Determining the individual masses in triple system LHS 1070: a new brown dwarf star

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CAPES

Abstract

We present an astrometric analysis of the triple system LHS 1070. The public data from NIRI/GEMINI, NACO/VLT, and CIAO/SUBARU were used to improve the orbital solutions for the LHS 1070 B/C and LHS 1070 A/BC binaries. Considering LHS 1070 as an hierarchical triple system, the two orbits can be simultaneously fitted and the individual masses of the three components obtained. The best solution gives $M_A = 0.132 \pm 0.016\,M_\odot$, $M_B = 0.085 \pm 0.005\,M_\odot$, and $M_C = 0.066 \pm 0.004\,M_\odot$. Therefore, LHS 1070 is a triple system composed by two low-mass stars and a brown dwarf.

1. Introduction

LHS 1070 is a triple system of low-mass stars at a distance of $7.72 \pm 0.15\,\mathrm{pc}$ [4]. It was discovered as a triple system in 1993 by [7]. The geometrical configuration of LHS 1070 is: components B and C form a close binary with an orbital period of $\sim$ 17 yr (hereafter referred to as LHS 1070 B/C) and LHS 1070 B/C barycenter and component A form a wide binary with an orbital period of $\sim$ 85 yr [1] (hereafter referred as to LHS 1070 A/BC). To illustrate, Figure 1 shows a sequence of images of the LHS 1070 system obtained from the public archive using the adaptive optics camera NACO attached to the Very Large Telescope at European Southern Observatory (VLT/ESO).

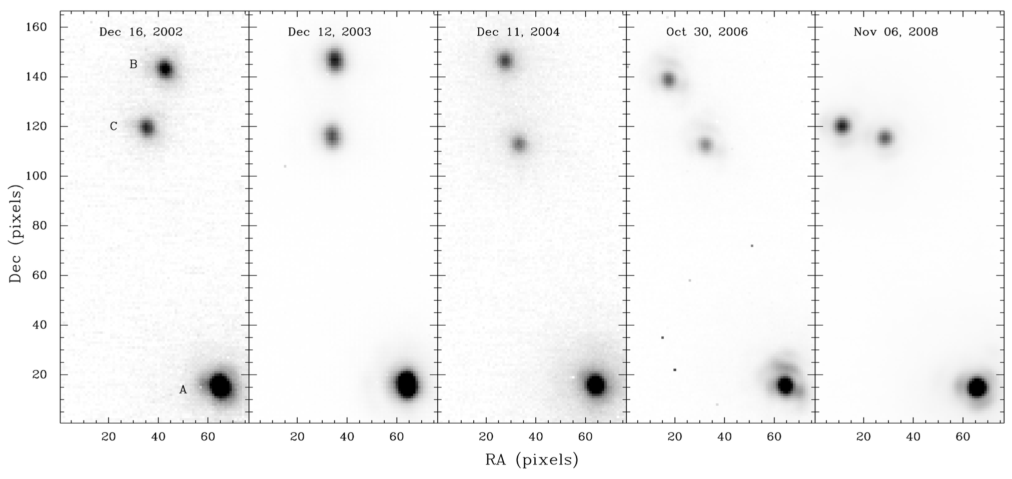

Figure 1: Sequence of images of the LHS 1070 system from NACO/VLT. The plate scale and detector orientation are 13.24 mas/pixel and zero degrees with respect to N-S orientation, respectively.

There is a great deal of interest in this system since the astrometric orbits (specially of components B+C) are well determined, making possible the derivation of precise masses. [8] derived the first orbital solution to LHS 1070 B/C. [10] improved the orbital solution for the LHS 1070 B/C binary and obtained the first distribution of the orbital parameters for LHS 1070 A/BC. They obtained for the combined mass of LHS 1070 B/C, $0.157 \pm 0.009\,M_\odot$, and for the dynamical mass of LHS 1070A/BC $0.272 \pm 0.017\,M_\odot$. The masses of LHS 1070 B and C are close to the H-burning limit making these objects interesting targets for detailed studies of the transition between low-mass stars and brown dwarfs and comparison with theoretical models. Therefore, it is important to know the individual mass of the three components. Thus, in this work, we use data from public archives as well as data from the literature for LHS 1070 to obtain the individual masses of the three components.

