THE ASTROPHYSICAL JOURNAL, 578:565–572, 2002 October 10

ON THE DOUBLE-PLANET SYSTEM AROUND HD 83443[1]

R. PAUL BUTLER,[2] GEOFFREY W. MARCY,[3] STEVEN S. VOGT,[4] C. G. TINNEY,[5] HUGH R. A. JONES,[6] CHRIS MCCARTHY,[2]
ALAN J. PENNY,[7] KEVIN APPS,[8] AND BRAD D. CARTER[9]
Received 2002 April 8; accepted 2002 June 20

ABSTRACT

The Geneva group has reported two Saturn-mass planets orbiting HD 83443 (K0 V) with periods of 2.98 and 29.8 days. The two planets have raised interest in their dynamics because of the possible 10 : 1 orbital resonance and the strong gravitational interactions. We report precise Doppler measurements of HD 83443 obtained with the Keck/HIRES and the Anglo-Australian Telescope (AAT) UCLES spectrometers. These measurements strongly confirm the inner planet with a period of 2.985 days, with orbital parameters in very good agreement with those of the Geneva group. However, these Doppler measurements show no evidence of the outer planet, at thresholds of one-fourth (3 m s^{-1}) of the reported velocity amplitude of 13.8 m s^{-1}. Thus, the existence of the outer planet is in question. Indeed, the current Doppler measurements reveal no evidence of any second planet with a period less than a year.

Subject headings: planetary systems — stars: individual (HD 83443)

1. INTRODUCTION

Several multiple-planet systems have been reported, including the triple-planet system around Upsilon Andromedae (Butler et al. 1999) and double-planet systems around GJ 876 (Marcy et al. 2001a), HD 83443 (Mayor et al. 2002), HD 168443 (Marcy et al. 2001b; Udry et al. 2002), and 47 UMa (Fischer et al. 2002). Double-planet systems have also been reported in a press release[10] for HD 82943 and HD 74156. These multiple-planet systems contain planets reported to range from a Saturn mass to nearly 10 $M_{\rm JUP}$, all orbiting within 4 AU.

Interactions between the planets in some of these systems, notably Gliese 876, are measurable on a timescale of a few years (Lissauer & Rivera 2001; Laughlin & Chambers 2001; Rivera & Lissauer 2001). Doppler measurements can reveal the ongoing gravitational perturbations and constrain both the planet masses and orbital inclinations. The interactions and orbital resonances, both mean-motion and secular, provide clues about the dynamical history of the systems (Snellgrove, Papaloizou, & Nelson 2001; Lee & Peale 2002; Chiang, Fischer, & Thommes 2002).

A most extraordinary double-planet system was reported for HD 83443 (Mayor et al. 2002). Their Doppler measurements made with the CORALIE spectrometer indicate the existence of two Saturn-mass planets that both reside within 0.2 AU. The inner planet has an orbital period of 2.985 days, an eccentricity of 0.079 ($\pm$0.033), a minimum ($M \sin i$) mass of 0.34 $M_{\rm JUP}$, and an orbital distance of 0.038 AU. The orbital period is the shortest known for extrasolar planets. The nonzero eccentricity of this inner planet is notable, as planets with periods less than 5 days suffer tidal circularization (Wu & Goldreich 2002). With the exception of the Saturn-mass planet around HD 46375 (Marcy, Butler, & Vogt 2000), all 15 of the previously discovered "51 Peg–like" planets have spectral types of G5 or earlier.

Mayor et al. (2002) report a remarkable second planet around HD 83443. It has an orbital period of 29.83 ($\pm$0.18) days, an eccentricity of 0.42, a minimum ($M \sin i$) mass of 0.16 $M_{\rm JUP}$, and an orbital distance of 0.17 AU. This outer planet induces a velocity semiamplitude in the star of $K = 13.8 \pm 1$ m s^{-1}, rendering it a 14 σ detection. This planet has the smallest $M \sin i$ yet reported and is only the third reported planet with a semiamplitude smaller than 15 m s^{-1} (e.g., Marcy et al. 2000; Fischer et al. 2002).

Both of the planets were indicated by Doppler measurements obtained with the 1.2 m Leonhard Euler telescope at the ESO La Silla Observatory, which feeds the CORALIE spectrometer (Queloz et al. 2000). Wavelength calibration is achieved by coupling the telescope and thorium lamp to the spectrometer with a double-scrambled fiber. The quoted instrumental precision is now 2 m s^{-1} (Udry et al. 2002).

As the two planets orbiting HD 83443 are crowded within 0.2 AU, the system is dynamically active. Calculations by J. Laskar and W. Benz (reported in Mayor et al. 2002), Wu & Goldreich (2002), and M. H. Lee & S. J. Peale (2002, private communication) suggest the occurrence of significant gravitational interactions between the two planets. The tidal circularization timescale for the inner planet of HD 83443 is estimated to be 3×10^8 yr (Wu & Goldreich 2002), while the star is estimated to have an age of 6.5 Gyr. In this context, the nonzero eccentricity of the inner planet and the apside

[1] Based on observations obtained at the Anglo-Australian Telescope, Siding Spring, Australia, and on observations obtained at the W. M. Keck Observatory, which is operated jointly by the University of California and the California Institute of Technology. Keck time has been granted by both NASA and the University of California.

[2] Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington, DC 20015-1305; paul@dtm.ciw.edu.

[3] Department of Astronomy, University of California, Berkeley, CA 94720; and Department of Physics and Astronomy, San Francisco State University, San Francisco, CA 94132.

