Exploring the connection of weak winds and magnetic fields

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Abstract: The theory of radiatively driven winds successfully explains the key points of the stellar winds of hot massive stars. However, there is an apparent break-down of this paradigm at $\log L/L_{\odot}$ <5.2: the stellar wind momentum is smaller than predicted for low luminosity early-type stars from metal poor environments, and there are also some Galactic examples. In this work we explore whether magnetic fields are playing a role.

1 Introduction

There is an apparent breakdown of the theory of radiation driven winds at $\log L/L_{\odot}$ <5.2, where the wind-momentum derived from the observations is smaller (beyond error bars) than prediced by theory. This was first thought a metallicity effect since it was detected in stars from metal-poor environments like the SMC (Bouret et al. 2003, Martins et al. 2004). However, there are also some Galactic cases (Martins et al. 2005, Marcolino et al. 2009).

We still lack an explanation but current hypothesis include a metallicity-dependent threshold luminosity to start the wind, an early evolutionary state previous to wind onset, decoupling of the driving ions from the plasma or magnetic fields.

We study a sample of O9-B0 young dwarfs in the Orion star forming region, together with τ Sco, a known magnetic star. Our first analysis of ultraviolet (UV) spectra (1150-1800Å) with WM-basic models revealed that all targets have smaller wind momentum than predicted by the theory, although τ Sco's was larger and closer to the theoretical relation. However, this analysis was not conclusive, as the photospheric properties ($T_{\rm eff}$ and $\log g$) were adopted from optical studies. We present here first results from an improved multiwavelength analysis (from UV to the optical range) for the same sample of stars, using CMFGEN synthetic spectra to fit the observations, where stellar and wind parameters are determined consistently. In this work we explore magnetic fields and the tightly connected wind x-ray emission as possible explanation for the weak wind problem.

2 Previous work: analysis with WM-basic models

We derived the wind properties of a sample of O9-B0.5V stars from their UV spectra. The sample includes stars in the Orion Nebula, 10 Lac and τ Sco (Garcia & Herrero, 2010).

The UV spectra were observed with the International Ultraviolet Explorer (IUE) and downloaded from the INES archive (Wamsteker et al. 2000). The spectra did not display any wind features in the IUE range with the exception of C IV1550 (and perhaps N V1240) in some stars in the sample.

To analyze the UV data, we built for each star a grid of spherical hydrodynamical line-blanketed non-LTE synthetic spectra calculated with the WM-Basic code (Pauldrach et al. 2001). WM-Basic provides a very detailed treatment of the spectral lines in the UV range, however, it lacks an appropriate treatment of the Stark broadening and is not suitable for analysis of photospheric lines in the optical range.

Consequently, the grid was run with photospheric ($\mathrm{T_{eff}}$, $\log\,\mathrm{g}$) parameters derived for these stars by Simón-Díaz et al. (2006) from detailed quantitative analysis of optical spectra using FASTWIND (Puls et al. 2005). The observed H_α line did not exhibit a wind profile, indicating a low mass loss rate. The H_α profiles of the synthetic spectra calculated with the derived photospheric parameters were in fact insensitive to variations of the wind parameters. Therefore, Simón-Díaz et al. could only set upper limits for the wind-strength Q-parameter ($Q = \dot{M}(v_\infty R_\star)^{1.5}$, $\dot{\mathrm{M}}$ being the mass loss rate, v_∞ the terminal velocity and $\mathrm{R}_\star$ the stellar radius).

Each object's customized grid has the following varying parameters:

- Mass loss rate. Starting from Simón-Díaz et al. upper limit of Q as first value, $\dot{\mathrm{M}}$ was decreased until it reproduced the observed weak UV features.
- Terminal velocity. The traditional method to derive this parameter could not be used, as the UV stellar spectra did not display any saturated lines. The values of v_∞ considered in the grid were estimated from the escape velocity (see Lamers et al. 1995), $\pm$ 500km/s.
- Shocks in the wind, parameterized by the X-ray luminosity released in the shock cooling zone. This parameter could not be constrained since observations of the O VI1033 line in the Far-UV were not available for all stars. The adopted values for this parameter were: $\log L_X/L_{bol}$ =-6.5, -7.0, -7.5, -8.0 and shocks off.

