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A NEPTUNE-MASS PLANET ORBITING THE NEARBY G DWARF HD 16417*

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ABSTRACT

Precision Doppler measurements from an intensive 48 night "Rocky Planet Search" observing campaign on the Anglo-Australian Telescope (AAT) have revealed the presence of a low-mass exoplanet orbiting the G1 dwarf HD 16417. Subsequent Doppler observations with the AAT, as well as independent observations obtained by the Keck Planet Search, have confirmed this initial detection and refine the orbital parameters to period 17.24 ± 0.01 d, eccentricity 0.20 ± 0.09, orbital semimajor axis 0.14 ± 0.01 AU, and minimum planet mass 22.1 ± 2.0 $M_{\rm Earth}$. HD 16417 raises the number of published exoplanets with minimum masses of less than 25 $M_{\rm Earth}$ to 18. Interestingly, the distribution of detected sub-25 $M_{\rm Earth}$ planets over the spectral types G, K, and M is almost uniform. The detection of HD 16417b by an intensive observing campaign clearly demonstrates the need for extended and contiguous observing campaigns when aiming to detect low-amplitude Doppler planets in short-period orbits. Perhaps most critically it demonstrates that the search for low-mass Doppler planets will eventually require these traditional "bright-time" projects to extend throughout dark lunations.

Key words: planetary systems – stars: individual (HD 16417)

Online-only material: color figures

1. INTRODUCTION

Pushing exoplanet detection thresholds down to lower and lower masses has been a significant science driver in exoplanetary science in recent years. 17 Doppler exoplanets have been published to date with minimum (i.e., $m \sin i$) masses of less than 25 $M_{\rm Earth}$ – GJ 426b (Butler et al. 2004): HD 219826b (Melo et al. 2007); HD 69830b,c,d (Lovis et al. 2004); HD 190360c (Vogt et al. 2005); Gl 581b,c,d (Udry et al. 2007); HD 4308b (Udry et al. 2006); HD 160691d (Santos et al. 2004); Gl 674b (Bonfils et al. 2007); 55 Cnc e (McArthur et al. 2004); Gl 876d (Rivera et al. 2005); Gl 176 (Forveille et al. 2009); and the recently announced HD 40307b,c,d (Mayor et al. 2009). The majority of these have been found in short-period orbits, with the only three (HD 69830c,d and Gl 581d) having orbital periods greater than 30 d. Of these 18 low-mass exoplanets, roughly equal numbers have been found orbiting M-, K-, and G-dwarfs (6, 6, and 5, respectively, in each of these spectral types). A further three microlensing planets with masses in this range have also been detected—in each case orbiting stars of M-class or later (Gould et al. 2006; Beaulieu et al. 2006; Bennett et al. 2008) because these stars dominate the field star population that microlensing surveys probe.

The roughly equal distribution with host spectral type for the low-mass Doppler exoplanets hides several selection effects. First that finding very low mass planets orbiting G-dwarfs is *much* harder than finding them orbiting M-dwarfs, since the lower mass of an M-dwarf primary will (for a given mass planet of a given orbital period) make the Doppler amplitude of an M-dwarf exoplanet at least three times larger than a G-dwarf one. And second that current planet search target lists are dominated by G-dwarfs.

The detection of such low-mass exoplanets within the last 4–5 years has in large part been due to the dramatic improvements achieved in the intrinsic, internal measurement precisions of Doppler planet search facilities. These have improved to such an extent that it is now clear that noise sources *intrinsic* to the parent star themselves are the limiting factor for very low mass exoplanet detection. Characterization of these noise sources (jitter, convective granulation, and asteroseismological *p*-mode oscillations) has become an important focus of Doppler planet detection. A few obvious modifications to current observing strategies have emerged: (1) target low-mass stars; (2) target chromospherically inactive and slowly rotating stars; (3) target high-gravity stars (where *p*-mode oscillations are minimized); and (4) extend the observations of stars over several *p*-mode fundamental periods, so that asteroseismological noise is averaged over.

In this paper, we first present results from a major observing campaign—the Anglo-Australian Rocky Planet Search–that focused on the last three of these observing strategies, in an effort to push to the lowest possible detection limits achievable with the Anglo-Australian Planet Search (AAPS) Doppler system. The AAPS began operation in 1998 January, and is currently surveying 250 stars. It has first discovered 31 exoplanets with $m \sin i$ ranging from 0.17 to 10 $M_{\rm Jup}$ (Tinney et al. 2001, 2002a, 2003, 2005, 2006; Butler et al. 2001, 2002; Jones et al. 2002, 2003a, 2003b, 2006; Carter et al. 2003; McCarthy et al. 2004; O'Toole et al. 2007; Bailey et al. 2008).

