

THE 2:1 RESONANT EXOPLANETARY SYSTEM ORBITING HD 73526¹

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ABSTRACT

We report the detection of a second exoplanet orbiting the G6 V dwarf HD 73526. This second planet has an orbital period of 377 days, putting it in a 2:1 resonance with the previously known exoplanet, the orbital period for which is updated to 188 days. Dynamical modeling of the combined system allows solution for a self-consistent set of orbital elements for both components. HD 73526 is the fourth exoplanetary system (of a total of 18 systems with two or more components currently known) to have components detected in 2:1 resonance. Finding such a large fraction of multiple planets (more than 20%) in 2:1 resonance strongly suggests that orbital migration, halted by stabilization in a trapping resonance, plays an important role in the evolution of exoplanets in multiple planet systems.

Subject headings: planetary systems — stars: individual (HD 73526)

1. INTRODUCTION

The Anglo-Australian Planet Search (AAPS) began taking data in 1998 January on the nearest and brightest Sun-like stars. Results from this program (Tinney et al. 2001, 2002a, 2003, 2005; Butler et al. 2001, 2002; Jones et al. 2002a, 2002b, 2003; Carter et al. 2003; McCarthy et al. 2004) have demonstrated long-term velocity precisions of 3 m s^{-1} or better, for suitably quiescent Sun-like stars. The AAPS, together with programs using similar techniques on the Lick 3 m and Keck 10 m telescopes (Fischer et al. 2001; Vogt et al. 2000), provides all-sky planet search coverage for inactive F, G, K, and M dwarfs out to distances of 50 pc. For recent reviews of the progress in exoplanetary detection and the Doppler technique, the interested reader is referred to Marcy et al. (2005b) and Mayor et al. (2005), and references therein.

The AAPS is being carried out on the 3.9 m Anglo-Australian Telescope (AAT), using the University College London Echelle Spectrograph (UCLES) and an I_2 absorption cell. UCLES is operated in its 31 lines mm^{-1} mode. Prior to 2001 September it was used with a MIT/LL $2048 \times 4096 \text{ } 15 \mu\text{m}$ pixel CCD, and since then has been used with an EEV $2048 \times 4096 \text{ } 13.5 \mu\text{m}$ pixel CCD. AAPS currently observes on 32 nights per year. The survey initially targeted 200 F, G, K, and M stars with $\delta < -20^\circ$ and $V < 7.5$. Where age/activity information was available from R'_{HK} indices (see, e.g., Henry et al. 1996; Tinney et al. 2002b), we required target stars to have $\log R'_{\text{HK}} > -4.5$, corresponding to ages greater than 3 Gyr.

In addition to the primary sample, a small subsample of twenty fainter dwarfs with *uvby* photometry suggesting metal enrichment over solar was added in 1999 October (Tinney et al. 2003). These dwarfs have $V < 9$ and were added to examine suggestions that metal-enriched stars preferentially host planets (see e.g., Laughlin 2000 and references therein). HD 73526 (the primary focus of this paper) was one of these stars. A further eight M dwarfs extending as faint as $V < 11$ were also included in the program. In 2002, AAPS further expanded the scope of its survey, increasing from 20 to 32 nights yr^{-1} . Sixty new stars were then added to the target list, and those stars found since their initial inclusion to have R'_{HK} activity levels inconsistent with high-precision velocity measurement (i.e., $\log R'_{\text{HK}} < -4.5$; Tinney et al. 2002b; Jenkins et al. 2006) were culled. The resulting AAPS target sample currently includes 253 stars. Our observing procedure and data analysis continue to substantially follow that described in Butler et al. (1996) and Butler et al. (2001), although over the last 24 months significant improvements have been made to the spectral extraction component of the analysis package (Tinney et al. 2005). A signal-to-noise ratio of at least 200 per pixel is now standard for all stars.

