The multi-messenger approach to particle acceleration by massive stars : a science case for optical, radio and X-ray observatories

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Outline

A few facts…

The 'catalogue' of particle-accelerating colliding-wind binaries

The parameter space covered by these objects

The role of multiwavelength (MW) observations

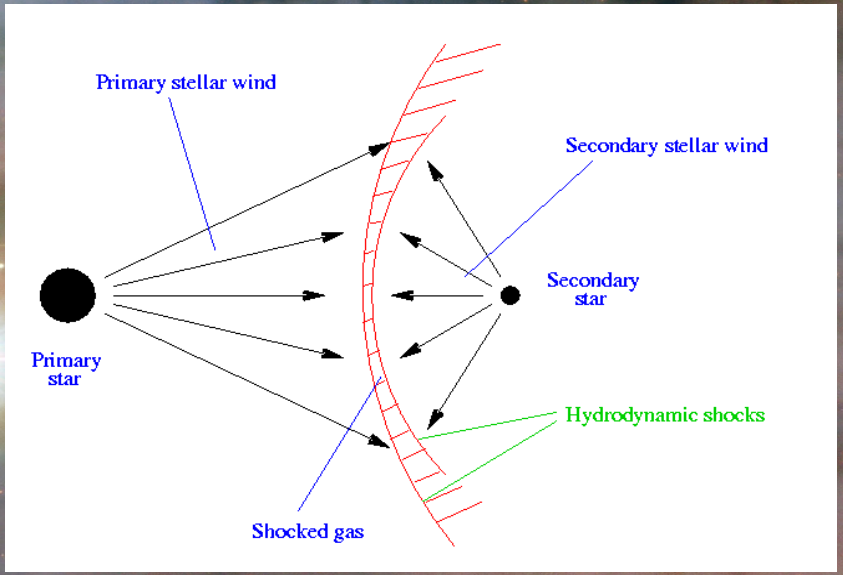
Concluding remarks

A few facts...

- At least a few tens of colliding-wind binaries are able to accelerate particles up to relativistic energies

- Most of them are identified through synchrotron radiation in the radio domain

- As we are dealing with (eccentric) binary systems, a significant variability is expected (time-scale = orbital period)



- The presence of high energy particles calls upon dedicated studies in the high energy domain

- These systems are potential contributors to the population of Galactic Cosmic-Rays

The catalogue

So far, about 40 systems identified to be particle accelerators among CWBs
- O-type stars
- Wolf-Rayet stars
- a few 'transitional' objects

Now unified in only one list!

(De Becker & Raucq 2013, A&A, 558, A28)

http://www.astro.ulg.ac.be/~debecker/pacwb/

Previous censuses used to separate systems of different evolution stages, e.g. Dougherty & Williams 2000, De Becker 2007, Benaglia 2010...

→ strong need to unify these objects into a unique class, occupying a rather wide parameter space.

