A gamma-ray view of Eta Carinae colliding wind binary system

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Cosmic rays & their interstellar medium environment
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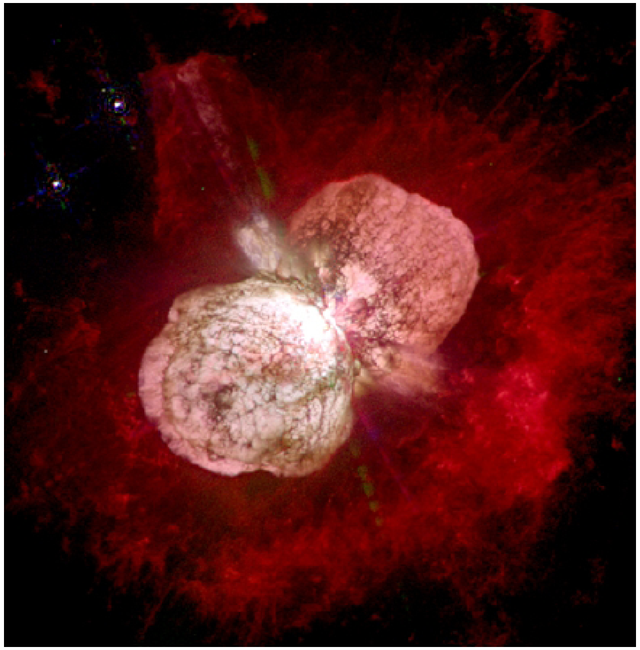
Outline

- Eta Carinae system
- High-energy emission status
- γ-ray spectral analysis
- Variability at high energy ?
- Spectral energy distribution
- Energetics
- Conclusion

Eta Carinae CWB system

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



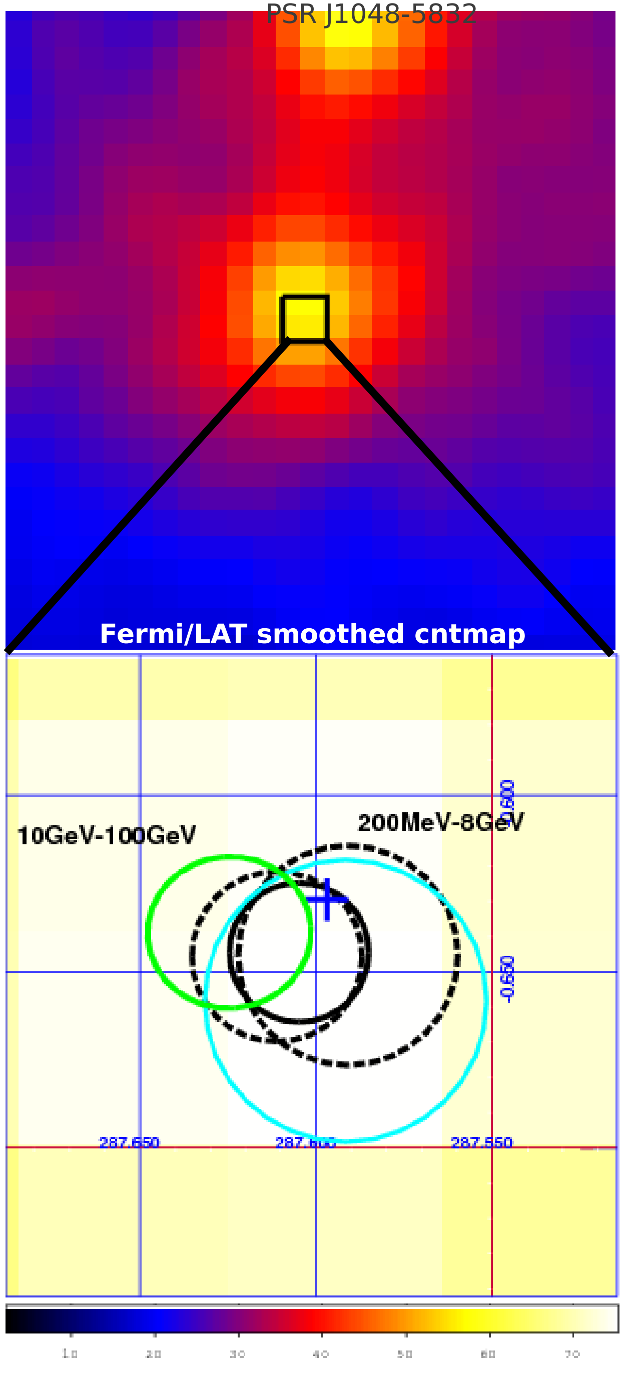
Primary star :
- Luminous blue variable (LBV)
- $M \sim 80 - 120\ M_{Sun}$
- $M_{dot} \sim 10^{-4}$–$10^{-3}\ M_{sun}\ yr^{-1}$
- Wind velocity : $v_{inf} \sim 500$ km/s
- Radius : $R \sim 100\ R_{sun}$

