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Dynamical masses in the young triple system TWA 5

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Abstract

We report on new observations and orbit fits of TWA 5, a triple system consisting of a close pair of low-mass stars and a brown dwarf. The period of the close pair is only 6 years, allowing the determination of its orbit in a relatively short time. The third component can be used as astrometric reference to measure the motion of the binary components around their center of mass. This yields their mass ratio and hence individual masses of the stars. With the help of new observations collected in January and February 2016, we improved our orbit fits published in 2013.

1 Introduction

The system TWA 5 is one of the five original members of the TW Hydrae association (Kastner *et al.*, 1997). It consists of at least three components: a pair of low-mass stars, TWA 5Aa-b, and a brown dwarf companion, TWA 5B (see Fig. 1). TWA 5Aa-b had a separation of 55 mas when it was discovered in 2000 (Macintosh *et al.*, 2001), while TWA 5B is located about 2 arcsec away (Webb *et al.*, 1999). In Köhler *et al.* (2013), we presented an orbit fit for TWA 5Aa-b with a period of ∼6 years. We also used TWA 5B as astrometric reference to solve for the individual orbits of Aa and Ab. This allowed us to estimate the mass ratio of Aa and Ab. Due to the lack of observations in the south-west section of the orbit, the result suffered from large uncertainties. While the goal of the project is to test theoretical pre-main-sequence models, these large uncertainties precluded us from distinguishing between the models.

2 Observations and data reduction

Due to the size and orientation of the orbit of TWA 5Aa-Ab, observations with single telescopes can resolve the binary only around the times of maximum elongation to the north-east or south-west (see Fig. 2). Astrometric data was lacking in the south-west section. Our old orbit solution predicted that TWA 5Ab would reach this part of the orbit in November 2015. On four nights in January/February 2016, we obtained new astrometric observations with the adaptive optics camera NACO at the European Southern Observatory's Very Large Telescope. We observed through the J-band filter, to take advantage of the smaller diffraction limit compared to the more commonly used K-filter. Despite the small separation of only ∼30 mas, we were able to resolve the binary by using our software for speckle interferometry (e.g., Köhler *et al.*, 2000). Separation, position angle, and flux ratio of the binary were measured by fitting models to the reconstructed visibility and phase of the Fourier-transformed image. The relative position of TWA 5B was measured using PSF-fitting with the starfinder software (Diolaiti *et al.*, 2000).

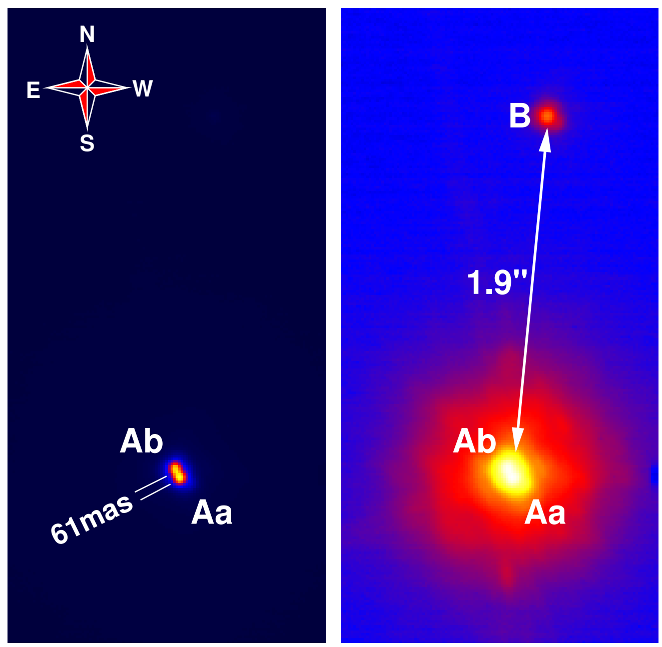

Figure 1: Image of TWA 5 taken with NACO in January 2012. Both panels show the same image, on the left with a linear scale, on the right with a logarithmic scale to unveil the low-mass companion TWA 5B.

2.1 The orbit of TWA 5Aa-Ab

To determine the orbit of TWA 5Aa and Ab around each other, we used the same method and software as in Köhler *et al.* (2013). The best-fitting orbit is shown in Fig. 2. Its orbital elements are listed in Table 1. To convert the semi-major axis from arcseconds to AU, we used a distance of 50.1 ± 1.8 pc (Weinberger *et al.*, 2013).

