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Editorial

Special issue: Plasma physics of gamma-ray emission from the pulsars and their nebulae

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Cosmic accelerators have been the earliest motivators for the study of cosmic plasmas, dating back to the century old (and continuing) problems of understanding the origin of the Earth's aurorae and cosmic rays. Observation demonstrates that the accelerating electric fields reside in highly conducting plasmas. Accelerators exist all the way from the upper atmosphere and inner magnetosphere of the Earth to active galactic nuclei and their jets billions of light years from the solar system. Accelerators outside the solar system are highly relativistic, with the plasmas often being fully relativistic. Rotation powered pulsars and their pulsar wind nebulae (PWNe) are cosmic accelerators containing the highest energy particles in identified sources. Modelling photon emission, which is synchrotron radiation from radio waves (μeV) up to GeV gamma rays, provides evidence for electrons and (probably) positrons with energies up to a few PeV,* as has been known for many years. Figure 1 shows modern optical and X-ray imaging of the PWN prototype, the Crab Nebula. This system, and other PWNe, also exhibit TeV photon emission, an effect of Compton scattering of low energy photons (either the PWN's own synchrotron radiation or background radiation from the galaxy and the Universe) by the relativistic $e^{\pm}$ within the inertially confined bag of relativistic particles and magnetic fields.

In the last decade, the new generation of satellite-borne gamma-ray telescopes, AGILE and FERMI, have probed these relativistic environments with greatly improved sensitivity, allowing much more sophisticated modelling of the systems. They revealed that the archetype, the Crab Nebula, shows strong variability in the $\varepsilon > 100$ MeV unpulsed gamma-ray flux (spectra shown in figure 2) that may revise, or at least extend, ideas about the acceleration of such very high energy particles in well-identified sources. These flares have properties rather similar to the flaring behaviour shown in active galactic nuclei, thus offering an astronomically near at hand laboratory for cosmic acceleration across the Universe.

The pulsars themselves emit GeV gamma rays, modulated with the rotation period of the underlying pulsar approximately 150 of these stars now fill the catalogues (in contrast to only 6 known a decade ago), with one example, the Crab pulsar, exhibiting pulsed emission up to 300 GeV. Modelling these accelerators, with the experimental information being entirely the spectral and temporal behaviour of the photons detected at the Earth, creates a challenge for theoretical, computational and experimental plasma physics.

*While the spectrum of ultra-high energy cosmic rays extends perhaps to several ZeV, the sources remain unknown, thus the nature of the plasma where the acceleration occurs remains uncertain.

FIGURE 1. The Crab Nebula in 1–10 keV X-rays and optical light, from the Chandra and Hubble space observatories. The X-ray and optical torus extends approximately 1.8 light years in each direction, including the 'jet' structure. The image contracts with increasing photon energy, an effect of the loss of particle energy to synchrotron photon emission as the particles flow out from the central pulsar. The particles themselves are thought to be electrons and positrons created by conversion of gamma rays within the magnetosphere into $e^{\pm}$ pairs, while most of their energy is thought to come from shock wave acceleration and possibly magnetic reconnection occurring at the inner ring structure around the pulsar.

The invited papers in this special collection address a wide range of the issues and results so far studied and obtained in characterizing these accelerators and their plasma environments. The collection includes essays on the observational underpinning of the subject – some of the observational studies are themselves plasma physics research problems, required to interpret the data in a quantitative manner. Others are theory and simulation of the underlying physical processes, mixed with theoretical modelling of the systems – this mixture of micro- and macro-physics is characteristic of the field.

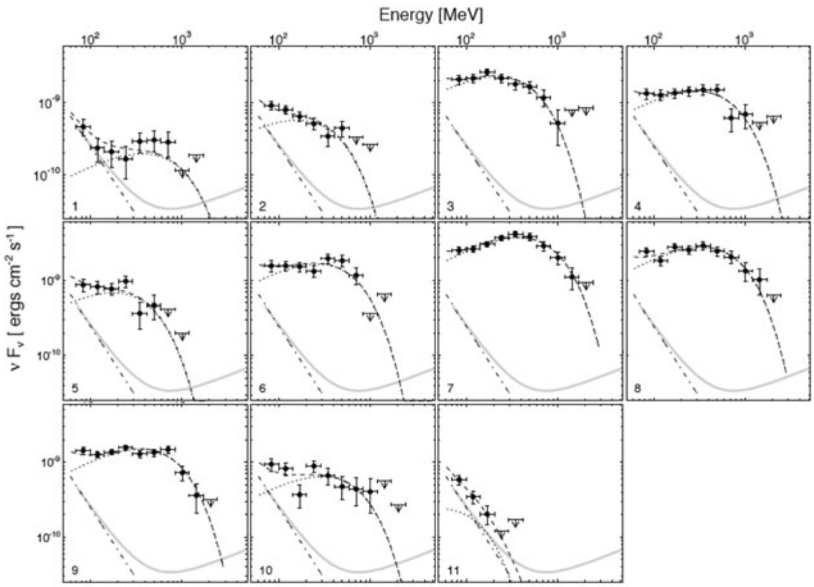

FIGURE 2. 0.1–10 GeV spectra of the Crab Nebula showing a prominent, day-long flare episode observed by the Fermi gamma-ray observatory in April, 2011. The dot-dash curve at the lower left is the quiescent synchrotron gamma-ray spectrum, while the lower solid curve is the total quiescent gamma-ray spectrum, including the Compton upscattered photons whose spectrum extends to 100 TeV. The gamma-ray telescopes have insufficient angular resolution to image the gamma-ray source, thus the exact location of the gamma-ray emission within the Nebula is unknown, although plausibly suspected to be from the inner part of the X-ray emitting region shown in figure 1.

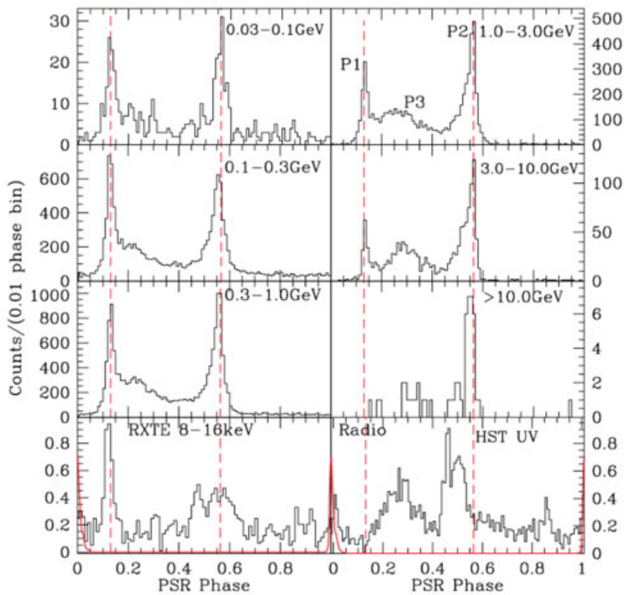

FIGURE 3. Light curve of the Vela Pulsar. The observed photon fluxes, in 6 gamma-ray bands, plus X-rays, radio waves and ultraviolet waves, are plotted as a function of stellar rotation phase, where 0 to 1 represents stellar rotation from 0 to 2π radians.

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