Revealing the particle acceleration in stellar shocks of massive colliding wind binaries

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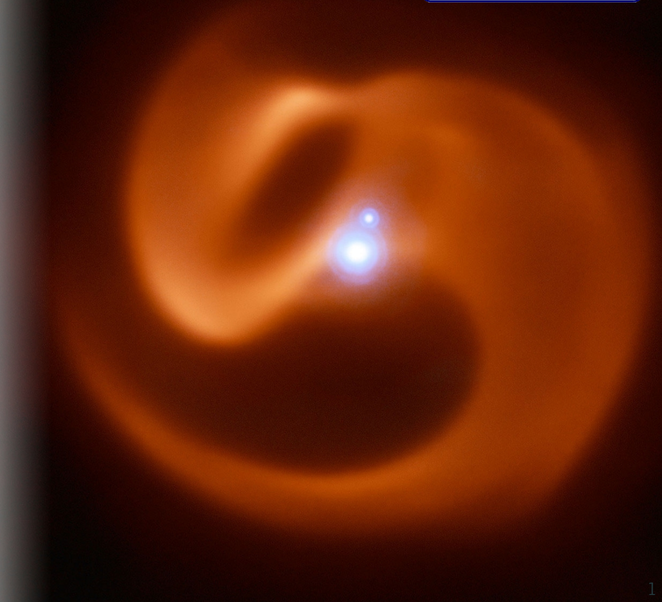


Part One

Followed by next talk by Santiago del Palacio

Particle Accelerating Colliding Wind Binaries

Massive stars of O, B, or Wolf-Rayet spectral type

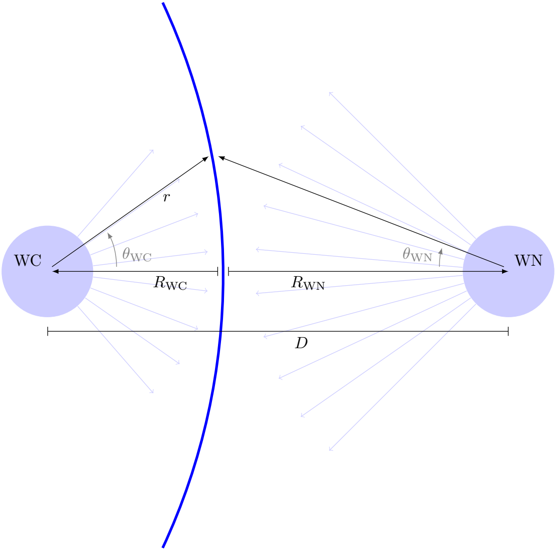
Often ($>$ 20–60%) in binary systems

Large mass-loss rates and wind velocities:

$$\dot{M} \sim 10^{-4}\text{–}10^{-7}\ \mathrm{M_\odot\ yr^{-1}}$$
$$v_{\mathrm{winds}} \sim 1\text{—}3\times 10^{3}\ \mathrm{km\ s^{-1}}$$

Large power reservoir to accelerate particles via Diffusive Shock Acceleration process:

$$P_{\mathrm{kinetic}} \sim 10^{36\text{–}38}\ \mathrm{erg\ s^{-1}}$$
$$E_{\mathrm{tot}} \sim 10^{50}\ \mathrm{erg}$$



(Apep; Marcote et al. 2022)

Particle Accelerating Colliding Wind Binaries

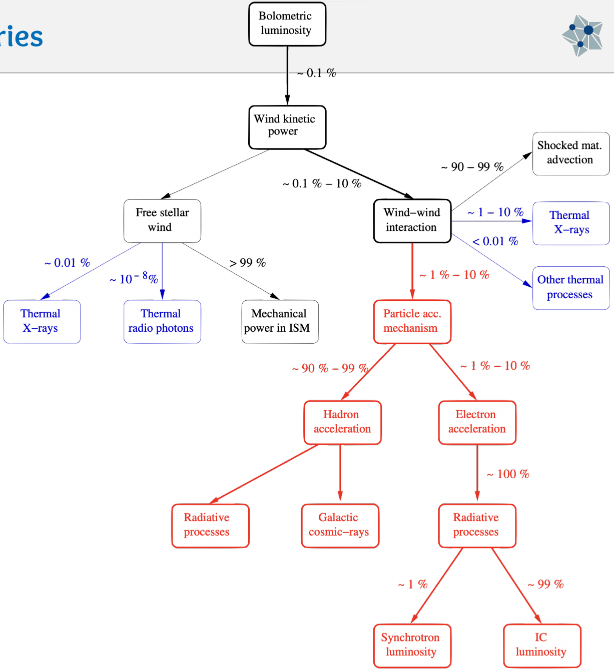
Strong photospheric UV/visible radiation field