Compared to our orbit in Köhler *et al.* (2013), the period is

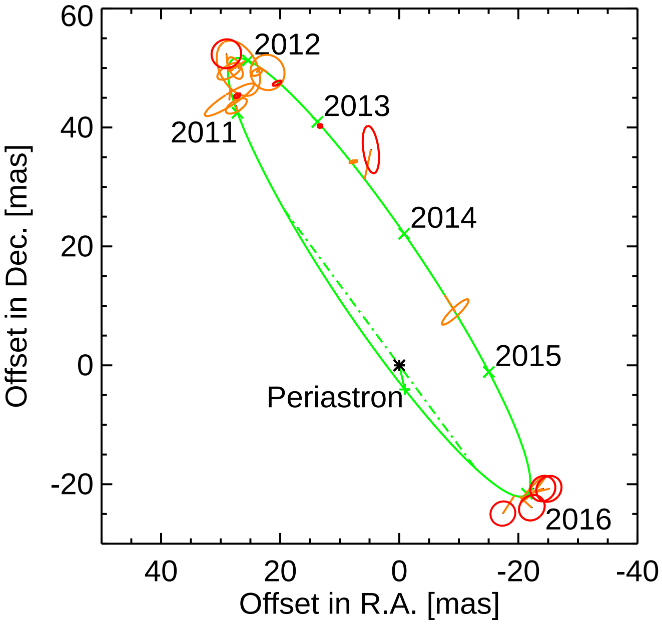

Figure 2: The orbit of TWA 5Ab around component Aa. Observed positions are marked by their error ellipses. The dash-dotted line indicates the line of nodes, the solid line the periastron. Crosses mark the expected positions at the beginning of the years 2011 to 2016.

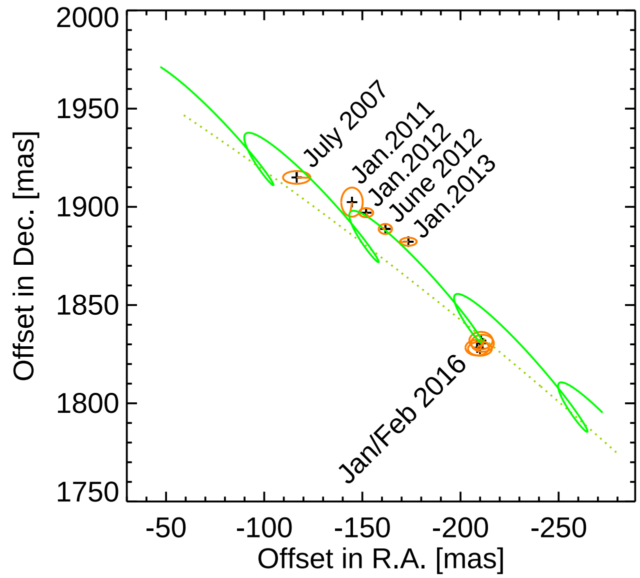

Figure 3: The motion of TWA 5B relative to the center of mass of Aa and Ab (dashed line) and relative to Aa (solid line). The dashed line is the Kepler-orbit of TWA 5B around the center of mass. The solid line is the combination of the orbit of B around the center of mass and the motion of the center of mass relative to Aa. Observed positions of TWA 5B relative to Aa are marked by their error ellipses.

Table 1: Parameters of the orbit TWA 5Aa-Ab.

Semi-major axis (AU)	3.4 ± 0.1
Period (years)	6.031 ± 0.01
Date of periastron (JD)	$2455348\,^{+9}_{-1}$ (2010 May 31)
Eccentricity	$0.790\,^{+0.004}_{-0.003}$
Argument of periastron (°)	$255.2\,^{+0.1}_{-0.2}$
P.A. of ascending node (°)	$37.0\,^{+0.3}_{-0.2}$
Inclination (°)	$97.0\,^{+0.2}_{-0.1}$
Binary Mass $M_{\mathrm{Aa+Ab}}$ ($\mathrm{M}_\odot$)	1.10 ± 0.10

marginally longer and the semi-major axis is larger. These results have to be regarded as preliminary, since we are still working on getting the best astrometric measurements and error estimates from the data.

2.2 The orbit of TWA 5B around A

We follow the method in Köhler *et al.* (2013) to estimate the orbit of TWA 5B and the mass ratio of TWA 5Aa and Ab. In short, the position of the center of mass of TWA 5Aa-Ab is described in two ways: 1) as the center of the Kepler-orbit of TWA 5B, and 2) as a point on the separation vector TWA 5Aa-Ab dividing the separation according to the mass ratio $M_{\mathrm{Aa}}/M_{\mathrm{Ab}}$. Hence, the orbital elements of TWA 5B and the mass ratio are free parameters of the fit, which are optimized to minimize the distance between the two models for the position of the center of mass. The best-fitting model is plotted in Fig. 3. Its parameters are listed in Table 2. The orbit of TWA 5B is only poorly constrained, since only ∼1 % of the orbital period has been covered by observations. However, the purpose of the orbit is only to describe the position of the center of mass at the times of the obsrrvations, in order to determine the mass ratio. This mass ratio is the most important result of the fit, and it is much better constrained than the orbital elements.

Table 2: Parameters describing the motion of TWA 5B relative to TWA 5A.

