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Binary stars in loose associations: AB Dor B and HD 160934

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Abstract

Precise determination of dynamical masses of pre-main- sequence (PMS) stars is necessary to calibrate PMS stellar evolutionary models, whose predictions are in disagreement with measurements for masses below $1.2\,M_{\odot}$. Binary stars in young, nearby loose associations are particularly good candidates, since all members share a common age. We present phase-reference VLBI observations of two binary systems that belong to the AB Doradus moving, HD 160934 A/c and AB Dor Ba/Bb, from which we have measured both the relative and absolute orbital motion. Accordingly, we obtained precise estimates of the mass of the components of these binaries (ranging from 0.25 to $0.7\,M_{\odot}$). We will show how these measurements provide precise calibration points for testing PMS models of low-mass stars.

1 Introduction

Stellar evolution models are used to derive fundamental parameters of stars, such as their mass. However, the predictions based on pre-main-sequence (PMS) models for stars with masses $< 1.2\,M_{\odot}$ are questionable since the contrast with the observational data reveals some discrepancies. Calibrating stellar evolution models is not an easy task, because it requires precise and independent measurements of luminosities and masses of these stars in order to compare them with the theoretical results. Some authors have noted the need to fit well the theoretical models for PMS stars ([7], [13], [11]), but there is a small number of these systems with masses $< 1.2\,M_{\odot}$ observed so far ([7]).

Binary stars in young nearby moving groups are good candidates to increase the number of PMS stars with dynamically determined masses ([16], [14]). Several of these moving groups have been discovered recently. Among them, the AB Doradus moving group (AB Dor-MG) is the best suited: it is the closest one (its mean distance to the Sun is 30 pc), the estimated age is relatively good (50-70 Myr; [9], [6]) and it contains stars with significant emission at radio wavelengths ([5], [1]). This last feature is essential, because it allows the use of radio interferometry techniques to obtain astrometric information. Following the list of AB Dor-MG members in [14], we initiated a VLA/VLBI program dedicated to monitor binary systems known to host low-mass companions, and which are likely to present radio emission. Two of the stars included in our program are AB Dor B and HD 160934.

2 Stellar systems and observations

The AB Doradus stellar system is the main system of the AB Dor-MG and it is placed at a distance of $\sim$15 pc. It has two pairs of stars separated $9''$: AB Dor A/C and AB Dor Ba/Bb. AB Dor A/C is a well-known PMS star, extensively observed, so we are studing the pair AB Dor Ba/Bb, which components are separated $\sim$50 mas. This star has a high rotation rate and a strong radio emission. We observed this target in three different epochs: 2007 November 11, 2010 October 25, and 2013 August 16. We used the Australian VLBI Network, the Long Baseline Array (LBA). Each observation lasted 12 hours at a frequency of 8.4 GHz at a data rate of 1024 Mbps in dual polarization. We use the phase-reference technique, interleaving scans of the quasar 0516−621 and the star AB Dor B. The observation sequence target-calibrator-target lasted about four minutes. The phase-referenced naturally-weighted images of the target are shown in Fig. 1.

On the other hand, the HD 160934 stellar system is placed at a distance of $\sim$30 pc and has also a high rotation rate. It is a tertiary system: HD 160934 A/B/c. We focus our study in the primary pair A/c, which components are separated $\sim 0.2''$. The component B is placed at a distance of $\sim 8.7''$ from the primary pair. We observed this target in three different epochs: 2012 October 30, 2013 May 23, and 2014 March 5. We use the European VLBI Network (EVN). Each observation lasted 10 hours at a frequency of 5 GHz at a data rate of 1024 Mbps in dual polarization and was scheduled in phase-reference style, interleaving scans of the ICRF quasar J1746+6226 and the target star HD 160934. The cycle target-calibrator-target lasted about six minutes. The phase-referenced naturally-weighted images of the target are shown in Fig. 2.

3 Results

3.1 Determination of orbital parameters and masses

With the images of the stars shown in Figs. 1 and 2, we can determine the relative position of one component respect to the other and the absolute position of each component respect to the external quasar. We included NIR data available in the literature ([9], [3], [8], [10], [4], and [15]) to determine simultaneously both the relative and the individual orbits of each pair. We used a least-square fit similar to that described in [5].