The Anglo-Australian Rocky Planet Search targets unevolved dwarfs with low-activity levels from our main AAPS program. The observing strategy is to observe every target, on every night

* This study is based on observations obtained at the Anglo-Australian Telescope, Siding Spring, Australia.

of a contiguous 48 night observing run (modulo, of course, the vagaries of weather). This 48 night observing run covered two bright lunations, and included an entire dark lunation. Each observation extends over at least 15 minutes in order to beat down *p*-mode oscillation noise to levels well below 1 m s^{-1} (O'Toole et al. 2008). The full Rocky Planet Search target list includes 55 objects, of which 24 were targeted on our first 48 night campaign in 2007 January and February.

In this paper, we present results for the most compelling new exoplanetary detection ([HD16417]HD 16417b) to arise from this concentrated, campaign-mode observing run, together with subsequent AAPS and Keck Planet Search observations.

2. HD 16417

HD16417 (GJ 101.1, HIP 12186) lies at a distance of 25.5 ± 0.4 pc (Perryman et al. 1997), and has a spectral type of G1V (Houk 1982; Gray et al. 2006), an absolute magnitude of $M_V = 3.74$ ($V = 5.78$) and color $B - V = 0.653$. *Hipparcos* photometry finds it to be photometrically stable at the 7 mmag level over 212 observations over the course of the *Hipparcos* mission (Perryman et al. 1997).

As a bright and nearby Sun-like star, HD 16417 has been the subject of multiple detailed atmospheric and isochrone analyses—the conclusions reached by the most recent of these are summarized in Table 1. The first point to note is that all these analyses agree that, while the gravity of HD 16417 is not low enough for it to be classified as a giant or subgiant, it is somewhat lower than the $\log g \approx 4.5$ one would expect from a main-sequence early-G dwarf, indicating that it has begun to evolve off the main sequence. Where ages have been estimated, they indicate HD 16417 to be somewhat older than the Sun—in the range 4–8 Gyr. The mass of HD 16417 is estimated to be somewhat larger than that for the Sun, with the most recent estimates of Valenti Fischer (2005) being 1.38 and 1.18 $M_{\odot}$ (based, respectively, on spectroscopic analysis and isochrone analysis) and that of da Silva et al. (2006) being 1.18 $M_{\odot}$. In the analysis that follows we assume a mass of 1.2 $M_{\odot}$.

Metallicity estimates for HD 16417 range from [Fe/H] of −0.01 to +0.19, with an average value of [Fe/H] = +0.06. Perhaps most critically for the purposes of this study, HD 16417 is a slow rotator ($v \sin i = 2.1$ km s^{-1}) and extremely inactive ($\log R'_{HK} = -5.08$), making it an ideal target for Doppler planet searching at very high precision. The updated Ca II jitter calibration of J. Wright (2007, private communication) for HD16417 indicates a jitter of 2.2 m s^{-1}. The somewhat lower gravity of HD16417 than solar indicates that Doppler observations will by slightly affected by Doppler noise due to *p*-mode oscillations; the relations of O'Toole et al. (2008) indicate a root-mean-square (rms) noise equivalent of less than 0.6 m s^{-1}, for observations of more than 10 minutes.

3. OBSERVATIONS

AAPS Doppler measurements are made with the UCLES echelle spectrograph (Diego et al. 1990). An iodine absorption cell provides wavelength calibration from 5000 to 6200 Å. The spectrograph point-spread function and wavelength calibration are derived from the iodine absorption lines embedded on every pixel of the spectrum by the cell (Valenti et al. 1995; Butler et al. 1996).

Observations of HD 16417 began as part of the AAPS main program in 1998, and over the following 7 years it was observed regularly in observations of 300–600 s (depending on observing conditions), giving a signal-to-noise ratio (S/N) of ≈200 per spectral resolution element in the iodine region. These are the observations listed in Table 2 between JD = 2450831.0428 and 245381.1880. In 2005 July, HD 16417 (together with a number of other bright AAPS targets) was elevated within our observing program to high-S/N status, such that its target S/N per epoch became 400 per spectral pixel. The result was that the median internal uncertainties produced by our Doppler fitting process dropped from 1.59 m s^{-1} to 0.77 m s^{-1}. This improvement gave us confidence that our Rocky Planet Search strategy (concentrating on a small number of targets observed as contiguously as possible over a long observing run) would significantly lower our noise levels for the detection of low-mass planets.

