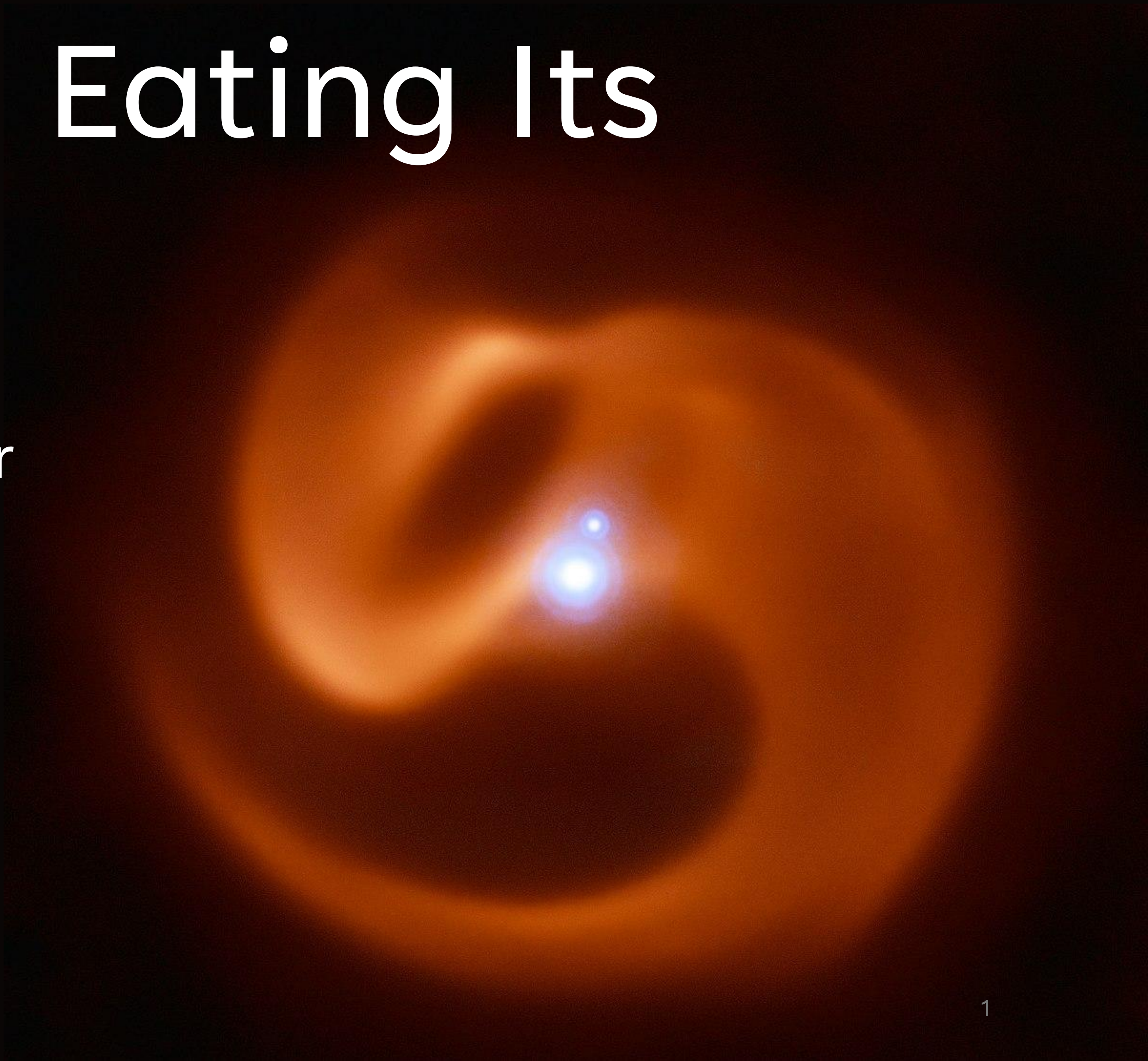
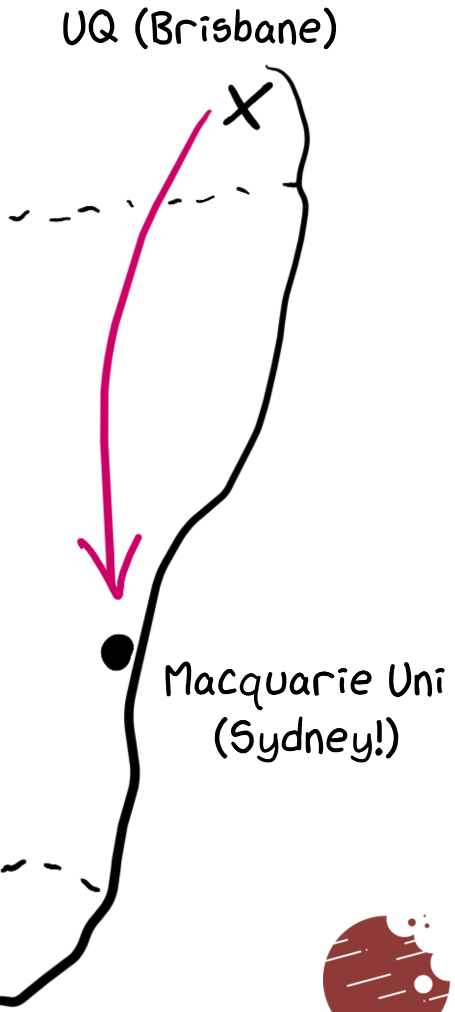
The Serpent Eating Its Own Tail

Strange geometry reveals some of the nastiest stellar interactions in the Galaxy



Ryan White
for the University of Sydney Astro Seminar

A little bit about me

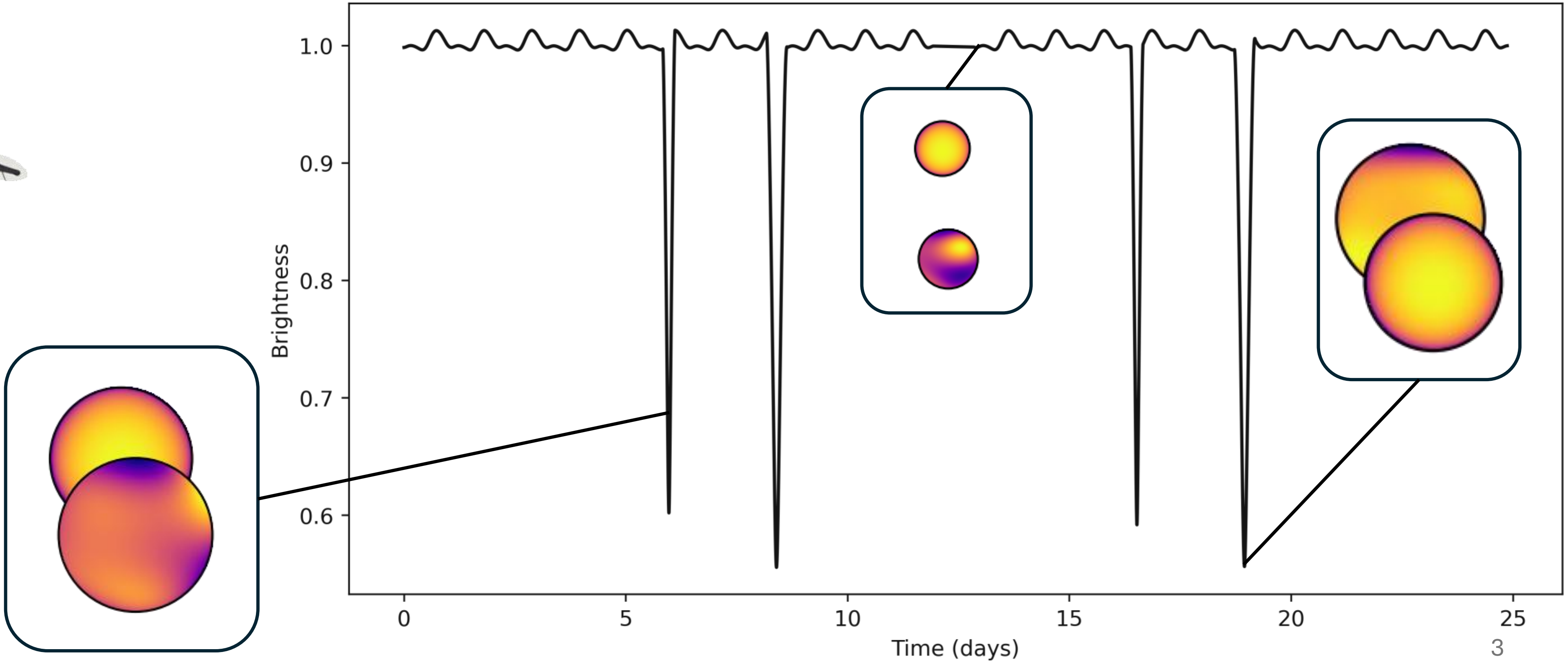


- Undergrad + Honours at the University of Queensland
- I love some science outreach
  - Writer for astrobites
  - Always looking for more public outreach e.g. solar telescopes, talks
- Recently moved to Sydney for MRes+PhD at Macquarie with Orsola De Marco and Ben Pope

astrobites
THE ASTRO-PH READER'S DIGEST | SUPPORTED BY THE AAS

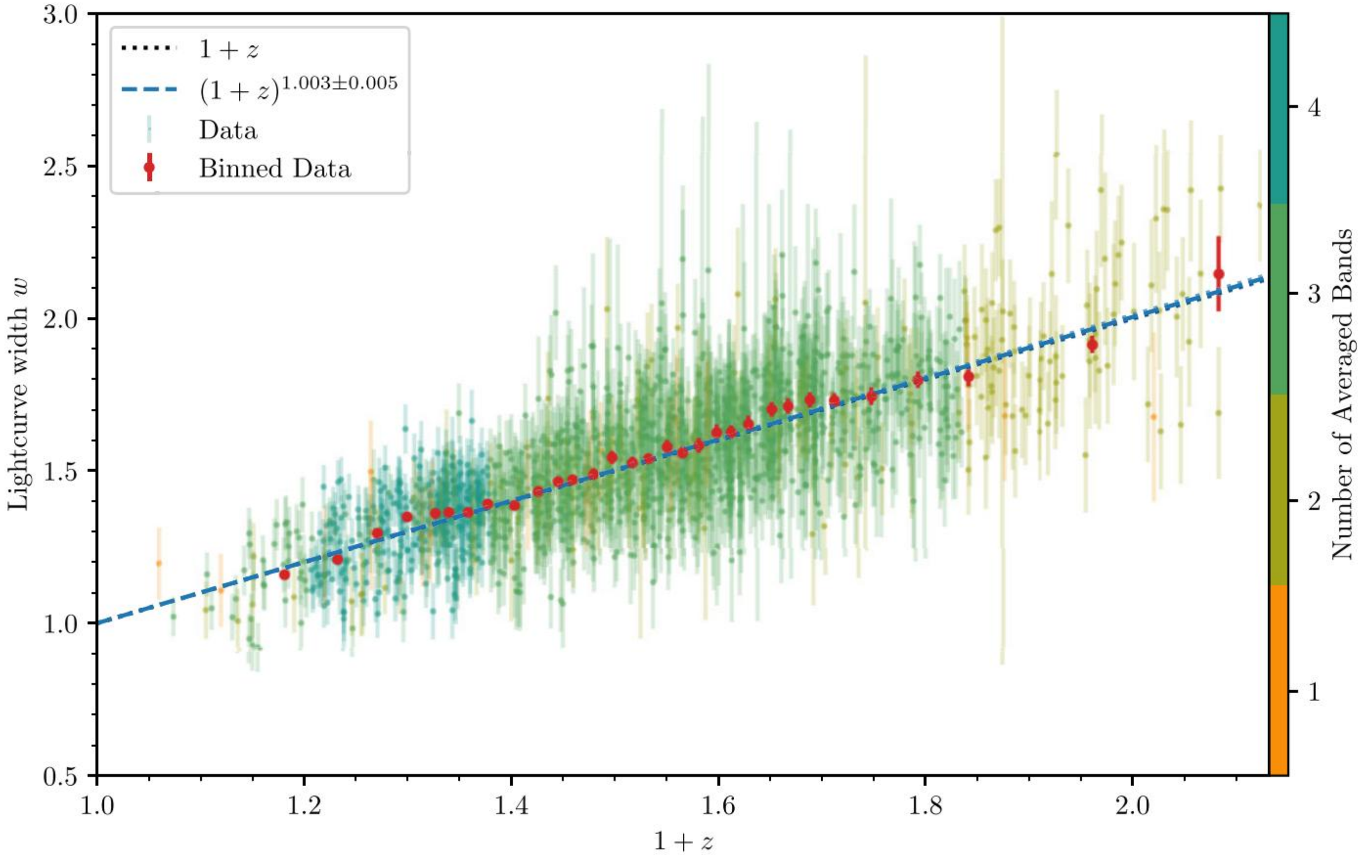
My previous work… at Uni of Queensland

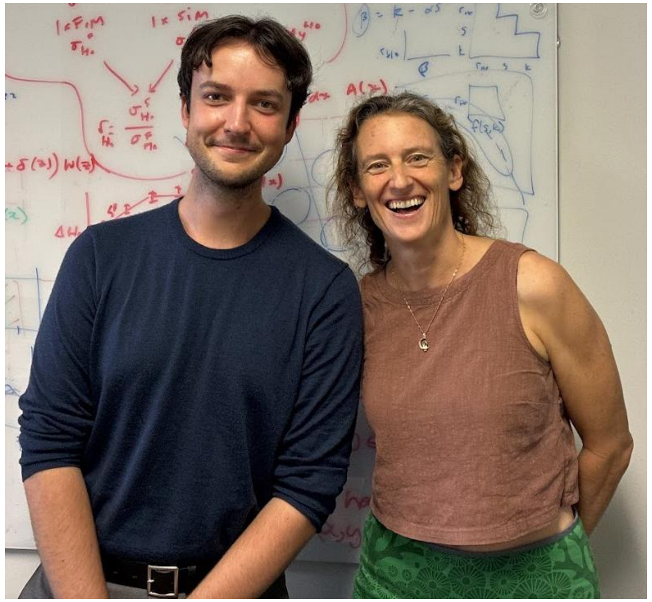
- Worked with Benjamin Pope and Shashank Dholakia to map the surface of the stars in DI Herculis using its TESS light curve



My previous work… at Uni of Queensland

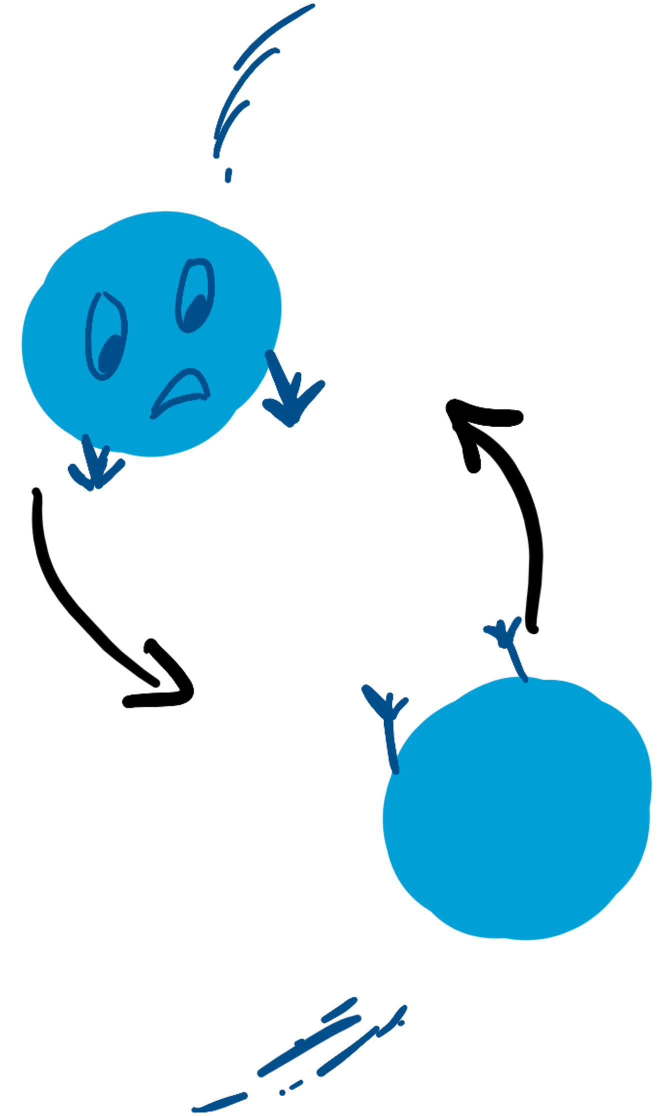
- Worked with Tamara Davis to show cosmological time dilation in ~1500 Type Ia supernovae from the Dark Energy Survey (DES)



