A blue ring nebula from a stellar merger several thousand years old

Ruonan Guo

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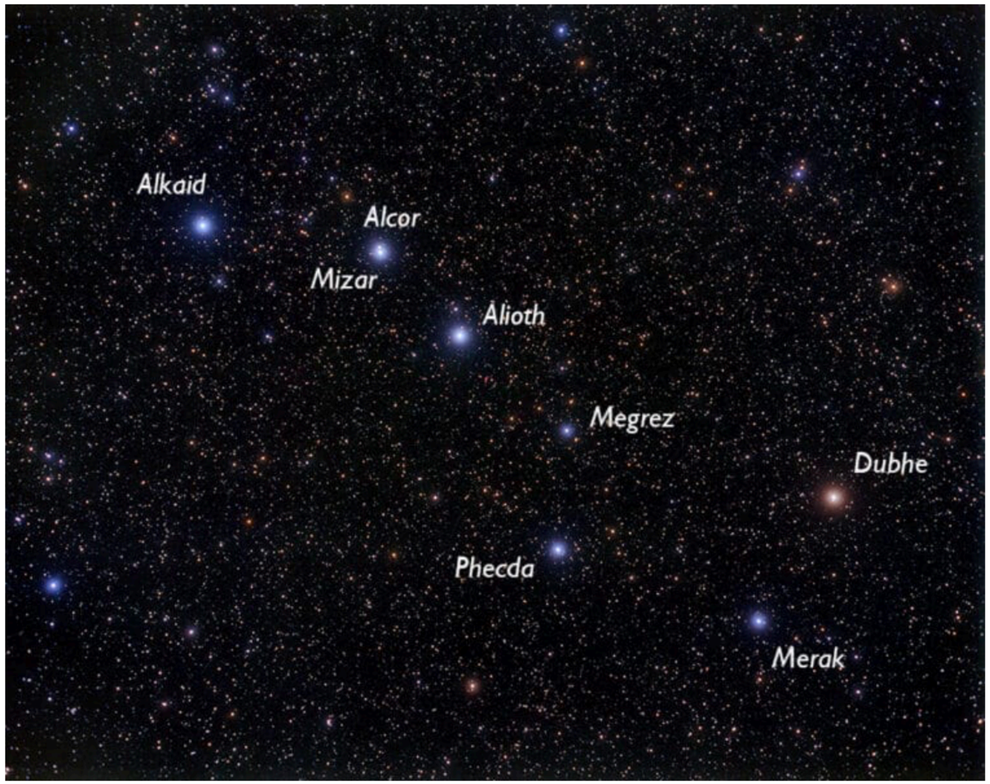
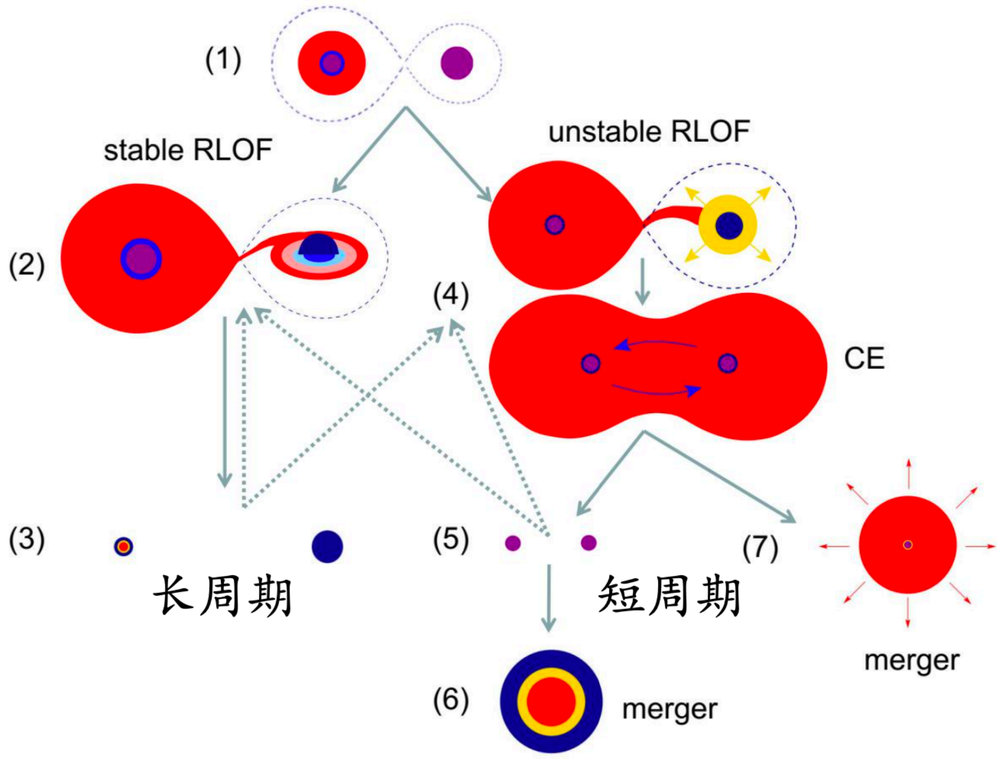
Binary star systems



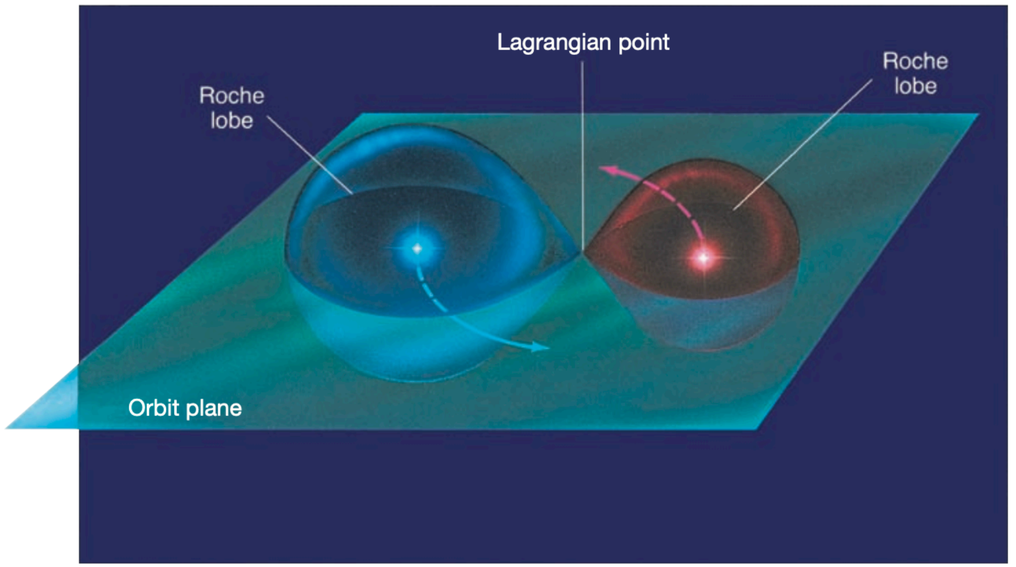
- In 1617, Galileo Galilei turned his telescope toward the second star from the end of the handle of the Big Dipper, discovering that one star seemed to be two.
- In 1802, Sir William Herschel cataloged about 700 pairs of stars and first used the term "binary" in reference to these double stars.
- ……
- In recent decades, knowledge of stellar multiplicity has greatly expanded in observations and theories, due to improvements in instrumentation and larger, more uniform samples.

