RADIO ASTRONOMY

Journal of the Society of Amateur Radio Astronomers

(SARA)

Special Winter Issue: January February/March 2007

Journal Contents

Published by the Society of Amateur Radio Astronomers
http://radio-astronomy.org

Society of Amateur Radio Astronomers – A membership supported, non profit [501 (c) (3)]
Educational Radio Astronomy Organization

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Because the Society of Amateur Radio Astronomers is a small, all-volunteer organization with no office or paid staff, the best way to reach our various Officers and Committee Chairs is through the email aliases below.

Note: To assist our email filters, please include 'SARA' in the subject line of any emails sent to SARA volunteers. Thank you (SARA Vice President).

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26th Anniversary
SARA 2007 Conference Keynote Speaker:

Dr. Andrew Clegg, W4JE

Dr. Clegg received his M.S. and Ph.D. degrees in radio astronomy and electrical engineering from Cornell University, and his B.A. degree in physics and astronomy from the University of Virginia.

He is Program Director for Electromagnetic Spectrum Management at NSF, where he spends most of his time trying to protect the frequency allocations used by the radio astronomy service from growing radio interference.

Dr. Clegg's keynote presentation is titled *Present and Future Radio Spectrum Trends: their impact on radio astronomy.*

He says, "I spend a lot of my time doing spectrum management on behalf of NSF's radio observatories. Many of the same topics that impact the big observatories (such as Broadband over Power Line (BPL), ultra-wideband emitters, unlicensed devices, satellites, the DTV transition) will also impact amateur radio astronomers."

(Excerpt from the SARA website, where more Conference details can be found: [http://radio-astronomy.org/])

The President's Page

The SARA Conference in 2007 will be at NRAO in Green Bank, WV from Sunday, July 1 through Tuesday, July 3, with July 4 being a travel day. If you plan to give a presentation or display a poster, please notify the vice president as soon as possible. More details appear on our http://radio-astronomy.org website. Also note that the 4th annual Green Bank Star Quest, a great dark-skies star party, will be at the NRAO site for the remainder of the week, July 4-7 [http://www.greenbankstarquest.org/]. This opens possibilities for a family vacation during the holiday week.

One new problem this summer is renovations at the Hermitage. It is likely to be closed during July. This leaves the Boyer motel, camping at Boyer campground, various Bed & Breakfast accommodations, and a new possibility of bunkhouse lodging at Green Bank. The bunkhouse is somewhat like a military barracks and more oriented for the kids and scouts NRAO often hosts. So those accommodations may not be for everyone. We will likely get a few dorm rooms with first priority given to handicapped, followed by speakers, conference organizers, officers, and then general membership. This usually means there are not enough rooms to count on and most should make their own reservations at the Boyer etc. Tom Crowley handles room assignments and conference registration.

As an aside, please remember to support SARA by purchasing SARA bumper stickers and Journal archive CDs containing all but the most recent year of Journal pdfs. Please contact Tom Crowley.

Charles Osborne, K4CSO.

From the Editor's Desk

The first issue, Nov/Dec 2006, under my editorship has been well received and I encourage more feedback. I want to thank all my contributors and reviewers. However, a few errors have slipped through and I take full responsibility for those mistakes. With my apologies, please note the corrections:

page 3, New Member David Westman (not Westfield)
page 4, the url to access the survey should be hyphenated (radio-astronomy)
page 21, Beaver, PA (not Beaverton)

In the previous issue, I mentioned the possibility that "the journal may go through some evolutionary iterations until equilibrium can be reached." One such change has occurred. This issue looks like a quarterly one, Winter 2007, which especially features Pulsar radio Astronomy because of the 40^{th} anniversary of their discovery by Jocelyn Bell.

I thank those who have been diligent in making contributions to this journal and encourage others to do so. Your work will be forthcoming in subsequent issues. Regular features will appear in a more regular format in the next issue. For entertainment and education, you can look forward to a radio astronomy crossword puzzle.

To better serve you, ***I also request each of you to fill out the interactive Questionnaire*** concerning your areas of interest. This is important so we can better understand what projects and activities SARA may engage in, including special interest groups and feature articles. Go to [http://radio-astronomy.org/admin/survey.htm] and take a few minutes to fill the electronic form.

Some exciting news: As some of you know, I have had my candidacy for Ph.D. in electrical engineering (University of Tennessee Knoxville) for quite some time, but due to untimely events, my clock timed-out. Serious efforts are currently being made to reinstate my status. The first incredibly difficult hurdle has been overcome- the sanction of the Graduate School and the support of the Department. What remains is to reform my doctoral committee, which remains a formidable task because of retired or deceased faculty. It is still likely that my research on space charge theory in dielectric liquids remains intact, but I'll have to verify that with another extensive literature search. In principle, all that remains is to rewrite the dissertation and defend it. Please keep me in your thoughts and prayers as I move towards completing this degree.

For an interesting blend of astronomy with other forms of outreach, please visit my website, Adventures in Astronomy [http://home.earthlink.net/~jcmannone/].

Submission Guidelines

Radio Astronomy is normally published bimonthly. Electronically, it will be release in the middle of that period near at the end of all the odd months: Jan, Mar, May, Jul, Sep, and Nov (there is some delay for print copies of the journal). Normally, the deadline for all submittals is on the 15th of that month. Very short pieces might make it in later.

At this time, I am only accepting electronic submissions, but special arrangements can be made for unwieldy files. Be sure you put SARA in the subject line together with any other key word so that I can quickly distinguish a legitimate email in case address is harvested by spammers: editor@radio-astronomy.org

Generally there is no minimum length requirement. Informal email blurbs to polished papers are accepted. Acceptance will be based predominantly on quality of contents. The length of a feature article is nominally 5 pages, but could be shorter; however, it should not exceed 10 pages, including figures. For longer works, a series might be considered.

Figures and photographs should be sent separately in case I need to resize them. Please be mindful of their file size. Between my ISP limitations and my unavoidably slow dial-up connections, combined files in excess of a couple of megabytes should be avoided. The size of the electronic issue of *Radio Astronomy* is also throttled to 1 or 2 megabytes because of similar concerns. Before you send larger files, please consult with me first. Since I encourage legible back-of-the-envelope sketches, circuits, etc. (much radio astronomy was done this way in the Drake Lounge), be aware that scanned images are gluttonous and will probably require reduction in file size before electronic transmission.

A call for letters to the editor, newsworthy items in amateur and professional radio astronomy, radio astronomy education/outreach activities, text book/website reviews, software/hardware product reviews, significant calendar dates for events or radio astronomy anniversaries, puzzle submissions (including word challenges, riddles, anecdotes, or expository on "bad astronomy"), profiles on amateur or professional astronomers, radio astronomy in the arts (including literary genres), and feature articles with a historical, scientific, or technological flavor, which can be at various levels from basic to advanced, cerebral to hands-on, but the articles should be clearly explained or referenced to tutorial sites so that the novice can appreciate your contribution.

Thank you in advance for your contributions and adherence to these guidelines.

John C. Mannone, Editor

Amateur Radio Astronomy Outreach: A Cameo of the Tamke-Allan Observatory & its New Radio Station N4TAO

The Tamke-Allan Observatory (TAO), located in east Tennessee just west of Knoxville and approaching the Cumberland Plateau [http://roanestate.edu/obs] has been very proactive in astronomy outreach. In keeping with novel and aggressive community efforts, TAO is helping to bridge the gap between amateur astronomers and amateur radio hobbyists.

In their most recent move, the observatory director, Dr. David Fields (N4HBO), and some of his students, especially Jay Galyon (KI4SHQ), a newly licensed ham, have established an Astronomy net on 147.015 MHz. (positive offset)— a no tone server. The Roane County Amateur Radio Club will generously provide the observatory station (N4TAO) with the use of their repeater. The primary purpose will be to make announcements of astronomy events. Amateur radio operators are encouraged to ask astronomy related questions or discuss astronomy topics of interest. Of course, optical astronomy is within the scope of discussion, but there will likely be a natural emphasis on radio astronomy.

Jay or David will be calling for logins on the new Tamke-Allan Observatory Astronomy Net every Thursday beginning January.18 at 2130-2200 eastern time. Because of the March 3, 2007 total lunar eclipse, they also made a special transmission, as well as the publicizing it in the QST [http://www.arrl.org/contests/spev.html] and with QRZ in their Special Event forum. Dual bands are used (14.240 and 7.240 meters). Participation initially was slow, but is looking encouraging.

TAO will host the Barnard Astronomical Society (BAS) who will be coming up on May 5 for a radio astronomy and ham radio program. BAS has been expressing much interest in radio astronomy so David and I were featured speakers on consecutive months (February and March). BAS is two hours south in Chattanooga.

TAO also has a very active radio astronomy program: Solar flare and Jovian decametric emission monitoring at 20.1 MHz with a RadioJove system, microwave demonstrations with a modified digital satellite TV dish, Milky Way surveys at 21 cm using a specially built *SpectraCyber* radio spectrometer, forward meteor scatter of FM radio broadcasts, remote controlled radio astronomy dish projects, and much more.

Special Feature: 40th Anniversary on Discovery of Pulsars:

by *John C. Mannone*

I. Introduction

This commemorative feature is a collage of scientific and historical information, human interest stories, articles, references, anecdotes and casual conversation that celebrate the monumental discovery of pulsars by graduate student, Jocelyn Bell under her advisor, Anthony Hewish, in Cambridge, MA on December 1967, but officially announced 39 years ago on February 1968. This profound breakthrough was enabled with radio astronomy. The significant parallel work of other Cambridge scientists, as well as many other historical figures are woven into this feature. it is noteworthy that the first Nobel Prize in Physics awarded in nontraditional *astrophysics* discipline was in radio astronomy (aperture synthesis interferometry and pulsar detection). Significant professional contributions are highlighted from select observatories: Arecibo, NRAO, and Jodrell Bank. Through these, we learn a little more about pulsar physics, but the discussions are kept light. Finally, a discussion of pulsar detection among amateurs should serve as an encouragement to get involved in the exciting world of rotating neutron stars.

II. Historical and Scientific Background

The following has been largely adapted from several sources cited in the References section of the cited article at the end of this section as well as other references at the end of this feature.

The origin of the concept of neutron stars can be traced to two brief, incredibly insightful publications, one from Landau and the other from Zwicky and Baade.

Work by Lev Landau (Phys. Z. Sowjetunion, 1, 285, 1932) predates the discovery of neutrons by Chadwick in 1932 —student of Rutherford at the notable Cavendish Laboratories. Nonetheless, Landau arrived at the notion of a collapsed star having nuclear density, a “nucleus star.”

According to legend, when Niels Bohr had heard of the discovery of the neutron, he threw a great party at his home in Copenhagen. Among his guests was a young Russian named Lev Landau. He is said to have quietly remarked, "stars could be made with this new particle.”

(Landau also demonstrated independently of Chandrasekhar of an upper mass limit for dense stellar objects of about 1.5 solar masses.)

