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Semi-empiric Radiative Transfer Modeling of FUSE Stellar Spectra

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Abstract. We present an overview of radiative transfer modeling efforts to interpret spectra of a variety of stellar objects observed with *FUSE*. Detailed radiative transfer modeling of high ion emission line profiles of C III and O VI observed in the far-UV spectrum, provides a powerful means to probe the thermal and dynamic properties of high-temperature plasmas in the atmospheres of stars. We model asymmetric emission lines of C III λ977 (and Mg II h & k) observed in spectra of luminous cool stars such as α Aqr, to infer the wind- and microturbulence velocity structures of the upper chromosphere. Semi-empiric radiative transfer models that include transition region temperature conditions, are further developed based on detailed fits to O VI resonance emission lines in the supergiant α Aqr, the classical Cepheid variable β Dor, and to self-absorbed O VI emission lines in the cataclysmic variable SW UMa.

We observe that the C III resonance line profile of α Aqr assumes a remarkable asymmetric shape, reminiscent of P Cygni type profiles observed in hot luminous supergiants. The model calculations indicate outflow velocities above $\sim$140 km s^{-1} at kinetic temperatures of 65 kK and higher. Based on detailed model fits to the narrow red-shifted and self-absorbed O VI emission lines of SW UMa we compute that the gas- and electron density exceed the density conditions of the upper solar transition region by about three orders of magnitude. We propose that the large gas density of $\rho \simeq 1.4\ 10^{-11}$ g cm^{-3} favors a region of warm dense plasma of 100 kK $\leq T_{\rm gas} \leq$ 300 kK that collapses onto the white dwarf with a mass accretion rate of $1-2\ 10^{15}$ g s^{-1} above or between the accretion disk. We discuss how detailed semi-empiric fits to emission lines observed with the high spectral resolution of *FUSE* can provide reliable constraints on the mass loss or mass accretion rates in these objects.

1. *FUSE* Observations and Detailed Radiative Transfer Modeling

We present a comparative study of transition region (TR) wind dynamics in α Aqr (G2 Ib), SW UMa (CV), β Dor (F-G Ia-Iab) and the Sun, to develop semi-empiric radiative transfer models of the thermal structure of the stellar chromosphere and TR, and to determine the velocity and electron density structures. *FUSE* spectra of the hybrid supergiant α Aqr have been observed for Science Team Program P218 (Dupree et al. 2005). The classical δ-Cepheid variable β Dor was observed in Aug. and Oct. 2003 for GI-D107 (PI A. Lobel), while the dwarf nova SW UMa was observed in Nov. 2001 for GI-B074. The left-hand panel of Fig. 1 shows non-LTE radiative transfer fits to C III λ977 through a

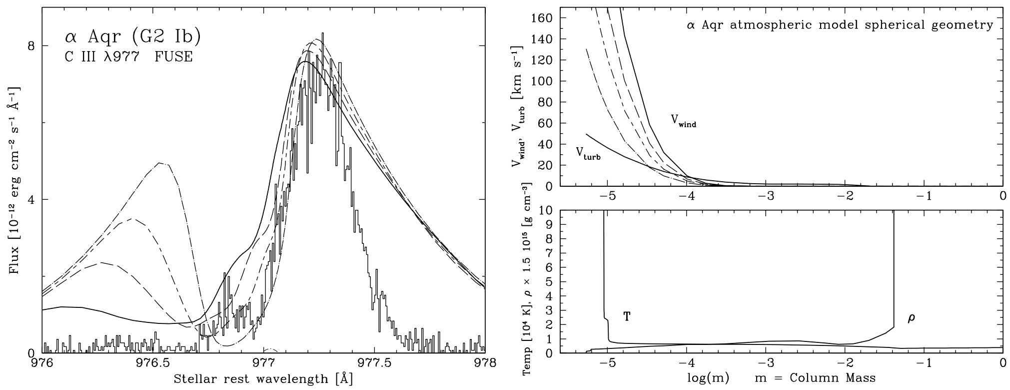

Figure 1. Radiative transfer best fit (*solid line*) to C III $\lambda977$ in α Aqr.

semi-empiric model of the chromosphere and lower TR of α Aqr. The outward decrease of ρ (*panels right*) produces a scattering core in the computed emission profile (Lobel & Dupree 2000; 2001), which assumes an asymmetric shape due to opacity in a fast accelerating wind. Best multi-level atom model fits are obtained for $V_{\rm wind}$>140 km s^{-1} in the lower TR ($T\simeq$65 kK), which strongly scatters the blue emission line wing. The model signals a supersonic optically thick warm wind in the outer atmosphere of this hybrid supergiant (Lobel & Dupree 2002).

