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Properties of Extrasolar Planets

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Abstract. To date, 97 extrasolar planets are known, most having $M \sin i < 10$ $\mathrm{M_{JUP}}$ (for updates, see `http://exoplanets.org`). The distribution of masses rises rapidly toward the lower masses, $\mathrm{dN} \propto \mathrm{M}^{-0.7}$, with the lowest $M \sin i$ being 0.12 $\mathrm{M_{JUP}}$ (for HD 49674). The distribution of orbit size reveals a minimum near $a = 0.3$ AU and an increasing number of planets in larger orbits ($\mathrm{d}N/\mathrm{dlog}\, a > 0$). Indeed more extrasolar planets are known orbiting beyond 1 AU than within, with signs of a large population beyond 3 AU. We report the first planet orbiting beyond 5 AU, the outermost of three planets around 55 Cancri. There is an obvious lack of massive planets ($\mathrm{M} > 4$ $\mathrm{M_{JUP}}$) orbiting within 0.3 AU, indicating that the migration mechanism is either inefficient or too efficient for them. The orbital eccentricities of all extrasolar planets are spread nearly uniformly from $e = 0$ to 0.7, indicating that some robust mechanism commonly occurs that pumps the eccentricities. Clues to this mechanism come from the multiple–planet systems of which 10 are known. Four of these systems reveal secular and mean motion resonances while the other planetary systems are "hierarchical", consisting of widely separated orbits. These two system architectures may result from multiple planets migrating in a viscous disk sometimes leading to their mutual capture in resonances. Subsequent eccentricity pumping and other perturbations may result in close encounters leading to scattering and ejection of planets. This scenario would explain the resonances commonly seen and the eccentric orbits common among single planets. Finally, there are indications of a less perturbed population of giant planets at 3–10 AU that would be the analogs of our solar system.

1. Introduction

As of October 2002, there are 97 strong planet candidates orbiting FGKM–type main sequence stars. All were discovered by detecting the wobble of the host star as inferred from precise Doppler measurements (e.g., Butler et al. 1996). The majority of extrasolar planets have $M \sin i < 2$ $\mathrm{M_{JUP}}$ and reside in distinctly non–circular orbits (Marcy, Cochran & Mayor 2000). Updates of all known planets and their orbital parameters are provided at: `http://exoplanets.org`.

The definition of the term, "planet" is controversial because several formation scenarios remain viable (e.g., Lissauer 1995; Boss 2000). Nonetheless, the distribution of masses delineates the planet population (see Figure 1). The *observed* number of planets declines so dramatically from 1 $\mathrm{M_{JUP}}$ to 8 $\mathrm{M_{JUP}}$ that a nominal upper limit for planet status can be set at 13 $\mathrm{M_{JUP}}$, conveniently corresponding to the deuterium–burning limit.

Three primary observables emerge from the Doppler measurements: planet minimum mass ($M \sin i$), orbital period (equivalently semi-major axis, a, from Kepler's 3rd Law), and the orbital eccentricity, e. The relationship between between these three observables and their distribution functions surely reflect the formation and subsequent dynamics of extrasolar planetary systems.

The Doppler technique suffers from notable limitations. It remains difficult to detect planets that induce a wobble of less than 10 m $\mathrm{s^{-1}}$ in the host star (corresponding to 0.5 $\mathrm{M_{JUP}}$ at 1 AU) and also difficult to detect planets having an orbital period over 10 yr, longer than the duration of the Doppler surveys. The statistically rare face–on orbits play only a minor role in the detectability and mass estimates (Jorissen et al. 2000). Multi–planet systems offer another set of useful observables as resonances and gravitational interactions between the multiple planets must stem from a restricted set of formation paths.

Fundamental questions remain regarding the origin of the considerable orbital eccentricities and the steep planet mass distribution. The dynamical processes that lead to resonances remain under study. Key anthropocentric questions remain regarding the occurrence of jupiter–mass planets that resemble our Jupiter in the Solar System and the occurrence of earth–mass planets. The Doppler surveys have barely lasted long enough to detect a jupiter–mass planet in a circular orbit at 5 AU that would serve as a signpost of a solar system architecture.

Planet discoveries are now pushing into several new realms of parameter space: periods longer than 10 yr, planet masses less than 1 $\mathrm{M_{SAT}}$, and multiple–planet architectures. Early results from these new realms will be described here, along with more secure statistical results from the well–observed domain.

