A SUBSTELLAR COMPANION TO THE INTERMEDIATE-MASS GIANT 11 COMAE

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ABSTRACT

We report the detection of a substellar companion orbiting the intermediate-mass giant star 11 Com (G8 III). Precise Doppler measurements of the star from Xinglong Station and Okayama Astrophysical Observatory (OAO) reveal Keplerian velocity variations with an orbital period of 326.03 ± 0.32 days, a semiamplitude of 302.8 ± 2.6 m s⁻¹, and an eccentricity of 0.231 ± 0.005. Adopting a stellar mass of 2.7 ± 0.3 M☉, the minimum mass of the companion is 19.4 ± 1.5 M⊕, well above the deuterium-burning limit, and the semimajor axis is 1.29 ± 0.05 AU. This is the first result from a joint planet-search program between China and Japan aimed at revealing the statistics of substellar companions around intermediate-mass giants. 11 Com b emerged from 300 targets of the planet-search program at OAO. The program’s current detection rate of brown dwarf candidates seems to be comparable to the rate of such detections around solar-type stars with orbital separations of ≤3 AU.

Subject headings: planetary systems — stars: individual (11 Comae = HD 107383) — stars: low-mass, brown dwarfs — techniques: radial velocities

1. INTRODUCTION

The “brown dwarf desert” is widely known as a deficit in the frequency of brown dwarf companions (10⁻³–10⁻⁴ M☉) to solar-type stars (see, e.g., Marcy & Butler 2000). The mass distribution of companions rises steeply toward planets at one extreme and toward stellar masses at the other, with a deficit of brown dwarfs in between (e.g., Grether & Lineweaver 2006). The presence of such a desert within orbital separations of ≲3 AU was revealed and confirmed by precise radial velocity surveys during the past decade (Butler et al. 2006 and references therein), and recent coronagraphic surveys have shown that the desert extends to separations of ≲1000 AU (McCarthy & Zuckerman 2004). This bimodal mass distribution of low-mass companions is considered to be the outcome of distinct formation mechanisms for planets and stellar companions to solar-type stars.

On the other hand, it remains to be cleared up whether the brown dwarf desert also exists around massive stars. The few absorption lines in the spectra of massive early-type dwarfs, which are often rotationally broadened, make it difficult to detect low-mass companions with precise radial velocity measurements, and their high luminosities prevent us from directly imaging close and faint companions. Therefore, massive stars have not been major targets of planet/brown dwarf searches, as compared with lower mass stars.

However, the existence of substellar companions to intermediate-mass stars (1–1.6 M☉) has been gradually uncovered, mainly through precise Doppler surveys of G and K giants (e.g., Frink et al. 2002; Setiawan et al. 2005; Hatzes et al. 2005; Sato et al. 2007; Johnson et al. 2007; Lovis & Mayor 2007; Niedzielski et al. 2007). These are massive stars in evolved stages and have many sharp absorption lines in their spectra appropriate for radial velocity measurements. The minimum masses of the discovered companions range from 0.6 to 19.8 M⊕, and the semimajor axes lie between 0.8 and 2.4 AU. Two of the most massive ones, NGC 4349 No. 127b (19.8 M⊕; Lovis & Mayor 2007) and HD 13189b (14 M⊕; Hatzes et al. 2005), fall in the brown dwarf regime. Galland et al. (2006) have undertaken a precise Doppler survey of low-mass companions to A–F dwarfs and have found one brown dwarf candidate, with a minimum mass of 25 M⊕, in a 25 day orbit around the A9 V star HD 180777. Kouwenhoven et al. (2007) found two distant (520 and 1500 AU) brown dwarf candidates to a B star in the Sco OB2association by direct near-infrared imaging with an adaptive optics system. They derived a frequency of brown dwarf companions (≥30 M⊕) of 0.5% ± 0.5% in the separation range 130–520 AU for late-B and for A-type stars in the association, which is comparable to the 0.7% ± 0.7% derived by McCarthy & Zuckerman (2004) for F–M stars with separations 120–1200 AU.

We report here the detection of a substellar companion to the intermediate-mass G-type giant 11 Com from Doppler planet-search programs at the Xinglong Station (National Astronomical Observatories, China) and Okayama Astrophysical Observatory (OAO, Japan). This is the third object with a minimum mass falling in the brown dwarf regime discovered around an intermediate-mass giant.

