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A DISTANT STELLAR COMPANION IN THE υ ANDROMEDAE SYSTEM

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ABSTRACT

Upsilon Andromedae is an F8 V star known to have an extrasolar system of at least three planets in orbit around it. Here we report the discovery of a low-mass stellar companion to this system. The companion shares common proper motion, lies at a projected separation of ∼750 AU, and has a spectral type of M4.5 V. The effect of this star on the radial velocity of the brighter primary is negligible, but this system provides an interesting test bed for stellar planetary formation theory and understanding dynamical stability since it is the first multiple planetary system known in a multiple stellar system.

Subject headings: astrometry — binaries: visual — planetary systems — stars: individual (υ Andromedae) — stars: low-mass, brown dwarfs

1. INTRODUCTION

Over the last several years, extrasolar planets have been discovered through precision Doppler velocity surveys (e.g., Marcy & Butler 2000). Butler et al. (1999) reported the first evidence for a multiple planetary system around the F8 V star υ Andromedae. Although the combined $M \sin i$ values for these three planets implied a mass at least 5 times more than the combined mass of the planets in our own solar system, this discovery was heralded as the first evidence that our own system of planets is not unique. Currently, there are seven systems of multiple planets known, and all are around apparent single stars like our own Sun.

During the course of our standardized search for wide companions to stars within 25 pc of the Sun, we discovered a stellar companion to υ Andromedae (=HD 9826, Gl 61; 01:36:47.98, +41:24:23.0, $V = 4.10$, $d = 13.5$ pc) at an apparent projected separation of ∼750 AU. In this Letter, we present astrometry and spectroscopy to confirm its companionship and discuss the possible influence this secondary might have on the planetary system.

2. OBSERVATIONS

2.1. *Discovery*

Finding companions at wide separations (greater than a few hundred AU) involves searching large pieces of the sky around the nearest stars. The Two Micron All Sky Survey (2MASS; Skrutskie et al. 1997) is currently presenting a wealth of new material with which previously unknown low-luminosity companions can be found at wide separations. We are in the middle of a 2MASS-based survey around all stars within the Third Catalogue of Nearby Stars (CNS3; Gliese & Jahreiss 1991) for possible companions out to separations of 0.1 pc. The CNS3 includes some 3800 stars believed to lie within 25 pc of the Sun. Companions that are M, L, and T dwarfs will have red optical–to–near-IR colors ($R-J$). Optical photometry from the USNO-A catalog, which is paired up with 2MASS data during routine 2MASS data processing, can be used for an appropriate color constraint. Our candidates are 2MASS detections within a search radius equivalent to a physical separation of 0.1 pc around the nearby star that either have no optical counterparts or have very red $R-J$ colors. Confirmation of companionship and classification are then found by astrometric and spectroscopic follow-up, respectively. Several stellar and substellar companions to nearby, main-sequence stars have been found in this manner (Kirkpatrick et al. 2001a, 2001b; Wilson et al. 2001; Gizis, Kirkpatrick, & Wilson 2001), and the search has been standardized around all nearby stars to provide more robust statistics on the frequency of brown dwarf companions to stars.

During our search, we uncovered a candidate in proximity to the bright, nearby F8 V star υ And. The candidate companion, 2MASSI J0136504+412332, has infrared flux and colors ($J = 9.39 \pm 0.03$; $J-K = 0.88$) consistent with a mid–M dwarf (Kirkpatrick & McCarthy 1994) at the distance of υ And. As shown in Figure 1, it lies 55″ from υ And at a position angle of 147°.

2.2. *Astrometric Confirmation*

The *Hipparcos* mission (Perryman et al. 1997) measured υ And to have the proper motion of $\mu_\alpha = -172.57 \pm 0.52$ and $\mu_\delta = -381.03 \pm 0.45$ mas yr^{-1}. From positions measured in the POSS I and POSS II digitized images and 2MASS (Table 1), we find the candidate companion to have a proper motion over a 44.5 yr baseline of $\mu_\alpha = -175 \pm 8$ and $\mu_\delta = -390 \pm 6$ mas yr^{-1}. Since the two objects' μ_α's agree to within 1 σ and the μ_δ's within 2 σ, we conclude they have the same proper motion within the errors. We therefore conclude that this object, hereafter referred to as υ And B, is a common proper-motion companion to the brighter star, which we will refer to as υ And A. The known radial velocity planets υ And b, υ And c, and υ And d orbit the brighter star υ And A. We note that if planetary and stellar companions are discovered in the same system, confusion can be avoided if stellar objects are noted with a capital letter and planets noted with a lowercase letter.