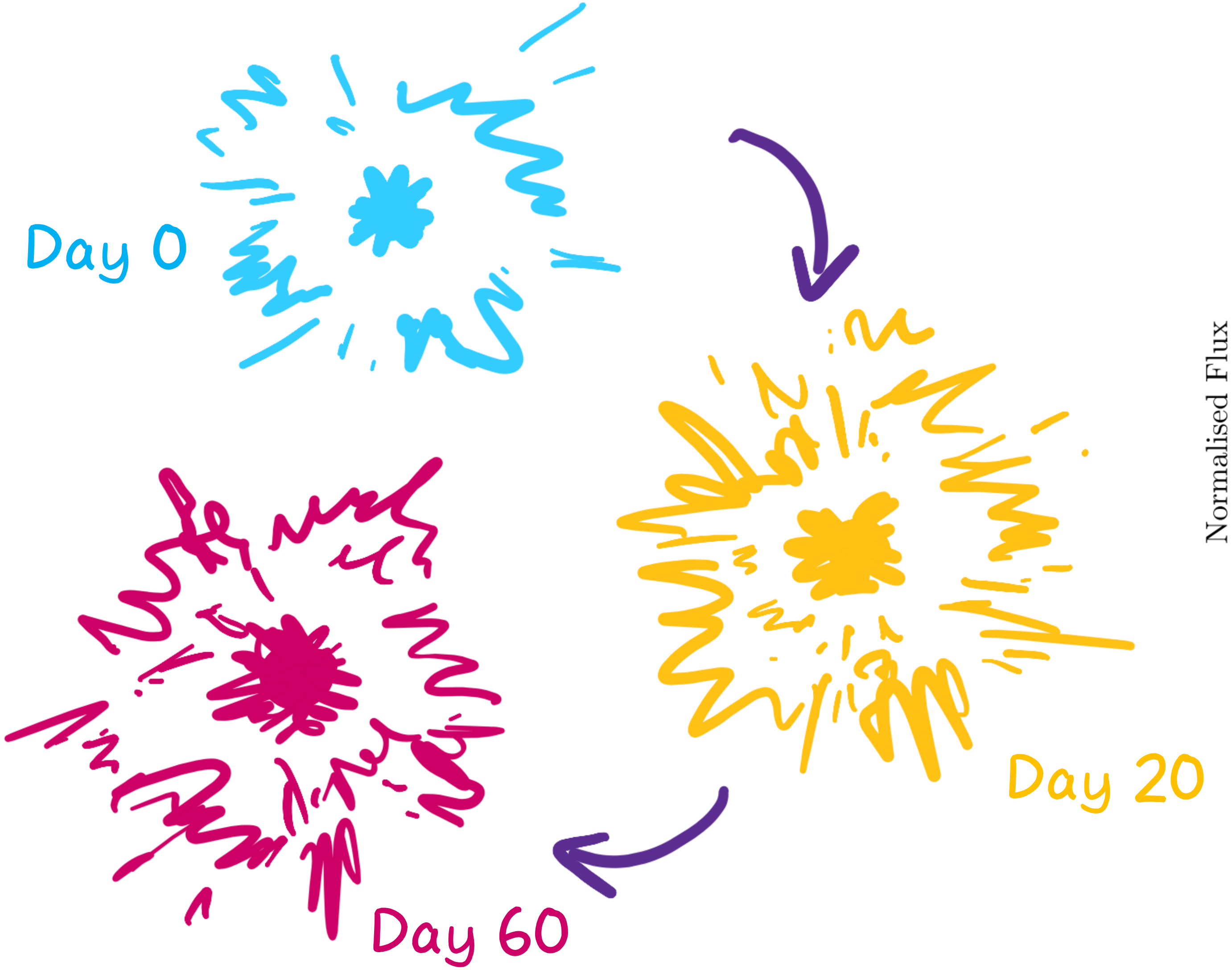


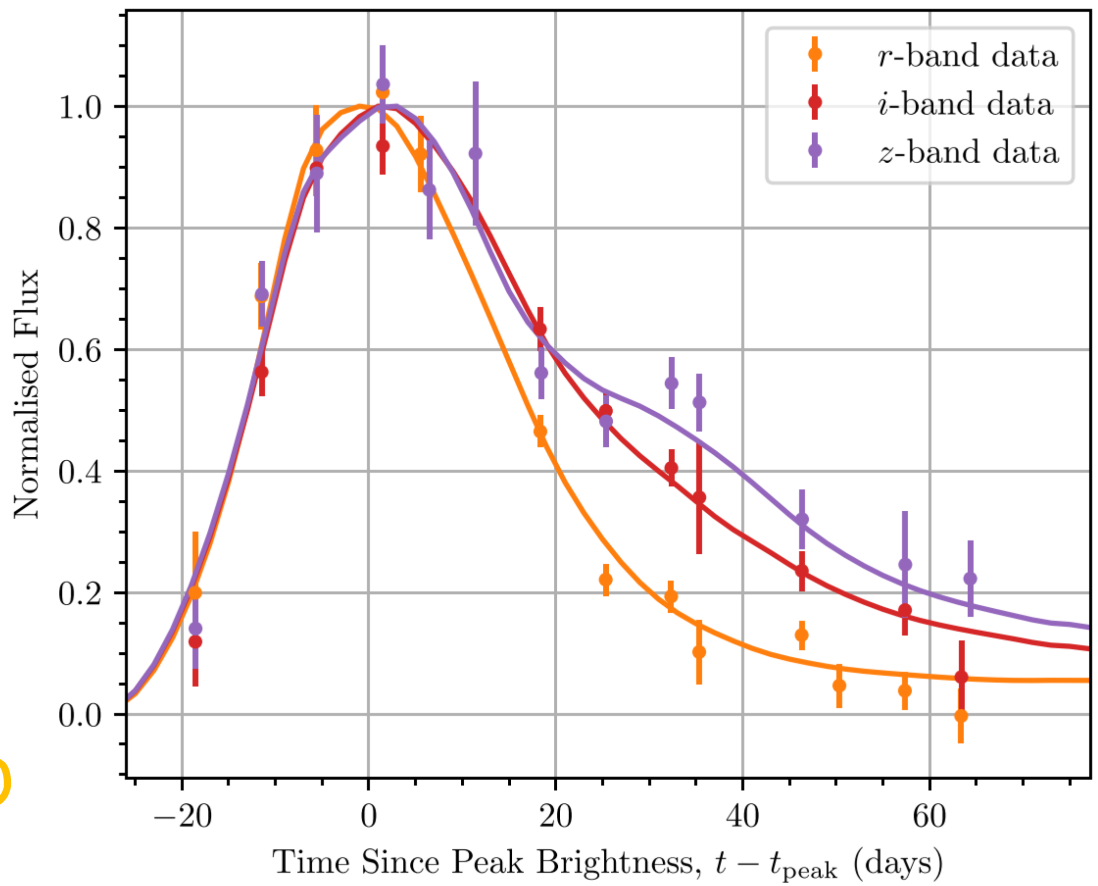
My previous work... at UQ

or

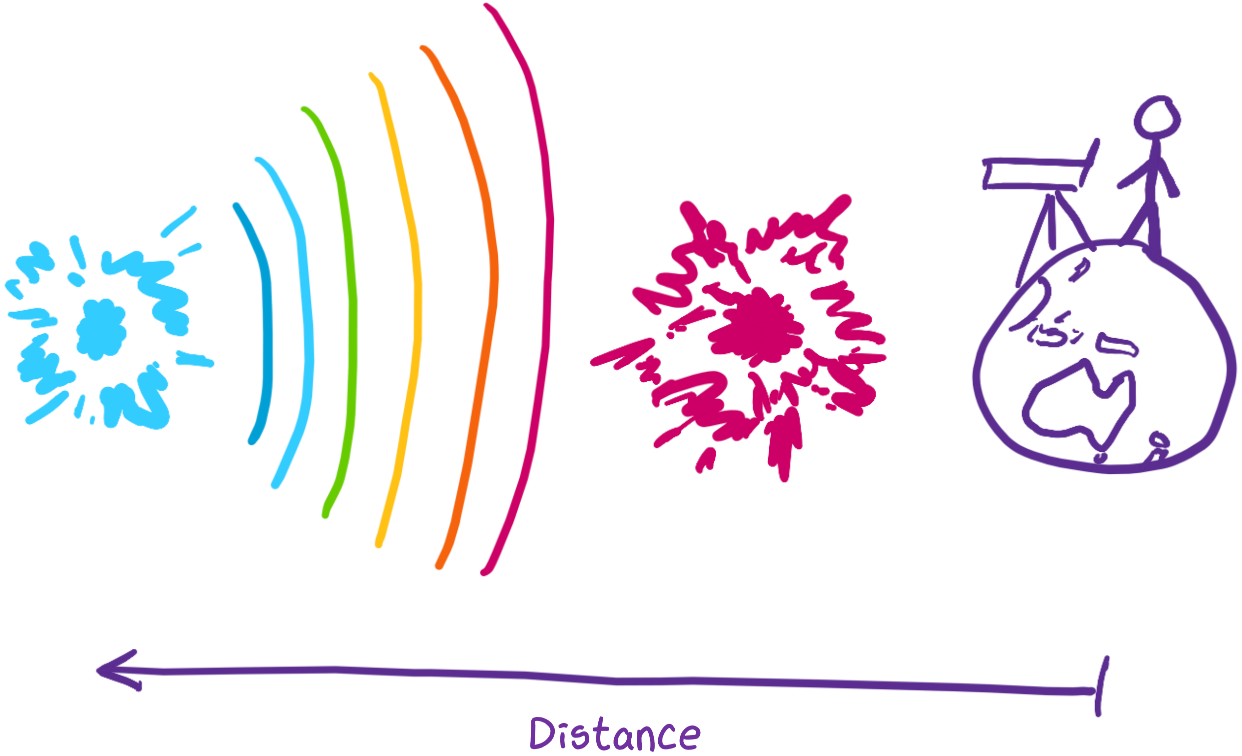


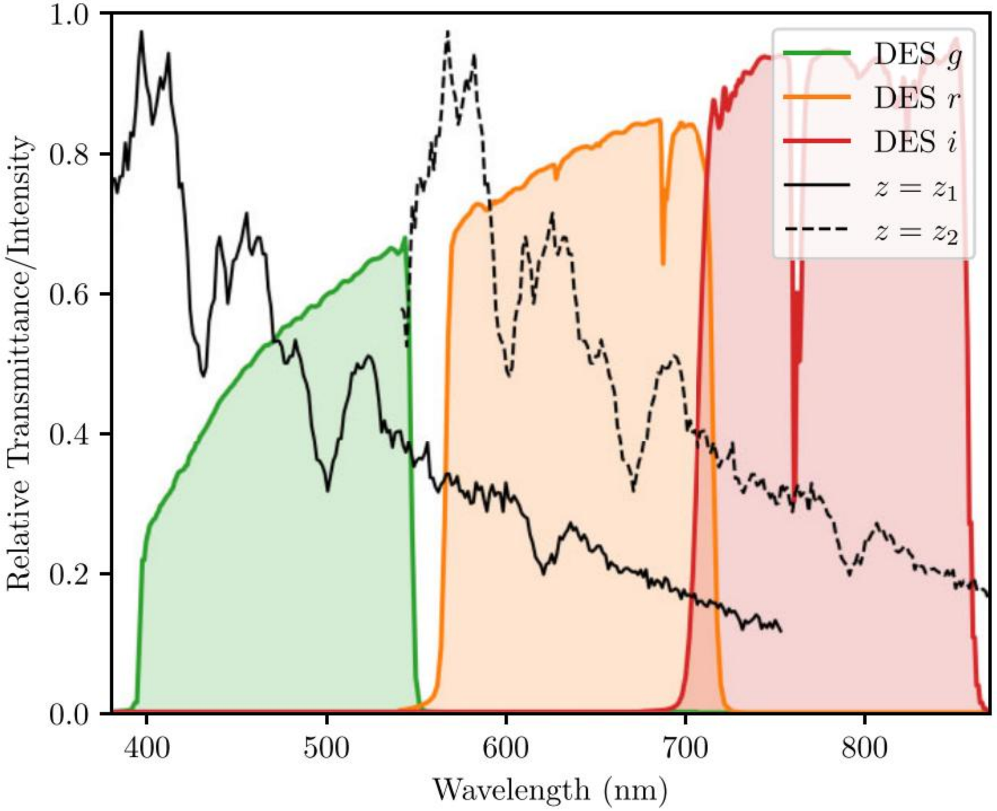
My previous work... at UQ



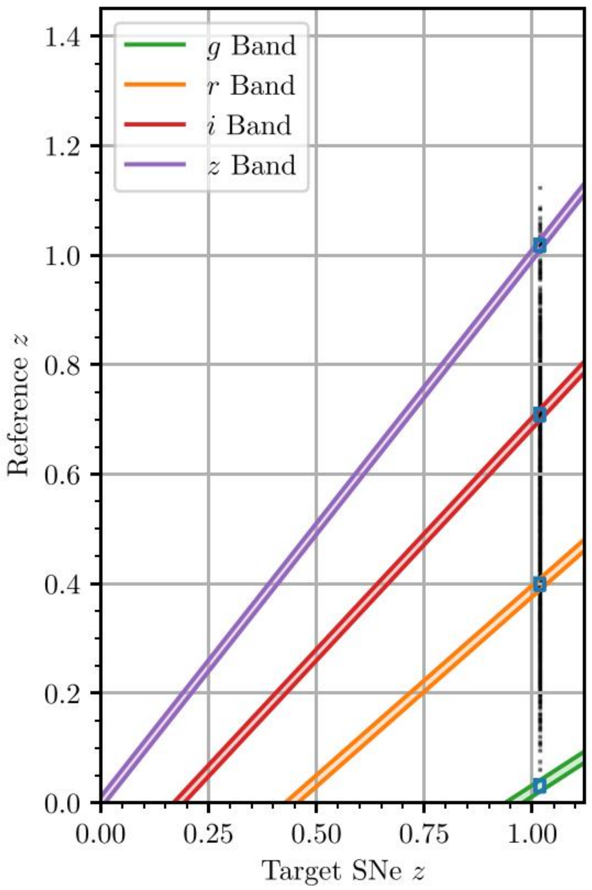


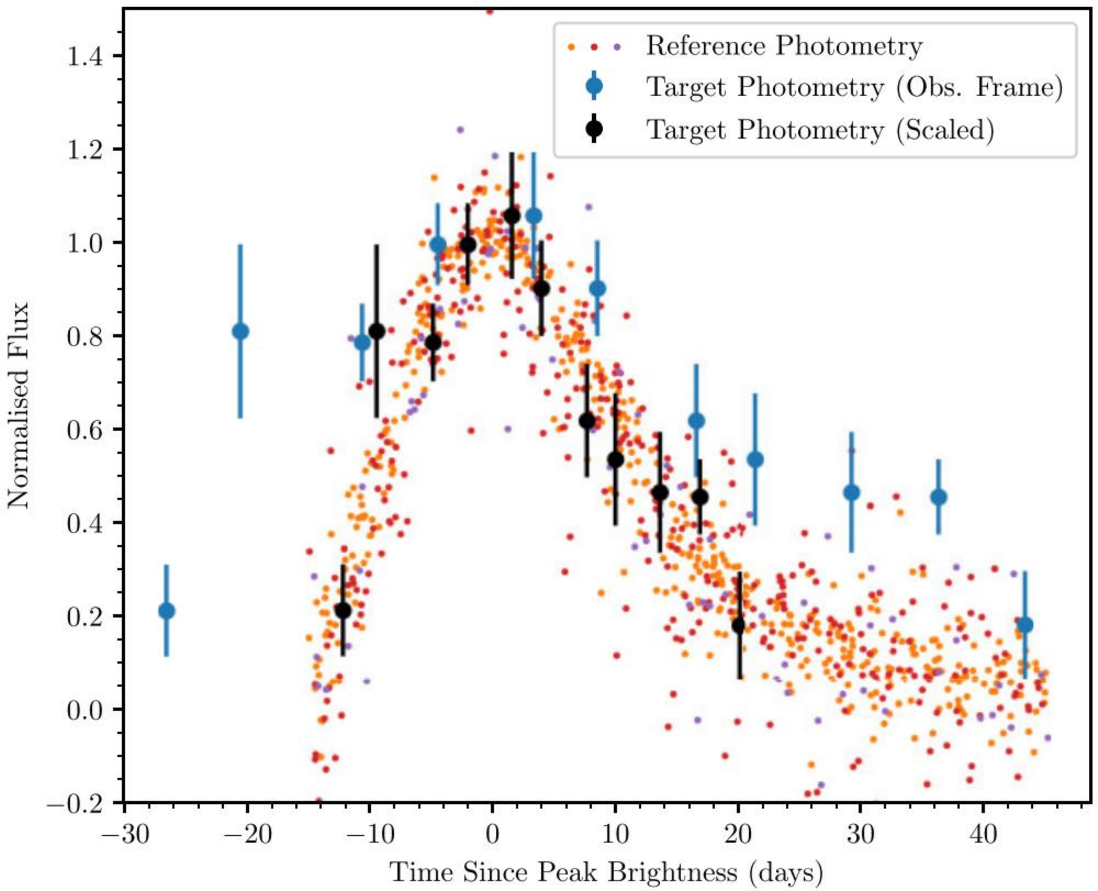
My previous work... at UQ



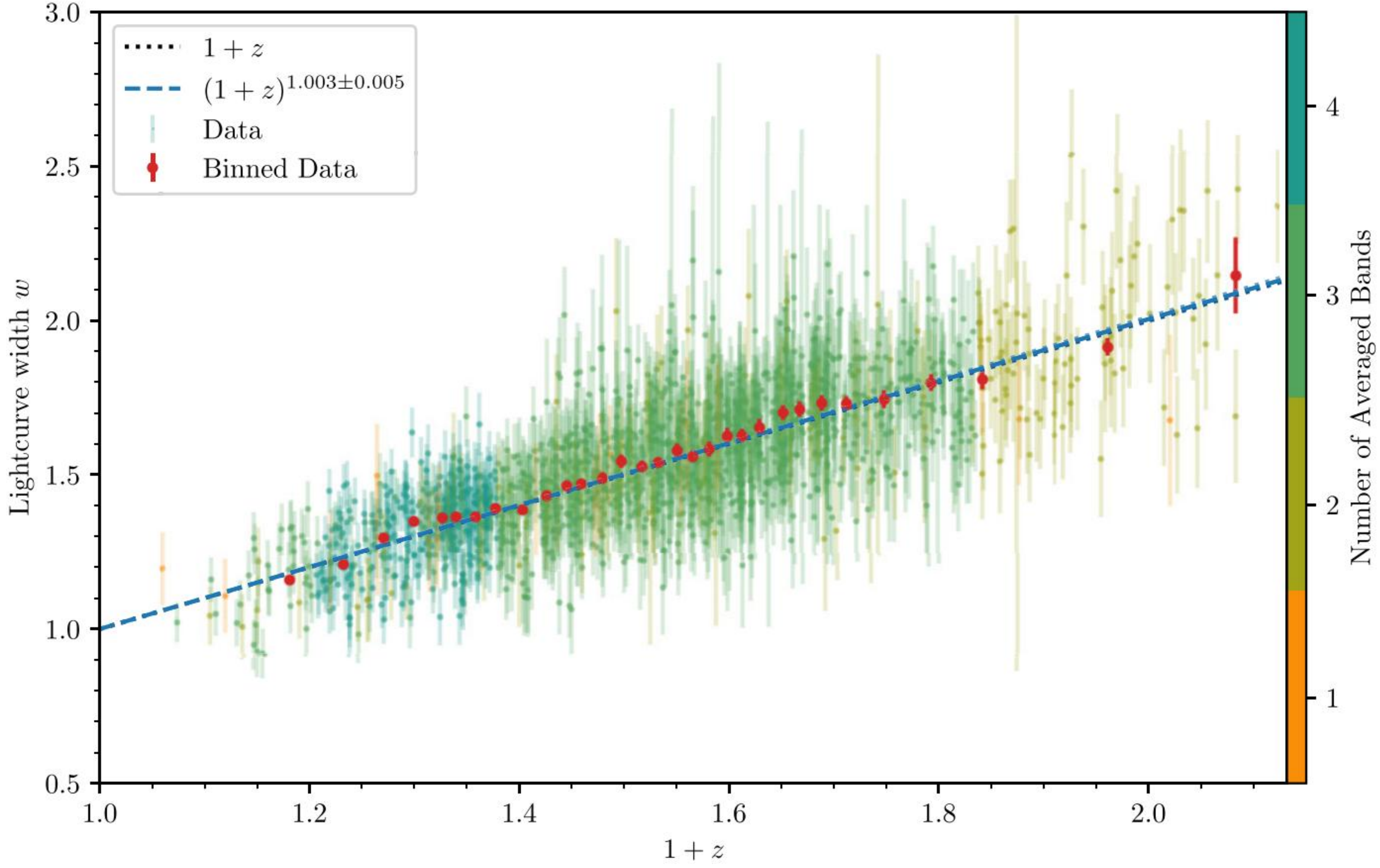


My previous work... at UQ



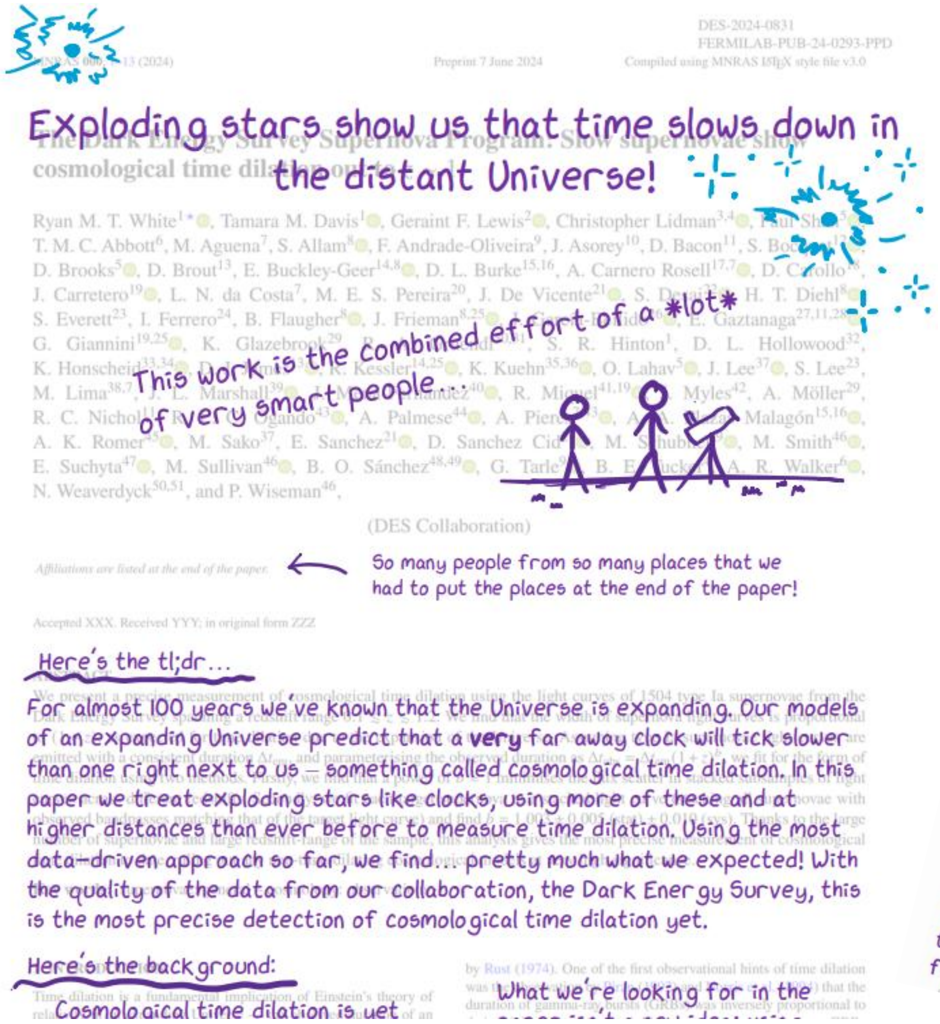


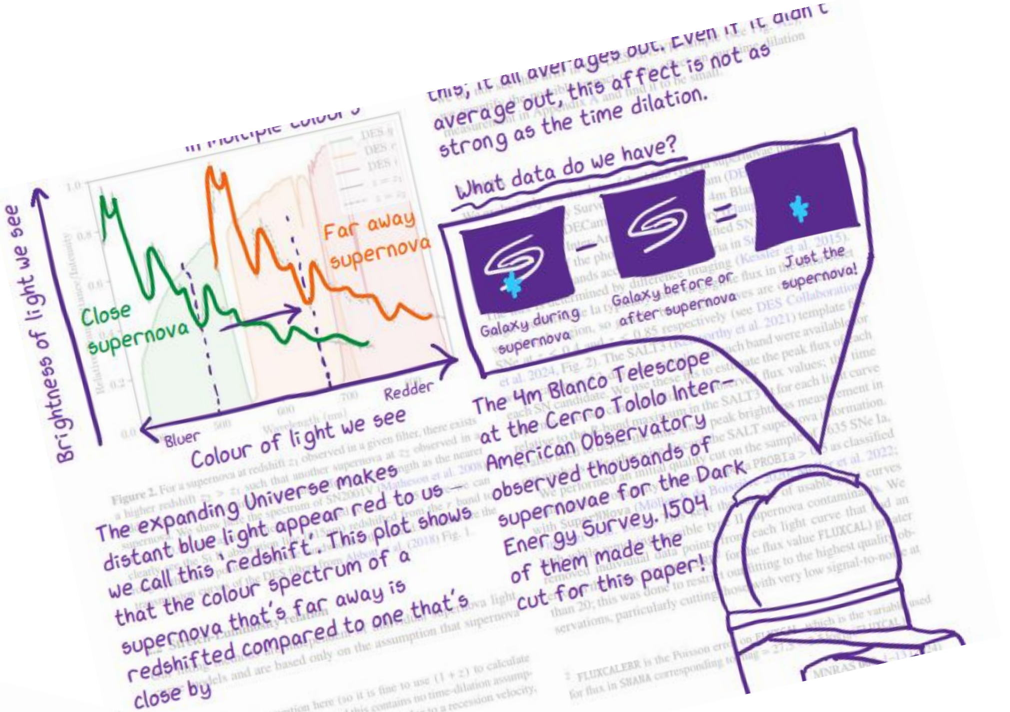
My previous work... at UQ

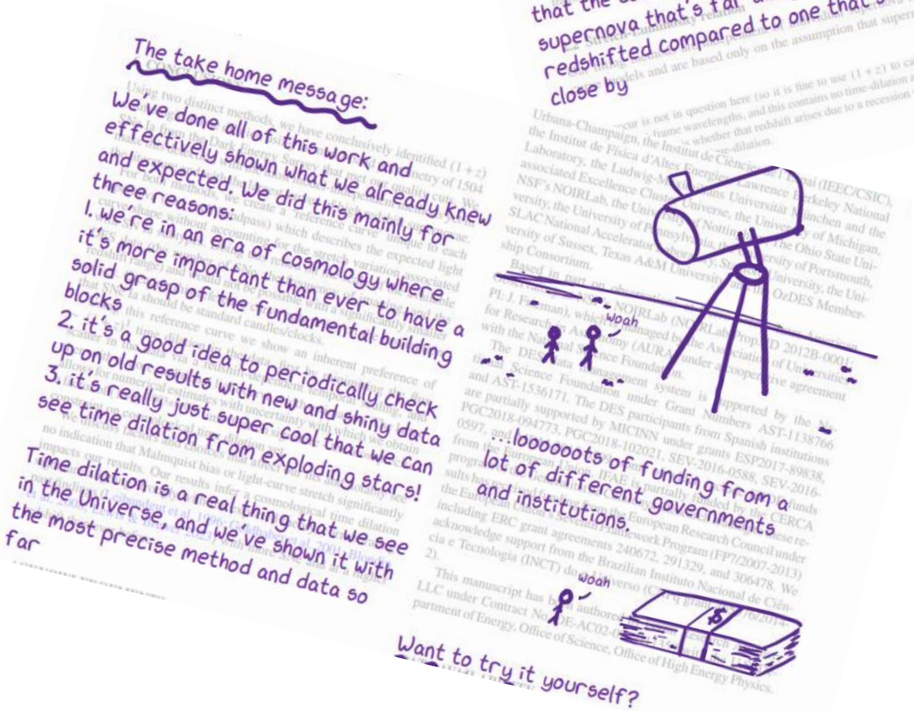


White, R. M. T., et al. (2024) "The Dark Energy Survey Supernova Program: slow supernovae show cosmological time dilation out to z~1.", MNRAS, 533, 3365

