Colliding winds in massive star binaries: expectations from radio to gamma-rays

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Outline

Colliding-wind massive binaries (CWB)

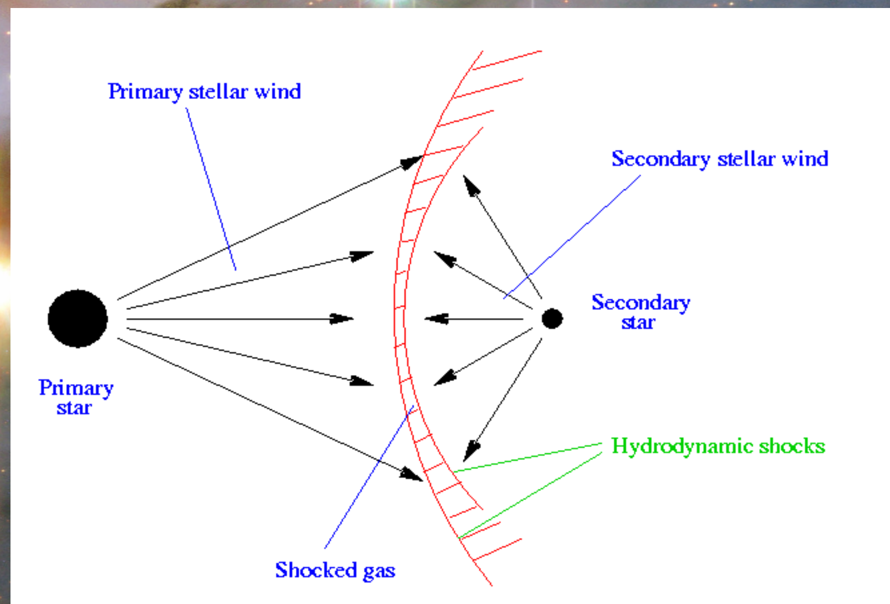
Observations across the electromagnetic spectrum

CWBs as variable GR sources?

Particle accelerating massive stars (PAMS)

Concluding remarks

Colliding-wind massive binaries (CWB)



Mean stellar wind : a few 10^4 K (up to 10^5 K)
Shocked gas in individual stellar winds : a few 10^6 K
Shocked gas in the wind-wind interaction region : up to several 10^7 K

Emission processes

What is expected in the radio domain?

- thermal emission : free-free radiation related to the population of thermal electrons in the stellar winds
- first modelling, for uniform winds: Wright & Barlow (1975), Panagia & Felli (1975)

$$S_\nu \propto \nu^\alpha \text{ with } \alpha = +0.6...+0.7$$

- thermal radio flux: measurement of mass loss rates of massive stars (!! overestimation !!)
- in CWBs, the wind interaction region can contribute to the global thermal radio emission : Pittard & Dougherty (2006)

Emission processes

What is expected in the radio domain?

- non-thermal emission discovered in the case of « some » systems: synchrotron radiation related to the presence of relativistic electrons : White (1981)

$$S_\nu \propto \nu^\alpha \text{ with } \alpha \text{ negative, or close to 0}$$

- generally, synchrotron radio emitters are revealed by (1) quite large radio fluxes, (2) a spectral index significantly lower than the thermal value, and (3) potentially, a variable behavior unexpected for a pure thermal emission process : Dougherty & Williams (2000), Pittard et al. (2006), De Becker (2007), Dougherty (2009)...

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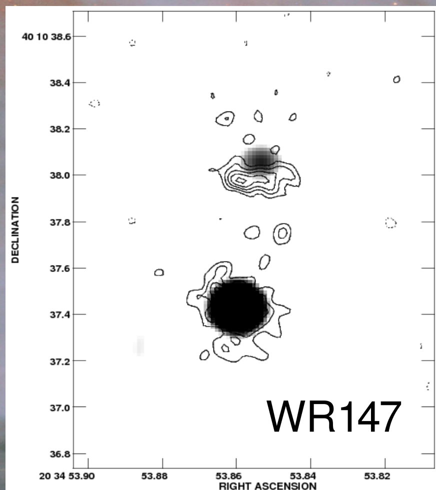
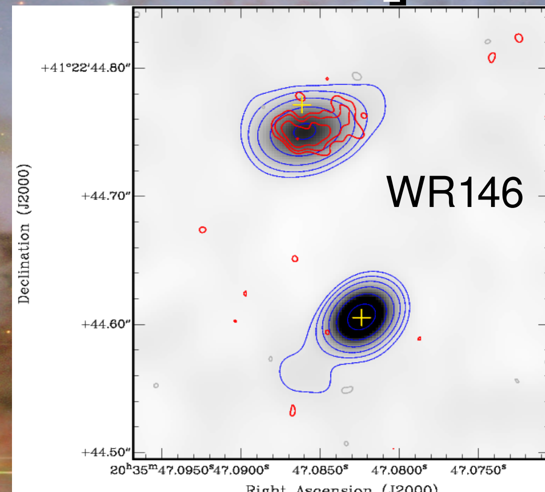
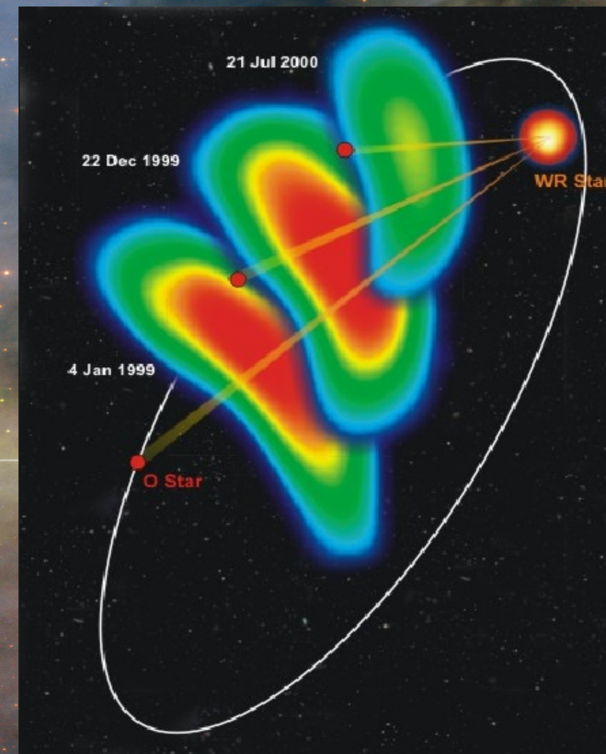
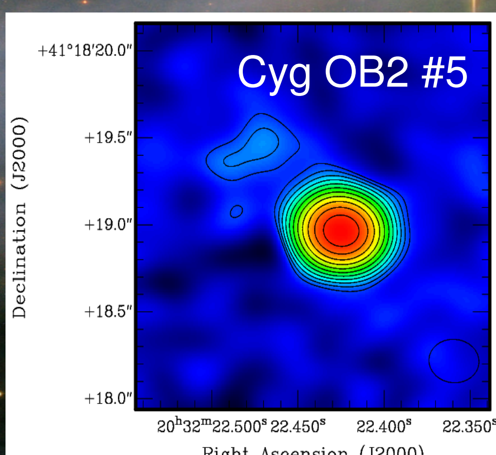
Synchrotron radio emitters are confirmed, or at least suspected, colliding-wind binaries, and relativistic electrons are most probably accelerated in the wind interaction region.

