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Some characteristics of binary T Tauri stars

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The radius–mass, excess radius–age, period–eccentricity relations and the mass ratio distribution are constructed for binary T Tauri stars. The period–eccentricity relation shows that the overwhelming majority of close binaries ($P < 10^d$) have eccentricity near to zero. All components T Tauri stars have excess radius in comparison with initial main sequence stars of corresponding mass. The younger the star the more excess radius it has. The mass ratio distributions of T Tauri stars show that the star formation mechanisms of close binary stars are fragmentation and fission, but wide binary systems can be formed by capture mechanism.

Keywords: Stars: binaries: pre-main sequence binaries: T Tauri binaries

1 Introduction

Binary stars are traditionally the main source of our knowledge about stellar masses, radii, luminosities and other characteristics. Many papers concerning the orbital and physical parameters of young binary stars were published previously (see references). However there are only a few papers with statistical analysis of these data.

T Tauri stars are young ($0.1 \cdot 10^6 < t < 20 \cdot 10^6$ year), low-mass ($0.08\ M_\odot < M < 2.5\ M_\odot$) stars and they contract to the initial main sequence (IMS). They have variable brightness in all spectral ranges. Emission lines Hα, CaII, FeI, K and lithium (6707.8 Å) absorption lines are present in their spectra.

In this paper we constructed some statistical distributions for binary T Tauri stars. The list of binary T Tauri stars are given in Section 2. The radius–mass, radius excess–age, period–eccentricity relations and the mass ratio distribution for these stars are presented in Section 3. We compare them with theoretical star formation mechanisms and with parameters of initial main sequence stars. Base results are summarized in Section 4.

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2 The sample

We collected the information about 55 binary T Tauri stars with known orbital elements. There are among them:

11 eclipsing double-lined spectroscopic binaries (EB+SB2): EK Cep (Popper 1987), BM Ori (Antokhina et al. 1989), TY CrA (Casey et al. 1998), AK Sco (Alencar et al. 2003), RS Cha (Alecian et al. 2005), V 1174 Ori (Stassun et al. 2004), RX J0529.4+0047 (Covino et al. 2004), JW 380 (Irwin et al. 2007), ASAS J052821+0338.5 (Stempels et al. 2008), Par 1802 (Chew et al. 2012), CoRoT 223992193 (Gillen et al. 2014);

4 visual double-lined spectroscopic binaries (VB+SB2): V773 Tau A (Boden et al. 2007), NTT 045251+3016 (Steffen et al. 2001), HD 98800 B (Boden et al. 2005), HARO 1-14c (Schaefer et al. 2008);

40 double-lined spectroscopic binaries (SB2): DQ Tau (Carr et al. 2001), MO Lup (Esposito et al. 2007), UZ Tau E (Martin et al. 2005), V807 (Schaefer et al. 2012), V826 Tau (Reipurth et al. 1990), V4046 Sgr (Stemples and Gahn 2004), HD 34700 (Torres 2004), HD 155555 (Strassmeier and Rice 2000), NTTS 162814-2427 (Mathieu et al. 1989), NTTS 155913-2233, NTTS 160905-1859, Par 1771, Par 1925 (Prato et al. 2002), NTTS 155808-2219, RX J0529.3+1210 (Mace et al. 2012), W 134 (Padgett and Stapelfeldt 1994), RX J1559.2-3814, GSC 06213-00306 (Guenther et al. 2007), RX J0539.9+0956, RX J0513.1+0851 (Ruíz-Rodríguez et al. 2013), RX J0528.9+1046 (Torres et al. 2002), RX J0532.1-0732, RX J0541.4-0324, RX J0530.7-0434 (Covino et al. 2001), RX J1603.9-3938 (Melo et al. 2001), RX J1622.7-2325Nw (Rosero et al. 2011), VSB 111, VSB 126 (Karnath et al. 2013), Par 1540 (Marschall and Mathieu 1988), Par 2494 (Reipurth et al. 2002), ROXR1 14 (Rosero et al. 2011), LkCa3 A, LkCa3 B (Torres et al. 2013), Cru 3 (Alcalá et al. 2002), S29, S53, S84, S85, S89, S89 (Sacco et al. 2008).

