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DISCOVERY OF PSR J0108-1431: THE CLOSEST KNOWN NEUTRON STAR?

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# of PSR J0108−1431: the closest known neutron star?

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Abstract

rt the discovery of the pulsar with the lowest known dispersion measure, −1431, during a survey of the southern sky for pulsars using the Parkes cope. The dispersion measure, 1.83 cm^{-3}pc, suggests that this pulsar is pc of the Sun, making it probably the closest known neutron star. Its osity is lower than that of any other known pulsar by more than an order de and it probably represents a very large population of similar objects in . X-ray observations of this pulsar will help distinguish between different the evolution of pulsar magnetic fields.

dings: pulsars: individual (PSR J0108−1431)

JCTION

bout 600 known radio pulsars in our Galaxy. Most of these are at relatively itudes and at distances of a few kpc, as indicated by the amount of dispersion

of the pulses in the ionized component of the interstellar medium (Taylor, Lyne 1993). About two years ago, we began a search of the entire southern sky and other low-luminosity pulsars using the Parkes 64-m radio telescope at a f MHz. This survey has already resulted in the discovery of eight millisecond half the total known in the Galactic disk (Johnston *et al.* 1993; Bailes *et al* *et al.* 1994). We have also discovered more than 70 pulsars with "ordinary" of these are relatively nearby and of low radio luminosity. Here we report t PSR J0108−1431, the most extreme example of this class of pulsar so far de

2 OBSERVATIONS AND ANALYSIS

The survey system has been briefly described in the papers reporting pulsar discoveries (Johnston *et al.* 1993; Bailes *et al.* 1994). The limitin long-period pulsars away from the Galactic plane is about 3 mJy. Survey obs direction of PSR J0108−1431 were made in 1992 April. Routine analysis show of a good pulsar candidate with very low dispersion measure. Because it is r has a long scintillation time scale, it was rather difficult to confirm, but 1993 April finally verified that it is a pulsar and that the dispersion measu pulsar position was initially determined using observations at a grid of posit nominal position, and subsequently by scans in right ascension and declinat

Since the confirmation, we have obtained a total of 40 pulse arrival frequencies of 436 and 1520 MHz. Analysis of these times using the pr (Taylor & Weisberg 1989) gives the parameters presented in Table 1. Inde times obtained at Jodrell Bank confirmed the timing solution. The pulsar 0.808 s, slightly longer than the median pulsar period, and a pulse profil component which is approximately Gaussian in shape and has a width at h 20ms or $\sim 2.5\%$, close to that expected using the Lyne and Manchester (19 between pulse width and period. No interpulse is seen above a level of 1% o peak. The pulsar's most notable feature is the very low dispersion measur the lowest known for any pulsar.

The pulsar has a small observed period derivative $\dot{P}$. This derivative may increased by the Shklovskii effect which produces a contribution of $\dot{P}_s = v^2 I$

ɔ is the transverse velocity and c is the velocity of light (Shklovskii 1970). alue for v of 100 km s^{-1}, $\dot{P}_s \approx 1.0 \times 10^{-17}$, or about 10% of the measured stic age $\tau = P/(2\dot{P}) = 160$ Myr may therefore underestimate the intrinsic by about 10%.

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nd Cordes (1993) model for the Galactic electron density distribution pre- ~ 90 pc for PSR J0108−1431, corresponding to a local mean electron)22 cm^{-3}. However, parallax measurements of three pulsars close to the +08 and B0823+26 (Gwinn *et al.* 1986) and B1451−68 (Bailes *et al.* 1990), higher value for $\langle n_e \rangle$ of 0.032 cm^{-3}, and hence a smaller estimated distance boundary of the so-called "Local Bubble" (Paresce 1984) is close to the ion, and so most of the path to the pulsar is not within the bubble, again he distance might be less than the Taylor and Cordes value. We adopt sequent discussion. Previously, the smallest estimated distance for a radio : (for PSR B0950+08). Geminga may be closer, but recent work suggests y further than 250 pc away (Halpern & Ruderman 1993). A parallax mea- nterferometric techniques would give a much more precise distance to PSR determine the value of $\langle n_e \rangle$ along the line of sight.

stance to this pulsar and the small measured flux density, $S_{436} \approx 8$ mJy, radio "luminosity" at 436 MHz, $L_{436} = S_{436}d^2 \approx 0.06$ mJy kpc^2. As Figure weaker than that of any other known pulsar by a factor of 20, and weaker observed pulsar with the same characteristic age by a factor of 10^3. We he possibility that the measured flux density has been affected by long-term ellar scintillation or that the observed pulse originates from well off the ssion beam. The detection of this pulsar emphasizes the very large scatter ties among pulsars with similar characteristic ages, and thus the difficulty raints on the decay of radio luminosity. In particular, attempts to model a function of P and $\dot{P}$ (e.g. Stollman 1987; Emmering & Chevalier 1989) ignificantly affected.

(1985) suggested that few active radio pulsars exist with luminosities lower

than 0.3 mJy kpc^2. Although statistical arguments based upon one object tentative, this pulsar indicates that there could be a very large population of pulsars in the Galaxy. Monte Carlo calculations assuming a beaming fact Lorimer *et al.* 1993) show that there could be at least 500,000 active pulsars with luminosity similar to PSR J0108−1431.

