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New triple systems in the RasTyc sample
of stellar X-ray sources[*],[**],[***]

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ABSTRACT

Context. During the study of a large set of late-type stellar X-ray sources, we discovered a high fraction of multiple systems.
Aims. In this paper we investigate the orbital elements and kinematic properties of three new spectroscopic triple systems, along with the spectral types and astrophysical parameters ($T_{\rm eff}$, $\log g$, $v \sin i$, $\log N({\rm Li})$) of their components.
Methods. We conducted follow-up optical observations of these systems, both photometric and spectroscopic ones at high resolution. We used a synthetic approach and the cross-correlation method to derive most of the stellar parameters.
Results. We estimated reliable radial velocities and deduced the orbital elements of the inner binaries. The comparison of the observed spectra with synthetic composite ones, obtained as the weighted sum of three spectra of non-active reference stars, allowed us to determine the stellar parameters for each component of these systems. We found all are only composed of main sequence stars.
Conclusions. These three systems are certainly stable hierarchical triples composed of short-period inner binaries plus a tertiary component in a long-period orbit. From their kinematics and/or lithium content, these systems turn out to be fairly young.

Key words. stars: binaries: close – stars: binaries: spectroscopic – X-rays: stars – stars: late-type – stars: fundamental parameters – techniques: radial velocities

1. Introduction

Binary and multiple stars are very important astrophysical laboratories. In particular, spectro-photometric and spectro-astrometric binaries offer the unique opportunity of determining the basic stellar parameters (mass, radius, and effective temperature) with a high level of accuracy to study stellar structure and evolution. However, the formation and evolution of binary stars are still debated subjects (e.g. Zinnecker & Mathieu 2001). In particular, a still unsolved problem is the formation of close binaries with main sequence components separated by few solar radii that should have been in contact in the proto-stellar phase.

In past years, relevant observational and theoretical efforts are being made to answer many of these open questions and to continuously improve the statistics of binary systems with different periods, mass ratios, etc. (e.g. Tokovinin et al. 2006).

Close binaries containing at least one late-type component, such as RS CVn or BY Dra systems, are objects with the strongest magnetic activity (starspots, plages, flares) induced by a dynamo action in the sub-photospheric convection zone. Their strong activity is mainly due to their very fast rotation (spin-orbit synchronization by tidal forces) and to proximity effects.

The X-ray sky surveys performed in recent years have allowed identification of thousands of active late-type stars in the field and in open clusters. Follow-up observations of the optical counterparts of X-ray sources have led to discovery of very young stars far from the typical birth sites, i.e. open clusters and star-forming regions (e.g. Wichmann et al. 2003a; Zickgraf et al. 2005; Torres et al. 2006; Guillout et al. 2008), as well as to detection of several spectroscopic binaries (e.g. Wichmann et al. 2003b; Frasca et al. 2006). The knowledge of the incidence of binaries and multiple systems in X-ray selected samples of active stars is extremely important to study the recent local star formation history.

One of the largest (∼14 000 active stars) and most comprehensive sets of stellar X-ray sources in the field is the so-called *RasTyc* sample, which is the result of the cross-correlation of the ROSAT All-Sky Survey (RASS) with the TYCHO catalog (Guillout et al. 1999). We began to analyze a representative sub-sample of the *RasTyc* population in the northern hemisphere (Guillout et al. 2008) to obtain some reliable statistics about the *RasTyc* stellar characteristics. For this purpose, we led campaigns of high-resolution spectroscopic observations, with the Elodie échelle spectrograph at the 193 cm telescope and the Aurelie spectrograph at the 152 cm telescope of the *Observatoire de Haute Provence* (OHP). For all the sources, we performed a detailed analysis of the cross-correlation function (CCF) and found that single-lined (SB1), double-lined (SB2), and triple-lined (SB3) spectroscopic systems altogether

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Table 1. Main data of the three *RasTyc* sources from the literature.

RasTyc Name	Name	α (2000) (h m s)	δ (2000) (° ′ ″)	V_T^a (mag)	π^b (mas)	μ_α^a (mas yr^{-1})	μ_δ^a	X-ray source 1RXS	Counts (ct s^{-1})
RasTyc 0524+6739	BD+67 381	05 24 53.2	+67 39 39	9.065	7.8 ± 9.3	−0.5	26.7	J052454.0+673939	4.21×10^{-1}
RasTyc 1828+3506	BD+35 3261	18 28 50.3	+35 06 34	9.049	12.2 ± 8.2	12.3	−3.5	J182849.7+350637	6.24×10^{-2}
RasTyc 2034+8253	BD+82 622	20 34 27.5	+82 53 35	9.730	–	61.5	35.5	J203426.2+825334	3.75×10^{-1}

[a] *V* magnitude and proper motions from the TYCHO-2 catalog (Høg et al. 2000). [b] Parallax from the TYCHO-1 catalog (ESA 1997).

account for more than 35% of the sample. In particular, at least 10 sources are clearly identified as triple systems. Our aim is to determine the orbital and physical parameters of these systems. For this reason, we have monitored these new multiple systems, both photometrically and spectroscopically, with the 91 cm telescope of the *Osservatorio Astrofisico di Catania* (OAC).

The majority of the triple systems studied so far are nearby objects and look as visual binaries where one component is a SB2 system. Here we study three of these newly discovered SB3 late-type systems for which we have obtained enough data. A detailed analysis of the entire sample of stellar X-ray sources and of the multiple systems discovered so far is necessary for drawing statistically significant conclusions. Nevertheless, the properties of these three systems can give us some insight into the typical composition of triple systems among stellar X-ray sources.

The paper is organized as follows. We summarize briefly the observations and their reduction in Sect. 2. The determination of radial velocity and physical parameters ($v \sin i$'s, lithium abundances, etc.) are shown in Sect. 2 as well. The photometric modulation, the spectral composition, and the age estimate are discussed in Sect. 3. The conclusions are outlined in Sect. 4.

2. Observations and spectral analysis

These three systems belong to the *RasTyc* sample of stellar X-ray sources (Guillout et al. 1999). Their spectra, acquired on different dates, show alternatively a triple-line or a single-line pattern (Fig. 1)[1], which is the unambiguous signature of SB3 systems. Table 1 lists the most relevant information from the literature. In the following, we briefly outline the observations and analysis methods and refer to Guillout et al. (2008) for a detailed description.

