Shedding light on the ultra-relativistic electron-positron wind of the Crab Pulsar

The Crab pulsar is a product of the historical supernova explosion that took place in 1054 AD. The generally accepted paradigm of this fast-rotating, highly magnetized neutron star and its nebula postulates [1,2] the existence of a relativistic electron-positron wind which originates in the pulsar's magnetosphere at $R = 10^8$ cm and terminates in the interstellar medium at $R = 3x10^{17}$ cm. The evolution of the wind is characterized by three consecutive processes: (i) transformation of the pulsar rotational energy to the electromagnetic energy (Poynting-flux), (ii) transformation of the Poynting flux to the kinetic energy of bulk motion of the electron-positron plasma ('acceleration of the wind'), and (iii) termination of the wind by a standing reverse shock which accelerates electrons up to 1 PeV, randomizes their pitch angles, and thus results in an extended nonthermal source: the Crab Nebula. All three processes should proceed with incredibly high (close to 100 %)

efficiency in order to explain the observational data. Remarkably, the strong belief of physicists and astronomers in the existence of the pulsar wind, over almost 40 years has been based on the indirect arguments from the analysis of properties of the pulsar and the surrounding nonthermal nebula, but not on the direct detection of the wind itself, the "bridge" which connects the pulsar and the nebula.

Two components of this complex system – the Crab Pulsar and the Crab Nebula are bright gamma-ray sources emitting predominantly in the high (Megaelectronvolt to Gigaelectronvolt) and very high (Teraelectronvolt) energy bands, respectively. Meanwhile, the third key component, the wind, via which the transfer of energy from the pulsar to the nebula is realized, is generally believed to be an 'invisible substance'. Indeed, despite the relativistic speed of the wind, in the frame of the outflow the electrons are 'cold'; they move together with the wind's magnetic field and therefore do not emit synchrotron radiation. However, the wind can radiate high energy gamma-rays through the mechanism of inverse Compton scattering when the ultrarelativistic electrons and positrons of the wind are illuminated by photons originating in the pulsar's magnetosphere and/or the surface of the neutron star [3]. In the paper published this week in Nature [4], Felix Aharonian, Sergey Bogovalov and Dmitry Khangulyan argue that the recent reports on surprise detections of pulsed very high energy (VHE) gamma-radiation from Crab by the VERITAS [5] and MAGIC atmospheric Cherenkov telescopes [6] are best explained by Comptonization of ultrarelativistic electrons of the wind by the pulsed X-ray emission of the pulsar (see Fig. 1). At first glance, the modulation of the reported VHE gamma-radiation with a period of the pulsar rotation indicates to the magnetospheric origin of radiation. However the models of the pulsar radiation generally predict suppression of emission above 10 Gigaelectronvolts, thus the extrapolation of the magnetospheric emission towards very high energies requires dramatic revision of the current models of pulsars. As demonstrated in ref. [4], more natural emitter of the pulsed VHE emission is the wind. It allows interpretation of both the spectral and temporal features of the detected radiation, with only three assumptions related to the (i) site of the acceleration of the wind, (ii) its final Lorentz factor and (iii) the level of anisotropy.

If this interpretation is correct, then the detection of the pulsed VHE gamma-ray emission implies the first observational evidence of formation of a cold ultrarelativistic electron-positron wind from the Crab pulsar. The reported gamma-ray data allow us to localize with a good precision the site and estimate the speed of transformation of the Poynting flux to the kinetic energy of wind's bulk motion. It appears that the acceleration of the wind to a Lorentz factor of (0.5–1.0) $\times 10^6$ should take place abruptly in the narrow cylindrical zone of radius between 20 and 50 light-cylinders centered on the axis of rotation of the pulsar. Although the ultrarelativistic nature of the wind and the derived Lorentz factor do support the general paradigm of pulsar winds, the requirement of the very fast acceleration of the wind in a narrow zone not far from the light cylinder challenges the current models.

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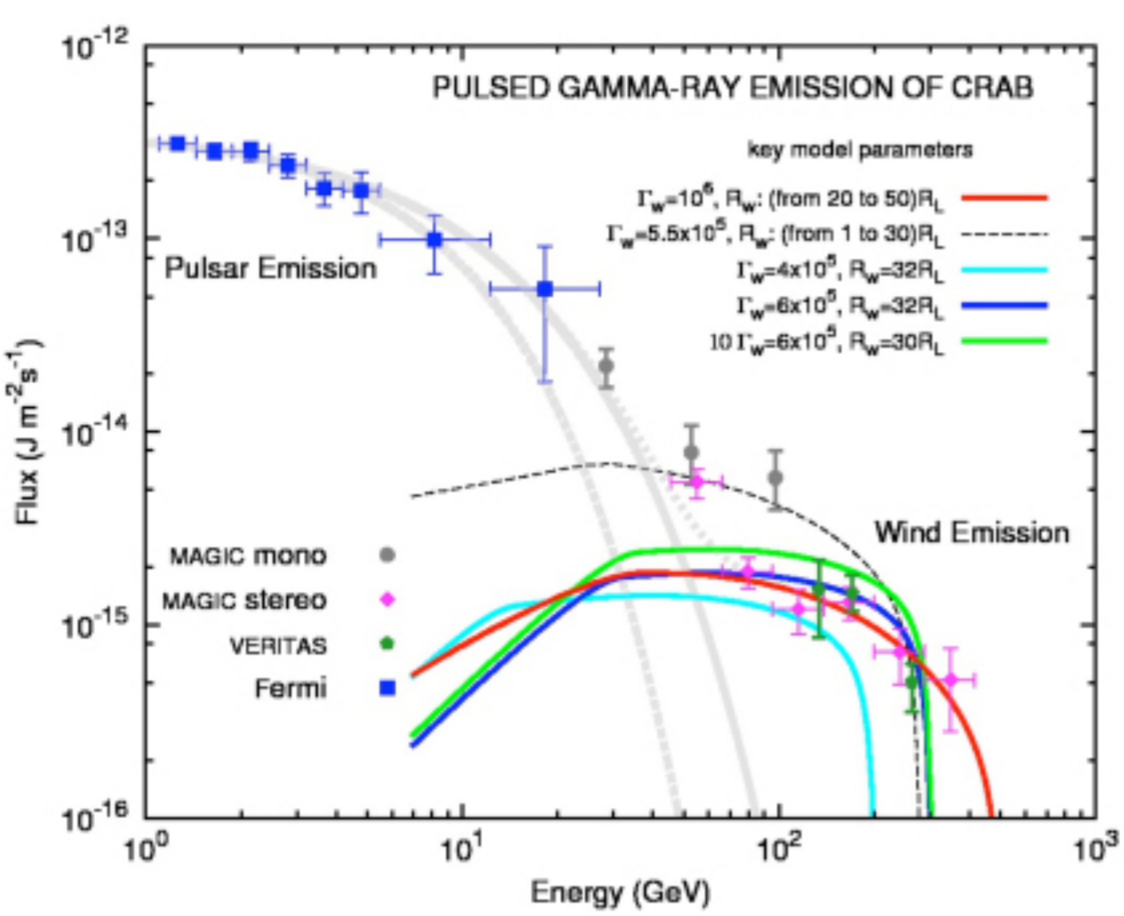

Fig.1: The spectral energy distribution of gamma-radiation produced by the pulsar magnetosphere and by the pulsar wind.

Reference : Explanation by researcher Dmitry Khangulyan

February 23, 2012