Searching for weak, isolated pulsars in the globular cluster Terzan 5

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Abstract:
Terzan 5 is one of the richest globular clusters in the Milky Way. It contains 33 known recycled millisecond pulsars, 16 of which are binary systems. We searched for very weak, isolated pulsars in Terzan 5 using an incoherent "stack-search" method that sums power spectra from several observations.[1] We summed power spectra from over a year's worth of GBT observations, and have so far uncovered two new, weak, isolated millisecond pulsars using this method. We plan to continue using this method to search GBT data from several star clusters and anticipate discovering several additional millisecond pulsars. This project was supported by NRAO, the NSF REU program, and Oberlin College.

Introduction:
One defining characteristic of a millisecond pulsar is an extremely steady pulse period. The pulse period of a typical isolated pulsar changes by as little as a few nanoseconds per year.[2] This means that signals from an isolated pulsar in several different observations can be reliably added together in the frequency domain. In principle, the Fourier amplitudes from an isolated pulsar should increase relative to noise as the square root of the number of observations added:

$$\mathrm{SNR} \sim \sqrt{n_{obs}}$$

"Stacking" multiple observations in this way allows for the detection of isolated pulsars too weak to identify in a single observation.

Why Terzan 5?
Terzan 5 is ideally suited for stack-searching for several reasons:

- It is known to contain many pulsars. 33 millisecond pulsars have been identified in Terzan 5.[3]
- It has a relatively high average dispersion measure (DM) of 238. This means that short-term diffractive scintillation effects average out, reducing fluctuations on the time scale of many observations.
- Similar observations of Terzan 5 have been taken at regular intervals for over a year (primarily by Scott Ransom), providing a good data set for stacking.

P-dot sensitivity[4]:
For the stack-search to function, the pulse period must appear in the same Fourier bin in each observation. This means the change in frequency must be

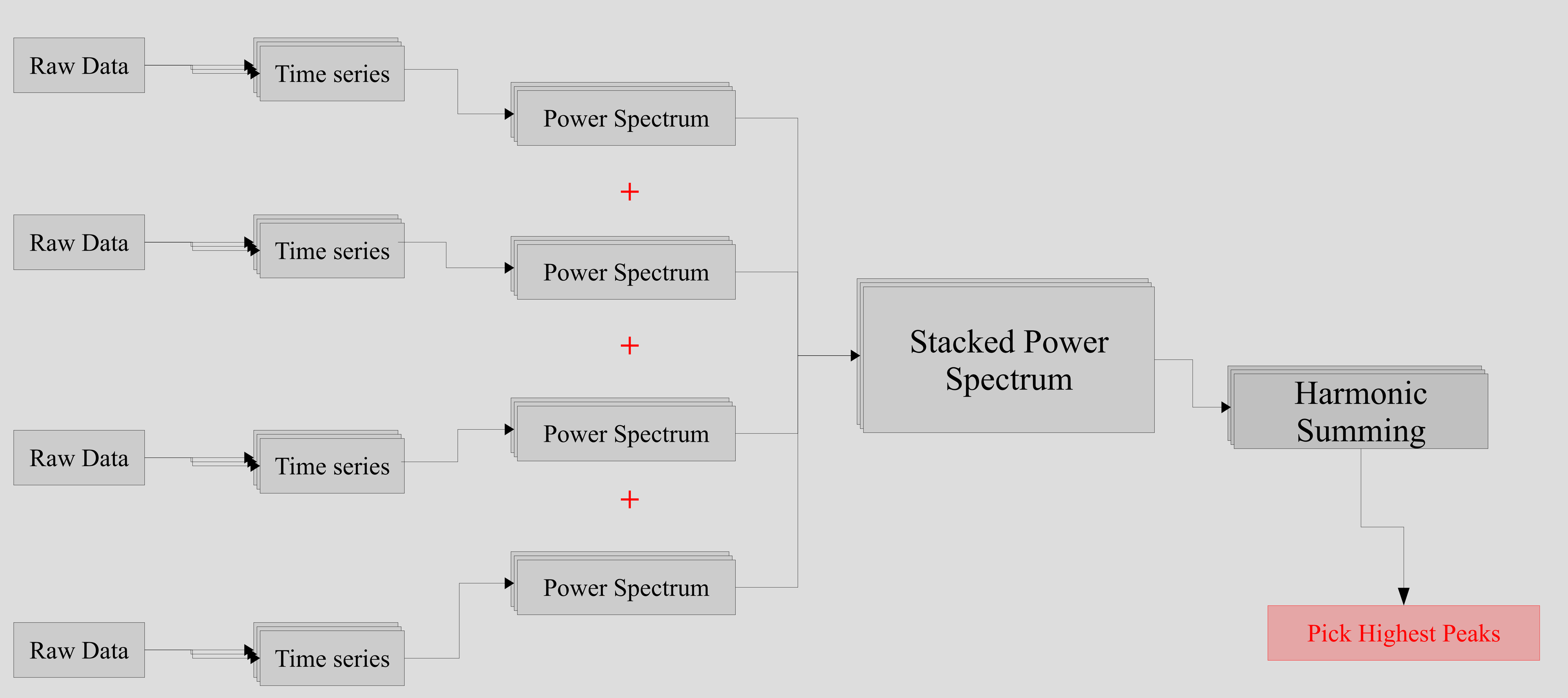
$$\left|\frac{\partial f}{\partial t}\right| T_{stacked} < \frac{1}{T_{obs}}$$

