Millisecond Pulsar Hunting
Matthew Bailes
Swinburne University of Technology/CAASTRO
HE only objects seen on a 200-in. plate near the positions of the components of the radio source 3C 273 reported by Hazard, Mackey and Shimmins in the preceding article are a star of about thirteenth magnitude and a faint wisp or jet. The jet has a width of 1″-2″ and extends away from the star in position angle 43°. It is not visible within 11″ from the star and ends abruptly at 20″ from the star. The position of the star, kindly furnished by Dr. T. A. Matthews, is R.A. 12h 26m 33.35s ± 0.04s, Decl. +2° 19′ 42.0″ ± 0.5″ (1950), or 1″ east of component B of the radio source. The end of the jet is 1″ east of component A. The close correlation between the radio structure and the star with the jet

Table 1. Wave-lengths and Identifications

<table>
<thead>
<tr>
<th>λ</th>
<th>λ/1.158</th>
<th>λ</th>
<th>Mg II</th>
<th>Hγ</th>
<th>Hδ</th>
<th>Hβ</th>
<th>[O III]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3230</td>
<td>2797</td>
<td>2798</td>
<td></td>
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<tr>
<td>4595</td>
<td>3968</td>
<td>3970</td>
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<tr>
<td>4753</td>
<td>4104</td>
<td>4102</td>
<td></td>
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<tr>
<td>5032</td>
<td>4545</td>
<td>4540</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>5200–5415</td>
<td>4490–4675</td>
<td>4861</td>
<td>Hβ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5682</td>
<td>4864</td>
<td>5002</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5792</td>
<td>5002</td>
<td>5007</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>6005–6190</td>
<td>5186–5345</td>
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<td></td>
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<tr>
<td>6400–6510</td>
<td>5527–5622</td>
<td></td>
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</tr>
</tbody>
</table>

Oke in a following article, and by the spectrum of another star-like object associated with the radio source 3C 48 discussed by Greenstein and Matthews in another communication.
A millisecond pulsar

D. C. Backer*, Shrinivas R. Kulkarni*, Carl Heiles*, M. M. Davis† & W. M. Goss‡

* Radio Astronomy Laboratory and Astronomy Department, University of California, Berkeley, California 94720, USA
† National Astronomy and Ionosphere Center, Arecibo, Puerto Rico
‡ Kapteyn Laboratorium, Groningen, The Netherlands

The radio properties of 4C21.53 have been an enigma for many years. First, the object displays interplanetary scintillations (IPS) at 81 MHz, indicating structure smaller than 1 arc sec, despite its low galactic latitude (−0.3°). IPS modulation is rare at low latitudes because of interstellar angular broadening. Second, the source has an extremely steep (∼ν−2) spectrum at decametric wavelengths. This combination of properties suggested that 4C21.53 was either an undetected pulsar or a member of some new class of objects. This puzzle may be resolved by the discovery and related observations of a fast pulsar, 1937+214, with a period of 1.558 ms in the constellation Vulpecula only a few degrees from the direction to the original pulsar, 1919+21. The existence of such a fast pulsar with no evidence either of a new formation event or of present energy losses raises new questions about the origin and evolution of pulsars.
Submillisecond optical pulsar in supernova 1987A

J. KRISTIAN†, C. R. PENNYPACKER‡, J. MIDDLEDRTCH†, M. A. HAMUY§, J. N. IMAMURA†, W. E. KUNKEL§, R. LUCINIO†, D. E. MORRIS†, R. A. MULLER†, S. PERLMAN†, Y. STEIMAN-CAMERON** & I. R. TUOHY††