2.3. *Spectroscopic Confirmation*

The companion was observed spectroscopically on 2001 July 26 UT using the Double Spectrograph (Oke & Gunn 1982) on the Hale 200 inch telescope at Palomar Observatory. The instrumental setup used the blue grating of 300 lines mm^{-1} and the red grating of 316 lines mm^{-1} with the 2″.0 slit to provide a wavelength coverage from 5200 to 9100 Å at a resolution of 9 Å. Observations were reduced using standard techniques following Kirkpatrick, Henry, & McCarthy (1991) and flux-

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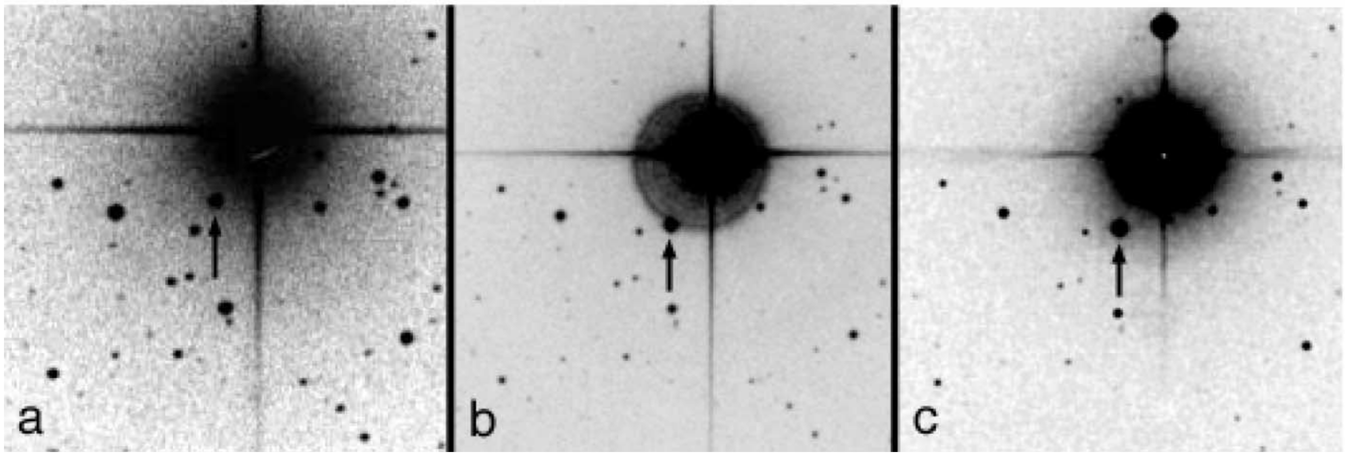

FIG. 1.—Discovery images of υ And B representing the (*a*) POSS I (O), (*b*) POSS II (N), and (*c*) 2MASS (J) images. As the brighter υ And A moves to the southwest over the 44.5 yr baseline, so does the fainter companion. (In the 2MASS image, the bright object due north of υ And A is a latent image caused by the 2MASS scanning procedure, and the glint due south of υ And A and west of υ And B is an internal reflection artifact. See http://www.ipac.caltech.edu/2mass/releases/second/doc/explsup.html.)

calibrated using the standard star LTT 9491 (Hamuy et al. 1994). The spectrum is plotted in Figure 2 and compared with spectral standards from Kirkpatrick et al. (1991). The companion's spectrum is best fit by the M4.5 V standard's spectrum. Based on the spectral-type mass relation for late F stars (Cox 2000, p. 382), we estimate υ And A has a mass of ∼1.2 $M_\odot$, and using the spectral-type mass relationship of Henry & McCarthy (1993), we estimate a mass of 0.2 $M_\odot$ for υ And B.

3. DISCUSSION

The radial velocity monitoring group of Marcy, Butler, and colleagues excluded binaries only if their separations were less than 2″ (G. Marcy 2002, private communication), so this system would still have been monitored had the companion been previously known. For υ And A, Butler et al. (1999) report a measured rms velocity semiamplitude of 15.1 m s^{-1}, after extracting the three planetary orbits from the measurements. We calculate a 0.2 $M_\odot$ stellar companion at 750 AU would have a period of ∼20,000 yr and a velocity amplitude of $K \sim 100$ m s^{-1} depending on the eccentricity and inclination of the orbit. However, the maximum radial velocity *change* Butler et al. might have measured over their 11 yr baseline would be a much smaller value, ∼0.4 m s^{-1} (for $i = 60$ and $e = 0.5$). For a highly eccentric ($e = 0.9$) orbit, it could reach as large as 0.9 m s^{-1}. Even so, this companion object would have not been detectable in the radial velocity measurements.

Since the announcement of the multiple planets around υ And A, there have been many theoretical models of the evolution and stability of three planets around a single star. While the inner planet is a "typical" close, hot Jupiter with a small eccentricity (0.04), the eccentricities of the outer two increase to 0.18 and 0.41, respectively. Interaction between the two outer planets has been proposed as the major influence of orbital evolution, but there has been much debate over the stability of such a system. Rivera & Lissauer (2000), who, like Laughlin & Adams (1999), ignore the innermost planet in the numerical simulations, found coplanar systems can be stable on small timescales, but the cause of the high eccentricities does not seem easily explained by only planetary interactions (Jiang & Ip 2001).