The left-hand panels of Fig. 2 show O VI lines in the cataclysmic variable SW UMa. The lines are remarkably far red-shifted with respect to heliocentric rest. We suggest that the double-peaked narrow profiles result from self-absorbed emission line formation in an infalling region near the white dwarf that is sufficiently optically thick at $T_{\rm gas}$ between 100 kK and 300 kK (*panels right*). The depth of the O VI $\lambda1032$ central absorption line core can only be computed with electron densities N_e at least 1100 times larger compared to the solar TR values.

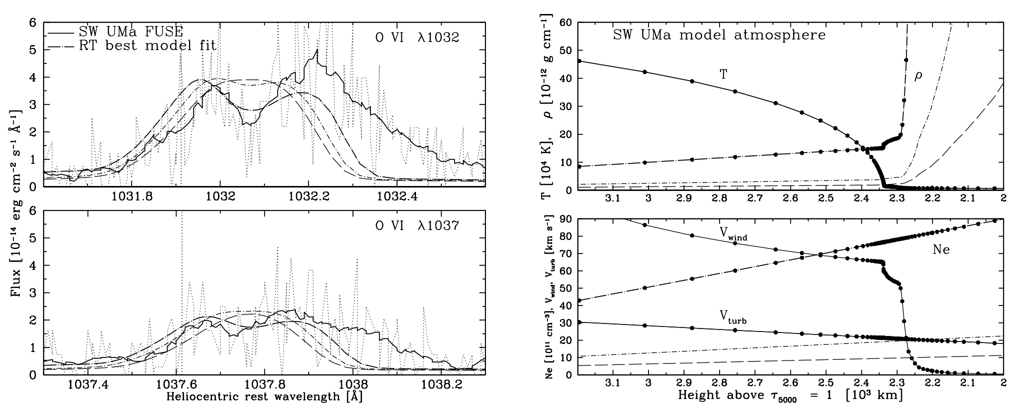

Figure 2. Best fit (*long-dash dotted line*) to O VI $\lambda1032$ & $\lambda1037$ in SW UMa.

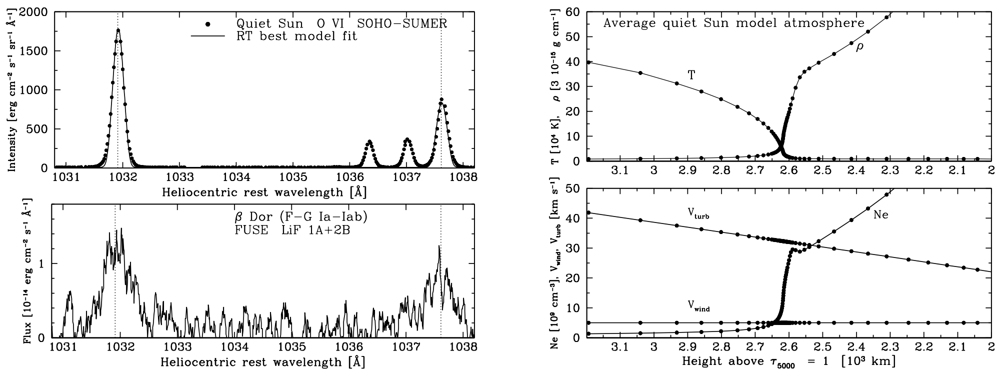

Figure 3. Best fit to solar O VI (*upper left panel*) emission compared to β Dor.

The downflow velocity ($V_{\rm wind}$) in the model is computed from the conservation of total mass in spherical geometry with $\dot{M} = 4\,\pi\,\rho(r)\,V_{\rm wind}(r)\,(r + R_{\rm WD})^2$, using a mass accretion rate $\dot{M}$ of 1 10^{15} g s^{-1}, and $R_{\rm WD}$=0.01 R$_\odot$. This $\dot{M}$-value provides the best fit to the wavelength position of the central self-absorption core where $V_{\rm wind}$=+70 to +65 km s^{-1} in the O VI lines formation region.

The upper left-hand panel of Fig. 3 compares the O VI lines we compute with an atmospheric model of the average quiet Sun with SOHO-SUMER observations (*solid dots*). The lines form over a rather small region of ∼10 model layers with 100 kK $\leq T_{\rm gas} \leq$ 300 kK, or ∼200 km into the solar TR above the upper chromosphere (*panels right*). A best fit to the FWHM and equivalent width of the lines is obtained with projected microturbulence velocities ($V_{\rm turb}$) increasing from at least ∼30 km s^{-1} to ∼39 km s^{-1} over this thermal range (Warren et al. 1997). A best fit to the core position of the O VI λ1032 line is computed with a mean downflow velocity of +5 km s^{-1}. Preliminary atmosphere models for β Dor (*lower left panel*) require $V_{\rm turb}$ exceeding 40 km s^{-1} in the O VI lines formation region to match the large line widths we also observe in α Aqr.

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