Pulsar

Background

Since the discovery of pulsars in the 1960's and their subsequent identification as rapidly rotating neutron stars (for which the 1974 Nobel Prize in Physics was awarded), pulsars have provided a unique insight into the nature of physics at high energies and in extreme conditions.

A neutron star is formed in a supernova explosion, which results when a massive star runs out of fuel at the end of its life. A neutron star is the remnant of such an explosion and is extremely dense, weighing as much as 3e33 grams (1.5 times as much as our own sun) but having only a 10 km radius (about the size of Manhattan). The combination of high mass and small size results in an extremely large gravitational field, estimated to be about 100 billion times that on Earth.

A newly-formed neutron star can be sent rapidly spinning in the supernova explosion, and such a star can have a magnetic field many orders of magnitude larger than those found on Earth. In some cases, the spinning highly magnetized neutron star generates enough electric potential to accelerate charges from the surface of the star, resulting in a beam of non-thermal radio emission which rotates with the star. An observer sees this rotating beam as a series of radio pulses as the beam sweeps across the line of sight, similar to the rotating beacon of a lighthouse. Such an object is called a pulsar.

The Crab pulsar, located in the Crab supernova remnant which was formed in the supernova explosion seen in 1054 A.D. by Chinese astronomers, is the youngest known pulsar and is considered to be the prototypical young pulsar with a spin period of 33 ms. More typical pulsars have much longer spin periods (about 1 sec), though there is a class of old, recycled pulsars which have obtained very fast rotation rates through the transfer of angular momentum from a stellar companion throughout its lifetime. This class of pulsars usually has spin periods of a few milliseconds, thereby lending the name millisecond pulsars to this class of objects. The fastest millisecond pulsar known has a spin period of 1.6 milliseconds, corresponding to 642 rotations per second.

Most pulsars which exhibit detectable radio emission are not detectable in other radiation wavebands, since the radiation that is produced falls off in brightness steeply with increasing radiation frequency. However, in some cases (such as the Crab pulsar, mentioned above), the pulsar can be detected in multiple wavelengths. In fact, a relatively new class of pulsars has been found, called Anomalous X-ray Pulsars (or AXPs for short), which shows only X-ray emission and no detectable radio emission. These AXPs are characterized by long spin periods and very large magnetic fields.

A tutorial on radio pulsars outlining more basic background information on the subject is available on the World Wide Web at http://www.atnf.csiro.au/ pulsar/psr/Tutorial/tut/tut.html.

Physics in Extreme Conditions

As a pulsar spins, it loses energy through electromagnetic radiation and a plasma wind. Thus, although the spin period of the pulsar is very steady, it does spin down over a long period of time as it loses energy. By invoking a simple dipolar model of the magnetic field and by making some other assumptions, an observer can convert a measured pulse period and period derivative for a pulsar into physical parameters, such as age of the pulsar, surface magnetic field strength, and energy loss rate. For typical pulsars, a value of a trillion Gauss is not uncommon for the surface magnetic field strength. More indirect means can be used to probe the interior structure of neutron stars, which are thought to have densities in excess of 100 trillion grams per cubic centimeter.

These kinds of magnitudes indicate the value of studying such systems: nothing approaching these conditions can be produced in terrestrial physics laboratories, and it is only through studying these kinds of systems that some theoretical models in physics can be tested. A prime example of this was the awarding of the 1993 Nobel Prize in Physics for the confirmation of general relativity as the correct gravitational theory through the use of radio pulse measurements of a binary pulsar system.

The Parkes Multibeam Pulsar Survey

Over the years a number of searches for new pulsars have been undertaken at a variety of observatories around the world using different instruments and techniques. As of 1997, thirty years after the discovery of the first pulsar, about 750 pulsars were known and had been catalogued. In mid-1997, an international collaboration involving research groups in the UK, Australia, USA, and Italy undertook a new high-frequency (1400 MHz) survey of the southern Galactic plane using a new instrument mounted on the 64-meter radio telescope in Parkes, Australia (Fig. 1). This survey was designed to search the range -100 to $+50$ degrees in Galactic longitude within 5 degrees of the Galactic plane.

The new instrument which has motivated this survey is a "multibeam" receiver and is capable of observing 13 distinct parts of the sky at once, thereby increasing surveying capacity by a factor of 13. This is equivalent to having 13 separate telescopes the size of the Parkes telescope for use in the pulsar search effort. This new survey (called the Parkes Multibeam Pulsar Survey, or PM Survey for short) is about 7 times more sensitive than previous surveys conducted at this radio frequency.

The high frequency of the PM Survey also has an important advantage over previous searches at more traditional lower radio frequencies (400 MHz), where pulsars are typically much brighter. In the Galactic plane, radio wave propagation effects such as dispersive pulse delays and multipath radio scattering of pulses severely limit sensitivity to pulsed emission at low frequencies. These effects get worse for pulsars which are distant since there is a great deal of interstellar dispersive and scattering plasma between the observer and the pulsar. The effect of the plasma is a frequency-dependent pulse delay which depends on the integrated electron density along the line of sight, which is called the dispersion measure. Thus, the PM Survey is the first large-scale pulsar survey to be sensitive to distant pulsars in the Galactic plane, where there are large dispersion measures (Fig. 2).

With only 65% of the survey completed to date, the PM Survey has already discovered over 500 new pulsars, making it by far the most successful pulsar survey ever conducted anywhere in the world (Fig. 3). The PM Survey is expected to double the known population of radio pulsars when it is completed in the near future.

The information from the survey is made available soon after a pulsar is found and its spin parameters are determined. This information, along with the details and current status of the PM Survey, is available on the World Wide Web at http://www.atnf.csiro.au/research/pulsar/psr/pmsurv/pmwww.

