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# Joint Discussion 2 On the present and future of pulsar astronomy

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## 1. Introduction

Neutron stars are formed in supernova explosions. They manifest themselves in many different ways, for example, as pulsars, anomalous X-ray pulsars (AXPs) and soft $\gamma$-ray repeaters (SGRs) and the so-called 'radio-quiet neutron stars'. These objects are made visible by high-energy processes occurring on their surface or in the surrounding region. In most of these objects, ultra-strong magnetic fields are a crucial element in the radio, optical, X-ray and gamma-ray emission processes which dominate the observed spectrum.

The physics of pulsars spans a wide range of disciplines, from nuclear and condensed matter physics of very dense matter in neutron star interiors, to plasma physics and electrodynamics of the magnetospheres, to relativistic magnetohydrodynamics of electron-positron pulsar winds interacting with the surrounding ambient medium. Not to forget the test bed they provide for general relativity theories as well as being sources of gravitational waves.

Observationally, pulsar research is advancing rapidly. A great array of space instruments (the *Hubble Space Telescope*, *ROSAT*, *ASCA*, *BeppoSAX*, *RXTE* and the *Compton Gamma-Ray Observatory*), launched in the last decade of the previous century, have opened new windows in pulsar research with high quality data in energy bands from optical to the gamma-rays. With the more recently launched satellite X-ray observatories *Chandra* and *XMM-Newton*, upgraded radio observatories and ground based optical telescopes like Keck, GEMINI, Subaru and the VLT lots of the questions remained unanswered from the previous generation of observatories could be addressed and resulted in new and exciting results which changed the previous picture of neutron star evolution substantially (e.g., making Crab-like pulsars the exception not the rule for the appearance of a young neutron star). The X-ray Observatory *SUZAKU* (formerly *ASTRO-E2*) launched in 2005, and the $\gamma$-ray observatories *AGILE* and *GLAST*, which are supposed to be launched end of 2007 or beginning of 2008, will complement the pulsar studies and will enlarge the class of pulsars detected at their energy bands.

However, even in view of these great observational capabilities, the physical processes responsible for the pulsars' broad-band emission, observed from the infrared to the $\gamma$-ray band are still poorly known. Although no uniquely accepted theory exists so far, a notable progress was made very recently in this respect. New developments include caustic slot gaps as well as modified outer gaps. Last but not least: polarization-dependent treatment of high-energy radiative processes is under way, since X-ray and $\gamma$-ray polarimetry – a new powerful tool to discriminate between competing models – is around the corner.

To face recent observational results obtained in multi-wavelength studies from neutron stars and pulsars with the various theoretical models and to discuss on future perspectives on neutron star astronomy we organized this Joined Discussion (JD02) during the IAU XXVI General Assembly which took place in 2006 August in Prague. More than 150 scientists took actively part in this Joint Discussion. Fourteen invited review talks were presented to view the present and future of pulsar astronomy. Fifty three poster contributions displayed new and exciting results. PDF-files of all review talks and most of the posters displayed during the meeting are available on the meeting website < http://www.mpe.mpg.de/IAU_JD02 >.

The following sections give an overview of the invited review talks and contributed posters. The review talks are subject of review articles which will be published elsewhere. More information on this will be available at the URL given above.

## 2. Invited Review papers

### 2.1. *Radio emission properties of pulsars*

**Richard N. Manchester:** Currently, 1765 pulsars are known. 170 of them are millisecond pulsars. 131 pulsars are in binary systems. 129 pulsars are detected in 24 globular clusters. Recent observational results on the radio emission properties of pulsars were reviewed.

### 2.2. *New results on rotating radio transients*

**Maura A. McLaughlin:** A new population of radio-bursting neutron stars discovered in a large scale search for transient radio sources was discussed. Unlike normal radio pulsars, these objects, which are called Rotating RAdio Transient (or RRATs), cannot be detected through their time-averaged emission and are radio sources for typically less than 1 second per day. The spin periods of these objects range from 0.4 to 7 seconds, with period derivatives indicating that at least one RRAT has a magnetar-strength magnetic field. Recent developments were detailed, including X-ray observations and observations with more sensitive radio telescopes, and it was discussed how these objects are related to other neutron star populations. Also, the implications of this new source class for neutron star population estimates was described.

### 2.3. *Isolated neutron stars in optical and X-rays: room for discovery*

**Patricia A. Caraveo:** The multi-wavelength behavior of isolated neutron stars evolves as they age. In particular, the X-ray and optical emissions allow us to follow the shift from the non-thermal regime, typical of young objects, to a mostly thermal one, typical of older specimen. New observations unveil tale-telling details both on young and old objects, reminding us that a lot remains to be discovered in the complex INS family tree.

### 2.4. *Gamma-ray and TeV emission properties of pulsars and pulsar wind nebulae*

**Ocker C. De Jager:** Although more than 1,600 radio pulsars have been discovered, only a few have been detected in the $\gamma$-ray band. This is not because they are intrinsically faint, but because the pulsed component seems to cut off below about 30 GeV (the *EGRET* range), where the sensitivity was severely limited. However, ground-based atmospheric Cerenkov telescopes operating above 100 GeV (the Very High Energy or

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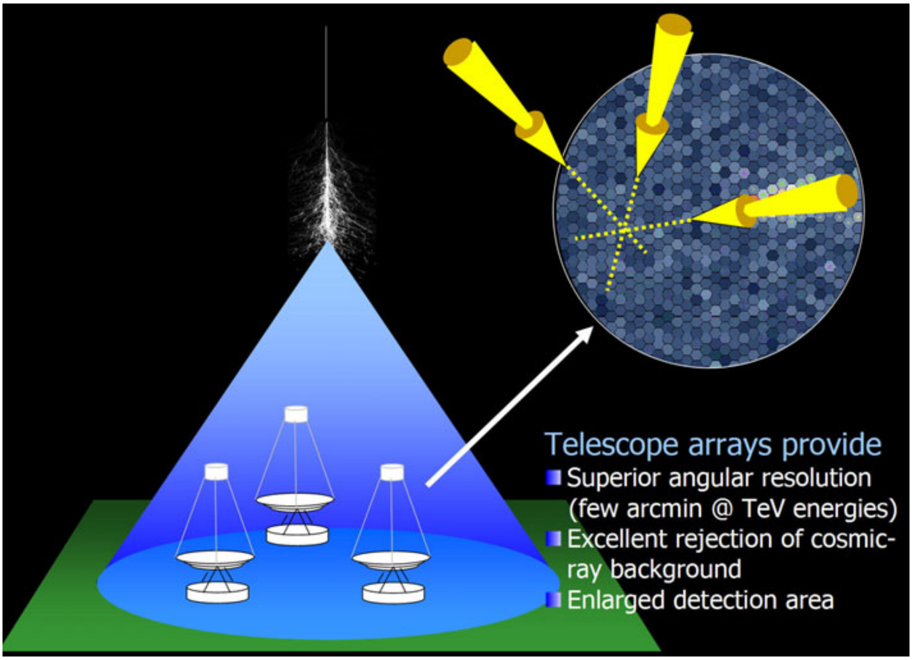


**Figure 1.** The detection of high energy gamma rays with, e.g., the H.E.S.S. telescopes is based on the imaging air Cherenkov technique. An incident high-energy $\gamma$-ray interacts high up in the atmosphere and generates an air shower of secondary particles. The number of shower particles reaches a maximum at about 10 km height, and the shower dies out deeper in the atmosphere. Since the shower particles move at essentially the speed of light, they emit the so-called Cherenkov light, a faint blue light. The Cherenkov light is beamed around the direction of the incident primary particle and illuminates on the ground an area of about 250 m diameter. Chart from the talk (2.4) presented by O.C. De Jager.

VHE domain), have both good sensitivity and good angular resolution to resolve several pulsar wind nebulae (PWN) in the VHE $\gamma$-ray domain. This review talk summarized the progress to date on pulsar and pulsar wind nebula observations and theory. Since $\gamma$-ray observations below 30 GeV have been limited by poor sensitivity, an instrument like *GLAST* should be able to resolve the pulsed component of a significant fraction of radio pulsars. This talk showed how the discovery potential of *GLAST* would be limited for fainter sources in the absence of contemporary radio pulsar parameters. This calls for the introduction of wide field-of-view radio pulsar monitors like KAT to resolve this problem. Most progress on PWN in the $\gamma$-ray domain is made by the HESS telescope system in Namibia. In this case we progressed to the level where VHE Gamma-ray Astronomy is taking the lead at all wavelengths (radio, IR, optical, X-ray and $\gamma$-ray) in the identification and understanding of new PWN. It was shown how the spin history of the PWN is more relevant to such VHE observations rather than X-rays, although the latter probe the more recent history of PWN evolution. It was then shown how these complementary wavebands can be combined to obtain new information about aspects such as the birth periods of pulsars and conversion efficiency of spin-down power to injected ultra-relativistic electrons.

### 2.5. *Pulsar timing and its future perspective*

**David J. Nice:** The present state of radio pulsar timing and prospects for future progress was surveyed. In recent years, pulsar timing experiments have grown rapidly in both

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**Masses of Neutron Stars in Neutron Star-Neutron Star Binaries**

| Pulsar | Recycled Pulsar | Companion Star |
|---|---|---|
| PSR B1913+16 | 1.4408±0.0003 | 1.3873±0.0003 |
| PSR B2127+11C | 1.349 ±0.040 | 1.363 ±0.040 |
| PSR B1534+12 | 1.3332±0.0010 | 1.3452±0.0010 |
| PSR J0737–3039 | 1.337 ±0.005 | 1.250 ±0.005 |
| PSR J1756–2251 | 1.40 ±0.03 | 1.18 ±0.03 |
| PSR J1518+4904 | average mass=1.352±0.003 | |
| PSR J1811–1376 | average mass=1.300±0.450 | |
| PSR J1829+2456 | average mass=1.250±0.010 | |
| PSR J1906+0746* | 1.31 ±0.05 | 1.31 ±0.05 |

*Preliminary

**Figure 2.** Masses of neutron stars in NS-NS binaries. Chart from the talk (2.5) of D. Nice.

quantity and quality, yielding new tests of gravitation, new constraints on the structure of neutron stars, new insight into neutron star kicks and the dynamics of supernovae, and better understanding of the evolution of compact objects in the Galaxy.

The tremendous success of recent pulsar surveys, especially those with the Parkes multi-beam receiver, have vastly increased the number of known pulsars. Ongoing surveys at Arecibo and elsewhere promise to continue yielding new and exciting pulsars. At the same time, advances in instrumentation – including the development of wide-band receivers and spectrometers and the routine use of software coherent de-dispersion data acquisition systems – are increasing the precision attainable in timing experiments. State of the art timing precision is now around 100 nanoseconds. Limitations have been discussed on present timing experiments and prospects for future improvements.

### 2.6. *Radio emission theories of pulsars*

**Vladimir Usov:** Pulsar magnetospheres contain a multi-component, strongly magnetized, relativistic plasma. The present review was mainly concerned with generation and propagation of coherent radio emission in this plasma, emphasizing reasons why up to now there is no commonly-accepted model of the radio emission of pulsars. Possible progress in our knowledge about the mechanism of the pulsar radio emission was discussed.

