Eta Carinae : a very large hadron collider

A&A, pre-print available

Christian Farnier

ISDC, Geneva

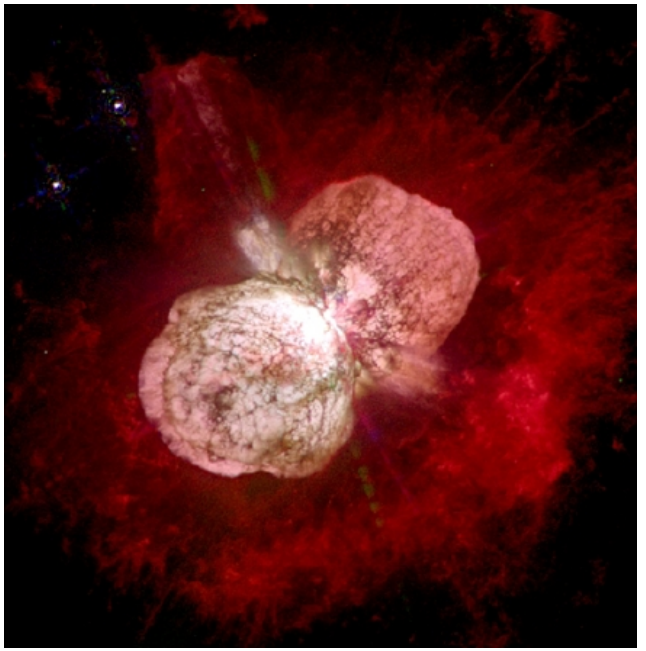
Galactic variable gamma-ray sources
Heidelberg - 2010

Outline

- Eta Carinae system
- High-energy emission status
- γ-ray spectrum
- Variability
- Spectral energy distribution
- Energetics

Eta Carinae CWB system

System :
- Binary system
- Distance : 2.3 kpc
- Period : 5.54 years
- Last periastron : 11th January 2009
- Eccentricity e : ~0.9
- Semi-major axis : a=16.16 a.u.
- Distance @ periastron : 1.66 a.u.
- ISM + nebula column density : ~10^{22} cm^{-2}



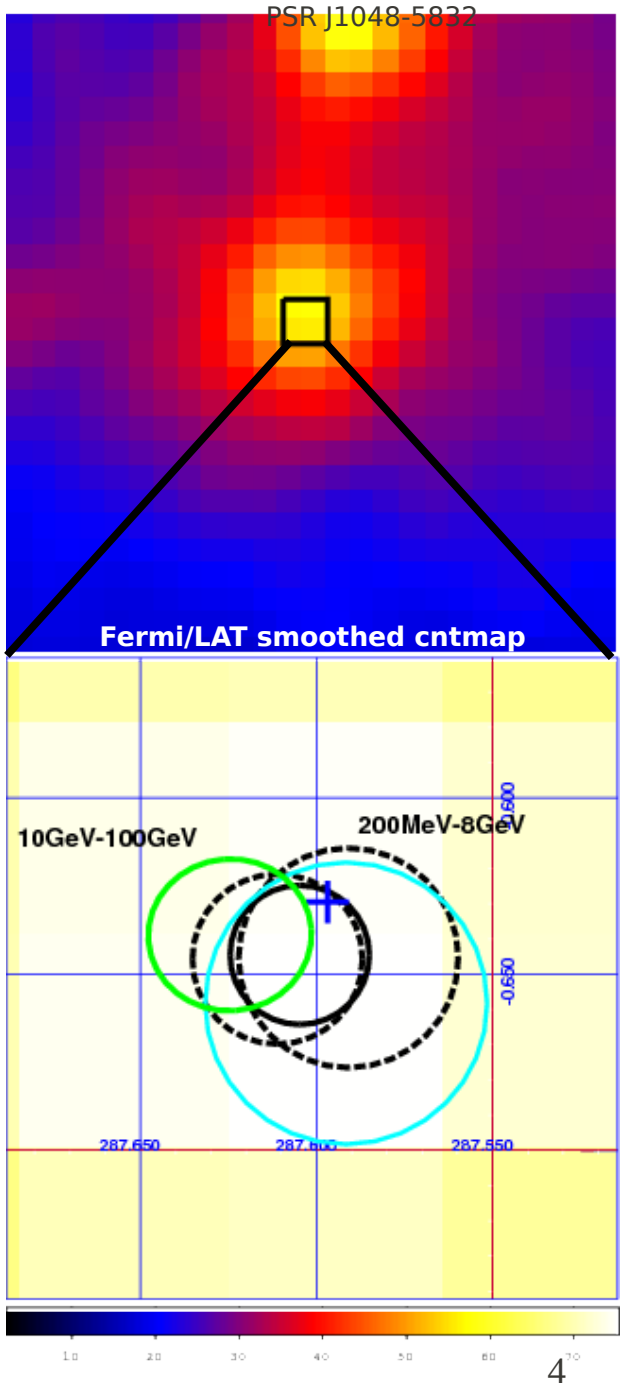
Primary star :
- Luminous blue variable (LBV)
- M ~ 80 - 120 M_{Sun}
- M_{dot} ~ 10^{-4}–10^{-3} M_{sun} yr^{-1}
- Wind velocity : v_{inf} ~ 500 km/s
- Radius : R ~ 100 R_{sun}

