A Systematic Search for Corotating Interaction Regions in Apparently Single Galactic Wolf-Rayet Stars:

A New Hope for the Determination of the Rotation Rate

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Science Background

Determining the basic parameters of stars is a fundamental undertaking in astronomy. In the case of massive stars, not only is it important for understanding the stars themselves, but it also has a much broader impact on other fields, such as galaxy evolution or the interaction of stars with the interstellar medium. The mass of a star and the mass-loss rate of its wind are the most determining factors for evolution in the upper H-R diagram. However, it has recently been demonstrated that these two parameters can be greatly affected by rotation, which becomes, consequently, of equal importance. Stellar rotation has now been fully incorporated into evolutionary models of massive stars (Maeder & Meynet 2000 ARA&A, 32, 143 and Heger, Langer & Woosley 2000, ApJ, 528, 368).

For Wolf-Rayet (WR) stars, evolutionary models predict low rotation rates as most of the angular momentum should be carried away by the high mass-loss rates (Meynet & Maeder 2003, A&A, 404, 975). On the other hand, the prediction that the collapse of rapidly rotating massive stars (very likely WR stars) is responsible for long Gamma-Ray Bursters (e.g. MacFadyen, Woosley & Heger 2001, ApJ, 550, 410), seems to point to relatively fast rotation rates for at least some WR stars. Unfortunately, the photosphere of WR stars is veiled by a hot and dense stellar wind and cannot be observed directly. Hence, no reliable direct observation of WR stars rotation rate could ever been obtained. However, the rotation period of WR stars can be deduced from periodic spectroscopic large-scale variability, when present. This type of variation is likely caused by perturbations at the base of the wind resulting from pulsations or magnetic fields. The density enhancements or deficiencies resulting from these perturbations are subsequently carried away by the wind combined with the rotation of the star, thereby generating spiral patterns called Co-rotating Interaction Regions (CIRs). This wind density distribution translates into large-scale periodic spectroscopic variations in the wind emission lines. A systematic search for large-scale spectroscopic variability in single WR stars brighter than V~12.5 has been already accomplished (St-Louis et al. 2009, ApJ, in press and Chené & St-Louis, in prep) and up to date, CIRs have been detected in the wind of a dozen of WR stars and the rotation rate of 6 WR stars could have been determined yet (including WR 6 already published in Morel et al. 1997, ApJ, 482, 470; see **Fig.1**).

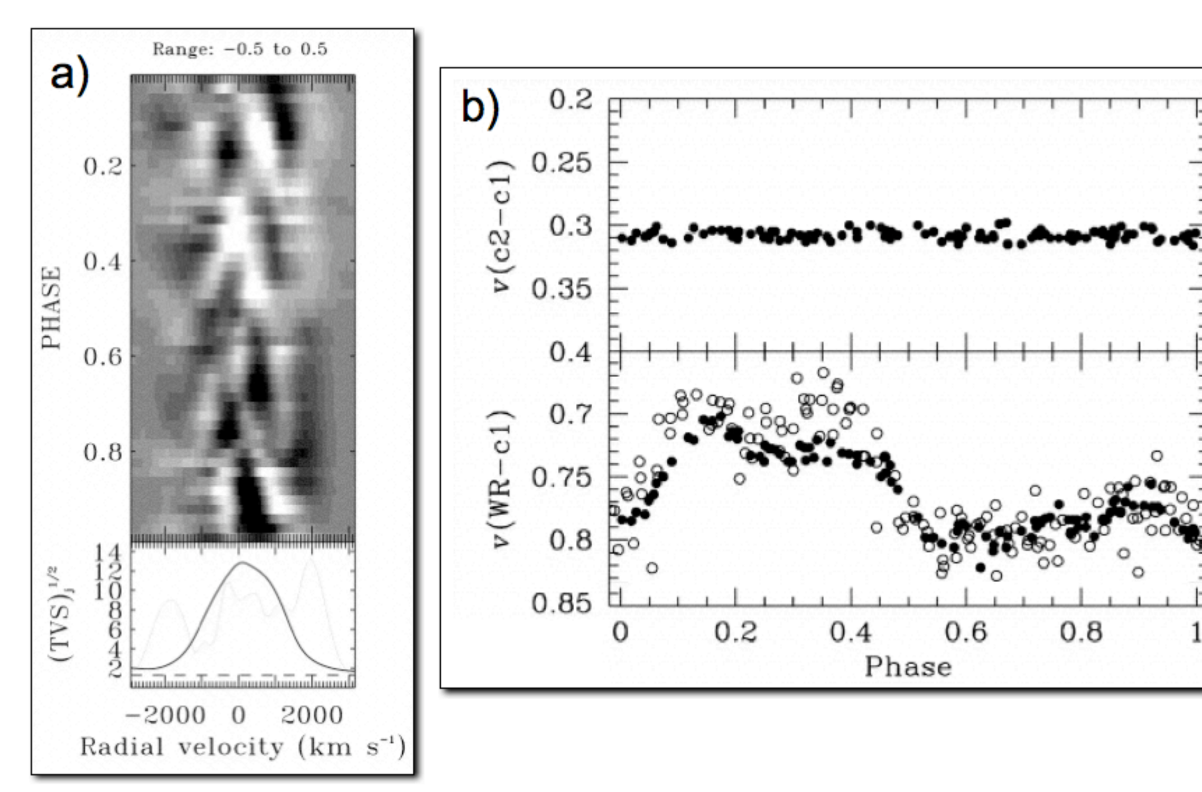

Figure 1: a) Grayscale of the HeII line profile variability folded with a 3.77-day period. b) UV (opened circles) and v (filled circles) bands photometry folded with the same period as the line-profile variability.