Our sample consists of two types of stars: the classical T Tauri stars (CTTS) with strong emission lines indicating accretion from a circumstellar disk, and the weak-line T Tauri stars (WTTS) that exhibit enhanced magnetic activity and show no signs of accretion. CCTS have equivalent width of emission line Hα more than 10 Å but WTTS – less than 10 Å (Bertout 1989).

3 Some statistical distributions for T Tauri stars

According to a theoretical point of view, T Tauri stars should have the radii excess relative to the radii of initial main sequence stars: $\Delta \lg R = \lg R - \lg R_{\rm IMS}$. The radius–mass relation is shown in Fig. 1 for stars with accurate known radii and masses (EB+SB2). Squares represent primary components, triangles – secondary components. Crosses indicate radius–mass relation for IMS stars (D'Antona and Mazzitelli 1994), smooth curve indicates radius–mass relation for detached main-sequence eclipsing binaries (Gorda and Svechnikov 1999). Figure 1 shows that primary and secondary components of T Tauri stars are located above the radius–mass relation for IMS stars. Both components of JW 380, Par 1802 and secondary component of BM Ori have the largest excesses of the radii. Primary components of EK Cep,TY

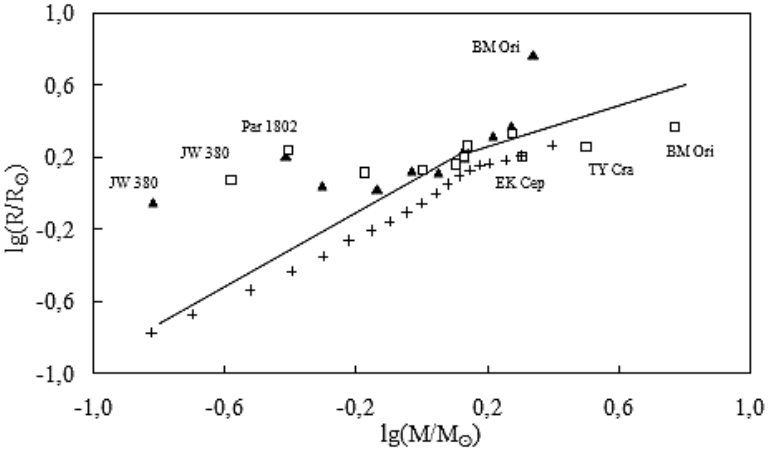


Figure 1 The radius–mass relation for T Tauri stars. Squares represent primary components, triangles – secondary components. Crosses indicate radius–mass relation for IMS stars (D'Antona and Mazzitelli 1994), smooth curve indicate radius–mass relation for detached main-sequence eclipsing binaries (Gorda and Svechnikov 1999).

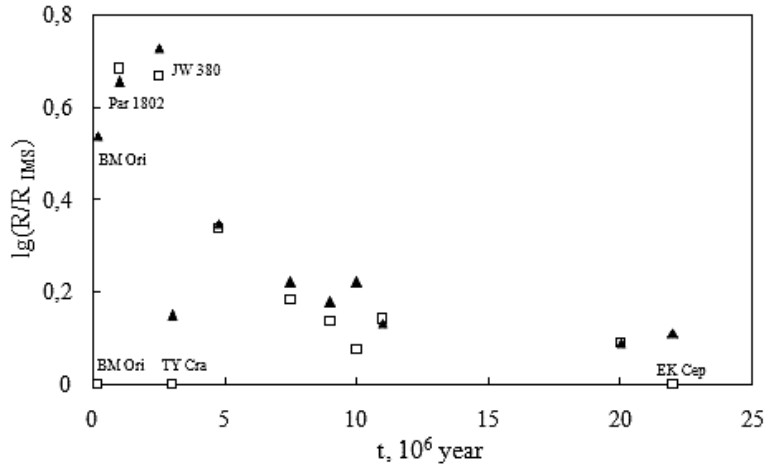


Figure 2 The radius excess–age relation for T Tauri stars. Squares represent primary components, triangles – secondary components.