Secondary star (unseen):
- O or WR
- M ~ 30 M_{Sun}
- M_{dot} ~ 10^{-5} M_{sun} yr^{-1}
- Wind velocity : v_{inf} ~ 3000 km/s
- Radius : R ~ 20 R_{sun}

Highest star mass loss rate observed
Still lot of controversial fact : star type, M_{dot}, orientation, positions of stars during periastron, ...

High-energy emission status

- Eta Carinae location
- INTEGRAL / Suzaku compatible with eta Car.
- AGILE steady source and flaring episode spatially coincident with eta Car.
- Fermi/LAT detection is quite clear :
  - TS > 2800 ~ 53σ (above 200MeV)
  - 1FGLJ1045.2-5942 slightly offset eta Car, oustide 95% confidence radius
  - New analysis with 21 months of data, Fermi/LAT source position slightly improved and consistent with eta Car: (1.02 ± 1.18)' away

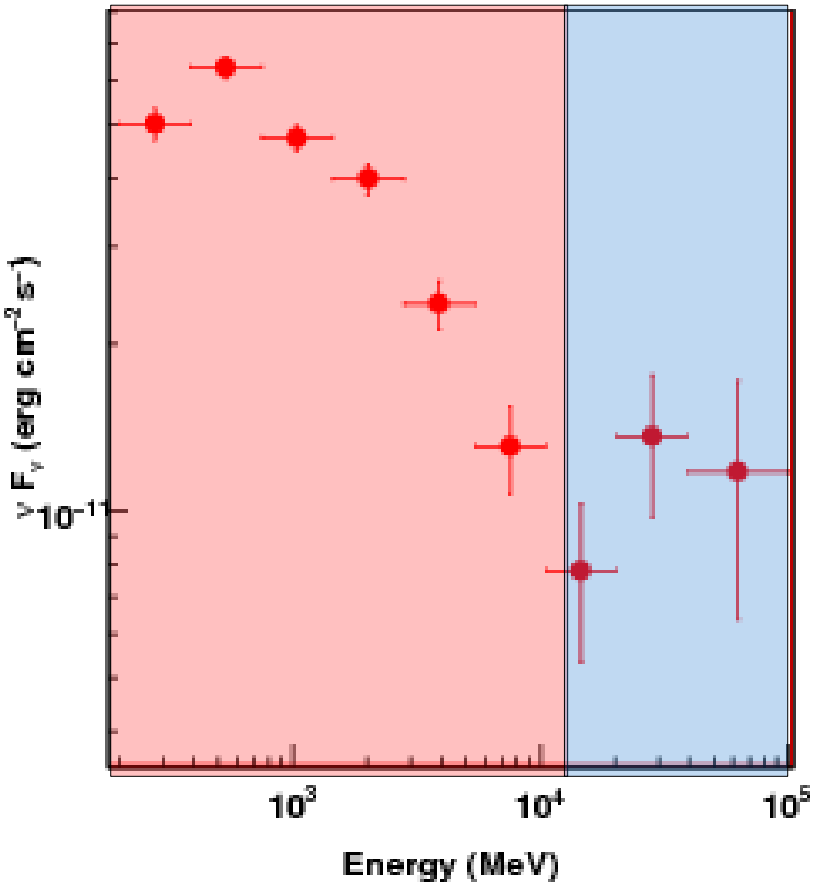


Spectral analysis in GeV domain

Analysis of Fermi/LAT data

- 2-components spectrum
  - *Soft* γ-ray component : Exponentially cut off PL :
    - TS ~ 2281 (47σ)
    - $\Gamma = 1.69 \pm 0.12$
    - $E_c = 1.8 \pm 0.5$ GeV
    - $F_{0.2\text{-}100} \sim 1.5 \times 10^{-7} cm^{-2} s^{-1}$
  - *Hard* γ-ray component : PL
    - TS ~ 73 (8.5σ)
    - $\Gamma = 1.85 \pm 0.25$
    - $F_{0.2\text{-}100} \sim 0.4 \times 10^{-7} cm^{-2} s^{-1}$
- Overall flux :

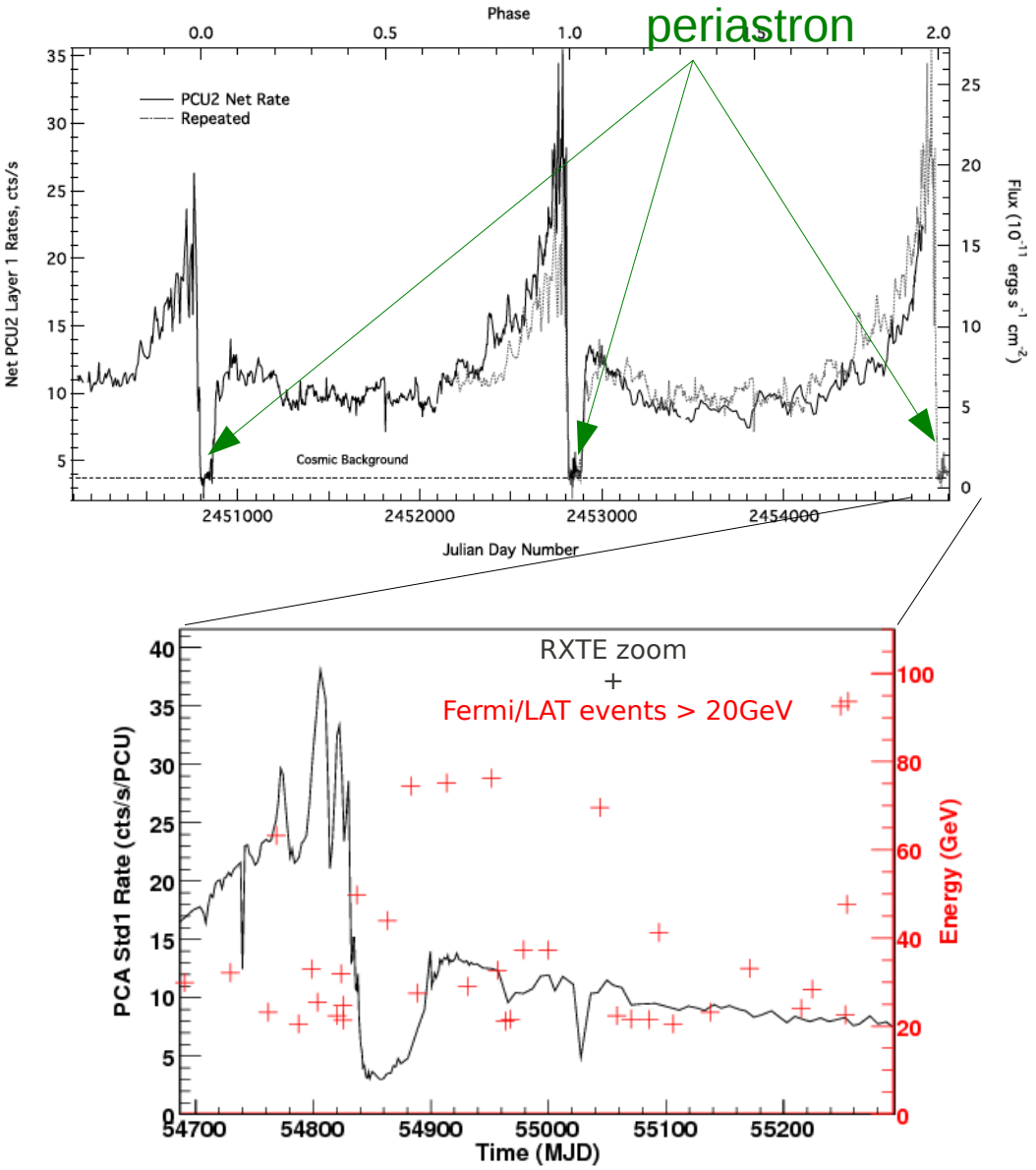
$$F_{0.2\text{-}100} \sim (1.93 \pm 0.03) \times 10^{-7} cm^{-2} s^{-1}$$



Both components consistent with eta Car.