†Mt Wilson and Las Campanas Observatories, Pasadena, California, USA
‡University of California, Lawrence Berkeley Laboratory, Berkeley, California 94720, USA
§Los Alamos National Laboratory, PO Box 1663, Los Alamos, New Mexico 87545, USA
**Cerro Tololo Inter-American Observatory, Casilla 603, La Serena 1353, Chile
††Institute of Theoretical Science, University of Oregon, Eugene, Oregon 97403, USA
**Mt Stromlo & Siding Spring Observatories, Australian National University, ACT 2606, Australia
§§University of Toronto, Toronto, Ontario, Canada M5S 1A1
**NASA Ames Research Center, Space Science Division, Moffett Field, California 94035, USA
††California Institute of Technology, Pasadena, California 91125, USA

WE have detected an optical pulsar with frequency $f = 1.968.629 \text{ Hz}$ at the location of supernova 1987A in the Large Magellanic Cloud. This pulsar is a submillisecond pulsar with a period of about 2.9 ms.
Pulsar puzzles for astronomers

R. N. MANCHESTER

The Australia Telescope National Facility, CSIRO, PO Box 276, Epping, New South Wales 2121, Australia.

References

A 5.75-millisecond pulsar in the globular cluster 47 Tucanae

R. N. Manchester*, A. G. Lyne†, N. D’Amico‡, S. Johnston†, L. Lim§ & D. A. Kniffen∥

* Australia Telescope National Facility, CSIRO, Epping, NSW, 2121, Australia
† University of Manchester, Jodrell Bank, Macclesfield SK11 9DL, UK
‡ Istituto di Fisica dell'Universita, via Archirafi 36, Palermo, Italy
§ School of Mathematics, Physics, Computing and Electronics, Macquarie University, North Ryde, NSW, 2113, Australia
∥ Goddard Space Flight Center, Greenbelt, Maryland, 20771, USA

Millisecond pulsars are generally believed to be old pulsars that have been spun up ('recycled') as a result of accretion of matter from a companion in a low-mass X-ray binary system. As there is a high incidence of such systems in globular clusters, these are good places to search for millisecond pulsars. So far, ten globular-cluster pulsars have been detected unambiguously. Using the Parkes radiotelescope in Australia, we have found a pulsar with a period of 5.75 ms and a dispersion measure of 25 cm⁻³ pc in the direction of 47 Tucanae. Despite its probable origin as a member of a binary system, timing measurements show that the pulsar is now single. The observed dispersion measure is consistent with the pulsar lying outside the galactic electron layer and within 47 Tucanae; but it is very different from the value of 67 cm⁻³ pc for the pulsars that were reported recently as being in this globular cluster, and we suggest that the latter pulsars probably do not in fact lie within 47 Tucanae.
A high-frequency survey of the southern Galactic plane for pulsars

Simon Johnston,1* A. G. Lyne,1 R. N. Manchester,2 D. A. Kniffen,3 N. D’Amico,4 J. Lim5 and M. Ashworth6†

1University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL
2Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia
3Goddard Space Flight Center, Greenbelt, Maryland 20771, USA
4Istituto di Fisica dell’Università di Palermo and Istituto di Radioastronomia del CNR, Via Irnerio 48, I-40126 Bologna, Italy
5School of Mathematics, Physics, Computing and Electronics, Macquarie University, North Ryde, NSW 2113, Australia
6Manchester Computer Centre, University of Manchester, Manchester

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SUMMARY
We report the results of a high-frequency survey designed to detect young, distant and short-period pulsars. The Parkes 64-m radio telescope was used at a central observing frequency of 1500 MHz to survey an area of 800 square degrees in the region $270^\circ \leq l \leq 20^\circ, |b| \leq 4^\circ$. To ensure that the system retained good sensitivity to periods of less than 10 ms, we used sampling intervals of 0.3 and 1.2 ms. The survey detected a total of 100 pulsars, 46 of which were previously unknown. The periods of the
Limits

![Graph showing limits on pulsar detection](image)

- Circles represent pulsars with a period of 1.6 ms.
- Squares represent pulsars with a period of 6.2 ms.