[4] UCO/Lick Observatory, University of California, Santa Cruz, CA 95064.

[5] Anglo-Australian Observatory, P.O. Box 296, Epping, NSW 1710, Australia.

[6] Astrophysics Research Institute, Liverpool John Moores University, Twelve Quays House, Egerton Wharf, Birkenhead CH41 1LD, UK.

[7] Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, UK.

[8] Physics and Astronomy, University of Sussex, Falmer BN1 9QJ, UK.

[9] Faculty of Sciences, University of Southern Queensland, Toowoomba, QLD 4350, Australia.

[10] ESO Press Release 07/01, 2001.

alignment of the two orbits are understood to be due to secular interactions between the two planets and tidal interactions with the star (Mayor et al. 2002; Wu & Goldreich 2002). These in turn constrain the orbital inclination of this system and the radius of the inner planet (Wu & Goldreich 2002). The dynamical evolution that led to the system may involve migration and resonances (M. H. Lee & S. J. Peale 2002, private communication).

Section 2 of this paper describes new Doppler measurements of HD 83443 made from the Keck and AAT telescopes, including a search for the two planets, notably the interesting outer planet. Our failure to detect the outer planet is dicussed in § 3.

2. DOPPLER VELOCITIES AND PERIODICITIES

HD 83443 (HIP 47202) is among the fainter G and K dwarfs surveyed by precision Doppler programs with $V = 8.23$ and $B-V = 0.811$ (Perryman et al. 1997), consistent with the assigned spectral type, K0 V. The *Hipparcos*-derived distance is 43.5 pc. (Note that the distance of 23 pc reported in Mayor et al. 2002 is incorrect.) The star is photometrically stable at the level of *Hipparcos* measurement uncertainty. The metallicity of the star, $[\mathrm{Fe/H}] = +0.38$ (Santos, Israelian, & Mayor 2000a), is similar to other stars with 51 Peg–like planets.

The precise Doppler observations presented in this paper were made with the HIRES echelle spectrometer (Vogt et al. 1994) on the 10 m Keck I Telescope and the UCLES echelle spectrometer (Diego et al. 1990) on the 3.9 m Anglo-Australian Telescope (AAT). These spectrometers are operated at a resolution of $R \sim 80,000$ and $R \sim 45,000$, respectively. Wavelength calibration is carried out by means of an iodine absorption cell (Marcy & Butler 1992) that superposes a reference iodine spectrum directly on to the stellar spectra (Butler et al. 1996). These systems currently achieve a photon-limited measurement precision of 3 m s^{-1}. Detailed information on these two systems, including demonstration stable stars, can be found in Vogt et al. (2000) (Keck) and Butler et al. (2001) (AAT).

Based on our photometrically estimated metallicity, $[\mathrm{Fe/H}] = +0.31$, we added HD 83443 to the Anglo-Australian precision Doppler survey in 1999 February. This is among the very faintest stars in the AAT survey. Exposures of 10 minutes on the 3.9 m AAT yield a typical signal-to-noise ratio (S/N) of $\sim$70, giving a median measurement uncertainty of 8.0 m s^{-1} (Butler et al. 2001). A total of 16 AAT observations of HD 83443 have been made between 1999 February and 2002 March. HD 83443 was added to the Keck precision Doppler survey (Vogt et al. 2000) in 2000 December as a result of the CORALIE announcement of a double-planet system. A total of 20 Keck observations have been obtained through 2002 March. The AAT and Keck velocity measurements are listed in Table 1.

We fitted the velocities with a simple Keplerian model for which the usual free parameters are P, T_p, e, ω, and K, as well as a system velocity zero point γ. Figures 1 and 2 show the Keck and AAT velocities, respectively, phased at the best-fit Keplerian orbital period of 2.9856 days. The reduced χ_ν^2 to the Keplerian fits to these data sets are 1.33 and 0.83, respectively. Figure 3 shows the combined set of velocities phased.

Figure 1 shows that a single-Keplerian model, without invoking a second planet, yields a fit to the Keck velocities

TABLE 1
VELOCITIES FOR HD 83443

Julian Date − 2,450,000	Radial Velocity (m s^{-1})	Error (m s^{-1})	Telescope
212.1830	−61.0	10.2	AAT
213.1756	−5.7	10.6	AAT
682.9088	26.5	8.6	AAT
898.0961	26.0	2.7	Keck
899.0788	−52.3	2.5	Keck
900.0854	39.9	2.5	Keck
901.0806	22.4	2.6	Keck
919.2047	4.1	11.6	AAT
920.1821	−48.0	9.6	AAT
971.9566	50.2	3.2	Keck
972.9432	−7.0	3.7	Keck
974.8502	47.2	3.3	Keck
981.9535	−7.0	3.2	Keck
982.9366	−46.2	2.9	Keck
983.0440	−29.4	9.0	AAT
984.0236	40.0	9.8	AAT
1003.7982	−40.1	3.1	Keck
1006.9015	−28.6	2.8	Keck
1007.8096	52.1	2.3	Keck
1009.0816	−32.8	9.7	AAT
1060.9180	0.5	7.8	AAT
1062.7608	−37.2	3.4	Keck
1064.7379	62.8	2.7	Keck
1091.8643	55.2	9.7	AAT
1092.8878	−57.8	8.4	AAT
1127.8521	35.1	13.4	AAT
1188.2812	−33.9	5.0	AAT
1189.2733	−11.3	10.6	AAT
1219.1297	−14.7	2.5	Keck
1236.1362	−50.4	2.2	Keck
1243.1498	−3.1	3.0	Keck
1307.9118	−56.5	2.3	Keck
1333.9629	21.6	2.3	Keck
1334.8507	−53.7	2.6	Keck
1359.1162	−28.7	7.4	AAT
1360.1546	67.3	11.1	AAT