Perhaps even more remarkable is the abstract of a talk presented at the December 1933 meeting of the American Physical Society published by Walter Baade and Fritz Zwicky at the California Institute of Technology in 1934 (Phys. Rev. 45, 138). It followed the discovery of the neutron by just over a year. Their report, which was about the same length as the present abstract: (1)

invented the concept and word supernova; (2) suggested that cosmic rays are produced by supernovae; and (3) in the authors own words, proposed "with all reserve ... the view that supernovae represent the transitions from ordinary stars to *neutron stars* [italics inserted], which in their final stages consist of extremely closely packed neutrons." Some believe Zwicky's insight for a neutron star was precipitated by Landau's remark.

The abstract by Baade and Zwicky probably contains the highest density of new, important and correct ideas in high-energy astrophysics ever published in a single paper.

They did not escape derision (especially Zwicky), but were vindicated in 1967 by Jocelyn Bell's discovery of rotating neutron stars. We get a sense of Zwicky's reprieve from an interview with Hans Bethe. Hans Bethe won the Nobel Prize in Physics in 1967 for his work on nucleosynthesis— production of elements by nuclear reactions in stars.

Below is a modified portion of the transcript where Goldstein asks Bethe about Zwicky:

BETHE: Zwicky and I met a couple of times on visits here. He was quite a character. He really did superb work on the supernova observations. He was not the only one. Walter Baade was involved even more. But Zwicky predicted, very early on, many things that we learned twenty years later—theoretical matters, too. He said, "Well, the remnant of a supernova will be a neutron star." Nobody else would have dared to say that at the time.

GOODSTEIN: That was in the thirties?

BETHE: Yes. There was a theory, which was published by Oppenheimer and [G.M.] Volkoff on the structure of neutron stars ["On Massive Neutron Cores," Phys. Rev. 55, Feb. 15, 1939]. But nobody but Zwicky would believe it. And he said, "Well, that's what it will be. And it will have a radius of ten kilometers." Which is right.

GOODSTEIN: Did you believe it at the time?

BETHE: I thought it was pure fantasy. How could such a thing be? So where supernovas came really into my knowledge was only with the work of Hoyle, Fowler, and the Burbidges, when they said that this is the way all the elements are formed. But Zwicky had predicted it all before.

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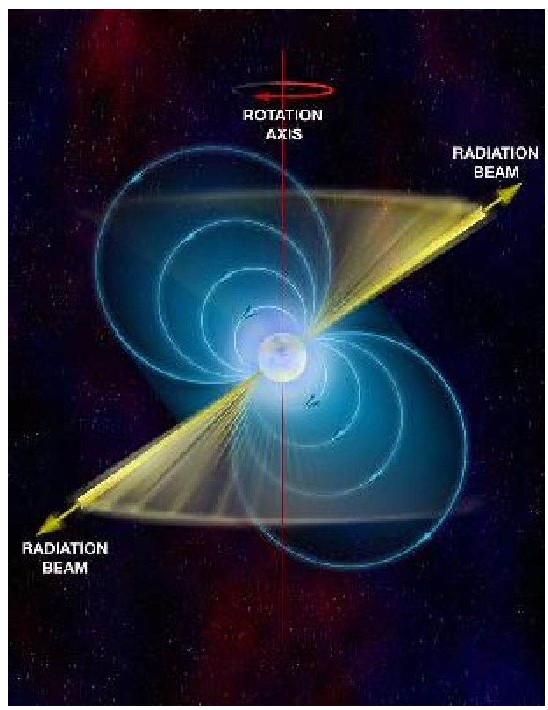

Figure 1: Lighthouse effect is apparent with the emissions along the magnetic axis, which is different from the spin axis.
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In 1967, doctoral student Jocelyn Bell, doing research with her advisor, Anthony Hewish, discovered a series of faint, pulsed radio signals while studying quasars at Cambridge University, actually she called the peculiarities “scruff” at first. The period of these signals was so precise that they were initially thought to be signs of extraterrestrial intelligence.
(See below for more biographical details on Jocelyn Bell.)

At Cornell University, Franco Pacini and Tommy Gold (Pacini later became president of the International Astronomical Union) detected more sources. They independently interpreted the signals using a “lighthouse" model saying that the radio beams are emitted by a rotating, highly magnetized neutron star. The radio waves are produced by synchrotron radiation from relativistic particles accelerated by the star's magnetic field. Though this explanation was quickly verified, a more accurate name was not promoted before a Daily Telegraph journalist coined the term “pulsar”. Though I am not convinced that “rotars” or “neutrars” is really any better than pulsars and I think rolls off the tongue more smoothly.

Neutron stars are compact objects that pack a solar mass into a volume about 20 km across (a spherical city). Neutron stars form directly from the gravitational collapse of a massive star or in supernova explosions or indirectly from another kind of supernova explosion of a white dwarf that had just exceeded its mass limit (extracting mass from a binary partner). It is believed that a black hole evolves via a neutron star in a supernova of a yet more massive star.

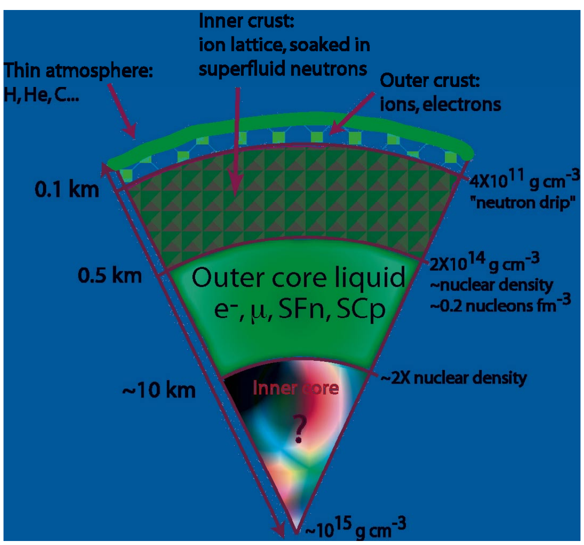

Figure 2: Neutron star interior
(Bennett Link, Montana State University)
The conditions in a neutron star are extreme. The ***average*** density is such that 1 cm^3 of material has a mass exceeding 10^8 metric tons. Typical internal temperatures are ~10^8 K and above. A neutron star contains about a solar mass of superconducting liquid, permeated by a magnetic field that is at least 10^6 times larger than what we can produce even briefly on Earth. Neutron stars have violent lives; they can suffer star quakes, produce jumps in spin rate, accrete matter from other stars or the interstellar medium, and produce explosions. Some of these events involve energies in excess of 10^{42} ergs (the amount of energy emitted by the Sun in 1000 years). The drawing on the right shows the current understanding of the neutron star interior. SFn denotes superfluid neutrons; SCp denotes superconducting protons.

As with any thermodynamically stable system, the balance of forces can be expressed in an equation of state. The structure of a neutron star is determined by an equation of state, which relates its pressure and density, which is close to that of a nucleus. However, the composition of a neutron star is critically dependent on this equation of state. It can vary from neutrons and protons to hyperons, particles that contain strange quarks and maybe free quarks. For example, a neutron star that weighs more than 1.6 solar masses requires an equation of state that includes "exotic" matter. However, most neutron stars are about 1.35 solar masses, albeit with interesting exceptions. So far no evidence has arisen for "strange" stars - neutron stars that contain strange quarks, but the search is on, and the equation of state is the best tool in the hunt [quark stars are believed to have been discovered were reported in April 2002].

Because there is a conservation of magnetic field intensity (Alfven), the magnetic field of a neutron star is increased to about 10^8 T by the gravitational collapse of a large star (recall 10,000 Gauss = 1 Tesla). This is also an important factor in the equation of state. Furthermore, the conservation of angular momentum demands that neutron stars and their magnetic fields rotate rapidly, with periods varying from milliseconds to seconds. This means that neutron stars are formidable radiation emitters and particle accelerators.

In 1970, Riccardo Giacconi and colleagues at American Science and Engineering stumbled across a new class of celestial X-ray sources that are bright and variable with a fast periodicity. Giacconi, who shared the 2002 Nobel Prize for Physics, was on his way to showing that neutron stars could be bound in binary systems along with normal stars. However, the extreme density of neutron stars makes their orbits much tighter and their periods much shorter than those of normal binary star pairs. Moreover, the neutron star's strong gravitational attraction pulls some of the external layers of its normal companion star onto itself. The in-falling matter, subject to the laws of celestial mechanics, can organize itself into an accretion disk that rotates around the neutron star. The temperature of this disk can be as high as 10^6 K due to internal viscosity and friction effects, which makes it visible in the X-ray region. The disk can also be eclipsed and give rise to spectacular variations in the star's X-ray flux, which provides an excellent hook for understanding a binary system. One can paraphrase John Wheeler on the discovery of neutron stars, "who suspected that they would come equipped with a bell and a handle?"

An enormous amount of data at various wavelengths has been collected from binary systems in the three decades since their discovery, and they remain one of the most important sources of neutron-star phenomenology. In particular, astronomers can calculate the mass of a neutron star by studying the gravitational interaction of the binary system.

In 1974, Russell Hulse and Joe Taylor [a graduate student at the time], at the University of Massachusetts, discovered the first binary system that contained two neutron stars. Their dynamical behavior provided the first indirect evidence for gravitational waves, for which Hulse and Taylor shared the 1993 Nobel Prize for Physics. In 2000, three pairs were found, and by 2003, 10 neutron star-neutron star binaries have been discovered, and radio astronomy has accumulated a spectacular database of more than 1500 pulsars (2003). Indeed, radio astronomy can also be used to study the equation of state of neutron stars. Since 1969, astronomers have found 25 pulsars that show "glitches" in their rotation periods, which are normally extremely precise. The transfer of angular momentum from the fast-rotating superfluid core of a neutron star to its solid crust may be cause of these glitches.

Andrew Lyne's group at the University of Manchester has recently observed intermittent behavior in the radio pulsar PSRB1828-11. This could be the first example of a freely precessing; i.e., wobbling, neutron star— something typically ruled-out by many equations of state (see Physics World October 2000, pp. 27-28).

Meanwhile, Curt Cutler at the Max Planck Institute for Gravitational Physics in Germany and co-workers at Caltech and Montana State University, have analyzed the impact of the behavior of PSRB1828-11 on the rigidity of its crust. They concluded that the crust of the star is under significant stress, which has far-reaching implications.

Neutron stars do not have any nuclear fuel so they do not shine like other stars. But we can see them in many other wavelengths. Their extremely high temperatures make them especially interesting sources of high-energy astrophysics and their extreme magnetic fields and fast rotation make them especially interesting sources of radio astronomy.

III. Theoretical Model of the Pulsar

Instead of going into the details here, I will refer you to a number of helpful websites for additional basics on pulsar physics theory:

A. Jodrell Bank has a *Tutorial on Pulsars* [http://www.jb.man.ac.uk/~pulsar/Education/Tutorial/tut/tut.html]; though it is ten years old, it still quite helpful.

