New Timing Solutions for Rotating Radio Transients

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Rotating Radio Transients (RRATs) are pulsars from which we detect only sporadic radio bursts, which makes them difficult to detect in traditional pulsar searches which employ frequency domain techniques and/or folding of data (McLaughlin, et al., 2006). They were first discovered in a reprocessing of the Parkes Multibeam Pulsar Survey data, and now roughly 70 of these sporadic pulsars are known. By using a single-pulse search method in the time domain, we can discover these sources. We can also measure periods from the single pulses and determine timing solutions. This is done in a similar way to other pulsars, but through using single pulses instead of folded profiles to calculate times-of-arrival. Timing solutions are crucial to determine how they relate to other pulsars and to understand the nature of their emission.

Here we introduce our result for six RRATs, along with a comparison between RRATs and normal pulsars. Five of these RRATs were discovered in a re-analysis of the Parkes Multibeam Survey data and one was discovered through a GBT drift-scan survey.

Figure 1:

Green Bank Telescope (left)
(105m Green Bank, WV, USA)

Parkes Telescope (right)
(64m Parkes, NSW, Australia)

1. Single-pulse Search

Since RRATs are not detectable through methods relying on average emissions, the classical search algorithms based on Fourier techniques or folding do not work. The first step in our analysis is to identify which pulses are from the RRAT. We do this by searching for pulses which are brighter at the DM of the RRAT than at zero DM.

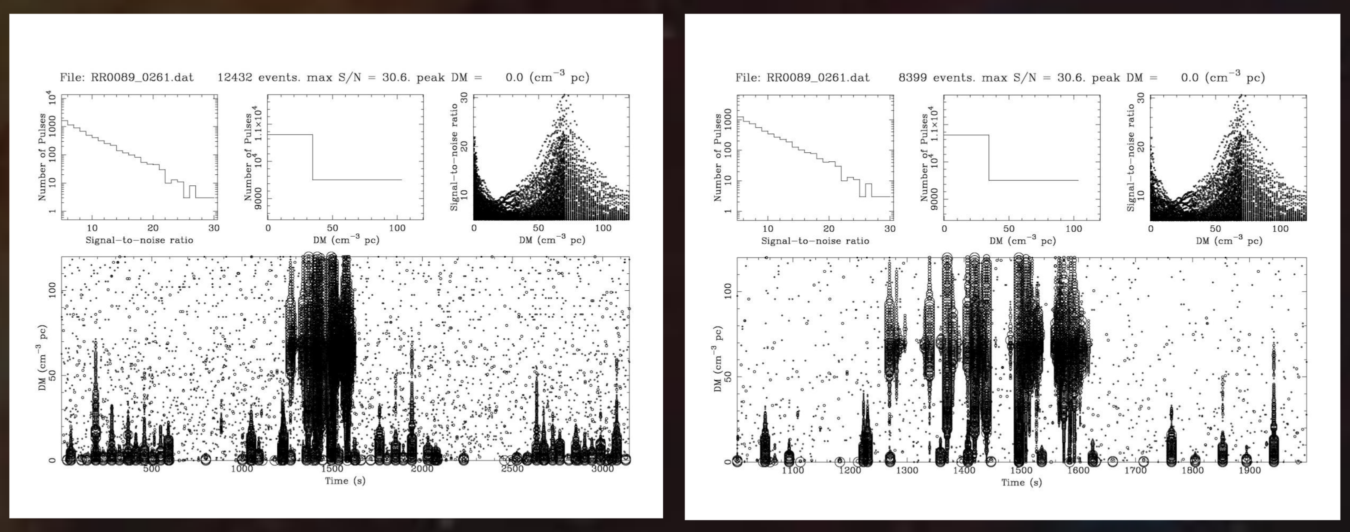

Figure 2: Single-pulse search plot for PSR J1048-5838 in one observation

Top: The first subplot shows how many pulses are above certain signal-to-noise ratio (SNR), and that at certain DM in the second subplot. The third one shows SNR vs. DM. Note this new RRAT is at DM = 69.3 pc/cm^3.

Bottom: Number of pulses detected vs. DM and time. We see very bright bursts peaking at DM 69 pc/cm^3 which differ from the signals peaking at 0 DM due to radio frequency interference (RFI).