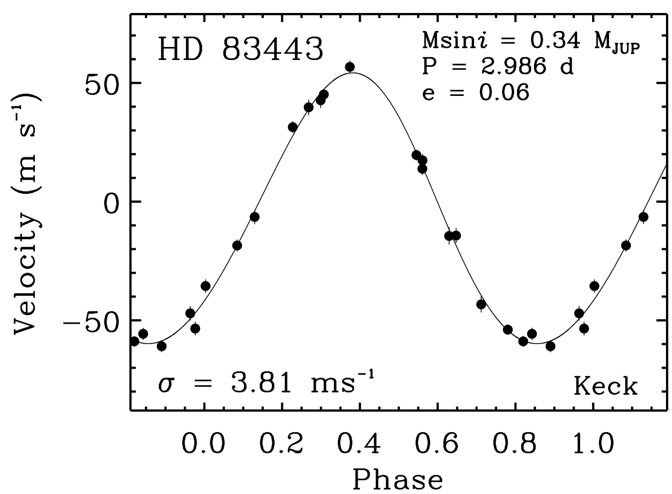

FIG. 1.—Phased Doppler velocities for HD 83443 from Keck. The solid line is the best-fit Keplerian orbit assuming only a single planet. The period $p = 2.986$ days and semiamplitude $K = 57$ m s^{-1} are nearly identical to the CORALIE parameters for the inner planet. The small rms of the residuals of 3.8 m s^{-1} is consistent with errors, implying no evidence for a second planet.

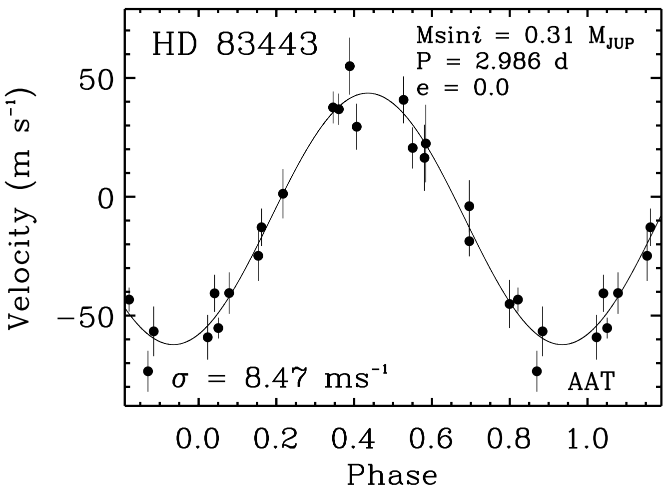

FIG. 2.—Phased Doppler velocities for HD 83443 from the AAT data. The solid line is the best-fit Keplerian orbit assuming only a single planet. The period $p = 2.986$ days and semiamplitude $K = 52.4$ m s^{-1} are similar to the CORALIE parameters for the inner planet. The rms to the Keplerian fit, 8 m s^{-1}, is consistent with measurement uncertainty.

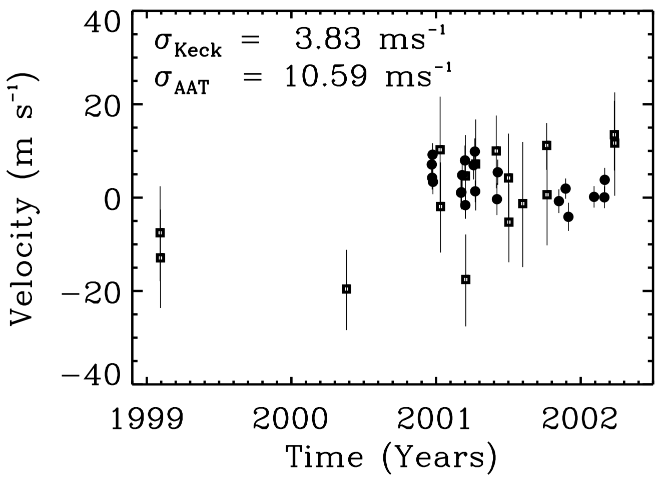

FIG. 4.—Residual velocities from the best-fit single Keplerian for HD 83443, using the combined Keck (*circles*) and AAT (*squares*) data. The Keck residuals have an rms of 3.8 m s^{-1}, consistent with the combined effects of measurement uncertainty and Doppler jitter. The AAT residuals have an rms of 10.6 m s^{-1}, consistent with measurement uncertainty and jitter.

with an rms of 4 m s^{-1}. While this strongly confirms the inner planet, the low rms is surprising because the reported second planet causes a semiamplitude of 13.8 m s^{-1} (Mayor et al. 2002) but is not included in this single-Keplerian fit. Similarly, the AAT velocities are well fitted, within measurement uncertainty, with a single-Keplerian model, as shown in Figure 2.

The combined velocities from Keck and AAT (Fig. 3) can also be fitted with a single-Keplerian model and yield a semiamplitude $K = 57$ m s^{-1}, an orbital eccentricity $e = 0.05$, and a minimum mass ($M \sin i$) of 0.34 $M_{\rm JUP}$. Here we have adopted a stellar mass of 0.79 $M_{\odot}$ (Mayor et al. 2002). The actual stellar mass is probably closer to 1.0 $M_{\odot}$ after properly accounting for the high metallicity of the star. The rms to this Keplerian fit for the combined Keck and AAT observations is 8.1 m s^{-1}, and the corresponding reduced χ^2_ν is 1.39.

