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Rotational periods of solar-mass WTTS in Orion

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Abstract. We present the results of a photometric monitoring program on 26 solar-mass weak-line T Tauri stars (WTTs) in the Orion clouds. The stars were discovered as X-ray sources in the ROSAT All-sky Survey (RASS) and pointed observations of the Orion complex and subsequently optically identified thanks to both low and high resolution spectroscopy. Photometric *B* and *V* data were collected from 1999 to 2004 at Catania Astrophysical Observatory (OACt). From the observed rotational modulation, induced by starspots, we derived the rotation periods, using both the Lomb-Scargle periodogram and the CLEAN deconvolution algorithms. The rotation periods range from about 0.5 to 13 days, with a major concentration around 1-2 days, giving further evidences for the spin up of solar-mass stars predicted by models of angular momentum evolution of pre-main sequence (PMS) stars. Though some of these stars have been found to be spectroscopic binaries, only a few of them are synchronized.

Key words. stars: pre-main-sequence – X-ray: stars – stars: activity – photometry – ISM: individual objects: Orion

1. Introduction

The knowledge of the rotation period of low-mass stars at different evolutionary stages is fundamental for studying their angular momentum evolution both from the observational and theoretical point of view. Measurements of low-amplitude periodic light variations, ascribed to the modulation induced by uneven starspot distributions on the stellar photospheres, are a direct way to obtain this physical parameter. Recently, strong efforts have been devoted to the determination of the rotation rate among pre-main sequence (PMS) stars. Indeed, it is very important to search for periods in the age range between the T Tauri stars (TTS) (age $\approx$ 1–5 Myr) and the youngest cluster dwarfs (age $\approx$ 50 Myr). This age gap might be filled by the oldest weak-T Tauri stars (WTTs) and post-TTS, that have lost the largest part of their circumstellar envelopes and are approaching the ZAMS on their radiative tracks. X-ray observations with the ROSAT satellite, mainly based on the ROSAT All-Sky-Survey (RASS), revealed strong X-ray emitters in star-forming regions (SFRs) and in their surroundings. Recent photometric and spectroscopic investigations have confirmed that many of these objects are bona-fide WTTs (Alcalá et al. 2000; Covino et al. 2001; Frasca et al. 2003). In this work we report on the results of a photometric monitoring campaign on 26 op-

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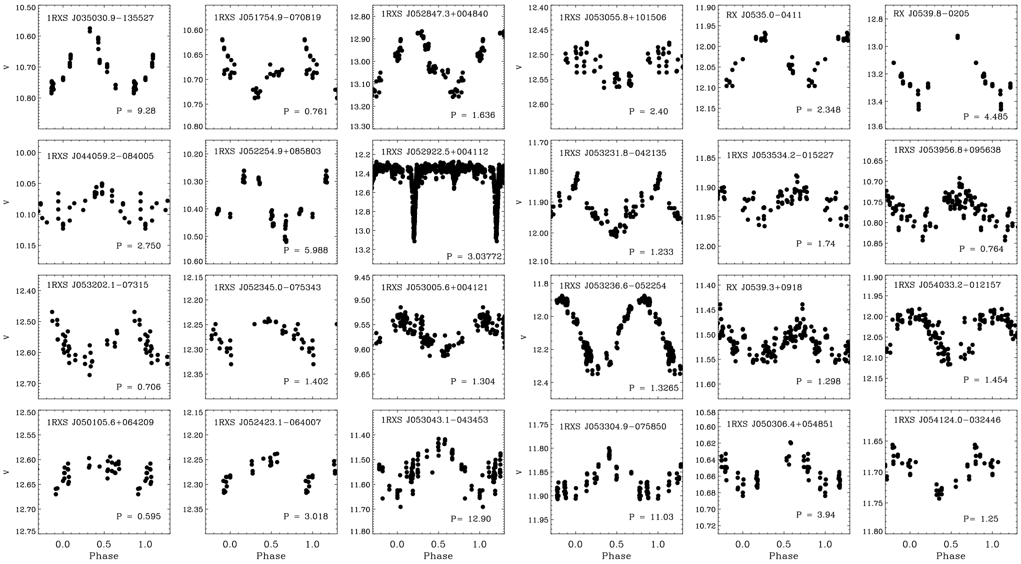

Fig. 1. Collection of V light curves. Source names and rotation periods are indicated.

tical counterparts of X-ray sources in the Orion complex previously identified as WTTs candidates, both singles and in binary systems.