Low-energy photons are up-scattered to high energies via inverse Compton scattering

Soft X-rays: dominated by thermal emission

Hard X-rays: non-thermal emission arises (above $\gtrsim$ 10 keV)

(De Becker & Raucq 2013;
De Becker et al. 2017)



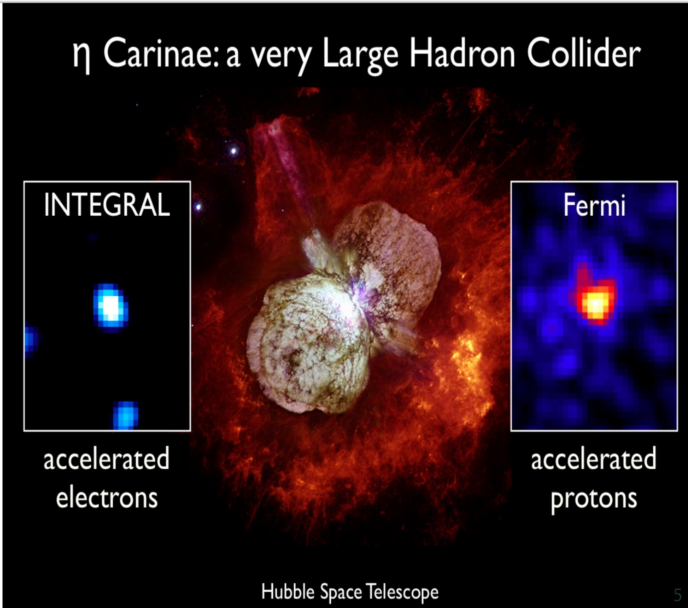
Eta Carinae

Luminous Blue Variable star
($\sim$ 100 $M_\odot$)

O- or B-type companion
($\sim$ 30 $M_\odot$)

Eccentric ($\sim$ 0.9) $\sim$ 5.5-yr orbit
Modulated High Energy emission
(Tavani et al. 2009)

Hadronic accelerator with
Very-High-Energy detected by
H.E.S.S. Collaboration et al. (2020)
Martí-Devesa & O. Reimer (2021)



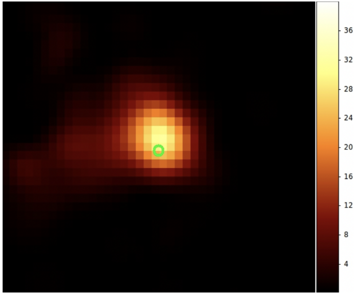
WR 11 - A second gamma-ray CWB emitter

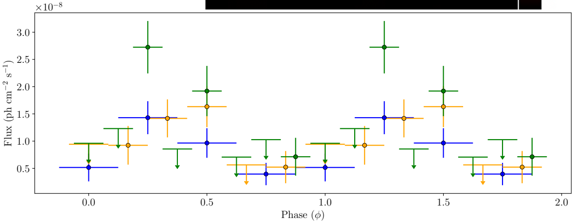
Also known as γ^2 Velorum

Composed of WC8 + O8 III
Orbital period of 79 d
at a distance of 336 pc

Fermi/LAT detection (Pshirkov 2016)
(Martí-Devesa et al. 2020)
Similar wind kinetic power than η Car
($\sim 2 \times 10^{37}$ erg s^{-1})

But $\sim$ 10 times lower mass loss rates
$\sim 10^{-5}$ of total wind kinetic power
$\sim 10^{-4}$ of power injected in the wind-wind interaction region (Benaglia 2016)





How to find CWBs?