Binary star systems

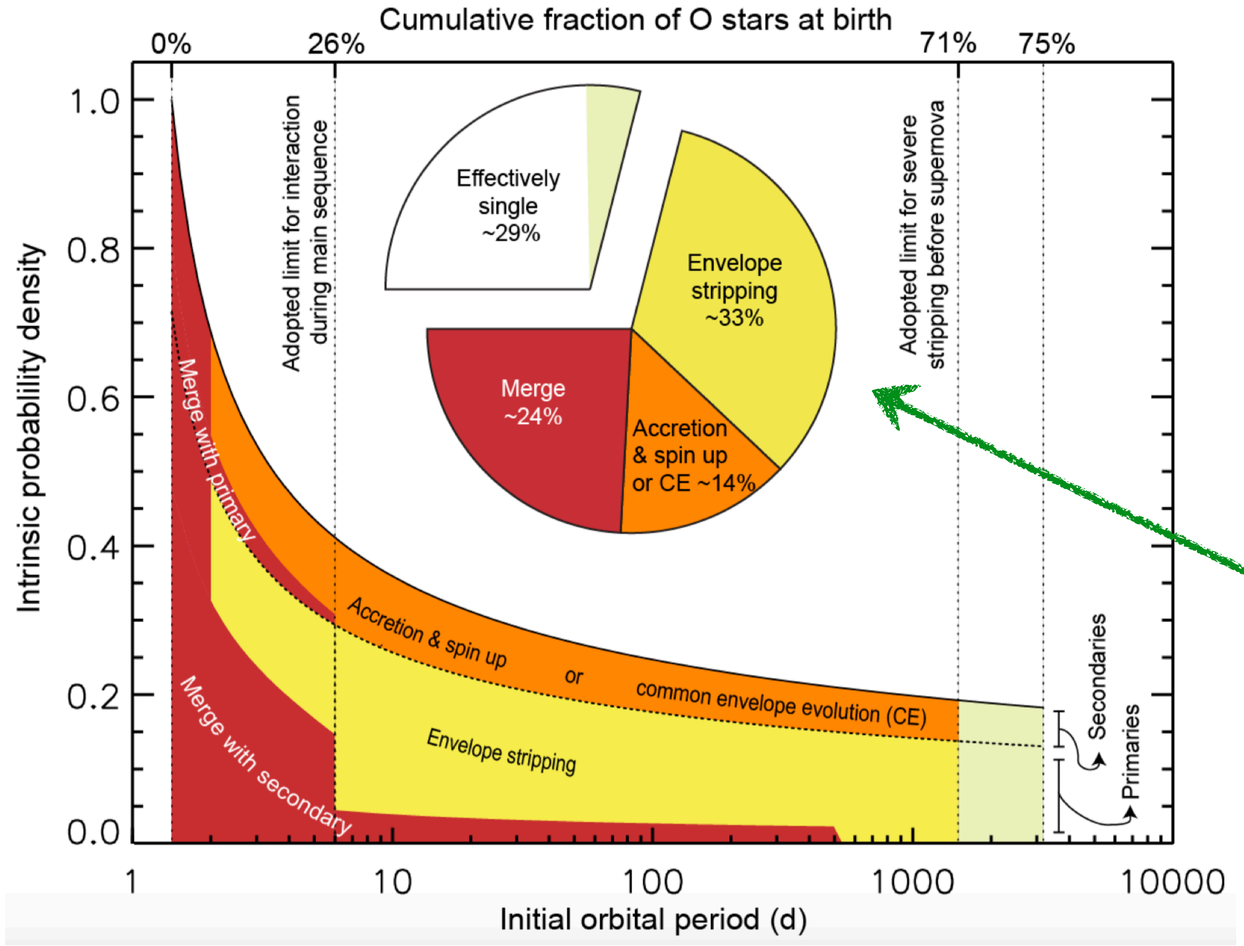


- Classification based on their orbit:
  - Wide binaries
  - Close binaries

- Classification based on how they are observed:
  - visual / spectroscopic / eclipsing / astrometric ……



Stellar mergers are common



Majority of stars are found in binary systems (more than 50%).

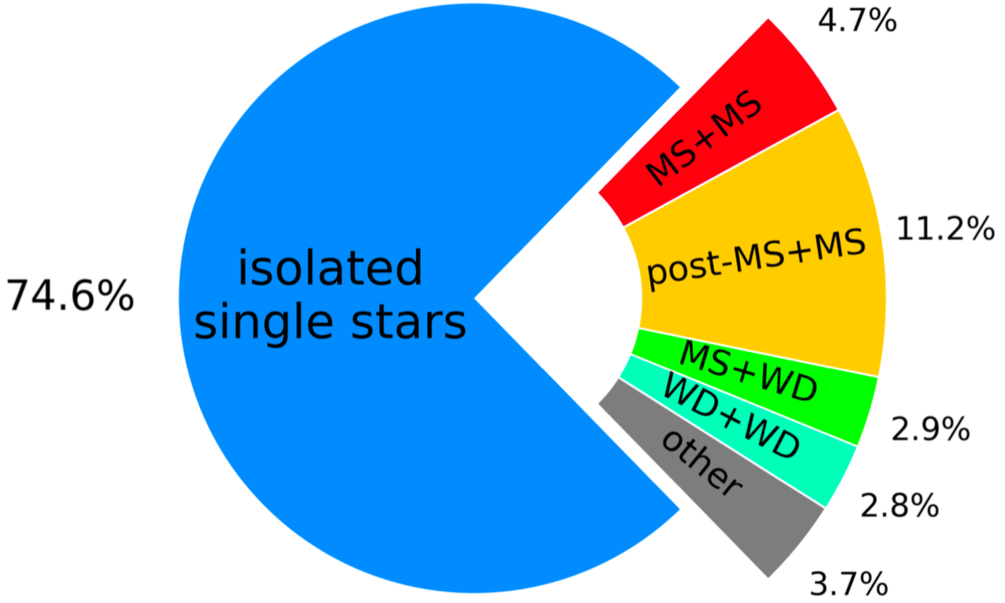
For Galactic massive O stars

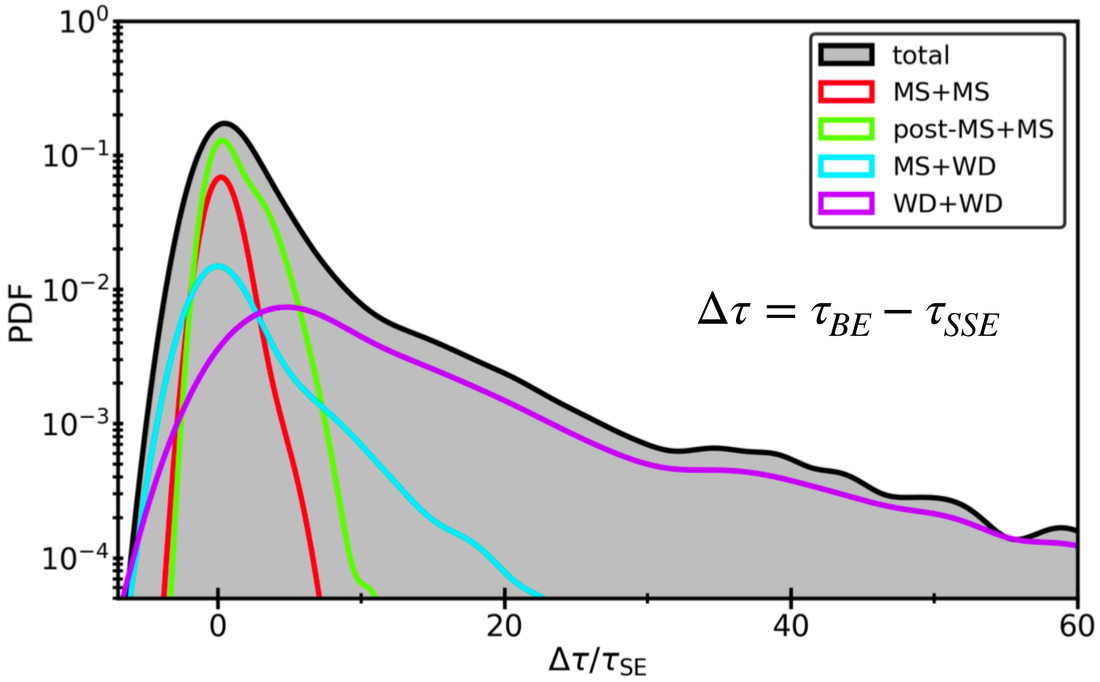
Over seventy per cent of all massive stars will exchange mass with a companion, leading to a binary merger in one third of the cases.

