Hadronic acceleration and obscuration in η Carinae at TeV energies

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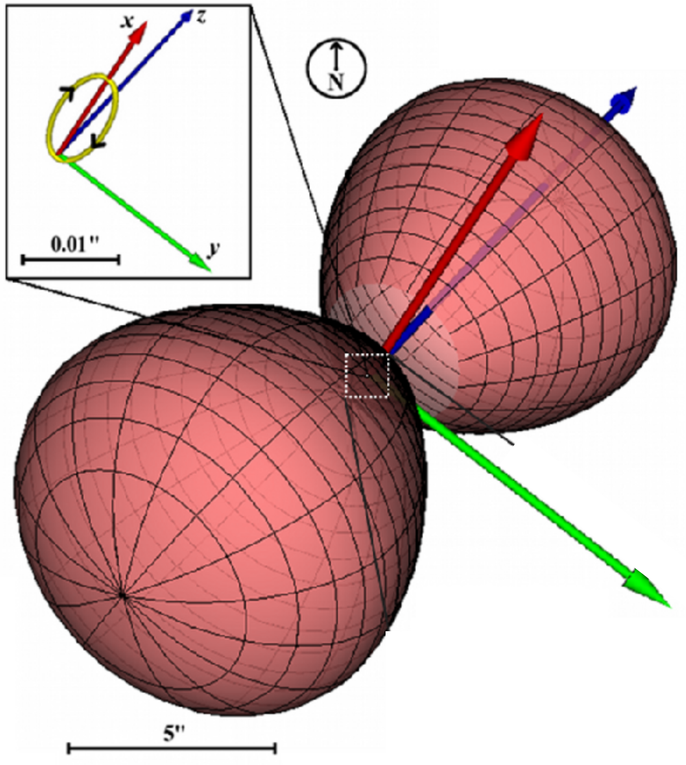
