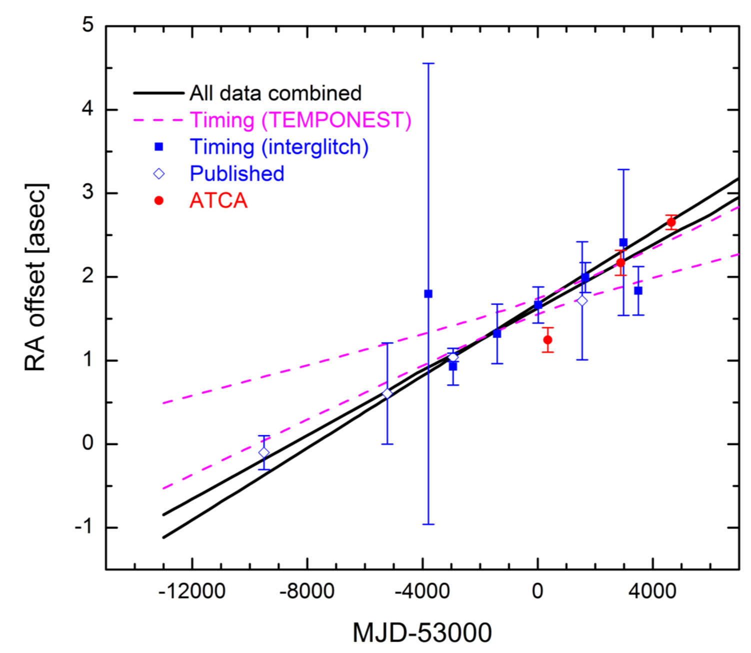


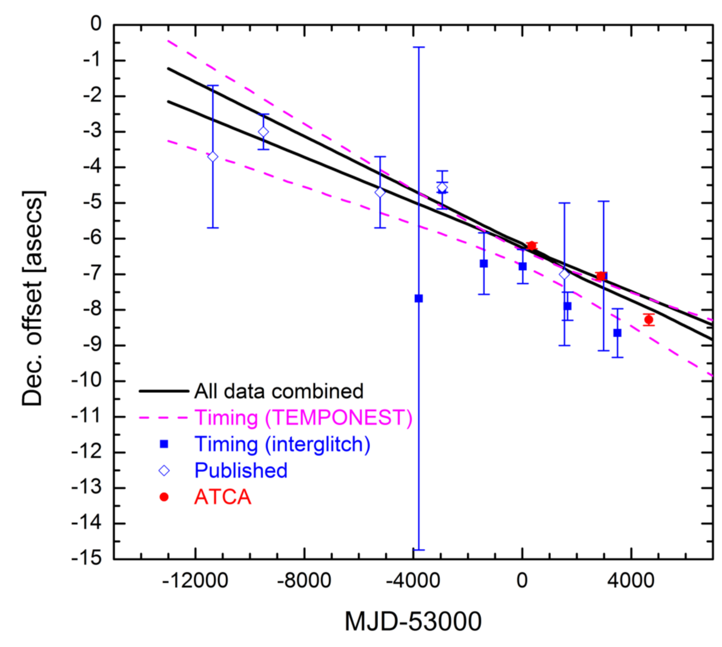
Proper motion

$$\mu_\alpha^I = 118 \pm 8 \text{ mas yr}^{-1}$$
$$\mu_\delta^I = -157 \pm 35 \text{ mas yr}^{-1}$$
$$\mu^I = 184 \pm 29 \text{ mas yr}^{-1}$$

Three methods demonstrate the significant proper motion of the pulsar. Despite the qualitative agreement between the results of the different methods, there are systematic discrepancies. The nature of this disagreement is under investigation