### 2.7. *Theory of high-energy emission from pulsars*

**Kwong Sang Cheng:** In this talk various models of high energy emission from pulsars were briefly reviewed. In particular it was pointed out that the light curves can provide important constraints in the radiation emission regions and the location of the accelerators (gaps). Furthermore, the energy dependent light curves and phase-dependent spectrum could not be explained in terms of simple two dimensional models, three dimensional models must be used to explain the full detail of the observed data. A three dimensional outer gap model was presented to study the magnetospheric geometry, the light curve and the phase-resolved spectra of the Crab pulsar. Using a synchrotron self-Compton mechanism, the phase-resolved spectra with the energy range from 100 eV to

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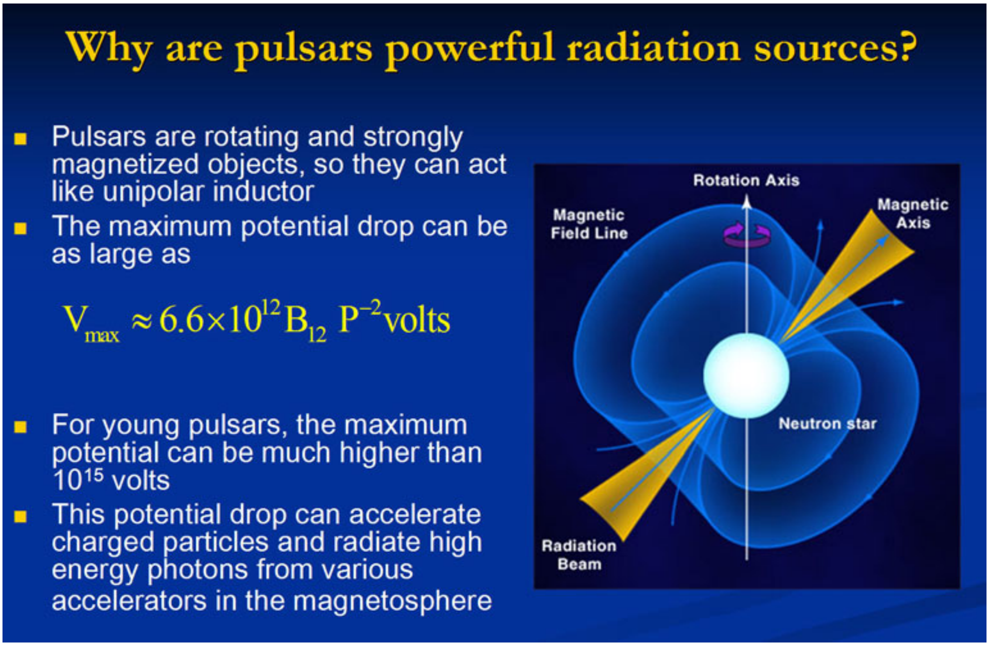


**Figure 3.** Why pulsars are powerful emitters of high-energy radiation (K.S. Cheng, 2.7).

10 GeV of the Crab pulsar can also be explained. The observed polarization angle swing of optical photons was also used to determine the viewing angle.

### 2.8. *On the theory of radio and high-energy emission from pulsars: where to go?*

**John Arons:** Recent progress in the theory of the energy loss from pulsars was discussed, focusing on the advances in force free models of the magnetosphere and on dissipation in the wind, with implications of the latter for unusually models of pulsed emission. Attention was also drawn to the implications the new global magnetosphere models may have for the generation of parallel electric fields, and the implications of these for high-energy emission, radio emission and the global mass loss rate through pair creation. Parallel electric field formation and consequences for photon emission was discussed in scenarios with self-consistent currents, which are rather different from the standard gap models with their starvation electric fields. Finally, remarks were presented on the importance of radiation transfer effects in unraveling the continuing mystery of pulsar radio emission.

### 2.9. *Cooling neutron stars: the present and the future*

**Sachiko Tsuruta:** Recent years have seen some significant progress in theoretical studies of physics of dense matter. Combined with the observational data now available from the successful launch of *Chandra* and *XMM-Newton* X-ray space missions as well as various lower-energy band observations, these developments now offer the hope for distinguishing various competing neutron star thermal evolution models. For instance, the latest theoretical and observational developments may already exclude both nucleon and kaon direct Urca cooling. In this way we can now have a realistic hope for determining various important properties, such as the composition, superfluidity, the equation of state and stellar radius. These developments should help us obtain deeper insight into the properties of dense matter.

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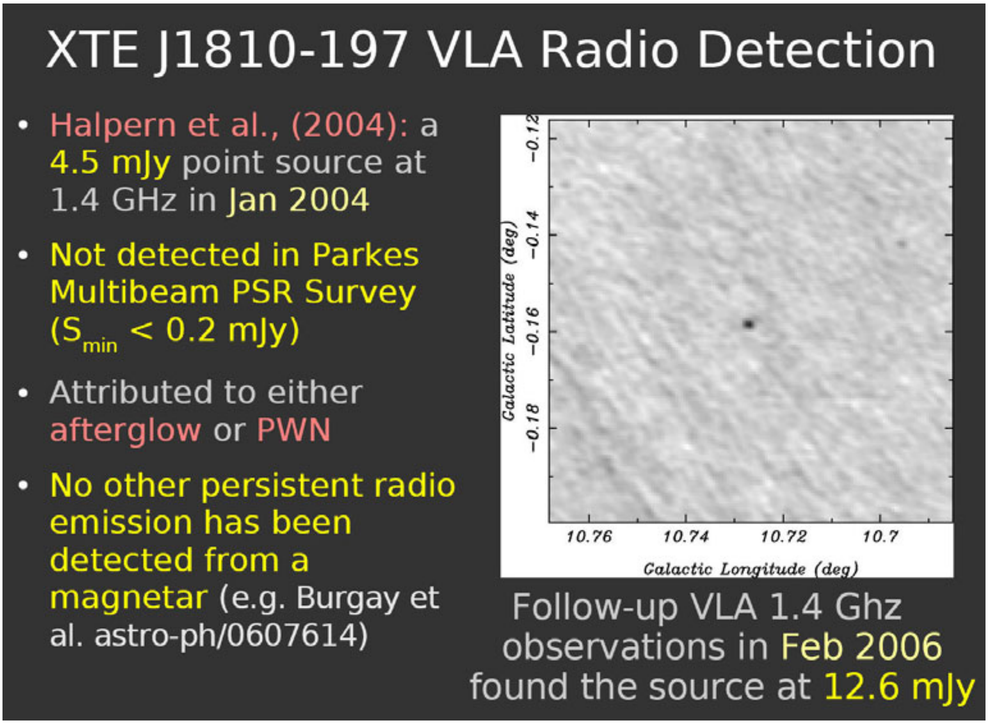


**Figure 4.** Radio detection of XTE J1810−197, as presented in the talk of S.M. Ransom (2.10).

### 2.10. *A decade of surprises from the anomalous X-ray pulsars*

**Scott M. Ransom:** A decade ago, the defining characteristics of the Anomalous X-ray Pulsars (AXPs) included slow spin periods (5–9 s), relatively soft but constant X-ray luminosities in the range of $10^{35}$–$10^{36}$ erg/s, and steady spin-down rates. The X-ray luminosities are too large to be powered by pulsar spin-down, and given the lack of evidence for accretion, are thought to be caused by the decay of $\sim 10^{14}$–$10^{15}$ G magnetic fields (i.e., the magnetar theory as proposed by Thompson and Duncan). Within the past decade, though, detailed X-ray monitoring observations have shown that these sources are anything but constant and steady. Timing noise, glitches, X-ray bursts, and pulse profile and pulsed flux variations are now known to be relatively common in these sources. In addition, at least one recently discovered AXP, XTE J1810−197, is a full-fledged transient object. Detections in the optical and infra-red (including pulsations) and recent hard X-ray observations have complicated our views of their emission mechanisms. Finally, very recent detections of magnetar-like radio pulsars, as well as strong (and transient) radio pulsations from XTE J1810−197, show that these sources are linked (at least in some way) with the much more common radio pulsars.

### 2.11. *Pulsars and gravity*

**Ingrid H. Stairs:** Radio pulsars are superb tools for testing the predictions of strong-field gravitational theories. The currently achieved tests of equivalence principles and of predictions for relativistic binary orbital parameters were described, as well as limits on a gravitational-wave background, and future prospects in each of these areas were discussed.

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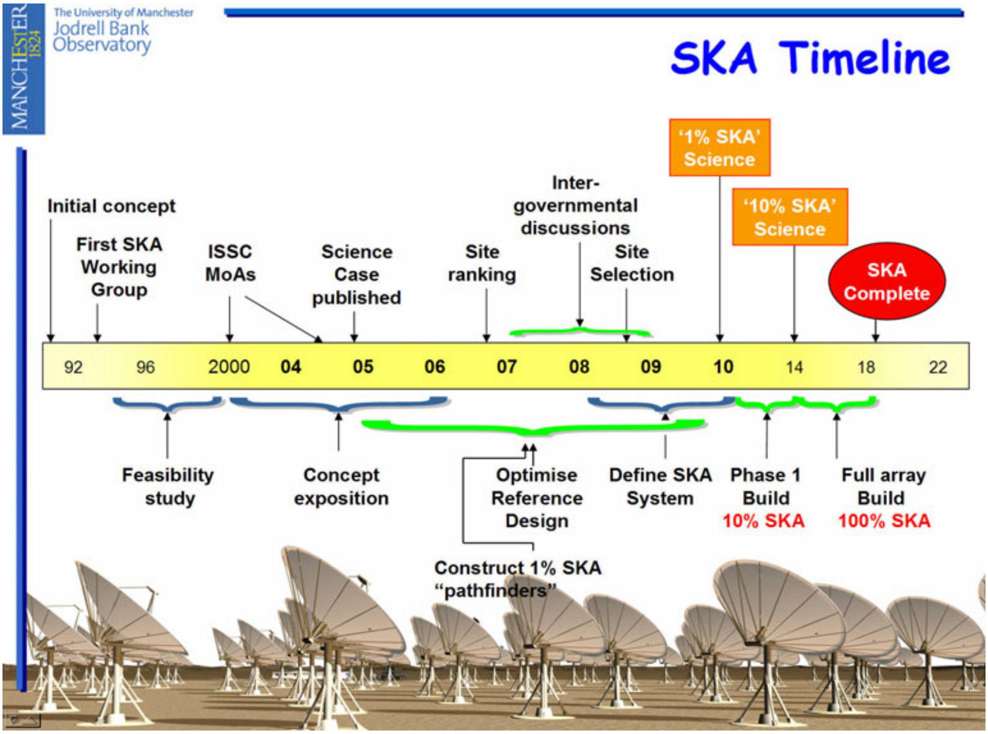


**Figure 5.** Time line of the SKA project, as presented by M. Kramer (2.12).

## 2.12. *Future radio observatories for pulsar studies*

**Michael Kramer:** Over the next decade, radio astronomers will have new, exciting instruments available to answer fundamental questions in physics and astrophysics. Without doubts, new discoveries will be made, revealing new objects and phenomena. We can expect pulsar astronomers to receive their fair share. In many respects, the field of pulsar astrophysics will change, as the science will not simply be a continuation of what has been done so successfully over the past 40 years. Instead, the huge number of pulsars to be discovered and studied with an unprecedented sensitivity will provide a step forward into exciting times. Instruments like the Low Frequency Array (LOFAR), the Square Kilometer Array (SKA) and their powerful pathfinder telescopes will enable a complete census of Galactic pulsars, ultimate tests of gravitational physics, unique studies of the emission process and much more. This talk demonstrated the potential of the future instruments by presenting highlights of the science to be conducted.

## 2.13. *Future optical and X-ray observatories for pulsar studies*

**Werner Becker:** Optical and X-ray astronomy has made great progress in the past several years thanks to telescopes with larger effective areas and greatly improved spatial, temporal and spectral resolutions. The next generation instruments like *XEUS*, *Constellation-X*, *Simbol-X*, *eROSITA*, the *James Webb Space Telescope* and the ESOs Extremely Large optical Telescope are supposed to bring again a major improvement in sensitivity. The purpose of this talk was to summarize the future plans for X-ray and optical telescopes with the emphasis of their application for pulsar and neutron star astronomy.