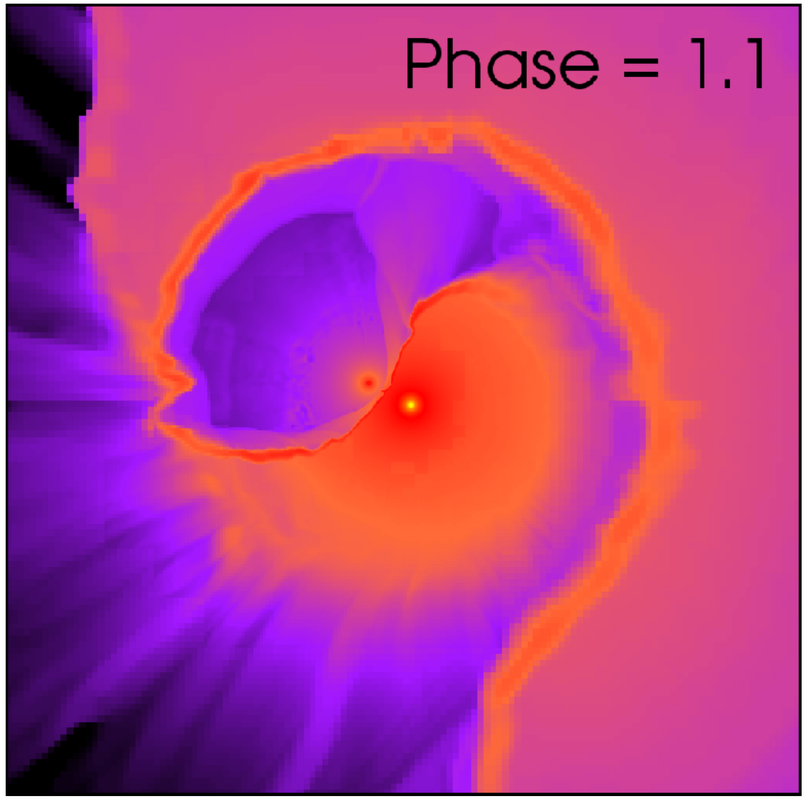
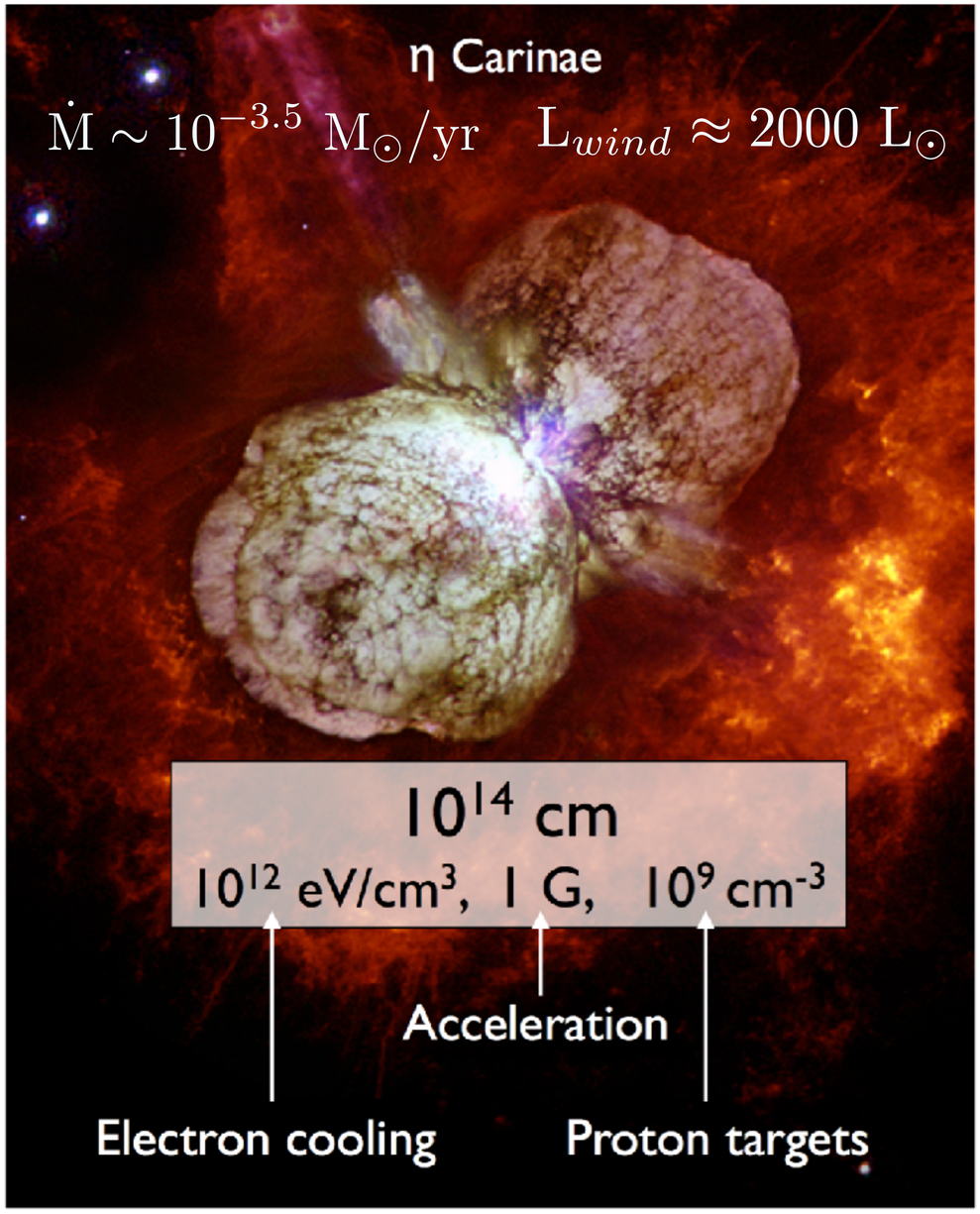
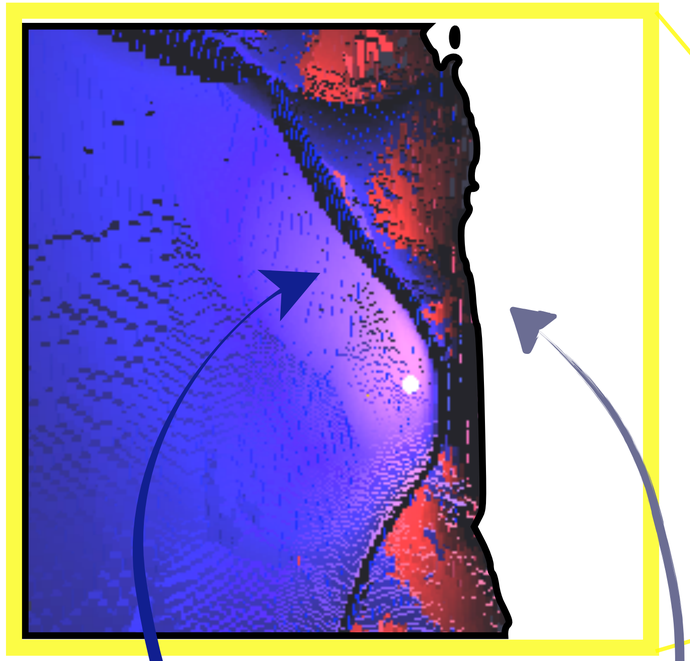
ISDC



