The challenges of identifying Particle-Accelerating Colliding-Wind Binaries

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Presentation of some results obtained in close collaboration with
Paula Benaglia *(IAR),* **Santiago del Palacio** *(Chalmers)*, **Benito Marcote** *(JIVE)*, **Mathilde Tasseroul** *(ULiège)*, **Agustina Blanco** *(ULiège)*, **Anandmayee Tej** *(IIST),* **Anindya Saha** *(IIST)*

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What objects are we talking about?

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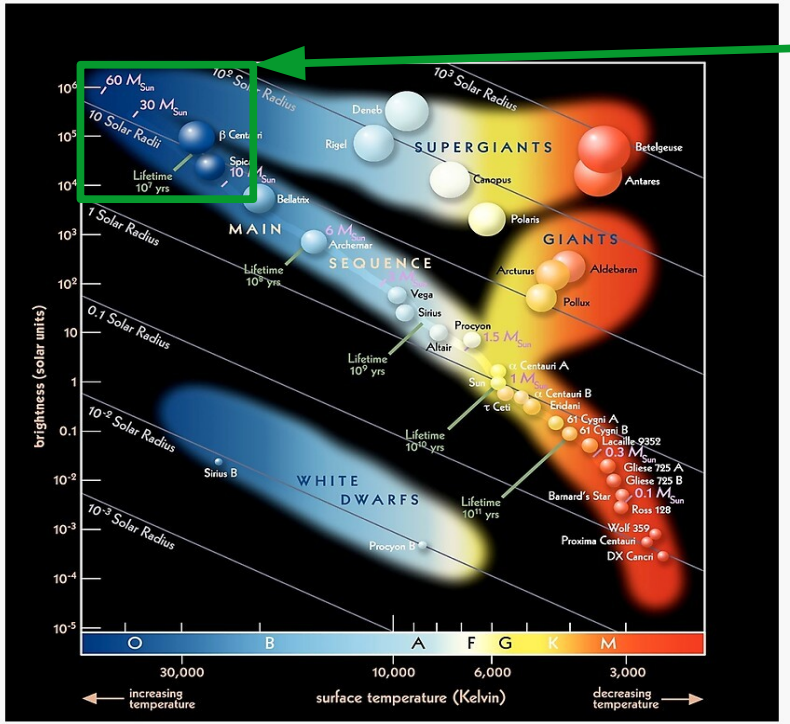

Massive stars → $M > 8–10\ M_{sol}$
Hot → $T > 25000$ K
Luminous → $L > 10^4\ L_{sol}$ (up to $10^6\ L_{sol}$!)
Short-lived → $t_{evol} < 10$ Myr
Rare → $f_{popul} \sim 1$ ppm

Important feature! → Stellar wind

Continuous outflow of stellar material driven by the strong radiation pressure (*reminder: high luminosity!*)
→ conversion of radiative energy into mechanical energy

Two main properties:
1. Mass loss rate : $10^{-7} – 10^{-5}\ M_{sol}$/yr
2. Terminal velocity : 1000 – 3000 km/s

→ **Wind kinetic power:**

$$P_{kin} = \frac{1}{2} \dot{M} V_\infty^2$$

Important for energy budget considerations!

