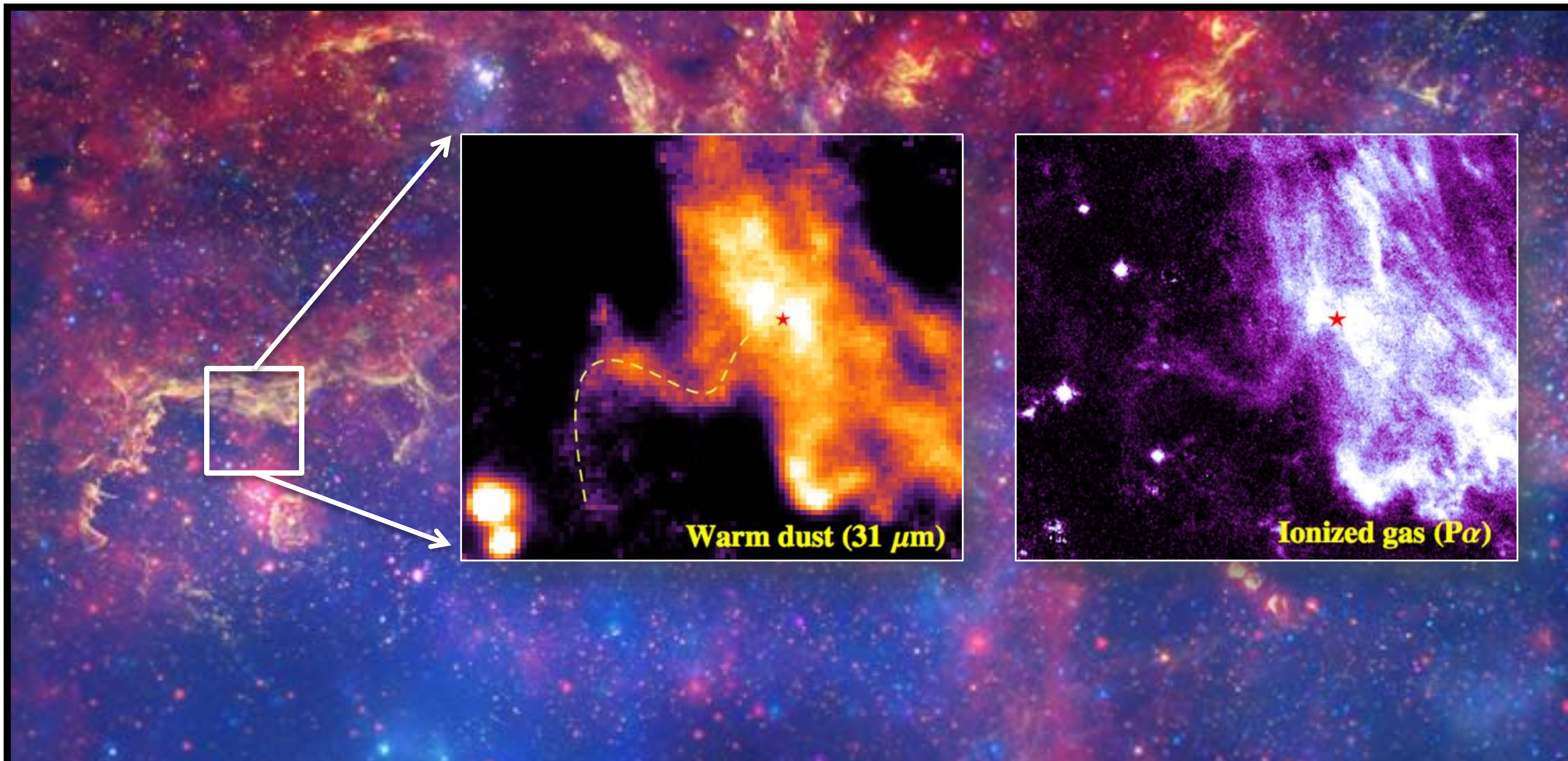
An Apparent Helical Outflow from a Massive Evolved Star: Evidence for Binary Interaction?



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Collaborators: Matt Hankins, Terry Herter, Mark Morris, Betsy Mills, Mike Ressler

SOFIA Community Tele-talk
Mar 9th, 2016

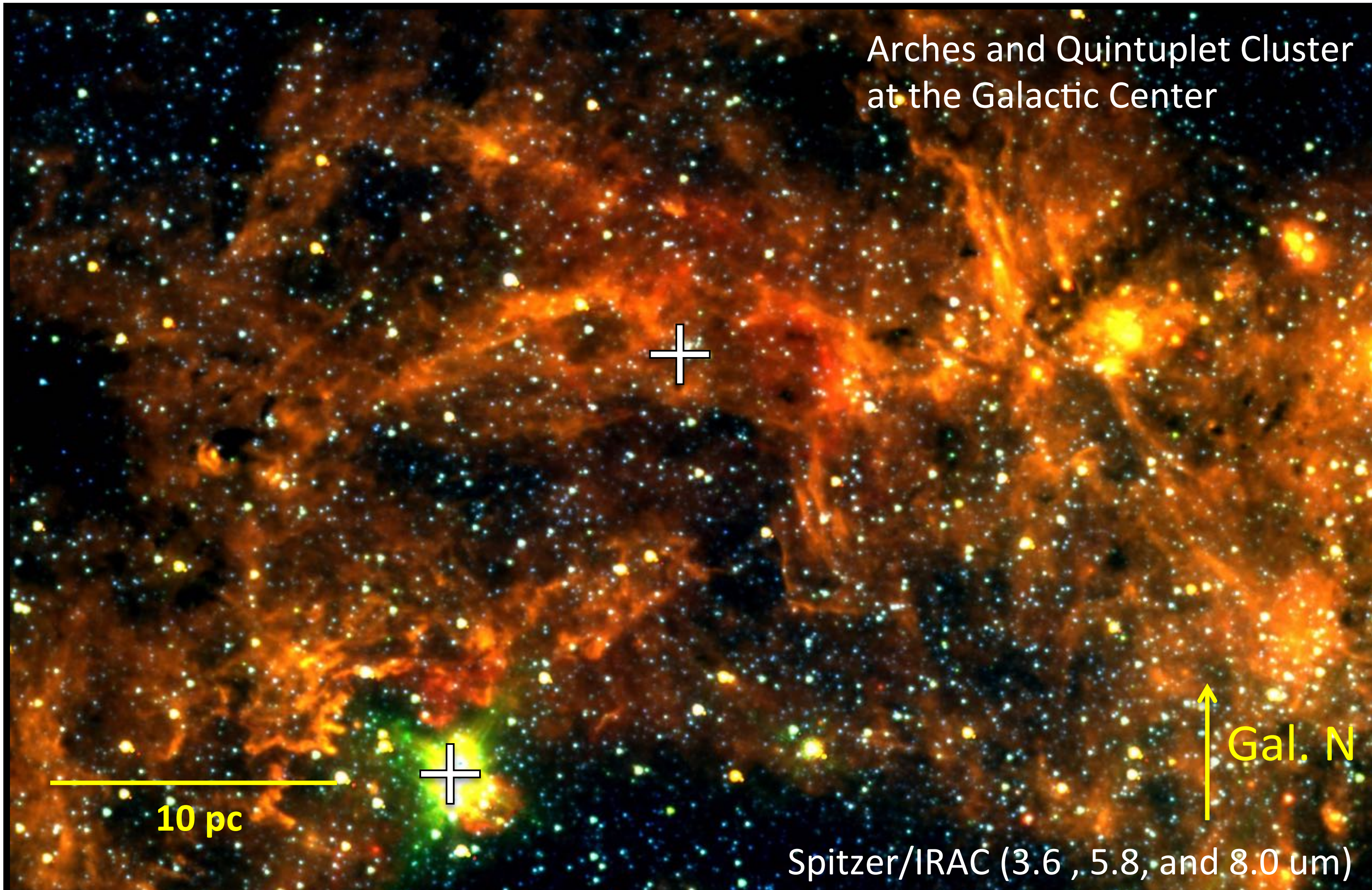
An Outline

- Background: Massive stars and the influence of binarity
- This Work: **A dusty, conical helix extending from a Wolf-Rayet Star**
- The Future: Exploring Massive Stars with the James Webb Space Telescope

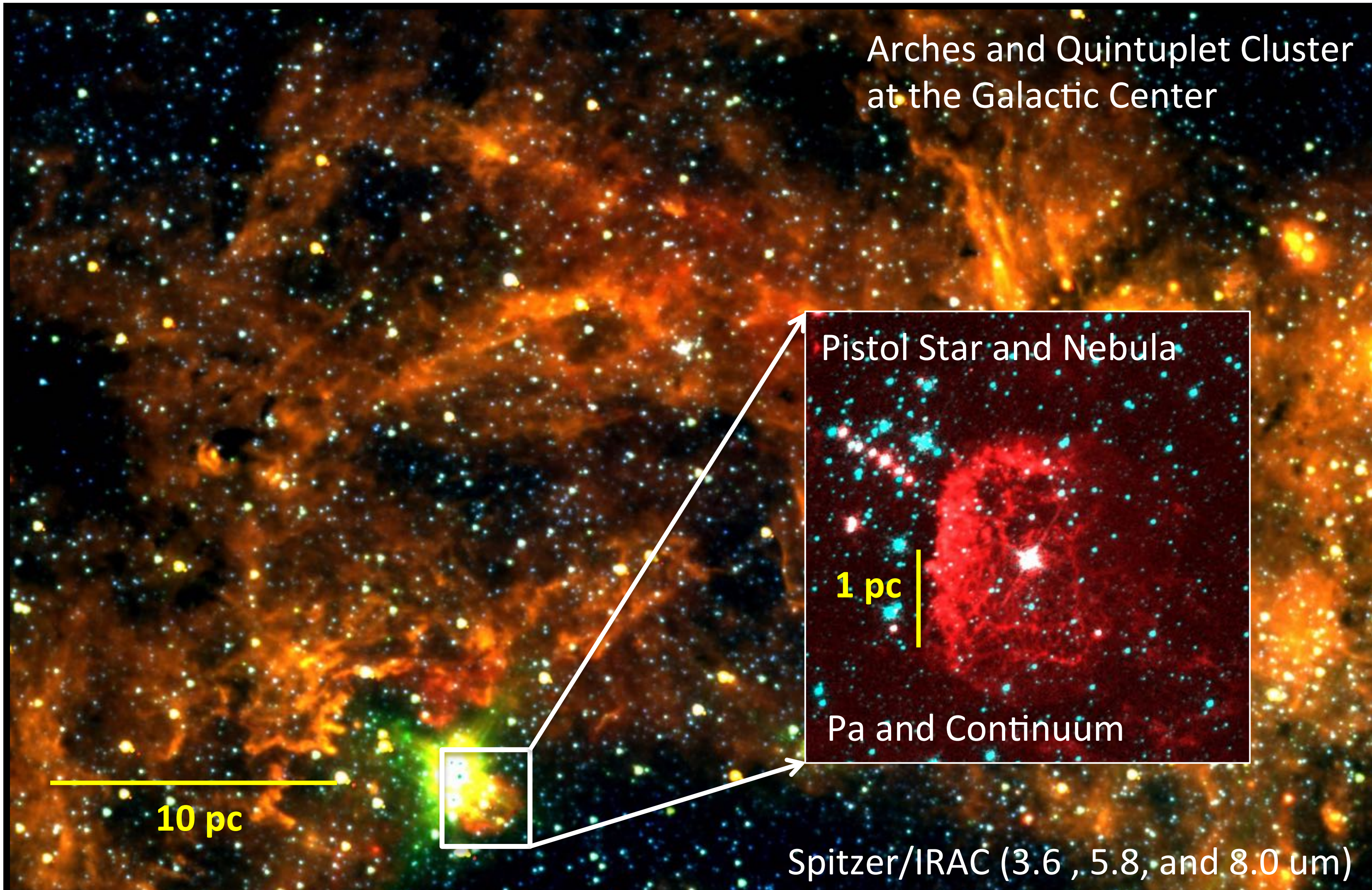
Massive Stars: Galactic Energizers and Refineries

- Dominant sources of optical and UV photons heating dust
- Exhibit strong winds, high mass-loss, and dust production after leaving the main sequence
- Explode as supernovae driving powerful shocks and enriching the interstellar medium

Massive Stars: Galactic Energizers and Refineries

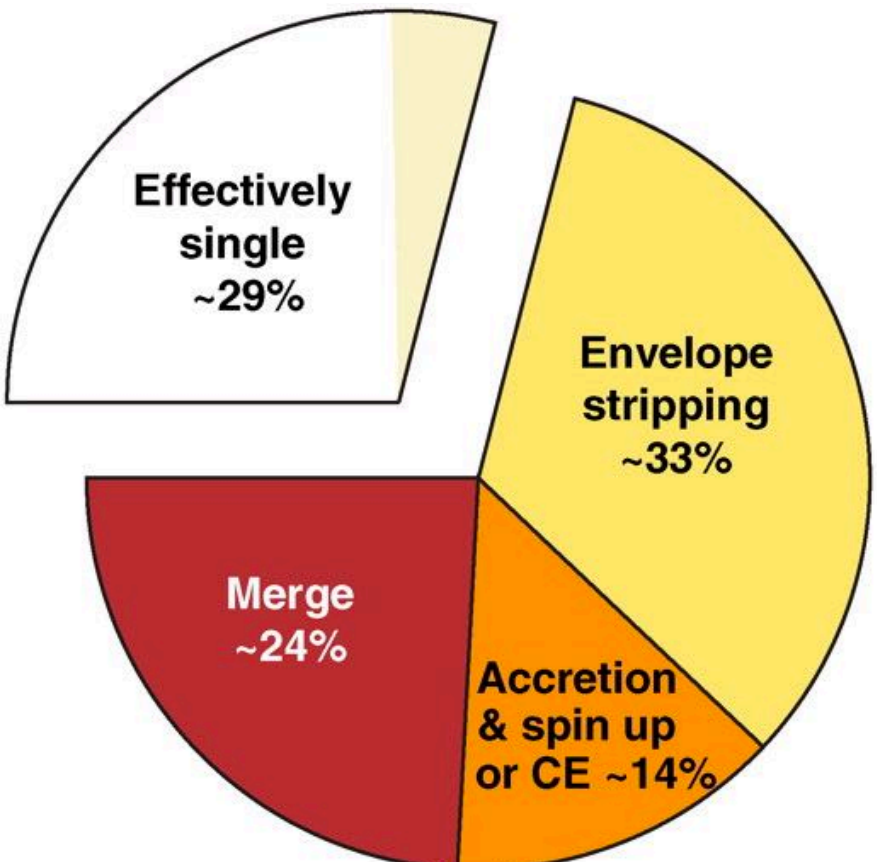


Massive Stars: Galactic Energizers and Refineries



Massive stars are not born alone…

Binary Interaction Pie Chart

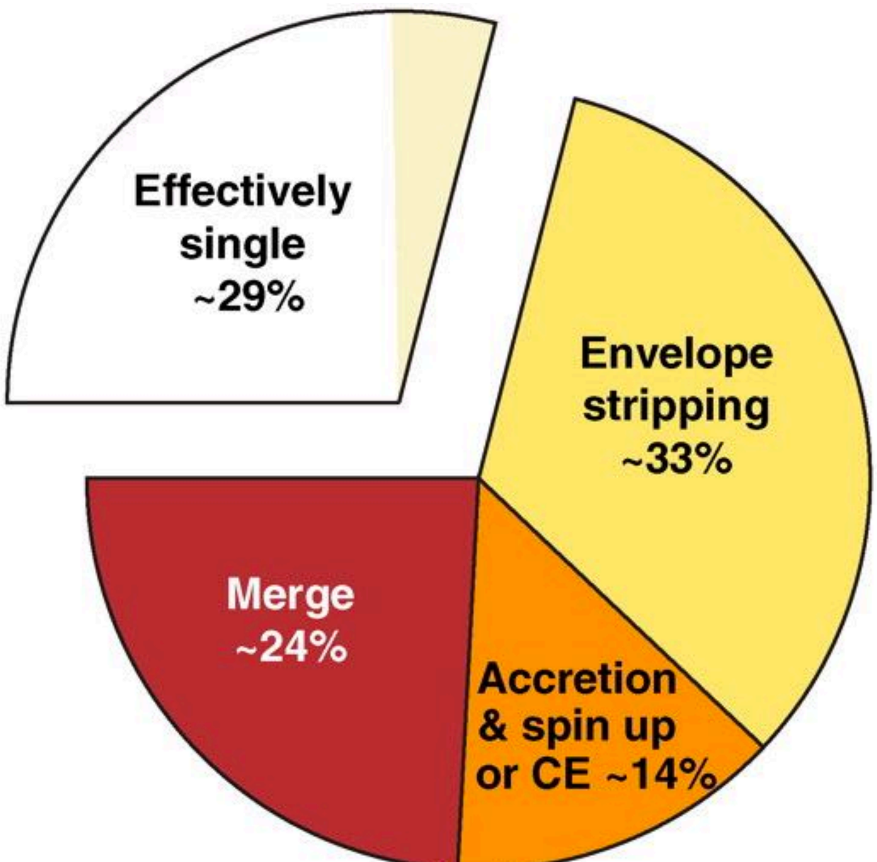


Sana+ (2012)