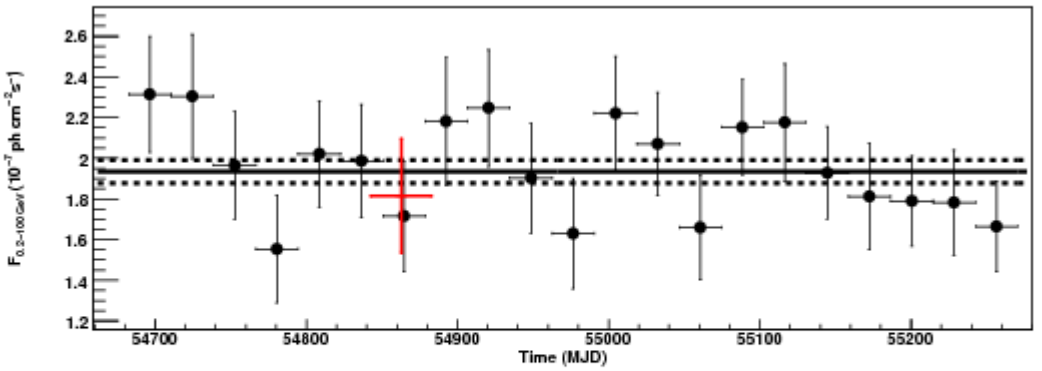
Temporal variability (I)

- The 2-10keV X-ray emission is clearly variable (RXTE lightcurve)
- AGILE reported a (rather soft) 2-days flaring episode in eta Car region on 2008 Oct. 11-13 (source reached $(27 \pm 7) \times 10^{-7} cm^{-2} s^{-1}$ above 100MeV), not observed by Fermi/LAT
- Observation of LAT high energy (E>20GeV) emission shows no sign of decline emission during periastron passage

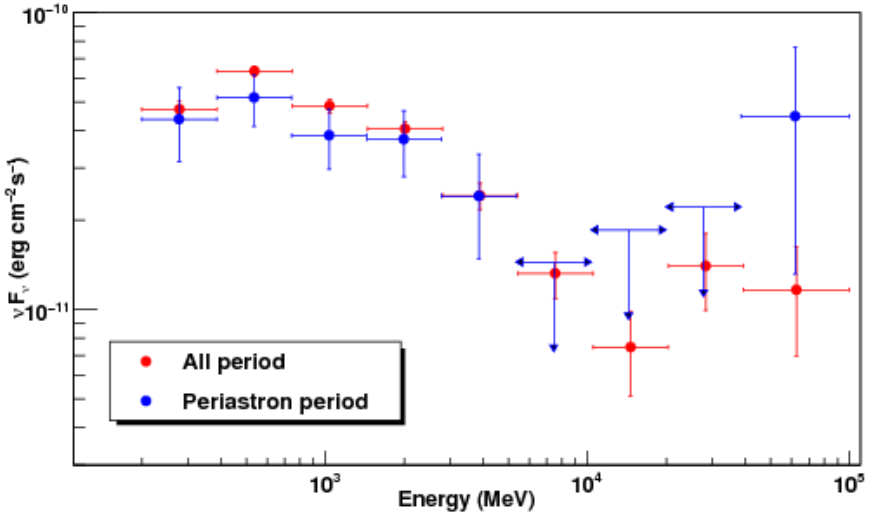


Temporal variability (II)