We found that the grid models predicted strong P Cygni profiles of C III1176, C IV1550, N V1240 and SI IV1398 not seen in the observations, unless mass loss rate was extremely small. Moreover, the models could not reproduce the observed strength of all these lines simultaneously. Only upper limits for $\dot{\mathrm{M}}$ could be set.

The subsequent upper-limits for the Wind momentum-Luminosity Relation (WLR) are systematically smaller than the theoretical prediction. Only τ Sco and HD 37020 are close to Vink et al. (2000)'s relation (see Fig. 1). **τ Sco is a known magnetic star and HD 37020 has been recently reported a candidate based on its X-ray behaviour (Steltzer et al. 2005) and its non-thermal radio-emission (Petr-Gotzens & Massi 2007).**

3 The interplay of magnetic fields and X-ray luminosity

Magnetically confined wind shocks, colliding loops and reconnection events may produce strong, hard X-ray emission in the lower wind (see for instance Puls et al. 2009). This leads to increased ionization; since ions have less lines, the radiative line-acceleration is weaker. To reproduce the observed wind features, models with enhanced $\dot{\mathrm{M}}$ are required. This could explain why τ Sco and HD 37020 are closer to the theoretical WLR.

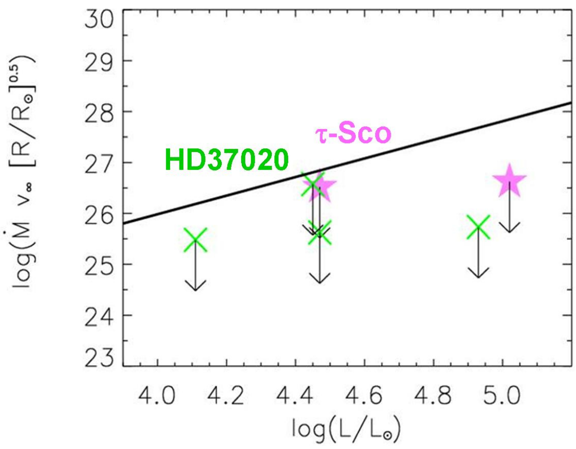

Figure 1: Wind-momentum Luminosity Relation (WLR) for the stars analyzed in Garcia & Herrero (2010). We include the theoretical relation of Vink et al. (2000) as reference .

3.1 A word of caution

Schulz et al. (2006) found that the X-ray emission of HD 37041 may be produced as close as less than 1 stellar radius from the photosphere (see also Cohen 2010).

X-rays in the expanding atmospheres of O stars alter the ionization balance of elements, shifting it towards higher values, thus mimicking the effects of higher temperature (Garcia 2005). This effect should not affect photospheric line diagnostics, nor the effective temperature derived from photospheric lines, as shocks were thought to be produced further out in the atmosphere. However, if produced close enough to the photosphere, X-rays may impact the T_{eff} determinations (Najarro et al. 2010 in prep.). The derived $\dot{M}$ would also change, as wind indicators are also sensitive to T_{eff} .

4 Panchromatic analysis with CMFGEN models

The complexity of this problem requires that all stellar (photospheric+wind) parameters must be derived jointly and consistently, to properly take into account the interplay of the different contributing factors. We have embarked on a project to re-analyze the same sample of stars, using better observations and a more suitable model atmosphere code.

We will use the IUE UV spectra, combined with high resolution echelle spectra from the IACOB database (see S. Simón-Díaz et al.'s contribution to these proceedings). By fitting simultaneously the UV and optical lines, tighter constraints are set on the temperature and velocity structure of the atmosphere, leading to a better characterization of the ion-stratification and the wind.

We used the CMFGEN code (Hillier & Miller 1998) to calculate synthetic spectra covering from the UV to the optical range. CMFGEN solves the spherically expanding non-LTE atmosphere in the co-moving frame, providing a consistent solution for the processes in the photosphere and the wind. In addition, the code includes a simulation of shocks, allowing the user to set up the temperature of the shock region and the wind-depth where they form.

