FUSE studies of O-type stars in Local Group galaxies

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Abstract

We are analysing high resolution spectra of a large sample of Galactic O-type stars from the far-UV to the optical, and of a small number of representative objects in the nearby galaxies M33 and M31, the faintest such stars accessible to the FUSE satellite. We present a first comparison of FUSE Galactic and LMC star spectra with a similar star in M33.

We also present the first results from detailed modeling of mid O-type Galactic stars. The wind lines in the far-UV range, such as OVI and PV, in addition to the NIV, NV, SiIV, CIII and CIV lines in the UV range, play a crucial role in constraining the stellar parameters, and in assessing the role of X-rays in the wind ionization. We find from the multiwavelength analysis that the effective temperatures are significantly lower than the canonical values currently assumed for their spectral types. These findings have important implications for our understanding of the massive star evolution (comparison with theoretical evolutionary tracks), in particular the derivation of masses and time-scales, as well as for energy balance calculations of H II regions. w(

Data and modeling

We present first results from a comprehensive program aimed to analyze (by consistent modeling) high resolution spectra from the optical regime to the far-UV wavelength range, of hot stars covering a range of spectral types and luminosity classes. This paper explores the properties of O 6 type Galactic stars of different luminosity classes, determined via detailed synthetic modeling, and a comparison with similar objects in Local Group Galaxies.

The FUSE data were taken in the 30″ x 30″ (LWRS) aperture. The data (Galaxy and M33) were reprocessed with pipeline version 2.0.5, which provides major improvements in spectral extraction, background subtraction, and wavelength calibration (Dixon, Kruk & Murphy 2001). Selected segments from the different FUSE channels were combined (details in Bianchi et al. 2002). The LMC data used here are from the FUSE MC atlas (Fullerton et al. 2002, Walborn et al. 2002.)

To derive the stellar parameters, we computed synthetic model spectra with mass loss in the UV and far-UV range using the WM-BASIC code (Pauldrach et al. 2001). The code computes the underlying atmosphere and the synthetic spectrum by solving the wind hydrodynamics with non-LTE line blanketing treatement, and including effects of sphericity and expansion. By modeling the whole 905-2000Å range, we derive $T_{\rm eff}$, log g, $L_{\rm bol}$, V_∞, $\dot{M}$, and information on the ionization. Soft-X rays produced by shocks in the wind affect the ionization of most observed stages (to different extents) and were taken into account in the ionization calculations, as this was proven necessary to reproduce all the observed lines consistently. In particular, O VI $\lambda\lambda$1032, 1037 is entirely produced by X-ray ionization. X-rays also significantly affect the relative strength of N V (and C IV) versus Si IV in the IUE range, and - to a lesser extent - the strength of P V $\lambda\lambda$1118, 1128 which is non saturated thus very sensitive to all wind parameters.

Results and Conclusions

For the Galactic O6 type stars, the temperature ranges constrained by modeling the UV and far-UV spectra, $T_{\rm eff}$= 32000 K – 36000 K, are significantly lower than previous determinations and than canonical values attributed to their spectral type by empirical calibrations over the last decades. For instance, Vacca et al. (1996) derived a $T_{\rm eff}$ calibration of O-type stars compiling determinations based on plane-parallel, non-LTE pure H and He hydrostatic models. Their calibration gives $T_{\rm eff}$= 41,710, 42,640, 43,560 K for O6 I-III-V types respectively. De Jager & Nieuwenhuizen's (1987) calibration gives $T_{\rm eff}$= 38,200 to 39,500 K from supergiants to dwarfs, less discrepant, but still significantly higher than our findings. We are analyzing optical spectra for the program stars, and we find good match to the Balmer lines - when mass loss and line blanketing are included - for parameters consistent with the values derived from our far-UV–UV analysis. More detailed analysis of the other optical lines is in progress. This study is also being extended to a larger number of stars. While it is being recognized that the use of models with full line blanketing treatement, and sphericity, in the optical range yields $T_{\rm eff}$ values lower than found by simplified (pure H and He) treatements, we also find in some cases that the values of $T_{\rm eff}$ and log g derived in previous determinations can still somehow reproduce the lines in the IUE range (by varying the other free parameters), but can not reproduce all the lines observed in the FUSE range with the same parameters combination. This shows how the extension of the analysis to the far-UV is essential to determine the fundamental parameters of hot stars.

The results (lower $T_{\rm eff}$ values than previously found) have enormous implications for our understanding of the ionization and energy balance of HII regions, as well as in the context of evolution of massive stars. The photons emitted below the Lyman limit, which can only be inferred by accurate $T_{\rm eff}$ determinations at longer wavelengths, are driving the ionization of the surrounding medium.

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Galactic O6 types at different luminosities

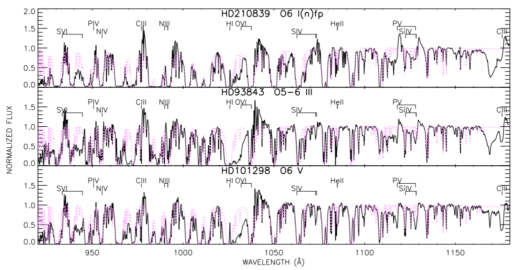

Figure 1a. Sequence of spectra of O6-type stars of different luminosity class in the FUSE range (black). Note the O VI emission common to the three stars, and the dependence of S IV , C III λ 1175 and P V on luminosity. These transitions are also very sensitive to the mass loss rate. To guide the eye to recognize the *bona fide* stellar features, we show models of H_2 plus HI absorptions (pink dotted line), calculated with column densities appropriate for each star's E(B-V). We did not attempt to precisely fit the interstellar lines (which is beyond our purpose, and is pursued by other authors in the FUSE science team) - H_2 plus HI models are shown only to identify which parts of the stellar features are not affected by the interstellar medium absorptions, and therefore were given weight in the stellar model fits.

