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# Searching for Millisecond Pulsars in Globular Clusters at Parkes

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**Abstract.** We report the preliminary results of a search of the Globular Cluster System for millisecond pulsars carried out at Parkes at 1.4 GHz. We have observed 60 clusters and have found so far 12 new millisecond pulsar in 6 clusters.

## 1. Introduction

Globular clusters are a rich source of millisecond pulsars, and despite the large difference in total mass between the Galactic disk and the Globular Cluster System, more than 50 % of the entire millisecond pulsars sample has been detected in globular clusters. Millisecond pulsars are believed to be formed in binary systems containing a neutron star which can be spun up by accretion of angular momentum from the evolving companion (Bhattacharya & van den Heuvel, 1991). Exchange interactions in the dense core of globular clusters provides a very efficient channel for the formation of exotic binary systems containing a neutron star which eventually result in the formation of a millisecond pulsar.

However, millisecond pulsars in globular clusters are difficult to find because the emission is weak and distorted by propagation through the interstellar medium, and because they can be still gravitationally bounded to their binary companion, and the apparent pulse period may change rapidly because of orbital motion. On the other hand, millisecond pulsars in binary system are very interesting objects. They are prone to manifest exotic phenomena such as eclipses due to interactions of the pulsed radio signal with the atmoshpere of the stellar companion. Also, millisecond pulsars are extremely stable clocks, and the observation of millisecond pulsars in binary systems provides a unique tool in order to probe General Relativity effects. Few years ago we have initiated a new systematic search of globular clusters for millisecond pulsars using the new multibeam 20-cm receiver (Staveley-Smith et al. 1996). This receiver has a system temperature of $\sim 21$ K and bandwidth of $\sim 300$ MHz, resulting in an unprecedented instantaneous sensitivity. We have constructed a new high resolution filterbank system, made of $512 \times 0.5$ MHz adjacent pass-band filters. This makes possible to remove the effects of dispersion in the interstellar medium more efficiently than previous searches, and allows the detection of millisecond pulsars with dispersion measures (DMs) of more than 200 $\mathrm{cm^{-3}pc}$. The combination of this new equipment with the relatively high frequency of the multibeam receiver and its sensitivity level gives a unique opportunity to probe distant clusters. We have implemented a new multi-dimensional code to search over a range of accelerations resulting from binary motion, in addition to the standard search over a range of DMs.

## 2. Observations and data processing

We have selected about 60 clusters (see Table I) on the basis of their central density and distance. Observations consist of a 2h or 4h integration on each target. The resulting nominal ($8\sigma$) sensitivity to a typical 3 ms pulsar with DM $\sim 200$ $\mathrm{cm^{-3}}$ pc is about 0.14 mJy, several times better than previous searches. Sampling the 512 channels every 125 $\mu$s, each observation produces a huge array, 32 Gsamples, or 4 Gbytes (packing the data at 1-bit/sample), and requires significant CPU resources for offline processing. So far, we have implemented our code on a local cluster of Alpha-500MHz CPUs in Bologna (D'Amico et al. 2001), and we are now porting the code to more powerful Beowulf systems available at Cagliari and Jodrell Bank. In the off-line processing, each data set is split into non-overlapping segments of 2100, 4200 or 8400 sec and these are separately processed. When the DM is not known precisely from the existence in a given cluster of a previously known pulsar, the data are first de-dispersed over a relatively wide range of dispersion measures centered on the value expected for each cluster on the basis of a model of the Galactic electron layer, and then transformed using a Fast Fourier Transform (FFT). The original time-domain data are then fast-folded at periods corresponding to a significant number of spectral features to form a series of 'sub-integration arrays' and these arrays are searched for the parabolic signatures of an accelerated periodicity. Suspect periodicities having significant signal-to-noise ratio are then output for visual examination. When a pulsar is detected and confirmed in a cluster, we usually reprocess the data. The raw data are de-dispersed at the single DM value of the newly discovered pulsar and the resulting time series is resampled to compensate for a wide range of accelerations and transformed using a FFT. In addition, we have developed a code which allows also to search for a significant derivative of the acceleration, improving the sensitivity for the detection of short period binary systems. Using the new multiprocessor systems available, we plan to perform a full multidimensional analysis of many clusters.

