Chromospheric activity of ROSAT discovered weak-lined T Tauri stars

D. Montes\textsuperscript{1,2}, L.W. Ramsey\textsuperscript{1}

\textsuperscript{1} The Pennsylvania State University, Department of Astronomy and Astrophysics, 525 Davey Laboratory, University Park, PA 16802, USA
\textsuperscript{2} Departamento de Astrofísica, Facultad de Físicas, Universidad Complutense de Madrid, E-28040 Madrid, Spain

To be published in ASP Conf. Ser., Solar and Stellar Activity: Similarities and Differences (meeting dedicated to Brendan Byrne, Armagh 2-4th September 1998) C.J. Butler and J.G. Doyle, eds

Abstract

We have started a high resolution optical observation program dedicated to the study of chromospheric activity in weak-lined T Tauri stars (WTTS) recently discovered by the ROSAT All-Sky Survey (RASS). It is our purpose to quantify the phenomenology of the chromospheric activity of each star determining stellar surface fluxes in the more important chromospheric activity indicators (Ca II H & K, H$\beta$, H$\alpha$, Ca II IRT) as well as obtain the Li I abundance, a better determination of the stellar parameters, spectral type, and possible binarity. With this information we can study in detail the flux-flux and rotation-activity relations for this kind of objects and compare it with the corresponding relations in the well studied RS CVn systems.

A large number of WTTS have been discovered by the RASS in and around different star formation clouds. Whether these stars are really WTTS, or post-TTS, or even young main sequence stars is a matter of ongoing debate. However, we have centered our study only on objects for which very recent studies, of Li I abundance (greater than Pleiads of the same spectral type) or radio properties, clearly confirmed their pre-main sequence (PMS) nature.

In this contribution we present preliminary results of our January 1998 high resolution echelle spectroscopic observations at the 2.1m telescope of the McDonald Observatory. We have analysed, using the spectral subtraction technique, the H$\alpha$ and Ca II IRT lines of six WTTS (RXJ0312.8-0414NW, SE; RXJ0333.1+1036; RXJ0348.5+0832; RXJ0512.0+1020; RXJ0444.9+2717) located in and around the Taurus-Auriga molecular clouds. A broad and variable double-picked H$\alpha$ emission is observed in RXJ0444.9+2717. Emission above the continuum in H$\alpha$ and Ca II IRT lines is detected in RXJ0333.1+1036 and a filling-in of these lines is present in the rest of the stars. Our spectral type and Li I EW determinations confirm the PMS nature of these objects.
Introduction

Weak-lined T Tauri stars (WTTS) are low mass pre-main sequence stars (PMS) with $\text{H}_\alpha$ equivalent widths $\leq 10$ Å in which no signs of accretion are observed. The emission spectrum of these stars is not affected by the complications of star-disk interaction which often masks the underlying absorption lines as well as extincts the stellar light in classical T Tauri stars (CTTS). The WTTS are thus ideal targets to study the behavior of surface activity in the PMS stage of the stellar evolution.

While there are a large number of studies in UV, X-ray and radio wavelengths, little research has been directed towards the study of the chromospheric activity using optical observations. Those which have been done are based on low resolution spectroscopic observations. Only some recent higher resolution studies centered in bona-fide WTTS in Taurus are available (see Feigelson et al. 1994; Welty 1995; Welty & Ramsey 1995, 1998; Poncet et al. 1998; Montes & Miranda 1999). In order to improve the knowledge of the WTTS chromospheres high resolution optical observations are needed. The WTTS discovered very recently by the ROSAT All-Sky Survey (RASS) are good targets to accomplish these objectives. A large number of them have been found far away from the star formation clouds (Neuhäuser et al. 1995; Alcalá et al. 1995, 1996; Wichmann et al. 1996; Magazzù et al. 1997; Krautter et al. 1997). Whether these stars are really WTTS, or post TTS, or even young main sequence stars is a matter of ongoing debate (Feigelson 1996, Briceño et al. 1997, Favata et al. 1997). However, we will study only those in the Taurus Auriga Molecular Cloud for which very recent studies clearly confirmed their PMS nature.