where $T_{stacked}$ is the cumulative stacked time (~1 yr) and T_{obs} is the length of each individual observation (~7 hrs).

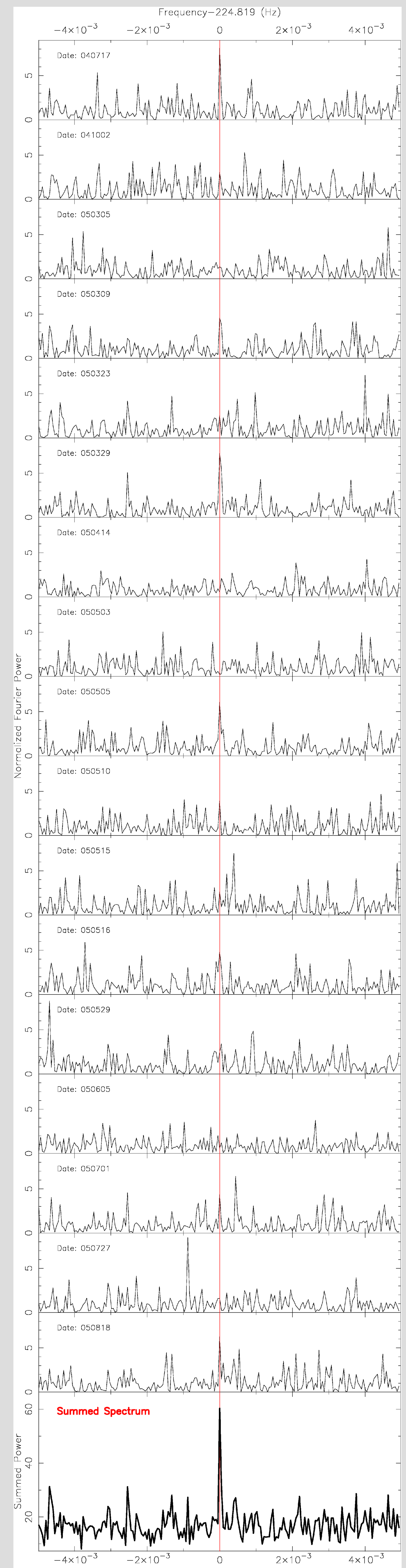
The sources of frequency drift in an isolated pulsar are:

- Intrinsic spin down: a few nanoseconds per year (negligible)
- Globular cluster acceleration (similarly negligible)
- Earth's orbital doppler shift: This is the most significant source of frequency drift, but is still small enough to allow stacking of Terzan 5 data to detect pulsars with periods as short as 1 ms.
- The orbital accelerations of virtually all weak millisecond pulsars in binary systems make them impossible to detect in a stack-search. We are exploring alternate methods for finding new binary pulsars.[5]

