The Parkes Multibeam Pulsar Survey and the Discovery of New Energetic Radio Pulsars

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Abstract.
The Parkes multibeam pulsar survey is a deep search of the Galactic plane for pulsars. It uses a 13-beam receiver system operating at 1.4 GHz on the 64-m Parkes radio telescope. It has much higher sensitivity than any previous similar survey and is finding large numbers of previously unknown pulsars, many of which are relatively young and energetic. On the basis of an empirical comparison of their properties with other young radio pulsars, some of the new discoveries are expected to be observable as pulsed γ-ray sources. We describe the survey motivation, the experiment characteristics and the results achieved so far.

INTRODUCTION

Since the pioneering γ-ray observations conducted early in the 70's with balloon-borne experiments [1], radio pulsars were privileged as targets for γ-ray emission searches. One of the reasons was partly observational. The angular resolution of γ-ray telescopes is rather poor, and the timing analysis is the only effective technique to identify point sources in γ-ray astronomy. The first systematic γ-ray observations conducted by the SAS-II satellite [2], showed that the Crab and Vela pulsars were strong sources of pulsed γ-ray emission [3, 4]. One of the other major contribution of the SAS-II satellite to γ-ray astronomy was the observation of significant γ-ray emission from the Galactic disk. In principle, on the basis of the SAS-II observations, most of Galactic γ-rays could be interpreted as due to diffuse emission only [5]. On the other hand, in the following years, the better statistics achieved by the γ-ray satellite COS-B [6] , proved the existence of several localised sources of γ-ray emission along the Galactic disk [7]. Since then, the identification of these sources has represented a challenge for γ-ray astronomy. The hypothesis that they could be young energetic pulsars similar to the Crab and Vela pulsars is interesting [8]. However, the low counting statistics available in γ-ray astronomy and the long integration times (several weeks) required to obtain a significant detection prevent an unbiased periodicity search of the γ-ray data. The discovery of potential radio pulsar counterparts, and the possibility of phasing the γ-ray counts using the radio timing parameters, represents the unique tool for the identification.

The first searches of the COS-B γ-ray error boxes for radio pulsars conducted at Arecibo and Parkes in the early 80's [9, 10], were unsuccesful. But in 1992, in a deep survey of the Galactic disk conducted at Parkes, Johnston et al (1992) [11], discovered a new sample of radio pulsars, including a few relatively young and energetic objects. One of them, PSR B1706-44, was coincident with the COS-B source 2CG342-02. Precise radio timing parameters obtained at the epoch of the EGRET observation of this source led to the detection of pulsed γ-ray [12]. Indeed, a long term radio timing program of a large sample of known pulsars conducted during the CGRO mission led to the detection of pulsed γ-ray emission from a few other radio pulsars [13, 14]. On the other hand, EGRET has also discovered a large number of new localised γ-ray sources [15], making their identification a serious challenge. If some of the Galactic EGRET sources are pulsars, they are likely to be relatively young and energetic, similar to the Crab and Vela pulsars. This hypothesis is strongly supported by the discovery that "Geminga", the third strongest γ-ray source in the sky, is indeed a pulsar [26].

Although young pulsars evolve relatively fast, so that they tend to be intrinsically rare in the population, the paucity of young pulsars in the observed sample is believed to be further enhanced by observational selection effects. Pulsars, being the remnant of massive stars, are believed to be born as a disk population. So young pulsars, which are expected to be found close to their birth place, tend to be located at low Galactic latitudes. The observation at radio wavelengths of pulsars (and in particular short-period pulsars) at low Galactic latitudes is limited by several factors, including pulse smearing due to dispersion and scattering in the interstellar medium, and Galactic background radiation.

Beside their potential role as counterparts of the Galactic gamma-ray sources, young pulsars are interesting for several reasons: they are likely to be associated with supernova remnants [16], they generally exhibit rotational instabilities including glitches [17, 18, 19], and they sometimes emit detectable pulsed radiation at optical [20] and X-ray frequencies [21, 22].

In this paper we report on a new survey of the Galactic plane for pulsars which is in progress at Parkes, including the discovery of a substantial number of new young and energetic radio pulsars.

THE PARKES MULTIBEAM PULSAR SURVEY

The new deep survey of the Galactic plane for pulsars is being carried out using a 13-beam receiver on the Parkes 64-m radio telescope [23, 24]. Observations are made using dual-polarization feeds with a bandwidth of 288 MHz centered on 1374 MHz. A large filterbank system gives 96 3-MHz channels for each polarization of each of the 13 beams. Signals from individual frequency channels are detected, added in polarization pairs, high-pass filtered, integrated, 1-bit digitised every 250 μs and output to digital linear tapes (DLTs). The excellent system noise temperature ($\sim$ 21 K), large bandwidth