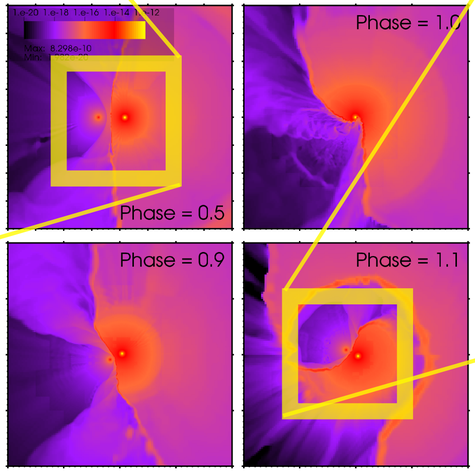




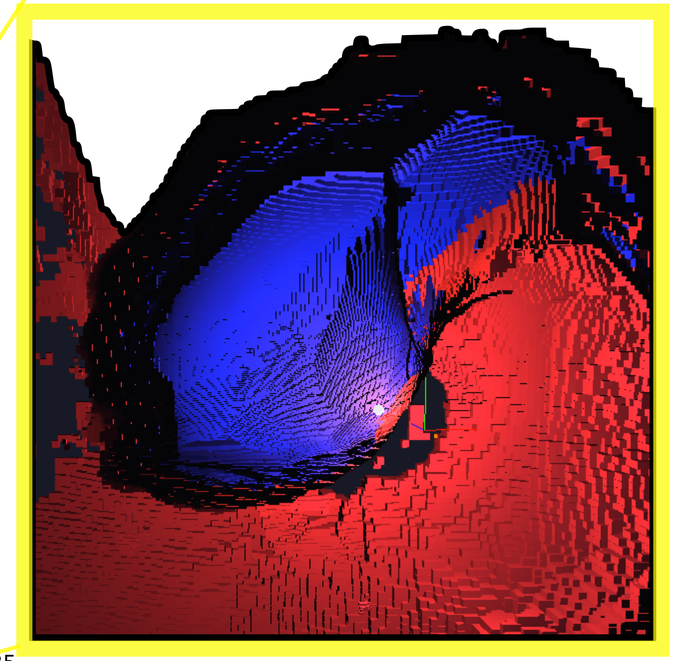
3D hydro simulations

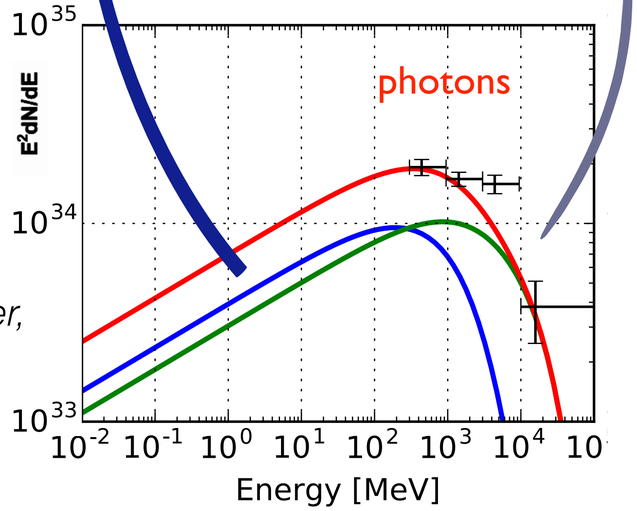


Parameter	Primary	Secondary
M ($M_\odot$)	120	30
R_* ($R_\odot$)	100	20
T_{cs} (K)	25,800	30,000
L_* ($10^6 L_\odot$)	4	0.3
k	0.30	0.50
α	0.52	0.68
$\dot{M}$ ($M_\odot\,yr^{-1}$)	4.8×10^{-4}	1.4×10^{-5}
v_∞ ($km\,s^{-1}$)	500	3000
B (G)	400	



Parkin et al, 2011

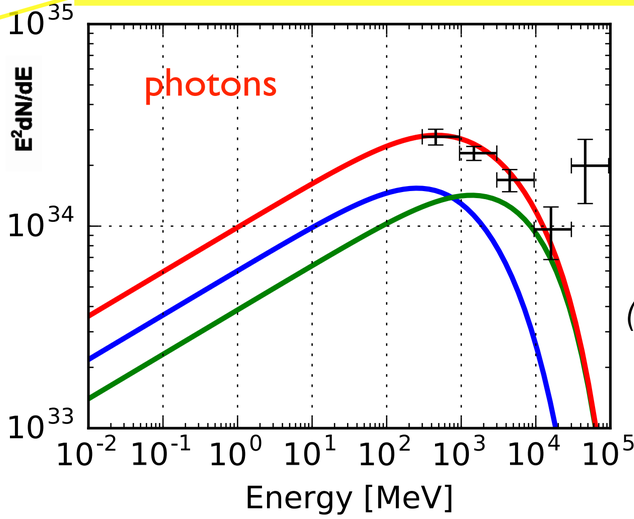




(MB and Walter, 2017 A&A)

