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Conference Highlights

IAU Colloquium 177: Pulsar Astronomy: 2000 and Beyond[1]

In order to discuss the latest and future developments in pulsar astronomy, more than 200 scientists met in Bonn. The meeting covered a wide variety of topics such as studies at radio, optical, X-ray, and γ-ray frequencies; the searching and timing of pulsars, pulsar (and possible companion) evolution, and the pulsar population; and the use of pulsars as tools for tests of general relativity and the studies of the interstellar medium and their surroundings. This summary cannot give justification to all $\sim$100 oral and $\sim$180 poster contributions but tries to give an overview about some highlights, referring to the proceedings of the conference for further details.

At present, the number of known pulsars has been increased to more than 1100 thanks to ongoing searches at almost every major radio telescope in the world, such as Arecibo, Bologna, Effelsberg, Nancay, or Parkes. By far the largest contribution to the number of new pulsars has been made by the Parkes Multibeam Survey, which alone has contributed more than 440 new sources already, making it the most successful pulsar search ever. A number of very exciting objects can be expected to be discovered, and bright examples were already presented. Two binary systems with massive companions have been discovered which appear to be double-neutron star systems, although it has been also suggested that one system, PSR J1141$-$6545, could well be a young pulsar with an old white dwarf companion. Another very interesting new binary system, PSR J1740$-$3052, contains a very massive companion with a minimum mass of 11 $M_\odot$ in a wide but eccentric orbit. Infrared observations so far suggest that the pulsar companion is a K supergiant rather than a stellar black hole.

The number of known millisecond pulsars has also increased by the discovery of eight recycled pulsars in the Swinburne intermediate-latitude survey, discoveries in the Arecibo and Bologna surveys, and the discovery of new millisecond pulsars in the globular cluster 47 Tuc. This cluster now contains a total number of 21 millisecond pulsars (including a binary pulsar with the shortest orbital period known, i.e., 96 minutes), which gives insight in the cluster dynamics and the formation of these systems, as discussed during the conference.

Three pulsars newly discovered in the multibeam survey are also remarkable as they exhibit large surface magnetic fields. The 3.97 s pulsar J1814$-$1744 exhibits a magnetic field of 5.5×10^{13} G, which places it close to the anomalous X-ray pulsar (AXP) 1E2259+586 on the P-$\dot{P}$diagram. The relation between radio pulsars on one side and AXPs and magnetars on the other was only one aspect discussed in a session solely devoted to the observations and evolution of these objects. A large number of remaining questions, such as those of proposed new associations of supernova remnants and radio quiet X-ray pulsars or those of the evolution of the latter objects, were also discussed in an informal evening session spontaneously organized during the conference.

A second, similar informal evening session was organized to discuss the phenomenon of orthogonal polarization modes often seen in the radio emission of pulsars. This discussion reflected on the previous experience as well as new results presented in the conference. The community proposed key observations to tackle the open questions in this context, such as to whether the polarization modes occur simultaneously or not.

Other new results about the radio emission of pulsars were, for instance, the reports about "ghost components" seen in the Crab pulsar. Two groups had independently observed a pulse echo approaching the main pulse and leaving it again on a timescale of several weeks. The nature of this echo is not yet fully understood, but it appears to be the result of a plasma lens of a certain shape in the vicinity of the pulsar, i.e., its nebula.

The second famous pulsar within a supernova remnant, the Vela pulsar, was also in focus during a lively discussion about the question as to whether scintillation or scattering measurements are able to resolve its emission region. Deviations from a polarization swing according to a rotating vector model, first derived for Vela, were discussed in view of single-pulse studies but also in view of other pulsars, in particular millisecond pulsars, where deviations are often visible as flat curves, some of which may be related to the profile changes reported for these fast-spinning objects.

An innovative technique to extract more information from radio single-pulse data about the processes above the polar cap was presented, which uses the analysis of drifting subpulses to draw a map of the emission processes in the polar gap region. Observations and subsequent computations result in movies which for the first time reveal subpulse entities circling around the polar cap in well-defined patterns.

Several contributions addressed the relation between the emission of pulsars seen at different wavelengths. One con-

[1] Conference was held in Bonn, Germany, in 1999 September. Proceedings will be edited by M. Kramer, N. Wex, and R. Wielebinski and published in the ASP Conference Series.

clusion of a multistation, multifrequency observation of the giant pulses of the Crab pulsar indicates that giant pulses are not related to the observed X-ray photons. In fact, comparison of data in X-ray and other wavelengths have benefited from new instruments such as the *Rossi X-Ray Timing Explorer* (*RXTE*). Other new instruments will further improve our overall knowledge; for example, first observations of pulsars with the Very Large Telescope (VLT) were also presented, which showed the detection of polarized emission in three pulsars, pointing to a nonthermal origin of the radiation.