11 HD 13189b has an uncertainty between 8 and 20 M⊕ depending on the uncertainty of the host star’s mass (2–6 M☉) (Hatzes et al. 2005).
2. OBSERVATIONS

2.1. OAO Observations

The Okayama Planet Search Program started in 2001 using a 1.88 m telescope and the High Dispersion Echelle Spectrograph (HIDES; Izumiura 1999) at OAO. It aims to detect planets around intermediate-mass G-type (and early K-type) giants (Sato et al. 2005), and about 300 targets are now under survey. For precise radial velocity measurements, we set the wavelength range to 5000–6100 Å and the slit width to 200 μm (0.76″), giving a spectral resolution (Δλ/Δλ) of 67,000, and we use an iodine absorption cell (Kambe et al. 2002) for precise wavelength calibration. Our modeling technique for an I₂-superoosed (“star+I₂”) stellar spectrum is detailed in Sato et al. (2002) and is based on the method of Butler et al. (1996), giving a Doppler precision of about 6 m s⁻¹ over a time span of 6 yr. The stellar template used for radial velocity analysis is extracted from several star+I₂ spectra by use of the method described in Sato et al. (2002). The reduction of echelle data is performed using the IRAF12 software package in the standard manner. For abundance analysis of 11 Com, we took pure (I₂-free) stellar spectra in the wave bands 5000–6100 and 6000–7100 Å with the same wavelength resolution as for the radial velocity measurements.

2.2. Xinglong Observations

The Xinglong Planet Search Program started in 2005 within a framework of international collaboration between China and Japan aiming to extend the ongoing program at OAO. Xinglong Station has mainly monitored about 100 G-type giants with visual magnitudes of V ~ 6 that have not been observed at OAO.

Before starting the planet-search program, in 2004 August an I₂ cell was installed on the Coude’ Echelle Spectrograph (CES; Zhao & Li 2001), attached to the 2.16 m telescope at Xinglong. The cell is a copy of those for HIDES at OAO and the High Dispersion Spectrograph at the Subaru Telescope (Kambe et al. 2002). The cell is placed in front of the entrance slit of the spectrograph, and its temperature is controlled to 60°C. We use the CES blue arm and middle focal length camera, a configuration that covers a wavelength range of 3900–7260 Å with a spectral resolution of ~40,000 by 2 pixel sampling. Although a wide wavelength range can be obtained with a single exposure, only a wave band at 470 Å is available for radial velocity measurements because of the small format (1K × 1K) of the current CCD, which is a thinned, back-illuminated, blue-enhanced Tektronix CCD with a pixel size of 24 × 24 μm².

The modeling technique for a star+I₂ spectrum and the extraction method for a stellar template are based on Sato et al.’s (2002) code. For the CES data, we use five Gaussian profiles to reconstruct the instrumental profile and a second-degree Legendre polynomial to describe the wavelength scale. An entire echelle spectrum is divided into about 40 segments (130–150 pixels for each), and Doppler analysis is applied to each segment. The current best short-term (~1 week) precision for bright stars is about 15 m s⁻¹, limited by the low wavelength resolution and the narrow wavelength coverage of the spectrograph. On longer time scales (~1 yr), the precision worsens to 20–25 m s⁻¹, including velocity offsets between different observing runs. In the case of fainter stars, the measurement precision is mainly limited by the signal-to-noise ratio (S/N). We can typically achieve a precision of 30–40 m s⁻¹ for a V = 6 star with S/N ~ 150 for an exposure time of 1800 s.

