η *Carinae: a very large hadron collider*

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Abstract

One of the most outstanding stellar object in our Galaxy, η Carinae, a colliding wind binary with the largest mass loss rate observed, presents a hard X-ray emission and is therefore a primary candidate to search for particle acceleration by probing its gamma-ray emission. We analyzed the first 21 months of Fermi/LAT data (0.2-100 GeV) around η Carinae and detected a bright gamma-ray source in coincidence. We also derived lightcurve and spectra that we combined with multi-wavelength observations. The non-thermal spectral energy distribution modeling obtained features an inverse Compton scattering of UV photons by electrons and a π^0 decay of accelerated hadrons arising from the colliding wind region. In such model, the colliding wind binaries would be as effective source of hadronic galactic cosmic rays as supernova remnants.

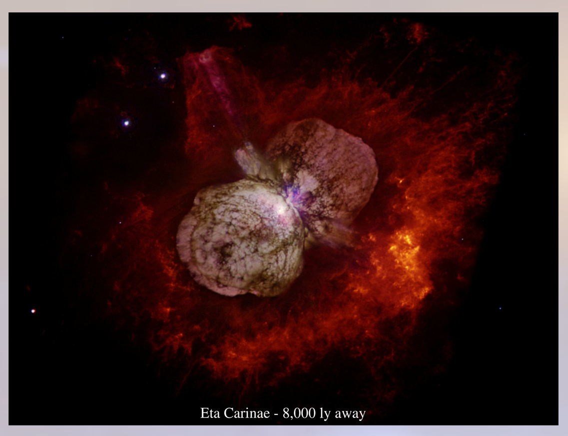
Context

Acceleration of electrons in colliding wind binaries had been measured through radio observations in around 30 early-type stellar systems (De Becker 2007). Recently hard X-ray components have been observed both in η Carinae (Leyder et al. 2008), (Leyder et al. 2010) and in WR140 (Sugawara et al. 2011). Colliding wind binaries had been considered as potential gamma-ray accelerators (Eichler & Usov 1993), (Bednarek 2005) but no detection of these objects were claimed prior to 2008. At this date, AGILE reported a γ-ray flare spatially coincident with the η Carinae system (Tavani et al. 2009), not confirms by the *Fermi*/LAT data.

η Carinae datasheet

Binary system:

- Distance: 2.3 kpc
- Periodicity: 5.54 years
- Last periastron: 11 Jan 2009
- Eccentricity: 0.9
- ISM + nebula column density: 10^{22}cm^{-2}



HST view of η Carinae.

Main star:

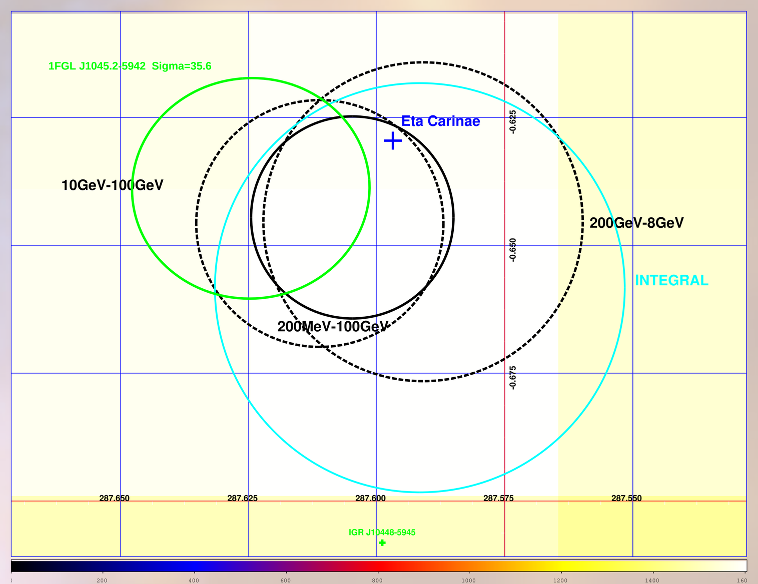
- Luminous Blue Variable
- Mass: $\sim 80 M_\odot$
- $\dot{M} \sim 10^{-3} M_\odot/yr$
- V_∞ 500 km/s

Secondary star (unseen):