The detection of a first extrasolar planet orbiting the star HD 73526 was presented in Tinney et al. (2003). This planet (hereafter HD 73526b) was estimated to have an orbital period $P = 190.5 \pm 3.0$ days, eccentricity $e = 0.34 \pm 0.08$, and amplitude $K = 108 \pm 8 \text{ m s}^{-1}$, leading to a minimum mass estimate of $M \sin i = (3.0 \pm 0.3) M_J$.

2. THE STAR HD 73526

The characteristics of the host star HD 73526 are summarized in Table 1; please refer to the table notes for references. HD 73526 (HIP 42282, SAO 220191) is a G6 V dwarf. No R'_{HK} estimate is currently available. *Hipparcos (High-Precision Parallax Collecting Satellite)* finds it to be photometrically stable. HD 73526 was initially added to our AAPS target sample based on a Strömberg *uvby* photometry suggestion of metal enrichment over solar, based on which Tinney et al. (2003) estimated a metallicity in the range $[\text{Fe}/\text{H}] = 0.10\text{--}0.16$ (see also Nordstrom et al. 2004 and references therein). Several independent detailed spectroscopic analyses have now been performed for this star leading to metallicity estimates of $[\text{Fe}/\text{H}] = +0.25 \pm 0.03$ (Fischer & Valenti 2005), $+0.27 \pm 0.06$ (Santos et al. 2004), and $+0.11 \pm 0.07$ (Bond et al. 2006). From these we conclude that the metallicity

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TABLE 1
STELLAR PARAMETERS FOR HD 73526

Parameter	Value	References
<i>Hipparcos</i> N_{obs}	137	1
<i>Hipparcos</i> σ	0.02	1
<i>Hipparcos</i> π (mas)	10.6 ± 1.0	1
M_V	4.1 ± 0.2	1
M_{Bol}	3.7 ± 0.2	2
Spectral type	G6 V	3
[Fe/H] (spectroscopic)	$+0.25 \pm 0.05$	4
T_{eff} (K)	5590	4
Mass (M_{\odot})	1.08 ± 0.05	5

REFERENCES.—(1) Perryman et al. 1997; (2) Cox 2000; (3) Houck 1978; (4) Santos et al. 2004, Fischer & Valenti 2005, Bond et al. 2006, see text; (5) Santos et al. 2004, Fischer & Valenti 2005, see text.

of this star is somewhat higher than that derived from Strömgren photometry and assume a metallicity of $[\text{Fe}/\text{H}] = +0.25$. The effective temperatures estimated by these various studies range from 5470 to 5700 K, and we have assumed a median value of 5590 K. Both Santos et al. (2004) and Fischer & Valenti (2005) have used isochrone interpolation to estimate a mass for this star, and they derive 1.05 and 1.08 M_{\odot} (respectively). We have adopted a mass of 1.08 M_{\odot} , giving more weight to the Fischer & Valenti (2005) estimate, which is based on more recent isochrones. These parameters are not significantly different from those assumed by Tinney et al. (2003) and continue to suggest that HD 73526 is beginning its evolution off the main sequence.

3. KINEMATIC ORBITAL SOLUTIONS

Thirty observations of HD 73526 are listed in Table 2. The velocity uncertainty given is produced by the least-squares fitting procedure. This fit simultaneously determines the Doppler shift and the spectrograph point-spread function (PSF) for each observation made through the iodine cell, given an iodine absorption spectrum and an “iodine-free” template spectrum of the object (Butler et al. 1996). The uncertainty is derived for each measurement by taking the mean of 400 useful spectral regions (each 2 Å long) from each exposure. This uncertainty includes the effects of photon-counting uncertainties, residual errors in the spectrograph PSF model, and variation in the underlying spectrum between the template and “iodine” epochs. Since the internal velocity uncertainties produced by the least-squares fitting procedure do not reflect the likely intrinsic variability or “jitter” of HD 73526, a nominal 3.3 m s^{-1} jitter uncertainty is added in quadrature to these internal velocity uncertainties to use in generating the reduced χ_{ν}^2 . All velocities are measured relative to the zero point defined by the template observation.