The graph plots the number of pulsars (upper limit) against the 1500 MHz luminosity (mJy kpc²).
Distribution
Parkes 70 cm Survey

- 256 channels x 2
- 1 bit sampling
- 300 us samples
- 32 MHz
- 430 MHz
- All sky < Dec = 0.0
Three MSPs!

DISCOVERY OF THREE BINARY MILLISECOND PULSARS

M. Bailes,1,2 P. A. Harrison,1 D. R. Lorimer,1 S. Johnston,2,3 A. G. Lyne,1 R. N. Manchester,2
N. D’Amico,4,5 L. Nicastro,5 T. M. Tauris,2,6 and C. Robinson1

Received 1993 September 27; accepted 1993 December 23

ABSTRACT

We report the discovery of three binary millisecond pulsars in circular orbits with low-mass companions from a continuing survey of the southern sky with the Parkes radio telescope. The three pulsars, PSR J0034−0534, PSR J1045−4509, and PSR J2145−0750 have pulse periods of 1.87, 7.47, and 16.05 ms and orbital periods of 1.6, 4.1, and 6.8 days, respectively. PSR J2145−0750 has a spin-down age of \( \gtrsim 12 \) Gyr, which raises interesting questions about its progenitor and initial pulse period. The properties of the growing class of radio pulsars with low-mass companions are discussed, and we suggest that their velocities, and a tendency for the short-period pulsars to have small orbital periods, are consistent with their formation from Type II supernova explosions.

Subject headings: pulsars: individual (PSR J0034−0534, PSR J1045−4509, PSR J2145−0750) — pulsars: formation
Discovery of a very bright, nearby binary millisecond pulsar

SIMON JOHNSTON*, D. R. LORIMER†, P. A. HARRISON†, M. BAILES†, A. G. LYNET†, J. F. BELL‡, V. M. KASPI§, R.

*Australia Telescope National Facility, CSIRO, PO Box 76, Epping, New South Wales 2121, Australia
†University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, UK
‡Mount Stromlo and Siding Spring Observatory, Private Bag, Woden, ACT 2606, Australia
§Physics Department, Princeton University, Princeton, New Jersey 08544, USA
¶Istituto di Fisica dell'Universita, via Archirafi 36, 90123 Palermo, Italy
||Istituto di Radioastronomia del CNR, via Irnerio 46, 40126 Bologna, Italy
‡Department of Geophysics, Peking University, Beijing 100871, China

Nature 361, 613 - 615 (18 February 1993); doi:10.1038/361613a0
Pulsar Profiles with Zero Smearing

PSR J0437-4715

Timing

5.75 ms
Detection of pulsed X-rays from the binary millisecond pulsar J0437 – 4715

WERNER BECKER & JOACHIM TRÜMPER

Max-Planck-Institut für extraterrestrische Physik, 85740 Garching bei München, Germany

THE X-ray properties of pulsars (highly magnetized rotating neutron stars) depend mainly on the age of the star. For millisecond pulsars, in particular, pulsed, appearing as sharp bursts with a power-law spectrum; these emissions are thought to arise from the acceleration of electrons. Most pulsars, on the other hand, exhibit broad X-ray pulses, a lower pulsed fraction and black-body spectra; this is ascribed to modulation of the X-rays reflecting temperature inhomogeneities induced by the strong magnetic fields. No thermal emission was observed in the absence of surface heating processes. Here we report the discovery of pulsed X-ray emission from a ~2 × 10^13 G field. The spectral properties of the pulsed emission suggest a thermal origin, requiring substantial heating of the neutron star surface by stream from the pulsar’s magnetosphere.
Optical detection of the companion of the millisecond pulsar J0437–4715

J. F. BELL†, M. BAILES† & M. S. BESSELL†

* Mount Stromlo and Siding Spring Observatory, Private Bag, Weston Creek, ACT 2611, Australia
† Australia Telescope National Facility, CSIRO, PO Box 76, Epping, New South Wales 2121, Australia

