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

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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

Arches and Quintuplet Cluster at the Galactic Center

Spitzer/IRAC (3.6, 5.8, and 8.0 μm)
Massive Stars: Galactic Energizers and Refineries

Arches and Quintuplet Cluster at the Galactic Center

Pistol Star and Nebula

Spitzer/IRAC (3.6, 5.8, and 8.0 μm)
Massive stars are not born alone…

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

**Sana+ (2012)**

Binary Interaction Pie Chart

- Effectively single: ~29%
- Envelope stripping: ~33%
- Merge: ~24%
- Accretion & spin up or CE: ~14%
Influence of Binarity on Stellar Evolution of Massive Stars

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

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

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Influence of Binarity on Stellar Evolution of Massive Stars

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*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”

NaSt1 (Wolf–Rayet 122)
HST WFC3/UVIS F658N–F645N

Mauerhan+ (2015)
Evidence of Binary Interaction: Dusty Precessing Outflow?

Lau+ (2016)
Not the first helical “jet” found around a massive, evolved star…

“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)

A possible origin
Formed due to a precessing accretion disk from an invisible secondary star

Nota+ (1995)
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
- $L_* \sim 4 \times 10^5 L_{\odot}$, $T_* \sim 70000 K$, $M_i \sim 40 M_{\odot}$

Warm Dust Emission around the Quintuplet Cluster and WR102c

**SOFIA/FORCAST**

WR 102c

3 pc

Warm Dust

Lau+ (2014b)

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A Dusty Conical Helix Extending from WR102c?

Lau+ (2014b)
Linking the Helix and WR102c

Observational Evidence
1. Dust and gas morphology
2. Dust Energetics and Composition
3. Lack of cold dust emission
1. Dust and Gas Morphology

- Helix extends \(\sim 1.5\) pc from WR102c
- Different from filamentary morphology of Sickle
- Orientation consistent with bipolar lobes around WR102c

Warm Dust
2. Dust SED and Composition

Warm Dust

Dust Mass: $M_D \sim 0.01 \, M_{\text{Sun}}$
3. Lack of Cold Dust

Sickle Blade SED

Flux (Jy)

Wavelength (µm)

$\text{d}_{\text{QC}} = 5.5 \text{ pc}$

$d_s = 7.2 \text{ pc}$

Helix East SED

Flux (Jy)

Wavelength (µm)

$\text{d}_{\text{QC}} = 2.4 \text{ pc}$

$d_s = 0.9 \text{ pc}$
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

Nebula believed to have an LBV origin

~ 50 km/s Nebula expansion velocity
and ~700 km/s Central WR winds

(Fernandez-Martin+ 2013 and ref therein)
Other WR Nebulae...

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

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

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

Fig. A.20. Same as Fig. A.1 for WR 131.

Fig. A.21. Same as Fig. A.1 for WR 134 (Anon).

Fig. A.22. 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 \(~80\ \text{km/s}\)

- Best fit implies precession period of \(~14000\ \text{yr}\)

- Mean mass loss rate of \(~4 \times 10^{-5} \ M_{\odot} \ \text{yr}^{-1}\)
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?**
What causes WR102c to precess? * *

a disk?

Unlikely because...

Will not survive strong winds from central star
What causes WR102c to precess?

Companion?
What causes WR102c to precess?

** Companions?**

- Will survive longer than $2 \times 10^4$ 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?

Companion?

- Will survive longer than $2 \times 10^4$ yr
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  - Consistent with being kicked from cluster
  - No x-ray emission indicating colliding winds a with MS-companion
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

800 d < Orbital Period < 1400 days

Sana+ (2012)
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

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

3 pc

Warm dust (31 µm)

Ionized gas (Pα)
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

- Nov 2003: Gemini/Michelle
  - 7.9 um
  - 12.5 um
- June 2004: Gemini/Michelle
  - 10.5 um
  - 4 um
- July 2005: UKIRT
- 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”

$F_{24} \sim 0.9$ Jy

Spitzer imaging does not reveal much...
Mapping WR140 with MIRI Spectrometer

MIRI IFU Map will contain ~3 dust outbursts

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

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