Particle acceleration in $\eta$ Carinae: the Expected and Unexpected

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η Carinae

Bubble nebula - NGC 7635

10^{14} \text{ cm}

10^{12} \text{ eV/cm}^3, 1 \text{ G}, 10^9 \text{ cm}^{-3}

10^{20} \text{ cm}

1 \text{ eV/cm}^3, \mu \text{G}? , 300 \text{ cm}^{-3}

O6.5III
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Who is η Car?

\[ \dot{M} \ll 10^{3.5} \frac{M}{\text{yr}} \]

\[ L_{\text{wind}} \approx 2000 L_\odot \]

\[ L_e \approx 50 L_\odot \]

**Humphrey & Davidson limit**

Formation of the «Homonculus»


Corcoran (2015)

Who is η Car?

Who is η Car?

L_{π0} \approx 10 L_☉
The physics behind $\eta$ Car

Shock acceleration is counterbalanced by:

- $e^-$ IC scattering
- $p^+$ interaction

Comparing the Fermi acceleration time scale to the cooling times provides:

- Spectrally independent from the orbital phase

Spectral fit parameters:

- Acceleration and cooling ("one zone")

Eichler & Usov, 93; A&A (2011) 526, 57
Our analysis of ηCar

From 2008 August 4 to 2015 July 1
ST: v10r0p5
IRF: P8R2_SOURCE_V6
Catalogue: 3FGL

E: 300 MeV - 300 GeV
ROI: ~15°
Sources: ~171 (1 ext.)
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★ Presence of a variable HE source closer than θ_ref (J1043.6-5930)
★ Galactic diffuse emission model
ηCar γ-ray lightcurve

Energy bin 1 (E: 0.3-0.95 GeV)

Energy bin 2 (E: 0.95-3 GeV)

Energy bin 3 (E: 3-9.5 GeV)

Energy bin 10 (E: 10-300 GeV)

0.3-0.95 GeV

0.95-3 GeV

3-9.5 GeV

10-300 GeV

flux [ph s⁻¹ cm⁻²]
Shock acceleration is counterbalanced by:

- e⁻ IC scattering
- p interaction

Comparing the Fermi acceleration time scale to the cooling times provides:

- Roughly independent from the orbital phase

Spectral fit parameters:

- Acceleration and cooling ("one zone")

Eichler & Usov, 93; A&A (2011) 526, 57

The X-ray emission varies by \( \sim 4 \)

The sub-GeV emission varies by < 2

Above 10 GeV emission varies by > 3

The pionization conversion efficiency \( \sim D^{-1} \)

1. **gamma-ray pulsar & PWN** *(Abdo et al, 2010)*
   - Variability excludes the PWN
   - Pulsar not detected by Chandra
   - Coincidence probability \( \sim 10^{-5} \)

2. **external shock** *(Ohm et al, 2010)*
   - Does not explain more than 20% of the 50 keV component.
   - Cannot explain the >10 GeV component, *nor its variability*
   - A contribution is possible

3. **two electron populations** *(Bednarek & Pabich, 2011)*
   - Acceleration parameters vary along the shock surface resulting in a smooth electron spectrum
   - Observed variations of the cutoff energy are much smaller than predicted

4. **electrons & hadrons** *(Eichler & Usov, 1993; Farnier & Walter, 2011)*
Energetics

Observations

- In the **sub-GeV** the orbital modulation is $< 2$
- Above **10 GeV**, the flux variability is $> 3$

Wind collision simulations

- The total electron spectrum is smooth
- The **mechanical luminosity** available to accelerate **electrons** is **not** strongly **modulated**
- The $\pi^0$ decay emission **depends** on the **density** and could be **modulated** in a **similar** way as the **X-ray** emission

Energetics

- **Thermal X-rays**: $25 \, \text{L}_\odot$ (2% $L_{\text{shock}}$)
- **Synchrotron**: $< 0.1 \, \text{L}_\odot$
- **Electron acceleration**: $50 \, \text{L}_\odot$ (6% $L_{\text{mec}}$)
- **$\pi^0$ emission**: $10 \, \text{L}_\odot$ (2% $L_{\text{mec}}$)

- **$\eta$ Carinae** shows evidences for **electronic** and **hadronic** acceleration
- **Proton cutoff energy** $\approx 10^{13}$ eV, **higher than measured in middle aged SNR**
- **Efficiency** of particle **acceleration** $\sim 5\%$ (Spitkovsky’s simulations: 10%)

**$\eta$Car is a Large Hadron Collider**
• We clearly have γ-ray emission (at all energies) from a region coincident with the nominal position of ηCar
• There are two main source of systematic errors:
  • Diffuse galactic model contribution
  • Variable source @ HE closer than $\theta_{\text{REF}}$
• The variation of the sub-GeV and super-GeV component are in agreement with the simulation and the model (IC and $\pi^0$)

...nevertheless
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X-ray intensity much bigger on the last periastron (Corcoran et al. 2015) suggesting structural changing in the dueling wind

No significant variation on the $\Gamma$ index, statistically consistent with a constant $\sim -2.25\pm0.17$ (BINNED) ; $2.34\pm0.14$ (UNBINNED)

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“Anomalous” (not straightforward) behavior during last periastron.
...staying hungry and staying foolish...

ASTROGAM

Energy [GeV]

$E_2 dN/dE$ [erg s$^{-1}$ cm$^{-2}$]

Stellar emission $5 \times 10^6 L_\odot$

Thermal infrared & radio emission (not shown)

Synchrotron

Inverse Compton

$\nu \nu^0$ decay

$\gamma \gamma$ abs.

CTA

HESS

Fermi LAT

INTEGRAL

ASDC

Université de Genève
...staying hungry and staying foolish...

ASTROGAM

\[ E^2 \frac{dN}{dE} \text{ [erg s}^{-1}\text{cm}^{-2}] \]

Energy [GeV]
...staying hungry and staying foolish...