The sum of the masses of the system can be calculated from the semimajor axis of the

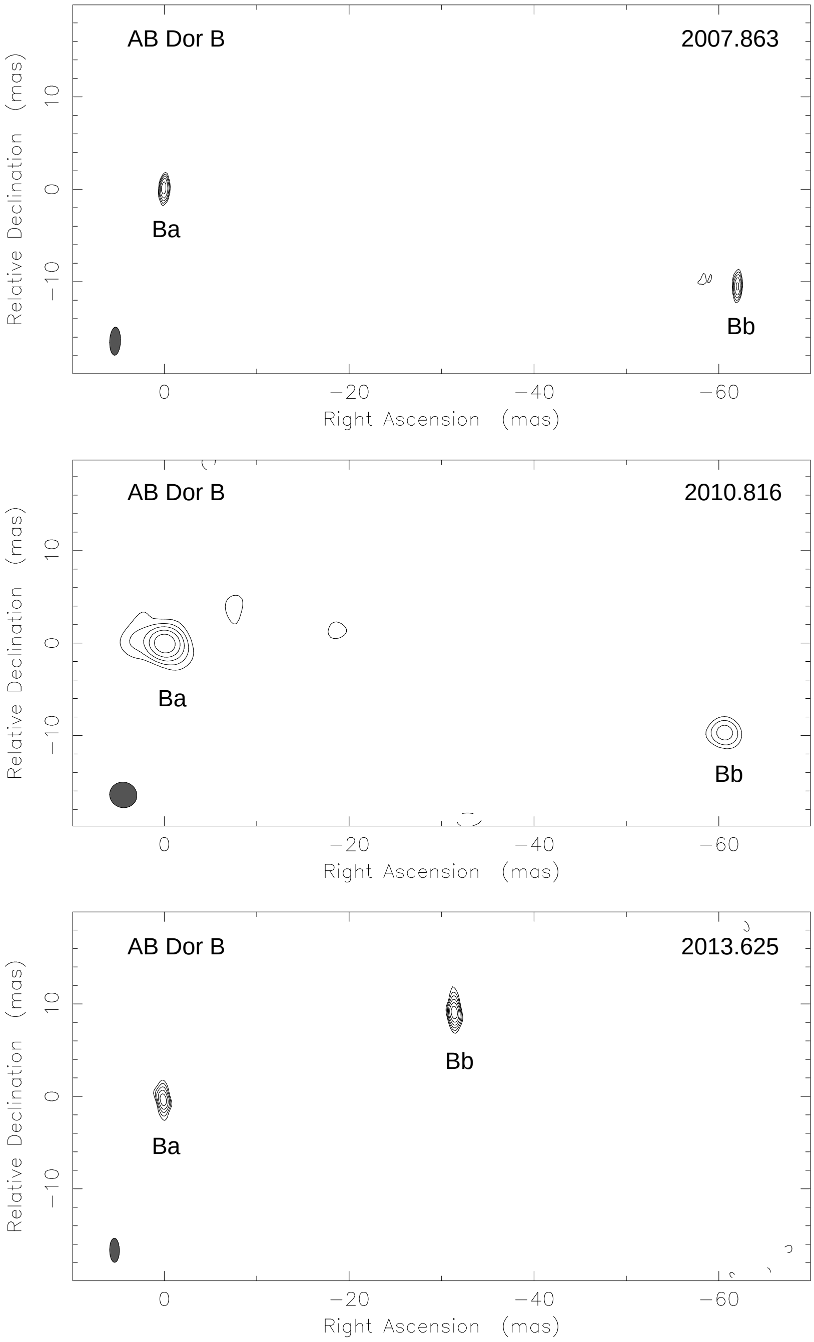

Figure 1: Clean maps of binary AB Dor B at the three LBA epochs using the antennas at ATCA, Ceduna, Hobart, Mopra, Parkes, Tidbinbilla, Warkworth, and Hartebeesthoek. The lowest contour levels are, respectively, 0.10, 0.15, and 0.10 mJy beam^{-1}. The scale factor between contiguous contours is $\sqrt{2}$. In all the maps we have centered the position of AB Dor Ba at the origin (Azulay et al. 2015, submitted).