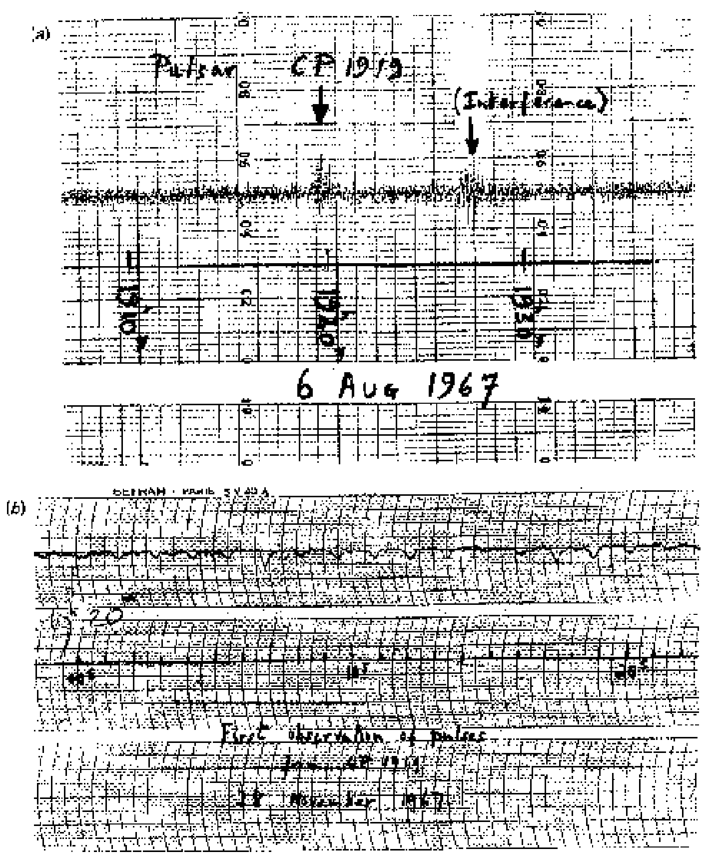

Figure 3: Discovery observations of the first pulsar. (a) The first recording of PSR 1919+21; the signal resembled the radio interference also seen on this chart. (b) Fast chart recording showing individual pulses as downward deflections of the trace. [A. G. Lyne and F. G. Smith, *Pulsar Astronomy*, Cambridge University Press, 1990.].

B. Links to pulsar sites/recordings: sounds of pulsars can be heard when an acoustical equivalent to the pulse frequency is generated.
[http://www.jb.man.ac.uk/~pulsar/Education/Sounds/sounds.html]

C. From Caltech, here is a 2 Mb-Powerpoint on neutron stars. It has some nice color slides [www.astro.caltech.edu/~srk/ay125/NeutronStars.ppt].

D. The life and death of a pulsar is summarized on chart showing the "state of existence" based on its rate of period change for a pulsar with a give period. The two figures are the same (different sources), but one is in color.

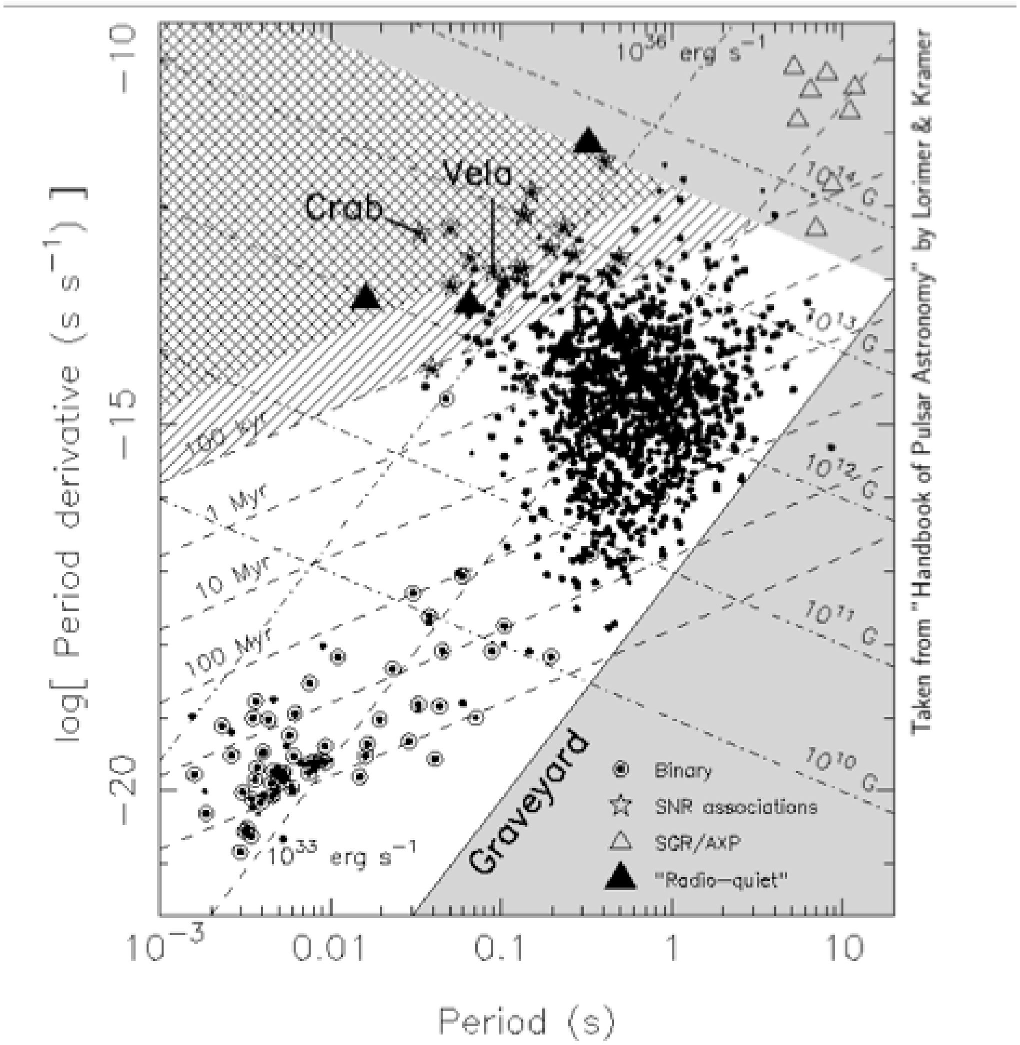

Figure 4a: The radio pulsar equivalent of the Hertzsprung-Russell diagram - a physical diagram indicating the nature and evolution of neutron stars. Each dot represents a pulsar, stars represent pulsars associated with supernova remnants, circles indicate pulsars in binary systems and ellipses indicate pulsars in binary systems with eccentric orbits.

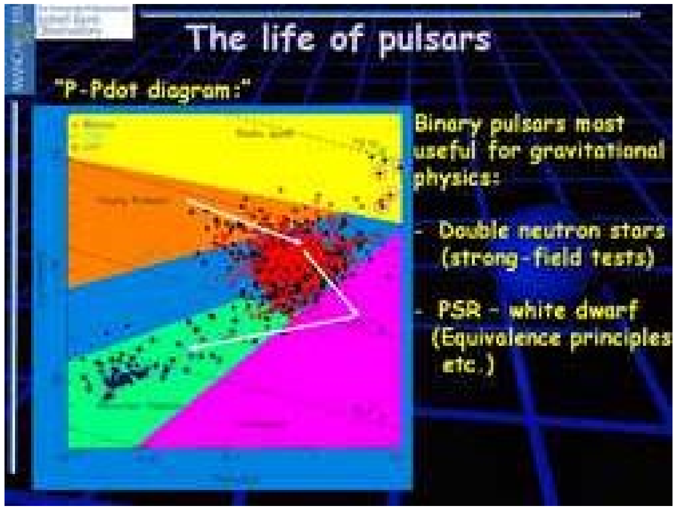

Figure 4b: Color version of figure 4a.

E. Frontiers of Astrophysics: Pulsar Astronomy. This is a 4-part lecture course given at the University of Manchester (Autumn 2005, Michael Kramer). The153-slide set is found at [http://www.jb.man.ac.uk/research/pulsar/Education/frontier/frontier.html]

IV. Jocelyn Bell Burnell Biography

Susan Jocelyn Bell was born on July 15, 1943 in Belfast Ireland. Jocelyn started her academic career in Northern Ireland "high school," but failed. However, she went on to earn a Physics degree at Glasgow University, Scotland in 1965 and then a Ph.D. at Cambridge University, England in 1968

As a research student under Anthony Hewish, Jocelyn began work on a radio astronomy project designed to study the interplanetary scintillation (twinkling) of compact radio sources called quasars. Research in radio astronomy research had begun in 1950s, but was severely limited until Cambridge astronomers developed a suitable radio telescope. Jocelyn was involved in the construction and operation of the telescope based on the principles of aperture synthesis developed by Sir Martin Ryle (also at Cambridge). The radio telescope consisted of 2000 dipoles about nine feet tall with 120 miles of wire and was spread over four and a half acres and became operational in July 1967 (but was not completed in construction).

Figure 5: Jocelyn Bell at the Mullard Radio Astronomy Observatory, near Cambridge, MA

One of her main responsibilities was to monitor and interpret the chart paper recordings of the radio transmissions—a very tedious analysis done by hand. She examined 100 feet of chart paper each day. Her perceptive persistence would prove to be fortuitous for her ultimate discovery.

In November 1967, Jocelyn began to take notice of unusual signals, which she termed as "scruff" that at first was thought to be some form of radio wave interference, a common occurrence with highly sensitive radio telescopes. But since the signals sidereal; i.e., were recurring earlier by 4 minutes on subsequent days, interference was ruled out and the signals were clearly extraterrestrial in origin.

During the next eight weeks the group at Cambridge had great difficulty convincing themselves that the strange signals had been emitted by naturally occurring astronomical objects. The news of the discovery spread and the astronomy community speculated on reflections from the moon or planets, transmissions from man-made satellite probes, or extraterrestrial civilizations.

The discovery was most suggestive of an extraterrestrial intelligent origin that had ever been detected and Jocelyn herself termed this first stellar discovery LGM-1 (Little Green Men).

Later, other signals were received the opposite parts of the sky, making it highly unlikely that two lots of little green men would both choose the same, improbable frequency, and at the same time try to signal the same planet Earth.

By December, she had found a total of 4 "scruffy" signal sources; Hewish announced in January 1968 that these radio signals were likely from a rapidly spinning neutron star that sends out regular burst of radio waves and other electromagnetic radiation. The LGM-1 designation was changed to CP-1 (Cambridge Pulsar) (today it's called CP 1919).

In 1974, Anthony Hewish, and Sir Martin Ryle were jointly awarded the Nobel Prize in physics. This was the first time the prize was given for work in astronomy. The Nobel Prize announcement triggered a public controversy regarding the recognition Bell failed to receive for her part in the discovery. Many argued (particularly Sir Hoyle) that Jocelyn Bell at least shared in the Nobel Prize.

