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Non-thermal radiation from a runaway early-type star

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Abstract. HD 195592 is an O-type supergiant star, known as a well-established runaway. Recently, a *Fermi* γ-ray source (2FGL J2030.7+4417) with a position compatible with that of HD 195592 has been reported. Our goal is to explore a scenario where HD 195592 is the counterpart of the *Fermi* γ-ray source. The high-energy emission would be inverse Compton radiation produced in the bowshock of the runaway star.

We calculate relativistic particle energy losses and the resulting radiation from the bowshock of HD 195592 and show that the latter is compatible with the detected γ-ray emission. We conclude that the *Fermi* source 2FGL J2030.7+4417 might be produced, under some energetic assumptions, by inverse Compton up-scattering of infrared photons from locally heated dust. HD 195592 might therefore be the very first object detected belonging to the category of γ-ray emitting runaway massive stars, whose existence has been recently predicted.

Keywords: gamma-rays: theory, stars: early-type, stars: winds
PACS: 97.10.Me, 95.85.Pw

INTRODUCTION

The star HD 195592 (DB+43 3630) is a massive runaway visible from the northern hemisphere, located at a distance $\sim$ 1.1 kpc. There is strong evidence supporting the hypothesis that HD 195592 is a binary system, with a period of about 5 days ([1]). HD 195592 produces a clearly detected bowshock, as it moves supersonically through the interstellar medium (ISM) as reported by [2].

Relativistic particles can be accelerated at strong shocks produced by the stellar wind of a massive runaway interacting with the ISM (i.e. bowshocks). These particles would yield non-thermal radiation ([3], [4]). Recently, a *Fermi* source, 2FGL J2030.7+4417, that might be associated with HD 195592, has been reported in the Fermi Large Area Telescope Second Source Catalog ([5]). In this work we apply the model developed in Ref. [6] for the non-thermal emission that takes place in the bowshocks of runaway stars to HD 195592. We confront then our theoretical spectral energy distribution with the measured flux of the *Fermi* source.

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THE STELLAR SYSTEM HD 195592

HD 195592 is an O9.5Ia-type runaway star that is thought to be originated in the open cluster NGC6913 ([7]). A detailed spectroscopic study revealed that HD 195592 is a binary system with a period of a few days, with a lower mass early B-type companion ([1]).

It is indeed well established that at least some colliding-wind binaries are able to accelerate particles up to relativistic energies and capable of producing non-thermal radiation ([8]; [9]). However, the short orbital period in HD 195592 suggests that the stellar separation in the system would not allow relativistic electrons to reach Lorentz factors high enough as to yield a significant γ-ray emission as detected by Fermi.

NON-THERMAL EMISSION

To calculate the non-thermal radiation we follow the model recently developed by us in Ref.[6]. The values for the relevant parameters are given in Table 1.

TABLE 1. Parameters for HD 195592

Parameter		value
R_0	Standoff radius	1.73 pc
$\dot{M}_{\rm w}{}^{*}$	Wind mass loss rate	3.3×10^{-7} $M_\odot$ yr^{-1}
α	Particle injection index	2
$V_{\rm w}{}^{*}$	Wind velocity	2.9×10^{8} cm s^{-1}
B	Magnetic field	$\sim 2 \times 10^{-6}$ G
$T_\star{}^{\dagger}$	Star temperature	2.8×10^{4} K
$L_\star{}^{\dagger}$	Star luminosity	3.1×10^{5} $L_\odot$
$T_{\rm IR}$	Dust temperature	~ 40 K

* Values from [10].
† Values from [11].

The collision of the supersonic stellar wind with the interstellar medium produces two shocks (e.g. [12]). Relativistic particles are accelerated at the reverse shock. This shock is adiabatic and strong. The particle acceleration mechanism is diffusive first order shock acceleration (e.g. [13]). The acceleration region is assumed to be a small region near the bowshock apex. In order to roughly estimate the magnetic field in the flow, we assume that the magnetic energy density is in sub-equipartition with respect to the kinetic energy $L_{\rm T}$ of the wind. Therefore, we adopt the constraint $\chi < 1$, i.e. $B^2/8\pi = \chi L_{\rm T}/V_{\rm w}A$, where A is the area of a sphere of radius R_0, $V_{\rm w}$ is the wind velocity, and $L_{\rm T}$ is the available power in the system (best fits are provided by $\chi \sim 5 \times 10^{-2}$).

The kinetic power of the stellar wind is $L_{\rm T} \sim \frac{1}{2}\dot{M}_{\rm w}V_{\rm w}^2$. For HD 195592, according to the best available data (Table 1): $L_{\rm T} \sim 10^{36}$ erg s^{-1}. Our estimate relies on the primary star parameters, even though we are dealing with a binary system, since the contribution of the second star is expected to be negligible because of its spectral type.

