A magnetic massive star has experienced a stellar merger

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Background

- Lower-mass stars' magnetic fields: convective dynamo.
- Massive stars: heat transfer in the envelopes is radiative.
- Of?p stars: show evidence of magnetism in their optical spectra & unusually strong emission lines of C-III 4650$\text{\AA}$ and N-III 4634$\text{\AA}$ to 4641$\text{\AA}$.
- Massive stars' magnetic fields potential origins:
  - Fossil magnetic field
  - Mixing of stellar material

The HD 148937 Binary System

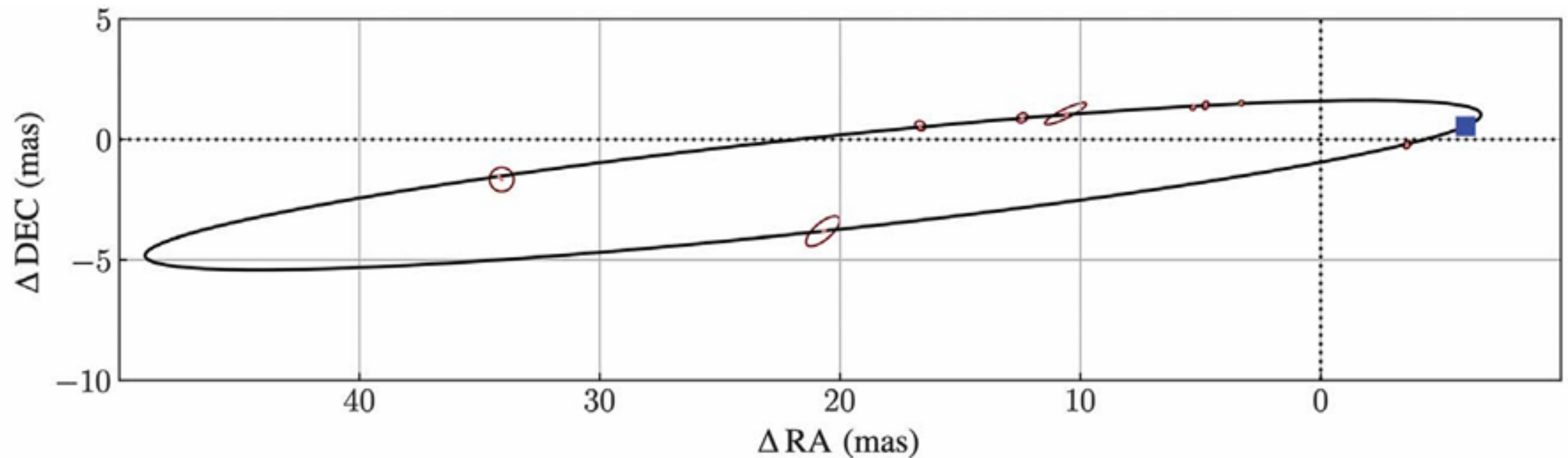
- Hα emission line displays short-period variability in its width (with a period of 7.08 days); (G. A. Wade et al., 2012)
- 2 possible orbital periods: 18.1 or 26.2 years, with corresponding orbital eccentricities of 0.58 and 0.75; (G. A. Wade et al., 2019)
- Mid-O-type and late-O-type: with only the latter showing signatures of a magnetically confined stellar wind, in the form of strong Balmer (including Hα) and He-II emission lines. (G. A. Wade et al., 2019)

Interferometric Observations

- They monitored HD 148937 for 9 years using the Very Large Telescope Interferometer.
- Observations were performed with two near-infrared instruments: the Precision Integrated-Optics Near-Infrared Imaging Experiment (PIONIER) (1.5–2.4 μm) and the GRAVITY instrument (2.0~2.4μm)
- From the interferometry data fitting they found:
  - K-band brightness of the secondary star is 94.6±0.41% that of the primary,
  - a strong Brackett emission line (Br-γ) is present at 2.16μm in the GRAVITY spectrum. (Fitting of the interferometric data shows it can only be associated with the primary star)

Astrometry

- $P = 25.76 \pm 0.82\ yr$
- $e = 0.7782 \pm 0.0051$
- $i = 84.07 \pm 0.10°$
- $M_1 = 29.9^{+3.4}_{-3.1} M_\odot, M_2 = 26.6^{+3.0}_{-3.4} M_\odot$

