NEWLY DISCOVERED ACTIVE BINARIES IN THE RASTYC SAMPLE OF STELLAR X-RAY SOURCES

A. Frasca¹, P. Guillout², E. Marilli¹, R. Freire Ferrero², K. Biazzo³

¹INAF - Osservatorio Astrofisico di Catania, via S. Sofia, 78, 95123 Catania, Italy
²Observatoire Astronomique de Strasbourg- ULP, 11 rue de l’Université, 67000 Strasbourg, France
³Dipartimento di Fisica e Astronomia, Università di Catania, via S. Sofia, 78, 95123 Catania, Italy

Abstract

We present preliminary results of follow-up optical observations, both photometric and spectroscopic, of stellar X-ray sources, selected from the cross-correlation of ROSAT All-Sky Survey (RASS) and TYCHO catalogues. Spectra were acquired with the ELODIE spectrograph at the 193-cm telescope of the Haute Provence Observatory (OHP) and with the REOSC echelle spectrograph at the 91-cm telescope of the Catania Astrophysical Observatory (OAC), while UBV photometry was made at OAC with the same telescope. In this work, we report on the discovery of six late-type binaries, for which we have obtained good radial velocity curves and solved for their orbits. Thanks to the OHP and OAC spectra, we have also made a spectral classification of single-lined binaries and we could give first estimates of the spectral types of the double-lined binaries. Filled-in or pure emission H\(\alpha\) profiles, indicative of moderate or high level of chromospheric activity, have been observed. We have also detected, in near all the systems, a photometric modulation ascribable to photospheric surface inhomogeneities which is correlated with the orbital period, suggesting a synchronization between rotational and orbital periods. For some systems has also been detected a variation of H\(\alpha\) line intensity, with a possible phase-dependent behavior.

Key words: Stars: binaries: spectroscopic – Stars: fundamental parameters – Stars: X-ray – Stars: activity

1. Introduction

The cross-correlation between the ROSAT All-Sky Survey (\(\approx 150,000\) sources) and the TYCHO mission (\(\approx 1,000,000\) stars) catalogues has selected about 14,000 stellar X-ray sources (RasTyc sample, Guillout et al. 1999). Although most of these soft X-ray sources are expected to be the youngest stars in the solar neighborhood, neither the contamination by older RS CVn systems nor the fraction of BY Dra binaries are actually known. This information is, however, of fundamental importance for studying the recent local star formation history and, for instance, for putting constrains on the spatial distribution of nearby young stars around the galactic plane. We thus started a spectroscopic observation campaign aimed at a deep characterisation of a representative sub-sample of the RasTyc population. In addition to derive chromospheric activity levels (from H\(\alpha\) emission) and rotational velocities (from Doppler broadening), high resolution spectroscopic observations allow to infer ages (by means of Lithium abundance) and to single out spectroscopic and active binaries. In this work we present some preliminary results of follow-up observations, both photometric and spectroscopic, of some RasTyc stars performed with the 193-cm telescope of OHP and the 91-cm telescope of the Catania Astrophysical Observatory (OAC).

In particular, we analyse six new late-type binaries, for which we have obtained good radial velocity curves and orbital solutions. An accurate spectral classification for the single-lined binaries has been also performed and the projected rotational velocity \(v \sin i\) has been measured for all stars. The chromospheric activity level and the lithium content have been also investigated using as diagnostics the H\(\alpha\) emission and the Li\(\lambda\)6708 line, respectively.

2. Observations and reduction

2.1. Spectroscopy

Spectroscopic observations have been obtained at the Observatoire de Haute Provence (OHP) and at the M.G. Fracastoro station (Mt. Etna, 1750 m a.s.l.) of Catania Astrophysical Observatory (OAC).

At OHP we observed in 2000 and 2001 with the ELODIE echelle spectrograph connected to the 193-cm telescope. The 67 orders recorded by the CCD detector cover the 3906-6818 Å wavelength range with a resolving power of about 42,000 (Barrani et al. 1996). The ELODIE spectra were automatically reduced on-line during the observations and the cross-correlation with a reference mask was produced as well.

The observations carried out at Catania Observatory have been performed in 2001 and 2002 with the REOSC echelle spectrograph at the 91-cm telescope. The spectrograph is fed by the telescope through an optical fiber (UV - NIR, 200 \(\mu\)m core diameter) and is placed in a stable position in the room below the dome level. Spectra were recorded on a CCD camera equipped with a thinned back-illuminated SITe CCD of 1024\(\times\)1024 pixels (size 24\(\times\)24 \(\mu\)m). The échelle crossed configuration yields a resolution...
of about 14 000, as deduced from the FWHM of the lines of the Th-Ar calibration lamp. The observations have been made in the red region. The detector allows us to record about 1 photon/sec.

The OAC data reduction was performed by using the ECHELLE task of IRAF\textsuperscript{1} package following the standard steps: background subtraction, division by a flat field spectrum given by a halogen lamp, wavelength calibration using the emission lines of a Th-Ar lamp, and normalization to the continuum through a polynomial fit.