In Tinney et al. (2003) it was noted that the rms residuals of 18 m s^{-1} about the best Keplerian fit to the HD 73526 velocity data were significantly higher than usually seen from AAPS data, even when the relative faintness of this star is taken into account. Indeed, the velocity uncertainties produced by our least-squares fitting process were typically at half this level, and the $\chi_{\nu}^2 = 1.63$ for this fit was significantly above the expected value of 1.0.

Figure 1 shows a power spectrum generated from the velocities in Table 2, indicating the presence of a strong peak in observed power near the 190 day period first detected by Tinney et al. (2003) and additional peaks (at increasing false-alarm probabilities) near 380 and 128 days. Figure 2 shows the results for a best-fit single Keplerian period near 190 days. As suggested by the large residuals in our initial fit to the earlier set of data, this single-planet fit is clearly inadequate to correctly model this data,

TABLE 2
VELOCITIES FOR HD 73526

JD (−2,450,000)	Radial Velocity (m s^{-1})
1212.1302	-2.1 ± 10.5
1213.1315	7.7 ± 10.5
1214.2390	2.8 ± 12.5
1236.1465	4.0 ± 12.8
1630.0280	0.0 ± 9.8
1717.9000	-180.8 ± 13.0
1920.1419	-82.4 ± 12.4
1984.0378	8.2 ± 9.0
2009.0976	10.0 ± 8.3
2060.8844	-106.7 ± 7.8
2091.8465	-221.2 ± 13.8
2386.9003	-3.8 ± 6.3
2387.8921	-1.7 ± 5.2
2420.9248	-65.4 ± 6.6
2421.9199	-68.9 ± 6.0
2422.8602	-71.5 ± 6.1
2424.9237	-77.4 ± 12.4
2454.8526	-154.8 ± 6.6
2655.1519	-79.4 ± 6.7
3008.1339	3.4 ± 4.5
3045.1355	-96.9 ± 6.1
3399.1625	-54.7 ± 5.6
3482.8801	20.6 ± 3.8
3483.8871	28.7 ± 4.8
3485.9622	21.0 ± 6.6
3488.9389	7.2 ± 4.2
3506.8863	3.0 ± 4.2
3508.9119	14.5 ± 3.8
3515.8937	-1.8 ± 5.6
3520.9103	-3.9 ± 6.3

NOTES.—Julian dates (JD) are barycentric. Radial velocities are barycentric, but have an arbitrary zero point determined by the radial velocity of the template.

leading us to conclude that a multiple-Keplerian fit is required. This situation led Gregory (2005), in an independent reanalysis of the 18 epochs published by Tinney et al. (2003), to suggest the likelihood of other periodicities near 128 and 376 days in that data.

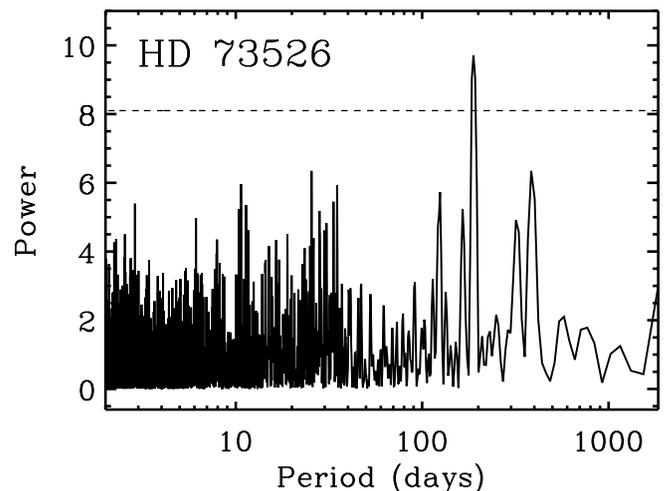


FIG. 1.—Power spectrum of velocities shown in Table 2. The horizontal dotted line represents a false-alarm probability level of 1%. The three most significant peaks in this power spectrum are near 190, 380, and 128 days.