The catalogue

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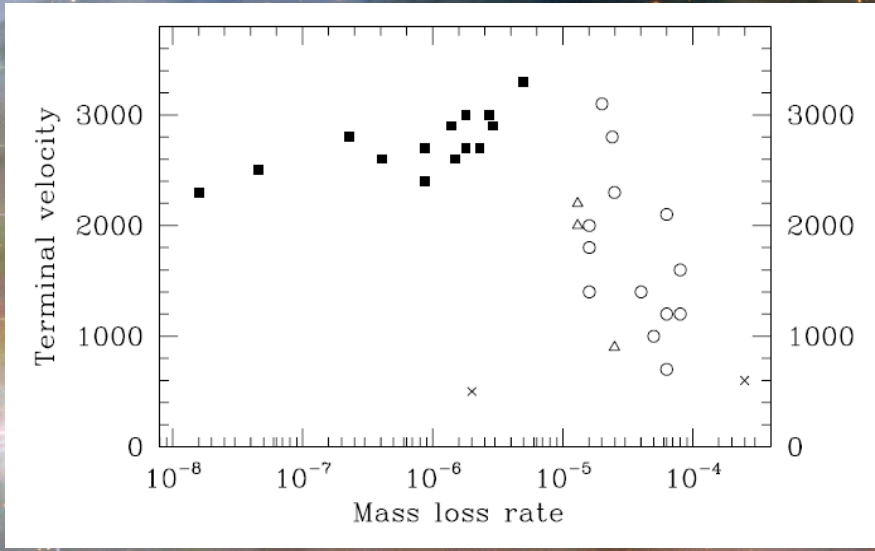
#	Usual ID	Status	Sp. type(s)	P
1	HD 15558	B (T?)	O5.5III(f) + O7V	442 d
2	δOri A	T	(O9.5II + B0.5III) + B?	5.733 d/>100 yr
3	σOri AB	M	O9.5V + B0.5V (+ OBs?)	?
4	15 Mon	B	O7V(f) + O9.5Vn	25.3 yr
5	WR 8	B	WN7 + WC(?)	38 d, 115 d
6	WR 11	B	WC8 + O7.5	78.53 d
7	WR 14	B?	WC7	?
8	CD–47 4551	U	O5If	–
9	WR 21a	B	O3f*/WN6ha + O4	32.673 d
10	HD 93129A	B	O2If* + O3.5V?	?
11	HD 93250	B	O4III + O4III	>100 d
12	η Car	B	? + ?	2022.7 d
13	WR 39	B?	WC7	?
14	WR 48	T	(WC5 + O6-7V) + OI?	19.138 d/?
15	HD 124314	B?	O6V(n)((f))	?
16	HD 150136	T	(O3-3.5V((f*)) + O5.5-6V((f))) + O6.5-7V((f))	2.675 d/8.2 yr
17	HD 151804	U	O8Iaf	–
18	WR 78	U	WN7h	–
19	WR 79a	B	WN9ha + ?	many years
20	HD 152623	T	(O7V((f)) + OB?) + OB?	3.9 d/?
21	WR 89	B	WN8h + OB	?
22	WR 90	U	WC7	–
23	WR 98	B	WN7/WC + O8-9	48.7 d
24	WR 98a	B	WC9 + OB?	565 d
25	WR 104	B	WC9 + B0.5V	220 d
26	WR 105	U	WN9h	–
27	9 Sgr	B	O3.5V((f*)) + O5V	~8.6 yr
28	WR 112	B?	WC9 + ?	?
29	HD 167971	T	(O6-7V + O6-7V) + O8I	3.321 d/~20 yr
30	HD 168112	B?	O5.5III(f*) (+ OB?)	>1 yr
31	CEN 1a	B	O4 + ?	?
32	CEN 1b	B	O4 + ?	?
33	WR 125	B	WC7 + O9III	>15 yr, ~20–22 yr
34	HD 190603	U	B1.5Ia	–
35	WR 133	B	WN5 + O9I	112.4 d
36	WR 137	B	WC7 + O9V-III	13.05 yr
37	WR 140	B	WC7 + O5	7.9 yr
38	Cyg OB2 #5	Q	(Ofpe/WN9 + O6–7Ia) + OB? + B0V	6.598 d/6.7 yr/>9000 yr
39	Cyg OB2 #9	B	O5I + O6-7I	2.35 yr
40	Cyg OB2 #8A	B	O6If + O5.5III(f)	21.908 d
41	Cyg OB2-335	B	O7V + O9V	a few days(?)
42	WR 146	B (T?)	WC6 + O8?	many years ?
43	WR 147	B	WN8 + B0.5V	many years ?