The nonthermal emission observed in radio, optical, X-ray, and γ-ray wavelengths was only one aspect of pulsar emission discussed in detail. Growing emphasis was also placed on the observation of thermal emission of pulsars, such as neutron star atmospheres or the emission of their companions. Most of these exciting results were addressed by colleagues working on theoretical modeling. Noticeable progress has been made in the understanding of the radio emission of pulsars, and although one satisfying model had not been singled out yet, there is at least growing consensus about which models have to be excluded. The theoreticians were also challenged by the discovery of a 8.5 s radio pulsar, which according to previous common wisdom is located beyond the death line in the P-$\dot{P}$ diagram. Possible solutions to this apparent contradiction were discussed. In fact, the processes involved in the creation and interaction of the pair plasma represented the major research interests of many of the conference participants.

In a session devoted to the timing of pulsars, it became clear that considering the emission properties of the observed pulsar can help to improve the accuracy of pulsar timing or lead to new insights. As an example, it was suggested that some sources may be better timed by using data which are the polarimetric analog of the Lorentz invariant interval, i.e., $I^2 - Q^2 - U^2 - V^2$. This procedure can exclude instrumental effects arising from the polarimetric properties of the observed pulsar as for PSR J0437$-$4715. However, pulsar B1828$-$11 shows large, systematic timing variations which are, as it turns out, correlated with profile changes. It was suggested that both effects are most likely caused by precession of the pulsar rather than by orbiting planets. Further work on the obviously (so far) unique planet pulsar B1257+12 confirms the existence of three planets, indicates a fourth one, and now allows the determination of the masses of planets B and C without any inclination ambiguity to $(5.1 \pm 0.3)m_E$ and $(4.0 \pm 0.3)m_E$. It is becoming clear that timing pulsars has attracted global interest; i.e., timing programs from America, Africa, Asia, Australia, and Europe were presented, and most of these programs are complementary.

Further observations of the double neutron-star systems B1534+12 and B1913+16 reveal and confirm profile changes which are consistent with the expectations of geodetic precession. The relatively simple profile of B1913+16 even allows the change of our line of sight to construct a two-dimensional beam-shape pattern of a pulsar for the first time.

As was demonstrated by several contributions, the astrometric parameters derived from timing of radio pulsars can now often be complemented or refined by results obtained in other parts of the electromagnetic spectrum; i.e., interferometric and also optical programs are very successful in providing us with accurate positions, proper motion, and sometimes parallax measurements. In particular, proper motions are important ingredients of full-scale population syntheses. These set limits on the minimum spin period of pulsars ($P \geq 0.65$ ms with 95% probability)—a question which was also addressed by many colleagues on theoretical grounds by investigating the equation of state. It was also predicted that 10 ms is a limiting period for young pulsars due to the existence of r-mode instabilities in young and hot neutron stars. Observational hints about the evolution of pulsars were provided by the discoveries of the accreting millisecond pulsar SAX J1808.4$-$3658 and the 16 ms Crab-like pulsar B0540$-$63. Neither object has detected radio counterparts, but *RXTE* observations show that B0540$-$63 does exhibit timing glitches similar to the Crab pulsar.

The Crab pulsar is the classical example of how a pulsar or neutron star can interact with its surrounding medium. If the pulsar has a companion, many more interesting phenomena can be observed, as was shown in detail for eclipsing binary pulsars or PSR B1259$-$63. The prospects, successes, and also difficulties in interpreting the data when using pulsars as tools to probe the interstellar medium were clearly demonstrated when the observers were urged to look for extreme scattering events in their data, or when the evidence for a Local Bubble was discussed.

The conference demonstrated very clearly that the future of pulsar astronomy will continue to surprise us with exciting and unexpected results. The wide range of new state-of-the-art instrumentation, newly developed algorithms (e.g., to find short-period binary systems) and first results of *Chandra*, the VLT, and the Giant Meterwave Radio Telescope showed that the future has already begun. We can expect to obtain similar exciting results from *XMM* or next-generation telescopes as the Square Kilometre Array or γ-ray telescopes. Finally, a new astronomical window will be opened when pulsars and neutron stars will finally be detected with gravitational wave telescopes.

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