Astrometric Orbits and Masses for Three Low-Mass Binaries

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Abstract. Masses for low-mass stars and brown dwarfs are best determined dynamically using binary systems. Accurate astrometry of the photocenter of the unresolved binary, combined with one observation resolving the binary, can be used to determine the orbital elements. We present data for three systems, two heretofore unknown binaries and one previously studied. The orbital periods range from 7 to 13 years, a range where astrometric orbits can be well determined. Gaia data can help with these ground-based solutions, even with its partial orbital coverage, by providing accurate astrometric data for reference stars as well as the binaries.

1. Introduction

Accurate relative astrometry is used to measure parallaxes and proper motions and to detect and measure perturbations caused by binary companions. For the three targets shown here, the binary motion was detected after a few years of observing for parallax. Using the 61-inch Strand Astrometric Reflector at USNO in Flagstaff, rms errors for a single observation are typically 2-3 mas, and typical errors in the parallax are 0.4 mas after 3–5 years of observing. Preliminary parallax values were given by Dahn et al. (2002); with another decade of data, and with the orbital motion measured and removed, we now have improved parallaxes and we show the new distances here.

The motion of the unresolved photocenter gives most of the orbital parameters (Table 1). However, resolved observations of the binary are necessary to measure the magnitude difference and the semi-major axis of the true orbit. Here we use aperture masking data taken with the Keck Observatory at H and K band on one night for two targets. The third star 2M0746+20 has been observed numerous times with HST, Keck, VLT, and Gemini.

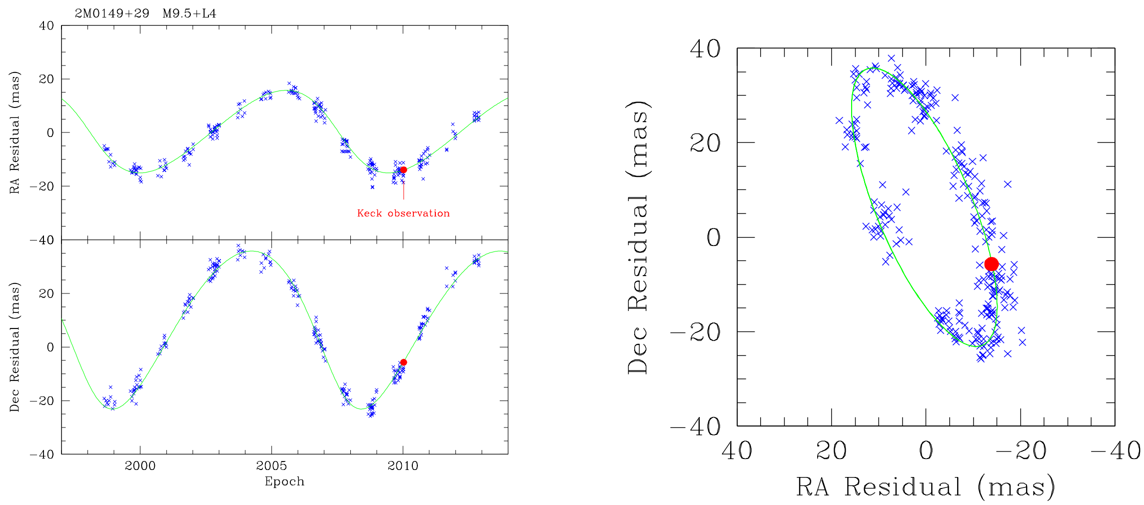

Figure .1: Photocenter orbital motion for 2M0149+29, after solving for and removing the parallactic and proper motion. The high-resolution resolved image from Keck is shown by the red dot.