OPTICAL observations of the companion stars in binary pulsar systems\(^1\)\(^–\)\(^3\) offer a way to estimate pulsar ages, measurements of the radio pulses, and can therefore provide important constraints for models of pulsar evolution. The companion star of the nearby binary millisecond pulsar J0437–4715. The companion seems to be a very cool, direct support for the hypothesis\(^1\) that millisecond pulsars are long-lived objects, and that their magnetic fields...
Optical ID
Fruchter et al. (1995)
letters to nature

A test of general relativity from the three-dimensional orbital geometry of a binary pulsar

W. van Straten*, M. Bailes*, M. Britton*, S. R. Kulkarni†, S. B. Anderson†, R. N. Manchester‡ & J. Sarkissian‡

* Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Hawthorn, Victoria 3122, Australia
† Division of Physics, Mathematics, and Astronomy, California Institute of Technology, Mail Code 220-47, Pasadena, California 91125, USA
‡ Australia Telescope National Facility—CSIRO, PO Box 76, Epping, New South Wales 1710, Australia
PRECISION TIMING OF PSR J0437–4715: AN ACCURATE PULSAR DISTANCE, A HIGH PULSAR MASS, AND A LIMIT ON THE VARIATION OF NEWTON’S GRAVITATIONAL CONSTANT

J. P. W. Verbiest,1,2 M. Bailes,1 W. van Straten,1 G. B. Hobbs,2 R. T. Edwards,2 R. N. Manchester,2 N. D. R. Bhat,1 J. M. Sarkissian,2 B. A. Jacoby,3 and S. R. Kulkarni4

Received 2007 October 4; accepted 2008 January 16
Bell’s revelation

A NEW METHOD FOR OBTAINING BINARY PULSAR DISTANCES AND ITS IMPLICATIONS FOR TESTS OF GENERAL RELATIVITY

J. F. Bell

Mount Stromlo and Siding Spring Observatories, Institute of Advanced Studies, Australian National University,
Private Bag, Weston Creek, ACT 2611, Australia; bell@mso.anu.edu.au

AND

M. Bailes

Australia Telescope National Facility, CSIRO, P.O. Box 76, Epping, NSW 2121, Australia; mbailes@atnf.csiro.au

Received 1995 September 12; accepted 1995 October 12

ABSTRACT

We demonstrate how measuring orbital period derivatives can lead to more accurate distance estimates and transverse velocities for some nearby binary pulsars. In many cases this method will estimate distances more accurately than is possible by annual parallax, as the relative error decreases as $t^{-5/2}$. Unfortunately, distance uncertainties limit the degree to which nearby relativistic binary pulsars can be used for testing the general relativistic prediction of orbital period decay to a few percent. Nevertheless, the measured orbital period derivative of PSR B1534+12 agrees within the observational uncertainties with that predicted by general relativity if the proper-motion contribution is accounted for.

Subject headings: gravitation — pulsars: general — relativity
D=156.3(1.3) pc

$D_{PB}=156 (2) \text{ pc}$

$(dG/dt/G) < 10^{-12} \text{ yr}^{-1}$

Parallax works!
New tim  Restart  J0437–4715 (Wrms = 0.790 μs) post–fit
J0437-4715 (Wrms = 0.799 μs) pre-fit
Parkes Major MSP Surveys 1993-2003?

- 17 Millisecond Pulsars
  - Backbone of timing arrays
- Parkes MB Survey (Manchester et al.)
  - More! 10-20 mainly weak/higher DM
- Edwards & Bailes
  - 9 MSPs
- Jacoby & Bailes
  - 8 MSPs
- Burgay et al.
  - 3 MSPs
PSR J2051-0827

- Eclipsing Pulsar
- 2.4 hour orbit
- 0.02 Mo Companion
A two-solar-mass neutron star measured using Shapiro delay

