

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' colliding-wind binaries
(PACWB)

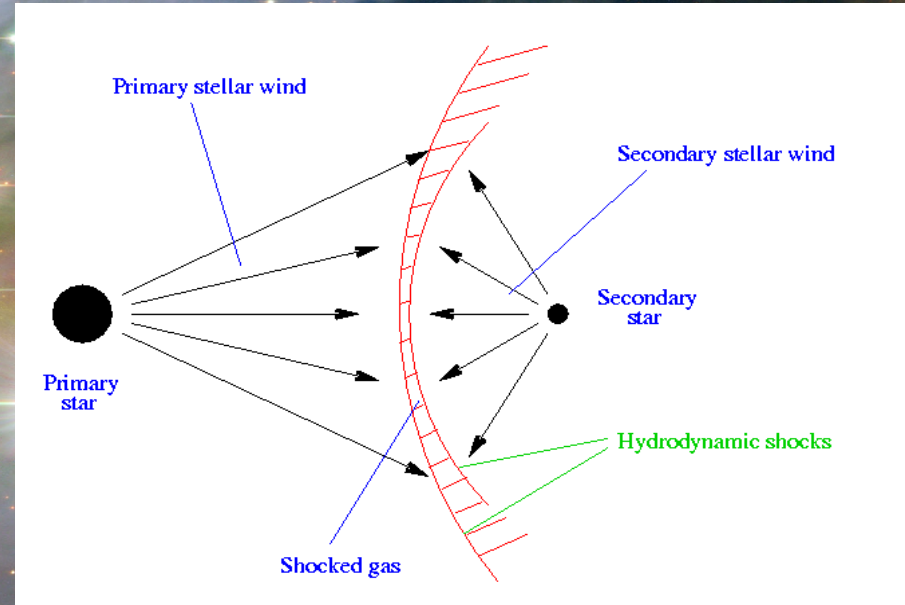
Concluding remarks

Colliding-wind massive binaries (CWB)

Binary system made of two stars belonging to the category of OB- or WR-type stars

No compact companion!

Main feature of such a system : a wind-wind interaction region likely to act as an astrophysical laboratory operating in particular physical conditions



Physics of stellar winds, see Stan Owocki's talk

Physics of colliding wind binaries, see Julian Pittard's talk

Mean stellar wind : up to several 10^4 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)**

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

- 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)...

Emission processes

What is expected in the radio domain?

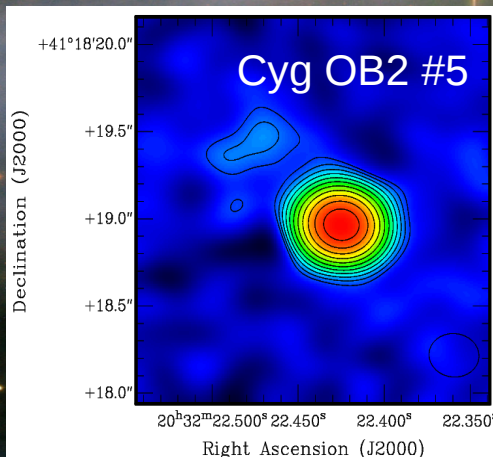
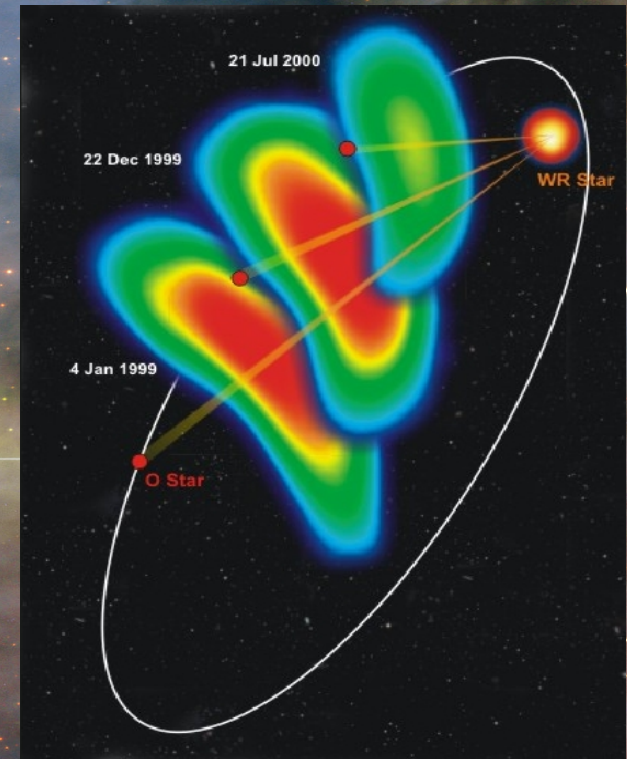
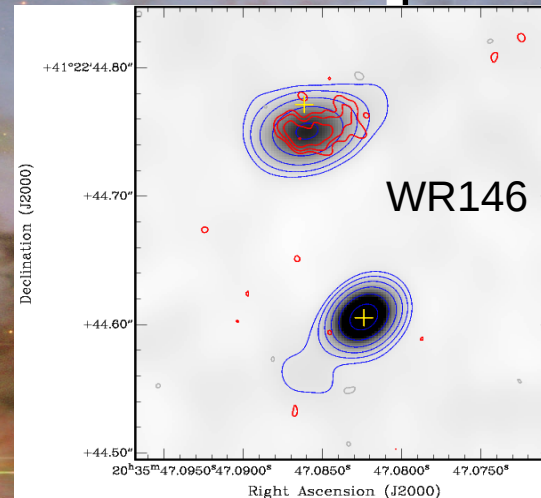
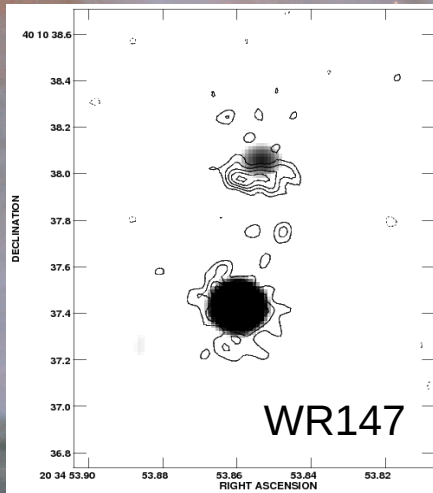
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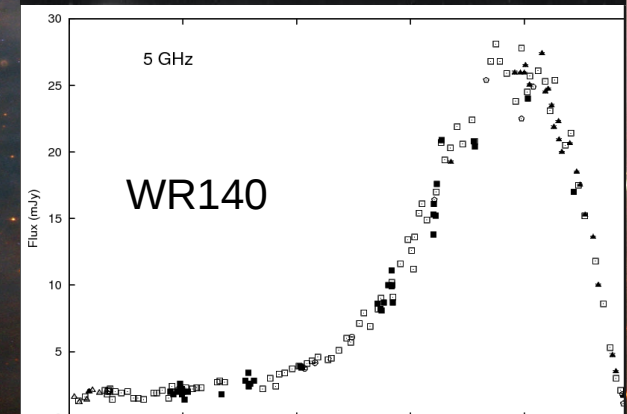
Synchrotron radio emitters are confirmed, or at least suspected, colliding-wind binaries, and relativistic electrons are most probably accelerated in the wind interaction region.