Table 1. Properties of the Binaries

Object	ST	P(yr)	α(mas)	e	i(deg)
2M J0149090+295613	M9.5e	9.46	32.4	0.28	72
2M J0326137+295015	L3.5	7.53	13.8	0.11	37
2M J0746425+200032	L0.5	12.71	32.4	0.49	138

2. Observations and Analysis

Using the improved parallaxes, the combined-light $IJHK$ photometry from Dahn et al. (2002), the combined-light spectral type, and the ΔH and ΔK magnitude differences from our Keck observations, we get M_H and M_K absolute magnitudes and estimates for M_J and M_I for both components of each binary. These are used to estimate the spectral type of the secondary components.

2.1 2M0149+29

This is a new binary, with the fit orbit shown in Figure 1. Its M9.5e spectral type shows weak Hα emission and at least one very strong flare (Liebert et al 1999). With an improved distance of 23.4 pc, we find the secondary component has magnitudes consistent with spectral type L4, but a mass somewhat larger than expected for type L4. Its tangential velocity 50 km s^{-1} does not indicate it is young. We do not know which component is active. One explanation for these data might be that the secondary is itself a close binary.

2.2 2M0326+29

This is a new binary, with the fit orbit shown in Figure 2. The derived masses indicate both components are brown dwarfs. The masses are still uncertain because only one resolved observation has been made. The improved distance for this object is 35.1 pc. Its low tangential velocity 11 km s^{-1} suggests it may be young; however, its spectrum shows no lithium absorption.

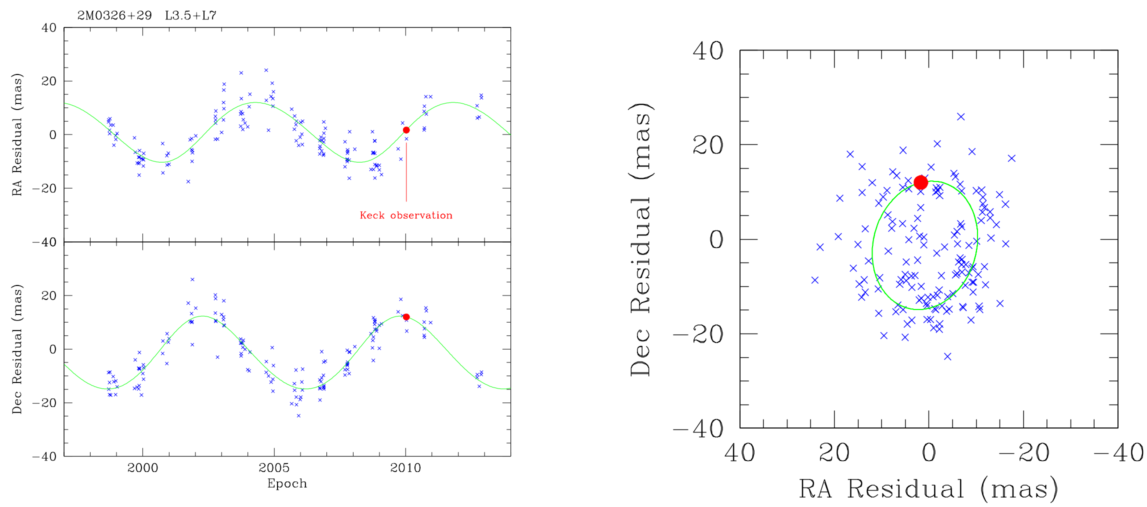

Figure .2: Photocenter orbital motion for 2M0326+29, after solving for and removing the parallactic and proper motion.

2.3 2M0746+20

This binary has been intensively studied. Both components are variable with 3.3 and 2.1 hr rotation periods (Harding et al. 2013). Our new parallax gives a distance of 12.31 pc, 1% larger than previously published. The orbit from Konopacky et al (2010), including data from Bouy et al. (2004), is based on resolved images from HST, Keck, Gemini, and VLT. The published orbit fits our data well, and is shown in Figure 3; it has smaller formal errors than the orbit derived from our data alone. Our photocenter amplitude α constrains the mass ratio, and both components have their masses very accurately determined.