We present in Figs. 2 and 3 our preliminary fits to HD 37020. The CMFGEN model reproduces simultaneously the photospheric and [weak] wind features, and produces a good fit to the optical and UV spectra.

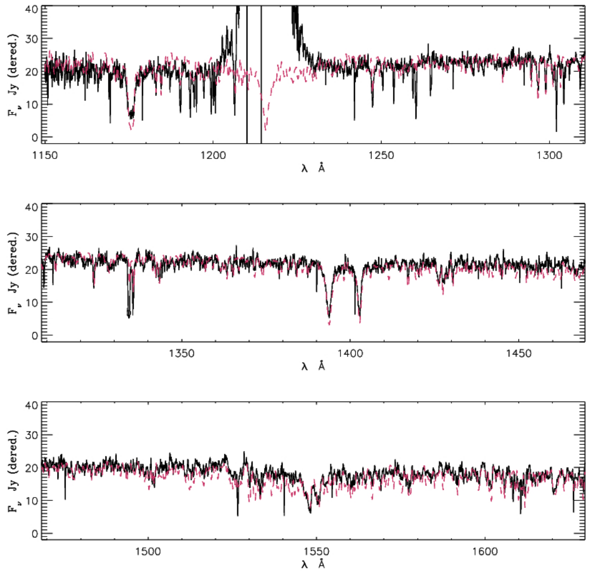

Figure 2: CMFGEN fit (red,dashed) to the IUE flux-calibrated spectrum (black, solid) of HD 37020. The observed wind signatures are very weak. The synthetic spectrum reproduces well the C III1176 blend, Si IV1400 and C IV1550 lines, and the iron-nickel continuum.

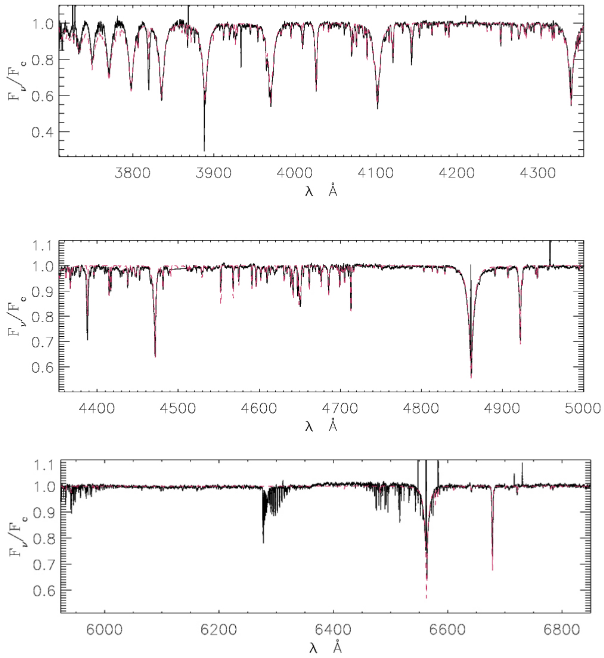

Figure 3: Same as Fig. 2, normalized spectra in the optical range. The CMFGEN model reproduces well the photospheric features observed in these wavelengths. This indicates a correct consistent determination of photospheric and wind parameters. H_α (bottom panel) exhibits no clear wind feature.

5 Conclusions

New analyses with CMFGEN models will shed new light on the problem of weak winds. We will model the UV and optical spectra of the sample of stars in Orion included in the high-resolution, high-S/N IACOB spectroscopic database. New results in the X-ray domain from Chandra (see for instance Steltzer et al. 2005) will be essential.

Results on this relatively large sample, which includes young stars, known magnetic rotators and X-ray emitters will help us disentangle the role played by each of these factors in the weak wind problem.

Acknowledgements

Funded by spanish MICINN under CONSOLIDER-INGENIO 2010, program grant CSD2006-00070, and grants AYA2007-67456-C02-01 and AYA2008-06166-C03-01.

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