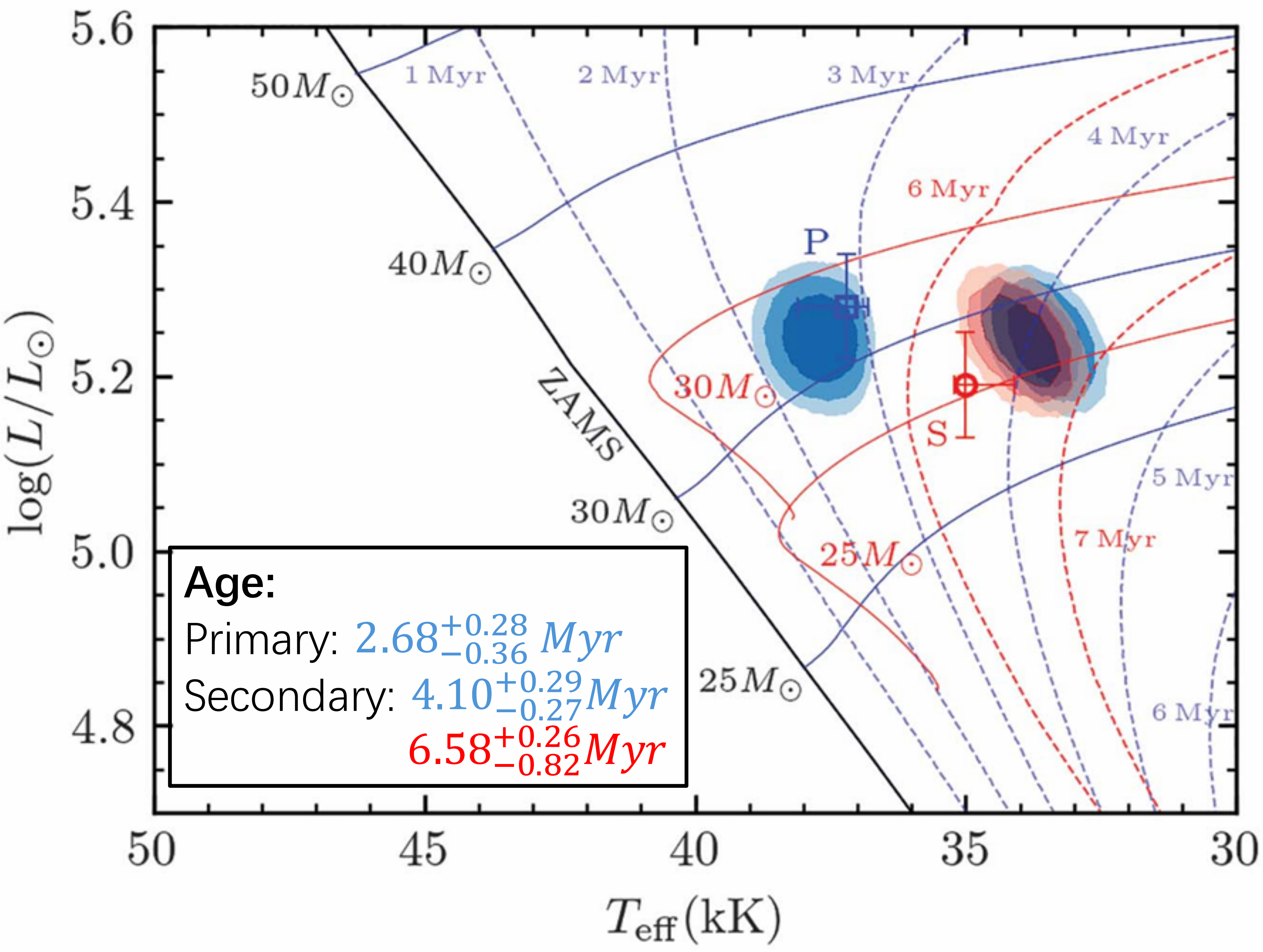


Physical Properties

- Spectral disentangling
- Atmosphere from CMFGEN
- $T_{eff1} = 37.2^{+0.9}_{-0.4} kK,$ $T_{eff2} = 35.0^{+0.5}_{-0.9} kK$
- $log\left|\frac{g_1}{cm/2}\right| = 4.00 \pm 0.09,$ $log\left|\frac{g_2}{cm/2}\right| = 3.61^{+0.02}_{-0.09}$
- $\log\left(\frac{L_1}{L_\odot}\right) = 5.28 \pm 0.06,$ $\log\left(\frac{L_2}{L_\odot}\right) = 5.19 \pm 0.07$
- … $\log\left(\frac{N}{H}\right)_2 + 12 = 8.74 \pm 0.10$
- Projected equatorial velocities $v_{eq} sini = 165 \pm 20\ and\ 67 \pm 15\ km/s$

Stellar Evolution

- Single star stellar evolution models from the BONNSAI web service; (solar metallicity)
- They consider two sets of inputs for the secondary star:
  - including the nitrogen measurements derived from the atmospheric analysis
  - without them.
- A high or low initial rotational velocity, depending on whether the nitrogen abundance measurement of the secondary is included or not. (rotational mixing)



