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RADIO STUDY ON THE MASS LOSS BI-STABILITY JUMP

P. Benaglia,[1] J. S. Vink,[2] J. Maíz Apellániz,[3] J. Martí,[4] B. Koribalski,[5] and P. A. Crowther[6]

RESUMEN

Por medio de observaciones en continuo de radio hacia 29 estrellas O8-B3 hemos buscado rastros del salto de bi-estabilidad en la tasa de pérdida de masa estelar. Los resultados obtenidos son compatibles con las predicciones teóricas. Observaciones hacia más estrellas son necesarias para confirmar la tendencia.

ABSTRACT

By means of radio continuum observations of 29 stars with spectral types O8-B3 we searched for evidence of the existence of a bi-stability jump in stellar mass loss around $T_{\rm eff} \approx 21$ kK. Although there are quantitative discrepancies, the qualitative behaviour of the wind efficiency with effective temperature appears to be in line with theoretical predictions. Observations of new cases are fundamental to confirm these results.

Key Words: radio continuum: stars — stars: early-type — stars: lass loss — stars: winds, outflows

1. INTRODUCTION

It is widely accepted that radiation pressure on millions of spectral lines is the physical mechanism driving the powerful stellar winds of OB stars. The theory has been very successful in explaining the overall mass loss ($\dot{M}$) properties. However, there are still open issues like for instance the relevance of wind clumping, or the so-called "bi-stability jump" (BSJ): an empirical drop in the ratio of the wind terminal velocity and the escape velocity ($v_\infty/v_{\rm esc}$) from 2.6 to 1.3, around temperatures of about 21 kK (Lamers et al. 1995).

On the theoretical field, the wind models computed by Vink et al.(2000) showed that for effective temperatures ($T_{\rm eff}$) between 50 and 27.5 kK, the mass-loss rates (or the wind efficiencies $\eta = c\dot{M}v_\infty/L_*$) drop rapidly, due to a growing mismatch between the wavelengths of the maximum opacity in the UV and the flux maximum. Around the BSJ, η increases by a factor of 2-3 to a local maximum when Fe IV recombines to the more efficient Fe III configuration. Below the BSJ, the first effect returns, and η again decreases with temperature (see Figure 1).

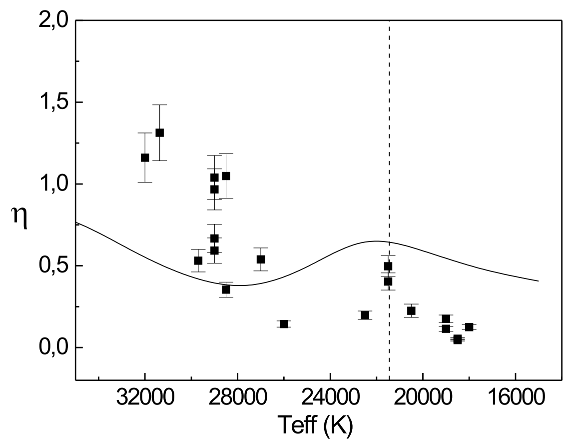

Fig. 1. Modelled efficiency for $\log(L/{\rm L}_\odot) = 6.0$, $M_* = 60$, $M_\odot$, $v_\infty/v_{\rm esc} = 2.6$ (solid line) superposed to the radio wind efficiencies (squares). The dashed vertical line shows the temperature of the local maximum, 21.5 kK.

The BSJ mechanism may be the crucial piece of physics for understanding the least understood phases of massive star evolution, i.e. the LBV and the B[e] phases (Vink & de Koter 2002), but the physics of the BSJ needs to be understood also in relation to the differences found between empirical UV mass-loss rates and radiation-driven wind models (Prinja et al. 2005; Vink et al. 2000).

We have investigated the expected jump in mass loss on observational grounds, by performing a comprehensive radio analysis of massive stars over the spectral range O8-B3 (35 kK $\geq T_{\rm eff} \geq$ 15 kK). Some important results are presented in this contribution.

[1]Instituto Argentino de Radioastronomía, C.C.5, (1894) Villa Elisa, Argentina (pbenaglia@fcaglp.unlp.edu.ar).

[2]Keele University, Astrophysics, Lennard-Jones Lab, ST5 5BG, UK.

[3]Instituto de Astrofísica de Andalucía, Camino bajo de Huétor 50, Granada 18008, Spain.

[4]Departamento de Física, EPS, Universidad de Jaén, Campus Las Lagunillas s/n, Edif. A3, 23071 Jaén, Spain.

[5]Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 1710, Australia.

[6]Department of Physics and Astronomy, Univ. of Sheffield, Hicks Building, Hounsfield Road, Sheffield S3 7RH, UK.