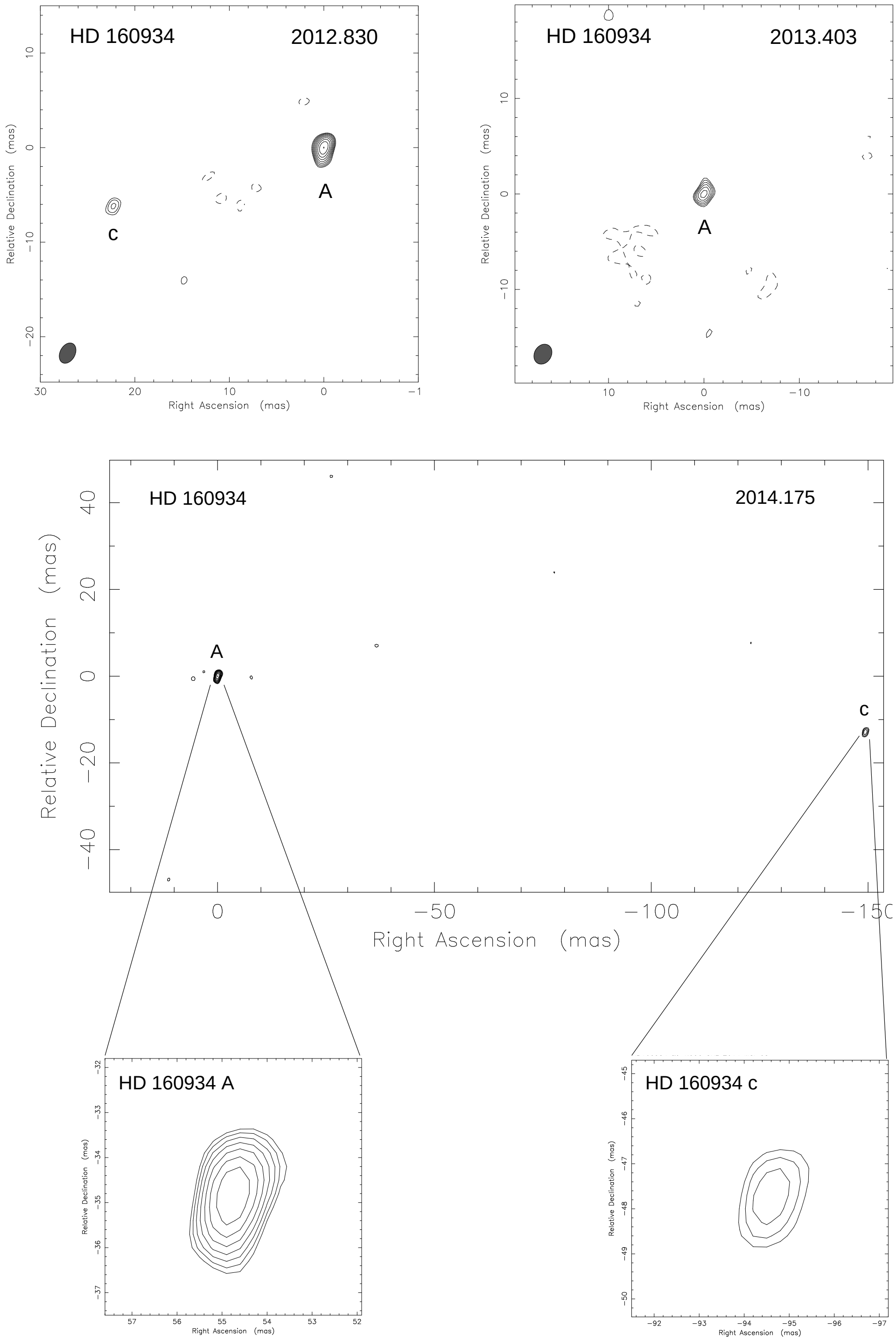

Figure 2: Clean maps of the binary HD 160934 at the three EVN epochs using the antennas at Effelsberg, Westerbork, Jodrell Bank, Onsala, Medicina, Noto, Torun, Yebes, Svetloe, Zelenchukskaya, Badary, Urumqi, and Shanghai. The lowest contour levels are, respectively, 0.04, 0.02, and 0.04 mJy beam^{-1}. The scale factor between contiguous contours is $\sqrt{2}$. In all the maps we have centered in the origin the position of HD 160934 A. Component c is not detected at epoch 2013.403. Orbital motion of c around A is evident from 2012.830 and 2014.175 (Azulay et al. 2015, in preparation).