Cra and BM Ori are IMS stars, therefore they do not have radius excess. Figure 2 illustrates the radius excess–age diagram. It can be seen from Fig. 2 that the largest excess of radius have the most young stars.

The mass ratio distribution informs us about a formation mechanism of binary stars. There are the following mechanisms (Zinnecker 1984):

a. *Capture* mechanism assumes that binary systems originate from single independent condensations as a result of gravitational capture. According to this mechanism, the most probable value of the mass ratio is close to zero;

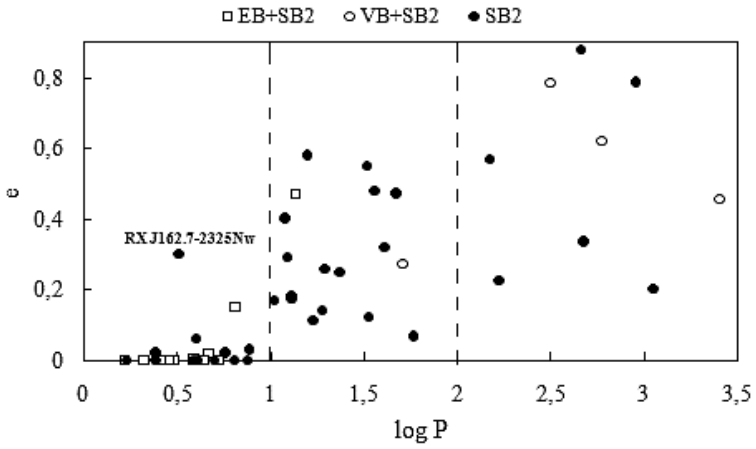


Figure 3 The period–eccentricity relation for T Tauri stars.

b. *Cluster disintegration* supposes that binary stars form in small bound clusters that subsequently lose most of their members by two-body encounters. The mass ratio should increase towards unity in this case;

c. *Fragmentation* of collapsing protostellar cloud into two and more parts. It follows from the fragmentation mechanism that the most probable value of the mass ratio is close to unity;

d. In the process of *fission* of a rapid rotating protostar during Kelvin–Helmholtz contraction the mass ratio obtains the value near unity.

The first and second mechanisms may be responsible for the formation of wide binaries, the third and the fourth ones – for the formation of close binary systems.

Since all 55 stars are observed as SB2, the mass ratio $q = M_2/M_1$ and the eccentricity e are determined well from radial velocity curves. Both close and wide T Tauri stars are in our sample. We constructed the period–eccentricity relation to separate close and wide systems (Fig. 3). It can be seen from Fig. 3 that there are three groups of stars:

1) wide binaries ($P > 100^d$), having elliptic orbits with eccentricity $e > 0.2$;

2) systems with $10^d < P < 100^d$ and eccentricity between 0.1 and 0.7;

3) close binaries ($P < 10^d$); the overwhelming majority of these stars have eccentricity close to zero.

Figure 3 shows that RX J1622.7-2325Nw has the highest eccentricity among the known short-period pre-main sequence (PMS) binaries. This star is a member of a hierarchical quadruple system. Rosero et al. (2011) suggested that the orbit of RX J1622.7-2325Nw has not yet circularized because of the perturbing action of companion, itself a close visual pair. Circular orbits of close T Tauri stars say that orbital circularization and synchronization of orbital and axial motions occured before their PMS phase. The theoretical works of Zahn and Bouchet (1989), Khaliullin and Khaliullina (2011) confirm this fact for binary stars with $P < 10^d$ because of tidal interaction of components lead to loss of orbital angular moment.

