Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 2 (OG part 1), pages 787–790

30TH INTERNATIONAL COSMIC RAY CONFERENCE

HESS sources possibly associated with massive star clusters

A. MARCOWITH[1], N. KOMIN[1], Y.A. GALLANT[1], D. HORNS[2], G. PÜHLHOFER[3], S. SCHWEMMER[3], O. REIMER[4] FOR THE H.E.S.S. COLLABORATION
[1]*Laboratoire de Physique théorique et astroparticules, université Montpellier II, CNRS/IN2P3, Montpellier, France*
[2]*Landessternwarte Universität Heidelberg, Germany*
[3]*Institut für Theorische Physik, Lehrstuhl IV: Wletraum und Astrophysik, Ruhr-Universität Bochum, Germany*
[4] *Stanford University, HEPL & KIPAC, CA 94305-4085, USA*
Alexandre.Marcowith@lpta.in2p3.fr

Abstract: In view of the discovery of HESS J1023-575 (discussed in a separate presentation), we examine another very high energy (VHE) gamma-ray source possibly associated with massive star clusters. Particle acceleration in massive star forming regions can proceed at the interface of two interacting winds or result from a collective process; e.g. multiple shock acceleration or MHD turbulence. The gamma-ray emission can also take place at the edge of the superbubble blown by the winds and multiple supernova explosions. Non-thermal radiation from the shell structure then traces the interaction of energetic particles (ions and/or electrons) with the surrounding interstellar matter. In particular, HESS J1837-069 is spatially coincident with a recently discovered very massive star cluster. We discuss the VHE gamma-ray data resulting from H.E.S.S. observations on this or other possible such associations. We consider data in other wavelength domains, in particular in X-rays, and examine the available evidence that the VHE emission could originate in particles accelerated by the above-mentioned mechanisms in massive star clusters.

Introduction

High energy radiative processes are strongly connected with very energetic events as only a fraction of the free energy of the source is necessary to be injected into a small amount of relativistic particles. The Galactic cosmic-rays (GCRs) are probably connected with the explosion of supernovæ (see [1]). A majority of the supernova (SN) progenitors are associated with massive stars (the so-called core collapse supernova) and a majority of massive stars are born, live and die in groups: in massive star clusters and/or OB associations (both hereafter together called massive star forming regions or MSFR); see [2], [3], [4]. The question of the production of energetic particles (EP), the non-thermal signatures and the contribution of MSFR to the GCR population then arises naturally. The acceleration and the propagation of EP in MSFR as well as their interaction with the ambient medium have been widely debated in the literature ([5], [6], [7], [8], [2]). Observational probes of energetic events in MSFR have concentrated on the search of radiative signatures of supernova remnants in superbubbles (SB); e.g. the low density high temperature region blown up by the collective interaction of stellar winds and supernova explosions (see [9]). Usually a firm detection have been proven to be difficult unless the shock is currently interacting with a molecular cloud (as it is probably the case of IC443 discussed by [10] and recently by [11]), or with the shell produced by the multiple wind system. The termination shock or wind-wind interaction shocks in massive star systems have been explored as sites of non-thermal radiation ([12] and references therein). With its improved sensitivity (able to detect at 5 σ level a source at 1% of the Crab in 25h), a large field of view (5^o) and a good angular resolution (about 0.1^o) the H.E.S.S. (High Energy Stereoscopic System) telescope has the technical capacities to explore the faint and diffuse VHE gamma-ray emission that may be produced in MSFR. In this work, we examine different acceleration and radiation scenarii that should contribute to the high energy emission in MSFR (section 2). We discuss the possible association of the source HESS J1837-069 with a MSFR (section 3).

Particle acceleration and non-thermal radiation

Several acceleration processes and radiation mechanisms could give rise to the TeV γ-ray emission detected from HESS J1023-575 (Reimer et al, these proceedings and [13]), as well as in the source TeV J2032+4130 detected by HEGRA in the Cygnus OB2 SB [14]. We discuss briefly here the most relevant acceleration and gamma-ray radiative mechanisms.

Scenario 1: Massive star termination shock: Several authors have considered the possibility of accelerating EP at the terminal shock of massive stars ([15], [16]). The shock particle acceleration efficiency appears to be highly reduced by the magnetic field configuration; the toroïdal component dominates at the termination shock radius $R_{\rm t}$ and is perpendicular to the shock normal. Unless a turbulent component randomizes the magnetic field orientation over a rotational period, the acceleration process is inoperant. Even in the case of a stronger stellar magnetic field, the maximum energy EP can reach would hardly be above the threshold for neutral pion production. The result is also relatively insensitive to the modelling of the wind modulation which uses mean free path estimates strictly valid for protons with energies $\sim$ GeV in the solar wind. The re-acceleration of an ambient CR population has also been proven to be inefficient [16]. It appears that the modulation factor (the ratio of advective and diffusive lengths) in the downstream region is probably so large that the shock region is shielded from the outer medium. Flare particles accelerated in the star atmosphere cool adiabatically in the strongly diverging wind flow and do not contribute to the EP at the shock front. Several issues seem however interesting to be investigated. Firstly, only proton or ion acceleration and radiation have been considered. A leptonic scenario (non-thermal bremsstrahlung or Inverse Compton) may contribute to a gamma-ray emission. Secondly, other turbulence regimes can lead to smaller and/or anisotropic mean free paths that are possibly more convenient for the particle transport.