>70% of all massive stars will exchange mass with companion

Influence of Binarity on Stellar Evolution of Massive Stars

Binary Interaction Pie Chart



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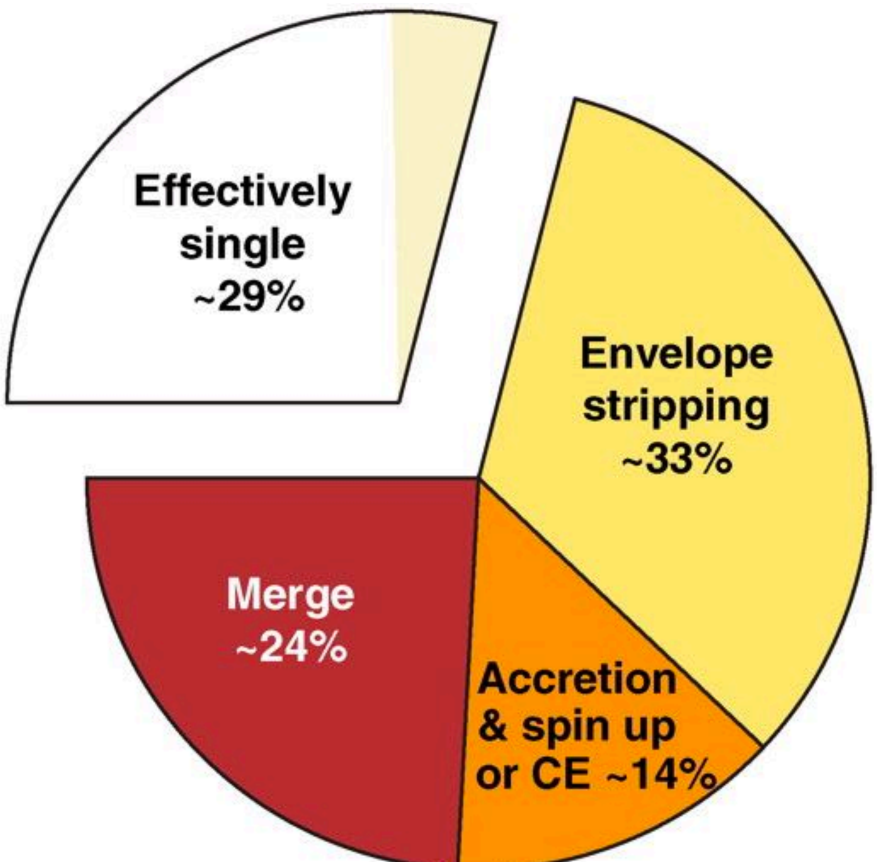
>70% of all massive stars will exchange mass with companion

Mass exchange will effect stellar luminosity and mass-loss rates…

Influence of Binarity on Stellar Evolution of Massive Stars

Binary Interaction Pie Chart



Sana+ (2012)

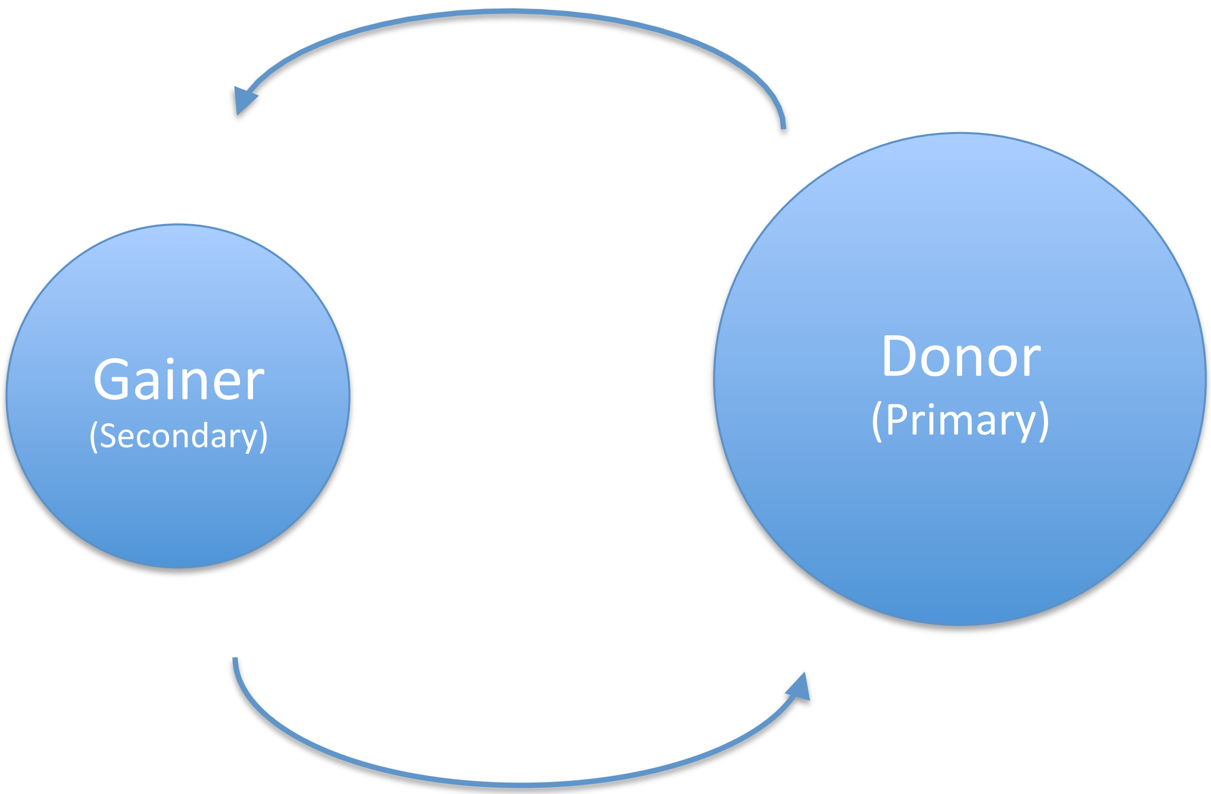
>70% of all massive stars will exchange mass with companion

Mass exchange will effect stellar luminosity and mass-loss rates…

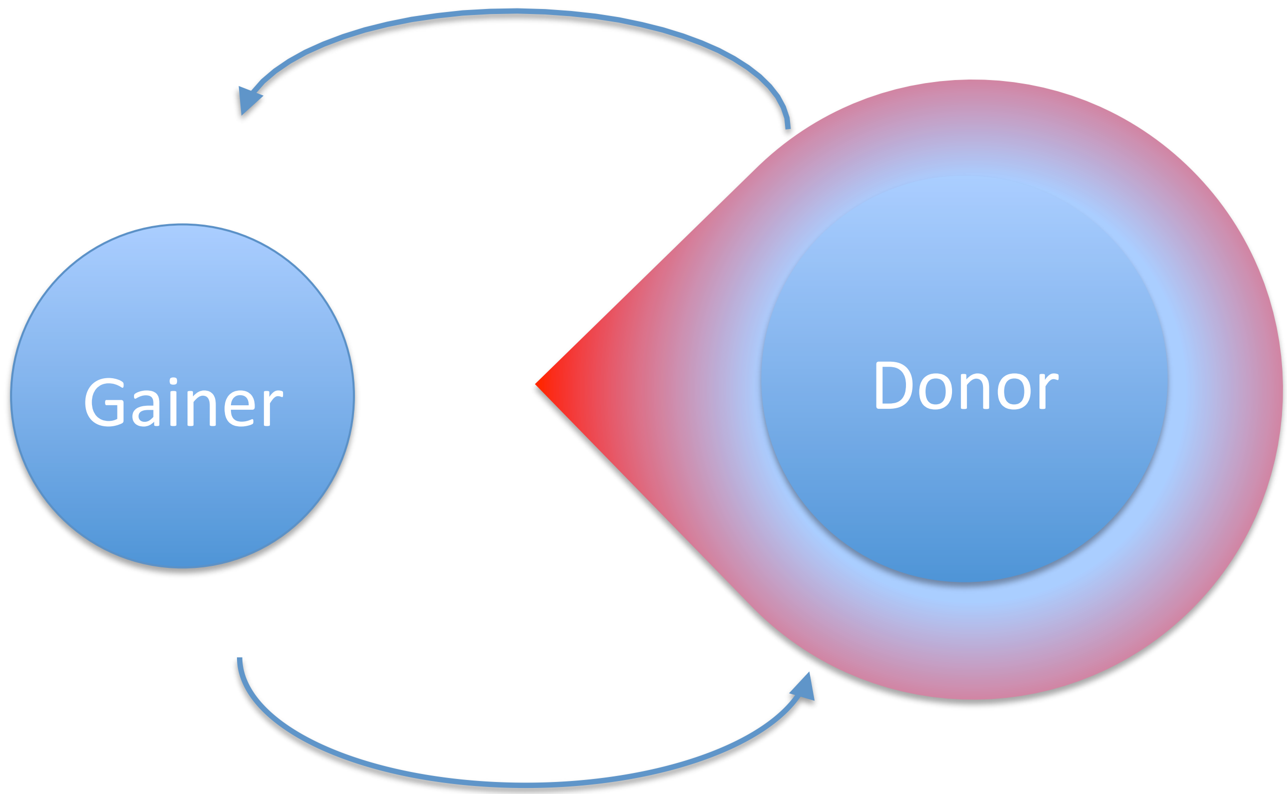
Binary interaction heavily influences massive star evolution

A (simplified) story of an interacting massive binary

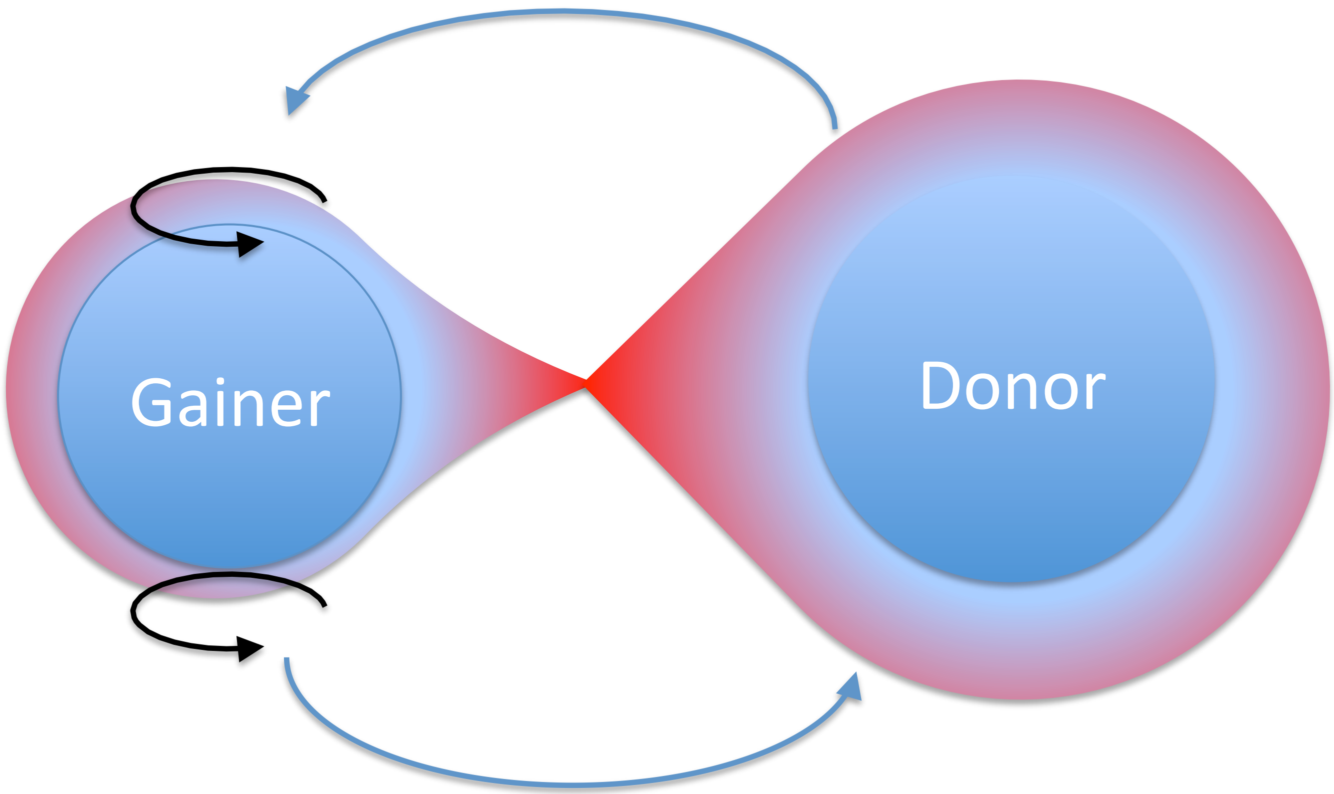
A Close, Massive Binary on the MS



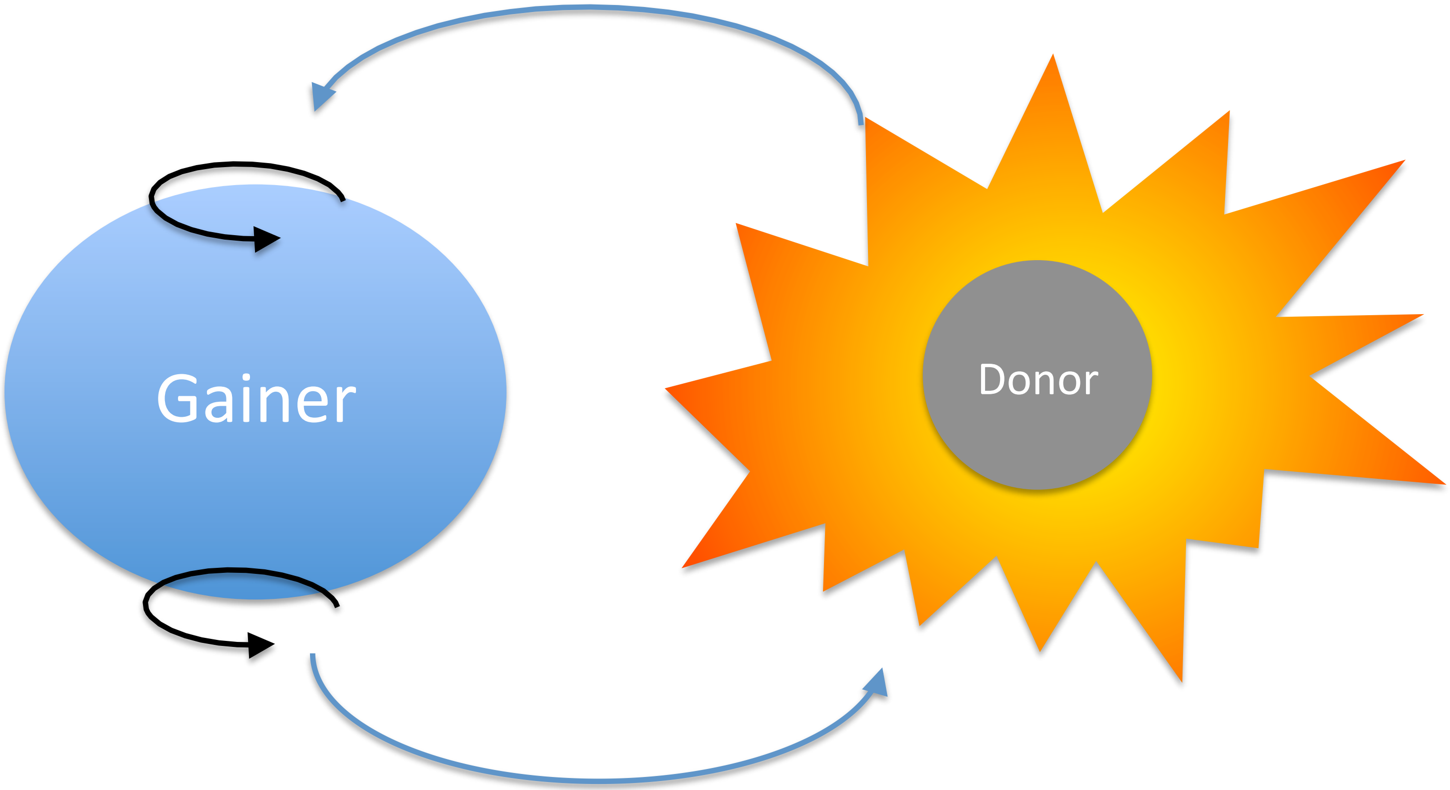
Donor exits MS and Fills Roche Lobe



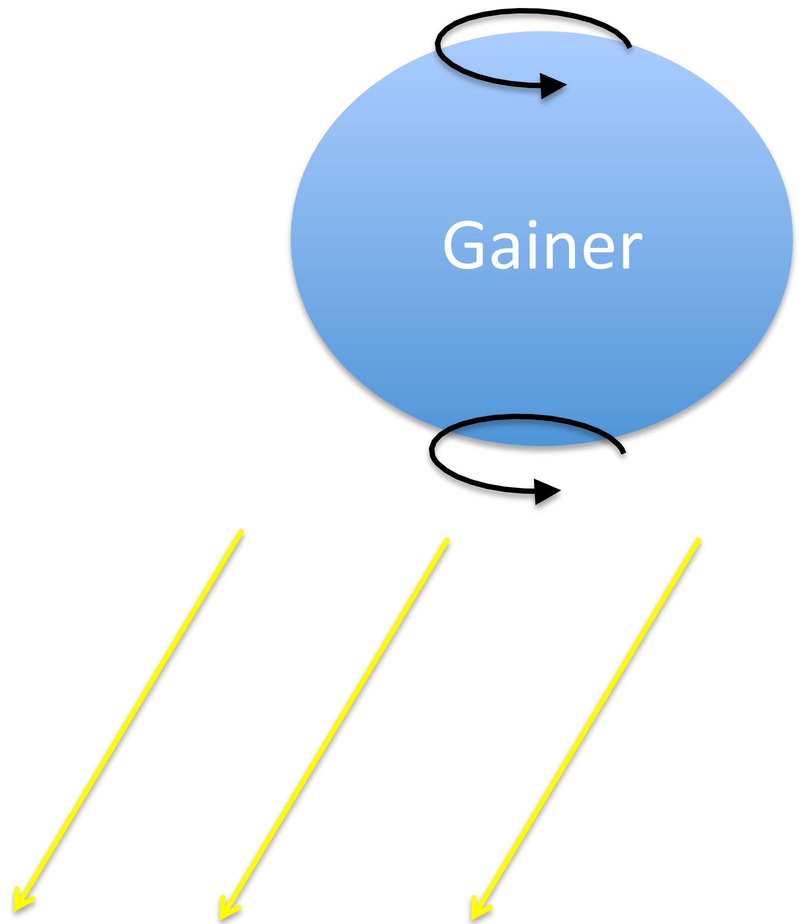
Gainer accretes mass and spins up. Donor loses its H-envelope (becomes a Wolf-Rayet Star)