3. STELLAR PROPERTIES

11 Com (=HR 4697, HD 107383, HIP 60202) is a G8 III giant star with magnitude V = 4.74, color index B–V = 0.99, and a precise astrometric parallax of π = 9.04 ± 0.86 mas (ESA 1997). The resulting distance is 112 pc from the Sun, and the absolute magnitude is M_V = −0.48. An effective temperature T_eff = 4742 ± 100 K was derived from the B–V and metallicity [Fe/H] using the empirical calibration of Alonso et al. (2001), and a bolometric correction BC = −0.36 was derived from the calibration of Alonso et al. (1999), which depends on temperature and metallicity. Then the stellar luminosity was estimated to be L ≈ 172 ± 31 L☉ and the radius R = 19.5 ± 2 R☉. A stellar mass M = 2.7 ± 0.3 M☉ was estimated from the star’s position in the theoretical Hertzsprung-Russell diagram by interpolating in the Yonsei-Yale evolutionary tracks (Yi et al. 2003). Surface gravity, log g = 2.31 ± 0.10, was determined using the relation between temperature, mass, luminosity, and gravity (see eq. [1] of Chen et al. 2000). The iron abundance was determined from the equivalent widths measured from the I₂-free spectrum (5000–6100 and 6000–7100 Å), combined with a model atmosphere (Kurucz 1993). We iterated this entire procedure until the value of the overall metallicity of the model converged. Finally, we obtain [Fe/H] = −0.35 ± 0.09 and a microturbulent velocity v_t = 1.5 ± 0.2 km s⁻¹. The rotational velocity of the star has been determined by De Medeiros & Mayor (1999) to be v sin i = 1.2 ± 1.0 km s⁻¹. Hipparcos made a total of 99 observations of the star, revealing photometric stability down to σ = 0.006 mag. The stellar parameters are summarized in Table 1.

Figure 1 shows the Ca H line for 11 Com together with those for G8–G9 III giants in our sample. Although the calibration to measure chromospheric activity for our spectra and the correlation between chromospheric activity and intrinsic radial velocity “jitter” for giants have not been well established yet, the lack of significant emission in this line for 11 Com suggests low chromospheric activity.

4. RADIAL VELOCITIES AND ORBITAL SOLUTION

We started observations of 11 Com at OAO in 2003 December. Soon after that, large radial velocity variations were detected, suggesting the existence of a substellar companion. Based on this result, we started observations at Xinglong in 2005 to check the measurement precision with CES and to confirm the star’s variations independently. Through 2007 February, we gathered a

| Parameter | Value |
|-----------|-------|
| Spectral type | G8 III |
| π (mas) | 9.04 ± 0.86 |
| V | 4.74 |
| B–V | 0.99 |
| M_V | −0.48 |
| BC | −0.36 |
| T_eff (K) | 4742 ± 100 |
| log g | 2.31 ± 0.1 |
| [Fe/H] | −0.35 ± 0.09 |
| v_t (km s⁻¹) | 1.5 ± 0.2 |
| L (L☉) | 175 ± 31 |
| R (R☉) | 19 ± 2 |
| M (M☉) | 2.7 ± 0.3 |
| v sin i (km s⁻¹) | 1.2 ± 1.0 |
total of 28 data points for the star at OAO with a typical S/N of 250 pixel\(^{-1}\) and a total of 18 at Xinglong with a typical S/N of 150.

The observed radial velocities are shown in Figure 2 and listed in Table 2 (OAO) and Table 3 (Xinglong), together with their estimated uncertainties. The best-fit Keplerian orbit was derived using both the OAO and Xinglong data. An offset of \(-205\) m s\(^{-1}\) was applied to the Xinglong radial velocities in order to minimize \(\chi^2\) when fitting a Keplerian model to the combined OAO and Xinglong velocities. The resulting orbit is shown in Figure 2 overplotted on the velocities, and its parameters are listed in Table 4. The uncertainty in each parameter was estimated using a