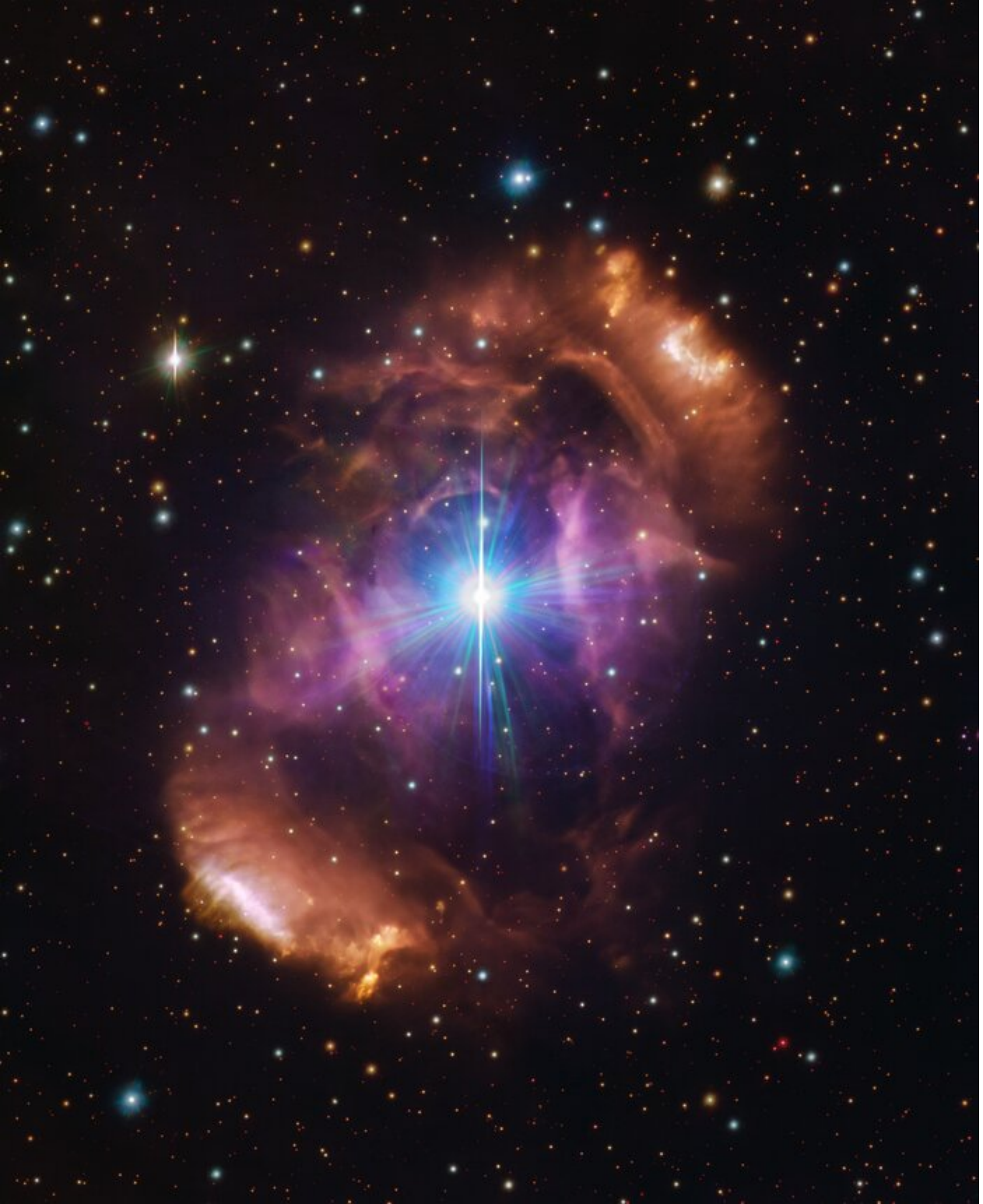
- **Squares:** best fitting atmospheric measurements, 1σ
- **Black solid:** ZAMS
- **Blue & Red Dashed:** isochrones
- **Blue & Red Solid:** evolution tracks
- **Blue & Red Shade:** posterior probability distributions from BONNSA
- **Blue:** 165km/s initial rotation (no nitrogen enrichment)
- **Red:** 490km/s initial rotation (accounting for the nitrogen enrichment of secondary).

Boundedness

- Large deviation from atmosphere model and singe-star evolution model;
- The single-star evolution model does not take magnetic fields of the primary star into account;
- 165km/s initial rotation equatorial velocity of the primary star may be low compared with the real value.