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



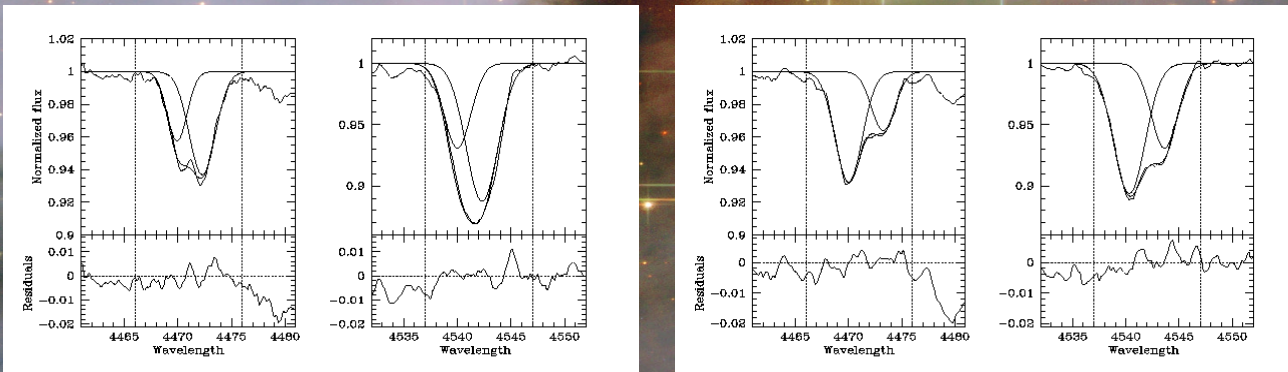
Emission processes

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 partly produced in the stellar winds; in extreme cases, the 'stellar surface' 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...

Emission processes

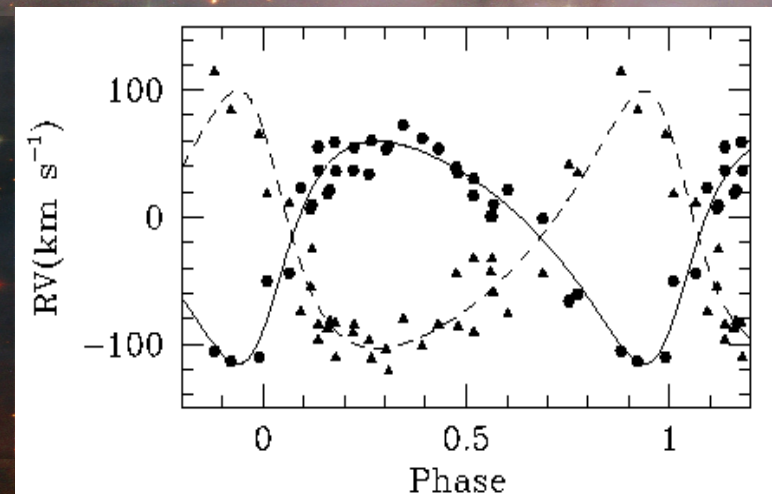
What is expected in the visible domain?