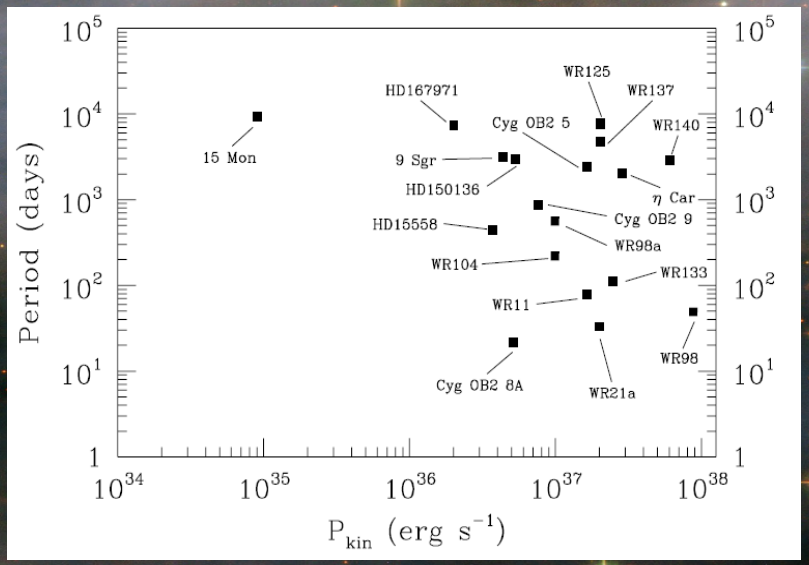
The parameter space

Positions of the dominating star of each system, in the wind parameter space (mass loss rate in solar mass per year, and terminal velocity in km/s).

Accurate determination of the stellar parameters of the companions is still lacking in several systems.



(De Becker & Raucq 2013, A&A, 558, A28)



Plot of the period of the system expressed (when available!) as a function of the kinetic power.

The lower limit on the period seems to be located at 'a few weeks'

The role of MW observations

1. As we are dealing with binary – or higher multiplicity – systems, multiplicity investigations are strongly needed. In addition, the determination of the spectral classification of the stars is also important.

Spectroscopic investigations and high angular resolution imaging techniques **(e.g. Sana et al. 2011, De Becker et al.2012, Sana et al. 2013, Le Bouquin et al. 2016)**

Output :

- orbital parameters → time evolution of the system

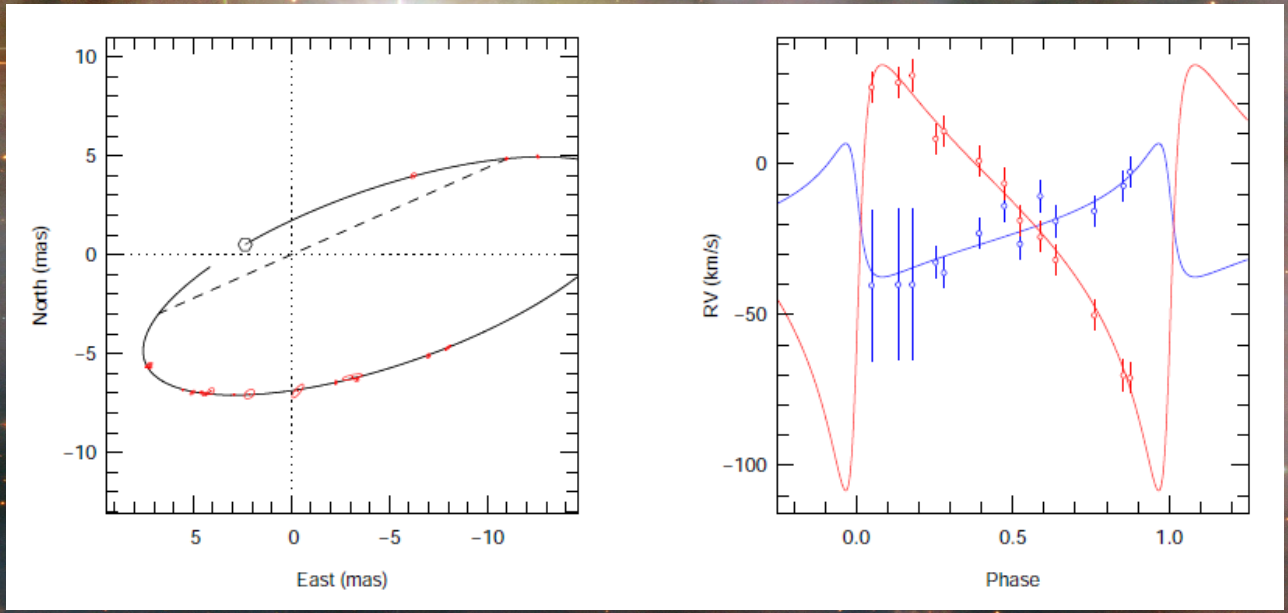
- spectral classification → stellar parameters