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

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

Non-thermal emission status

- Eta Carinae location
- INTEGRAL / Suzaku compatible with eta Car.
  Leyder et al. (2008, 2010), Sekiguchi (2009)
- AGILE steady source and flaring episode spatially coincident with eta Car.
  Tavani et al. (2009)
- Fermi/LAT detection is quite clear :
  - TS > 2800 ~ 53σ (above 200MeV)
  - 1FGLJ1045.2-5942 slightly offset eta Car, oustide 95% containment radius
  - New analysis with 21 months of data, Fermi/LAT source position slightly improved and consistent with eta Car: (1.02 ± 1.18)' away



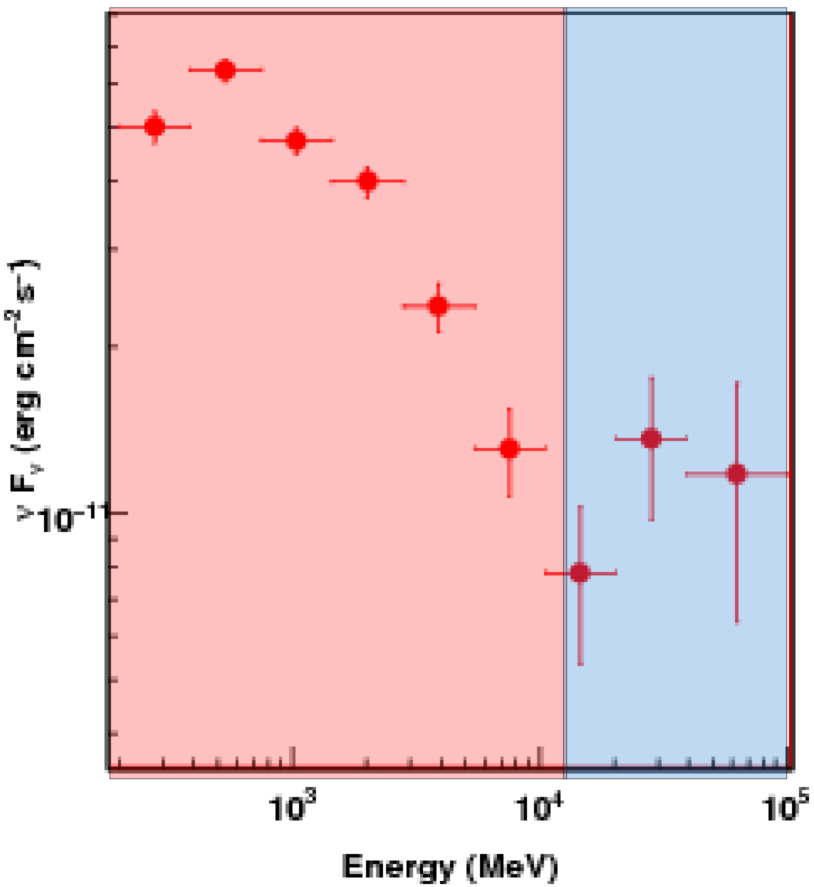
Farnier et al. 2011, A&A, 526, 57

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 :

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



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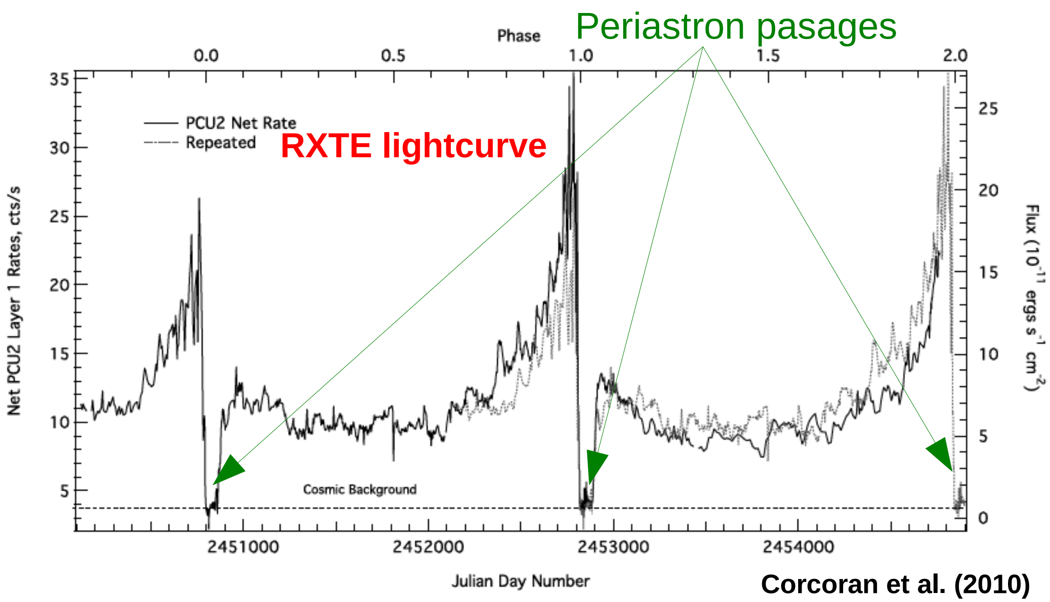
Both components are spatially consistent with eta Car.

