Apsidal Motion in Massive Binaries: CPD-41° 7742, an Extreme Case?

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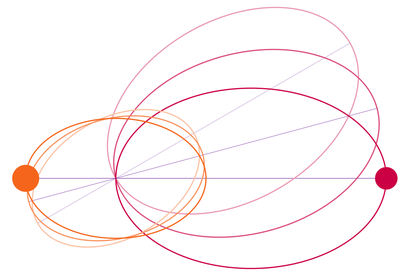


Abstract

We study the apsidal motion in close eccentric massive binaries. We focus on CPD-41° 7742, located in the very young and rich open cluster NGC 6231. Measuring the rate of apsidal motion in such a binary system gives insight into the internal structure and evolutionary state of the stars composing it.

Independent studies of CPD-41° 7742 in the past showed large discrepancies in the longitude of periastron of the orbit, hinting at the presence of apsidal motion (i.e. slow precession of the line of apsides with time). We perform a consistent analysis of all observational data explicitly accounting for the apsidal motion. We make use of the extensive set of spectroscopic and photometric observations of the binary to infer fundamental parameters of the stars and of the binary. The age estimates are in good agreement with estimates obtained for other massive binaries in NGC 6231. This study confirms the need for enhanced mixing inside the stellar evolution models of the most massive stars to reproduce the observational stellar properties. This points toward larger convective cores than usually considered.

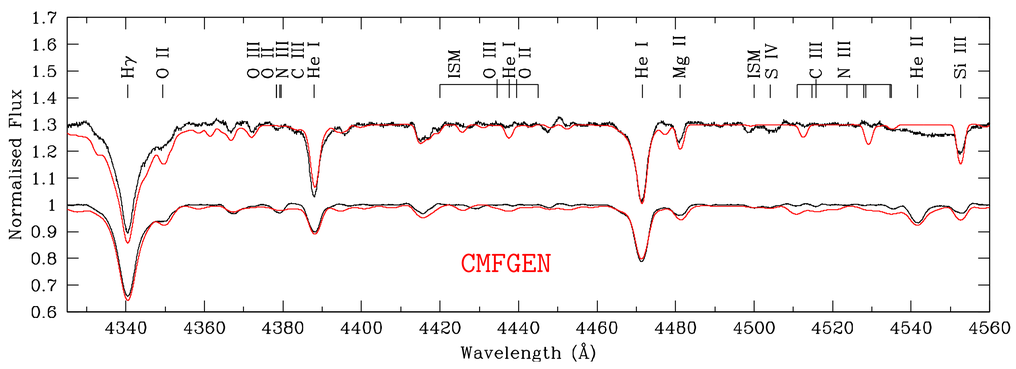
Motivations [5]

- The **majority** of massive stars belong to **binary** systems:
  - Considerably affects the **evolution** of the stars;
  - Offers possibilities to constrain the **properties** of the stars.
- Interesting systems: **double-line spectroscopic eclipsing binaries**
  - Combine the photometric eclipses and the radial velocities obtained with spectroscopy;
  - Determine the masses and radii of the stars in a **model independent** way.
- Most interesting systems: binaries showing a significant **apsidal motion**
  - Slow precession of the line of apsides in an eccentric binary;
  - Arises from tidal interactions occurring between the stars of a close binary, interactions which are responsible for the non-spherical gravitational field of the stars.
- The **rate of apsidal motion** is **directly related to the internal structure of the stars**. Measuring the rate of apsidal motion hence
  - Provides a diagnostic of the **internal mass-distribution of the stars**, which is otherwise difficult to constrain;
  - Offers a test of our understanding of **stellar structure and evolution**.