Observations for our Rocky Planet Search program began on 2007 January 10 and continued through 2007 February 26. HD 16417 was able to be observed on 24 of those nights. Since this 48 night run, it has been observed on a further 10 nights at the Anglo-Australian Telescope (AAT), and on 10 nights on the Keck I telescope with High Resolution Echelle Spectrometer (HIRES; Vogt et al. 1994). The Doppler velocities derived from all these observations are listed in Table 2.

4. ANALYSIS

The rms scatter about the mean velocity of all data taken before 2005 July was 4.9 m s^{-1}. The rms about the mean for all data taken since that date is 4.4 m s^{-1}. This is slightly smaller than that seen in the earlier, lower S/N data, but is still significantly larger than would be expected based on the internal measurement uncertainties, and the noise from jitter and *p*-modes in this star. However, in spite of being observed with this improved precision at 16 epochs over the period 2005 July to 2006 November, no convincing periodicity could be extracted from the resultant Doppler velocities.

The 48 night run in 2007, however, provided a clear indication of periodicity at ≈17 d. It was then prioritized for intensive observation over the following 18 months, and subsequent data have confirmed the detection first made in our large, contiguous observing block.

The traditional Lomb–Scargle periodogram (Lomb 1976; Scargle 1982) estimates power as a function of period by fitting sinusoids to a data set. The two-dimensional Keplerian Lomb–Scargle periodogram (2DKLS; O'Toole et al. 2007) extends this concept by fitting Keplerians as a function of both period and eccentricity. We show in Figure 1, for three subsets of the HD16417 data, slices through the 2DKLS at the eccentricity corresponding to the peak power. The subsets examined are (1) all AAT data taken since 2005 July 27, (2) the AAT data taken in 2007 January and February, (3) all AAT data taken since 2005 July *except* that taken in 2007 January–February, and (4) AAT and Keck data taken since 2005 July (with Keck data zero-point-corrected to the AAT system as described below). The first point to note is that Figure 1 clearly shows evidence for a periodicity at 17 d. The second point to note is that periodicity is clearly seen in just the 24 epochs obtained for HD 16417 in the major campaign run in 2007 (Figure 1(b)). But perhaps most interestingly, if the long series of continuous data from that major run is removed (Figure 1(c)), no convincing evidence for any periodicity is detectable. The number of data points and the internal measurement uncertainties of the data that produce Figures 1(b) and (c) are almost exactly the same. The difference is in the window function of the observations. This is a key point to which we return below. And finally the Keck data