2. Observations and data reduction

The data were collected on public archives at VLT/ESO, GEMINI, and SUBARU. We analyzed these data together with the measurements already published in the literature.

The reduction of the photometric data was done in a standard way (i.e., linearization, sky and bias subtraction and flat-fielding division) using standard routines of IRAF. The plate scale and the CCD orientation were calibrated using astrometric wide binaries measured in every night that the target was observed. The positions of the LHS 1070 components were obtained fitting a 2D Gaussian model to describe the point spread function (PSF) of each component. We used Amoeba routine from [9] for the fitting procedure. The error was obtained considering the error in the calibration and the error in the position determination.

3. Analysis and Results

As can be seen in Figure 1, LHS 1070 can be approached as an hierarchical triple system. Thus, the dynamical analysis of LHS 1070 can be separated into two binaries: components B and C composing a close binary (LHS 1070 B/C) and component A plus the LHS 1070 B/C barycenter forming a wide binary (LHS 1070 A/BC).

3.1 Close Binary

We started with the relative positions of LHS 1070 B-C to obtain the orbital solution of the LHS 1070 B/C binary. For this, we use the genetic algorithm PIKAIA [3] to search for the global solution, followed by a Markov Chain Monte Carlo approach to explore the distribution of probability of the orbital elements. Figure 2 shows the relative positions of LHS 1070 B/C together with the best orbital solution for the LHS 1070 B/C binary and Table 1 lists the numeric values of the orbital elements with the associated $\pm 1\sigma$ uncertainties.

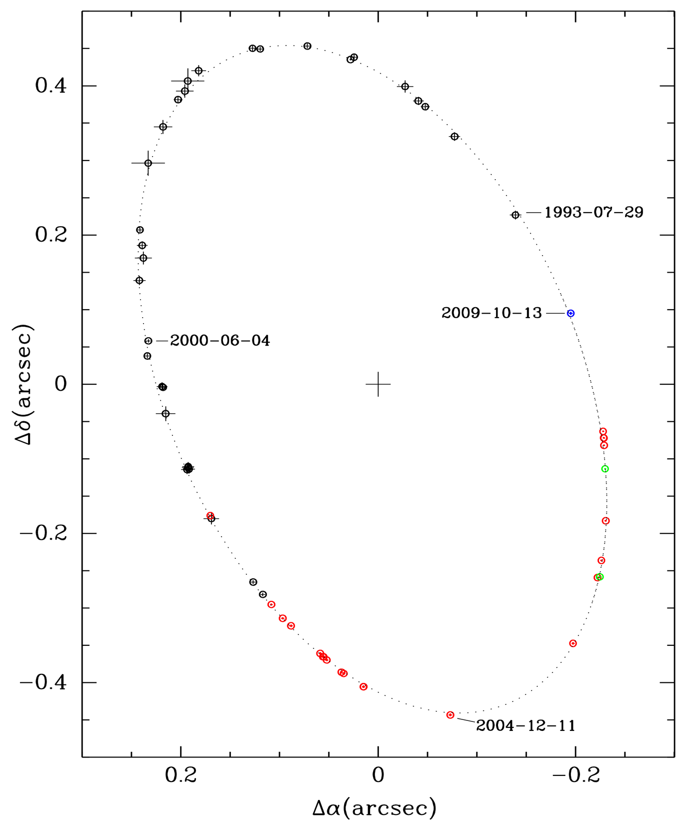

Figure 2: Relative positions of LHS 1070 B-C. The astrometric data are presented with black circles [11], red circles (VLT data), green circles (SUBARU data), and blue circle (GEMINI data). The solid line is the best orbital solution for the LHS 1070 B/C binary.