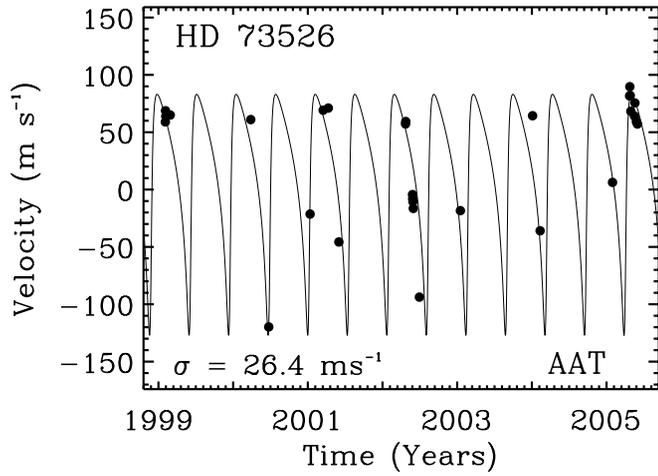


FIG. 2.—Measured velocities of HD 73526. A single Keplerian fit to the data with a period of 187.5 days is plotted over the data. The rms residuals to this fit (26.4 m s^{-1}) are very large, which suggests that this fit does not adequately parameterize the system. (Only epochs from Table 2 with internal uncertainty less than twice the value of the median internal uncertainty are included.)

Adopting the set of parameters fit for a single Keplerian near the dominant 190 day period as a likely neighborhood for the orbital parameters of a first planet, the data were searched for a subsequent planet by performing dual Keplerian fits to the data with these first planet parameters and a period for the second planet selected as (1) the four highest peaks in the periodogram of the residuals to the first planet model; (2) 20 orbital periods spaced in equal logarithmic intervals, with 10 being less than and 10 being greater than the period of the first planet; and (3) three periods that are 2, 3, and 4 times the highest periods found in (1) and (2), as trials for a planet with a period much longer than the duration of observations. For each of these 27 guesses for the period of the second planet, a search of the vicinity is done to find a minimum of χ^2_ν . The use of periodogram peaks and the logarithmic spacing of trial periods will catch second planets as a minimum in χ^2_ν . This process revealed that a 190 day + 380 day system clearly demonstrated a minimal χ^2_ν . To reinforce this conclusion, we show in Table 3 the χ^2_ν for dual Keplerian fits to all the data epochs, using starting periods at pairwise choices from the three dominant periodogram peaks: 190, 380, and 128 days.

Figure 3 shows our best-fitting dual Keplerian model. The orbital parameters of this solution are listed in Table 4. Only epochs from Table 2 with internal uncertainty less than twice the value of the median internal uncertainty are included. The uncertainties in the kinematic orbital parameters are derived from simulations as follows (Marcy et al. 2005b). The set of residuals about the best-fit Keplerian orbits is treated as a population of random deviations with a distribution characteristic of the noise in the data. We then randomly redistributed this “noise” onto velocities calculated from the best-fit solution at the observation epochs and refit to redetermine the orbital parameters. The un-

TABLE 3
HD 73526b,c POSSIBLE DUAL KEPLERIAN ORBITS

Starting Periods (days)	Fit Period 1	Fit Period 2	Reduced χ^2	rms (m s^{-1})
128 + 190.....	125.7 ± 0.1	186.1 ± 0.2	2.7	9.7
128 + 380.....	125.3 ± 0.2	384.5 ± 2.1	2.4	8.9
190 + 380.....	187.3 ± 0.5	376.8 ± 1.2	1.07	7.3