If pulsar magnetic fields do not decay (Bhattacharya *et al.* 1992), the cha of 160 Myr is probably a reasonable estimate of the actual age. If we take represent half the mean lifetime of this class of pulsars, their required birthr about one per 640 yr. Lorimer *et al.* (1993) derived a Galactic birthrate for pul luminosities > 10 mJy kpc^2 of one per 250 years, and so low-luminosity pulsar J0108−1431 need not dominate the Galactic birthrate. However, the questi or not pulsar magnetic fields decay is controversial, with many studies (Lyne Salter 1982; Lyne, Manchester, & Taylor 1985; Narayan & Ostriker 1990) indic time scales of 5 to 15 Myr. If we assume an exponentially decaying magnetic fiel time scale, τ_d, of 5 Myr, the true age of PSR J0108−1431 is only $t \approx (\tau_d/2)$ ln 10 Myr. This would suggest a birthrate of about one per 40 yr, six times t Lorimer *et al.* and requires either that most pulsars are born with luminositi mJy kpc^2, or that PSR J0108−1431 is a statistical anomaly. Since this pulsar the spin-up line, it is also possible that its evolutionary history has included a binary companion which has since been lost, probably as a result of super of the companion. In this case, the low magnetic field may be a consequence evolution (Romani 1990; Srinivasan *et al.* 1990) and the true age would agai the characteristic age.

If the true age of PSR J0108−1431 is only 10 Myr, thermal X-ray emi neutron star surface should be detectable. Cooling models (Umeda *et al.* 1 surface temperature near 5.0 $\times 10^5$ K, depending on the assumed equation of st of internal frictional heating. Because of the very small spin-down luminosity s^{-1}, heating of the neutron-star surface by magnetospheric processes (Cheng 1980) is unlikely to be significant. The typical sensitivity limit of the ROSAT (Becker, Trümper, & Ögelman 1993) in the soft X-ray band (0.1 – 2.4 kev) is erg cm^{-2} s^{-1}. Emission from a 5 $\times 10^5$ K neutron star at a distance of the pul

T band and the anticipated flux would be almost two orders of magnitude ROSAT limit. To date, thermal X-ray emission has been detected from n & Holt 1992), three young radio pulsars, PSRs B0656+14 (Córdova *et al.* (Ögelman & Zimmerman 1989) and B1055−52 (Brinkmann & Ögelman J0437−4715 (Becker & Trümper 1993), an old millisecond and probably Johnston *et al.* 1993). Detection of X-ray emission from PSR J0108−1431, e characteristic age, but a low spin-down luminosity, has the potential of tween the various cooling and heating models. On the other hand, failure to ssion would indicate that the pulsar is much older than 10 Myr and, hence, ic field decay time is much greater than 5 Myr. While this is certainly ield millisecond and recycled pulsars (Kulkarni 1986; Bell, Bailes, & Bessell Baade, & Della Valle 1993; Bailyn 1993), it has yet to be proven conclusively ron stars.

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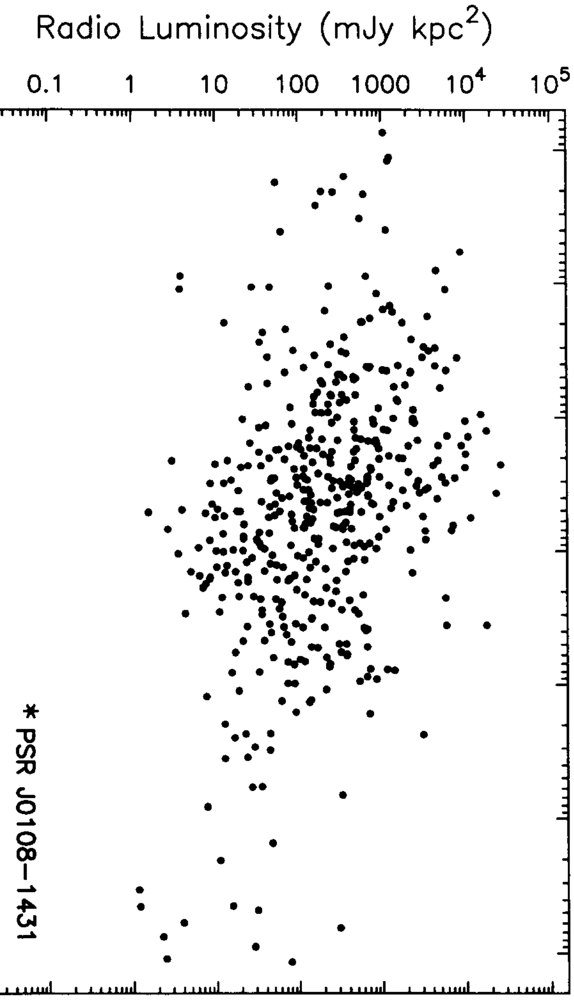
Table 1: Observed and derived parameters of PSR J0108−1431

R.A. (J2000)	$01^h\ 08^m\ 08^s.20 \pm 0^s.10$
Decl. (J2000)	$-14^\circ\ 31'\ 46'' \pm 1''$
Galactic longitude, l	$140^\circ.9$
Galactic latitude, b	$-76^\circ.8$
Period, P	0.80756460125(5) s
Epoch of period (MJD)	48967.0
Period derivative, $\dot{P}$	$8.2(1)\times10^{-17}$
Dispersion measure, DM	1.83(2) $cm^{-3}pc$
Pulse width at FWHM	20 ms
Mean flux density at 436 MHz, S_{436}	8 mJy
Mean flux density at 1520 MHz, S_{1520}	1.5 mJy
Spectral index	−1.3
Distance, d	85 pc
Radio luminosity, L_{436}	0.06 mJy kpc^2
Magnetic field strength, B	2.5×10^{11} G
Characteristic age, τ	1.6×10^{8} yr

Figure Caption.

Figure 1. Radio luminosity plotted against characteristic age for the known the isolated location of PSR J0108−1431. The difficulty of detecting pulsars w luminosity allows the possibility that they are extremely numerous (see text).


Radio Luminosity (mJy kpc^2)
0.1
1
10
100
1000
10^4
10^5
* PSR J0108−1431