2. Observations and Data Analysis

The photometric observations were performed, in the Johnson B and V bands, at the *M.G. Fracastoro* station (Serra La Nave, Mt. Etna, 1750 m a.s.l.) of the OACt, with the 91-cm Cassegrain telescope, from 1999 to 2004. A single-head photon-counting photometer equipped with an EMI 9893 QA/350 photomultiplier, cooled at −15 °C, was employed. We reduced our data to the standard Johnson system using local zero-point stars and standard stars selected in some Landolt (1992) areas. The photometric errors, estimated from measurements of standard stars with a brightness comparable to the program stars, are typically σ_V =0.01 and σ_{B-V} = 0.02.

We derived the periods of light variations by applying to the V and B magnitudes a periodogram analysis (Scargle 1982) and the CLEAN deconvolution algorithm (Roberts et al. 1986), which allows us to reject aliases generated by the incompleteness of the data sampling and by the finite time-span of the obser-

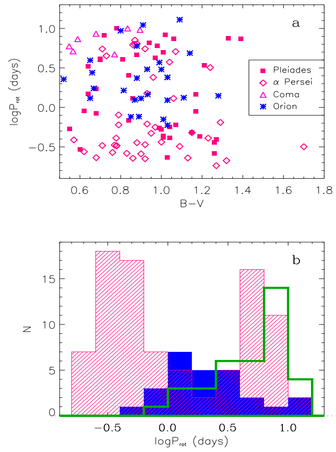

Fig. 2. a) Rotation periods versus B-V color indices for Orion stars (asterisks) and stars belonging to the young open clusters α Persei (50 Myr), Pleiades (100 Myr) and Coma (500 Myr). **b)** log($P_{\rm rot}$) distributions for young cluster stars (hatched area), our sample of Orion WTTs (filled area) and ONC members (empty area) from Herbst et al. (2002).

vations. For each light-curve (LC), the highest peak was selected in the *cleaned* power spec-

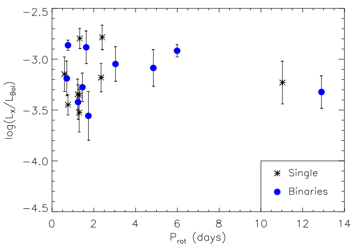

Fig. 3. $\log L_X / \log L_{bol}$ versus P_{rot} plot for sources in our sample.

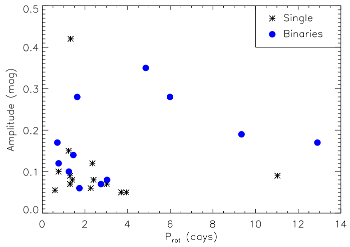

Fig. 4. Plot of V light-curve amplitude versus P_{rot}

trum. False alarm probabilities for the peaks in the periodograms were also computed according to the definitions given by Scargle (1982) and by Horne & Baliunas (1986). With the exception of only three stars, the periods have been detected at a 99.9% confidence level. A LC collection is displayed in Fig. 1, where the source names and the rotation periods are indicated.

3. Results

Eight of our targets are double-line spectroscopic binaries (SB2) whose orbital parameters have been found from high-resolution spectroscopy (Covino et al. 2001). One of them, namely 1 RXSJ052922.5+004112, is also an eclipsing binary (Covino et al. 2000, 2004). The sources 1 RXSJ052847.3+004840, 1 RXSJ054033.2-012157 and 1 RXSJ053534.2-015227 are also given by Alcalá et al. (2000) as SB2 with partially blended lines, but no solution for their orbital parameters is given. Their V light-curves, show well defined rotation periods of $1\overset{\rm d}{.}64$, $1\overset{\rm d}{.}45$ and $1\overset{\rm d}{.}74$, and modulation amplitudes of $0\overset{\rm m}{.}28$, $0\overset{\rm m}{.}14$ and $0\overset{\rm m}{.}06$, respectively, with a quasi-sinusoidal LC behavior. The star 1 RXSJ 053956.8+095638 is reported as a single-lined (SB1) spectroscopic binary (Alcalá et al. 2000), but no radial velocity curve has been derived so far. The very low rotation period ($0\overset{\rm d}{.}76$) could be symptomatic of an evolved low-mass WTTS approaching the ZAMS with a steady increase of the rotation rate during its contraction along the evolutionary track. The remaining objects of the sample can be considered as bona-fide single stars.