The power available to accelerate particles in the reverse shock is $L = fL_{\rm T} \sim 2 \times 10^{34}$erg s^{-1}, where f is the ratio of the volume of a sphere of radius R_0 and the volume of the acceleration region. Some fraction of this power goes into relativistic particles $L_{\rm rel} = q_{\rm rel} L$. The energetics of the gamma-ray source requires to $L_{\rm rel} \sim 4 \times 10^{33}$ erg s^{-1}, so $q_{\rm rel} \sim 0.2$, which seems to be a reasonable value if compared, for instance, with supernovae, which are expected to convert about 20% of their kinetic power into relativistic particles (e.g. [14]).

In the calculations of the spectral energy distribution we take into account both hadronic and leptonic content in the relativistic power, $L_{\rm rel} = L_{\rm p} + L_{\rm e}$. We consider $L_{\rm p} = L_{\rm e}$, which means equal efficiency in the acceleration of both types of particles. In Fig. 1 we show the cooling rates for both electrons and protons in the acceleration region.

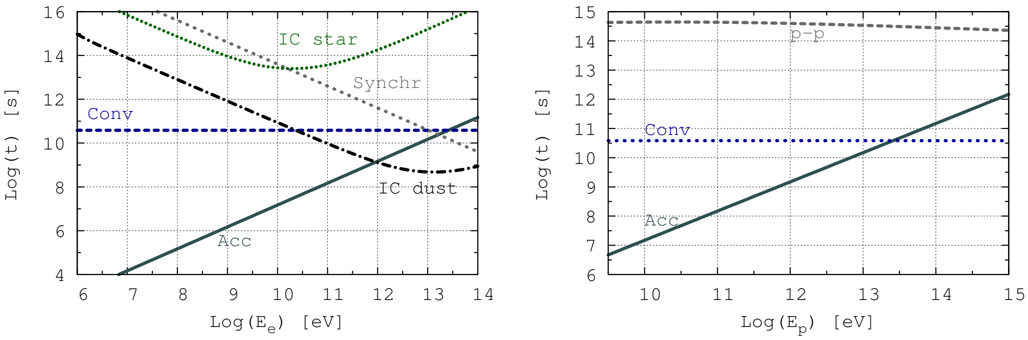

FIGURE 1. Acceleration and cooling time scales for electrons and protons for HD 195592. Left panel is for electrons and right panel is for protons.

To determine the steady state particle distributions for electrons and protons, we solved the transport equation in steady state (see [14]). We refer to [6] for details of calculation. At the energies of interest in this paper both the emission from the shocked ISM and the absorption are negligible.

Figure 2 shows the computed spectral energy distribution (SED) for the emission produced at the bowshock of HD 195592. *Fermi* data are also shown.

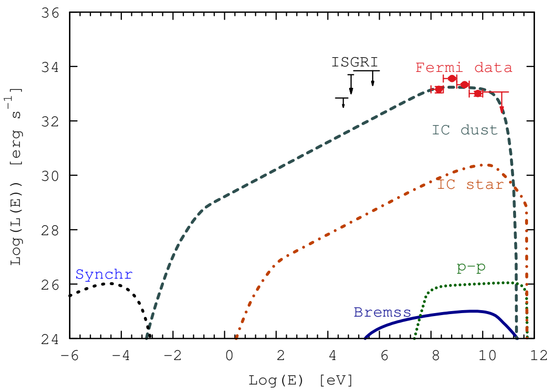

FIGURE 2. Computed SED for HD 195592 bowshock, at d $\sim$ 1 kpc. *Fermi* data of 2FGL J2030.7+4417 and hard X-rays upper limits are also shown.

DISCUSSION

Runaway massive stars offer a unique opportunity to detect GeV-TeV emission from single massive stars. The recent detection of non-thermal radio emission from the bowshock of BD +43°3654 by [3], and of non-thermal X-ray emission from the bowshock of AE Aurigae by [4], confirm the capability of some of these stars to accelerate at least electrons up to relativistic energies. The presence of rich infrared photon fields locally generated by the heated dust swept by the shocks guarantees suitable targets for IC interactions, that might yield, in some cases, detectable γ-ray fluxes.

The star HD 195592 presents some characteristics that makes it a good candidate to be the very first gamma-ray emitting bowshock runaway identified so far. A confirmation of the nature of this source would require deep X-ray observations to check whether there is a power-law spectrum as expected from our modeling.

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