Temporal variability status

- Soft X-rays (2 – 10 keV) :
  Large variability of the thermal X-ray emission near and during apastron.
  Thermal X-ray emission = free-free emission, variability due to post shock gas density rising at periastron



Corcoran et al. (2010)

- Hard X-rays :
  Intensity measured by INTEGRAL **far from** periastron : 0.18 ± 0.02 cnt/s
  Intensity measured by INTEGRAL **close to** periastron : 0.16 ± 0.05 cnt/s

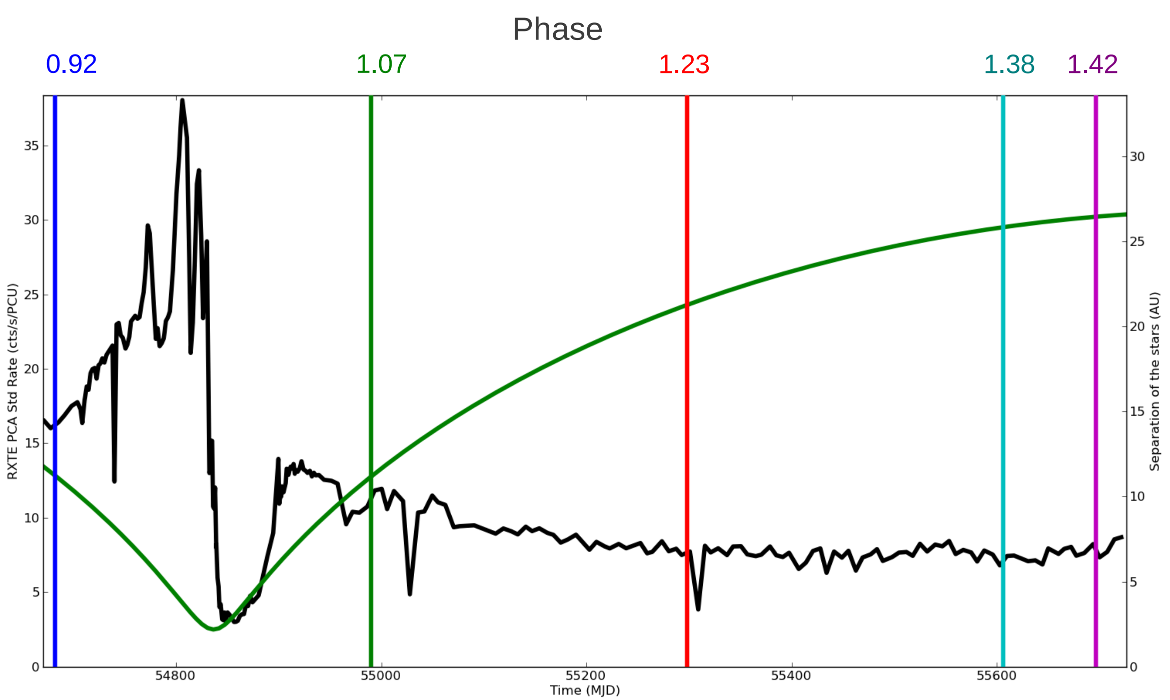
$\Rightarrow$ No significant variation of the hard X-ray component.

Variability in gamma-rays

- <u>Gamma rays :</u>
  AGILE reported a (rather soft) 2-days flaring episode in eta Car region on 2008 Oct. 11-13 (source reached $(27 \pm 7)\times10^{-7}cm^{-2}s^{-1}$ above 100MeV), *not observed by Fermi/LAT.*

- <u>Low energy gamma-rays :</u>
  No indication of significant variability along the orbit in Fermi/LAT data.

- <u>High energy gamma-rays :</u>
  Emissivity of the system decrease after periastron passage.