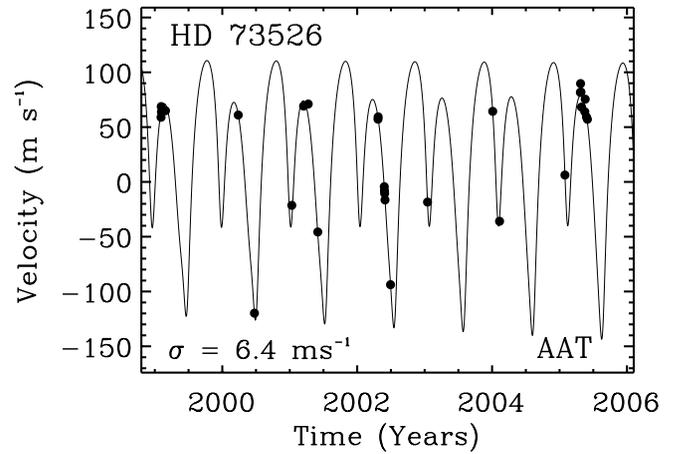


FIG. 3.—Measured velocities of HD 73526. A double Keplerian fit to the data with periods of 187.5 and 376.9 days and the parameters shown in Table 4 is plotted over the data. The rms residuals to this fit are 6.4 m s^{-1} , and the reduced $\chi^2 = 1.09$, indicating that the residuals about the fit are consistent with measurement uncertainties. (Only epochs from Table 2 with internal uncertainty less than twice the value of the median internal uncertainty are included.)

certainties reported in Table 4 are the standard deviations for each parameter that result from repeating this procedure 50 times.

This fit suggests that the system is in a 2:1 resonance with periods of 187.5 and 377 days. It should be noted, however, that due to the similarity of the period of HD 73526c to the orbital period of the Earth (and the consequent annual lack of phase coverage when HD 73526 passes behind the Sun), there is some degeneracy between eccentricity and amplitude in our detailed solution for the orbits of this system. This degeneracy is not reflected in the uncertainties quoted in the table, which uses our observation epochs as a basic assumption. While we can be confident of the orbital periods of HD 73526’s two planets, equally valid solutions (as measured by χ^2) can be derived with eccentricities and amplitudes ranging from $(e_b, e_c) = (0.12, 0.33)$ and $(K_b, K_c) = (141, 96)$ to $(e_b, e_c) = (0.36, 0.38)$ and $(K_b, K_c) = (76, 67)$ (where the families of solutions trade off lower eccentricities for large amplitudes). This state of affairs will change as monitoring of this system continues, although it will take some years for full phase coverage to be accessible with HD 73526c’s orbital phase advancing at just $12 \text{ days}/376 \text{ days} = 3.2\%$ per year.

4. DYNAMICAL ANALYSIS

The parameters listed in Table 4 were derived under the approximation that the orbits are fixed Keplerian ellipses. In reality,

TABLE 4
HD 73526b,c KINEMATIC ORBITAL PARAMETERS

Parameter	HD 73526b	HD 73526c
Orbital period P (days).....	187.5 ± 0.3	376.9 ± 0.9
Velocity amplitude K (m s^{-1}).....	76 ± 5	67 ± 4
Eccentricity e	0.39 ± 0.05	0.40 ± 0.05
ω (deg).....	172 ± 11	183 ± 30
$a_1 \sin i$ (km).....	$(180 \pm 4) \times 10^3$	$(318 \pm 8) \times 10^3$
Periastron time (JD - 2,450,000).....	37 ± 15	184 ± 33
$M \sin i$ (M_J).....	2.07 ± 0.16	2.30 ± 0.17
a (AU).....	0.66 ± 0.05	1.05 ± 0.08
χ^2_ν		1.09
rms (m s^{-1}).....		6.4

