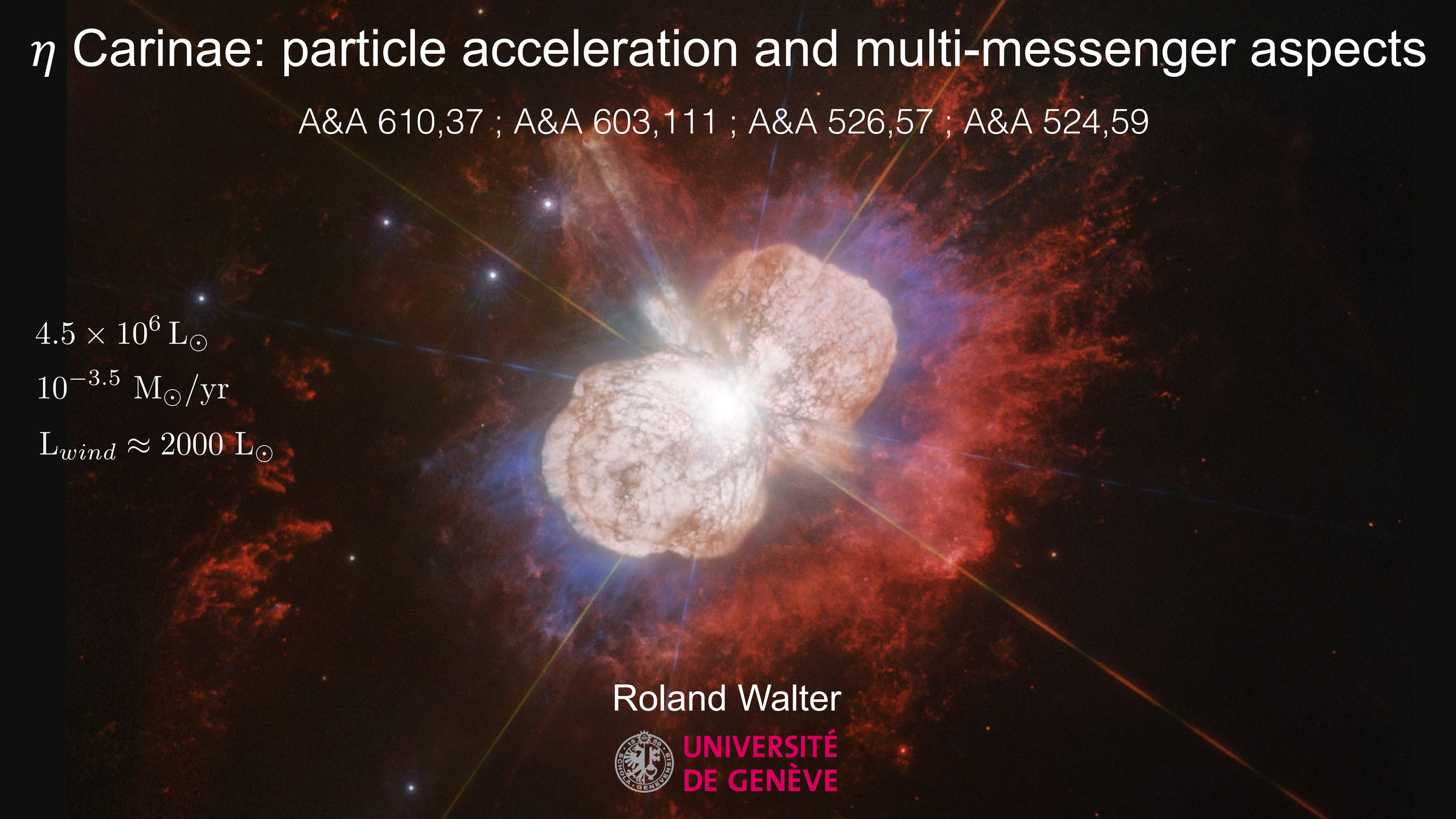
η Carinae: particle acceleration and multi-messenger aspects

A&A 610,37 ; A&A 603,111 ; A&A 526,57 ; A&A 524,59



$4.5 \times 10^6\ \mathrm{L}_\odot$

$10^{-3.5}\ \mathrm{M}_\odot/\mathrm{yr}$

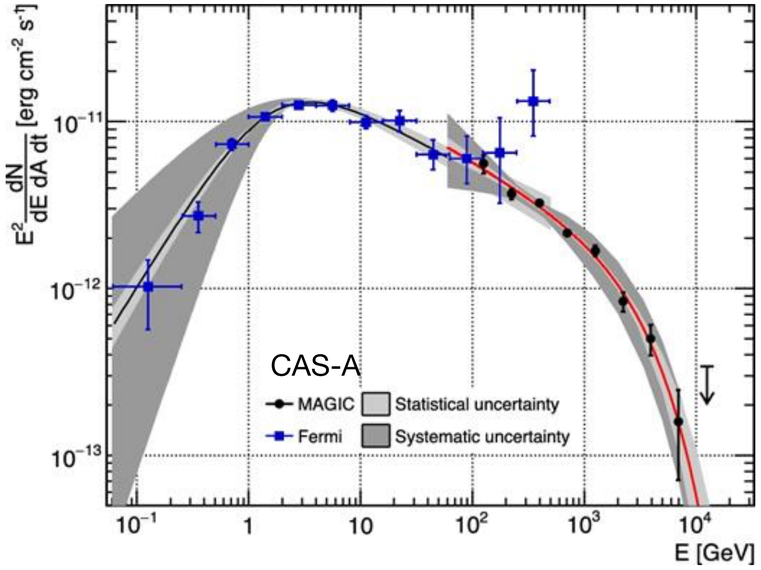
$\mathrm{L}_{wind} \approx 2000\ \mathrm{L}_\odot$