2. Properties of Extrasolar Planets

Several research teams have contributed to the detection of extrasolar planets, with most found by the Geneva team and our team (e.g., Butler et al. 2002b; Fischer et al. 2003; Santos et al. 2002; Udry et al. 2002, 2003). Here we include only the most secure detections from `http://exoplanets.org`. (For example, we exclude HD 83443 c, HD 192263 b (Butler et al. 2002a; Henry, Donahue & Baliunas 2002), and several other dubious planets.) Approximately 2000

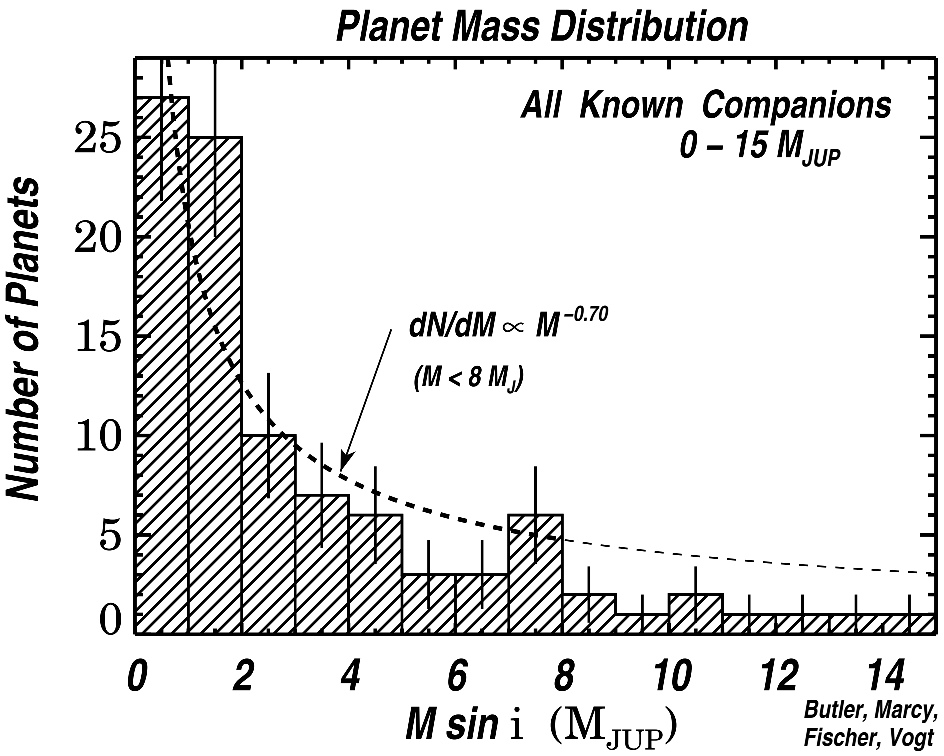

Figure 1. Mass histogram of all 97 securely known extrasolar planets. The rise to smaller masses is clearly visible and is best–fit by $dN/dM \propto M^{-0.7}$ for masses less than 8 M_{JUP}. Planets less than 1 M_{JUP} suffer incompleteness, implying a steeper rise after correction.

nearby FGKM main sequence and subgiant stars have been surveyed, including most such stars within 50 pc and brighter than V = 8 mag. The Doppler planet surveys are less complete for M dwarfs because only Keck and VLT have sufficient aperture to achieve a precision of 3 m s^{-1}. Our Keck survey of 120 M dwarfs is only 3 years along.

2.1. Planet Masses

The mass distribution of all known extrasolar planets is shown in Figure 1. The planet mass distribution reveals a sharp rise toward lower masses, down to 1 M_{SAT} (Marcy & Butler 2000). A fit gives $dN/dM \propto M^{-0.7}$ and the actual rise is probably steeper because the lowest mass planets (below 1 M_{JUP}) remain more difficult to detect. Note that the Doppler method measures only $M \sin i$, and in the context of the Doppler programs we mean $M \sin i$ when we refer to planet masses. However, Jorissen et al. (2000) have shown that the correction for $\sin i$ is very small on average, so the distinction is minor in a statistical sense.

