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The mass function of young spectroscopic binaries and stars with protoplanetary disks

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Abstract. The observational data on 58 pre-main sequence (PMS) double-lined spectroscopic binaries (SB2) and 115 stars with protoplanetary disks are compiled for statistical investigation. These stars are located in different star-forming regions. The constructed distributions of young stars by component masses, taking into account the effects of observational selection (discovery probability and/or occupied volume), are approximated with a power law $dN \sim M^{-\Gamma} d\log M$. The slopes are determined on the interval from the maximum of the distributions to the largest mass value and are equal to $\Gamma = 0.92 \pm 0.23$ for the components of SB2 systems and $\Gamma = 1.51 \pm 0.30$ for the stars with disks, respectively, which are close to the Salpeter's mass function. The most probable values of the mass are $M_p = 0.48 \pm 0.02\, M_\odot$ for stars with protoplanetary disks and $M_p = 0.95 \pm 0.05\, M_\odot$ for SB2 components.

Keywords: stars: pre-main sequence, binaries: spectroscopic, mass function; methods: statistical

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1 Introduction

The initial mass function (IMF) for main-sequence stars has been investigated by many authors, starting with the pioneer works of E. Salpeter (Lee et al. 2020). Over the last years, the spatial resolution of astronomical instruments have been improved, which made it possible to discover young binaries and stars with disks in star-forming regions. These objects are at the stage of contraction to the IMS and are an intermediate evolutionary link between molecular cloud cores and IMS-stars. This is why the study of the mass distribution of young stars is of considerable interest.

2 Sample of young stars

We used observations on 58 young SB2 systems and 115 stars with protoplanetary disks. The masses of 36 SB2 are reliably determined from observations and are given by Dudorov & Eretnova (2021); Eretnova (2023). Among them 31 systems are eclipsing variables and five are visual binaries. We have added the eclipsing SB2 TIC 43152097 to them (Frasca et al. 2023). The masses of the remaining components are obtained by interpolation between the evolutionary tracks by Baraffi et al. (2015) for stars with 0.1–1.4 $M_\odot$ and by Dotter et al. (2008) for stars with 1.5–5.0 $M_\odot$. The masses of 34 stars with disks are determined from the Keplerian orbit of gas in the disks (Guilloteau et al. 2014; Simon et al. 2019), while other masses are calculated from the tracks obtained by Ginski et al. (2024); Garufi et al. (2024); Valegård et al. (2024).

3 The discovery probability of SB2 system

The discovery probability of SB2 star ($p_{\rm SB2}$) can be divided into two factors. The first one (geometric probability p) is estimated as time fraction during which the duality of the components can be established by measuring the half-amplitudes of their radial velocities K_1 and K_2, i.e.

$$p = 1 - \frac{2}{\pi \arcsin{(\mathit{\Delta}/K)}},$$

where $\mathit{\Delta}$ is the separation threshold of spectral lines, $K = K_1 + K_2$ (Popov 1970). The second factor (p_K) is the occurrence frequency of SB2 with measured values of K_1 and K_2 among all possible SB2 variants. The relationship $K = 2\pi \sin iA/P$ allows us to run the translation algorithm of the differential probabilities

$$df_{jklm} = f_{M_1}\, dM_1\;\, f_q\, dq\;\, f_A\, dA\;\, f_i\, di,$$

calculated on the basis of known functions of distributions of close binaries by primary mass (M_1), mass ratio (q), semi-major axis (A), and orbital inclination (i), into a

K-matrix of probabilities. The j, k, l, m-indices "run" values of M_1, q, A, i, which would be convenient to divide into intervals to compute K^{jklm} for each parameter in the center of the interval. These values fill the K-matrix with elements, which will be in strict indexical correspondence with the df_{jklm}. Then the definition area of K is divided into n-intervals, inside which the number of elements K^{jklm} is summed up and at the same time the corresponding elements df_{jklm} are also summed by the same indices. Thus, the K-matrix gives the number of elements in the sum and the indices by which the elements of the differential probabilities df_{jklm} should be summed up. Then we construct the distribution $f(K)$, and thus determine p_K and $p_{\rm SB2} = p \times p_K$.

4 Results and discussion

Figure 1a, b show the histograms of the mass distribution of SB2 components and the stars with disks. Important effects of observational selection (OSE) are the discovery probability of SB2 and the space occupied by the stars. The V_i is calculated as a spherical layer with a thickness of 180 pc for stars at the distances $r < 90$ pc (Istomin 1978). As a result, we can estimate the "true" number of stars in a given interval of $\log M_i$ as $dN_0 = \sum 1/p^i_{\rm SB2}$. Then divided by the space volume, in which stars with the given masses are observed, one can evaluate the spatial density of SB2 stars, $dN_V = dN_0/V_i$ pc^3. We exclude three SB2 with $p_{\rm SB2} < 0.005$ and three stars located in NGC 2264 at $r \approx 700$ pc, since it may lead to noticeable distortions of the distribution. The majority of the stars in our sample are located at $r < 450$ pc. For young stars with disks, only the correction for the spatial is considered.