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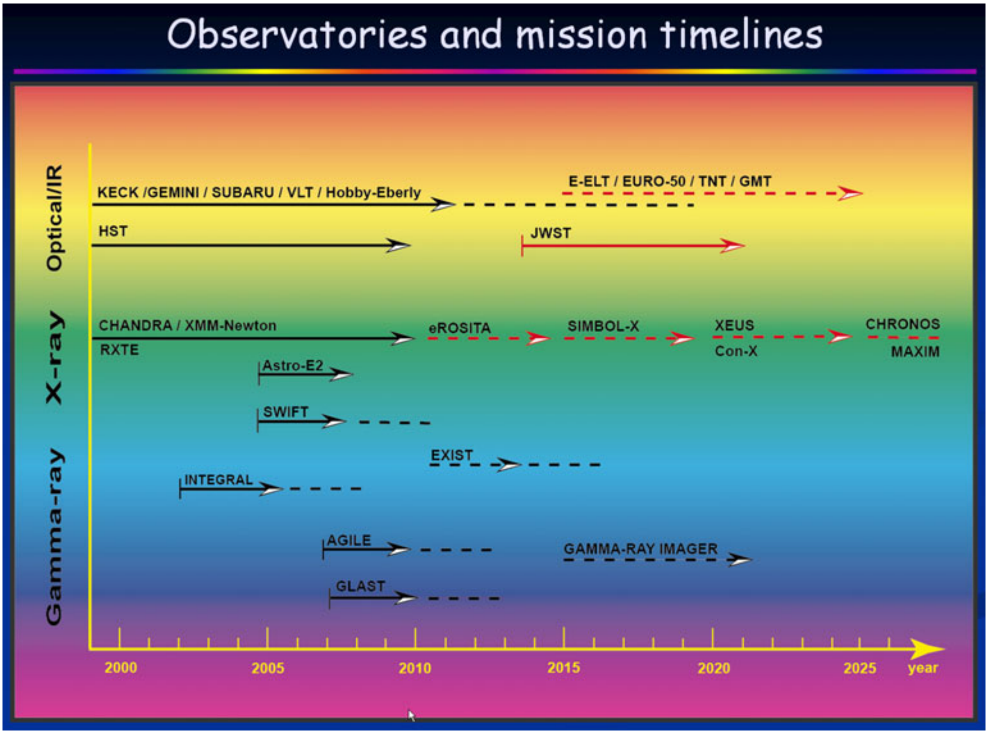


**Figure 6.** Time line of future high-energy missions, as presented by W. Becker (2.13).

### 2.14. *Future $\gamma$-ray and TeV observatories for pulsar searches*

**David A. Smith:** GeV measurements of pulsar lightcurves *versus* energy provide information on beam geometry, and spectral cut-offs give insights into the particle acceleration region(s) around the neutron star. The two together can help build a better picture of neutron star populations in the Galaxy. We are on the verge of instrumental break-through that promise to increase the sample of measured objects by $\sim 10$. This talk described instruments able to detect multi-GeV pulsations for the next few years. Developments of ground-based atmospheric Cherenkov detectors were covered, AGILEs prospects were reviewed, and then the talk focused on the *LAT (Large Area Telescope)* on *GLAST*, including sensitivity estimations. Accurate radio ephemerides can greatly enhance the $\gamma$-ray pulsar science. Efforts to build a large ephemerides database were described.

## 3. Poster papers

### 3.1. *Effects of core magnetic fields in evolution of binary neutron stars*

**Taghi Mirtorabi, Atefeh J. Khasraghi, and Shohre Abdolrahimi:** The standard scenario for evolution in a close binary system in which the neutron star pass through four evolutionary phases (isolated star, propeller, wind accretion and Roche-lobe accretion) was employed to calculate transport of orbital angular momentum to the neutron star or loss of angular momentum from the whole system. The evolution of core magnetic field of neutron stars in close binary systems with a low mass main sequence companion was explored. Assuming the core as a type II superconductor so the magnetic flux

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can be transported as quantized fluxoids, calculation have been performed to determine magnetic filed decay and its interaction with the mater accreted from the companion. The evolution of semi major axis of the binary in a time scale of $10^9$ years comparable with the main sequence life time of the low mass companion was also investigated.

### 3.2. *External electromagnetic fields of slowly rotating relativistic magnetized NUT stars*

**Bobomurat J. Ahmedov and A.V. Khugaev:** Analytic general relativistic expressions for the electromagnetic fields external to a slowly-rotating magnetized NUT star with non-vanishing gravitomagnetic charge have been presented. Solutions for the electric and magnetic fields have been found after separating the Maxwell equations in the external background spacetime of a slowly rotating NUT star into angular and radial parts in the lowest order approximation in specific angular momentum and NUT parameter. The relativistic star was considered isolated and in vacuum, with different models for stellar magnetic field: (i) mono-polar magnetic field, and (ii) dipolar magnetic field aligned with the axis of rotation.

It was shown that the general relativistic corrections due to the dragging of reference frames and gravitomagnetic charge were not present in the form of the magnetic fields but emerge only in the form of the electric fields. In particular, it was argued that the frame-dragging and gravitomagnetic charge provide an additional induced electric field which is analogous to the one introduced by the rotation of the star in the flat spacetime limit.

### 3.3. *PSR J0538+2817 as the remnant of the first supernova explosion in a massive binary*

**Vasilii V. Gvaramadze:** It is generally accepted that the radio pulsar PSR J0538+2817 is associated with the supernova remnant (SNR) S 147. The only problem for the association is the obvious discrepancy (Kramer *et al.* 2003) between the kinematic age of the system of $\sim 30$ kyr (estimated from the angular offset of the pulsar from the geometric center of the SNR and pulsar's proper motion) and the characteristic age of the pulsar of $\sim 600$ kyr. To reconcile these ages one can assume that the pulsar was born with a spin period close to the present one (Kramer *et al.* 2003; Romani & Ng 2003).

An alternative explanation of the age discrepancy based on the fact that J0538+2817 could be the stellar remnant of the first supernova explosion in a massive binary system and therefore could be as old as indicated by its characteristic age was proposed. The proposal implied that S 147 is the diffuse remnant of the second supernova explosion (that disrupted the binary system) and that a much younger second neutron star (not necessarily manifesting itself as a radio pulsar) should be associated with S 147. The existing observational data on the system PSR J0538+2817/SNR S 147 were used to suggest that the progenitor of the supernova that formed S 147 was a Wolf-Rayet star (so that the supernova explosion occurred within a wind bubble surrounded by a massive shell) and to constrain the parameters of the binary system. The magnitude and direction of the kick velocity received by the young neutron star at birth was also restricted and it was found that the kick vector should not strongly deviate from the orbital plane of the binary system.

### 3.4. *Ensemble pulsar time scale*

**Alexander E. Rodin:** The purpose of this work was to construct an algorithm of a new astronomical time scale based on the rotation of pulsars, which has comparable accuracy with the most precise terrestrial time scale TT.

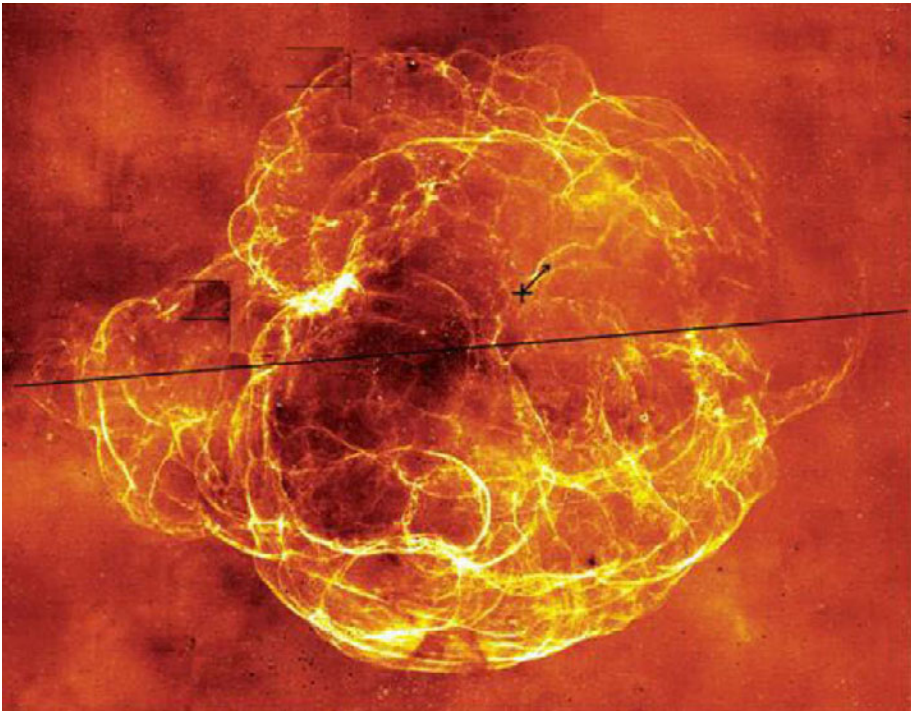

**Figure 7.** $H_\alpha$ image of the SNR S 147 (Drew *et al.* 2005; reproduced in the poster with the permission of the IPHAS collaboration). The position of PSR J0538+2817 is indicated by a cross. The arrow shows the direction of the pulsar proper motion vector (Kramer *et al.* 2003). The line drawn in the east-west direction shows the bilateral symmetry axis. North it up, east is west. Image from V.V. Gvaramadze (3.3).

This algorithm is based on the Wiener optimal filtering method and allows separating contributions to the post-fit pulsar timing residuals of the atomic clock used in pulsar timing and spin variations of the pulsar itself. The optimal filters were constructed with use of the cross and auto covariance functions (in time domain) or auto and cross power spectra (in frequency domain) of the post-fit timing residuals of pulsars participating in construction of the ensemble time scale.

The algorithm was applied to the timing data of millisecond pulsars PSR B1855+09 and B1937+21 (Kaspi *et al.* 1994) and allowed to obtain the corrections of UTC scale relative to ensemble pulsar time scale PTens. Comparison of the differences UTC PTens and UTC TT displays significant correlation between them at level 0.79. Subsequent analysis of TT and PTens shows that TT coincides with PTens within $0.40 \pm 0.17$ mcs and has a fractional stability $10^{-15}$ at the 7 years time interval.

Relatively close angular distance (15.5 degrees) on the sky between these pulsars gives grounds to expect that there is a correlated signal in the post-fit timing data caused by the stochastic gravitational wave background (GWB). A new limit of the fractional energy density of GWB based on the difference TT and PTens was established to be $\Omega_g h^2 \simeq 2 \times 10^{-10}$. This new value is by one order lower than the previously published one owing to application of the new algorithm that separates the proper pulsars spin and local atomic standard variations.

### 3.5. *Comparison of giant radio pulses in young pulsars and millisecond pulsars*

**Agnieszka Slowikowska, Axel Jessner, Gottfried Kanbach, and Bernd Klein:** Pulse-to-pulse intensity variations are a common property of pulsar radio emission. For some of the objects single pulses are often 10-times stronger than their average pulse. The most dramatic events are the so called giant radio pulses (GRPs). They can be 1000-times stronger than the regular single pulses from the pulsar. Giant pulses are a rare phenomenon, occurring in very few pulsars which split into two groups. The first group contains very young and energetic pulsars like the Crab pulsar, and its twin in the LMC (PSR B0540−69), while the second group is represented by old, recycled millisecond pulsars like PSR B1937+21, PSR B1821−24, PSR B1957+20, and PSR J0218+4232 – the only millisecond pulsar detected in $\gamma$-rays. The characteristics of GRP's for these two pulsar groups was discussed. In particular, the poster focused on the flux distributions of GRPs which were compared. Moreover, the latest findings of new features in the Crab GRPs were presented. Analysis of Effelsberg data taken at 8.35 GHz have shown that GRPs do occur in all phases of its ordinary radio emission, including the phases of the two high-frequency components (HFCs) visible only between 5 and 9 GHz. This suggests that a similar emission mechanism may be responsible for the main pulse, the inter pulse and the HFCs. Finally, the similarities and differences between both groups of pulsars in the context of timing, spectral and polarization properties of these pulsars were discussed. It was also attempted to answer the question why pulsars belonging to so different classes do show the same giant radio emission phenomena.

### 3.6. *Integral IBIS and JEM-X observations of PSR B0540−69*

**Agnieszka Slowikowska, Gottfried Kanbach, Jurek Borkowski, and Werner Becker:** The high-energy pulsar PSR B0540−69 in the Large Magellanic Cloud ($d \simeq 49.4$ kpc), embedded in a synchrotron plerion in the center of SNR 0540−69.3 is often referred to as an extragalactic 'twin' of the Crab pulsar. Its pulsed emission has been detected up to about 48 keV so far. The results from the search for PSR B0540−69 up to 300 keV in the 1 Ms *INTEGRAL* data was presented. *INTEGRAL* was pointed to the LMC during 6 revolutions in January 2003, and 3 revolutions in January 2004. The events used for timing and spectral analysis of the source come from the *IBIS/ISGRI* and *JEM-X* detectors. Moreover, the details of data analysis technique used for this weak source were presented.