Results

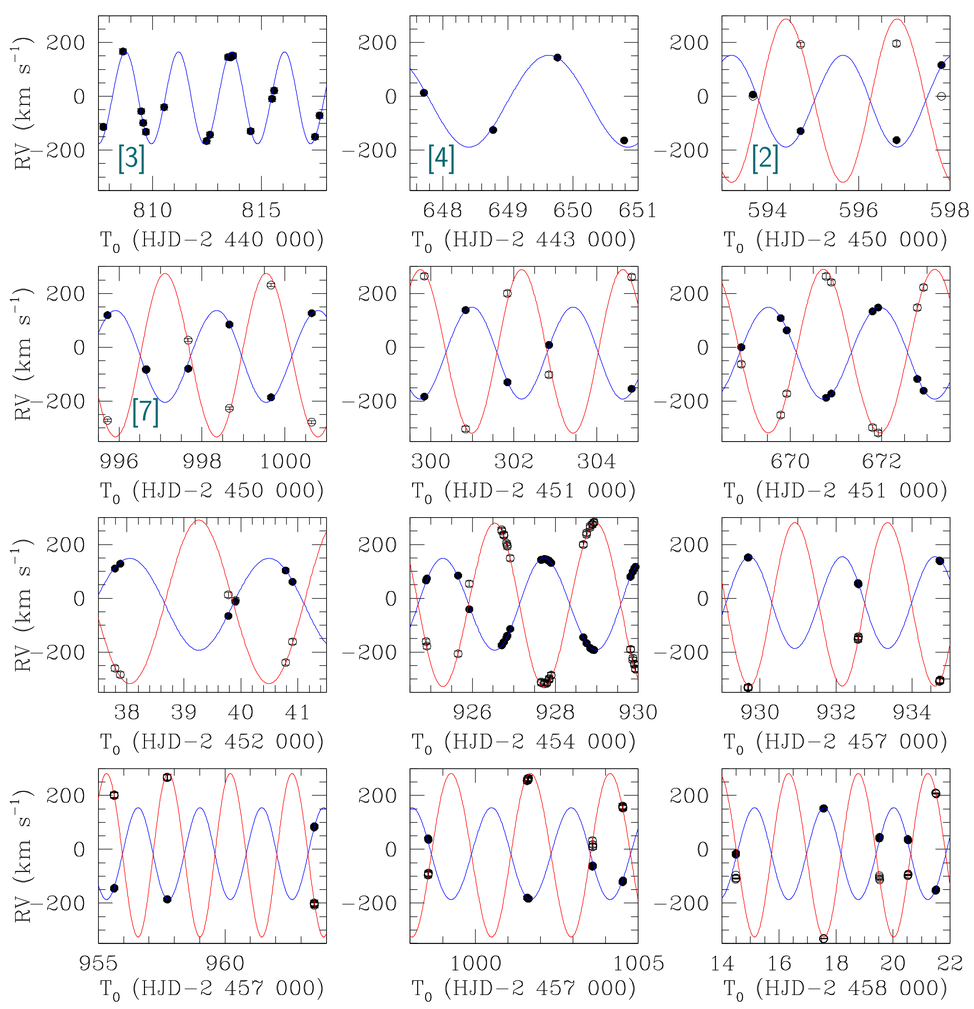
Spectroscopy

Disentangling → Individual spectra & Radial velocities



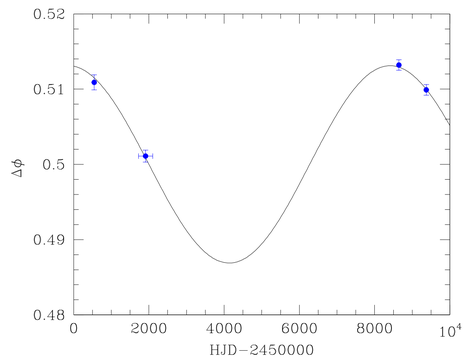
Radial Velocities

$$RV_P(t) = \gamma_P + K_P\,[\cos(\phi(t) + \omega(t)) + e\cos\omega(t)]$$
$$\omega(t) = \omega_0 + \dot{\omega}(t - T_0)$$



Phase Shift of Eclipses

Phase difference $\Delta\phi = \frac{T_2 - T_1}{P_{ecl}}$



Observational Properties

Parameter	Value	
	Primary	Secondary
M ($M_\odot$)	17.8 ± 0.5	10.0 ± 0.3
R ($R_\odot$)	7.57 ± 0.09	$4.29^{+0.04}_{-0.06}$
T_{eff} (K)	$31\,800 \pm 1000$	$24\,098 \pm 1000$
i (°)	$82.0^{+0.6}_{-0.5}$	
e	0.0204 ± 0.0016	
P_{orb} (d)	2.441320 ± 0.000001	
$\dot{\omega}$ (° yr^{-1})	$15.38^{+0.42}_{-0.51}$	

Stellar Evolution Models: Clés [6]

