Hydrodynamic and Radiative Modelling of Colliding Wind Nebulae

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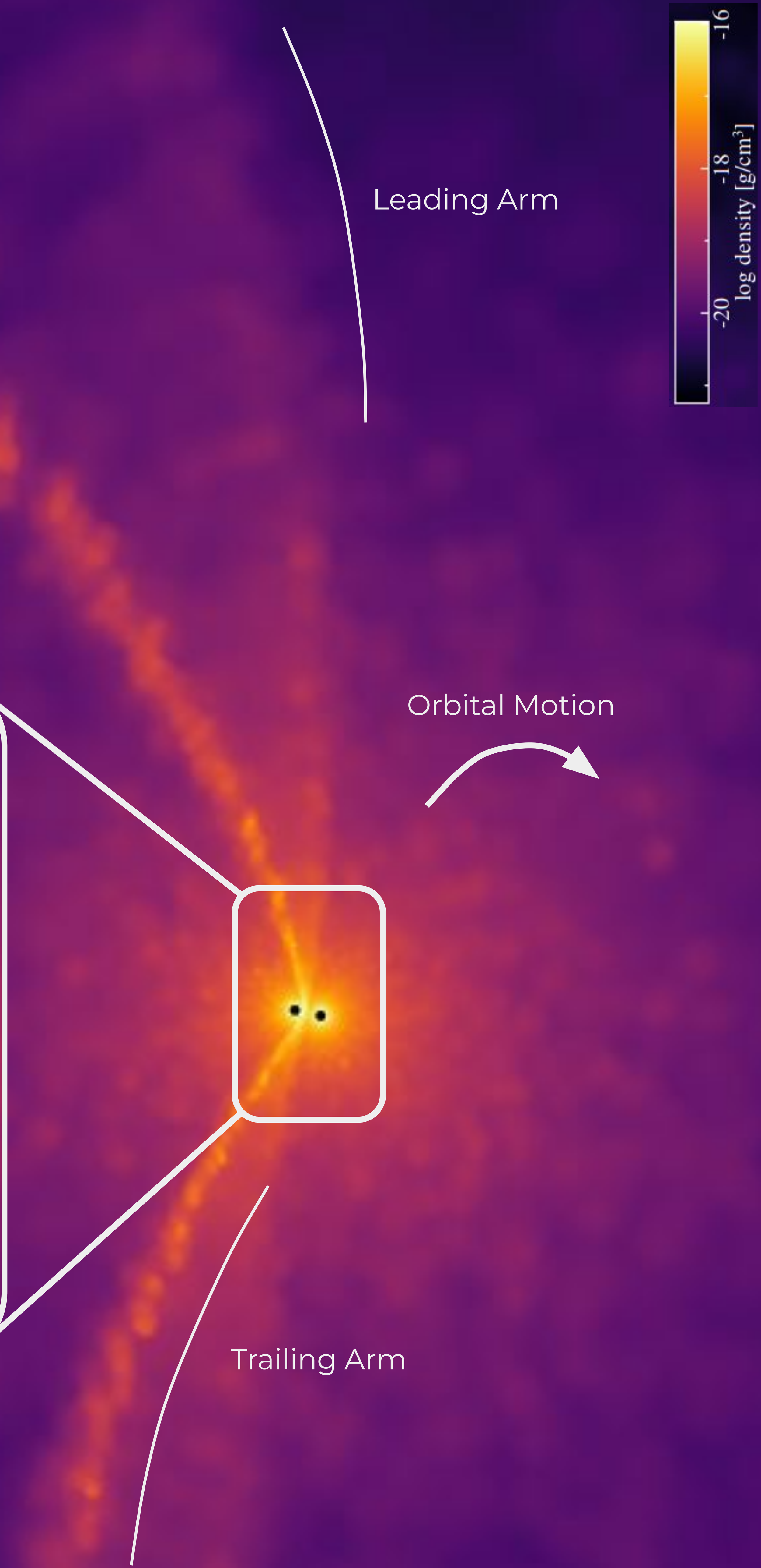
Intro