### 3.7. *Plasma modes along open field lines of neutron star endowed with gravitomagnetic NUT charge*

**Bobomurat J. Ahmedov and Valeria G. Kagramanova:** Electrostatic plasma modes along the open field lines of a rotating neutron star endowed with gravitomagnetic charge or NUT parameter have been considered. Goldreich-Julian charge density in general relativity was analyzed for the neutron star with non-zero NUT parameter. It was found that the charge density is maximal at the polar cap and remains almost the same in a certain extended region of the pole. For a steady state Goldreich-Julian charge density it was found that the usual plasma oscillation along the field lines; plasma frequency resembles the gravitational redshift close to the Schwarzschild radius. The results in studying the nonlinear plasma mode along the field lines were presented. The equation contained a term that described the growing plasma modes near Schwarzschild radius in a black hole environment. The term vanished with the distance far away from the gravitating object. For initially zero potential and field on the surface of a neutron star, Goldreich-Julian charge density was found to create the plasma mode which was en-

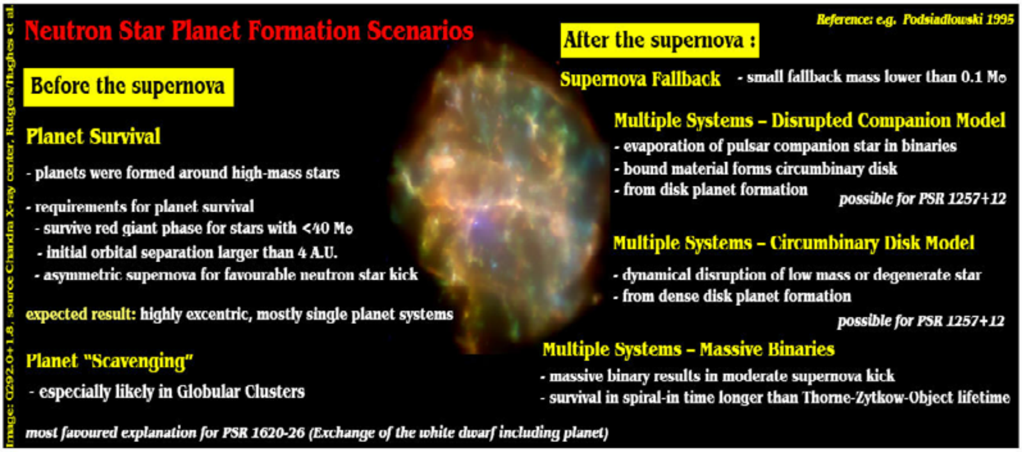


**Figure 8.** Image from Posselt, Neuhäuser and Haber (3.9).

hanced and propagated almost without damping along the open field lines of magnetized NUT star.

### 3.8. *The drift model of magnetars*

**Igor F. Malov and George Z. Machabeli:** It was shown that the drift waves near the light cylinder can cause the modulation of emission with periods of order several seconds. These periods explain the intervals between successive pulses observed in "magnetars" and radio pulsars with long periods. The model under consideration gave the possibility to calculate real rotation periods of host neutron stars. They are less than 1 sec for the investigated objects. The magnetic fields at the surface of the neutron star are of order $10^{11}$–$10^{13}$ G and equal to the fields usual for known radio pulsars.

### 3.9. *Sub-stellar companions around neutron stars*

**Bettina Posselt, Ralph Neuhäuser, and Frank Haberl:** Planets or sub-stellar companions around neutron stars can give valuable insights into a neutron star's formation history considering for example birth kicks or fallback disks. They may also help to derive neutron star masses which would be very welcome especially if the radius can be derived by other means as for the radio-quiet X-ray thermal neutron stars. Currently there are two planetary systems around millisecond pulsars known. They have been found by the pulse timing technique which is most sensitive to old millisecond pulsars. Some of the formation theories can already be ruled out for these systems. However, statistics are very poor and other search techniques are needed to cover also young, even radio-quiet neutron stars.

The first results of direct imaging search for sub-stellar companions around the closest and youngest neutron stars started three years ago with ESO's VLT were presented. Among the objects was the famous RX J1856.5−3754 for which a sub-stellar object could help to constrain the equation of state as the radius was already previously derived by its X-ray thermal emission.

### 3.10. *Detection of the individual pulses of the pulsars B0809+74, B0834+06, B0950+08, B0943+10, B1133+16 at decameter wave range*

**O.M. Ulyanov, V.V. Zakharenko, Alexander A. Konovalenko, *et al.*:** Radio emission of single pulses for five pulsars was found at frequencies 18 - 30 MHz. It was

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reported that the radio emission is caused by the strong subpulses that have peak intensity of more than 20 times larger than the peak intensity of average profiles. It was found that the intensity of single pulses has a strong variation in frequency and time. The probability of detection of the anomalous intense pulses thus does not exceed several percents at Decameter wave range. Usually such pulses are detected in short series (not more than 10 pulses). Typical band values of detection for the pulses with anomalous intensities lies in the range from 0.2 to 0.5 octaves.

### 3.11. *An analytical description of low-energy secondary plasma particle distribution in pulsar magnetospheres*

**Victor M. Kontorovich and A.B. Flanchik:** A simple analytical approximation of the form of low-energy cut-off of the secondary particle distribution was proposed. This approximation is acceptable for describing the known cascade numerical simulation. The distribution form and maximum position as function of pulsar parameters have been found theoretically by considering the curvature radiation process and the electron-positron pairs production. An influence of synchrotron radiation on the form and maximum of the low-energy distribution was considered.

### 3.12. *Timing irregularities and the neutron star stability*

**Johnson O. Urama:** Observations show that the different manifestations of neutron stars exhibit measurable departures from the predicted slow down. This has been largely attributed to rotational irregularities, timing noise, glitches, and precession. The analysis of the regular spin-down and jump parameters for a combined set of the pulsars (radio, optical, X-ray and $\gamma$-ray) and magnetars was presented. It was also attempted to quantify the stability of neutron stars in general.

### 3.13. *Force-free pulsar magnetosphere*

**Andrey N. Timokhin:** The properties of a force-free pulsar magnetosphere and address the role of electron-positron cascades in determining a particular configuration among other possible force-free magnetospheric configurations were discussed. Results of high resolution numerical simulations of the force-free magnetosphere of aligned rotator and analyze in details properties of an aligned pulsar were reported. It was argued that the closed field line zone should grow with time slower than the light cylinder; this yield the pulsar braking index less than 3. However, models of aligned rotator magnetosphere with widely accepted configuration of magnetic field, when the last closed field line lies in equatorial plane at large distances from pulsar, have serious difficulties. The solutions of this problem were discussed and it was argued that in any case, also for inclined pulsar, energy losses should evolve with time differently than it is predicted by the magneto-dipolar formula and the pulsar braking index should be different from the "canonical" value equal to 3.

### 3.14. *Crab pulsar optical photometry and spectroscopy with microsecond temporal resolution*

**Gregory Beskin, Sergey Karpov, Vladimir Plokhotnichenko, *et al.*:** The results of fast photometry and spectroscopy of the Crab pulsar with microsecond temporal resolution were presented. The observations have been performed on William Herschel 4 m and BTA 6 m telescopes using APD avalanche photon counter and PSD panoramic photon imager. The stability of the optical pulse was analyzed and the search for the variations of the pulse shape along with its arrival time stability was performed. Upper

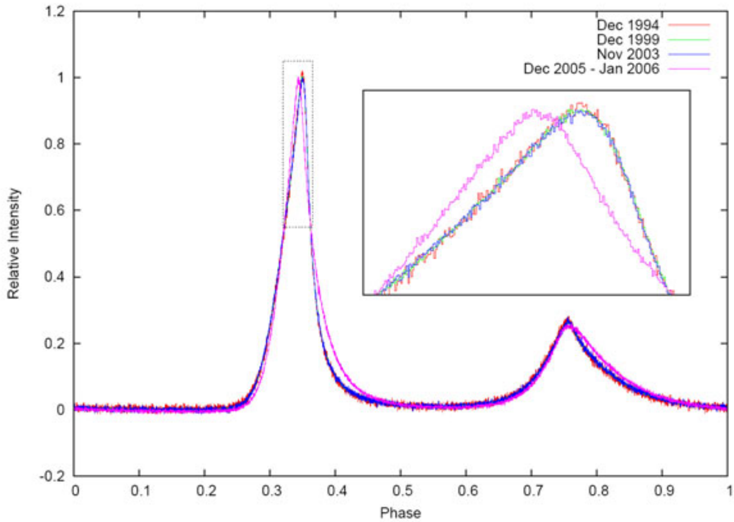


**Figure 9.** Phase-aligned light curves of the Crab pulsar from optical observations at different epochs all scaled to the same pulse height. In the observation at the 6 m SAO telescope in January 2007 the Crab pulsar light curve was similar to the one observed in 1994, 1999 and 2003. This means that the change of the light curve observed in December 2005/January 2006 was either a stochastic (rare) event or a not understood instrumental effect. Image from G. Beskin *et al.* (3.14).

limits on the possible short time scale free precession of the pulsar and the stochastic variable optical emission component were placed. The results of the low resolution ($\sim 300$ Å) phase-resolved spectroscopy of the pulsar emission were discussed, first of all the distinction of the spectra of pulses and off-pulse phase intervals.

### 3.15. *Discovery of a large time scale cyclic evolution of radio pulsars rotational frequency*

**Gregory Beskin, Anton Biryukov and Sergey Karpov:** The recent massive measurements of pulsar frequency second derivatives have shown that they are 100–1000 times larger than expected for standard pulsar slowdown. Moreover, the second derivatives as well as braking indices were even negative for about half of the pulsars. It was explained that these paradoxical results from statistical analysis of the rotational parameters (frequency, its first and second derivatives) of the subset of 295 pulsars taken mostly from the ATNF database. The strong correlation of second and first frequency derivatives either for positive (correlation coefficient $r \simeq 0.9$) and negative ($r \simeq 0.85$) values of second derivative, and of the frequency and its first derivative ($r \simeq 0.7$) were found. These dependencies were interpreted as evolutionary ones due to the first frequency derivative being nearly proportional to the characteristic age. The derived statistical relations as well as "anomalous" values of the second frequency derivative were well explained in the framework of the simple model of cyclic evolution of the rotational frequency of the pulsars. It combined the secular change of the rotational parameters according to the power law with braking index $n \simeq 5$ and harmonic oscillations of 100–1000 years period with an amplitude from $10^{-3}$ Hz for young pulsars to $10^{-10}$ Hz for older ones. It was found that the physical nature of these cyclic variations of the rotational frequency may be similar to the well-known red timing noise, however, with much larger characteristic time scale.

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### 3.16. *Abnormal phases in nuclear matter in supernova core collapse model*

**D.J. Bora, Hira L. Duorah, and Kalpana Duorah:** The role of abnormal phases in nuclear matter on the basis of the well-known Lee-Wick theory was studied for the determination of the shock strength at the core bouncing of type II supernova. Relativistic equation for collapse beyond nuclear density with a still stronger magnetic field was developed to study the effect of appearance of the abnormal phases. This lead to the softening of the equation of state giving rise to strong shock. The magnetar thus formed can be a store-house of many high-energy events including rapid $\gamma$-ray bursts. A strong magnetic field beyond some critical value sometimes can exponentially accelerate certain reactions producing rapid bursts of energy. Some seismic events on the solidified crusts of magnetars can also be alluded for the short $\gamma$-ray burst discovered in December 2004 at the site of SGR 1806−20.

### 3.17. *Instant radio spectra of giant pulses from the Crab pulsar over decimeter to decameter wave bands*

**Michail V. Popov, Arkady D. Kuzmin, O.M. Ulyanov, *et al.*:** The results of simultaneous multi-frequency observations of giant radio pulses (GPs) from the Crab pulsar PSR B0531+21 at frequencies of 23, 111 and 600 MHz were presented. For the first time GPs were detected at such low frequency as 23 MHz. Among 45 GPs detected in the overall observations time with 600 MHz, 12 GPs were identified as simultaneous ones at 600 and 23 MHz. At 111 MHz among 128 GPs detected in the overall observations time with 600 MHz, 21 GPs were identified as simultaneous ones at 600 and 111 MHz. Spectral indices for the power-law frequency dependence of GPs energy were enclosed between −3.1 and −1.6. The mean spectral index equals to $-2.7 \pm 0.1$ and was the same for both frequency combinations 600 − 111 MHz and 600 − 23 MHz.

A big scatter in values of the individual spectral indexes and a large number of unidentified giant pulses indicated that a real form of spectra of individual giant pulses did not follow a simple power law. The shape of giant pulses at all three frequencies was governed by the scattering of radio waves on the inhomogeneities of the interstellar plasma. The pulse scatter broadening and their frequency dependence was measured as $\tau_{\rm SC} = 20(\nu/100)^{-3.5\pm0.1}$ ms, where frequency $\nu$ is in MHz.

### 3.18. *Pulsar nulling quantitative analysis*

**John H. Seiradakis and Kosmas Lazaridis:** Using long sequences of single pulses the nulling behavior of several pulsars was analyzed. Each pulsar has been characterized by a ‘nulling parameter’, which represents the average length of consecutive null pulses and a ‘nulling max’ parameter, which represents the maximum length of consecutive null pulses. These two parameters were compared to other pulsar parameters. Some interesting correlations were derived.

