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Evidence of a Substellar Companion to AB Dor C

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Abstract

Studies of fundamental parameters of very low-mass objects are indispensable to provide tests of stellar evolution models that are used to derive theoretical masses of brown dwarfs and planets. However, only objects with dynamically determined masses and precise photometry can effectively evaluate the predictions of stellar models. AB Dor C (0.090 $M_{\odot}$) has become a prime benchmark for calibration of theoretical evolutionary models of low-mass young stars. One of the ambiguities remaining in AB Dor C is the possible binary nature of this star. We observed AB Dor C with the VLTI/AMBER instrument in low-resolution mode at the *J, H*, and *K* bands. The interferometric observables at the *K* band are compatible with a binary brown dwarf system with tentative components AB Dor Ca/Cb with a *K*-band flux ratio of 5% ± 1% and a separation of 38 ± 1 mas. This implies theoretical masses of 0.072 ± 0.013 $M_{\odot}$ and 0.013 ± 0.001 $M_{\odot}$ for each component, near the hydrogen-burning limit for AB Dor Ca, and near the deuterium-burning limit, straddling the boundary between brown dwarfs and giant planets, for AB Dor Cb. The possible binarity of AB Dor C alleviates the disagreement between observed magnitudes and theoretical mass–luminosity relationships.

Unified Astronomy Thesaurus concepts: Binary stars (154); Interferometric binary stars (806); Low mass stars (2050); Brown dwarfs (185); Exoplanets (498); Interferometry (808); Infrared astronomy (786); Pre-main sequence stars (1290); Young stellar objects (1834); Stellar evolutionary models (2046); Stellar evolution (1599); Stellar evolutionary tracks (1600)

1. Introduction

Stellar evolution models are essential to infer star fundamental parameters such as radius, mass, and/or age. Their reliability has long been tested and validated by the general good agreement between predictions and measurements. However, only recently have accurate measurements of stellar masses and radii become accessible in the case of low- and very low-mass stars, thus allowing more stringent tests on stellar models. In the particular case of pre-main-sequence (PMS) stars, the models show an increasing difficulty in accurately reproducing some of the characteristics of a star with masses below 1.2 $M_{\odot}$ (see, e.g., Hillenbrand & White 2004; Gennaro et al. 2012; Stassun et al. 2014).

Only stellar systems with dynamically determined masses can effectively be used to test and check the predictions of the models (see recent works of Dupuy & Liu 2017 and Mann et al. 2019). AB Doradus (AB Dor) represents one such case. It is a PMS quadruple system formed by two pairs of stars separated by 9″, AB Dor A/C and AB Dor Ba/Bb (Close et al. 2005; Guirado et al. 2006), giving name to the AB Doradus moving group (AB Dor-MG). The main star of this system, the K0 dwarf AB Dor A ($K_s = 4.686$) has been extensively studied at all wavelengths, from the UV to radio (Gómez de Castro 2002; Guirado et al. 1997). Precise *Hipparcos* and very long baseline interferometry (VLBI) observations provided an accurate distance measurement (d = 15.06 ± 0.07 pc) and revealed the presence of AB Dor C, a low-mass companion with 0.090 $M_{\odot}$, orbiting AB Dor A at an average angular distance of 0$''\!.$2 (Guirado et al. 1997). The pair AB Dor A/C has also been observed by different near-infrared instruments at the Very Large Telescope (VLT; Close et al. 2005, 2007; Boccaletti et al. 2008), allowing independent photometry of AB Dor C ($K_s = 9.5$), which, along with the dynamical mass determination, served as a benchmark for young, low-mass stellar evolutionary models (Azulay et al. 2017 and references therein).

Previous comparisons of observed magnitudes with theoretical mass–luminosity relationships suggested that the models tend to underpredict the mass of AB Dor C or, equivalently, overpredict the flux of the object, especially at the *J* and *H* bands (Close et al. 2005). This disagreement was also noted in studies of the other pair of the system, AB Dor Ba/Bb (Wolter et al. 2014; Janson et al. 2018). The authors argued that theoretical models tend to be consistent in the case of young moving groups but not in older associations such as the AB Dor moving group. This tendency was reinforced by the study of other members of this moving group, such as GJ 2060 AB (Rodet et al. 2018) or LSPM J1314+1320 AB (Dupuy et al. 2016). In the case of AB Dor C, most of the difficulty in validating the model predictions comes from the uncertainty in age and the possible binary nature of the object. Regarding the latter, Marois et al. (2005) pointed out that if AB Dor C were a binary brown dwarf, the overluminosity shown by the models, including the permanent disagreement in the *J* and *H* filters, could easily be corrected assuming reasonable mass ratios. Indeed, the determination of the possible binary nature of AB Dor C is an important issue for an object acting as calibrator of young, low-mass objects that needs to be addressed.