## 3. Results

So far we have discovered 12 new pulsars in 6 clusters none of which had previously known pulsars associated with them. Six of these pulsars are members of relatively short period binary systems, and six have relatively high DM, so they would have been undetectable without the new capabilities of the present search system. The parameters of the new millisecond pulsars are reported in Table I

Table I - Parameters of the MSPs Discovered at Parkes

| Cluster | Pulsar | P (ms) | DM ($cm^{-3}$ pc) | $P_b$ (days) | Mass $f$ ($M_\odot$) |
|---|---|---|---|---|---|
| NGC6266 | J1701-3006A | 5.24156623863 | 114.4 | 3.8059483 | 0.0031 |
| | J1701-3006B | 3.59385222797 | 114.4 | 0.1445454 | 0.0009 |
| | J1701-3006C | 3.80642436460 | 114.4 | 0.2150000 | 0.0002 |
| NGC6397 | J1740-5340 | 3.65032889692 | 71.8 | 1.3540597 | 0.0027 |
| NGC6544 | J1807-2459 | 3.05944879740 | 134.0 | 0.0710920 | $3.85\times10^{-7}$ |
| NGC6752 | J1911−5958A | 3.26618657079 | 33.68 | 0.8371134 | 0.0029 |
| | J1910−5959B | 8.35779850080 | 33.28 | single | |
| | J1911−6000C | 5.27732693231 | 33.21 | single | |
| | J1910−5959D | 9.03528524779 | 33.32 | single | |
| | J1910−5959E | 4.57176593976 | 33.29 | single | |
| NGC6441 | J1750-3703 | 111.600836390(3) | 233.25 | 17.334282 | 0.0519 |
| NGC6522 | J1803-3002 | 7.10139200(4) | 193.4 | single | |

We now discuss the properties of these objoects in turn.

### 3.1. NGC 6266

The first millisecond pulsar discovered in this cluster, PSR J1701-3006A (D'Amico et al 2001a), has a spin period og 5.25 ms, a moderately short orbital period of 3.8 days, and minimum companion mass of 0.19 $M_\odot$. The knowledge of the DM value (114.4 $cm^{-3}$ pc) for this cluster, obtained from this discovery, made it possible to perform a coherent acceleration search, resulting in the discovery of two ultra-short binary period millisecond pulsars, PSR J1701-3006B and J1701-3006C (Possenti et al. 2002).

### 3.2. NGC 6397

In this cluster we have discovered a binary millisecond pulsar, PSR J1740-5340 (D'Amico et al 2001b, Ferraro et al 2001), having a spin period os 3.65 ms and an orbital period of 1.35 days, which displays eclipses at 1.4 GHz for more than

40 % of the orbital phase, and in which the radio signal exhibits irregularities, such as delays and intensity variations, over a wide range of orbital phases. In this system, the millisecond pulsar is probably orbiting within a large envelope of matter released from the companion, which is probably undergoing the presumed final stages of mass loss.

### 3.3. NGC 6544

The millisecond pulsar discovered in this cluster, PSR J1807-2459 (D'Amico et al 2001a), is a rather bright source and was not detected in previous searches because of the relatively large DM (134 $cm^{-3}$ pc). Timing observations carried out at Jodrell Bank show that this millisecond pulsar is part of an extremely compact binary system, with an orbital period of 1.7 hr only and a minimum companion mass of about 10 Jupiter masses.

### 3.4. NGC 6752

In this cluster we have first discovered a binary millisecond pulsar with a spin period of 3.26 ms and an orbital period of 20.6 hr (D'Amico et al 2001a), and then flux amplification due to scintillation helped in the detection of four additional millisecond pulsars in the same cluster (D'Amico et al 2002), all of them isolated. The millisecond pulsars discovered so far in this cluster are all interesting in many aspects. Two of them (A and C) have been ejected out of the cluster core and are located rather far from the cluster center, at 1.4 and 3.3 half-mass radii respectively, suggesting the occurrence of highly effective non-thermal dynamics in the core. In addition, two of the isolated millisecond pulsar (B and E) have large negative $\dot{P}$ values, corresponding to line-of-sight accelerations larger than the maximum value predicted by the central mass density derived from optical observation. This provides dynamical evidence for a central mass-to-light ratio $\sim 10$, much higher than for any other globular cluster.

### 3.5. NGC 6441

The radio pulsar discovered in this cluster, PSR J1750-3703 (Possenti et al 2001), has a spin period of 111.6 ms, the longest spin period among the known radio pulsars in globular clusters, an orbital period of 17.3 days, and a rather high eccentricity e=0.71. The resulting mass function suggests that the companion could be a massive white dwarf or a neutron star.

### 3.6. NGC 6522

We have discovered only a single millisecond pulsar in this cluster, PSR J1803-3002 (Possenti et al 2001), which is relatively strong and was probably missed in previous searches because of the large DM value (192 $cm^{-3}$ pc).

## 4. Conclusions

The 12 millisecond pulsars discovered so far by this new experiment are probably the tip of the iceberg of a much larger sample of potentially observable objects. Indeed, some of them were detected because a *first* millisecond pulsar in a given cluster was relatively *easy* to find and the DM value could be then held fixed during subsequent searches. If a globular cluster contain *difficult* millisecond pulsars only (for instance ultra-short period binaries), they can be found only devoting a huge amount of computing resources. We are now in the process of porting our code to much more powerful computer systems, so we expect to find many new and probably exotic objects.

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