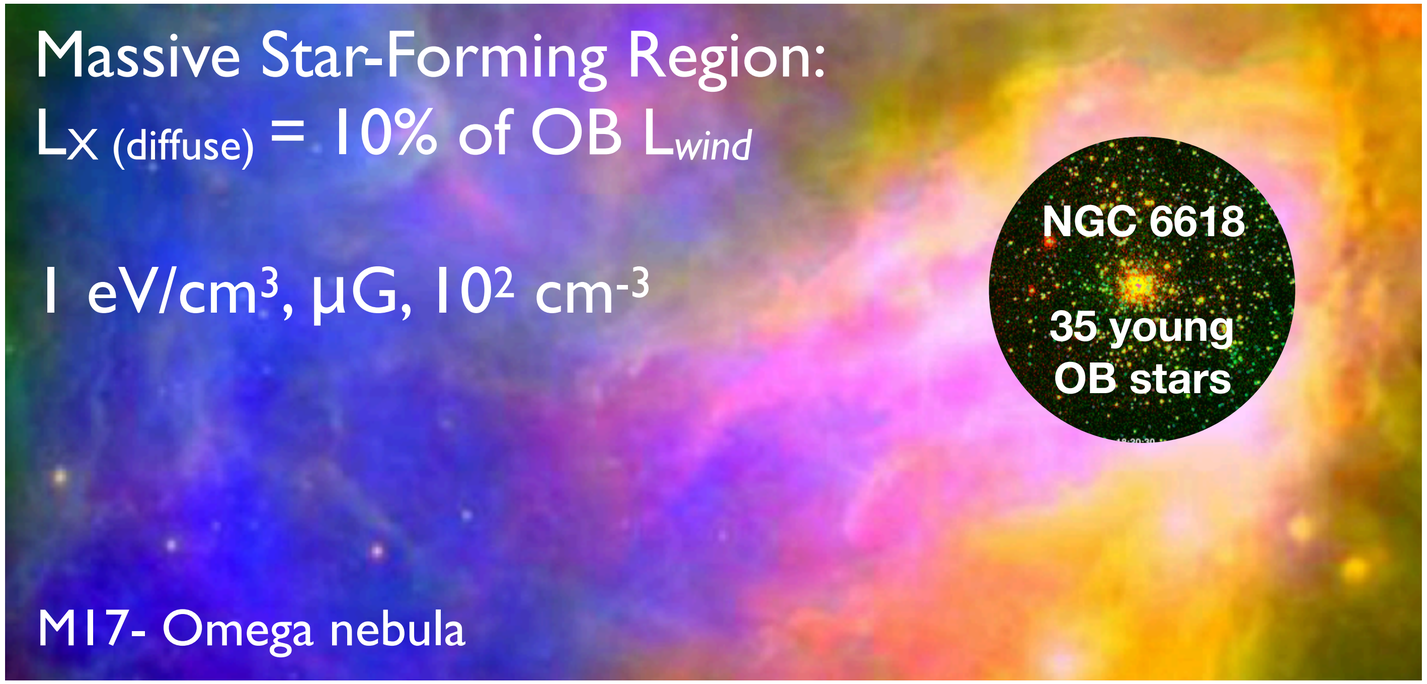
Roland Walter

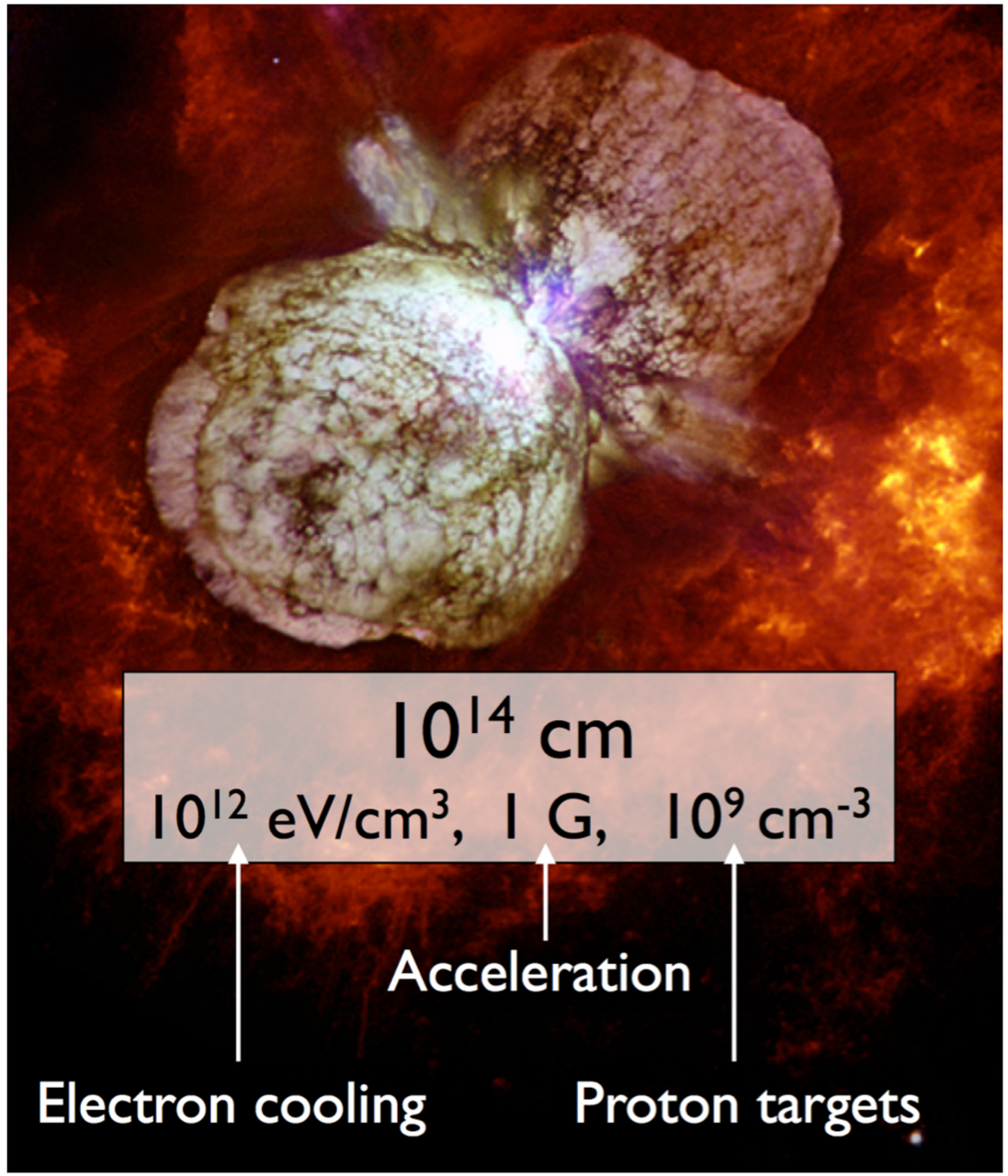
UNIVERSITÉ DE GENÈVE

Galactic Cosmic-Rays

SNR: energy cutoff is 1000x too low to explain the knee of the CR spectrum

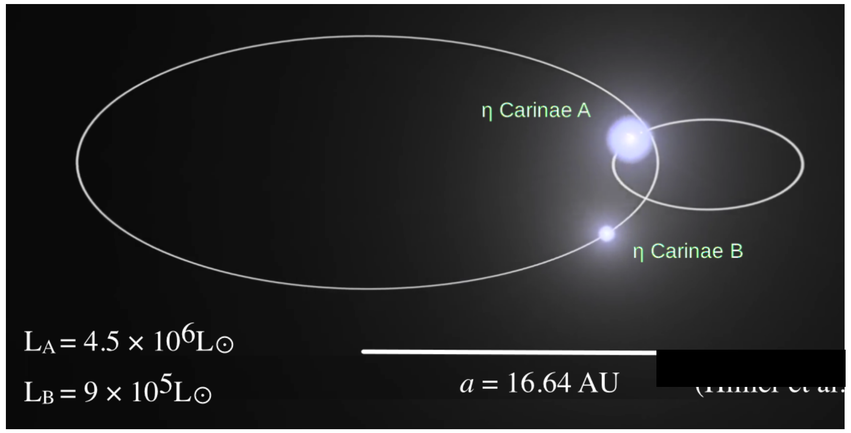


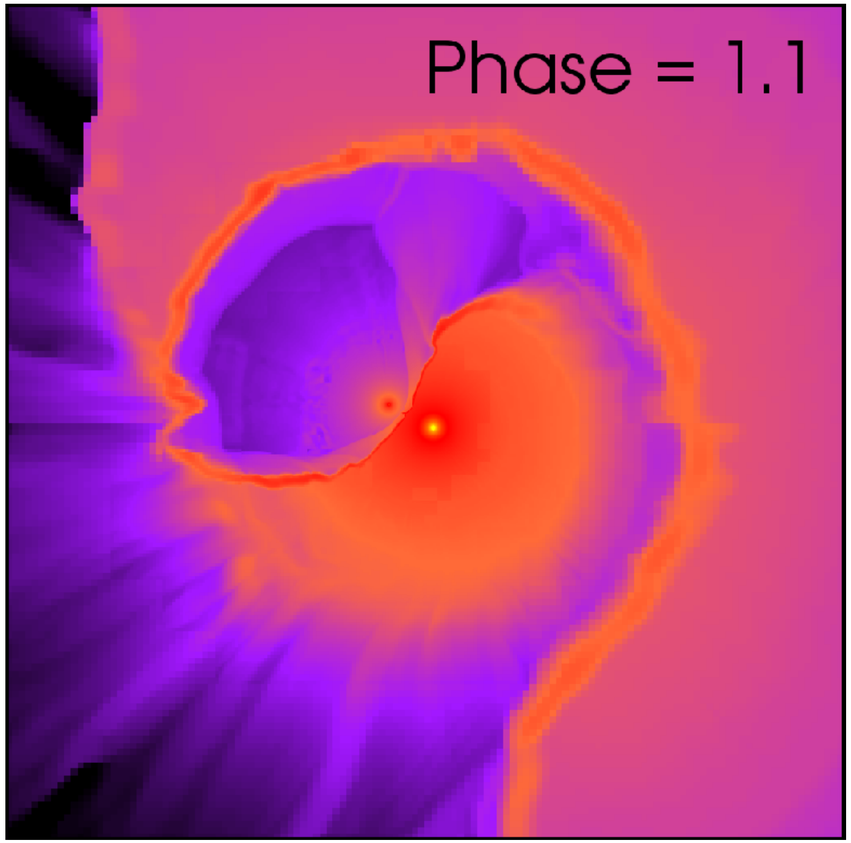


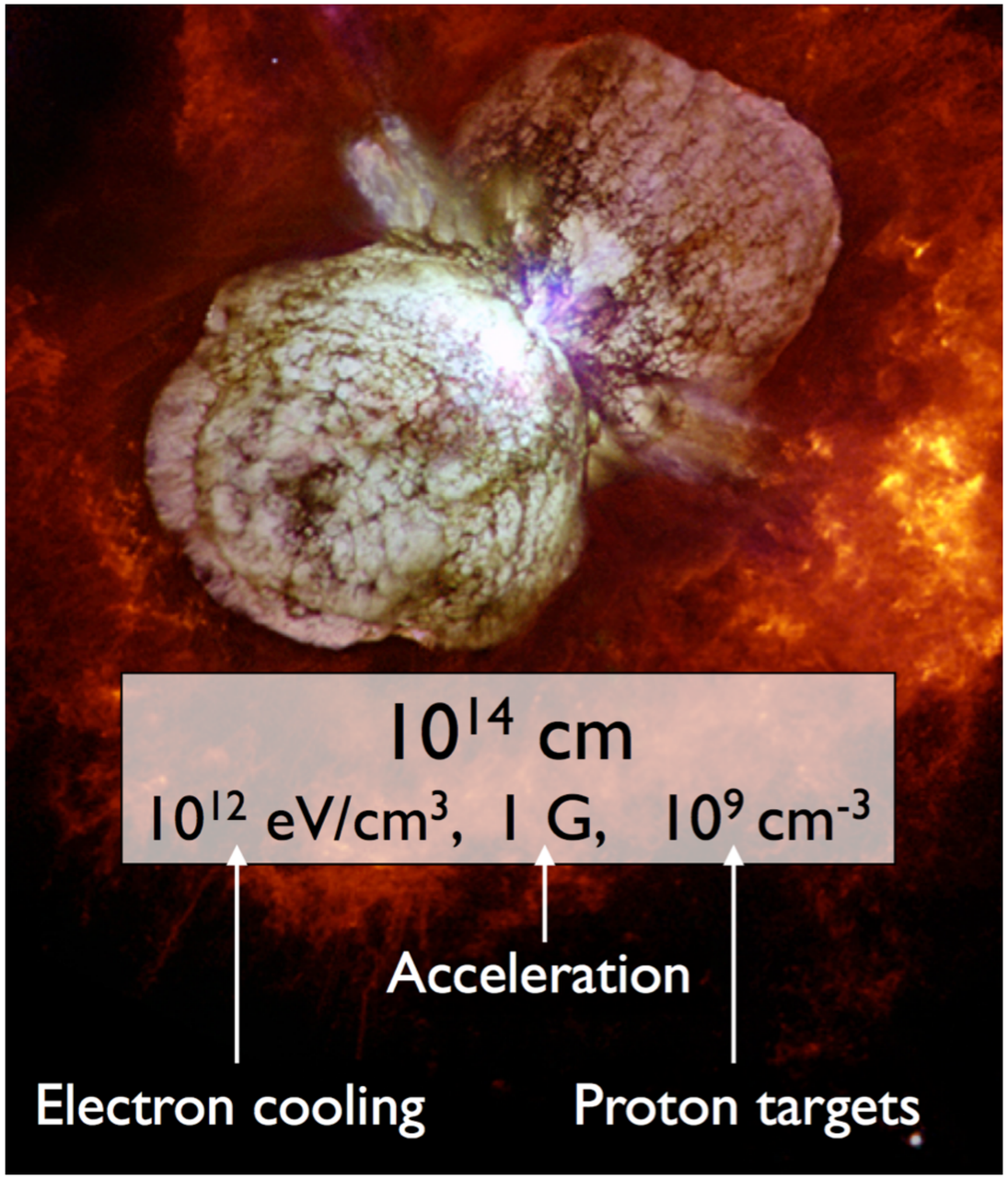


η Carinae

Shocks, where the densities of UV photons and of the ISM are among the highest in the Galaxy