The rising mass distribution can be extrapolated, speculatively, to lower masses, implying the existence of more Neptune–mass and perhaps 10 Earth–

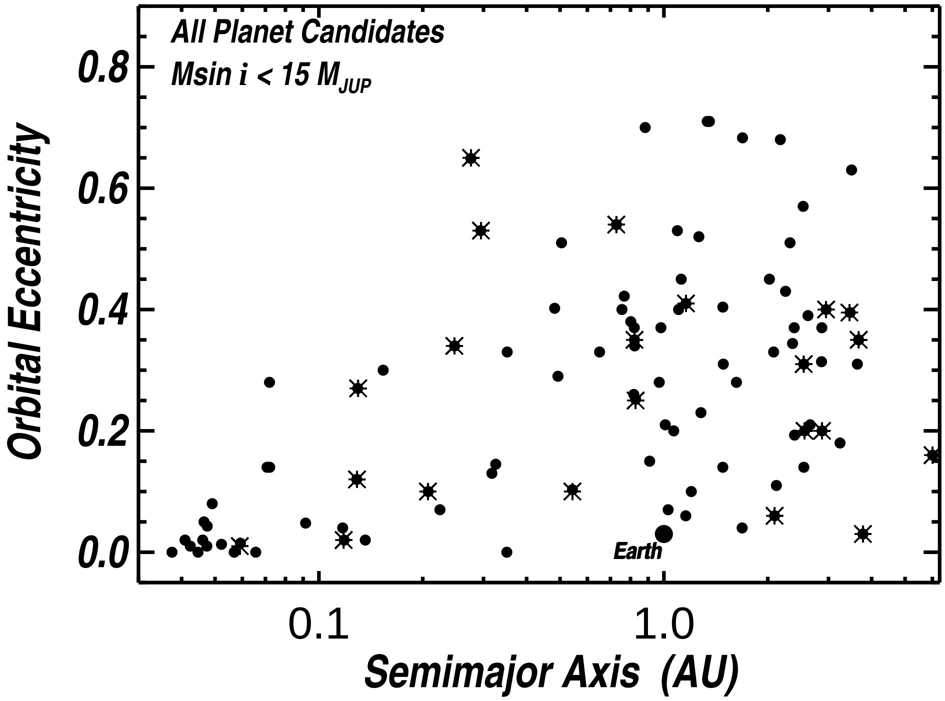

Figure 2. Eccentricity vs. semi-major axis for all known extrasolar planets. Planets in multiple–planet systems are displayed with asterisks. Eccentricities scatter between 0.0 and 0.7, with an apparent upper limit at $e = 0.7$ and an increasing upper envelope between $a = 0.1$–0.5. Planets in multi–planet systems have eccentricities similar to single planets. (HD 80606 b, with $e = 0.93$, sits off the plotted range.)

mass planets than the saturns and jupiters observed so far. The failure of the power law to adequately fit the observed mass distribution above 8 M_{JUP} (see Figure 1) implies that a planet mass scale exists at a few M_{JUP}. Above that scale, the mass distribution falls faster than the power law. We identify the mass distribution shown here with planets formed in protoplanetary disks because alternative mechanisms for the formation of stars (and brown dwarfs) do not predict a rise toward masses below 1 M_{JUP}. Nonetheless, for masses above ~ 8 M_{JUP} it remains plausible that brown dwarf companions also orbit stars within ~ 5 AU. The semantic distinction between planets and such brown dwarfs carries little meaning without the associated physical processes of formation.

2.2. Eccentricities

The known orbital eccentricities are plotted against semi-major axis in Figure 2. Planets within 0.06 AU all reside in circular orbits, likely a result of tidal circularization by the star. The remaining planets exhibit eccentricities distributed nearly uniformly between 0 and 0.7. There is an apparent upper limit at $e = 0.7$ and an apparent trend in the upper envelope between $a = 0.1$–0.5 AU. The star HD 80606 (Naef et al. 2001) has a stellar companion, possibly responsible for its extreme eccentricity of 0.93, off the plot.

The origin of the eccentricities for single planets is not well understood. Plausible mechanisms include gravitational interactions between the planet and other planets, stellar companions, or the protoplanetary disk (Rasio & Ford 1996; Lin & Ida 1997; Marzari & Weidenschilling 2002; Goldreich & Sari 2002; Malhotra 2002). Eccentricity pumping among multiple planets is quite promising (Lee & Peale 2002; Chiang, Fischer, & Thommes 2002; Marcy et al. 2001).