### 3.19. *Eclipse study of the double pulsar*

**René P. Breton, Victoria M. Kaspi, Maura A. McLaughlin, *et al.*:** The double pulsar system PSR J0737−3039 offers an unprecedented opportunity for studying General Relativity and neutron-star magnetospheres. This system has a favorable orbital inclination such that the millisecond pulsar $A$, is eclipsed when its slower companion $B$, passes in front. High time resolution light curves of the eclipses reveal periodic modulations of the radio flux corresponding to the fundamental and the first harmonic of pulsar $B$ spin frequency. Eclipse modeling is highly sensitive to the geometrical configuration of the system and thus provides a unique probe for parameters like the inclination angle

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of pulsar $B$ spin axis as well as their time evolution due to relativistic effects. Detailed fitting of the pulsar $A$ eclipse light curves to a model that includes, for pulsar $B$, a simple dipolar magnetic field was presented. It was found that the eclipses can be reproduced very well, and one obtains precise measurements of pulsar $B$'s orientation in space. Results on a search for secular changes caused by geodetic precession of pulsar $B$'s spin axis were reported.

### 3.20. *Observations of southern pulsars at high radio frequencies*

**Aris Karastergiou and Simon Johnston:** A number of pulsars at 1.4, 3.1 and 8.4 GHz in full polarization at the Parkes radio-telescope was observed. The main objective was to study the frequency evolution of polarization by means of new high quality polarization data at high frequencies. Average polarization profiles with high-time resolution to update already existing previous observations were also obtained. Detailed description of a total of 97 polarization profiles at the three aforementioned frequencies was provided. This relatively large sample provided the opportunity to study effects related to the linear and circular polarization as well as the polarization position angle. An evidence was found that: (1) a simple model where two orthogonal polarization modes with competing spectral indices can account for many observational properties of the linear polarization and total power; (2) the position angle dependence on frequency depends on the different relative strength of profile components at different frequencies; (3) young, energetic pulsars remain highly polarized at high frequencies; and (4) highly polarized components may originate from higher up in the pulsar magnetosphere then unpolarized components. A summary of these results was presented.

### 3.21. *Pulsar braking indices*

**Altan Baykal and M. Ali Alpar:** Almost all pulsars with anomalous positive second derivative of angular acceleration measurements (corresponding to anomalous braking indices in the range $5 < n < 100$), including all the pulsars with observed large glitches as well as post glitch or inter-glitch second measurement obey the scaling between glitch parameters originally noted in the Vela pulsar. Negative second derivative values can be understood in terms of glitches that were missed or remained unresolved. The glitch rates and *a priori* probabilities of positive and negative braking indices according to the model developed for the Vela pulsar were discussed. This behavior supports the universal occurrence of a nonlinear dynamical coupling between the neutron star crust and an interior superfluid component.

### 3.22. *Electrodynamics of pulsar's electrosphere*

**Jérôme A. Pétri:** A self-consistent model of the magnetosphere of inactive, charged, aligned rotator pulsars with help of a semi-analytical and numerical algorithm, was presented. In this model the only free parameter was the total charge of the system. This "electro-sphere" is stable to vacuum breakdown by electron-positron pair production. However, it appears to be unstable to the so-called "diocotron" instability which is an electrostatic instability. Eigenspectra and eigenfunctions for different disc models, which differ by the total charge of the disc-star system were presented. The evolution of this instability on a long time-scale was studied in a fully non-linear description by means of numerical simulations. For multi-mode excitation, the average macroscopic response of the system could be described by a quasi-linear model. It was found that in the presence of an external source feeding the disk with positive charges, representing the effect of pair creation activity in the gaps, the diocotron instability may give rise to an efficient diffusion of charged particles across the magnetic field lines.

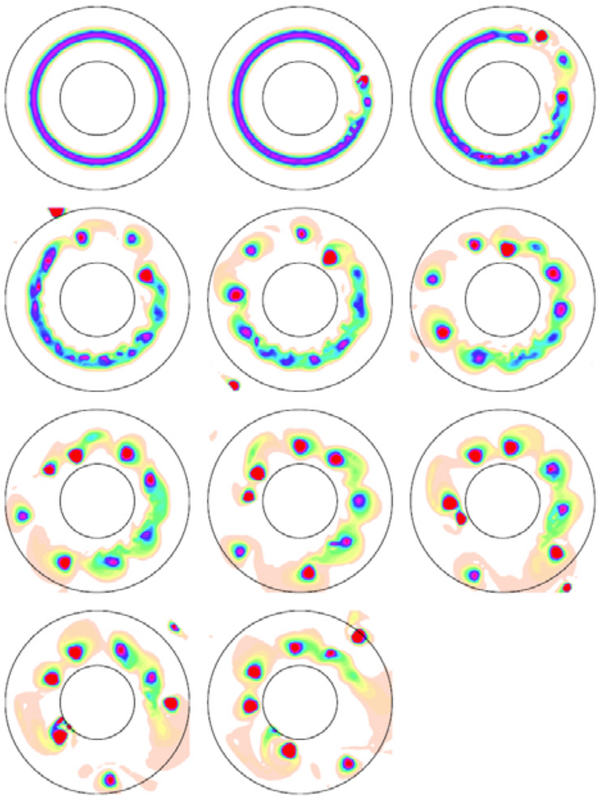

**Figure 10.** Non-linear evolution of the diocotron instability in an infinitely thin disk. Image from poster 3.22 of J.A. Petri.

### 3.23. *About one hypothesis on the origin of anomalous X-ray pulsars and soft γ-ray repeaters*

**Fikret K.O. Kasumov, A. Allakhverdiev, and Abdul I. Asvarov:** The possibility of realization of the scenario, according to which anomalous X-ray pulsars (AXPs) and soft $\gamma$-ray repeaters (SGRs) originate from the radio pulsars with the very close initial parameters (period, magnetic field, etc.), subjected to considerable and prolonged glitches, was analyzed. This scenario provides both an increase in the period of ordinary pulsars and the attainment of magnetic field strengths typical of these objects ($B \simeq 10^{13}$–$10^{14}$ G), a new class of neutron stars, called magnetars, at an insignificant initial magnetic field value $B \simeq 3 \times 10^{10}$-$10^{11}$ G. With this aim, the criteria to be satisfied by a potential progenitor of AXPs and SGRs were determined and analyzed. So, taking into account the combined action of all factors (magnetic field, distance, birth place, satisfying to our criteria, etc.) we restricted our analysis to 100 pulsars with $B > 5 \times 10^{12}$ G and $P > 0.5$ s. The observed characteristics of such pulsars, their association with supernova remnants, and their evolution in the $P - \dot{P}$ diagram with allowance made for the actual age of the possible AXP and SGR progenitor were shown to be in conflict with the suggested scenario and can be better described in the framework of the standard magneto-dipole model of pulsar evolution.

### 3.24. *Combined models of evolution and real ages of pulsars*

**A. Allakhverdiev, Fikret K.O. Kasumov, and Sevinc O. Tagieva:** The test for checking the applicability of fall-back or propeller models for the pulsar evolution was

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proposed. This test was based on the comparison of the pulsars ages predicted by these models with the real kinematical ages of pulsars. With this goal two groups of pulsars, namely relatively young and old pulsars with the distances from the galactic plane $z < 100$ pc and $z < 300$ pc, respectively, were selected. At the same time, the irregular character of deviation of the pulsars birthplaces from the geometrical plane of the Galaxy has been taken into account. The distribution of these groups of pulsars in $P - \dot{P}$ diagram was compared with the theoretical tracks of the evolution of the pulsars predicted by fall-back and combined dipole + propeller models at various values of the initial parameters of radio pulsars (magnetic field and accretion rate of matter). As it is well known, characteristic feature of combined model (unlike to the pure magneto-dipole) is the increase of period derivative up to some critical value with increase of the period of pulsars, i.e., the age of pulsars. It was shown that the distribution of selected pulsars in the mentioned diagram contradicts to this model and can be easily explained by standard model of pulsar evolution.

### 3.25. *X-ray emission from hot polar cap in pulsars with drifting subpulses*

**Janusz Gil and George I. Melikidze:** Within the framework of the partially screened inner acceleration region the relationship between the X-ray luminosity and the circulational periodicity of drifting subpulses was derived. This relationship was quite well satisfied in pulsars for which an appropriate radio and X-ray measurements exist. A special case of PSR B0943+10 was presented and discussed. The problem of formation of a partially screened inner acceleration region for all pulsars with drifting subpulses was also considered. It was argued that an efficient inner acceleration region just above the polar cap can be formed in a very strong and curved non-dipolar surface magnetic field.

### 3.26. *Pulsed radio emission from two XDINS*

**Valerii M. Malofeev, O.I. Malov, and D.A. Teplykh:** Investigations of two X-ray dim isolated neutron stars: J1308.6+212708 and J2143.03+065419 were reported. The observations were carried out on two sensitive transit radio telescopes in Pushchino at a few frequencies in the range 111–42 MHz. Mean pulse profiles, the flux density and the dispersion measures were presented. The measures of periods and their derivatives were reported, as well as the estimation of distances and integral radio luminosities. The comparison with X-ray observations was made.

### 3.27. *Magnetospheric eclipses in the double pulsar system J0737−3039*

**Roman R. Rafikov and Peter Goldreich:** The recently discovered double pulsar system, PSR J0737−3039, consisting of a millisecond and a normal pulsars in a 2.4 hr orbit, provides us with unprecedented tests of general relativity and magnetospheric effects. One of the most interesting phenomena observed in this system is the eclipse of the millisecond pulsar in the radio at its conjunction with the normal pulsar. A theory which explains this observation as a result of synchrotron absorption of the millisecond pulsar radio beam in the magnetosphere of the normal pulsar was presented. Absorption was induced in a sense that the intense radio beam of the millisecond pulsar itself strongly modifies the properties of the plasma in the closed part of the normal pulsar magnetosphere: absorption of high-brightness temperature radio emission heats up particles already present there and also allows additional pair plasma to be trapped in this region by magnetic bottling effect. This theory self-consistently predicts the size of the eclipsing region which agrees very well with the observed duration of eclipse. Recent observations of the variability of transmission during the eclipse modulated at the rotation period of

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the normal pulsar have been interpreted as resulting from the absorption by the rigidly rotating dipolar-shaped magnetosphere which is in perfect agreement with the presented theory.

### 3.28. *Electromagnetic fields of magnetized neutron stars in braneworld*

**Bobomurat J. Ahmedov and F.J. Fattoyev:** The dipolar magnetic field configuration in dependence on brane tension and present solutions of Maxwell equations in the internal and external background spacetime of a magnetized spherical neutron star in a Randall-Sundrum II type braneworld was studied. The star was modeled as a sphere consisting of perfect highly magnetized fluid with infinite conductivity and frozen-in dipolar magnetic field. With respect to solutions for magnetic fields found in the Schwarzschild spacetime brane tension introduces enhancing corrections both to the interior and the exterior magnetic field. These corrections could be relevant for the magnetic fields of magnetized compact objects as pulsars and magnetars and may provide the observational evidence for the brane tension through the modification of formula for magnetodipolar emission which gives amplification of electromagnetic energy loss up to few orders depending on the value of the brane tension.

### 3.29. *On dependence of some parameters of radio pulsars radiation on their age*

**Viquen H. Malumian and Avetik N. Harutyunyan:** The relationship between parameters of the radiation from pulsars and the dependence of the rates of the radiation periods of these objects on their characteristic ages was studied. The following results were obtained:

(*a*) The rate of change in the radiation periods (derivatives of periods, dP/dt) of pulsars depends on their characteristic age. These changes proceed more slowly with age. The rate of change of the radiation period of pulsars can in some way serve as an indicator of their age.

(*b*) The relationship between the rate dP/dt of change of the period and the period P has been demonstrated. For young pulsars this relationship is weak. In the course of evolution with age, the relationship between the derivative of the period and the period becomes closer. Whereas for young ($T < 10^6$ years) pulsars the correlation coefficient for the log dP/dt – log P plot is only 0.49 ($p < 0.0001$), for old ($T \geqslant 10^8$ yr) pulsars the correlation coefficient approaches unity ($p < 0.0001$). Since, as shown above, the rate of change of the radiation period decreases with age in pulsars, one can say that the lower the rate of change of the radiation period of a pulsar is, the closer is the relationship between the derivative of its period and its period.

The data in the catalog of Taylor *et al.*, which contains 706 objects, were examined separately. After eliminating the members of binary and multiple systems, as well as the members of the Magellanic Clouds, slightly more than 500 objects remain.

