CHROMOSPHERIC AND TRANSITION REGIONS FEATURES IN SOLAR LIKE STARS

I. Pagano\textsuperscript{1}, C. De Martino\textsuperscript{2}, A.F. Lanza\textsuperscript{1}, D. Spadaro\textsuperscript{1}, and J.L. Linsky\textsuperscript{3}

\textsuperscript{1}INAF – Catania Astrophysical Observatory, Italy
\textsuperscript{2}Department of Physics and Astronomy – Catania University, Italy
\textsuperscript{3}JILA, University of Colorado, Boulder CO, USA

ABSTRACT

We present here preliminary results from the analysis of the HST/STIS spectrum of the solar type star $\xi$ Boo A (G8 V). The echelle spectrum we analyze was obtained with the E140M grating covering the complete spectral range 1140–1670 Å with a resolution of 6.6 km s$^{-1}$ and an absolute wavelength accuracy of 3 km s$^{-1}$. We show here the $\xi$ Boo A transition region line profiles, the behavior of line shift versus temperature of line formation and discuss our results with respect to those obtained for the Sun.

Key words: solar-stellar connection; transition region.

1. INTRODUCTION

Emission lines originating from the transition region (10$^5$ K) to the corona (10$^7$ K) of magnetically active stars show enhanced emission in the wings (Linsky & Wood, 1994; Wood et al., 1996, 1997). These profiles are usually well fitted by double Gaussians, with a narrow component fitting the line cores and a broad component accounting for the excess in the wings. This bimodal structure of the transition region lines is typically observed for several RS CVn-type stars (i.e., Capella and HR 1099), main sequence type stars (i.e., AU Mic, Procyon, $\alpha$ Cen A & B), and also giants: 31 Com, $\beta$ Cet, $\beta$ Dra, $\beta$ Gem, and AB Dor (Linsky & Wood, 1994; Linsky et al., 1995; Pagano et al., 2000, 2004). Similar line profiles have been observed on the Sun (Kjeldseth Moe & Nicolas, 1997), and have been interpreted as signatures of explosive events (Dere & Mason, 1993). Peter et al. (2001) however suggest that the broad components are due to waves propagating up into the corona. Recently, by analyzing a full disk VUV spectrum of the Sun, Peter (2005) showed that the broad component originates from the magnetic chromospheric network. He also proposed that the broad components of other solar-like stars are a consequence of the mixture of surface structures, and not necessarily a signature of small-scale heating processes like explosive events.

Observations of the Sun (e.g., Teriaca 1999 and references therein) and late-type stars (e.g., Ayres et al. 1983, 1988, Wood et al. 1997, Pagano et al. 2004) have shown that transition region emission lines are, on average, redshifted, and that the redshifts increase with increasing formation temperature up to about 10$^5$ K. This behaviour is not anticipated by models of upward propagating acoustic waves, for which both optically thin and optically thick lines are predicted to be blueshifted. On the other hand, statistically, the observed solar redshifts are strongest over active regions (e.g. Peter 2000), compared with quiet areas (Achour et al. 1995), and some TR models (Reale et al. 1996) predict larger redshifts in regions permeated by strong magnetic fields than in quiet regions. The maximum redshift ($\approx$15 km s$^{-1}$) is reached at about 1–1.2 $\times$ 10$^5$ K (active regions and quiet Sun, respectively). At higher temperatures, the centroid velocities decrease, crossing over to blueshifts at T$\approx$10$^6$ K (reaching about $-$10 km s$^{-1}$). A similar behaviour is seen in $\alpha$ Cen A (Pagano et al. 2004), $\alpha$ Cen B (Wood et al. 1997), El Eri (Jordan et al. 2001), and Procyon (Wood et al. 1996), although the latter shows a maximum redshift at somewhat higher temperatures (Wood et al. 1997). On the other hand, the TR lines of the very active dM1e star AU Mic show hardly any redshifts, and certainly show no conspicuous trend of line shift versus formation temperature (Pagano et al. 2000 and Redfield et al. 2002).