Cyg OB2 #8A:
O6If + O5.5III(f)
 $P = 21.908 \pm 0.040$ d
 $E = 0.24 \pm 0.04$
(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

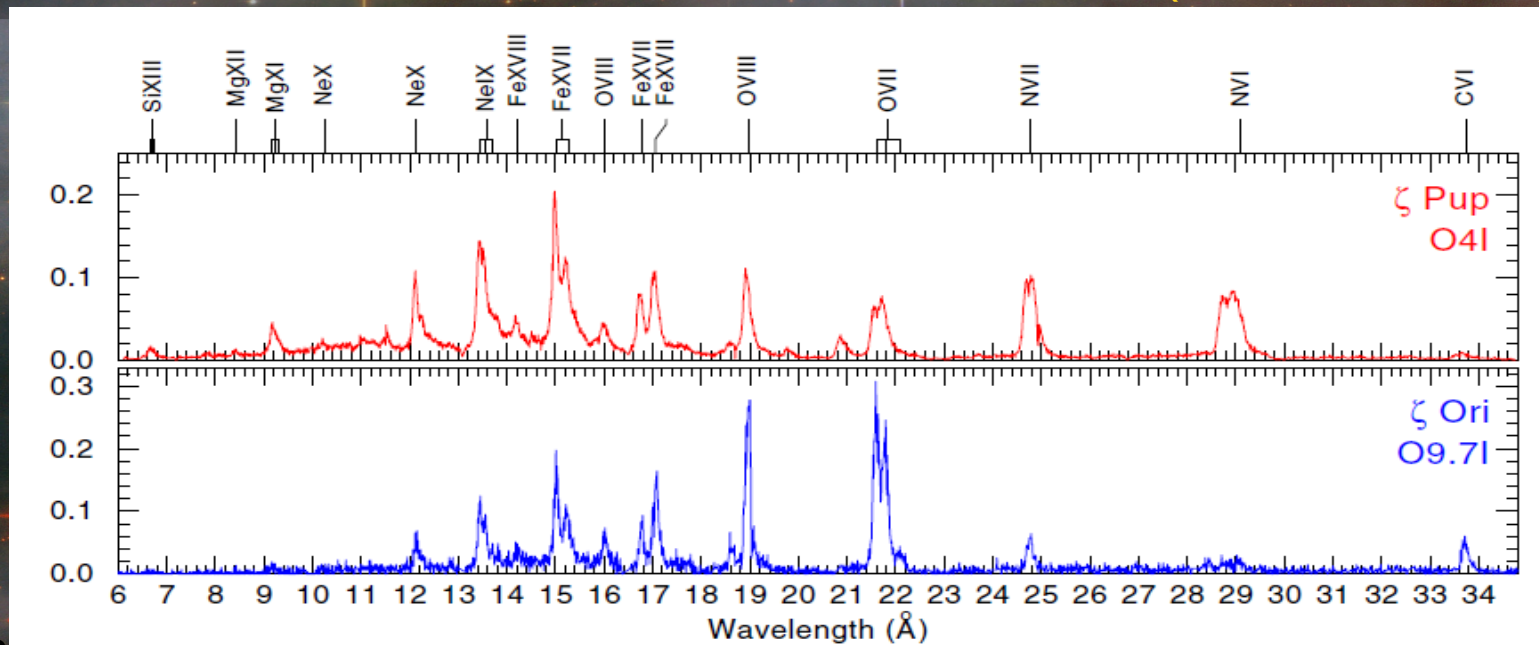


Emission processes

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)

