Clues to unveil the emitter in LS 5039:
powerful jets vs colliding winds

V. Bosch-Ramon*, D. Khangulyan* and F. A. Aharonian†,*

*Max Planck Institut für Kernphysik, Saupfercheckweg 1, Heidelberg 69117, Germany
†Dublin Institute for Advanced Studies, Dublin, Ireland

Abstract. LS 5039 is among the most interesting VHE sources in the Galaxy. Two scenarios have been put forward to explain the observed TeV radiation: jets vs pulsar winds. The source has been detected during the superior conjunction of the compact object, when very large gamma-ray opacities are expected. In addition, electromagnetic cascades, which may make the system more transparent to gamma-rays, are hardly efficient for realistic magnetic fields in massive star surroundings. All this makes unlikely the standard pulsar scenario for LS 5039, in which the emitter is the region located between the star and the compact object, where the opacities are the largest. Otherwise, a jet-like flow can transport energy to regions where the photon-photon absorption is much lower and the TeV radiation is not so severely absorbed.

Keywords: gamma-rays, X-ray binaries, stars: individual: LS 5039
PACS: 43.35.Ei, 78.60.Mq

INTRODUCTION

LS 5039 is a high-mass X-ray binary located at distances of 2.5 kpc [1] that presents extended non-thermal radio emission [2]. This source has been detected in the very high-energy (VHE) range all along the orbit and also during the superior conjunction of the compact object [3, 4], when the photon-photon absorption is expected to be the strongest [5].

The primary object in LS 5039 is an O star, and the compact object is still of unknown nature [1]. Although thought to be a microquasar after the discovery of the extended radio emission [2], the non detection of accretion features in the X-ray spectrum led [6] to suggest the presence of a non-accreting pulsar in the system. More recently, the nature of the non-thermal emitter has been discussed in several works (e.g. [7, 8, 9]), the discussion focusing basically in two possible energy providers for the VHE radiation: a supersonic outflow or jet ejected from the surroundings of the compact object (e.g. [10]); or an ultrarelativistic wind produced by a non-accreting pulsar (e.g. [7]).

In this work, we study in detail the photon-photon absorption and its consequences, and point out that, under reasonable values for the ambient magnetic field, the TeV emitter should be located in the borders of the binary system at least around the superior conjunction of the compact object. Otherwise, the electron-positron pairs created via photon-photon absorption in the stellar photon field could radiate overcoming the observed broadband emission levels. These pairs can radiate as well all along the orbit, and may be dominant over a primary component of electrons (see also [11]). We remark that, in [8], it was suggested that the X-ray emitter in LS 5039 may be far from the star, given the negligible inferred soft X-ray absorption in the stellar wind. In addition, in [12], from acceleration efficiency arguments, it was proposed that the VHE emitter should be in the borders of the binary system.

THE TEV EMITTER IN LS 5039

We have plotted a 2-dimensional map of the absorbed luminosity via photon-photon absorption depending on the location of the emitter in LS 5039. This is presented in Figure 1. The XZ coordinates correspond to the plane formed by the emitter and the star (0,0) positions, and the observer line of sight. To compute these maps, we have deabsorbed the observed spectra and fluxes >100 GeV from LS 5039 around the superior conjunction of the compact object. The regions forbidden by the X-ray observational constraints are limited by a contour line. The VHE emitter cannot be located to the left of the dashed line or the X-ray observed fluxes will be overcome by the secondary pair synchrotron emission, expected to be the dominant secondary pair cooling channel for reasonable magnetic field values in the stellar surroundings. O-star surface magnetic fields may reach ~ kG [13], and values of ≥ 10 G could be realistic at few stellar radii from the stellar surface, more than enough to suppress electromagnetic cascades [12]. In the plot, the compact object is located in the left half of the XZ plane at 1.4 × 10^{12} cm from the star independently of the orbital inclination.