In this contribution we present preliminary results of our high resolution echelle spectroscopic observations of RX J0312.8-0414NW, SE; RX J0333.1+1036; RX J0348.5+0832; RX J0512.0+1020; and RX J0444.9+2717.
Observations

The spectroscopic observations were obtained during a 10 night run 12-21 January 1998 using the 2.1m telescope at McDonald Observatory and the Sandiford Cassegrain Echelle Spectrograph (McCarthy et al. 1993). This instrument is a prism crossed-dispersed echelle mounted at the Cassegrain focus and it is used with a 1200X400 Reticon CCD. The spectrograph setup was chosen to cover the H\(\alpha\) (6563 Å) and Ca II IRT (8498, 8542, 8662 Å) lines. The wavelength coverage is about 6400-8800 Å and the reciprocal dispersion ranges from 0.06 to 0.08 Å/pixel. The spectral resolution, determined by the FWHM of the arc comparison lines, ranges from 0.13 to 0.20 Å (resolving power R=\(\lambda/\Delta\lambda\) of 50000 to 31000) in the H\(\alpha\) line region. In one of the nights we changed the spectrograph setup to include the He I D\(_3\) (5876 Å) and Na I D\(_1\) and D\(_2\) (5896, 5890 Å) with a wavelength coverage of 5600-7000 Å. The spectra have been extracted using the standard reduction procedures in the IRAF package (bias subtraction, flat-field division, and optimal extraction of the spectra). The wavelength calibration was obtained by taking spectra of a Th-Ar lamp. Finally, the spectra have been normalized by a low-order polynomial fit to the observed continuum. The chromospheric contribution in these features is determined using the spectral subtraction technique (Huenemoerder & Ramsey 1987; Montes et al. 1995; 1997). The synthesized spectrum was constructed using the program STARMOD developed at Penn State (Barden 1985).
Results

We have analysed the H\(\alpha\) and Ca II IRT lines of six WTTS (RX J0312.8-0414NW, SE; RX J0333.1+1036; RX J0348.5+0832; RX J0512.0+1020; RX J0444.9+2717) located in and around the Taurus-Auriga molecular clouds. These targets were selected from two sources:

(1) From the ROSAT detected late-type stars south of the Taurus (Neuhäuser et al. 1995; Magazzù et al. 1997 (hereafter M97)) we selected the stars that the spectroscopic studies of M97 and Neuhäuser et al. (1997, hereafter N97) clearly identified as WTTS from their greater Li abundance than Pleiades of the same spectral type. Some of them have been classified by these authors as single- and double-lined spectroscopic binaries (SB1, and SB2) and others are visual binaries (Sterzik et al. 1997, hereafter S97).

(2) From the list of Wichmann et al. (1996) (hereafter W96) of new WTTS stars in Taurus, we selected the stars in which radio emission was detected by Carkner et al. (1997, hereafter C97) supporting their identification as genuine WTTS rather than ZANS.

Representative spectra of these stars are plotted in Fig. 1 (H\(\alpha\)), Fig. 2 (Li I 6708 Å), and Fig. 3 (Ca II IRT). A K1V reference star is also plotted for comparison. The observed and subtracted spectra for the case of RX J0444.9+2717 are plotted in Fig. 4.
RX J0312.8-0414NW, SE
RX J0312.8-0414 is a visual binary with components NW and SE separated by 14” (M97, S97). The NW component is a G0V with $v_{\sin i} = 33$ km s$^{-1}$ and is a SB2. The SE component is a G8V with $v_{\sin i} = 11$ km s$^{-1}$. Both components exhibit H$\alpha$ absorption with a EW(H$\alpha$) of 3.5 and of of 2.5 Å respectively (M97; N97). Our spectra exhibit a strong Li I 6708 Å line confirming the PMS nature of these objects. However, the level of chromospheric activity is very low, only a small filling-in of H$\alpha$ and Ca II IRT lines is detected, in agreement with the earlier spectral type of both stars.

RX J0333.1+1036
This star is classified as a confirmed PMS star by M97 and N97 on the basis of its Li I abundance, however, C97 detect no radio emission. M97 give a spectral type of K3 and observed the H$\alpha$ line in emission with a EW of -0.8 Å. N97 measured a $v_{\sin i}$ of 20 km s$^{-1}$
Emission above the continuum in H$\alpha$ and Ca II IRT lines is detected in our five spectra from January 14 to January 20 1998 with small variations from night to night.