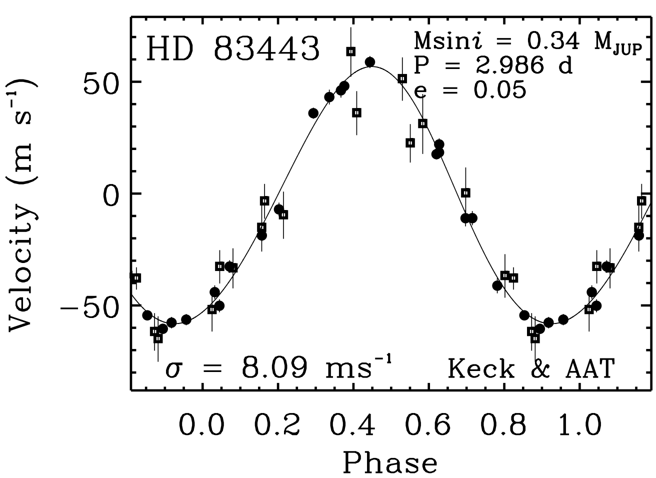

FIG. 3.—Phased Doppler velocities for HD 83443 from the combined Keck (*circles*) and AAT (*squares*) data. The solid line is the best-fit Keplerian orbit. The period $p = 2.986$ days and semiamplitude $K = 57$ m s^{-1} are nearly identical to the CORALIE parameters for the inner planet. Within measurement uncertainty, the eccentricity derived from the Keck-AAT data set is consistent with zero, similar to other "51 Peg–like" planets.

Figure 4 shows the residuals to the single-Keplerian fit to the combined Keck and AAT data. The rms of the residuals are 3.8 and 10.6 m s^{-1}, respectively, for the Keck and AAT observations. The Keplerian orbital parameters derived from the separate and combined Keck and AAT observations are listed in Table 2, along with the orbital parameters from the Geneva Web site for both of the planets announced from the CORALIE data.[11] The orbital parameters for the inner planet, HD 83443b, derived from the Keck and AAT data sets are in good agreement with the CORALIE result, differing primarily in that the Keck-AAT orbit is nearly circular, within measurement uncertainty, as are other extrasolar planets within 0.05 AU.

The median internal uncertainty of the Keck observations is 2.8 m s^{-1}. Based on the Ca II H and K lines, we measure the chromospheric diagnostic $R'_{\rm HK}$ of HD 83443 to be $\log(R'_{\rm HK}) = -4.85$. The Doppler velocity "jitter" associated with this level of activity for a K0 V star is 3.0 m s^{-1} (Saar, Butler, & Marcy 1998; Saar & Fischer 2000; Santos et al. 2000b). Adding the Doppler jitter in quadrature with the measurement uncertainty of 3 m s^{-1} produces an expected Keplerian rms to the Keck data of 4.1 m s^{-1}, which is consistent with the observed rms of 3.8 m s^{-1}.

The AAT and Keck data sets have independent and arbitrary velocity zero-points. The velocity offset between these two data sets was thus left as an additional free parameter in the combined Keplerian fit. As this velocity zero point is dependent on the model used to fit the data, it is not possible to use the combined data set to search for multiple periodicities. As the Keck data has both better phase coverage and significantly higher precision than the AAT data, we intensely searched the Keck velocity set for evidence of a second planet with a period of 29.83 days. However, we also searched the AAT velocities for the second planet, yielding similar results as from the Keck data.

[11] See http://obswww.unige.ch/~udry/planet/planet.html.

TABLE 2
ORBITAL PARAMETERS

Star	Period (days)	K (m s^{-1})	e	ω (deg)	T_0 (Julian Date − 2,450,000)	$M \sin i$ (M_{JUP})	a (AU)	N_{obs}	rms (m s^{-1})
Keck[a]	2.98571(0.001)	57.0(4)	0.059(0.06)	44(40)	1876.99(0.15)	0.35	0.0375	20	3.81
AAT[b]	2.98559(0.0006)	52.9(5)	0.00	0	1213.8(0.1)	0.32	0.0375	21	8.47
Keck-AAT[c]	2.98553(0.0004)	57.5(2)	0.052(0.05)	46(30)	1211.24(0.1)	0.34	0.0375	36	8.09
CORALIE b	2.9853(0.0009)	56.1(1.4)	0.079(0.033)	300(17)	1386.50(0.14)	0.34	0.0380	93	6
CORALIE c	29.83(0.18)	13.8(1)	0.42(0.06)	337(10)	1569.59(0.73)	0.16	0.17	93	6

[a] Linear slope −5.5(3) m s^{-1} yr^{-1}.
[b] Forced circular orbit, linear slope +7.4(3) m s^{-1} yr^{-1}.
[c] Linear slope 0.0(1) m s^{-1} yr^{-1}.

Periodogram analysis (Scargle 1982; Gilliland & Baliunas 1987) reveals a strong periodicity near 3 days for both the Keck and AAT data sets. Figure 5*a* shows the periodogram for the Keck data. The highest peak is the 2.986 day period. The dotted line is the 1% false alarm level. There remain no other significant peaks notably near 29.83 days. Since a strong primary peak can hide secondary peaks (Butler et al. 1999), we have removed the primary peak by subtracting off the best-fit Keplerian from Figure 3. Figure 5*b* shows the periodogram of the Keck velocity residuals from Figure 4. No significant peaks remain.