2.1. Observations and data reduction

Spectroscopic observations were first conducted at the OHP between 2001 and 2005 with the AURELIE spectrograph (Gillet et al. 1994) within the framework of a key program on the Coudé 152 cm telescope. We used grating #7, which yields a high spectral resolution, $R = \lambda/\Delta\lambda$, of about 38 000 in the wavelength range of our observations, i.e. both in the Hα (6490–6630 Å) and the lithium (6650–6780 Å) spectral regions. We obtained 16, 15, and 18 spectra for RasTyc 0524+6739, RasTyc 1828+3506 and RasTyc 2034+8253, respectively. The signal-to-noise ratio (S/N) was in the range 70–200. All these spectra were reduced using standard MIDAS procedures.

The observations at the OAC were carried out from 2004 to 2006 with the FRESCO échelle spectrograph mounted on the 91 cm telescope. The spectral resolution, as deduced from the FWHM of the lines of the Th-Ar calibration lamp, is $R \simeq 21\,000$.

The 300-line/mm cross-disperser allowed about 2500 Å to be recorded at a time. The 19 échelle orders recorded by the CCD cover the 4310–6840 Å spectral region. We obtained 13, 6, and 12 spectra for RasTyc 0524+6739, RasTyc 1828+3506, and RasTyc 2034+8253, respectively, with an *S/N* ranging from 30 to 100, depending on the star magnitude and sky conditions. In all cases, given the wide spectral range, the *S/N* was always adequate for performing good radial velocity (RV) measurements. The reduction of all these spectra was performed using the ÉCHELLE task of IRAF[2] package.

Photometric observations were carried out from 2004 to 2006 in the standard *UBV* system with the 91 cm telescope of OAC. For each field of the three *RasTyc* sources studied here, we chose two or three stars with known *UBV* magnitudes to be used as local standards for determining the photometric instrumental "zero points". Additionally, several standard stars, selected from the list of Landolt (1992), were also observed during the run to determine the transformation coefficients to the Johnson standard system. The data were reduced by means of the photometric data reduction package PHOT designed for the photoelectric photometry of OAC (Lo Presti & Marilli 1993). The errors are typically $\sigma_V = 0.006$, $\sigma_{B-V} = 0.008$, and $\sigma_{U-B} = 0.010$.

2.2. Radial and projected rotational velocities determination

From the analysis of the CCF (Figs. 2–4)[1], we could accurately measure the RV and the projected rotational velocity ($v \sin i$) of each one of the stellar components. The RV measurements of these new systems are listed in Tables 2–4[1], together with their standard errors.

2.3. Spectral types and stellar parameters

With the aim of guessing the spectral types of these objects, we applied the ROTFIT code (Frasca et al. 2003, 2006) to spectra for which only one peak is visible in the CCF. For the evaluation of the spectral type of each individual component, we analyzed those spectra for which the CCF shows three distinct peaks. We used another IDL code, similar to ROTFIT, to estimate the spectral type, the astrophysical parameters (APs), and the continuum flux contribution of the tertiary component. The subtraction of the spectrum fitted to this component provided us with a "cleaned" spectrum of the inner binary that we could analyze with COMP O2 (Frasca et al. 2006) in the usual way. In Sect. 3.3, we discuss the results of this procedure concerning the spectral type and the contribution to the continuum flux (weight), as well as the values (the weighted mean of the best

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[1] Available in electronic form only.

[2] 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.

Table 5. Orbital parameters of the three systems.

Name	HJD0 (2 450 000+)	$P_{\rm orb}$ (days)	e	ω (°)	γ (km s^{-1})	k (km s^{-1}) [P/S]	$M \sin^3 i$ ($M_\odot$) [P/S]	$M_{\rm P}/M_{\rm S}$
RasTyc 0524+6739	2212.02(5)^a	3.65884(2)	0.042(3)	294(5)	−13.4(2)	82.2(3)/84.5(3)	0.889(6)/0.865(6)	1.028(4)
RasTyc 1828+3506	3565.95(4)^b	7.595(5)	0	–	−21.5(4)	72.4(5)/73.7(5)	1.24(2)/1.22(2)	1.018(9)
RasTyc 2034+8253	2471.3(3)^b	4.9543(2)	0	–	−11.2(3)	38.8(3)/39.5(3)	0.124(2)/0.122(2)	1.02(1)

The errors on the last significant digit are enclosed in parenthesis. P = Primary and S = Secondary; ^{a} Heliocentric Julian Date (HJD) of the periastron passage; ^{b} HJD of the inferior conjunction of the primary (more massive) component.
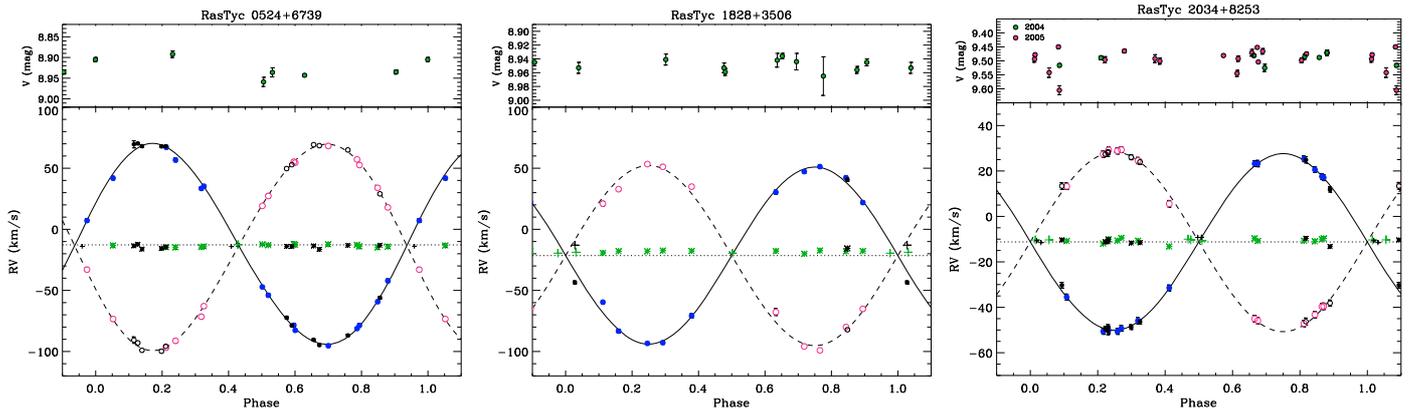

Fig. 5. Radial velocity curves of the new three *RasTyc* triple systems. Large symbols refers to AURELIE data while smaller symbols are used for FRESCO spectrograph data. Filled and open circles for the primary (more massive) and secondary component of the inner binaries have been used, respectively. In each panel, the solid and dashed lines represent the orbital solutions for the primary and secondary components, respectively, whereas the dotted line represents the barycenter of the inner binary. The asterisks are used for the tertiary component and plus symbols refer to blended RV values. The RV errors are always smaller than, or comparable to, the symbol size. The *V* photometry is displayed as a function of the orbital phase in the *top panel* of each box.