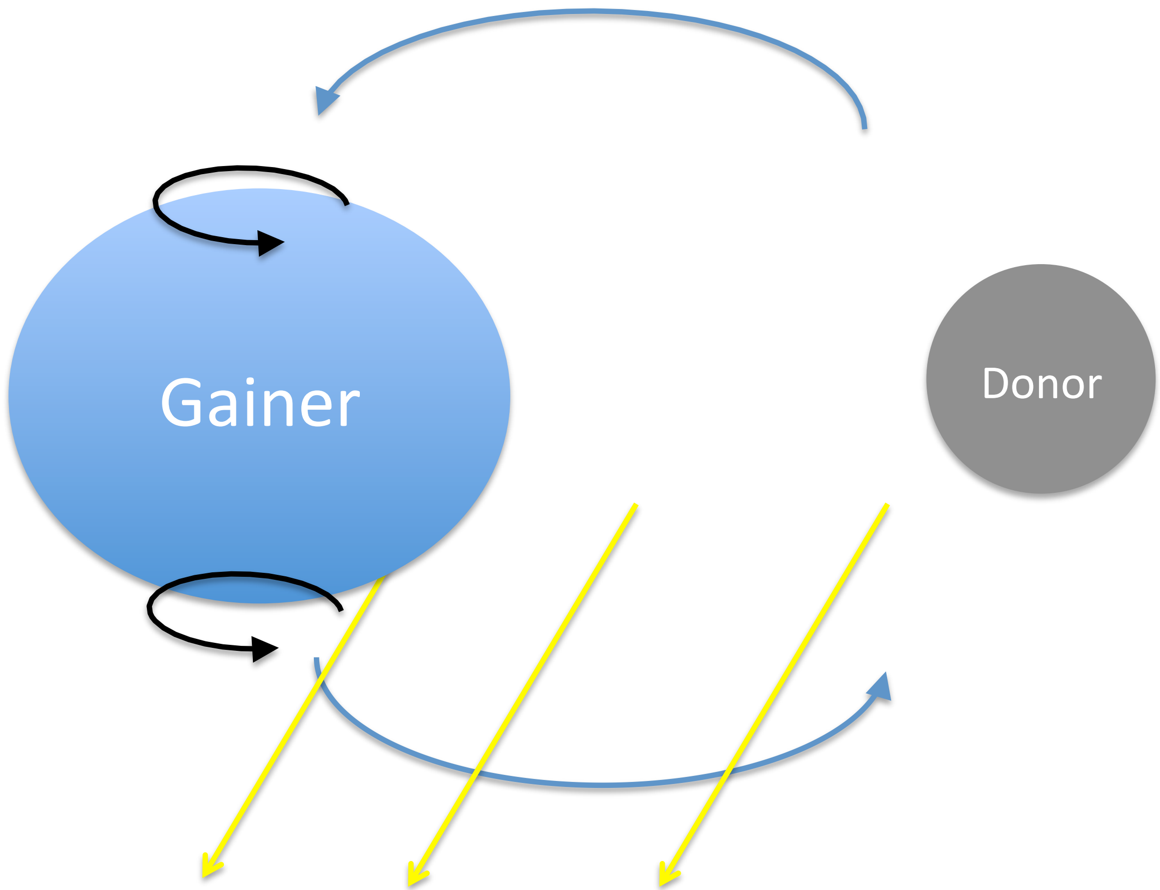
Donor Explodes as Type Ibc SN (no H)



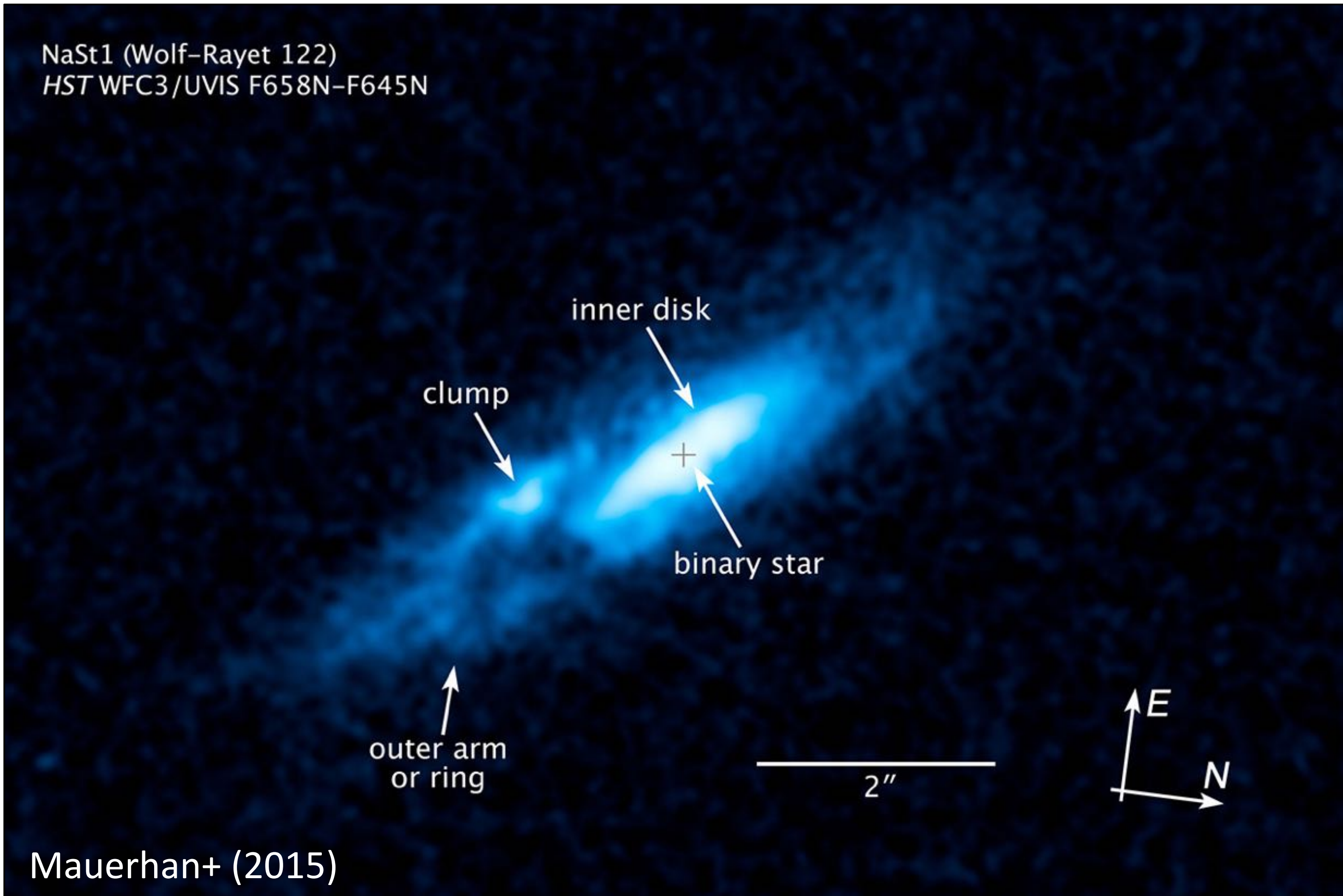
Gainer gets kicked from birth cluster, or…



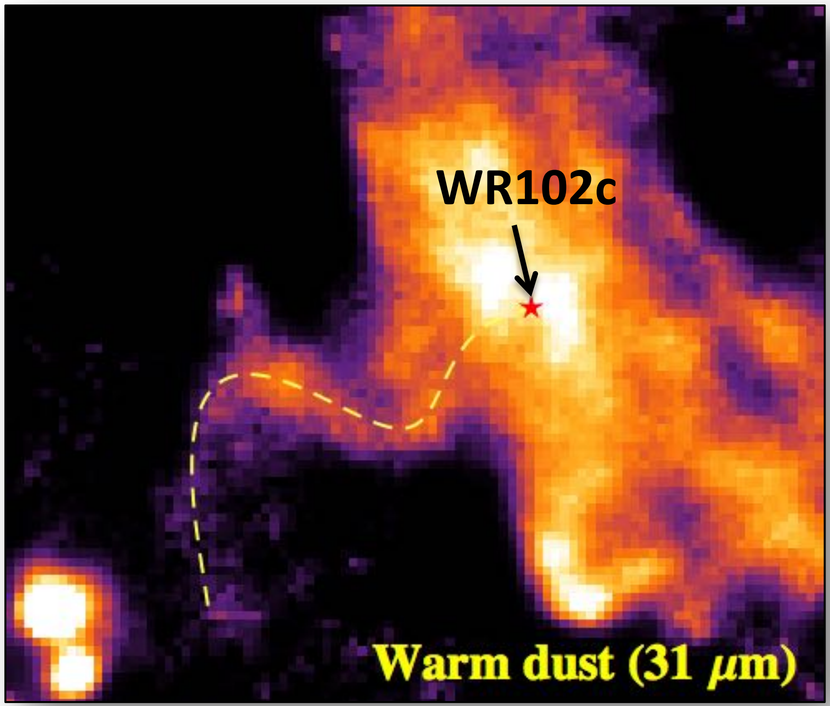
…depending on the SN explosion symmetry, the donor may remain bound

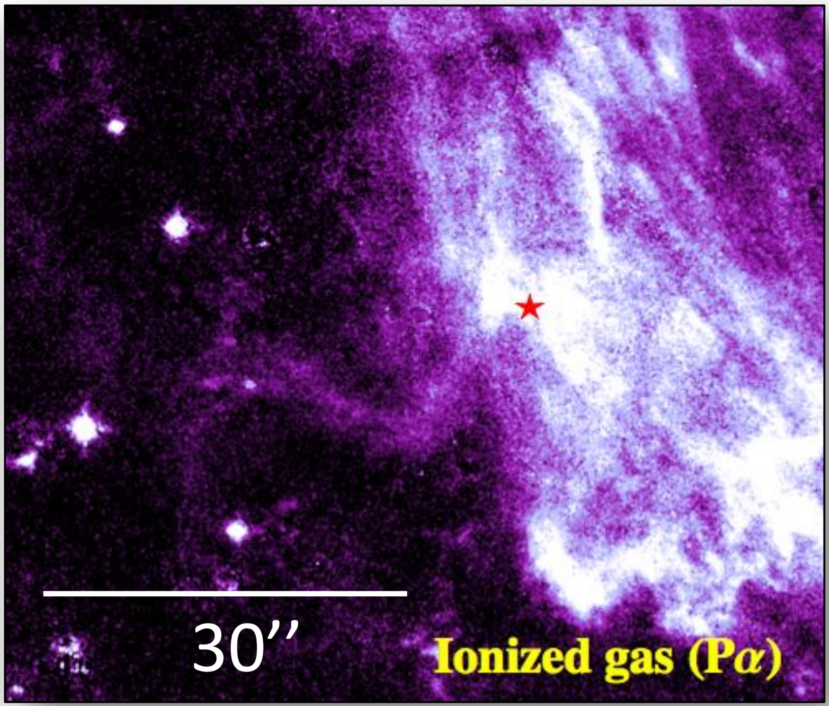


Evidence of Binary Interaction: "Sloppy Stellar Cannibalism"



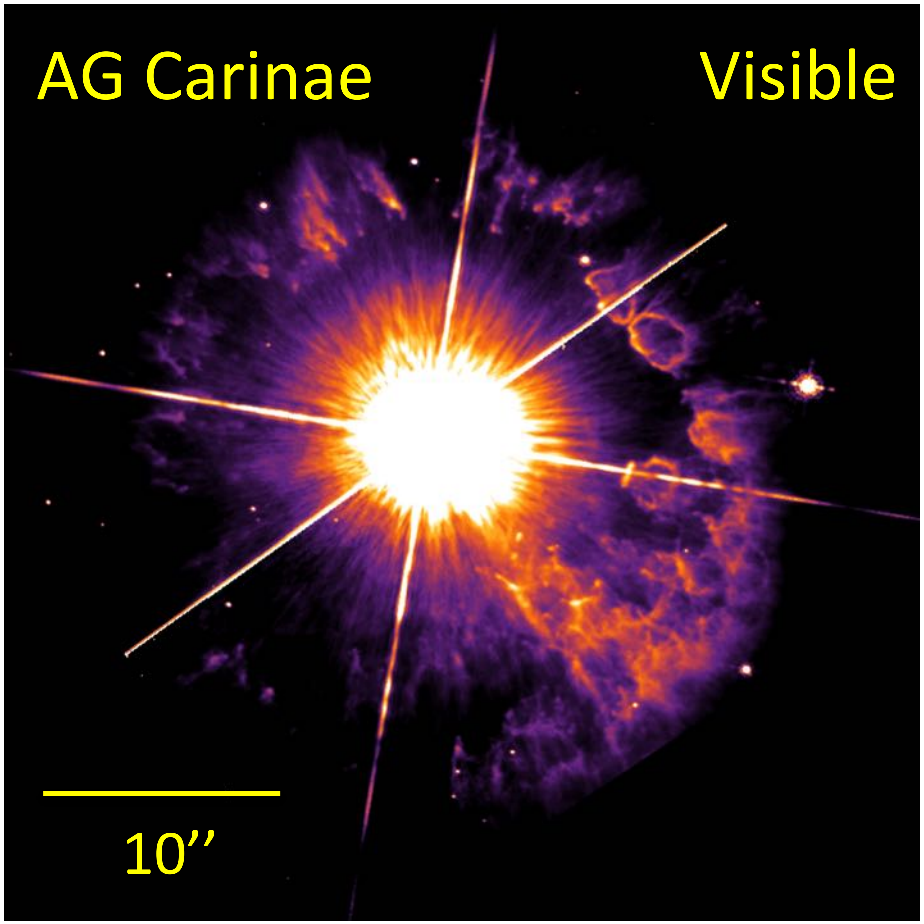
Evidence of Binary Interaction: Dusty Precessing Outflow?





Lau+ (2016)

Not the first helical "jet" found around a massive, evolved star…



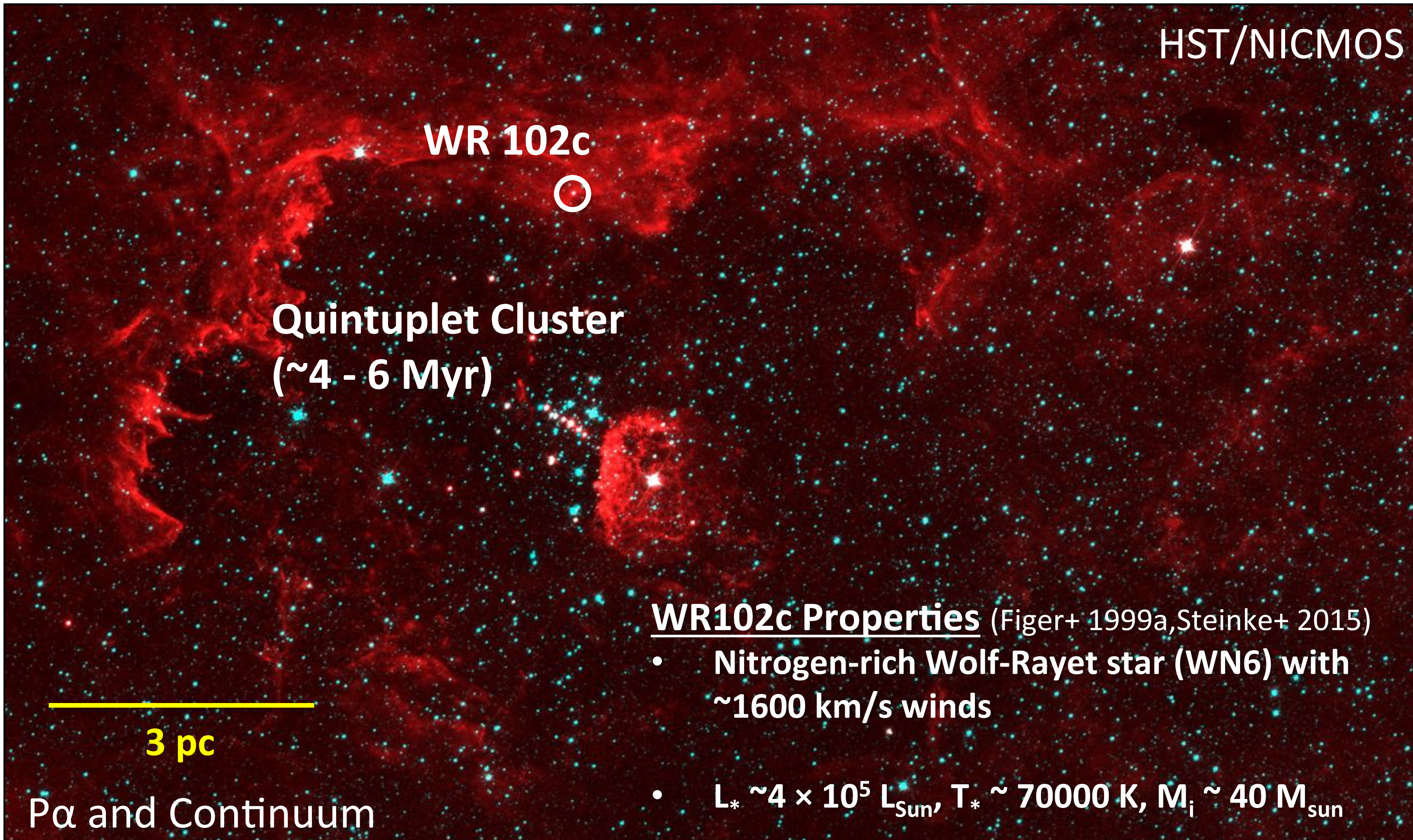
Nota+ (1995)

"This feature is extremely well defined in the B, V, I images and seems to consist of two thick helical filaments spiraling towards the external portion of the nebula" (Paresce & Nota 1989)

<u>A possible origin</u>
Formed due to a precessing accretion disk from an invisible secondary star