Semi-major axis (AU)	106 ± 4
Period (years)	$1000\,^{+60}_{-30}$
Triple Mass $M_{\mathrm{Aa+Ab+B}}$ ($\mathrm{M}_\odot$)	1.22 ± 0.14
Mass ratio $M_{\mathrm{Ab}}/M_{\mathrm{Aa}}$	0.93 ± 0.13

3 Results

By combining the data in Tables 1 and 2, we can derive the masses of the three objects:

$$M_{\mathrm{Aa}} = 0.57 \pm 0.07\,\mathrm{M}_\odot$$
$$M_{\mathrm{Ab}} = 0.53 \pm 0.06\,\mathrm{M}_\odot$$
$$M_{\mathrm{B}} = 0.12 \pm 0.17\,\mathrm{M}_\odot$$

As expected, TWA 5Aa and Ab turn out to be low-mass stars. At first sight, the mass of TWA 5B is too high for a brown dwarf. However, the uncertainty is large. It would be

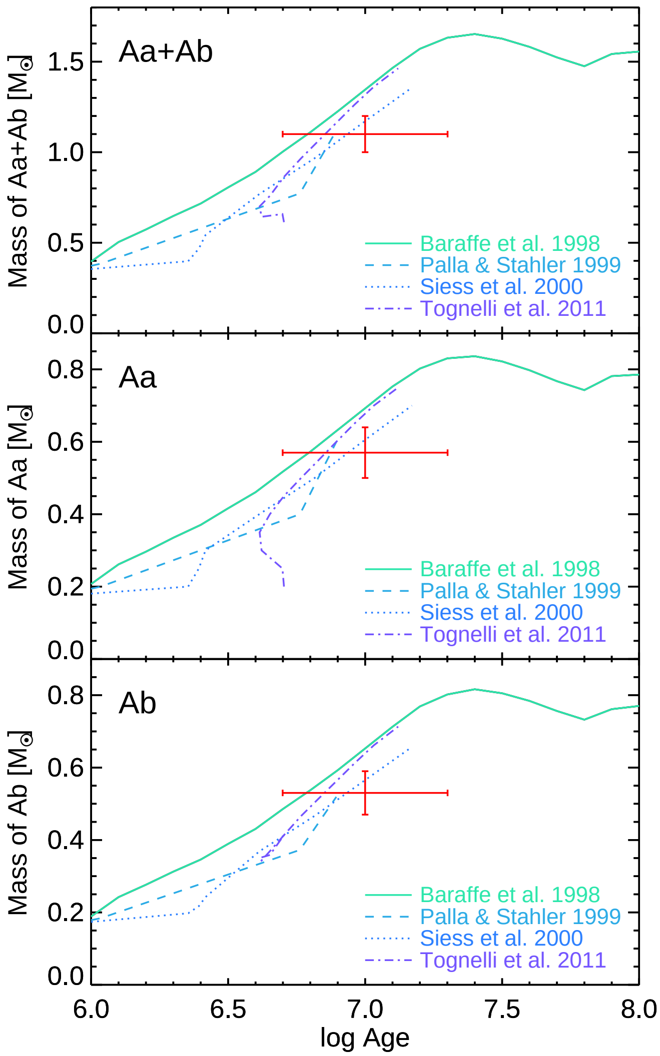

Figure 4: Mass as function of age for models with the luminosity of TWA 5Aa and Ab, respectively. The error bars mark the measured mass and age. The top panel shows the combined mass of TWA 5Aa and Ab, while the lower two panels depict the individual masses.

premature to make any statement about the physical nature of TWA 5B based on the dynamical mass.

In Fig. 4, we plot the masses predicted by a number of pre-main-sequence model calculations for stars of the same luminosities as TWA 5Aa and Ab (Baraffe *et al.*, 1998; Palla & Stahler, 1999; Siess *et al.*, 2000; Tognelli *et al.*, 2011). The age of TWA 5 is constrained to be 5 − 15 Myr by a number of methods (Weintraub *et al.*, 2000, and references therein). The comparison of the models with the measured masses shows agreement if TWA 5 is on the younger side of its estimated age range. All models can reproduce the measured mass if the age is adjusted accordingly.

4 Discussion

Our dynamical masses are in reasonable agreement with theoretical models for the pre-main-sequence evolution of stars. The errors of the mass and age determinations are still too large to distinguish between the models. We are working on improving the reduction of the new data, therefore the results presented here are only preliminary. Even these preliminary results reduced the error of the mass ratio by a factor of 4 compared to Köhler *et al.* (2013). In contrast to our estimate in Köhler *et al.* (2013), the new mass ratio indicates that the brighter binary component is also more massive, as expected for co-eval stars.

By far the largest contribution to the errors of the dynamical masses is the uncertainty of the distance or parallax. The astrometric satellite Gaia will provide much better parallaxes in the future. The first Gaia data release does contain data on TWA 5, although binary and multiple systems were supposed to be excluded (Gaia Collaboration, 2016). As a consequence, the error of the Gaia parallax is almost as large as the error of the parallax by Weinberger *et al.* (2013) (50.1 ± 1.8 pc), which was used for this work.

Acknowledgments

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