(Sana et al. 2012)

Stellar mergers are common

Between about 10 - 30% of all observable single WD are formed through binary mergers.

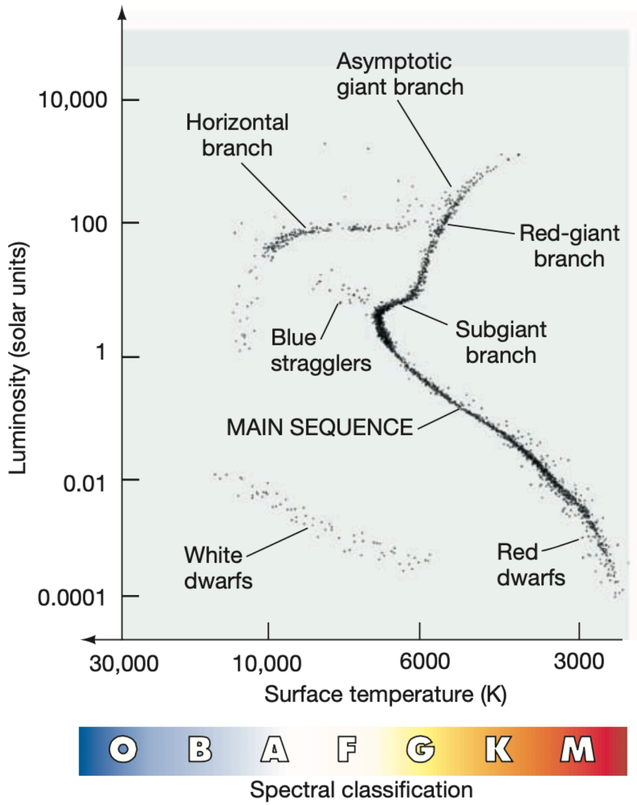




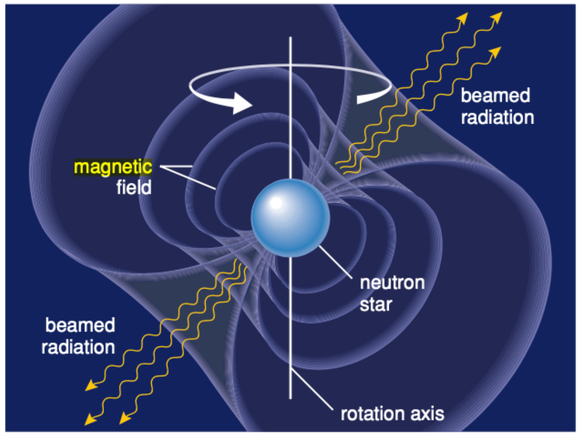
Was from binary mergers have a formation time longer than the time of an equal mass WD formed through single stellar evolution.

(Temmink et al. 2020)

Implications of mergers

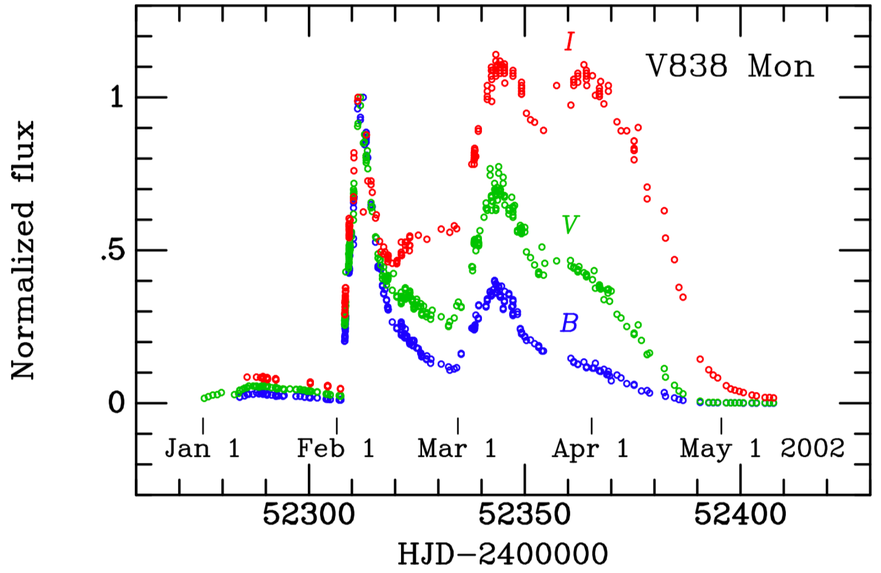


- Atypical stars (e.g. magnetic stars, blue stragglers, rapid rotators)
- Interpretation of stellar populations
- Formation channels of LIGO-detected compact object mergers



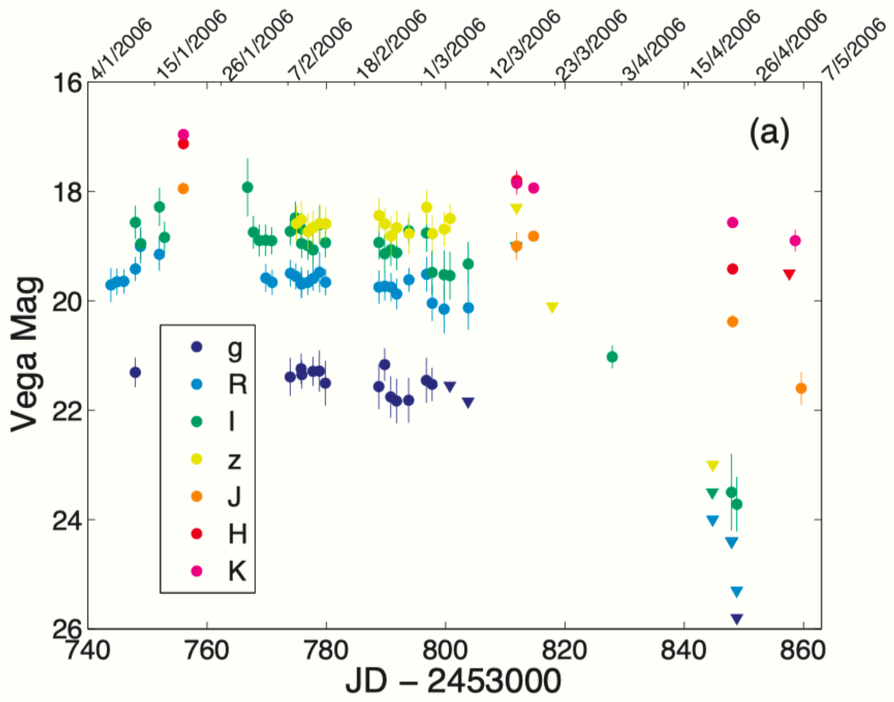
Observation of possible merger systems

- V838 Monocerotis (Howard et al. 2003)