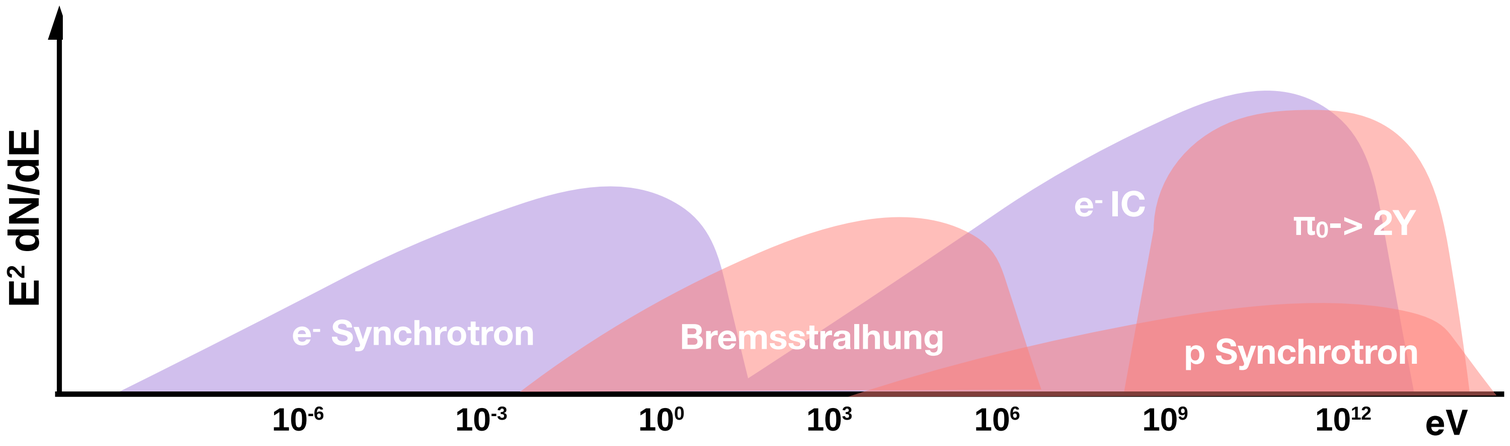




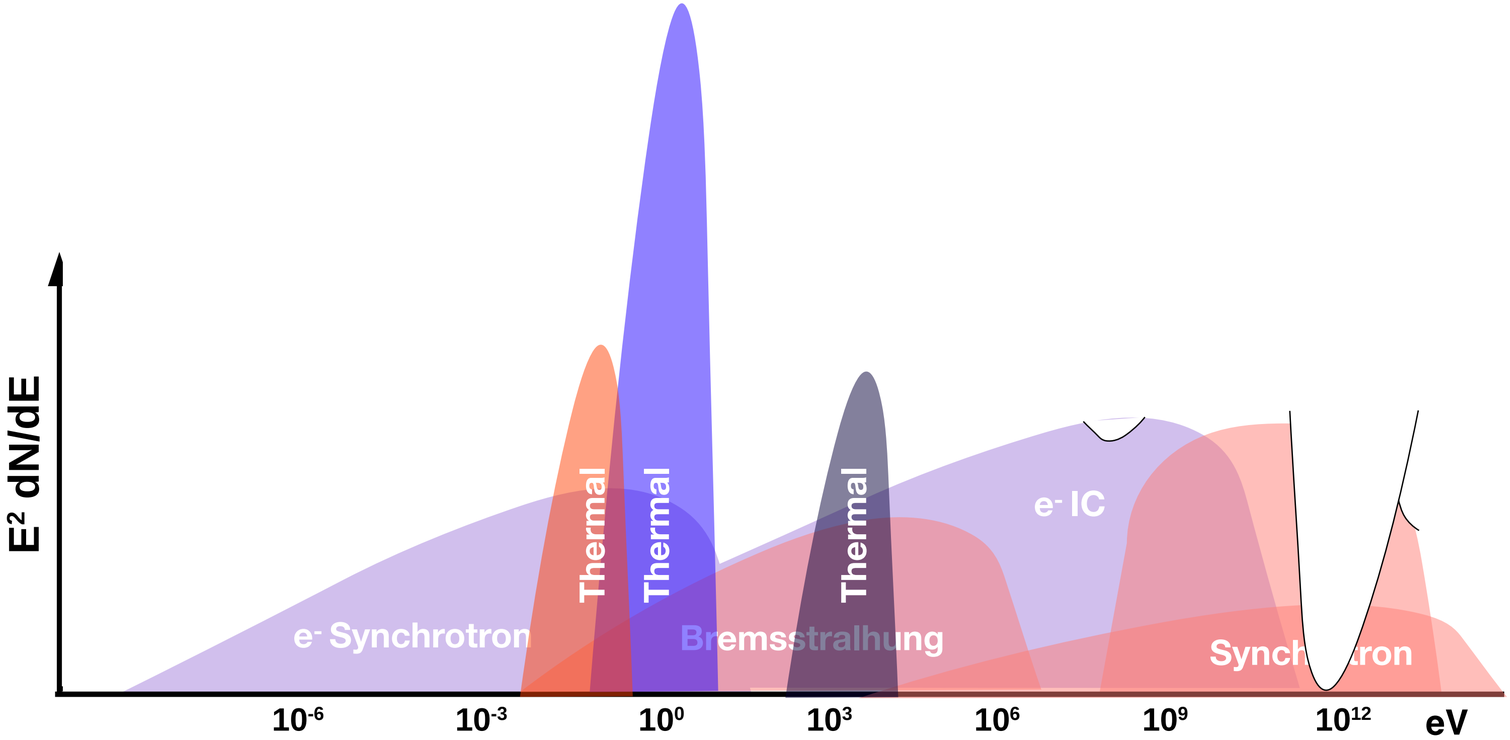


Wind shocks: Hadronic & leptonic acceleration

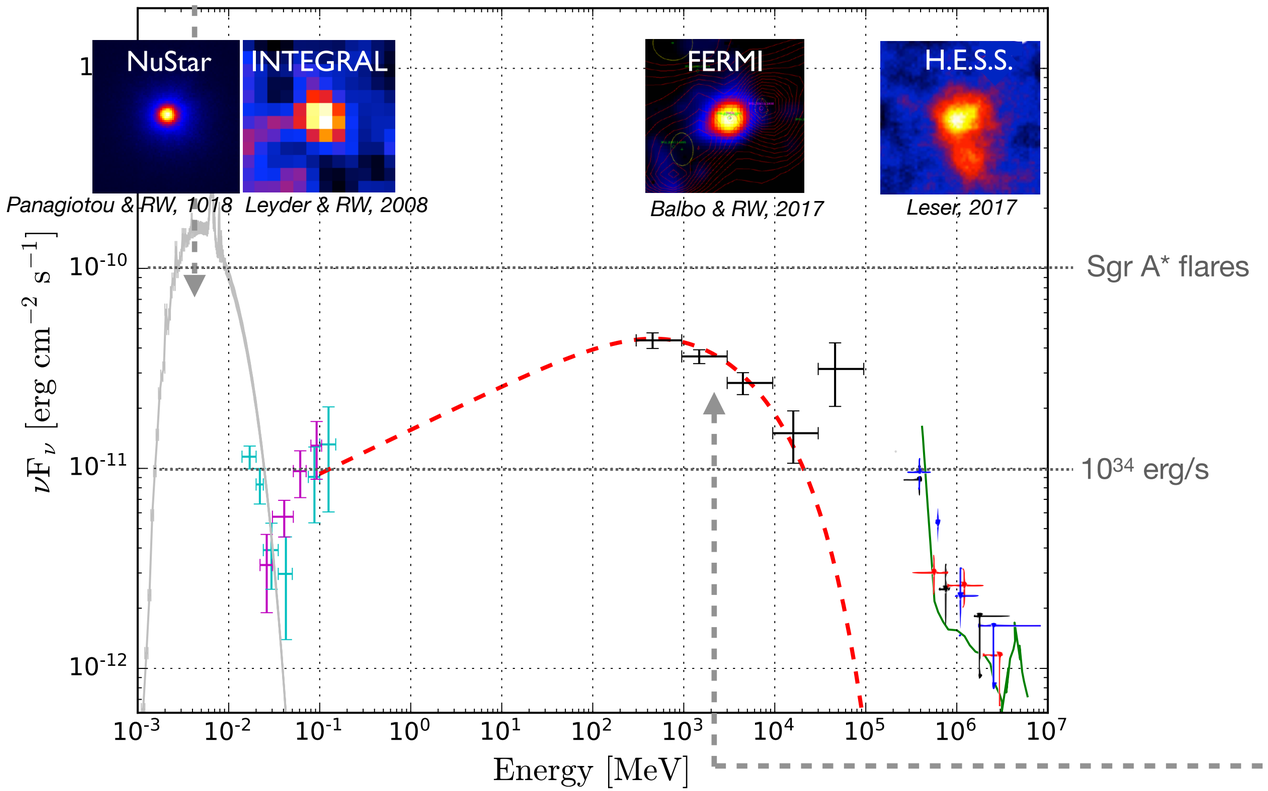
A shock with targets:

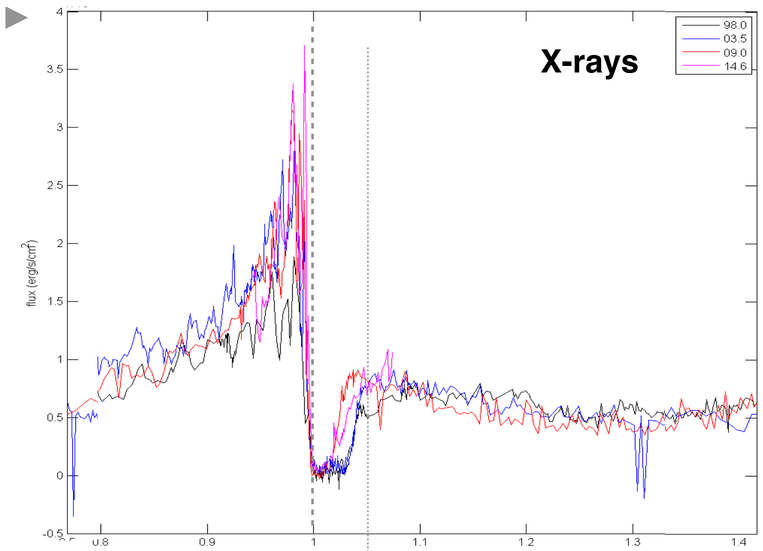


& sources of thermal photons:

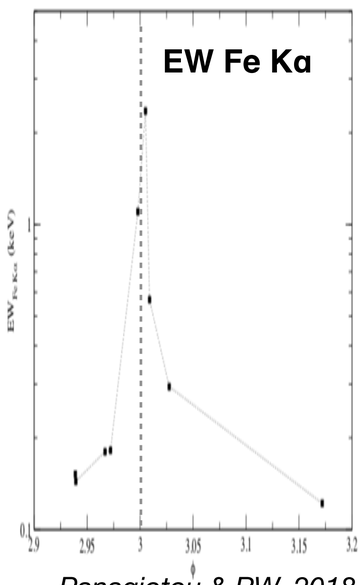


Orbital variability

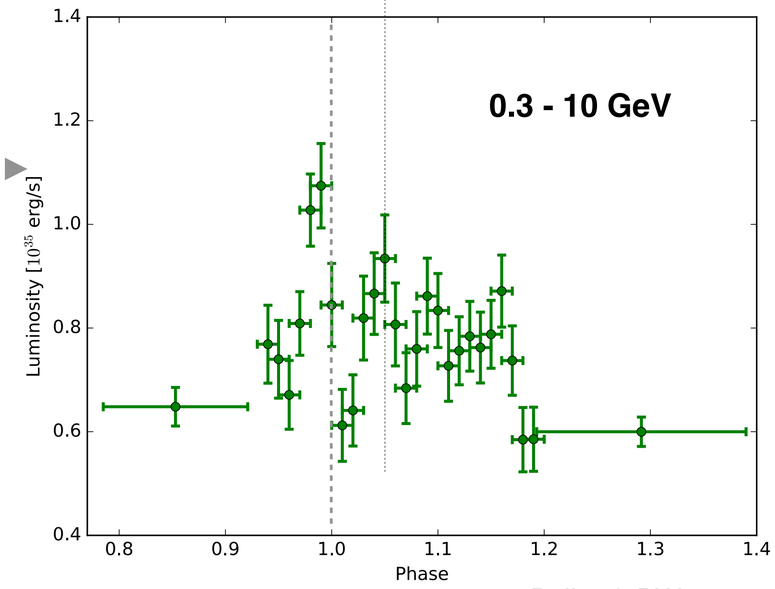




Corcoran/Russel



Panagiotou & RW, 2018

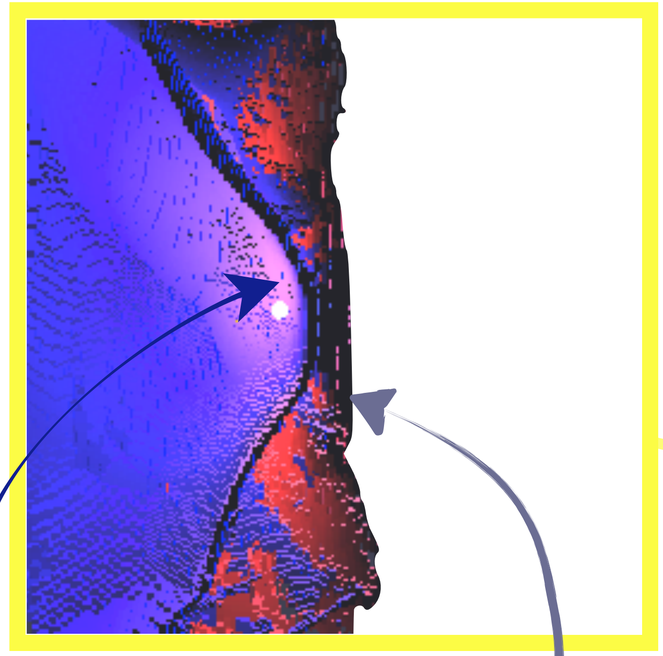


Balbo & RW, 2017