- Wolf-Rayet or O star
- Mass: $\sim 30 M_\odot$
- $\dot{M} \sim 10^{-5} M_\odot/yr$
- V_∞ 3000 km/s

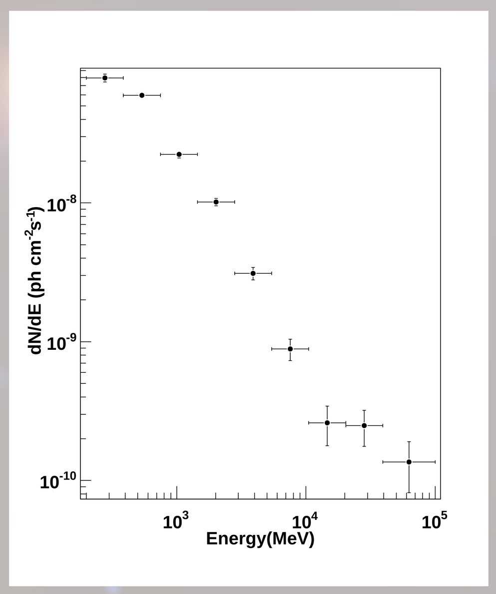
Fermi/LAT location

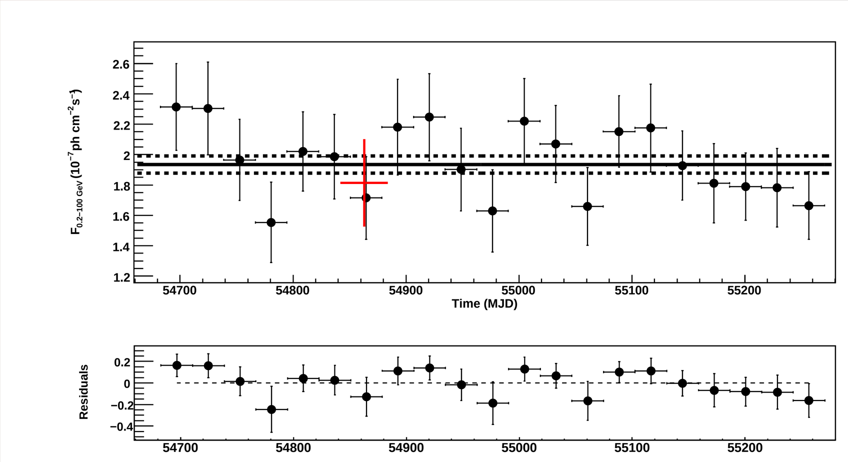
The analysis of the 21 first months of *Fermi*/LAT data shows a γ-ray emission (plain and dashed black circles) spatially coincident with η Carinae (blue cross). The best position of the hard X-ray source detected by *INTEGRAL* (Leyder et al. 2010) is also reported (cyan circle) as well as the location of the source as it appears in the *Fermi*/LAT first year catalog (green circle).



Spectral & timing analysis

η Carinae γ-ray spectrum best model is a combination of two components: a power-law of spectral index $\Gamma = -1.7 \pm 0.12$ with an exponential cut-off (E_{cut} = 1.8 $\pm$ 0.5 GeV) describing the spectrum up to 10 GeV plus another power-law of spectral index $\Gamma = -1.9 \pm 0.3$ for the hard γ-ray tail.