Scenario 2: Wind-wind interaction in massive binary systems: As discussed above, non-thermal radio synchrotron emission from several massive star binaries supports the scenario of particle acceleration at the interface of two colliding winds. Eichler & Usov (1993) [17] demonstrated the possibility of an efficient particle acceleration at strong shocks created by the wind-wind collision. A more precise treatment of both acceleration and loss effects lead generally to a gamma-ray spectrum with a cut-off in the sub-TeV regime [18]. Good knowledge of the viewing angle and the system parameters are also necessary to evaluate the $\gamma - \gamma$ absorption properly. Alternatively, VHE radiation could be produced by the interaction of a SNR shock wave and a stellar wind [19]. The result is the production of two reflected shocks, one propagating inside the SNR, the second one inside the wind bubble and a converging flow which develops between the two shocks where particle acceleration can take place.

Scenario 3: Collective wind scenario: Gamma-rays produced by neutral pion decay can also result from collective interaction of winds, where the interaction region could serve both as accelerating region and target for the high energy hadrons, or just provide the target material alone. The former has been partly discussed above, the sources of radiation being in that case the termination shock of massive stars or the colliding winds. The second case requires an accelerator relatively close to the star cluster and has been considered by [20]. There are several issues to the gamma-ray observability of these sources. Firstly, the opacity from $\gamma - \gamma$ pair production in the stellar photon field should be low enough. Secondly, if the CR source is outside the star cluster where the interaction takes place, as discussed above, the wind modulation can prevent low energy particles to enter the wind regions. The threshold energy $E_{\rm lim}$ is very sensitive to the structure of the magnetic field, both to normalisation and energy dependence of the spatial diffusion coefficient and to the dominance of the parallel to the perpendicular diffusion coefficient. Depending on the strengths of these effects, $E_{\rm lim}$ can range from

GeV to TeV energies. The modulation is treated similarly to the modelling in [15].

Scenario 4:MHD turbulence and collective particle acceleration processes: The SB turbulent model ([7] and references therein) predicts a peak in the acceleration efficiency after a few times 10^5 years after the ingnition of the turbulence (a network of MHD fluctuations and weak reflected shocks). The peak is reached at the maximum of turbulence conversion into non-thermal particles. The particles accelerated by the last or the aforementioned scenarii can interact with dense surrounding shells [5]. In that case gamma-rays are expected to be produced not only from neutral pion decay but also by non-thermal Bremsstrahlung in dense surroundings shells or in molecular clouds. An accurate spectral measurement at lower energies by AGILE and GLAST would offer better constraints to the emitting process.

A new possible association with a MSFR:HESS 1837-069

HESS 1837-069 is an extended source discovered during the galactic plane scan survey [21]. It shows a flux characterised by a power-law $I_0(E/TeV)^{-\Gamma}$ with $I_0 \simeq 5 \times 10^{-12}\ \mathrm{TeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ and $\Gamma = 2.27(\pm 0.06)$. The source has still no clear counterpart. At the edge (towards the north-east) of the peak flux, [22] reported on a cluster composed of 14 red super-giants (RSGs) using 2MASS data. The cluster is located at an estimated distance of 5.8 kpc with an age of $\sim$ 10 Myrs. In X-rays, a bright source AX J1838.0-0655 (with a photon index of $\Gamma = 0.65$) was previously reported [23] located at the south-East of the star cluster and close to the peak of the HESS source. Our Chandra observations (see figure 1) reveal a large number of previously unknown X-ray sources. Although diffuse X-ray emission is often associated with MSFRs, we find no evidence for extended emission coincident with the RSG star cluster. AX J1837.8-0653 appears as a point source coincident with a radio source (GPSR5 25.252-0139) itself at the center of elongated radio emission [22]. Structure is resolved in the X-rays source AX J1838.10648 (coincident with the HII region W42) but this source appears too distant to power the H.E.S.S. source. Diffuse emission is apparent surrounding the hard X-ray source AX J1838.0-0655 (also detected by INTEGRAL [24]).