Emission processes

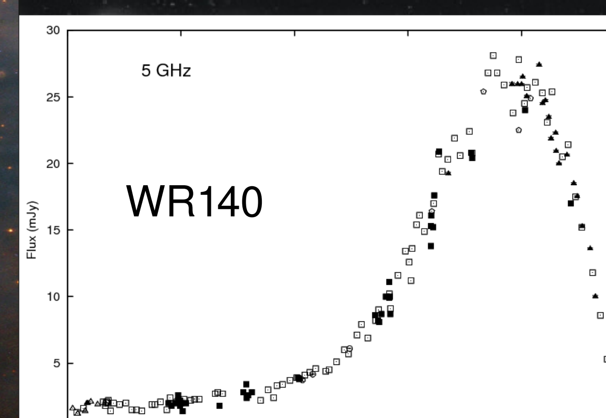








In some cases, high angular resolution observations allowed to disentangle thermal and non-thermal emission components, associating the synchrotron emitting region to the wind-wind interaction region



Very interesting reviews: Dougherty 2009, arXiv:0908.2660 and Benaglia 2009, arXiv:0904.0533

Emission processes

What is expected in the visible domain?

- globally, visible spectra are populated by only a few lines (w.r.t. low mass stars)
- lines are broad, many are at least produced in the stellar winds; in extreme cases, the photosphere is not accessible (Wolf-Rayet stars with very dense stellar winds)
- studies in the visible are crucial to derive fundamental parameters, and to investigate the multiplicity of massive stars...

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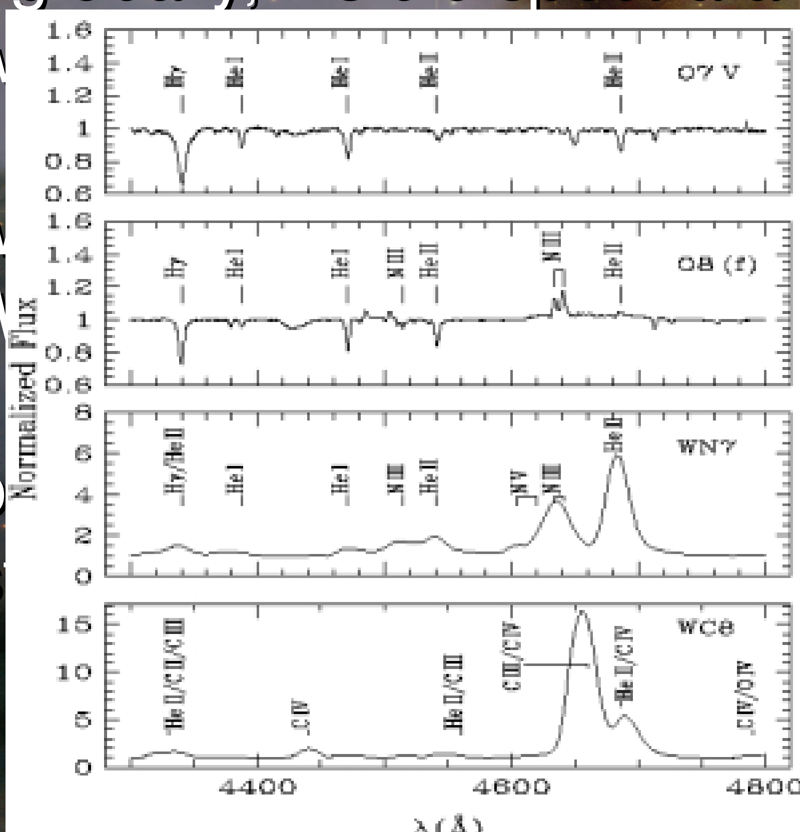
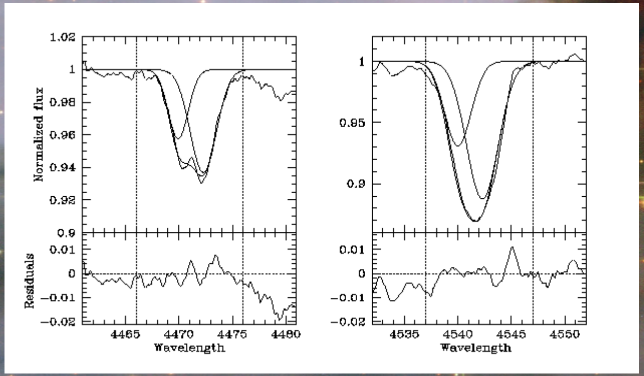
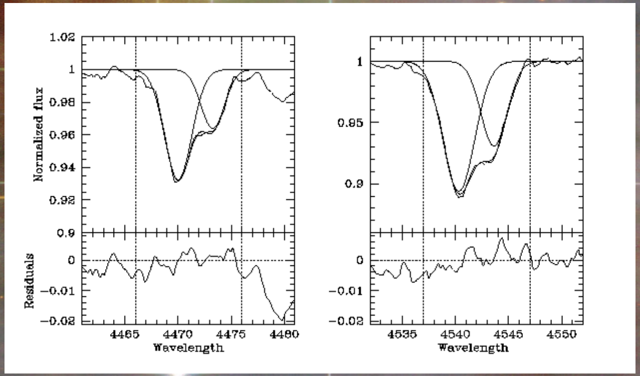