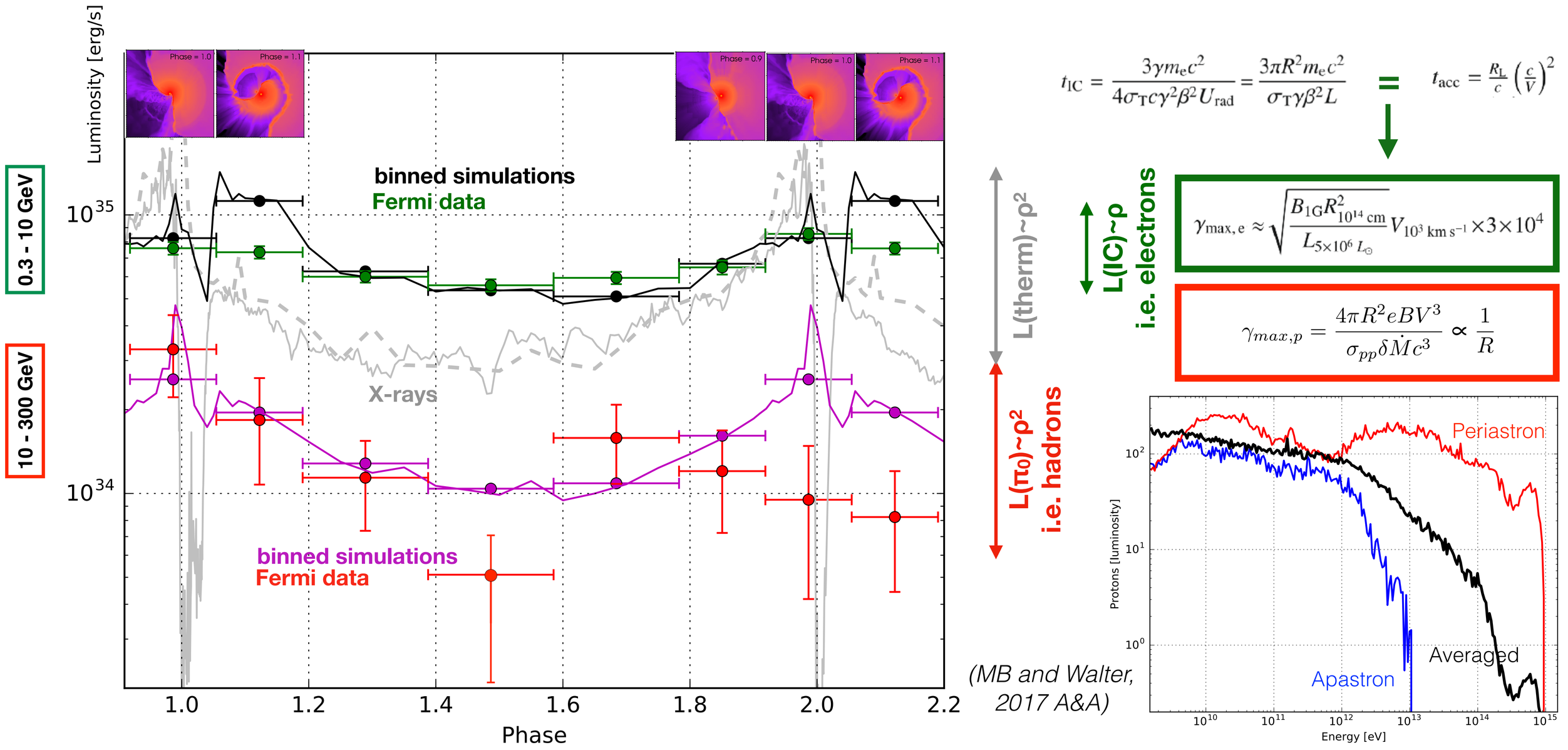
e⁻ spectrum

smooth IC spectrum



(MB and Walter, 2017 A&A)

η Carinae γ-ray light-curve



$$t_{\rm IC} = \frac{3\gamma m_e c^2}{4\sigma_T c \gamma^2 \beta^2 U_{\rm rad}} = \frac{3\pi R^2 m_e c^2}{\sigma_T \gamma \beta^2 L} = t_{\rm acc} = \frac{R_L}{c}\left(\frac{c}{V}\right)^2$$

L(therm)~ρ²

L(IC)~ρ i.e. electrons

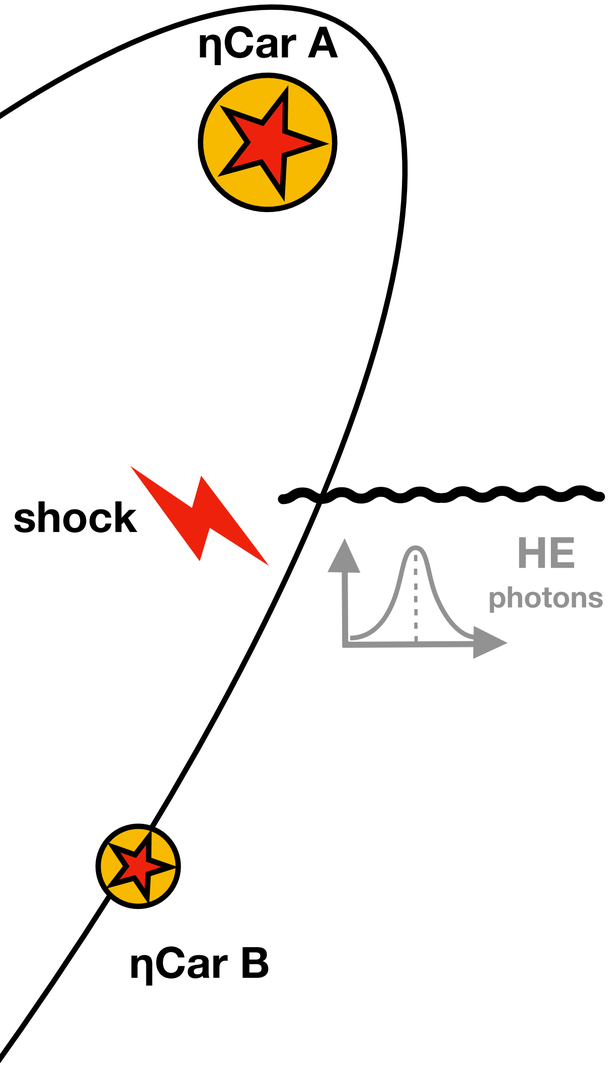
$$\gamma_{\rm max,e} \approx \sqrt{\frac{B_{1\rm G} R^2_{10^{14}\,\rm cm}}{L_{5\times10^6\,L_\odot}}} V_{10^3\,\rm km\,s^{-1}} \times 3\times10^4$$

