Gamma-rays from the compact colliding wind region in Cyg OB2 #5

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Abstract. In this contribution we model the non-thermal emission (from radio to γ -rays) produced in the compact (and recently detected) colliding wind region in the multiple stellar system Cyg OB2 #5. We focus our study on the detectability of the produced γ -rays.

Keywords: stars: binaries; stars: individual: Cyg OB2 #5; radiation mechanism: non-thermal; gamma-rays: theory

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INTRODUCTION

The collision between stellar winds of massive stars is a promising scenario to produce non-thermal emission. In early type binaries, a strong shock is created between the stars, where the wind ram pressures are equated. In those shocks particles can be accelerated up to relativistic energies via the Fermi-I acceleration mechanism, and produce non-thermal emission. In particular, γ -rays can be produced by the interaction of the accelerated particles with the photon and matter fields provided by the stellar radiation and wind, respectively.

Non-thermal radio emission from colliding wind regions (CWRs) has been firmly detected from many systems and they are putative candidates to be γ -ray sources since many years ago. In the past, only marginal correlations between CWRs and unidentified γ -ray sources (of e.g. EGRET catalog) has been found. However, the recent detection of Eta-Car by *Fermi* [1] and *Agile* [2] shows that the γ -ray emission of CWRs is not only a theoretical prediction. In this work we study other promising γ -ray source to be detected by *Fermi*: the peculiar system Cyg OB2 #5.

The source Cyg OB2 #5

Cyg OB2 #5 is a radio-bright early-type multiple system located into the big stellar association Cyg OB2, at a distance of ~ 1.4 kpc. This peculiar source is a (possible) quadruple stellar system that shows radio structures over different scales, from about 10 milliarcseconds (mas) to about 30 arcseconds [3]. At the 10 mas scale, there is a non-thermal, arc-like structure that traces the CWR between the wind of an eclipsing contact binary and that of an unseen nearby companion. About 1" to the NE of the contact binary, there is another non-thermal component that results from the interaction of the winds of



FIGURE 1. *Left*: Compact and extended components of the system Cyg OB2 #5. The sketch is not drawn to scale. *Right*: Escape, radiative cooling and acceleration times for the cases discussed in the text.

the contact binary and that of a known B-type star. Finally, there is an extended ($\sim 30''$) synchrotron structure that could also be associated with Cyg OB2 #5. In Figure 1 (left) we show a sketch of the three non-thermal structures that compose this complex source. In this study we model the γ -ray emission produced in the compact CWR (produced by the contact binary and an unseen companion).

PARTICLE ACCELERATION AND LOSSES

Both stars of the compact CWR are separated a distance $D = x_p + x_s$, and the CWR is located at a distance x_p and $x_p = \sqrt{\beta} x_s$ from the primary and the secondary components of the system, respectively. Being $\beta \equiv \dot{M}_p v_{\infty,p} / \dot{M}_s v_{\infty,s}$, where \dot{M} is the mass-loss rate, and v_{∞} is the terminal wind velocity, the stagnation point is located closer to the less powerful star (the unseen companion in our case). Characterizing the wind of the contact binary by $v_{\infty,p} \sim 1500 \text{ km s}^{-1}$ and $\dot{M}_p \sim 2 \times 10^{-5} \text{ M}_{\odot} \text{ yr}^{-1}$, and considering that the companion is a B0.5 early-type star [4] x_s results $\sim 1.5 \text{ AU}$, where we have estimated $x_p = 25 \text{ AU}$ from radio data. At the location of the stagnation point, a discontinuity surface and a double bow-shock structure is created. In long period binary systems, the formed CWR is thick and it is not affected by disruptive instabilities. Thus, CWRs are good places for particle acceleration, since at least one of the shocks is adiabatic and the shocked region will be sufficiently large to allow charged particles to reach relativistic energies. In this work we assume Fermi-I as the operating mechanism to accelerate particles. Being the wind of the contact binary the most powerful, we will consider only the acceleration of particles in the shock produced by this wind.

The detection of synchrotron emission is an evidence that there is a population of relativistic electrons (*e*) in the CWR. However, protons (*p*) can be accelerated as well. Particles accelerated by the Fermi-I mechanism follow a power-law energy distribution $N_{e,p} = K_{e,p}E_{e,p}^{-2.1}$, where we have assumed that both electrons and protons are injected with the same spectral index 2.1. Considering that the same number of electrons and



FIGURE 2. Spectral energy distributions for the cases discussed in the text. The *Fermi* sensitivity is also plotted in order to show that the source is detectable by this instrument.

protons are accelerated at energies $\leq m_e c^2$ [5], and neglecting ionization/coulomb losses, we relate $K_p = (m_p/m_e)^{(2.1-1)/2} K_e$.