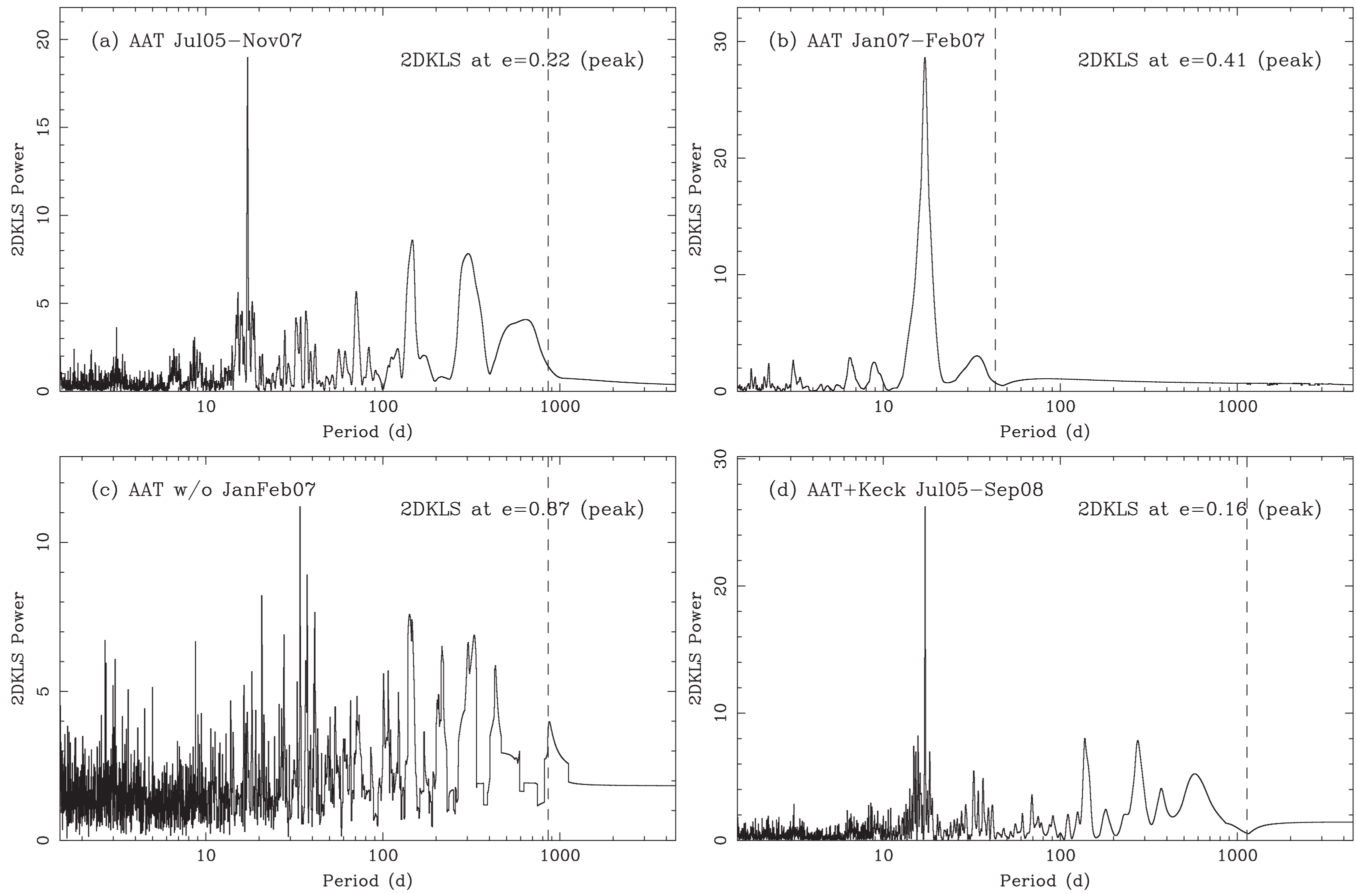

Figure 1. Cuts through 2DKLS periodograms for HD 16417 at the eccentricities where the 2DKLS peaks, from velocities obtained (a) at the AAT 2005 July to 2007 November, (b) at the AAT 2007 January–February (Rocky Planet Search), (c) at the AAT 2005 July to 2007 November, but *not* including velocities from 2007 January–February, and (d) at the AAT and Keck from 2005 July to 2008 September. The dashed vertical line in each panel is at the period corresponding to the length of each data set.

Table 1
Properties of HD 16417

Refereces	$T_{\rm eff}$	[Fe/H]	Mass	log(g)	Age	$v \sin i$	$R'_{\rm HK}$
Gray et al. (2006)	5745 K	+0.00	...	4.11	...	...	−5.093
Valenti & Fischer (2005)	5817 K	+0.07	$1.38 \pm 0.12\ M_\odot$	4.17	5.8 ± 0.6 Gyr	2.1 km s^{-1}	
da Silva et al. (2006)	5936 K	+0.19	$1.18 \pm 0.04\ M_\odot$	4.12 ± 0.03	4.3 ± 0.8 Gyr		
Bond et al. (2006)	...	+0.03	...	4.05	...	...	
Nordström et al. (2004)	5649 K	−0.01	$1.10 \pm 0.04\ M_\odot$	...	7.6 ± 0.7 Gyr	2 km s^{-1}	
Jenkins et al. (2006)	...	...	...	...	...	...	−5.08

(Figure 1(d)) confirm and sharpen the 17 d peak seen at the AAT.

Using the 2DKLS to identify an initial period (O'Toole et al. 2007), a least-squares Keplerian fit to all AAT data obtained since 2005 July results in the orbital parameters for HD 16417b shown in Table 3. Figure 2 displays this fit (and the residuals to it) as a function of both time and orbital phase. The rms scatter to this fit is 2.7 m s^{-1}, and the reduced chi-squared (χ^2_ν) is 1.46. This fit indicates the presence of a planet with period 17.22 ± 0.02 d, eccentricity 0.22 ± 0.11, semimajor axis 0.14 ± 0.01 AU, and minimum mass, $m \sin i$, $21.3 \pm 2.3\ M_{\rm Earth}$.