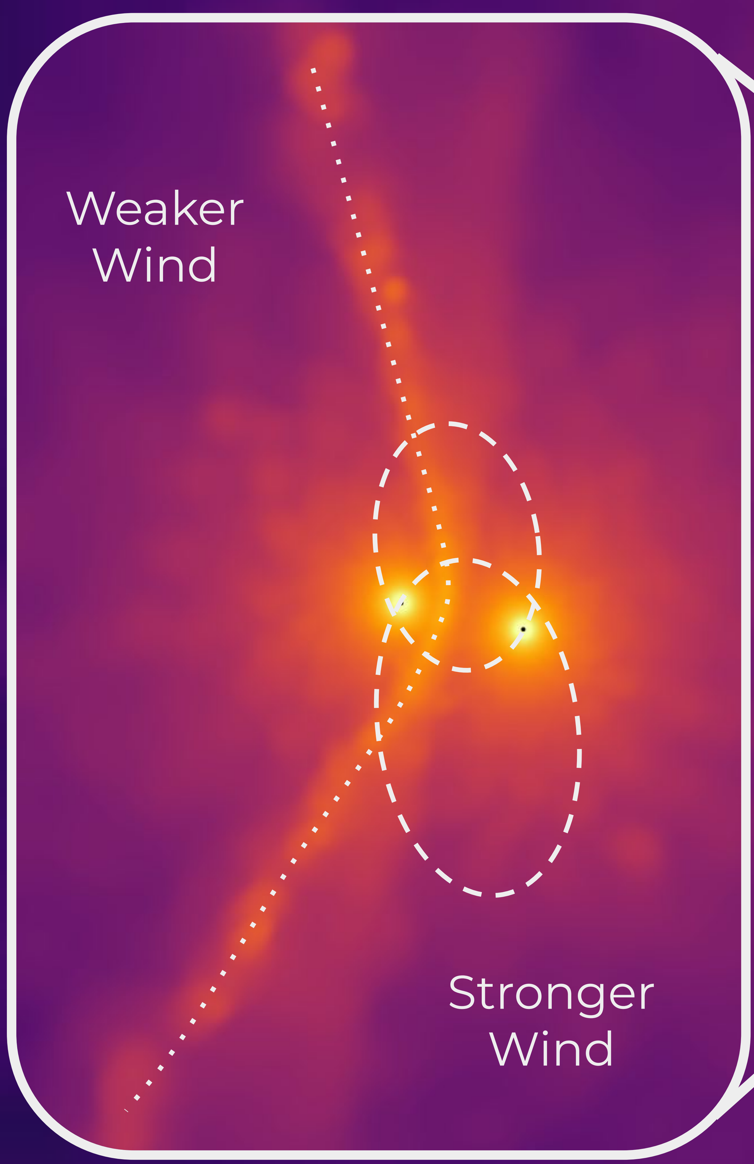
There are a handful of Wolf-Rayet (WR) colliding wind binaries (CWBs) in the Galaxy – binary stellar systems where stellar winds collide to copiously form dust in the shocked, turbulent material. Systems like these formed the first carbon dust in the Universe, and modelling them helps us understand how they have shaped the Galaxy.

Hydrodynamic Modelling

The Apep system (pictured below) stands out as the most unique WR CWB: it is the only dusty CWB to have *two* WR stars[1], its orbital period is an order of magnitude longer than the next longest dusty CWB[2], and it has been confirmed to have an O supergiant tertiary that carves a cavity in the dusty nebula[3].

We use the smoothed particle hydrodynamics code PHANTOM to model the colliding wind shock and dust nucleation in the Apep system for the first time. We use results from geometric models of the nebula[3] to reproduce the observed nebula phenomenology: the simulation on the right of the poster shows the cross-section gas density of the system, where wind collision results in two shocked arms that are wrapped into a spiral by the orbital motion.





Han et al., White et al., Alyssa Pagan, NASA/ESA

Our simulations help explain the flocculation (fluffiness) seen in the JWST imagery of the system (left) and the shock opening angle derived from the momentum ratio of the winds.

One of the main goals of this project is to include the tertiary O supergiant in hydrodynamic simulations and see how it interacts with the dust plume as proposed in our submitted paper – we have validated the inner binary, and the tertiary is next on our list!