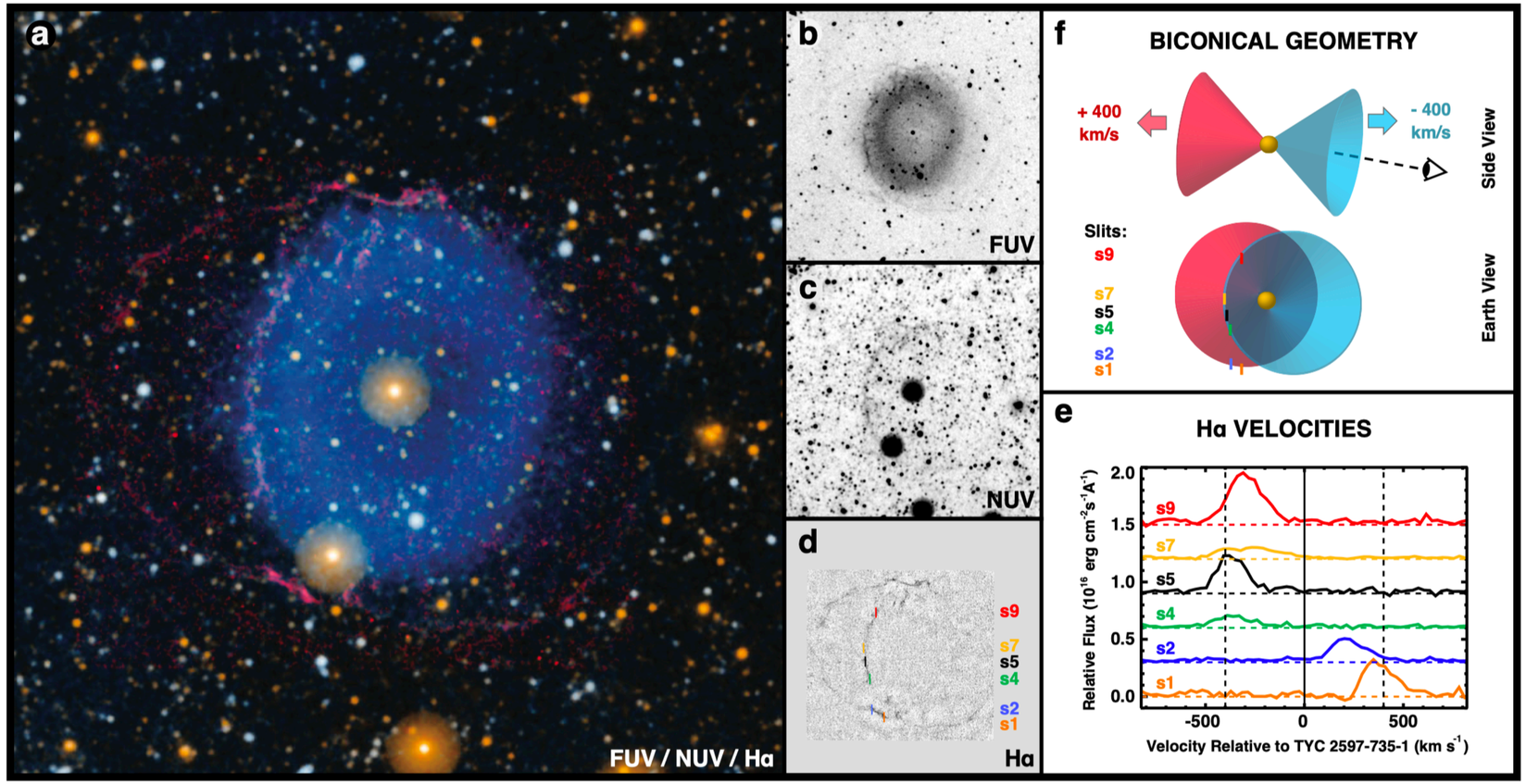
- M85 OT2006-1 (Kulkarni et al. 2007)

- TYC 2597-735-1 (This paper)

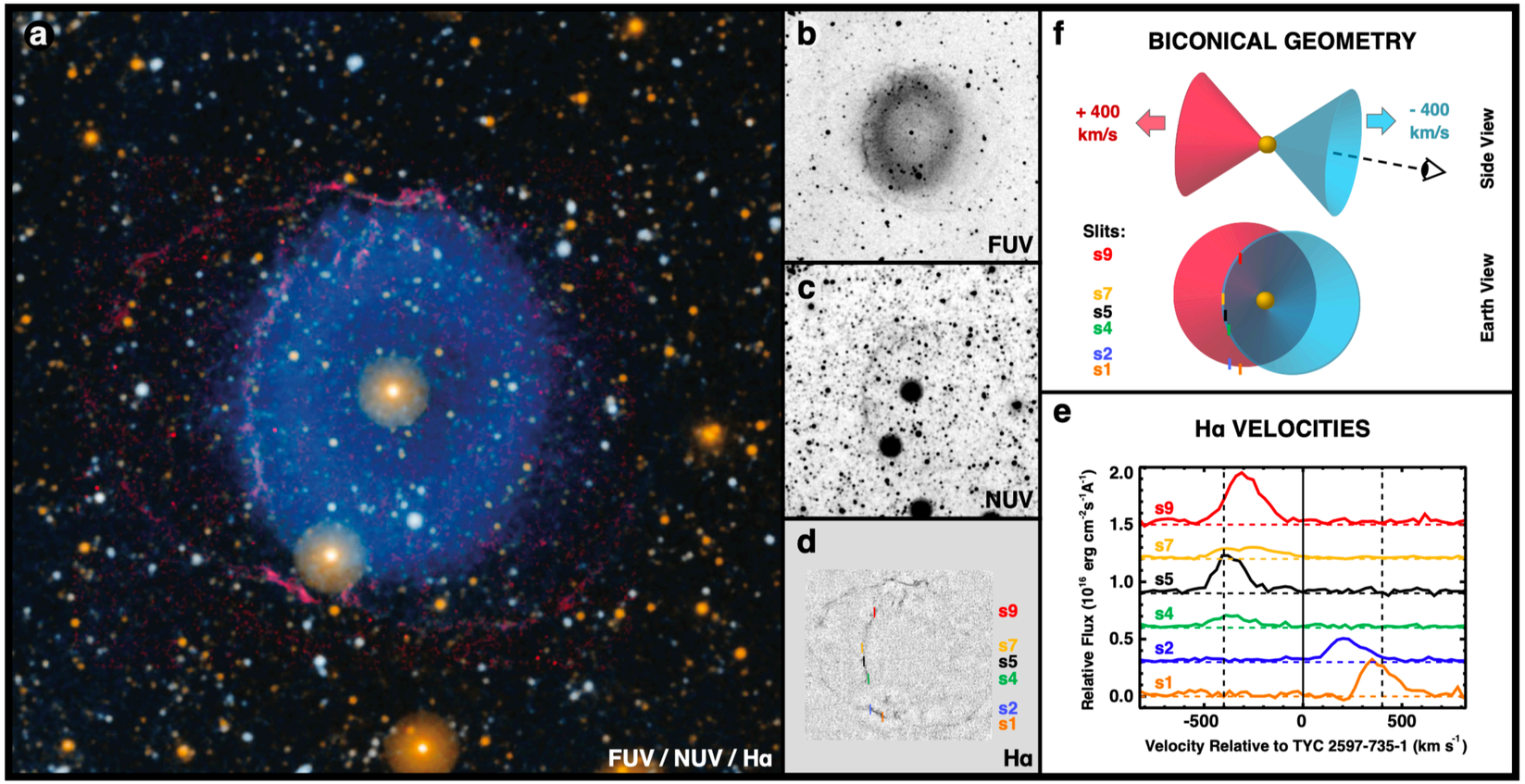


A “blue” ring nebula

- ring-shaped and smooth
- extending ~ 8 arcmin across sky
- slightly inclined (15 degree), face-on view