Weak non-thermal (soft) X-ray emission

Most of them in crowded fields

x hard *Fermi*/LAT searches

Long orbital periods (year to decades)

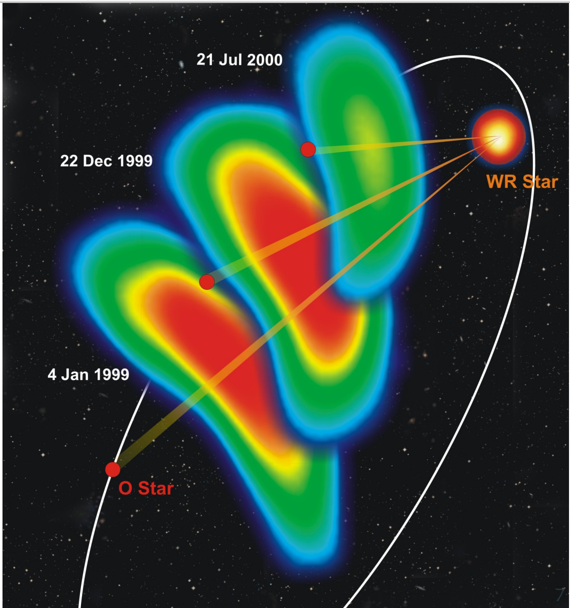
x Multiplicity not revealed by *Gaia* astrometry

How to identify PACWBs?

Clear signatures at radio wavelengths!

(De Becker & Raucq 2013; De Becker et al. 2017)

(WR 140; Dougherty et al. 2005) ⟶



HD 93129A — one of the most massive binaries

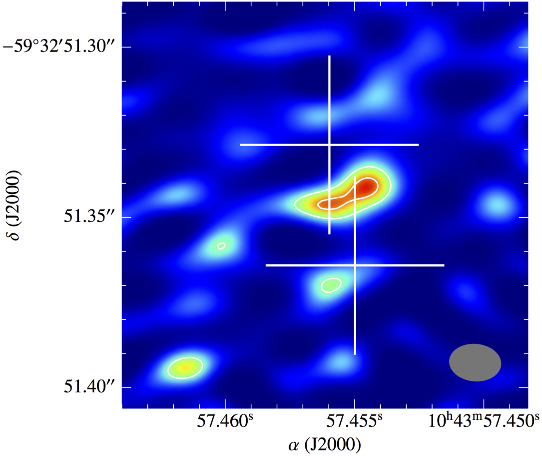
O2 If* and O2/O3.5 V stars at 2.5 kpc

Total mass of $200 \pm 45\ M_\odot$

Orbital period of $\gtrsim 100$ yr and minimum separation ~ 10 AU

Very high resolution radio observations resolved the wind collision region (Benaglia, Marcote, et al. 2015, A&A, 579, A99)

High Energy and Very High Energy candidate (del Palacio et al. 2016, A&A 591, A139) ***and next talk for further details!***



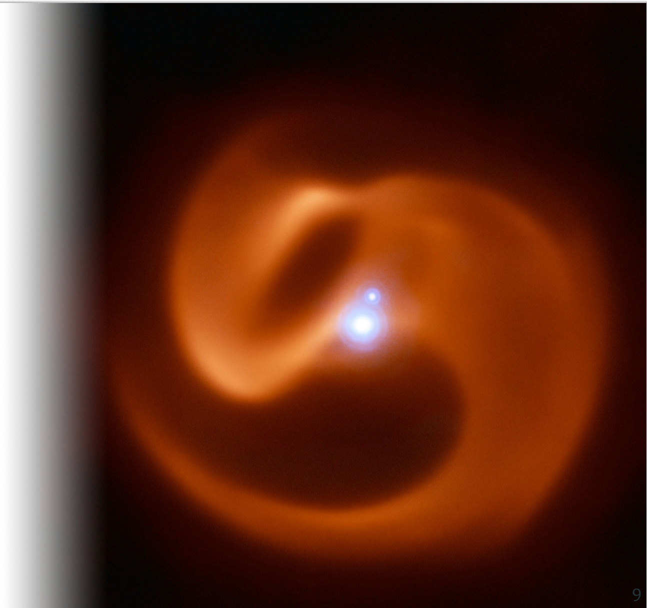
Apep — the most luminous binary in the Galaxy

Exceptionally bright IR and radio source (Callingham et al. 2019)

Spiral dust plume (pinwheel nebula)

WN4–6b and WC8 stars

Orbital period of $\sim$ 100 yr
Star separation of $\sim$ 100 AU
Callingham et al. (2020)
Han et al. (2020)
Marcote et al. (2021)