3.2 Wide Binary

To obtain the individual masses of the LHS 1070 components, the LHS 1070 A-B and LHS 1070 A-C relative positions were used to simultaneously fit the orbits of the LHS 1070 B/C and LHS 1070 A/BC binaries. As the LHS 1070 B/C orbital parameters are well determined (see Table 1), six of them $P_{\rm orb}$, T, e, i, ω, and Ω can be fixed. Thus, only the semi-major axis of the components B and C with respect to the LHS 1070 B/C barycenter and the LHS 1070 A/BC orbital parameters were leaved as free parameters in the fit procedure. However, as the available astrometric data covers a few tenths of the wide-binary orbit, was decided to scan the solutions using a grid in a wide range of orbital periods, 30−140 yr, with steps of 0.5 yr, and eccentricities, 0−0.9, with steps of 0.05. For each fixed pair of orbital period and eccentricity, the best set of parameters was searched using the genetic algorithm PIKAIA and the minimum $\chi^2_{\rm red}$ minimum saved. The result of this procedure is shown in Figure 3. In this figure, two regions can be seen around ($P_{\rm orb} \sim 45$ yr and $e \sim 0.5$) and ($P_{\rm orb} \sim 80$ yr and $e \sim 0$) with $\chi^2_{\rm red}$ minimum. Using the critical distance parameter, $\alpha_{A/BC}(1 - e_{A/BC})/\alpha_{B/C} \geq 3.3$ [5], as a stability criterion, which is represented with a dashed line in Figure 3, all solutions above this curve are long-term unstable. Thus, as the estimated age of this system is 1 Gyr [12], the solutions below $P_{\rm orb} = 78$ yr can be excluded. Finally, the best solution obtained using MCMC for LHS 1070 A/BC is shown in Table 1.

Table 1: Orbital elements for the LHS 1070 B/C and LHS 1070 A/BC binaries.

Parameter	LHS 1070 B/C	LHS 1070 A/BC
P (yr)	17.1877 ± 0.0009	84.5 ± 2.9
T_0 (yr)	1990.481 ± 0.002	1997.3 ± 1.2
$\alpha_{\rm B\text{-}C)}$ ($''$)	0.4590 ± 0.0005	
$\alpha_{\rm A/(B+C)}$ ($''$)		1.64 ± 0.03
$\alpha_{\rm (B+C)\text{-}B}$ ($''$)		0.438 ± 0.009
$\alpha_{\rm (B+C)\text{-}C}$ ($''$)		0.478 ± 0.009
e	0.026 ± 0.002	0.04 ± 0.02
i (°)	61.98 ± 0.11	64.3 ± 0.6
Ω (°)	14.36 ± 0.08	14.0 ± 0.5
ω (°)	229.0 ± 0.5	330 ± 5
[1] $M_{\rm LHS\,1070\,BC}$ ($M_\odot$)	0.149 ± 0.006	
[1] $M_{\rm LHS\,1070\,B}$ ($M_\odot$)		0.085 ± 0.005
[1] $M_{\rm LHS\,1070\,C}$ ($M_\odot$)		0.066 ± 0.004
[1] $M_{\rm LHS\,1070\,A/BC}$ ($M_\odot$)		0.283 ± 0.010
$\chi^2_{\rm red}$	2.6	5.6

[1] Using the distance of 7.72±0.15 pc [4]