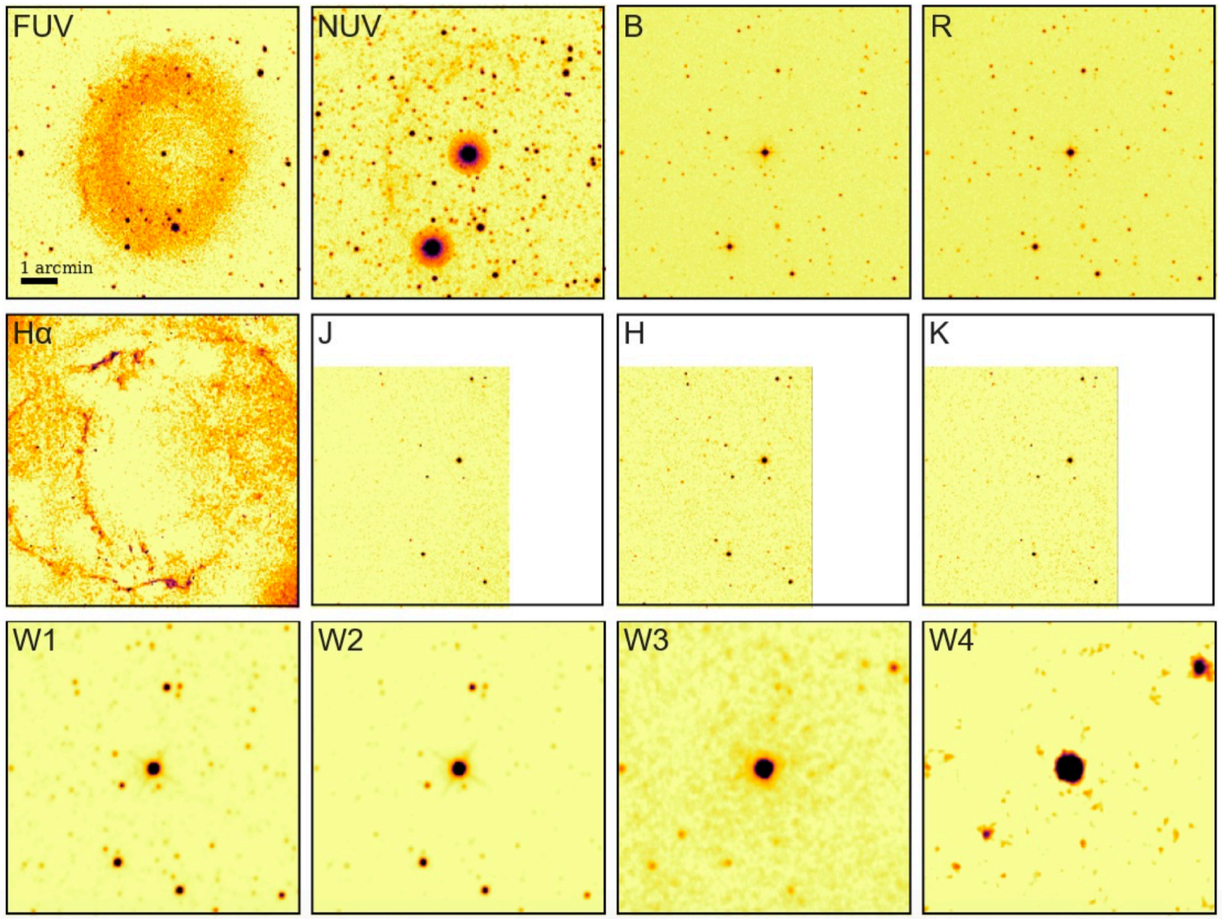


A “blue” ring nebula



- expanding in opposite directions with $v_{shock} \pm 400 km/s$
- a bipolar outflow originating from a center star

Center star: TYC 2597-735-1 in the thick-disk population



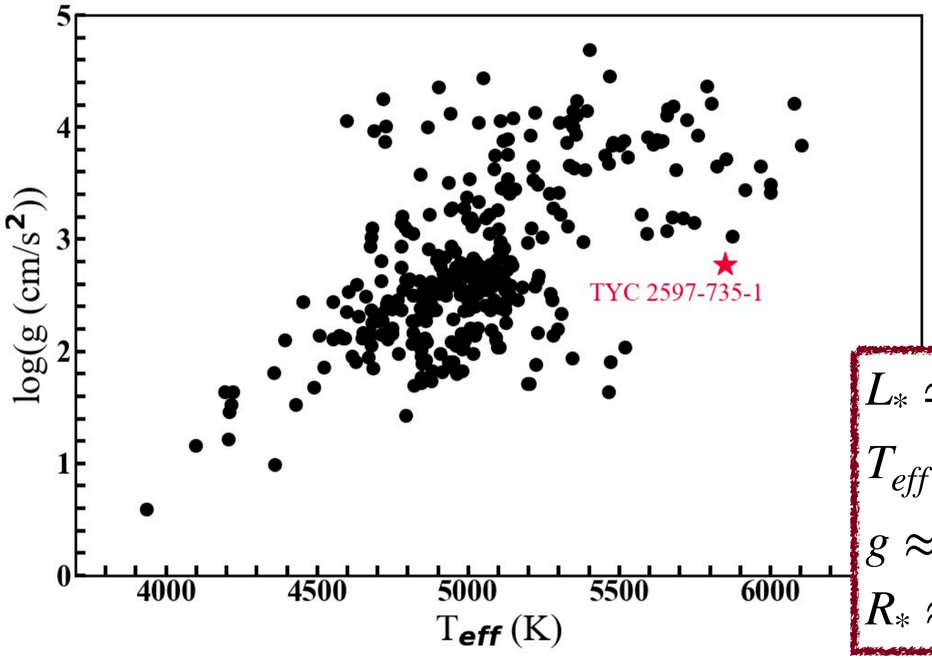
1.9 kpc away and 1.5 kpc above the Galactic plane

