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MASSIVE STARS HERE AND THERE, ALWAYS WITH SOME IMPACT

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RESUMEN

Puede decirse que las estrellas masivas, con sus fuertes vientos, intensa radiación ionizante y explosión final en forma de supernova, son los principales causantes de la evolución de las galaxias. Esta contribución examinará resultados recientes obtenidos para dos estrellas masivas magnéticas, HD108 y HD148937, los cuales ponen de relieve el impacto en sus respectivos entornos circumestelares.

ABSTRACT

With their strong winds, intense ionizing radiation, and supernova explosion ending, massive stars can truly be said to be main shaping agents in galaxies. This contribution will examine the case of two magnetic stars, HD108 and HD148937. Recent results obtained for both of them highlight the properties of their circumstellar environments.

Key Words: stars: massive — stars: mass-loss — stars: individual (HD108, HD148937)

1. INTRODUCTION

Massive stars play a key role when stellar feedback on the interstellar medium (ISM) is considered. Indeed, their intense ionizing radiations, combined to their fast and dense outflows and their deaths as supernovae, are able to shape the ISM on various scales. This contribution examines two cases of magnetic massive stars. Contrary to low-mass stars, magnetism is far from ubiquitous in the high-mass range: only about 7% of such stars were found to be magnetic. The magnetic fields appear strong, temporally stable, and dipolar - all characteristics again in contrast to those of low-mass stars. Such magnetic fields influence the feedback of massive stars on several levels. First, the wind outflows are channelled towards the magnetic equator by the magnetic field (ud-Doula & Owocki 2002). If the star rotates fast, this material can accumulate, creating a dense circumstellar region. If the rotation is slow (as found for most magnetic O-type stars), the material falls back onto the star, reducing the amount of mass injected into the ISM. In addition, strong magnetic fields may modify the inner structure of the stars which, combined to the mass-loss change, modify the stellar evolution hence the overall stellar feedback (Petit et al. 2017; Takahashi & Langer 2021; Keszthelyi et al. 2022). Magnetic massive stars thus appear relevant in a conference dedicated to circumstellar and interstellar environments.

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2. HD108

HD108 has a spectral type Of?p. Historically, this peculiar spectral type was introduced to describe O-type spectra with strong C III emission lines near 4650Å (Walborn 1972). With time, it was found that stars of this type exhibited additional peculiarities, notably periodic variabilities of the Balmer emission lines and X-ray overluminosities. The detection of magnetic fields in these stars led to an understanding of these characteristics. The narrow optical emission lines are born in the magnetically confined winds and the plasma collision at the magnetic equator leads to an increase of temperature hence of the X-ray emission. The variability of these features can be explained by a magnetic oblique rotator geometry, which changes the viewing angle on the magnetospheric regions as a function of rotational phase.

The Liège Astrophysics Institute has a long story of studying this star. Its former director, Pol Swings, observed HD108 in the 1940s, then his pupil Jean-Marie Vreux took the succession in the 1970s–1980s, and the Liège co-authors of this paper have continued since. This long chain of observation led us to identify the period of HD108: 54 years (Nazé et al. 2001; Rauw et al. 2023 and references therein). In the context of the magnetic oblique rotator model, this extremely long period should correspond to stellar rotation. This might seem surprising, but the combination of a strong magnetic field and a strong stellar wind can result in a strong magnetic braking (ud-Doula et al. 2009).