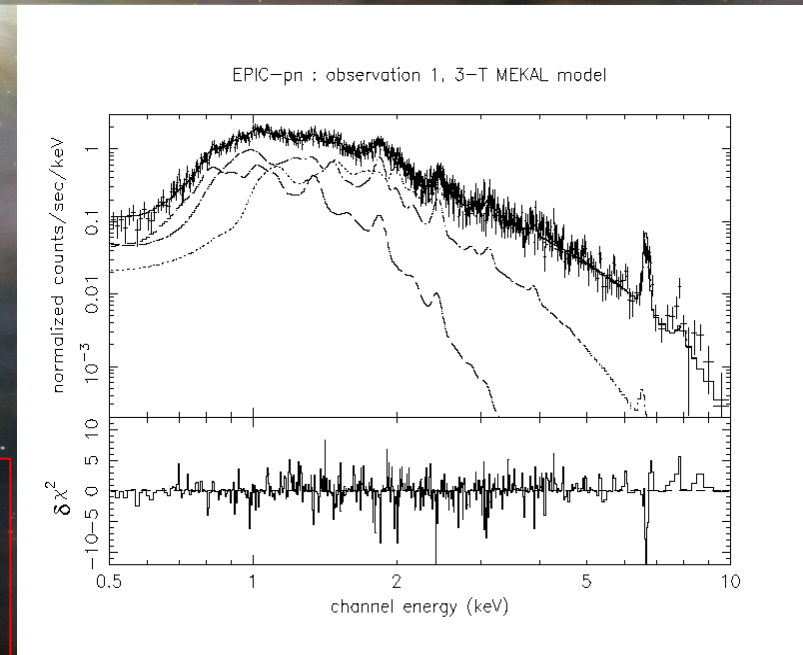


Emission processes

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

X-rays: phase-locked variability

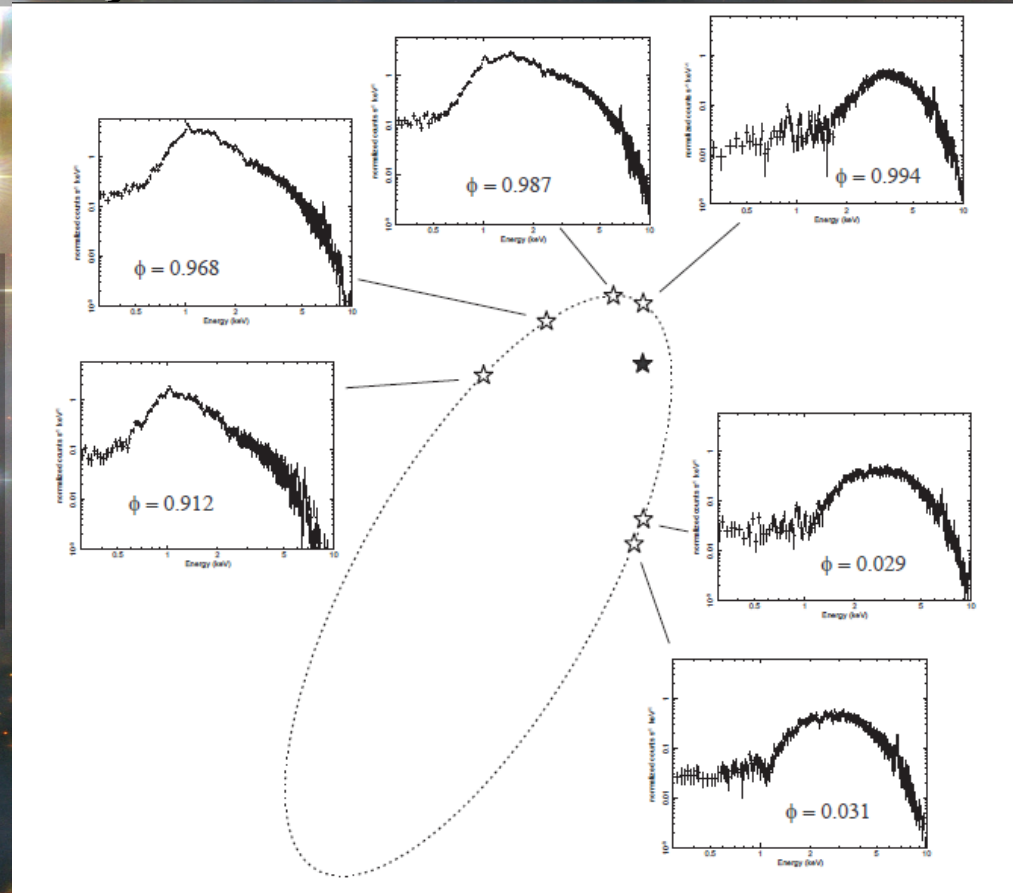
WR140: WR + O:
P \sim 7.9 yr; e \sim 0.88