100 combinations) of the APs, namely the effective temperature ($T_{\rm eff}$), gravity ($\log g$), and metallicity ([Fe/H]), for the three components of each triple system.

Moreover, we applied the "spectral subtraction" technique (e.g. Frasca & Catalano 1994; Montes et al. 1995) to measure the Li I equivalent width, EW(Li), of each stellar component (Fig. 7, bottom of each box) and used the Pavlenko & Magazzù (1996) calculations to deduce a lithium abundance, $\log N$(Li). From these parameters, we estimated the age of these three systems in Sect. 3.4.

3. Results and discussion

3.1. Orbital solutions

We initially searched for eccentric orbits and found low eccentricity values ($e = 0.042 \pm 0.003$, $e = 0.026 \pm 0.007$, and $e = 0.020 \pm 0.012$ for RasTyc 0524+6739, RasTyc 1828+3506, and RasTyc 2034+8253, respectively). Following the precepts of Lucy & Sweeney (1971, Eq. (22)), we considered as significant only the eccentricity of RasTyc 0524+6739 and adopted $e = 0$ (circular orbits) for the other two systems. The CURVEFIT routine (Bevington 1969) was used to fit the observed RV curves and to determine the orbital parameters and their standard errors for each inner binary (Table 5). The observed RV curves of the three triple systems are displayed in Fig. 5.

For the two RasTyc systems with the shortest orbital periods, the RV value of the tertiary component is very close to the barycentric velocity (γ) of the inner binary during different observing seasons. Thus, we could not try any evaluation of the

orbital period of the tertiary component. Like the vast majority of the already known triple systems, each of our sources consists of a short-period inner binary with a third component orbiting around the close pair in a long-period orbit. These systems display a typical "hierarchical" configuration (Evans 1968). In particular, RasTyc 2034+8253 was already known as a visual binary (Muller 1976). From the observations of Muller (1976, 1978, 1990) and Fabricius et al. (2002), this component seems to have a regular evolution because the position angle and the separation are constantly growing. Thus, its orbital period must be significantly greater than the period of observations (about 20 years) implying a degree of hierarchy $X \gg 1500$, where X is defined as the ratio of the "external" period (orbit of tertiary component around the center of mass to the inner binary) to the "internal" period (that of the inner binary).

On the contrary, in 2005, the tertiary component of RasTyc 1828+3506 displays an RV systematically higher (3.3 km s^{-1}) than that of the barycenter of the inner binary (see Fig. 5, middle panel). Moreover, we found a highly significant RV increase (more than 15 km s^{-1}) for the tertiary component during the four seasons of observations (Fig. 6). This relevant RV variation prevented us from using all the RV values to obtain the orbital solution of the inner binary. Thus, we deduced the orbital parameters from the solution of OHP and OAC data acquired only in 2005. The four RVs obtained at OAC in 2006 allowed us to estimate the barycentric velocity $\gamma = -29.5 \pm 1.5$ km s^{-1} at that epoch, by adopting the values of semi-major axes, $k_{\rm P} = 72.4$ km s^{-1} and $k_{\rm S} = 73.7$ km s^{-1}, found from the solution of 2005 data. We could not evaluate the orbital period of the tertiary, but, from the data trend, we can argue that
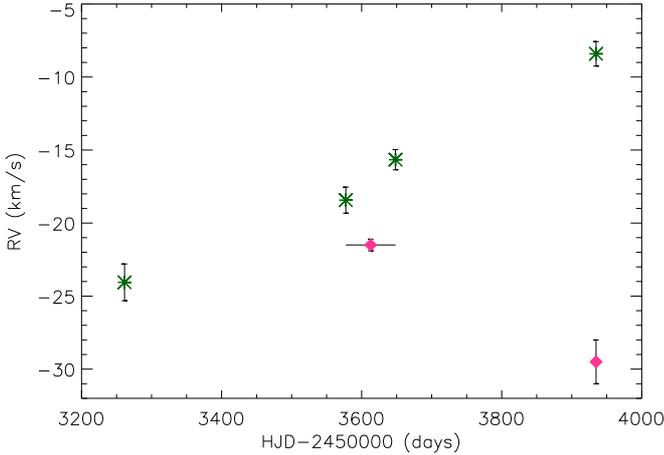
Fig. 6. RV variation for the tertiary component of RasTyc 1828+3506 (asterisks) during the four seasons of observations that span 2004 to 2006. The barycenter RV of the inner binary in 2005 and 2006 is also displayed by two diamonds.

the period must be longer than 6 years (but presumably shorter than some tens of years) implying $X \geq 300$. New observations will enable us to obtain the solution for the tertiary orbit.

Using the empirical stability criterion described by Orlov & Petrova (2000), we can conclude that these three newly discovered triple systems are in a gravitationally stable orbital configuration.

3.2. Photometric variability

The photometric monitoring of our sources in UBV bands allowed us to determine the mean magnitudes and color indices, as well as to detect any eventual variability. The average values of V, $B-V$, and $U-B$ are reported in Table 6.

As the system with the shortest orbital period, RasTyc 0524+6739 is the only one showing a clear variation that is likely to be correlated with the orbital period. Unfortunately, because of poor weather conditions during the winter observing season, the photometric data were obtained only on six nights and are not sufficient to cover evenly the light curve. However, we estimated the amplitude of the V light curve to about $0\overset{m}{.}07$. Illegal variable name.