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In this Letter we present interferometric evidence of the presence of a low-mass companion to AB Dor C from VLT Interferometer (VLTI) observations performed with the Astronomical Multi-BEam combineR (AMBER) focal instrument (Petrov et al. 2007), installed at the ESO facilities in Cerro Paranal, Chile. Attempts to observe this object with the GRAVITY instrument are also reported. We describe the observations and data reduction in Section 2. The analysis is presented in Section 3 and the comparison with stellar models and discussion are presented in Section 4. Finally, in Section 5 we present our conclusions.

2. Observations

The observations of AB Dor C were performed with the VLTI using the AMBER instrument with the external fringe tracker Fringe-Tracking Instrument of NIce and TOrino (FINITO) in low-resolution mode at the *J, H*, and *K* bands (programme 090.C-0559(A)). However, due to a technical problem, the *J* band did not perform well and was not used in our analysis. The *H* band was tested but finally also discarded in the analysis, as discussed below. The observations were performed on 2012 December 28 from 02:40 to 04:40 UT using the 8.2 m unit telescopes (UT) with the configuration UT1-UT2-UT4. Due to the faint magnitude of AB Dor C ($K_s = 9.5$), we used a nonstandard observing configuration that consisted of using AB Dor A as a fringe tracker to increase the integration time on AB Dor C. To achieve this, first we set AMBER in low-resolution mode with a DIT of 0.1 s; second, we found and locked the fringes of AB Dor A in the fringe tracker FINITO; and third, we offset AMBER (through tip/tilt correction) to find the fringes of AB Dor C. This "off-axis" fringe tracking allowed an exposure time on AB Dor C longer than that imposed by the atmospheric piston. Fringes were seen in every single frame (see Figure 1), which could be properly averaged to obtain the visibility data. The procedure above benefited from (i) a precise knowledge of the orbit of AB Dor C (Guirado et al. 2006), which allowed us to predict with milliarcsecond precision the relative position AB Dor A/C; (ii) an optimum observing epoch, 2012 December, with AB Dor C near apoastron (0.″42 separated from A; see Figure 2), thus minimizing the possible contamination from the brighter star AB Dor A; and (iii) good atmospheric conditions with a seeing of ∼0.″7. The star HD 35199 (disk-equivalent diameter of 0.86 mas; Mérand et al. 2006) was also observed to calibrate the AB Dor C visibilities. The logs of these observations are shown in Table 1.

In addition to the AMBER data, 4 hr of VLTI/GRAVITY time were allocated (program 0102.C-0297, with the telescopes UT1-UT2-UT3-UT4) and scheduled on 2017 December 9 to confirm our findings. However, the proximity of the much brighter AB Dor A (located at 0.″2 from C) during the observing epoch prevented AB Dor C to be properly identified in the GRAVITY acquisition camera, therefore making the observation technically unfeasible.

3. Data Reduction and Analysis

We obtained the raw visibility data using the software package amdlib v.3.0.8[7] (Tatulli et al. 2007; Chelli et al. 2009). We selected and averaged the resulting visibilities of each frame using different criteria for the baseline flux and for the fringe signal-to-noise ratio (S/N; for more information see the AMBER Data Reduction Software User Manual[8]). In particular, (i) we selected frames having a baseline flux with an S/N larger than 1, 2, 3, 4, 5, 6, 7, 10, 15, and 20; (ii) for each of these selections, we kept 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 100% of the remaining frames with the highest fringe S/N, which effectively created a grid of 10 × 10 reduced data sets with different selection criteria; (iii) we made extensive tests to determine the robustness and consistency of each one of the data sets above (basically, we compared each data set to simulated visibilities of different source geometries, discarding those data sets producing unacceptable fits); and (iv) based on the previous tests, we selected the data set containing 5% of the frames with highest fringe S/N chosen from those with a baseline flux S/N larger than 6. The calibration of the transfer function was made using the calibrator star HD 35199.

The values of the squared visibilities panel (Figure 3, left) are far from corresponding to those of a pointlike source;