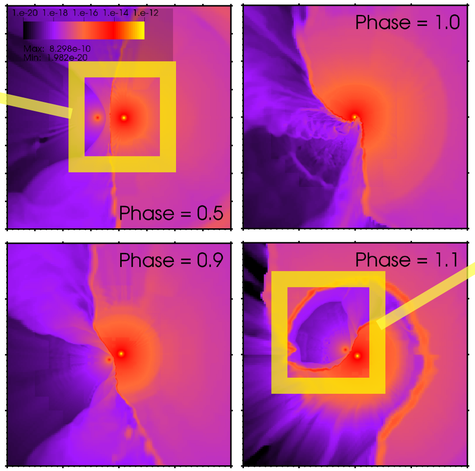
$$t_{\rm IC} = \frac{3\gamma m_{\rm e} c^2}{4\sigma_{\rm T} c \gamma^2 \beta^2 U_{\rm rad}} = \frac{3\pi R^2 m_{\rm e} c^2}{\sigma_{\rm T} \gamma \beta^2 L} \quad = \quad t_{acc} = \frac{R_L}{c}\left(\frac{c}{V}\right)^2$$

$$\gamma_{\rm max,\,e} = \sqrt{\frac{3\pi e c^2}{\sigma_{\rm T}\beta^2}}\sqrt{\frac{BR^2}{L}}\frac{V}{c} \approx \sqrt{\frac{B_{\rm 1G} R^2_{10^{14}\,\rm cm}}{L_{5\times10^6\,L_\odot}}} V_{10^3\,\rm km\,s^{-1}} \times 3\times10^4$$