After completing dissertation (with a mention of the pulsar work in the appendix) and obtaining her Ph.D. degree at Cambridge, Jocelyn Bell left for Cornell, married, Dr. Burnell, and went into x-ray and gamma-ray astronomy.

Jocelyn Bell Burnell has received numerous awards for her professional contributions. She was first elected as a fellow of the Royal Astronomical Society in 1969 and has served as its Vice President. Among many of her awards she received the Beatrice M. Tinsley Prize from the American Astronomical Society in 1987 and the Herschel Medal from the Royal Astronomical Society in 1989. She is a recipient of the Oppenheimer Prize and The Michelson Medal.

Today Jocelyn concerns and efforts are directed towards the advancement of astronomy and she is deeply involved in the teaching and public understanding of physics and astronomy. Even to this day, she is teaching adults who were also told they were failures and could not continue in the educational field. Currently she teaches at the Open University (the largest part-time/distance learning campus in the UK with a distinguished faculty and high student satisfaction).

In her spare time she walks, gardens, sews, swims, and knits, listens to choral music and is active in the Religious Society of Friends Quakers).

(Largely adapted from the resources at the California State University at Ponoma.)

V. The Nobel Prizes

Presentation of the 1974 Nobel Prizes in Physics to Ryle and Hewish by Professor Hans Wilhelmsson of the Royal Academy of Sciences follows (with minor correction of typographical errors and insertion of some words in italics for clarification):

“The subject of the Nobel Prize in Physics this year is the science of Astrophysics, the Physics of the stars and galactic systems. … Radio Astronomy offers unique possibilities for studying what is taking place, or in reality what occurred very long ago, at enormous distances from Earth, as far out as thousands of millions of light years from us. The radio waves now reaching us have been traveling for thousands of millions of years at the speed of light to reach our Earth from those very remote sources. It is indeed a thrilling fact that the radio signals we record today here on Earth left their cosmic sources at a time when hardly any flowers or living creatures, and certainly no physicists, existed on Earth. New and epoch-making discoveries have been made in the field of Radio Astrophysics during the last decade, discoveries that are also exceedingly important contributions to Modern Physics; for example, in *the* establishing through radio astronomical observations, the presence of matter in a superdense state. …

This year's Nobel Prize winners in Physics *are* Martin Ryle and Antony Hewish, *who* developed new radio astronomical techniques. Their observations of cosmic radio sources represent extremely noteworthy research results. In order to collect radio waves from cosmic radio sources, one utilizes radiotelescopes. It is important that a radiotelescope should have a large area, both for highest possible sensitivity and for the high angular resolution that is needed to discriminate among the various cosmic sources of radio radiation. For observation of exceedingly small sources, it is, however, no longer possible to build a single radiotelescope of sufficient size. Ryle and his collaborators, therefore, developed the method of aperture synthesis. Instead of making one huge aerial, a number of small aerials are used in this method, and the signals received by them are combined in such a way as to provide the necessary extreme accuracy. Instead of many small aerials, Ryle, in fact, made use of a few aerials that could be moved successively to different positions on the ground. Ryle also invented the extremely elegant and powerful technique utilizing the rotation of the Earth to move his radiotelescopes. With this technique, he obtained a resolution in his observations that corresponded to an aerial of enormous size. Ryle's measurements enable us to conclude that a steady state model of the Universe cannot be accepted. The cosmos, on a large scale, has to be described by dynamic evolutionary models. In his latest construction in Cambridge, Ryle obtained an angular resolution permitting the mapping of cosmic radio sources with an error less than one second of arc! The radioastronomical instruments, invented and developed by Martin Ryle and utilized so successfully by him and his collaborators in their observations, have been one of the most important elements of the latest discoveries in Astrophysics.

Antony Hewish and his collaborators in Cambridge, in the autumn of 1967, made a unique and unexpected discovery that has revolutionized Astrophysics. They had constructed new aerials and instruments to study the influence of the outer corona of the Sun on the radiation detected from remote point sources. A special receiver capable of extremely rapid response had been built. The fast receiver provided a result quite different from its intended purpose. By chance, the receiver detected short pulses of radio signals that were repeated periodically about every *second…*, and with exceedingly high precision in the pulse repetition rates. It was concluded that the radiation originated from cosmic sources of previously unknown type. These sources were subsequently named pulsars. One has come to the conclusion that the central part of a pulsar consists of a neutron star. The pulsars are also accompanied by magnetic fields many millions of times stronger than those found in laboratories on Earth. The neutron star is surrounded by an electrically conducting gas or plasma. Each pulsar rotates and emits beams of radiation in the universe resembling those from a lighthouse. The beams strike the Earth periodically with high precision. These pulsars are indeed the world clocks, which our Nobel Prize winner *in Literature,* Harry Martinson, mentions in his poetry. Allow me to quote this poet of space:

World clocks tick and space gleams everything changes place and order.

Early in the history of pulsar research, it was suspected that neutron star matter existed in the centers of supernovas. Radiotelescopes were aimed towards the center of the Crab nebula, a magnificent glaring gaseous remnant of a supernova event that is known from Chinese annals to have occurred in 1054 A.D., and indeed, they detected a pulsar! This pulsar emits not only radio pulses, as expected from a pulsar, but also pulses of visible light and x-rays. It is comparatively young, rotates rapidly and is in fact, exceptional among pulsars. Antony Hewish played a decisive role in the discovery of pulsars. This discovery, which is of extraordinary scientific interest, opens the way to new methods for studying matter under extreme physical conditions. The contributions of Ryle and Hewish represent an important step forward in our knowledge of the universe. Thanks to their work, new fields of research have become part of Astrophysics. The gigantic laboratory of the universe offers rich possibilities for future research….”

(Excerpts from Nobel Lectures, Physics 1971-1980, Editor Stig Lundqvist, World Scientific Publishing Co., Singapore, 1992 Copyright © The Nobel Foundation 1974.)

As Jocelyn Bell was discovering the first pulsar, Joseph Taylor was completing his doctoral work in radio astronomy at Harvard. He later helped confirm the existence of pulsars after becoming an assistant professor at the University of Massachusetts in 1969. Three years later, Taylor enlisted Russell Hulse, a graduate student in his department, to help him refine a method he'd developed for speeding the discovery of pulsars. And 21 years later, their corroboration resulted in their sharing a Nobel Prize.

In September 1974, Taylor remembers, "Russell called and told me that he was onto something interesting, and I was on the next plane down [to Arecibo] with a bunch of equipment." Hulse had noticed an anomaly: one of the sources was emitting bursts that were slightly less regular than the others. He and Taylor deduced correctly that the signal was coming from a pulsar in co-orbit with an unseen companion star. (As the pulsar circled in its orbital embrace, it moved toward and away from an observer on earth. This relative movement produced the irregularities in the recorded signal.) They had found a binary pulsar, the first known to science.

Subsequent observations of the binary pulsar led in 1978 to an indirect proof of the existence of gravity waves. Taylor's research team measured a tiny decrease (75 millionths of a second a year) in the interval between the pulses. As gravity waves carried away energy from the binary system, the pulsar and its companion were drawing closer together. This in turn altered the timing of the pulsar's signal as observed from earth, and the change in the signal was just as Einstein's theory said it should be.

(Adapted from the Princeton archives, [http://www.princeton.edu/~paw/archive_old/PAW95-96/02_9596/1011feat.html])

VI. Selected Professional Contributions

A list of select major contributions by professional radio astronomy facilities is highlighted below. Of course, there is much more scientific research forged by these facilities than what is indicated here and there are many other facilities that have made meritorious contributions.

A. Arecibo

(1) **First Binary Pulsar (1974)**

As discussed above, the first pulsar in a binary system was discovered in Arecibo leading to important confirmation of Einstein's theory of general relativity and a Nobel Prize for astronomers Russell Hulse and Joseph Taylor (1993).

(2) **Two Classes of Pulsars Discovered (1980s):**

Millisecond pulsars, which rotate several hundred times per second, and slower-rotating pulsars, which rotate about once per second. Discovery of the first millisecond pulsar, PSR B1937+21 was in 1982. The slow-rotating pulsars speed through space (see NRAO below), while millisecond pulsars move slowly through space.

(3) **First Extrasolar Planet Around a Pulsar (early 1990s)**

The first planets outside the solar system were discovered around Pulsar B1257+12, a rapidly rotating pulsar with three Earth-like planets in orbit.

(4) **Discovery of the Youngest Ever Binary Pulsar (January 13, 2006)**

With a state-of-the-art receiver system on the 305-m Arecibo radio telescope, an international team discovered a new binary system, with the relative youthful pulsar (about 112 thousand years old). This pulsar, PSR J1906+0746, consists of a 144-ms pulsar in a 4-hr orbit around an as yet unseen companion that is very likely another neutron star or a white dwarf. This will improve the estimates of the rate at which such systems will spiral in and destroy themselves. [http://www.spaceref.com/news/viewpr.html?pid=18744]

B. NRAO Green Bank Telescope

(1) **Newly Commissioned Green Bank Telescope Bags New Pulsars (January 4, 2002)**

"This globular cluster, known as Messier 62, has been very well studied, and it would have been an exciting discovery to find just one new pulsar. The fact that we were able to detect three new pulsars at one time is simply remarkable," said Bryan Jacoby, a graduate student at the California Institute of Technology.

(2) **Pulsar Bursts Coming From Beach ball-Sized Structures (March 12, 2003)**

A pulsar's magnetosphere is "the most exotic environment in the Universe," said Kern. Researchers detected very short sub-pulses that could only be generated by density waves in the plasma interact with their own electrical field. The waves becoming progressively denser until they "collapse explosively" into super strong bursts of radio waves.

The Crab pulsar is one of only three pulsars known to emit super strong "giant" pulses. "Giant" pulses occur occasionally among the steady, but much weaker "normal" pulses coming from the neutron star.

As an aside, the optical target, M1, is enigmatic in many respects. As a radio target, it is known as Taurus A. This was the first optical pulsar found. See the end of this feature for a 19th century sketch of the Crab Nebula and visit *Moments of Discovery* for actual recordings of scientists in the process of discovery, [http://www.aip.org/history/exhibits/mod/].* Furthermore, John Bolton (1922-1993) discovered Taurus A, and his contributions were celebrated in January in Houston, TX. See tribute at the end of the journal.