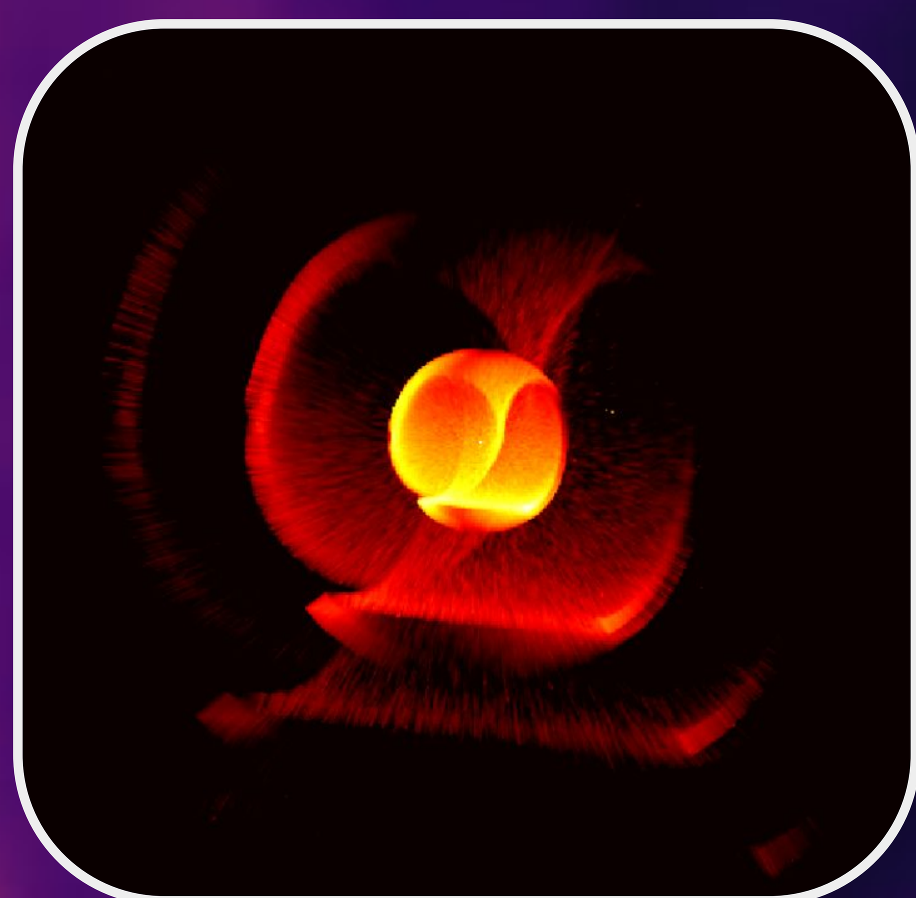
Radiative Transfer

We aim to recreate the above image with the hydrodynamic model; doing so will require simulating the radiation transport in the system using MCFOST. This ray-traces photons in 3D space, capturing the emission and scattering from the stars + the nebula in the system – exactly what happens in reality.

We also are using MCFOST together with our geometric models to simulate Apep and other WR CWBs in a fraction of the time it would take a hydrodynamics code. We show a preliminary example for the first 4 shells of WR 140 (right figure). This will allow us to constrain:

- The dust mass produced by the colliding winds
- The dust grain size distribution in the nebulae
- The infrared light curves of CWBs

By using what we learn on already-imaged systems, we may eventually be able to model far away systems that can never be directly imaged.



Summary

We are modelling the Apep system with hydrodynamic and radiative transfer codes so that we may understand dust formation and destruction in one of the most puzzling triple systems known – an important analogue to early dust formation in the Universe.

Our results so far are in good qualitative agreement with observations, and further work 1) including the tertiary in the hydrodynamic simulations and 2) interfacing geometric models with radiative transfer codes will allow us to shed light on the processing of dust in the Galaxy.

Scan to see our Apep paper!

1. Callingham et al (2020) '*Two Wolf-Rayet stars at the heart of colliding-wind binary Apep*' MNRAS, 495, 3323
2. Han, White et al (2025) '*The formation and evolution of dust in the colliding-wind binary Apep revealed by JWST*' arXiv:2507.14498
3. White et al (2025) '*The Serpent Eating Its Own Tail: Dust Destruction in the Apep Colliding-Wind Nebula*' arXiv:2507.14610