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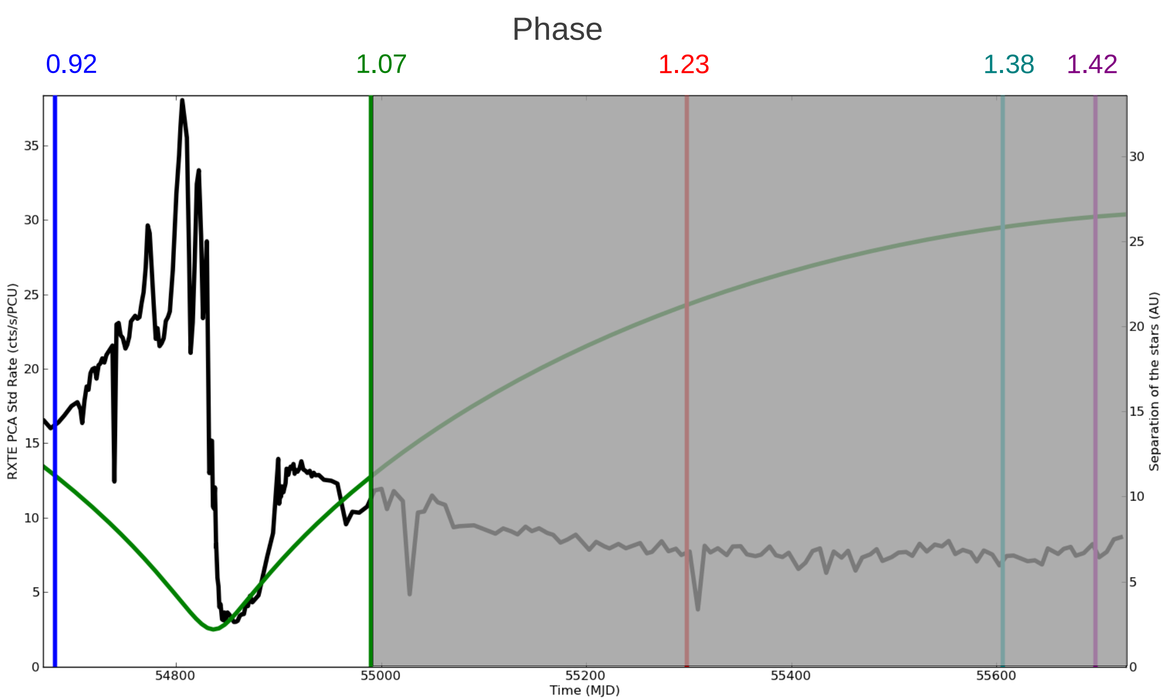
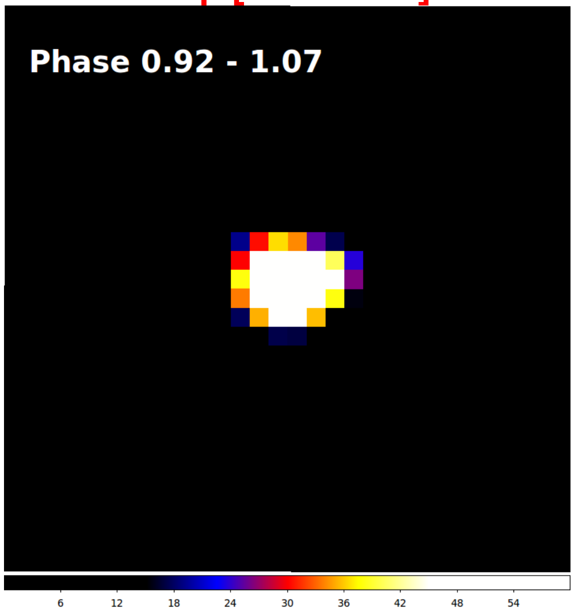


Test statistic (significance^2) map [E>10 GeV]