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

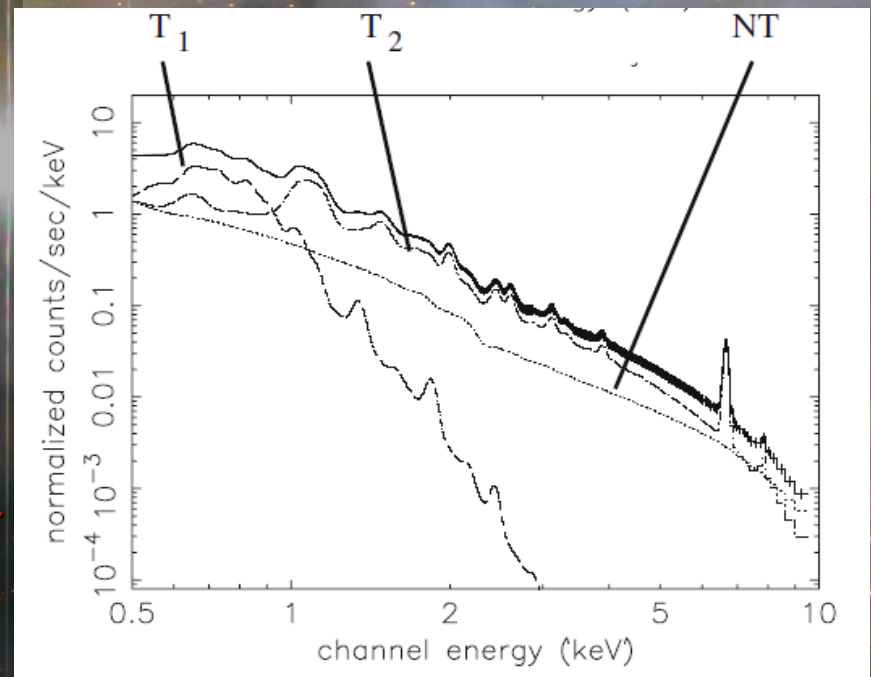
X-rays: what about **non-thermal X-rays**?

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 in X-rays is expected to be a power law

but...



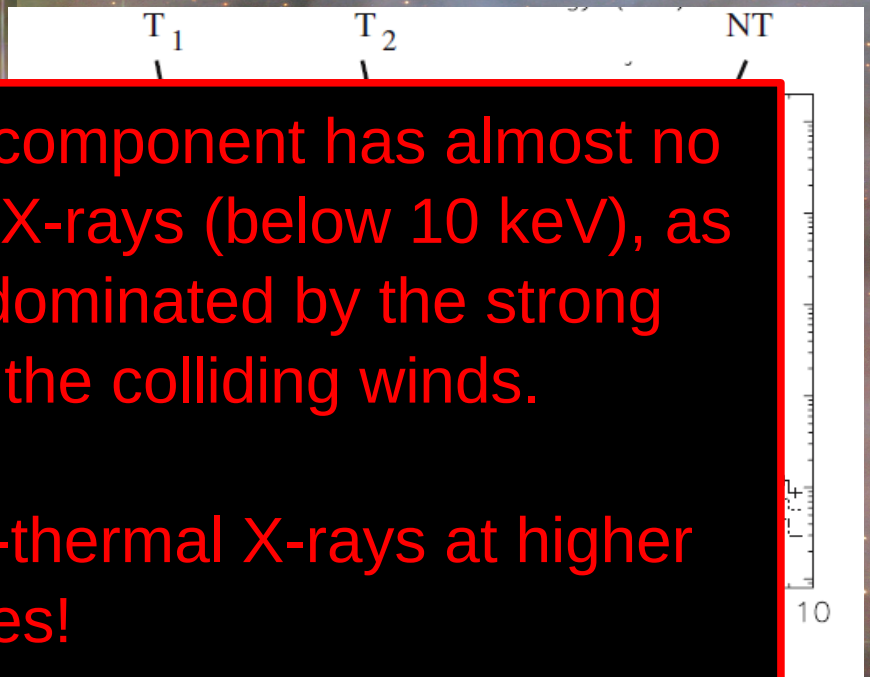
Emission processes

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 X-ray emission is produced.

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.

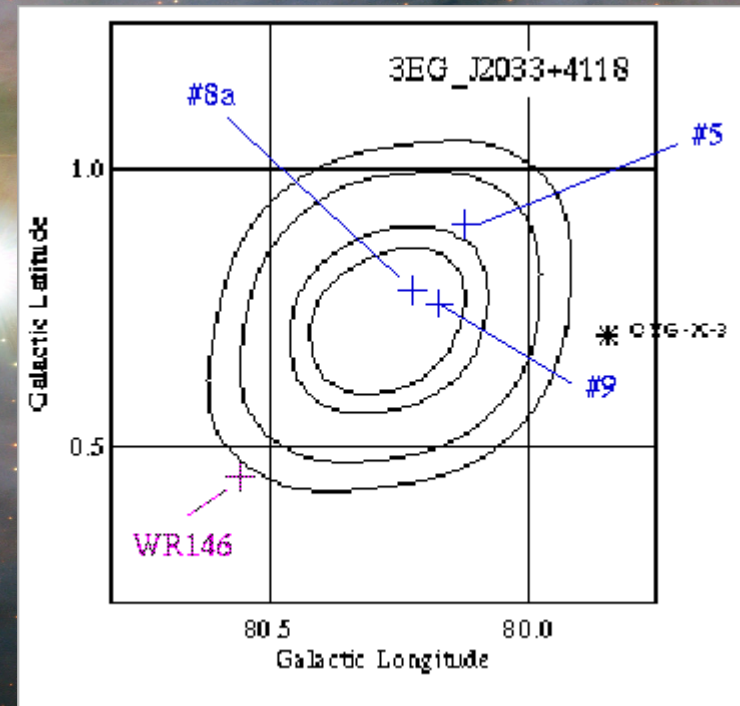
One needs to check for non-thermal X-rays at higher energies!