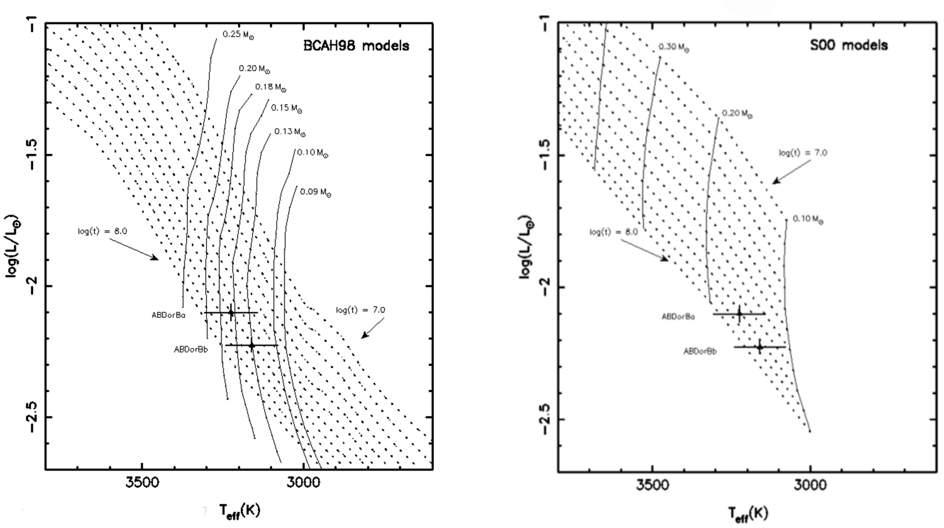

Figure 3: BCAH98 and S00 models for PMS stars. See Sect. 3.2.

relative orbit, $a_{\rm rel}$, and the period, P, using the Kepler's Third Law ($m_1 + m_2 = a_{\rm rel}^3/P^2$), and it is 0.53±0.05 M$_\odot$ for AB Dor B and 1.20±0.25 M$_\odot$ for HD 160934. Since our data also provide the semimajor axis of the absolute orbits, we can also calculate the masses of the individual components using the Kepler's Third Law in the form ($m_2^3/(m_1+m_2)^2 = a_1^3/P^2$), that are 0.28±0.05 M$_\odot$ and 0.25±0.05 M$_\odot$ for AB Dor Ba and AB Dor Bb, respectively. We have preliminary values of the individual masses of HD 160934, that are ∼0.7 M$_\odot$ for the component A and ∼0.5 M$_\odot$ for the component c.

3.2 Comparison with theoretical models

We still have to refine the determination of the masses of HD 160934. But, for the case of AB Dor B, with our result of the individual masses and with the measures of temperature and luminosity taken by [9] is possible to place each individual object in an H-R diagram to calibrate theoretical models for PMS stars. We compare with the [2] (BCAH98) and [12] (S00) models (Fig. 3). We can conclude that the mass values reported in our work are ∼40% larger than those predicted by the BCAH98 and S00 models. Our result seems to be compatible with the comparison of dynamical and theoretical masses done by other authors ([7], [13], [11]), who reported that models underpredict stellar masses by 10%-30% for PMS stars with masses in the range 0.3–1.2 M$_\odot$.

4 Conclusions and future work

The determination of dynamical masses is essential to calibrate the stellar evolution models. In particular, is necessary to obtain dynamical masses for low-mass PMS stars, because, in this case, the theoretical models underestimate the observational values. Here, we presented some results of our VLA/VLBI program focused to determine dynamical masses for PMS stars using radio techniques. Specifically, we obtained masses of $0.28\pm0.05\,M_\odot$ and $0.25\pm0.05\,M_\odot$ for AB Dor Ba and AB Dor Bb, respectively, and preliminary results of $\sim0.7\,M_\odot$ for HD 160934 A and $\sim0.5\,M_\odot$ for HD 160934 c. These results are very useful to provide new observational data to calibrate stellar evolution models for PMS stars, because there are not much values. Moreover, we are continuing with a similar study with other stars of the AB Dor-MG: EK Draconis, PW Andromedae, and LO Pegasus. The more dynamical masses we have, the better we can calibrate the theoretical models.

Acknowledgments

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