* *If the link appears to be inoperative, simply cut and paste the url into your browser*

(3) Astronomers Discover Fastest-Spinning Pulsar (January 12, 2006)

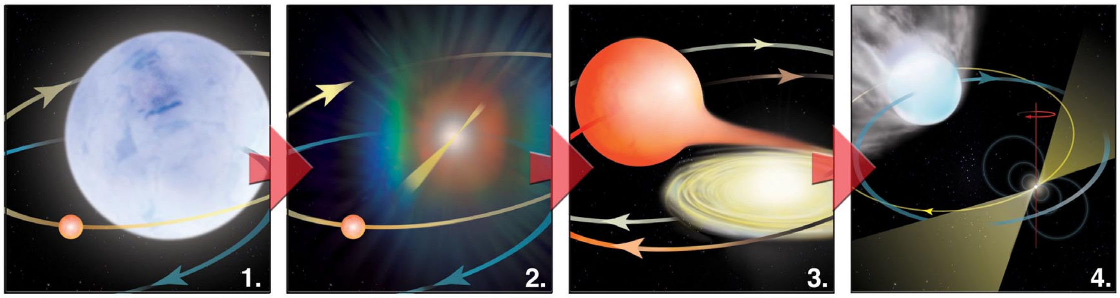

Figure 6: Formation of Millisecond Pulsars

i. A supergiant star and a Sun-like star are in binary orbit.
ii. The massive star supernovas leaving a neutron star, which is active for several tens of millions of years, likely active as a radio pulsar. Eventually it slows down, turns off and becomes a cooling neutron star.
iii. After billions of years, lower-mass star evolves to a red giant. The neutron star surface accretes material from the red giant. Angular momentum is transferred to the neutron star and spins up more rapidly and system becomes an X-ray binary.
iv. Once accretion ends, the fast spinning neutron star is spinning very rapidly and emerges as a millisecond radio pulsar. Strong pulsar winds slowly erode away the companion star (recycling), which can eclipse the pulsar's radio emission.

But in a globular cluster there are many interactions between "dead" neutron stars and normal stellar binaries. In a process called "exchange," the lowest mass star in a normal binary is usually ejected from the binary and the neutron star replaces it. And then proceeds with the recycling scenario noted above. These interactions and exchanges explain why globular clusters have so many more millisecond pulsars per unit mass than the Galactic disk.

One such pulsar, PSR J1748-2446ad, is in a globular cluster called Terzan 5 located 28,000 light years from Earth in the constellation Sagittarius. It is spinning 716 times per second, or at 716 Hertz (Hz), readily beating the previous record of 642 Hz from a pulsar discovered in 1982. For reference, the fastest speeds of common kitchen blenders are 250-500 Hz.

Assuming less than two solar masses, the rotation speed limits the size to 20 miles across.

The spinning pulsar orbits a companion star once every 26 hours. The companion passes in front of the pulsar, eclipsing the pulsar about 40 percent of the time, making it difficult to learn details of the orbital configuration and subsequent masses of the pulsar and its companion.

The great sensitivity of the GBT and the special signal processor called the Pulsar Spigot enabled the discovery of many millisecond pulsars in Terzan 5. See the article, "How Are Millisecond Pulsars Formed?" (Jan 12, 2005) for some details:
[http://www.nrao.edu/pr/2006/mspulsar/mspulsar.graphics.shtml]

(4) **Fastest Pulsar Speeding Out of Galaxy Discovered (August 31, 2005)**

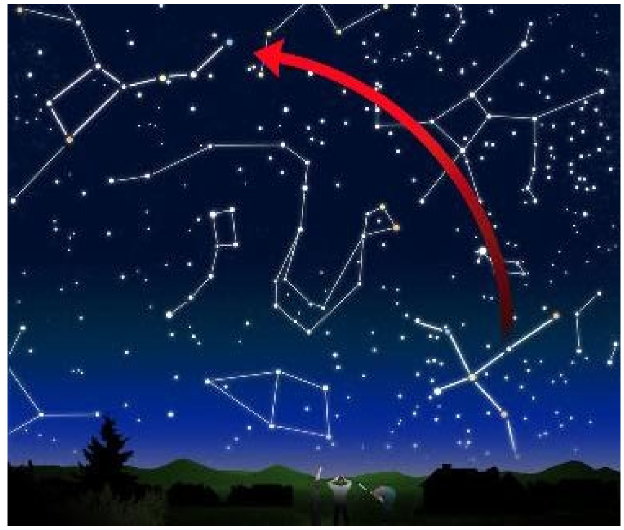

Figure 7: Over about 2.5 million years, Pulsar B1508+55 has moved across about a third of the night sky as seen from Earth.

A speeding, superdense neutron star somehow got a powerful "kick" that is propelling it completely out of our Milky Way Galaxy into the cold vastness of intergalactic space. Its discovery is puzzling astronomers who used the National Science Foundation's Very Long Baseline Array (VLBA) radio telescope to directly measure the fastest speed yet found in a neutron star.

"We know that supernova explosions can give a kick to the resulting neutron star, but the tremendous speed of this object pushes the limits of our current understanding," said Shami Chatterjee, of the National Radio Astronomy Observatory (NRAO) and the Harvard-Smithsonian Center for Astrophysics. "This discovery is very difficult for the latest models of supernova core collapse to explain," he added.

(For more detailed discussions, see NRAO Press Releases [http://www.nrao.edu/pr/])

C. Jodrell Bank

(1) **Looking Inside a Neutron Star (August 2, 2000)**

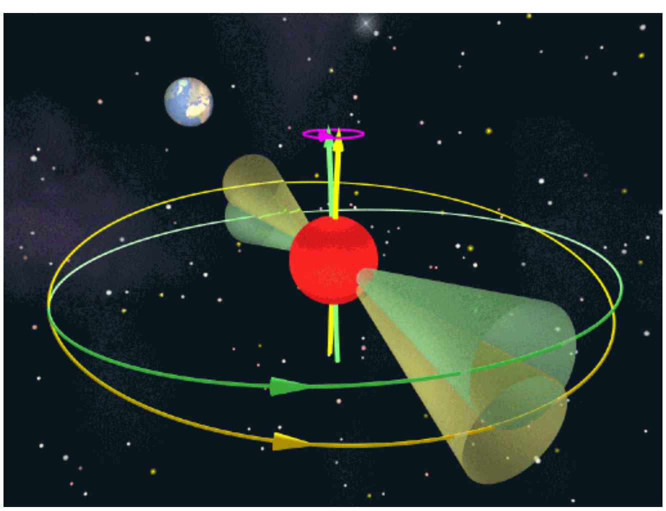

Figure 8: The wobbling (or precession) causes the rotation axis of the pulsar to follow a circle-like motion in time (see yellow and green axes at different epochs). The motion is very much like the wobble of a top or gyroscope. As a result, we see the cone-like lighthouse beam of the radio pulsar under different angles, resulting in the observed changes in pulse shape and arrival times. (Image by M. Kramer)

The Jodrell Bank scientists (Ingrid Stairs, Andrew Lyne and Setnam Shemar) have been studying 13 years' worth of data from the pulsar PSR B1828-11. This pulsar rotates 2.5 times per second, but, unlike any other, wobbles regularly with a period of about 1000 days.

Stairs explains: ``The bulge in the neutron star causes the angle between the pulsar's rotation axis and its radio beam to change with time, creating the wobbling effect that we measure." Lyne emphasizes that the oblateness is incredibly small: ``This star departs from being a perfect sphere by only 0.1 mm in 20 km. On Earth this would mean that no mountain could be higher than 3 cm!"

The surprising aspect to the discovery is not the small size of the wobble, but that fact that it is seen at all. Astronomers know from other long-term observations, mostly done at Jodrell Bank, that a pulsar is made up largely of a neutron superfluid, with a solid crust. Current theories predict that the interaction between the superfluid and the crust should cause any precession to die out extremely quickly. ``But this pulsar is one hundred thousand years old, and it's still wobbling!" exclaims Lyne. ``We really don't understand how this precession can be happening, and theorists are going to have to do some work to explain it," adds Stairs.

A NASA Science feature, Journey to the Center of a Neutron Star, by Christopher Wanjek, discusses further the neutron star interior,
[http://solarsystem.nasa.gov/scitech/display.cfm?ST_ID=249]

(2) First-Known Double Pulsar Opens up New Astrophysics (January 8, 2004)

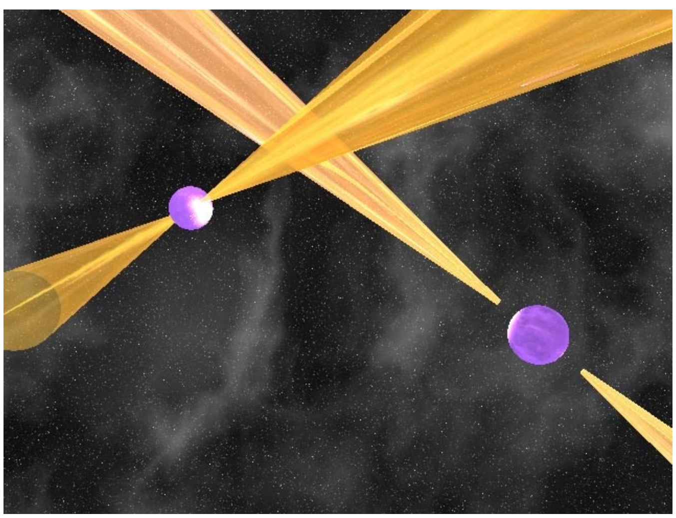

Figure 9: Artistic impression of the two pulsars orbiting around the common centre of mass in 2.4 hours. The faster rotating pulsar spins 45 times per second or almost 3000 times per minute. In the same time, the slower rotating pulsar spins only 22 times or every 2.8 seconds. Credit: Michael Kramer (Jodrell Bank Observatory, University of Manchester).

(Several MPEG animations available)

Pulsars make exceptional clocks, which enable a number of unique astronomical experiments. Some appear to be rotating so smoothly that they may even "keep time" more accurately than the best atomic clocks here on Earth. Very precise timing observations of systems in which a pulsar is in orbit around another neutron star have been able to prove the existence of gravitational radiation as predicted by Albert Einstein and have provided very sensitive tests of his theory of General Relativity.

The neutron star binary system reported in this paper is one of these systems, with an orbit, which is decaying more rapidly than any previously discovered.

The Parkes survey using a 13-beam system that led to the discovery of the double-pulsar system in the Milky Way, PSR J0737-3039

(3) **New Type of Star: Rotating Radio Transient (February 21, 2006)**

Dr Maura McLaughlin explained: "It was difficult to believe that the flashes we saw came from outer space, because they looked very much like man-made interference". The isolated flashes last for between 2 and 30 milliseconds. In between, for times ranging from 4 minutes to 3 hours, the new stars are silent.

After confirmation of their celestial nature, studies over the next 3 years revealed that 10 of the 11 sources have underlying periods of between 0.4 seconds and seven seconds.

"The periodicities found suggest that these new sources are also rotating neutron stars, but different from radio pulsars", says Professor Andrew Lyne. "It is for this reason that we call them Rotating Radio Transients or RRATs. It's as if, following a flash, a RRAT has to gather its strength during perhaps a thousand rotations before it can do it again!"