On the left are results for a nearly one hour observation of J1048-5838. The pulsar is only bright for six minutes of this observation. On the right is a zoom-in during the "on" time of the pulsar.

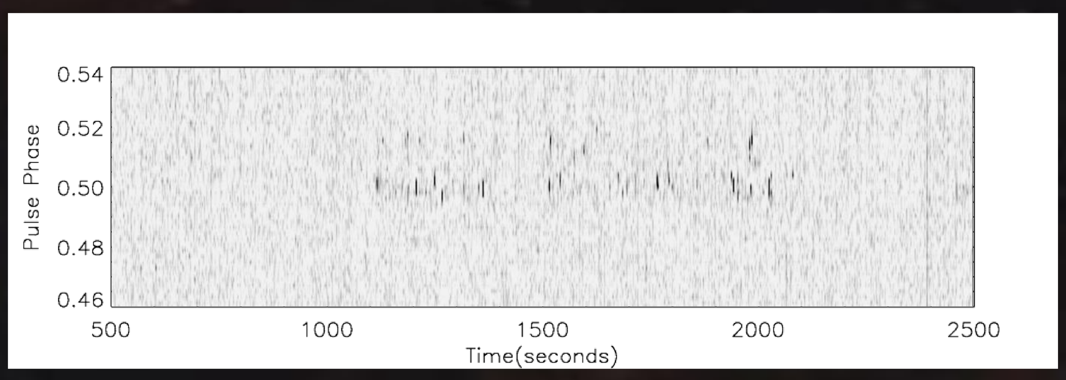

Figure 3: Single pulses of J1048-5838 during one observation.

These data were taken with the Parkes telescope at a frequency of 1.4 GHz. The pulsar is detectable during only one 15-minute segment of the 60-minute observation. This RRAT is unusual as within the "on" phase it behaves like a normal pulsar. We can clearly see substantial pulse jitter in this observation.

2. Timing Solutions

To get a timing solution, we must first calculate the spin period. We do this by measuring differences between pulse arrival times and calculating the greatest common denominator. Once a period is known, we bin the data into single pulse periods and calculate times-of-arrival (TOAs) for each detected pulse. Because we are timing from single pulses and the shapes of these pulses can change dramatically, we calculate TOAs as the peak of each single pulse instead of through cross-correlation with a template.

We report timing solution for six RRATs. PSR J1048-5838 has the longest span of observation of these RRATs: four years of post-discovery timing observations and a 13-year span including the discovery. Note that this RRAT was found in an even later reprocessing of the Parkes Multibeam Survey after the initial RRATs (Keane 2010).

Parameters	J1048-5838
Right Ascension (J2000)	10:48:12.548(25)
Declination (J2000)	-58:38:19.18(17)
Spin Period (s)	1.231304776625(5)
Period Derivative (s s^{-1})	1.219386(6)$\times 10^{-14}$
RMS Residual (ms)	2.8
Dispersion Measure (pc cm^{-3})	69.3
Reference Epoch (MJD)	53510
Span of Timing Data	51030—55990
Surface Magnetic Field (10^{12} G)	3.9
Spin-down Luminosity (10^{31} ergs s^{-1})	25.8
Characteristic Age (Myr)	1.6

