Resolving stellar wind shocks of massive binary stars

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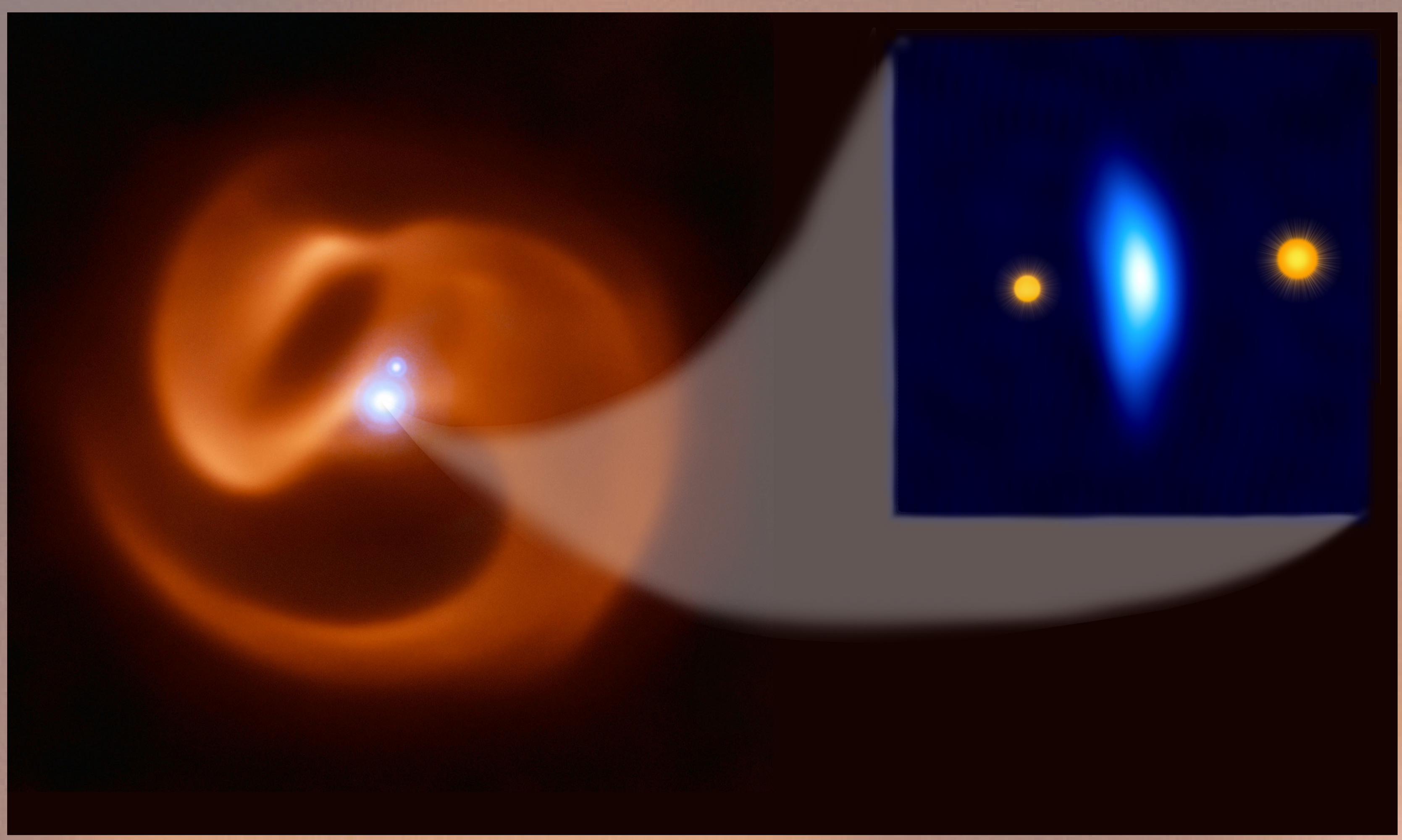
Introduction

Binary systems comprising massive stars in relatively close orbits allow the presence of strong interaction between the two stellar winds. When the distance is close enough, an energetic shock is produced due to the collision of the two stellar winds, which can shine at radio wavelengths, and even reach production of high-energy gamma rays.

Only tens of these particle-accelerating colliding wing binaries (PACWBs) are known to date (De Becker & Raucq 2013; De Becker et al. 2017). And only a handful of them had their wind-collision regions resolved.



Credit: Marcote & Callingham/ESO.

Colliding wind binaries with Wolf-Rayet stars produce significant amounts of dust that due to the orbital motion is seen as a pinwheel nebula (the orange spiral for the case of Apep). Zooming-in the system, one case detect and resolve the shock (blue) between the two stars (in yellow) at radio frequencies using very long baseline interferometry (VLBI).

VLBI radio observations

Radio observations are the best tool to unveil PACWBs. In particular, very long baseline interferometry (VLBI) observations further allow astronomers to trace the morphology of the shock and its evolution along the orbit. The structure of this region is directly related to the physical properties of the two stellar winds (wind velocity, mass-loss rate, magnetic field) and thus allows a full characterization of the stellar system and its orbital evolution.