As an independent test of the validity of the Keplerian fit to the AAT data, observations of HD 16417 were acquired on 10 epochs in 2008 August–September with the HIRES spectrograph on the Keck I telescope. These data were processed as described by Vogt et al. (2005). Being acquired with a completely different telescope, spectrograph, and detector system, these data provide an independent test of our AAT orbit. The Doppler observations from these 10 epochs have a different arbitrary velocity zero point from our AAT data, which we solve for by determining the mean difference (5.30 ± 0.8 m s^{-1}) between them and the AAT Keplerian fit listed in Table 3. The Keck data have an rms scatter about the AAT Keplerian fit of 2.6 m s^{-1}, and are consistent with the AAT orbital fit. The scatter of the Keck data about the AAT fit is consistent with the scatter seen about the AAT data, and is also consistent with being dominated by the 2.2 m s^{-1} stellar jitter assumed for HD 16417. A Keplerian fit to both the AAT and Keck Doppler data is plotted in phased format in Figure 3 and has the parameters listed in Table 3. Inspection of the table shows that the AAT and AAT + Keck solutions are essentially identical.

To test the probability that the noise in our data set might have resulted in a false detection, we have run Monte Carlo simulations using the "scrambled velocity" approach of Marcy

Table 2
AAT and Keck Velocities for HD 16417

JD (−2,450,000)	RV (m s^{-1})	Uncertainty (m s^{-1})	JD (−2,450,000)	RV (m s^{-1})	Uncertainty (m s^{-1})
AAT data			4112.0116	4.3	0.8
831.0428	−4.9	1.3	4113.0269	4.9	0.7
1235.9478	−4.6	1.7	4115.0118	2.2	0.7
1383.3280	−6.2	1.3	4120.0503	−8.1	0.8
1527.0042	−6.2	1.5	4121.0305	−7.6	0.7
1745.2774	−3.0	2.1	4122.9829	−6.2	1.0
1918.9828	1.7	1.7	4125.9886	−3.4	0.8
2093.3381	2.5	1.3	4126.9851	−5.7	0.8
2152.1484	−6.4	1.7	4127.9908	−1.4	0.8
2187.2044	−13.0	1.6	4128.9865	−1.2	0.7
2510.2888	−6.2	1.7	4130.0112	0.9	0.8
2511.1718	4.5	1.8	4130.9868	4.1	0.7
2592.0257	3.4	1.7	4132.0035	1.7	0.7
2595.0301	4.0	1.8	4133.9993	−4.8	0.8
2653.9925	−7.8	1.5	4134.9980	−5.4	0.8
2654.9466	−5.3	1.2	4136.0016	−7.6	0.8
2709.9252	−4.2	1.6	4136.9966	−6.5	0.8
2858.3358	−12.8	2.3	4141.0055	−3.2	1.0
2859.2674	−9.0	1.4	4142.9713	−2.5	0.9
2943.1533	2.8	1.5	4145.9938	0.2	0.9
2947.1022	−0.3	1.5	4149.9572	−2.8	0.9
3008.0274	−3.4	1.4	4151.9790	−3.1	1.3
3042.9591	−1.8	1.4	4153.9422	−8.8	0.9
3044.9355	1.3	1.6	4154.9652	−7.1	0.8
3214.2841	0.6	1.6	4334.2403	4.4	0.9
3216.3303	−1.0	1.3	4336.2952	1.9	1.1
3243.3165	−7.5	1.5	4337.0800	3.4	1.2
3245.3017	−3.5	1.7	4338.3181	3.7	1.0
3281.1880	−4.1	1.4	4369.2268	4.6	0.8
3571.3031	−3.3	0.8	4370.2132	1.1	0.8
3573.2777	−6.5	0.7	4372.1686	5.8	1.0
3574.3199	−3.2	0.6	4375.2326	−0.2	0.8
3576.2722	−3.9	0.6	4425.1309	−0.5	1.0
3577.2801	−2.1	0.8	4430.0449	−6.0	0.8
3579.2940	0.3	0.7	*Keck data*		
3628.2300	0.0	0.8	4668.1283	6.6	0.5
3632.2301	0.6	0.8	4672.1241	−2.4	0.5
3665.1501	2.7	0.8	4673.1315	0.1	0.5
3700.0923	1.5	0.8	4674.1344	−3.5	0.5
3702.1209	−1.3	0.9	4676.1059	1.5	0.5
3749.9836	9.3	0.8	4687.1134	−4.1	0.5
4008.2198	−0.0	0.8	4702.1000	3.4	0.6
4015.1835	−6.1	1.0	4703.0879	−0.3	0.5
4038.1589	4.7	0.8	4704.0405	0.8	0.6
4041.1044	4.7	0.8	4705.0833	−0.7	0.6