### 3.30. *The Nancy pulsar instrumentation: The BON coherent dedispersor*

**Ismaël Cognard and Gilles Theureau:** A summary of the Nancay pulsar instrumentation and the on going observational pulsar timing programs was presented. The BON coherent dedispersor is able to handle 128 MHz of bandwidth. It is made of a spectrometer, plus four data servers to spread data out to a 70-node cluster of PCs (with Linux Operating System). De-dispersion is done by applying a special filter in the complex Fourier domain. This backend has been designed in close collaboration with the UC Berkeley. It benefits from the many qualities of the large Nancy radio telescope (NRT, equivalent to a 94 m circular dish), which receivers were upgraded in 2000: a factor of

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2.2 sensitivity improvement was obtained at 1.4 MHz, with an efficiency of 1.4 K/Jy for a system temperature of 35 K; a better frequency coverage was also achieved (from 1.1 to 3.5 GHz). The first two years of BON data acquisition demonstrates that the timing data quality is comparable with the Arecibo and Green Bank results. As an example, a Time of Arrival (ToA) measurement accuracy better than 200 ns (170 - 180 ns) is obtained in only 30 s of integration on the millisecond pulsar PSR B1937+21. With this up to date instrumentation, two main observational programs in pulsar timing with the Nancy antenna are operated: (1) the radio follow-up of X- and $\gamma$-ray pulsars for the building of a complete multi-wavelength sample and (2) the monitoring of both a millisecond pulsar timing array and a targeted list of binary or unstable pulsars for gravitational wave detection. Joining both list of targets, a total sample of 150 pulsars is then monitored regularly with a dense sampling in time.

### 3.31. *Relation of pulsars to the remnants of supernova bursts*

**Viquen H. Malumian and Avetik N. Harutyunyan:** Based on a large volume of statistical data it was shown that the spatial distributions of radio pulsars in the galaxy with characteristic ages $T < 10^6$ yr and $T > 10^6$ yr differ significantly. The overwhelming majority of the pulsars with $T < 10^6$ yr lie within a narrow band of width 400 pc around the Galactic plane. A large portion of the pulsars with $T > 10^6$ yr is concentrated outside this zone. In the case of younger pulsars, a larger fraction of them lies within the confines of the above mentioned zone. It is also shown that pulsars with $T < 10^6$ yr and the remnants of supernova explosions have essentially the same spatial distribution. These facts support the existence of a relationship between pulsars and supernova remnants, as well as the acquisition of high spatial velocities by pulsars during their birth.

### 3.32. *The multi-photon electron-positron pair production in the magnetosphere of pulsars*

**Ara K. Avetissian:** In general, the single-photon reaction $\gamma \to e^- + e^+$, as well as the inverse reaction of the electron-positron annihilation can proceed in a medium that must be a plasma-like. To provide a macroscopic refractive index $n(\omega) < 1$ necessary for pair production $\gamma$-frequencies one needs plasma densities $\rho > 10^{33}\,\mathrm{cm}^{-3}$. Such superdense matter exists in the core of the neutron stars/pulsars. At these densities the electron component of the superdense plasma is fully degenerated and taking also into account the Pauli principle the probabilities of these processes actually turn to zero. Hence, the possibility of multi-photon electron-positron pair production by strong electromagnetic radiation of soft frequencies in magnetosphere of pulsars is considered, which is possible at ordinary densities of plasma. Such multi-photon process occurs via nonlinear channels at high intensities of electromagnetic radiation in wide region of frequencies from radio to UV and soft X-ray in pulsars magnetosphere.

Numerical simulations for various pulsars ($\Omega \simeq 1$–$200\,\mathrm{s}^{-1}$) with the help of analytical distribution functions of magnetospheres plasma with densities $\rho \simeq 10^{20}$–$10^{22}\,\mathrm{cm}^{-3}$ and pair production probabilities have been made, and both energetic and angular distributions of produced electron-positron pairs were presented.

### 3.33. *Relativistic, electromagnetic waves in pulsar winds*

**Olaf Skjaeraasen:** Extremely nonlinear, coherent electromagnetic waves in the context of relativistic, expanding plasma flows, where a confining external medium triggers the formation of a shock, were considered. Using a combination of analytical methods and Particle-In-Cell simulations, the mechanisms of wave generation and dissipation, as well

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as how the waves affect the particle distribution were discussed. For a large-amplitude wave of general polarization, any given set of wave parameters uniquely fixes the particle and energy flux associated with the flow. In cases where the wave properties can be constrained, this can be used to estimate the flow parameters.

The prime application of this work is to pulsar winds and pulsar wind termination shocks, where our model provides a viable alternative to magneto-hydrodynamic models. Using canonical parameters for the Crab, the mode couplings and transitions between the inner and outer parts of the wind were discussed. The simulation data were explored to shed new light on the microphysics of the wave as it reaches the shock.

### 3.34. *Coupled spin, mass, magnetic field, and orbital evolution of accreting neutron stars*

**M. Mirtorabi, A.J. Khasraghi, and S. Abdolrahimi:** The presented study was mainly addressed to the coupled spin, mass, magnetic field, orbital separation, and orbital period evolution of a neutron star entering a close binary system with a low mass main sequence companion, which loses mass in form of homogenous stellar wind. Flux expulsion of the magnetic field from the superfluid superconductive core of a neutron star, based on different equation of states was applied, and its subsequent decay in the crust, which also depends on conductivity of the crust, and hence on the temperature, $T$, and the neutron star age. The initial core and surface magnetic field were of the same order of magnitude. To derive the rate of expulsion of the magnetic flux out of the core various forces which act on the fluxoids in the interior of a neutron star were considered, including a force due to their pinning interaction with the moving neutron vortices, buoyancy force, curvature force, and viscous drag force due to magnetic scattering of electrons. Various effects accompanying mass exchange in binaries can influence the evolution of spin and magnetic field of the neutron star. The orbital separation of the binary clearly affects the estimated value of, and it itself evolves due to mass exchange between the components, mass loss from the system, and two other sinks of the orbital angular momentum namely magnetic braking and gravitational waves. The neutron star passes through four evolutionary phases (isolated pulsar-propeller-accretion from the wind of a companion- accretion resulting from Roche-lobe overflow). Models for a range of parameters, and initial orbital period, magnetic field and spin period were constructed. The impurity parameter, $Q$, was assumed to be constant during the whole evolution of the star and range from 1 to 0.001. Final magnetic field, spin and orbital period were presented in this paper. The suggested mechanism could explain the lower magnetic field and faster spins of millisecond pulsars that have been recycled by accretion in close binaries.

### 3.35. *Investigating the magnetic field of the solar corona with pulsars*

**Stephen M. Ord:** A novel experiment to examine both the magnetic field and electron content of the solar corona was proposed. It was intended to measure the Faraday rotation and dispersion evident in observations of background pulsar sources as they are occulted by the Sun. With a number of simultaneous lines of sight that cut different paths through the corona as the Sun rotates, strong constrains on the global topology of both the plasma and the magnetic field should be obtained. Although similar experiments have been performed using other background radio sources and space probes, this experiment differs in that many lines of sight can be examined simultaneously, and the magnetic field and plasma density can be measured independently. The Parkes radio telescope is proposed to observe a number of pulsars as they are occulted by the Sun in December 2006. An outline of the experiment and a discussion of the expected results were presented.

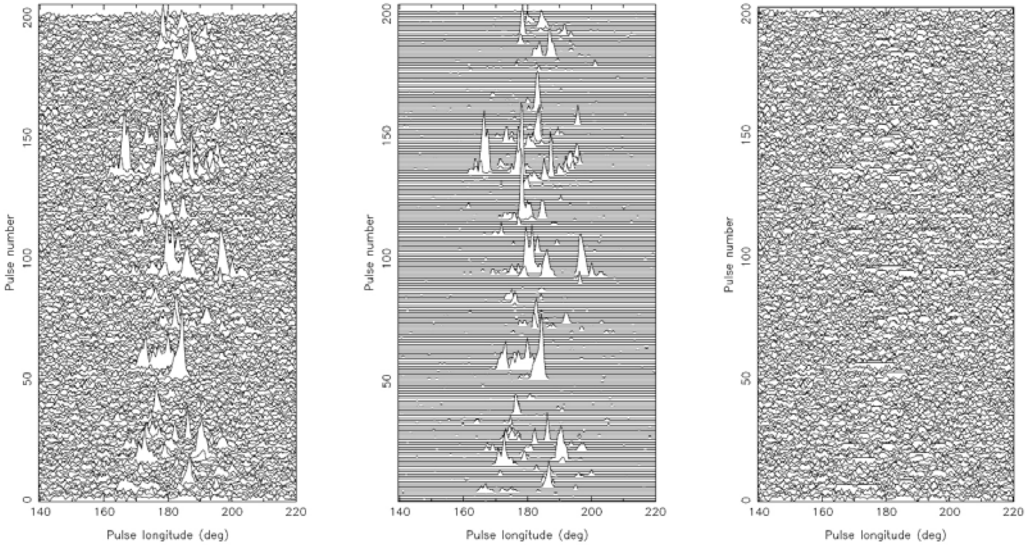


**Figure 11.** A typical sequence of successive pulses (left panel) from PSR B0656+14. The same pulses are shown in the middle and right panel, but there the emission is separated into the spiky and weak emission, respectively. See poster 3.37 of Weltevrede *et al.* and astro-ph/0701189 for further details.

## 3.36. *RRATs and PSR B1931+21*

**Xiang Dong Li:** The recent discovery of rotating radio transients and the quasi-periodicity of pulsar activity in the radio pulsar PSR B1931+24 has challenged the conventional theory of radio pulsar emission. It was suggested that these phenomena could be due to the interaction between the neutron star magnetosphere and the surrounding debris disk. The pattern of pulsar emission depends on whether the disk can penetrate the light cylinder and efficiently quench the processes of particle production and acceleration inside the magnetospheric gap. A precessing disk may naturally account for the switch-on/off behavior in PSR B1931+24.

## 3.37. *Is PSR B0656+14 a very nearby RRAT source?*

**Patrick Weltevrede, Benjamin W. Stappers, Joanna M. Rankin, and Geoffrey A.E. Wright:** The recently discovered RRAT sources are characterized by very bright radio bursts which, while being periodically related, occur infrequently. Bursts with the same characteristics for the known pulsar B0656+14 were found. These bursts represent pulses from the bright end of an extended smooth pulse-energy distribution and were shown to be unlike giant pulses, giant micro-pulses or the pulses of normal pulsars. The extreme peak-fluxes of the brightest of these pulses indicates that PSR B0656+14, were it not so near, could only have been discovered as an RRAT source. Longer observations of the RRATs may reveal that they, like PSR B0656+14, emit weaker emission in addition to the bursts.

The emission of PSR B0656+14 can be characterized by two separate populations of pulses: bright pulses have a narrow 'spiky' appearance consisting of short quasi-periodic bursts of emission with microstructure, in contrast to the underlying weaker broad pulses. The spiky pulses tend to appear in clusters which arise and dissipate over about 10 periods. It was demonstrated that the spiky emission builds a narrow and peaked profile,

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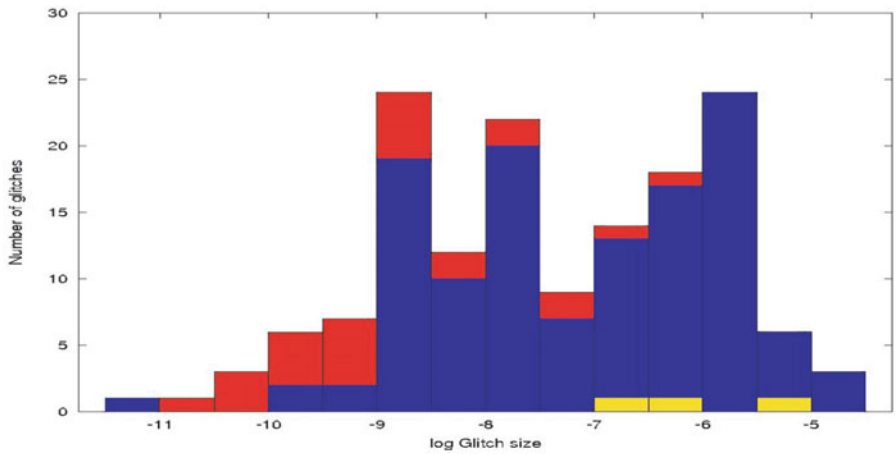


**Figure 12.** Glitch size histogram showing all known glitches. Glitches found in this study are shown in red, AXP glitches (overlapping) in yellow. See poster 3.38 of Janssen & Stappers and A&A 2006, 457, 611.

whereas the weak emission produces a broad hump, which is largely responsible for the shoulders in the total emission profiles at both high and low frequencies.

