High energy photon absorption in hot stellar radiation fields

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Abstract

Recently, high energy photons up to TeV-energies have been detected from the direction of regions harboring massive star populations at high number density that produce intense hot radiation fields. The transparancy of γ-ray propagation in this environment may be rendered by photon absorption in $\gamma\gamma$ collisions causing pair production. In this paper I study the escape probability of γ-rays in the vicinity of early-type stars and in the Cyg OB2 complex as an example of a rich aggregate of massive stars. I demonstrate that γ-rays can in general *not* escape the base of winds from early type stars (with temperatures > 15000K). Even at distances that are typical for the location of colliding wind regions in massive binaries γ-ray absorption is shown to be non-negligible. Though γ-ray propagation in the Cyg OB2 complex is found to be not strongly affected by $\gamma\gamma$ collisions, the collective effects of the stellar radiation fields in dense stellar clusters can in general significantly enhance the photon density which may lead to substantial underestimates of the photon absorption probability if not taken into account.

1. Introduction

Regions of dense supersonic stellar winds from hot massive stars has been proposed as a source of γ-ray emission reaching even up to TeV-energies (e.g.[7]). In fact, the first unidentified TeV-source detected by the HEGRA telescope system [1] lies in the direction of several thousands of massive stars, the Cyg OB2 complex. The purpose of the present work is to point out the potential problem of high energy photons being possibly absorbed in the intense radiation field of massive stars by $\gamma\gamma$ pair production. In this work I discuss photon absorption in the vicinity of single hot massive stars and clusters thereof, using the Cyg OB2 association as an example.

pp. 2505–2508

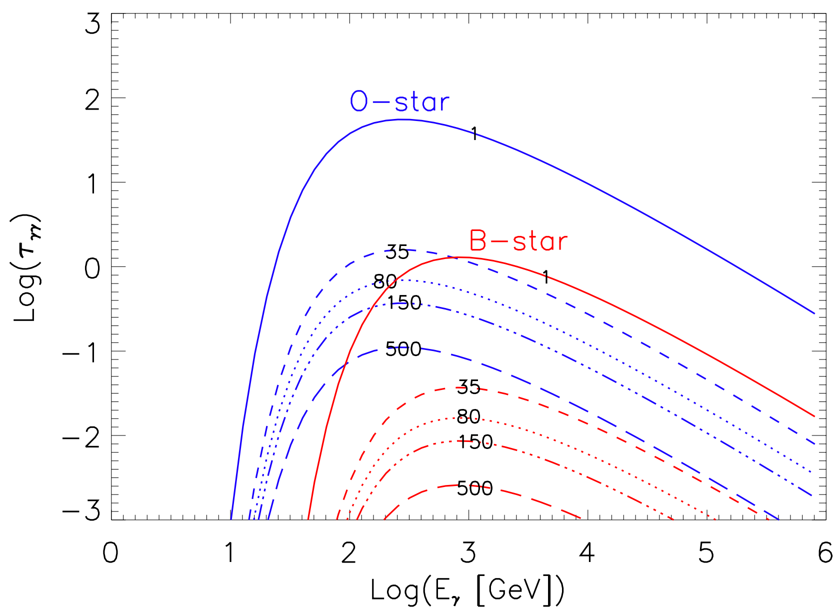

Fig. 1. Optical depth due to $\gamma\gamma$ pair production in the radiation field of an O4V-star (blue left curves; $R_* = 12R_\odot$, $T_{\rm eff} = 47400$K) and of a B5V-star (red right curves; $R_* = 8R_\odot$, $T_{\rm eff} = 15500$K) towards γ-rays produced at distances $q = 1, 35, 80, 150, 500R_*$ (as labelled) from the stars.

2. Photon absorption in the radiation field of hot single stars

Attenuation of optical photons by the process $\gamma + \gamma \rightarrow e^+ + e^-$ pair production was first considered by [6], showing that the effect can be appreciable for TeV-photons. I extend this work by calculating the optical depth $\tau_{\gamma\gamma}$ of this process in a stellar radiation field with a radially decreasing photon density $n(\epsilon) \propto r^2$ where r is the radial distance of the stellar photon from the star. q ($\ll$ distance to the observer) shall be the distance between the star (which shall have a radius R_*) and the γ-ray production site. In the following both, the star and the γ-ray production site, are assumed to be located at exactly the same distance to the observer. Pair creation is expected provided that $\bar\epsilon E_\gamma > (m_e c^2)^2$ with $\bar\epsilon$ and E_γ the energy of the colliding photons. For a mono-energetic photon field and a constant cross section I find

$$\tau_{\gamma\gamma} = \frac{3L(\bar\epsilon)\sigma_{\gamma\gamma}}{8\pi c\bar\epsilon q}(\frac{\pi}{2} - 1)$$

with $\bar\epsilon$ the energy of the stellar photon and $L(\bar\epsilon)$ the luminosity of the star. The factor $(\pi/2 - 1)$ is caused by contributions to the $\gamma\gamma$ collisions that are originating at locations $r > q$ in the radially decreasing photon density of the radiation field. Fig. 1 shows calculations of $\tau_{\gamma\gamma}$ in the radiation field of an O- and a B-type star