The Poor Weather Program at Gemini

Of course, this determination of the rotation rate of WR stars is of limited impact since it is based on only 6 stars. The best way to eventually double the number of candidates is to search among fainter WR stars, i.e. with V=12.4-16.0; this would double our sample of WR stars observed for the survey. Hence, using the Gemini-South Poor Weather time, we have carried out a spectroscopic observing campaign on as many single galactic WR stars as possible with a magnitude V>12.5. So far, 15h40m of observing time has been done with CC=50%-ile for this program, as well as 7h06m with CC=70%-ile and 1h39m with CC=90%-ile. We have obtained a series of 4 to 5 medium resolution spectra with a S/N~100 for 6 stars. In the coming next months, similar series will be completed for 6 other stars. Finally, 4 stars with a magnitude V=15-16 have been observed only once and may be re-observed if the time allows it. Among these 18 WR stars observed (out of 33 WR stars within the targeted magnitude range in the southern hemisphere), 2 have shown clear large-scale spectroscopic variability that is similar to what is expected from CIRs. In Fig. 2, we show the montage of the residuals obtained from the subtraction of the individual spectra by the mean profile for three stars. The two first stars, WR 7 (of the nitrogen sequence) and WR 13 (of the carbon sequence) show a small-scale variability that is expected to be present in almost all WR stars due to clumping in the wind. But WR 20 shows a large-scale variability with an relative amplitude of ~10% of the line intensity. This star will be observed later more intensively in order to determine the periods of its changes, which may directly translate into the rotation periods of the star.

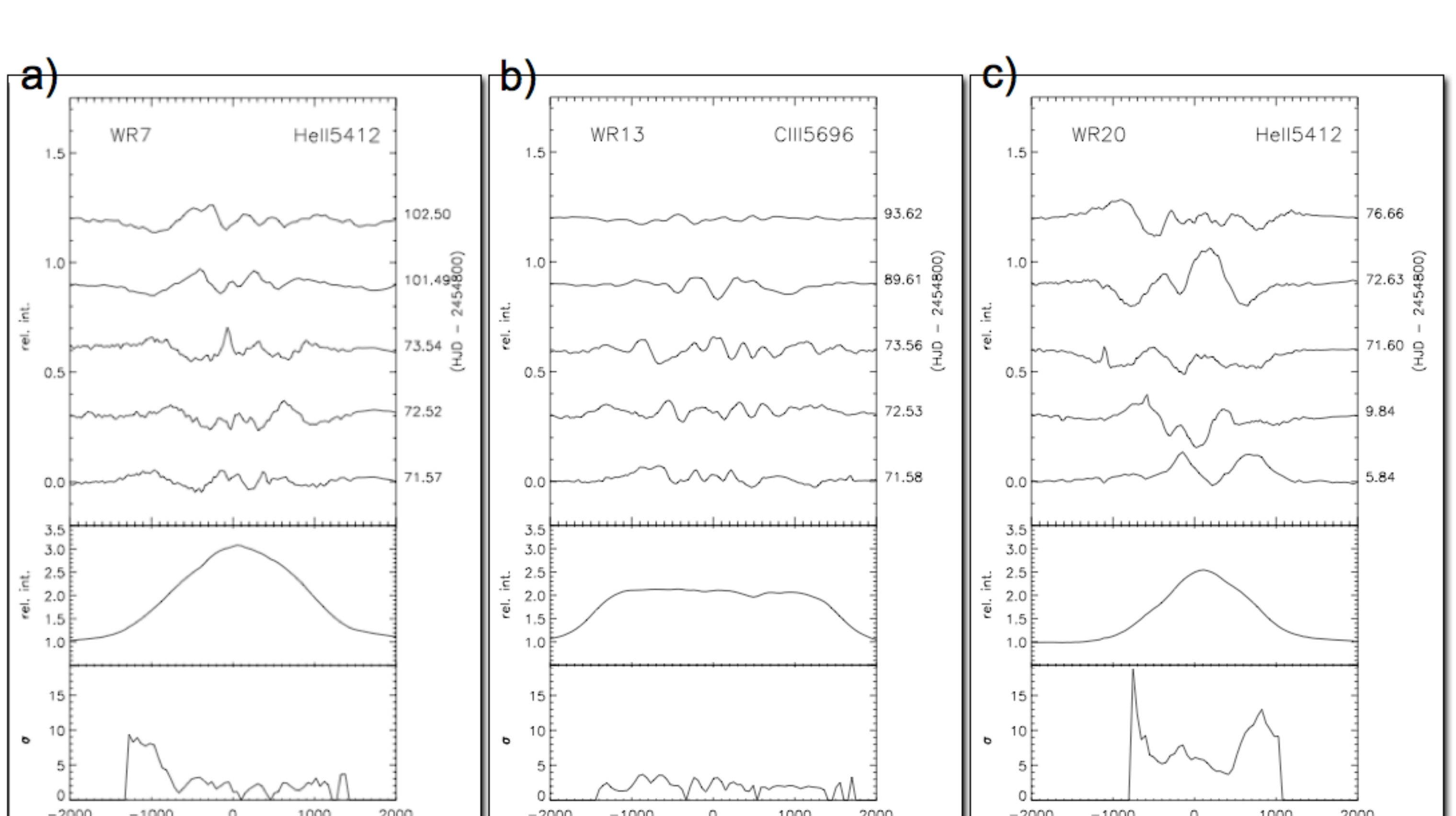

Figure 2: Montage of the residuals obtained from the subtraction of the individual spectra with the mean profile for a) WR 7 (HeII5412 line), b) WR13 (CIII5696 line) and c) WR 20 (HeII5412 line). The middle panel shows the mean profile and the bottom panel shows the relative amplitude of the variability as a function of the wavelength.