### 3.38. *Glitch observations in slow pulsars*

**Gemma H. Janssen and Benjamin W. Stappers:** An analysis of 5.5 years of timing observations of seven "slowly" rotating radio pulsars, made with the Westerbork Synthesis Radio Telescope was presented. The improved timing solutions were presented and 30, mostly small, new glitches were found. Particularly interesting were the results on PSR J1814−1744, which is one of the pulsars with similar rotation parameters and magnetic field strength to the anomalous X-ray pulsars (AXPs). Although the high-$B$ radio pulsars don't show X-ray emission, and no radio emission is detected for AXPs, the roughly similar glitch parameters provide another tool to compare these classes of neutron stars. Furthermore, it was possible to detect glitches one to two orders of magnitude smaller than before, for example in our well-sampled observations of PSR B0355+54. The total number of known glitches in PSR B1737−30 was doubled, and improved statistics on glitch sizes for this pulsar individually and pulsars in general were obtained. No significant variations in dispersion measure for PSRs B1951+32 and B2224+65, two pulsars located in high-density surroundings, were detected. The effect of small glitches on timing noise was discussed. It was shown that it is possible to resolve timing-noise looking structures in the residuals of PSR B1951+32 by using a set of small glitches.

### 3.39. *Mode coupling in pulsar magnetospheres due to plasma gradients perpendicular to the magnetic field*

**Alex C. Judge:** Conventional ideas regarding plasma instabilities suggest that the polarization of pulsar radio emission should be dominated by that corresponding to the fastest growing mode. The presence of two distinct polarizations, indicating emission in two distinct modes, is, however, almost ubiquitous in observations of these objects. In order to reconcile the basic theory with the observations it has been proposed that energy is exchanged between the natural modes of the plasma as the radiation propagates through the magnetosphere of the pulsar.

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The basic theory of mode-coupling in stratified media has already been developed in work relating to wave propagation in the ionosphere and the solar corona. This formalism was applied here to a relativistically streaming plasma and gradients in the plasma perpendicular to the direction of the local magnetic field were investigated as a possible mechanism for effective mode-coupling in a pulsar magnetosphere.

### 3.40. *Software aspects of WSRT-PUMA-II*

**Ramesh Karuppusamy and Benjamin W. Stappers:** The Pulsar Machine II (PuMa-II) is a state-of-the-art pulsar machine, installed at the Westerbork Synthesis Radio Telescope (WSRT), in December 2005. PuMa-II is a flexible instrument and is designed around an ensemble of 44 high-performance computers running the Linux operating system. Much of the flexibility of PuMa-II comes from the software that is being developed for this instrument. The radio signals reaching the telescope undergo several stages of electronic and software processing before a scientifically useful data product is generated. The electronic processing of signals includes the usual RF to IF conversion, analog to digital conversion and telescope dependent electronic digital delay compensation that happen in the signal chain of WSRT. Within PuMa-II, this data is acquired, stored and suitably processed. In this poster various aspects of PuMa-II software was presented and its pulsar signal processing capabilities were illustrated.

### 3.41. *High time resolution low-frequency pulsar studies*

**Benjamin W. Stappers:** Low frequency observations of radio pulsars have, to a certain extent, fallen out of favor in recent times. This is despite exciting and interesting work in Russia, Ukraine and India. The move to higher frequencies has mainly been due to the deleterious effects of the interstellar medium. However, with the increased availability of baseband recording and coherent de-dispersion techniques and new facilities such as the LFFEs at the Westerbork Synthesis Radio Telescope (WSRT) and in the future LOFAR/LWA, the interest in observations at frequencies below 300 MHz is growing again. Some exciting results on single pulse studies from observations at the WSRT (115–180 MHz) were presented here. These include the first full polarization observations of Crab giant pulses at these frequencies. The prospects for pulsar research with LOFAR. LOFAR will have unprecedented collecting area and bandwidth at frequencies below 220 MHz, allowing for a wide range of pulsar studies, in particular in emission physics, were also presented. The results from simulations which show that an all-sky survey with LOFAR could be expected to find up to 1500 new pulsars were shown. This survey would provide significant constraints on the low-end of the pulsar luminosity distribution which has important consequences for the total pulsar population. It was argued that LOFAR could detect pulsars in nearby galaxies.

### 3.42. *The 8gr8 Cygnus survey for New pulsars and RRATs*

**Eduardo Rubio-Herrera, Robert Braun, Gemma H. Janssen, *et al.*:** A survey to search for new pulsars and the recently found Rotating RAdio Transients (RRATs) in the Cygnus OB complex was currently undertaken. The survey uses the Westerbork Synthesis Radio Telescope in a unique mode which gives it the best sensitivity of any low-frequency wide-area survey. Few new pulsars were found so far. The program of using routines for the detection of RRATs. Some initial results on the new pulsars and possible transients were presented. It is expected to find a few tens of new pulsars and a similar number of RRATs. The latter discoveries should help to improve the knowledge about the population and properties of the poorly known objects as well as provide an

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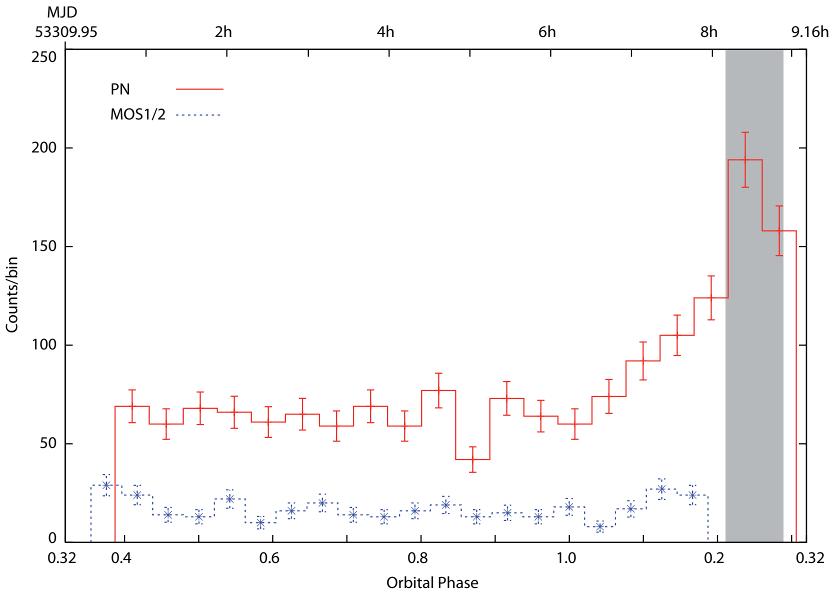


**Figure 13.** X-ray emission from PSR B1957+20 within 0.3–3.0 keV as function of the pulsar's orbital phase ($\phi$). One complete orbital period of this system is mapped with the starting point MJD = 53309.95, i.e., $\phi = 0.32$. $\phi = 1.0$ corresponds to the ascending node of the pulsar orbit. The upper curve was obtained from the *XMM-Newton* EPIC-PN (background level at 65 cts/bin). The lower lightcurve is obtained from the MOS1/2 data. The gray strip between the orbital angle 0.21 - 0.29 indicates the eclipse of the pulsar. Phase bins with zero counts correspond to phase angles not covered in the observation. Image from poster 3.45 by Huang & Becker. (See also astro-ph/0701611.)

improved knowledge of the number of young pulsars associated with the OB complexes in the Cygnus region.

### 3.43. *Pulsar coherent de-dispersion observation at Urumqi Observatory*

**Aili Yishamuding:** Based on a Mark5A VLBI backend and a four node cluster, pulsar off-line coherent de-dispersion observations have been conducted by using Urumqi 25 m telescope. The observing system was described and the initial results were presented in this paper.

### 3.44. *X-ray monitoring of the pulsar PSR B1259−63*

**Hsiu-Hui Huang and Werner Becker:** PSR B1259−63, a rotation-powered radio pulsar with a ∼48 millisecond period, is in a highly eccentric ($e \simeq 0.87$) 3.4 yr orbit around the massive Be-type star SS 2883. The results of the *XMM-Newton* observations performed between 2001 and 2004 were summarized. Combining the *XMM-Newton* observations with the previous results from *ASCA*, it was found that the best-fit power-law models in 1.0 − 10.0 keV energy band show long term variations in the photon indices from ∼1.11 to ∼1.95. The X-ray flux was observed to increase by a factor of > 10 from apastron near to periastron. No X-ray pulsations at the pulsar's spin period were found in any observations so far. A model invoking the interaction between the pulsar and the stellar wind was likely to explain the observed orbital phase-dependent time variability in the X-ray flux and spectrum.

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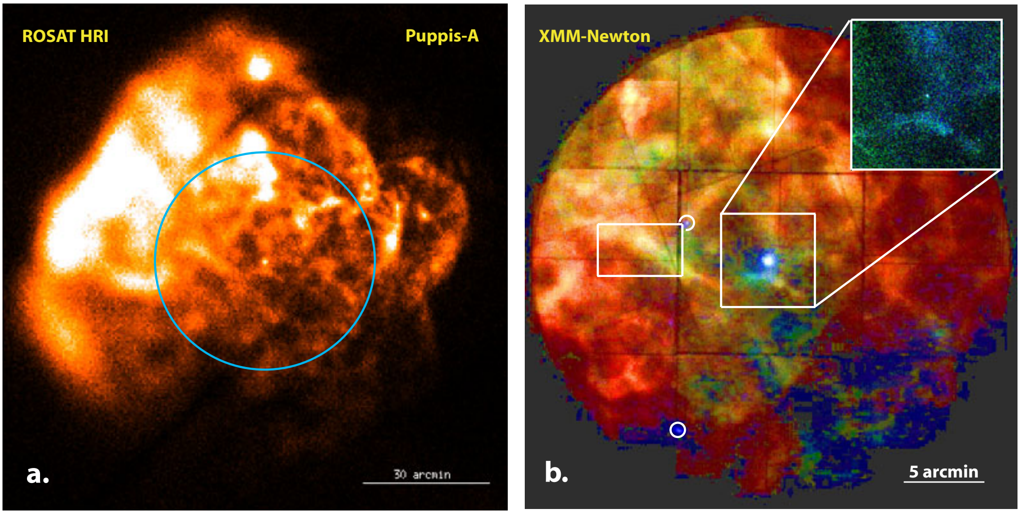


**Figure 14.** (*a*) Composite *ROSAT*-HRI image of the Puppis-A supernova remnant. The blue ring indicates the 30′ central region observed by *XMM-Newton*. (*b*) *XMM-Newton*-MOS1/2 false color image of the central region of Puppis-A (red: 0.3–0.75 keV, green: 0.75–2 keV, blue: 2–10 keV). The central source is the CCO RX 0822−4300. Inset: the squared region as observed by the *Chandra*-HRC-I. Further details in poster 3.47 by Hui & Becker and A&A 454, 543 (2006).

### 3.45. *XMM-Newton observation of PSR B1957+20*

**Hsiu-Hui Huang and Werner Becker:** The "Black Widow pulsar", PSR 1957+20, is a millisecond pulsar which is in a 9.16-hr binary system. H$\alpha$ bow-shock nebula created by the interaction between the relativistic wind of the pulsar and the surrounding ISM and ablation of the low-mass companion star by the pulsar wind were observed. 30 ksec observation of PSR B1957+20, using the EPIC-MOS detector on-board the *XMM-Newton* observatory, were reported. The X-ray diffused emissions detected from this source was found to be consistent with the results derived from *Chandra* observations. The spectrum of the nebular emission was modeled with a single power-law spectrum of photon index $2.1^{+0.4}_{-0.3}$. This extended emission generated by accelerated particles in the post shock flow was considered to explain this result. For the first time, a significant X-ray flux modulation near to the pulsar's radio eclipse was detected.

### 3.46. *Optical observations of binary millisecond X-ray pulsars in quiescence*

**Paul J. Callanan, Mark T. Reynolds, Alexei V. Filippenko, *et al.*:** The discovery of accreting binary millisecond pulsars finally provided firm confirmation of the link between bright accreting Low Mass X-ray Binaries and millisecond pulsars. Little is known about their optical properties in quiescence, however. Here the optical observations of SAX J1808.4−3658 and IGR J00291+5934 in quiescence were presented, and comparison of them to other quiescent X-ray transients was made.