The role of MW observations

1. As we are dealing with binary – or higher multiplicity – systems, multiplicity investigations are strongly needed. In addition, the determination of the spectral classification of the stars is also important.

The triple system HD150136, with its 3D orbit derived from a combination of spectroscopic and astrometric measurements

Periods of 2.7 d and ~8 yr. ; e ~ 0.7.



(Le Bouquin et al. 2016, A&A, in press)

The role of MW observations

2. Identification of additional members of the catalogue through dedicated radio observations.

Select targets for radio observations :
- no need to investigate strongly magnetic objects
- no need to focus on the systems with huge wind kinetic power (though, late-type main-sequence objects are less favorable)
- no need to investigate objects with very strong wind collisions
- no need to restrict to a narrow range of orbital periods

→ At this stage, no specific parameter/ingredient seems to be required to discriminate between PA and non-PA
(De Becker, Benaglia, Romero & Peri, 2016, submitted)

→ Plenty of system deserve to be considered

The role of MW observations

2. Identification of additional members of the catalogue through dedicated radio observations.

Apply adequate observation strategies

- Variability → repeated observations, ideally at well-selected orbital phases

- Spectral characterization → measurements, at least, at 2 frequencies

- Longer wavelengths → where synchrotron emission should dominate the spectrum (e.g. 20 to 100 cm with GMRT, I. Chandra,)

- If feasible, VLBI imaging → resolve spatially the NT and the T components of the system

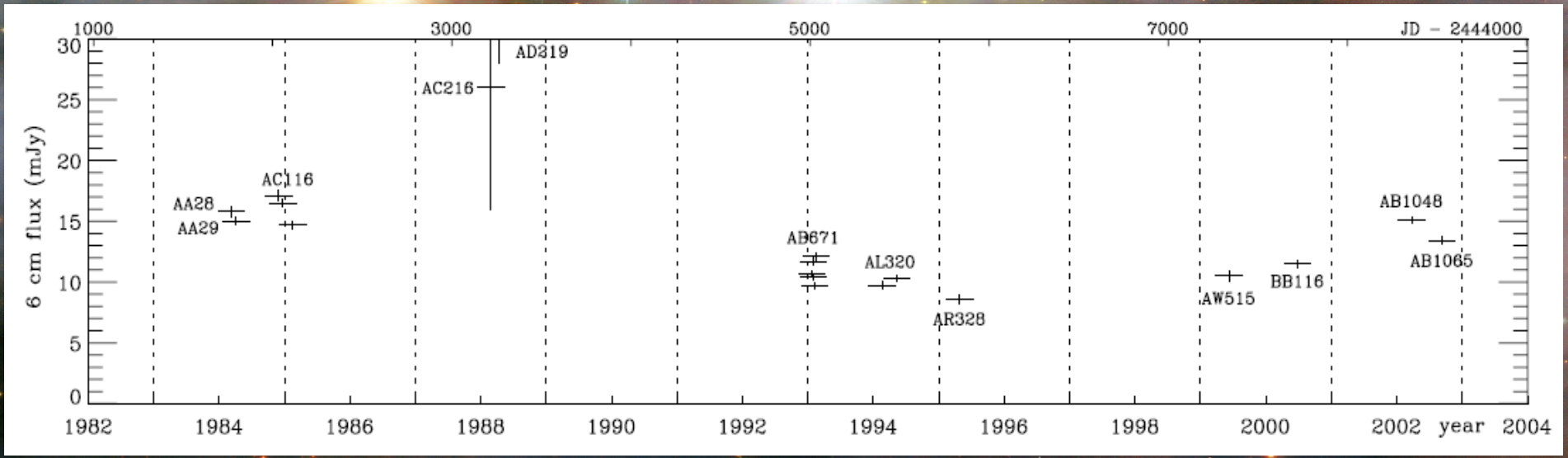
→ upgrade the catalogue and improve our estimate of the frequency of PA among CWBs