Emission processes

X-rays: **above 10 keV!**

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

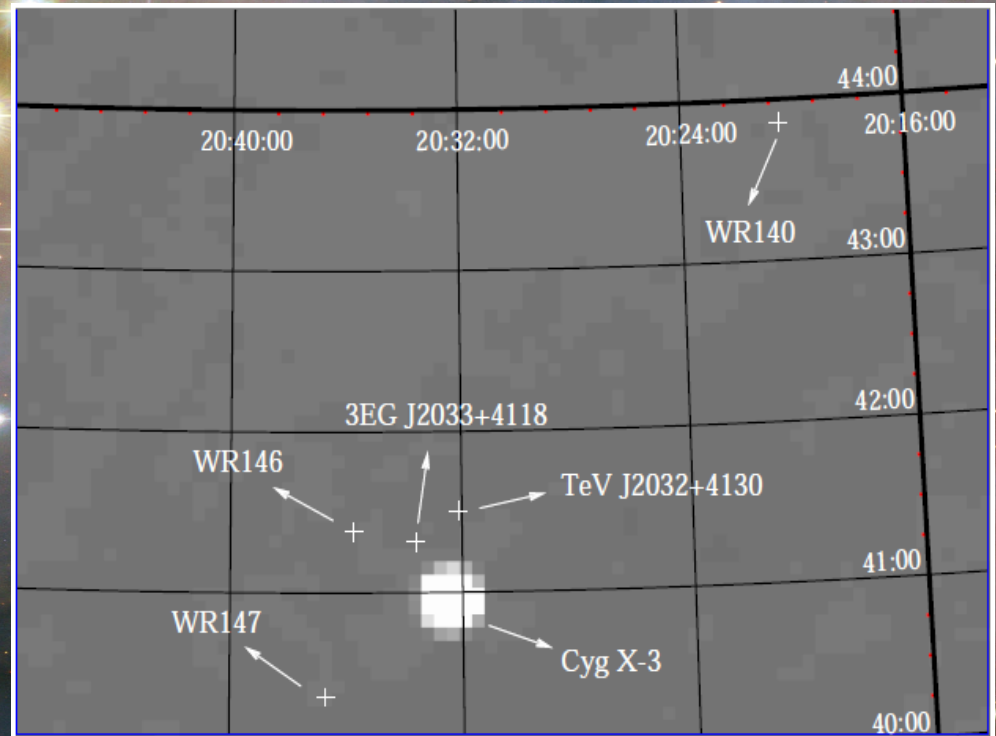


Emission processes

X-rays: **above 10 keV!**

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

--> non detection!
... lack of sensitivity,
--> only upper limits were derived
--> **If these stars are hard X-ray non-thermal emitters, they should not be very bright sources**



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

Emission processes

Hard X-rays and Gamma-rays ---> !! Eta Car !!

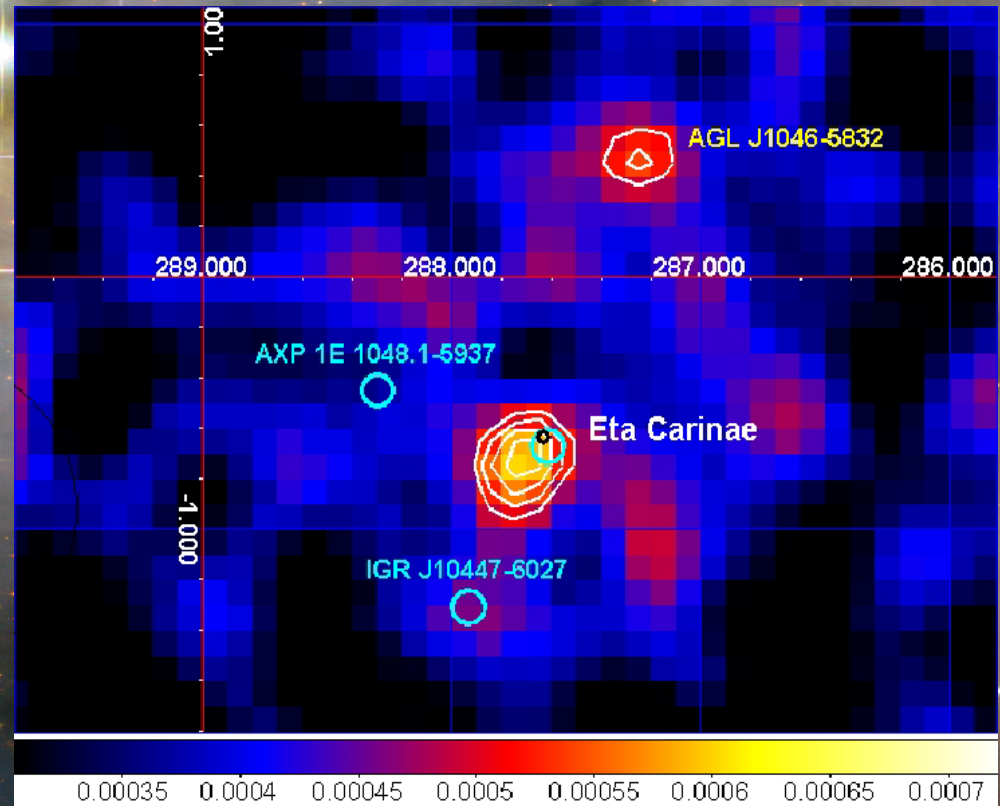
- Search for hard X-ray emitters in the Carina region with INTEGRAL