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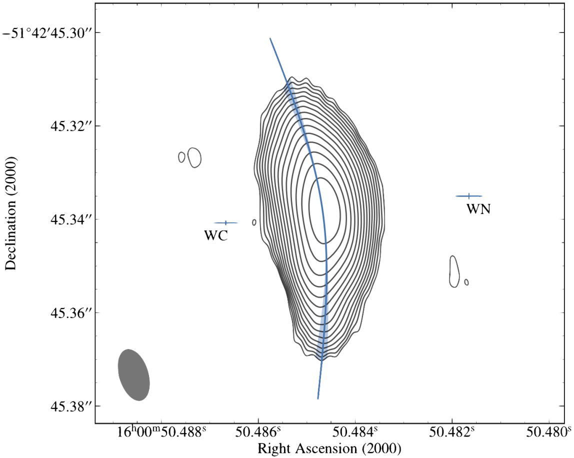
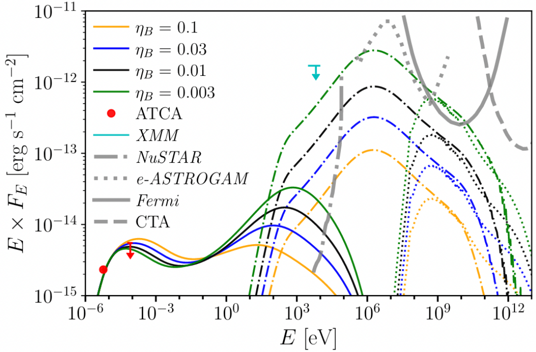


Apep — the most luminous binary in the Galaxy

Thermal soft X-rays
(Callingham et al. 2019,2020)

Star	$\dot{M}$ / $M_\odot$ yr^{-1}	v_∞ / km s^{-1}
WC8	$\sim 10^{-4.5}$	$2\,100 \pm 200$
WN4–6b	$\sim 10^{-4.1}$	$3\,500 \pm 100$

Non-thermal radio emission more than one order of magnitude brighter than η-Car
(Marcote et al. 2021)
(Sana, Callingham & Marcote 2022)



$\eta_B \sim 0.003$–0.1 ($B \sim 0.08$–0.4 G)
(del Palacio et al. 2022)

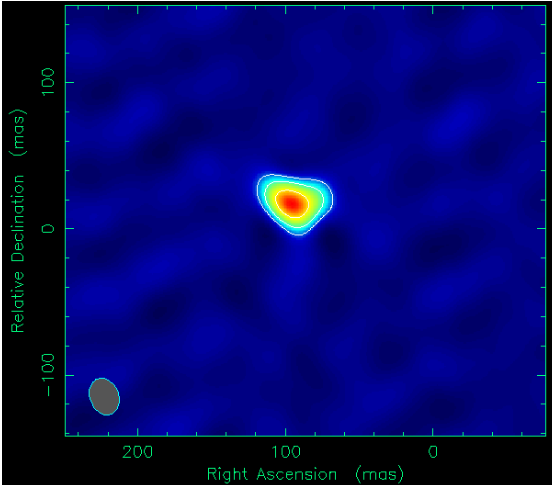
Increasing the number of PACWBs

On-going surveys to unveil PACWBs

Special focus on specific sources:

WR 133 (WN5 + O9I):
a potential triple system?

WR 125 (WC + O9III)
29 yr orbit (at 2.5 kpc) with
a total mass of $\sim$ 40 $M_\odot$
Periodic dust maker
$\sim$ 3 AU periastron separation
Most energetic CWB in the northern hemisphere?



(Théo Furst, Master Thesis, on HD 168112
defended last week at U. Liège, Belgium!)

PACWBs as contributors to the comic ray background?

Most Galactic cosmic rays come from SNe

With an energy injection ~ 0.01–1%:
CWBs convert $\sim 10^{32}$–10^{34} erg s^{-1}
into relativistic particles

$\sim 10^5$ Galactic massive stars

Energy production rate of cosmic rays:
10^{37}–10^{39} erg s^{-1}

Up to $\sim 1\%$ of the total power in cosmic rays!

(de Becker et al. 2017; Seo et al. 2018
Kalyashova et al. 2019)

Take home messages

- CWBs can be efficient particle accelerators and gamma-ray emitters
  Only one case has been "widely" explored to date (η Car)
- Several potential candidates are yet to be discovered
- We are discovering new PACWBs through radio searchers
- *Two new candidates to reach HE/VHE emission*
- *What is the contribution to Galactic cosmic rays from PACWBs?*

Thank you!

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Particle Acceleration and Non-Thermal Emission of Radiation in Astrophysics - Stars Collaboration

M. De Becker, P. Benaglia, V. Bosch-Ramon, C. H. Ishwara-Chandra,
B. Marcote, S. del Palacio, G. Romero, A. Tej

`https://www.astro.ulg.ac.be/~debecker/pantera/`