This Work: A Conical Dusty Helix Extending from the Wolf-Rayet Star WR102c

WR102c, a Luminous Wolf-Rayet Star near the Quintuplet Cluster

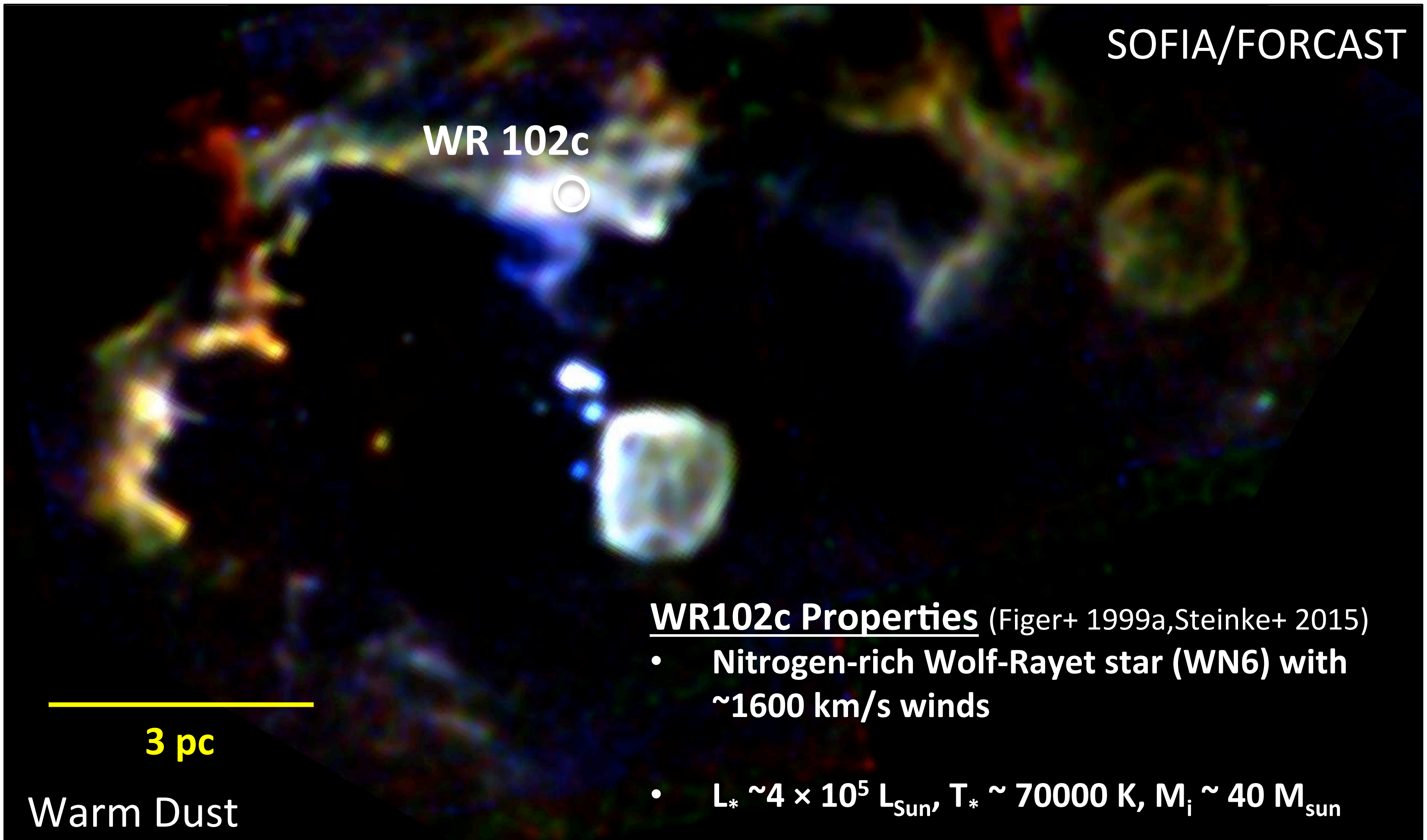


WR102c Properties (Figer+ 1999a,Steinke+ 2015)

- Nitrogen-rich Wolf-Rayet star (WN6) with ~1600 km/s winds
- $L_* \sim 4 \times 10^5\ L_{Sun}$, $T_* \sim 70000$ K, $M_i \sim 40\ M_{sun}$

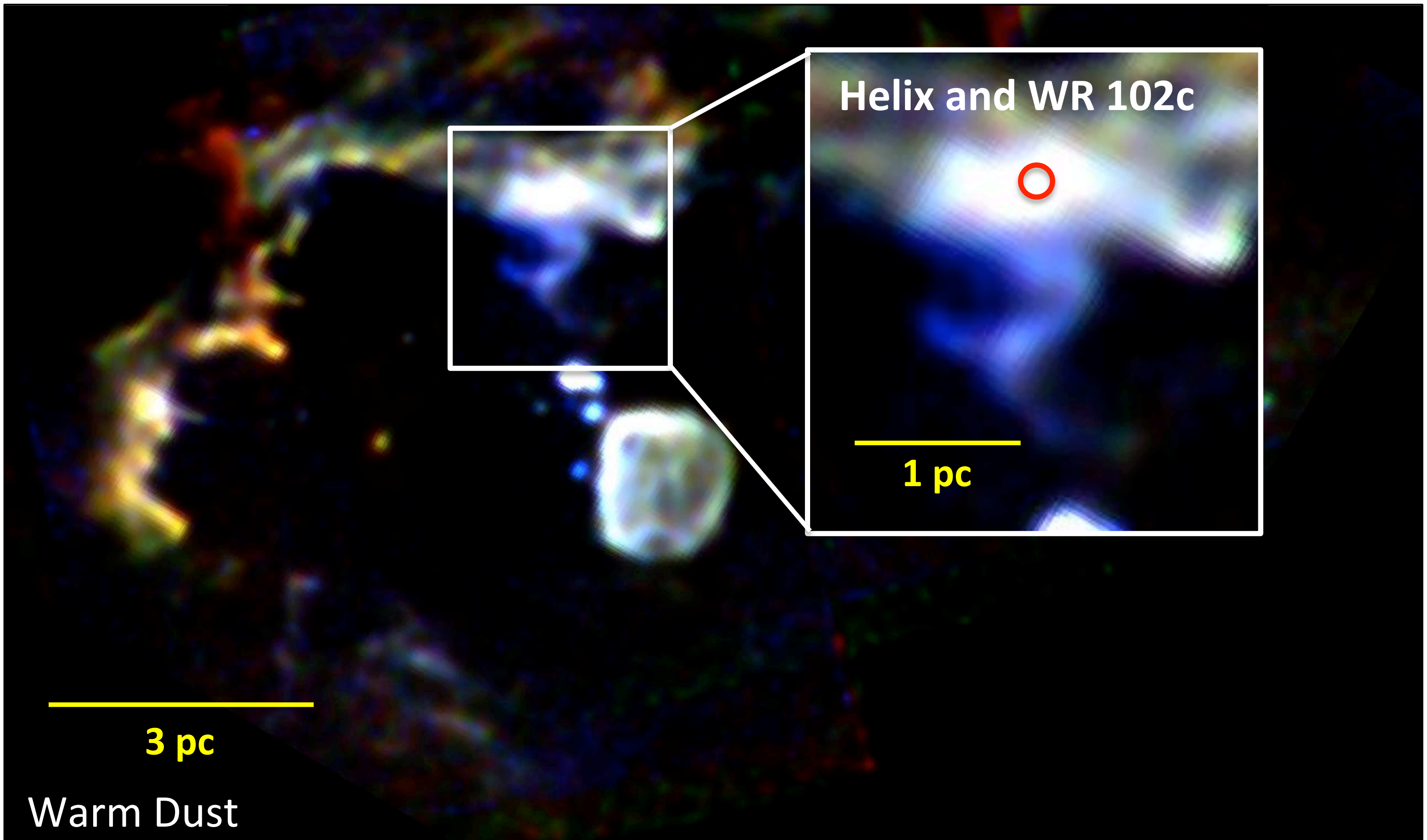
Dong+ (2011), Wang+ (2010)

Warm Dust Emission around the Quintuplet Cluster and WR102c



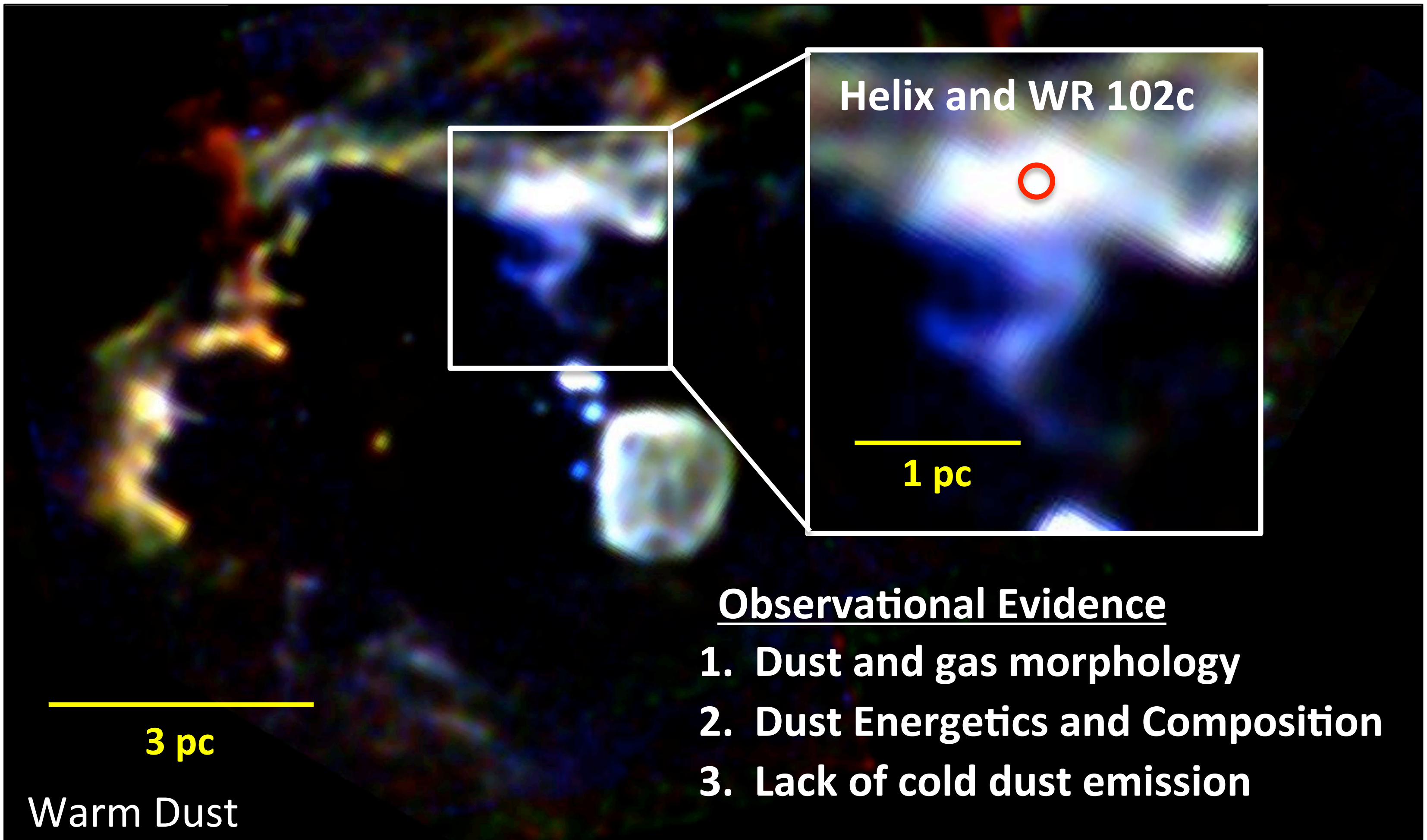
Lau+ (2014b)

A Dusty Conical Helix Extending from WR102c?

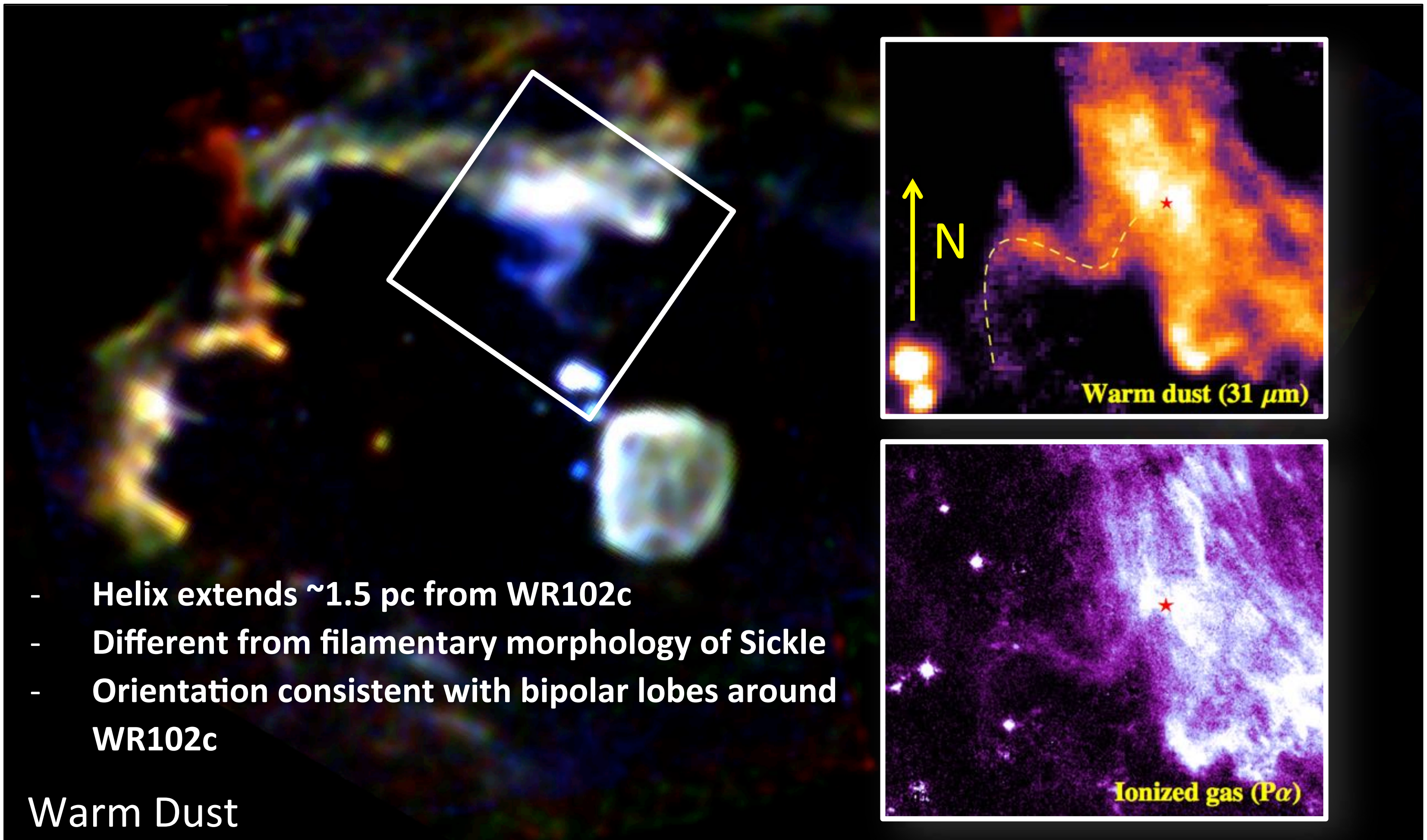


Lau+ (2014b)

