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A surprising dynamical mass for Oph-S1

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Combining 35 Very Long Baseline Array observations of the intermediate-mass young stellar object S1 in the Ophiuchus complex, we determine the dynamic masses of the two members of the system to be 4.11 ± 0.10 $M_\odot$ and 0.831 ± 0.014 $M_\odot$. The mass of the primary is at least 25% higher than expected from stellar evolutionary models.

Very long baseline interferometry (VLBI) provides images with an angular resolution of order one milliarcsecond (mas) and an astrometric accuracy better than 0.1 mas relative to distant quasars. This can enable accurate determinations of *individual* masses in a tight stellar system if multi-epoch observations are combined. In this contribution, we report on such observations of S1, the most luminous and massive stellar member of the Ophiuchus star-forming region. Oph-S1 has long been known to be a binary intermediate-mass young stellar system, and provides a rare opportunity to obtain empirical constraints on theoretical models of stellar evolution for that mass range. The measured positions of the two components of Oph-S1, S1A and S1B, of the system relative to their center of mass are shown in Figure 1, together with the best Keplerian fits. The masses deduced from these fits are 4.11 ± 0.10 $M_\odot$ for S1A and 0.831 ± 0.014 $M_\odot$ for S1B.

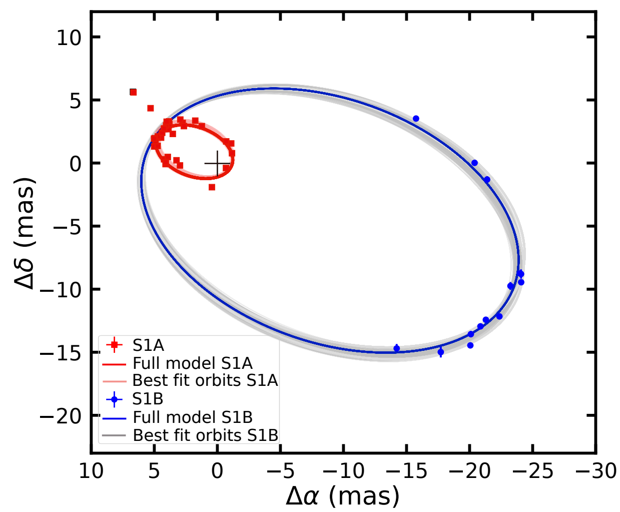

Figure 1. Orbits of S1A (red) and S1B (blue) relative to the center of mass (black cross). To illustrate the range of solutions allowed by the errors in our fit, 100 orbits are shown in light red for S1A and grey for S1B. The measured positions of S1A (red squares) and S1B (blue circles) after correction of parallax and proper motions are also shown. Position errors are on the order of 0.1 mas, barely seen at the scale of the plot. Adapted from Ordóñez-Toro et al. (2024).

Existing optical and infrared photometric observations of S1A can be interpreted as a reddened blackbody, but there is a significant degeneracy between the temperature of the blackbody on the one hand, and the stellar radius and amount of foreground extinction on the other (Ordóñez-Toro et al., 2024). Temperatures between 14,000 K and 17,000 K provide adequate fits, but for different values of the luminosity – between about 700 $L_\odot$ and 2,100 $L_\odot$, respectively. Regardless of the chosen $(T_{\rm eff}, L)$ combination, however, S1A falls above the ZAMS in the HR diagram, suggesting an age of order 0.5 Myr. On the other hand, the theoretical evolutionary track for a 4 $M_\odot$ star (e.g. Tognelli et al. 2011) falls significantly below the locus of S1A in the HR diagram. Conversely, if theoretical models were used to estimate the mass of S1A from its position in the HR diagram, they would suggest a mass of 5 to 6 $M_\odot$, at least 25% higher than measured dynamically. In contrast, the dynamical mass of S1B is reasonably consistent with its de-reddened absolute K magnitude ($M_K \approx 1 \pm 0.5$) deduced from the scant resolved infrared observations of the S1 system.

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