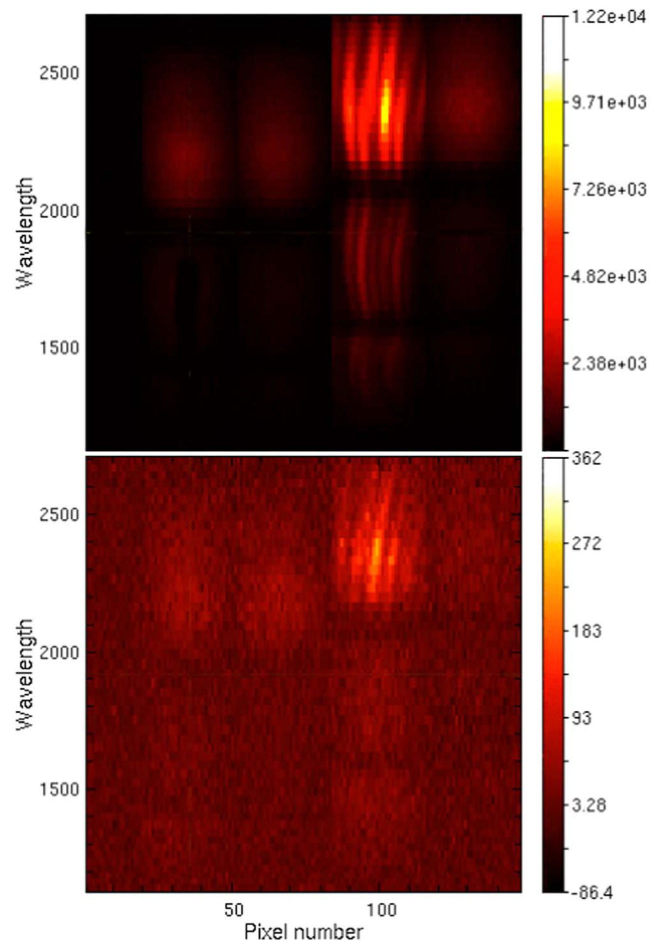

Figure 1. AMBER raw detector image (single frame) obtained with the triplet UT1-UT2-UT4 in low-resolution mode on AB Dor A (upper plot) and AB Dor C (lower plot), the latter taken with a nonstandard, off-axis fringe-tracking configuration (see the text). The upper (lower) half of the plots corresponds to the *K* (*H*) band. From left to right, the first, second, and fourth columns represent the photometric beams for each one of the three telescopes, while the third column contains the interferometric signal. Notice the clear *K*-band detection on AB Dor C. The ratio between the intensity of both interferometric channels roughly indicates the flux ratio between AB Dor A and C.

[7] The AMBER reduction package amdlib is available at http://www.jmmc.fr/data_processing_amber.htm.

[8] http://www.jmmc.fr/doc/approved/JMMC-MAN-2720-0001.pdf

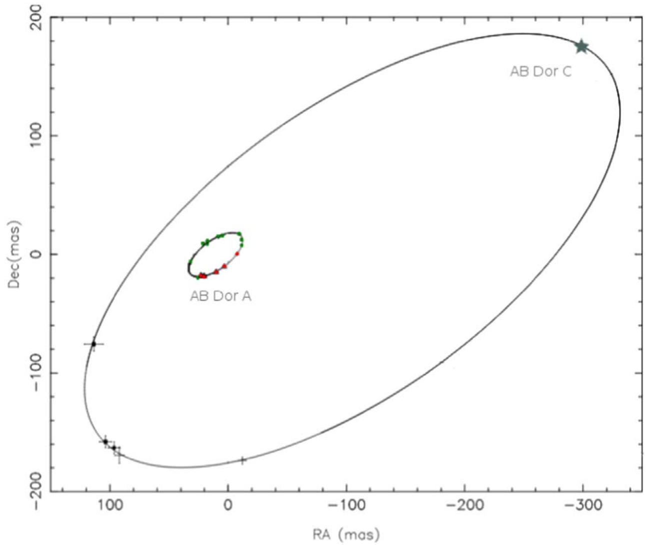

Figure 2. Absolute orbits of AB Dor A and AB Dor C, adapted from Azulay et al. (2017). The map is centered at the center of mass of the system. Measured positions of AB Dor A are marked with red (Hipparcos data) and green (VLBI data) dots. Previous VLT/NACO measurements of AB Dor C are plotted with points, while the expected position of AB Dor C at the time of our observation (2012.9918) is marked by a star.

Table 1
Observation Log of AB Dor C and Calibrators

Obs. Time	Target	Triplet	Mode	Seeing
2012 Dec 28 02:40	HD 35199	U1-U2-U4	Low *JHK*	0.″79
2012 Dec 28 03:17	AB Dor C	U1-U2-U4	Low *JHK*	0.″63
2012 Dec 28 03:43	AB Dor C	U1-U2-U4	Low *JHK*	0.″72
2012 Dec 28 04:17	AB Dor C	U1-U2-U4	Low *JHK*	0.″74
2012 Dec 28 04:40	AB Dor A	U1-U2-U4	Low *JHK*	0.″74

Note. Due to the nonstandard observing configuration (see the text), HD 35199 could only be observed at the beginning of the observation.

rather, they indicate either the presence of an extended structure around AB Dor C, and/or the binary nature of the object. Actually, the sinusoidal behavior seen in the visibilities is a typical signature of a binary system (e.g., Millour et al. 2009). Supporting the previous statement, the closure phase (Figure 3, right) displays a nonnegligible departure from the null value, indicating that the contrast between binary components should be relatively high (Monnier 2003). The fact that the visibilities do not decrease with baseline suggests, in principle, that the components are not resolved.