The plot of the rotation periods versus $B-V$ color indices (Fig. 2a) does not show any particular trend in the spectral range from F9 to K6. This behavior confirms what already found for young open clusters (e.g. Marilli et al. 1997 and references therein). However, while for the young clusters the period distribution displays a clear separation between fast and slow rotators, such bimodal behavior is not present in our sample, which displays a nearly flat distribution, with a faint peak at $P_{rot}=1\overset{\rm d}{.}8$ (Fig. 2b). We have also compared our distribution with that of the rotation periods of stars in the Orion Nebula Cluster (ONC) measured by Herbst et al. (2002). Selecting stars in the same spectral range of our targets ($M > 0.7 M_{\odot}$), a distribution peaked at $P_{rot}=7\overset{\rm d}{.}1$, with a tail toward periods shorter than 1 day, is found. The period difference between the peak centers of the two distributions could be due to: *i)* an age effect on our sparse population of WTTs, with a possible larger age spread than the ONC members. The latter ones could be, on the average, younger and still rotationally coupled to their circumstellar disk (Bouvier et al. 1997); *ii)* an observational bias in our data toward the detection of shorter periods, due to a limited temporal base-line and to the larger amplitude of light variations associated to faster rotators; *iii)* the choice of our targets as optical counterparts of X-ray sources, that might have selected stars with very high coronal emission, typical of faster rotators.

Single and binary stars display a saturated level of X-ray luminosity ($\log L_X$ in the range

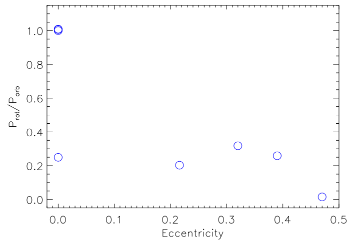

Fig. 5. $P_{\mathrm{rot}}/P_{\mathrm{orb}}$ versus eccentricity for the spectroscopic binaries with solved orbits.

30.8–31.8) with an apparent distribution independent of the rotation period. $\log L_X / \log L_{\mathrm{bol}}$ (Fig. 3) reaches a maximum value of about −2.8, comparable with the value of −2.6 found for the WTTs in the Chamaeleon SFR (Alcalá et al. 1997). Binaries seem to have a period distribution wider than that of the single stars.

Light-curve amplitudes do not show any definite trend as a function of P_{rot} (Fig. 4). The simultaneous presence of large and small amplitudes among fast rotators, could be due both to intrinsic effects, like *magnetic saturation* (Randich 1998), or to projection effects. Relatively large amplitudes for P_{rot} greater than about 4 days are observed only for four binaries.

Three systems with eccentricity $e \simeq 0$ appear to be also tidally synchronized (Fig. 5). Two of these systems have P_{orb} values well below the cut-off period of 7.56 days found by Melo et al. (2001) for orbital circularization in PMS binaries. The third system with a circular orbit, 1RXSJ035030.9-135527, has a $P_{\mathrm{orb}} > 7\overset{\mathrm{d}}{.}56$, but, due to its kinematics and the low lithium content, it could be an evolved active binary of the RS CVn type (Covino et al. 2001). 1RXSJ054124.0-032446 does not fit this picture, since it has a circular orbit, but it results to be non-synchronous, though the rotation period we derived could be an alias of the true one. However, if the asynchronism would be confirmed by further observations, this would give support to the suggestion of Zahn & Bouchet (1989) that the systems around the cut-off period reach the ZAMS with their components rotating faster than the orbital rate. Note that all the non-synchronous systems have a ratio $P_{\mathrm{rot}}/P_{\mathrm{orb}}$ lower than about 0.3.

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