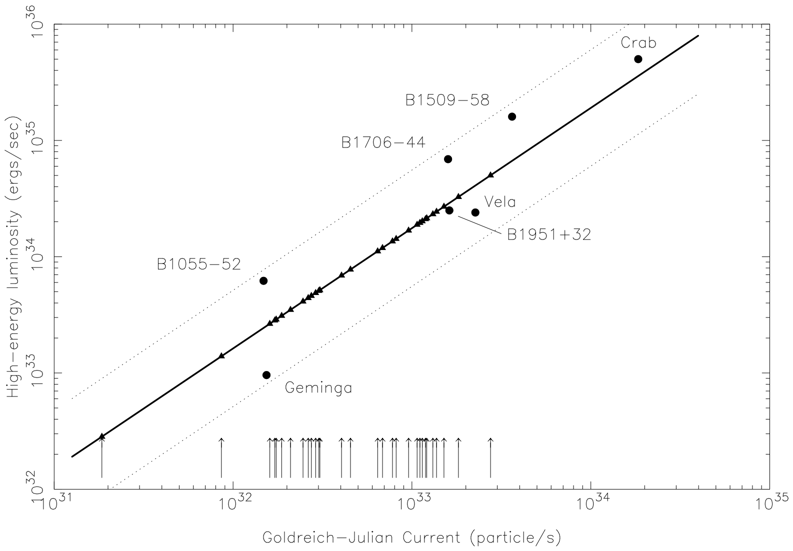

FIGURE 1. High energy luminosity of pulsars as a function of the so-called Goldreich-Julian current parameter (thick line)(e.g., Thompson et al (1999) [30]). Dots correspond to known γ-ray pulsars. The dotted lines represent a region containing all the known γ-ray pulsars. For each of the new 30 young radio pulsars, the value of the Goldreich-Julian current is indicated with a vertical arrow. Dark triangles show where on the line the new young pulsars would be located

and relatively long integration time of 35 min per pointing give a sensitivity limit for long-period pulsars of about 0.2 mJy.

Offline processing is performed on networked workstations at Jodrell Bank Observatory, ATNF, McGill and Bologna. Data are searched for periodic signals over a range of dispersion delays, using an analysis procedure similar to that employed in the Parkes Southern pulsar survey [25]. Candidates are re-observed for confirmation using the centre beam of the multibeam receiver. Confirmed candidates are then regularly observed at Parkes or Jodrell Bank for at least a year, in order to measure precise positions, pulse periods P and period derivatives $\dot{P}$, and orbital parameters if binary motion is present.

SURVEY STATUS AND RESULTS

At the time of writing, the survey is about 90% complete, and has resulted in the discovery of more than 600 new pulsars. Among them are a number of interesting objects including: a double-neutron-star system, PSR J1811-1736 [23]; two young pulsars, PSRs J1119-6127 and J1814-1744, which have the highest dipole magnetic field strengths among radio pulsars [27]; a young binary pulsar in an eccentric 5-hour orbit, PSR J1141-6545, for which the measurement of the relativistic precession of periastron was already obtained [28]; a high-mass binary system, PSR J1740-3052, for which the minimum mass for the companion is 11 $M_\odot$ [29].

Timing observations have also shown that at least 30 of the new discoveries are young pulsars, with characteristic age $\tau_c = P/2\dot{P} < 100{,}000$ years. These pulsars are prime

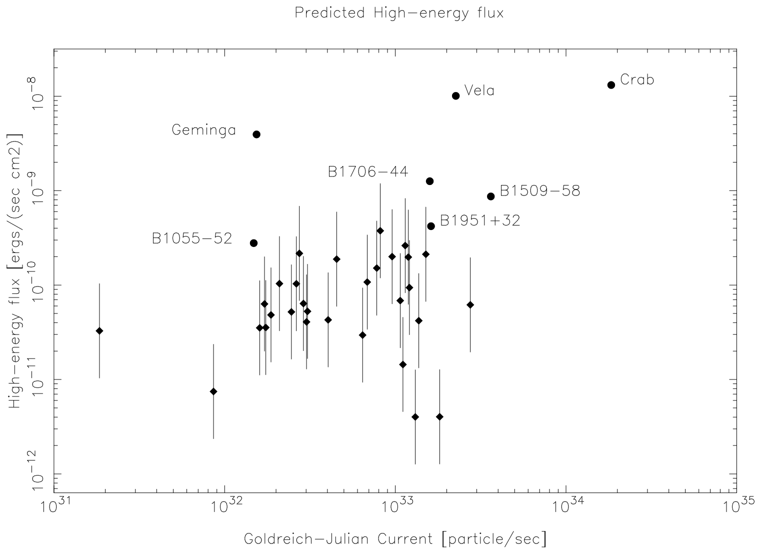

FIGURE 2. High energy flux of pulsars as a function of the Goldreich-Julian current. Full dots indicated known γ-ray pulsars. Predicted values for the new young radio pulsars are indicated. Their uncertainty is derived from the dotted line region of Fig. 1. The distance adopted for each pulsar is the nominal value derived from the observed dispersion measure

candidates for pulsed γ-ray emission searches. There is a strong correlation of high-energy luminosity and the spin-down luminosity $\dot{E}$. In particular, Thompson et al (1999) [30] have shown that the high-energy luminosity, integrated over photon energies above 1 eV, is proportional to the Goldreich-Julian current $\dot{N} \simeq 1.7 \times 10^{38} \dot{P}^{1/2} P^{-3/2}$. Fig. 1 shows the predicted high-energy luminosity for the 30 new young pulsars as a function of the Goldreich-Julian current parameter, computed from the observed spin parameters.

Adopting for each pulsar the distance derived from the observed dispersion measure, we can convert the predicted high-energy luminosity into a predicted flux. Fig. 2 shows the observed and predicted high-energy flux from pulsars. Some of the new young radio pulsars have predicted flux values similar to those already observed from other known radio pulsars. Indeed, some of the new pulsars are coincident with EGRET sources [31]. Future γ-ray experiments like AGILE and GLAST should search these new young radio pulsars for pulsed γ-ray emission.

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