### 2.2. Photometry

The photometric observations have been carried out in 2001 and 2002 in the standard UBV system also with the 91-cm telescope of OAC and a photon-counting refrigerated photometer equipped with an EMI 9789QA photomultiplier, cooled to $-15^\circ$C. The dark noise of the detector, operated at this temperature, is about 1 photon/sec.

For each field of the RasTyc sources, we have chosen two or three stars with known UBV magnitudes to be used as local standards for the determination of the photometric instrumental “zero points”. Additionally, several standard stars, selected from the list of Landolt\textsuperscript{2} were also observed during the run in order to determine the transformation coefficients to the Johnson standard system.

A typical observation consisted of several integration cycles (from 1 to 3, depending on the star brightness) of 10, 5, 5 seconds, in the $U$, $B$ and $V$ filter, respectively. A 21" diaphragm was used. The data were reduced by means of the photometric data reduction package PHOT designed for photoelectric photometry of Catania Observatory\textsuperscript{4}. Seasonal mean extinction coefficient for Serra La Nave Observatory were adopted for the atmospheric extinction correction.

\textsuperscript{1} IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

\textsuperscript{2} Le радиометром, оборудованным с электрофотометрическим пакетом PHOT рассчитанным для фотометрического навигационногоファーфора Catania Observatory. Сезонные средние коэффициенты затенения для Serra La Nave Observatory были использованы для коррекции атмосферного затенения.

\textsuperscript{3} IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

3. Results

#### 3.1. Radial velocity and photometry

The radial velocity (RV) measurements for the ELODIE data have been performed onto the cross-correlation functions (CCFs) produced on-line during the data acquisition.

Radial velocities for OAC spectra were obtained by cross-correlation of each echelle spectral order of the RasTyc spectra with that of bright radial velocity standard stars. For this purpose the IRAF task FXCOR, that computes RVs by means of the cross-correlation technique, was used.

The wavelength ranges for the cross-correlation were selected to exclude the Hα and Na I D2 lines, which are contaminated by chromospheric emission and have very broad wings. The spectral regions heavily affected by telluric lines (e.g. the O2 lines in the $\lambda$ 6276 – $\lambda$ 6315 region) were also excluded.

The observed RV curves are displayed in Fig.\textsuperscript{4} where, for SB2 systems, we used dots for the RVs of primary (more massive) components and open circles for those secondary (less massive) ones. We initially searched for eccentric orbits and found in any case very low eccentricity values (e.g. $e = 0.010$ for HD 183957, $e = 0.030$ for 221428). Thus, following the precepts of Lucy & Sweeney (1971) we adopted $e = 0$. The circular solutions are also represented in Fig.\textsuperscript{4} with solid and dashed lines for the primary and secondary components, respectively.

The orbital parameters of the systems, orbital period ($P_{\text{orb}}$), barycentric velocity ($\gamma$), RV semi-amplitudes ($k$) and masses ($M \sin^3 i$), are listed in Table\textsuperscript{4} where P and S refer to the primary and secondary components of the SB2 systems, respectively.

With the only exception of HD 183957, for which any modulation is visible neither in OAC data nor in TYCHO V$_T$ magnitudes, all sources show a photometric modulation well correlated with the orbital period, indicating a high degree of synchronization. The low amplitude of the light curve of 215940 and the very low values of $M \sin^3 i$ imply a very low inclination of orbital/rotational axis.

\begin{table}[h]
\centering
\caption{Properties of the systems}
\begin{tabular}{cccccccc}
\hline
RasTyc & Name & $P_{\text{orb}}$ & $\gamma$ & $k$ & $M \sin^3 i$ & $v \sin i$ & Sp. Type & $B - V$ & \text{W}_{\text{LM}} \\
& & (days) & (km s$^{-1}$) & (km s$^{-1}$) & $M_\odot$ & (km s$^{-1}$) & & & (mÅ) \\
\hline
193137 & HD 183957 & 7.954 & $-29.0$ & 57.5/63.1 & 0.758/0.691 & 4.0/4.4 & K0-1V/K1-2V & 0.84 & < 10 \\
215940 & OT Peg & 1.748 & $-27.0$ & 16.6/23.2 & 0.007/0.005 & 9.2/9.4 & K0V/K3-5V & 0.79 & 50 \\
221428 & BD+33 4462 & 10.12 & $-20.9$ & 59.2/60.4 & 0.905/0.887 & 16.1/32.6 & G2 + K & 0.70 & 15: \\
040542 & DF Cam & 12.60 & $-19.5$ & 22.8 & SB1 & 35 & K2III & 1.14 & — \\
072133 & V340 Gem & 36.20 & +37.0 & 42.1 & SB1 & 40 & G8III & 0.83 & 70 \\
102623 & BD+38 2140 & 15.47 & $+47.4$ & 31.3 & SB1 & 11.5 & K1IV & 1.03 & 40 \\
\hline
\end{tabular}
\end{table}
3.2. Spectral Type and $v\sin i$ Determination