A deep survey in these systems (and dozens of potential PACWBs) would unveil for the first time the limits at which particle acceleration can take place. Studying the low-limit in the systems with the lowest energy (and thus the faintest ones) would allow us to unveil population properties. Rather than study the particular (most extreme) cases.

The PANTERA-Stars Collaboration

The Particle Acceleration and Non-Thermal Emission of Radiation in Astrophysics – Stars Collaboration has just born as an international collaboration involving researches who work on various aspects of particle acceleration in astrophysical sources, with an emphasis on Galactic stellar objects (including massive stars at various stages of their evolution, either in binaries or higher multiplicity systems, or as bow-shock runaways), along with young stellar objects.

Observations with the European VLBI Network (EVN) and the LBA are providing valuable information on specific PACWBs, but also potential candidates.

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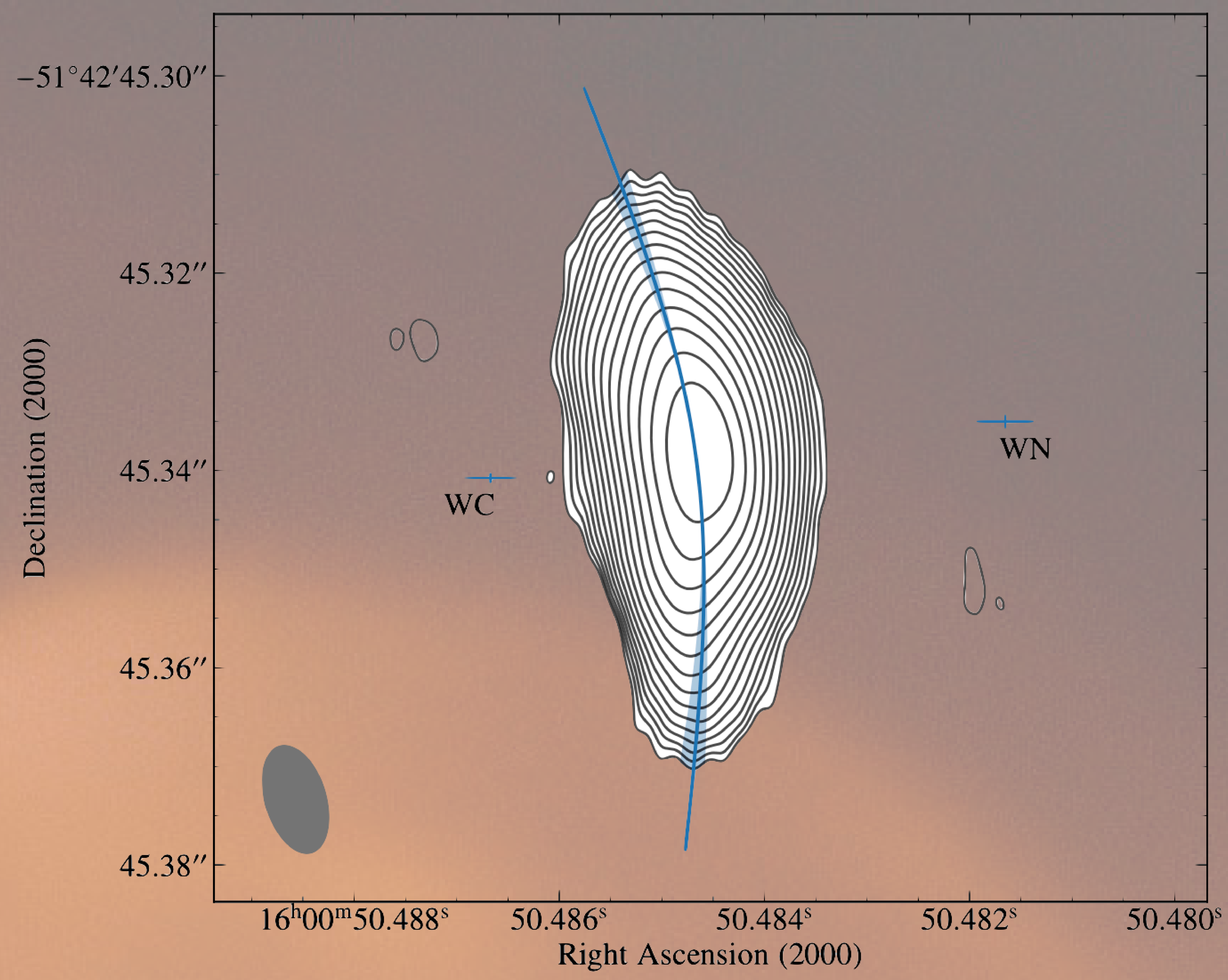
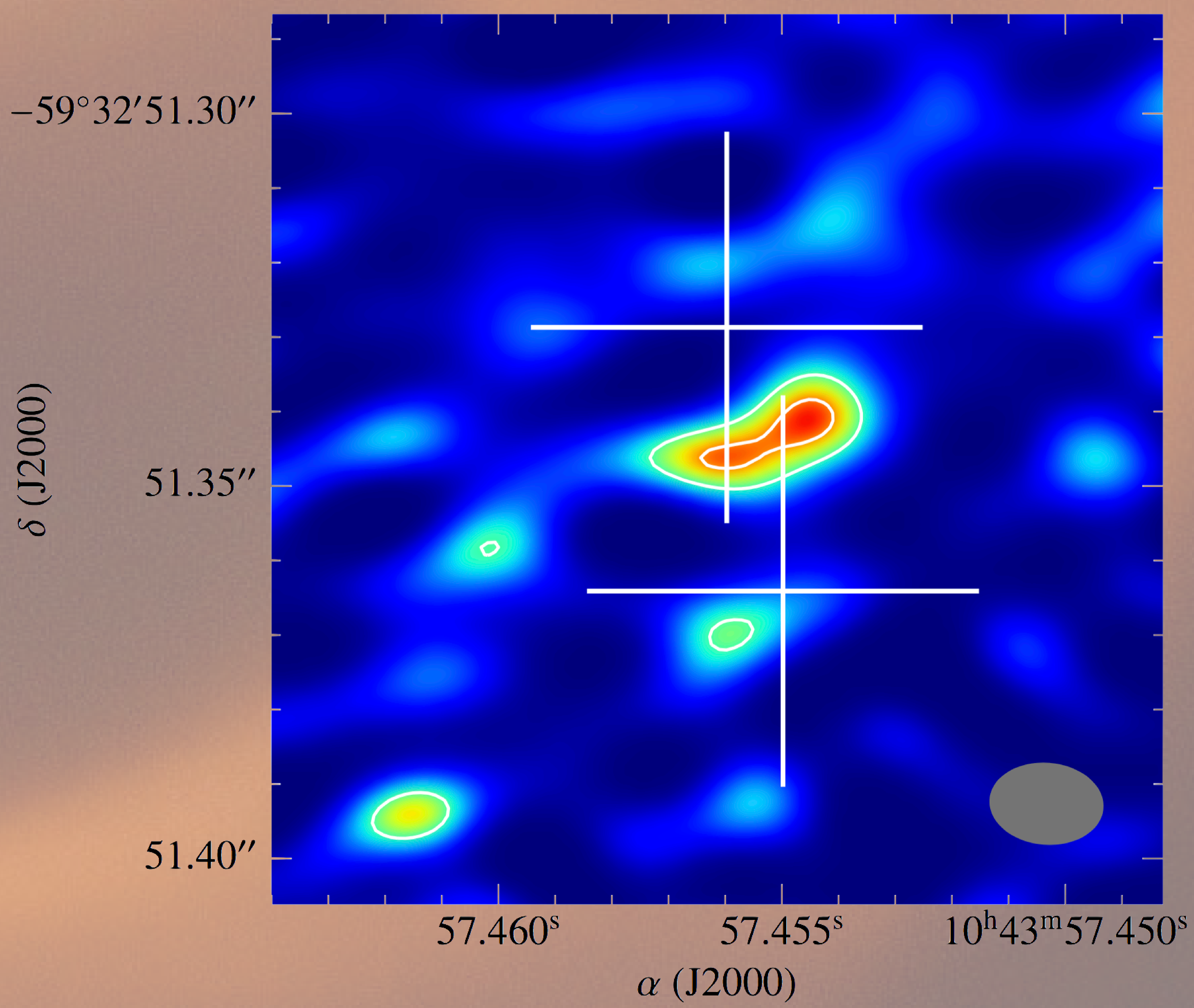
Two extreme cases