Table 3
Orbital Solutions for HD 16417b

Parameter	AAT[a]	AAT + Keck[b]
Orbital period *P* (d)	17.22 ± 0.02	17.24 ± 0.01
Velocity semiamplitude *K* (m s^{-1})	4.8 ± 0.5	5.0 ± 0.4
Eccentricity *e*	0.22 ± 0.11	0.20 ± 0.09
Periastron date (JD−2,450,000)	103.1 ± 4.8	99.74 ± 3.3
ω (degrees)	70 ± 29	77 ± 26
$m \sin i$ ($M_{\rm Earth}$)	21.3 ± 2.3	22.1 ± 2.0
Semimajor axis (AU)	0.14 ± 0.01	0.14 ± 0.01
$N_{\rm fit}$	50	60
Rms (m s^{-1})	2.7	2.6

Notes.
[a] Solutions for all AAT data obtained since 2005 July 19.
[b] Solutions for all AAT data obtained since 2005 July 19 and all Keck data.

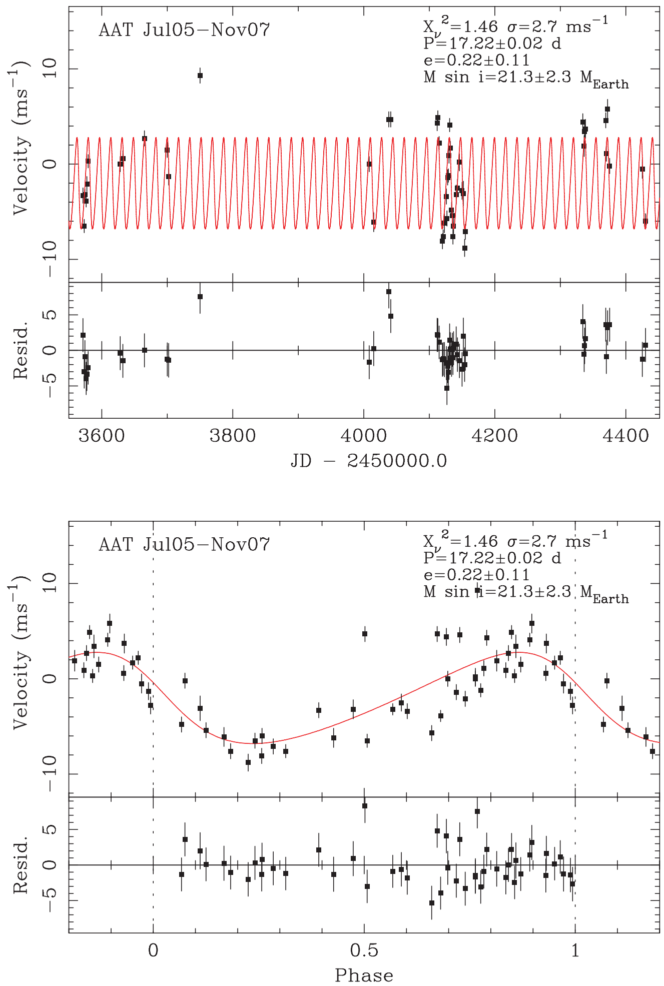

Figure 2. Keplerian best fit to AAT data for HD 16417 from 2005 July to 2007 November, shown as both a function of time (upper plot) and phased at the best-fit period (lower plot). The bars show the internal measurement uncertainty produced by the Doppler measurement process. In each plot, the lower panel shows the residuals to the fit—these bars also include the jitter estimated for HD 16417. A host star mass of 1.2 $M_\odot$ and an intrinsic stellar Doppler variability (i.e., jitter) of 2.2 m s^{-1} are assumed.