We performed an exhaustive and systematic search for companions to AB Dor C using the software CANDID[9] (Gallenne et al. 2015). CANDID performs a least-squares fit of both the companion position and flux ratio at each starting position of a 2D grid using the interferometric observables, the squared visibilities, and the closure phases. We first used CANDID with only K-band data, revealing a companion to AB Dor C at a level of 24σ with separation and flux ratio detailed in Table 2, where the number of sigmas indicates how significant the binary model is compared to a single star and is computed using formula (8) in Gallenne et al. (2015). In agreement with this, the calculation of the corresponding χ^2 for both the single and binary scenarios yields a clear preference for the presence of a companion: $\chi^2_{\rm single}$=14.07 and $\chi^2_{\rm binary} = 2.60$.

On the other hand, the quality of the fit is degraded (from 24σ to 16σ) when using both the K and H bands, adding, at least, another spurious solution. Moreover, no detection is found with CANDID when using only the H band. Given the results above, we conservatively restricted our interferometric data set to K band only.

To assess the validity of the CANDID results, we also fitted the observed visibilities with the Lyon Interferometric Tool prototype (LITpro), developed by the Jean-Marie Mariotti Center (JMMC; Tallon-Bosc et al. 2008). We used a simple two-point model to simulate the suspected binary nature of AB Dor C. In contrast to the CANDID procedure, LITpro does not perform a systematic search of the parameters; therefore, aiming at identifying the best model, we initialized the fitting program with different sets of values for the free parameters, namely: flux ratio, binary separation, and position angle. In practice, we explore the following parameter space around the CANDID position: flux ratio between 2% and 8% in steps of 0.5%, separation between 25 and 50 mas in steps of 0.5 mas, and P.A. between 140° and 220° in steps of 0.°5. We selected as plausible fits the range of χ^2 values that correspond to a 95% confidence interval. The results of this parameter search are given in Table 2, and coincide, within uncertainties, with the position found with the CANDID software and the K band, strengthening the validity of our binary hypothesis for AB Dor C. Given the plausibility of the results obtained with this binary model (and, admittedly, to avoid a possible overinterpretation of the data), we did not explore more complicated geometries with LITpro (i.e., binary with disks or envelopes).

From the analysis above, we conclude that AB Dor C is a binary system with components separated by 38 ± 1 mas, and a flux ratio at the K band of 5% ± 1%, where the uncertainties have been conservatively enlarged to cover the results of both software.

4. Results and Discussion

The interferometric results presented allow us to characterize the components of the tentative binary in AB Dor C (AB Dor Ca/Cb). The combination of the flux ratio (Cb/Ca), 5% ± 1%, with the total (Ca+Cb) K_s absolute magnitude of 8.38 ± 0.16 (Boccaletti et al. 2008) implies a binary with magnitudes $K_s = 8.43 \pm 0.16$ and $K_s = 11.7 \pm 0.3$ for Ca and Cb, respectively.

4.1. Comparison with Evolutionary Models

With the individual magnitudes of the components, an estimate of the individual masses can be obtained by using PMS evolutionary models. We computed the models using the Pisa stellar evolutionary code (Tognelli et al. 2018) for masses in the range 0.01–0.4 $M_\odot$ and solar metallicity ([Fe/H] = 0). We also used an interpolation of the DUSTY models (Chabrier et al. 2000) and BHAC15 models (Baraffe et al. 2015) to infer the dependence of the derived parameters on the adopted evolutionary tracks. The boundary between DUSTY and BHAC15 models was based on mass, with each model covering the ranges of 0.001–0.1 $M_\odot$ for the former and 0.01–1.4 $M_\odot$ for the latter.

[9] Companion Analysis and Non-Detection in Interferometric Data, available at https://github.com/amerand/CANDID.