Emission processes

What is expected in the visible domain?

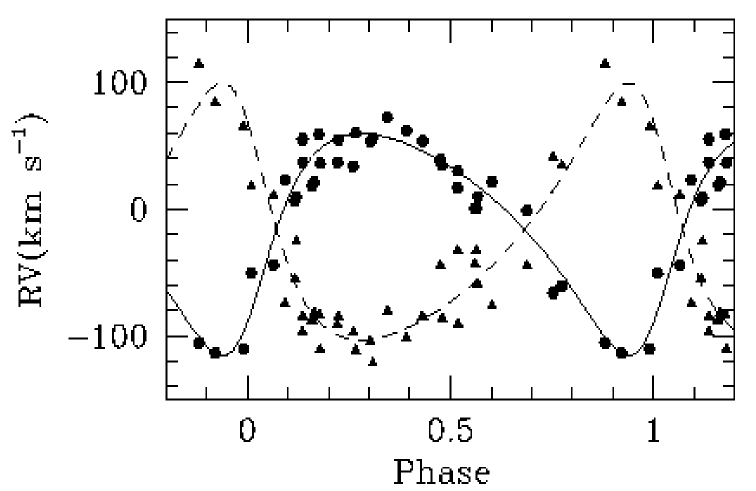




Cyg OB2 #8A:
O6If + O5.5III(f)
P = 21.908 +/- 0.040 d
E = 0.24 +/- 0.04
(De Becker et al. 2004)

- inspection of individual lines : line profile variations
- disentangling of spectral lines from two stars
- radial velocity measurements : determination of the orbital elements

The orbital elements are crucial in order to study physical processes related to the interaction between the stellar winds

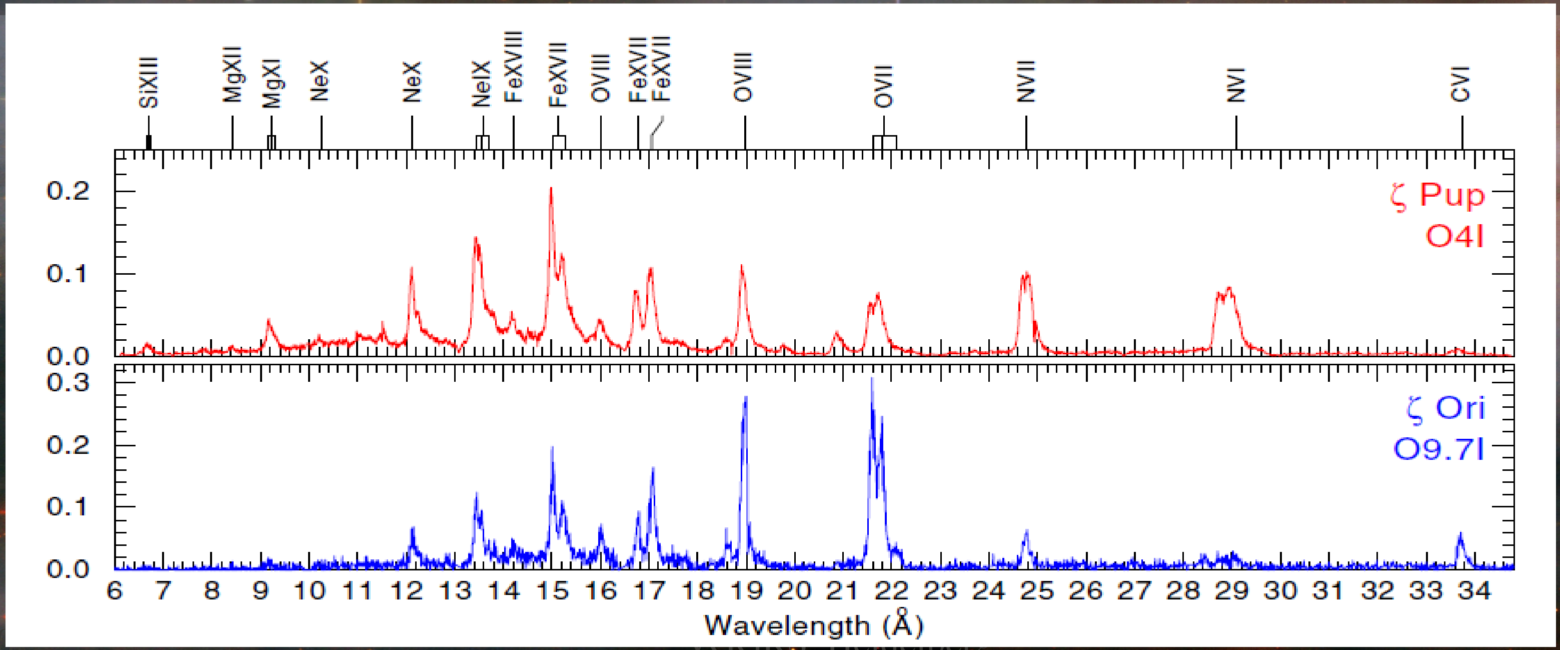


Emission processes

What is expected in X-rays?