(A color version of this figure is available in the online journal.)

et al. (2005). This technique makes the null hypothesis that no planet is present, and then uses the actual data as the best available proxy for the combined noise due to our observing system and the star. Multiple realizations of that noise are then created by keeping the observed timestamps, and scrambling the observed velocities among them. We created 6000 scrambled AAT velocity sets, and then subjected them to the same analysis as our actual data set (i.e., identifying the strongest peak in the 2DKLS followed by a least-squares Keplerian fit). No trial among 6000 showed a χ^2_ν better than that obtained for the original AAT data set, and the distribution of the scrambled reduced χ^2_ν (see Figure 4) shows a clear separation from that obtained with the actual data. We conclude that the probability of obtaining a false planetary detection from our velocities of HD 16417 is <0.017%.

5. DISCUSSION

The velocity semiamplitude of HD 16417b is quite low ($K = 4.8$ m s^{-1}), so we must consider the possibility that the observed variation could be due to a stellar effect, such

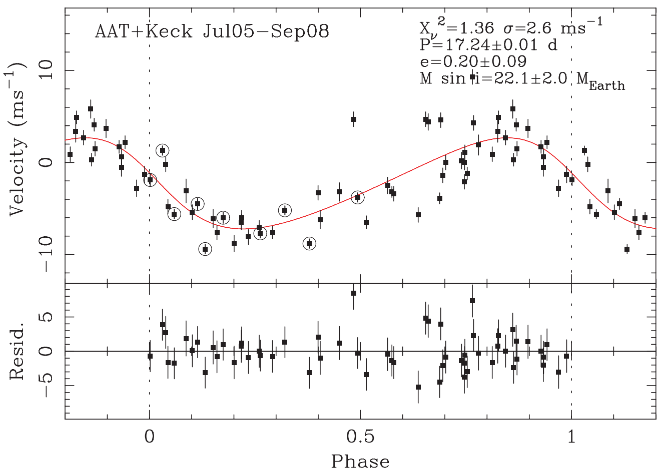

Figure 3. AAT and Keck data (2005 July to 2008 September) phased at period obtained when a Keplerian is fit to both AAT and Keck data. The Keck data are highlighted with circles. The bars show the internal measurement uncertainty produced by the Doppler measurement process. The lower panel shows the residuals to the fit—these bars also include the jitter estimated for HD 16417. A host star mass of 1.2 $M_{\odot}$ and an intrinsic stellar Doppler variability (i.e., jitter) of 2.2 m s^{-1} are assumed.

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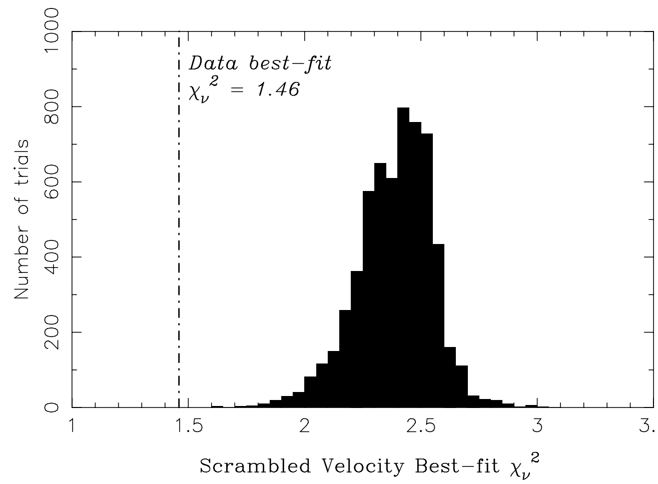

Figure 4. Scrambled false alarm probability results. The histogram shows the χ_{ν}^2 values that result from the best Keplerian fits to 6000 realizations of scrambled versions of the AAPS velocities for HD 16417. The dashed line shows the reduced χ_{ν}^2 for our actual data.

as a rotating starspot, rather than a planet. Unfortunately, the velocity amplitude is much too small for an analysis of line bisectors to reveal any surface kinematics. However, from the activity measure log $R'_{\mathrm{HK}} = -5.08$, we can predict a rotation period of 23–33 d (Wright et al. 2004). This is inconsistent with our measured orbital period of 17.22 d. It is conceivable (as suggested by Vogt et al. 2005 for the similarly short-period, low-mass planet orbiting the inactive star HD 190360) that a ∼17 d Doppler periodicity could be caused by *two* spot complexes at opposite longitudes on a star with a rotation period of ∼34 d. However, the presence of two such complexes would also wash out their Doppler signal, such that each individual complex would need to be roughly twice as large as that required to produce a similar velocity signal from a single complex. Given the implausibility of the contrived spot features required on HD 16417 to produce the observed Doppler periodicity, *and* the fact that the 17 d periodicity has been observed to be coherent in phase over more than 3 years, we argue that the most probable explanation for the observed velocity signal is a low-mass planet in a 17 d orbit.