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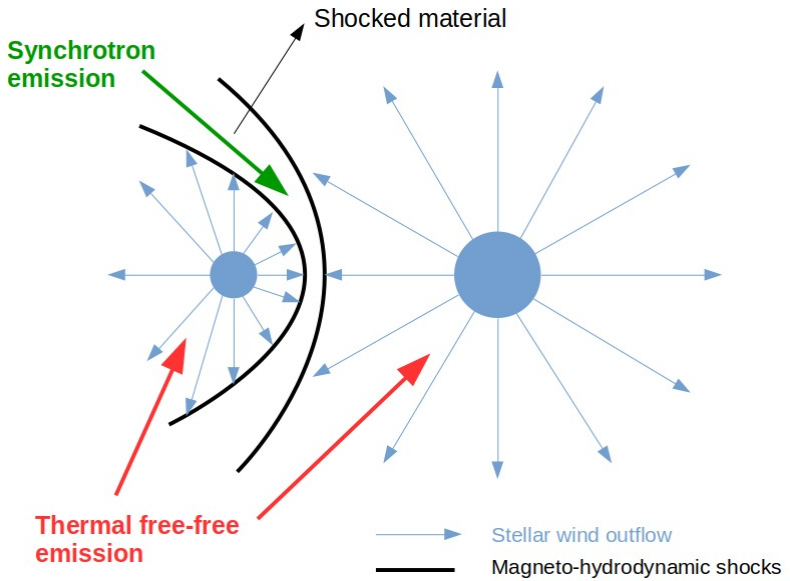
Particle-Accelerating Colliding-Wind Binaries (PACWBs)



Requirement: binary (or higher multiplicity) system → ***ok, most MS are in multiple systems!***

Colliding-winds → high Mach number shocks in between the two stars

Acceleration mechanism : very likely Diffusive Shock Acceleration (DSA)

Relativistic particles → non-thermal emission processes used as tracers to identify them (including synchrotron radio emission)

Note: stellar winds are thermal radio emitters

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How do we identify these objects?

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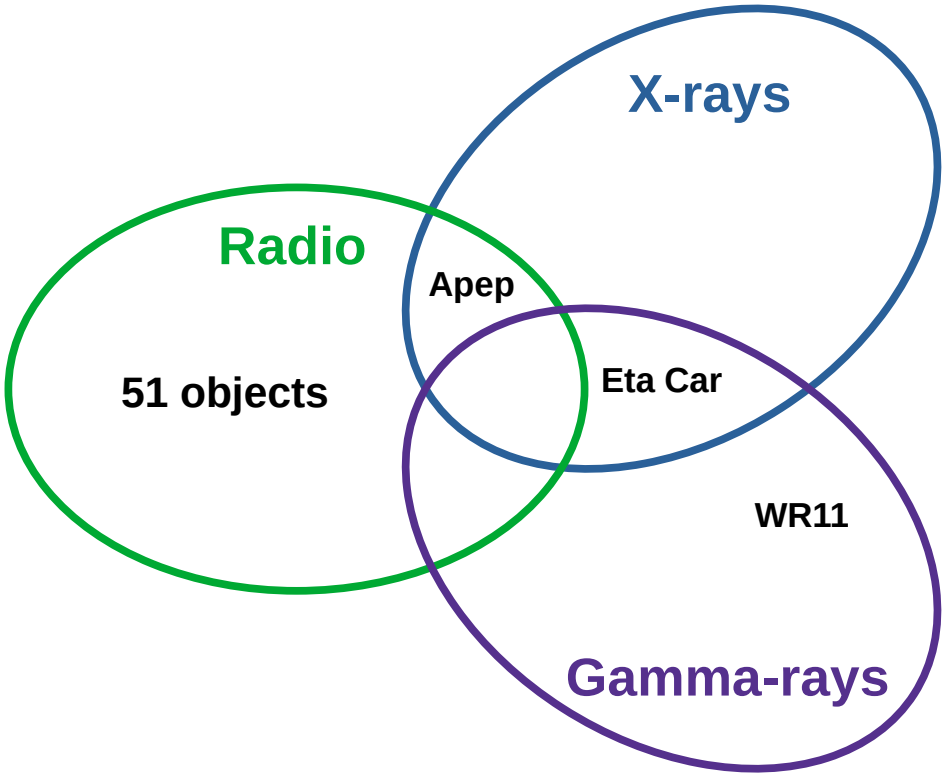
Catalogue of PACWBs*:
www.astro.uliege.be/~debecker/pacwb
(De Becker & Raucq 2013, A&A, 558, A28
De Becker et al. 2017 A&A, 600, A47)