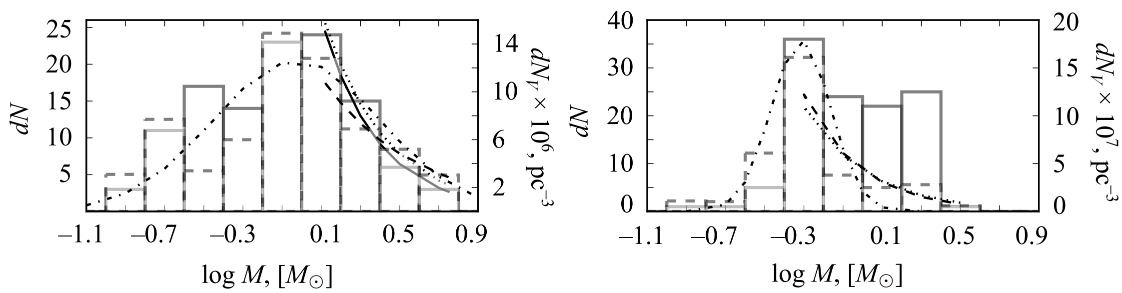

Fig. 1. The mass distributions of the components of young SB2 stars (a) and stars with disks (b). The observed and corrected for OSE histograms and their approximation with a power law are shown by a solid and dashed curves, respectively. A dash-dotted curve shows the approximation of OCE histograms with a lognormal law. A dotted curve shows the Salpeter IMF.

Figure 1 shows that the maximum in OSE-distribution for SB2 stars is slightly shifted towards lower masses compared to the observed distribution. We can identify a secondary maximum, $\log M/M_\odot \in [-0.8; -0.6]$. For stars with disks, the maxima of both distributions coincide, but in the second case it is more pronounced. These stars are located in the Ophiuchus, Chamaeleon, Taurus, Orion star-forming regions. Orion is the most distant region and the stars in it have masses of $\log M/M_\odot > -0.2$.

The histograms are approximated with a power law $dN \sim M^{-\Gamma} d\log M$. The slopes are $\Gamma = 1.52 \pm 0.42$ for SB2 observed distribution, $\Gamma = 0.92 \pm 0.23$ and $\Gamma = 1.51 \pm 0.3$ for OSE-distributions of SB2 and stars with disks, respectively, constructed on the interval from the distributions maxima to the largest mass. It is close within the error to the Salpeter IMF, $\Gamma = 1.35$. Over the entire mass interval, the corrected for OSE histograms are approximated with a lognormal law:

$$F(\log M_i) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\log M_i - \mu)^2}{2\sigma^2}\right).$$

The most probable masses are $M_p = 0.48 \pm 0.02\, M_\odot$ for the stars with disks and $M_p = 0.95 \pm 0.05\, M_\odot$ for SB2 systems. The mass function obtained for molecular cloud cores in Aquila, Cepheus, Perseus give $M_p = 0.4$–$0.6\, M_\odot$. Chabrier obtained $M_p = 0.25\, M_\odot$ from IMF analysis (Lee et al. 2020). PMS stars occupy an intermediate position between pre-stellar cores and IMS stars. The values of M_p are the same for young stars with disks and for molecular cloud cores, while for components of SB2 stars they are significantly larger. This is probably due to the difficulty in SB2 detecting with decreasing stellar mass, that is reflected in the sample incompleteness in the region of $M < 1\, M_\odot$.

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References

Baraffe I., Homeier D., Allard G., et al., 2015, Astronomy & Astrophysics, 577, id. A42
Dotter A., Chaboyer B., Jevremovič D., et al., 2008, Astrophys. Journal Supplement, 178, 1, p. 89
Dudorov A.E. and Eretnova O.V., 2021, Chelyabinskiy Fiziko-Matematicheskiy Zhurnal, 6, p. 347
Eretnova O.V., 2023, Astronomy Reports, 67, 9, p. 902
Frasca A., Alonso-Santiago J., Catanzaro G., et al., 2023, Astronomy & Astrophysics, 677, id. A154
Garufi A., Ginski C., van Holstein R.G., et al., 2024, Astronomy & Astrophysics, 685, id. A53
Ginski C., Garufi A., Benisty M., et al., 2024, Astronomy & Astrophysics, 685, id. A52
Guilloteau S., Simon M., Piétu V., et al., 2014, Astronomy & Astrophysics, 567, id. A117
Istomin L.F., 1978, Zvezdnye skopleniya i dvojnye sistemy, p. 148
Lee Y.-N., Offner S.S.R., Hennebelle P., et al., 2020, Space Science Reviews, 216, 4, id. 70
Popov M.V., 1970, Peremennye zvezdy, 17, p. 209
Simon M., Guilloteau S., Besk T. L., et al., 2019, Astrophysical Journal, 884, 1, id. 42
Valegård P.-G., Ginski C., Derkink A., et al., 2024, Astronomy & Astrophysics, 685, id. A54