Results on the PSR proper motion





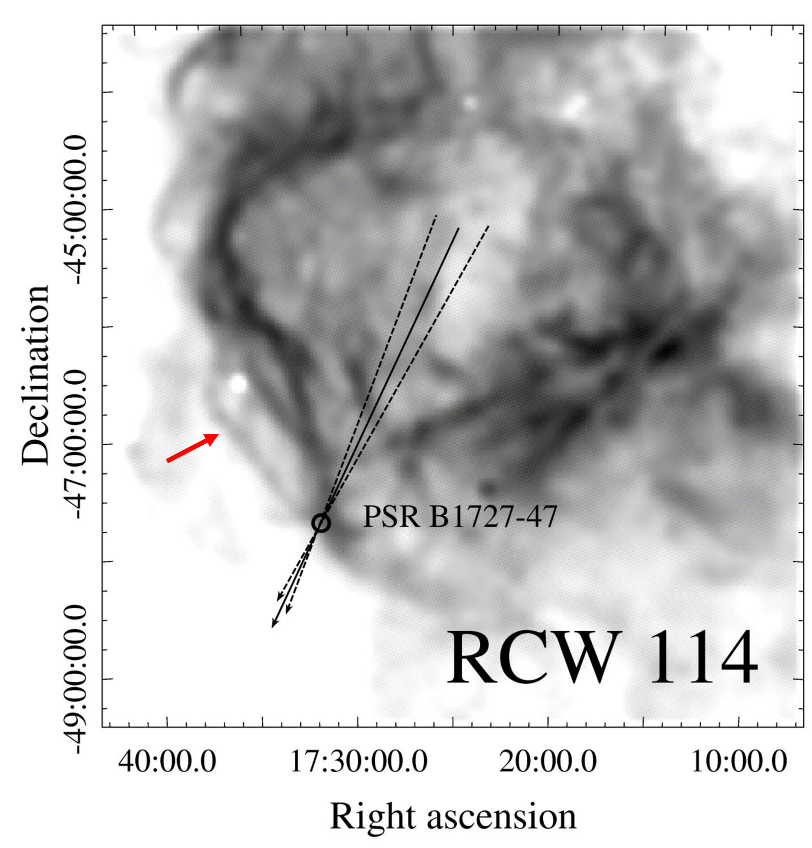
Pulsar positions compilation: Previously published (green diamonds); ATCA (red points); inter-glitch Parkes positions (blue squares). Magenta lines show 1σ credible intervals according to the TEMPONEST full timing solution. Black solid lines are the fit results based on the ATCA, Parkes, and two earlier timing positions.

Proper motion: Formal fit with account for all data. The uncertainties given are probably underestimated. Additional interferometric observations are necessary.

$$\mu_\alpha^F = 73 \pm 5 \text{ mas yr}^{-1} \qquad \mu_\delta^F = -127 \pm 13 \text{ mas yr}^{-1} \qquad \mu^F = 148 \pm 11 \text{ mas yr}^{-1}$$