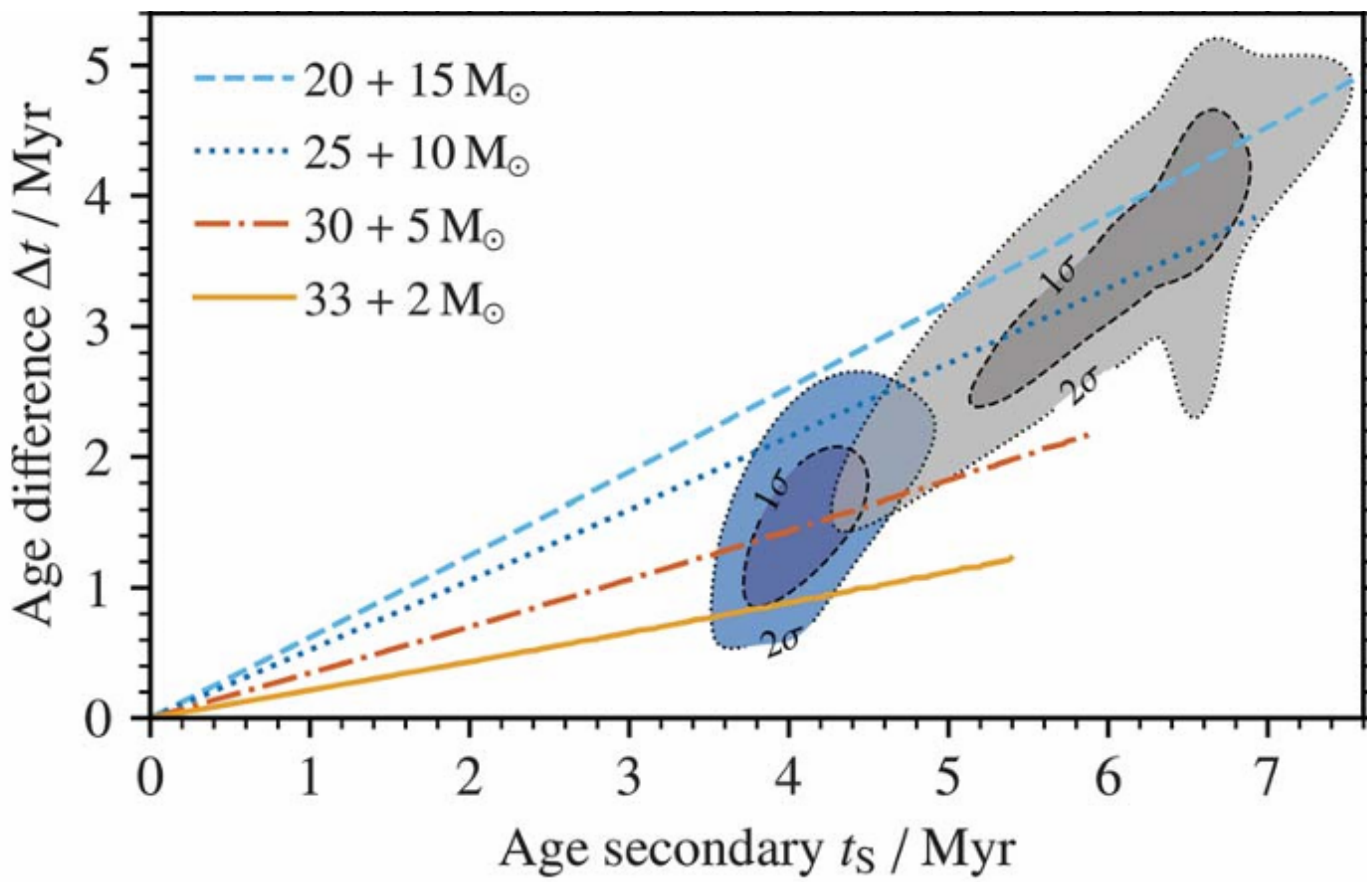
Rejuvenation event

- Mass transfer: disagrees with the radii that they determined
- Merge



The nebula (NGC 6164/6165) surrounding HD 148937 as seen in visible light (VLT Survey Telescope)

$1.6 \sim 12.6 M_\odot$ (L. Mahy et al., 2017)



- Mass loss (calculated with the merge model):

  1.7~8.2$M_\odot$

Conclusions

- HD 148937 was originally a higher-order multiple system, likely a triple system, with a close inner binary
- This inner binary underwent a merger a few thousand years ago, which produced a magnetic field in the merged star and the nebula surrounding the system.
- The fraction of O stars theoretically predicted to experience a merger is 8±3% (S. E. de Mink et al,. 2014), which is similar to the ~7% fraction observed to have magnetic fields. Thus, the merger mechanism could be the dominant origin of magnetic fields in massive stars.

Thank you!