Tab. 1: Timing solution of J1048-5838

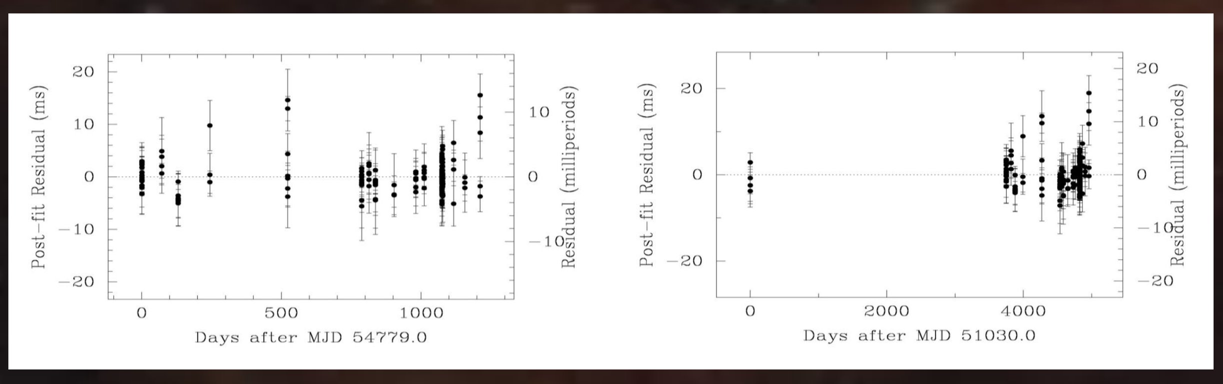

Figure 4: Two plots of timing residuals ex/including discovery

Some data points vary by more than the error bar; this may indicates that pulse jitter is occurring.

New timing solutions for six RRATs. The solutions for J1623-0841, J1739-2521, J1754-3014, J1839-0141, and J1848-1243 were achieved with the Green Bank Telescope and that for 1048 was achieved with Parkes.

Parameters	J1623-0841	J1739-2521	J1754-3014	J1839-0141	J1848-1243
Right Ascension (J2000)	16:23:42.71	17:39:32.83	17:54:30.08	18:39:07.03	18:48:17.98
Declination (J2000)	-08:41:36.45	-25:21:16	-30:14:42	-01:41:56.09	-12:43:26.65
Spin Period (s)	0.503	1.818	1.320	0.933	0.414
Period Derivative (10^{-15} s s^{-1})	1.96	0.29	4.42	5.94	0.44
RMS Residual (ms)	0.8	4.8	3.6	1.8	1.4
Dispersion Measure (pc cm^{-3})	60.4	186.4	99.4	293.4	88.0
Surface Magnetic Field (10^{12} G)	1.0	0.7	2.4	2.4	0.4
Spin-down Luminosity (10^{31} ergs s^{-1})	60.6	0.2	7.6	28.9	24.4
Characteristic Age (Myr)	4.1	99.2	4.7	2.5	14.9

Tab. 2: Timing solution of 5 new RRATs

3. Pulse Profiles

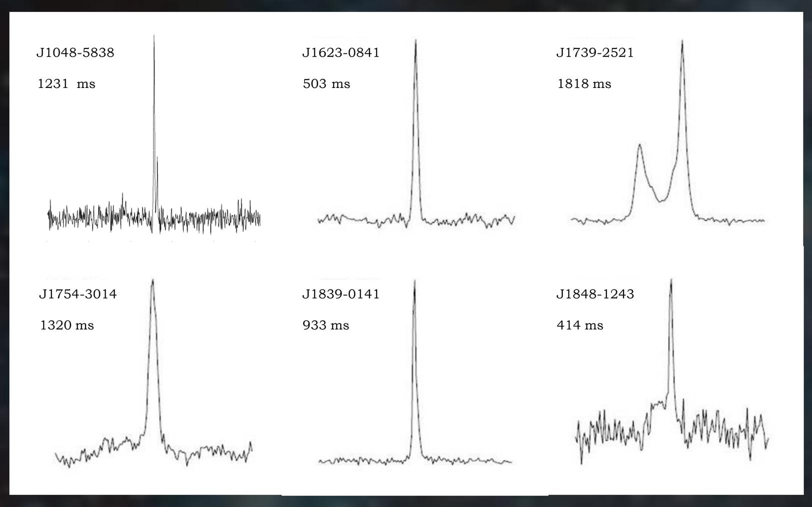

Figure 5: Pulse Profiles of 6 RRATs

Here, Pulse profiles of J1739-2521 and J1839-0141 are sum of data only when the RRATs are on. Profile of J1048-5838 is made by folding on-phase data in a single observation. Other profiles are created by folding each observation and summing all the profiles.

4. Long timescale periodicities

Instead of using Fourier transform, we use Lomb Scargle analysis (LS test, Scargle 1982) upon these uneven sampled pulse arrival times of PSR J1048-5838 to see if there's any hidden periodicities in the timeseries.