Linking the Helix and WR102c

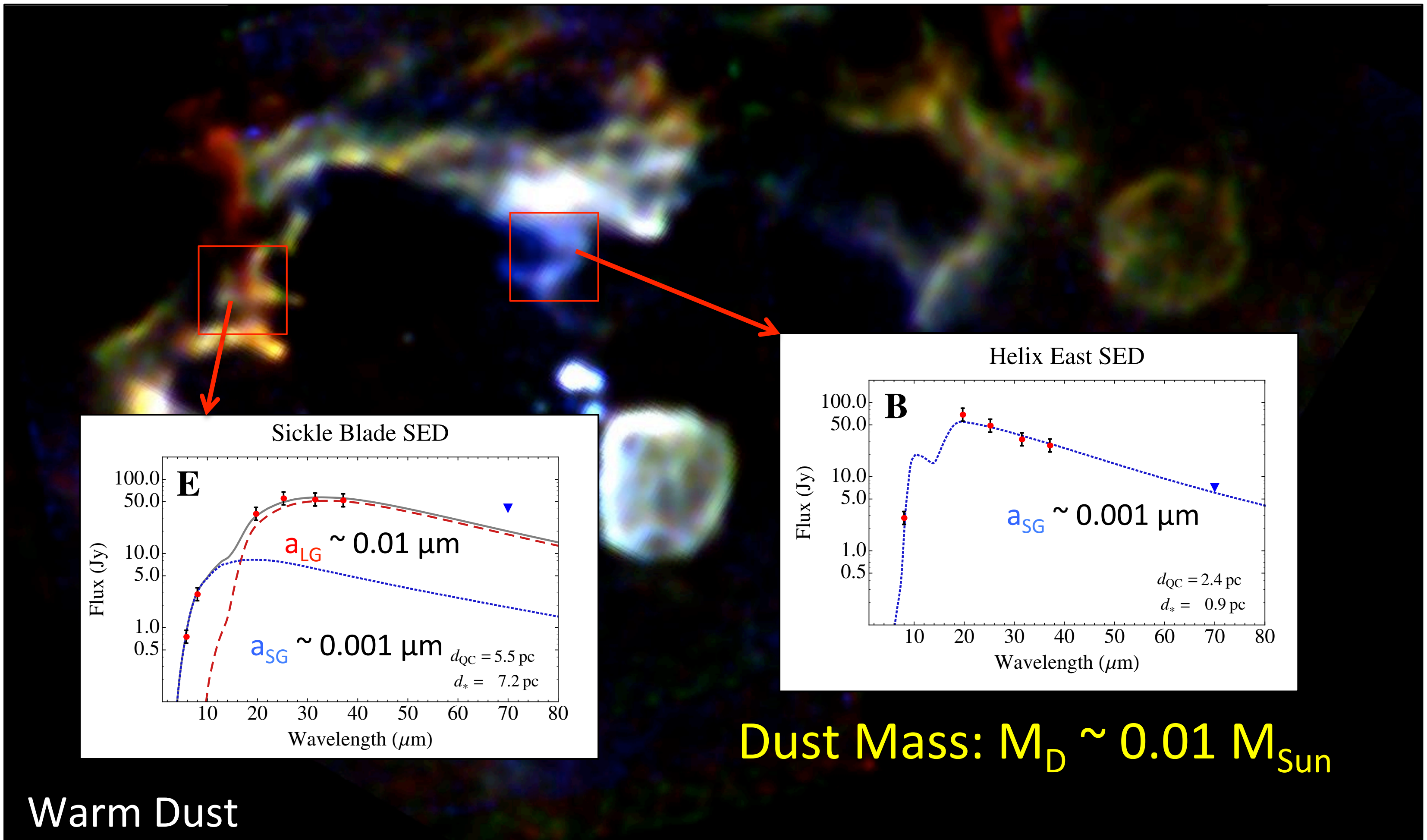


1. Dust and Gas Morphology

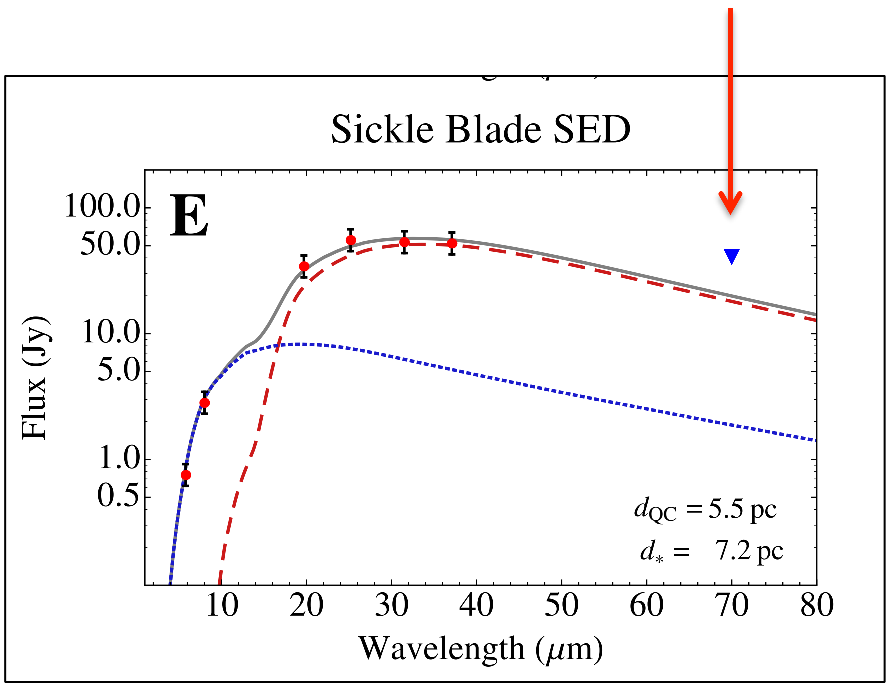


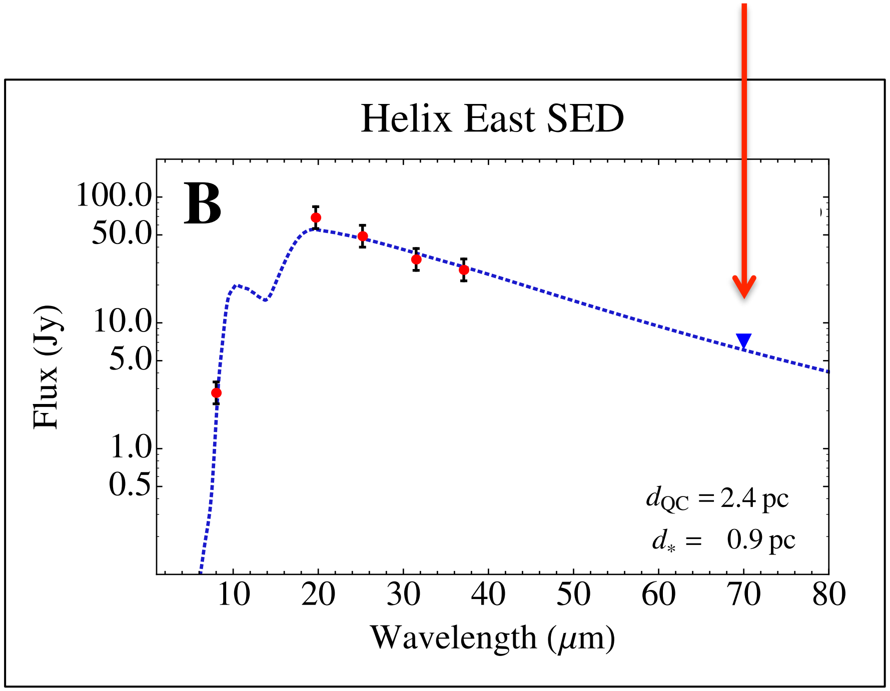
- Helix extends ~1.5 pc from WR102c
- Different from filamentary morphology of Sickle
- Orientation consistent with bipolar lobes around WR102c

2. Dust SED and Composition

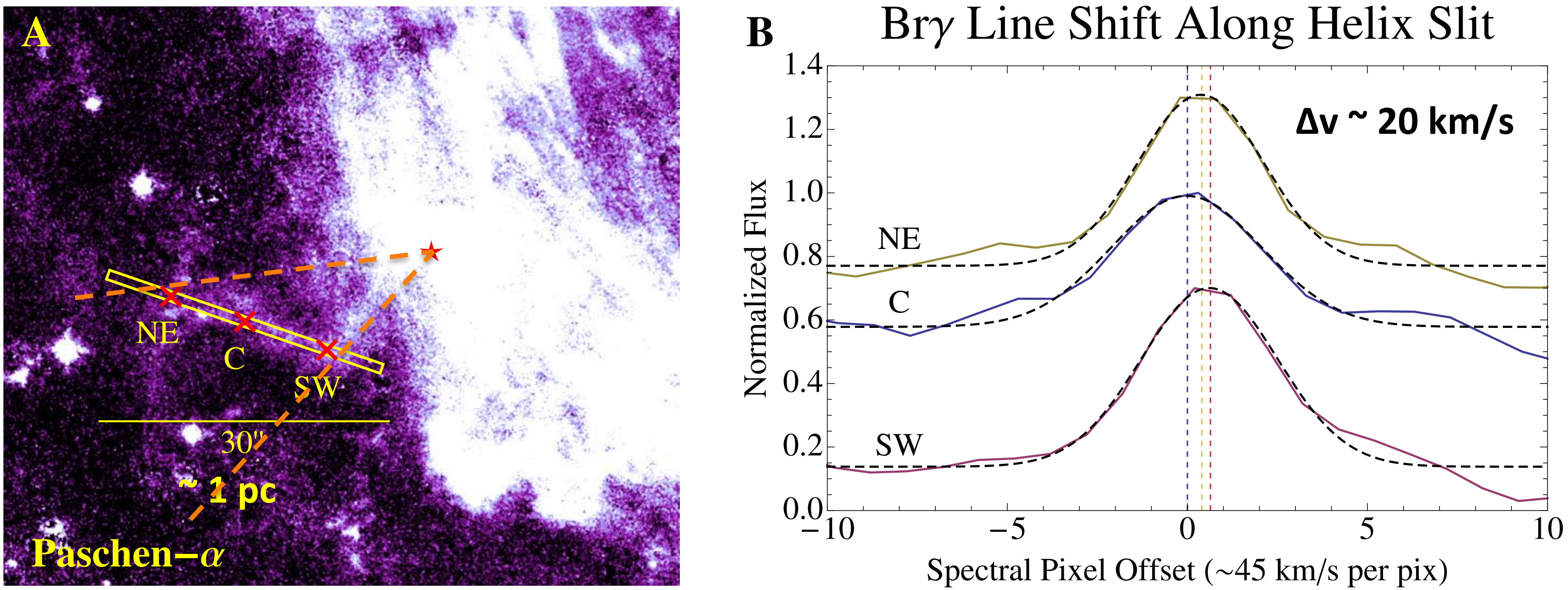


3. Lack of Cold Dust





Outflow Kinematics?



Observations from the Palomar/TripleSpec
- R ~ 3000 near-IR spectrograph

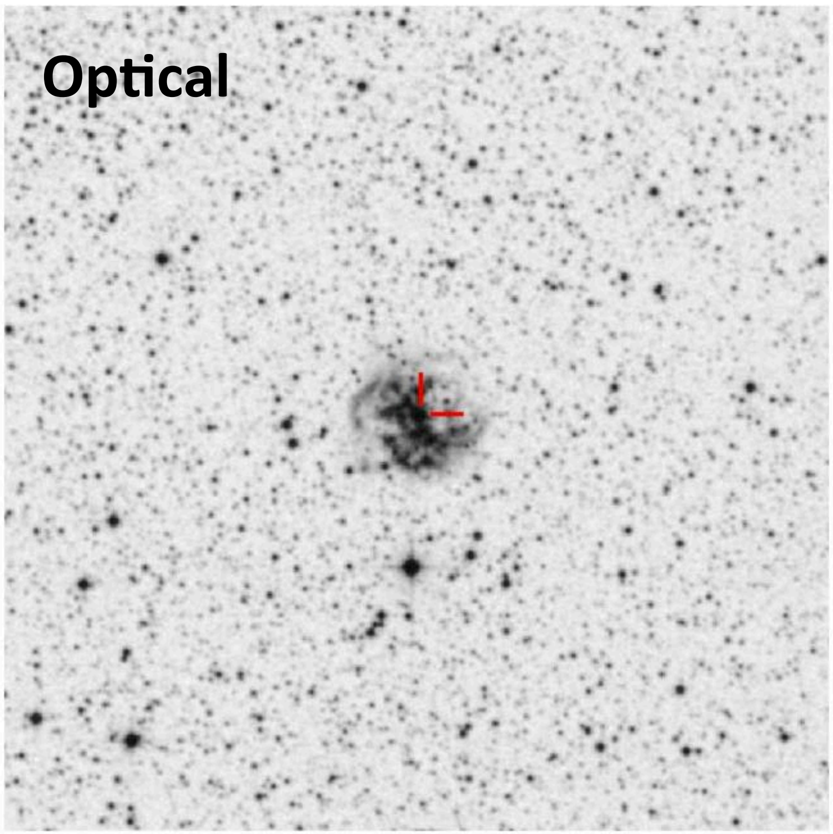
Consistent with helical outflow kinematics, but need higher spectral resolution follow-up

When would the helix have formed?

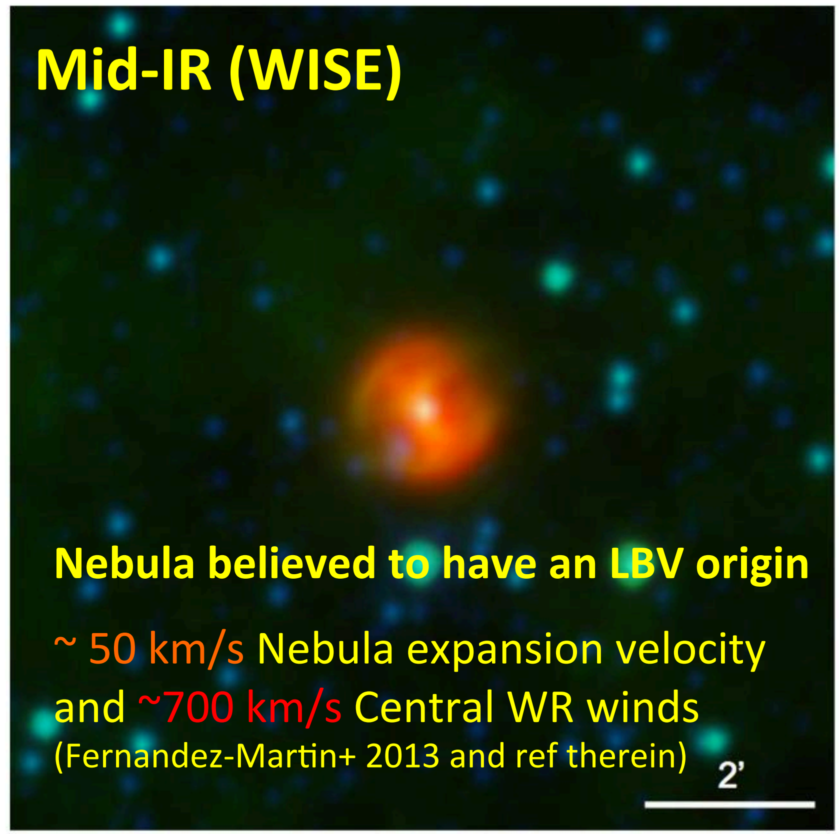
Dust will not condense in the high velocity (~1000 km/s) outflows from Wolf-Rayet stars…

…likely formed during previous, eruptive Luminous blue variable (LBV) or Red supergiant (RSG) phase

For Example: M1-67 around WR 124



(Toala+ 2015)



Other WR Nebulae…

Toalá et al.: *WISE* morphological study of WR nebulae

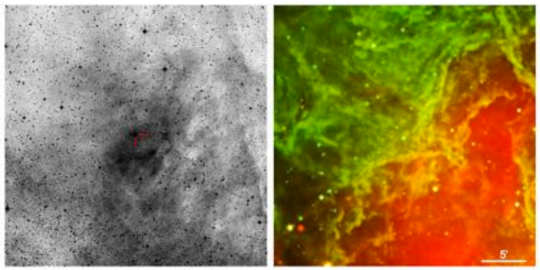


Fig. A.17. Same as Fig. A.1 for WR 113 (RCW 167).

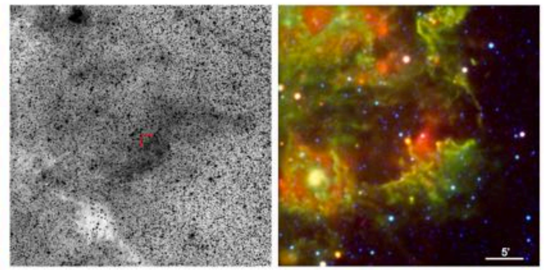


Fig. A.21. Same as Fig. A.1 for WR 131.

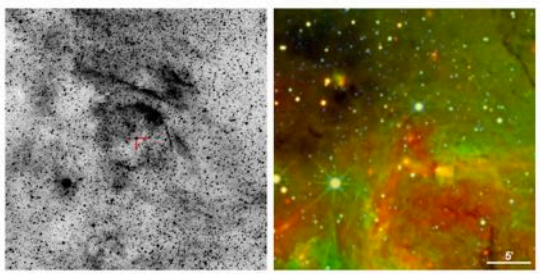


Fig. A.18. Same as Fig. A.1 for WR 116 (Anon).

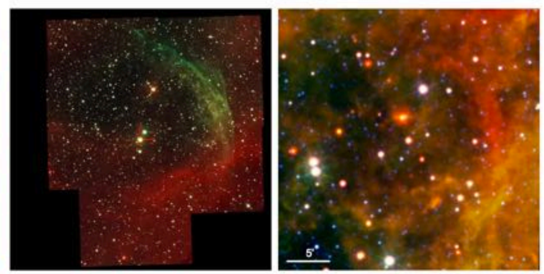


Fig. A.22. Same as Fig. A.1 for WR 134 (Anon).

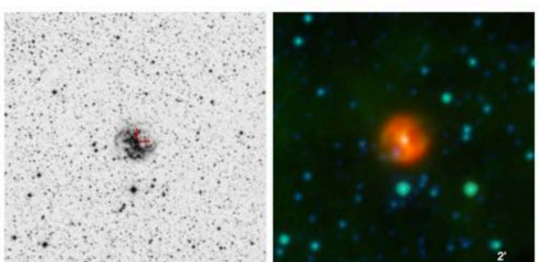


Fig. A.19. Same as Fig. A.1 for WR 124 (M1-67).

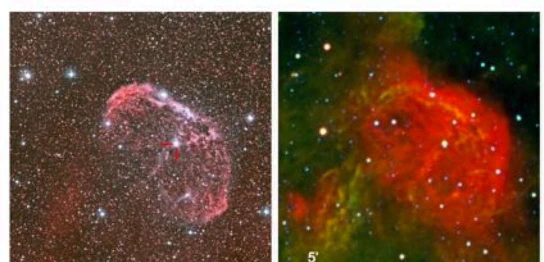
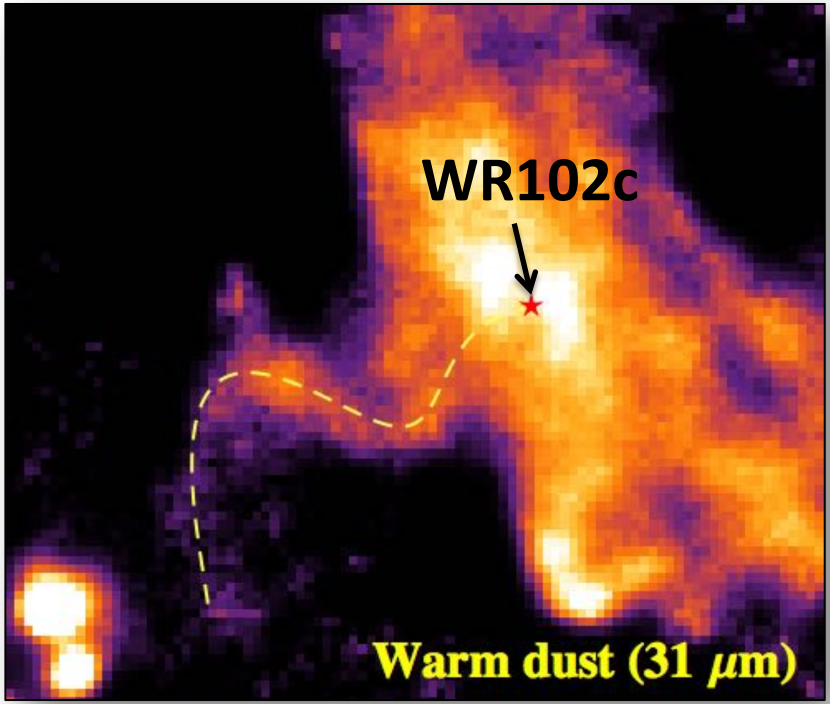
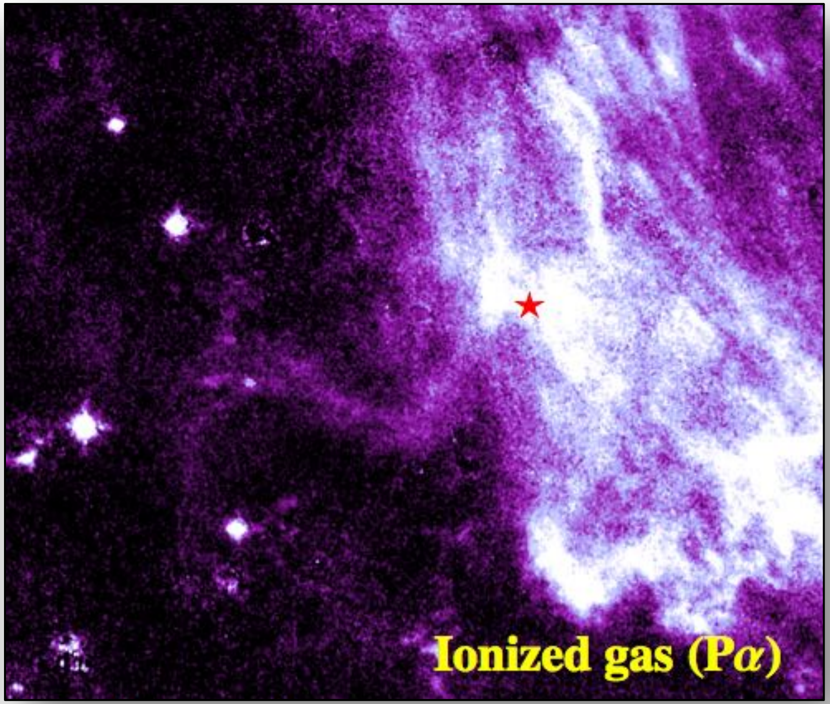


Fig. A.23. Same as Fig. A.1 for WR 136 (NGC 6888).