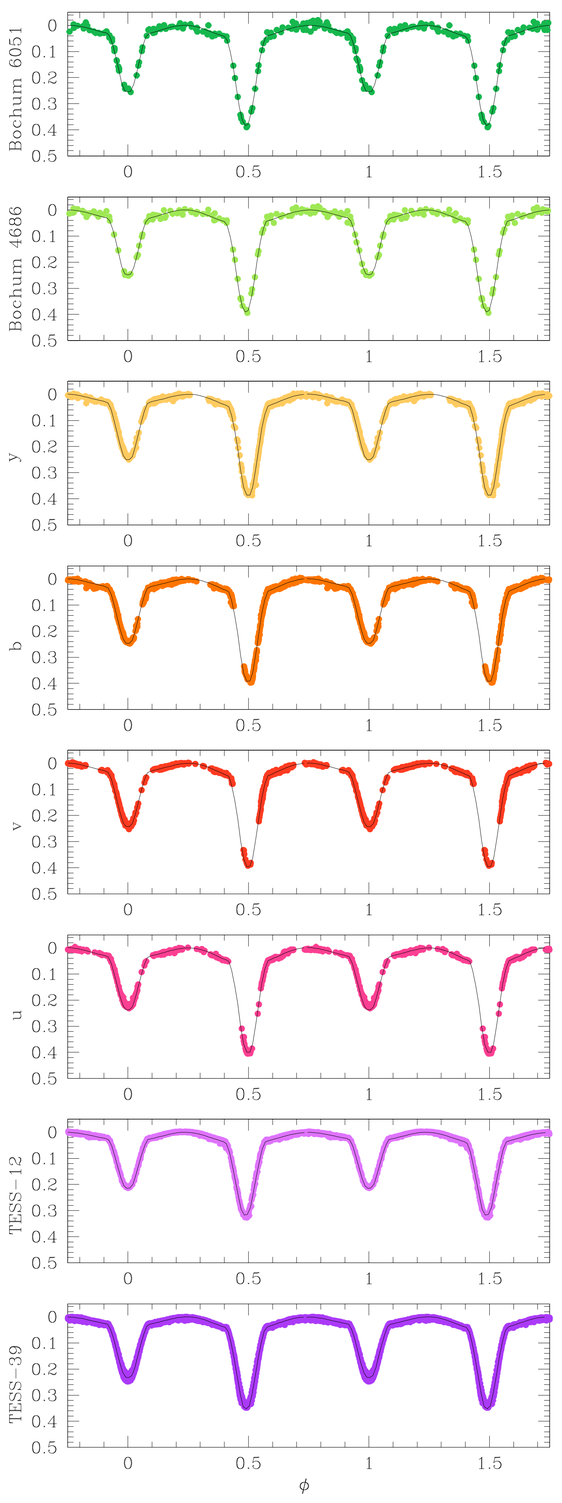
- High overshooting $\alpha_{ov} \geq 0.2$ & Turbulent diffusion $D_T \sim 10^6\,cm^2\,s^{-1}$
- M_{init}: 18.0 ± 0.5 & $9.9 \pm 0.3\,M_\odot$
- Age: 6.8 ± 1.4 Myr
- Age NGC 6231 from massive stars: 5.0 – 9.5 Myr

Conclusion

The large discrepancies in the longitude of periastron found by independent studies are solved through the apsidal motion. This study suggests that massive stars have larger convective cores than usually considered in stellar evolution codes.

Photometry

Bochum [8]: 2 450 545.8 HJD
uvby [1]: 2 451 911.7 HJD
TESS-12: 2 458 646.5 HJD
TESS-39: 2 459 373.9 HJD



References

[1] Bouzid et al. 2005, A&A, 437, 769
[2] García & Mermilliod 2001, A&A, 368, 122
[3] Hill et al. 1974, AJ, 79, 1271
[4] Levato & Morrell 1983, Astrophys. Lett., 23, 183
[5] Rosu et al. 2020, A&A, 642, A221
[6] Rosu et al. 2022, A&A, [arXiv:2202.02012]
[7] Sana et al. 2003, A&A, 405, 1063
[8] Sana et al. 2005, A&A, 441, 213

Further Information

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Acknowledgements: S. R., Y. N., & E. G. are supported by the FNRS (Fonds National de la Recherche Scientifique) - FNRS PhD grant.