Radio : synchrotron
X-rays : IC scattering
Gamma-rays : p-p with neutral pion decay



*This doesn't include potential unpublished results

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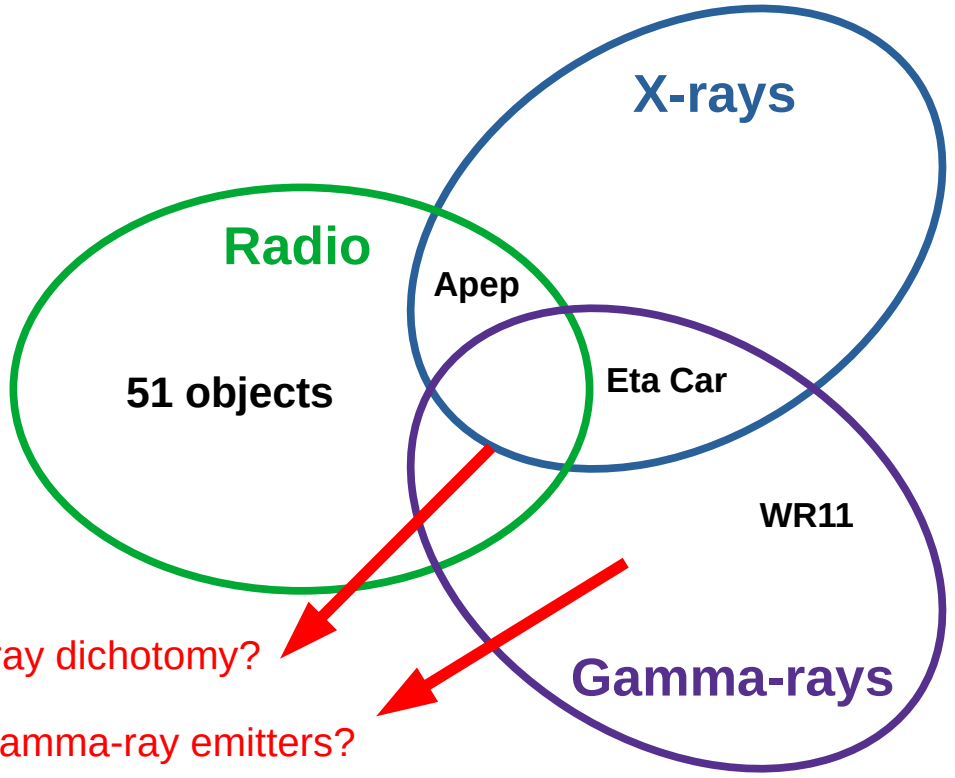

What about this radio/gamma-ray dichotomy?

Where are the gamma-ray emitters?

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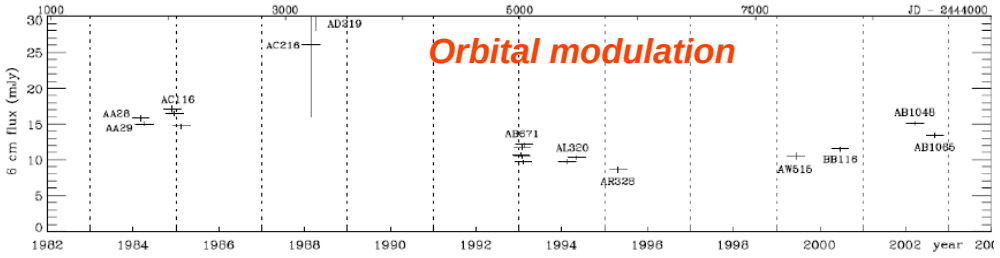
Radio signatures :

A few results...