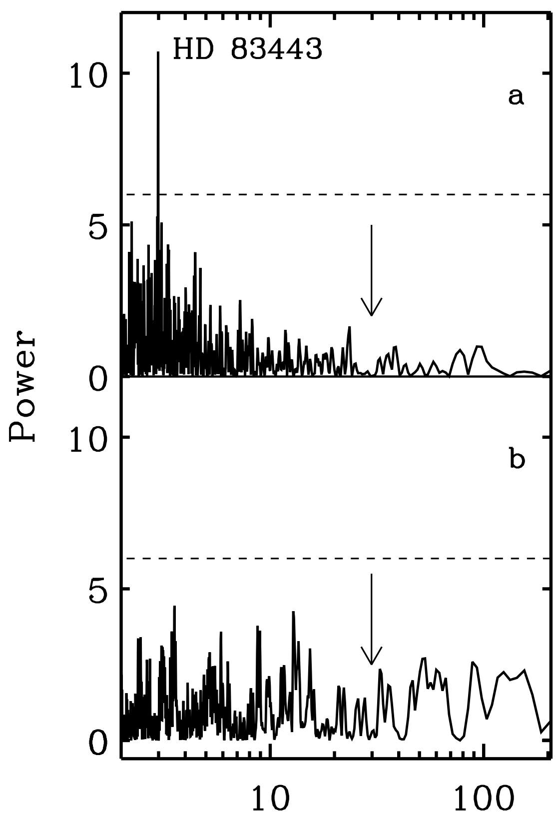

FIG. 5.—Periodogram of HD 83443 Keck velocities. (*a*) Periodogram of measured velocities. The 2.986 day periodicity is indicated by the highest periodogram peak. The 1% false alarm level is indicated with the dotted line. (*b*) Periodogram of residual velocities, after subtracting off the best-fit Keplerian. No significant periodicities remain after subtracting off the best-fit single Keplerian. The arrows indicate 29.83 days, the purported period of the outer planet from the CORALIE data.

We considered the possibility that a 29.8 day periodicity in our velocities, caused by an outer planet, might have been missed in the Keck data because of the temporal sampling of velocity measurements. The observational window function may cause blind spots at certain periods. To test this possibility, we constructed 1000 artificial velocity sets. The fake velocities were calculated from the Keplerian orbital parameters of both planets by simply adding the motion of the star caused by each planet. We adopted the orbital parameters for both planets from Mayor et al. (2002), listed here in Table 2 as planets "b" and "c." In the simulation, we sampled the reflex velocity of the star at the times of the 20 Keck observations listed in Table 1. In addition, random noise with an rms of 4.0 m s^{-1} was added to each of these artificial data sets to simulate the combined effects of Doppler jitter and the Keck measurement errors.

Each of these fake data sets was then fitted with a single least-squares Keplerian, and the rms to this single-Keplerian fit was recorded. A histogram of the rms for the resulting single-Keplerian fits is shown in Figure 6. The rms of these fits ranges from 6.7 to 14.0 m s^{-1}. The median rms to the

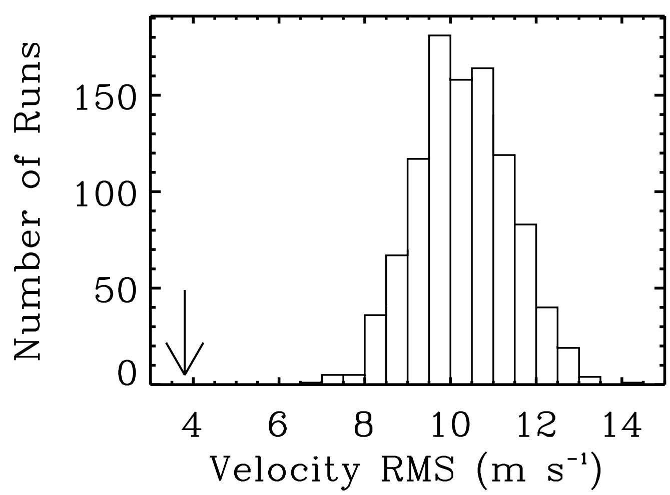

FIG. 6.—Histogram of the rms of the residuals of a single-Keplerian fit to synthetic velocities that stem from a double-planet system. One thousand synthetic Doppler velocity sets were constructed and sampled at the times of the Keck observations, including Gaussian noise. The rms of the residuals to these fits ranges from 6.7 to 14.0 m s^{-1}, with a median of 10.3 m s^{-1}, well above our errors of 3 m s^{-1}. Thus, a single-Keplerian model should fail to adequately fit the double-planet system that was reported. In contrast, the rms of the single Keplerian fitted to the actual Keck data yields an rms of only 3.8 m s^{-1}, consistent with noise, indicated by the arrow, suggesting that the second planet does not exist.

single-Keplerian fit is 10.3 m s^{-1}. In contrast, the rms of the single-Keplerian fit to the actual Keck data is 3.8 m s^{-1}, as indicated by the arrow in Figure 6. Since none of our 1000 artificial velocity sets could be adequately fitted with a single-Keplerian model, the supposed outer planet, if it exists, would similarly not permit an adequate fit with a single-Keplerian model. Thus, there is a less than 0.1% probability that the outer planet can hide in our actual velocities. We conclude that the window function of the Keck observations would not prevent the detection of the outer planet of HD 83443. Such an outer planet, if it existed, should have caused an excess rms in the velocity residuals of $\sim$10 m s^{-1} when fitted by a single Keplerian. Such velocity residuals are not seen.