For RasTyc 1828+3506 and RasTyc 2034+8253, there is no indication of rotational modulation in the V magnitude, in spite of all the data. However, some indication of a stochastic variation comes out for RasTyc 2034+8253, whose magnitude varies in the range $9\overset{m}{.}45$–$9\overset{m}{.}60$ with errors lower than $0\overset{m}{.}02$. No clear periodicity was found in these data.

The detection of a V modulation only on the system with the shortest orbital period ($P_{\text{orb}} \simeq 3.6$ days) is in line with the well-established enhancement of magnetic activity in the components of close binaries due both to fast rotation and nearness. Moreover, tidal interaction in these binaries leads to synchronization between orbital and rotational periods of both components. It is worth noticing that the periods of all these three systems are shorter than, or very close to, the cut-off value of 7.56 days found by Melo et al. (2001) for orbital circularization in pre-main sequence (PMS) binaries. According to Zahn & Bouchet (1989), the cut-off period may be as long as 7.2 to 8.5 days for close late-type binaries with masses ranging from 0.5 to 1.25 $M_{\odot}$ depending on the masses and on the assumptions of the initial conditions. Since all these systems

Table 6. Photometric data and distance for the three systems.

Name	V (mag)	$B-V$ (mag)	$U-B$ (mag)	Dist. (pc)
RasTyc 0524+6739	8.892(7)[a]	0.773(7)	0.235(9)	75 ± 20
RasTyc 1828+3506	8.951(8)	0.578(6)	0.015(8)	115 ± 25
RasTyc 2034+8253	9.49(2)	0.96(1)	0.70(3)	80 ± 20

The error on the last significant digit is enclosed in parenthesis; [a] V magnitude at maximum brightness.

are older than PMS stars, they should already be circularized, in substantial agreement with the results from the solution of their RV curves. Not detecting photometric variation in RasTyc 1828+3506 could be related both to the fairly long orbital/rotational period (7.595 days) and to the relatively early spectral types of the system components with shallower convective envelopes and, consequently, with a reduced dynamo action compared to cooler stars with the same rotation rate.

3.3. Astrophysical parameters and other properties

The use of ROTFIT and COMPO2 codes allowed us to derive the spectral type and the APs for the components of each system (Table 7). We used spectra of stars with the same spectral types retrieved from the ELODIE Archive (Prugniel & Soubiran 2001) to build up the reference spectra displayed in Fig. 7. Moreover, the relative continuum contributions of the tertiary components agree with their spectral types as found by us, taking into account the errors derived from the distribution of the best spectral combinations. This uncertainty is about 1.5 spectral subclasses, except for the tertiary component of RasTyc 0524+6739, the coolest star, for which the uncertainty is more than 2 spectral subclasses. Regarding $\log g$ and [Fe/H], despite the rather large errors, we can state that the three systems are composed of main sequence (MS) stars with a nearly solar metallicity.

We found that the weight for the components of all inner binaries is nearly equal (Table 7), i.e. their luminosity ratio is $\simeq 1$. This is compatible with the mass ratio (M_P/M_S) $\simeq 1$ (Table 5) derived from the solution of the RV curves, if the two *twin* stars are both on the MS. Our results, although not statistically significant, favor an excess of twins in spectroscopic binaries containing a third body as suggested by Tokovinin et al. (2006). Moreover, the CCF dips of RasTyc 1828+3505 and RasTyc 2034+8253 would suggest a tertiary component brighter than each star in the inner binary. However, the weights quoted in Table 7 for RasTyc 1828+3505 conflict with the depth of the CCF dips. The inconsistency is removed if we take into account the earlier spectral type and the faster rotation of the components of the inner binary of this system compared to the tertiary star.

We used the nomenclature proposed by Lafrenière et al. (2008) assigning the letter A to the brightest (more massive for MS stars) component and enclosing in parentheses the components forming the inner binary. We found one system (RasTyc 2034+8253) and two systems (RasTyc 0524+6739 and RasTyc 1828+3506) in the A, (B, C) and (A, B), C configurations, respectively. Although our sources appear to be older than PMS stage (Sect. 3.4), these configurations are similar to those typically encountered in PMS stars (Lafrenière et al. 2008; Correia et al. 2006). Moreover, Mayor & Mazeh (1987) and Tokovinin et al. (2006) find that the most massive component in the multiple stellar systems is primarily in the close binaries. In particular, Tokovinin et al. (2006) find a small fraction of

Table 7. Physical parameters for each component of the three systems.

Component	Primary (P)	Secondary (S)	Tertiary (T)
RasTyc 0524+6739 :			
T_{eff} (K)	5350 ± 280	5270 ± 270	4700 ± 450
$\log g$	4.2 ± 0.3	4.2 ± 0.4	4.2 ± 0.4
[Fe/H]	−0.21 ± 0.18	−0.24 ± 0.21	−0.12 ± 0.11
$v \sin i$ (km s^{-1})	12 ± 2	12 ± 3	<5
Weight	0.45 ± 0.05	0.43 ± 0.05	0.12 ± 0.02
Sp. Type	G9V	G9V	K5V
RasTyc 1828+3506 :			
T_{eff} (K)	5800 ± 400	5800 ± 350	5480 ± 300
$\log g$	4.2 ± 0.2	4.2 ± 0.2	4.3 ± 0.2
[Fe/H]	−0.27 ± 0.17	−0.24 ± 0.18	−0.21 ± 0.12
$v \sin i$ (km s^{-1})	12 ± 1	11 ± 2	<5
Weight	0.38 ± 0.08	0.33 ± 0.08	0.29 ± 0.03
Sp. Type	G1V	G1V	G4V
EW(Li) (mÅ)	–	–	49 ± 15
$\log N$(Li)	–	–	1.8–2.0
RasTyc 2034+8253 :			
T_{eff} (K)	4960 ± 260	4920 ± 300	5090 ± 200
$\log g$	4.3 ± 0.2	4.4 ± 0.2	4.4 ± 0.2
[Fe/H]	−0.23 ± 0.24	−0.23 ± 0.23	−0.05 ± 0.17
$v \sin i$ (km s^{-1})	<5	<5	<5
Weight	0.31 ± 0.04	0.30 ± 0.04	0.39 ± 0.04
Sp. Type	K3V	K3V	K1V
EW(Li) (mÅ)	72 ± 20	76 ± 10	96 ± 14
$\log N$(Li)	1.9–2.0	1.9–2.0	1.9–2.0

Fig. 7. The spectral region containing the Li I $\lambda6707.8$ and the Ca I $\lambda6717.7$ lines in a high-resolution spectrum of the three triple systems (dots). The reference spectrum built up with the weighted sum of three standard-star spectra (Table 7) is shown superimposed by a thin line. The lithium and calcium lines for the three components of this system are also marked by vertical lines. We note the absence of three Li I absorption lines in each reference spectrum. Each box also displays at the bottom the difference (observed – synthetic) with a thin line.

systems (17 ± 4%) where the spectroscopic primary is not the most massive star.