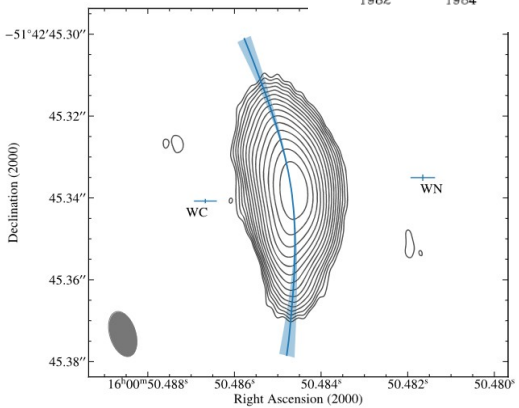


Orbital modulation

HD167971: triple system with a long period of about 20 yr (VLA light curve @6 cm)

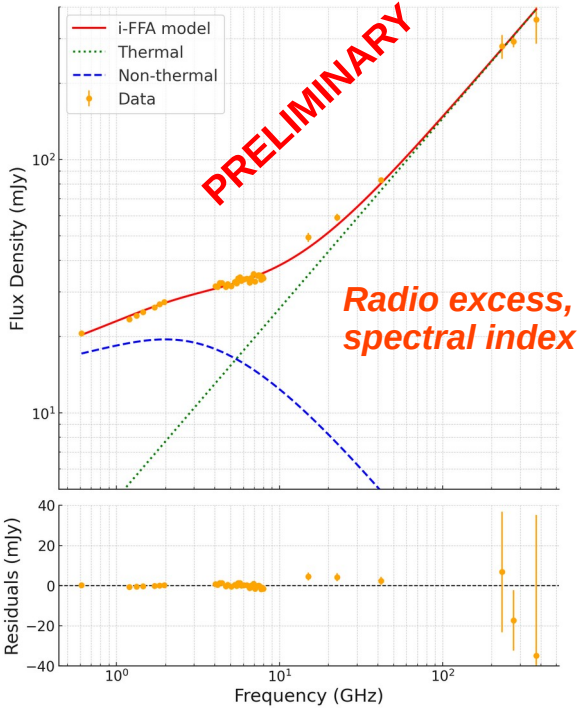
(Blomme et al. 2017 A&A, 501, 2478)

Mapping of the CWR



Apep: strongest synchrotron emitter (LBA map @2.3 GHz)

(Marcote et al. 2021 MNRAS, 501, 2478)



WR147: binary system with undetermined long period (SED, VLA+GMRT+...)

(Tasseroul et al. 2025, A&A, in prep.)

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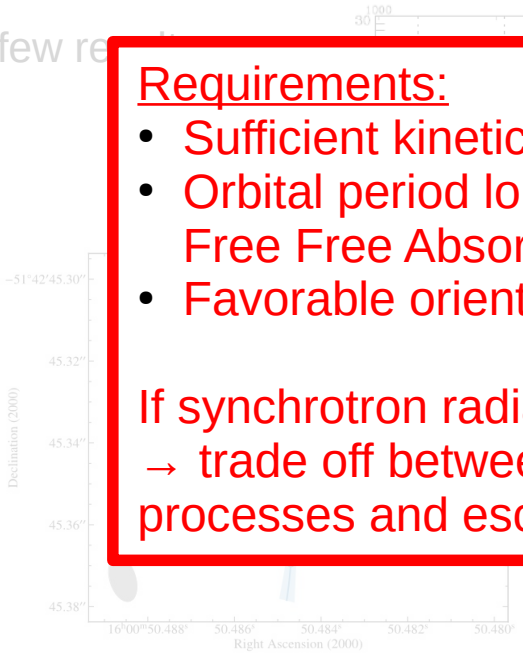
Radio signatures :

A few re

Requirements:

- Sufficient kinetic power (but...)
- Orbital period long enough (need for synchrotron radiation to escape: Free Free Absorption)
- Favorable orientation

If synchrotron radiation is produced, its main killer is FFA
→ trade off between high kinetic power (strong winds) to feed the processes and escape probability that drops for thicker winds