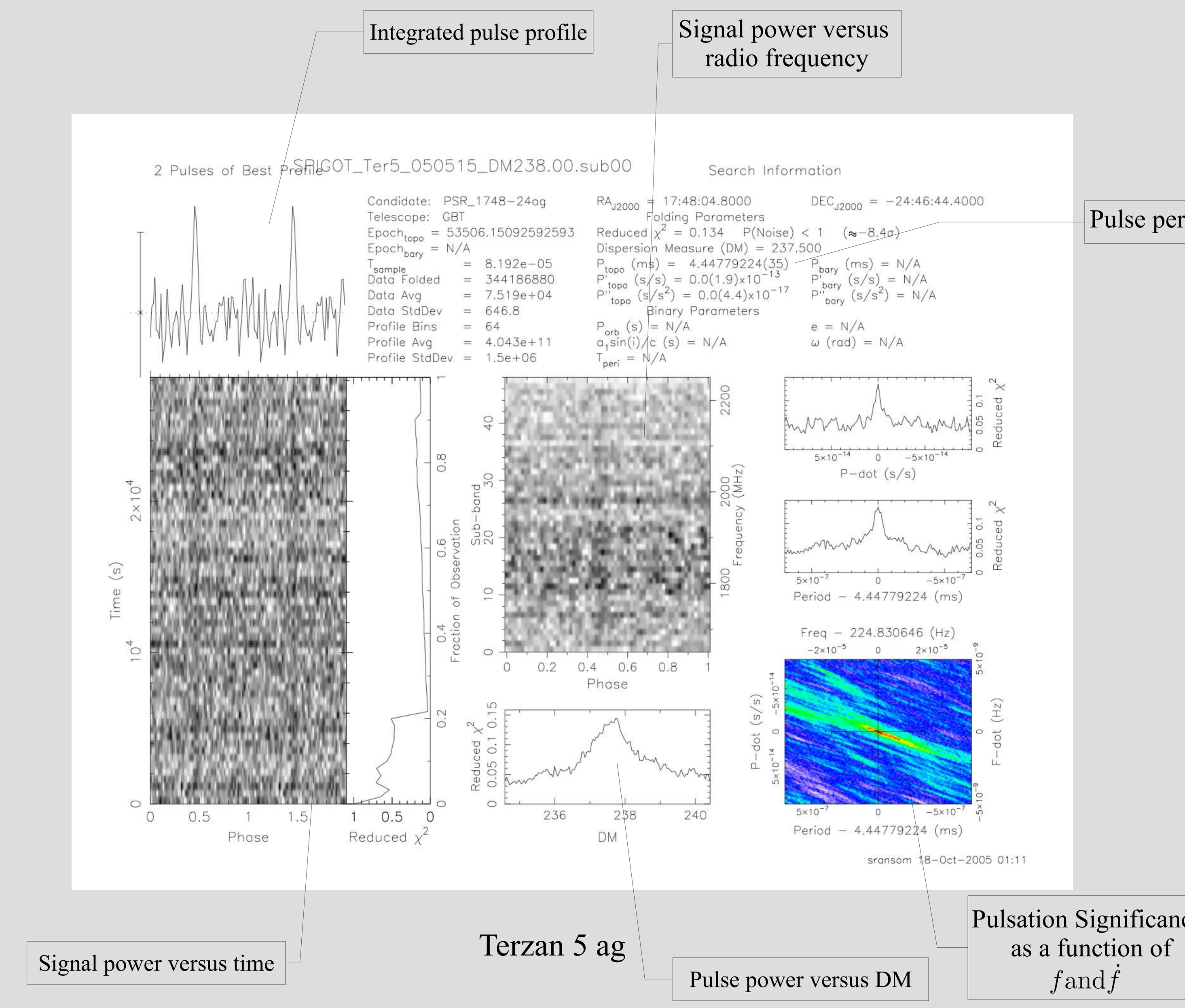
Implementation:
The stack-search method was implemented using Scott Ransom's PRESTO pulsar searching package[6] in combination with a set of python programs. Each of 17 data sets spanning a total of about a year was dedispersed at DM's in steps of 0.5 from 234.0 to 241.0 pc/cm^3. Each dedispersed time series was Fourier transformed to the frequency domain, converted into a power spectrum, and normalized such that the powers had a mean and standard deviation of unity. The normalized power spectra at each DM were then added to produce a stacked power spectrum, which was harmonically summed (a step necessary due to the highly structured pulse profiles of millisecond pulsars) and then searched for the highest peaks. Pulsar candidates were folded and plotted in the top few observations.