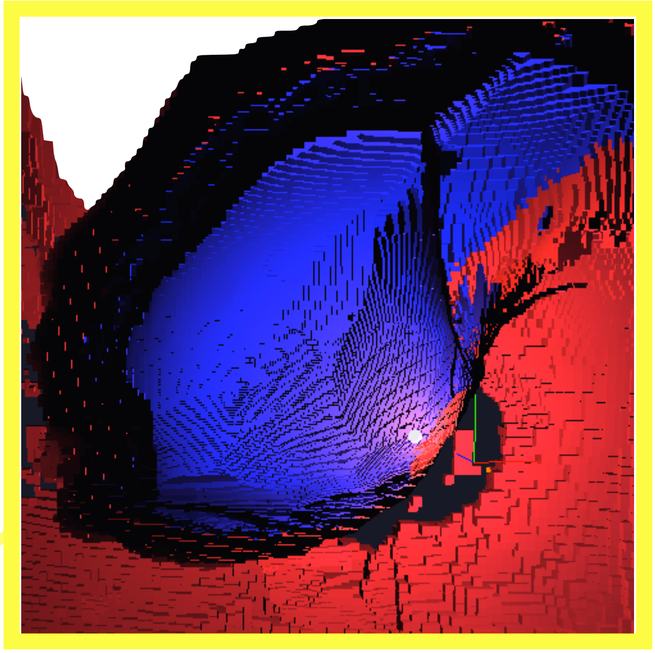
3D hydro simulations

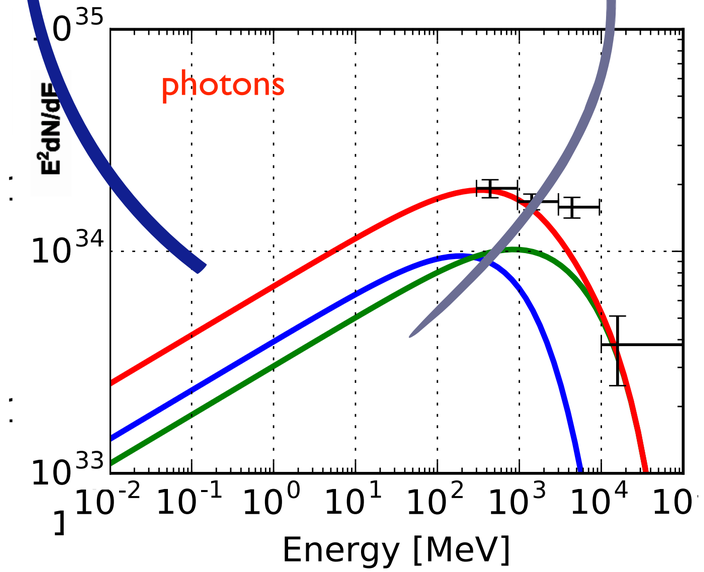


Parameter	Primary	Secondary
M ($M_\odot$)	120	30
R_* ($R_\odot$)	100	20
T_{cs} (K)	25,800	30,000
L_* ($10^6 L_\odot$)	4	0.3
k	0.30	0.50
α	0.52	0.68
$\dot{M}$ ($M_\odot\,yr^{-1}$)	4.8×10^{-4}	1.4×10^{-5}
v_∞ ($km\,s^{-1}$)	500	3000
B (G)	500	