P. B. Demorest, T. Pennucci, S. M. Ransom, M. S. E. Roberts & J. W. T. Hessels

Affiliations | Contributions | Corresponding author

Nature 467, 1081–1083 (28 October 2010) | doi:10.1038/nature09466
Received 07 July 2010 | Accepted 01 September 2010 | Published online 27 October 2010
PSR J1909-3744

40 μs wide!!
Shapiro Delay in PSR 1909-3744

![Graph showing Shapiro Delay in PSR 1909-3744]
Astrophysics:
MSP 1.44 Mo

\[a-b=5\mu\]
Berkeley-Parkes-Swinburne-Recorder

“BPSR”

5 TB/day
Data Explosion:

• Parkes 70cm Survey (1993+)
  – Several Years, 1 TB
• Parkes MB Survey (1997+)
  – Several years, 5 TB
• Swinburne + Marta Surveys (2000+)
  – Several years, 12 TB
• HTRU surveys (2009+)
  – Several years, 1000 TB
FFTing?

- 98,000 pointings
- 1197 trial DMs
- 200 acceleration trials
- Need to do 23 billion 8 Mpt FFTs!
  - 1990
    - 10 minutes/trial
    - 450,000 years on a Sparc 2!
  - G-star supercomputer (3 months)
The Legacy of the Scientific Method

- **1981:**
  - Zero Millisecond Pulsars

- **1984:**
  - 3 Millisecond Pulsars

- **2011:**
  - 200+ Millisecond Pulsars

- **Drama, Intrigue, Joy, Hostility**
  - General Relativity
  - Distances
  - Stellar Evolution
  - Gravity Waves
Hurricane Irene: Latest developments

A buoy that sits at the end of the Ocean City, Md. jetty is toppled over due to heavy surf caused by the arrival of Hurricane Irene on August 27, 2011.

Irene pounding Jersey Shore  Asbury Park Press
Irene hammers North Carolina but damage not too bad, officials say  CNN International

Highly Cited: Irene May Require Evacuations of Some New York City Areas, Bloomberg Says  Bloomberg
From New York: Forecasters: Irene makes landfall in New Jersey  Forbes
In Depth: Ferocious Hurricane Irene shuts down New York City  Reuters

See all 16,267 sources »

Survivor in Libya: Gadhafi Forces Killed Detainees

A giant portrait of Moamar Gadhafi is bullet-riddled on the wall of a building in the Bab al-Aziziya district in Tripoli, Libya, Saturday, Aug. 27, 2011.

Eight-year-olds take centrestage at Ramlila Maidan

PTI Eight-year-old Ikrah and Simran took centrestage at the Ramlila Maidan on Sunday when they gave a glass of tender coconut water to Anna Hazare for ending his fast on the Lokpal issue after 12 days.

Kim Kardashian Back From Honeymoon, Heading To VMAs

Kim Kardashian and her new hubby, basketballer Kris Humphries, are back Stateside. The pair made their way to Los Angeles after a mini-honeymoon abroad.

First Diamond Planet Ever Discovered Orbits Pulsar 4000 Light Years Away

According to the study led by Professor Matthew Bailes of Swinburne University of Technology in Australia, the planet is denser than anything discovered so far, and is entirely made of carbon.
Mauna Loa Data

Atmospheric CO₂ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
Diamond planets, climate change and the scientific method
Research vs Propaganda

• Hypothesis
• Observations
• Test
• Peer review

• Say what you want
• Selected observations
• No Peer Review
• Selected “experts”

“The Big Bang Never Happened!”
100 Authors Against Einstein (1931)

• Message:
  – Einstein was wrong

• You can find experts if you need them
Sales in Science

• Press Releases
• Graphic Imagery
• International Conferences in Exotic Locations
• Grant Proposals
• Empire Building
• Corporate Logos/Brand Recognition
• Understatement of Risk
• Claimed economic benefits
Dimishing respect for Science?

- Science vs Religion
- Science vs Politicians
- We need to be ethical and responsible
  - SKA/ASKAP/MWA/GMT