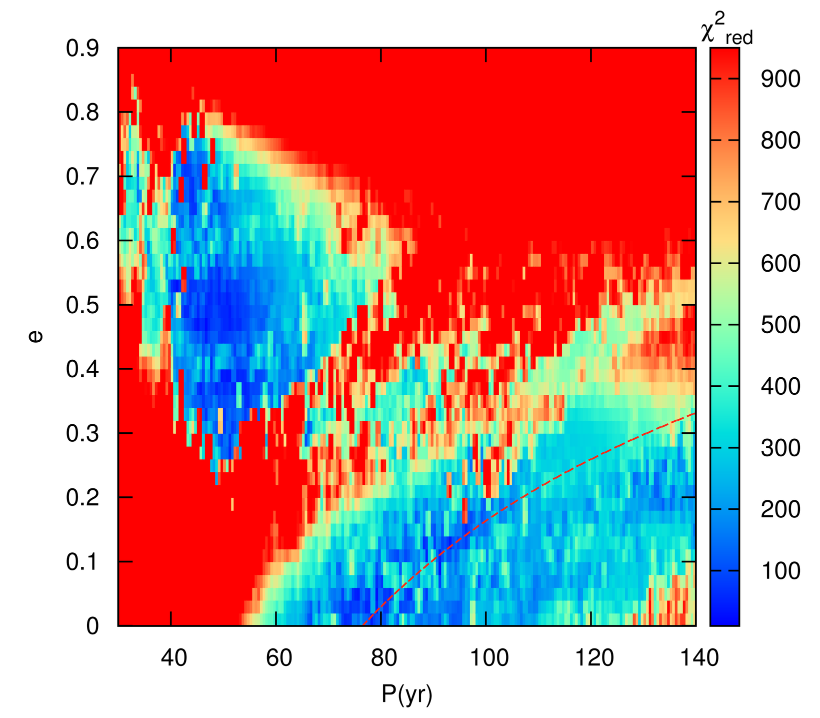

Figure 3: Orbital period versus eccentricity diagram for the LHS 1070 A/BC binary solution.

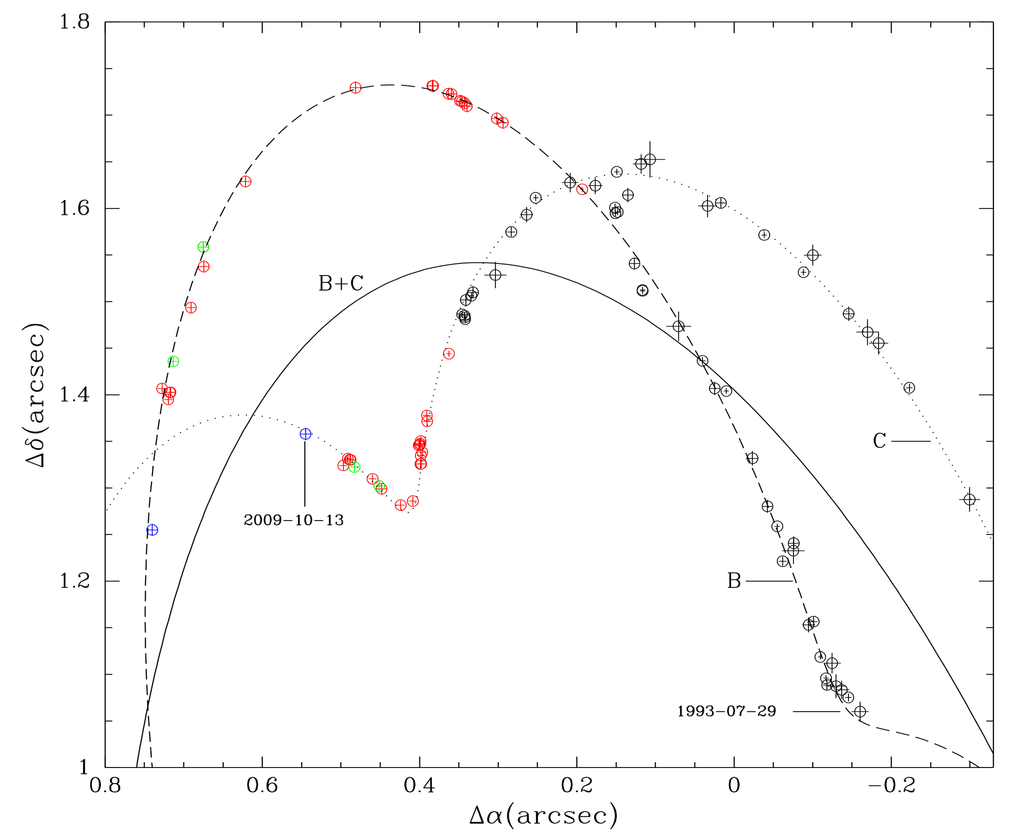

Figure 4: The best orbital solution for the LHS 1070 BC and LHS 1070 A/BC binaries. The astrometric data are presented with black circles [11], red circles (VLT data), green circles (SUBARU data), and blue circle (GEMINI data). The solid line represents the trajectory of the barycenter of LHS 1070 BC around LHS 1070 A, which is at the origin. The dashed and dotted lines are the best fits to the trajectories of components B and C around the barycenter of LHS 1070 BC.