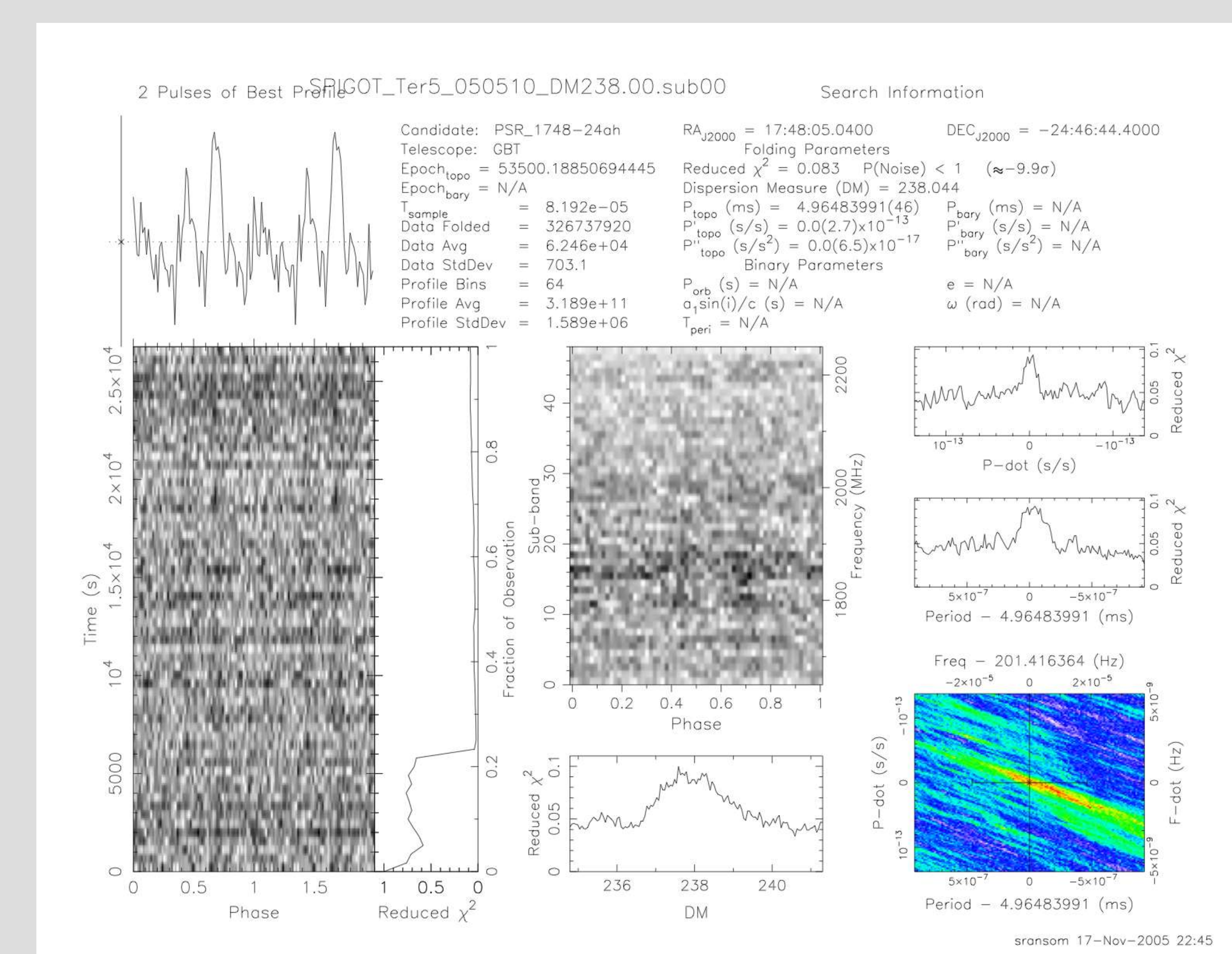
Stacked Spectra:
Shown are the 17 stacked power spectra in a range of .005 Hz about Terzan 5 ag (4.45 ms). Note the increased peak height in the stacked spectrum. The stacked spectrum was produced by summing the individual spectra and then summing at the second and fourth harmonics.



Results:
We have discovered two isolated pulsars in the Terzan 5 globular cluster using the stack-search method. The plots shown are folded modulo the detected pulsar spin period from the strongest detection of each pulsar. We have timing solutions for both pulsars, providing arc-second precision position information. This may allow for future correlation with X-ray counterparts. Both pulsars are located within 10" (~1 core radii) of the cluster's center. These positions will help us calculate a statistical measurement of the average mass of isolated millisecond pulsars.[7]



Terzan 5 ag



Terzan 5 ah

References:
1. Anderson, Stuart Bruce, "A Study of Recycled Pulsars in Globular Clusters," PhD thesis, CalTech, 1993, p. 31-35.
2. Manchester, Richard N, Joseph H. Taylor, *Pulsars*, San Francisco: W. H. Freeman and Company, 1977.
3. Hessels et al., 2006, submitted.
4. Anderson, Stuart Bruce, "A Study of Recycled Pulsars in Globular Clusters," PhD thesis, CalTech, 1993, p. 32-34.
5. See poster 183.07 by McCarty et al.
6. See Ransom, Scott, "New Search Techniques for Binary Pulsars," PhD thesis, Harvard University, 2001. Additional information at www.nrao.edu/~sransom/presto.
7. See poster 32.05 by Ransom et al.