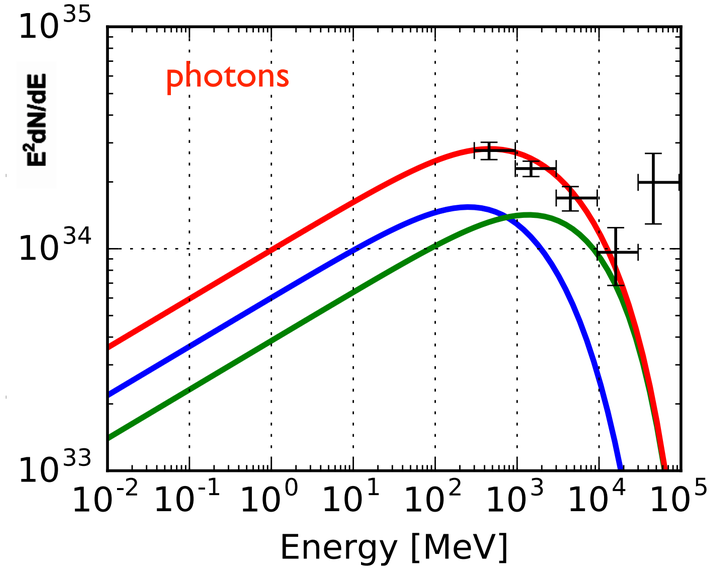
Parkin et al, 2011





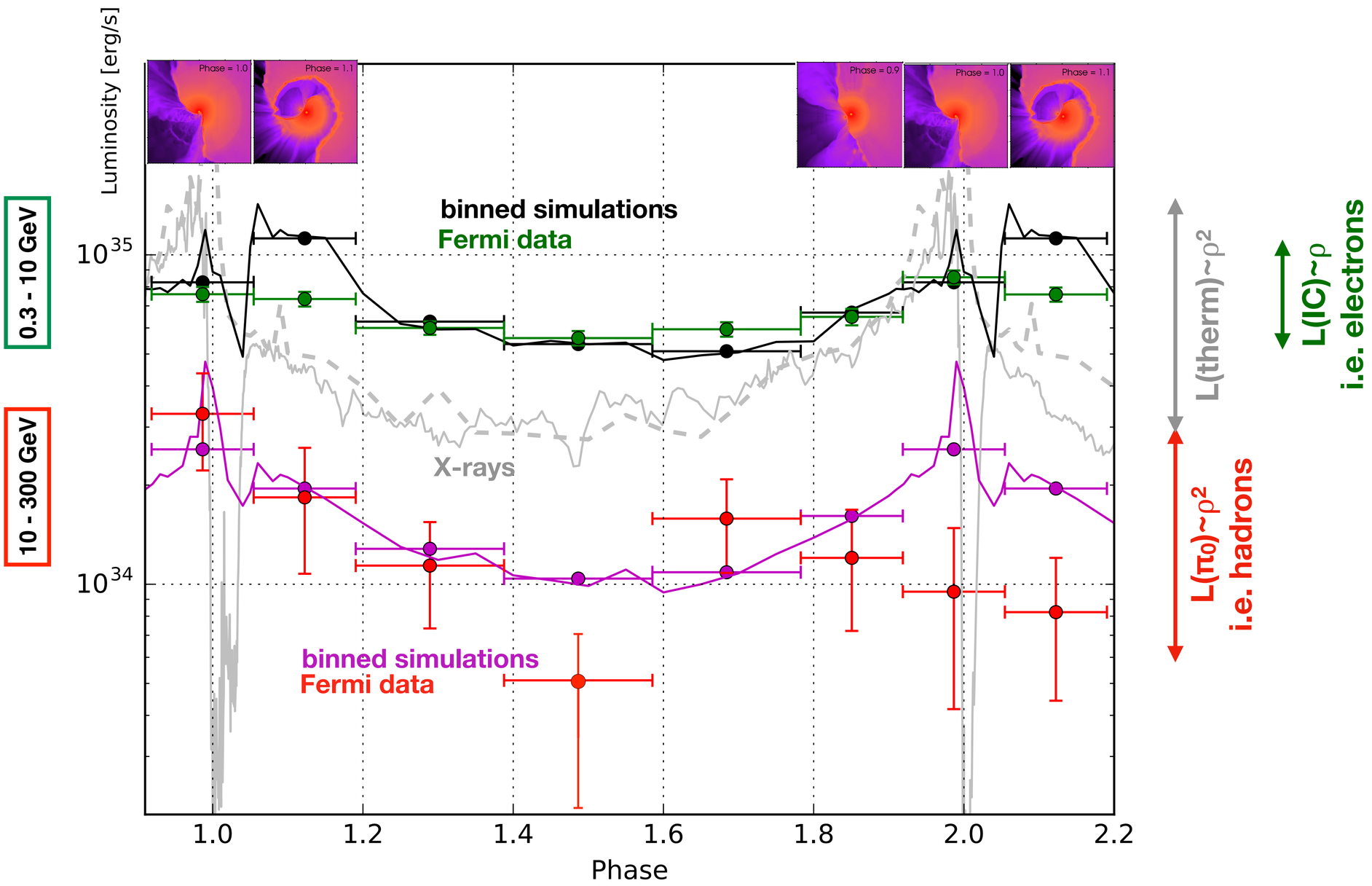
e⁻ spectrum

smooth IC spectrum



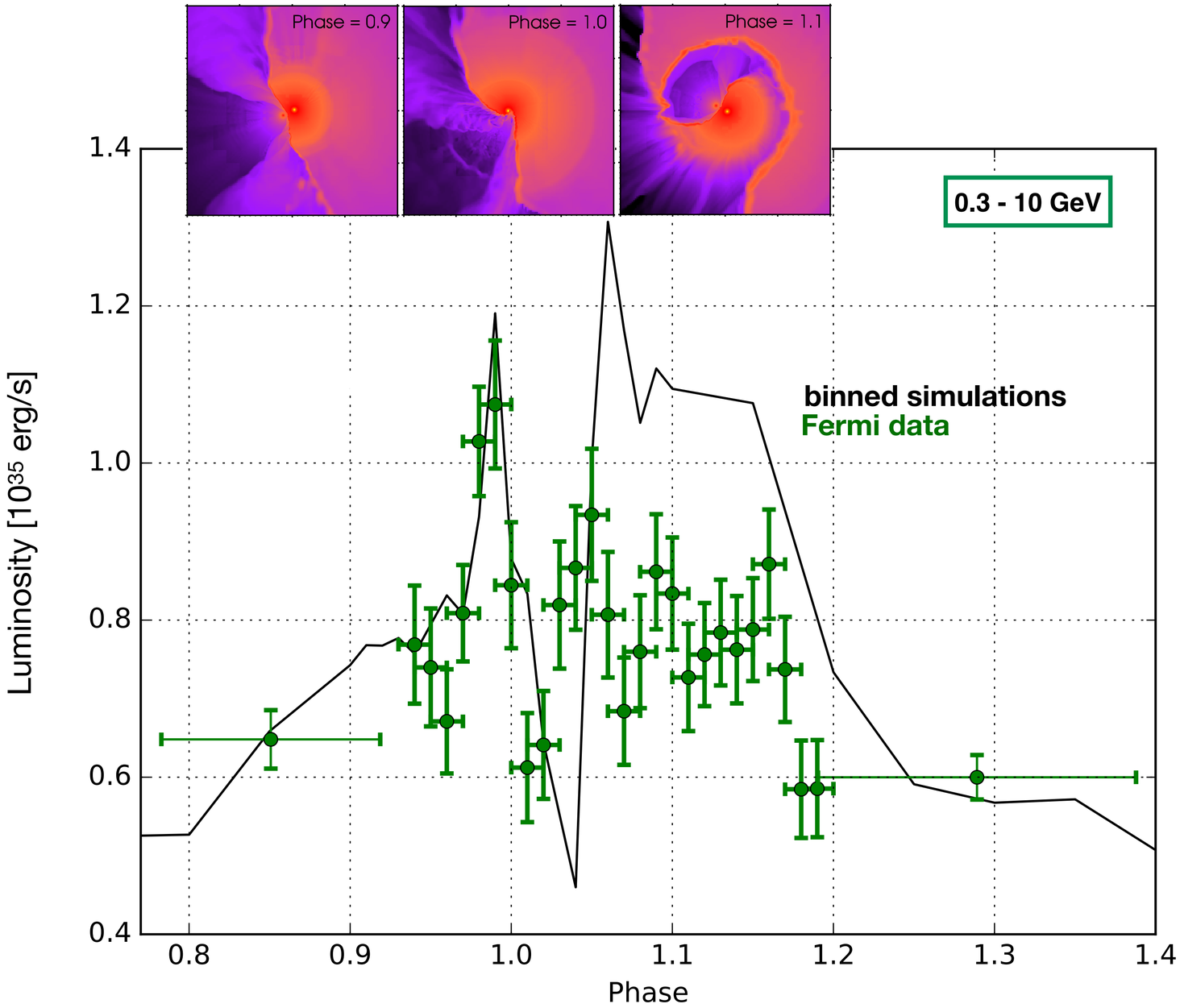
(Balbo & RW, 2017, thermal simulations from Parkin et al, 2011)