My previous work... at UQ



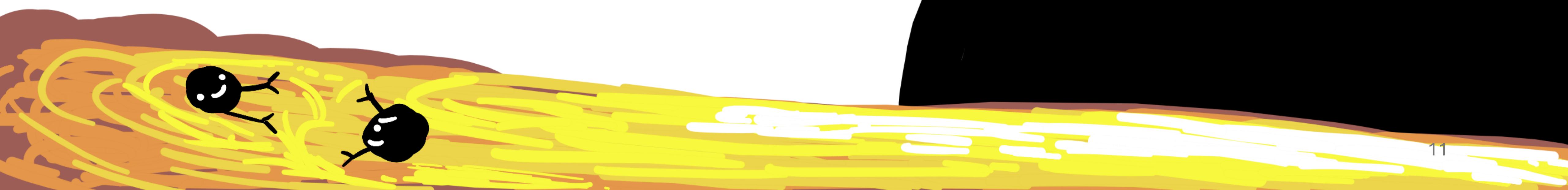




ryanwhite1.github.io/time-dilation.html

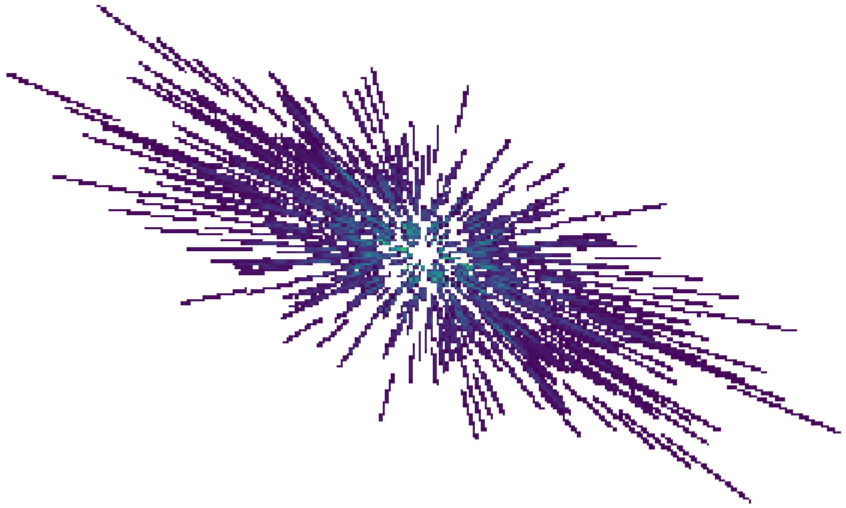
My previous work… at Swinburne

- Investigated the AGN channel of binary black hole mergers with Simon Stevenson
- Integrating numerical relativity and disk models into the REBOUND code
- This channel could explain very massive (hierarchical) mergers such as GW190521

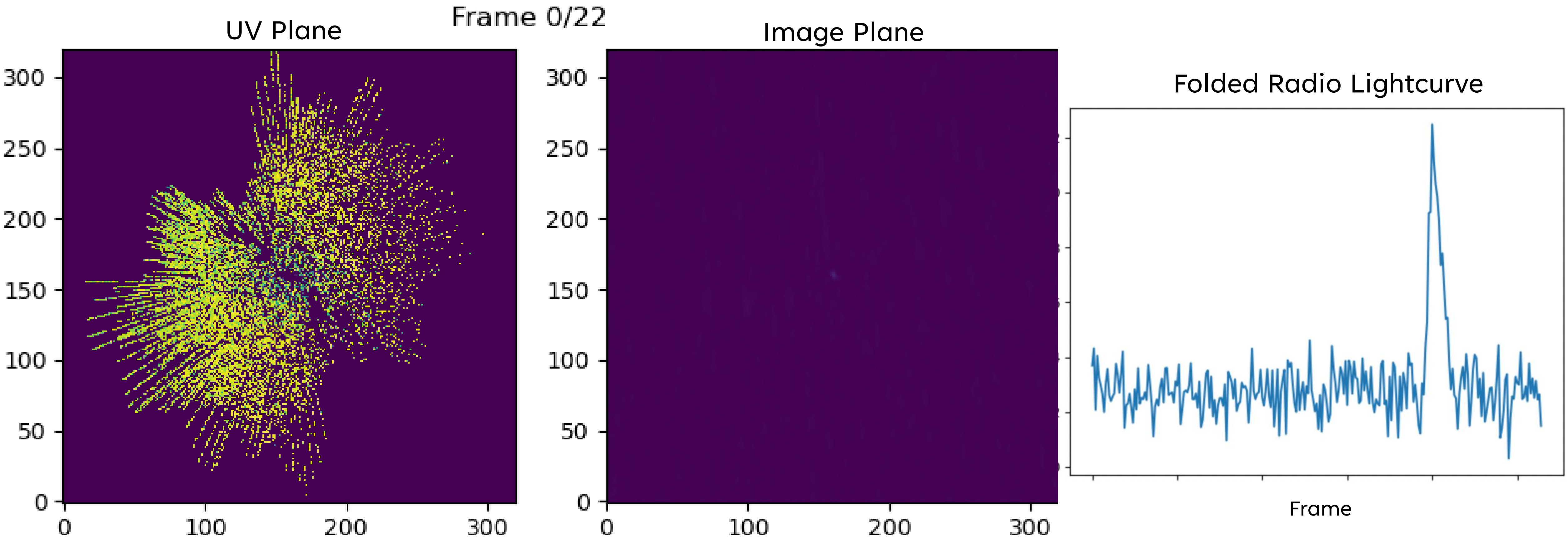


My previous work... at CSIRO

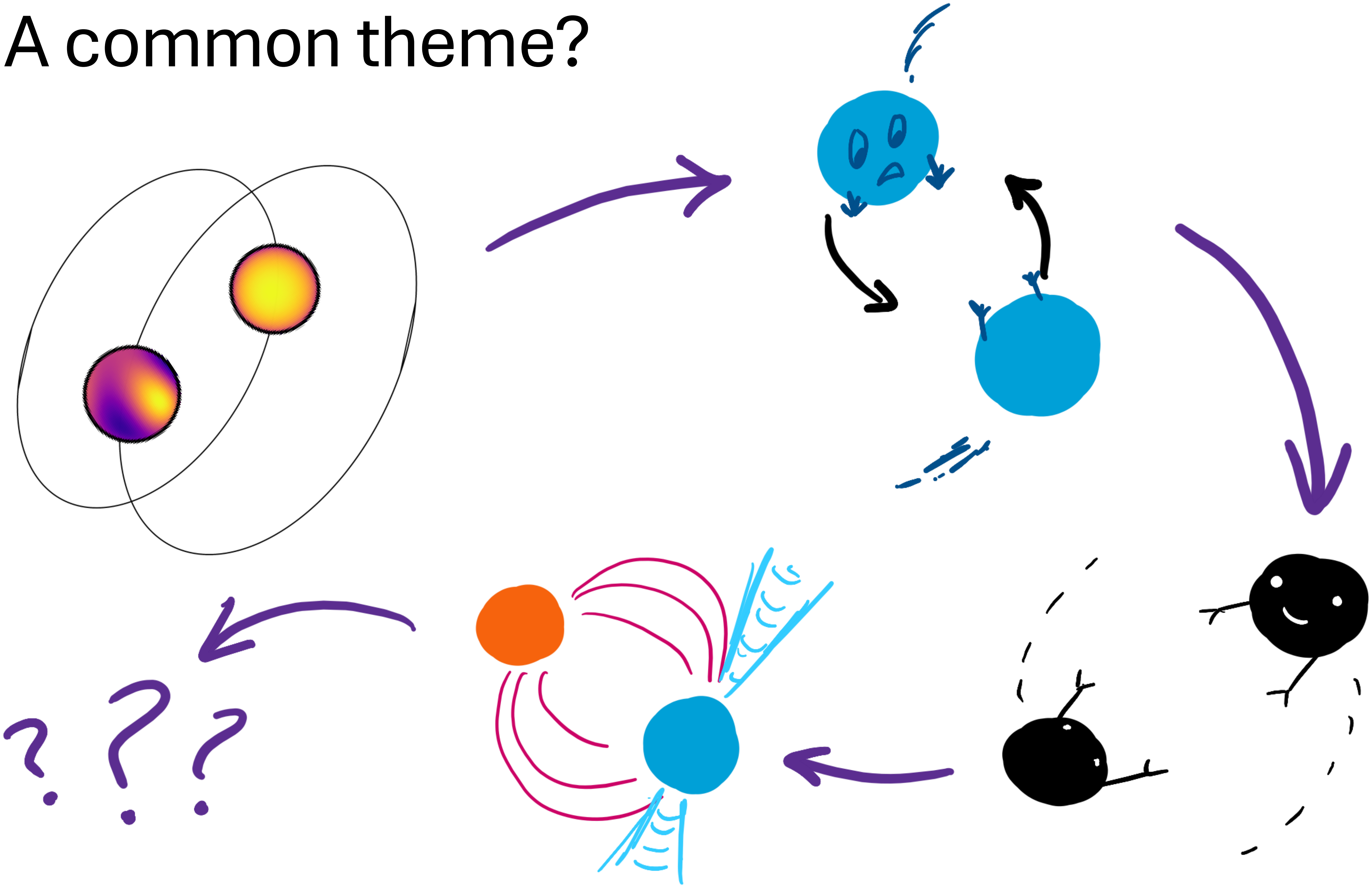
- Developed a new method to search for Long Period Radio Transients with Andrew Zic
- Transients are traditionally looked for by searching pixel by pixel in a set of images
- With radio interferometric data, we can save computation (and time) by directly folding visibilities at trial periods



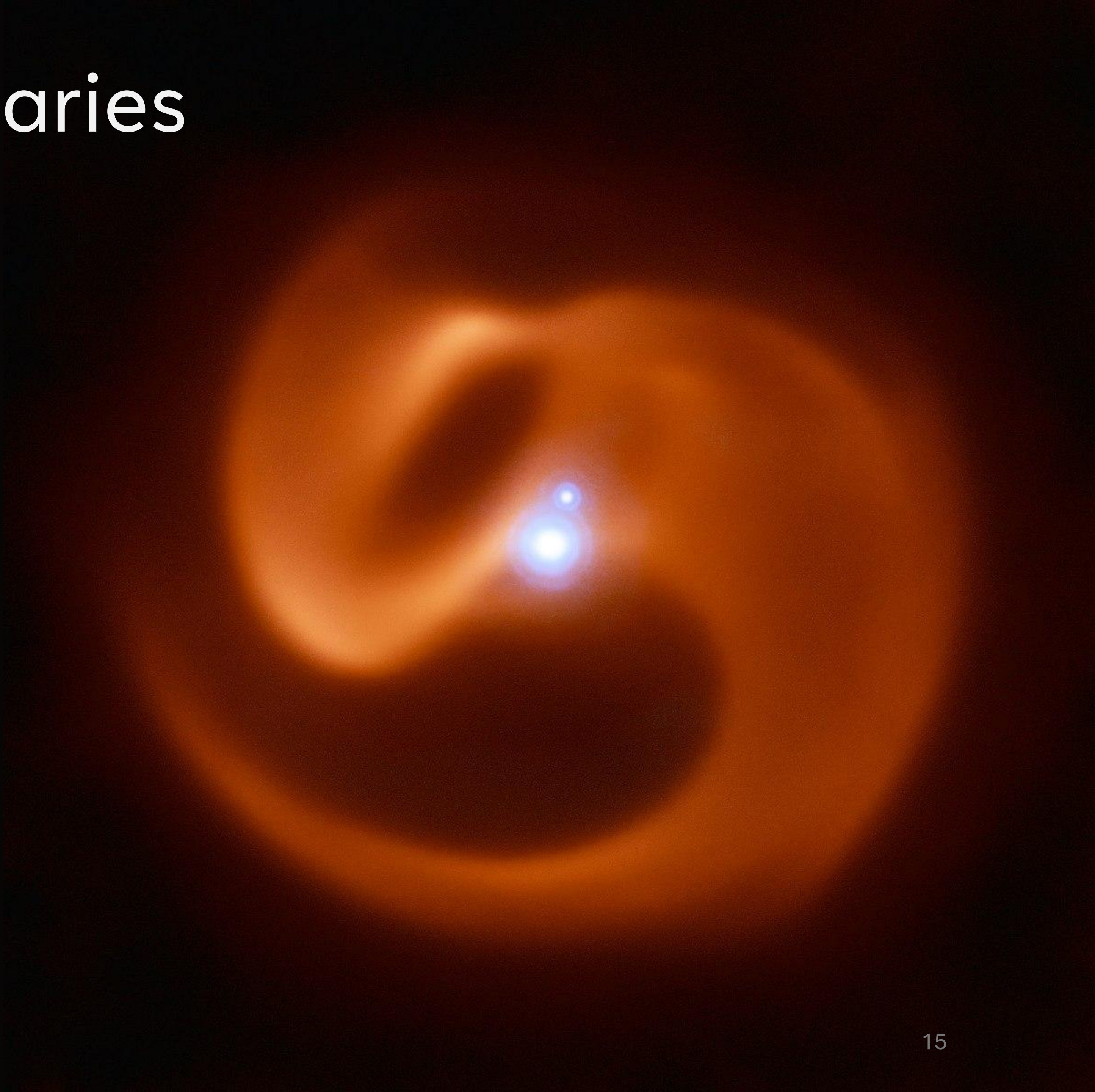
My previous work... at CSIRO



A common theme?

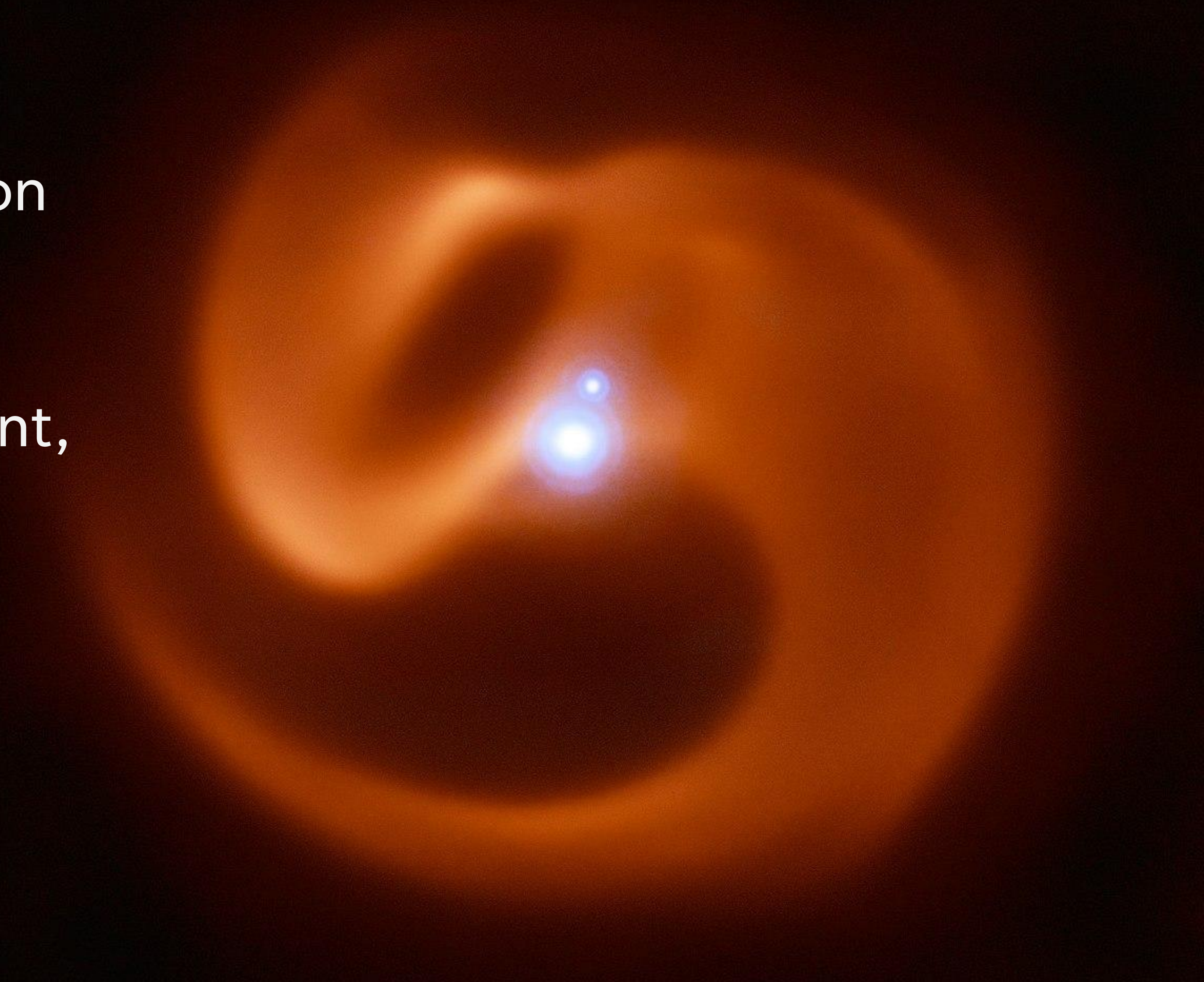


Colliding Wind Binaries



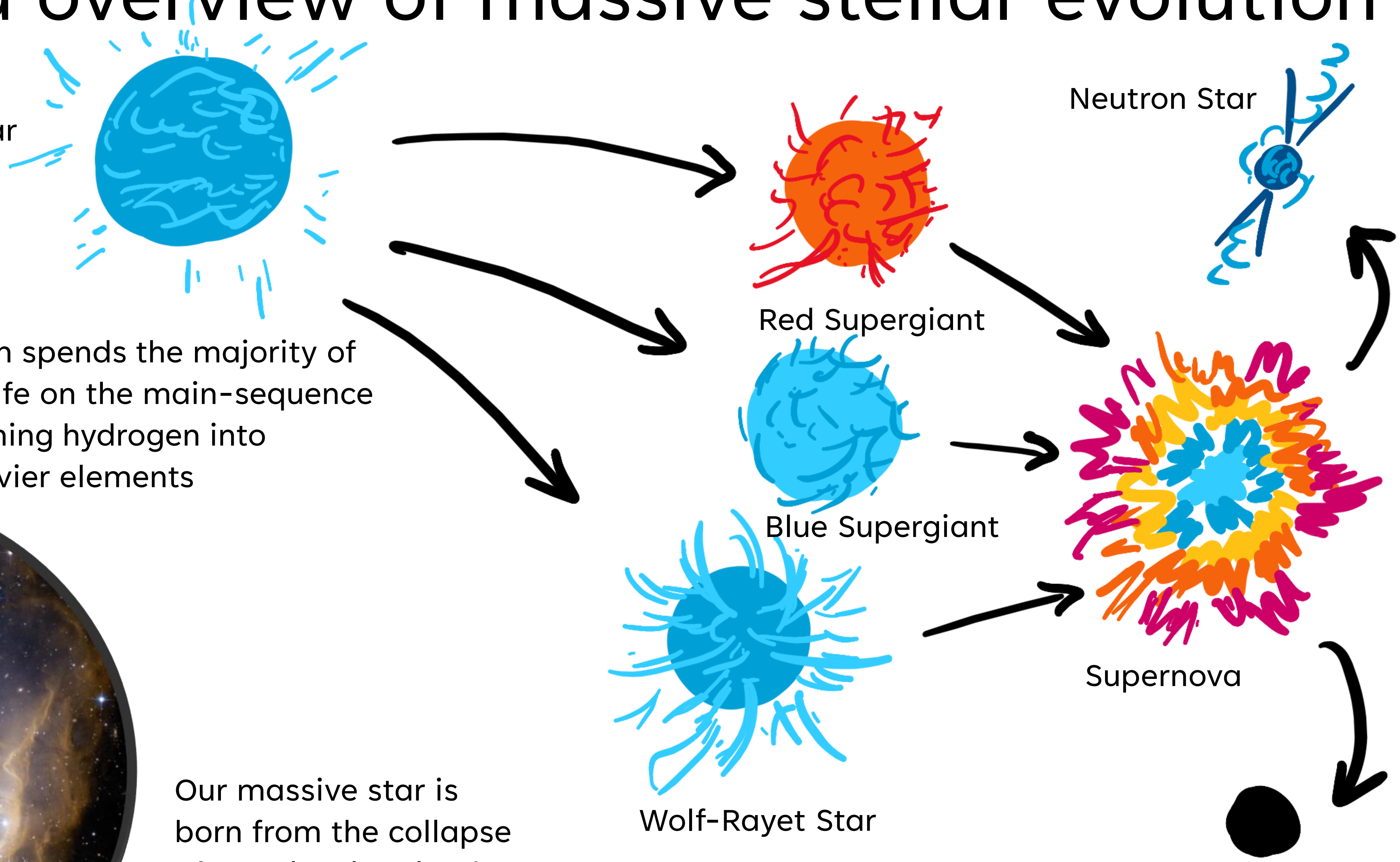
Colliding Wind Binaries

- Are the dominant influences on their environment,
- made up a large part of the Universe’s early carbon content,
- allow us to peer into binary stellar evolution and the evolution of massive stars,
- and just look unreasonably cool.



Apep with ESO’s VLT

A broad overview of massive stellar evolution



Then spends the majority of its life on the main-sequence burning hydrogen into heavier elements

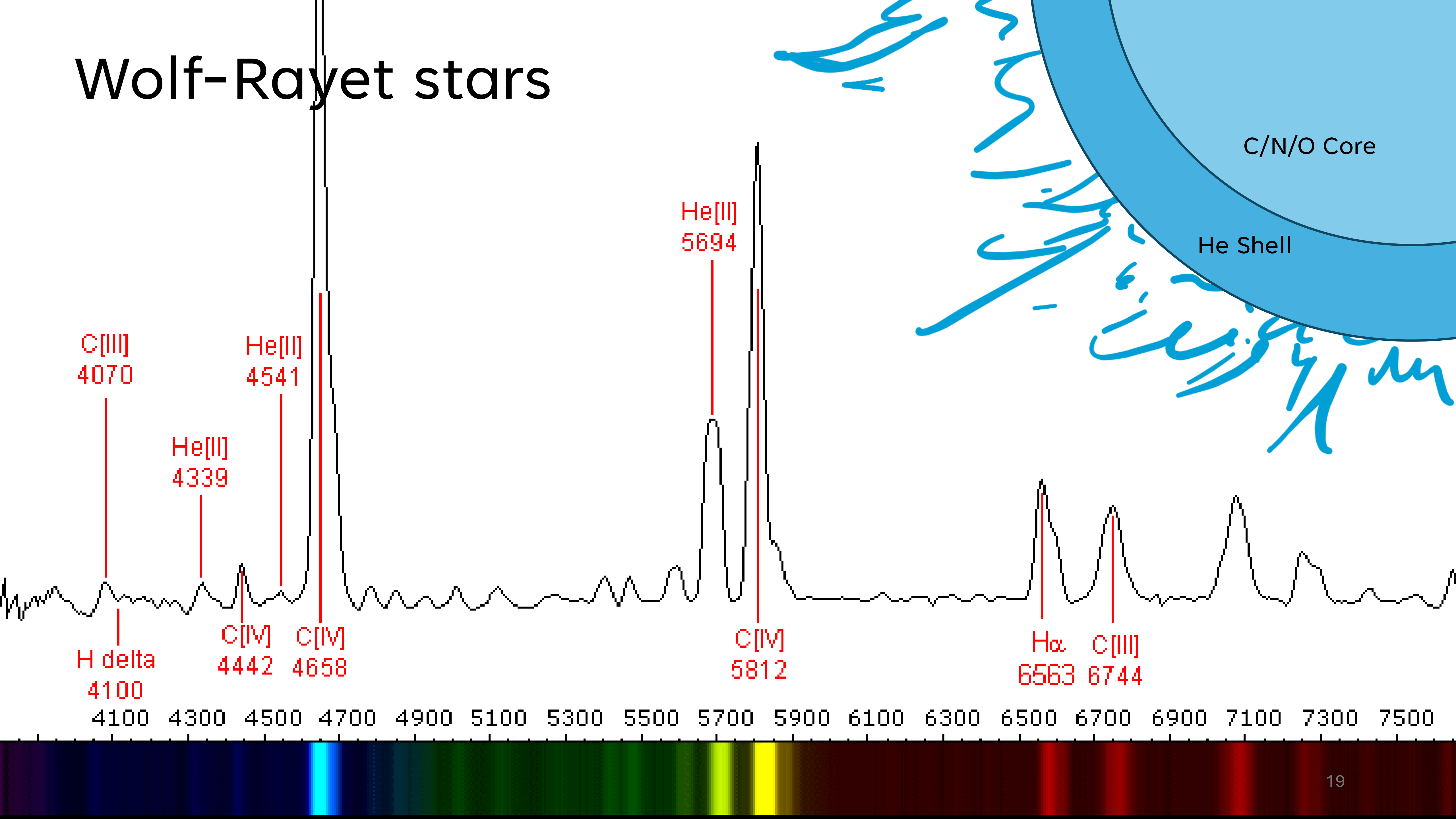
Our massive star is born from the collapse of a molecular cloud