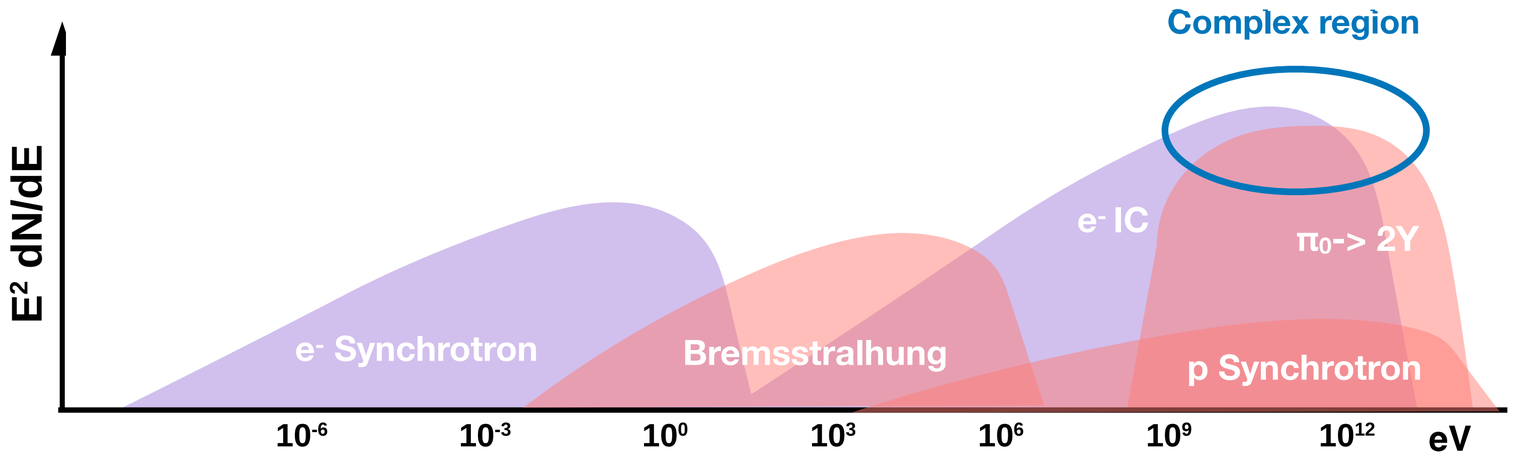
L(π₀)~ρ² i.e. hadrons

$$\gamma_{max,p} = \frac{4\pi R^2 e B V^3}{\sigma_{pp}\delta \dot{M} c^3} \propto \frac{1}{R}$$

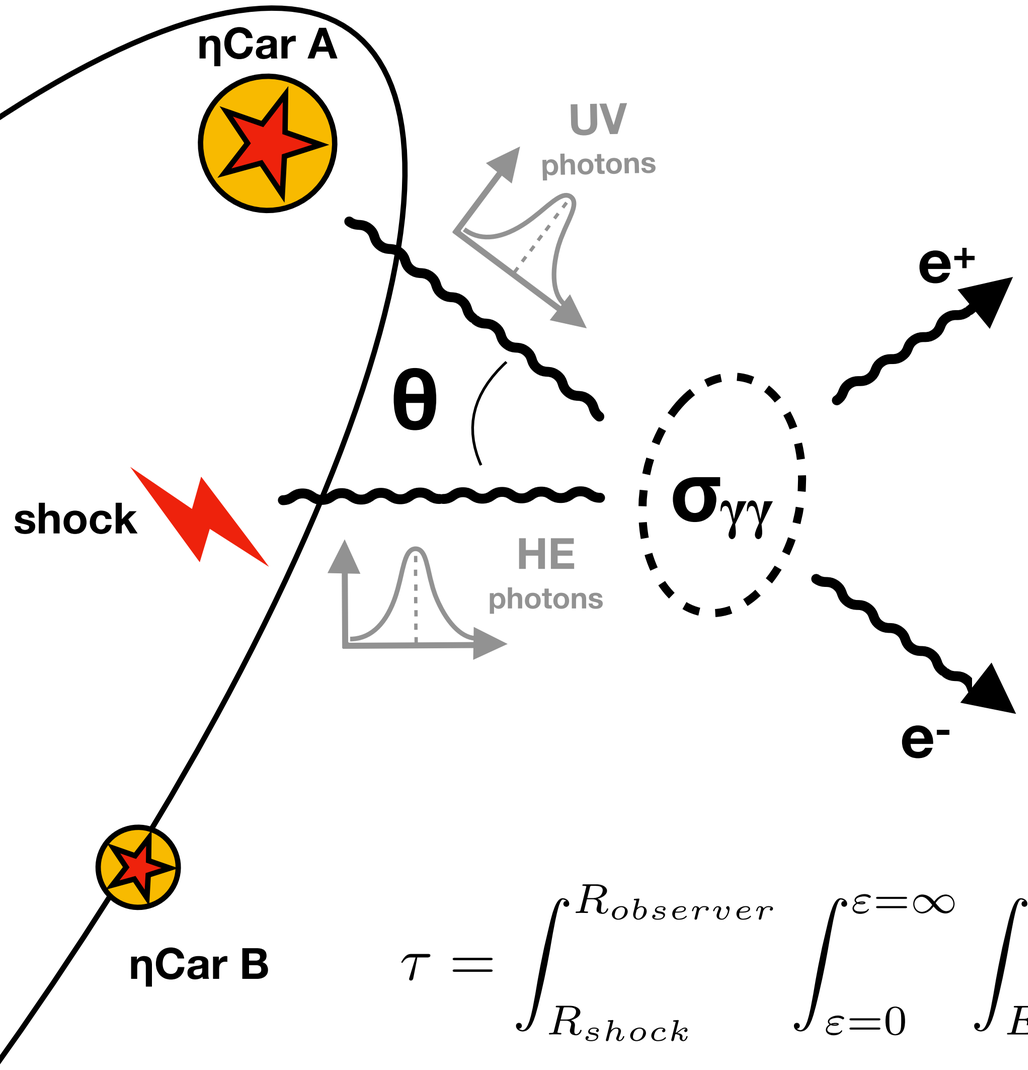
(MB and Walter, 2017 A&A)