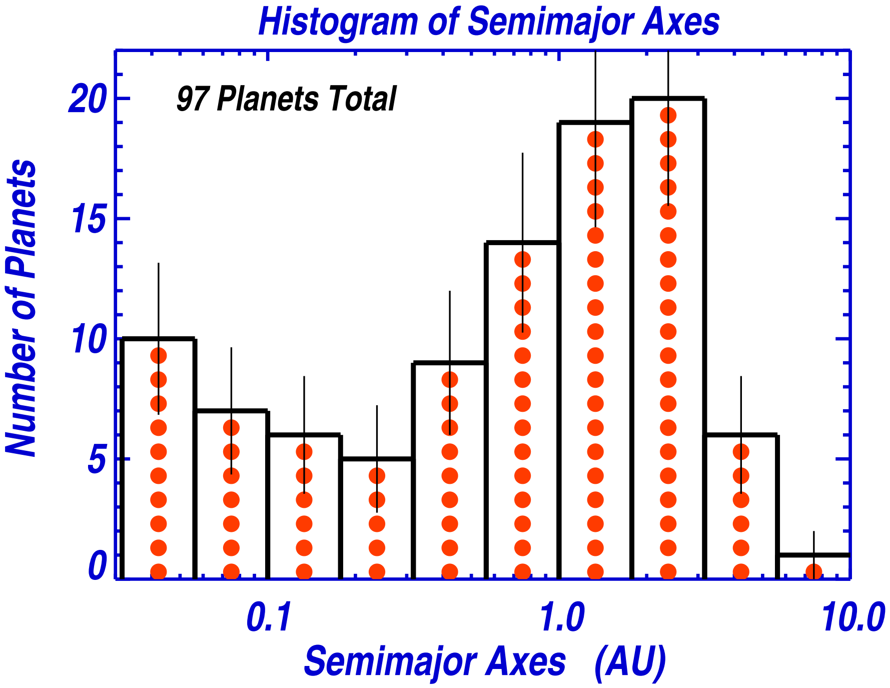

Figure 3. Distribution of semi-major axes among extrasolar planets (in equal log intervals) showing a minimum at 0.3 AU, and a rise toward 3 AU. Incompleteness is severe beyond 3 AU, increasing the likelihood that the number of giant planets increases with semi-major axes from 0.3–3 AU.

2.3. Semi-major Axes

The distribution of orbital semi-major axes is shown in Figure 3, showing a minimum near 0.3 AU, indicating a paucity of planets at that distance. This minimum suggests that the migration mechanism (e.g., Lin et al. 1996) rarely allows them to stop near 0.3 AU (Jones et al. 2003). The number of planets increases for semi-major axes larger than 0.3 AU, out to 3 AU. Beyond 3 AU, the Doppler surveys have had inadequate lifetimes (~ 8 yr) to securely detect planets in the correspondingly long orbital periods. Indeed, there is poor detectability of planets for semi-major axes greater than 2 AU, where planets with $M < 1$ $\mathrm{M_{JUP}}$ are currently difficult to detect, given the precision and duration of surveys. Thus, Figure 3 strongly indicates the existence of a rise in the distribution of planets with increasing orbital distance from the host star.

Our survey of 50 chromspherically quiet stars at Lick Observatory has proceeded since 1987, and indeed some planets in long–period orbits are emerging, such as 55 Cancri d and 47 UMa c, both in somewhat circular orbits. A few more years of Doppler measurements are needed to constrain the eccentricities further.