Wolf-Rayet stars

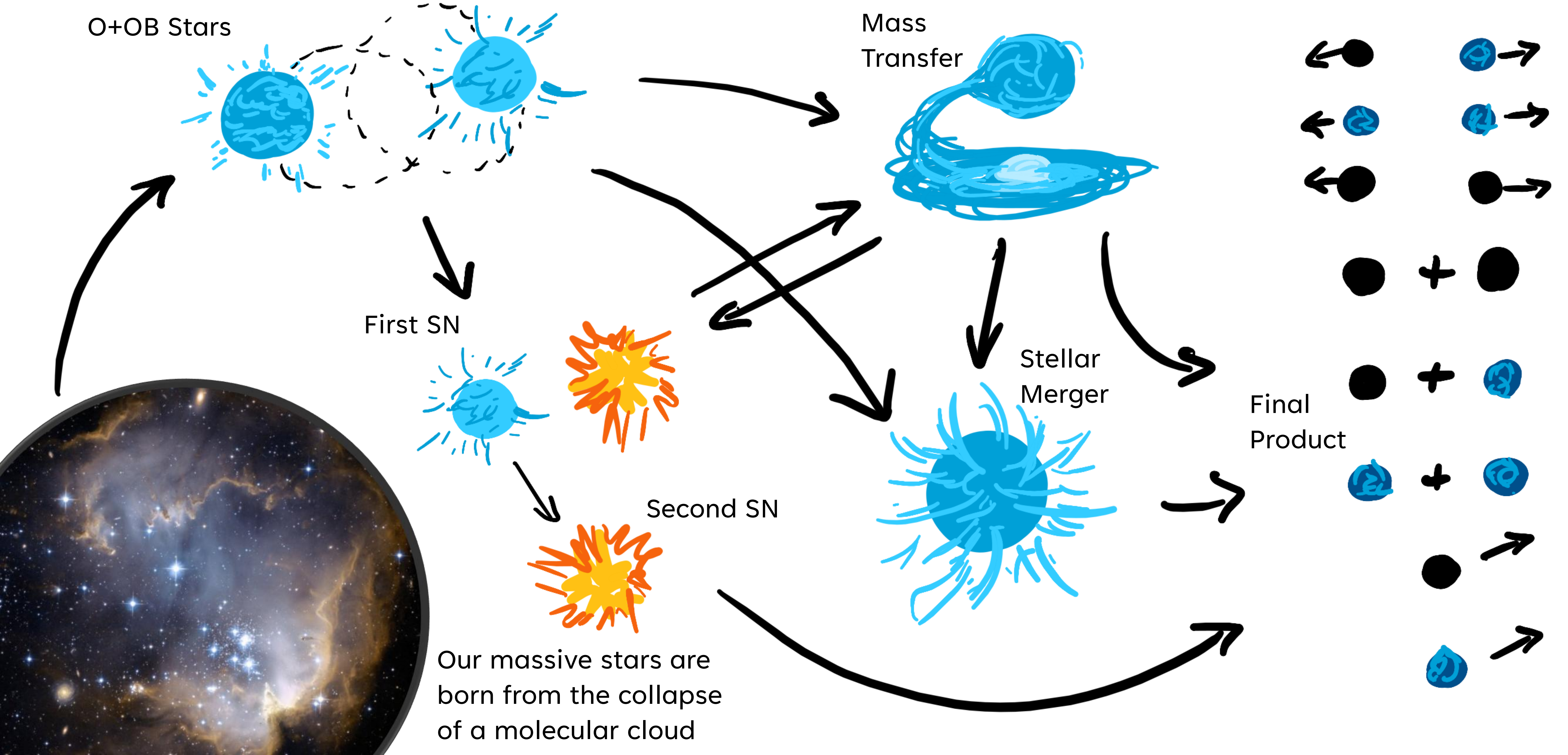
- End-of-life phase of the most massive stars
  - Very short lived and rare
- Extremely high mass loss rates and fast winds
  - ~10^{-5}-10^{-4} $M_{\odot}$/yr
  - 500-3000 km/s
- Ib/c SNe progenitors

WR 124 with NASA/ESA's JWST

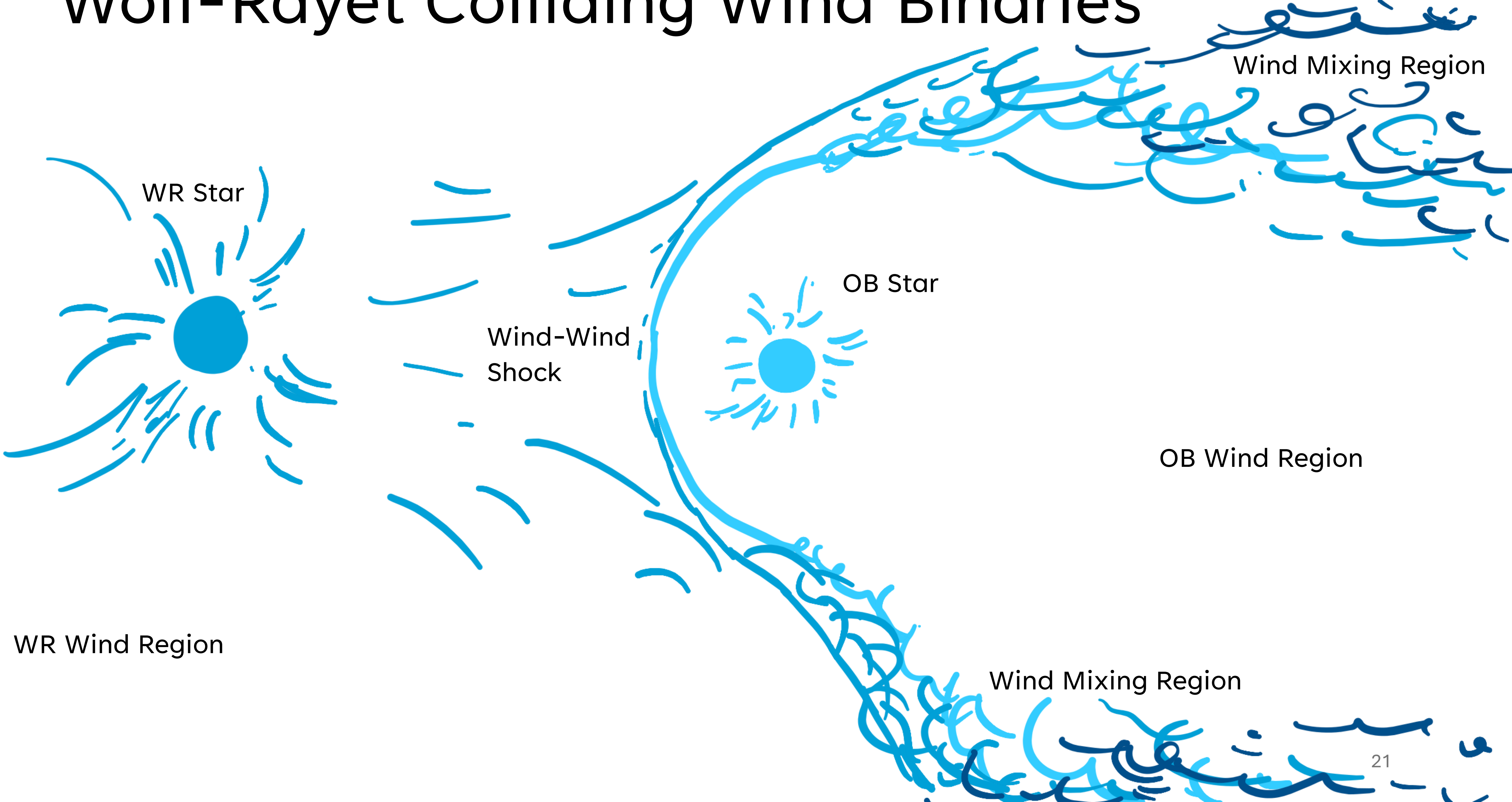
Wolf-Rayet stars



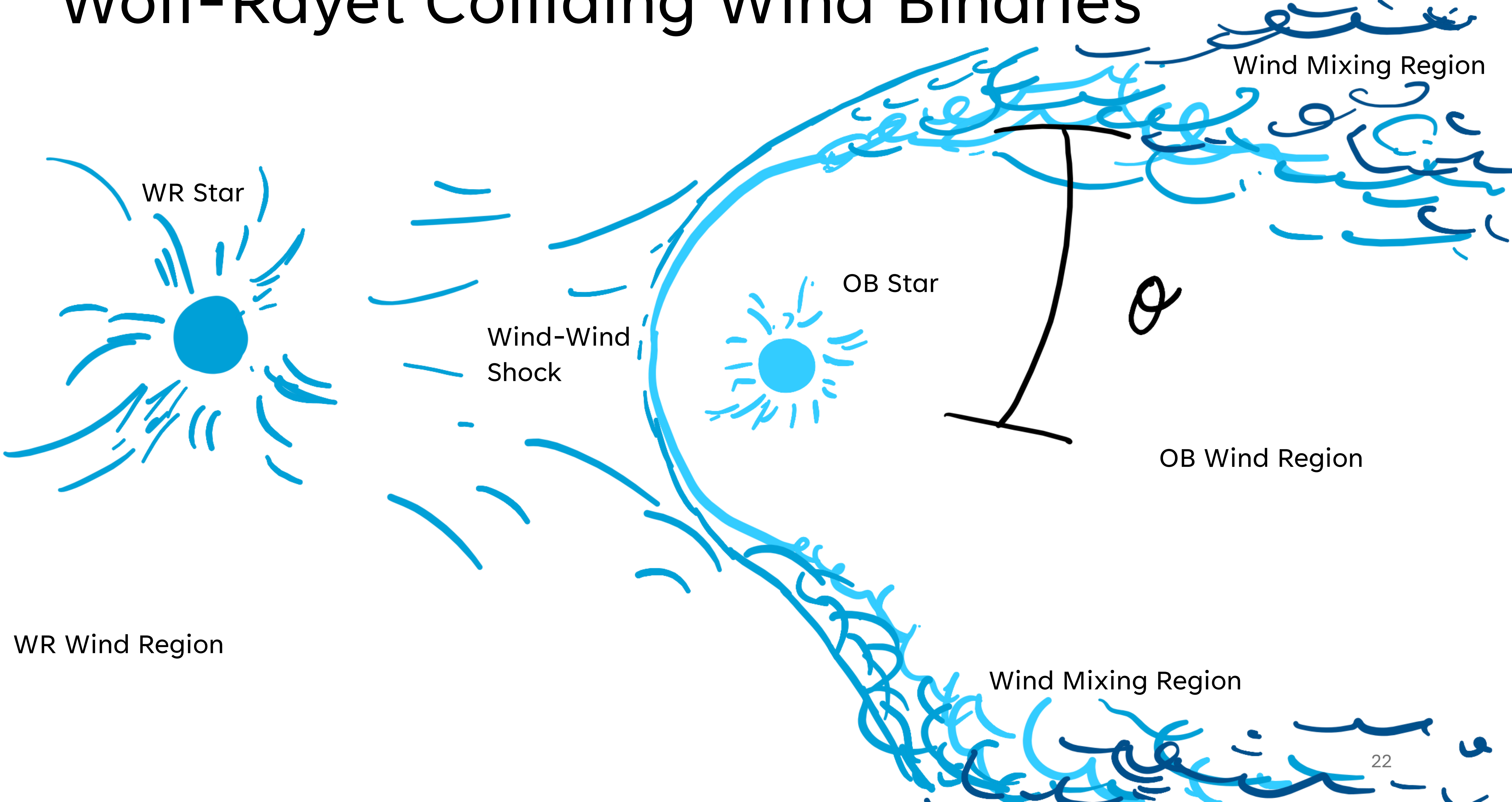
A broad overview of massive binary stellar evolution



Wolf-Rayet Colliding Wind Binaries

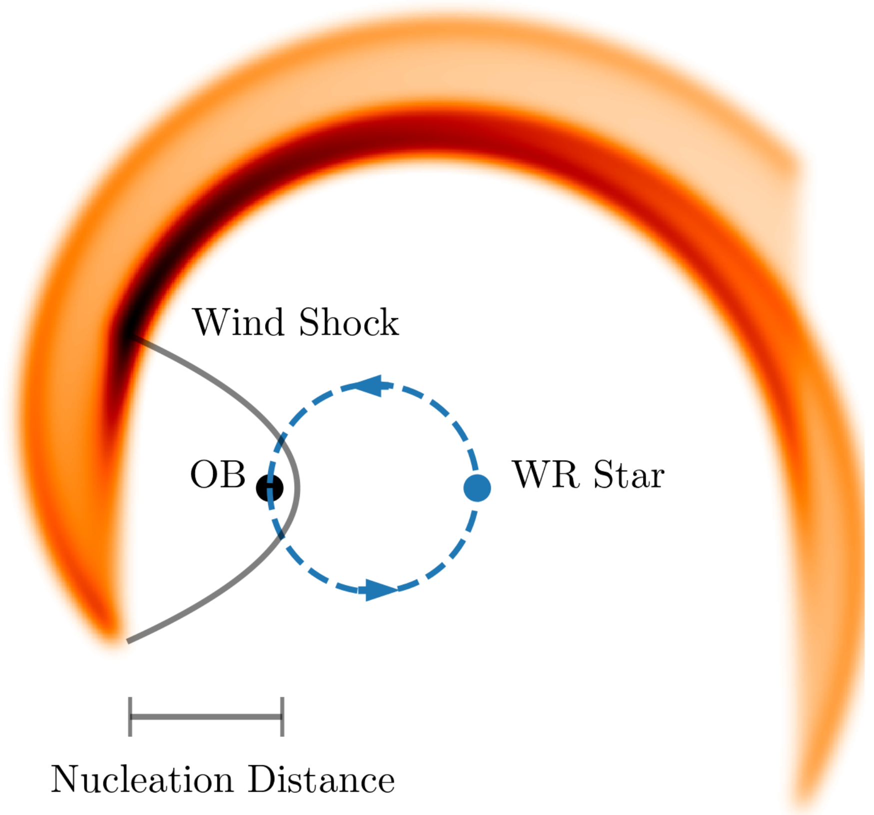


Wolf-Rayet Colliding Wind Binaries



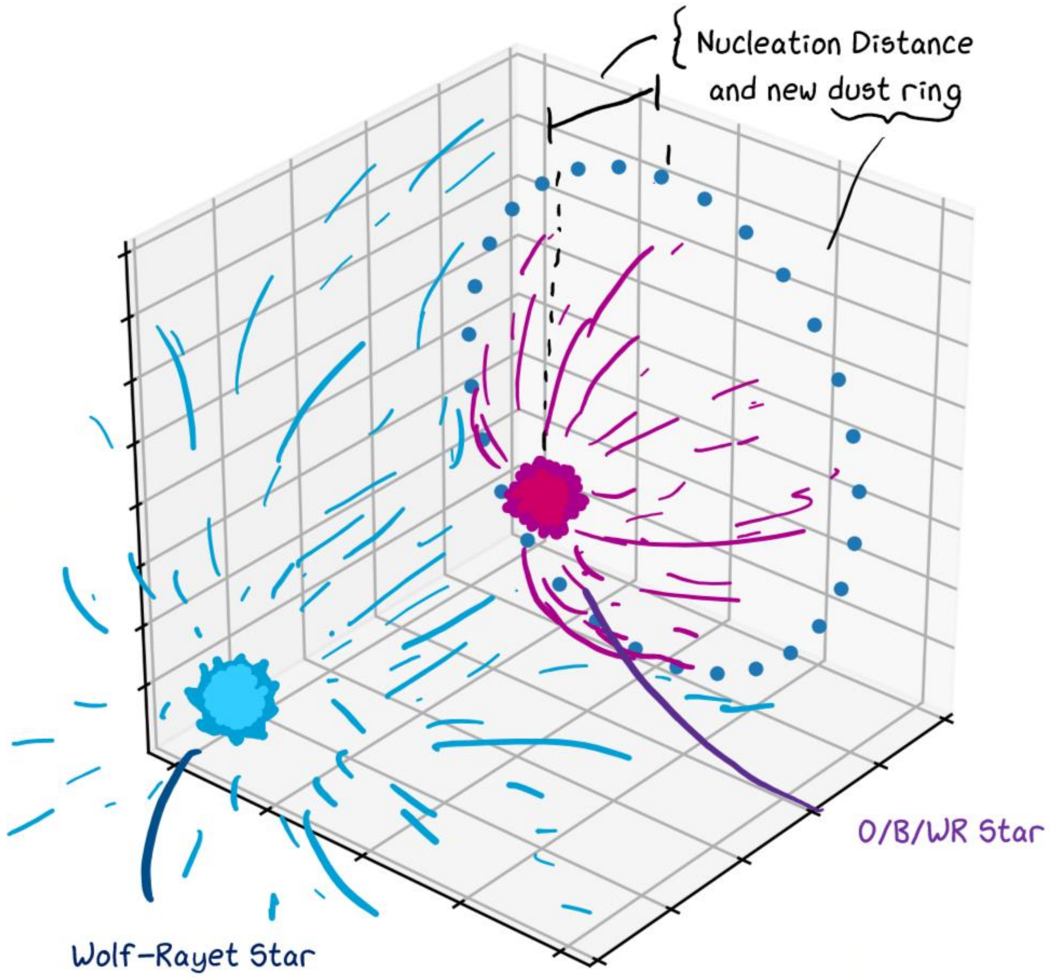
Wolf-Rayet Colliding Wind Binaries

- Intense dust formation takes place in systems with WC stars
    - Forms in a hollow cone tracing the shocked wind
    - This occurs far enough ‘downstream’ of the shock once the wind is mixed and cooled
- The dust expands away from the stars
- The orbital motion of the binary wraps this dust into a spiral

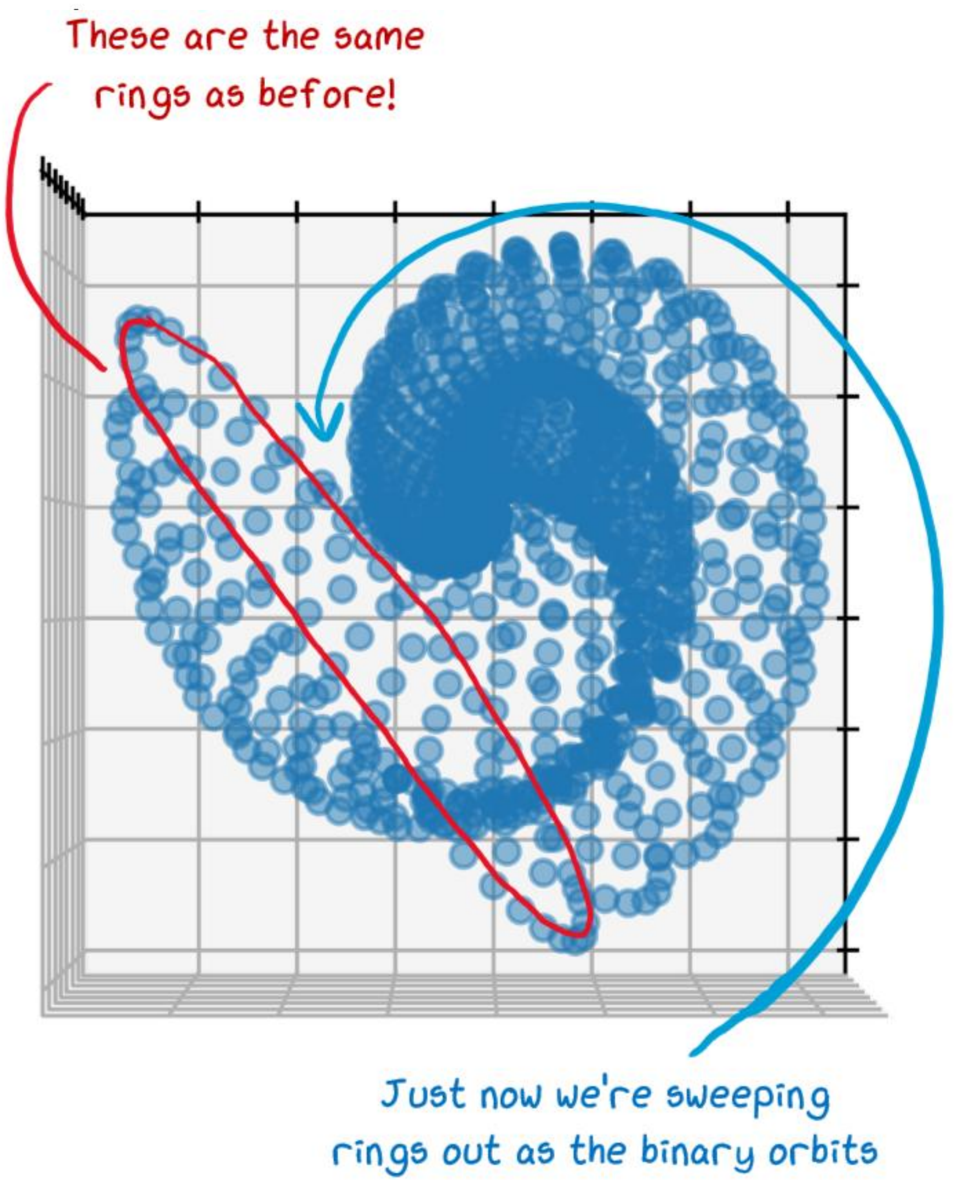


Modelling using geometry

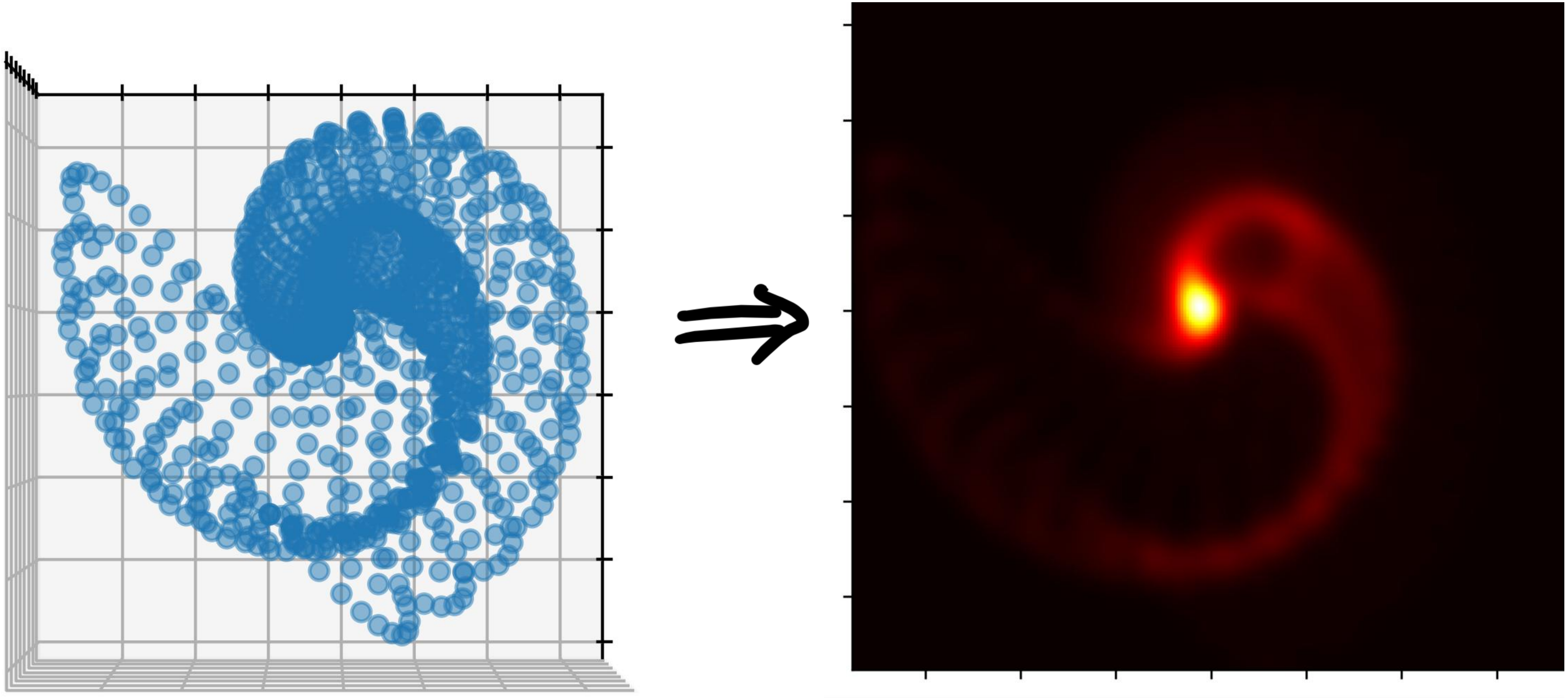
- Model the orbits of the two stars
- The wind-wind shock enshrouds the star with the weaker wind
- Dust nucleation occurs on the surface of the conical shock
- At each point in time, we approximate this dust nucleation as a ring of particles on the surface