↓

nebular extends ~ 4 pc

↓

age of the nebula < 5,000 years



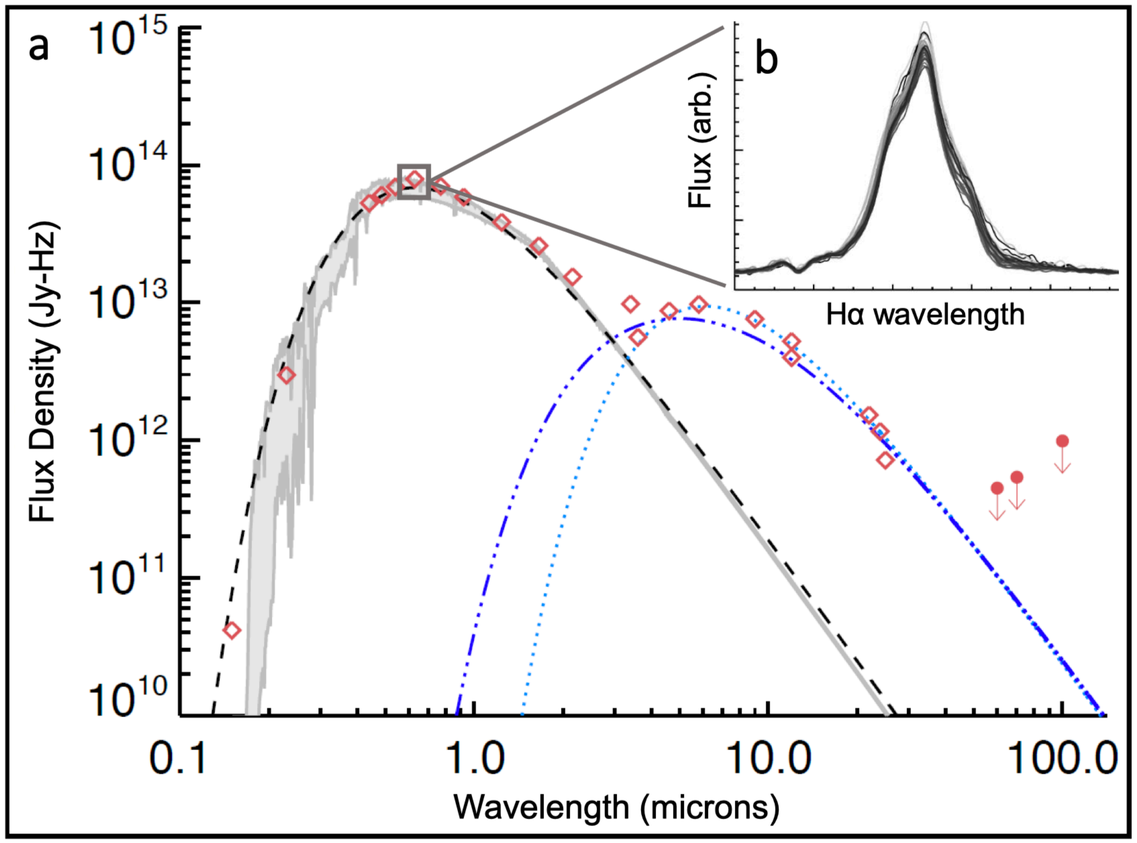
$L_* \simeq 110 L_\odot$

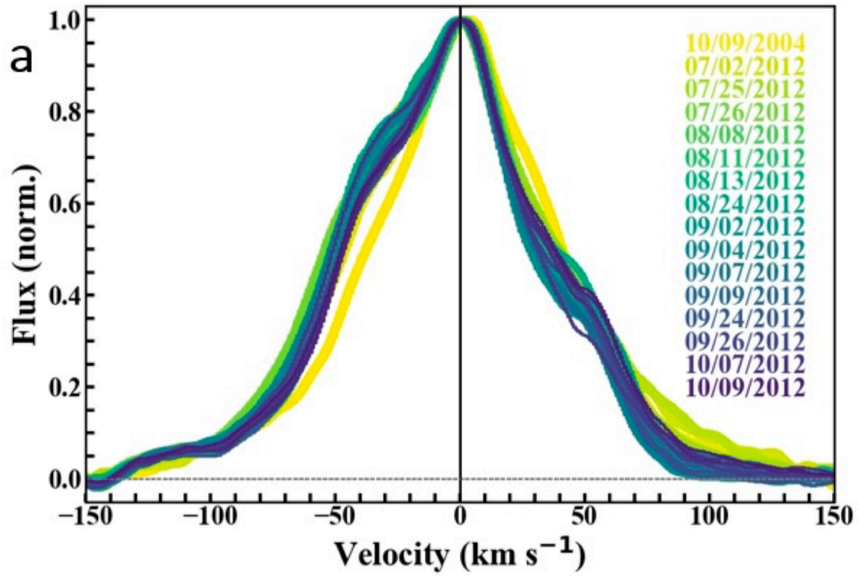
$T_{eff} \approx 5850K$

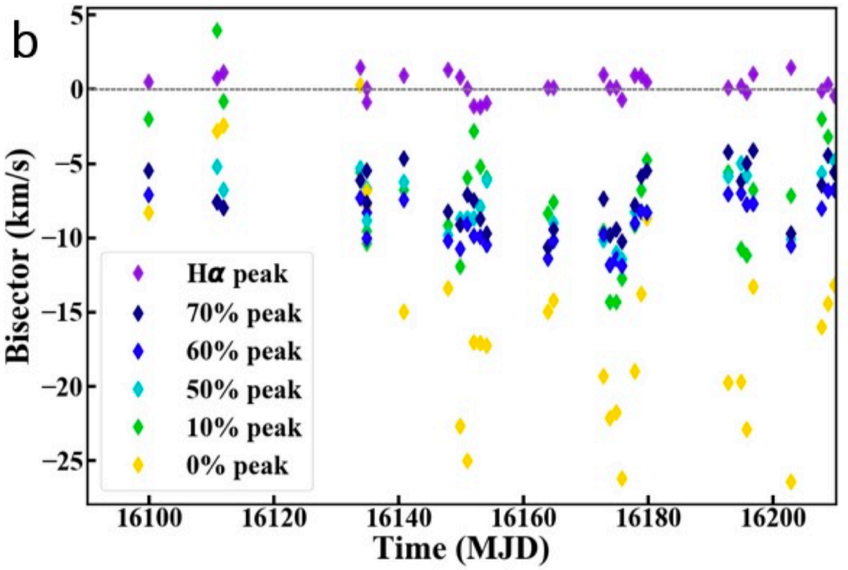
$g \approx 600 cm/s^2$

$R_* \approx 11 R_\odot$

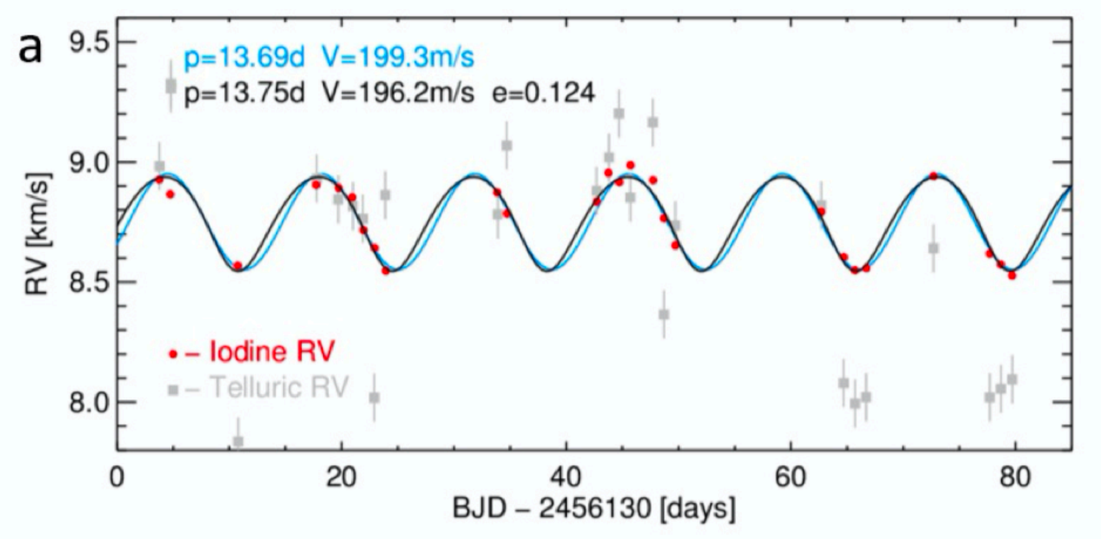
Prominent *Hα* line emission and Excess infrared radiation