Supernova remnant RCW 114

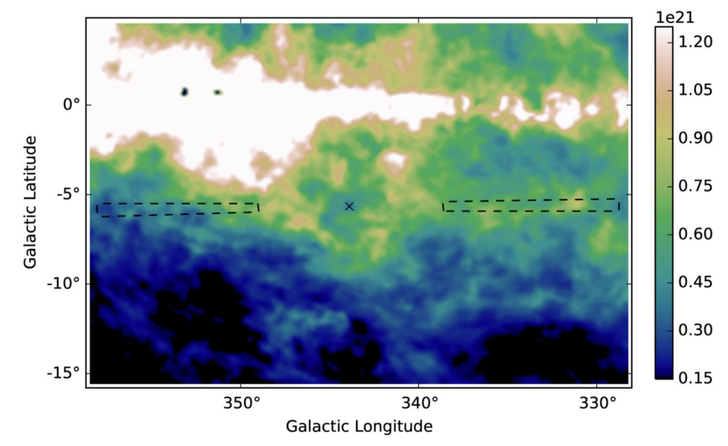
Hα image of the RCW 114 field



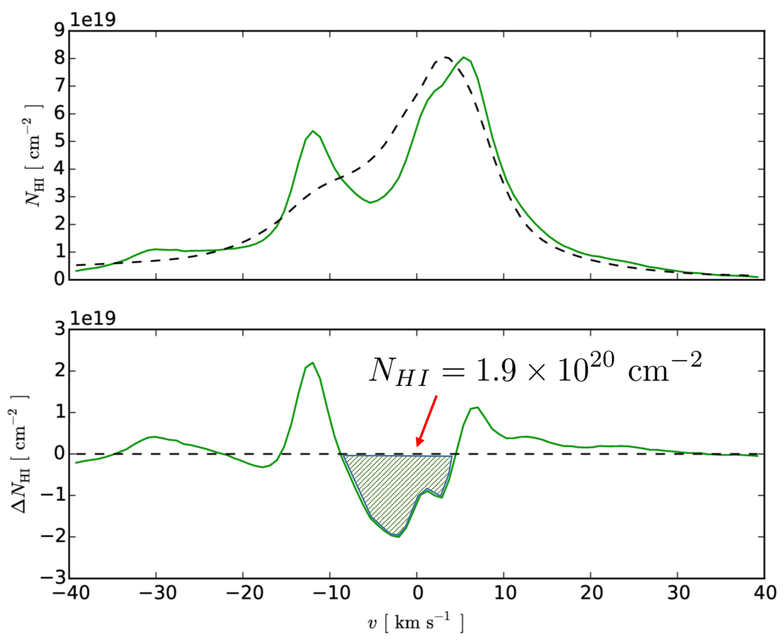
B1727-47 proper motion extrapolation by 80 kyr backwards suggests its association with the SNR RCW 114 (other name G343.0-6.0).
It is one of the largest SNRs in the Galaxy (4° diameter). Red arrow indicate the outer filament with the velocity of -80 км/c (Meaburn et al. 1991). This can be identified with the SNR expansion velocity.
SNR radio emission is weak and no X-ray data on the remnant is available;
In UV the CIV (λλ 1548,1551) emission is seen.
This indicates on the relatively small distance, less than 1 kpc (Kim et al. 2012).
Optical spectroscopy of several stars (in NaI lines) in the RCW 114 field gives the distance greater than 0.5 kpc (Welsh et al. 2003).

Analysis of RCW114 in HI

Image in the velocity interval -1 – -8 km/s



Top: Line profile in the remnant center direction (marked as x in the image) and the background profile (dashed line), averaged over the dashed rectangles in the image.
Bottom: Profile difference. The characteristic void structure is seen. The ambient number density estimate is then possible (hatched)



SNR parameters are typical for the *snow plough* stage. According to Cioffi et al. 1988:

$$v_s = 96 \text{ km s}^{-1}\, E_{51}^{0.22} n_0^{-0.26} \left(\frac{t}{80 \text{ kyr}}\right)^{-0.7}$$

$$R_s = \frac{10}{3} v_s t = 26 \text{ pc}\, E_{51}^{0.22} n_0^{-0.26} \left(\frac{t}{80 \text{ kyr}}\right)^{0.3}$$

$$D = 2R_s/4^\circ = 630 \text{ pc} \left(\frac{v_s}{80 \text{ km s}^{-1}}\right)\left(\frac{t}{80 \text{ kyr}}\right)$$

$$n_0 = N_{HI}/2R_s = 1.4 \text{ cm}^{-3} \left(\frac{N_{HI}}{1.9 \times 10^{20} \text{ cm}^{-2}}\right)\left(\frac{630 \text{ pc}}{D}\right)$$

Conclusions

The prominent proper motion of the PSR B1727–47 is found at the level of 150 mas per year. For the dispersion measure-based distance of 2.7 kpc this corresponds to extremely high transverse velocity of 1900 km/s

Size and direction of the pulsar proper motion strongly suggest its association with the supernova remnant RCW 114. In this case the system must be much closer, and reside on the distance about 0.7 kpc.

At this distance, the transverse velocity is about 500 km/s, well in line with the velocities found for other pulsars (Hobbs et al., 2005). This however require tuning of the Galaxy electron density models in the direction to B1727–47.