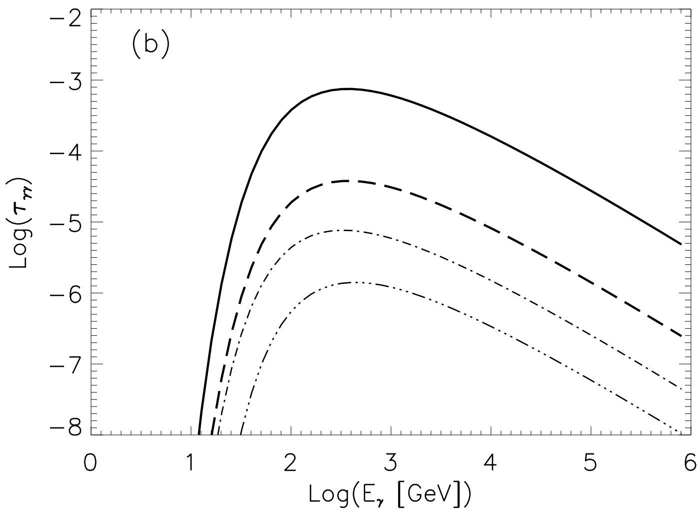

Fig. 2. Optical depth for γ-ray absorption towards the Unid-TeV-source (α(J2000) = $20^h32^m7^s$, δ(J2000) = $+41^o30'30''$) in the Cyg OB2 region due to the O- and B-star radiation fields that are closest to the TeV-source (O7IIIf with $R_* = 14.7R_\odot$, $T_{\rm eff} = 39860$K, $q = 3.5$': dashed-dotted line; B1.5V with $R_* = 8R_\odot$, $T_{\rm eff} = 30000$K, $q = 2.4$': dashed-triple-dotted line), due to the radiation fields of all OB-stars with $q <$ 9' to the TeV-source (dashed line) and due to the radiation fields of all $\sim$ 2600 OB-stars in the Cyg OB2 cluster (solid line).

with temperature $T_{\rm eff} = 47400$K and 15500K, respectively, using the exact cross section [3] and a diluted blackbody spectrum to simulate the stellar radiation field. It is obvious that $>$ 100GeV photons can not escape the base of the wind ($q = R_*$) of O-stars (which is relevant for the model proposed in [7]) and can even be significantly affected by absorption at distances q that are typical for the location of colliding winds [5] in massive binaries ($q \approx 35R_*$ for WR 140). The effect becomes less pronounced in later-type/cooler stars.

3. Photon absorption in stellar assocations: the case Cyg OB2

The first and only still unidentified (Unid) TeV-source [1] is associated with one of the most massive OB associations known in our Galaxy: the Cyg OB2 complex at a distance of ~1.7 kpc houses ~2600 OB-stars within a diameter of only $\sim 2^o$ (~60pc) [4]. In the following I consider the Unid TeV-source to be located in this conglomerat of stars. Fig. 2 shows the photon absorption optical depth $\tau_{\gamma\gamma}$ towards the TeV-source due to the radiation field of the 20 OB-stars in its vicinity (< 9'; as tabelled in [2]), in comparison to the ones caused by the O- and B-star radiation fields closest to the TeV-source only. Taking into account all closeby stellar radiation fields increases $\tau_{\gamma\gamma}$ by more than an order of magnitude in this example. This effect becomes even more pronounced when including the radiation fields of all (∼2600) OB-stars of the cluster into the calculations. The calculations are based on the star density distribution published in [4], and assume that the spectral type distribution in the vicinity of the TeV-source applies to the whole Cyg OB2 association. Fig. 2 shows that significant γ-ray absorption towards the Unid TeV-source is not expected even in the dense Cyg OB2 region. However, taking into account only radiation fields in the very proximity of the TeV-source and neglecting photon fields outside a region that is smaller than the whole cluster size could lead to underestimating γ-ray absorption by several orders of magnitude.

4. Conclusions

Regions of intense stellar radiation fields originating from early type stars are often considered as an ideal environment for γ-ray production because of their enormous supply of photospheric optical/UV photons as targets for Inverse Compton scattering. At high γ-ray energies ($> (m_e c^2)^2/\epsilon$) the expected γ-ray intensity is, however, suppressed due to γ-ray absorption by pair production. This is especially relevant for γ-ray production sites that lie in the very vicinity to early type stars. In particular I demonstrated that > 100 GeV photons can hardly escape the base of dense winds from massive stars. Furthermore, wind collision regions in massive binary systems may also be affected by severe γ-ray attenuation (see also [5]). Finally, the absorption optical depth for γ-rays propagating in the intense radiation field of an association of stars can be substantially underestimated if not the radiation fields of all cluster members are taken into account.

Acknowledgements:
The research of AR is funded by DESY-HS grant 05CH1PCA/6.

References:

1. Aharonian F. & the HEGRA Collaboration 2002, A&A 393, L37.
2. Butt Y.M., Benaglia P., Combi J.A. et al. 2003, ApJ submitted; astroph/0302342.
3. Gould R.J. & Schréder G.P. 1967, Phys.Rev. 155, 1404.
4. Knödlseder J. 2000, A&A 360, 539.
5. Mücke A. & Pohl M. 2002, Proc. "Interacting Winds from Massive Stars", eds. A.F.J. Moffat et al., ASP Conf. Ser., 260, 355.
6. Nikishov A.I. 1962, Soviet. Phys.-JETP, 14, 393.
7. Romero G.E. & Torres D.F. 2003, ApJ 586, L33.