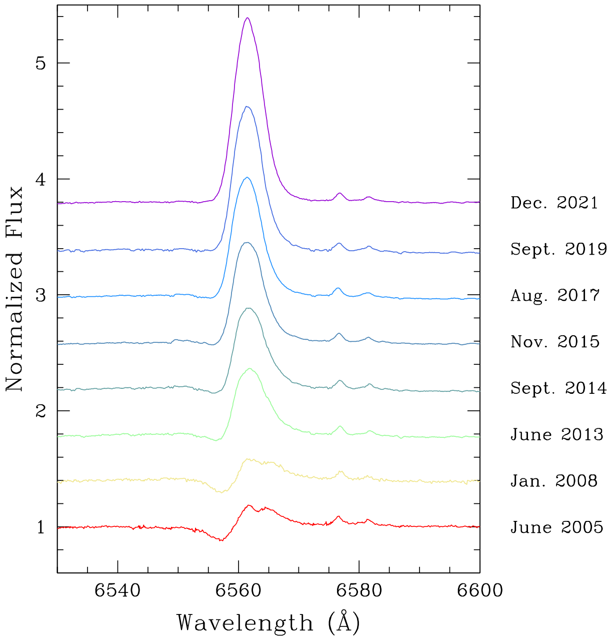

Fig. 1. Time evolution of the Hα profile in the spectrum of HD108, showing how the emission is now recovering after the 2007 minimum.

Over the last two decades, the "minimum emission state" occurred in 2007, as the confined winds were then seen close to edge-on. The optical emissions are now seen to increase again (Fig. 1). While the exact value of the field is not yet known, modelling of the emission variations favors a value around -4 kG (Rauw et al. 2023). In parallel, new X-ray observations show an increase in luminosity and X-ray hardness, as expected. Finally, radial velocity changes with a period of 8.5 yrs clearly indicate that HD108 is a binary, with a mid-B companion.

3. HD148937

HD148937 is one of the other "historic" Of?p stars, but with a much shorter (7d) rotational period and a lower variation amplitude due to its pole-on configuration (see Mahy et al. 2017; Lim et al. 2024 and references therein for details). It is also a binary with $P \sim 20$ yrs, with a companion of similar mass. Finally, it is surrounded by several nebulosities. Faint arcs delineate a large shell $12'$ in radius, considered to be a wind-blown bubble, while even larger nebulosities are seen as tracing the Strömgren sphere of the star. Closer, on each side of the star, are found the bright nebulae NGC6164 and NGC6165 that form a single elongated structure $5'$ in diameter centered on HD148937. Due to its expanding motion and its peculiar abundances, it was interpreted as ejecta, as seen around some LBVs and WR stars.

A recent study of the main NGC6164/5 nebula was performed in the infrared using *WISE*, *Spitzer*, and *Herschel* data (Mahy et al. 2017). The total ejected mass was estimated to be more than 1.6 $M_\odot$. This study further derived abundances in different places of the nebula: in the bright lobes, N/O=1.54 and C/O=2.24, which is clearly much larger than solar (values of 0.14 and 0.5, respectively), but the fainter nebulosities closer to the star display a lower enrichment: N/O=1.06 and C/O=1.42. When compared to evolutionary tracks, such abundances yield ages of 0.5–0.7 and 1.2–1.3 Myr for the ejections from the stellar surface giving rise to the faint close and bright distant features, respectively.

Such a distribution of the abundances is difficult to understand within the context of the proposed nebular models. If the ejected material has a helical geometry (Carranza & Agueero 1986), then it would require mass to flow away from the equator, while magnetic channeling works in the other direction. Considering the close and distant features as the result of a two-step ejection also yields problems: if the bright lobes are equatorial and the inner parts polar, the latter ones should have large radial velocity shifts compared to the former, which is not the case (Leitherer & Chavarria-K. 1987); if the bright lobes are polar and the inner features equatorial (Leitherer & Chavarria-K. 1987), then it contradicts the low inclination, pole-on geometry of the star, established through different means. A last possibility is to have both features born in a single event. While magnetic fields of massive stars are sometimes advocated to be the result of a merger event, it remains to be established that the current slow rotation of the magnetic star and the current configuration (mass and orbit) of its companion, initially a third star in this context, are compatible with such an idea. Another event could be a periastron passage, as has been proposed for the eruptions of η Car.