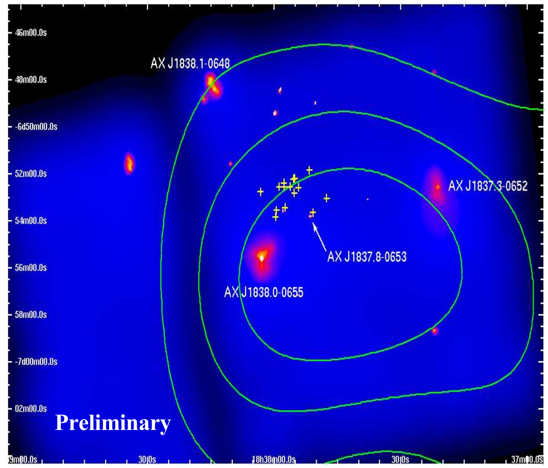

Figure 1: Adaptively smoothed Chandra map (0.3-7 keV band - ObsId 6719 - 20 ks exposure) background-subtracted and exposure corrected. H.E.S.S. excess contours are in green, RSG cluster stars as yellow crosses. Coordinates are J2000

Several possible scenarios can produce the gamma-ray radiation. The RSG stage is short compared to the main sequence phase (about one order of magnitude less). In this stage a massive star is known to have slow winds ($v_{\mathrm{w}} \sim 10 - 15$ km/s) and mass losses a few times $10^{-6} M_{\odot}/\mathrm{yr}$. This aspect does not favor scenarios relying on the wind activity (scenarios 1 to 3 above). Another important issue is that SN have probably already exploded (contrary to Westerlund 2) in the RSG cluster as suggested by [22]. In the framework of an association between HESS J1837-069 and the RSG cluster, the scenarios of type 4 offer an interesting alternative. Further multiwavelength observations are necessary to confirm or reject them.

Perspectives and conclusions

The high energy gamma-ray H.E.S.S. observations (as well as well multi-wavelength survey) are of prime importance to directly probe the occurrence of efficient particle acceleration processes in MSFR in connection with the origin of galactic cosmic rays. Unfortunately, these regions are complex and associated with diverse environments (extended ionised regions, multiple shell structures, molecular clouds), all in themselves potential sites of particle acceleration and non-thermal radiation. Several scenarios of particle acceleration and radiation mechanisms in MSFR have been examined. They differ by the extension of the cluster and the acceleration / radiation zone, the massive star content, the impact of SN explosion over the cluster or the amount of dense material in the environment. The production of TeV gamma-rays is not systematic and requires favorable conditions: efficient conversion of free energy into turbulence or supersonic flows, sufficiently weak radiation losses, optically thin media. We discuss in some details the source HESS J1837-069. This VHE source is still unidentified and close to an exceptional cluster of RSG stars in the Galactic ridge. Among the scenarios we considered, an extended source associated with dense shells or a molecular cloud seems to be possible but further multi-wavelength observations are necessary to support this conclusion.

Acknowledgements

The support of the Namibian authorities and the University of Namibia in facilitating the construction and the operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Ministry of Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Particle Physics and Astronomy Research Council (PPARC), the IPNP of the Charles University, the Polish Minisitry of Science and Higher Education, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia.We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment.

References

[1] Drury L. C. et al. *SSR*, 99:329–352, 2001.

[2] Higdon J. C. and Lingenfelter R. E. *ApJ*, 628:738–749, 2005.

[3] Higdon J. C., Lingenfelter R. E., and Ramaty R. *ApJ*, 509:L33–36, 1998.

[4] Parizot E., Marcowith A., van der Swaluw E., Bykov A., and Tatischeff V. *A&A*, 424:747–760, 2004.

[5] Bykov A. and Fleishmann G.D. *A&A*, 280:L27–L29, 1993.

[6] Klepach E.G., Ptuskin V.S., and Zirakashvili V.N. *Astr.Phys.*, 13:161–172, 2000.

[7] Bykov A. *SSR*, 99, 317–326, 2001.

[8] Parizot E. and Drury L.C. *A&A*, 349, 673–684, 1999.

[9] Chu Y.-H.. and Kennicutt R.C. *Astr.& Sp.Sc.*, 216, 253–262, 1994.

[10] Esposito J.A., Hunter S.D., Kanbach G., Sreekumar, P.Y.-H. *ApJ*, 421, 820–827, 1996.

[11] Albert J. et al. (MAGIC collaboration) arXiv:0705.3119

[12] Dougherty S. M. et al. *ApJ*, 623, 447–459, 2005.

[13] Aharonian F.A. et al. (H.E.S.S. collaboration) *A&A*, 467, 1075–1080 2007.

[14] Aharonian F.A. et al. (HEGRA. collaboration) *A&A*, 431, 197–202 2005.

[15] Völk H.J. and Forman M.A. *ApJ*, 253, 188–198, 1982.

[16] Webb G.M., Axford W.L., Forman M.A. *ApJ*, 298, 684–709, 1985.

[17] Eichler D. and Usov V. *ApJ*, 402, 271–279, 1993.

[18] Reimer A., Pohl M., Reimer O. *ApJ*,644, 1118–1144, 2006.

[19] Velàzquez P.F., Koenigsberger G., Raga A.C. *ApJ*, 584, 284–292, 2003.

[20] Domingo-Santamaría E. and Torres D.F. *A&A*, 444, 403–415, 2005.

[21] Aharonian F.A. et al. *ApJ*, 636, 777–797, 2006.

[22] Figer D.F. et al. *ApJ*, 643, 1166–1179., 2006.

[23] Bamba A., Ueno M., Koyama K., Yamauchi S. *ApJ* 589, 253–260, 2003.

[24] Malizia A. et al. *ApJ*,630, L157-L160, 2005.