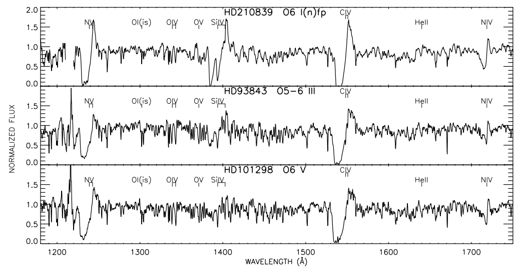

Figure 1b. The sequence of spectra in IUE range. Here the strongest luminosity indicator is the Si IV doublet, which is also extremely sensitive to the mass loss rate, thus helps constraining this parameter. The strong P Cygni profiles of C IV and N V are saturated thus rather insensitive to mass loss rate variations within a wide range; however, because they are fully developed profiles and not affected by interstellar absorptions, they are useful to precisely determine the terminal velocity.

Comparison of O6 types at different metallicities

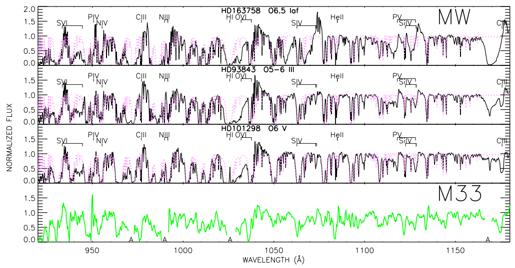

Figure 2a. Comparison of a star in M33 classified O6 III from its optical spectrum (Massey et al. 1996) with Galactic stars in the FUSE range. Galactic stars are shown for different luminosities: the M33 star is similar to the Galactic giants in most of the wind lines, except for P V which differs from all these (and other) Galactic comparisons. For the Galactic stars, the ISM absorption is shown again (pink) since it is significant.

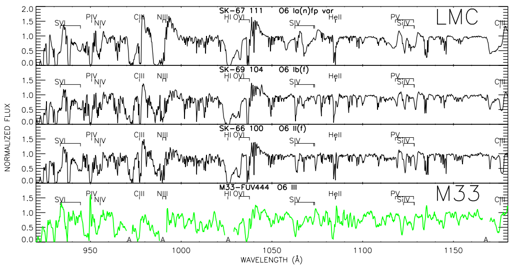

Figure 2b. Comparison of the same M33 O6-type star with LMC counterparts. The M33's metallicity is more similar to the LMC metallicity than to the Galactic one. From this comparison, the M33 features resemble more LMC stars of luminosity class Ib-II than giants.

Examples of synthetic model fitting

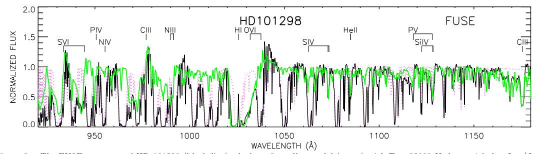

Figure 3a. The FUSE spectrum of HD 101298 (black line), the best fit stellar model (green) with $T_{\rm eff}$=32000 K, log g=4.0, log $L_{\rm bol}/L_{\rm sun}$=4.89, $\dot{M}$=4 x 10^{-6} $M_\odot$ yr^{-1}, V_∞=2900km s^{-1} , $L_x/L_{\rm bol}$ = -7.4 . The interstellar absorptions are repeated (pink dots) as in Figure 1a. Note especially the good match to the O VI wind feature, and to the red component of S VI and S IV (the blue components of both these doublets are masked by interstellar absorption. This temperature is the low end of the acceptable range determined by our modeling. (from Bianchi and Garcia 2002)

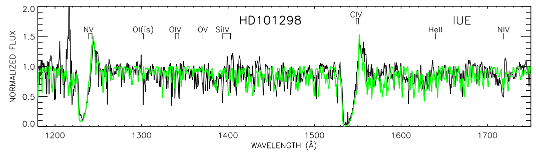

Figure 3b. The same model fit shown in Fig. 3a, in the IUE range (green = model, black = IUE spectrum).

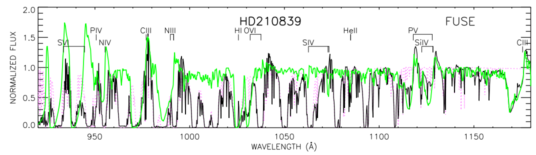

Figure 4a. The FUSE spectrum of HD 210839 (black line), the best fit stellar model (green) with $T_{\rm eff}$=34700 K, log g=3.6, $L_{\rm bol}/L_{\rm sun}$=5.53, $\dot{M}$=1.5 x 10^{-6} $M_\odot$ yr^{-1}, V_∞=2100km s^{-1} , $L_x/L_{\rm bol}$ = -6.5

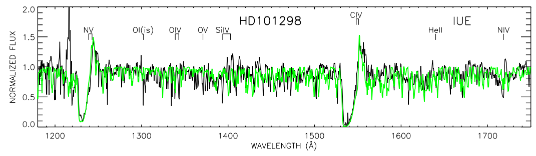

Figure 4b. The same model fit shown in Fig. 4a, in the IUE range (green = model, black = IUE spectrum).