4. Discussion

We add new measurements collected on public archives at GEMINI, VLT/ESO and SUBARU to the dynamical analysis. Considering the system as an hierarchical triple system, we can simultaneously fit the LHS 1070 A/BC and LHS 1070 B/C orbits and derive the individual masses of the B ($M_{\rm LHS\,1070\,B} = 0.085 \pm 0.005\,M_\odot$) and C ($M_{\rm LHS\,1070\,B} = 0.066 \pm 0.004\,M_\odot$) components and the dynamical mass of the whole system $M_{\rm LHS\,1070\,A/BC} = 0.283 \pm 0.010$. Subtracting from the total mass the well-constrained combined mass of LHS 1070 B/C, $M_{\rm LHS\,1070\,B/C} = 0.149 \pm 0.006$, one obtains $M_A = (0.132 \pm 0.016)\,M_\odot$. Therefore, LHS 1070 has in its composition two low-mass stars (components A and B) and a brown dwarf (component C).

Once obtained the individual masses of the three components, we can compare the result with the magnitude-mass relationship from theoretical and empirical models. Figure 5 shows the M_V − mass relationship for the low-mass stars and brown dwarfs range. In this figure, the dashed and dotted lines represent the theoretical model for 1 Gyr [2] and the empirical relation obtained by [6], respectively. We notice that, both, theoretical and empirical relations, do not explain all three components locations.

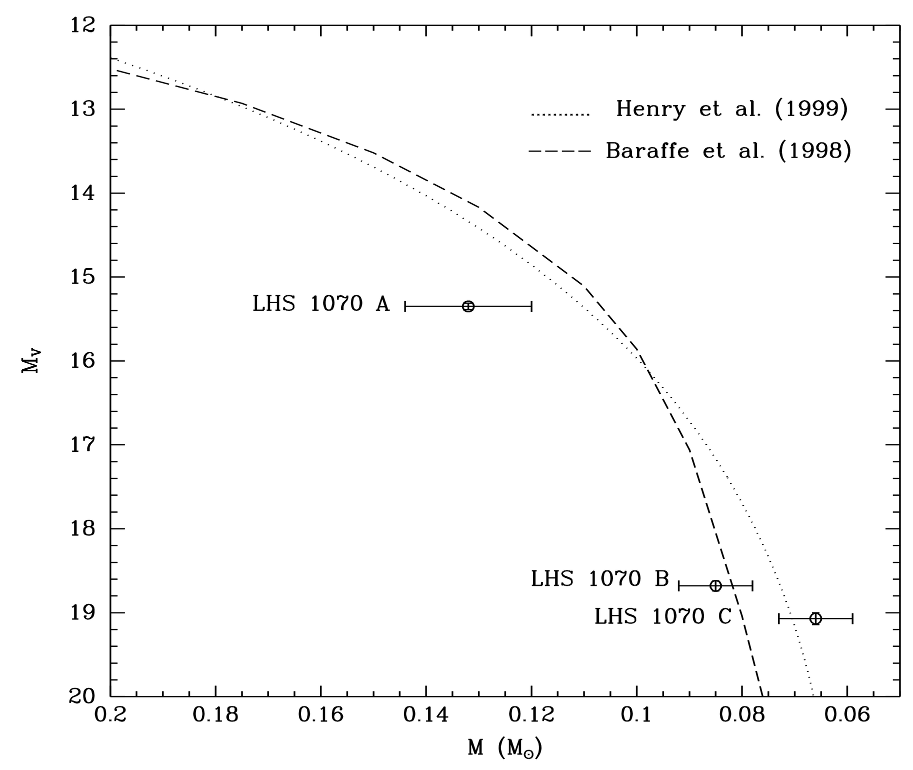

Figure 5: Magnitude-mass relationship on the low-mass star and brown dwarf domains. The dashed and dotted lines represent the theoretical models for 1 Gyr obtained by [2] and the empirical relationship from [6].

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