Our results seem to be consistent with those of these authors and need to be confirmed with a larger statistical sample of multiple systems. The analysis of all the triple systems found by us in the *RasTyc* sample, for which we are still collecting RV data, will help us to confirm these findings.

3.4. Age estimation and kinematics

For stars later than about mid-G spectral type, it is well-established that the strength of the Li I $\lambda6707.8$ line can be used as an age estimator, since a high $\log N$(Li) indicates youth. Although the lithium abundance cannot be simply converted into age, we can give a rough evaluation of the age by comparing the $\log N$(Li) value of our systems (Table 7) to that of Pleiades and Hyades stars having the same temperature (see e.g. Soderblom et al. 1993; Jeffries 2000). We report the estimated age in Table 8.

The parallaxes (π) from the TYCHO-1 catalog (ESA 1997) are not accurate enough. Thus, we estimated photometric distances (Table 6) from the "integrated" V magnitude measured by us and the mean V absolute magnitude for each triple system. The precision of proper motions for these systems is 1.5 mas yr^{-1} in TYCHO-2 catalog (Høg et al. 2000). From these two parameters and barycentric RVs of the inner binary, we computed the space-velocity components (U, V, W) of these SB3s in the left-handed coordinate system. Their space velocities are consistent with those of the young-disk (YD) population (Fig. 8)[1]. Based on two kinematics methods (Klutsch et al. 2008), we determined the membership probability (Table 8) to five young stellar kinematic groups (SKGs; Montes et al. 2001).
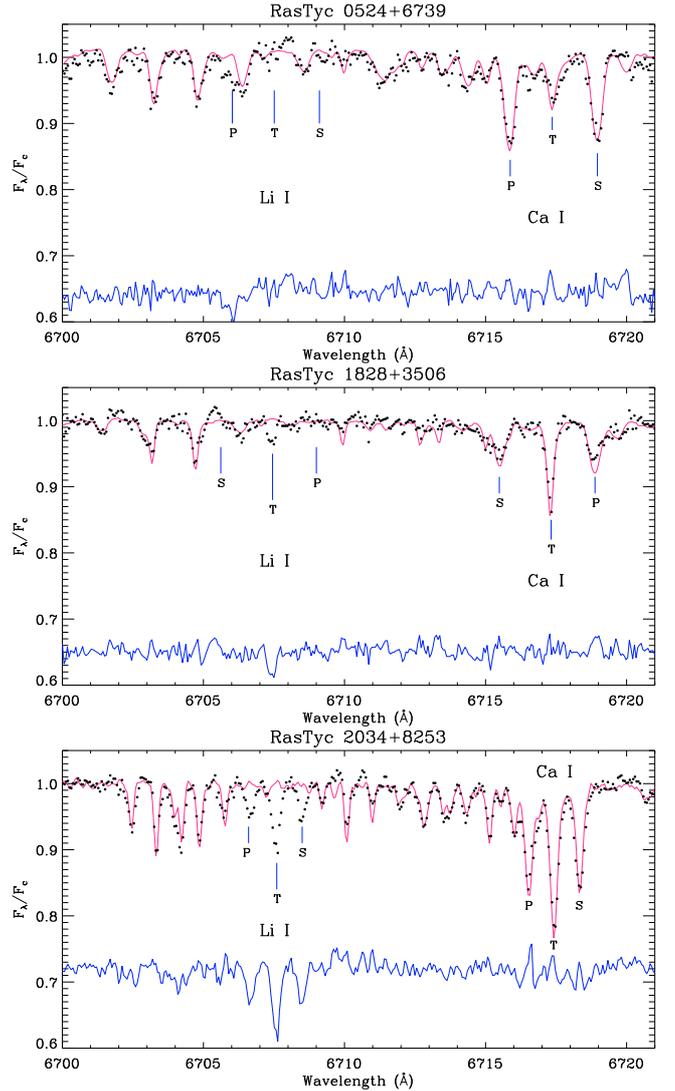
For RasTyc 0524+6739, we did not observe any Li I absorption lines in the spectra (Fig. 7, top panel), notwithstanding the spectral types of its components that would permit the detection of the Li I line also with a moderate abundance. Thus, this system should be older than the Hyades. Therefore, even though its position in the UVW diagrams points to a marginal association with the young Ursa Major (UMa) group (Age ~ 300 Myr), we do not consider this star as a new member of this SKG.

Trusting only the kinematics, RasTyc 1828+3506 could be a new member of the Pleiades moving group (Age ~ 100 Myr), whose members display strong lithium absorption. However, this is not consistent with the non-detection of Li I absorption lines in the spectra of RasTyc 1828+3506, except for the tertiary component (Fig. 7, middle panel). The $\log N$(Li) value we deduce for it is only slightly higher than that of Hyades stars. Therefore, the

Table 8. Kinematic parameters of the new triple systems.

Name	Age (Myr)	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	Moving group	Probability (%)
RasTyc 0524+6739	>600	−16.1 ± 1.9	−1.1 ± 1.9	0.6 ± 1.5	UMa	5–35
RasTyc 1828+3506	400–600	8.5 ± 1.0	−15.6 ± 1.0	−13.7 ± 1.9	Pleiades	25–55
RasTyc 2034+8253	100–300	19.1 ± 4.1	−14.0 ± 2.0	−17.3 ± 4.8	IC 2391	5–15

age of the system could be in the range 400–600 Myr, ruling out its membership in the Pleiades moving group.