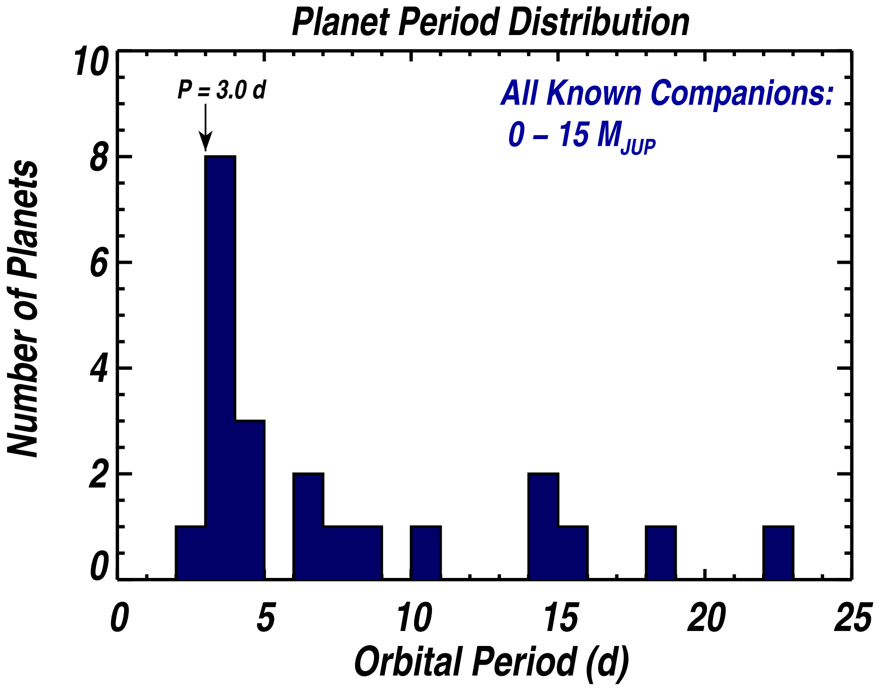

Figure 4. Distribution of orbital periods among the close–in planets. There is a remarkable pile–up of planets with periods of almost exactly 3.0 d.

The increasing numbers of planets in larger orbits is consistent with models that invoke orbital migration and a contemporaneous clearing of the gaseous disk to explain the final positions of giant planets (Armitage et al. 2002; Trilling et al. 2002). Many planets beyond 5 AU are simply left stranded there when the disk gas vanishes. Such models predict the existence of a population of giant planets that still reside at 5 AU, never having migrated inward. If the disk clears its gas on a time scale shorter than the migrational time scale, then giant planets beyond 5 AU could be more numerous than the extrasolar planets discovered so far. Moreover, such planets may well have suffered few gravitational perturbations, leaving them in circular orbits, not unlike that of our Jupiter and Saturn. Thus Figure 3 hints at a population of as–yet–unobserved giant planets at 5–20 AU

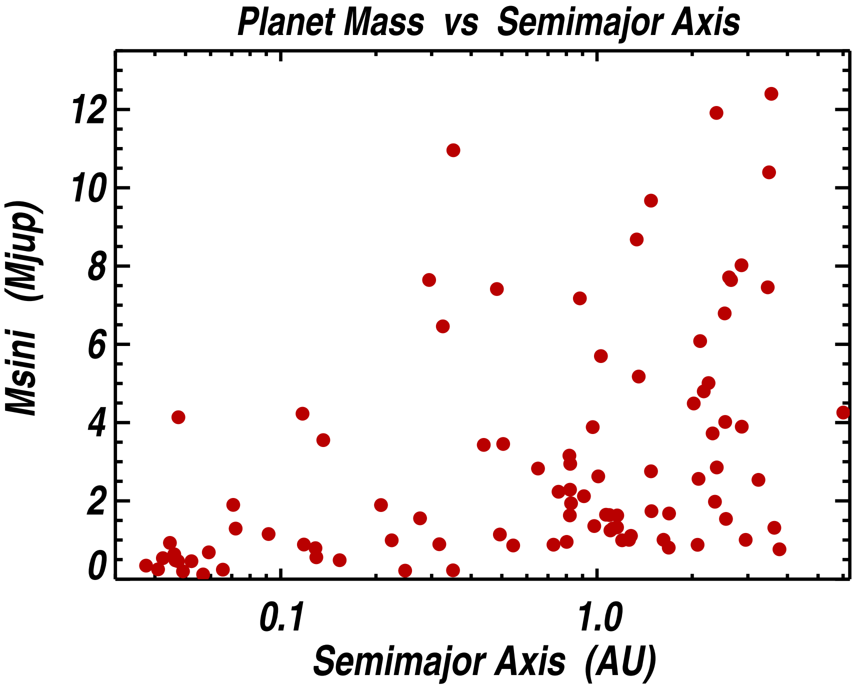

Figure 5. Mass vs. semi-major axis for all known extrasolar planets. There is a remarkable absence of massive planets residing within 0.3 AU.

that experienced a gentler dynamical history than that of the known extrasolar planets.

