Compact Gamma-Ray Binaries

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Abstract: In the recent years a new window on the universe has been opened by ground based and space telescopes that survey the sky by detecting high energy photons, which have energies from a few, up to hundreds of gig electron volts (GeV). Because of the poor angular resolution of the gamma-ray telescopes relative to that of telescopes for longer wavelengths, the ultimate nature of a large fraction of the thousands of sources of gamma-rays observed so far remains unknown. Compact astrophysical objects are among those high energy sources, and recently were discovered in the Milky Way sources that belong to a particular class called "Compact Gamma-Ray Binaries". They are neutron stars or black holes orbiting around massive stars[1,2]. The challenges are: 1) to identify the gamma-ray source with a source observed at other wavelengths, 2) determine the properties of the binary system, and 3) understand the physical mechanisms by which gamma-rays are produced. In the Milky Way have been unambiguously identified only a handful of compact binaries radiating at gamma-rays (Cygnus X-3; Cygnus X-1; PSR B1259-63; LSI +61° 303; LS 5039; HESS J0632+057; 1FGL J1018.6-5856). However, from models of the evolution of massive stellar binaries it is inferred that in the Galaxy there should be a much larger population of Gamma-ray Binaries.

The Large Area Telescope (LAT) on board of the Fermi satellite has so far catalogued more than 1400 high energy sources. Many of them are in the Milky Way, but because of the uncertain positions in the sky provided by the gamma-ray telescope (typically few arc-min), and the complexity of the star formation regions where Gamma-ray Binaries are usually located, the association of these high energy sources with objects observed at other wavelengths is usually highly uncertain. is a new Gamma-ray Binary. The potential of the searches for periodic modulation at gamma-rays and other wavelengths to unravel the putative population of Gamma-ray Binaries in the Milky Way has been applied successfully to unambiguously identify with Fermi 1FGL J1018.6-5856[3] and Cygnus X-3[4] as sources of gamma-rays. Cygnus X-3 is a microquasar[5] source of collimated relativistic jets, which was also observed at gamma-rays with the Agile satellite[6].

Figure 1, shows schematically and in very general terms, how the dominant physical mechanisms to produce the gamma-ray emission and its orbital modulation, may depend on the specific type of the massive star in the compact binary. When the star is very massive and produces a high density field of UV photons, the main mechanism would be inverse Compton up-scattering to gamma-rays of those UV photons, by the relativistic particles in the microquasar jets or pulsar winds[7,8]. In this scenario the maximum of gamma-ray emission takes place at superior conjunction. This may be at work in both types of compact binaries; in high mass microquasars as Cygnus X-3 where the compact object orbits a Wolf Rayet star, or in pulsars orbiting around very massive stars that produce high density fields of UV photons, as may be the case of the O6V((f)) stars in LS 5039 and 1FGL J1018.6-5856.