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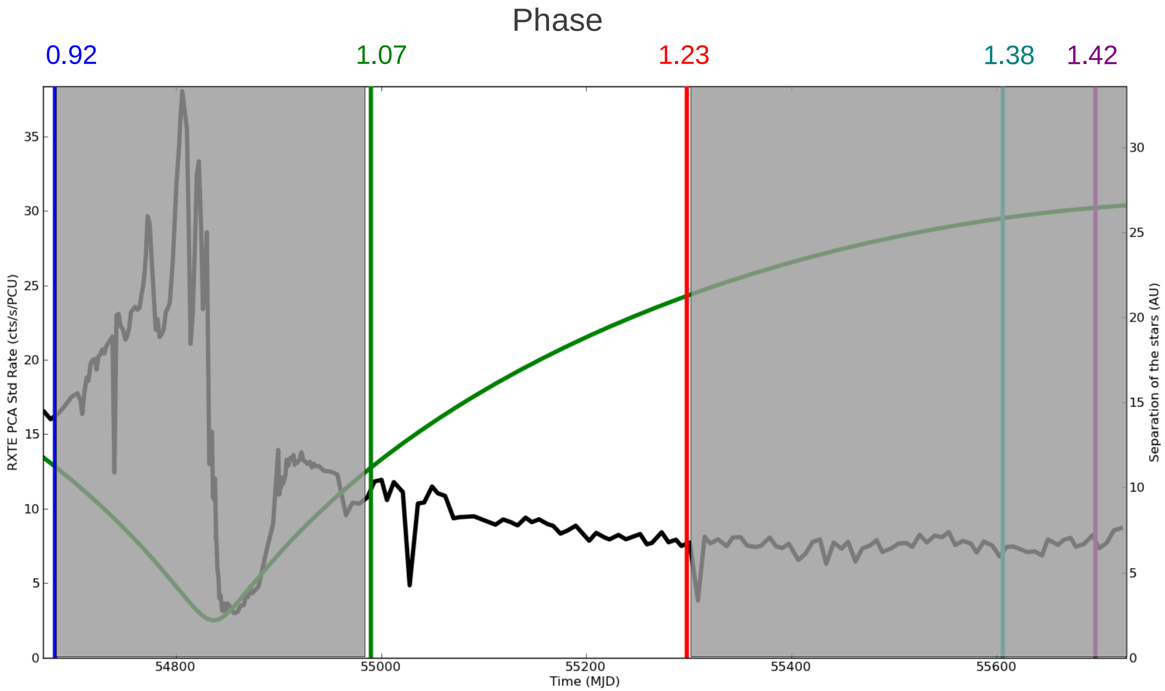

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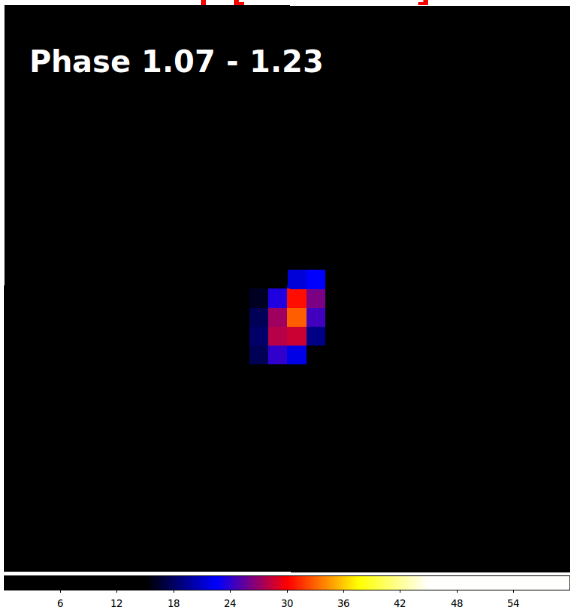

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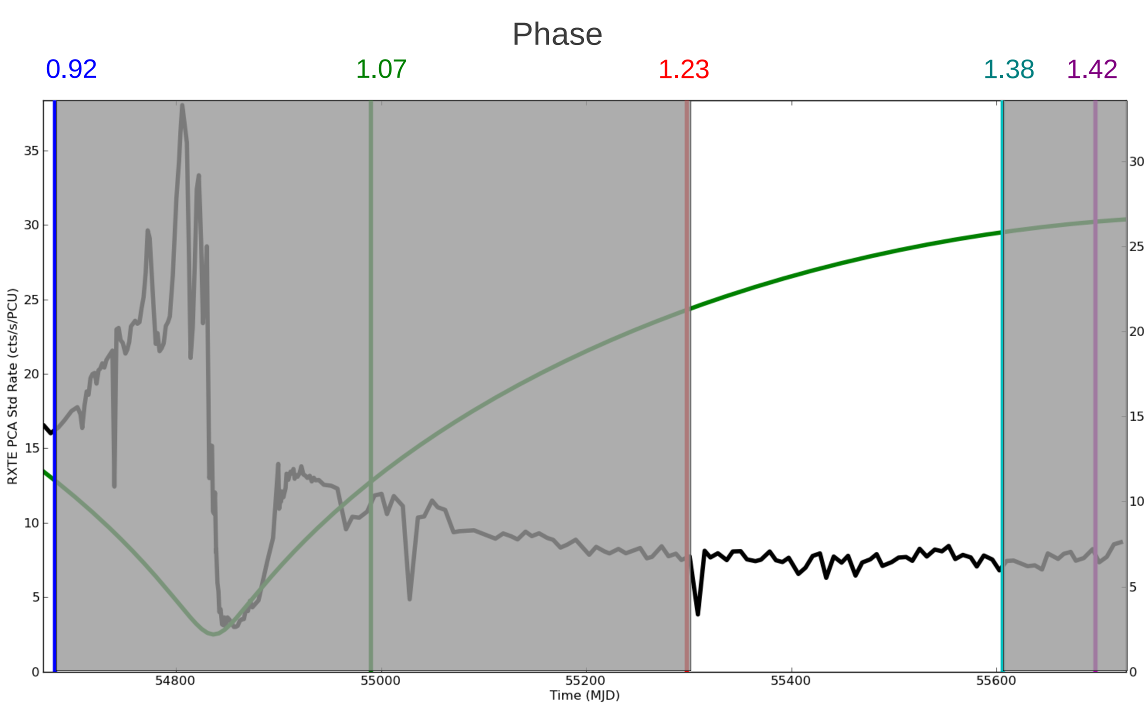