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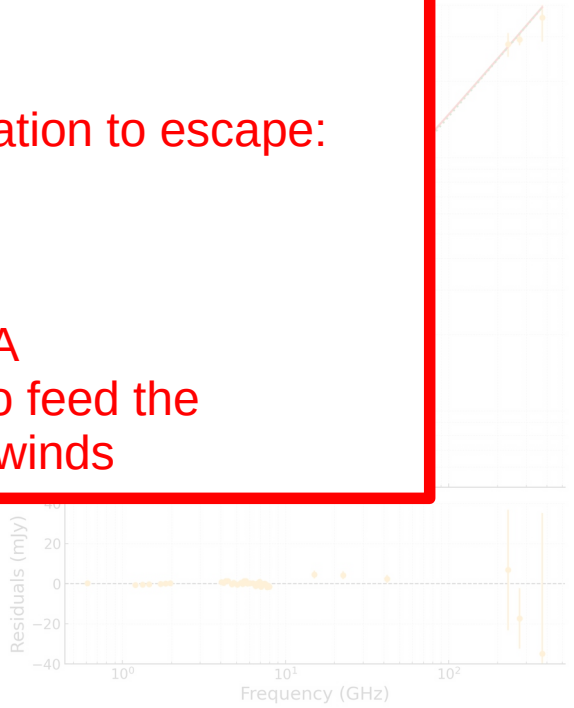

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Radio signatures :

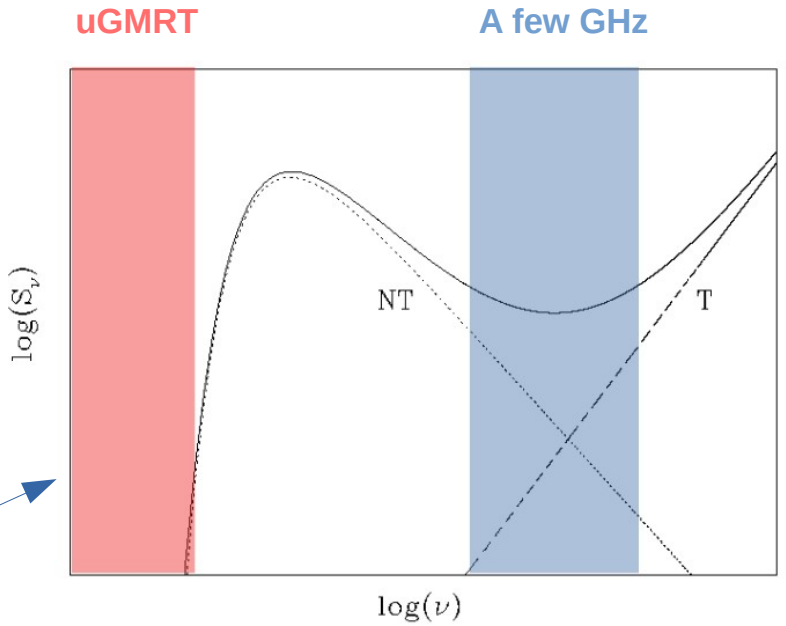
On-going projects...

Low frequency observations (uGMRT)

- Investigating the radio spectrum where the synchrotron radiation should *a priori* dominate (← negative index)
- Non-detection of several WR stars : either they do not emit synchrotron radiation or the emission if free-free absorbed

(Saha et al. 2023, MNRAS, 526, 750 ;
Blanco et al. 2024, A&A, 609, A78)

- Example of **WR98a** : NT signature at a few GHz, but no detection at uGMRT bands
  → likely occurrence of FFA
  → ***scrutinizing low frequencies is not necessarily the best solution***



(Blanco et al. 2024, A&A, 609, A78)

