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Astroparticle physics of pulsar magnetospheres

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Pulsars are extreme cosmic lighthouses that emit a broadband spectrum spanning nearly 19 decades of energy. Being the remnants of supernova explosions, these stars represent incredibly compact, highly-magnetized, fast-rotating objects. Their stability make them high-quality natural clocks that rival the accuracy of terrestrial atomic clocks. (This property enables the search for gravitational waves using a network of suitable pulsar candidates.) Their severe environments imply that they are unique laboratories for testing fundamental physics. Over 2 000 radio pulsars are known, a few tens are visible in X-rays, only a handful in optical, and an increasing number (˜150) are being detected in gamma rays. There is also a rich diversity of pulsar classes, including magnetars with gigantic magnetic fields, ancient millisecond pulsars, pulsars in binary systems (e.g., redbacks and black widows), energetic young pulsars, ensembles of pulsars in globular clusters, and pulsars that drive pulsar wind nebulae. Although an all-encompassing answer as to the origin of the pulsar broadband emission remains elusive nearly 50 years after their discovery, great strides have been taken toward the construction of a self-consistent model. Such a model should ultimately involve microphysics of particles being accelerated and radiating from within different regions of the pulsar magnetosphere. On a macroscopic level, the geometry and radiative properties of emission regions should be understood to be able to fully interpret the measured data. Researchers have followed both avenues to constrain ideas about how the observed emission is created and modulated during its transport to the observer. Different observables lead to constraints on different aspects of radiation. Phase-averaged spectra give clues as to the emitting particles, their acceleration, environment, and the radiation mechanism. The phase-evolution of spectra in turn constrains the radiation energetics and environment on a more detailled level as different parts of the magnetosphere are exposed to the observer during the pulsar's rotation. In addition, light curve modelling probes the large-scale emission geometry, which is closely tied to the magnetospheric structure. Polarization properties may provide complementary constraints on the magnetic field orientation and pulsar geometry. Comparison of parameters inferred from independent models for the different wavebands yields necessary crosschecks. A third way to make progress is by studying many versions of the same system which may help to constrain critical population-averaged quantities, discover population trends, and probe model performance for different regions of phase space. When coupled with population synthesis, such population modelling can provide powerful discrimination between competing emission models. In this talk, we will cover some basic pulsar physics, touch on the different pulsar classes, review current understanding of the relevant macro- and microphysics, discuss the interplay of data and theory that shapes our understanding of the pulsar phenomenon, and outline future steps for model refinement.

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