For SB1 systems observed with ELODIE we have determined effective temperatures and gravity (i.e. spectral classification) by means of the TGMET code, available at OHP [Katz et al. 1998]. We have also used ROTFIT, a code written by one of us [Frasca et al. 2003] in IDL (Interactive Data Language, RSI), which simultaneously finds the spectral type and the $v\sin i$ of the target by searching, into a library of standard star spectra, for the standard spectrum which gives the best match of the target one, after the rotational broadening. As standard star library, we used a sub-sample of the stars of the TGMET list whose spectra were retrieved from the ELODIE Archive [Prugniel & Soubran 2001]. The ROTFIT code was also applied to the OAC spectra, using standard star spectra acquired with the same instrument. This was especially advantageous for DF Cam, for which we have no ELODIE spectrum.

For SB2 systems we made a preliminary classification on the basis of a visual inspection of ELODIE and OAC spectra. However, we are developing a code for spectral type determination in double-lined binaries which will allow us to improve the spectral classification. We found at least two binaries composed by main sequence stars, while the remaining systems contain an evolved (giant or sub-giant) star.

Measurements of $v\sin i$ were also made using the ELODIE CCFs and the calibration relation between CCF width and $v\sin i$ proposed by Queloz et al. (1998). The lower rotation rate ($v\sin i \approx 4$ km s$^{-1}$) has been detected for both components of HD 183957, which display also the lowest H$\alpha$ activity among the six sources.

3.3. H$\alpha$ Emission and Lithium Content

The H$\alpha$ line is an important indicator of chromospheric activity. Only the very active stars show always H$\alpha$ emission above the continuum, while in less active stars only a filled-in absorption line is observed. The detection of the chromospheric emission contribution filling in the line core is hampered in double-lined systems in which both spectra are simultaneously seen and shifted at different wavelengths, according to the orbital phase. Therefore a
comparison with an “inactive” template built up with two stellar spectra that mimic the two components of the system in absence of activity is needed to emphasize the H$\alpha$ chromospheric emission.

The inactive templates have been built up with rotationally broadened ELODIE archive spectra (HD 10476, K1 V for both components of HD 183957; $\gamma$ Cep, K1 IV for 102623; $\delta$ Boo, G8 III for 072133; HD 17382, K1 V for 215940) or with OAC spectra of $\alpha$ Ari (K2 III), for DF Cam, acquired during the observing campaigns.

The two components of HD 183957 show only a small filling of their H$\alpha$ profiles (Fig. 3), while the other RasTyc stars display H$\alpha$ emission profiles with a variety of shapes, going from a simple symmetric emission profile (102623) to a double-peaked strong emission line (215940). It has been also observed a very broad, complex feature with a filled-in core and an emission blue wing (072133). A H$\alpha$ profile similar to that displayed by the latter star has been sometimes observed in some long-period RS CVn’s, like HK Lac (e.g. Catalano & Frasca 1994). RasTyc 072133 was classified as a semi-regular variable after Hipparcos, but displays all the characteristics of a RS CVn SB1 binary. The ELODIE spectra of 221428 in the H$\alpha$ region show that the secondary (less massive) component displays a H$\alpha$ line always in emission with a stronger intensity around phase 0.7. The OAC spectra of DF Cam always display a pure H$\alpha$ emission line, whose intensity varies with the orbital/rotational phase. Similarly to 072133, DF Cam, considered as a semi-regular variable after Hipparcos photometry, is very likely an active binary of the RS CVn or BY Dra class.

The equivalent width of the lithium $\lambda$6708 line, $EW_{\text{Li}}$, was measured on the ELODIE spectra. For the three sources for which we were able to detect and measure $EW_{\text{Li}}$, we deduced lithium abundance, log $N$(Li), in the range 1.3–1.8, according to Pavlenko & Magazzù (1996) NLTE calculations.

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References
Baranne A., Queloz D., Mayor M., et al., 1996, A&AS 119, 373
Catalano S. and Frasca A. 1994, A&A 287, 575
Frasca A., Alcalà J.M., Covino E., Catalano S., Marilli E. and Paladino R. 2003, A&A 405, 149
Guillout P., Schmitt J. H. M. M., Egret D., Voges W., Motch C. and Sterzik M. F. 1999, A&A 351, 1003
Katz D., Soubiran C., Cairel R., Adda M. and Cautain R. 1998, A&A 338, 151
Landolt, A. U. 1992, AJ, 104, 340
Lo Presti, C., & Marilli, E. 1993, PHOT. Photometrical Data Reduction Package. Internal report of Catania Astrophysical Observatory N. 2/1993
Lucy, L. B. and Sweeney, M. A., 1971, AJ 76, 544
Pavlenko Y.V. & Magazzù A. 1996, A&A 311, 961
Prugniel, P. and Soubiran, C. 2001, A&A 369, 1048
Queloz D., Allain S., Mermilliod J.-C., Bouvier J. and Mayor, M. 1998, A&A 335, 183