Finally, even though the RasTyc 2034+8253 kinematics is marginally consistent with that of the already known members of IC 2391 supercluster, we can clearly distinguish the lithium lines for the three components (Fig. 7, lower panels). The log N(Li) value found for its three components is very similar and reinforces the idea of a common origin for all the components. This value is only slightly lower than that of Pleiades stars. Therefore, we estimate an age between 100 and 300 Myr, which is compatible with that of two stellar populations in the IC 2391 supercluster (Eggen 1991). The agreement between the kinematic age and what is inferred from the lithium suggests that this system can be a possible new member of this SKG.

4. Conclusions

This paper is devoted to analyzing of three new triple systems discovered in the *RasTyc* sample of stellar X-ray sources. Their spectroscopic and photometric data allow us to conclude that they are almost certainly stable hierarchical triple systems composed of short-period inner binaries plus a tertiary component in a long-period orbit. The orbital periods of the inner binaries range from 3.5 to 7.6 days and the orbits are practically circular. From the high-resolution spectra we also found the spectral composition and the astrophysical parameters of the components that turn out to be all G-K main sequence stars. In all cases, the components of the inner binaries have nearly the same masses, spectral types, and luminosities. From their kinematics and/or lithium content, these systems turn out to be fairly young. RasTyc 2034+8253 is the only system in which the Li I λ6707.8 line is strong enough to be clearly visible in the spectra of all the three components and suggests an age in the range 100–300 Myr. It is possibly a new member of the IC 2391 supercluster. For the remaining systems, the membership in young moving groups is rather uncertain.

Our spectroscopic survey has revealed that multiple systems represent a high fraction of the *RasTyc* sources. However, a detailed analysis is absolutely necessary for drawing statistically significant conclusions. Since *RasTyc* objects are relatively close, the discovery and the study of new triple systems, such as those presented here, can contribute to a better understanding of the formation and the evolution of close binaries and multiple systems in the solar neighborhood.

References

Bevington, P. R. 1969, Data Reduction and Error Analysis for the Physical Sciences (McGraw-Hill, Book Company), 237
Correia, S., Zinnecker, H., Ratzka, T., & Sterzik, M. F. 2006, A&A, 459, 909
Eggen, O. J. 1991, AJ, 102, 2028
Eggen, O. J. 1996, AJ, 112, 1595
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
Evans, D. S. 1968, QJRAS, 9, 388
Fabricius, C., Høg, E., Makarov, V. V., et al. 2002, A&A, 384, 180
Frasca, A., & Catalano, S. 1994, A&A, 284, 883
Frasca, A., Alcalá, J. M., Covino, E., et al. 2003, A&A, 405, 149
Frasca, A., Guillout, P., Marilli, E., et al. 2006, A&A, 454, 301
Gillet, D., Burnage, R., Kohler, D., et al. 1994, A&AS, 108, 181
Guillout, P., Schmitt, J. H. M. M., Egret, D., et al. 1999, A&A, 351, 1003
Guillout, P., Klutsch, A., Frasca, A., et al. 2008, A&A, to be submitted
Høg, E., Fabricius, C., Makarov, V. V., et al. 2000, A&A, 355, L27
Jeffries, R. D. 2000, in Stellar Clusters and Associations: Convection, Rotation, and Dynamos, ed. R. Pallavicini, G. Micela, & S. Sciortino, ASP Conf. Ser., 198, 245
Klutsch, A., Guillout, P., Freire Ferrero, R., Frasca, A., & Marilli, E. 2008, in Star Formation across the MILKY WAY Galaxy, ESO Workshop, http://www.eso.org/sci/meetings/MilkyWayStarFormation/posters2.html
Lafrenière, D., Jayawardhana, R., Brandeker, A., et al. 2008 [arXiv:0803.0561]
Landolt, A. U. 1992, AJ, 104, 340
Lo Presti, C., & Marilli, E. 1993, PHOT – Photometrical Data Reduction Package. Internal report of Catania Astrophysical Observatory No. 2/1993
Lucy, L. B., & Sweeney, M. A. 1971, AJ, 76, 544
Mayor, M., & Mazeh, T. 1987, A&A, 171, 157
Melo, C. H. F., Covino, E., Alcalá, J. M., & Torres, G. 2001, A&A, 378, 898
Montes, D., Fernández-Figueroa, M. J., de Castro, E., & Cornide, M. 1995, A&AS, 109, 135
Montes, D., López-Santiago, J., Gálvez, M. C., et al. 2001, MNRAS, 328, 45
Muller, P. 1976, A&AS, 23, 205
Muller, P. 1978, A&AS, 33, 275
Muller, P. 1990, A&AS, 84, 619
Orlov, V. V., & Petrova, A. V. 2000, Astron. Lett., 26, 250
Pavlenko, Y. V., & Magazzù, A. 1996, A&A, 311, 961
Prugniel, P., & Soubiran, C. 2001, A&A, 369, 1048
Soderblom, D. R., Jones, B. F., Balachandran, S., et al. 1993, AJ, 106, 1059
Tokovinin, A., Thomas, S., Sterzik, M., & Udry, S. 2006, A&A, 450, 681
Torres, C. A. O., Quast, G. R., da Silva, L., et al. 2006, A&A, 460, 695
Wichmann, R., Schmitt, J. H. M. M., & Hubrig, S. 2003a, A&A, 399, 983
Wichmann, R., Schmitt, J. H. M. M., & Hubrig, S. 2003b, A&A, 400, 293
Zahn, J.-P., & Bouchet, L. 1989, A&A, 223, 112
Zickgraf, F.-J., Krautter, J., Reffert, S., et al. 2005, A&A, 433, 151
Zinnecker, H., & Mathieu, R. D., ed. 2001, The formation of binary stars, Proc. IAU Symp., 200, ASP Conf. Ser.