Given that multiple planet systems are being found around an increasing number of extrasolar planet hosting stars (Butler et al. 2006), we have carried out some simple tests of our data to see if further planets may be present. The next most significant Doppler peak in our data (after the first planet has been removed) is found at ∼290 d. Two-planet fits have been tested, and suggest the possibility of a second highly eccentric planet ($e > 0.8$) at $P \approx 289$ d. However, at present we are hesitant to propose this as a firm candidate given the low Doppler amplitudes involved. The rms scatter about our single planet fit is just 2.6 m s^{-1} (from AAT and Keck data combined), which is consistent with being due to our measurement uncertainties (1 m s^{-1}) and jitter (2.2 m s^{-1}) alone. It is the nature of eccentric Keplerian fits that they are eminently capable of producing apparently good fits to roughly constant data sets with a few velocity outliers—however, if those outliers are truly due to noise, then such fits are essentially meaningless. As this is just the case we see here, more data will be required to confirm or deny the presence of further planets in this system via the repeated observations of periodic outliers to the single planet Keplerian solution.

The orbit of HD 16417b appears to be noncircular ($e = 0.20 \pm 0.09$), adding to the growing list of short-period exoplanets with nonzero orbital eccentricities. Tidal interaction with the planet host star is expected to circularize the orbits of planets with short periods, with circularization timescales typically shorter than the ages of their hosts. We have used the relationship of Goldreich Soter (1966) to estimate the circularization timescale to be ∼350 Gyr. This is much longer than the upper limit to the age of HD 16417 (∼7 Gyr). We used a tidal quality factor, Q_{p}, of 10^5, which is in line with the value estimated for solar system planets, and used a radius estimate based on the measured radius of similar object HAT-P-11b (Bakos et al. 2009).

The origin of the noncircular orbits is not entirely clear. Matsumura et al. (2008) suggested that either basing tidal circularization calculations on our solar system is not appropriate, or that these systems are affected by an external perturbation—i.e., an outer (possibly undetected) planet. In the case of low-mass, short-period exoplanets such as HD 16417b, however, we advise caution in placing too great an emphasis on nonzero eccentricities. Two recent studies by O'Toole et al. (2009) and Shen Turner (2008) have found that there is a bias *against* measuring zero-eccentricity orbits when S/Ns are low. We note that the fit uncertainty for HD 16417b is also quite high ($\sigma_e = 0.1$), and so coupled with this bias, it is not clear that the orbital eccentricity is well constrained. Monitoring of the star is ongoing: this will provide future constraints on all orbital parameters.

HD 16417b raises the number of known planets with $m \sin i$ minimum masses of Neptune mass (or less) to 18. Interestingly, roughly equal numbers have been found in orbit around G-, K-, and M-dwarfs (6, 6, and 6, respectively, in each spectral type). Interpreting these numbers, though, is fraught with difficulty. On the one hand, low-mass planets are easier to find around K- and M-dwarfs as their host star masses are smaller. On the other hand, substantially fewer K- and M-dwarf stars are under survey by Doppler programs at present, and they tend to be fainter and more difficult to obtain optical Doppler velocities for.

What we can clearly conclude from our observations of HD 16417 is that the efficiency of detecting low-mass planets in short-period orbits can *significantly* be enhanced through the use of contiguous, targeted observing campaigns. As noted earlier, 24 epochs of data on HD 16417 obtained over a 48 night observing run show clear evidence for the existence of a low-mass planet orbiting this star. The same quality and quantity of data spread sparsely over an 18 month period in observing blocks of 4–8 nights (and subject to the exigencies of both telescope scheduling and weather) is *not* able to detect the same planet. Such intensive observing—extending across dark, as well as bright, lunations—may well need to become the norm for future high-precision Doppler planet search observations to continue probing to lower mass planets in short-period orbits.

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