Gamma-gamma absorption in gamma-ray binary systems

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Abstract:

Gamma-ray binaries are a class of high-energy binary systems which are distinguished by their spectral energy distributions peaking above 1 GeV. Gamma-ray binaries consist of a neutron star and an exciting compact object which is either a white dwarf or a black hole. Generally, in these systems the nature of the compact object is unknown. For two cases, both known as RX J0852.0-4622 and RX 2003+4217, where the compact objects have been identified as pulsars. For a neutron star compact object the non-thermal emission is believed to originate from the interaction between the stellar and polar winds. It has been suggested that there are multiple regions of emission in these systems with the white dwarf and the neutron star probably originating from different locations. It is, however, not yet known if this is the case. The explanation of the origin of this gamma-ray emission can be a test in constraining the location of the TeV emission region. We have calculated the gamma-gamma absorption expected around the TeV-brightness gamma-ray binaries and are studying the influence on the observed spectrum. With this we plan to place constraints on the TeV production location. The results of this study will be used for predictions based on the upcoming Cherenkov Telescope Array (CTA).

Introduction:

The nature of the compact object is a key known in two of the near systems discovered so far, namely, RX J0852.0-4622 and RX 2003+4217, which both contain a radio binary identified by pulsar and/or X-ray emission (Avila et al., 2005; Casares et al., 2009). Gamma-ray binaries produce absorbed, non-thermal radiation from radio up to TeV energy γ-rays. The TeV emission is produced via inverse Compton scattering of electrons off stellar photons. If the compact object is an accreting white dwarf, it is believed to have sufficient rotational velocity to halt accretion from the companion stellar wind. Due to the stellar winds having a higher angular momentum than the polar winds, this leads to the formation of a corotating stellar disk around the pulsar. Gravitational instability of locked polar and stellar wind matter forms a新生儿 nebula which is believed to explain the absorption continuum in the high-energy emission from the system. The companion stars can be stars like Wolf-Rayet stars, which might lead to additional absorption features, but this is not demonstrated by numerical simulations by Massi et al. (2012). The possibility of a shock front compact object cannot be ruled out and has been ruled out as a possibility for many systems, most notably for 1H 1921+043. In contrast to radio observations, the 100 GeV to 1 TeV emission has been observed from PSR J1713+0747, a well-studied gamma-ray binary system. The optical star is indicated by a blue circle at the right and the white ellipse shows the orbit of the compact object. All plots, the observer is viewing this binary system from the bottom of the page.

Theory:

The geometry of the ζ-rays attenuation in the binary system is shown in Fig. 1. A γ-ray with energy ɛγ, travelling in the direction 0, in the stellar photon with energy ɛ0, travelling in the direction θ, will scatter and/or cross over absorption in the system. The absorption at the point of the line of sight 0, along the path length L, is given by

\[ \rho_{\gamma\gamma} = \int_0^L \int_0^L \rho_{\gamma\gamma}(\theta, \phi) \, d\theta \, d\phi \]

where \( \rho_{\gamma\gamma}(\theta, \phi) \) is the energy of stellar photon 0, the distance to the centre of the star from 0 and \( \theta, \phi \) are the spherical coordinates along the line of sight.

\[ \rho_{\gamma\gamma}(\theta, \phi) = \frac{\sigma_{\gamma\gamma}}{\pi} \frac{1}{\varepsilon_0} \theta_0 \left( \frac{\varepsilon_0}{\varepsilon_\gamma} \right)^2 \]

where \( \theta_0 \) is the Thomson cross section and

\[ g^2 = 1 - \frac{2\varepsilon_0}{\varepsilon_\gamma} - \frac{2\varepsilon_0}{\varepsilon_\gamma} \frac{\varepsilon_0}{\varepsilon_\gamma} \]

The distance to the apex of the shock, the “shadow” of absorption, can be determined from the ratio of the stellar (\( \varepsilon_0 \)) and pulse (\( \varepsilon_\gamma \)) pressures

\[ R_{\text{sh}} = 2 \varepsilon_0 \frac{\theta_0}{\varepsilon_\gamma} \]

where \( \theta_0 \) is the angular distance.

Discussion and Conclusion:

Due to the high angular dependency of inverse Compton scattering the maximum γ-ray and ζ-ray emission near 1 TeV is observed. The higher TeV emission will, in a first explanation, occur at superior conjunction. However, superior conjunction is only the phase in which most favorable for γ-ray absorption and will lead to a possible emission peak between 100 GeV and 1 TeV. However, in this case, the system is expected to be an infrared source. Interestingly, the observed TeV emission might be a result of the current γ-ray emission from the system. This effect should be observable in the future, with a new generation of instruments. However, in the future, γ-ray emission from the system will be observable with instruments. This effect should be observable in the future, with a new generation of instruments. However, in the future, γ-ray emission from the system will be observable with instruments.

Parameters:

The results presented were modelled using the parameters given in Table 1. All of the parameters are for a neutron star compact object.

References:


Shannon et al. (2014); Miller et al. (2013).

Miller et al. (2013).

Du Plooy et al. (2016).