(Toala+ 2015)

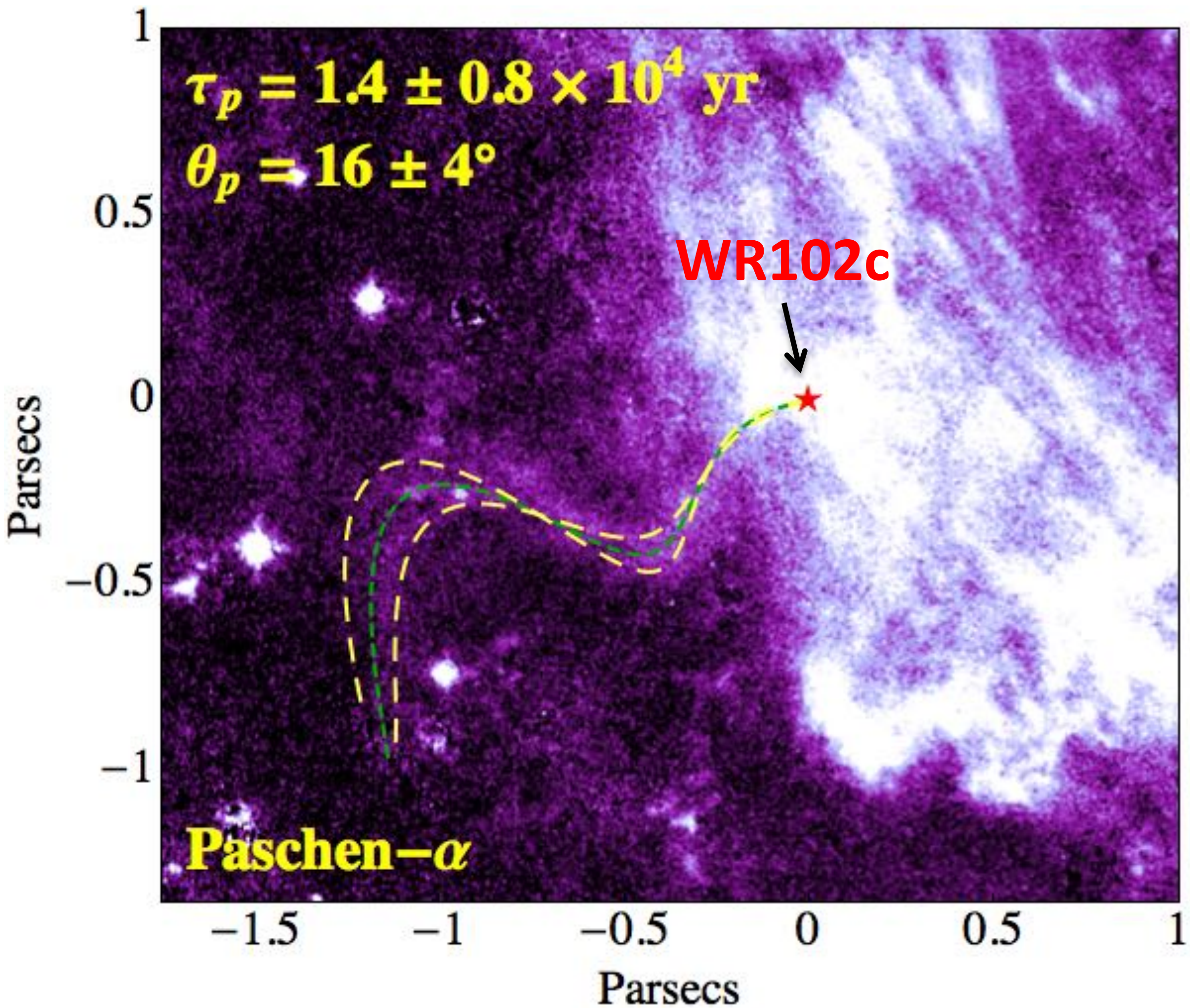
Interpretation of Helical Outflow?





A dusty, precessing polar outflow from WR102c during previous LBV/RSG phase

A Precessing Outflow Model

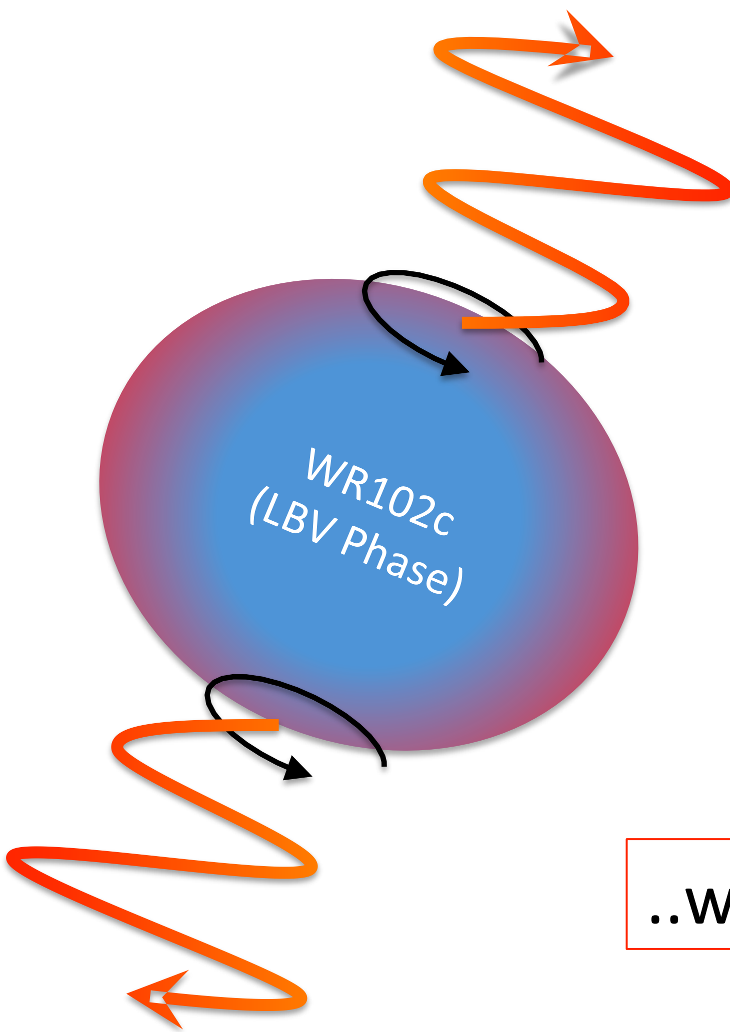


- Outflow model (green line) assumes a velocity of ~**80 km/s**

- Best fit implies precession period of **~14000 yr**

- Mean mass loss rate of **~4 × 10^{-5} M$_{sun}$ yr^{-1}**

Why would it be precessing?

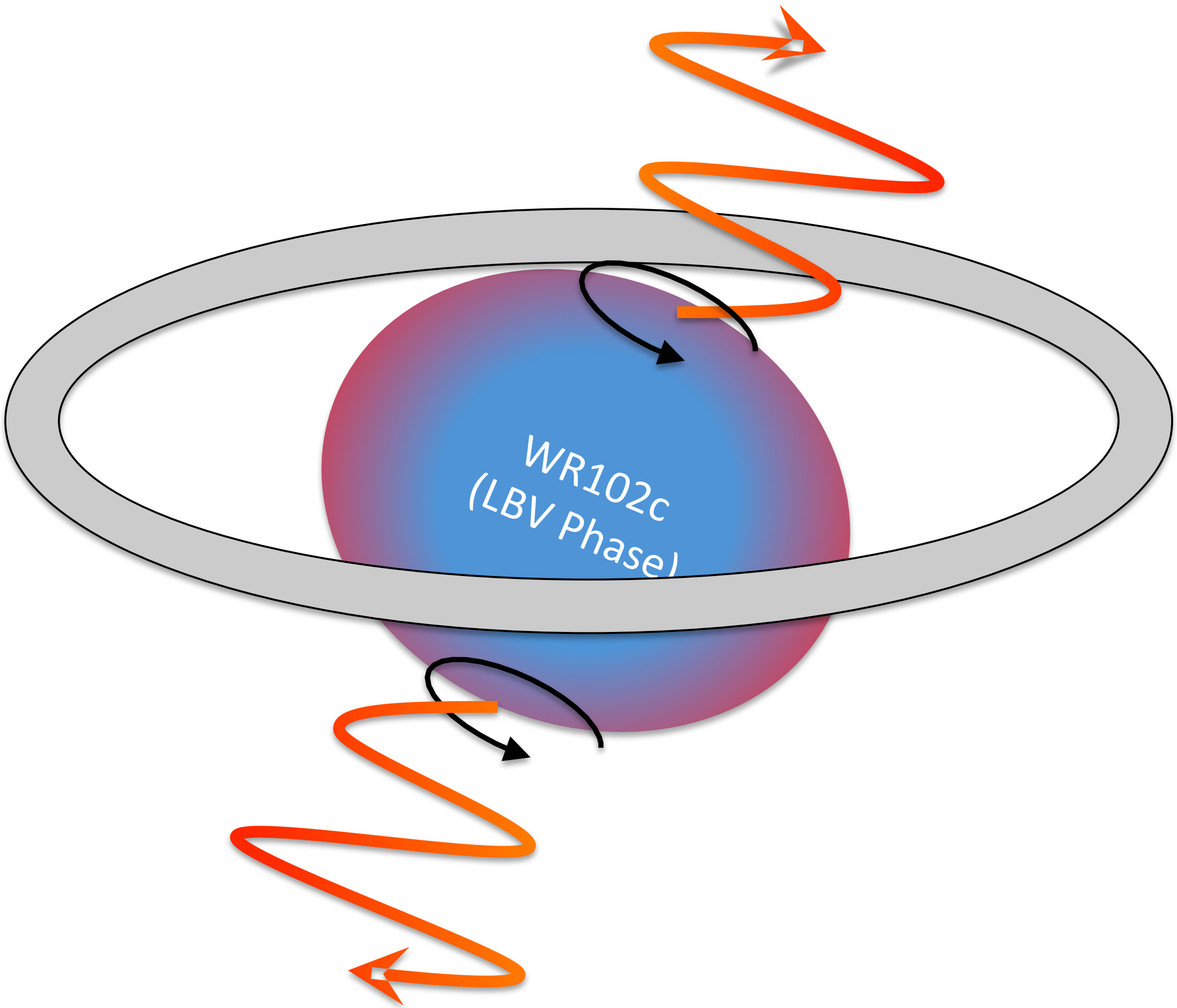


A Bloated Star

- LBVs are observed to have **high rotational velocities** (Groh+ 2009) and are likely **“bloated”** around the equator
- Due to gravity darkening at the equator, the outflow is believed to be strongest at poles (Dwarkadas & Owocki 2002)

..what is it interacting with?

What causes WR102c to precess?



a disk?

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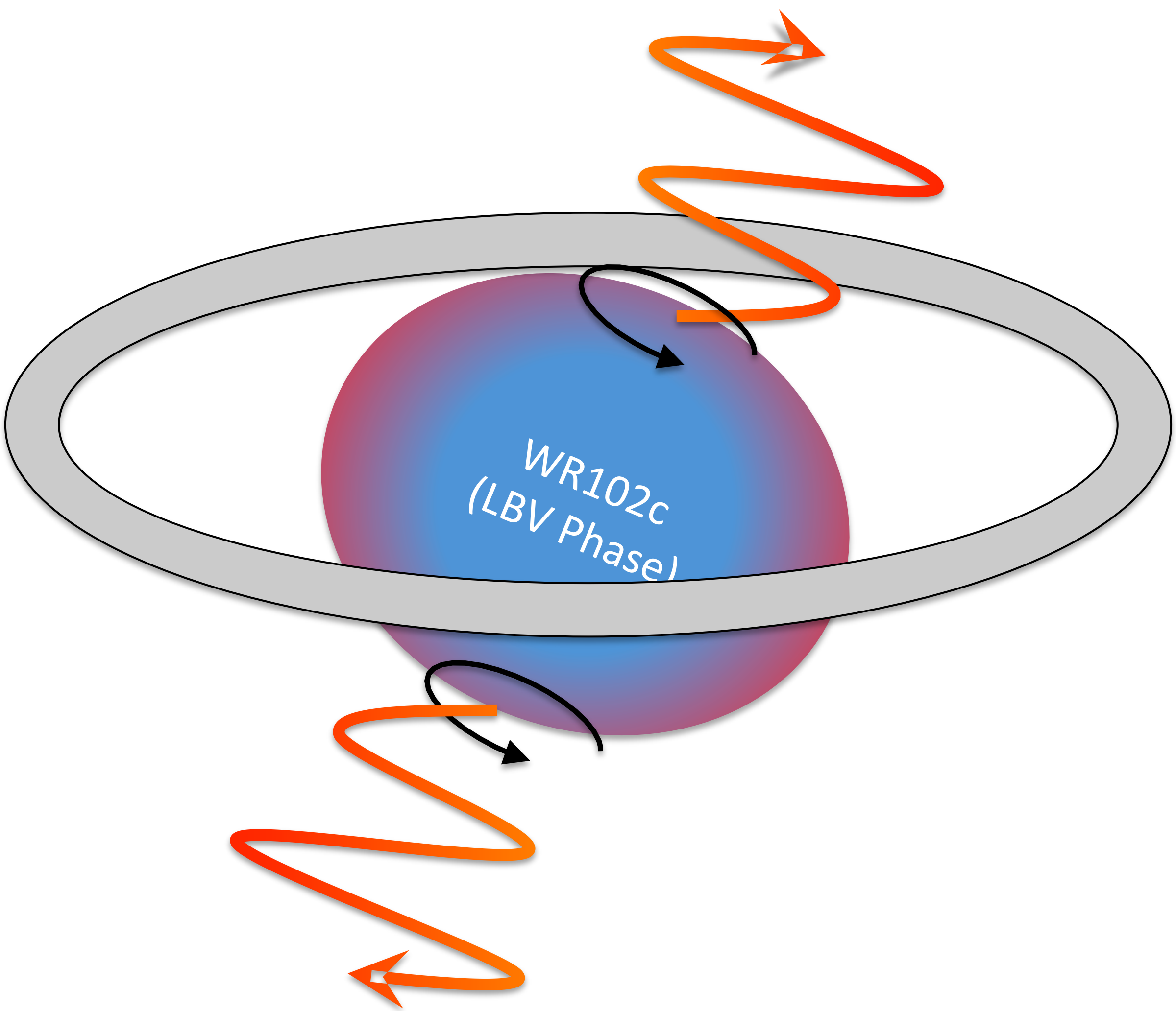


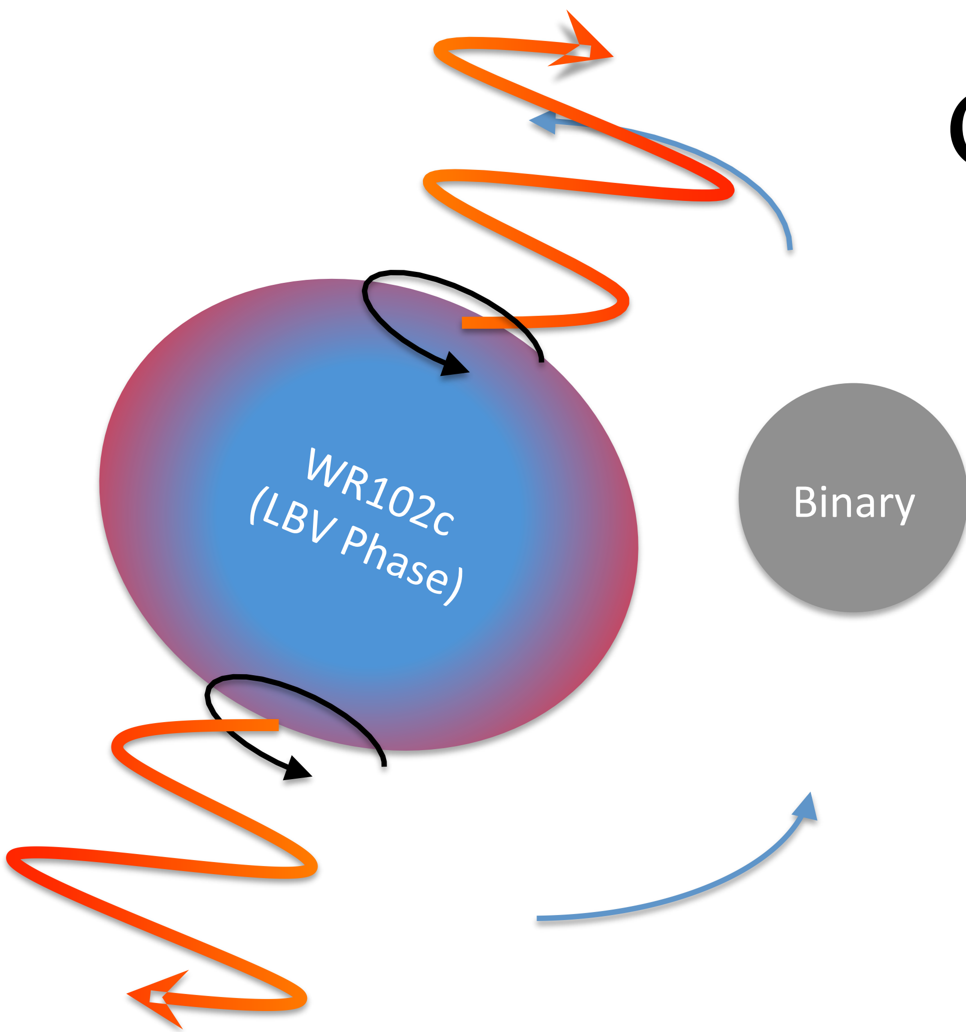
a disk?

Unlikely because…

Will not survive strong winds from central star

What causes WR102c to precess?

Companion?