Recently, Spadaro et al. (2006) have successfully reproduced the temperature dependence of the persistent redshifts observed on the Sun, together with the observed emission measure distribution over the entire range logT=4.7–6.1 by using an hydrodynamic model accounting for small (length scale of order 1 Mm), cool magnetic loops undergoing transient heating (timescales of order 20 s every 100 s, and energy deposition within the typical range of nanoflares) spatially localized near the chromospheric footpoints.

Here we show preliminary results from the analysis of the VUV spectrum of the G dwarf star $\xi$ Boo A, discussing the behaviour of the TR line centroids and profiles.
2. THE DATA

We have analyzed the E140M HST/STIS spectrum of ξ Boo A (G8 V, V=4.55) downloaded from the CoolCat archive (Ayres 2004). The spectrum covers the complete 117-173 nm spectral range with a resolving power of 45,800 corresponding to a velocity of 6.6 km s\(^{-1}\). The observations were obtained on 1998 Dec 16 with an exposure time of 2450 s using an aperture of 0.2x0.006. Data were obtained in TIME-TAG mode and were reduced by means of the STIS team IDL-based CALSTIS software. Analysis have been carried out by means of multi-Gaussian fit procedures as in ICUR package (Neff et al 1989) under IDL.

3. THE BROAD LINE WINGS OF TRANSITION REGION LINES

Figure 1. Broad and asymmetric wings of the TR lines in ξ Boo A spectrum. The broad component is red-shifted compared to the narrow one for all the TR emission lines. Note that the chromospheric O I 130.6 nm line does not show broad wings.

We find that TR lines in ξ Boo A spectrum show broad and asymmetric wings. Line profiles (histograms in Figure 1) are well fit by the sum of a narrow and a broad Gaussians (the 133.6 nm C II line profile could be fit by accounting also for the central reversal, being this an optically thick line). The broad component is red-shifted compared to the narrow one for all the TR emission lines (mean velocity shift between the broad and the narrow components, \(\Delta v_{BC-NC} = +6.1 \pm 2.3 \text{ km \ s}^{-1}\)). Note that the O I 130.6 nm line, like all of the chromospheric lines, does not show broad wings. The broad components generally account for half of the line emission.

4. LINE SHIFT VERSUS TEMPERATURE OF LINE FORMATION

In Figure 2 we show the Doppler shifts of chromospheric and transition region lines of ξ Boo A, derived from the measurement of the line centroid, relative to the photospheric radial velocity as a function of temperature of line formation. The dotted and dashed lines are fits to the Doppler shifts for a solar active region and the quiet Sun, respectively, by Teriaca et al. (1999).

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We recall here that, in the same temperature range, α Cen A (G2 V) does not reach the maximum redshift, but shows an increasing trend of redshift vs. temperature of line formation, while AU Mic (dM1e) does not show any trend of line shift with temperature of line formation.
5. FUTURE

Even though qualitatively similar to the solar case, stellar TR lines reveal peculiarities that may depend on the activity level or on the small differences in spectral and luminosity class. ξ Boo A is much more active than the Sun and could well have a different magnetic field configuration. In Figure 3 of Wood et al. (2005) ξ Boo A is below the solar trend line suggesting a different magnetic field configuration, perhaps a more dipolar field than the Sun. This could be important for explaining the slight difference in redshifts behaviour.

After the failure of STIS on HST in Aug 2004, there are no more facilities for UV stellar spectroscopy available to the worldwide astronomical community. Moreover, the stellar data collected up to date, consists of snapshots: we need the information on the variability; for example, it would be interesting to investigate the variations of TR and coronal line profiles during the activity cycles.

From the observational point of view, the future for stellar spectroscopy depends on the implementation of new space missions, the only one we see close to the horizon being the World Space Observatory for Ultraviolet (Pagano et al. 2006, Wamsteker & Shustov 2004, Barstow et al. 2003).

In meantime, developments of the theoretical models proposed for the Sun (Spadaro et al. 2003, 2006, Peter 2004) to account for the stellar case are useful and welcome.

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REFERENCES