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Pulsars

Benjamin W. Stappers

School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL,UK
email: Ben.Stappers@manchester.ac.uk

Invited Talk

Summary. Pulsars can be considered as the ultimate time-variable source. They show variations on time-scales ranging from nanoseconds to as long as years, and they emit over almost the entire electromagnetic spectrum. The dominant modulation is associated with the rotation period, which can vary from slighty more than a millisecond to upwards of ten seconds (if we include the magnetars). Variations on time-scales shorter than the pulse period are mostly associated with emission processes and are manifested as giant pulses, microstructure and sub-pulses (to name a few). On time-scales of a rotation to a few hundred rotations are other phenomena also associated with the emission, such as nulling, moding, drifting and intermittency.

By probing these and slightly longer time-scales we find that pulsars exhibit "glitches", which are rapid variations in spin rates. They are believed to be related to the interaction between the superfluid interior of the neutron star and the outer crust. Detailed studies of glitches can reveal much about the properties of the constituents of neutron stars—the only way to probe the physics of material at such extreme densities. Time-scales of about an hour or longer reveal that some pulsars are in binary systems, in particular the most rapidly rotating systems. Discovering and studying those binary systems provides vital clues to the evolution of massive stars, while some of the systems are also the best probes of strong-field gravity theories; the elusive pulsar-black hole binary would be the ultimate system.

Pulsars are tools that allow us to probe a range of phenomena and time-scales. It is possible to measure the time of arrival of pulses from some pulsars to better than a few tens of nanoseconds over years, making them some of the most accurate clocks known. Concerning their rotation, deviations from sphericity may cause pulsars to emit gravitational waves which might then be detected by next-generation gravitational-wave detectors. Pulsars themselves can be used as the arms of a Galactic-scale gravitational-wave detector. Measuring correlated deviations in the arrival times of pulses from a number of pulsars distributed throughout the Galaxy could give rise to a direct detection of the stochastic gravitational-wave background, which is associated with the astrophysics of the early Universe—most likely from supermassive black-hole binary systems, but potentially also from cosmic strings. While they are famed for their clock-like rotational stability, some pulsars—in particular the more youthful ones—exhibit modulation in pulse arrival times, often called timing noise. It was recently demonstrated that in at least some cases this variability is deterministic and is associated with modulations in the pulsar emission properties and the spin-down rate. This breakthrough may lead to further improvements in the precision which can be achieved with pulsar timing, and enhance still further the ability to test theories of gravity directly and to make a direct detection of gravitational waves.

I presented some of the history of what is known about the variations in pulsars on all these time-scales and reviewed some of the recent achievements in our understanding of the phenomena. I also highlighted how new transients associated with radio-emitting neutron stars are being discovered, and how other transient sources are being identified by the same techniques. These continued improvements have come about without new telescopes, but the next generation of very sensitive wide-field instruments will permit observational cadences which will reveal many new manifestations and will further revolutionise our understanding of this class of objects which have such high astrophysical potential.

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