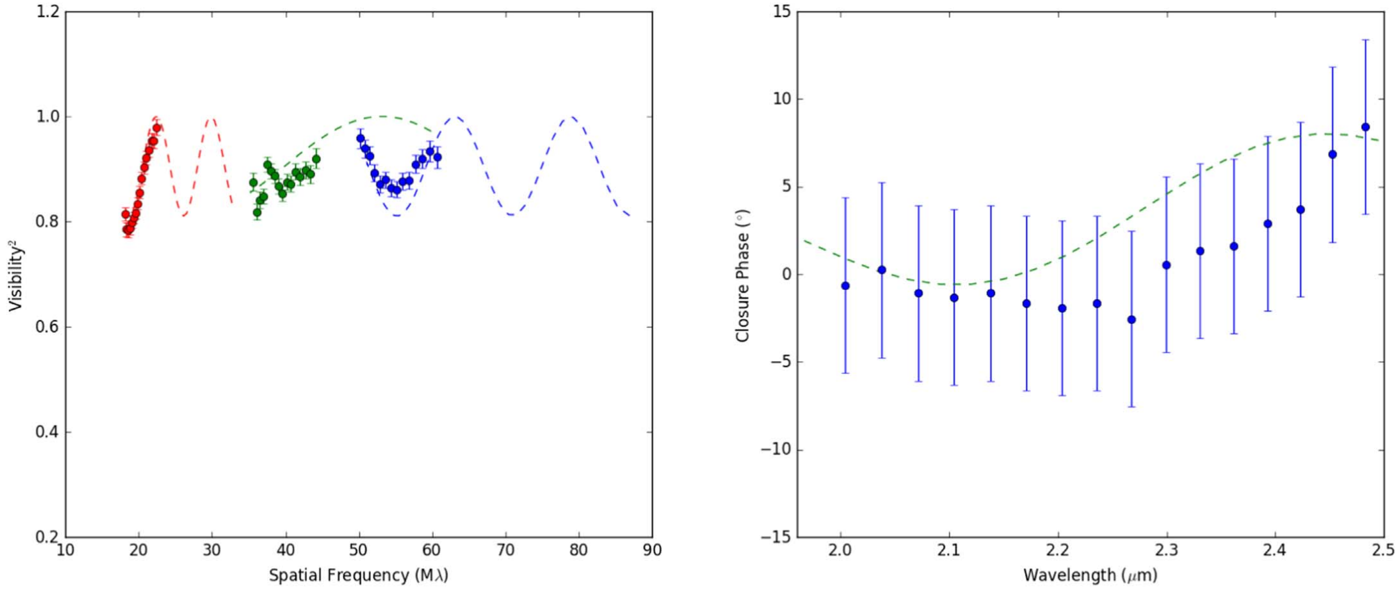

Figure 3. (left) AMBER visibilities of AB Dor C. Different colors represent different baselines. The K-band observational data (circles) are best fitted by a binary system with the properties given in Table 2 with the CANDID K-band method and whose visibilities are plotted in colored discontinuous lines. (right) AMBER K-band closure phases of AB Dor C. Blue dots correspond to observational data, while the dashed line represents the theoretical closure phases of the model given above. Indeed, the deviation from 0° suggests that AB Dor C is not a point source and possesses a more complex structure, modeled here by a binary.

Table 2
Best-fitting Binary-model Parameters for AB Dor C

Method	Flux Ratio	Separation (mas)	P.A (°)
CANDID K band	0.054 ± 0.004	38.1 ± 0.2	178 ± 1
LITpro	0.05 ± 0.01	39 ± 1	177 ± 1

Following the procedure described in Section 4.2 of Liu et al. (2008), we used these evolutionary models and our inferred magnitudes of Ca and Cb to estimate the mass of each one of the components; the sum of these masses is the the total mass of the system, which is represented against the age in Figure 4. The shadowed gray area indicates the possible combinations of masses for Ca and Cb accomplishing that the total mass of the system lies within the measured dynamical mass of 0.090 ± 0.008 $M_{\odot}$ for AB Dor C (Azulay et al. 2017). This implies masses of 0.072 ± 0.013 $M_{\odot}$ and 0.013 ± 0.001 $M_{\odot}$ for each one of the components of the binary, which interestingly lie near the hydrogen-burning limit for the case of AB Dor Ca, and near the deuterium-burning limit, straddling the boundary between brown dwarfs and giant planets, for the case of AB Dor Cb. Given the relatively large mass ratio between AB Dor Ca/Cb, we notice that the tentative binarity of AB Dor C would not result in a substantial change in the age range when compared with previous estimates based on the same evolutionary models (Azulay et al. 2017). Likewise, the presence of AB Dor Cb does not affect the age determinations based on model isochrones fitting to the members of the AB Dor moving group (Bell et al. 2015).

4.2. Binary Hypothesis and Photometry

How is the interpretation of published AB Dor C photometry affected by our binary hypothesis? In Figure 5 we represent the cooling curves of AB Dor Ca/Cb (models by Tognelli et al. 2018) compared with published AB Dor C photometric measurements (Close et al. 2005, 2007; Luhman & Potter 2006;