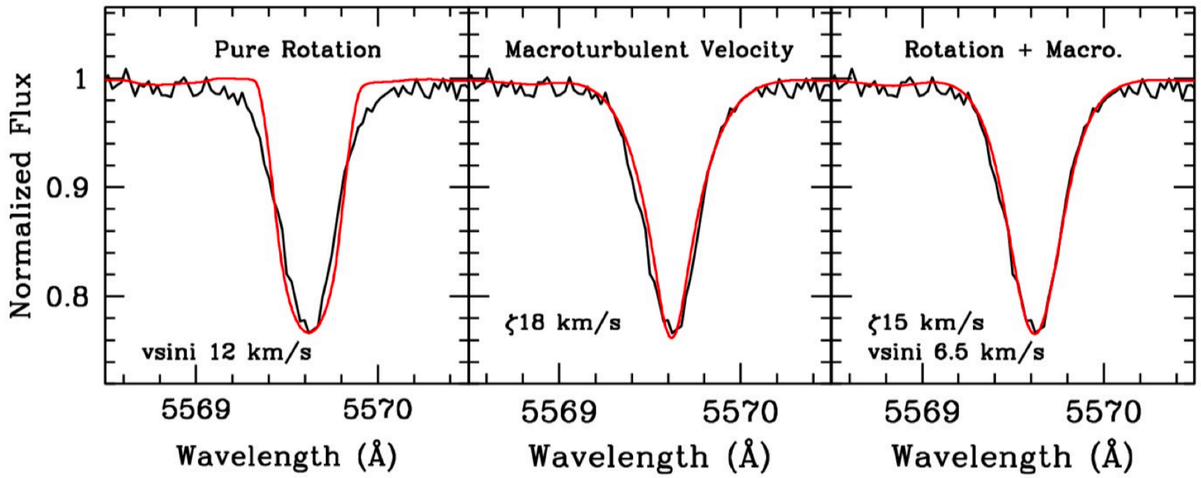


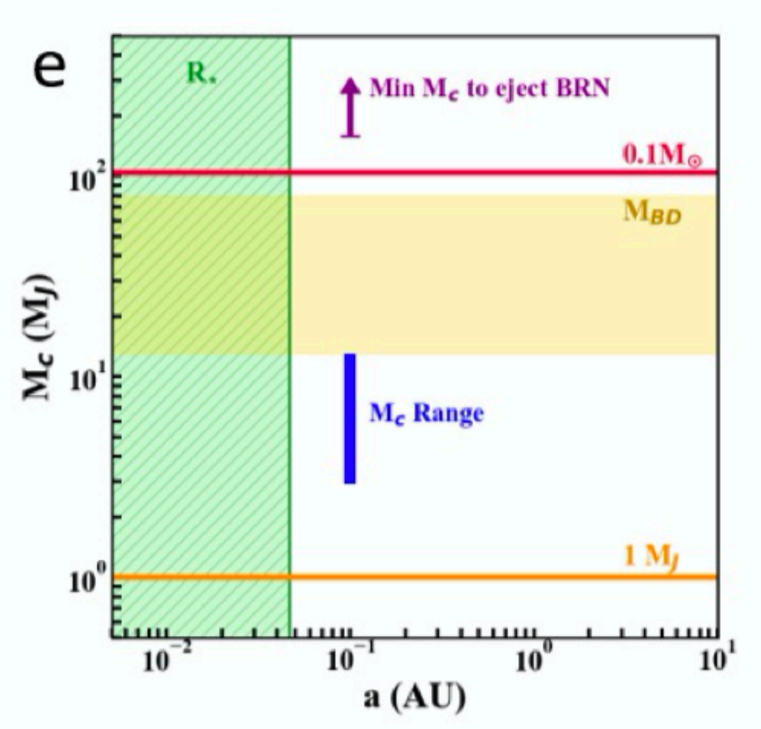




Line profile and Radial velocity variations



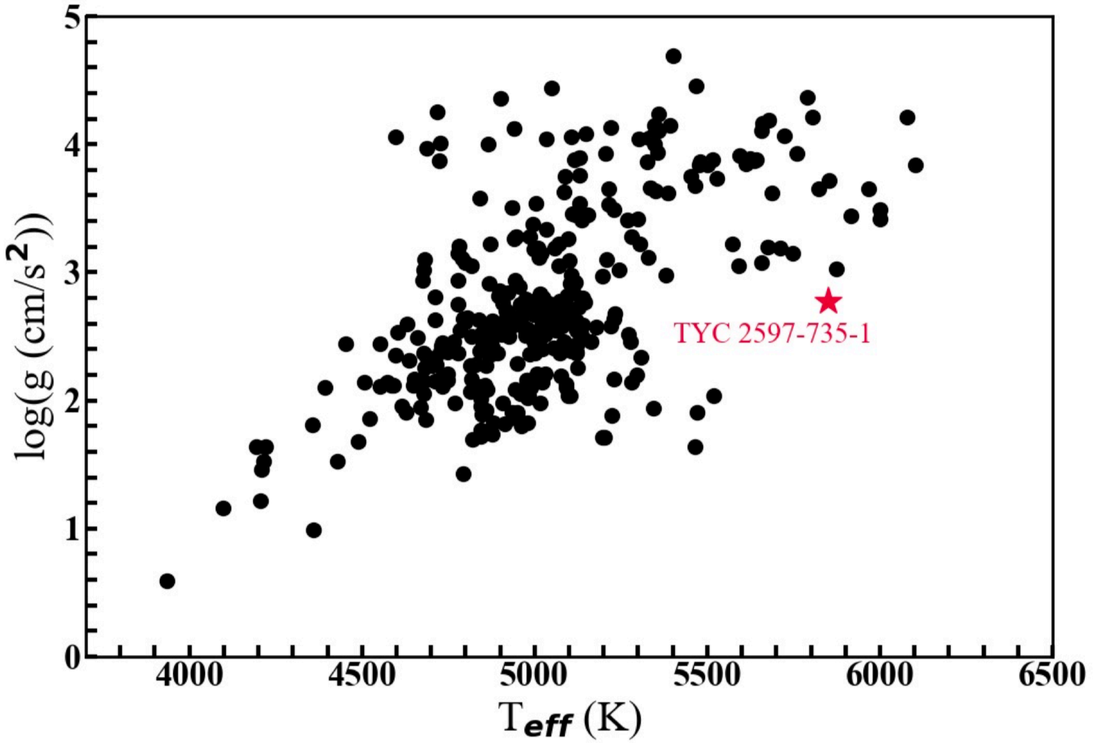




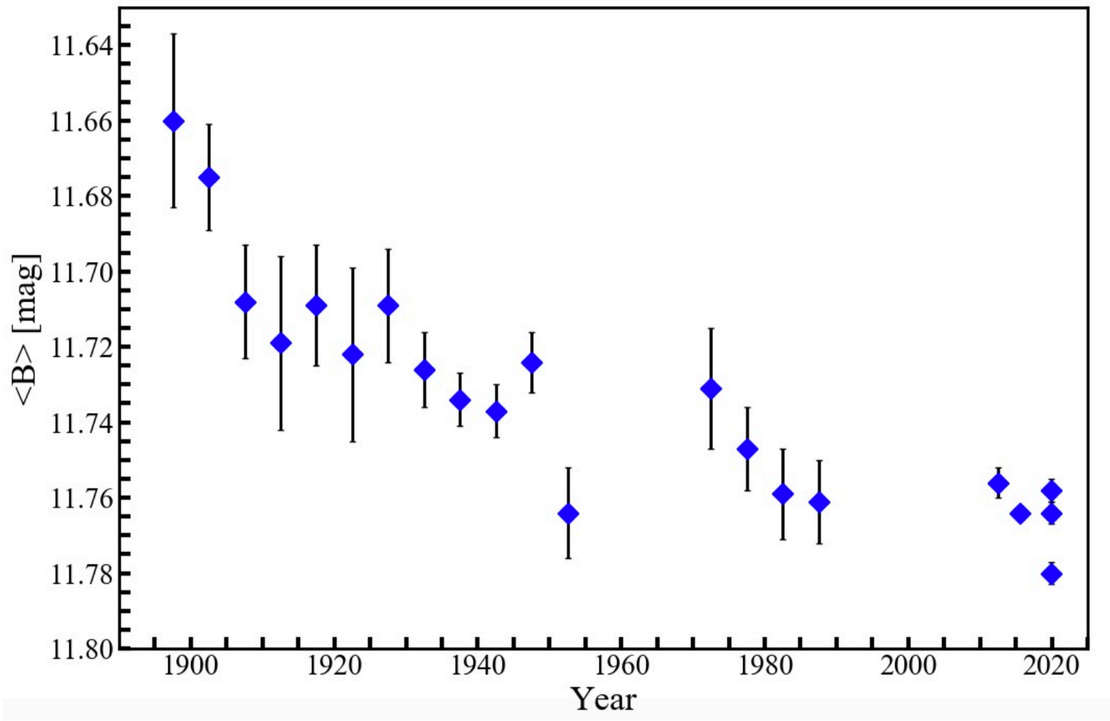
~ 200m/s Doppler shift, exclude the presence of a binary companion with mass $\geq 0.01 M_\odot$ in tight orbit

Test Scenario of Merger: MESA

- A low mass companion ($M_c \sim 0.1 M_\odot$) reasonably reproduces similar properties



- Predicting ~ 0.1 B-mag brighter a century ago.