**Table 2**

| JD (2,450,000+) | Radial Velocity (m s\(^{-1}\)) | Error (m s\(^{-1}\)) |
|----------------|-------------------------------|----------------------|
| 3002.2791      | -201.7                        | 5.7                  |
| 3101.0241      | 178.7                         | 4.6                  |
| 3216.0035      | 74.5                          | 7.9                  |
| 3334.3172      | -184.5                        | 5.5                  |
| 3340.3401      | -160.2                        | 4.6                  |
| 3364.3191      | -76.9                         | 7.9                  |
| 3366.2249      | -76.6                         | 5.2                  |
| 3367.2333      | -79.3                         | 5.4                  |
| 3376.3243      | -12.5                         | 4.7                  |
| 3403.2636      | 65.3                          | 5.1                  |
| 3424.1132      | 150.7                         | 5.1                  |
| 3447.1803      | 232.5                         | 4.6                  |
| 3468.0504      | 251.2                         | 5.6                  |
| 3495.1120      | 293.4                         | 4.5                  |
| 3521.0884      | 212.5                         | 7.5                  |
| 3577.9651      | -217.7                        | 6.2                  |
| 3694.3575      | -38.2                         | 5.0                  |
| 3728.3204      | 63.2                          | 5.1                  |
| 3743.3484      | 127.7                         | 5.0                  |
| 3775.2089      | 241.6                         | 4.7                  |
| 3810.1629      | 311.6                         | 3.9                  |
| 3831.1262      | 301.0                         | 4.5                  |
| 3853.1393      | 188.7                         | 5.8                  |
| 3887.0520      | -148.5                        | 5.7                  |
| 4051.3576      | 43.8                          | 4.6                  |
| 4088.3683      | 189.0                         | 4.8                  |
| 4121.2706      | 239.6                         | 5.9                  |
| 4143.2374      | 274.5                         | 4.0                  |

**Table 3**

| JD (2,450,000+) | Radial Velocity (m s\(^{-1}\)) | Error (m s\(^{-1}\)) |
|----------------|-------------------------------|----------------------|
| 3420.2939      | 195.4                         | 33.5                 |
| 3422.2517      | 126.7                         | 36.2                 |
| 3422.2627      | 112.0                         | 33.1                 |
| 3511.0423      | 281.9                         | 29.9                 |
| 3514.0647      | 249.4                         | 25.6                 |
| 3514.0779      | 304.8                         | 20.6                 |
| 3775.2678      | 243.1                         | 30.6                 |
| 3778.3433      | 220.6                         | 30.3                 |
| 3839.1013      | 229.1                         | 36.6                 |
| 3839.1229      | 204.4                         | 18.6                 |
| 3839.1462      | 246.7                         | 31.8                 |
| 3841.1569      | 227.5                         | 28.9                 |
| 3891.0521      | -124.4                        | 18.3                 |
| 3894.0998      | -178.1                        | 22.7                 |
| 4045.3959      | 78.7                          | 21.1                 |
| 4046.3706      | 58.3                          | 26.7                 |
| 4132.3744      | 249.1                         | 30.9                 |
| 4132.3976      | 253.2                         | 19.7                 |
Monte Carlo approach. The radial velocity variability can be well fitted as a Keplerian orbit with period \( P = 326.03 \pm 0.32 \) days, a velocity semi-amplitude \( K_1 = 302.8 \pm 2.6 \) m s\(^{-1}\), and an eccentricity \( e = 0.231 \pm 0.005 \). When we determine a Keplerian orbit using only OAO data, the rms scatter of the residuals to the fit is 17.8 m s\(^{-1}\), which is slightly larger than the typical intrinsic radial velocity scatter of late-G-type giants in our sample (Sato et al. 2005), but we found no significant additional periodicity in the residuals at this stage. The Keplerian orbit derived with only OAO data fits the Xinglong data with an rms scatter of 33.2 m s\(^{-1}\), which is comparable to the observational errors. Adopting a stellar mass of \( 2.7 M_\odot \), we obtain for the companion a mass \( m_2 \sin i = 19.4 \pm 1.5 M_\odot \) and a semimajor axis \( a = 1.29 \pm 0.05 \) AU. The uncertainties mostly come from that in host star’s mass. If we assume the orbit is randomly oriented, there is a 3\% chance that the true mass exceeds 80 \( M_\odot \) (\( i < 14^\circ \)), the border between brown dwarf and stellar mass regimes.