What influence would a distant stellar companion have on the orbits of a planetary system? In the numerical models of the stability of planets within binary systems, Holman & Weigert (1999) found certain critical semimajor axes for which disruption of the orbit could occur, depending on the eccentricity of the binary stars. For the υ And system, the critical orbital

TABLE 1
MEASURED POSITIONS OF υ AND B

Epoch (UT)	R.A. (J2000.0)	Decl. (J2000.0)	Survey
1953 Sep 16 ……	01 36 51.1	+41 23 49.9	POSS I (O)
1995 Nov 14 ……	01 36 50.5	+41 23 33.1	POSS II (N)
1998 Feb 11 ……	01 36 50.42	+41 23 32.57	2MASS (J)

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

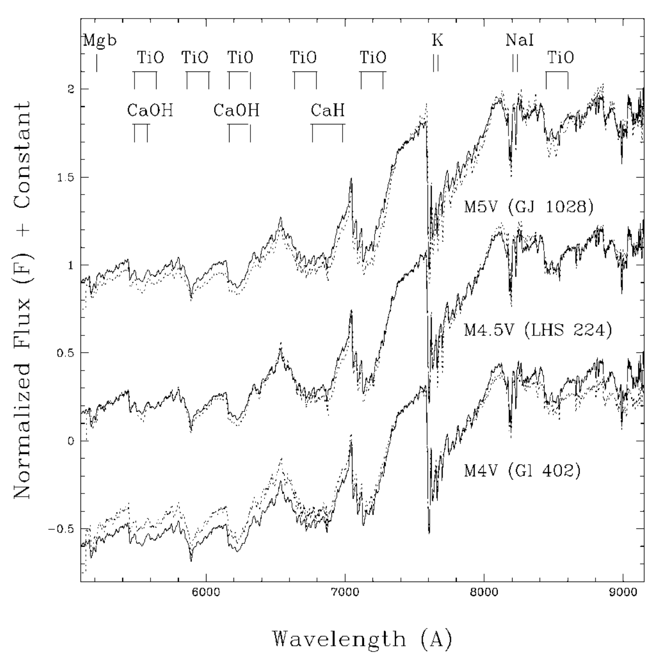

FIG. 2.—Spectrum of υ And B (*solid line*; in units of ergs s^{-1} cm^{-2} $Å^{-1}$) compared with standard late-type M dwarf spectra (*dashed line*; Kirkpatrick et al. 1991). The spectra are normalized to the flux at 7500 Å and offset by integers. The best fit is consistent with an M4.5 V spectral type.

radii range from approximately 40 to 240 AU for $e = 0.8$–0.0, respectively. While the known radial velocity planets are all well within this limit, we note that a circumprimary disk or remnant Kuiper belt could be disrupted by this companion, depending on its inclination and eccentricity. In the HD 141569 disk, it has been suggested that the outer gap observed in the debris disk could have its origin in gravitational perturbations caused by distant companions (Weinberger et al. 2000).

Another radial velocity planet with a highly eccentric orbit ($e = 0.63$) is 16 Cygni Bb. It has been suggested that its high eccentricity might be due to interaction with the stellar companion, 16 Cygni A, at a projected separation of 800 AU (Mazeh, Krymolowski, & Rosenfeld 1997; Holman, Touma, & Tremaine 1997). The tidal force of the secondary on the smaller body was proposed to induce a modulation of the eccentricity over a long timescale (∼10^8 yr). This would cause a planetary orbit that forms with a small eccentricity to slowly increase its eccentricity over the current age of the star (∼3 Gyr). They calculate the total increase is only weakly sensitive to the semimajor axis ratio if the period of the modulation is long and therefore can be a large effect over the lifetime of that system.

The projected separation of the 16 Cygni binary is consistent with the projected separation we find here (750 AU), although υ And B is approximately 0.4 the mass of 16 Cygni A. However, the presence of multiple planets in the υ And system rules out the kind of effect noted above since the apsidal precession rate of the planets due to mutual interactions greatly outweighs any induced by the stellar companion (Chiang & Murray 2002). Just as the Moon, because of its proximity, has a larger effect on the terrestrial tides than the more massive but more distant Sun, the mutual interaction of the planets υ And c and υ And d is much larger than any tidal forces from distant υ And B.

4. CONCLUSION

We present astrometric and spectroscopic evidence that 2MASSI J0136504+412332 is an M4.5 V common proper-motion companion to the star υ And, which harbors a multiple planetary system. This represents the first system in which multiple planets exist within a multiple stellar system, but such a scenario might not be rare. There are residual velocity trends hinting of the presence of more than one planet around the binary stars 55 Cnc and τ Boo (Fischer et al. 2001). There are currently only single planets known around the multiple stars 16 Cyg B, 94 Cet, HD 142, HD 179811B, HD 80606, HD 195019, Gl 86, and HD 89774.

Unifying all aspects of extrasolar planetary formation and evolution into a consistent model that accounts for the distribution of known orbital parameters remains a daunting task. Previously unknown stellar or substellar companions might be gravitationally affecting the entire system. The complete picture surely includes several factors including disk viscosities, planetary interactions, and companions.

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