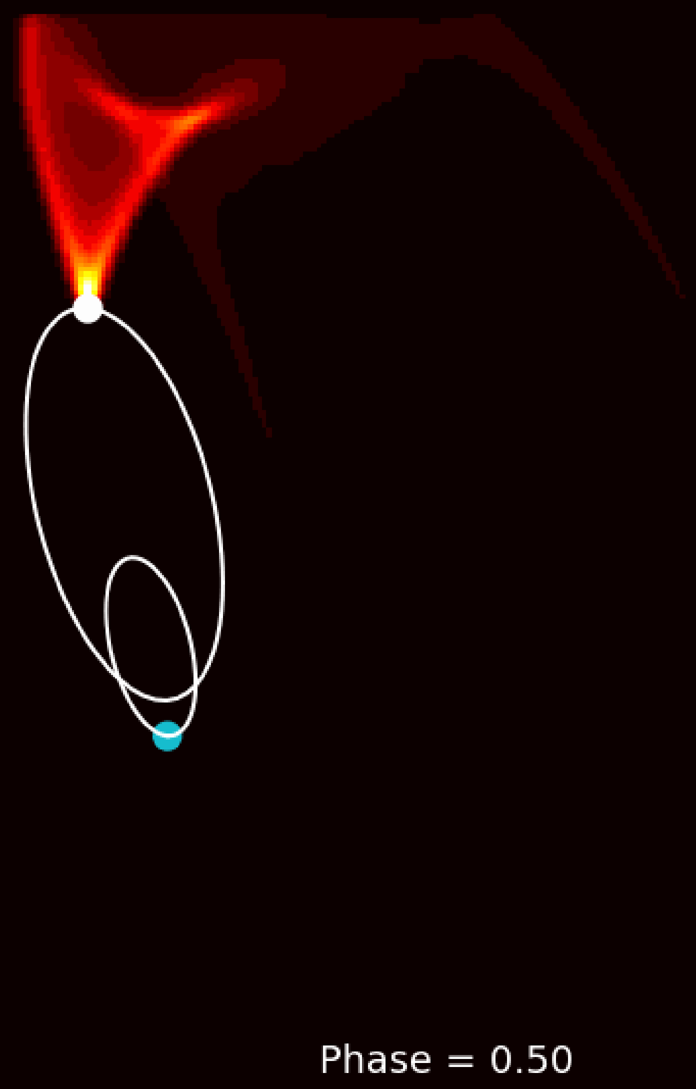
Modelling using geometry



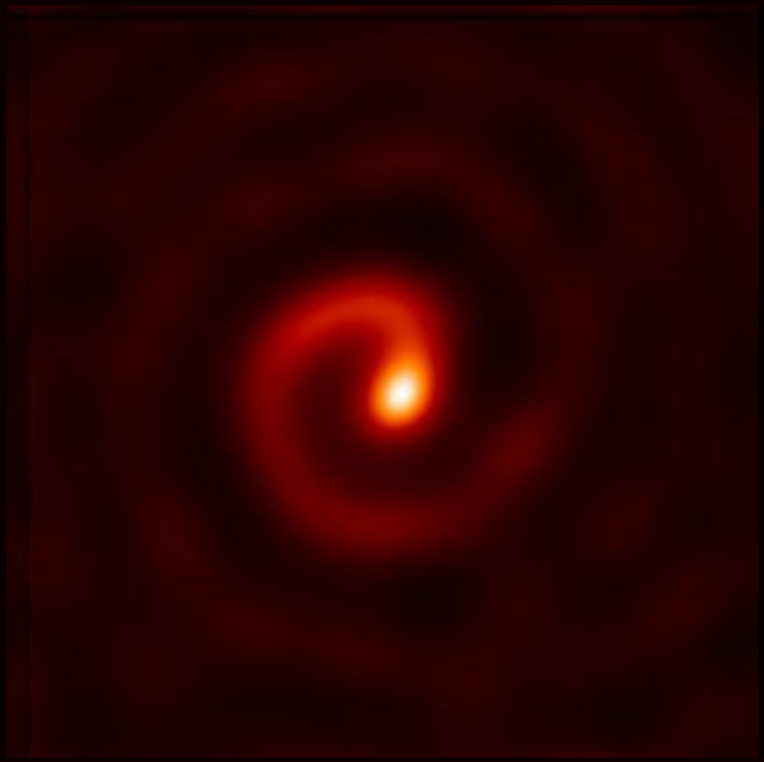
Modelling using geometry



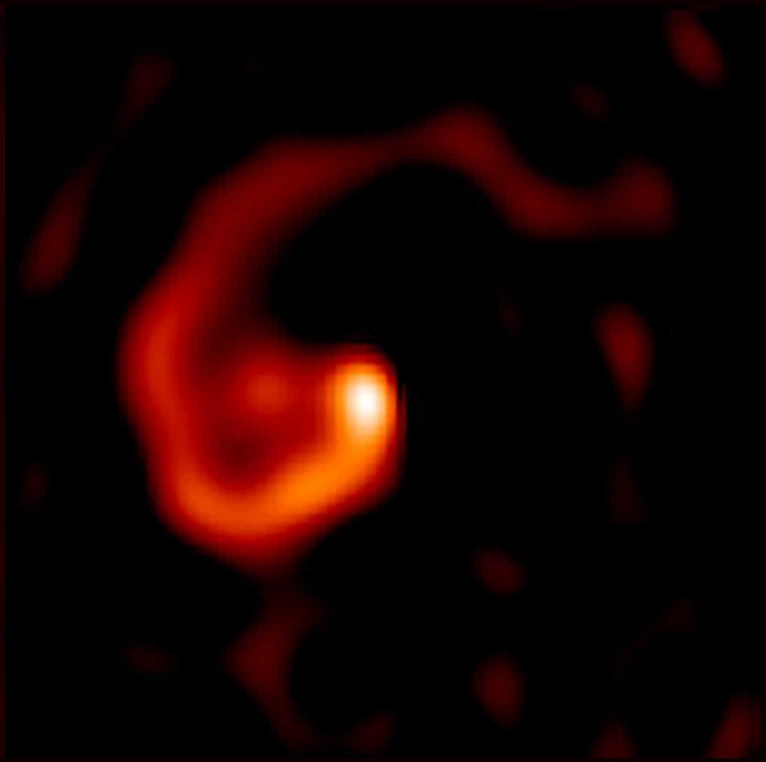
Wolf-Rayet Colliding Wind Binaries



Wolf-Rayet Colliding Wind Binaries

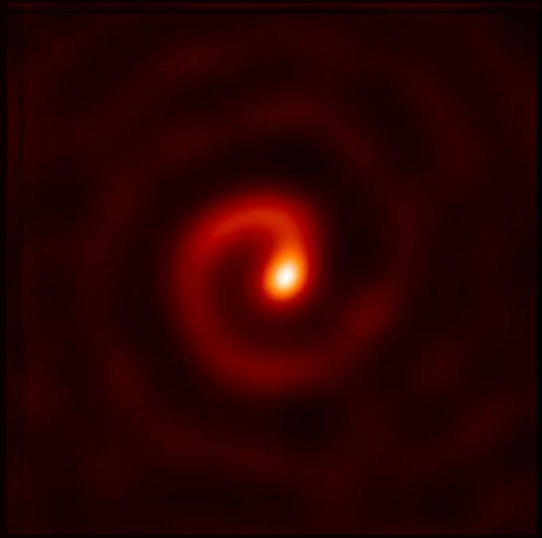


WR 104/Keck

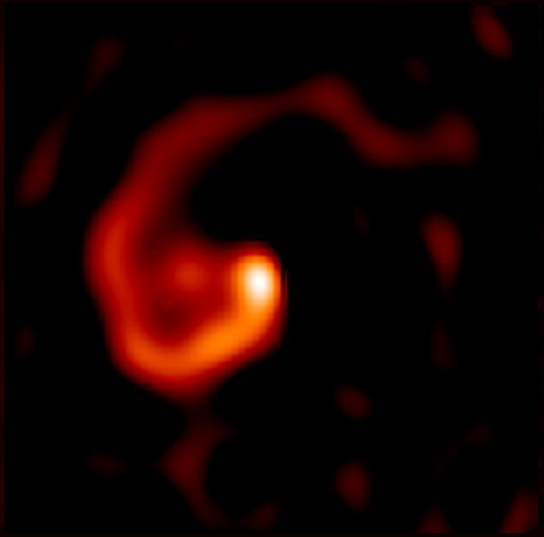


WR 98a/Keck

Wolf-Rayet Colliding Wind Binaries

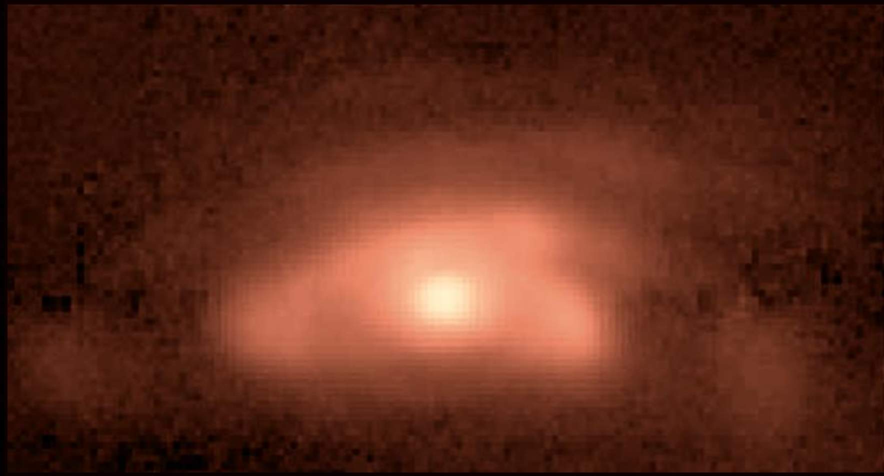


WR 104/Keck



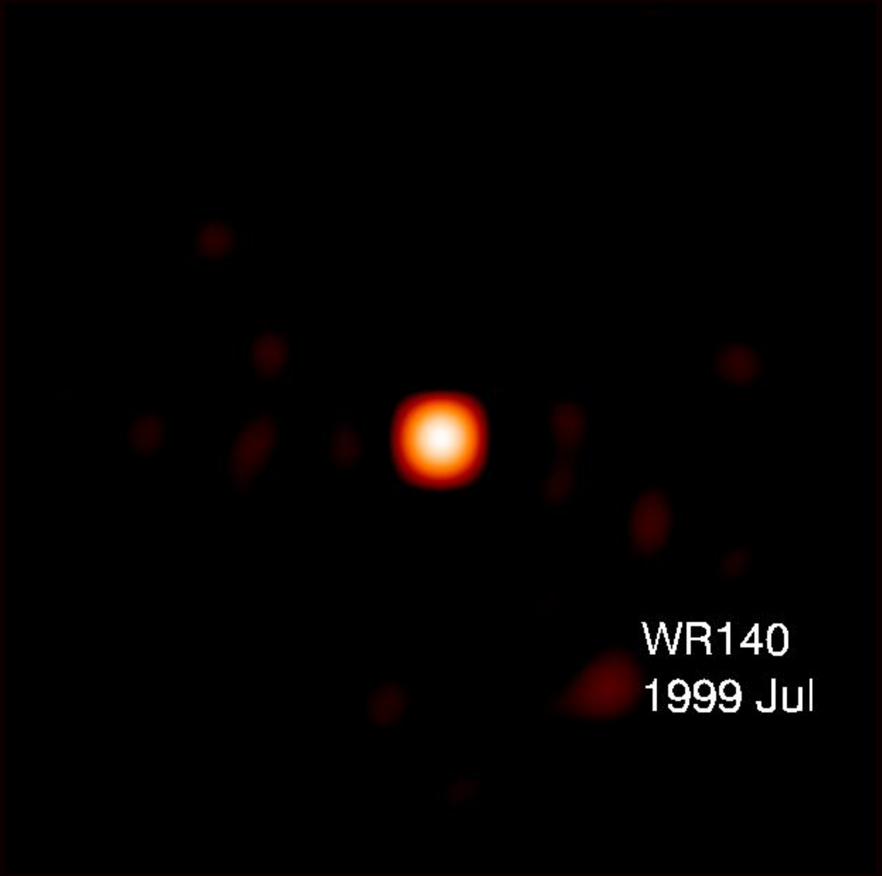
WR 98a/Keck

WR 112/Subaru



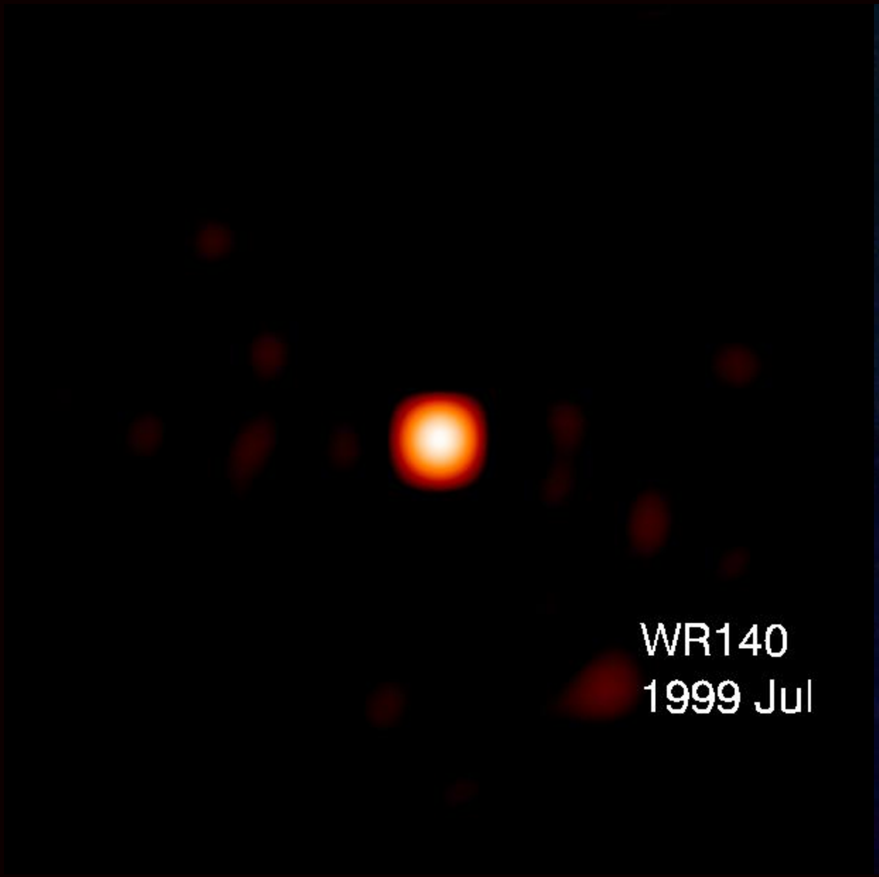
WR 48a/Gemini

WR 140



WR 140/Keck

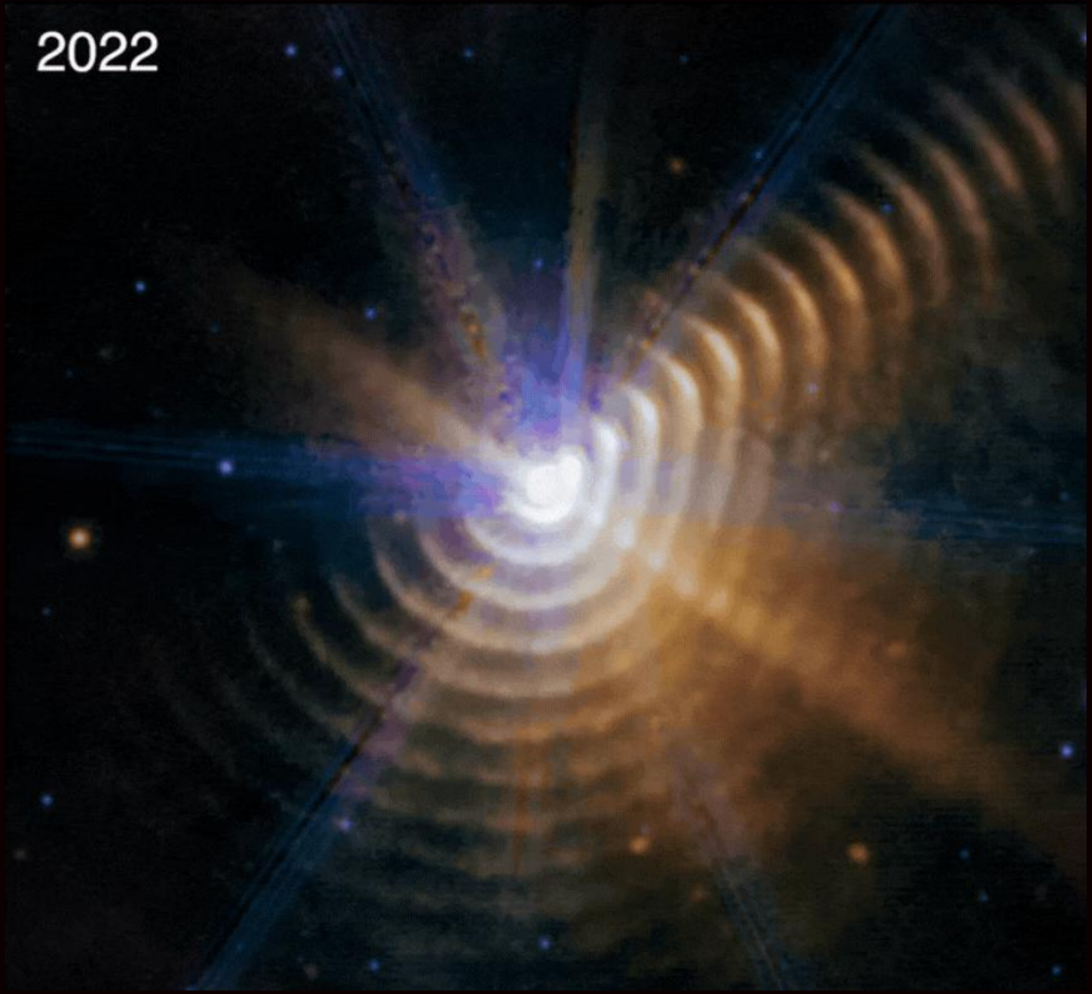
WR 140



WR 140/Keck

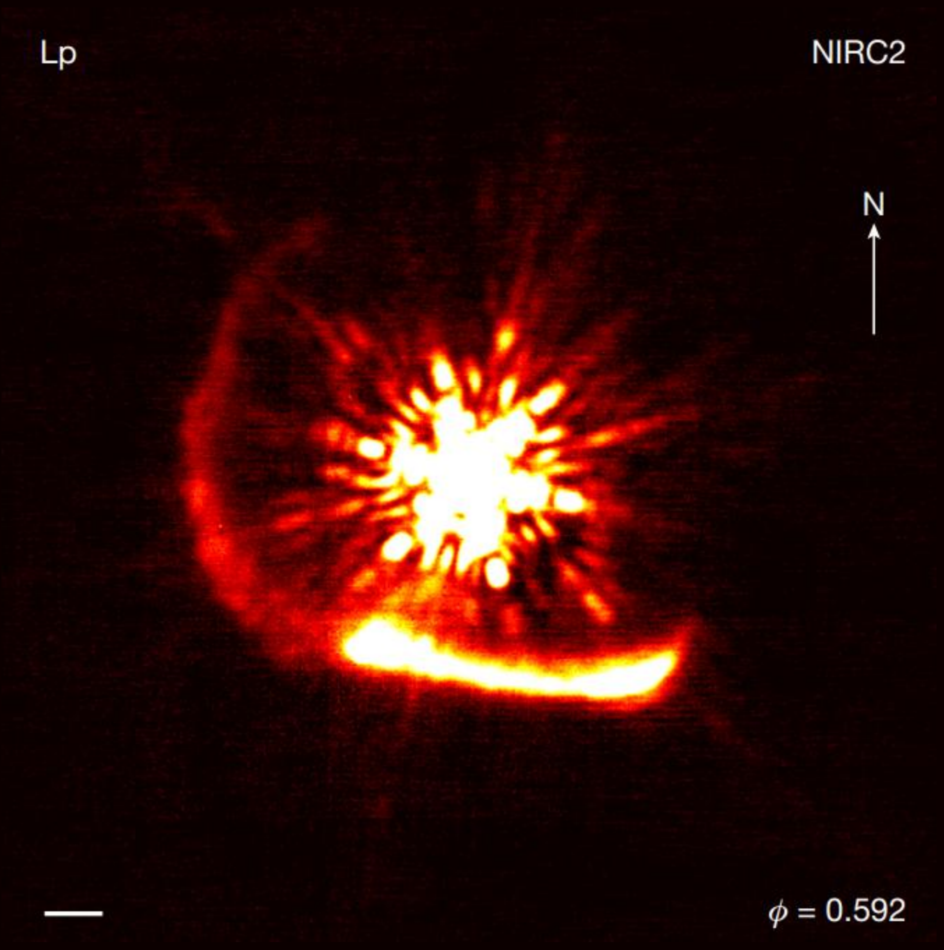

WR 140/JWST

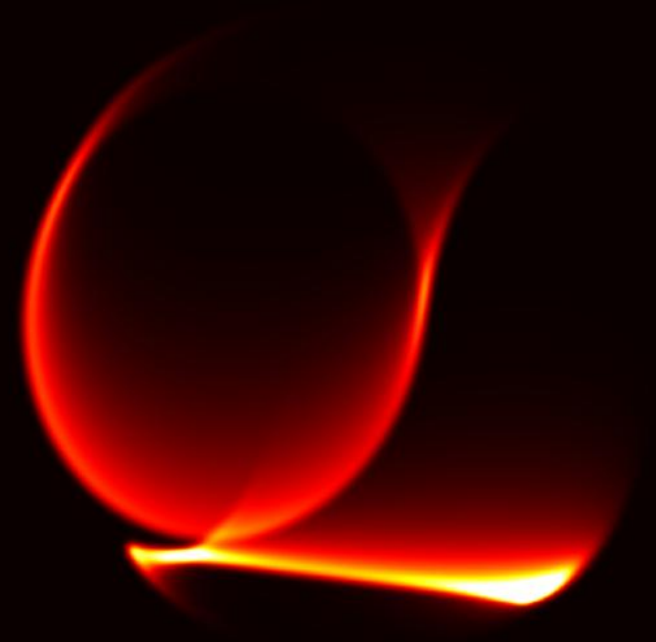
WR 140



WR 140/JWST, Lieb et al 2025

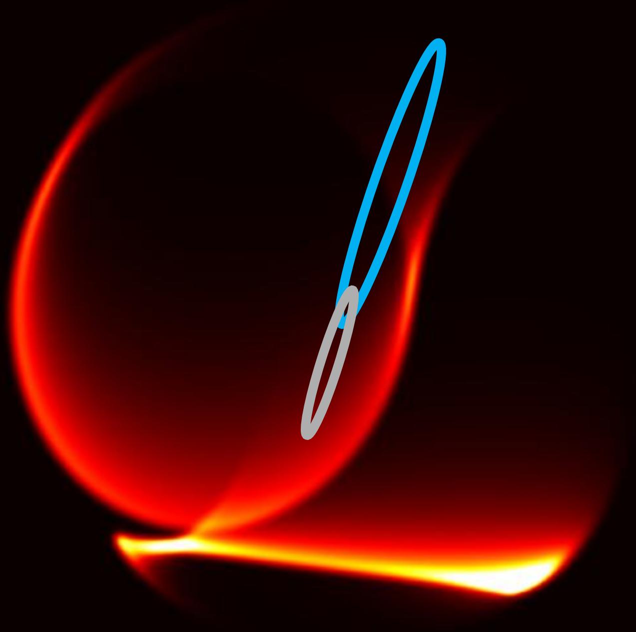
WR 140



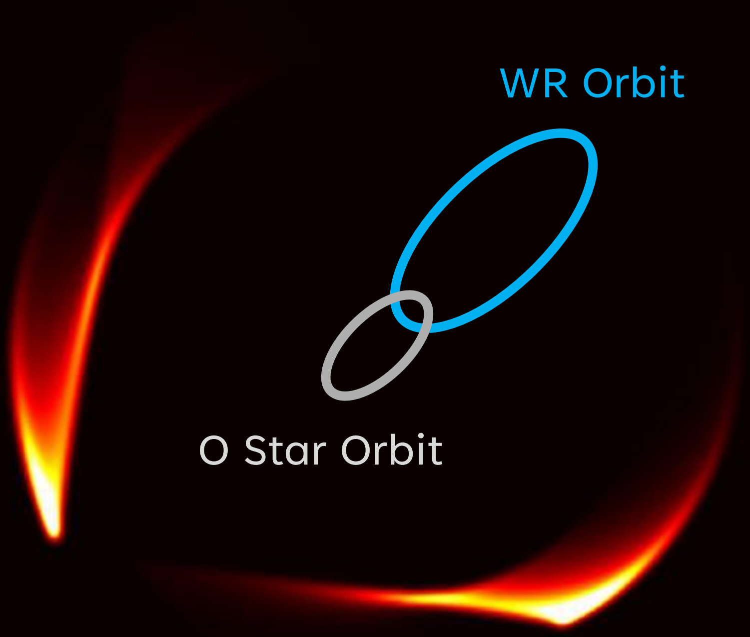


WR 140/Keck, Han et al 2022

WR 140



Observer view



Top-down view

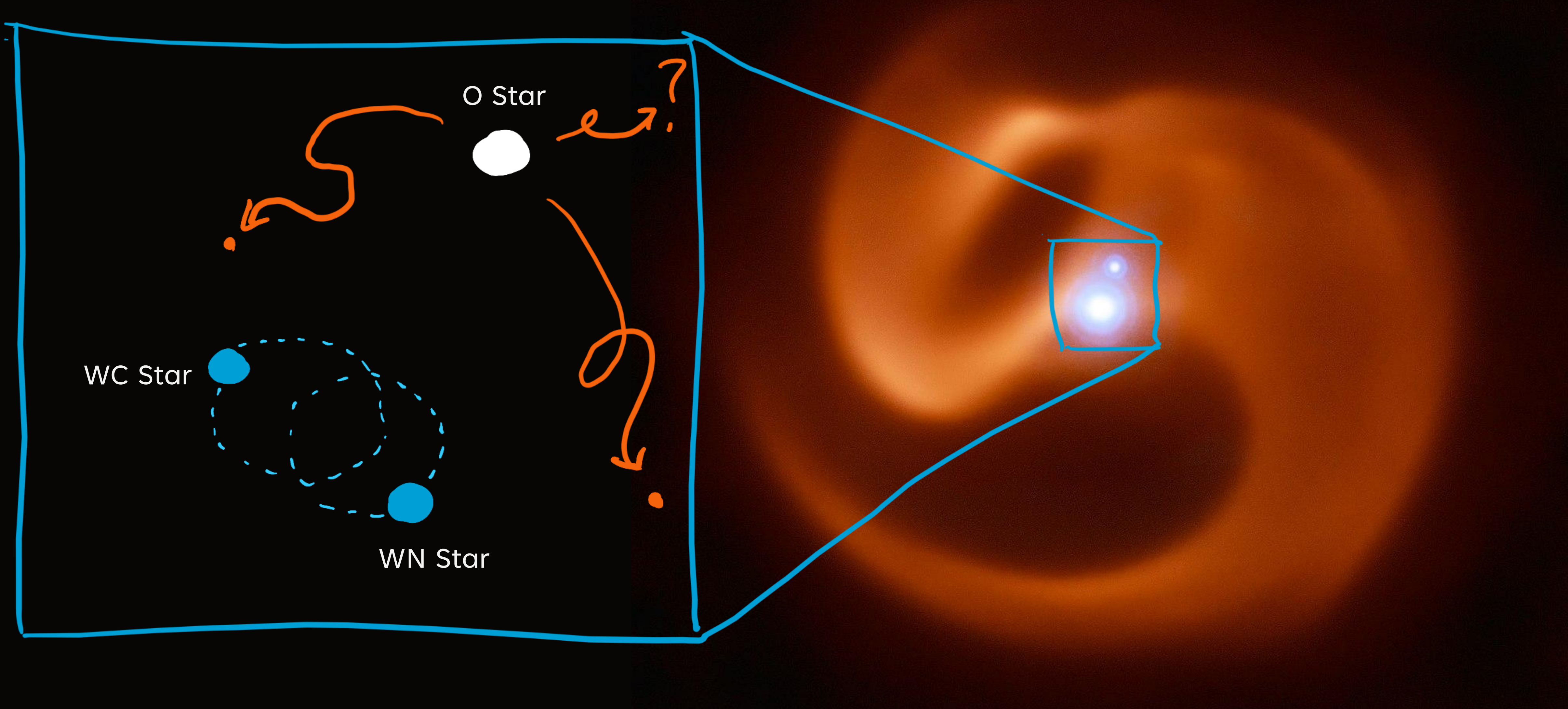
Han et al 2022

Apep

- The only dusty WR+WR CWB
- The longest period dusty CWB
- Potentially a tertiary O supergiant, making the system a hierarchical triple
- Could harbour a LGRB progenitor