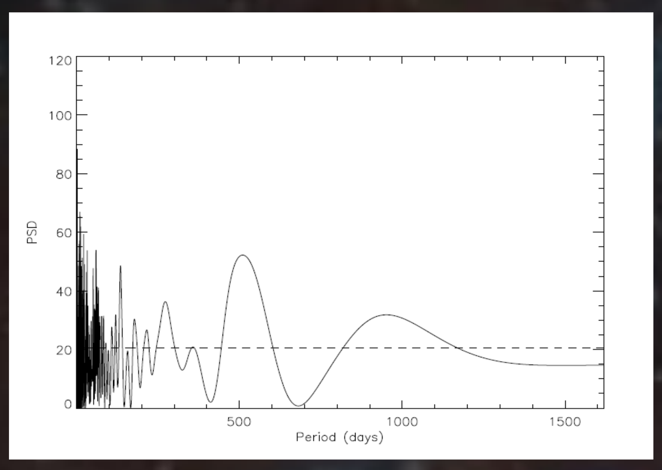

Figure 6: Result of LS test

This spectrum gives the most significant periodic signal to be of period = 19.15 hours. The dash line represents 95% significant level. Since there are more peaks above the dash line, further investigation need to be applied on this test.

5. Population of RRATs

At this time, 21 of roughly 70 RRATs have timing solutions with period and period derivative, shown on this P - $\dot{P}$ diagram below:
(All latest RRATs' data can be found in RRATalog www.as.wvu.edu/~pulsar/rratalog)

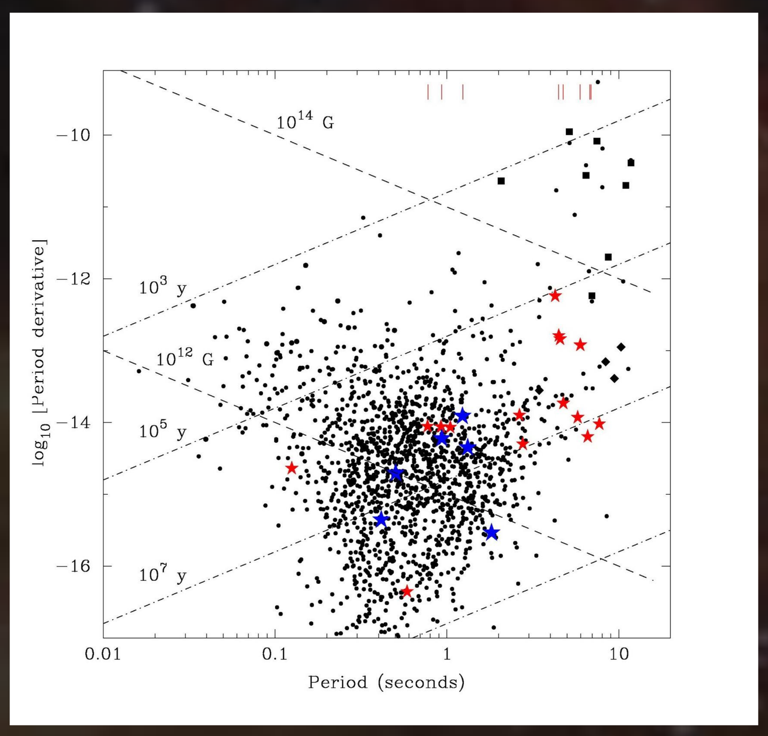

Figure 5: P - $\dot{P}$ diagram of all solved RRATs and pulsars

This P - $\dot{P}$ diagram shows the new RRATs as blue stars and previously timed RRATs as red stars. The black dots are pulsars in the ATNF pulsar catalog. The black squares are magnetars, and black diamonds indicate x-ray isolated neutron stars.

6. RRATs: Why different?

We also applied the Kolmogorov-Smirnov test (KS test) to the RRAT and normal pulsar populations to see how their spin-down properties compare. "Prob" is the probability that the distributions are the same.

	Period	Period derivative	Magnetic field	Characteristic Age	Spin-down energy-loss rate
Prob.	1.12$\times 10^{-19}$	2.45$\times 10^{-4}$	1.94$\times 10^{-5}$	0.16	0.04

Tab. 3: Results of KS test

Thus we conclude that the RRATs have longer rotation periods and stronger magnetic fields than other pulsars. While selection effects may be responsible for some of the period dependence, the difference in period derivative distributions hints that there is a fundamental difference in these populations.

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