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

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

--> first detection of gamma-rays associated with a CWB: Eta Car
(Tavani et al. 2009, ApJ, 698, L142 ;
Abdo et al. 2009, ApJS, 183, 46)

Gamma-ray emission from Eta Car,
see Christian Farnier's talk



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

Emission processes

Hard X-rays ---> **!! WR140 !!**

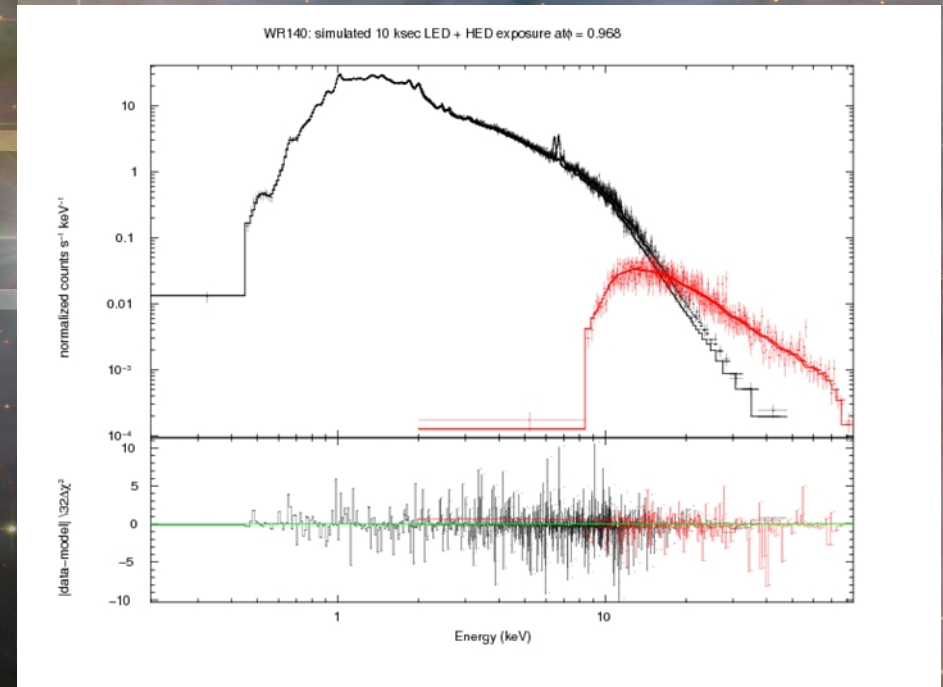
- Observations of the emblematic CWB WR140 with the SUZAKU satellite

--> 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?

Not a new idea : Eichler & Usov (1993), Benaglia, Romero, Stevens & Torres (2001), Benaglia & Romero (2003)

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

Non-thermal radio emitters belong obviously to the category of PACWB, but the investigation should focus on physical processes (particle acceleration, NT emission) and not on a biased observational fact (detection of synchrotron radiation in the radio domain from 'some' CWBs).

CWBs as GR sources?

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What are the processes likely to be involved?

CWBs as GR sources?

Electrons

- plenty of UV photons
--> **IC scattering** is likely to be efficient
- the hard X-rays detected from Eta Car and WR140 should be produced through this process

What is the maximum energy reached by electrons in PACWBs ? ~ **GeV**

(e.g. Pittard & Dougherty 2006 ; Reimer, Pohl & Reimer 2006)

Protons

- Could **hadronic processes** also be at work in such environments?
- protons should also be accelerated in PACWBs
- the Gamma-ray emission detected in the case of Eta Car could be due to such a process

The nature of the gamma-ray emission from Eta Car, see Christian Farnier's talk

Models for particle acceleration in CWBs, see Julian Pittard's talk

Particle accelerating colliding-wind binaries

'Catalogue': criteria to consider...

Non-thermal radio emitters: lists 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 emitters:

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

Gamma-ray emitter(s):

- so far... 1 (Eta Car)

Concluding remarks

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

Among CWBs, **PACWBs deserve a particular attention** in the context of the study of Galactic Variable Gamma-Ray Sources...