- stellar winds are confirmed thermal X-ray emitters : emission line spectrum over a thermal bremsstrahlung continuum
- X-rays in individual stellar winds are produced by the plasma heated by hydrodynamic shocks due to the line driving instability (e.g. Feldmeier et al. 1997)

(Rauw et al. 2008)



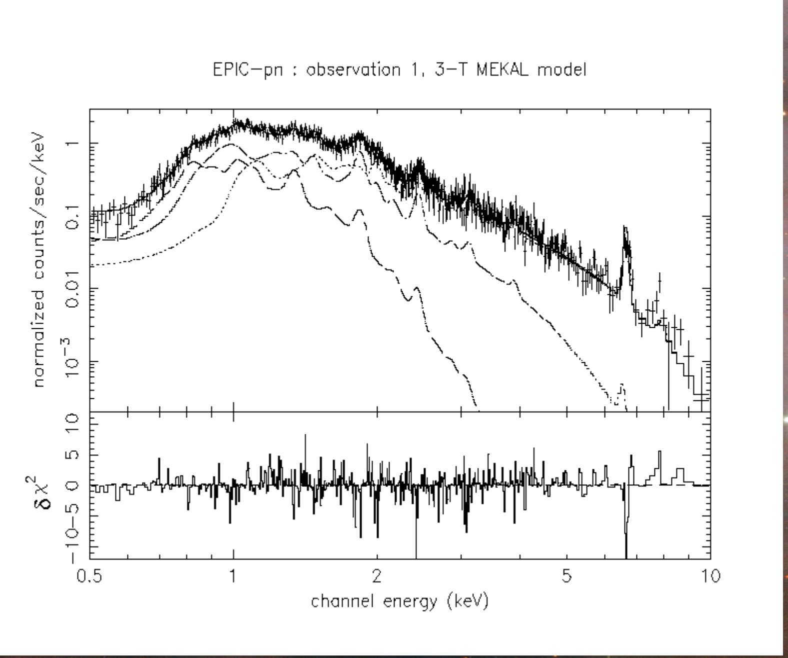
Emission processes

What is expected in X-rays?

- the shocked plasma in the wind-wind interaction region constitutes an additional source of X-rays in CWBs; the wind interaction region can even dominate the X-ray emission in massive binaries (e.g. Stevens et al. 1992, Pittard & Stevens 1997, Pittard & Parkin 2010...)

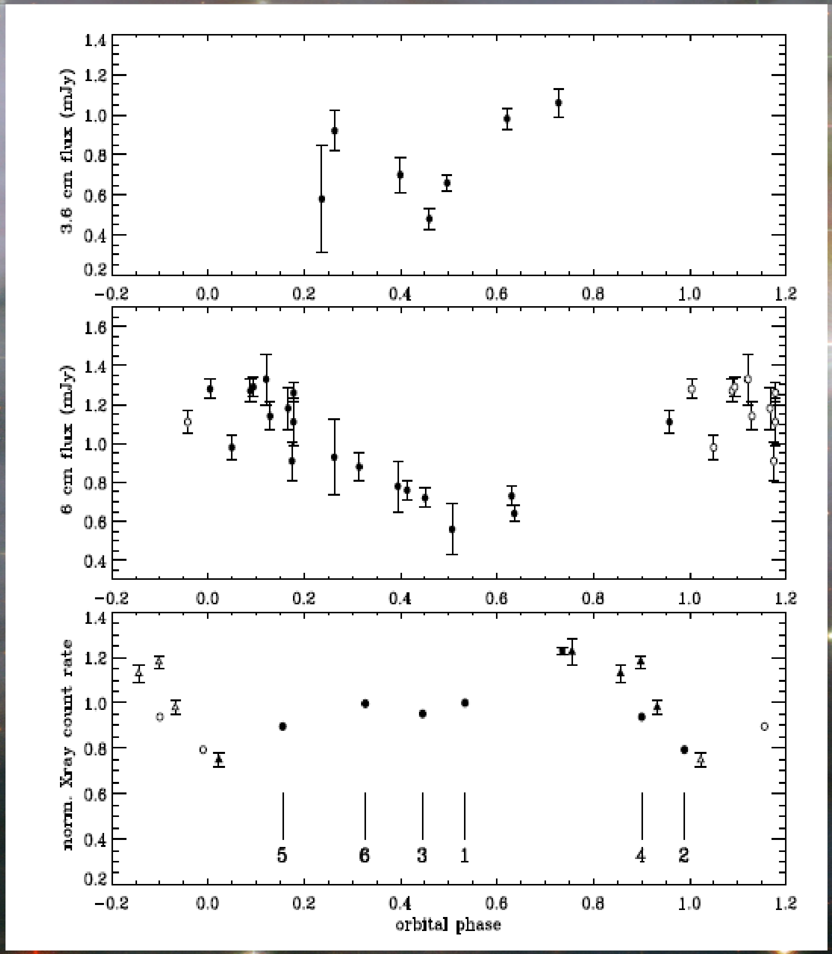
- in CWBs, the thermal spectrum is generally significantly harder than in the case of single massive stars; the emission process is the same, but the post-shock temperature is higher