To test this idea, new spectra were obtained with ESO's FLAMES+GIRAFFE instrumentation (Lim et al. 2024). The profiles of the Hα and nearby [SII], [NII] lines were fitted by a set of Gaussians. This revealed that NGC6164/5 has a complex velocity field, with multiple layers of material superimposed along our line-of-sight. To model it, three expanding features were considered: the nitrogen-enriched cores of the bright lobes, their envelopes, and expanding hollow shells close to the equatorial plane. Such a geometry is able to reproduce the observed geometry and velocity field with a single expansion velocity

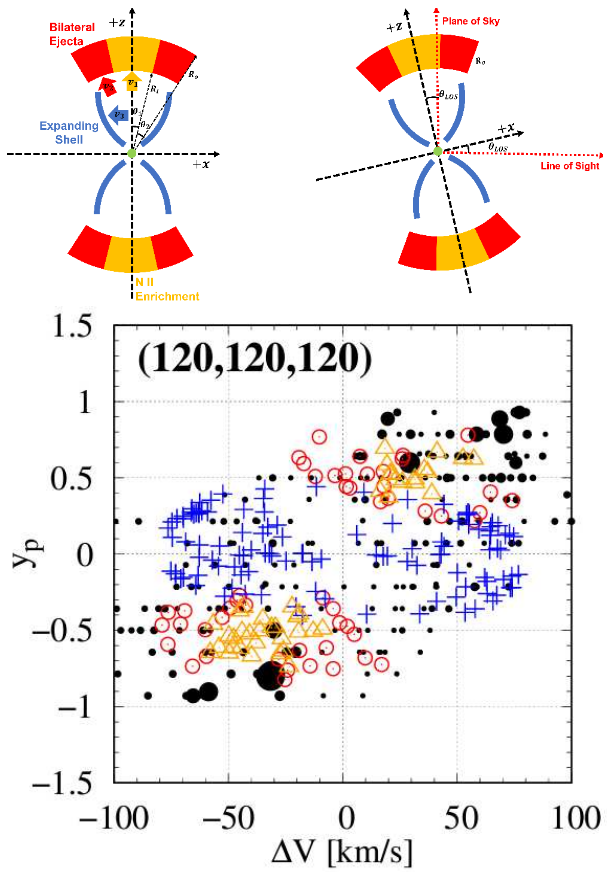

Fig. 2. *Top:* Schematic illustration of the 3-structures model, with nitrogen-enriched cores (orange), envelopes (red), and expanding hollow shells (blue). *Bottom:* Position-velocity diagrams of the measured Hα velocities (black dots) compared to velocities from the model nebula with 120 km s^{-1} expansion velocity (nitrogen-enriched cores, envelopes, and hollow shells are shown by orange triangles, red circles, and blue plus symbols, respectively). Figure adopted from Lim et al. (2024).

of 120 km s^{-1} (Fig. 2). This would result in an age of 7500 yrs for the nebula, much less than previously believed. The different abundances would then be understood in the framework of a periastron ejection, in which matter from both stars would mix in various proportions depending on the feature under consideration. Further studies are now required to understand whether and how this could happen exactly.

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REFERENCES

Carranza, E. & Agueero, E. L. 1986, Ap&SS, 123, 59. doi:10.1007/BF00649124

Keszthelyi, Z., de Koter, A., Götberg, Y., et al. 2022, MNRAS, 517, 2028. doi:10.1093/mnras/stac2598

Leitherer, C. & Chavarria-K., C. 1987, A&A, 175, 208

Lim, B., Naze, Y., Chang, S.-J., et al. 2024, ApJ, 961 72

Mahy, L., Hutsemékers, D., Nazé, Y., et al. 2017, A&A, 599, A61. doi:10.1051/0004-6361/201629585

Nazé, Y., Vreux, J.-M., & Rauw, G. 2001, A&A, 372, 195. doi:10.1051/0004-6361:20010473

Petit, V., Keszthelyi, Z., MacInnis, R., et al. 2017, MNRAS, 466, 1052. doi:10.1093/mnras/stw3126

Rauw, G., Nazé, Y., ud-Doula, A., et al. 2023, MNRAS, 521, 2874. doi:10.1093/mnras/stad693

Takahashi, K. & Langer, N. 2021, A&A, 646, A19. doi:10.1051/0004-6361/202039253

ud-Doula, A. & Owocki, S. P. 2002, ApJ, 576, 413. doi:10.1086/341543

ud-Doula, A., Owocki, S. P., & Townsend, R. H. D. 2009, MNRAS, 392, 1022. doi:10.1111/j.1365-2966.2008.14134.x

Walborn, N. R. 1972, AJ, 77, 312. doi:10.1086/111285