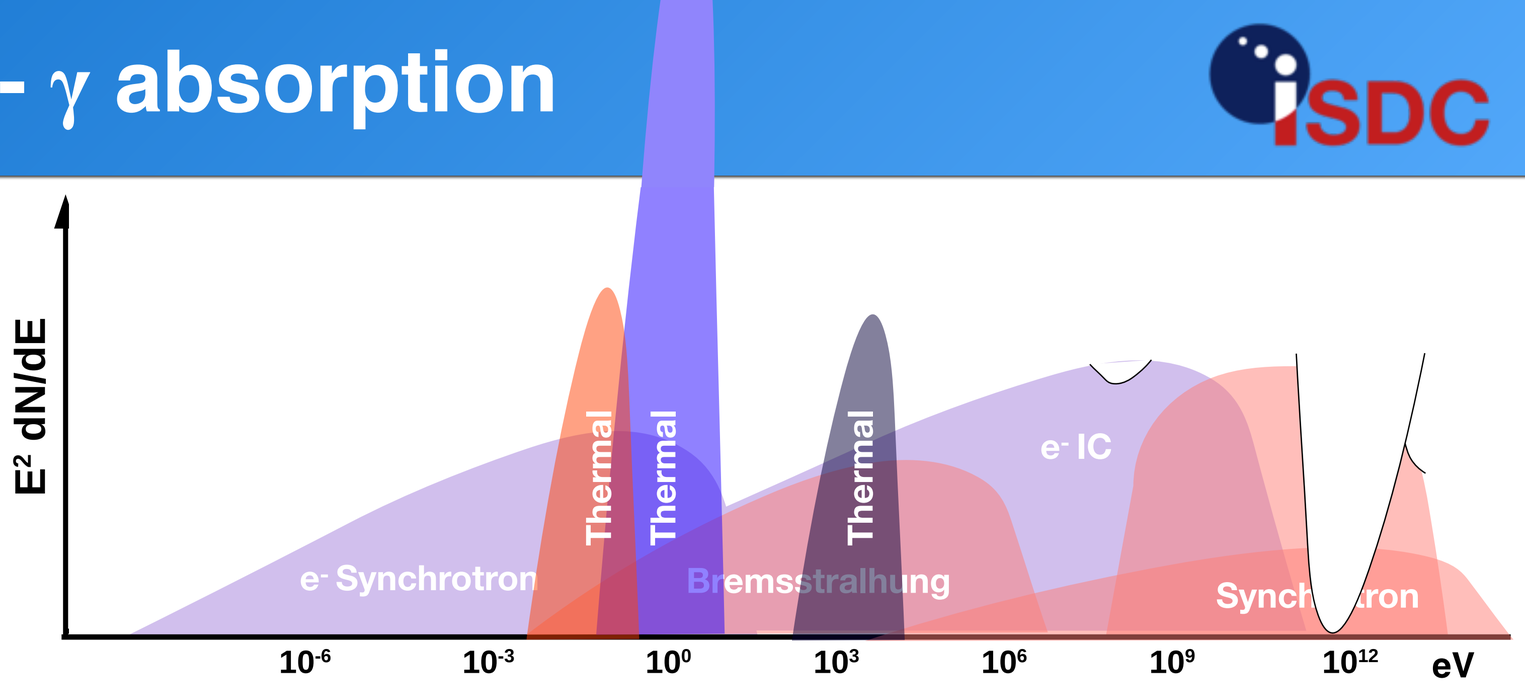
γ - γ absorption



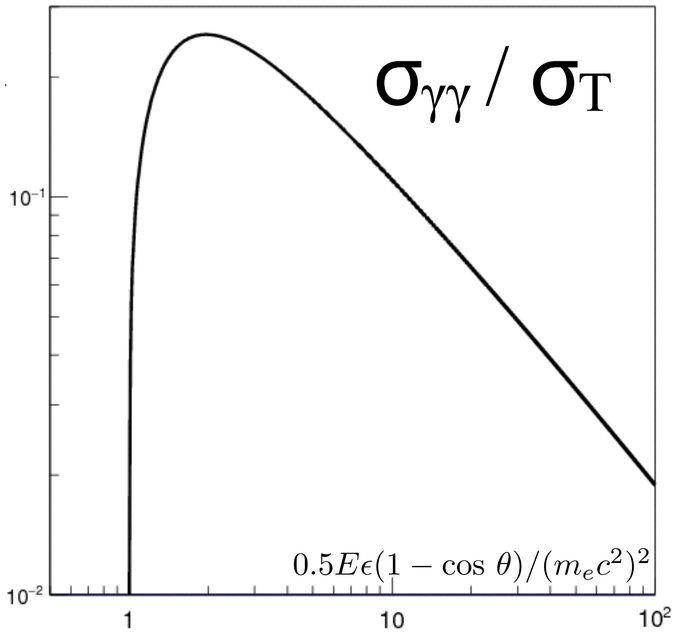


γ - γ absorption





$$E_{threshold} = 0.52/\epsilon_{\rm eV}(1-\cos\theta)\ {\rm TeV}$$
$$E_{th}(25^\circ) \sim 10 \times E_{th}({\rm head-on})$$