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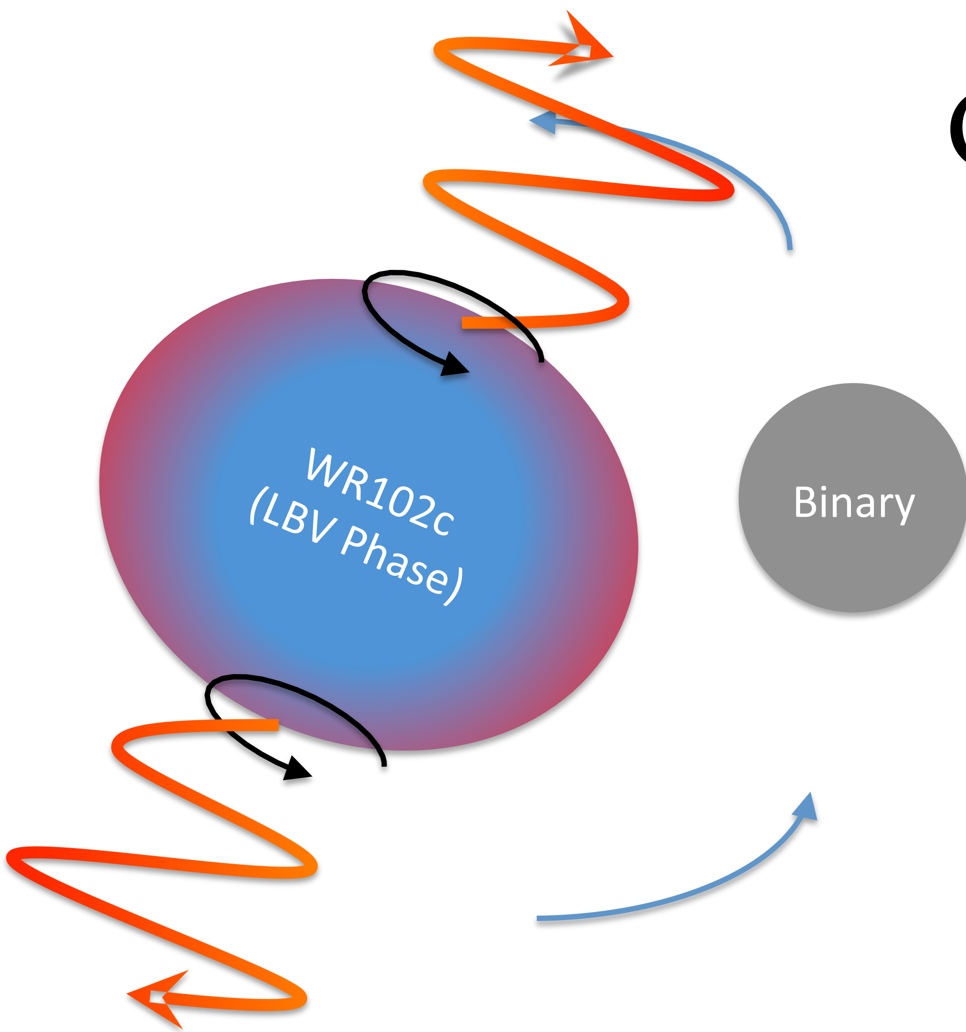
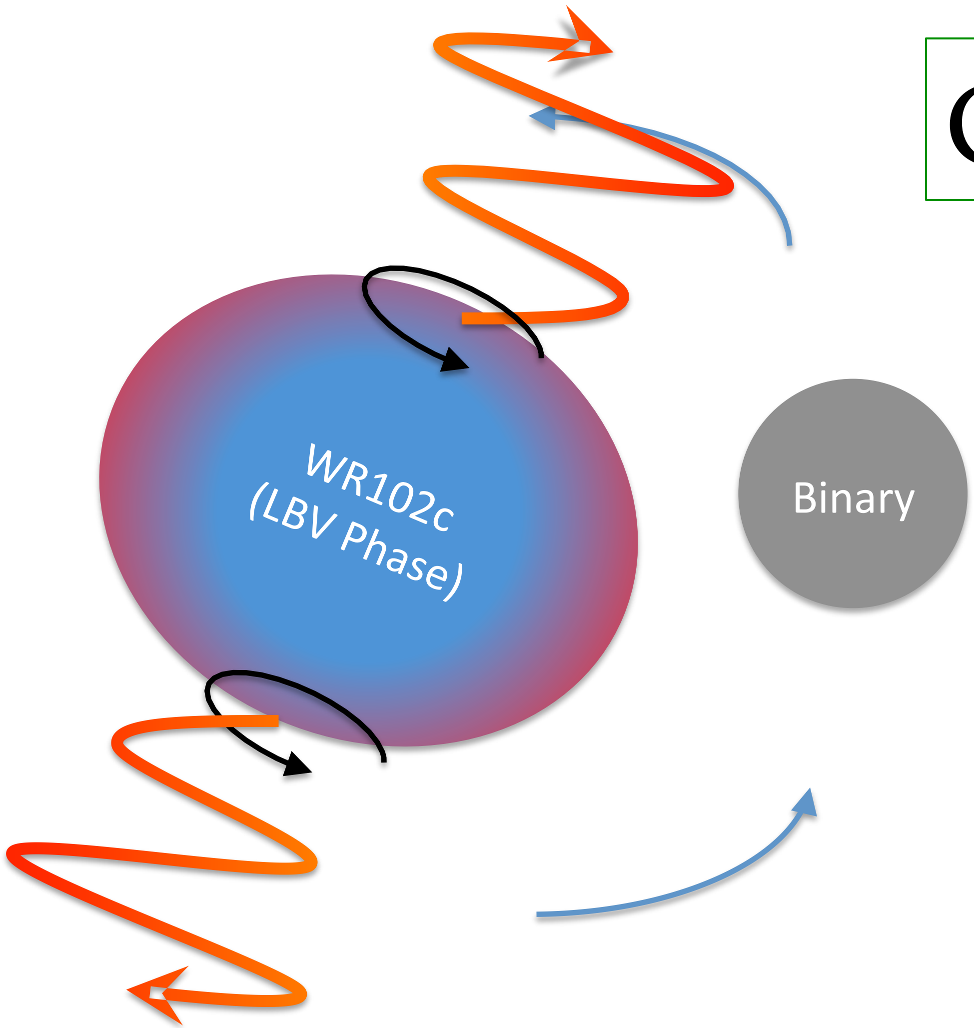


Companion?

- Will survive longer than 2×10^4 yr
- *Compact remnant?*
  - Consistent with being kicked from cluster
  - No x-ray emission indicating colliding winds a with MS-companion

What causes WR102c to precess?



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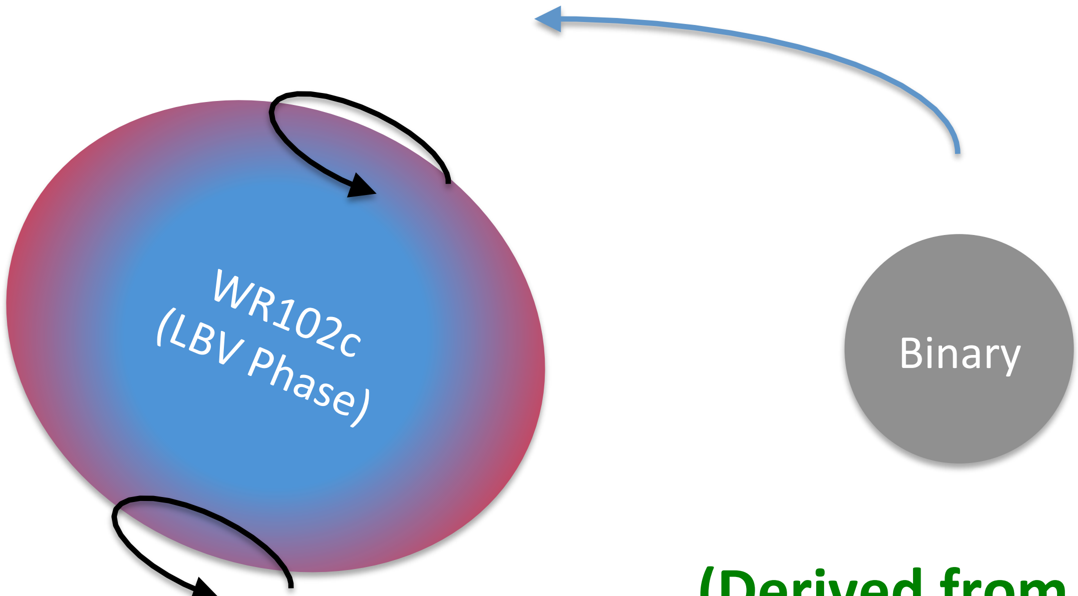
Orbital Constraints on WR102c



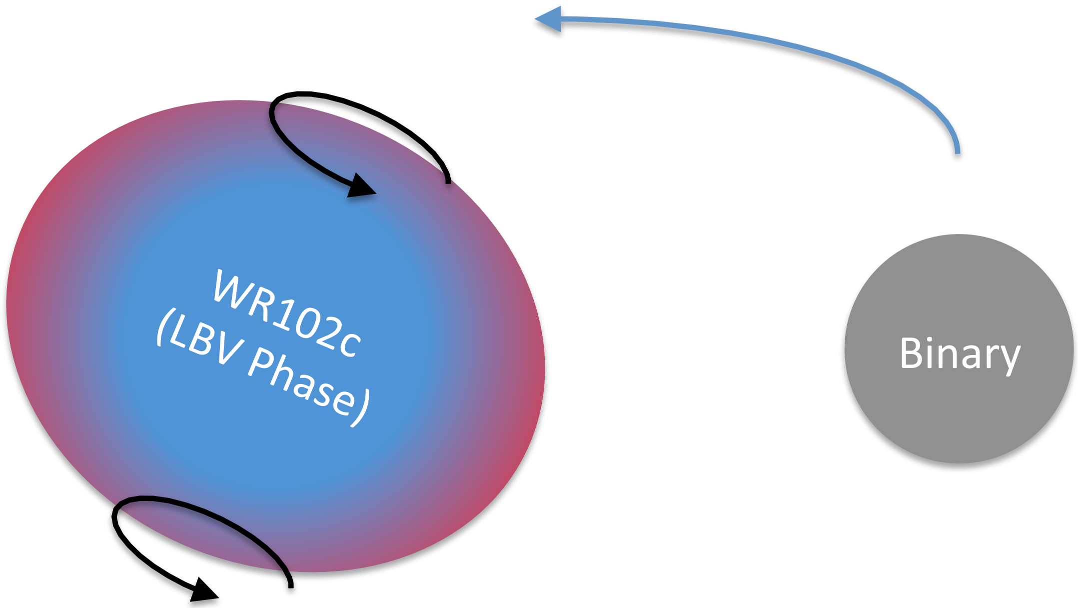
(Derived from observations)

(Adopted values)

For forced precession by binary:

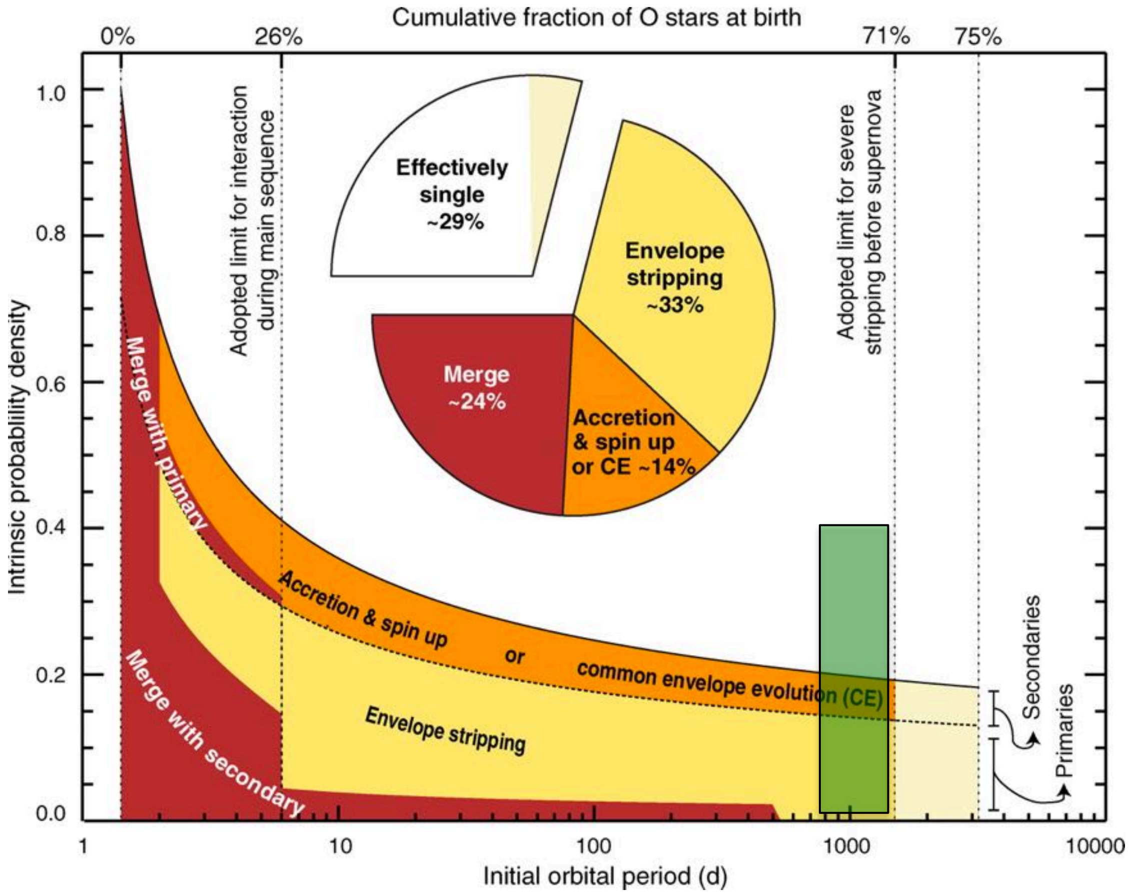
Orbital period is a function of… precession period, primary and companion masses, primary rotation rate, primary equatorial radius, and the angle between the spin and orbital axes

Orbital Constraints on WR102c



800 d< Orbital Period < 1400 days

Consistent with Orbital Period Range of Binary Interaction

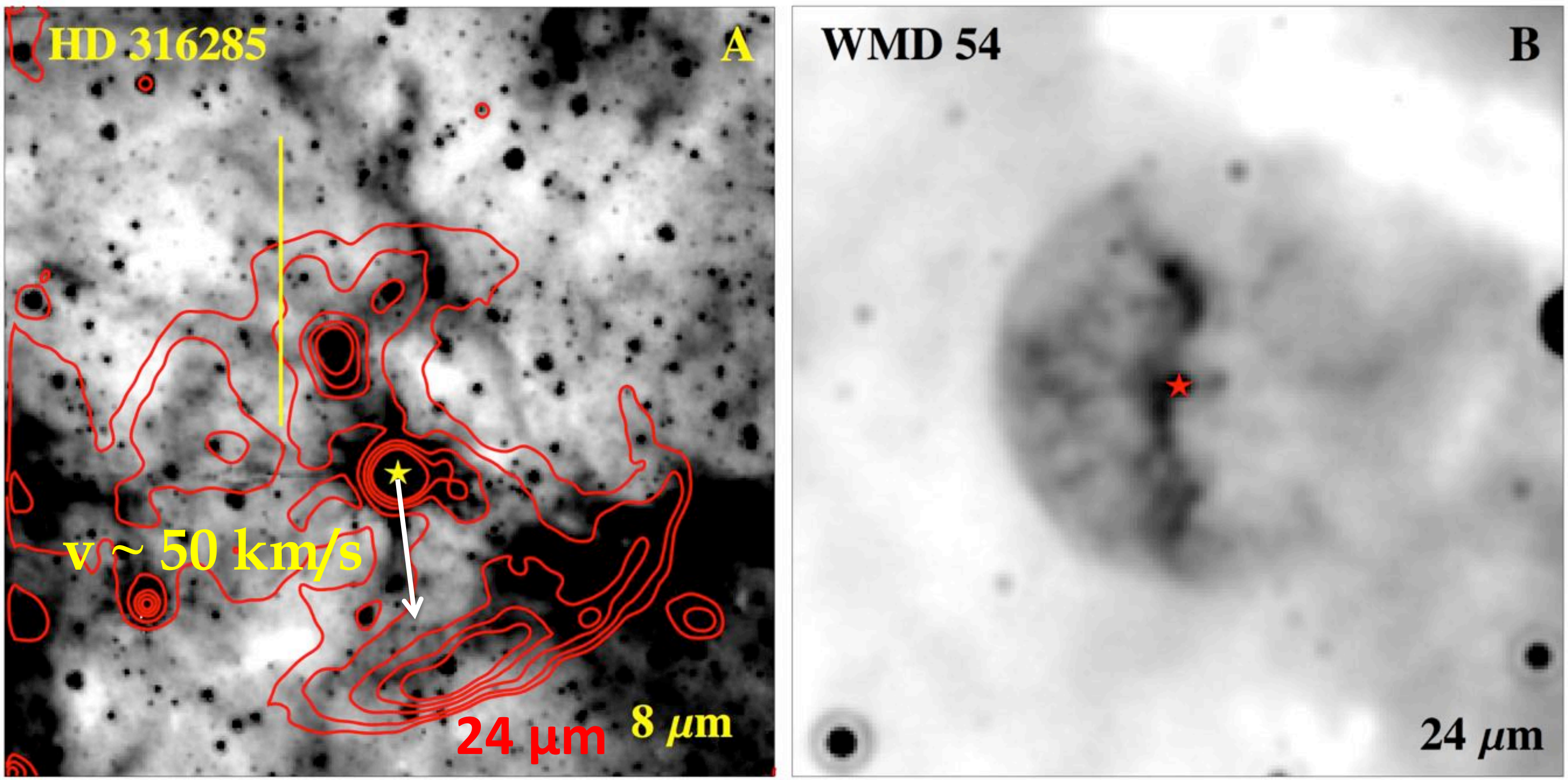


Sana+ (2012)

800 d< Orbital Period < 1400 days

Other Helices?

Other Helices?



