

A Dozen New Pulsars from the Parkes Globular Cluster Search

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Abstract. Twelve new recycled pulsars in six clusters have been found so far in the ongoing Parkes Globular Clusters survey at 1.4 GHz. After reporting about the status of the search, we focus on the results from timing and multi-wavelength follow-up observations of the discovered sources.

1. Introduction

Globular clusters (GCs) are a fertile environment for the formation of recycled pulsars: besides evolution from a primordial system, exchange interactions in the ultra-dense core of the cluster favor the formation of various types of binary systems suitable for spinning up the neutron stars they host (e.g., Davies & Hansen 1998). Because of this, about 60% of all known millisecond pulsars (MSPs) are in GCs. Being point-like objects and, often, also extremely stable clocks, the MSPs in GCs allow one to investigate: *(i)* the gravitational potential of the GC (e.g., Camilo et al. 2000); *(ii)* the dynamical interactions in the GC core (e.g., Phinney & Sigurdsson 1991); *(iii)* the gas content in a GC (Freire et al. 2001); *(iv)* the neutron star retention (Pfahl, Rappaport & Podsiadlowski 2002); *(v)* the binary evolution in a dense stellar environment (e.g., Davies & Hansen 1998; Ivanova & Rasio, in this volume); *(vi)* the equation of state of nuclear matter (Edwards, van Straten & Bailes 2001).

Unfortunately, pulsars in GCs are elusive sources. Their large distances make their flux density typically very small and their signals strongly distorted by propagation through the dispersive interstellar medium. In addition, they frequently are members of close binary systems, causing large changes in the observed spin period and sometimes periodic eclipsing of the radio signal.

2. Status of the PKSGC Survey

Five years ago we undertook a new search for MSPs in GCs (the Parkes Globular Cluster, PKSGC, survey) exploiting the low system temperature (~ 21 K) and the large bandwidth (~ 300 MHz) of the new 20-cm receiver installed at the 64-m Parkes radiotelescope. We have built at Jodrell Bank and Bologna a new high-resolution filterbank, made of 512×0.5 MHz adjacent pass-band filters, providing an unprecedented opportunity to probe distant clusters. Also, we have implemented a new multi-dimensional code to search over a wide range of accelerations resulting from binary motion in addition to the standard search over a range of DMs (see Possenti et al. 2003 for a detailed description of data acquisition and processing).

We have selected 65 GCs in the framework of the PKSGC survey. All of them have been observed and we have now completed the regular processing of 2/3 of the data. In Table 1 we list the parameters for the 12 new MSPs which we have discovered so far in six clusters which did not contain previously known pulsars. Full-precision parameters and related uncertainties are reported in the following papers: D’Amico et al. 2001a, D’Amico et al. 2001b, D’Amico et al. 2002, Possenti et al. 2003. These discoveries contribute 25% to the total number of globular clusters hosting a known millisecond pulsar. Taking advantage of the availability at the Cagliari Observatory of *Mangusta* (a new large cluster of 40 CPUs), we are completing the regular processing of the collected data, while simultaneously undertaking a re-processing of all the observations, applying a fully coherent search for “ultra-accelerated” pulsars.

Table 1. Parameters of the MSPs Discovered in the PKSGC Survey

Cluster Name	Pulsar Name	P_{spin} ms	DM $\text{cm}^{-3} \text{pc}$	P_{orb} days	$a \sin i$ lt-s	$M_{\text{c,min}}$ $M_{\odot}$	offset R_{core}
NGC6266	J1701–3006A	5.24	115.0	3.80	3.48	0.20	2.0
	J1701–3006B	3.59	113.4	0.14	0.25	0.12	0.15
	J1701–3006C	3.80	114.6	0.21	0.19	0.07	1.0
NGC6397	J1740–5340	3.65	71.8	1.35	1.65	0.19	11
NGC6441	J1750–3703	111.6	233.2	17.3	24.4	0.58	2.0
NGC6522	J1803–3002	7.10	193.4	single			4.4
NGC6544	J1807–2459	3.06	134.0	0.071	1.65	0.009	1.2
NGC6752	J1911–5958A	3.27	33.7	0.84	1.21	0.19	73
	J1910–5959B	8.36	33.3	single			0.8
	J1911–6000C	5.28	33.2	single			30
	J1910–5959D	9.03	33.3	single			0.6
	J1910–5959E	4.57	33.3	single			0.5