To investigate other causes that could produce apparent radial velocity variations, such as pulsation and rotational modulation, a spectral line shape analysis was performed with the use of high-resolution stellar templates followed by the technique of Sato et al. (2007). We extracted two templates from the star+I\(_2\) spectra obtained at OAO: one was from five spectra with observed radial velocities of 250–300 m s\(^{-1}\), and the other was from spectra with velocities of approximately 200 m s\(^{-1}\). Cross-correlation profiles of the templates were calculated for 50 spectral segments (4–5 \( \lambda \) width each) that did not include severely blended lines or broad lines. Three bisector quantities were calculated for the cross-correlation profile of each segment: the velocity span (BVS), which is the velocity difference between two flux levels of the bisector; the velocity curvature (BVC), which is the difference in the velocity span of the upper half and lower half of the bisector; and the velocity displacement (BVD), which is the average of the bisector at three different flux levels. We used flux levels of 25\%, 50\%, and 75\% of the cross-correlation profile to calculate the above quantities. Figure 3 shows the resulting bisector quantities plotted against the center wavelength of each segment. As expected under the planetary hypothesis, both the bisector velocity span and the curvature are essentially identical to zero (\(-2.3\) and \(-2.4\) m s\(^{-1}\) on average, respectively), which means that the cross-correlation profiles are symmetric, and the average bisector velocity displacement of \(-453.0\) m s\(^{-1}\) is consistent with the velocity difference between the two templates. Furthermore, these values are independent of wavelength. Based on these results, we conclude that the radial velocity variability observed in 11 Com is best explained by orbital motion.

### 5. Discussion and Summary

We report the discovery of a brown dwarf–mass companion to the intermediate-mass giant 11 Comae. This is the first result from the joint planet-search program between China and Japan. We obtained radial velocities of the star over a span of 3 years at OAO and 2 years at Xinglong. The two sites independently detected the velocity variability of the star, and the agreement of the two data sets ensures the reliability of our discovery and the radial velocity measurements at both sites.

11 Com b is the third ever discovered substellar companion to an intermediate-mass giant to fall in the brown dwarf regime.

### Table 4

| Parameter | Value |
|-----------|-------|
| \( P \) (days) | 326.03 ± 0.32 |
| \( K_1 \) (m s\(^{-1}\)) | 302.8 ± 2.6 |
| \( e \) | 0.231 ± 0.005 |
| \( \omega \) (deg) | 94.8 ± 1.5 |
| \( T_p \) (JD 2,450,000) | 2899.6 ± 1.6 |
| \( a_1 \sin i \) (10\(^{-3}\)AU) | 8.848 ± 0.073 |
| \( f_1 \) (m/s) | 8.68 ± 0.21 |
| \( m_2 \sin i \) (M\(_\odot\)) | 19.4 ± 1.5 |
| \( a_2 \) (AU) | 1.29 ± 0.05 |
| \( N \) | 46 |
| rms (m s\(^{-1}\)) | 25.5 |
| Reduced \( \chi^2 \) | 2.8 |

![Fig. 3.](image1)  
**Fig. 3.** Bicorrelation quantities of the cross-correlation profiles between the templates of 11 Com at peak (250–300 m s\(^{-1}\)) and valley (−200 m s\(^{-1}\)) phases of the observed radial velocities. Shown are the bicorrelation mean (BVS, circles), bicorrelation curvature (BVC, triangles), and bicorrelation displacement (BVD, squares). The definitions of these quantities are given in § 4. The mean values and their standard errors are shown in the figure. Dashed lines represent mean values (an offset of 300 m s\(^{-1}\) is added to the BVS).

![Fig. 4.](image2)  
**Fig. 4.** Mass distribution of substellar companions discovered by precise Doppler surveys (including all of the host stars with \( \leq 4\) \( M_\odot \)). The data are based on the list at http://exoplanets.org/planets.shtml. NGC 2423 No. 3b (10.6 \( M_\odot \)), NGC 4349 No. 127b (19.8 \( M_\odot \)), HD 13189b (K2 II, 14 \( M_\odot \)), HD 17092b (K0 III, 4.6 \( M_\odot \)), and HD 180777b (A9 V, 25 \( M_\odot \)) are not included in this list but have been added to the histogram.
(Fig. 4). To date, 10 planetary-mass companions (0.6–10 M$_J$) have been found around intermediate-mass (≥1.6 M$_*$) giants by precise Doppler surveys, but only three brown dwarf–mass ones (≥14 M$_J$) have been found, despite the larger radial velocity amplitudes being easily detectable. These results may suggest a shortage of brown dwarfs relative to planets around intermediate-mass giants within orbital separations of ~3 AU.