3. Results

Orbital elements determined from photocenter motion are reliable for determining component masses if they are supplemented with accurate resolved observations. Resolved observations on opposite sides of the orbit are helpful in order to determine the location of the center of mass, and thus the scale factor between the photocenter semi-major axis and the semi-major axis of the true relative orbit. The photocenter amplitude also helps determine the mass ratio. When several resolved observations are made, masses can be determined very accurately.

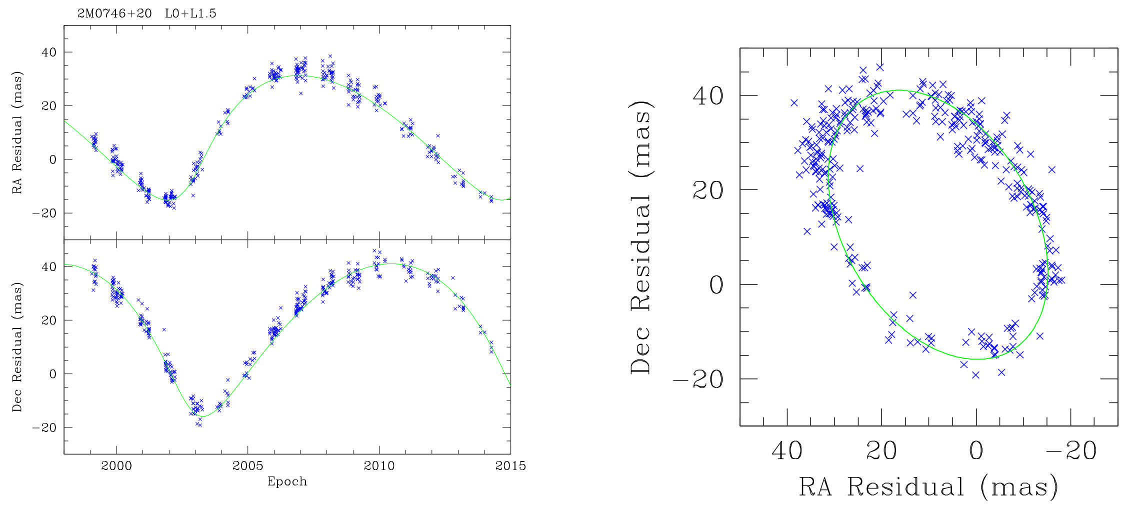

Figure .3: Photocenter orbital motion for 2M0746+20, after solving for and removing the parallactic and proper motion. For this binary, the orbit is from Konopacky et al. (2010) with the amplitude scaled to fit the observed photocenter orbit.

Table 2 gives the results for the three binaries studied here. The target 2M0746+20 is a good example of accurate derived masses, where the errors in the individual masses are now 0.002 $M_\odot$.

Table 2. Masses of Individual Binary Components

Component	ST	M_J	Mass ($M_\odot$)
2M0149+29A	M9.5	11.74	0.084±0.008
2M0746+20A	L0	11.85	0.080±0.002
2M0746+20B	L1.5	12.21	0.074±0.002
2M0326+29A	L3.5	12.99	0.061±0.010
2M0149+29B	L4	13.40	0.069±0.010
2M0326+29B	L7	14.5	0.044±0.008

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References

Bouy, H., Duchêne, G., Köhler, R., et al. 2004, A&A, 423, 341

Dahn, C.C., Harris, H.C., Vrba, F.J., et al. 2002, AJ, 124, 1170

Harding, L.K., Hallinan, G., Konopacky, Q.M., Kratter, K.M., Boyle, R.P., Butler, R.F., & Golden, A. 2013, A&A, 554, 113

Konopacky, Q.M., Ghez, A.M., Barman, T.S., et al. 2010, ApJ, 711: 1087

Liebert, J., Kirkpatrick, J.D., Reid, I.N., & Fisher, M.D. 1999, ApJ, 519, 345