PACWBs constitute valuable astrophysics laboratory to investigate particle acceleration processes and non-thermal emission processes

Among PACWBs, a few have been intensively studied, and constitute valuable targets for present and future **modelling of particle acceleration processes in CWBs** using information gathered in various wavelength domains

Concluding remarks

The binary nature, typically with eccentric orbits, of PACWBs is an obvious source of **variability**

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

Open questions :

What is the fraction of PACWBs among CWBs?

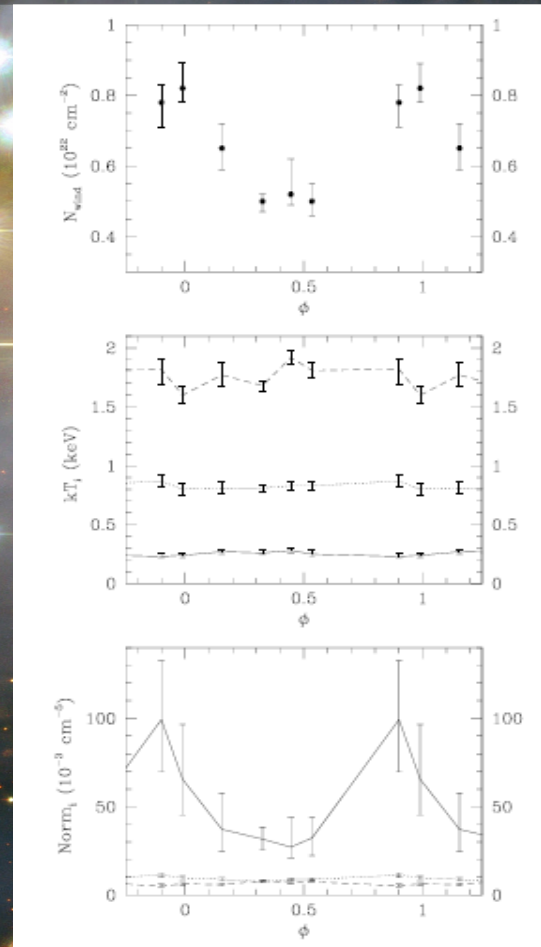
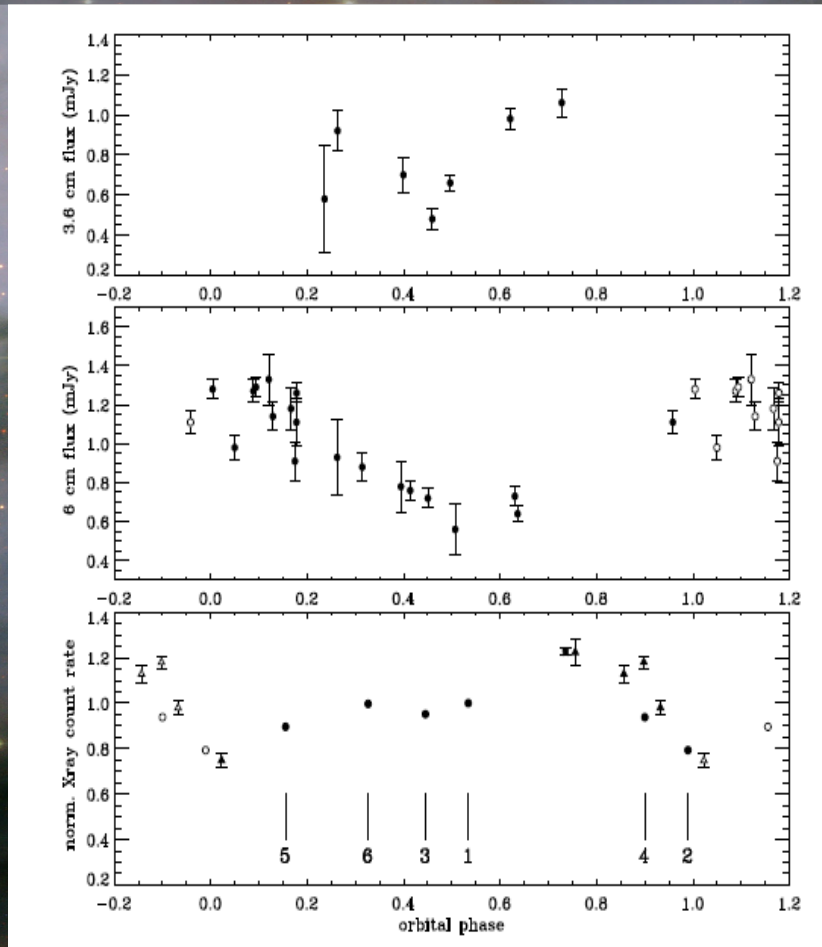
What are the exact properties of relativistic particles in CWBs?

How are these properties variable as a function of orbital phase?

Could PACWBs be considered as significant sources of cosmic rays?...

Emission processes

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



Variability is an important point when dealing with CWBs : if the orbit is eccentric, significant changes are expected to occur in the wind-wind interaction region

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