The role of MW observations

2. Identification of additional members of the catalogue through dedicated radio observations.

The triple system HD167971, with a radio modulation on a time-scale of about 21 years → most probably the orbital period

- *(Blomme et al. 2007, A&A,464, 701)*

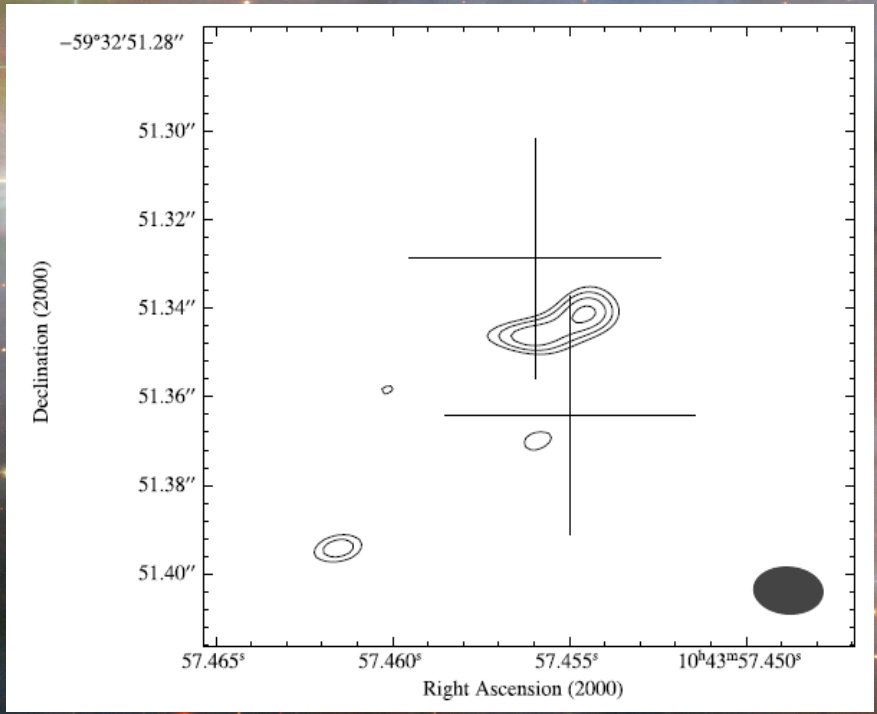


The role of MW observations

2. Identification of additional members of the catalogue through dedicated radio observations.

HD93129A, a very long period O-type system with imaged colliding-wind region using the Long Baseline Array at 2.3 GHz.