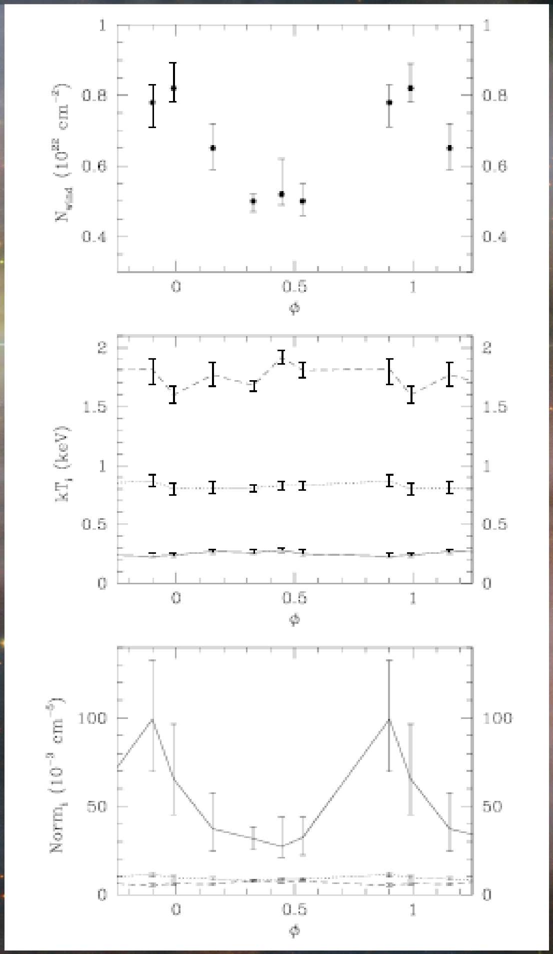
For instance, see the case of Cyg OB2#8A as seen by XMM-Newton ---->
(De Becker, Pittard, Blomme et al. 2006)



Emission processes

Radio and X-ray view of Cyg OB2 #8a as a function of the orbital phase...





(Blomme, De Becker, Volpi & Rauw, 2010, A&A, 519, A111)

Emission processes

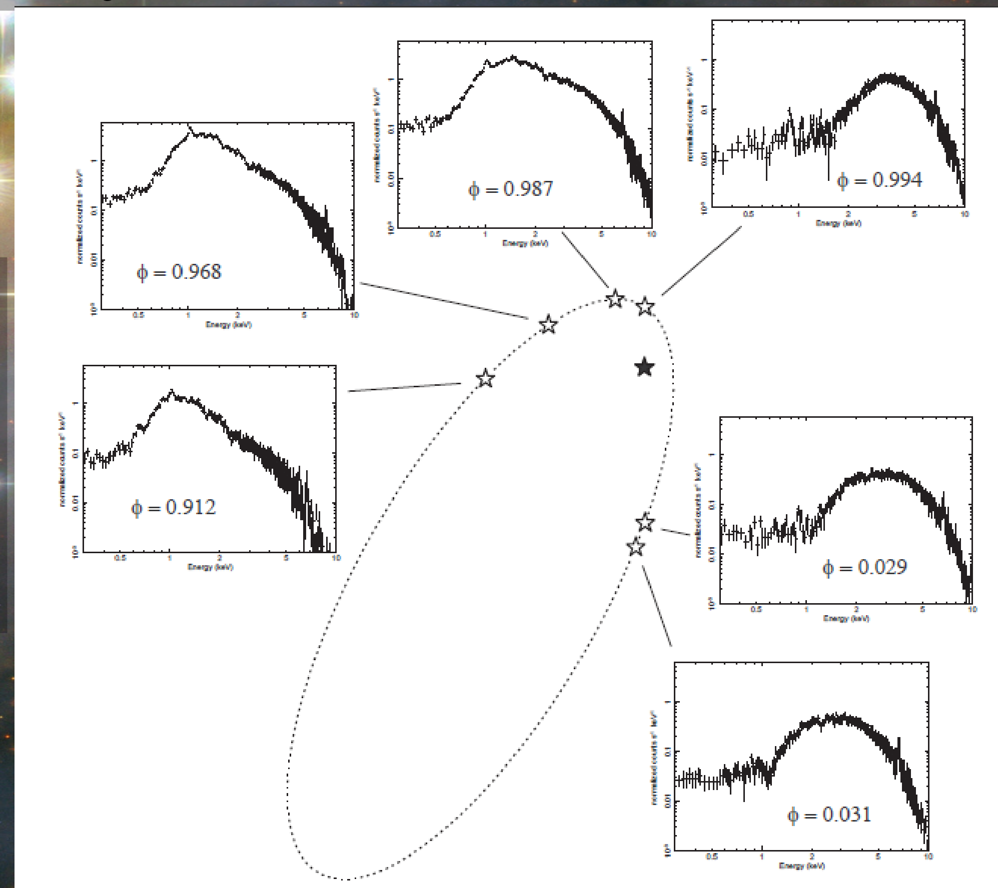
X-rays: phase-locked variability

WR140: WR + O:
P ~ 7.9 yr; e ~ 0.88

X-ray spectrum dominated by the colliding winds

Strong phase-locked variations
- absorption by the WR wind
- variation of the emission measure

The physical conditions in the wind-wind interaction region vary substantially along the orbit



(De Becker, Pittard & Williams 2011, Bull. Soc. Roy. Sc. Liège, in press)