η Car γ-ray light-curves



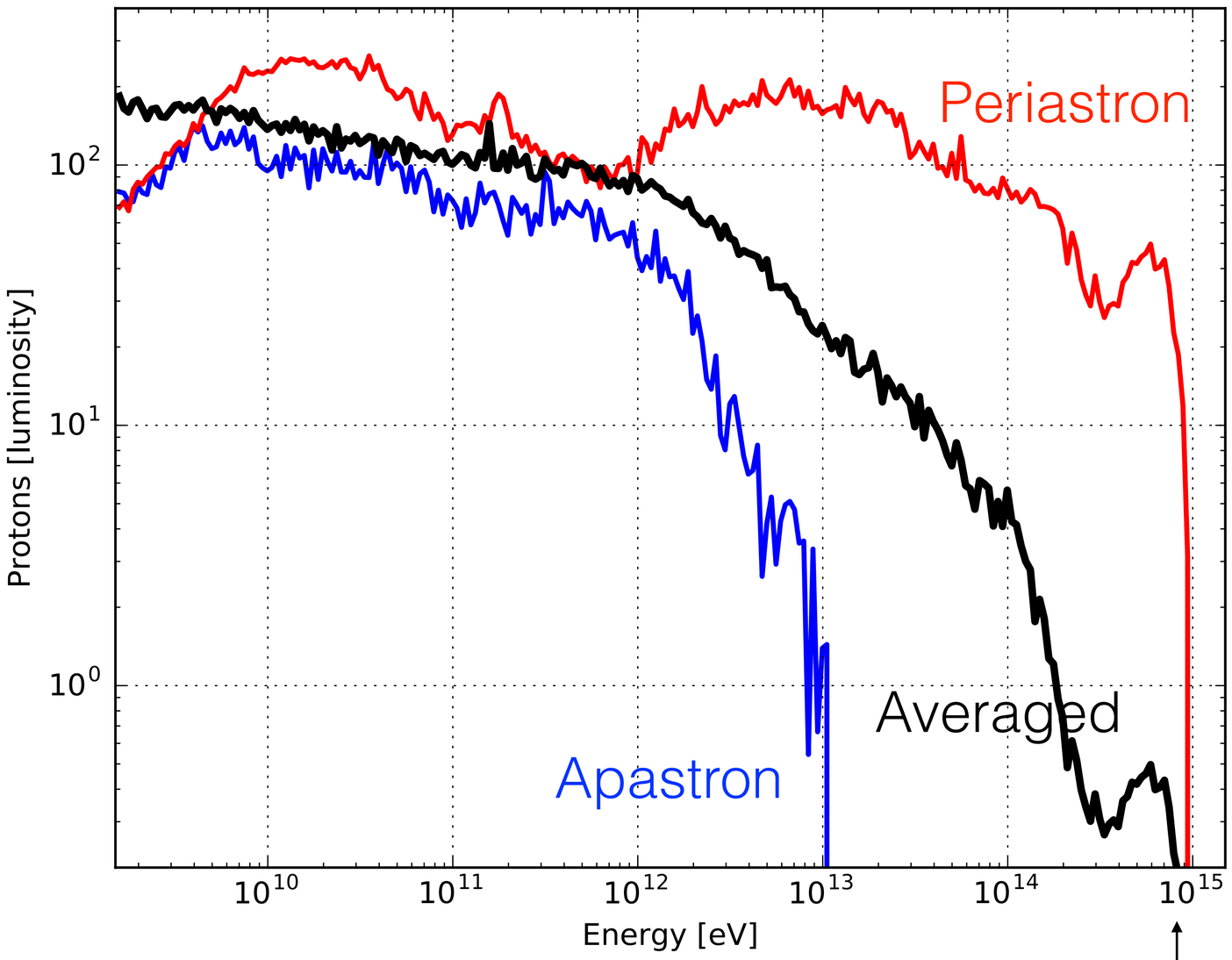
Balbo & RW, 2017

Inverse Compton emission



Balbo & RW, 2017

Hadronic spectrum

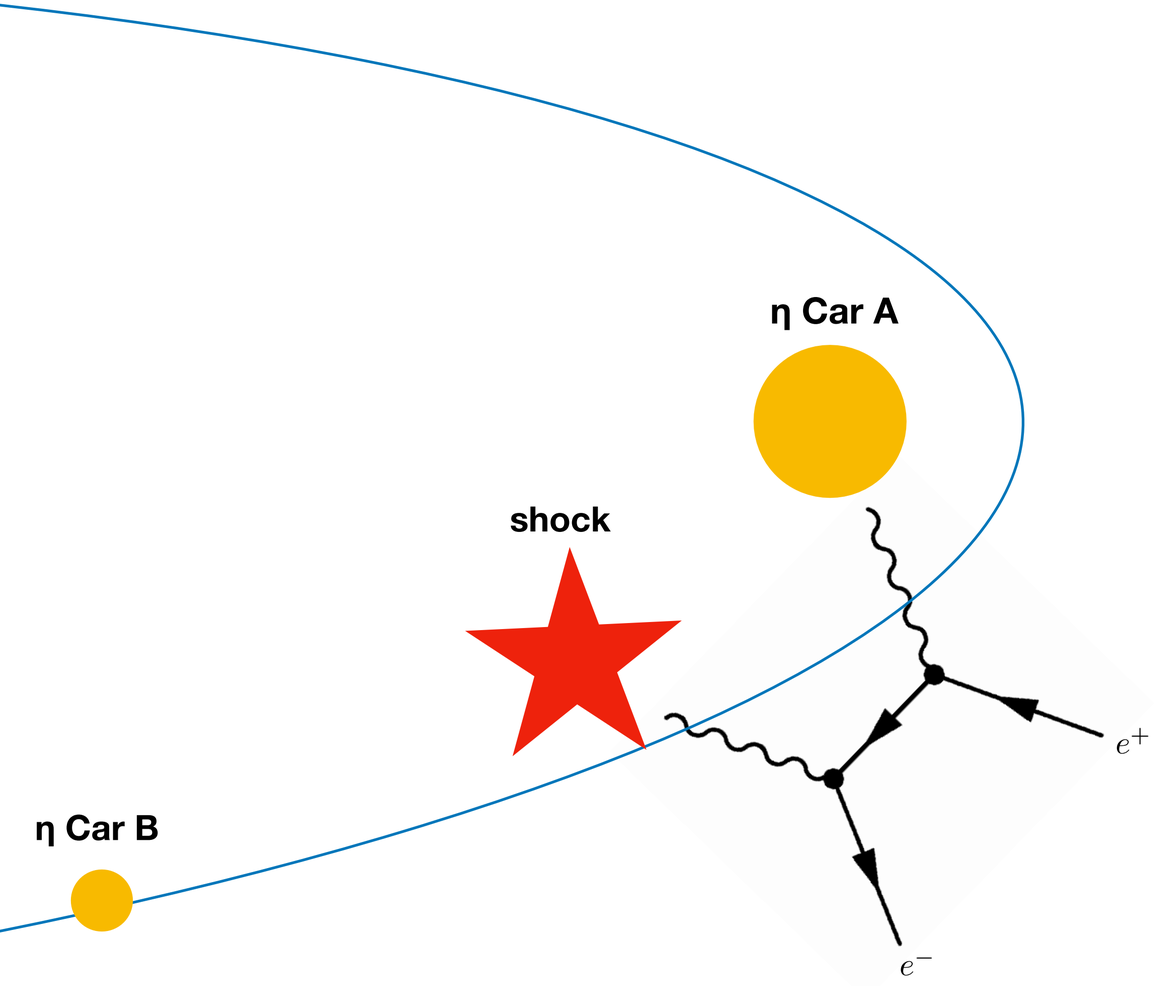


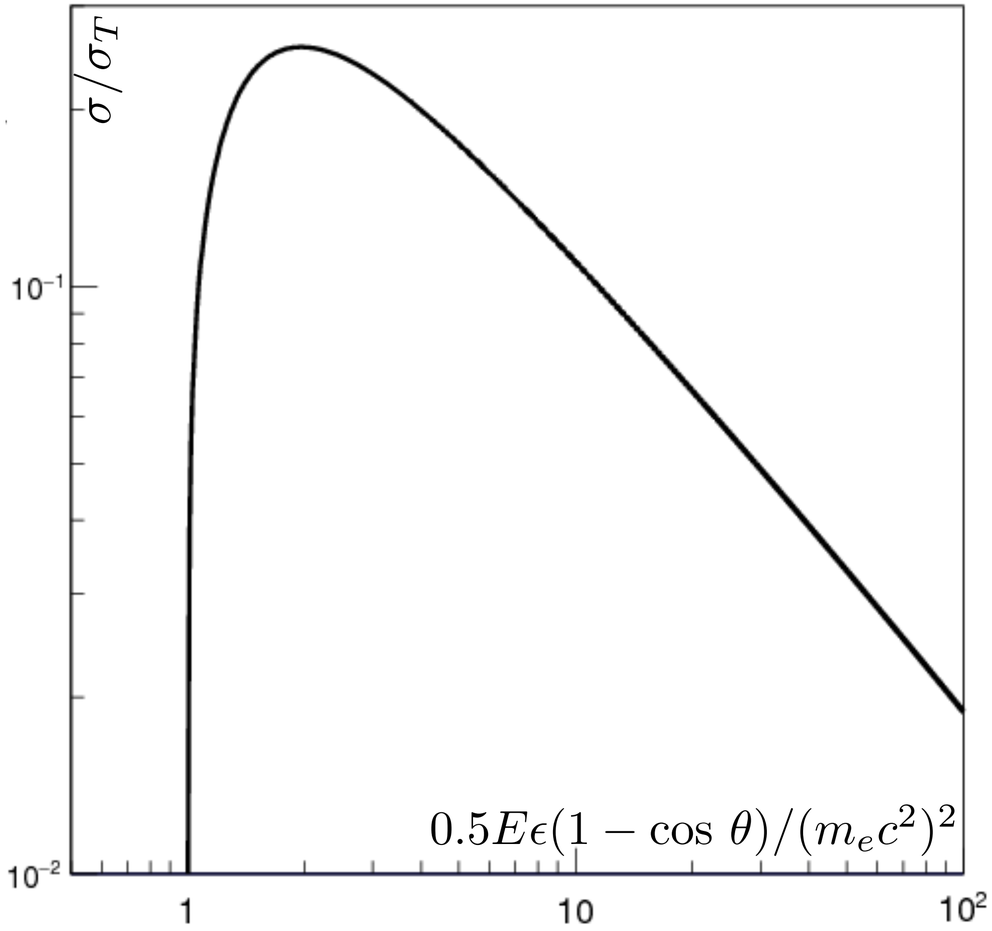
$$\gamma_{max,p} = \frac{4\pi R^2 e B V^3}{\sigma_{pp} \delta \dot{M} c^3} \sim \frac{1}{R}$$

knee of the CR spectrum

Balbo & RW, 2017

Photo-photo absorption





$$E_{threshold} = 0.52/\epsilon_{\rm eV}(1-\cos\theta)\ \text{TeV}$$

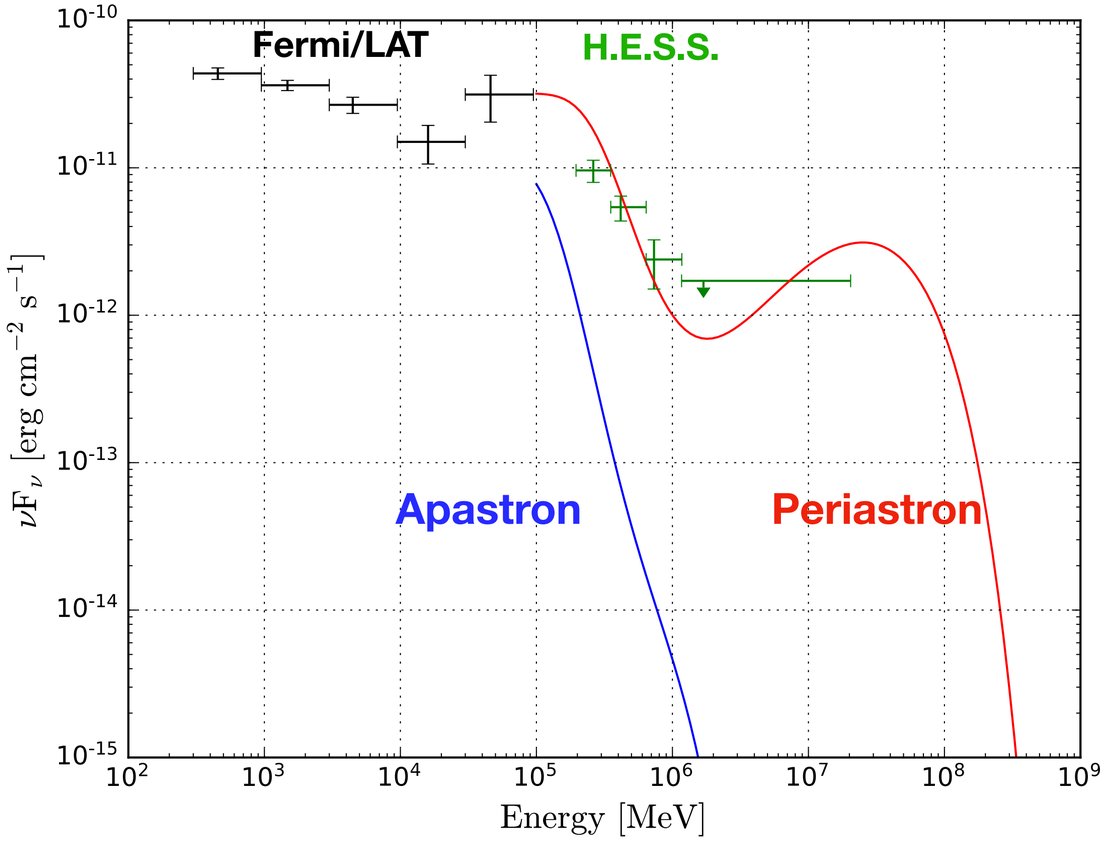
$$E_{th}(25^\circ) \sim 10 \times E_{th}(\text{head}-\text{on})$$