TABLE 1

TARGET STARS

Star	Sp. Class.	$T_{\rm eff}$ (K)	$\log \dot{M}$	S_ν ref.
HD 156154	O8 Iab(f)	33179[a]	< -5.4	b
HD 151804	O8 Iaf	29000[b]	-5.0	c
BD-11 4586	O8 Ib(f)	33179[a]	< -5.3	b
HD 112244	O8.5 Iab(f)	32274[a]	< -5.5	b
HD 76341	O9 Ib	31368[a]	-5.1	b
CygOB2-10	O9.5 I	29700[d]	-5.4	d
HD 195592	O9.5 I	29000[e]	-5.3	f
HD 30614	O9.5 Ia	29000[e]	-5.5	f
HD 209975	O9.5 Ib	32000[d]	-5.6	d
HD 37742	O9.7 Ib	28500[e]	-5.8	c
HD 47432	O9.7 Ib	28500[e]	< -5.5	b
HD 152424	OC9.7 Ia	28500[e]	-5.3	c
HD 37128	B0 Ia	27000[e]	-5.8	f
HD 204172	B0 Ib	27500[e]	< -5.3	b
HD 154090	B0.7 Ia	22500[e]	-5.9	b
HD 2905	BC0.7 Ia	21500[e]	-5.6	f
HD 169454	B1 Ia	21500[e]	-5.5	g
HD 157246	B1 Ib	20800[h]	< -6.2	b
BD-14 5037	B1.5 Ia	20500[e]	-5.6	b
HD 152236	B1.5 Ia+	18000[e]	-5.1	i
HD 190603	B1.5 Ia+	18500[e]	< -5.7	f
HD 148379	B1.5 Iape	18500[b]	-6.1	b
HD 194279	B2 Ia	19000[e]	-5.8	f
HD 41117	B2 Ia	19000[e]	-5.7	f
HD 80077	B2 Ia+	18500[e]	-5.8	j
HD 165024	B2 Ib	18000[e]	< -6.2	b
HD 198478	B2.5 Ia	16500[e]	< -6.3	f
HD 42083	B2.5 Ib	19000[b]	< -6.0	b
HD 43384	B3 Iab	15500[e]	< -5.8	b

[a]Martins et al. 2005. [b] This work. [c] Lamers & Leitherer 1993. [d] Puls et al. 2006. [e] Crowther et al. 2006. [f] Scuderi et al. 1998. [g] Bieging et al. 1989. [h] Lamers et al. 1995. [i] Stevens, priv. comm. [j] Leitherer et al. 1995. $\sigma_T \leq 2000$ K, see Benaglia et al. 2007.

2. THE STELLAR SAMPLE

We have searched the literature for radio continuum observations of OB supergiants of spectral types O8-B3. Radio flux densities S_ν (or upper limits) for 17 stars were published by Bieging et al. (1989), Lamers & Leitherer (1993), Scuderi et al. (1998), and Puls et al. (2006). The database was complemented with new observations toward 12 targets, performed by us (Benaglia et al. 2007) (see Table 1). The spectral types were taken from the GOS Catalogue (Maíz Apellániz et al. 2004) and the Simbad database.

We proceeded first to adopt a common $T_{\rm eff}$-scale; most values were taken from Crowther et al. (2006) (see Table 1). The mass loss rates were derived assuming the flux density is thermal in nature. This hypothesis is based on the high observing frequencies (≥ 8 GHz) and the fact that non-thermal emission should not be important for the spectral types under consideration. The wind efficiencies obtained are shown in Figure 1.

3. RESULTS

Predicted mass-loss rates can be computed by means of a recipe derived by Vink et al.(2000), produced from several mass-loss rate models for different (L_*,M_*) values.

A direct comparison between predicted and radio-derived mass-loss rates shows that for stars above the BSJ, the predicted values are larger than the radio ones. The contrary holds for stars below the BSJ. The discrepancy in the first group may be attributed to wind clumping, but this would not explain the discrepancy for the objects below the BSJ.

In summary, the study has revealed that for stars around the BSJ, the wind efficiency appears to be above the predicted general declining function towards later spectral types. The temperature of the potential local maximum (21.5 ± 1.5 kK) also agrees with the predicted temperature of the BSJ. The detection of more Galactic supergiants in radio waves around $T_{\rm eff}$=20–25kK is needed to confirm the predicted mass-loss BSJ.

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DISCUSSION

A. Herrero - You mentioned that you were assuming the stars being thermal emitters. Is that an hypothesis or did you check your list for non-thermal emission? And, what's the green point deviating so much from the 1:1 relation in the $\dot{M}$(radio) vs $\dot{M}$(Hα) relation?

P. Benaglia - About half of our sample lack information of spectral indices, since they were observed at only one frequency. However, in all cases we assumed the emission was predominantly thermal, because none of the targets of the largest samples included in previous works, at the particular spectral type range considered by us, evidenced a non-thermal behaviour. The isolated point you mention represents the star HD 151804. The difference between radio and Hα mass loss rate values could be explained for example advocating clumping effects.

A.Maeder - Do you expect a different sensitivity of radio observations to clumping effects with respect to Hα or UV observations?

P. Benaglia - In principle yes, because the methods to derive $\dot{M}$ probe different part of the stellar wind: from Hα ones at the inner part, to radio ones at the outer layers. In that sense we find the result of $\dot{M}$(radio) $\sim$ $\dot{M}$(Hα) on average quite interesting.

Nolan tries a "slide-less" explanation of the fundamentals of stellar classification.