(Benaglia et al. 2015, A&A,479, A98)



The role of MW observations

3. Identification of additional members of the catalogue through dedicated hard-X-ray observations.

Soft X-rays dominated by thermal emission
→ strong need to explore hard X-rays (i.e. above 10 keV) to search for an inverse Compton scattering spectrum (power law)

Non-thermal high energy emission processes constitute a complementary indicator of PA
→ good sensitivity (e.g. INTEGRAL lack the required sensitivity)
→ good angular resolution (~ a few arcmin, or better)
→ spectral analysis capability (spectral index determination)

→ this provides a complementary and independent approach to identify additional PACWBs

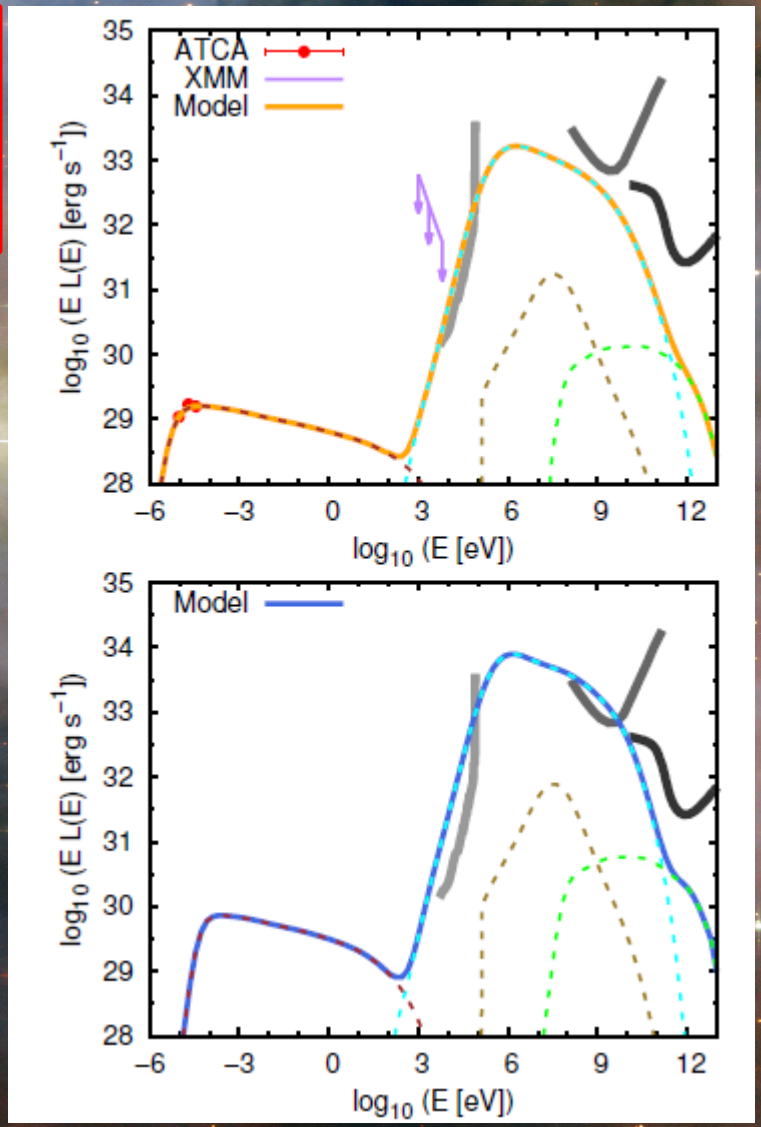
The role of MW observations

4. Improving our understanding of the non-thermal physics of these objects

Recent modelling allows to refine our understanding of the physics of these objects (e.g. HD93129A)

→ predicting capability

→ identification of necessary measurements to go one step further



(del Palacio et al. 2016, A&A, 591, A139)

Concluding remarks

Particle acceleration in CWBs is not a scarce phenomenon

The study of PACWBs is now switching to a new regime. From a few individual studies of massive binaries, one can now consider the study of a real class of objects.

The role of MW observations is highly important

I. Optical (and IR) observation :

- determination of the orbital parameters
- determination of the nature of the companion(s)

→ starting point for defining observation strategies

II. Radio observations to identify synchrotron radio emitters, and hard X-ray (and gamma-ray) investigations needed as well

→ indentification of additional members in the catalogue


Hopefully, BINA in its present form is only a first step,
as it could develop well beyond the scope of optical observations...
Thank you !