The mass ratio distribution for close T Tauri stars is illustrated in Fig. 4. The figure shows that the pairs with $q < 0.5$ are rare among close binaries. 50% of these

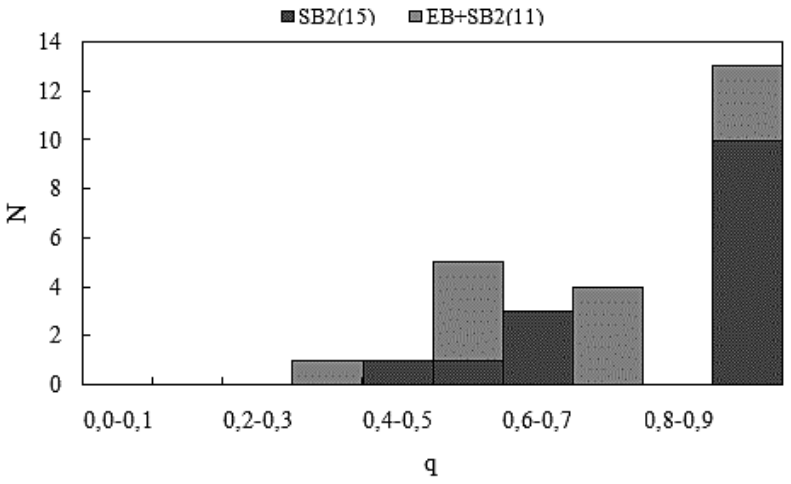


Figure 4 The mass ratio distributions for close T Tauri stars. The numerals in parentheses show the number of stars of these types.

systems have a mass ratio in the range $q = 0.9$–1.0. This fact does not contradict the fragmentation and fission mechanisms. 8 of the 26 close systems have the mass ratio in the range $q = 0.5$–0.7. Possibly these systems are members of dense young clusters and were formed by capture mechanism.

We have only 9 wide T Tauri binaries, so we combined them with systems having $10^d < P < 100^d$. Figure 5 shows the mass ratio distribution for T Tauri binaries with $P > 10^d$. More than 20% of these binaries have $q < 0.5$. Only one third of these stars have a mass ratio in the range $q = 0.9$–1.0. The number of these stars does not decrease so sharply with decreasing mass ratio as in the case of close binary stars.

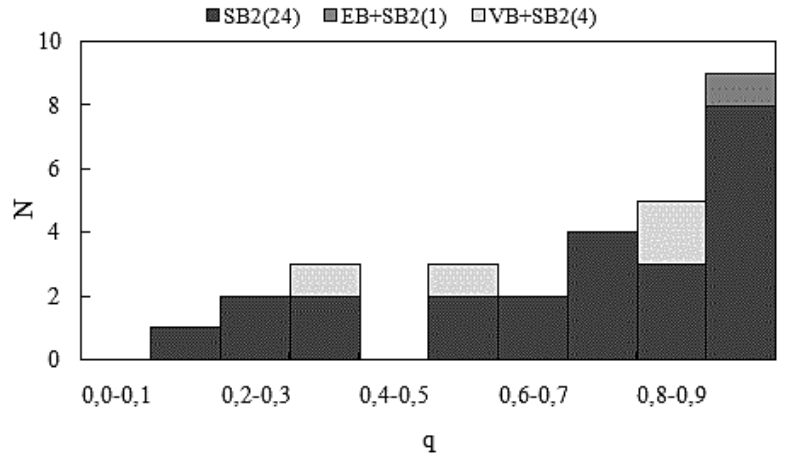


Figure 5 The mass ratio distributions for T Tauri stars with $P > 10^d$. The numerals in parentheses show the number of stars of these types.

4 Summary and conclusion

The radius–mass, excess radius–age, period–eccentricity relations and the mass ratio distribution are obtained for binary T Tauri stars. The analysis of these distributions leads to the following conclusions.

1. T Tauri stars have radius excess in comparison with IMS stars of corresponding mass. The younger the star the more excess radius it has.

2. For 50% of close binaries have mass ratio in the range $q = 0.9$–1.0. The stars with $q < 0.5$ are rare among these systems.

3. Only 30% of pairs with $P > 10^d$ have mass ratio from 0.9 to 1.0. More than 20% of these stars have $q < 0.5$. The number of stars with $P > 10^d$ does not decrease so sharply with decreasing mass ratio as in the case of close binary stars.

4. The mass ratio distributions illustrate the difference of formation mechanism between close and wide binary stars. The stars formation mechanisms of close binary stars are fragmentation and fission, but wide binary systems can be formed by capture mechanism.

We plan to add into our sample the young binary brown dwarfs and the Herbig Ae/Be stars in future investigations.

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