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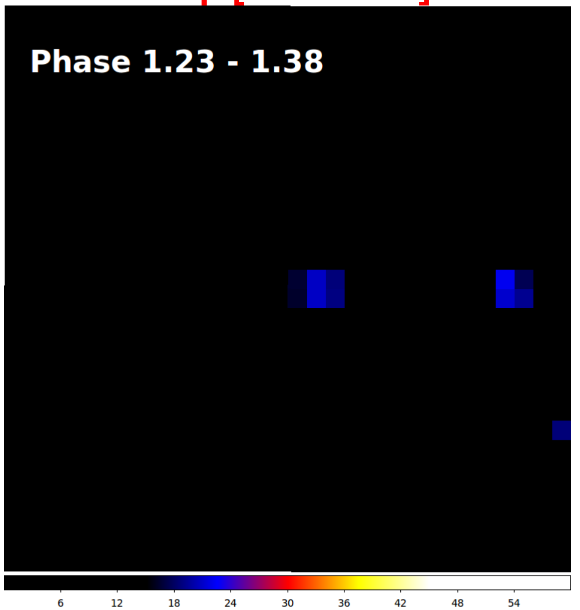

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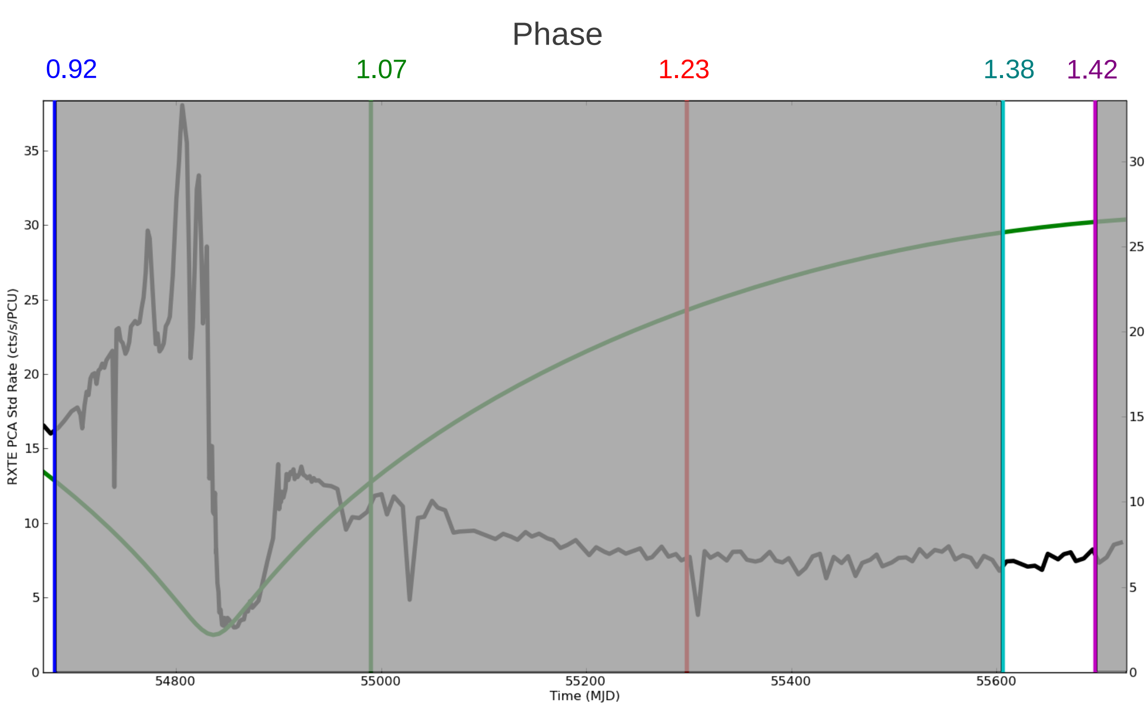