RX J0348.5+0832
This PMS is a rapidly-rotating star ($v_{\sin i} = 127$ km s$^{-1}$, N97) of spectral type G7 and with a small emission in the H$\alpha$ line (EW = -0.1 Å, M97).
In our five spectra (from 01/12/98 to 01/18/98) we observe the H$\alpha$ line always in absorption, but filled in. The Ca II IRT lines are also filled in by chromospheric emission.

RX J0512.0+1020
M97 give a spectral type K2 for this star and observed a small emission in the H$\alpha$ line (EW = -0.1 Å). N97 measured a rotational velocity of 57 km s$^{-1}$.
In our three spectra (from 01/14/98 to 01/17/98) we observe a variable filling-in of the H$\alpha$ and Ca II IRT lines. The H$\alpha$ line shows emission in the blue wing in one of the spectra.


RX J0444.9+2717

This is a K1 star with Hα emission above the continuum (EW = -2.1 Å) and classified as a PMS star by W96 on the basis of its Li I abundance. The detection of radio emission by C97 confirm its PMS nature. Kohler & Leinert (1998) found a IR companion with a separation of 1.754” and a brignness ratio at K of 0.102. We have eight spectra of this star available (from 01/12/98 to 01/20/98). The observed spectra are well matched using a K1V reference star with a rotational broadening of 65 km s\(^{-1}\). Some of the more intense photospheric lines exhibit a flat-bottomed core (i.e. the core is noticeable filled in with respect to the reference profile) as is observed in other rapidly-rotating and spotted stars. A broad and variable double-picked Hα emission above the continuum is observed (see Fig. 4). The Hα EW in the observed spectra changes from -1.2 Å to -2.6 Å. The Ca II IRT lines exhibit a strong filling-in.
References

Alcalá, J. M., et al. 1995, A&AS, 114, 109
Alcalá, J. M., et al. 1996, A&AS, 119, 7
Briceño, C., Hartmann, L. W., Stauffer, J. R., et al. 1997, AJ, 113, 740
Barden, S. C. 1985, ApJ, 295, 162
Carkner, L., Mamajek, E., Feigelson, E. D., et al. 1997, ApJ, 490, 735
Favata, F., Micela, G., Sciortino, S. 1997, A&A, 326, 647
Feigelson, E. D., et al. 1994, ApJ, 432, 373
Feigelson, E. D. 1996, ApJ, 468, 306
Huenemoerder, D. P., & Ramsey, L. W. 1987, ApJ, 319, 392
Kohler, R. & Leinert, C. 1998, A&A, 331, 977
Krautter, J., 1997, A&AS, 123, 329
Magazzù, A., Martín, E. L., Sterzik, M. F., et al. 1997, A&AS, 124, 449
McCarthy, J. K., Sandiford, B. A., Boyd, D., & Booth, J. 1993, PASP, 105, 881
Montes, D., Fernández-Figueroa, M. J., De Castro, E., & Cornide, M. 1995, A&A, 294, 165
Montes, D., Fernández-Figueroa, M. J., De Castro, E., & Sanz-Forcada J. 1997, A&AS, 125, 263
Montes, D., Miranda, L. F. 1999, A&AS, in preparation
Neuhäuser, R., Sterzik, M. F., Torres, G., & Martín, E. L. 1995, A&A, 299, L13
Neuhäuser, R., Torres, G., Sterzik, M. F., & Randich, S. 1997, A&A, 325, 647
Poncet, A., Montes, D., Fernández-Figueroa, M. J., & Miranda, L. F. 1998, in ASP Conf. Ser. 155, Cool Stars, Stellar Systems, and the Sun, 10th Cambridge Workshop, eds. R. A. Donahue & J. A. Bookbinder (San Francisco: ASP), CD-1772
Sterzik, M. F., Durisen, R. H., Brandner, W., et al. 1997, AJ, 114, 1673
Welty, A. D., 1995, AJ, 110, 776
Welty, A. D., & Ramsey, L. W. 1995, AJ, 110, 336
Welty, A. D., & Ramsey, L. W. 1998, AJ, in press
Wichmann, R., Krautter, J., Schmitt, J. H. M. M., et al. 1996, A&A, 312, 439
Figure 1. Spectra in the region of the Hα line
Figure 2. Spectra in the region of the Li I λ 6708 Å line
Figure 3. Spectra in the region of the Ca II IRT $\lambda$ 8542 Å line
Figure 4. Observed spectra of RX J0444.9+2717 in the Hα line region
Figure 5.  Subtracted spectra of RX J0444.9+2717 in the Hα line region