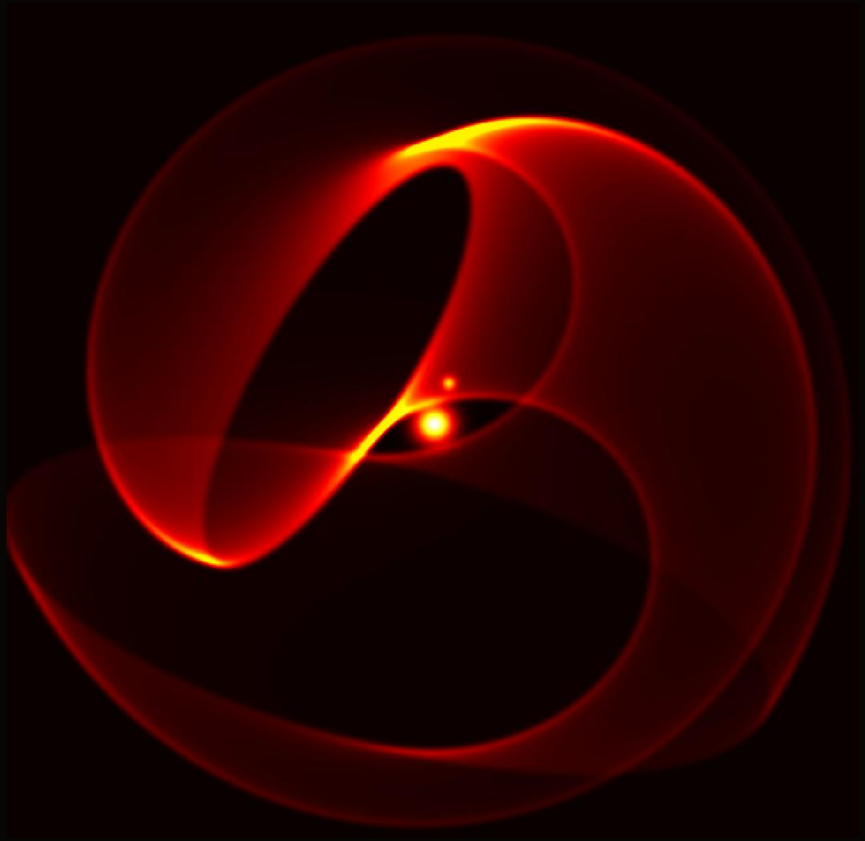
Apep with ESO’s VLT

Apep

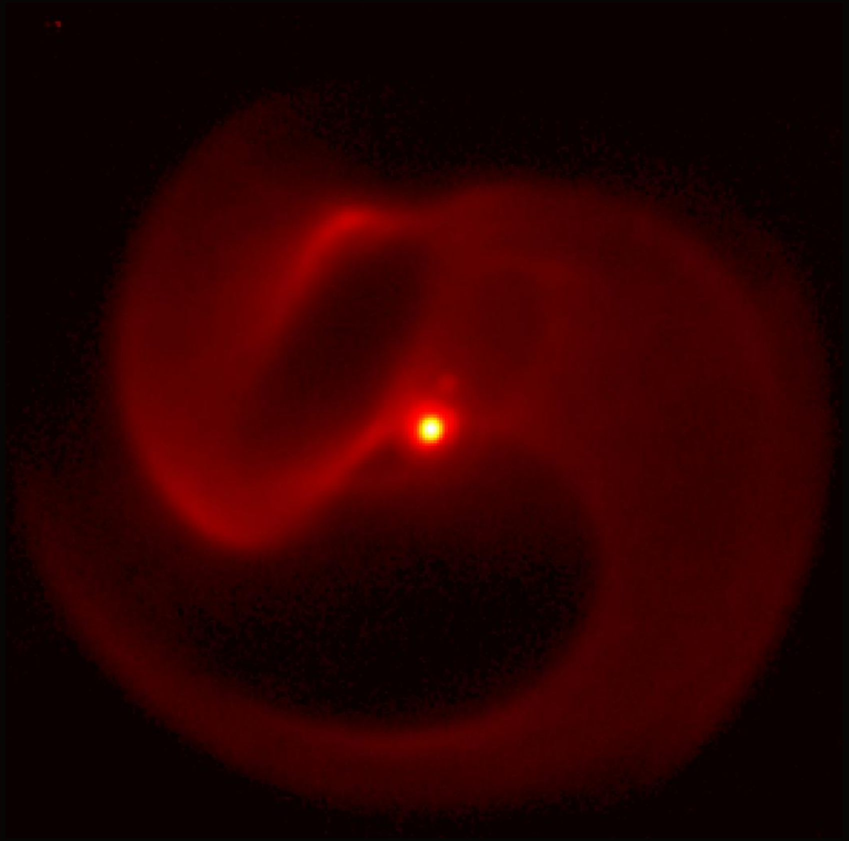


Apep with ESO’s VLT

Apep



Standard Apep Model



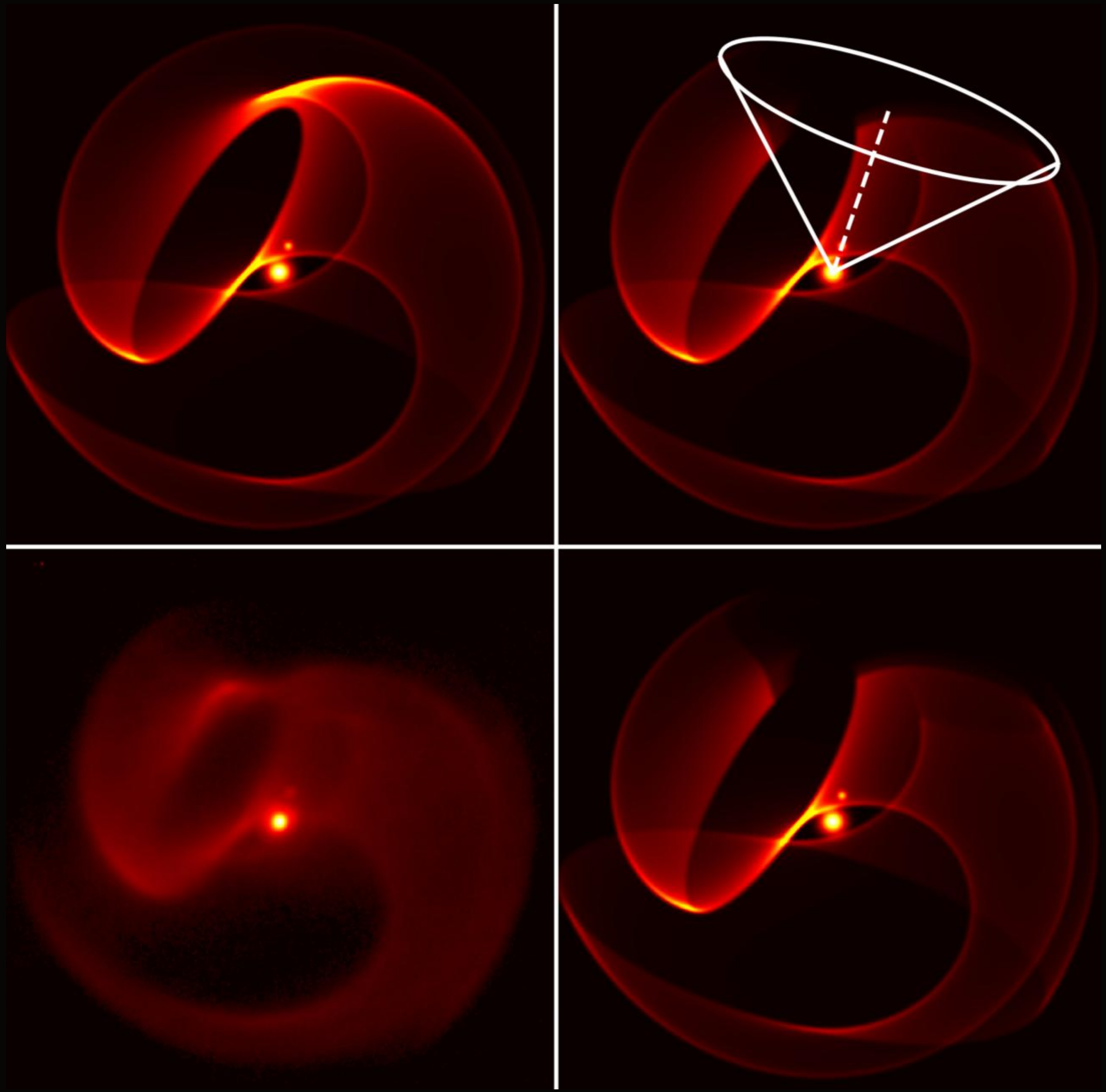
VLT Image

Apep

Apep

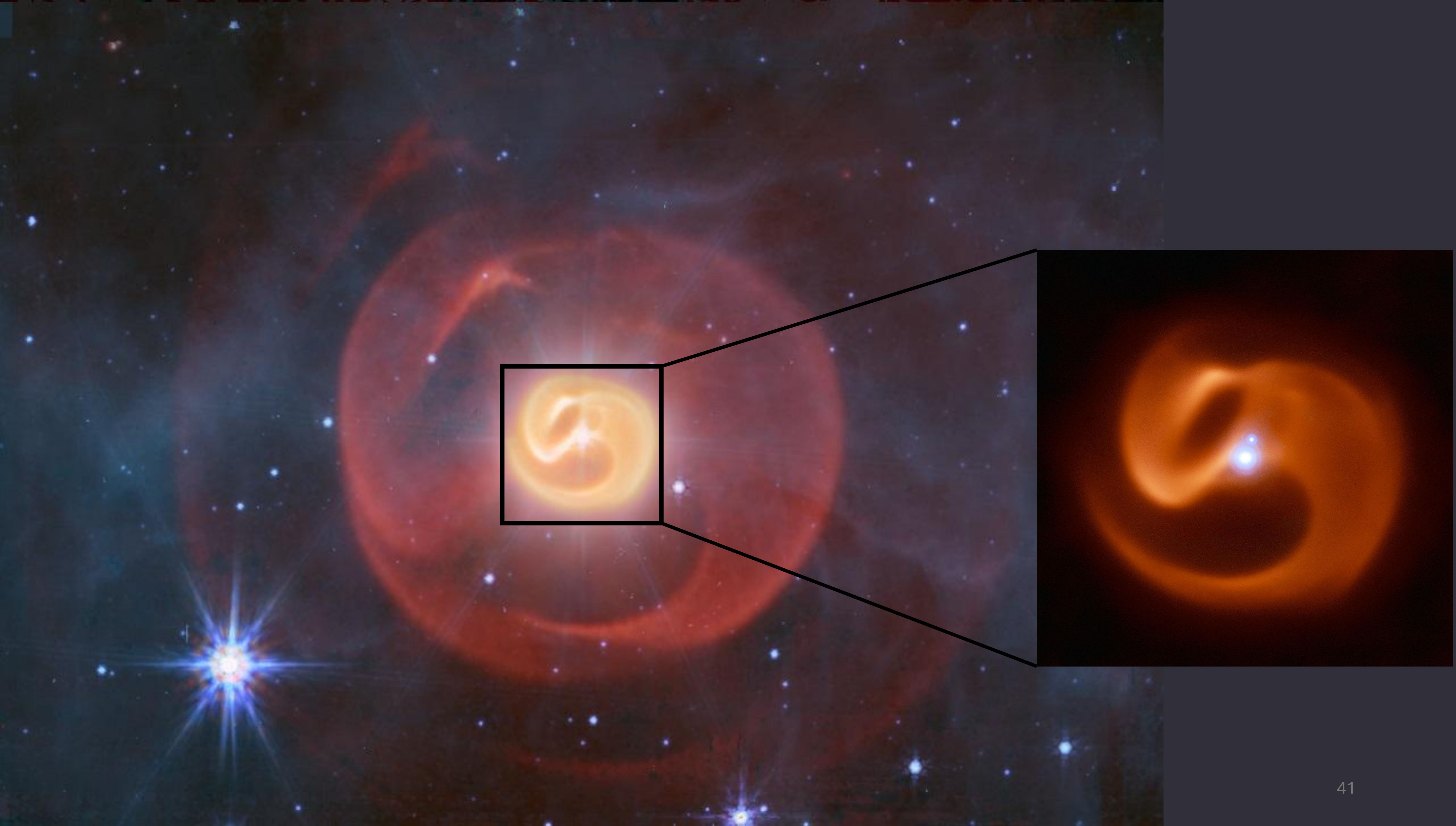
Standard Apep Model

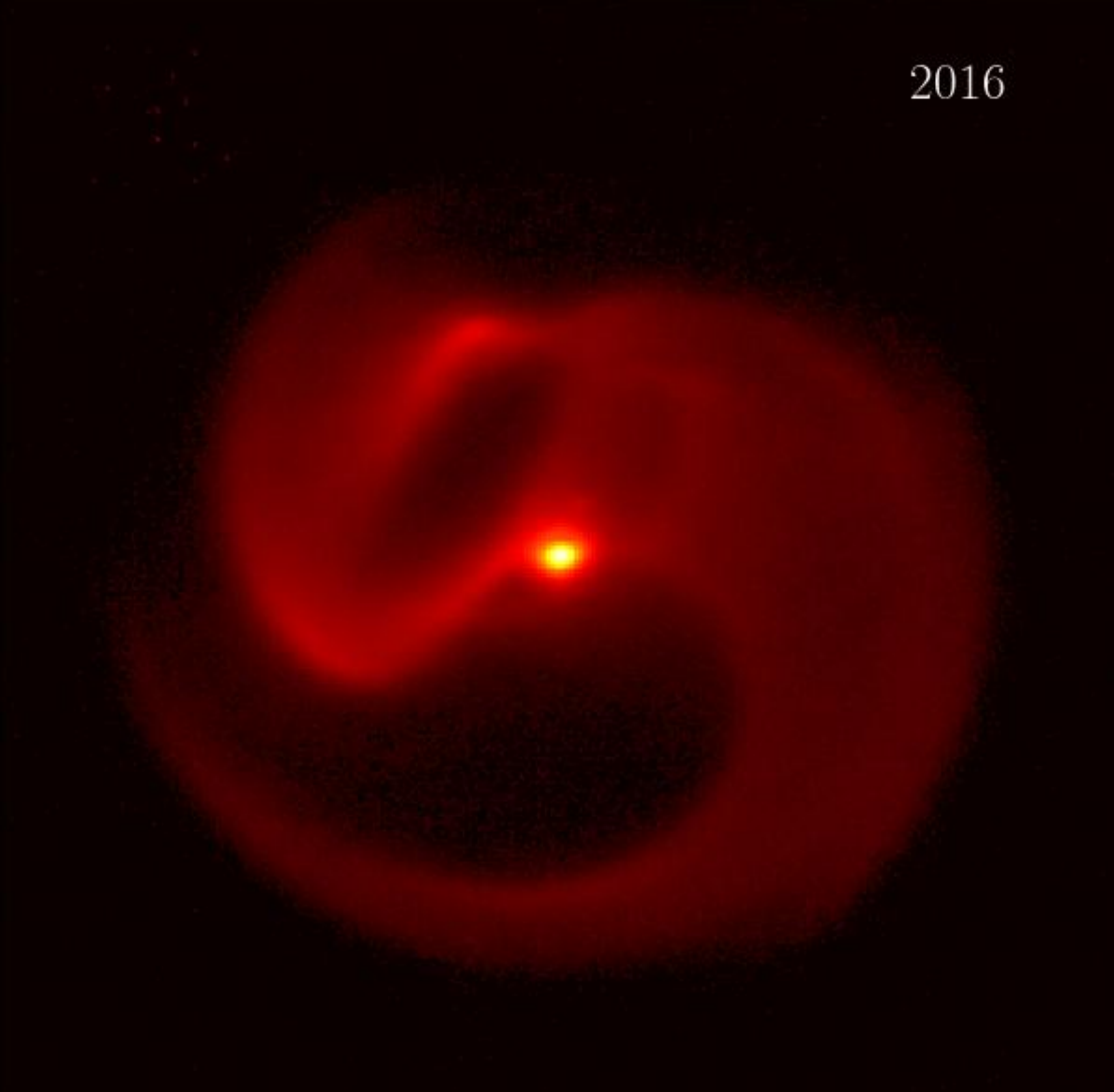
Tertiary Shock Geometry



VLT Image

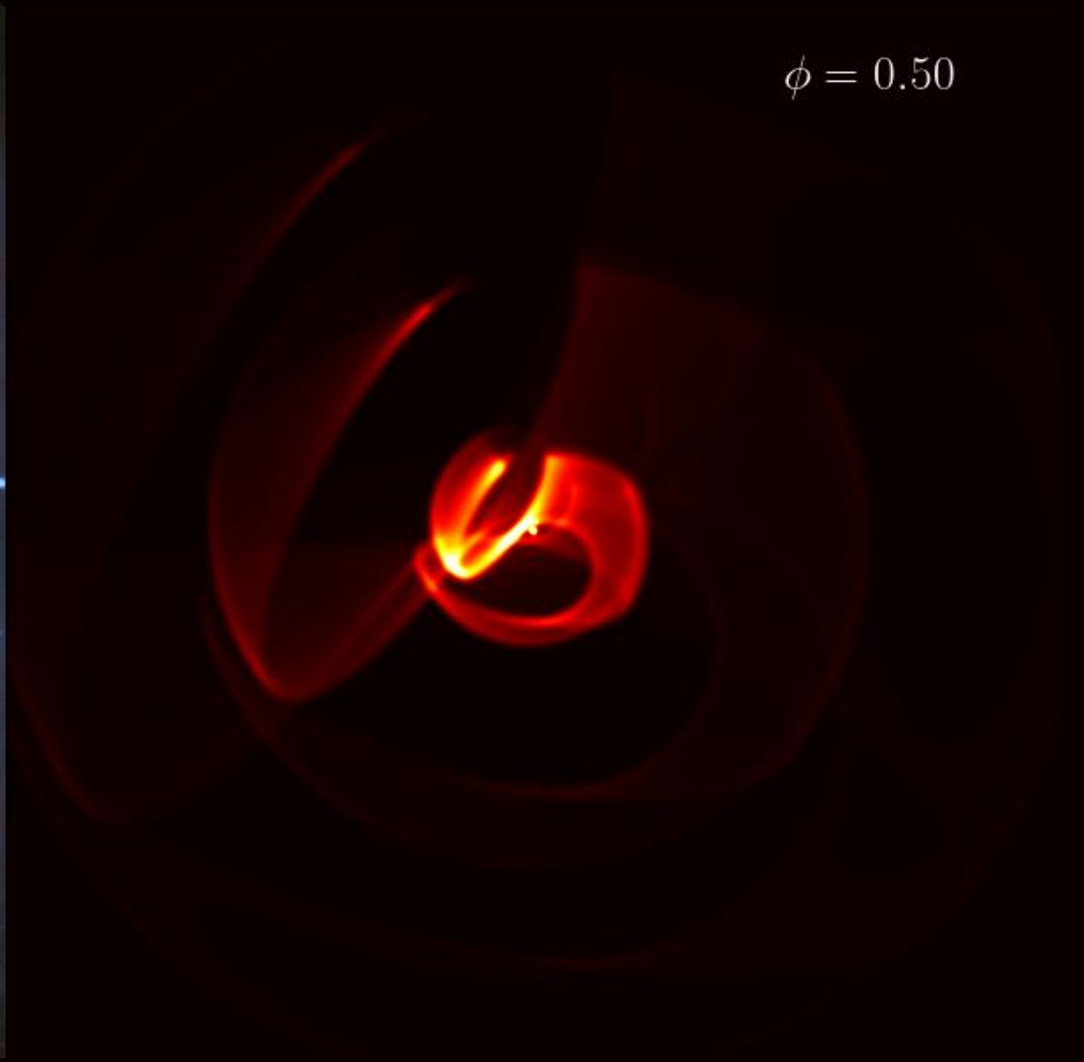
Apep Model incl.
Tertiary Shock





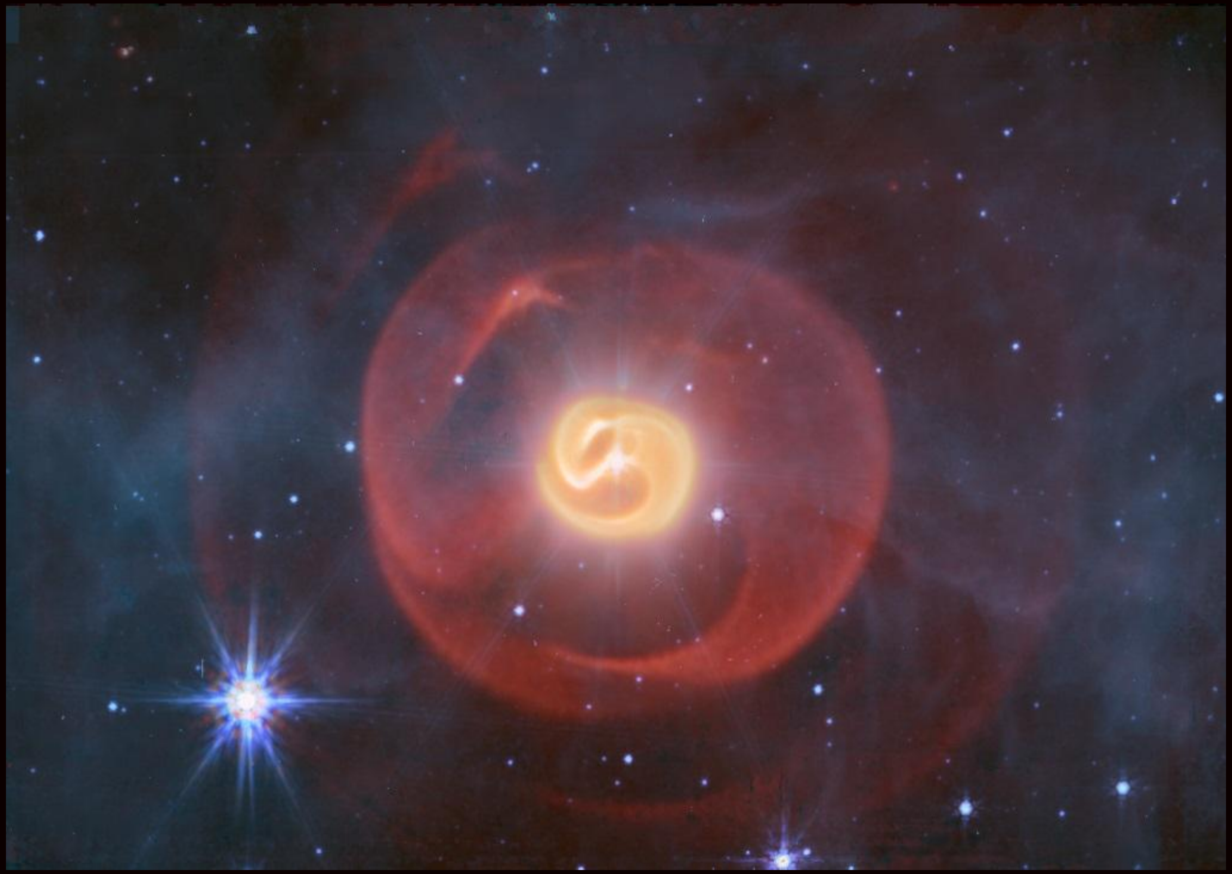
5”

Apep



Apep

- WR+WR orbital period is ~235 years
  - About 8x longer than the next longest period dusty CWB
- A confirmed hierarchical triple
  - The orbit of the inner WR+WR binary has certainly been affected by the O star
- No evidence of wind anisotropy in plume geometry
  - which doesn’t necessarily rule out an anisotropic wind

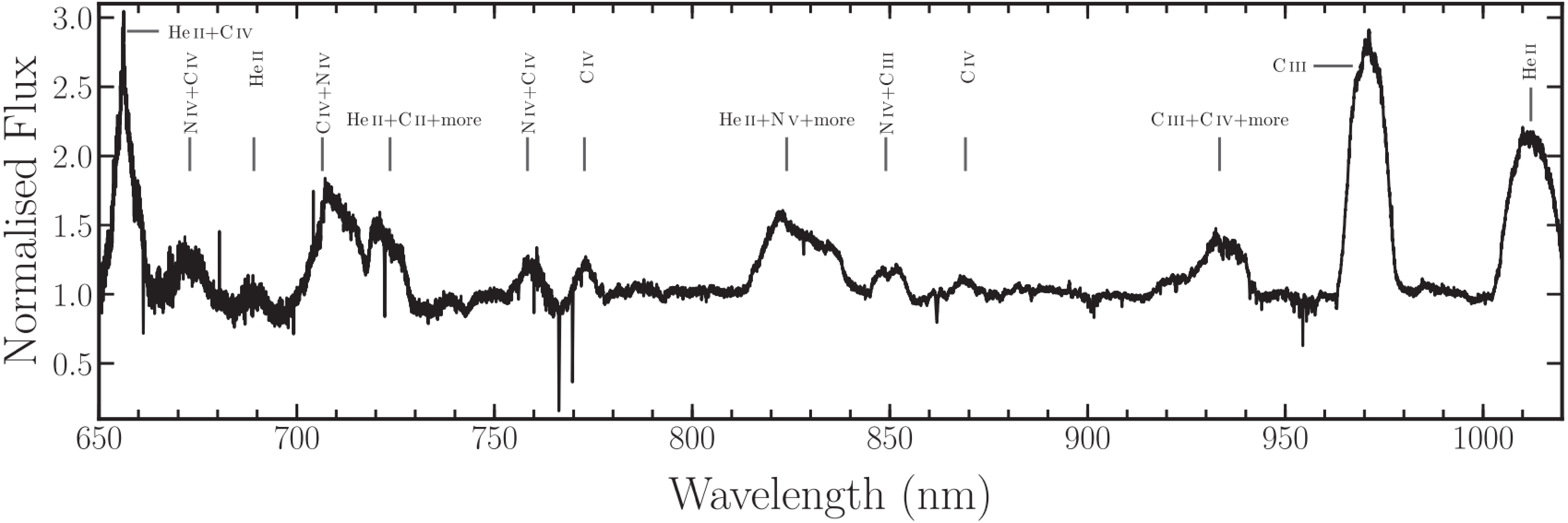


In summary…