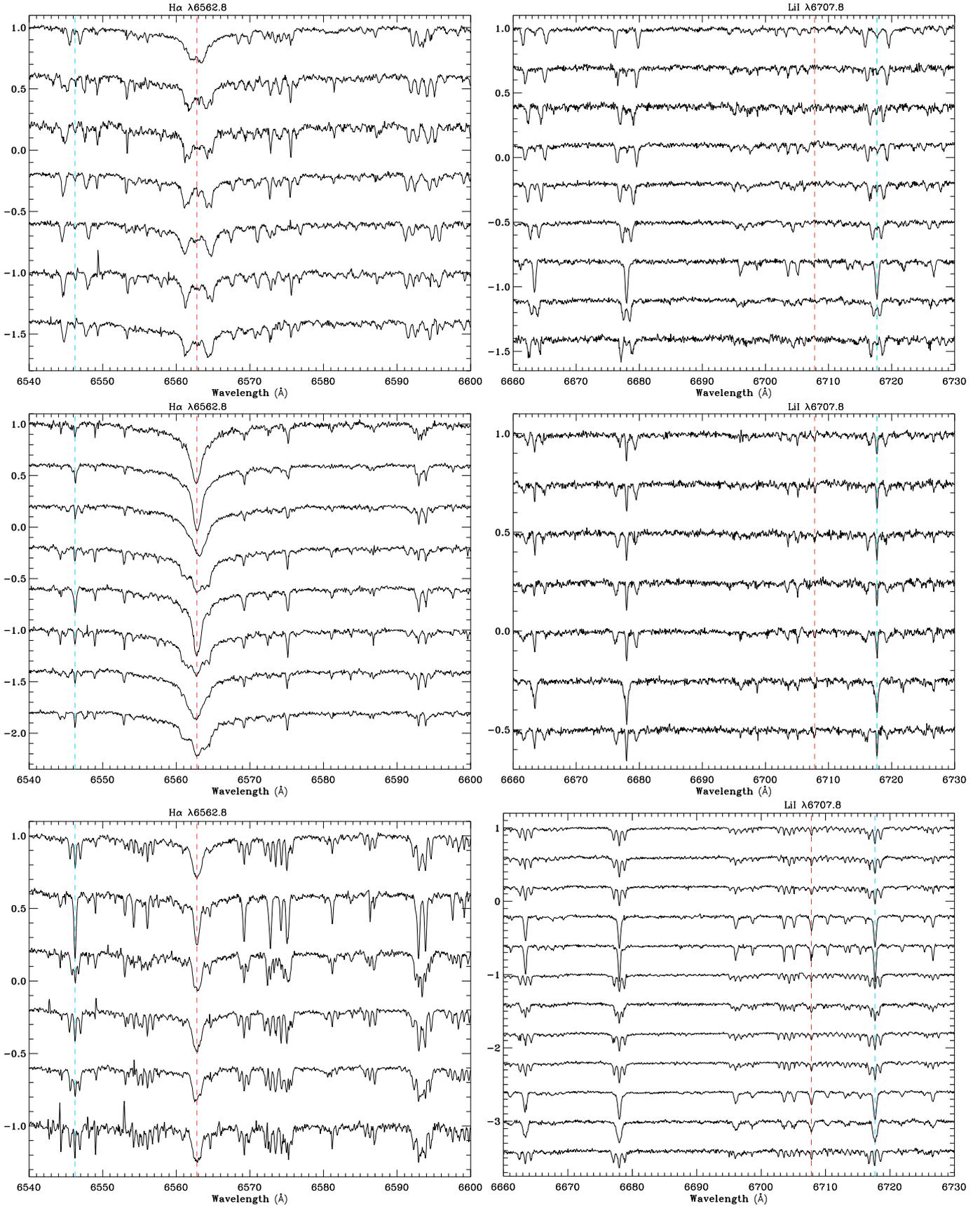**Fig. 1.** High resolution spectra of RasTyc 0524+6739 *(top panels)*, RasTyc 1828+3506 *(middle panels)* and RasTyc 2034+8253 *(lower panels)*. These spectra was acquired with the AURELIE spectrograph at the 152 cm telescope of the OHP both in the Hα *(left panels)* and the lithium spectral regions *(right panels)*. The laboratory wavelengths of the Fe I λ6546.2 and the Hα lines as well as those of the Li I λ6707.8, and the Ca I λ6717.7 are marked with vertical dashed lines in the Hα and lithium spectral regions, respectively.
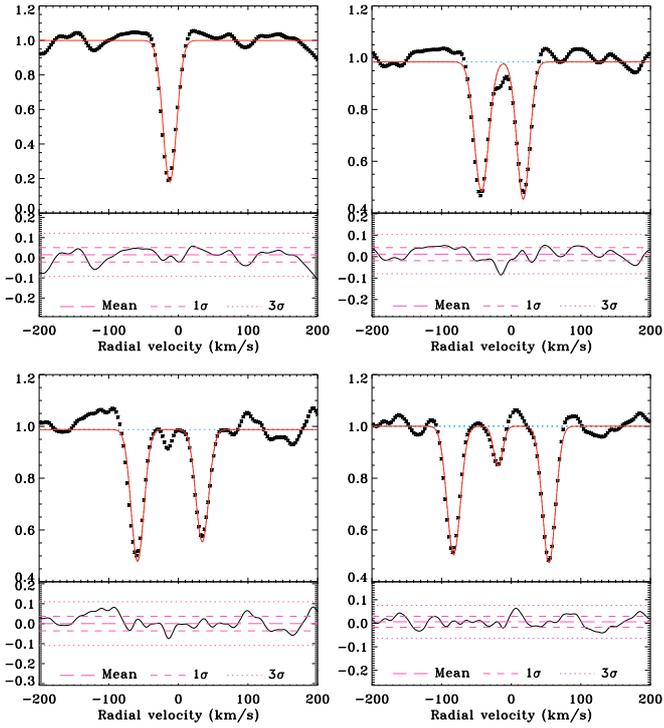
Fig. 2. The CCFs of RasTyc 0524+6739 at various orbital phases. These CCFs permit emphasis of the change of configuration from a one-peak shape at a conjunction *(left top panel)* to a three-peak shape *(right lower panel)*, passing through phases of partial blending in which only two peaks are easily distinguished *(left lower panel and right top panel)*. The RV uncertainty is about 1 km s^{-1} at our spectral resolution. On each panel, the multiple Gaussian fits of the CCFs are over-plotted with full lines *(top box)* and the residuals of the fits are plotted in the *lower box*.