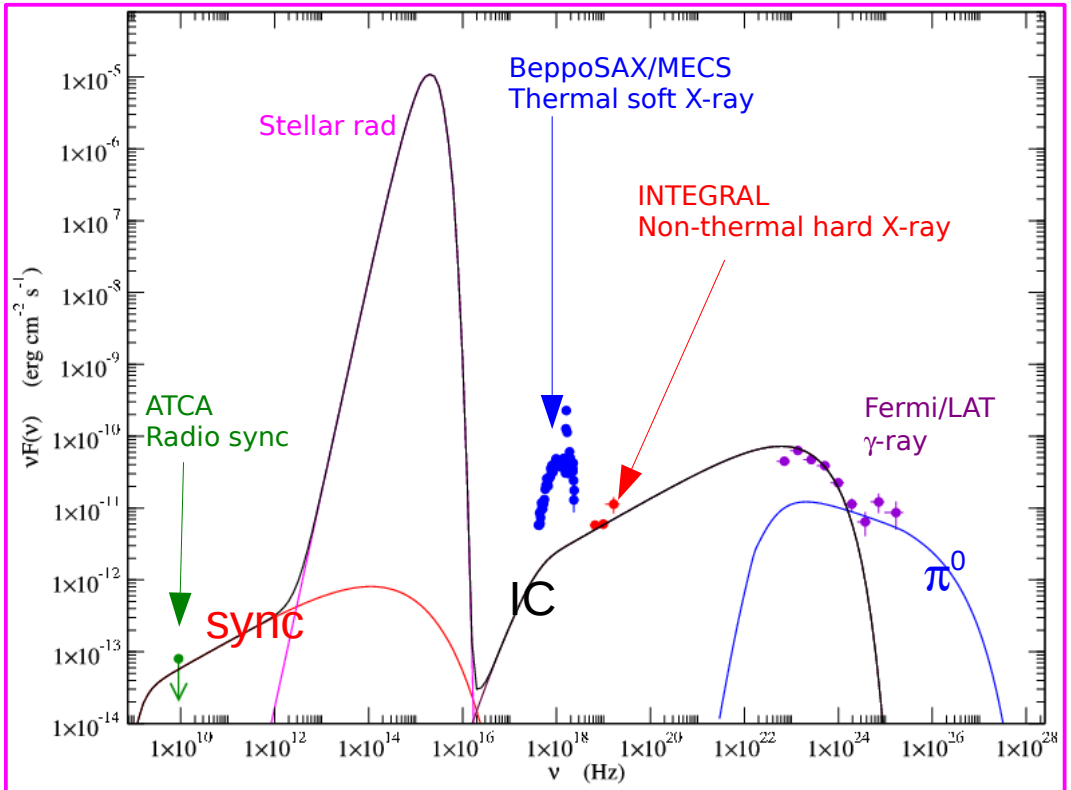
- Fermi/LAT observed flux steady on all 21 months
- No observable flux variation at periastron



- No indication of spectrum variation for periastron wrt global spectrum
  - but low statistic
  - variation might be difficult to observe due to long orbit



Spectral energy distribution



	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

- e^- IC with intense UV radiation field+ π^0 decay pp interaction of the stellar winds
  - Simple model explaining both hard X-ray and GeV fluxes
  - maximal proton energy not constrained by Fermi/LAT

pro : hard tails
con : no variability detected

- Alternative explanation for the 2 components γ-ray shape : γγ absorption

pro (?): single component
con : absorption not really expected for the 3-10 GeV range

- IC scattering on IR photons in external shock between Homonculus and ISM

pro : no variability expected for γ-ray
con : hard γ-ray tail not explained

Energetics

- Wind momentum ratio : $\eta = (M_{dot,2}\, v_{inf,2})/(M_{dot,1}\, v_{inf,1}) \sim 0.2$
- Fraction of wind involved in wind-wind col. ~ 10%
- Mechanical energy available ~ 200 L_{Sun}
- Total interacting proton energy $E_p \sim 10^{40}$ erg
- <=> energy injected to sustain shock : $E_p/t_{pp} \sim 10 L_{Sun}$

  <=> 5% of shocked mechanical energy

  <=> < 1% of total wind mechanical luminosity
- Integrated over massive star lifetime, massive stars stellar winds might be at a similar order of efficiency to accelerate hadrons than SNRs
  - Need VHE observations to contrain their contribution up to the knee

Conclusions

- Steady emission observed with Fermi/LAT in γ-ray
  - Lack of high-energy emission variability might be a challenge to describe the global system (X-ray / γ-ray)
- Spectrum exhibits 2 components shape
  - IC + pp
  - Other explanations possible
- H.E.S.S. should be able to detect eta Carinae or put a strong constraint on the maximum proton energy

Thanks for your attention