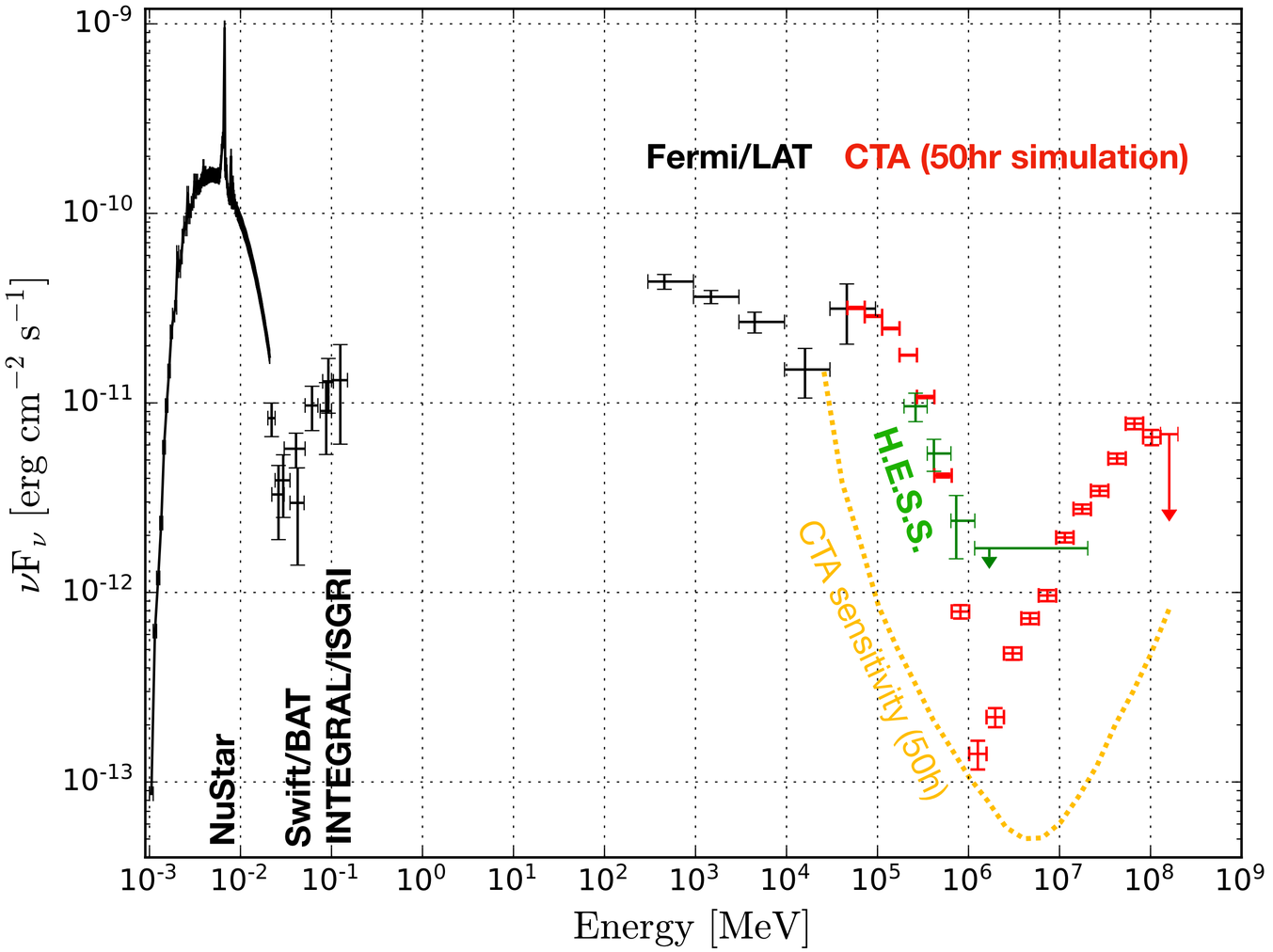
Photo-photo absorption

Increasing γ-UV obscuration

(convolution of uncertain UV spectrum with cross section)

Absorption peak energy varies with orbital phase





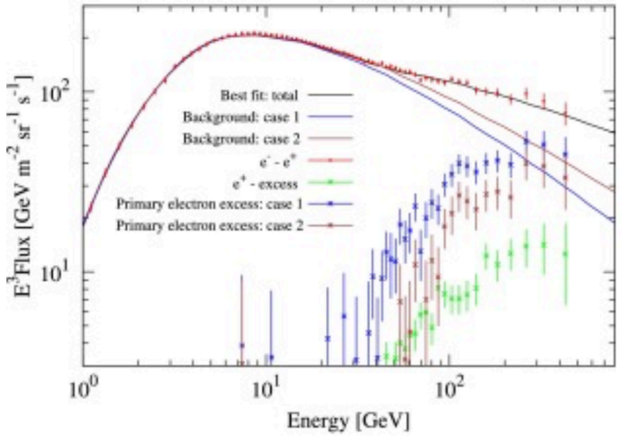
Expected τ (head-on) : 10

τ (catch-up) : ~1

τ (suggested by HESS): ~7 (depends on E_{cut})

Energetics

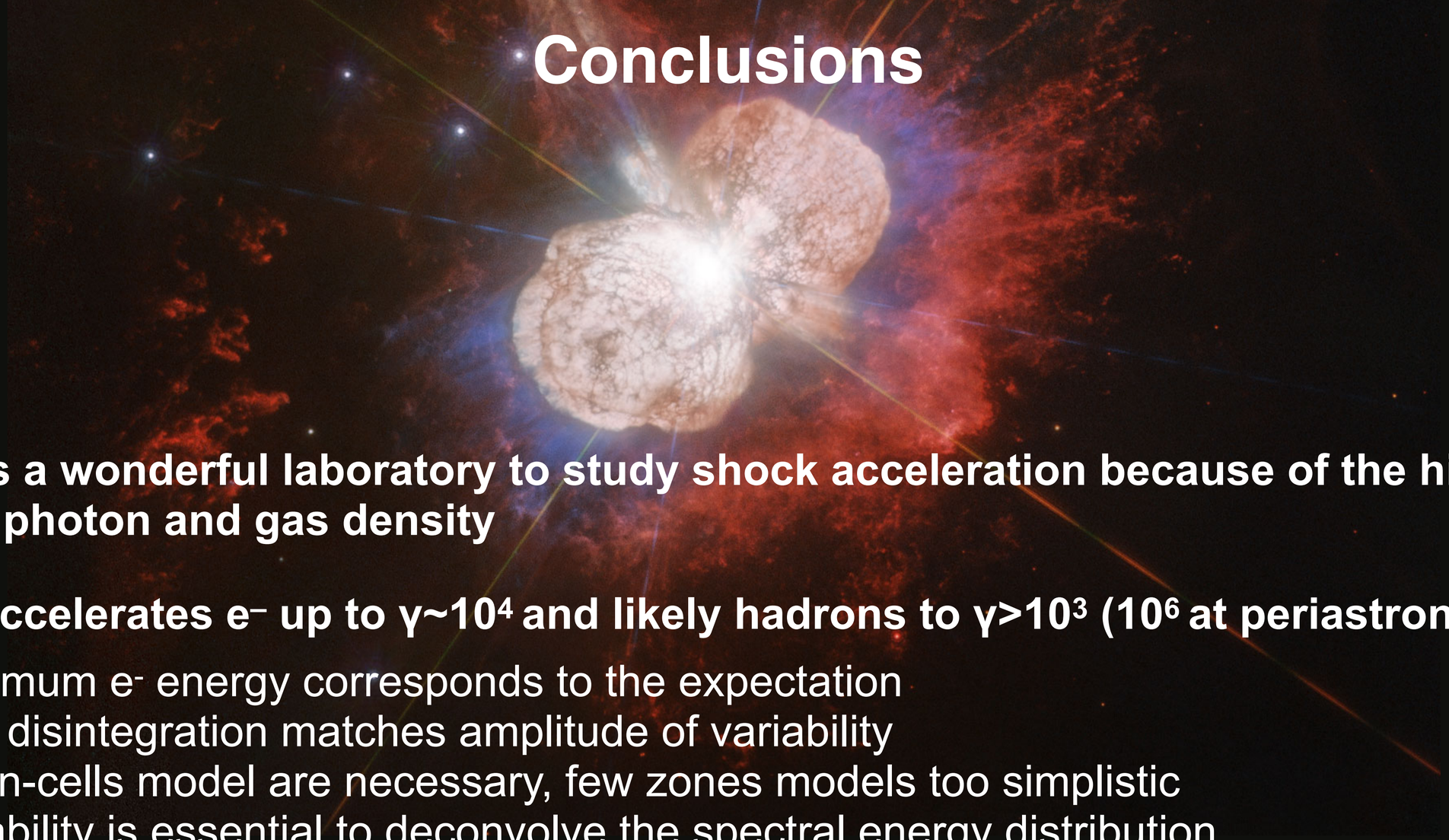
- **Thermal X-rays:** 25 $L_\odot$
- **Synchrotron:** < 0.1 $L_\odot$
- **Electron acceleration:** 50 $L_\odot$
- **π^0 emission:** 10 $L_\odot$
- **neutrino:** ~ 10^{-9} GeV s^{-1} cm^{-2} (above 10 TeV)
- **0.1-1 TeV e^+-e^-:** ~ 3 10^{34} s^{-1}



- **η Carinae** shows evidences for **electronic** and **hadronic** acceleration
- Electron **spectral index** is compatible with 2.25
- **Proton cutoff energy** ≳10^{13} eV, higher than measured in middle aged SNR
- **Efficiency** of particle **acceleration ~ 1-3%**

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

Conclusions



η Carinae is a wonderful laboratory to study shock acceleration because of the high luminosity, photon and gas density

η Carinae accelerates e^- up to $\gamma \sim 10^4$ and likely hadrons to $\gamma > 10^3$ (10^6 at periastron ?)

- Maximum e^- energy corresponds to the expectation
- Pion disintegration matches amplitude of variability
- Zillion-cells model are necessary, few zones models too simplistic
- Variability is essential to deconvolve the spectral energy distribution
- CTA is needed to confirm hadronic acceleration and photo-absorption

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

- If OB associations are relevant remains to be seen