In Fig. 2, we show the spectral energy distribution (SED) of the synchrotron emission produced by the sec-
ondary pairs created in the surroundings of the VHE emitter during the superior conjunction of the compact object. The emitter location has been taken close to the compact object, with an ambient magnetic field of 10 G, and an inclination angle of 60°. This value for the inclination angle would correspond to the case of a neutron star as the compact object [1], e.g., a pulsar. As seen in the figure, the resulting X-ray luminosity is seven orders of magnitude larger than the one found by observations [8]. As noted in Fig. 1 only in case the emitter were located far from the compact object, and far as well from the line joining the compact object and the star, the synchrotron radiation would not overcome the observed fluxes. This is consistent with the fact that the X-rays may come from the system borders, as suggested in [8].

When the system is in the inferior conjunction of the compact object, the opacities in the direction to the observer are low, implying a smaller energy budget to power the TeV emission, but the absorbed energy in all the directions is still relatively large. In Fig. 3, we show the SEDs of the synchrotron and inverse Compton (IC) emission of the primary electrons (top) and the secondary pairs (bottom) created by photon-photon absorption. The primary (absorbed) IC component reproduces the spectrum detected during the inferior conjunction of the compact object. The fluxes can be easily converted to luminosities multiplying by $\approx 10^{45} \text{cm}^2$. The X-ray secondary pair luminosities could be even larger than those produced by the primaries. The produced pairs, for reasonable magnetic fields, would generate efficiently synchrotron emission with fluxes similar to those observed in X-rays. The secondary pair IC component would contribute to the GeV range.

CONCLUSIONS

In summary, the detection by HESS of VHE radiation from LS 5039 during the superior conjunction of the compact object, plus a realistic value of the ambient magnetic field, point strongly to an emitter located far away from the compact object, and far as well from the region between the pulsar and the star. This cannot discard a more general pulsar scenario (e.g., [14]), but disfavors...
any pulsar scenario in which the emission would come from the region between the star and the pulsar, as in those proposed for LS 5039 to date (e.g. [7, 15, 16, 17]). A jet-like emitter scenario, whatever the formation mechanism, is favored, given the capability of jets to transport energy and radiate it at large distances from the compact object and the star.

ACKNOWLEDGMENTS

V.B-R. gratefully acknowledges support from the Alexander von Humboldt Foundation. V.B-R. acknowledges support by DGI of MEC under grant AYA2007-68034-C03-01, as well as partial support by the European Regional Development Fund (ERDF/FEDER).

REFERENCES

1. Casares, J., Ribó, M., Ribas, I., et al. 2005 MNRAS, 364, 899
2. Paredes, J. M., Martí, J., Ribó, M. & Massi, M. 2000, Science, 288, 2340
3. Aharonian et al. 2005, Science, 309, 746
4. Aharonian et al. 2006, A&A, 460, 743
5. Dubus 2006a, A&A, 451, 9
6. Martocchia, A., Motch, C., Negueruela, I. 2005, A&A, 430, 245
7. Dubus 2006b, A&A, 456, 801
8. Bosch-Ramon, V., Motch, C., & Ribó, M., et al. 2007, A&A, 473, 545
9. Ribó, M., Paredes, J. M.; Moldón, J., Martí, J., & Massi, M. 2008, A&A, 481, 17
10. Paredes, J. M., Bosch-Ramon, V. & Romero, G. E. 2006, A&A, 451, 259
11. Bosch-Ramon, V., Khangulyan, D., & Aharonian, F. A. 2008, A&A, 482, 397
12. Khangulyan, D., Aharonian, F. A., & Bosch-Ramon, V. 2008, MNRAS, 383, 467
13. Donati, J. F., Babel, J., Harries, T. J. et al. 2002, MNRAS, 33, 55
14. Bogovalov, S. V., Khangulyan, D., Koldoba, A. V., Ustyugova, G. V., Aharonian, F. 2008, MNRAS, 387, 63
15. Dubus, G., Cerutti, B., Henri, G. 2008, A&A, 477, 691
16. Sierpowska-Bartosik, A. & Torres D. F. 2007, ApJ, 671, 145
17. Sierpowska-Bartosik, A. & Torres D. F. 2008, ApJ, 674, 89