### 3.47. *X-Ray studies of the central compact objects in Puppis-A & RX J0852.0−4622*

**Chung Yue Hui and Werner Becker:** The supernova remnants (SNRs) Puppis-A and RX J0852.0−4622 (Vela-Junior) are located along the line of sight towards the outer rim of the Vela SNR. Central compact objects (CCOs) were discovered in each of them. Both CCOs are thought to be the compact stellar remnants formed in core-collapsed supernova explosions. Nevertheless, the emission properties observed from these sources

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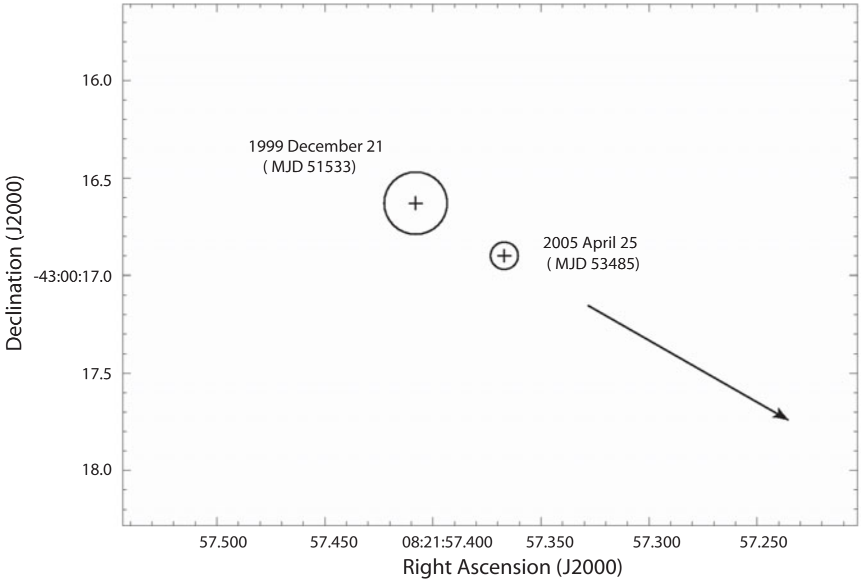


**Figure 15.** The best-fitted X-ray positions of RX J0822−4300 at two different epochs separated by 1952 d are marked by crosses. The circles indicate the 1 $\sigma$ error. The arrow shows the direction of proper motion inferred from both positions. Image from poster 3.48 of Hui & Becker. See also Hui & Becker (2006, A&A,457, 33).

were found to be completely different from what is observed in other young canonical neutron stars. Based on observations with the X-ray observatories *Chandra* and *XMM-Newton*, the most recent results from a detailed spectro-imaging and timing analysis of these two enigmatic sources were presented.

### 3.48. *Probing the proper motion of the central compact object in Puppis-A*

**Chung Yue Hui and Werner Becker:** Using two observations taken with the High Resolution Camera (HRC-I) aboard the *Chandra* X-ray satellite, we have examined the central compact object RX J0822-4300 for a possible proper motion. The position of RX J0822−4300 was found to be different by $0.574 \pm 0.184$ arcsec, implying a proper motion of $107.49 \pm 34.46$ mas/yr with a position angle of $241 \pm 24$ deg. For a distance of 2.2 kpc, this proper motion is equivalent to a recoil velocity of $1121.79 \pm 359.60$ km/s. Both the magnitude and the direction of the proper motion are in agreement with the birth place of RX J0822−4300 being near to the optical expansion center of the supernova remnant. Although this is a promising indication of a fast moving compact object in a supernova remnant, the relative large error prevents any constraining conclusion.

### 3.49. *Exposing drifting subpulses from the slowest to the fastest pulsars*

**Joeri van Leeuwen:** Pulsar emission is surprisingly similar over a vast range of periods and magnetic fields: all the way from the 2-millisecond $10^8$ G recycled pulsars to the 6-second $10^{14}$ G magnetar-like regular pulsars. It was investigated how the curious instabilities called 'drifting subpulses' can discern between different mechanisms for pulsar emission.

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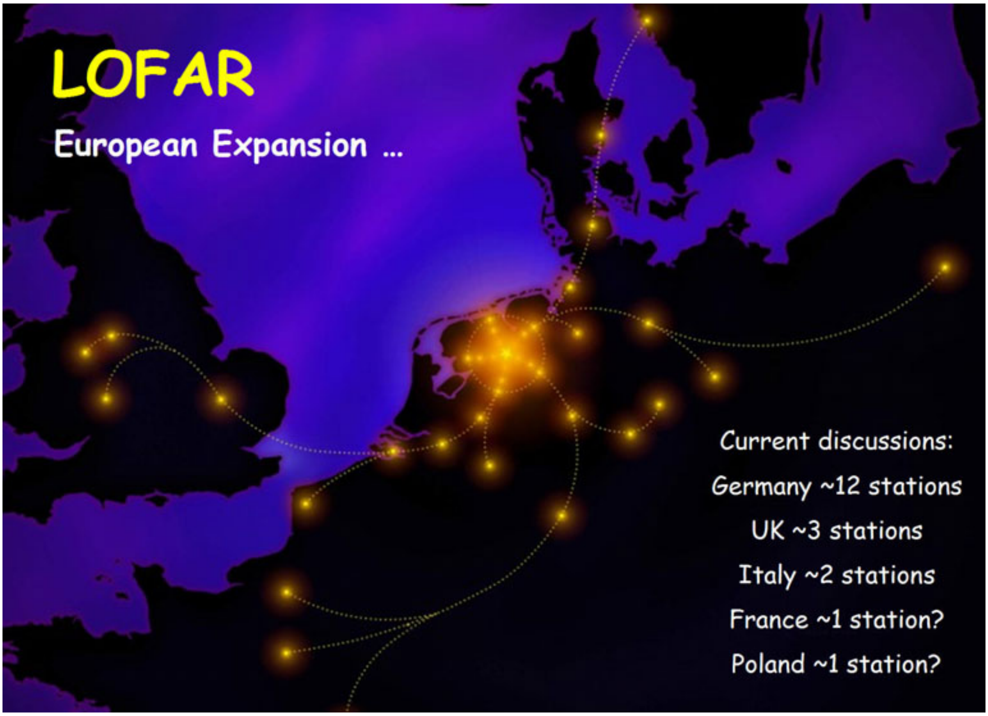


**Figure 16.** Distribution of radio antennas planned in the LOFAR project as presented in the talk by M. Kramer and in poster 3.50 by J. van Leeuwen and B.W. Stappers.

3.50. *Pulsar research with LOFAR, the first next-generation radio telescope*

**Joeri van Leeuwen and Benjamin W. Stappers:** LOFAR is a low-frequency radio telescope of revolutionary design that is currently being constructed and will become operational in 2007. In stark contrast to radio dishes, LOFAR is the first telescope that relies on a central supercomputer to combine the signals of ten thousand individual dipoles to form several extremely sensitive, independently steerable beams on the sky. It was discussed how LOFAR opens up a new frequency window with unprecedented sensitivity and why LOFAR will have considerable impact on radio pulsar research.

3.51. *Non-dipolar surface magnetic field of neutron stars: general approach and observational consequences*

**George I. Melikidze, A. Szary, and Janusz Gil:** It is widely accepted that the magnetic field structure near the surface of neutron stars may significantly differ from the star centered global dipole structure. Due to flux conservation of the open magnetic field lines, strong non-dipolar surface field results in significant shrinking of the canonical polar cap, in general. We have modeled different possible configurations and found out that for some configurations the pair creation is possible not only along the open field lines, but also in the region of closed field lines. Therefore, in this case, we can naturally explain some peculiarities of pulsar activities, such as unusual thermal x-ray emission, reversible radio emission and rotating radio transients.

The pairs created along the closed field lines can easily reach the stellar surface near the polar cap at the opposite side of the neutron star and heat the surface area that can even exceed that of the canonical polar cap. Both smaller (often) and larger (rarely) bolometric surface areas of the hot polar cap are observed.

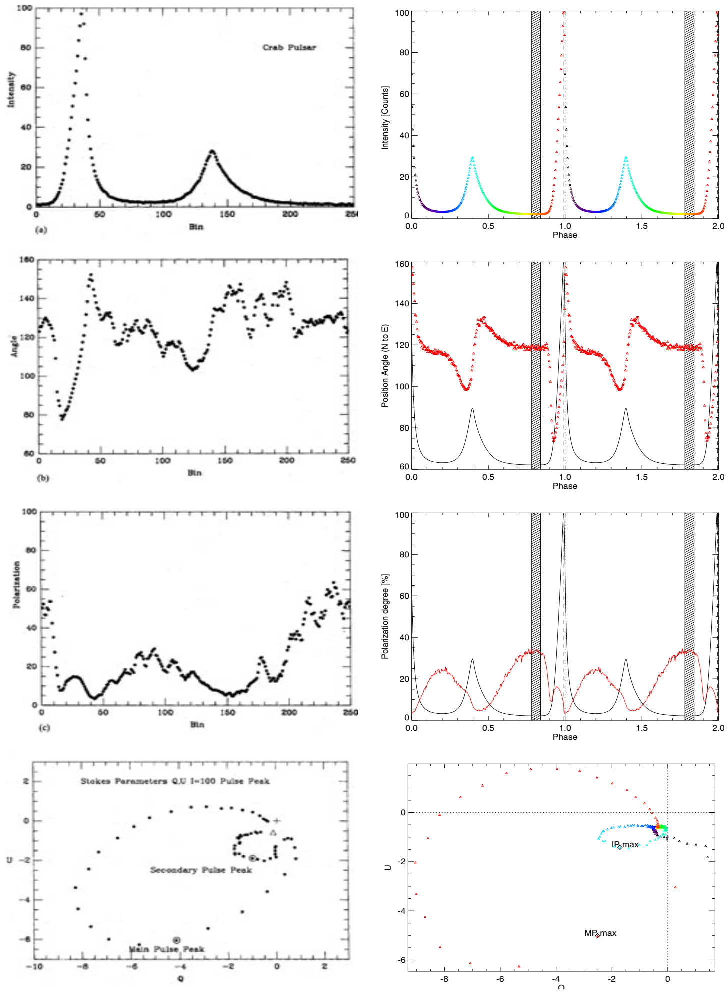


**Figure 17.** Comparison of the optical polarization of the Crab pulsar obtained by Smith *et al.* 1988 (*left*) and Slowikowska, Kanbach, and Stefanescu (*right*). From *top* to *bottom*: the intensity, position angle, and polarization degree are plotted as a function of the pulsar phase, while the Stokes parameters $Q$, $U$ are plotted as a vector diagram. There are 250 bins per cycle in both cases, the only difference is that for clarity two periods are shown in the right chart. As a DC component Smith *et al.* took 50 out of 250 bins, whereas in the right chart only 7 % of the rotational period was taken. Figure and caption from Slowikowska *et al.* (3.53).

In the frame of this model, we can easily realize the configuration, which allows the pair creation near both polar caps (along the same field). In this case, two streams of the pair plasma penetrate each other creating a favorable condition for the two-stream instability to be developed. Such a process can lead to the radio emission generation, either in quasi-stationary or stochastic process. Consequently, either quasi-stationary reversible radiation, or stochastic emission of the transients can be observed.

### 3.52. *Glitches in the Vela pulsar*

**Stephen J. Buchner, and Claire S. Flanagan:** The Vela pulsar undergoes occasional sudden spin-ups in rotational frequency. The recovery from these glitches provides insight into the internal structure of the neutron star. The HartRAO was used to monitor Vela

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since 1984 and eight large glitches were observed. These data were presented in this paper.

3.53. *Optical polarization of the Crab pulsar with 10 μs time resolution*

**Agnieszka Slowikowska, Gottfried Kanbach, and A. Stefanescu:** The Crab nebula and pulsar were observed for about 25 hours with the high-speed photo-polarimeter OPTIMA in November 2003 at the Nordic Optical Telescope (NOT), La Palma. The instrument's sensitivity (white light) extends from about 450 nm to 950 nm and reaches about 60 %. Linear polarization is measured with a continuously rotating polaroid filter which modulates the incoming radiation. The astronomical target is viewed through the polaroid and imaged onto a hexagonal bundle of optical fibers which are coupled to single photon APD counters. The spacing and size of the fibers at the NOT correspond to about 2 arcsec. GPS based time tagging of single photons with 4 microsec resolution, together with the instantaneous determination of the angular position of the rotating polaroid filter, allowed to measure the phase dependent linear polarization state of the pulsar and the surrounding nebula simultaneously.

The Crab pulsar and its net optical polarization were determined at all phases of rotation with extremely high statistical accuracy. On time scales of a few tens of microseconds significant details of the polarization of the main emission peak became visible.

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