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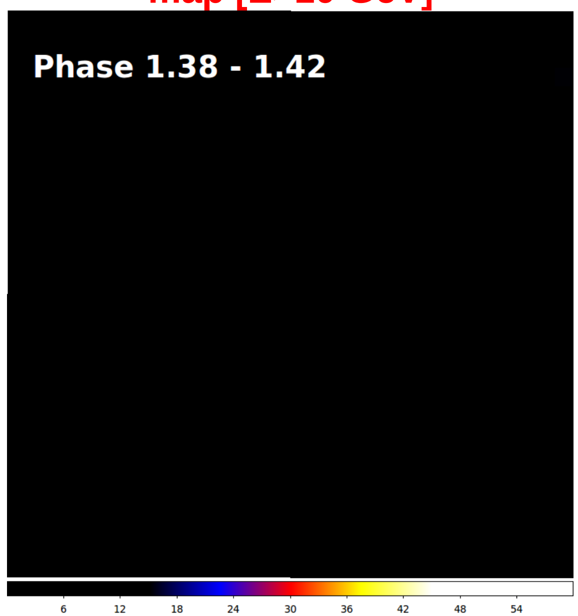

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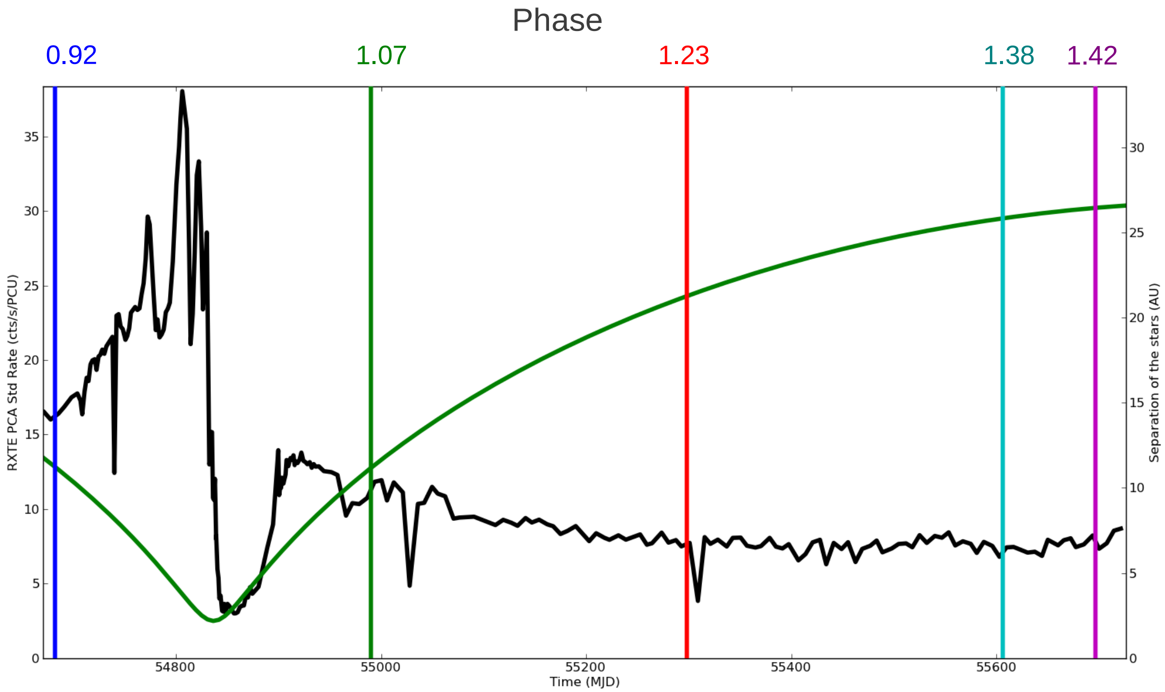
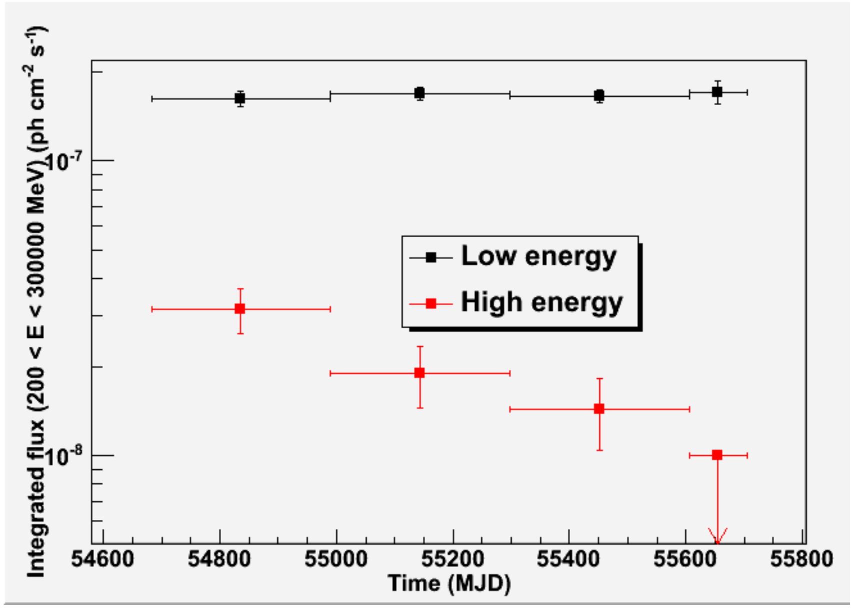
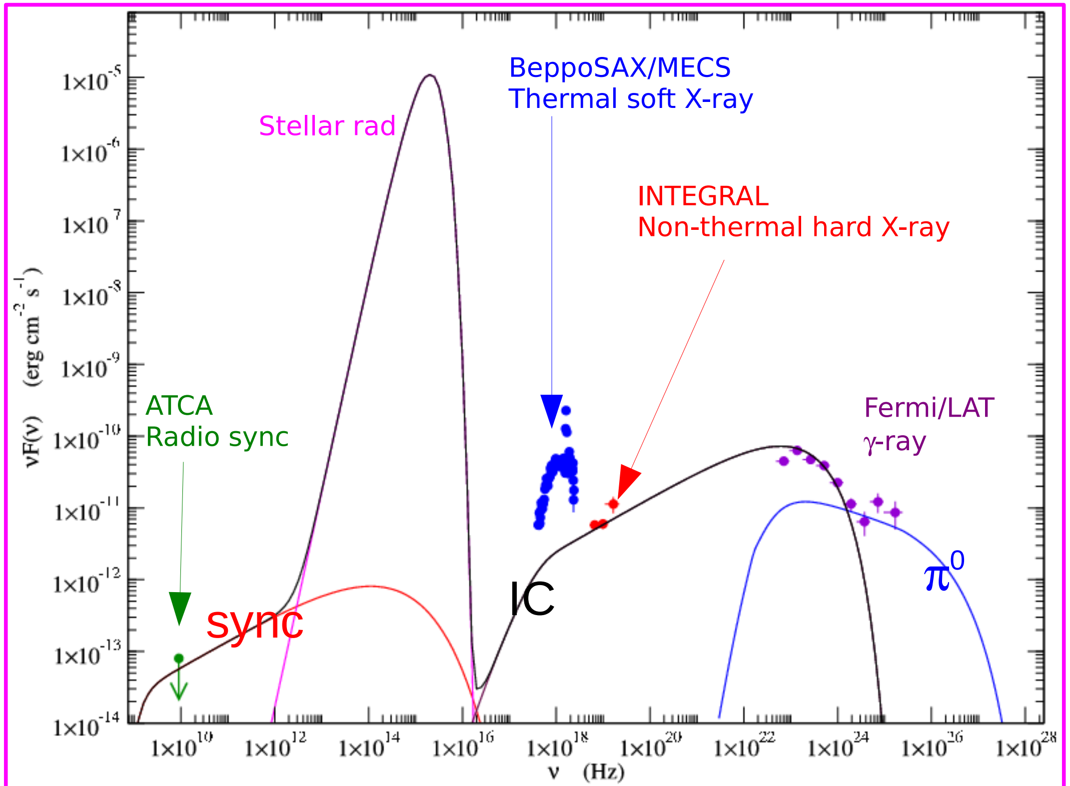




Variability discussion

- The temporal variability strengthens the hypothesis of gamma emission related to eta Carinae system :
  FIRST COLLIDING WINDS BINARY SYSTEM OBSERVED IN GAMMA-RAYS !
- The lack of variability both in hard X-rays and soft gamma-rays may suggest a common origin which differs from the hard gamma-ray one.
- The soft X-ray component is likely due to free-free emission.
  In this case, the luminosity variation observed in the thermal component suggests a rise of the post shock gas density near periastron.
- In case of hadronic origin of the hard gamma-ray tail, protons might be efficiently accelerated in the colliding winds region all along the orbit but only efficiently cooled down at periastron, when the opacity is large enough.

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

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- 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 (?): acceleration of a single population

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

- Single component emission very unlikely due to 2 component spectrum + variability at high energies :
  - Inverse Compton scattering of electrons
  - π^0 decay from pp interactions
- For future periastron passage (summer 2014), H.E.S.S. should be able to detect eta Carinae or put a strong constraint on the maximum proton energy
- X-ray observations of eta Carinae led to the discovery of the binary system, gamma-rays might help to caracterize its geometry.

Thanks for your attention

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