Future Developments

The plethora of results coming from the PM Survey not only provides a significant source of information for statistical studies of the pulsar population, but there are also a number of interesting individual pulsar systems which have been discovered, including several unusual and interesting binary systems, a large number of young pulsars, and two pulsars which which have magnetic field strengths larger than any previously known radio pulsar. These kinds of pulsar systems are interesting to study in their own right.

For instance, one of the pulsars with a record-breaking magnetic field also has a very long spin period (4 seconds), which suggests that it might somehow be related to the population of AXPs mentioned above, which have similar spin properties to this pulsar but emit only X-rays and no detectable radio emission. The fact that radio emission has been detected from this pulsar has already been used to rule out a recently proposed model of the pulsar emission mechanism in which it was predicted that radio emission should be suppressed in such a high magnetic field pulsar.

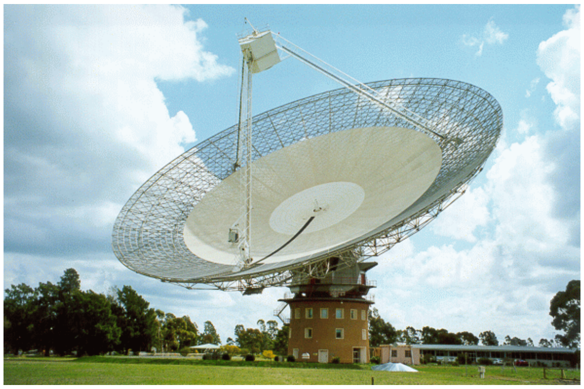

Figure 1: *The 64-meter radio telescope in Parkes, Australia. The Parkes Multibeam Pulsar Survey is being conducted with this telescope using the multi-beam receiver, located in the focus cabin of the telescope.*

Continued follow up studies of all of these new discoveries are underway, and investigation into areas such as the pulsar spin properties of the sample, their spatial distribution in the Galaxy, their polarized emission properties, and the interstellar environments in which these pulsars lie (to name just a few) promises to provide an array of exciting new scientific results in the near future as the PM Survey progresses.

Fronefield Crawford III
Massachusetts Institute of Technology
Room 37-624, Cambridge, MA 02139
email: crawford@space.mit.edu
phone: 617.253.7457
fax: 617.253.0861

Bibliography

F. Camilo, A. G. Lyne, R. N. Manchester, J. F. Bell, V. M. Kaspi, N. D'Amico, N. P. F. McKay, F. Crawford, I. H. Stairs, and D. J. Morris, The Parkes Multibeam Pulsar Survey, Proceedings of IAU Colloquium 177: Pulsar Astronomy - 2000 and Beyond, 2000 (http://xxx.lanl.gov/abs/astro-ph/9911185)

R. N. Manchester and J. H. Taylor, Pulsars, San Francisco: W. H. Freeman, 1977.

A. G. Lyne and F. Graham-Smith, Pulsar Astronomy, New York : Cambridge University Press, 1998

A. G. Lyne, F. Camilo, R. N. Manchester, J. F. Bell, V. M. Kaspi, N. D'Amico, N. P. F. McKay, F. Crawford, D. J. Morris, D. C. Sheppard, and I. H. Stairs, The Parkes Multibeam Pulsar Survey: PSR J1811−1736 — A Pulsar in a Highly Eccentric Binary System, to appear in Monthly Notices of the Royal Astronomical Society, 2000 (http://xxx.lanl.gov/abs/astro-ph/9911313)

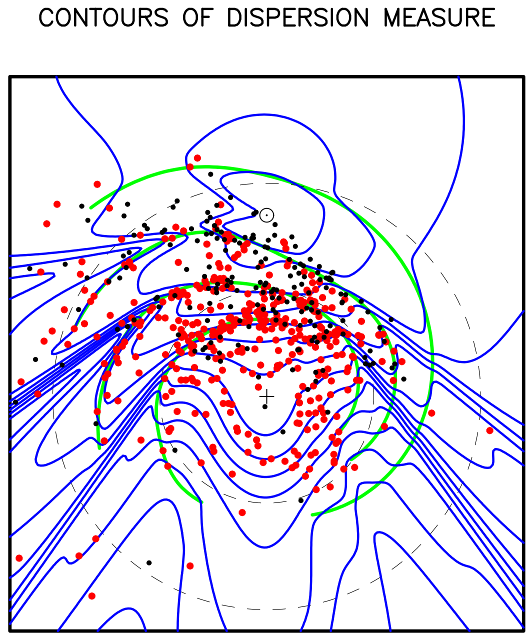

Figure 2: *Projection onto the Galactic plane of the distribution of newly discovered pulsars from the Parkes Multibeam Pulsar Survey (red) and previously known pulsars redetected in the survey (black). Blue lines indicate contours of constant dispersion measure, the integrated plasma density along the line of sight. Green lines show the location of spiral arms in the Galaxy. Earth's location is the dotted circle and the Galactic center is the cross.*

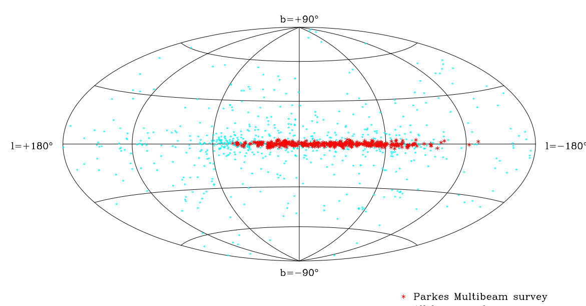

Figure 3: *The distribution in Galactic coordinates of new pulsars from the Parkes Multibeam Pulsar Survey (red) and all previously known pulsars (blue).*