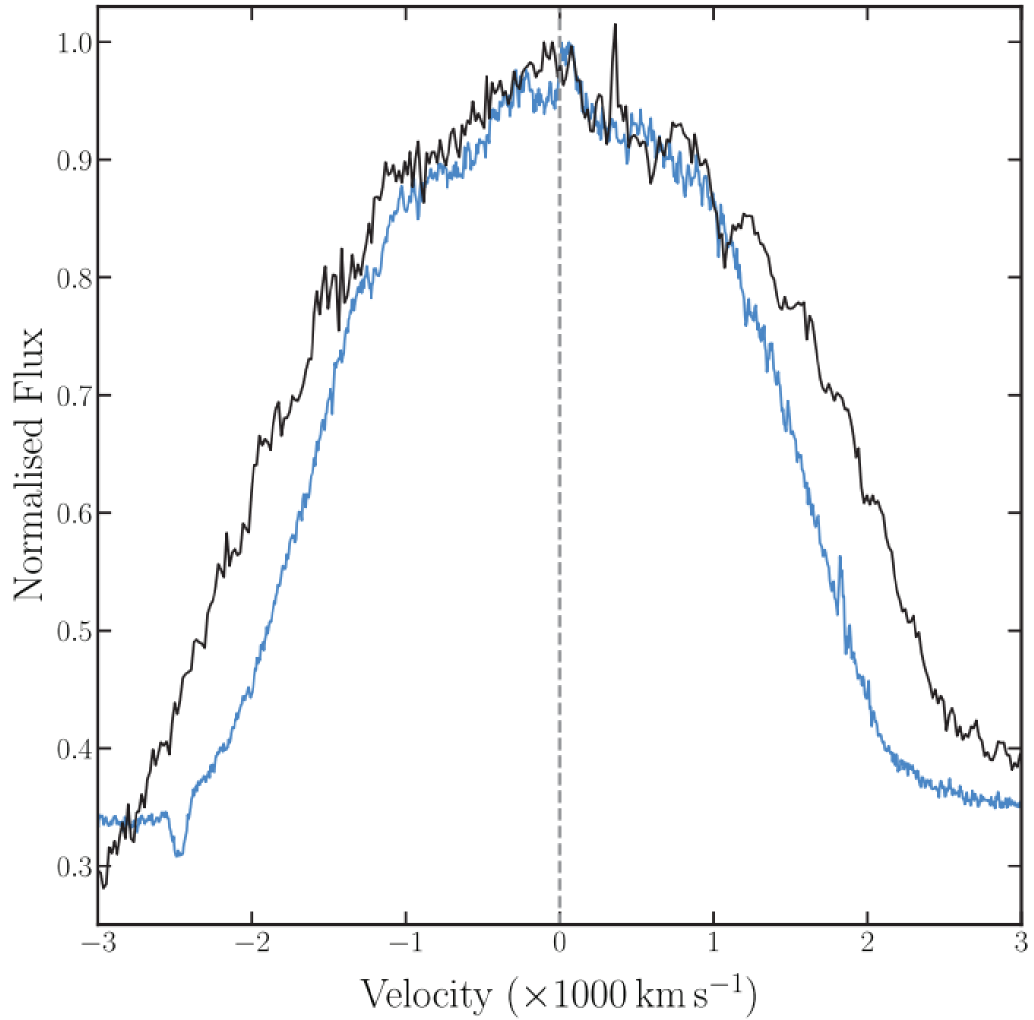
- I can't get away from binary interactions
- Wolf-Rayet Colliding wind binaries, the rare binary interactions of pre-supernova massive stars, can be simply modelled with geometry
  - I've developed a new and fast code to do this, with handy features like a GUI velocity partitioning, and more physics than ever (ask me about it!)
  - We have a book chapter on WR-CWBs (QR code) to learn more
- The dust cavity in the Apep nebula confirms a hierarchical triple
  - New JWST+VLT imagery was vital for this and the updated orbit

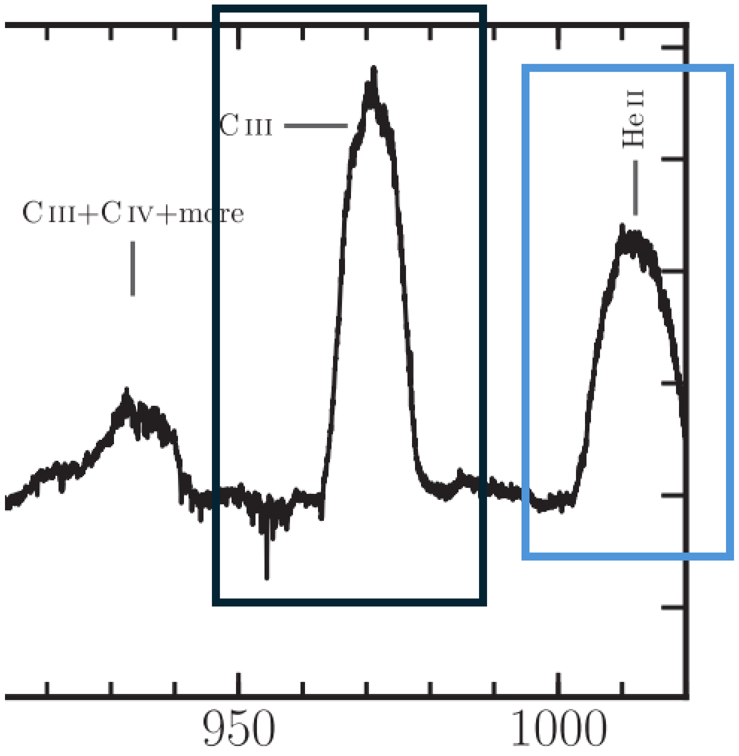
arXiv:2412.12534

Apep's wind anisotropy

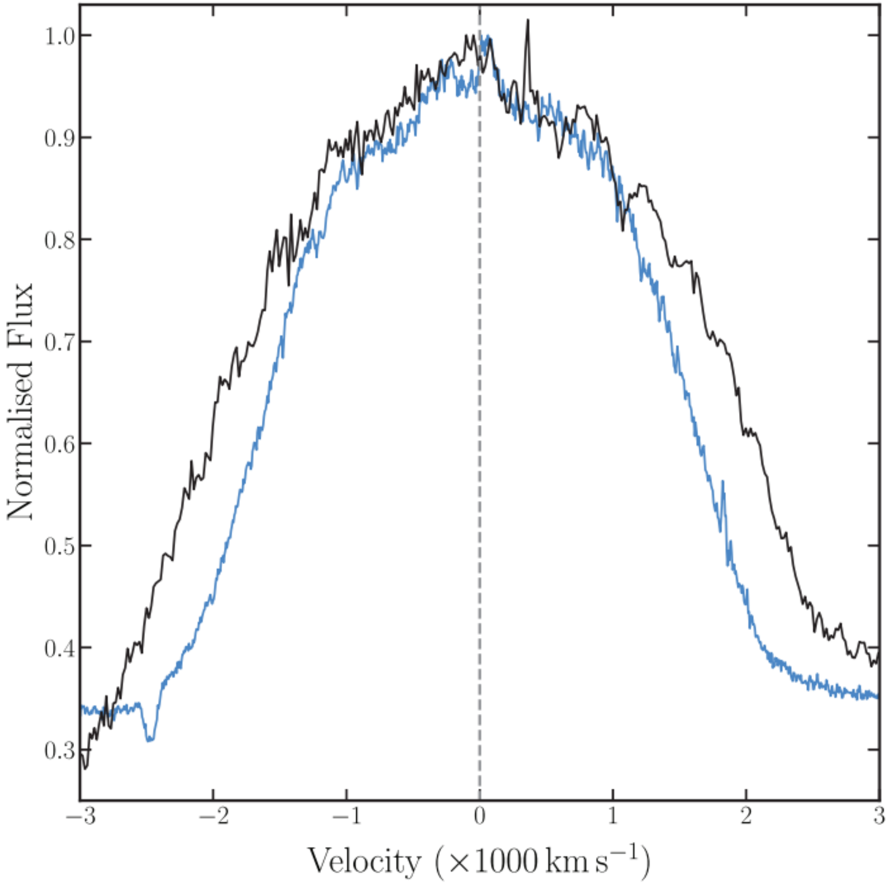


Apep's wind anisotropy





Apep's wind anisotropy



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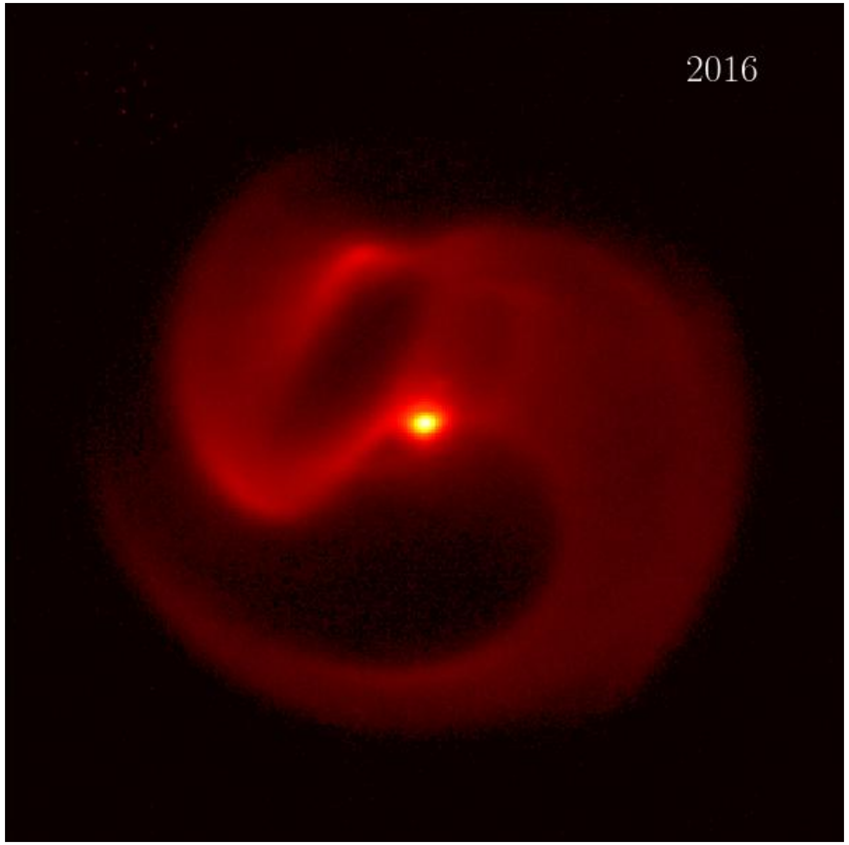
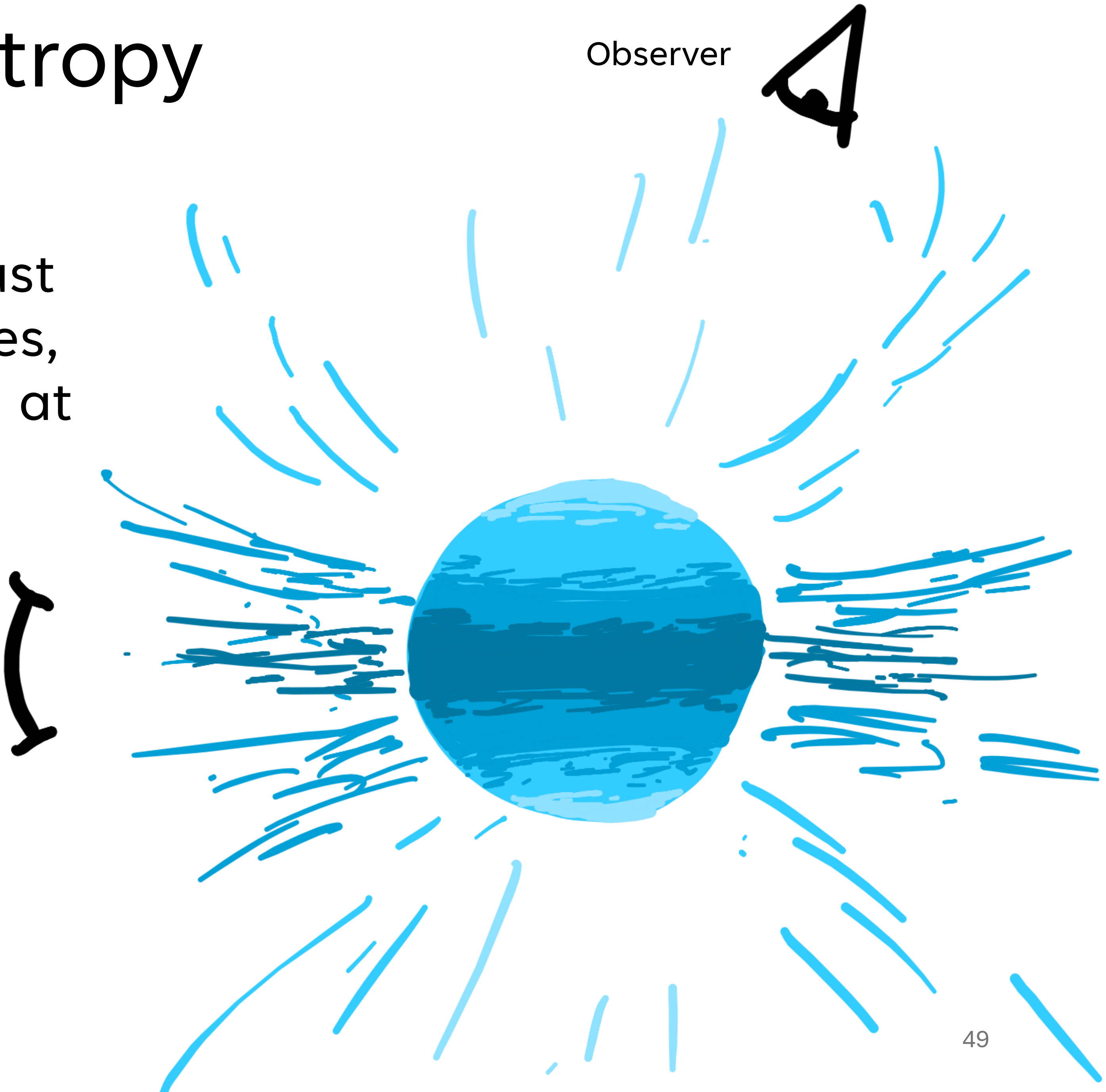