Emission processes

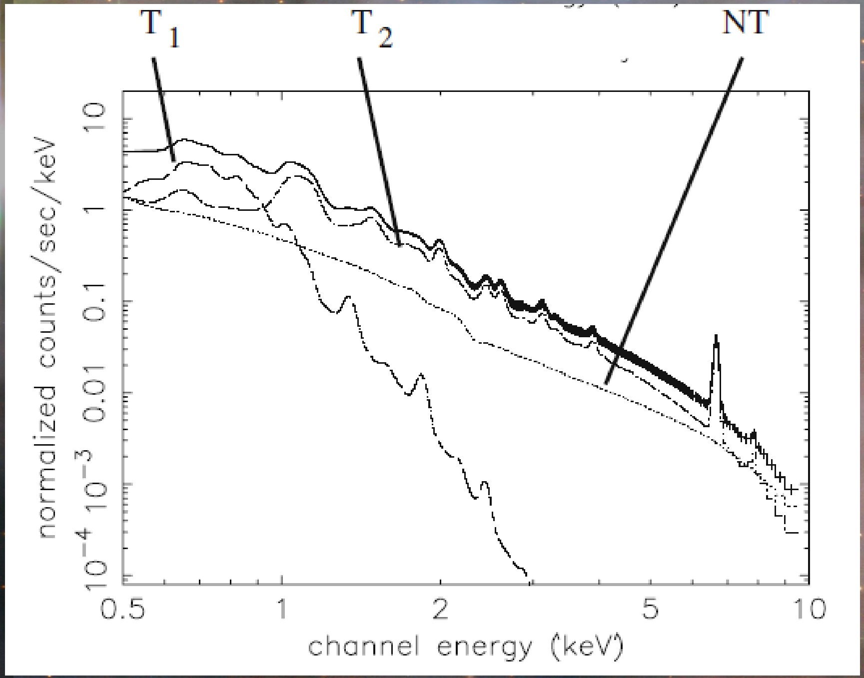
X-rays: what about non-thermal X-rays?

In some systems, a population of relativistic electrons is present, and a large amount of UV and visible photons is available,

Inverse Compton scattering could be efficient at producing non-thermal X-rays, in addition to the thermal emission component related to the hot plasma

Such a non-thermal emission component is expected to be a power law, with a photon index equal to ~ 1.5

but...



(De Becker 2007, A&ARev, 14, 171)

Emission processes

X-rays: what about non-thermal X-rays?

In some systems, a population of relativistic electrons is present, and a large amount of UV a

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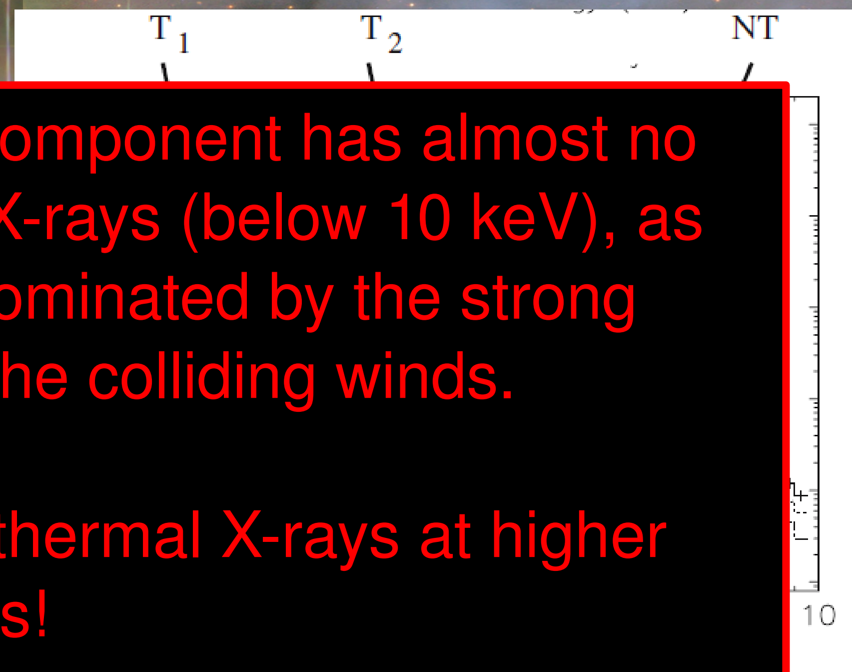
A non-thermal (IC) emission component has almost no chance to be detected in soft X-rays (below 10 keV), as the soft X-ray spectrum is dominated by the strong thermal emission from the colliding winds.

One needs to check for non-thermal X-rays at higher energies!

but...

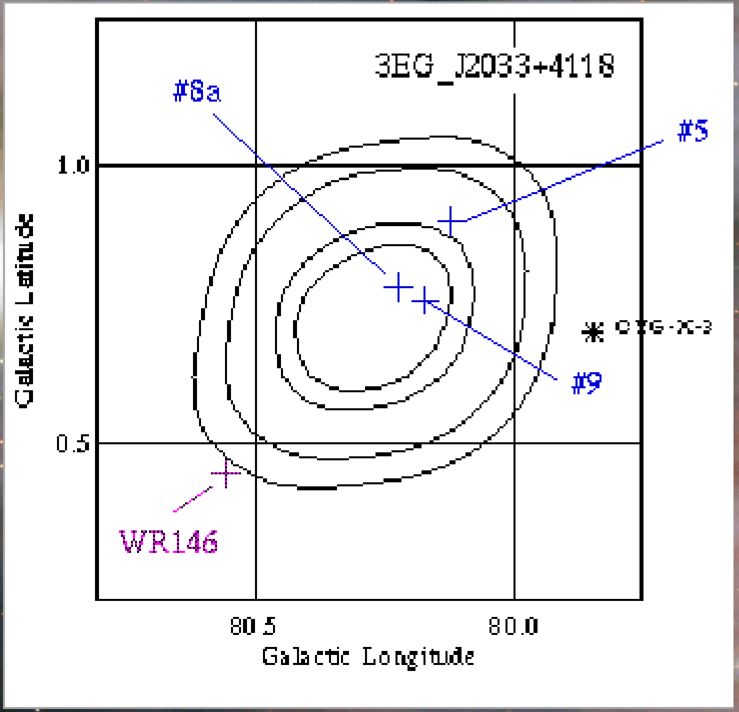


(De Becker 2007, A&ARev, 14, 171)