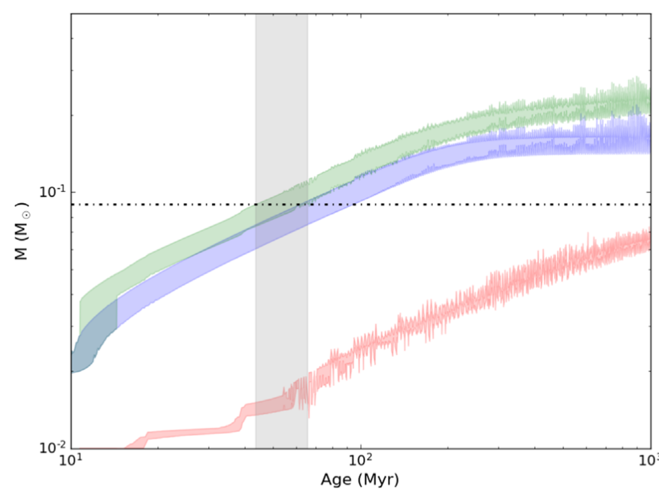

Figure 4. Mass vs. age at constant K_s magnitude: 8.43 ± 0.16 (blue; Ca) and 11.7 ± 0.3 (red; Cb) and the corresponding binary system (green; Ca+Cb). A dashed–dotted line represents the measured dynamical mass of 0.090 $M_{\odot}$ (Azulay et al. 2017), while the shadowed gray area represents the age range (44–66 Myr) resulting from the intersection of this measured dynamical mass with the measured Ca+Cb magnitude, according to the models by Tognelli et al. (2018). The irregularities in the model are more likely a product of the interpolation than a real physical effect. The use of the DUSTY+BHAC15 models produces very similar results.

Boccaletti et al. 2008) for the two scenarios considered: (1) the (old) single-object scenario (with AB Dor C as a single object of 0.090 $M_{\odot}$) and (2) the (new) binary scenario resulting from our detection (with AB Dor C as a binary with estimated masses of 0.072 $M_{\odot}$ and 0.013 $M_{\odot}$, according to the parameters given in Table 2). Published magnitudes at the J, H, and K bands are shown for the two most-considered age ranges in the literature: 75 ± 25 Myr (Janson et al. 2007; Boccaletti et al. 2008) and 120 ± 20 Myr (Luhman et al. 2005; Ortega et al. 2007), the latter being favored by the recent works of Bell et al. (2015) and Gagné et al. (2018).