2100 + 3500km/s winds

~860km/s nebular expansion

Apep’s wind anisotropy

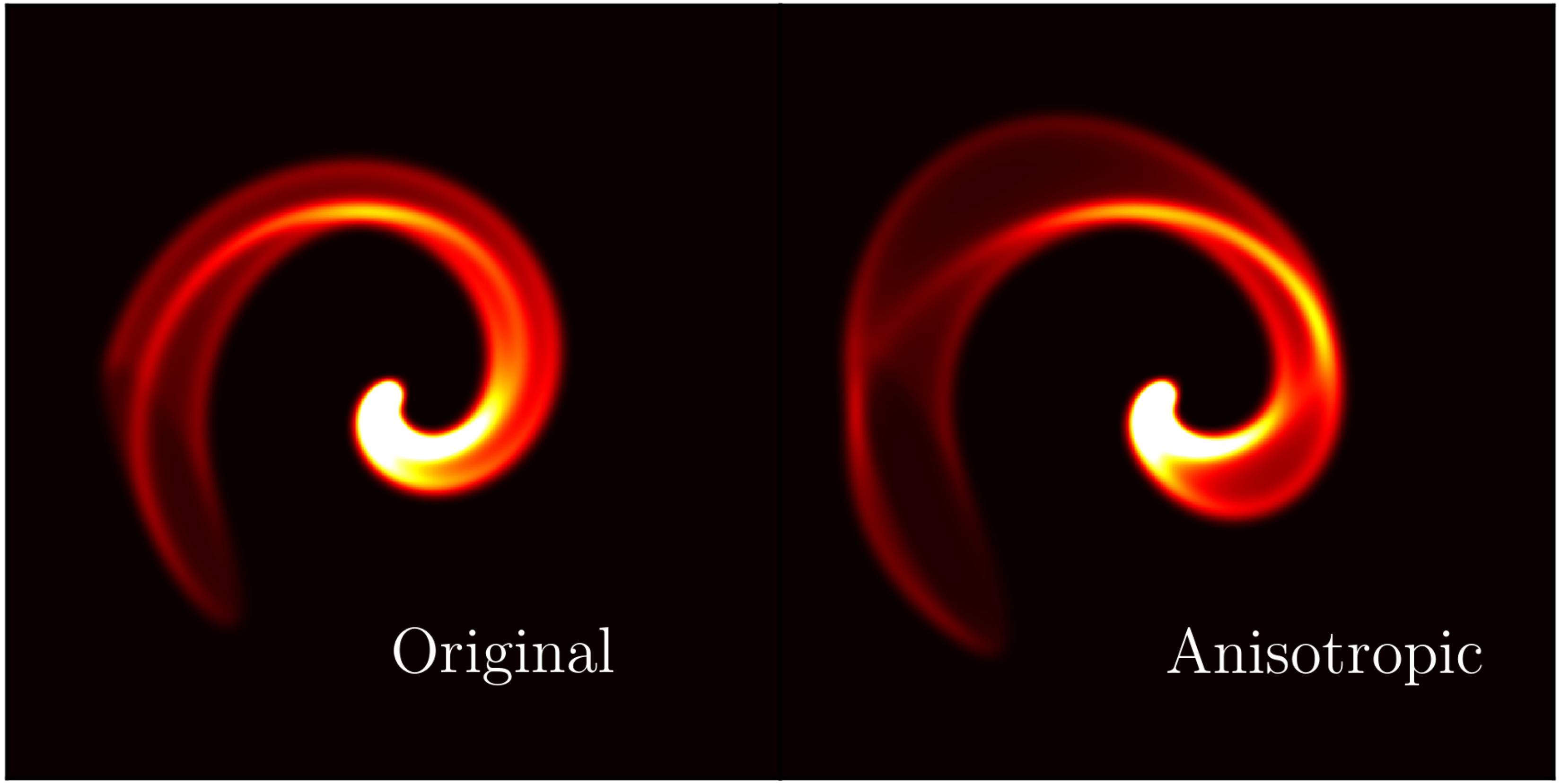
- Rapid rotation leads to a fast and sparse wind at the poles, and a slow and dense wind at the equator



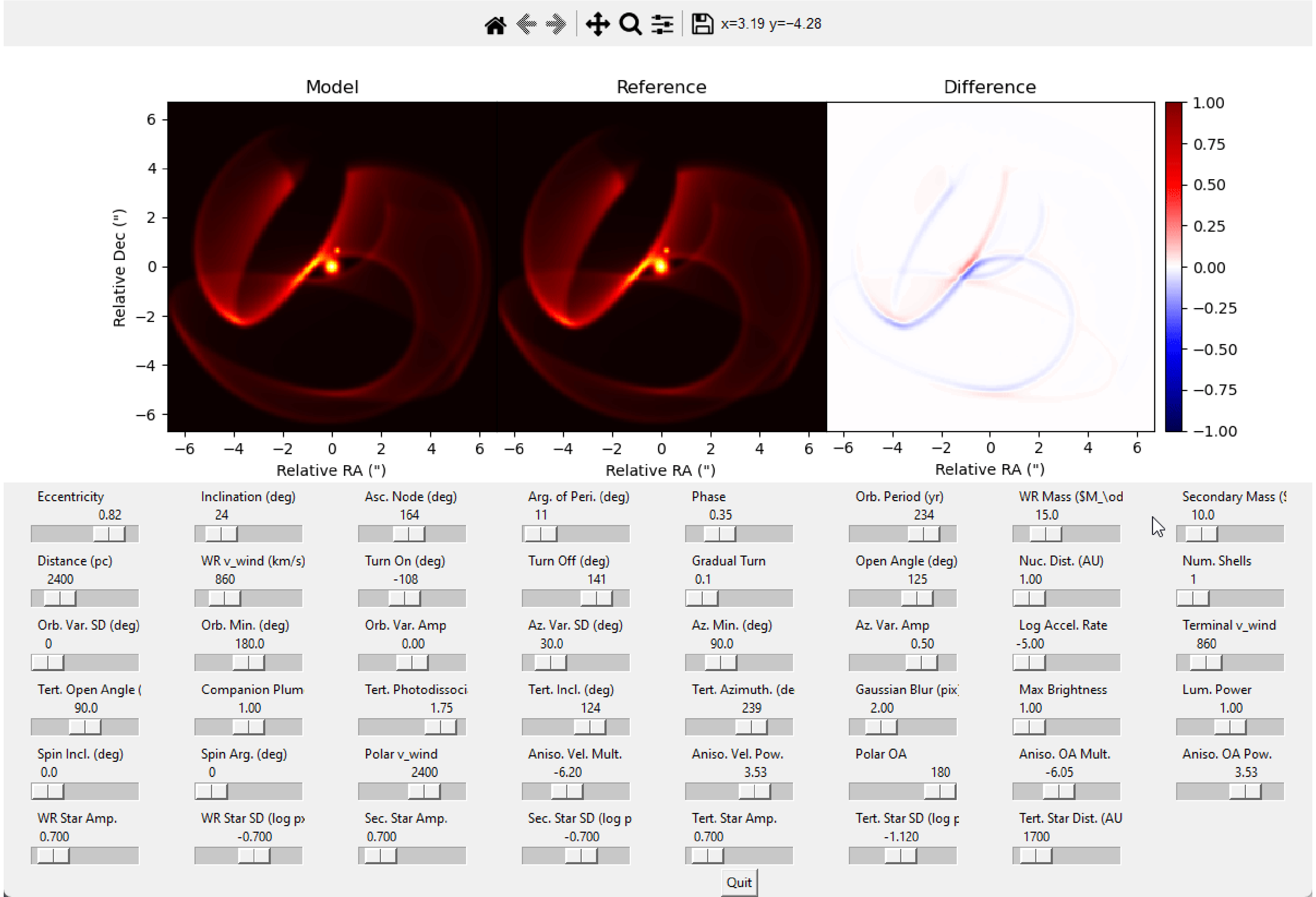
- We can observe a fast spectroscopic wind simultaneous with a slow nebula expansion

Apep’s wind anisotropy

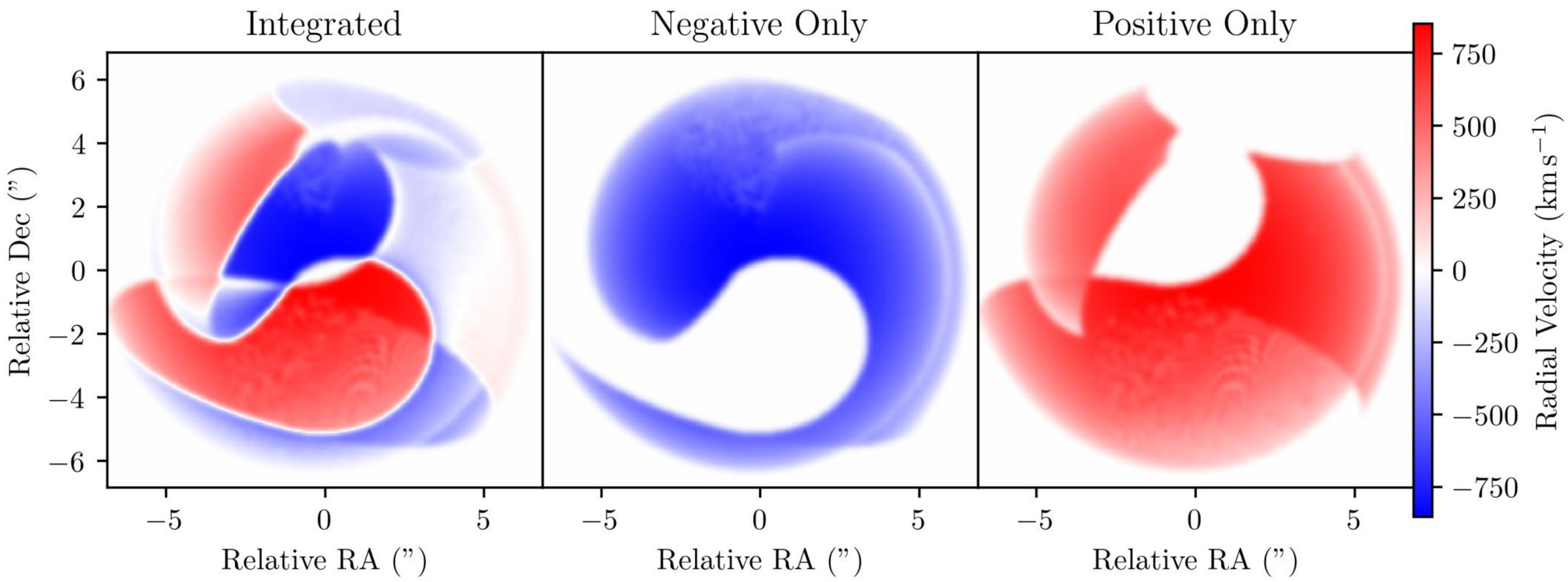
- We emulate anisotropy by changing open angle and expansion speed as a function of true anomaly
  - This is only relevant when the spin and orbit are misaligned



xenomorph – Our new geometric code



xenomorph – Our new geometric code

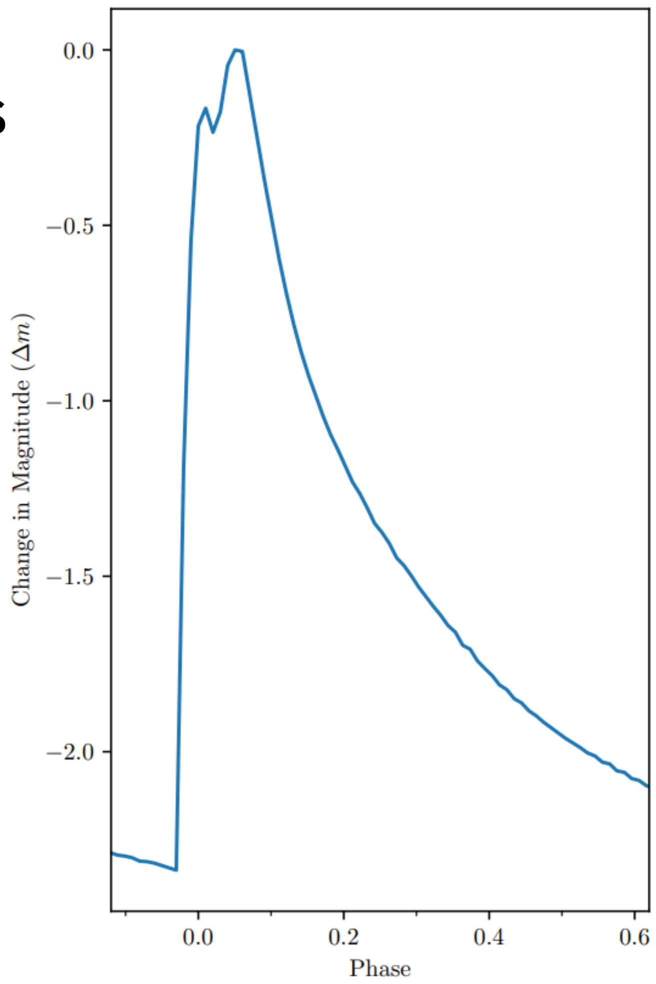


xenomorph – Our new geometric code

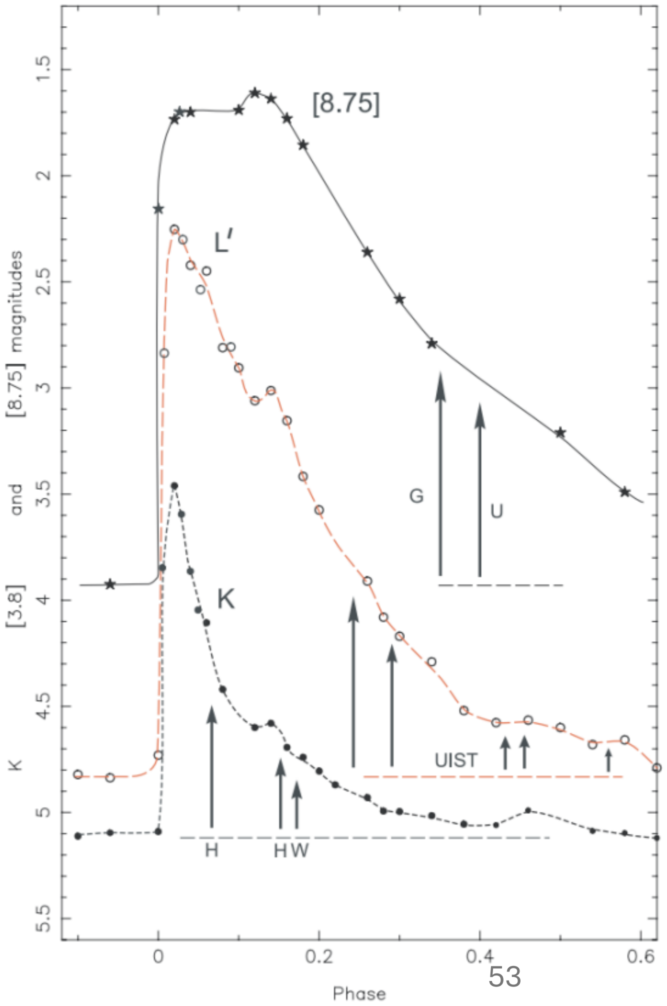
- We can (roughly) model the infrared light curves of CWBs by looking at the brightest pixels over time

- More work needed here
  - E.g. radiative transfer

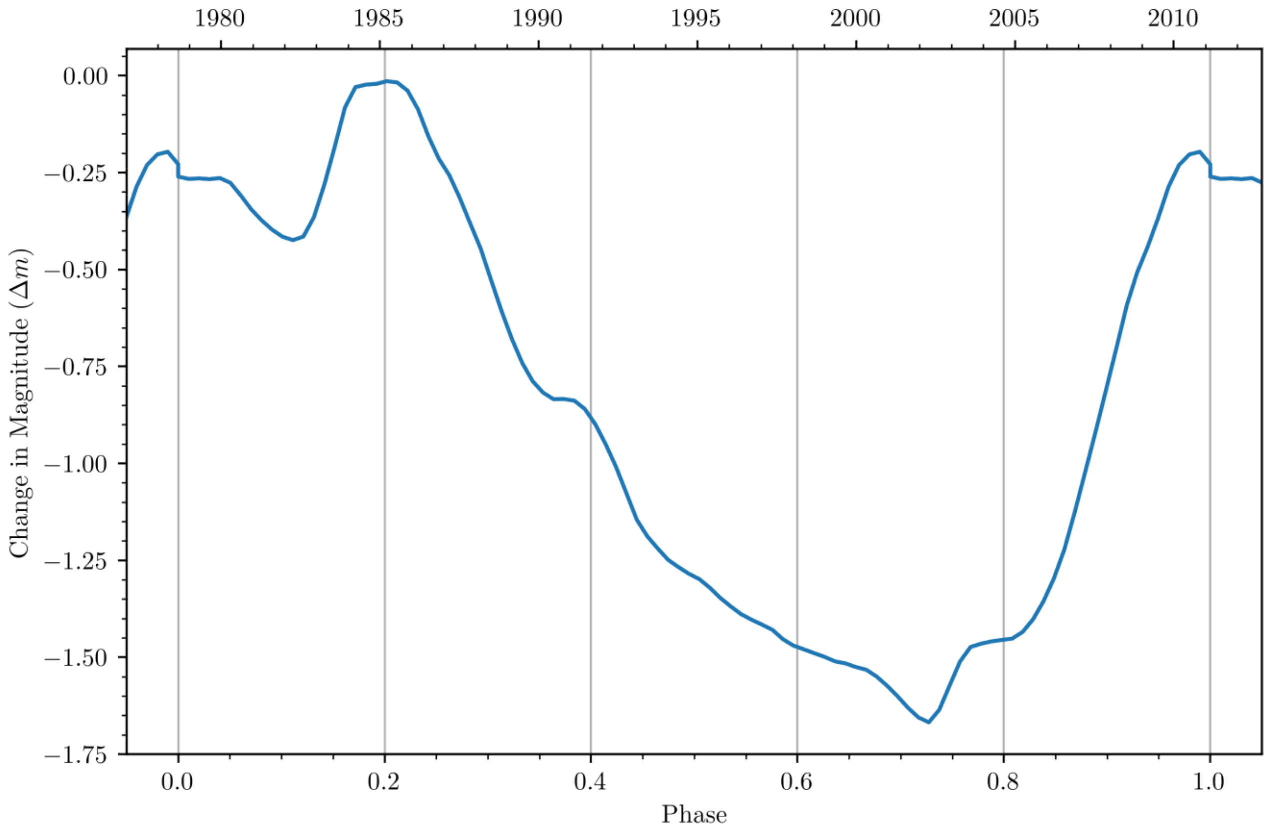
WR 140 from xenomorph



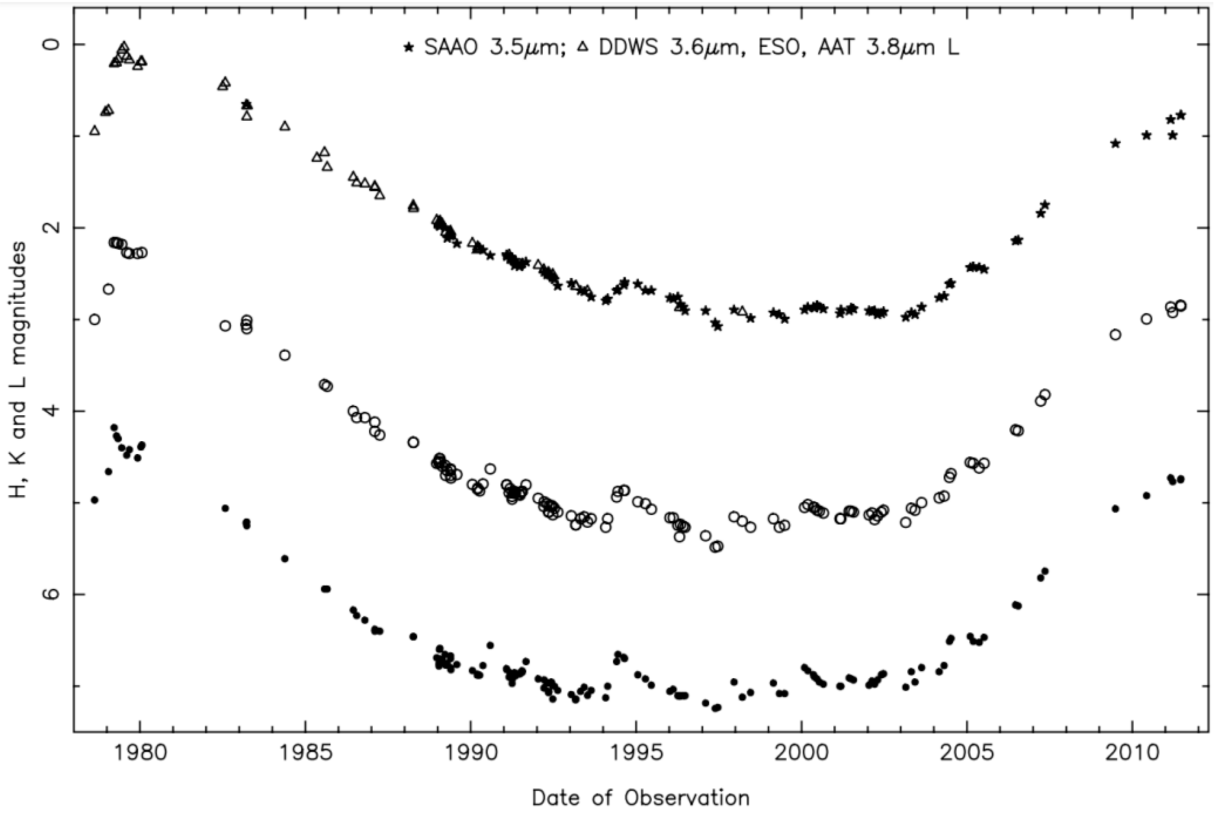
WR 140 from Williams et al (2009)



xenomorph – Our new geometric code



WR 48a with xenomorph



WR 48a from Williams et al (2012)