Proper motion consistent with morphology

Identified by Wachter+ (2010)

Evidence for Binary Interaction

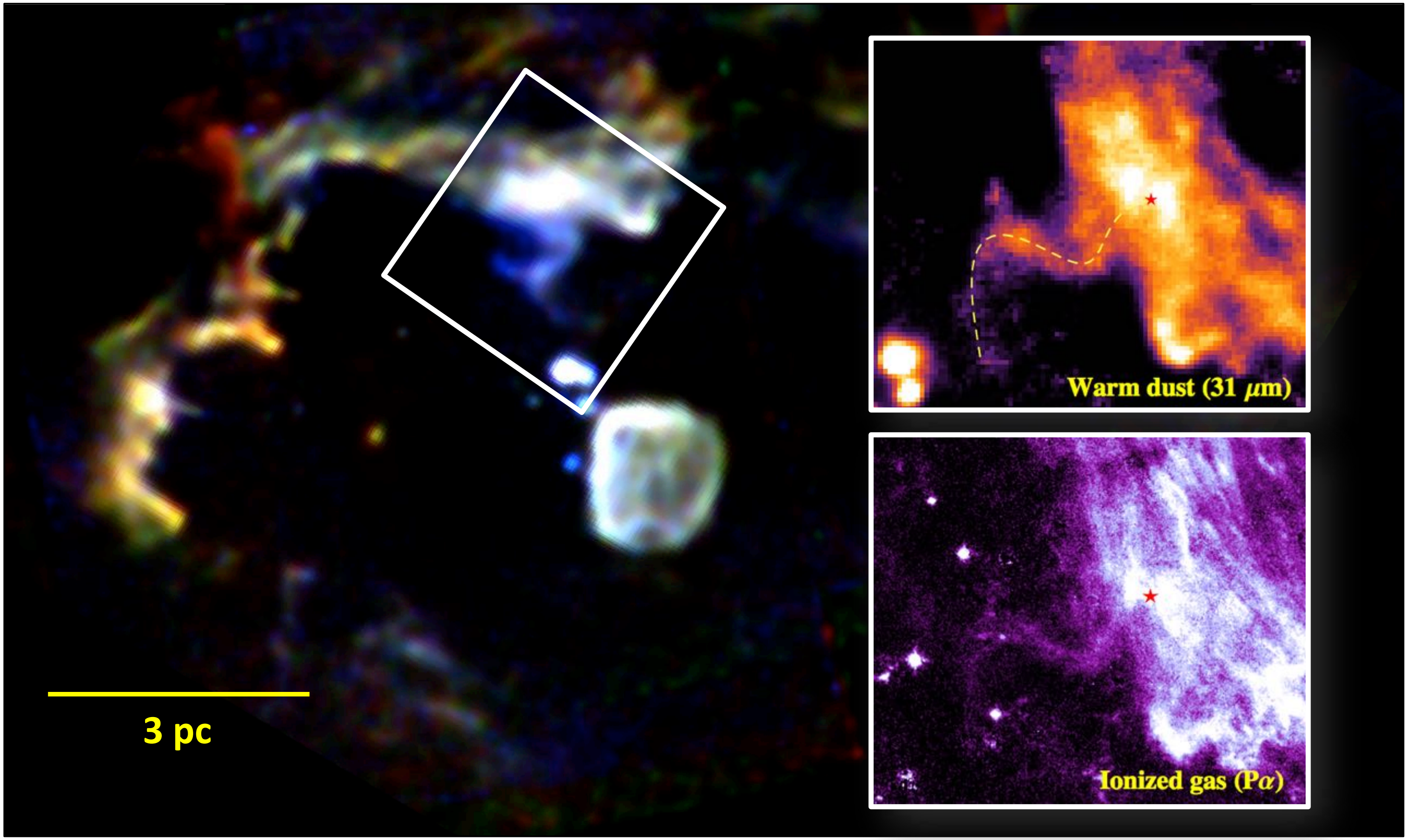
- Presented evidence of a helical outflow from the massive, evolved star WR102c (and 2 others)

- Interpreted as a collimated outflow from previous LBV/RSG phase and precessing due an unseen binary

- The next step: follow-up observations on other sources (especially HD316285*), and higher resolution velocity measurements of 102c helix

*Awarded VLT/VISIR time to do mid-IR imaging!

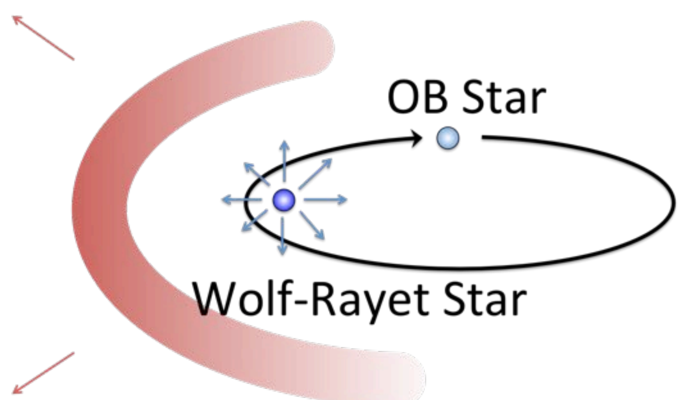
Thanks!



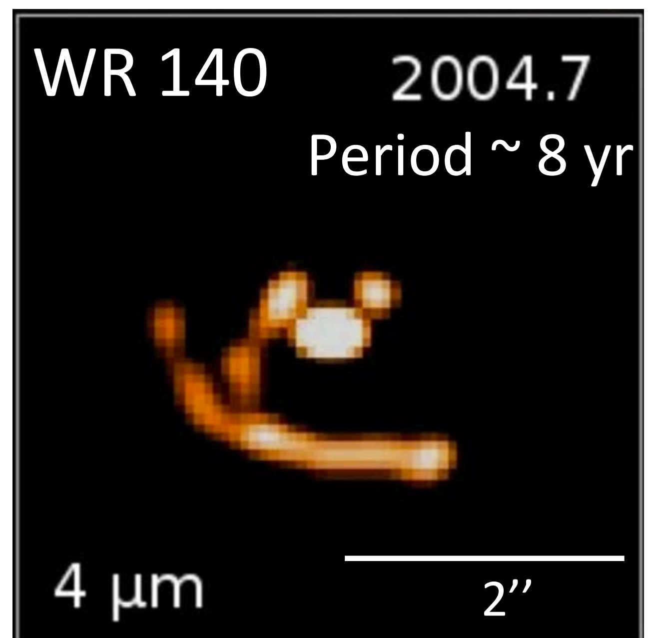
Future: Exploring Massive Binaries with JWST

Exploring Massive Binaries w/ JWST

- Study **dust production**, **mass loss**, and **chemical evolution of ejecta** from dust producing late type carbon Wolf Rayet+O/B-star binaries

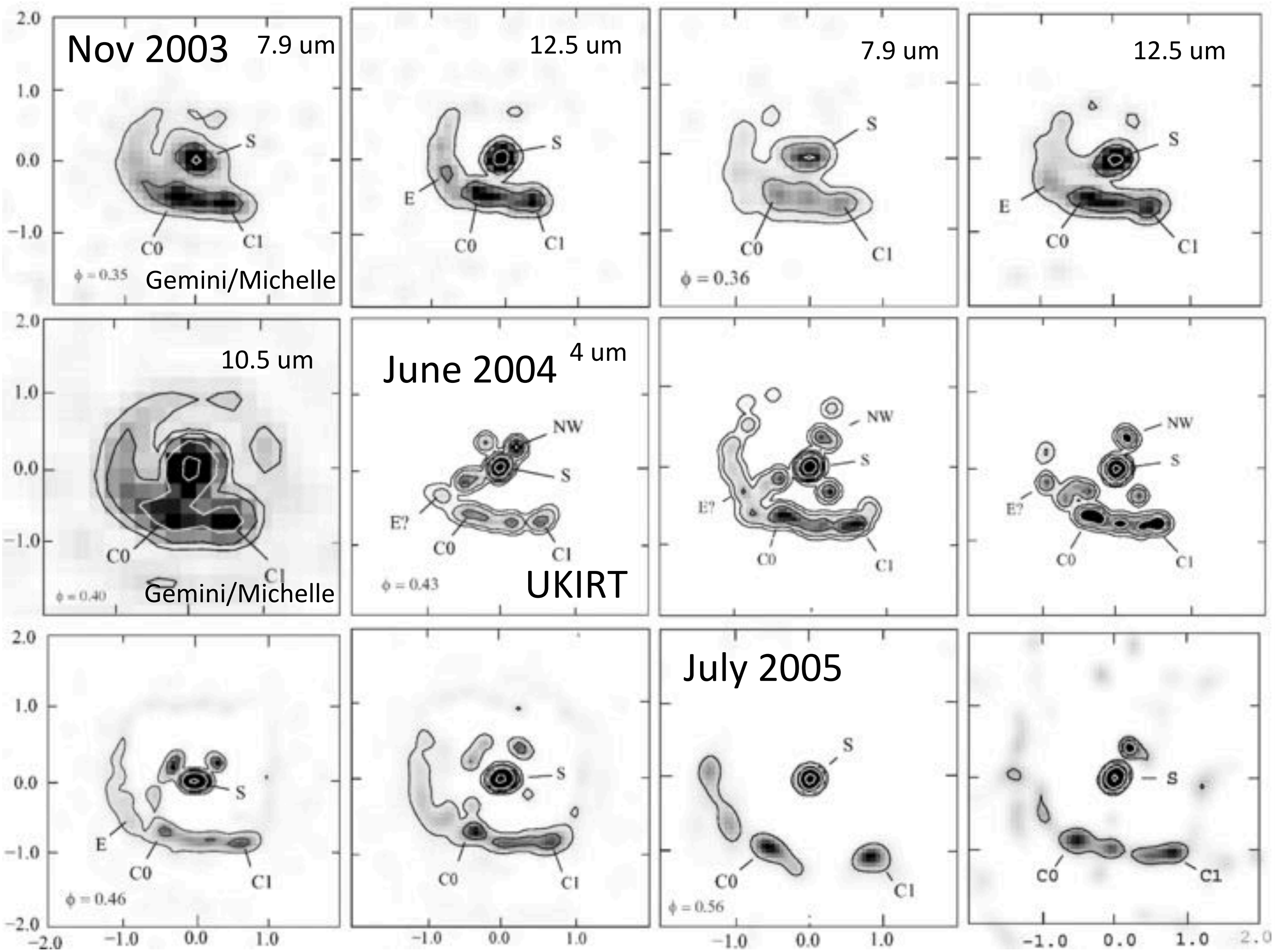


"Periodic" Dust Producer



Williams+ (2009)

Ground-Based Mid-IR Observations of WR140



Williams+ (2009)

PSF FWHM

7.9 um – 0.5’’

12.5 um – 0.6’’

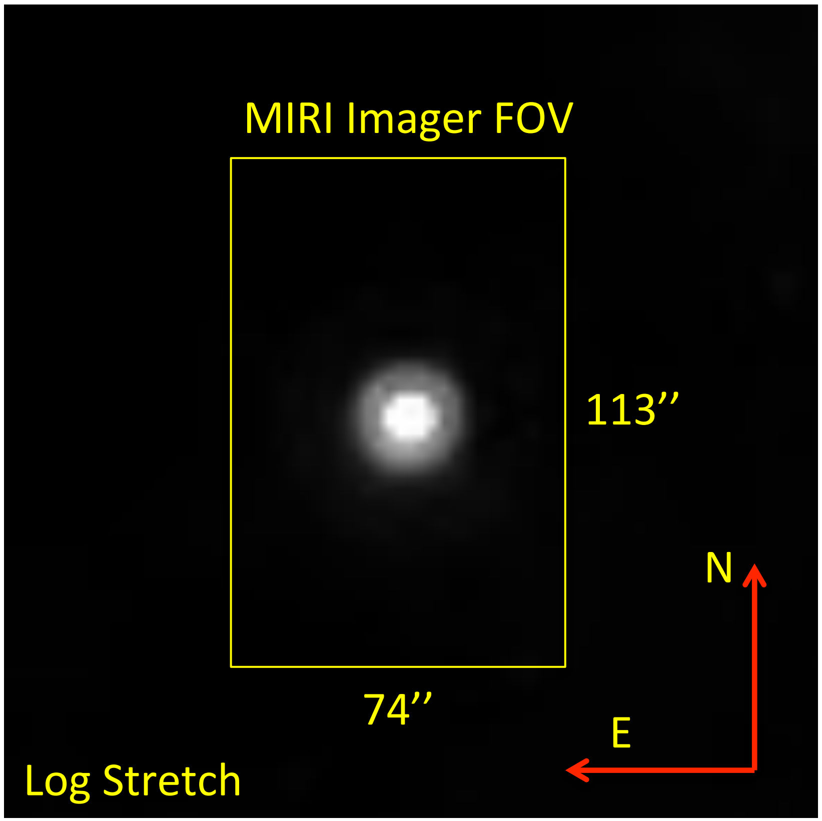
10.5 um – 0.8’’

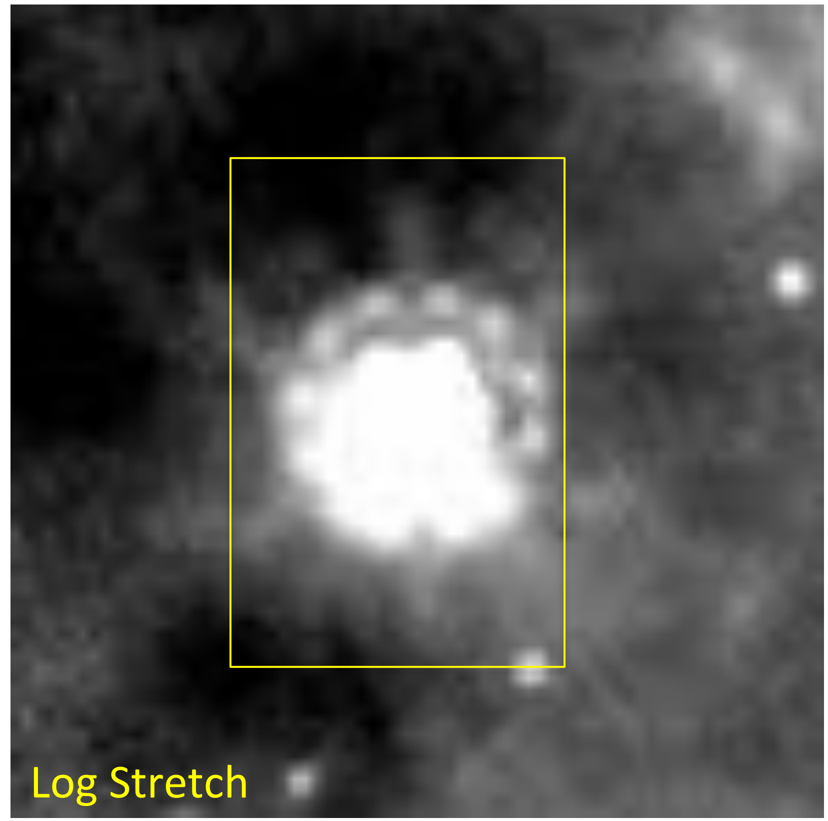
4 um – 0.36’’

MIRI

25 um – ~0.9’’ and more sensitive!

Spitzer/MIPS 24 μm Imaging of WR140





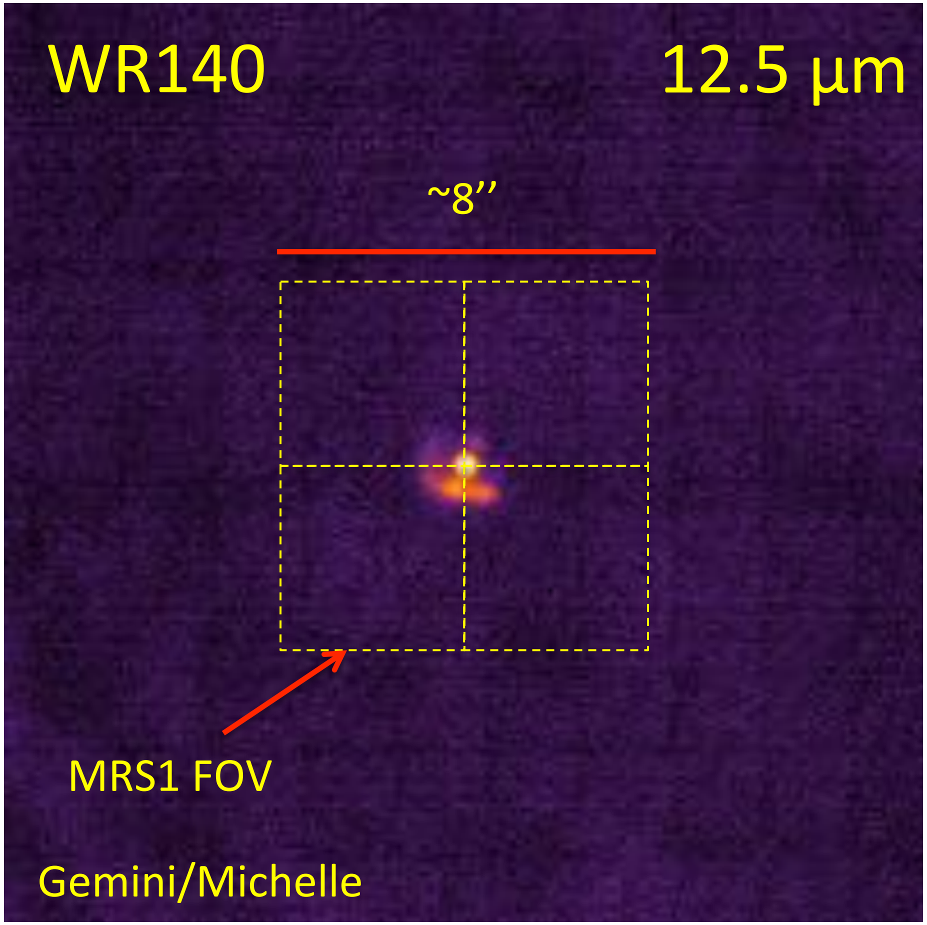
WR 140 FWHM – 6.6''

Field Star FWHM – 5.6''

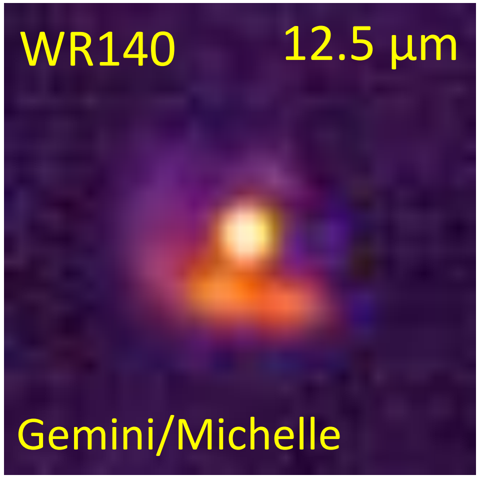
F_{24} ~ 0.9 Jy

Spitzer imaging does not reveal much…

Mapping WR140 with MIRI Spectrometer



MIRI IFU Map will contain ~3 dust outbursts



MRS1 FOV

Mid-IR spectra (R ~ 3000) will reveal…

- Kinematics
- Dust mass and energetics
- Chemical evolution through previous dust outbursts

Thanks!