TABLE 5
HD 73526b,c DYNAMICAL ORBIT FIT

Parameter	HD 73526b	HD 73526c
Orbital period P (days).....	188.3 ± 0.9	377.8 ± 2.4
Mean anomaly (deg).....	86 ± 13	82 ± 27
Mass (M_J).....	2.9 ± 0.2	2.5 ± 0.3
Eccentricity e	0.19 ± 0.05	0.14 ± 0.09
ϖ	203 ± 9	13 ± 76
Velocity offset (m s^{-1}).....		-29.96
Epoch (JD).....	$2,451,212.1302$	
χ^2_ν		1.57
rms (m s^{-1}).....		7.9

the star and the two planets constitute an interacting three-body system. If one interprets the Keplerian parameters as osculating orbital elements corresponding to a particular epoch, there is no guarantee that the resulting configuration of masses is either dynamically stable or consistent with the radial velocity data set. Indeed, in this particular case, when the dual Keplerian orbital elements listed in Table 4 are integrated forward in time, the system becomes unstable within a few thousand years. Furthermore, when the system is integrated from JD 2,451,212.1302, the epoch of the first radial velocity data point, the χ^2_ν for the fit increases from $\chi^2_\nu = 1.4$ to $\chi^2_\nu = 68.9$, and the rms scatter increases from 7.3 to 35.6 m s^{-1} . (In these fits and in the following dynamical analysis, all data epochs are used and the uncertainties used are the straight internal uncertainties from Table 2 without additional jitter terms being used, which is why the dynamical values of χ^2_ν are all slightly higher than their kinematic equivalents.)

To date, this situation, in which Keplerian orbits with a near two-to-one period ratio provide an excellent fit to the radial velocity data and yet correspond to initial conditions that are either dynamically inconsistent and/or dynamically unstable, has arisen for three other published radial velocity data sets. The most dramatic example is the GJ 876 system (Marcy et al. 2001) in which the outer $2.5M_J$ planet has orbited more than 50 times since the beginning of observations of the system with the Keck telescope (Rivera et al. 2005). As has been shown by a number of authors, starting with Laughlin & Chambers (2001) and Rivera & Lissauer (2001), dynamical fits to the GJ 876 system indicate that the outer two planets are participating in a 2:1 resonance in which the critical angles, $\theta_1 = 2\lambda_2 - \lambda_1 - \varpi_1$ and $\theta_2 = 2\lambda_2 - \lambda_1 - \varpi_2$, both librate with small amplitudes of $\theta_{1\text{max}} \sim 5^\circ$ and $\theta_{2\text{max}} \sim 20^\circ$.

The other two stars that appear to harbor planetary companions participating in the 2:1 resonance are HD 128311 with $M_1 \sin(i) = 2.6M_J$, $M_2 \sin(i) = 3.2M_J$, $P_1 = 449$ days, $P_2 = 920$ days, $K_1 = 85 \text{ m s}^{-1}$, and $K_2 = 80 \text{ m s}^{-1}$ (Vogt et al. 2005) and HD 82943 with $M_1 \sin(i) = 1.85M_J$, $M_2 \sin(i) = 1.84M_J$, $P_1 = 221.6$ days, $P_2 = 444$ days, $K_1 = 67 \text{ m s}^{-1}$, and $K_2 = 46 \text{ m s}^{-1}$ (Mayor et al. 2004; Ferraz-Mello et al. 2005; Lee et al. 2006). While the HD 73526 system is broadly similar to the HD 82943 system, it bears a strikingly close outward resemblance to the HD 128311 system. Both systems have pairs of near-equal $m \sin(i) \sim 2M_J$ companions and periods in the $P_1 \sim 200$ days, $P_2 \sim 400$ days range, although the total radial velocity semi-amplitude is larger for HD 73526, and the period is shorter. This means that aside from GJ 876, the HD 73526 system has the best potential for exhibiting non-Keplerian dynamics over timescales accessible to radial velocity observations.

In anticipation of the potential future importance of the HD 73526 system, we have carried out a self-consistent three-body dynamical fit to the observed velocities (see Laughlin et al. 2005).