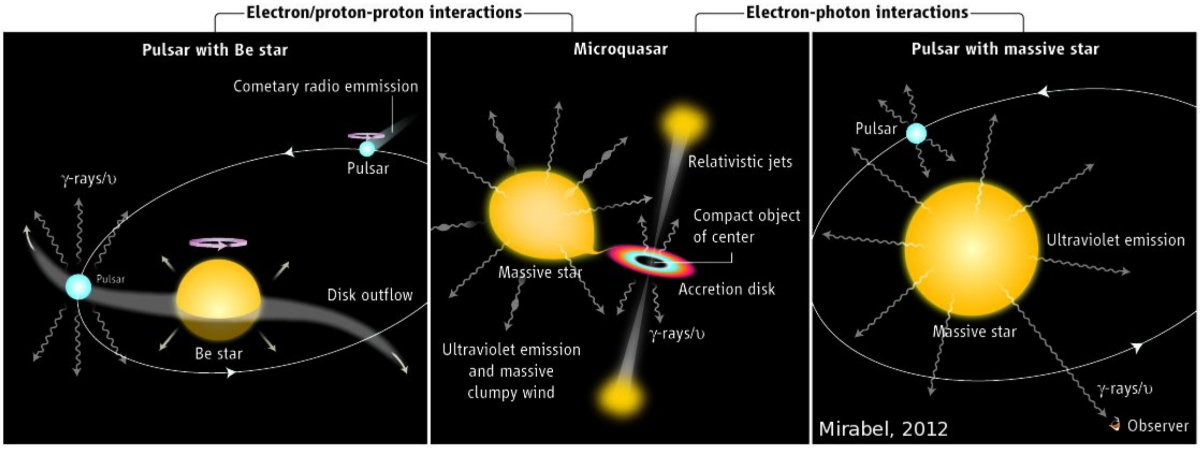

Figure 1: (from Mirabel, Science 335, (2012): High mass compact binaries and physical mechanisms for the production of gamma-rays and high energy neutrino flux. (Left and right panels) Pulsar winds are powered by the rapid rotation of magnetized neutron stars; gamma-rays can be produced either by the interaction of the relativistic particles of the pulsar wind with the outflowing protons in the disk/envelope of a Be star (left panel; e.g. PSR B1259-63), or by their interaction with ultraviolet photons from a very massive main sequence star (right panel; could be the case in LS 5039 or 1FGL J1018.6-5856). Microquasars are powered by compact objects (neutron stars or stellar-mass black holes) via mass accretion from a companion star (Center panel). When feed by a massive star, the relativistic jets may produce gamma-rays by either electro/proton-proton interaction in the clumps of a Wolf-Rayet wind, or by electron-photon interaction in the UV/optical radiation field (e.g. Cygnus X-3). High energy neutrino emission can be produced in Gamma-ray Binaries by the decays of secondary charged mesons produced at proton-proton and/or proton-gamma photon interactions.

When the star in the compact binary is of Be type an alternative hadronic mechanism to inverse Compton may be at work. These stars are characterized by a massive outflow with disk and/or flattened envelope geometry, in fast rotation. In this case the gamma rays may be produced by the interaction of the pulsar wind particles with the ions in the massive outflow, at the time when the compact object crosses the disk/envelope, which does not necessarily takes place at periastron. This could be the case in the Be compact binaries PSR B1259-63 and LSI +61° 303, where the phasing of gamma-ray maximum at GeV energies is delayed relative to periastron or superior conjunction, and therefore not consistent with inverse Compton scattering of UV stellar photons. Detailed hadronic mechanisms that produce gamma-rays have been proposed in a diversity of astrophysical contexts[9,10].

In gamma-ray hadronic mechanisms high energy neutrino flux could also be produced in compact binaries of the type shown in Figure 1. The neutrinos emerge from the decays of secondary charged mesons produced at proton-proton and/or proton-gamma photon interactions[11]. In microquasars, relativistic protons from the jets interact with cold protons in clumps of the massive stellar wind, at large distances from the compact object[12]. In the case of a Pulsar-Be binary, neutrino bursts could be produced by the interaction of relativistic protons from the pulsar wind with high density clumps of cold protons in the massive outflowing disk/envelope of the Be star. Depending on the specific parameters of these Gamma-ray Binaries, it is an open question whether neutrino signals may be detected from this type of astrophysical objects with present and future neutrino telescopes.

TeV emission has been detected in Gamma-ray Binaries observed by Fermi (PSR B1259-63; LSI +61° 303 and LS 5039), and it is an open question whether 1FGL J1018.6-5856 is also a TeV source. Its position is consistent with the TeV source HESS J1018-589[13], but due to possible confusion with other objects in this complex star forming region, it is not clear whether the Fermi source and a component of the HESS source are one and the same object. To solve this type of questions by using time modulation and/or more accurate positions of TeV sources, the sensitivity and angular resolution of ground based Cherenkov telescopes must be significantly improved. It is expected that the large collecting area and separation of the telescope elements in the future Cherenkov Telescope Array[14] will provide the sensitivity and angular resolution that will allow a significant expansion and consolidation of this emerging research area in High Energy Astrophysics.

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