It remains possible that the period of the outer planet of HD 83443 might be slightly different from that given on the CORALIE Web site. If this were so, and the window function of the Keck observations were unfortunately aligned, it might still be possible that the outer planet could be lurking in the Keck data set. To test this, we fitted the Keck data set with a double Keplerian, using as the input guess the double-Keplerian parameters from the CORALIE Web site (listed in Table 2). The period, eccentricity, and velocity semiamplitude of the inner and outer planets were frozen at the reported values of the supposed outer planet, but the remaining Keplerian parameters, including time of periastron and ω, were allowed to float. Outer planet periods ranging from 28 to 32 days were systematically attempted in steps of 0.001 days. Figure 7 shows the resulting best-fit reduced χ_ν^2 for each of the trial periods. The arrow indicates the location of the 29.83 day period, which yields a best-fit reduced χ_ν^2 of 2.31, much worse than the single-Keplerian fit to the Keck data set with a reduced χ_ν^2 of 1.33.

To estimate the largest semiamplitude allowed by the Keck velocities for a planet in a $\sim$30 day orbit, we again fitted the Keck data with a double Keplerian as in Figure 7, but this time allowed the velocity semiamplitude of the outer planet to float. Figure 8 shows this best-fit semiamplitude for a potential outer planet having orbital periods ranging from 28 to 32 days. At 29.83 days, the best-fit amplitude is 2.8 m s^{-1}. The Keck data rule out any periodicities between 29 and 31 days with an amplitude greater than 3 m s^{-1}. Given the temporal sampling of the Keck data, it remains possible to hide a 13.8 m s^{-1} semiamplitude with a period near 27.7 days from the current Keck data set. This is $\sim$10 σ removed from the CORALIE period of 29.83 days.

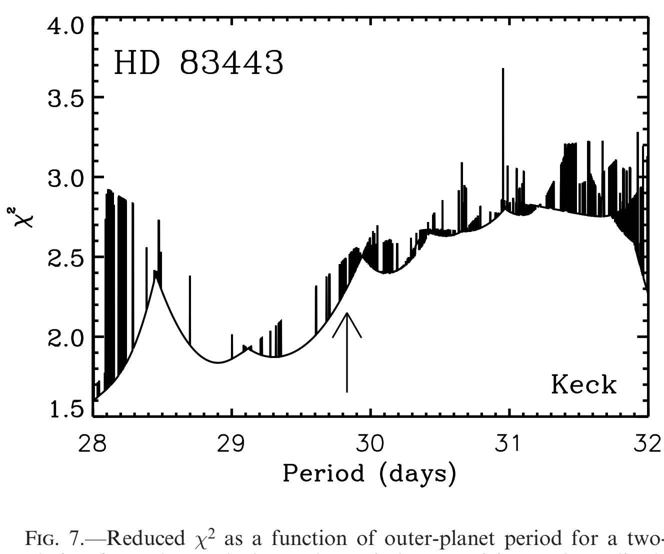

FIG. 7.—Reduced χ^2 as a function of outer-planet period for a two-Keplerian fit to the Keck data. The period, eccentricity, and amplitude of the inner planet have been frozen at the CORALIE values, as have the eccentricity and amplitude of the outer planet. No minimum is seen in the reduced χ^2 near 29.83 days, the purported period of the outer planet.

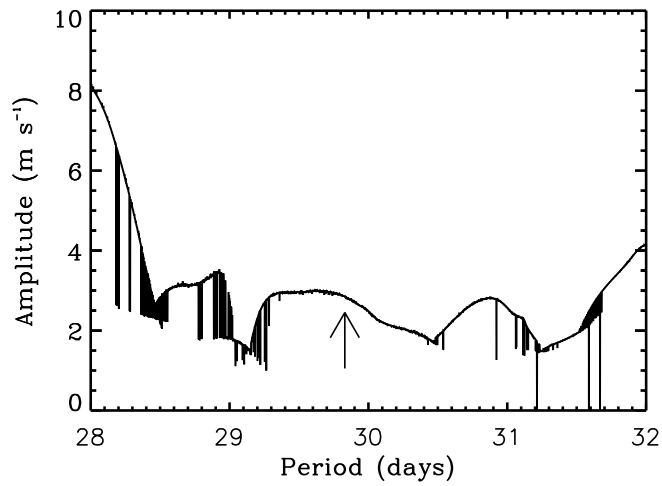

FIG. 8.—Best-fit semiamplitude for the outer planet in a double-Keplerian fit to the Keck data. The period, eccentricity, and amplitude of the inner planet have been frozen at the values reported by CORALIE, as well as the eccentricity of the outer planet. The Keck data rule out an outer planet with a semiamplitude greater than 3 m s^{-1} for periods between 29 and 31 days.

3. DISCUSSION

Precision Doppler observations made with the 10 m Keck and the 3.9 m AAT strongly confirm the existence of the inner planet orbiting HD 83443 and indicate that the orbital parameters are in very good agreement with those reported by Mayor et al. (2002). The present orbital parameters differ only marginally in that the orbit of the inner planet is circular within measurement uncertainty for the Keck and AAT data, similar to other known close-in planets.

However, our Doppler measurements did not detect the 29.8 day outer planet, despite the clear ability to do so. The present measurements impose a limit on any such velocity periodicity at a level of no more than 3 m s^{-1}, well below the reported velocity amplitude of 13.8 m s^{-1}. Orbital periods within 2 days of 29.8 days would have been detected. The supposed velocity amplitude of 13.8 m s^{-1} is 4 times larger than the uncertainties in our velocity measurements, rendering the outer planet immediately detectable. Various tests quantitatively suggest that the velocities should have revealed the outer planet. The velocities from the Keck and AAT telescopes could have independently detected the outer planet, but neither data set revealed it.