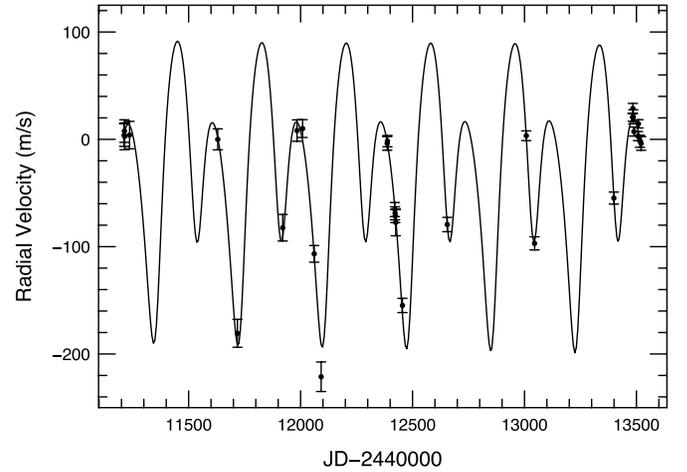


Fig. 4.—Dynamical reflex velocity fit of Table 5 with measured velocities. The rms residuals to this fit are 7.9 m s^{-1} , and the reduced $\chi^2_\nu = 1.57$. (This fit uses all data epochs and measures χ^2_ν relative to the internal uncertainties of Table 2, which is why the rms and χ^2_ν appear higher than those reported for the kinematic fits.)

The fitting procedure employs the dual Keplerian model listed in Table 4 as an initial guess and uses a Levenberg-Marquardt algorithm (similar to that described by Press et al. 1992) to obtain osculating orbital elements (defined at JD 2,451,212.1302) that give a stellar reflex velocity that minimizes χ^2 . The orbits are assumed to be coplanar and edge-on. The resulting fit is listed in Table 5 and plotted in Figure 4.

The system implied by this fit is dynamically stable over a 1 Myr test integration. It is evidently protected by a 2:1 mean motion resonance in which θ_1 librates with width $\theta_{1\text{max}} = 95^\circ$. The resonant argument θ_2 , however, is circulating, indicating that the apsidal lines for the orbits precess relative to one another. The system is subject to the competing influences of both the 2:1 resonant interaction, which forces θ_1 to librate, as well as the Laplace-Lagrange secular interaction, which drives $\varpi_2 - \varpi_1$ through the full 2π range (see Murray & Dermott 1999).

In order to derive the quoted uncertainties in the orbital elements of the dynamical fit, we have adopted the procedure described in Vogt et al. (2005). We take the self-consistent two-planet fit listed in Table 5 and apply a Monte Carlo algorithm in which alternate radial velocity data sets are generated by scrambling the residuals to the fit and then adding them to the model velocities. We then use the Levenberg-Marquardt algorithm to generate a self-consistent fit to each of the Monte Carlo-generated data sets, adopting an unbiased initial guess with $P_1 = 188$ days, $P_2 = 377$ days, $M_1 = M_2 = 0^\circ$, $e_1 = e_2 = 0$, $m_1 = 2M_J$, and $m_2 = 3M_J$.

When a trial has converged, the resulting system is integrated for 10^4 yr, and the maximum eccentricity attained by each planet during the integration is noted. Orbital instability is generally indicated when the eccentricity of either planet approaches unity. We also monitor the maximum excursions of θ_1 and θ_2 , in order to determine whether each individual fit is in 2:1 resonance for the entire 10^4 yr. In 500 such trials, we obtain 268 unstable systems. Among the remaining systems, 159 have θ_1 librating and θ_2 circulating, and 49 have both θ_1 and θ_2 librating. The remaining 24 systems have both resonant arguments circulating. Integrations of these 24 systems to times longer than 10^4 yr have shown instability in every case that has been tested so far.

We note that, as for dual Keplerian fitting, the aliasing is also problematic for our dynamical fits. This results in a degeneracy between our ability to determine e and planet mass. The resulting

uncertainty in these parameters is of a similar scale to that seen in our purely kinematic Keplerian fits. Nonetheless, the period determinations (again as for our kinematic fits) are well determined, as is the conclusion of 2:1 resonance.