Evolution from the best-fit model

M_p: the primary star (red)
M_c: the companion star (yellow)

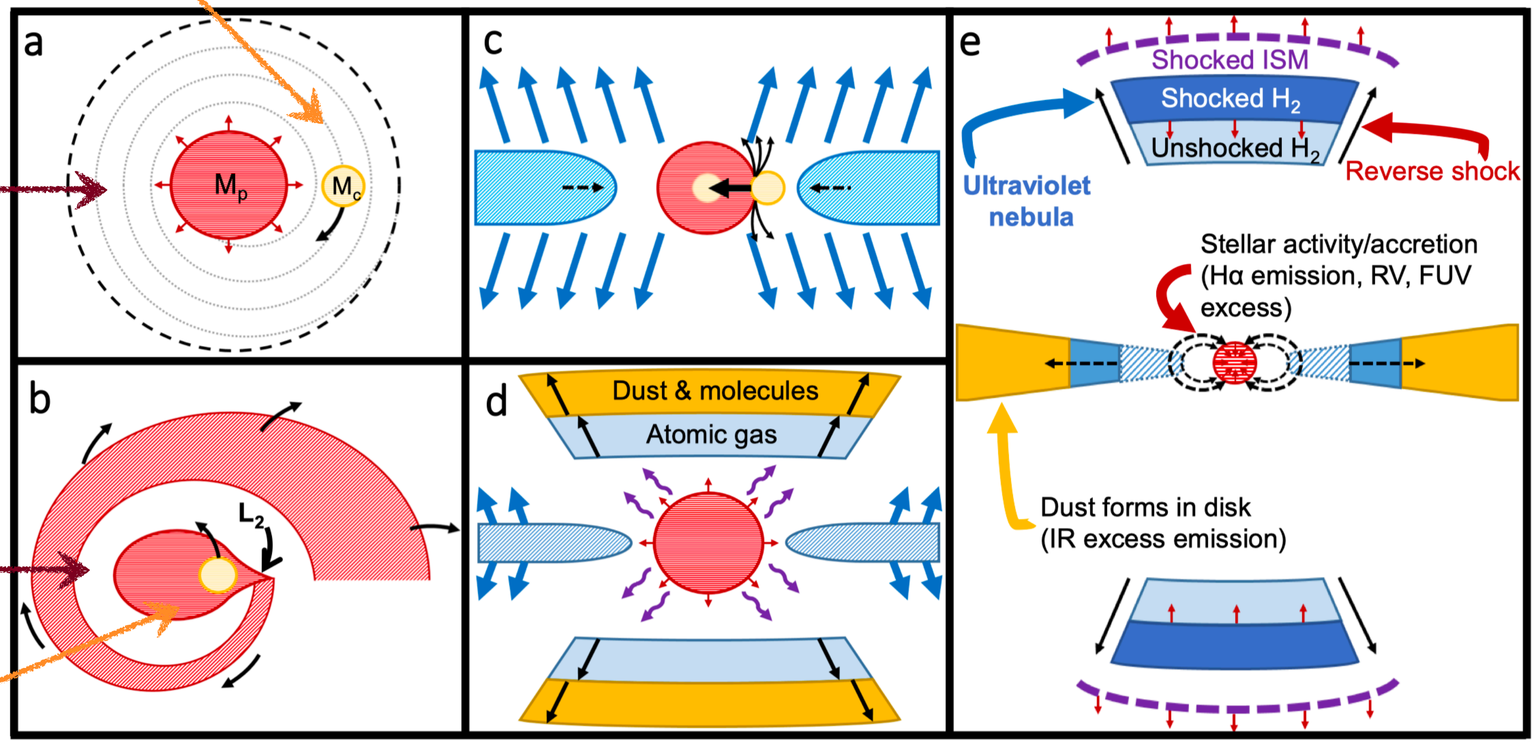
evolve off the MS & envelope expand

overflow its Roche lobe

deposit mass & spill through common L_2

slowly drag inward

M_c plunges into M_p eject additional mass

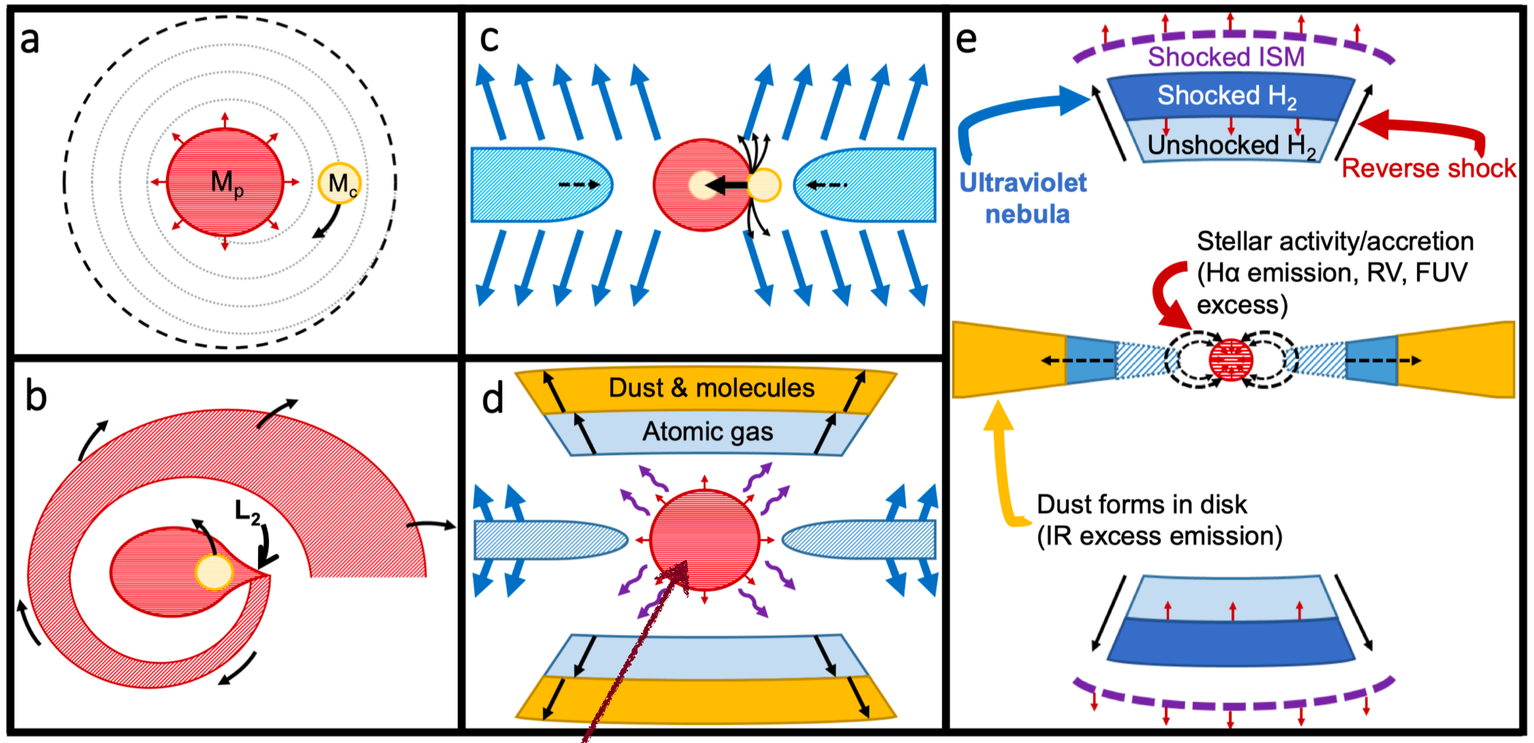


M_c begins to spiral into M_p

Evolution from the best-fit model

M_p: the primary star (red)

M_c: the companion star (yellow)



puffs up and brighten

a bipolar outflow

expand and cool to form dust and molecules

The forward shock id seen in UV and *Hα* emission outlining the nebula today

Summary

- Stellar mergers are a brief-lived but common phase in the evolution of binary star systems, which may lead to implications such as creation of atypical stars.
- An observations of an unusual, ring-shaped ultraviolet nebula shows two opposing fronts, suggesting a bipolar outflow from TYC 2597-735-1.
- The combined observations, paired with stellar evolution models, suggests TYC 2597-735-1 merged with a lower-mass companion several thousand years ago.
- TYC 2597735-1 poses a unique opportunity to study post-merger morphology as the only known merger system not enshrouded by dust.

Possible Question ?

- Question 1: Is there any other system or model except stellar merger, which can explain the observation phenomena of this nebular system?

- Question 2: Dust is always observed in the ejecta of stellar mergers as previous observation, but why we don’t find evidence of dust in the ultraviolet nebula?