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Gamma-ray Pulsars: Puzzles and Progress

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Pulsars are spectacular, enigmatic, astrophysical objects that emit regular pulsations across the electromagnetic spectrum. Moreover, they are thought to be factories of cosmic rays as well as gravitational waves upon merging events, making them true multi-messenger objects. They are Nature's exquisitely accurate timepieces, being the super-dense remnants of supernova explosions. They are extremely stable rotators with magnetic fields that are a trillion times stronger than that of Earth. These fascinating attributes make them valuable laboratories to test theories of gravity, nuclear physics, plasma physics, beaming effects, quantum mechanical effects, and radiation physics in relativistic, strong-field regimes that cannot be replicated on Earth. In the gamma-ray energy band, there has been a number of revolutionary discoveries, including the milestone detection of 300 high-energy pulsars; the detection of pulsations from the famous Vela pulsar up to 20 TeV and the Crab pulsar up to 1 TeV; mode-changing phenomena observed in the Gamma Cygni pulsar; and the existence of a pulsar fundamental plane that relates gamma-ray luminosity, spectral cut-off energy, surface magnetic field, and spin-down luminosity, to name a few. There has also been evidence for multipolar field structures and highly efficient acceleration processes in these systems. Pulsars reveal themselves in interesting settings such as binaries, globular clusters, pulsar wind nebulae, and supernovae. Several models that attempt to capture the essence of pulsar radiation have been developed and refined over the years, involving several techniques ranging from geometrical to electrodynamical to particle-in-cell to magneto-hydrodynamics. Even 50 years after their discovery, many open questions remain. In this talk, I will review the status of the field, highlighting the major breakthroughs that we can expect with the substantial increase in the pulsar population and quality of temporal, spectral, spatial, and polarisation data with the advent of several new experiments.

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