We considered various possible reasons that we failed to detect the outer planet. One possibility is that some interactive resonance between the two planets causes the reflex velocity of the star to insidiously mimic a single-Keplerian orbit. That is, perhaps the 10 : 1 ratio of the orbital periods, along with gravitational interactions, yields a final reflex velocity that traces a single-Keplerian velocity curve. If so, we might be fooled into fitting the velocities with such a simple model. We find this possibility unlikely. As shown by W. Benz (Mayor et al. 2002) and by Wu & Goldreich (2002),

TABLE 3

PRECISION DOPPLER PLANETS

Star (HD)	Star (*Hipparcos*)	Star	Paper	Date Received	Velocities	Telescope
217014	113357	51 Peg	Mayor & Queloz 1995	1995[a]	N	Elodie
			Marcy et al. 1997	1996 Sep 19	Y	Lick
117176	65721	70 Vir	Marcy & Butler 1996	1996 Jan 22	N	Lick
95128b	53721b	47 UMa b	Butler & Marcy 1996	1996 Feb 15	N	Lick
			Fischer et al. 2002	2001 Jun 29	Y	Lick
120136	67275	τ Boo	Butler et al. 1997	1996 Aug 12	N	Lick
75732b	43587b	55 Cnc b	Butler et al. 1997	1996 Aug 12	N	Lick
9826b	7513b	υ And b	Butler et al. 1997	1996 Aug 12	N	Lick
			Butler et al. 1999	1999 Apr 8	Y	Lick, AFOE
186408	96895	16 Cyg B	Cochran et al. 1997	1996 Nov 21	Y	Lick, McDonald
143761	...	HR 5968	Noyes et al. 1997	1997 Apr 18	N	AFOE
...	113020b	GJ 876 b	Marcy et al. 1998	1998 Jul 7	N	Lick, Keck
			Delfosse et al. 1998	1998 Aug 17	N	Elodie, CORALIE
			Marcy et al. 2001a	2000 Dec 27	Y	Lick, Keck
187123	97336	...	Butler et al. 1998	1998 Sep 6	N	Keck
			Vogt et al. 2000	1999 Nov 15	Y	Keck
195019	100970	...	Fischer et al. 1999	1998 Oct 8	Y	Lick
			Vogt et al. 2000	1999 Nov 15	Y	Keck
217107	113421	HR 8734	Fischer et al. 1999	1998 Oct 8	Y	Lick
			Vogt et al. 2000	1999 Nov 15	Y	Keck
			Naef et al. 2001a	2000 Aug 30	Y	CORALIE
210277	109378	...	Marcy et al. 1999	1998 Dec 16	Y	Keck
			Vogt et al. 2000	1999 Nov 15	Y	Keck
			Naef et al. 2001a	2000 Aug 30	Y	CORALIE
168443b	89844b	...	Marcy et al. 1999	1998 Dec 16	Y	Keck
			Marcy et al. 2001b	2000 Dec 13	Y	Keck
9826c	7513c	υ And c	Butler et al. 1999	1999 Apr 8	Y	Lick, AFOE
9826d	7513d	υ And d	Butler et al. 1999	1999 Apr 8	Y	Lick, AFOE
13445	10138	GL 86	Queloz et al. 2000	1999 Apr 22	N	CORALIE
			Butler et al. 2001	2000 Dec 25	Y	AAT
17051	12653	ι Hor	Kurster et al. 2000	1999 Oct 19	Y	ESO
			Naef et al. 2001a	2000 Aug 30	Y	CORALIE
			Butler et al. 2001	2000 Dec 25	Y	AAT
10697	8159	...	Vogt et al. 2000	1999 Nov 15	Y	Keck
37124b	26381b	...	Vogt et al. 2000	1999 Nov 15	Y	Keck
			Butler et al. 2002	2002 May 21	Y	Keck
222582	116906	...	Vogt et al. 2000	1999 Nov 15	Y	Keck
177830	93746	...	Vogt et al. 2000	1999 Nov 15	Y	Keck
134987	74500	...	Vogt et al. 2000	1999 Nov 15	Y	Keck
			Butler et al. 2001	2000 Dec 25	Y	AAT
209458	108859	...	Henry et al. 2000	1999 Nov 18	N	Keck
			Mazeh et al. 2000	1999 Dec 3	N	Elodie, CORALIE
130322	72339	...	Udry et al. 2000	1999 Dec 2	N	CORALIE
75289	43177	...	Udry et al. 2000	1999 Dec 2	N	CORALIE
			Butler et al. 2001	2000 Dec 25	Y	AAT
89744	50786	HR 4067	Korzennik et al. 2000	2000 Jan 20	N	AFOE, Lick
16141	12048	...	Marcy et al. 2000	2000 Mar 6	Y	Keck
46375	31246	...	Marcy et al. 2000	2000 Mar 6	Y	Keck
...	...	BD −103166	Butler et al. 2000	2000 Apr 21	Y	Keck
52265	33719	HR 2622	Butler et al. 2000	2000 Apr 21	Y	Keck
			Naef et al. 2001a	2000 Aug 30	Y	CORALIE
12661b	9683b	...	Fischer et al. 2001	2000 Jul 19	Y	Lick, Keck
92788	52409	...	Fischer et al. 2001	2000 Jul 19	Y	Lick, Keck
38529b	27253b	...	Fischer et al. 2001	2000 Jul 19	Y	Lick, Keck
22049	16537	ϵ Eri	Hatzes et al. 2000	2000 Aug 22	Y	McDonald, CFHT, ESO
169830	90485	...	Naef et al. 2001a	2000 Aug 30	Y	CORALIE
1237	1292	GJ 3021	Naef et al. 2001a	2000 Aug 30	Y	CORALIE
179949	94645	...	Tinney et al. 2001	2000 Oct 11	Y	AAT, Keck
160691	86796	HR 6585	Butler et al. 2001	2000 Dec 25	Y	AAT
27442	19921	HR 1355	Butler et al. 2001	2000 Dec 25	Y	AAT
...	113020c	GJ 876 c	Marcy et al. 2001a	2000 Dec 27	Y	Lick, Keck
80606	45982	...	Naef et al. 2001b	2001 May 29	Y	CORALIE
95128c	53721c	47 UMa c	Fischer et al. 2002	2001 Jun 29	Y	Lick
28185	20723	...	Santos, Israelian, & Mayor 2001	2001 Jul 30	Y	CORALIE
213240	111143	...	Santos et al. 2001	2001 Jul 30	Y	CORALIE