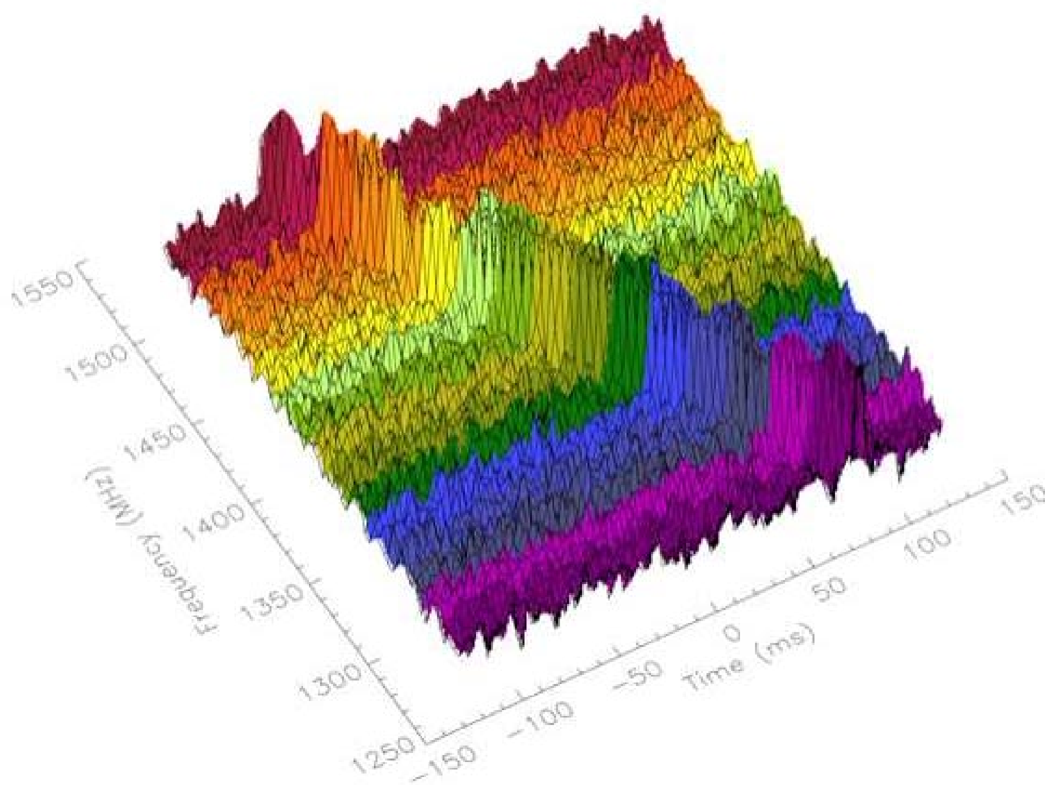

Figure 10: A flash from a RRAT, showing the sweep in radio frequency, which is the signature of a particular RRAT.

RRATs are a new flavor of neutron stars in addition to the conventional radio pulsars and to the magnetars, which are also believed to be rotating neutron stars and are known to give off powerful X-ray and gamma-ray bursts. It is possible that RRATs represent a different evolutionary phase of neutron stars to or from magnetars.

The new objects probably far outnumber both their cousins. "Because of their ephemeral nature, RRATs are extremely difficult to find and so we believe that there are about 4 RRATs for every pulsar," says Dr Richard Manchester of the Australia Telescope National Facility. He is part of the team which also includes astronomers from the US, Canada and Italy.
[http://www.spaceref.com/news/viewpr.html?pid=19085]

(4) **Pulsar Virtual Observatory (May 2006)**

(See Recent Papers, [http://www.jb.man.ac.uk/~pulsar/Publications/publications.html])

Scientists in all fields will be able to access and analyze the large data sets stored in pulsar surveys without specific knowledge about the data or the processing mechanisms, but through abstract tasks using data and processing tools on a grid resource via intelligent scheduling middle-ware. This removes the user from issues of interconnecting tasks and allocating resources. And opens up large sets of radio time-series data to a wider audience, enabling greater cross-field astronomy, which is in line with the virtual observatory concept (PDF available).

(Jodrell Bank Pulsar Home Page
[http://www.jb.man.ac.uk/~pulsar/research/jodsum/node1.html])

VII. Amateur Pulsar Detection

Though there is much activity in pulsar detection, these radio sources remain largely elusive to amateur radio astronomers, at least as far as their discovery is concerned. However, these are weak sources can be "brought out of the noise" if their precise timing and location is known by using spectral analysis techniques. It seems to be a natural capability of software defined radio.

From a recent flurry of discussion on the SARA *Listserve* (February 9-18, 2007), typical questions have been addressed. This casual exchange discloses a wealth of information concerning pulsar detection. Researchers at PARI have made significant strides in this area with 26-meter dishes. Subsequent to this dialogue, a Jeff Lichtman article in a British journal highlights what other amateurs are attempting to do with much smaller dishes. This article is adapted for its inclusion here.

A. SARA *Listserve* Subject: Pulsar Observations

From: lehtinen@astro.helsinki.fi
Date: February 9, 2007 11:11:41 AM EST

I am interested in observing pulsars. It is an interesting combination of hardware and signal processing.

I will observe in the 406 or 608 MHz radio astronomy bands.

Here is a list of some questions:

Is it possible for an amateur to make a system, which can hear the pulses in real time? I mean can I hear the pulses with a loudspeaker?

The 'Radio Astronomy Supplies' sells a CD titled 'Pulsars', which has also some circuits for pulsar observations. Do you have experience with the circuits?

I should choose between a hardware-based and software-based receiving system. With the former I mean a traditional analog receiver, without digital signal processing. With the latter I mean software defined receivers and digital signal processing. Can you recommend which is the better way to go?

There are two software-defined receivers that could be used for pulsar observations:

1) The SDR-IQ from rfspace.com. They say that they 'also plan on having a pulsar mode with both internal and external triggers'.

2) The GNU Radio software with USRP board from ettus.com. The www-page http://www.gnu.org/software/gnuradio/ says that 'the gr-radio-astronomy component has very cool code for observing pulsars'. This component has been described at www-page: [www.propulsionpolymers.com/radioastronomy/sara_2006.doc]

I have not seen any real pulsar observations made with these receivers using a small radio telescope (2m diameter dish or Yagi antennas).

The SDR-14 hardware from rfspace.com has been used to observe pulsars using a big telescope, *(See the block diagram [http://www.moetronix.com/pulsar/block2.gif] and the webpage of Ibelings and Wheatley in the next subsection, VII-B-2.)*

In fact, I do have access to a computer controlled 2.3 m dish, which is used mainly for hydrogen spectral line observations. But I think a parabolic dish is not very efficient at 400 MHz. Furthermore, I do not want to remove the 1.4 GHz feed horn and replace it with a feed for 400 MHz. The best way is to put some long 400 MHz Yagis piggyback on the dish.

I have also read that one could use a soundcard of a PC for pulsar detection, but have not found any detailed instructions. With a sound card one could digitize the signal and then make the so called 'epoch folding'. That means dividing the signal into blocks, which have the same duration as the pulse period. One can then take a mean of the blocks and the weak signal becomes visible.

A receiver for pulsar observations has to be a single sideband receiver, I suppose. Otherwise the pulses would be smeared because the pulses from the image sideband do not arrive at the same time as signals from single sideband because of the dispersion. Is this correct?

Cheers,
Kimmo Lehtinen, Finland

From: marcus@propulsionpolymers.com
Date: February 9, 2007 6:50:00 PM EST

Even the strong pulsars are quite weak. There's no chance of hearing them in real-time with an amateur-sized dish. Even the folks at PARI with their 85-foot dish couldn't actually hear any pulsars through the speakers.

The SDR-based radio astronomy platform that I've been developing has a pulsar mode, which was successfully used recently to detect pulsars at PARI. I'm a software guy (who has also built significant hardware in the past), so I'm biased towards a software approach.

Success is more likely if you can observe over a large bandwidth, but that requires that you do dedispersion, which pretty much means a DSP-based approach.

Doing this with a small dish is definitely problematic, although Jim Van Prooyen has used his 3 m dish to observe pulsars at 408 MHz. At 408 MHz, the pulsars are stronger than at 21cm, but are more dispersed.

PARI used my GNUradio -based approach to observe pulsars a few months ago.

An SSB receiver of less than 50 KHz bandwidth won't suffer much dispersion, even at 408 MHz. But sensitivity will suffer somewhat from the reduced bandwidth.

From: sietetrescincoprimo@HOTMAIL.COM
Date: February 9, 2007 8:26:34 PM EST

With the PARI antenna (85 ft), we were able to see individual pulses in real-time using the SDR-14. If we had amplified the pulses, we would have been able to hear them on a loudspeaker. The strong pulsar was slightly over a one hertz repetition, so it would just have been a thump on the speaker every 0.7 seconds or so. I think you will have a very tough time receiving a pulsar with a small setup. Getting any details on the pulse requires an even a bigger antenna. There are some hams that have been able to see very detailed pulses using their 28ft EME dishes.

From: lowen@pari.edu
Date: February 13, 2007 11:34:13 PM EST

It might be possible, but it is going to be difficult, primarily due to the dispersion of the pulse (unless you do real-time dedispersion, and then listen to the detected audio).

RF Space builds excellent hardware, and the packaged software is top notch. But, in order to get the triggering to work with the SDR-14 (don't know about the IQ, as an IQ has not been up here at PARI for testing), you have to literally manually dial in the pulse rate for the gated trigger and the resulting data stream is not continuous due to the slow USB 1 interface.

But you get a great display of the data in *SpectraVue*. The triggering relies upon an external timing generator (that must be VERY precise) and you have to manually calculate (using TEMPO or similar) the fully adjusted pulse rate based on local standard of rest and position.

The first pulsar detections at PARI were done with a modified SDR-14 driven with a custom divider and a precise frequency synthesizer.

The USRP and GNUradio are more of a kit approach rather than a packaged product. It is a completely continuous USB 2.0 solution and can grab far more bandwidth continuously than can the SDR-14 (you do lose 2 bits of bit depth, though). The current software does not tie in yet to the TEMPO pulsar timing package to directly grab the timing information and adjust for the LSR, but that tie-in is planned so that no hardware adjustments are necessary.

But, and I'll repeat, the USRP and GNUradio are more of a kit approach, both hardware and software. It works on Linux well, Mac OS X somewhat, and not real well on Windows, although that is changing. With the GRC gui builder, you can really put the GNUradio blocks to use in a drag and drop building block manner; it is also in heavy development and is not as refined as one might like, but it sure is getting better.

For the USRP and the full supported bandwidth you need a fast PC with fast disks; the full bandwidth requires continuous 32MB/s over the USB, and older PC's simply will not do that.

Yep, I was here for that observation, and I did the observation that Marcus refers to with the USRP and GNUradio.

Epoch folding as you have described it is basically how the gated SDR-14 approach works, just at much greater sample rates and skipping many samples while the buffer in the SDR-14 is downloaded over the USB 1.1 interface. The USRP solution is also folded, but it's done completely in software and by using an FFT-based technique (Marcus can describe the technique better, as he wrote it), which is made possible by the continuous data transfer. But it requires a fast CPU to do so.

Lamar Owen, Director of Information Technology
Pisgah Astronomical Research Institute
www.pari.edu

From: marcus@propulsionpolymers.com
Date: February 14, 2007 11:06:40 AM EST

A description of how the pulsar processor works can be found by following the SARA paper links on my homepage: [http://www.propulsionpolymers.com/radioastronomy/index.html]

I haven't had much chance to refine it since last year. I have only a small dish, and I'm distracted by total-power mode at the moment, which is currently suffering from outrageous instability. Huge 1000 Jy saw-tooth patterns in the total-power data that correspond exactly to my forced-air heating cycle. The receiver is in a thermally controlled environment, but the 50 ft of coax between outside and it, isn't thermally controlled.