3. Highlights

3.1. The Eclipsing Pulsar in NGC 6397

NGC 6397 hosts a MSP (PSR J1740–5340) whose characteristics are unique: it is a member of a binary with orbital period 1.35 days and suffers eclipses for about 40% of the orbital phase at 1.4 GHz (D’Amico et al. 2001b). Light curves (Ferraro et al. 2001; Orosz & van Kerkwijk 2003; Kaluzny et al. 2003) and spectroscopic observations (Ferraro et al. 2003a) of the optically identified companion (Ferraro et al. 2001) suggest that it must have a mass in the interval $0.22\text{--}0.32 M_{\odot}$ and completely (or almost completely) fills its Roche lobe. These facts, combined with radio measurements, indicate that the companion may be either (i) the remnant of the star that spun up the pulsar (Ferraro et al. 2001) and is now experiencing the so-called *radio-ejection* phase (Burderi, D’Antona & Burgay 2002); (ii) a star which exchanged its position in the binary with that of the star which originally spun-up the pulsar (Grindlay et al. 2002); (iii) a sub-subgiant resulting from a binary–binary encounter in the cluster core (Orosz & van Kerkwijk 2003); or (iv) a combination of (i) and (ii), hence making this binary the archetype of the *black-widow* systems whose mass loss is driven by the nuclear evolution of the companion (King, Davies & Beer 2003). In all cases, it appears a very promising target for studying how the pulsar energetic flux interacts with the plasma released by the companion: the complex structure of the H_{α} emission line (Sabbi et al. 2003a) could be a confirmation that the *radio-ejection* mechanism is indeed at work in this system; the presence of He-lines in absorption may be ascribed to a hot barbecue-like strip on the companion surface heated by an highly anisotropic pulsar flux (Sabbi et al. 2003a); the enhanced Lithium abundance can result from nuclear reactions triggered by accelerated particles flowing from the pulsar (Sabbi et al. 2003b).

The strong timing noise due to the unpredictable delays occurring at orbital phases far from the eclipse edge made the original timing parameters much more uncertain than the nominal errors quoted in D’Amico et al. (2001a). With a three-times-longer data span (Possenti et al., in preparation), the astrometry has been improved (RAJ=17^h40^m44^s.630(4), DECJ=−53°40′41″.75(8)), in agreement with a recent optical determination (Bassa et al., in preparation). This affects $\dot{P} = 4.0(9) \times 10^{-20}$ and in turn the characteristic age $\tau_c \sim 1.4$ Gyr, surface magnetic field $B_s \sim 3.9 \times 10^8$ G and spin-down power $\dot{E} \sim 3.3 \times 10^{34}$ erg s^{−1}. Under the hypothesis of an isotropic pulsar flux, the new smaller value of $\dot{E}$ could account for the lack of any visible irradiation involving the majority of the companion surface facing the pulsar (Orosz & van Kerkwijk 2003).

3.2. The Peculiar Dynamics of the Pulsars in NGC 6752

The stellar density profile of NGC6752 is quite complex (Ferraro et al. 2003b), but this cluster is very interesting mostly because of the features of the embedded 5 MSPs (D’Amico et al. 2002). PSR-B and PSR-E (located within the cluster core) have very high *negative* spin derivatives. If these negative derivatives are ascribed to the overall effect of the cluster potential (as customarily assumed), the resulting central mass-to-light ratio (M/L) is much larger (Ferraro et al.