Emission processes

X-rays: above 10 keV!

- Search for hard X-ray emitters in the **Cygnus** region with INTEGRAL



Emission processes

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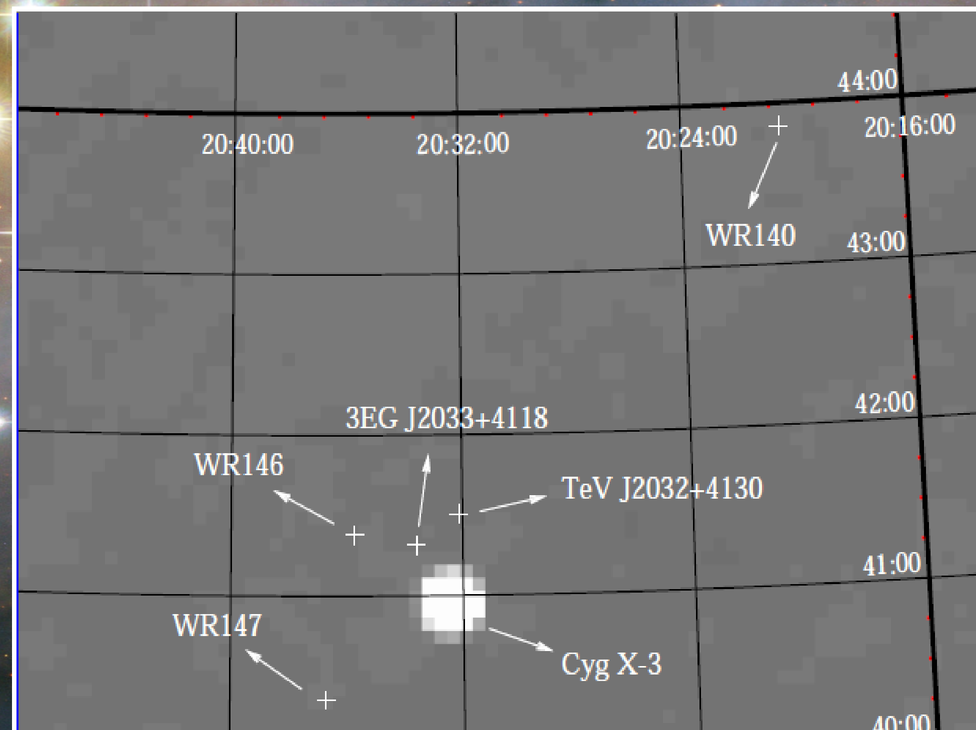


--> non detection!
... lack of sensitivity,
--> the upper limits provided constraints on the modelling

(De Becker et al. 2007, A&A, 472, 905)

Emission processes

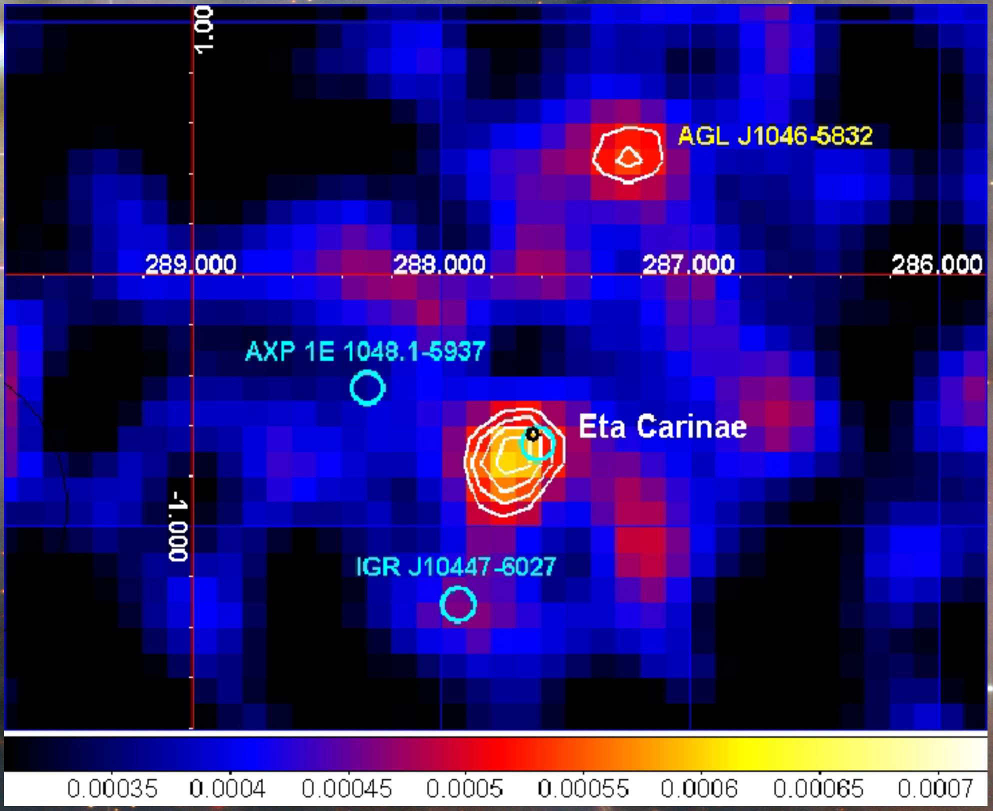
X-rays: above 10 keV ! ---> !! Eta Car !!