The configuration listed in Table 5 is strongly reminiscent of the dynamical fit to the HD 128311 radial velocity data set reported by Vogt et al. (2005), although the orbital eccentricities ($e_{\text{inner}} = 0.38$, $e_{\text{outer}} = 0.21$) were higher in that case than they are here. It will be very interesting if the planets in these systems are indeed trapped in dynamical states in which the 2:1 resonance argument θ_1 librates while θ_2 circulates. Librating-circulating configurations are not observed to arise from the coplanar migration scenarios that have been studied by Lee and collaborators (Lee & Peale 2002; Lee 2004; Lee et al. 2006), which have been successfully applied to model the origin of the GJ 876 and HD 82943 systems. In the Lee et al. migration scenarios, the planets invariably wind up having both arguments in libration. Configurations such as the one given in Table 5 would have to arise either (1) through migration with initial planetary eccentricities, (2) via migration that occurred very rapidly, or (3) as a result of a dynamical scattering event. Work is currently underway to study these three possibilities.

The unusual best-fit dynamical configuration for HD 73526, in which the planets participate in 2:1 resonance with only θ_1 librating, is apparently not an accessible state of the coplanar disk migration scenarios investigated by Lee (2004). It may be possible, however, for capture into a θ_1 -librating, θ_2 -circulating state to occur via fast migration, or migration with initial eccentricities, or migration with significant initial mutual inclination (M. H. Lee 2005, private communication). In theory, the dynamical interactions between planets b and c should allow the mutual inclination of the planets to be obtained via dynamical fitting to radial velocities. In practice, however, such a determination will be difficult to carry out. Even the much more extensive, higher signal-to-noise ratio GJ 876 data set is not yet sufficient to allow a definitive measurement of mutual inclination (Rivera et al. 2005).

It has been suggested by Goździewski & Konacki (2005) that the radial velocity variations in the HD 128311 and HD 82943 systems are caused not by 2:1 resonant configurations, but rather by pairs of planets in 1:1 resonances that resemble high-eccentricity retrograde satellite configurations (see Laughlin & Chambers 2001). We have searched for dynamical fits to the HD 73526 data set that involve pairs of planets in 1:1 resonance, but were not able to find satisfactory coplanar, $i = 90^\circ$ fits. The dearth of such fits likely arises from the fact that the osculating orbital eccentricities of the HD 73526 planets are smaller than in either the HD 128311 or HD 82943 systems.

5. CONCLUSION

The HD 73526 resonant system joins a growing list of exoplanetary multiples in resonant configurations; if it is added to the 17 multiple planets published or in press as at 2005 September (Marcy et al. 2005a), we have eight of 18 planetary systems containing at least one resonance, and four of 18 planetary systems (GJ 876, HD 82943, HD 1128311, and HD 73526) containing a 2:1 resonance. Given the difficulties imposed by the detection of multiple planetary systems (it takes many more observations to detect a multiple than it does to detect the largest velocity signature in a system) and the tendency for resonances to be masked by aliasing and window function effects, these numbers are almost certainly lower limits.

The core-accretion paradigm for planetary formation predicts gas giant planets to form in circular orbits beyond 3–5 AU. However, planets orbiting beyond 0.1 AU (i.e., not circularized by the host star) are seen to have a median eccentricity of 0.25 (Marcy et al. 2005a), so exoplanets in circular orbits are the exception, rather than the rule. Interactions between forming planets and their gaseous disk are thought to dampen, rather than excite, eccentricities (Tanaka & Ward 2004). This suggests that orbital eccentricities arise *after* major gas accretion and that the observed orbital eccentricities are the result of subsequent interactions between planets and their disk, or between planets as they migrate. Certainly, the significant number of gas giants found on small orbits suggests that orbital migration for such gas giants must be common, if not almost ubiquitous. If this is indeed the case, then the detection of a large number of planetary systems trapped into stabilizing resonances (more than a third at present) would arise as a logical consequence.

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