The contribution of e-ASTROGAM to pulsar physics

M. López
Universidad Complutense Madrid
Av. Complutense S/N, Madrid E-8040, Spain

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Abstract Pulsars, both isolated and in binary systems, will be observable by the e-ASTROGAM mission in a spectral range rich in information to discriminate between different particle acceleration models. e-ASTROGAM will shed light on the physical mechanisms taking place in pulsar magnetospheres, by carrying out measurements that are difficult or impossible to conduct with current instruments. It will provide gamma-ray light curves with great level of detail, enclosing important information on the emission geometry in the neutron star magnetosphere. Conversely to traditional gamma-ray telescopes, which relied exclusively on spectroscopy and timing, e-ASTROGAM will be able for the first time to measure as well the polarization characteristics of the gamma-ray emission in pulsars. The optical polarization measurements of the Crab pulsar have demonstrated how useful these measurements are for constraining the emission models. Since the vast majority of the known gamma-ray pulsars lack optical pulsations, the unique polarization capabilities of e-ASTROGAM will be a powerful tool for understanding the nature of high-energy pulsar emission.

Pulsars are interpreted as rotating magnetic dipoles which transform the rotational energy into electromagnetic radiation. The latter is observed as pulsed emission when the magnetic axis crosses the observer's line of sight at each rotation (lighthouse effect). The space surrounding the neutron star, called magnetosphere, is populated with electromagnetic fields and free-force plasma (the electric field induced by the surface charge pulls the charges out against the gravitational forces). A commonly-accepted picture of the pulsar magnetosphere distinguishes two separate zones: the *inner magnetosphere*, where the pulsed emission is thought to come from, and the *wind zone* populated by a relativistic magnetized wind.

- The inner magnetosphere is contained within the *light cylinder*, that is to say, the cylinder around the neutron star where the velocity of the plasma reaches the speed of light. Its radius has a typical value of $\sim$ 100 km. The charged particles extracted from the star surface by strong electric fields move along the closed and electric equipotential lines of the magnetic field. Therefore, they corotate with the star. The corotation breaks at large distances close to the light cylinder: particles bound to the lines closing outside the light cylinder can escape.
- The wind zone is the region included between the light cylinder and the termination shock.The particles which have escaped the inner magnetosphere form an ultra-relativistic wind with Lorentz factor as large as $\Gamma \sim 10^6$: the *unshocked pulsar wind*. This wind carries most of the spin-down energy of the neutron star in the form of electromagnetic, and particle energy density.

The region where the electrons are accelerated remains the main open question of the standard pulsar paradigm. Two main models were proposed. One locates the acceleration region close the neutron star surface, the so-called *polar-cap* [1]. If γ-rays are produced close to the star surface where the magnetic field is very intense ($\sim 10^{12}$ G), magnetic-pair production is unavoidable, and an electromagnetic shower develops. Only those γ's below the pair-production threshold can escape from the magnetosphere and be detected by a potential observer on Earth. The cross-section of the magnetic pair-production would translate into a sharp super-exponential cutoff in the observed spectrum. The competitor model places the acceleration region far away from the stellar surface, in the outer region of the magnetosphere, giving rise to the so-called *outer gap* model [2]. In this case, the magnetic field is not strong enough as to produce pairs, but nevertheless, γ-rays still undergo an attenuation process due to the interaction with ambient photons. This would produce again a spectral cutoff in the observed spectrum, but softer than the one predicted in the polar cap model. Since both models predict a similar spectrum up to the cutoff energy, which typically occurs from hundreds of MeV to few GeV, it was thought that the best way to study the validity of these models is by precise measurements of the energy spectrum around the cutoff energy.

The launch of the Fermi/LAT instrument, on-board of the *Fermi* satellite, has revolutionized our knowledge of gamma-ray pulsars, increasing the number of known gamma-ray pulsars from seven up to more than two hundred [3], Fermi, along with ground-based gamma-ray telescopes as MAGIC [4] and VERITAS, have firmly established that pulsar high-energy emission comes from the outer magnetosphere, giving rise in the last few year to refined version of external magnetospheric models. However, due to low statistics it is usually quite difficult to distinguish between competitive models based on spectral and timing information alone. Moreover, model predictions depend on the pulsar inclination and viewing angles, which in the best cases are just poorly known. In contrast, the expected polarization signature differs significantly from one model to another because it is very sensitive to the electromagnetic geometry, and hence to the location of the emitting zones [5]. The promise of gamma-ray polarimetry comes from the fact that nearly all high-energy emission mechanisms can give rise to linearly polarized emission, though the polarization angle and degree of polarization are highly dependent on the source physics and geometry. Both Synchrotron and curvature radiation produce linearly polarized radiation in which the angle traces the field direction and the degree is independent of energy. Compton scattering of photons off electrons, on the other hand, produces scattered radiation whose polarization degree depends on energy and scatter angle.

Gamma-ray polarimetry observations with e-ASTROGAM will be then crucial to deliver information on the neutron star magnetic field and locate the region in the magnetosphere where the acceleration of particles takes place.

References

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