From the measured synchrotron flux $S_v(v = 8.4\text{GHz}) = 3 \text{ mJy} [4]$ we estimate the magnetic field *B* in the CWR by equating magnetic and non-thermal energy densities: $U_B = U_e + aU_p$, where U_e and U_p are the energy densities of relativistic electrons and protons, respectively, and *a* takes two values: 0 (no protons are accelerated) and 1 (protons are accelerated as well as electrons). We obtain B = 0.07 G in the former case and 0.29 G in the latter. Once we know *B*, we can calculate the acceleration and synchrotron cooling time. To calculate the losses by Inverse Compton (IC) scattering, the largest density of target photons ($U_{ph} = 4.45 \text{ erg cm}^{-3}$ at the location of the CWR) is provided by the unseen companion with luminosity $L_s \sim 6.1 \times 10^4 \text{ L}_{\odot}$ [4]. In addition to synchrotron and IC losses, accelerated electrons in the field of ions in the wind can produce relativistic Bremsstrahlung radiation at γ -ray energies. However, the density of these ions in the CWR is not enough ($n_w = 1.3 \times 10^7 \text{ cm}^{-3}$) for the relativistic Bremsstrahlung losses to be more efficient than IC cooling. Thus, the maximum energy of accelerated electrons is constrained by IC losses, given $E_{e,max} \sim 40$ and 93 GeV in the cases with a = 0 and 1, respectively, as is shown in Fig. 1 (right).

Relativistic protons interacting with ions in the stellar winds produce neutral pions and then γ -rays. However, relativistic hadrons escape from the CWR on a time shorter than the *pp* cooling time. At energies $E_p < 5$ TeV, advection losses are dominant $(t_{adv} \sim 4x_p/v_{\infty,p} \sim 10^7 \text{ s})$, and at larger energies the diffusion escape become more relevant. This produces that N_p shows a break at energy $E_b = 5$ TeV. The maximum energy of protons is constrained by diffusion losses given $E_{p,max} \sim 50$ TeV.

GAMMA-RAY EMISSION AND DISCUSSION

We computed the spectral energy distribution (SED) of synchrotron, IC, relativistic Bremsstrahlung, and pp, in the CWR considering the distributions N_e and N_p derived

previously by adjusting the synchrotron spectrum with radio data and below the equipartition condition. We obtain that the most important radiation mechanism to produce γ rays in the compact CWR of Cyg OB2 #5 is the IC scattering due to the dense photon stellar field provided by the unseen companion when only electrons are considered (case with a = 0). In this case synchrotron, IC and relativistic Bremsstrahlung bolometric luminosities result $L_{\rm syn} \sim 1.5 \times 10^{30}$, $L_{\rm IC} \sim 2.6 \times 10^{34}$, and $L_{\rm Brem} \sim 5.4 \times 10^{31}$ erg s⁻¹, respectively, as is shown in Fig. 2 (left). In the case with a = 1, the non-thermal energy is distributed between electrons and protons resulting that $U_p > U_e$ as a consequence of $m_p > m_e$ [5]. The achieved bolometric luminosities are $L_{\rm syn} \sim 1.7 \times 10^{30}$, $L_{\rm IC} \sim 1.7 \times 10^{33}$, and $L_{\rm Brem} \sim 2.9 \times 10^{30}$ erg s⁻¹. In this case proton-proton collisions are the most important cooling channel in the γ domain, reaching a bolometric luminosity $L_{pp} \sim 7.8 \times 10^{32}$ erg s⁻¹, as is shown in Fig. 2 (right).

The γ -ray spectrum is attenuated at energies greater than ~ 0.3 TeV, where the optical depth due to photon-photon electron-positron pair production $(\gamma + \gamma \rightarrow e^+ + e^-)$ in the intense stellar radiation field of the B0.5 companion star reaches non-negligible value. In the case with a = 0, photon-photon absorption is not relevant because $E_{\rm ph} \sim 0.3$ TeV is larger than the maximum energy of photons produced there, but in the case with a = 1 the attenuation is significant.

From Fig. 2 it can be seen that the γ -ray emission produced in the compact CWR of Cyg 0B2 #5 (by the simple model described in the present contribution) can be detected with the *Fermi* satellite. In particular, when only the relativistic electrons (that produce the detected synchrotron emission) are considered, IC scattering of photons from the unseen companion reach specific luminosity values in the GeV domain detectable with *Fermi* in a deep exposure. When protons are also accelerated up to relativistic energies, γ -rays from *pp* collisions are also detectable by *Fermi*. These results shown that even in the case in which the *Fermi* detection from the Cyg OB2 region has been associated with the pulsar PSR J2032+4127, under certain conditions a significant amount of γ -rays can be produced in Cyg OB2 #5. The detection of γ rays from CWRs can help us to understand the properties of stellar winds, as well as the development of high-energy processes in stellar environments.

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REFERENCES

- 1. Abdo et al. [Fermi collaboration] 2010, ApJS 188, 405
- 2. Tavani, M., Sabatini, S., Pian, E., et al. 2009, ApJL, 698, L142
- 3. Ortiz-León G.N., Loinard L., Rodríguez L.F., Mioduszewski, A.J. & Dzib A.S. 2011, ApJ 730, 30
- 4. Dzib, A.S., et al. 2012 (submitted)
- 5. Bell, A.R. 1978, MNRAS 182, 443