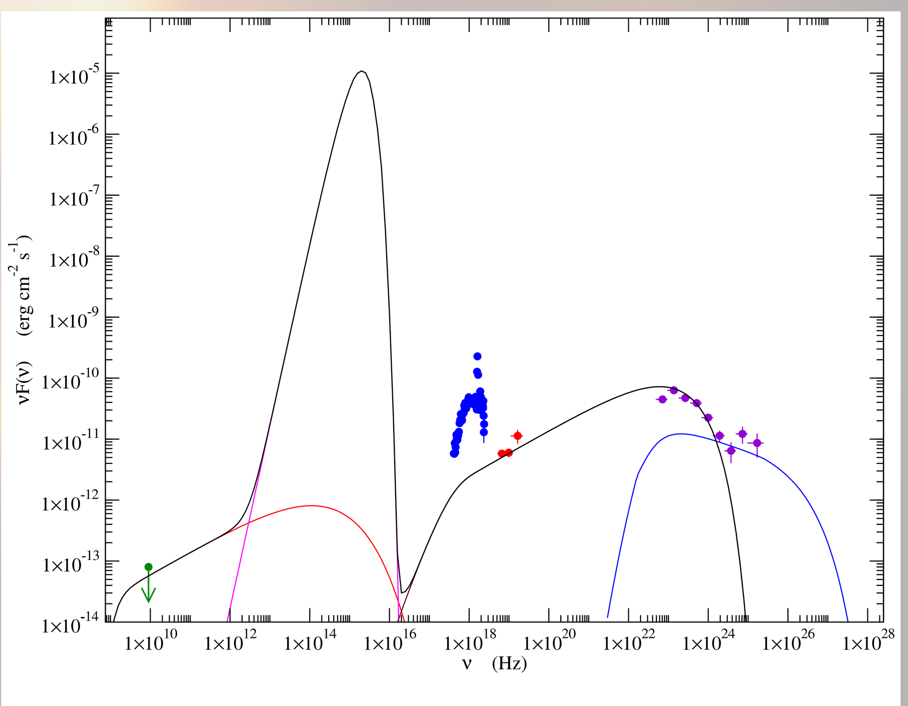


The overall integrated flux of the source is $F_{0.2-100\mathrm{GeV}} = (1.93 \pm 0.05)$ ph cm^{-2} s^{-1}. The integrated flux between 200 MeV and 100 GeV is compatible with a steady source, including at periastron passage, contrary to η Carinae behavior as observed in thermal X-ray band with RXTE. Analysis of *Fermi*/LAT data does not confirm the AGILE two days flaring episode of 2008 Oct. 11-13 (Tavani et al. 2009).

Modelling

We assume that particle accelerations takes place in η Carinae by means of diffusive shock acceleration in the colliding wind region of the binary system. Particle acceleration in the shock is mainly counterbalanced by inverse Compton scattering for electrons and proton-proton interactions. Both processes produced γ-ray emissions respectively represented in black and blue on the aside figure.

	Parameter	Value
Environment	Photon energy density	2.7 erg/cm^3
	Magnetic field	0.5 G
	Density	$3 \cdot 10^9$ cm^{-3}
Electron distribution	Power law index	2.25
	$\gamma_{max,e}$	10^4
	Total energy	10^{40} erg
Proton distribution	Power law index	2.25
	$\gamma_{max,p}$	10^4
	Total energy	$1.3 \cdot 10^{40}$ erg



BeppoSAX/MECS (blue), *INTEGRAL/ISGRI* (red) and *Fermi/LAT* (purple) data, and a radio upper limit to the synchrotron emission (green).

Discussion

The energy injected in the shock to sustain the observed proton distribution is of the order of $E_p/t_{pp} = \gamma_{max,p}\sigma_{pp}\delta nc \sim 10 L_\odot$. The wind momentum ratio of η Carinae is $\eta = (\dot{M}_2 V_{\infty,2})/(\dot{M}_1 V_{\infty,1}) \approx 0.2$, implies a half-opening angle of the shock of ~ 1 rad leading to a mechanical energy available in that region of $\sim 200 L_\odot$. Thus $\sim 5\%$ of the shock mechanical energy is transferred to accelerated protons downstream, agreeing with recent simulations (Spitkovsky 2008).

Integrated over the average lifetime of a massive star, the cosmic-ray acceleration efficiency of these objects may be as effective as supernovae remnants to accelerate hadrons. Future Cherenkov observations will allow to determine whether stellar wind collisions could accelerate particles up to to the knee of the cosmic-ray spectrum.

References

Bednarek, W. 2005, *MNRAS*, 363, L46
De Becker, M. 2007, *A&A Rev.*, 14, 171
Eichler, D. & Usov, V. 1993, ApJ, 402, 271
Farnier, C., Walter, R., & Leyder, J.-C. 2011, *A&A*, 526, A57+
Leyder, J., Walter, R., & Rauw, G. 2008, *A&A*, 477, L29
Leyder, J., Walter, R., & Rauw, G. 2010, *A&A*, in press
Spitkovsky, A. 2008, *ApJ*, 682, L5
Sugawara, Y., Maeda, Y., Tsuboi, Y., et al. 2011, Bulletin de la Societe Royale des Sciences de Liege, 80, 724
Tavani, M., Sabatini, S., Pian, E., et al. 2009, *ApJ*, 698, L142

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