TABLE 3—*Continued*

Star (HD)	Star (*Hipparcos*)	Star	Paper	Date Received	Velocities	Telescope
178911b	94075	...	Zucker et al. 2002	2001 Oct 7	Y	Elodie
4208	3479	...	Vogt et al. 2002	2001 Oct 16	Y	Keck
114783	64467	...	Vogt et al. 2002	2001 Oct 16	Y	Keck
4203	3502	...	Vogt et al. 2002	2001 Oct 16	Y	Keck
68988	40687	...	Vogt et al. 2002	2001 Oct 16	Y	Keck
33636	24205	...	Vogt et al. 2002	2001 Oct 16	Y	Keck
142	522	HR 6	Tinney et al. 2002	2001 Nov 12	Y	AAT
23079	17096	...	Tinney et al. 2002	2001 Nov 12	Y	AAT
39091	26394	HR 2022	Jones et al. 2002	2001 Nov 29	Y	AAT
108147	60644	...	Pepe et al. 2002	2002 Feb 26	Y	CORALIE
168746	90004	...	Pepe et al. 2002	2002 Feb 26	Y	CORALIE
141937	77740	...	Udry et al. 2002	2002 Feb 26	Y	CORALIE
137759	75458	ι Dra	Frink et al. 2002	2002 Mar 21	Y	Lick
83443b	47202	...	This paper	2002 Apr 8	Y	AAT, Keck

NOTE.—In the star columns, ellipses indicate no designation for a star in that catalog, and blank spaces indicate the same star as the row above.
[a] Nature does not publish "Date Received."

the gravitational interactions yield a temporal evolution of the orbits on a timescale of $\sim$1000 yr rather than a few years. Thus, we expect the outer planet, if it exists, to remain in a coherent orbit during the few year duration of the present observations. Moreover, the 10 : 1 ratio of the two periods does not constitute a powerful Fourier harmonic from which a single Keplerian can be constructed (as is the case with a 2 : 1 ratio of periods).

We remain puzzled by the discrepancy between the reported CORALIE results and the velocities we have obtained with Keck/HIRES and AAT/UCLES.

Of the 75 extrasolar planet candidates ($M \sin i < 13 M_{\rm JUP}$) announced from precision Doppler surveys,[12] a total of 57 have been published in refereed journals. These planets are listed in Table 3, which also notes the telescope from which the data originate and whether the actual Doppler velocities are publicly available. Refereed precision velocity confirmations are also included. Substellar candidates found by other techniques such as astrometry and low-precision Doppler velocities are not included. An additional four planet candidates have been announced in conference proceedings[13] (Queloz et al. 2002; Sivan et al. 2002). Doppler velocity measurements are not available for candidates that have only been published in conference proceedings. An additional 12 claimed Doppler planets, all of which were announced more than 1 year ago, have not been submitted to either a conference proceeding or a refereed journal.

[12] See http://exoplanets.org/almanacframe.html.
[13] The candidates are HD 6434, HD 19994, HD 121504, and HD 190228.

While the discovery of extrasolar planets has become seemingly commonplace over the past 6 years, we still consider the detection of planets orbiting other stars as extraordinary, and as such worthy of the dictum, "extraordinary claims require extraordinary evidence." Publishing discovery data in a refereed journal remains a crucial part of the process, although this is not in itself sufficient to establish the credibility of a planet claim. It remains extremely likely that at least a handful of the reported planets do not in fact exist. Multiple confirmation both by independent precision Doppler teams and by completely independent techniques remain the only means by which to ensure the veracity of extrasolar planet claims.

We acknowledge support by NSF grant AST 99-88087 and NASA grant NAG 5-12182 and travel support from the Carnegie Institution of Washington (to R. P. B.), NASA grant NAG 5-8299 and NSF grant AST 95-20443 (to G. W. M.), NSF grant AST 96-19418 and NASA grant NAG 5-4445 (to S. S. V.), and by Sun Microsystems. We thank the NASA and UC Telescope assignment committees for allocations of Keck telescope time, and the Australian (ATAC) and UK (PATT) telescope assignment committees for allocations of AAT time. We thank Debra Fischer, Greg Laughlin, Doug Lin, Stan Peale, and Man Hoi Lee for valuable conversations. The authors wish to extend special thanks to those of Hawaiian ancestry on whose sacred mountain of Mauna Kea we are privileged to be guests. Without their generous hospitality, the Keck observations presented herein would not have been possible.

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