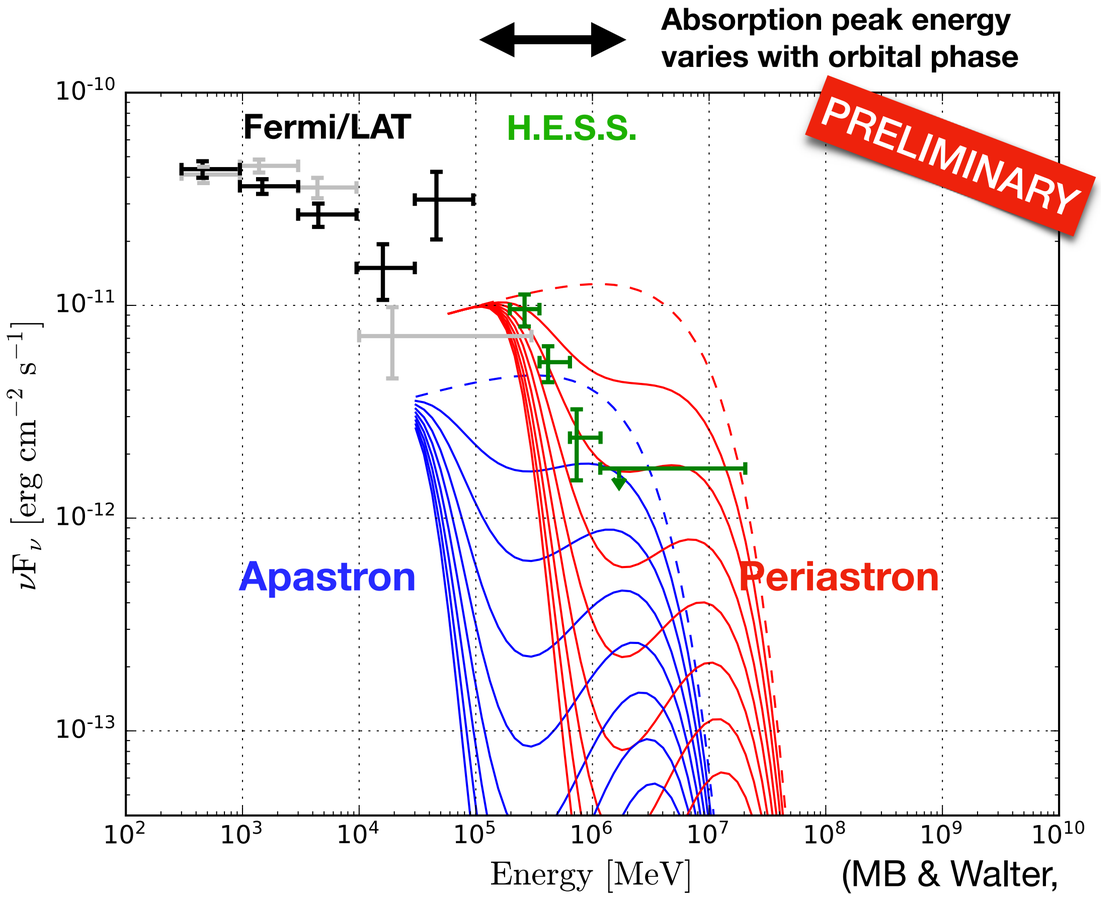


$$\tau = \int_{R_{shock}}^{R_{observer}} \int_{\varepsilon=0}^{\varepsilon=\infty} \int_{E=0}^{E=\infty} n(\varepsilon)\sigma_{\gamma\gamma}(\varepsilon E,\theta)\, dR\, d\varepsilon\, dE$$

η Carinae with CTA

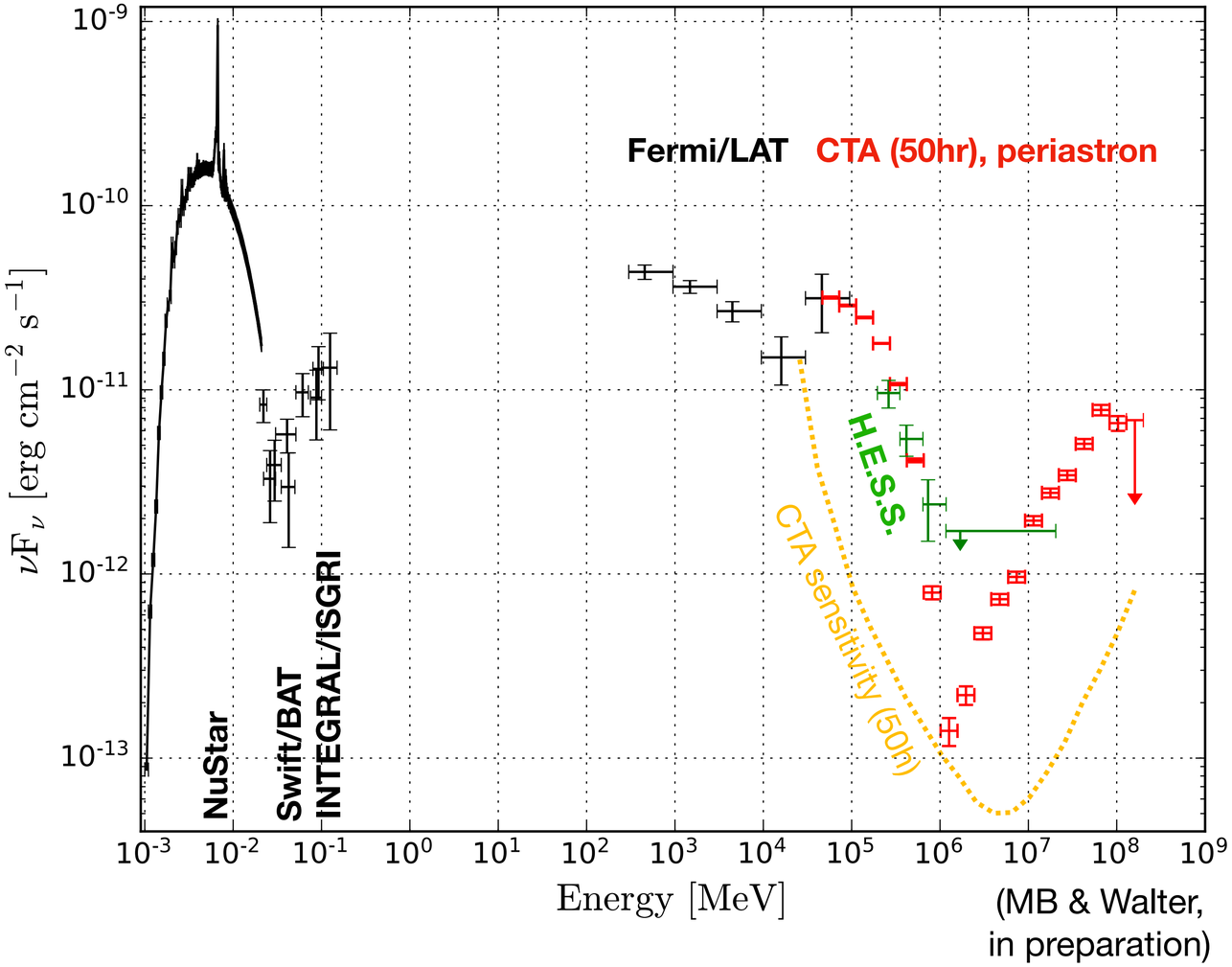
Increasing γ-UV obscuration

(convolution of uncertain UV spectrum with cross section)