See Paula's talk for other examples at various frequencies

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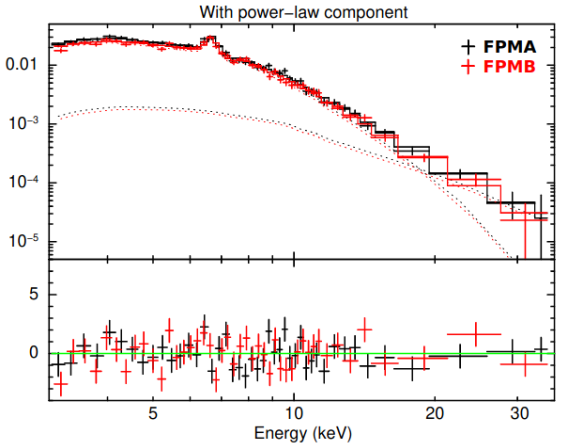
X-ray signature :



Apep : WC + WN system system with a long period (Nustar X-ray spectrum)

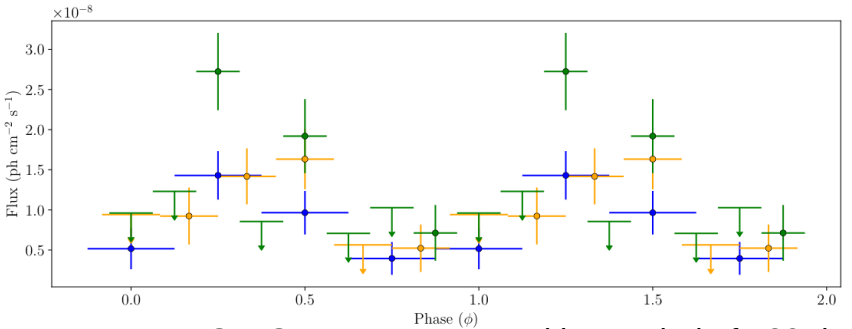
(del Palacio et al. 2023, A&A, 672, A109)

See Santi's talk

Requirements:

- Very good sensitivity above 10-20 keV
- High radiative energy density and high kinetic power to feed IC scattering

Gamma-ray signature :



WR11 : WC + O system system with a period of ~80 d (Fermi phase-folded light curve)

(Marti-Devesa et al. 2020, A&A, 635, A141)

See Guillem's talk

Requirements:

- Very good sensitivity
- High wind density that favors p-p interactions

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Take away message…

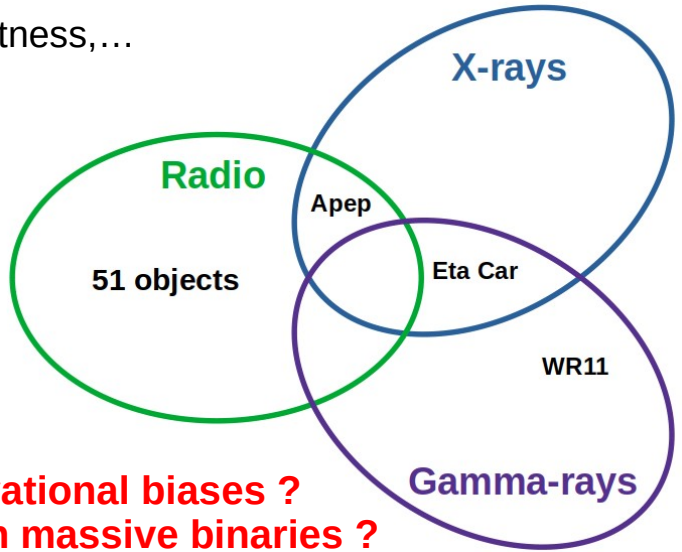
- Radio measurements constitute the main tool (nowadays) to identify PACWBs: ***synchrotron radio emission is a good tracer of particle acceleration***
  However! Some severe difficulties: FFA, time dependence, low brightness,…

- High energy signatures are much more elusive

→ only 1 source identified as a NT radio and X-ray emitter, only 2 are gamma-ray sources

- Gamma-ray emission seems to require conditions not compatible with the detection of synchrotron radio emission :

→ radio/gamma-ray dichotomy ! Observational bias or fact?



What is the part of the problem that is attributable to observational biases ?
What is the actual occurrence rate of particle acceleration in massive binaries ?

Thank you for your attention !