The only FFT part that's used is an FFT-based filter for dedispersion. I was also using an FFT-based post-detection filter based on the pulse frequency and its harmonics, but that didn't work very well, so I took it out. Once the signal is de-dispersed, it's detected, and then folded using a parallel IIR filter (that is, the time series is converted into parallel form, with each "bin" IIR filtered) this is precisely equivalent to the "add and normalize" technique that is often used.

From: stephensrw@stn.net
Date: February 14, 2007 3:27:31 PM EST

Marcus,

Your temperature related receiver noise power output that you have traced to the coax cable might be due to cable Z mismatch causing standing waves in the line. The amplitude of standing waves as measured at a line end will be seen to change due to line temperature changes resulting in change of line length. Coax cables do change length with temperature, which can be seen by phase shift in an interferometer for example, but should not be seen to change their temperature contribution so much to the receiver if employed post LNA gain. I would suggest you try placing coaxial attenuators at each end of the long coax line in question. 3- to 6-dB attenuators usually help a lot. You may have to add an additional gain block (on the source end of the line) in order to accommodate the increased line loss added by the attenuators.

From: marcus@propulsionpolymers.com
Date: February 14, 2007 8:09:21 PM EST

This is a good insight. I have plenty of gain ahead of the coax that suffers wild temperature fluctuations, so I couldn't see how the tiny changes (loss vs. temp.) would be "visible". The feed system is largely 75-ohm, whereas the receiver input is 50-ohm, which has a max SWR of 1.5:1, but perhaps this is still a problem with small phase length changes due to coax heating.

Presumably, if I have a short length between "building entry" and the receiver, the phase length changes over temperature won't be so noticeable.

I'm considering moving the receiver to right next to where the outside (buried in the ground) coax enters the building, which will also require that I move the computer down there, too (the receiver has a USB 2.0 interface, and long-distance USB 2.0 extenders are $$$$).

I'm testing having the receiver software display remotely on one of my other computers, and that is working well. That means I can simply run some CAT5 down to the receiver computer in the basement, and display remotely on my office computer.

From: marcus@propulsionpolymers.com
Date: February 18, 2007 10:29:02 PM EST

I completed the move this afternoon, with the receiver, and its companion computer in the basement, as close to where the outdoor feed comes in as practical. The coax from the receiver to the through-wall is insulated with foam pipe insulation. The results so far are that it's much more stable. The furnace has cycled several times, and the receiver doesn't seem to have noticed.

I'm still getting good HI peaks from the galactic plane (1 to 2 dB out of the noise), so this is encouraging. I'll see how Sgr A does tomorrow morning.

B. Some "Amateur" Sites Using Larger-than Typical Dishes

(1) Pisgah Astronomical Research Institute (PARI) [http://www.pari.edu/], is a not-for-profit public foundation dedicated to providing hands-on educational and research opportunities for a broad cross-section of users in radio and optical astronomy, and in the related disciplines of physics, mathematics, engineering, earth sciences, chemistry and computer science. It is noteworthy that their 26-meter radio telescopes are available for scientific research and for student projects. Student pulsar projects might be available under the direction of Dr. Moffett [http://www.furman.edu/press/pressarchive.cfm?ID=3654].

(2) Amateur Pulsar Observations, by P. Ibelings, N4IP, and M. Wheatley, AE4JY, is a fascinating webpage. They demonstrate some of the challenges in detecting known pulsars, even with a 26-meter dish antenna [http://www.moetronix.com/pulsar/index.htm].

(3) For those fortunate to have a larger dish to work with, they should look at the recent work of amateur Joe Martin, K5SO [http://www.k5so.com/]. His pulsar work is done with a 28-ft dish and SDR14 system like the one on the RFSPace webpage."

C. Pulsars: History of Amateur Detection
(Small Dish)

(1) Premier amateur radio astronomer, Robert M. Sickels was the first amateur to detect a pulsar (1980s) at his home in Fort Lauderdale, Florida. The operating frequencies were 408 MHz and 612 MHz, using a 4-meter parabolic antenna.

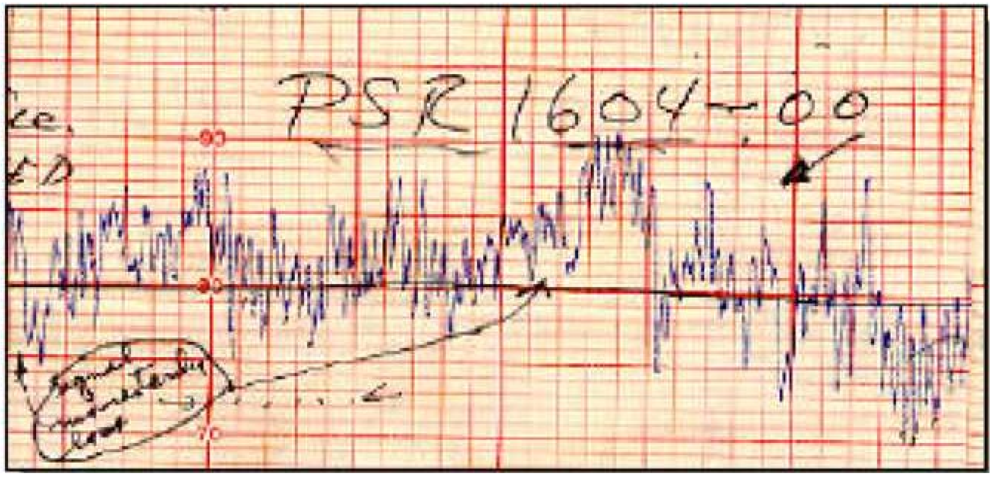

Figure 11: Sickles Pulsar Observation

The pulsar pulses are usually embedded in the noise floor. Additional hardware or software is needed to make the pulses "audible." Among several designs, Bob Sickels used an 'Audio Pulse Enhancer'.

Pulsar Detection at 406 MHz

Modern detection methods rely on signal processing software to extract the very weak signals from the receiver noise. From 2001, Jim van Prooyen has developed to detect Pulsars. Jim says,

"As a software engineer by trade and with my interest in Radio Astronomy, the two areas seemed to be perfect for this research.

In my research, I had read about the detection of Pulsars, the history of Jocelyn Bell and Dr. Anthony Hewish. In addition, I had read of the efforts of Robert M. Sickels (Fort Pierce, Florida, deceased 1993) and his work at 612 MHz. In further readings I found notes on the frequency range of 406 - 410 MHz as well as some microwave regions. My first task was to find the best system for doing this type of research. As many of us are on one budget or another, this was my first concern. While attending a radio astronomy conference, at the National Radio Astronomy Observatory, Green Bank, West Virginia, I was introduced to the 406 MHz area by an engineer named Carl Lyster. After returning from the conference, I researched different off the shelf receivers/scanners being used for radio astronomy. Most of the receivers were quite highly priced and were not made primarily for doing radio astronomy. After careful consideration, I decided to adapt the existing Radio Astronomy Supplies 406.7 MHz Radio telescope (which was field proven and showed excellent system sensitivity). I started the process of adapting the current software and found that while the it was more than adequate for doing radio astronomy continuum observations, I would need to design a new software package for my special project, Pulsars."

Signal Processing

Jeff Lichtman and Jim van Prooyen have corroborated on the pulsar detection at 406.7 MHz. Other Radio Telescope receivers and computers may be used with this software as long as the output file format is compatible with the input file format of the Pulsar Detector.

Paraphrasing Jeff, the way the Pulsar Detector works is that it samples the radio signal using a time base that is some integral fraction of the *known* pulsar period. Each sample taken during the duration of a single pulse period is assigned to a bin. The sample is folded back over each period so that samples from corresponding bins are added together. Each time a new series of bin values is added to the running totals, the data is "renormalized" by subtracting the value of the smallest signal bin from all the bins. This will average out the random noise in each bin, allowing the signal to grow with each iteration. The picture that emerges shows how the average strength of the pulsar signal varies over its period. A filter, based on the pulsar period, is then used for final data processing. Data is subsequently sent to a file.

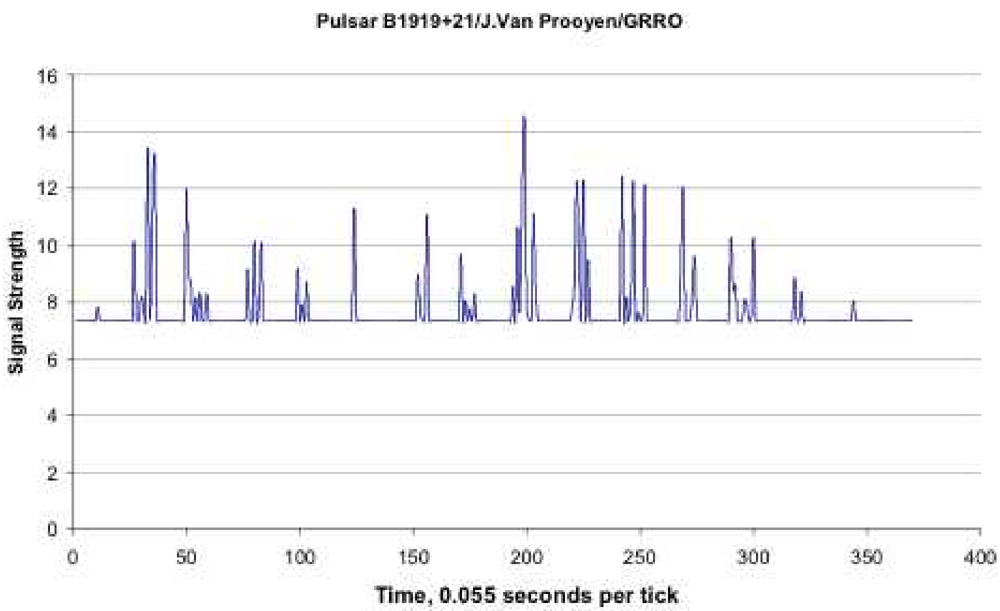

Figure 12: Jim van Prooyen data for pulsar B1919+21 clearly shows the pulses, though fading in and out during the observation period.

Latest Hardware and Software Updates

An itemized list of some improvements:
-New 16 bit high speed A/D installed (Fall of 2005)
-Higher speed sampling achieved (up to 1000 times per second)
-Pulsar survey completed; 45 pulsars test receiver/software system
-New filing system now allows continuous operation

Future developments

A 4-node cluster of computers has been added to do processing in real time. The interface between the data Pulsar Detector collection system and the Beowulf cluster is almost complete with initial testing starting in March of this year [2006/2007]. New features are planned to do searches for standard Pulsars and RRAT's.