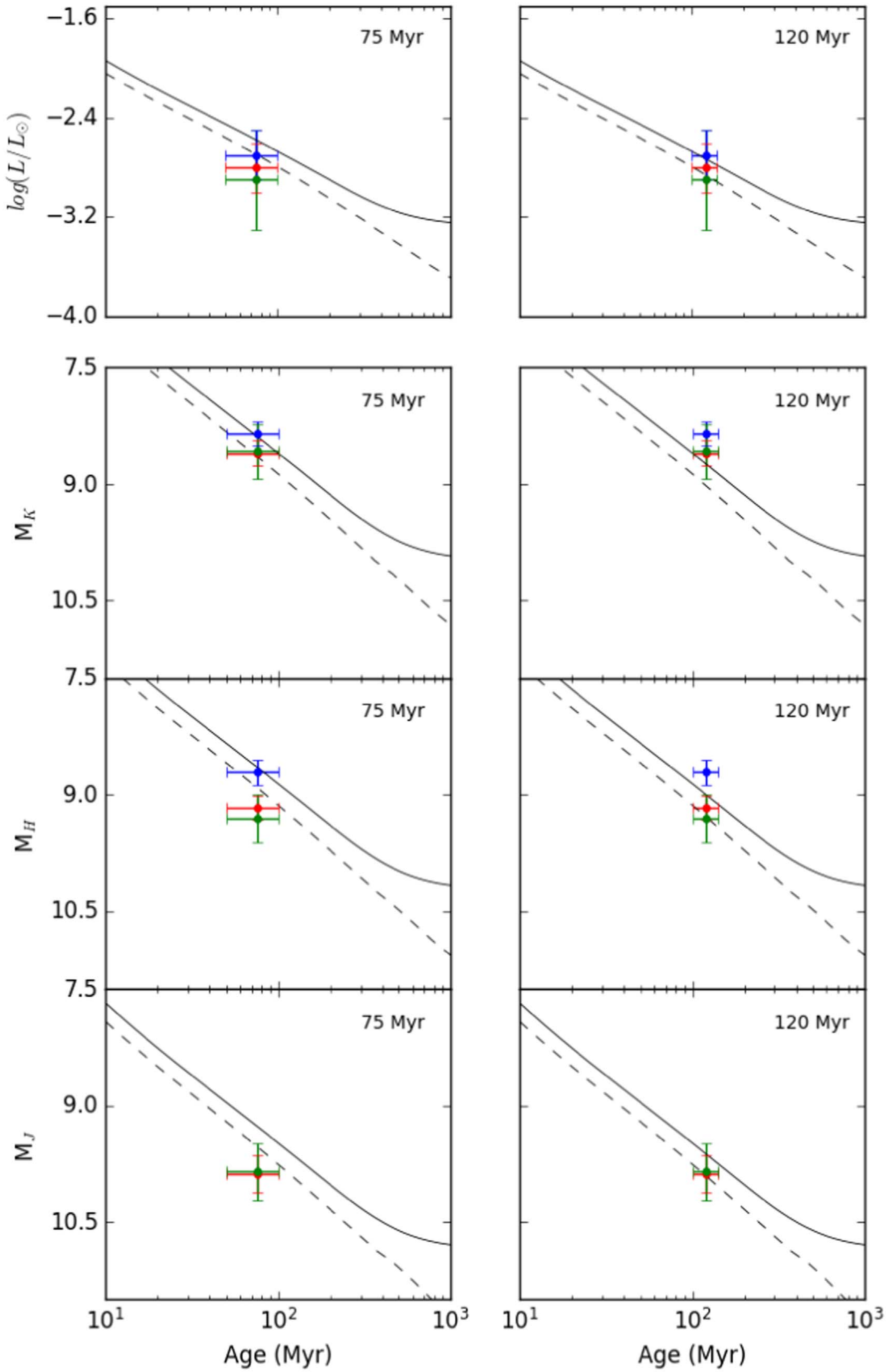

Figure 5. Evolutionary tracks of theoretical models (Tognelli et al. 2018) for a single object of 0.090 $M_{\odot}$ (solid) and a binary system of 0.072 ± 0.013 $M_{\odot}$ and 0.013 ± 0.001 $M_{\odot}$ (dashed) compared with photometric measurements of Luhman & Potter (2006; green dots), those of Close et al. (2007; red dots), and those of Boccaletti et al. (2008; blue dots). The first row represents the bolometric luminosity derived from the photometric measurements and the bolometric corrections found in Filippazzo et al. (2015). The second, third, and fourth rows are for *K, H*, and *J* photometry, respectively. The left plots represent the first age scenario (75 ± 25 Myr) and the right plots represent the second one (120 ± 20 Myr). The DUSTY+BHAC15 models produce extremely similar results.

For the discussion that follows we use solely the fact that AB Dor C may be a binary system with masses 0.072 $M_{\odot}$ and 0.013 $M_{\odot}$ (as obtained in Section 4.1) and previously reported photometric measurements. As we can see in Figure 5, for an age of 75 Myr (left column plots), the binary hypothesis produced an overall better agreement considering all the three bands than the single-object hypothesis. In fact, the binary tracks are compatible (to within 1.2σ of the showed uncertainties), with all the photometric measurements, slightly favoring those reported by Close et al. (2007) and Luhman & Potter (2006). Turning to the age of 120 Myr (right column plots in Figure 5), we found that the binary track nicely reproduces the J-band measurements; however, the tracks for this older age range seems to underestimate some of the H- and K-band measurements (especially those from Boccaletti et al. 2008). The most relevant result of the comparisons above is that the small disagreements in the J and H bands reported by Luhman & Potter (2006) and Close et al. (2007) are partially alleviated (for an age of 75 Myr), or completely removed (for an age of 120 Myr), considering AB Dor C as a binary system.

We also estimated the bolometric luminosity ($L_{\rm bol}$) using the photometric published measurements and the bolometric corrections found in Pecaut & Mamajek (2013) and Filippazzo et al. (2015). Both corrections produce very similar results and are consistent within the errors. Conservatively we adopt the bolometric correction value of 3.10 $\pm$ 0.13 from Filippazzo et al. (2015) for an M7 dwarf. Differences in bolometric luminosity or in magnitudes could highlight two scenarios. On one hand, a discrepancy in luminosity would suggest problems in the fundamental physics used to compute very low-mass stars models, in particular due to the adopted equation of state, outer boundary conditions, magnetic fields, and surface spots (Siess 2001; Chabrier et al. 2007; di Criscienzo et al. 2010; Feiden & Chaboyer 2013; Somers & Pinsonneault 2015; Tognelli et al. 2018). On the other hand, a difference visible only in magnitudes should point out the need for more accurate synthetic spectra, which, especially in the case of low- and very low-mass stars, still represents a challenging task. The top panels of Figure 5 show that the binary scenario produces a slightly better agreement with the estimated bolometric luminosities. This is especially notable at the younger age of 75 Myr. Although small, this effect may be pointing to a problem in the fundamental physics used in very low-mass stars models, as previously stated.

Regarding the spectral type of AB Dor C, and according to the binary scenario, the M5.5 $\pm$ 1 classification reported by Luhman & Potter (2006) should be assigned to the heavier component of the system, AB Dor Ca. To obtain an estimate of the spectral features of the weaker component Cb we used the color–magnitude calibration provided by Zapatero Osorio et al. (2014), in turn based on the least massive population, brown dwarfs, and giant planets, belonging to the Pleiades cluster (age 120 Myr). Following this calibration, and for a K_s magnitude of 11.7 $\pm$ 0.3 (Section 4), a spectral type of L4–6 could be expected for component AB Dor Cb.