2003b) than that reported in the literature and at least *twice* as large as the typical value $M/L \simeq 2 - 3$ observed in other core-collapsed clusters. This peculiarity could be explained with $\sim 1000 M_{\odot}$ of low-luminosity unseen matter (Ferraro et al. 2003b) enclosed within the central 0.08 pc of the cluster. Given the observed shape of the cluster density profile, it could be due to: (a) a very high concentration of white dwarfs; or (b) a central (single or binary) intermediate-mass black hole. On the other hand, (b) is a viable hypothesis to account for the unprecedented positions of PSR-A and PSR-C: in fact PSR-A (a binary pulsar, whose companion has been recently identified as a Helium white dwarf; Bassa et al. 2003; Ferraro et al. 2003c) holds the record of being the farthest MSP ($\simeq 3.3$ half-mass radii) ever observed from the centre of a globular; PSR-C, an isolated pulsar, ranks second in the list. These locations are in contrast to what is expected from mass segregation and call for the occurrence of some recent dynamical events that propelled the pulsars from the core to the cluster outskirts. These ejections are much more probable if the scattering target is significantly more massive than the propelled system and that strongly favors the black-hole scenario. In particular it has been shown that a double black hole of intermediate mass ($\sim 100 M_{\odot}$) could explain the location of the ejected pulsars (Colpi, Possenti & Gualandris 2002; Colpi, Mapelli, & Possenti 2003), satisfy the requirements of the stellar density profile (Ferraro et al. 2003b) and properly fit the dynamical evolution of the cluster (Sigurdsson 2002).

3.3. The Predominance of Binaries in NGC 6266

In NGC 6266, six MSPs have been discovered: three during the PKSGC survey (D’Amico et al. 2001a; Possenti et al. 2003) and three more by Jacoby et al. (2002). The inferred luminosities of the MSPs A, B and C ($\sim 10 - 20 \text{ mJy kpc}^2$ at 1400 MHz; Possenti et al. 2003) place them at the bright end of the luminosity function of the MSPs in GC, entailing the possible existence of many slightly dimmer MSPs in NGC 6266. A recent *Chandra* pointing revealed the presence in the inner part of the cluster of a few tens of X-ray sources (Pooley et al. 2003), whose colours suggest that NGC 6266 should harbour tens of MSPs.

In contrast to the other GCs in which at least five pulsars have been discovered (47 Tuc, M15, and NGC 6752), all the 6 known MSPs in NGC 6266 are in binaries. The absence of isolated pulsars cannot be explained by invoking a selection effect since, for a given spin period and flux density, an isolated MSP is easier to detect than a binary MSP. Unfortunately, the observational biases affecting the fraction $\mathcal{F}_{\text{is}}$ of isolated pulsars discovered in a given cluster (with respect to the total observed MSP population) are difficult to quantify precisely. Considering all the other clusters, $\mathcal{F}_{\text{is}} \geq 2/5$. If this ratio applies to NGC 6266, the probability of having the first 6 detected pulsars all in binaries is $\leq 5\%$. If this absence of isolated pulsars in NGC 6266 is not a statistical fluctuation, it must relate to the mechanisms of formation of these objects and their interplay with the dynamical state of the cluster. Detailed numerical simulations would be helpful in investigating if trapping of almost all the neutron stars in close binary systems can really occur, for instance, during the phase immediately preceding the core collapse or its reversal.

3.4. The Eccentric Pulsar in NGC 6441

PSR J1750–3703 in NGC 6441 (Possenti et al. 2001) is a mildly recycled radio pulsar orbiting a companion whose minimum mass is $0.58 M_{\odot}$. This fact and the large orbital eccentricity ($e = 0.71$) favor two interpretations for the nature of the system: (*a*) a pulsar orbiting a star (a heavy white dwarf or a main-sequence star) acquired during an exchange interaction in the cluster core; or (*b*) a double-neutron-star binary. A longer data span of timing observations will allow us to reduce the present uncertainties in the determination of the periastron advance (and hence the total mass of the system), probably discriminating between these two possibilities.

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