Fig. 4. The CCFs of RasTyc 2034+8253 at two orbital phases. The triple system nature appears from the CCF *(left panel)*, while it is completely hidden at another phase of observation *(right panel)*.
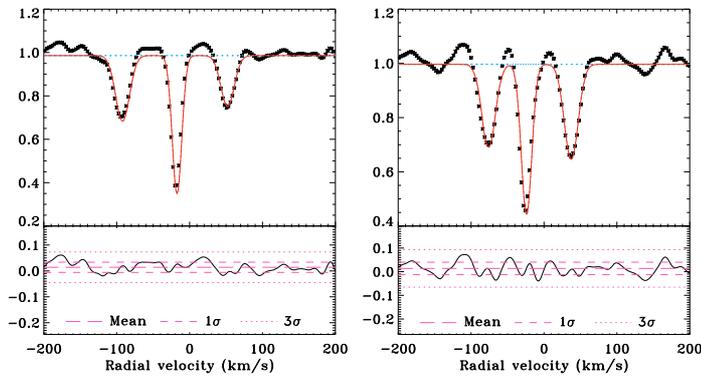

Fig. 3. The three peaks with different widths of the CCFs of RasTyc 1828+3506. The two components of the inner binary appear to rotate faster than the third star, probably due to spin-orbit synchronization.
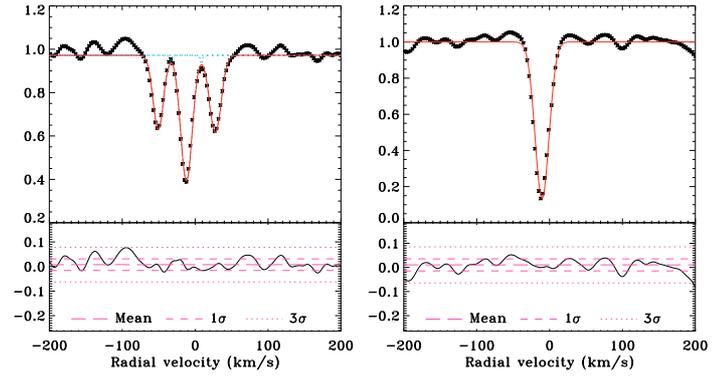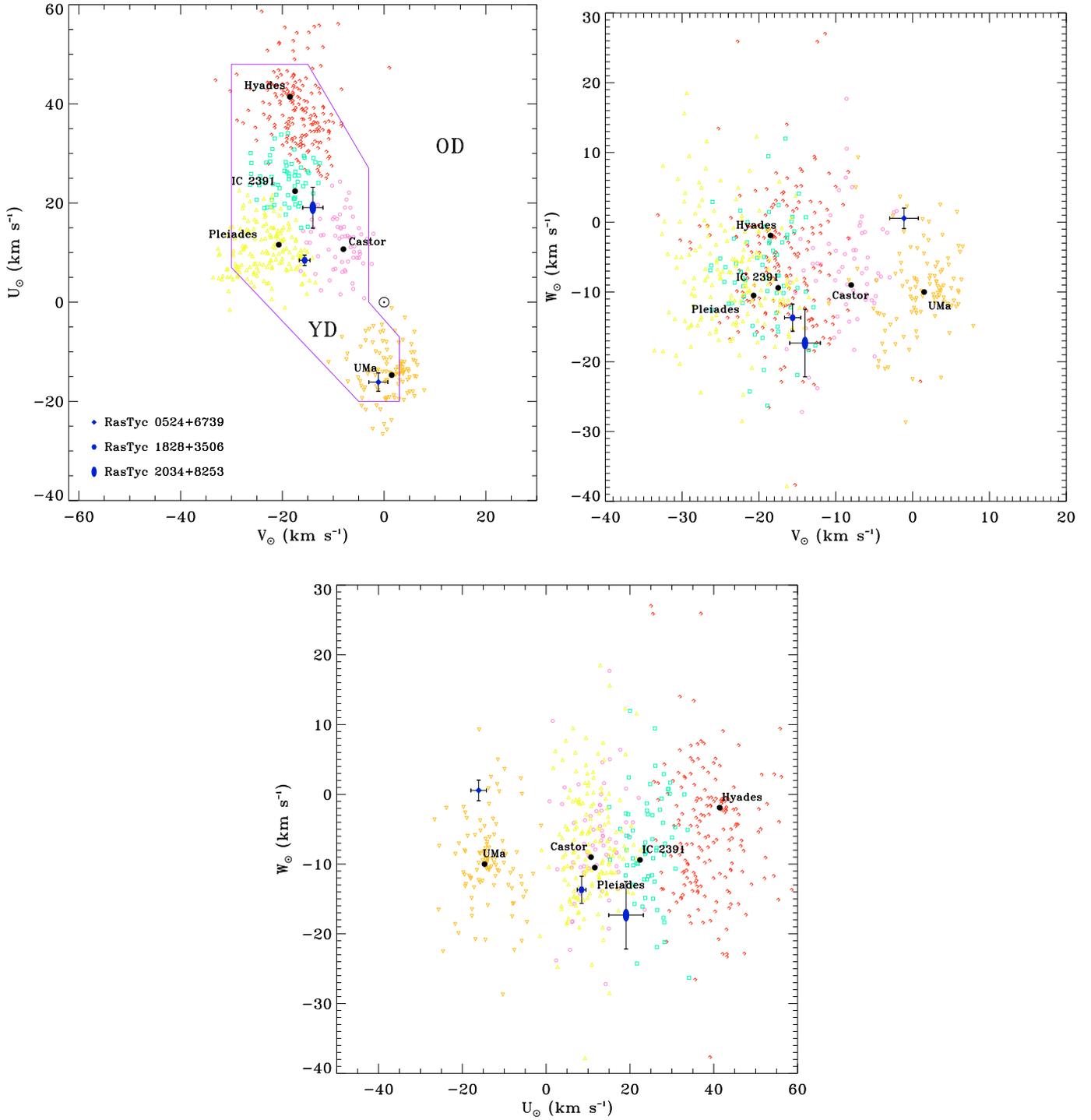
Fig. 8. The *U–V (left top panel)*, *V–W (right top panel)*, and *U–W (lower panel)* diagrams of the *RasTyc* triple systems. The average velocity components (dots) of some young SKGs and those of some late-type stars members of these young SKGs (Montes et al. 2001) are also plotted (square, triangle, circle, upside down triangle, and U symbols for the IC 2391 supercluster, Pleiades, Castor, UMa moving groups, and Hyades supercluster, respectively). The locus of the young-disk (YD) and the old-disk (OD) populations (Eggen 1996) are also marked on the *U–V* diagram.