4.3. Orbit and Stability of AB Dor Ca/Cb

Although our interferometric measurements do not provide any information about the orbit of Cb and Ca, we can derive estimates for the semimajor axis using the conversion factors from projected separation to semimajor axis provided by Dupuy & Liu (2011). The median values given in their Table 6 for very low-mass binaries range from 0.85 to 1.16, which, considering our Ca/Cb separation (38.1 mas) and the dynamical mass of AB Dor C (0.090 $M_{\odot}$), translate to a semimajor axis for the Ca/Cb orbit of 32.4–44.2 mas with a period of 418–666 days. The Ca/Cb binary is, in turn, orbiting the 0.89 $M_{\odot}$ AB Dor A with a period of 11.78 yr (Azulay et al. 2017). It is obvious that the complete system is dynamically dominated by the presence of AB Dor A, and accordingly, its gravitational pull exerted on the inner orbit Ca/Cb should be evaluated to ascertain if the latter pair is in a stable orbit. For this purpose (and neglecting the effect of the 9$''$ apart AB Dor Ba/Bb) we can consider AB Dor as a triple system (A, Ca, Cb) where AB Dor Cb is in an S-type orbit, that is, Cb is orbiting near one of the bodies (Ca) while the third body (AB Dor A) acts as a perturber. The critical semimajor axis at which the orbit of the system Ca/Cb is stable depends on the eccentricity of the binary A/C, the mass ratio A/C, and the separation between the host object (Ca) and the perturber (A). Assuming the estimated mass of AB Dor Ca, and adopting the orbital parameters of AB Dor C around AB Dor A given in Azulay et al. (2017), the formulae provided by Holman & Wiegert (1999) yield stable orbits for AB Dor Ca/Cb for separations <50 mas. This implies that our measured separation for the binary in AB Dor C ($\sim$38 mas) would correspond to a stable binary system. A similar conclusion can be reached following a different reasoning based on the simulations of Musielak et al. (2005): according to their Figure 1, stable S-type orbits are obtained for the estimated distance ratio ($d_{\rm Ca-Cb}/d_{\rm A-C} \sim 0.27$) and mass ratio ($M_{\rm C}/M_{\rm A} \sim 0.10$) of the triple system AB Dor A/Ca/Cb.

Finally, should AB Dor Cb have been detected in previous observations? The presence of the solar-type star AB Dor A ($K_s = 4.686$) at only 0$''$.2 made it extraordinarily difficult to detect and characterize AB Dor C ($K_s = 9.5$; Close et al. 2005, 2007), given the high-contrast imaging needed in the vicinity of AB Dor A; as AB Dor Cb is about three magnitudes weaker, it is very likely that this newly discovered companion remained unnoticed in the observations reported by Close et al. (2007) or Boccaletti et al. (2008). Assuming a face-on, circular orbit and masses of 0.072 $\pm$ 0.013 $M_{\odot}$ and 0.013 $\pm$ 0.001 $M_{\odot}$ for AB Dor Ca/Cb, the radial velocity semi-amplitude produced in Ca would be $\sim$2 km s^{-1} with a period of 418–666 days. At 2.3 μm of wavelength, the expected spectral shift due to the presence of the companion Cb would be $\sim$0.02 nm, while the finest spectral resolution achieved in the spectra of AB Dor C is 1.5 nm (Close et al. 2007), explaining why this radial velocity signal has not been discovered before.

5. Conclusions

We present interferometric evidence that AB Dor C is not a single pointlike star but most likely a binary system of very low-mass objects. Our results show that both squared visibilities and closure phases are in good agreement with a binary system of $\sim$38 mas separation between the components and a K-band flux ratio of $\sim$5%. This configuration implies masses for the tentative binary AB Dor Ca/Cb of 0.072 $\pm$ 0.013 $M_{\odot}$ and 0.013 $\pm$ 0.001 $M_{\odot}$, according to the PMS evolutionary models of Chabrier et al. (2000), Baraffe et al. (2015), and Tognelli et al. (2018). It is worth noting that, with these masses, one of the objects would lie near the hydrogen-burning limit (AB Dor Ca), while AB Dor Cb would lie at the frontier between brown dwarfs and planets. The binarity of AB Dor Ca/Cb may have gone unnoticed in previous observations given the three-magnitude difference between Ca and Cb and the great difficulty of discerning AB Dor C itself from the nearby, five-magnitude brighter AB Dor A. However, the binary hypothesis would alleviate the disagreement between observed magnitudes and theoretical mass–luminosity relationships. We considered the two most frequently used scenarios (75 ± 25 Myr and 120 ± 20 Myr) and found that especially at the *J* and *H* bands the binary hypothesis produces a better agreement than a single 0.090 $M_{\odot}$ object.

The perturbation caused by the more massive AB Dor A would destabilize a binary system of separation larger than 50 mas. With a separation of about 38 mas, the newly discovered binary AB Dor Ca/Cb appears stable under such perturbation. Yet, although our result defines a very plausible scenario for AB Dor C, it is based on a limited number of visibilities taken near the performance limit of AMBER and, therefore, further confirmation of our findings would be convenient. Advanced instrumentation (i.e., GRAVITY dual-field on-axis mode observations) will help to clarify the nature of this remarkable system.

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