Apep is the first CWB confirmed to host two Wolf-Rayet stars (a WC8 and a WN4–6b star). The dust production in this system is tremendous and generates the dust spiral plume visible in the infrared (orange pinwheel emission in the left image). The non-thermal radio emission is by far (over an order of magnitude) the brightest and most luminous known for a CWB in our Galaxy (Callingham et al. 2019). Apep is actually a potential γ-ray producer, only clearly seen before in η-Carinae (del Palacio et al. 2021).

At Apep's core, the stellar winds from the two stars collide, producing an extreme shock that allowed us to estimate the absolute positions of the two stars in the system and the properties of their winds (Marcote et al. 2021).

The figure shows the radio emission produced in these shocks (black contours), as seen by the Australian Long Baseline Array (LBA), plus the modeled contact discontinuity that traces the region (blue line). The derived positions of the two stars are represented by the blue crosses. The synthesized beam is represented by the gray ellipse at the bottom left corner.



HD 93129A is one of the hottest and most massive binaries known in our Galaxy and is composed of two O spectral type stars with stellar masses of ~ 100 and $\sim 37\ M_{\odot}$ in a $\gtrsim 100$-yr orbit.

Very-high-resolution radio imaging of HD 93129A confirmed its nature as PACWB (Benaglia et al. 2015). The above image shows the radio emission, where the two white crosses represent the absolute positions of the two stars as seen by the *Hubble Space Telescope*. The synthesized beam is represented by the gray ellipse at the bottom right corner.

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