Beowulf is a design for high-performance parallel computing clusters on inexpensive personal computer hardware. Originally developed by Donald Becker at NASA, Beowulf systems are now deployed worldwide, chiefly in support of scientific computing, [http://en.wikipedia.org/wiki/Beowulf_%28computing%29]

(Citation: British Astronomical Association Radio Astronomy Group. London, England, Baseline, April 2006, Volume 1, Number 3, *Pulsars, History and Amateur Detection*, Jeffrey M. Lichtman, pp 20-23. [www.britastro.org/radio]*)*

(2) Of course, the early pioneering work of Jim Carroll and Tom Clark should be credited as well as Bob Sickles. A Raleigh NC SARA member, Jim Carroll has done much work on detecting pulsars in the 1980's using a bucket brigade memory system (a series sample-and-hold circuit, see [http://arts.ucsc.edu/ems/music/tech_background/TE-09/teces_09.html] for a block diagram) and a discrete chip digital timing generator with thumbwheel switches to set the repetition rate.

This is similar to the PIC processor based clocking approach in use with the RFSpace SDR14 at PARI. Except that the SDR14 triggering clock is synthesized and varied in 0.1 Hz steps. The synthesizer is locked to a 10 MHz GPS frequency standard for precision and stability. Both approaches allow correction of the local standard of rest until the pulses no longer smear across multiple bins during the integration, greatly increasing the sensitivity.

A similar bucket brigade memory pulsar detector was described by retired NASA scientist and radio astronomer, Dr. Thomas A. Clark K3IO (ex-W3IWI) at the 1982 Central States VHF Society Conference in Baton Rouge Louisiana. (Clark works with many timing projects like differential GPS and the totally accurate clock [http://www.setileague.org/hardware/clock.htm]. His email is found here.)

The amateur pulsar radio astronomer today should be most careful of techniques of clocking at the pulsar rate, because potential artifacts may appear. This is a prudent concern whenever digital signal processing is done. One way to assure that the known pulsar is actually detected is by doing a double blind experiment; i.e., when the rate is slightly changed, the pulsar signal should disappear or gradually precess across the waterfall diagrams.

Fortunately, PC based Digital Signal Processing allows many experimental techniques to be tried and refined in software instead of the hard-wired approaches used in the past. Data capture technology utilized in various software-defined radios, such as USRP, SDR14, SDR-IQ, and HPSDR, allow data to be captured and post-processed repeatedly until the pulsar is seen with a sufficient signal-to- noise ratio to reveal the pulsar peaks and pulse shape details.

For instance, in an SDR14 trace of the elusive Crab pulsar (see B0531+21 towards the bottom of the link below), an artifact near the base turned out to be a real behavior inherent in that pulsar. Joe Taylor, in looking over Pieter Ibelings' pulsar data, remarked that he recognized this pulsar by that baseline peculiarity [http://www.moetronix.com/pulsar/index.htm].

(Much of this information was kindly provided by Charles Osborne.)

(3) Though there was some discussion of dedispersion in the *Listserve*, I want to expound on it here because it is least understood among amateurs and really should be considered.

The propagation of pulsar signals through the tenuous plasma of the interstellar medium (ISM) produces dispersion of the pulses. This is because the speed of propagation through plasma varies with the frequency of the wave. Low frequency waves travel progressively slowly, with a cut-off in propagation at the plasma frequency. At high frequencies, the velocity reaches the velocity of light asymptotically. The difference in travel time between two radio frequencies is proportional to the difference of the inverse squares of the frequencies, f_1 and f_2. To put things in more practical terms, suppose a pulsar frequency measurement is made at f_0 using a detector with bandwidth, B, then the pulsar timing is smeared in direct proportion with the bandwidth. So the narrowest B possible is desired. Also, the smearing is reduced in proportion to the inverse cube of the measurement frequency; i.e., provided $B \ll f_0$. The dispersion Measure, DM, characterizes the ISM. It typically ranges from 10 to 60 parsecs/cm^3. With the frequency and bandwidth expressed in MHz, the smeared pulsar timing, in milliseconds, is approximately,

$$\tau_{dispersion} = 30\left(\frac{202}{f_0}\right)^3 B$$

To correct for this smearing, which could bury the signal in the noise, the signal, the smearing by dispersion must be undone—this is called dedispersion. There are two main methods used for dedispersion: incoherent dedispersion and coherent dedispersion.

Incoherent dedispersion is the more practical technique and involves post-detection processing. The total observing bandwidth, B, is split into N-channels and the pulsar signal is acquired and detected in each of these. The dispersion smearing in each channel is less than the total smearing across the whole band by the factor, N. The detected signal from each channel is delayed by the appropriate this amount so that the dispersion delay between the centers of the channels is compensated. These differentially delayed data trains from the N channels are added to obtain a final signal that has the dispersion smearing time commensurate with a bandwidth of B/N, thereby reducing the effect of dispersion. In practical realizations of this scheme, the splitting of the band into narrow channels is usually carried out on-line in dedicated hardware (see [http://www.gmrt.ncra.tifr.res.in/gmrt_hpage/Users/doc/WEBLF/LFRA/node154.html#sect:BasicBlock] for a block diagram of a pulsar detector) while the process of delaying and adding the detected signals from the channels can be done on-line using special purpose hardware or can be carried out off-line on the recorded, multi-channel data. In this scheme, the final time resolution obtained for a given pulsar observation is limited by the number of frequency channels that the band is split. This appears to be the technique used in the van Prooyen scheme.

In coherent dedispersion, one tries to correct for interstellar dispersion in a pulsar signal of bandwidth B before the signal goes through a detector, i.e., when it is still a voltage signal. Though this is the preferred method for high-resolution work, it is a computationally intense procedure out of the capabilities of most amateurs. But this is precisely what was needed in Ibelings' and Wheatley's work cited earlier (see section VII-B-2) to coax the Crab pulsar out of the noise and perhaps iteratively adjust the Dispersion Measure.

(Citation: [http://www.gmrt.ncra.tifr.res.in/gmrt_hpage/Users/doc/WEBLF/LFRA/node155.html])

VIII. Additional References

Physics World, *Astronomy of the Invisible*, Giovanni F. Bignami (University of Pavia, Pavia, Italy), September 2003.

The Papers of the Century, *Origin of Neutron Stars*, K. Brecher (Boston University, Boston, MA.), AAS 195th Meeting (Session 130. HAD), January 2000.

Archives of California Institute of Technology, Pasadena, California, Interview of Hans A. Bethe (1906-2005) by Judith R. Goodstein, February 17, 1982 and January 28, 1993, p. 33-35.

Swiss American Historical Society Review, *A Propensity for Genius: That Something Special About Fritz Zwicky (1898-1974)*, John Charles Mannone, Vol. 42, No.1, Picton Press, Rockland, ME, February 2006, pp. 3-42.

Supplemental reference on general relativity:
Graduate Level Course Notes and Tutorial Papers Related to General Relativity (original by Chris Hillmam). [http://math.ucr.edu/home/baez/RelWWW/grad.html]

PARI work and Amateur RA Pulsar Detection: Amateur Pulsar Observations P. Ibelings, N4IP and M. Wheatley, AE4JY

SARA back issues on van Prooyen's work and Radio Supplies (Carl Lyster design for amateur detection).

The Open SETI Organization, The Forgotten Challenge: Pulsars
[http://openseti.org/OSPulsars.html]

Neutron Stars for Dummies? No, Ira Wasserman, Cornell University
[http://209.85.165.104/search?q=cache:lgmG534TKAwJ:www.astro.cornell.edu/academics/courses/a290/nsfordummies.pdf+pulsars+for+dummies&hl=en&ct=clnk&cd=1&gl=us&client=safari]

En Memoriam John G. Bolton

Dr Lonsdale, from Haystack observatory and MIT, spoke on "The Future of Radio Astronomy" at Rice University on January 25, 2007 in memory of renowned radio astronomer John G. Bolton, who left Cambridge University in his native England to serve in the Royal Navy during World War II. After the war, he stayed in Australia to develop radio astronomy for the Commonwealth Scientific and Industrial Research Organization. With an ingenious interferometer using reflection from the sea as one element, his team achieved sufficient angular resolution to identify the first known radio sources, Taurus A, Centaurus A, and Virgo A, as the Crab Nebula and the galaxies NGC 5128 and M 87. Later they located Sagittarius A, the galactic center. They also made an important discovery relating a solar flare to the aurora. Bolton built Caltech's Owens Valley Radio Observatory and directed it from 1955 - 60, then returned to Australia to supervise the completion of and become the first director of the Australian National Radio Astronomy Observatory at Parkes. His southern sky surveys led to the discovery of many quasars and increased interaction between optical and radio astronomy. His students became leaders in radio astronomy in the United States and the United Kingdom as well as Australia. [http://www.phys-astro.sonoma.edu/BruceMedalists/Bolton/index.html].
A significantly more detailed biography is by the Australian Science Archives Project: [http://www.asap.unimelb.edu.au/bsparcs/aasmemoirs/bolton.htm]

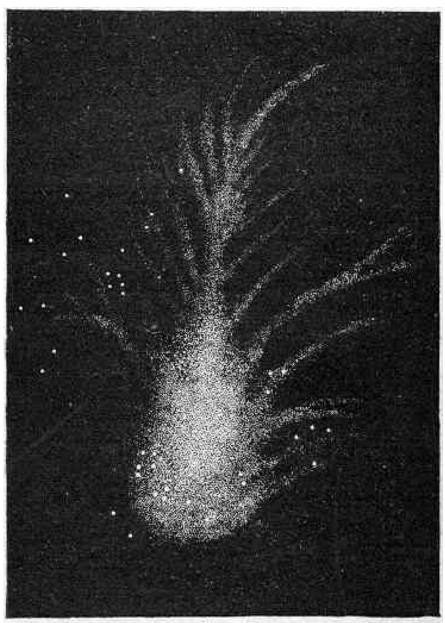

Fig. 438.

Figure 13: Drawing of the Crab Nebula by William Parsons, the Third Earl of Rosse (~1844)
Taurus A discovered by Bolton (1947/48); first Optical Pulsar Discovered John Cocke and Michael Disney (Jan/Feb1968)

Radio Astronomy Resources

SARA
http://radio-astronomy.org

Friends of the Bracewell Observatory
www.bambi.net/stanford_dishes/rescue.html
Bob Lash: bob@bambi.net

Radio Astronomy Supplies
(Jeffrey M. Lichtman)
P.O. Box 450546
Sunrise, FL 33345-0546
954 722-5243 / jmlras@mindspring.com
http://www.nitehawk.com/rasmit/ras.html

Radio Sky Publishing
(Jim Sky)
PMB 242, Box 7063
Ocean View, HI 96737
808-328-1114
http://radiosky.com

NRAO
http://www.nrao.edu

RF Associates
(Richard Flagg)
1721-I Young Street
Honolulu, HI 96826
(808) 947-2546

SETI League
http://www.setileague.org

European Radio Astronomy Club (ERAC)
http://www.eracnet.org/

Pisgah Astronomical Research Institute (PARI)
http://www.pari.edu

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