- Search for hard X-ray emitters in the **Carina** region with INTEGRAL

--> first detection of hard X-rays associatied with a CWB: **Eta Car** (Leyder et al. 2008, A&A, 477, L29)

- Search for gamma-ray emission in the **Carina** riogion with AGILE and FERMI

--> first detection of gamma-rays associatied with a CWB: **Eta Car** (Tavani et al. 2009, ApJ, 698, L142 ; Abdo et al. 2009, ApJS, 183, 46, Abdo et al. 2010, Fermi LAT First Source Catalogue)



AGILE gamma-ray intensity map in Galactic coordinates of the Car region above 100 MeV (Tavani et al. 2009)

Emission processes

X-rays: above 10 keV! ---> !! WR140 !!

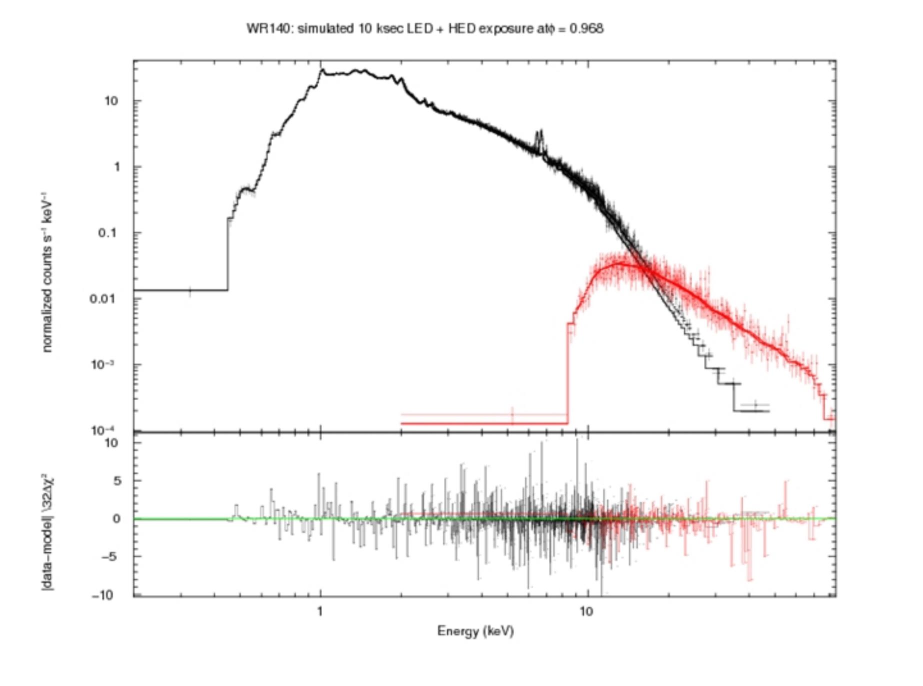
- Observations of the emblematic CWB WR140 with the SUZAKU satellite

--> first detection of hard X-rays from WR140 (Sugawara et al. 2010, 2011)

- Identification of a power law component in the X-ray spectrum, likely attributable to IC scattering

- The non-thermal emission component is variable in flux, as a function of the orbital phase

--> a better sensitivity in the hard X-rays is needed : next generation hard X-ray observatories!



Simulated COSPIX (proposed ESA M-class mission project) spectrum obtained using the thermal X-ray parameters from XMM observations, and the power-law parameters from SUZAKU observations.

CWBs as GR sources?

In the context of the issue of the gamma-ray emission, a sub-category of colliding-wind binaries should be considered: particle accelerating massive stars (PAMS)

Non-thermal radio emitters constitute obviously a sub-category of PAMS, and the investigation should focus on physical processes (particle acceleration) and not on an biased observational fact (detection of synchrotron radiation in the radio domain from 'some' CWBs).

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What are the processes likely to be involved?

CWBs as GR sources?

The highest Lorentz factor reached by relativistic electrons in CWBs: ~ 10^4 – 10^5

(competition between DSA and IC cooling)

Maximum energies for electrons: a few GeV

--> leptonic processes (IC) may contribute to gamma-ray emission processes

What about protons?

Higher energies?

--> hadronic processes such as neutral pion decay should be considered as well!

(Pittard & Dougherty 2006; Reimer, Pohl & Reimer 2006)

Particle accelerating massive stars (PAMS)

Catalogues: O-type and WR-type

Non-thermal radio emitters: lists of PAMS already exist, see e.g. De Becker (2007), with some additional good candidates identified by Benaglia (2010)

- O-type: about 20 targets
- WR-type: about 15 targets

Non-thermal X-ray emitter(s):

- so far... 2 (WR140 and Eta Car (?))

Concluding remarks

CWBs display interesting properties studied across the electromagnetic spectrum using various techniques...

Among CWB, PAMS deserve a particular attention in the context of the study of Galactic Variable Gamma-Ray Sources...

Among PAMS, a few have been intensively studied, and consitute valuable targets for present and future modelling of particle acceleration processes in CWBs

High energy facilities (present and future), with the required angular resolution and sensitivity, should be used in order to investigate CWBs in gamma-rays, in order to complete the multiwavelength investigation of these objects...