Brown dwarf companions are generally thought to form by gravitational collapse in protostellar clouds, like stellar binary systems (Bonnell & Bastien 1992; Bate 2000). It is difficult, however, to form close binary systems with a large difference in mass between the primary and the secondary (Bate 2000). According to this scenario, fewer brown dwarf companions are expected in higher mass systems than in lower mass ones. Around solar-type stars, the frequency of brown dwarf companions is estimated to be less than 0.5% within 3 AU (Marcy & Butler 2000). So far in our survey, 11 Com b has emerged from a sample of 300 stars at OAO. The current detection rate seems to be comparable to that around solar-type stars, although the exact detection limits for all the targets in our sample have not been derived yet. A detailed statistical analysis will be presented in a forthcoming paper. Ongoing large-scale Doppler surveys of G–K giants (Frink et al. 2002; Setiawan et al. 2005; Hatzes et al. 2005; Sato et al. 2007; Johnson et al. 2007; Lovis & Mayor 2007; Niedzielski et al. 2007) and B–A dwarfs (Galland et al. 2006) around the globe will derive a statistically reliable value of the frequency.

Gravitational instability in protostellar disks is another scenario to form brown dwarf companions (Boss 2000; Rice et al. 2003). This has also been proposed as the formation mechanism for massive gaseous planets. Half of the planetary-mass companions discovered around intermediate-mass stars have minimum masses greater than 5 M$_J$, so-called superplanets (Setiawan et al. 2003, 2005; Hatzes et al. 2005; Sato et al. 2003, 2007; Lovis & Mayor 2007). Can these companions and 11 Com b be put into the same context in terms of formation mechanism? One remarkable feature of these substellar companions is that most of them (including 11 Com b) orbit stars with subsolar metallicity. This apparently favors the gravitational instability scenario as their formation mechanism (Boss 2002), which is less sensitive to metallicity than is the core accretion scenario (Ida & Lin 2004; Fischer & Valenti 2005). However, if the surface density of dust in the disk scales as $M_*/Z$ ($\alpha > 0$), where $M_*$ is the stellar mass and $Z$ is the metallicity, massive stars may have higher disk surface densities, which may compensate for lower metallicities. Such disks could form massive solid cores that can accrete huge gas envelopes, up to 20 M$_J$. Further investigation of the mass and metallicity distribution of substellar companions to massive stars will help to discriminate between these formation scenarios.

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REFERENCES

Alonso, A., Arribas, S., & Martinez-Roger, C. 1999, A&AS, 140, 261
—and—. 2001, A&A, 376, 1039
Bate, M. R. 2000, MNRAS, 314, 33
Bonnell, I., & Bastien, P. 1992, ApJ, 401, 654
Boss, A. P. 2000, ApJ, 536, L101
—and—. 2002, ApJ, 567, L149
Butler, R. P., Marcy, G. W., Williams, E., McCaughrean, C., Dobschek, P., & Vogt, S. S. 1996, PASP, 108, 500
Butler, R. P., et al. 2006, ApJ, 646, 505
Chen, Y.-Q., Nissen, P. E., Zhao, G., Zhang, H.-W., & Benoni, T. 2000, A&AS, 141, 491
De Medeiros, J. R., & Mayor, M. 1999, A&AS, 139, 433
ESA, 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noordwijk: ESA)
Fischer, D. A., & Valenti, J. 2005, ApJ, 622, 1102
Frink, S., Mitchell, D. S., Quirrenbach, A., Fischer, D. A., Marcy, G. W., & Butler, R. P. 2002, ApJ, 576, 478
Galland, F., Lagrange, A.-M., Udry, S., Bezit, J.-L., Pepe, F., & Mayor, M. 2006, A&A, 452, 709
Grether, D., & Lineweaver, C. H. 2006, ApJ, 640, 1051
Hatzes, A. P., Guenther, E. W., Endl, M., Cochran, W. D., Döllinger, M. P., & Beaulieu, A. 2005, A&A, 437, 743
Ida, S., & Lin, D. N. C. 2004, ApJ, 616, 567
Izumiya, H. 1999, in Observational Astrophysics in Asia and Its Future: Proceedings of the 4th East Asian Meeting on Astronomy, ed. P.-S. Chen (Publ. Yunnan Obs. Suppl. 80) (Kunming: Yunnan Obs.), 77

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

No. 1, 2008 SUBSTELLAR COMPANION TO 11 COMAME 557