Expected τ (head-on) : 10
τ (catch-up): ~1
τ (suggested by HESS): ~2

CTA simulation:
PROD = prod3b-v1
IRF = South_z20_average_50h



Energetics and conclusions

- Thermal X-rays: 25 $L_\odot$
- Synchrotron: < 0.1 $L_\odot$
- Electron acceleration: 50 $L_\odot$
- π_0 emission: 10 $L_\odot$
- neutrino: ~ 10^{-9} GeV s^{-1} cm^{-2} (> 10 TeV)

With this efficiency, a massive star could accelerate ~ 10^{49} ergs of CRs as much as an average SNR

η Carinae shows evidences for e^- (γ~10^4) and hadronic (γ~10^3 ; γ~10^6 @ peri ?) acceleration

Electrons:

- Max e^- energy match the expectation
- e^- spectral index ~ 2.25
- IC emission is ruled out at TeVs

Hadrons:

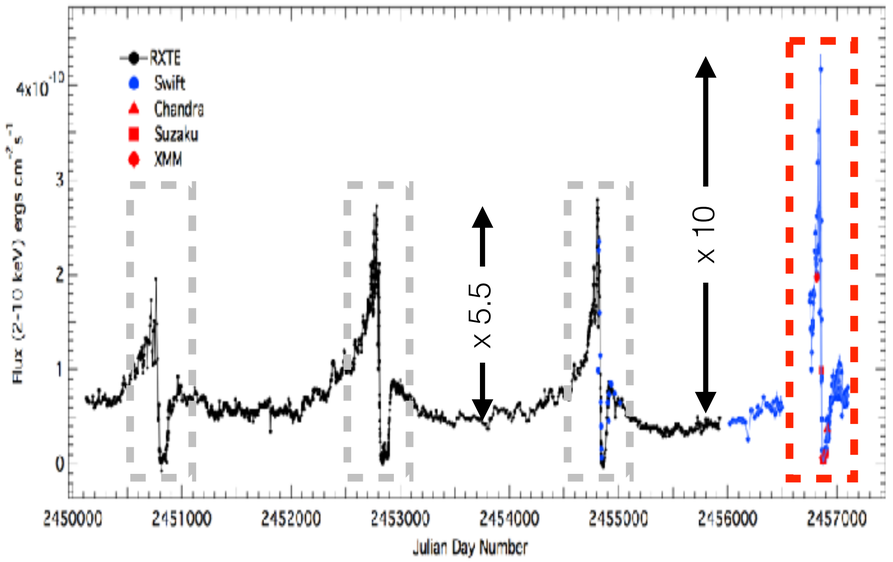
- $\pi \rightarrow \gamma$ emission matches amplitude variability
- cutoff energy ≥10^{13} eV (> middle aged SNR)
- Efficiency of particle acceleration ~1% (Spitkovsky's sim: 10%)
- Peri 2009 ≠ peri 2014 (system changed? instabilities?)

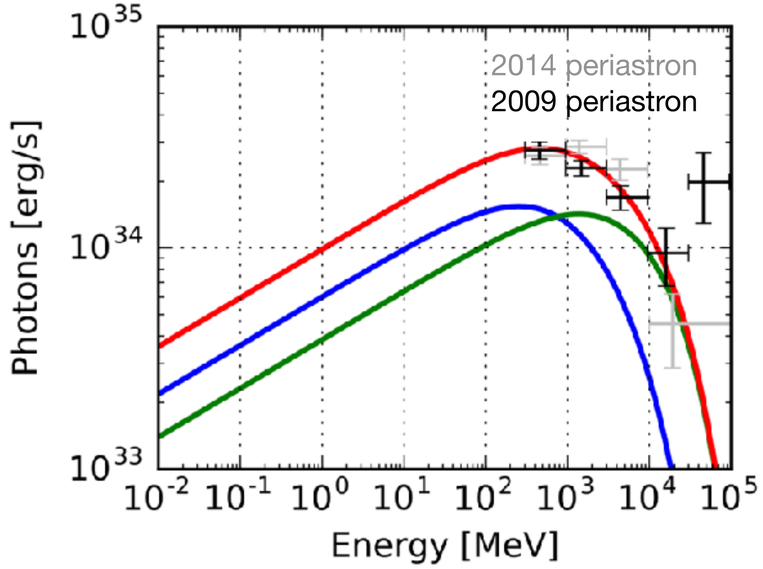
- **Variability** is essential to deconvolve spectral energy distributions (spectral analysis @ different orbital-phases)
- **Few zones models** are too simplistic → **Zillion-cells model** necessary (Hydro, Fermi acceleration, photon propagation, …)
- **CTA** will confirm:
  - **hadronic acceleration**
  - **γ-γ absorption**
  - **τ variations** along the orbit

η Carinae could accelerate as much cosmic-rays as a SNR

BACK UP

Corcoran (2015)





Possible interpretation

Larger wind clumpiness :

- ➙ Stronger thermal emission (~ ρ^2)
- ➙ Stronger IC emission (~ ρ)
- ➙ Increased probability for escaping protons, i.e. decreased pion emission
- ➙ Lower $\gamma_{max,p} = \dfrac{4\pi R^2 e B V^3}{\sigma_{pp}\delta \dot{M} c^3} \sim \dfrac{1}{\rho}$

(MB and Walter, 2017 A&A)