At $a \sim 0.05$ AU, there is an apparent pile–up of planets. This is shown in Figure 4, which contains a magnified view of the distribution of the closest planets. Figure 4 shows 8 planets having an orbital period of 3–4 days, and one at 2.989 d (HD 83443 b). Clearly this pile–up is statistically significant. The pile–up suggests that some mechanism must be responsible for halting the migration of planets at an orbital period of 3 days. Some hole in the protoplanetary disk extending to Keplerian periods of $P = 3$ or 6 days seems a likely cause.

2.4. Mass vs. Semi-major Axis

Figure 5 shows a plot of planet mass vs. orbital semi-major axis. There is an obvious lack of massive planets having small semi-major axes, i.e. in the upper left quadrant (see Zucker & Mazeh 2003). Planets with masses above 4.1 $\mathrm{M_{JUP}}$ are absent within 0.3 AU and few massive planets reside within 1 AU. In contrast, 1/3 of the extrasolar planets beyond 1 AU have $M \sin i > 4\ \mathrm{M_{JUP}}$. Thus, Figure 5 suggests either that planets with masses above 4 $\mathrm{M_{JUP}}$ rarely migrate inward of 1 AU or that they migrate all the way into the star. At present, we cannot distinguish between these possibilities.

3. Multi–Planet Systems

Approximately 50% of the stars that show clear evidence of one planet, eventually show Doppler evidence of additional planets (Fischer et al. 2001). Remarkably, 10 multiple–planet systems are now known, including Upsilon And, 55 Cnc, GJ 876, HD 37124, HD 12661, 47 UMa, HD 168443, HD 38529, and HD 82974 and one or two candidate systems. The properties of the planets in multiple planet systems may be compared to those of single giant planets, and the overall structures of the multi–planet systems seem to fall into two classes, interacting and hierarchical, as described in this section.

3.1. Upsilon Andromedae

The first multi–planet system discovered, Ups And, happened to have three planets (Butler et al. 1999). The current data and three–planet fit are shown in Figure 6.

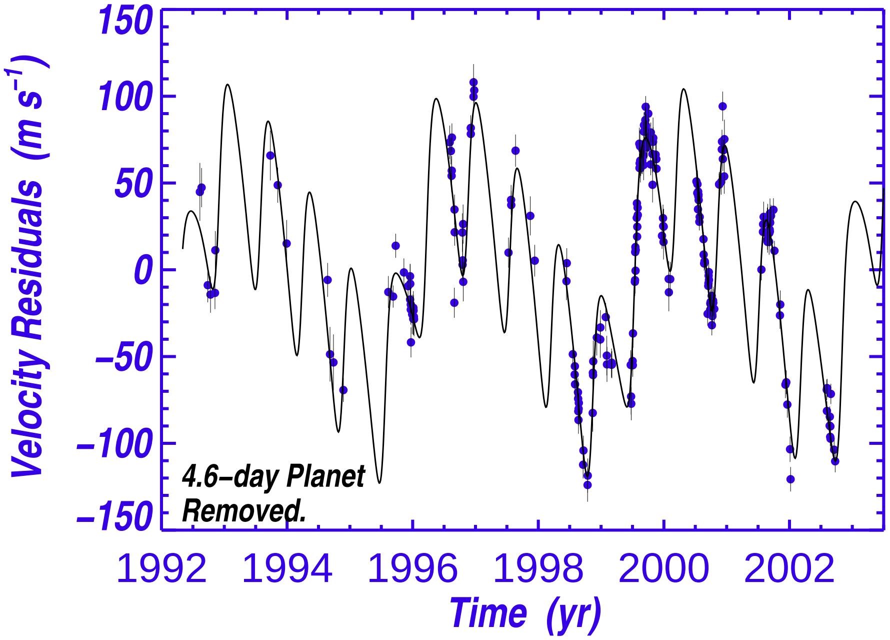

Figure 6. Orbital fit for three planets orbiting Upsilon And. Measured velocities (dots) and the best–fit model (line) consisting of three Keplerian orbits independently perturbing the star. Both the velocities and model are shown after subtracting the effects of the inner (4.6 d) planet, for clarity.

For each planet, our Doppler measurements determine ω which is the angle, as viewed from the star, between periapse of the planet and a reference line where the plane of the sky cuts the orbital plane. The values of ω for the outer two planets around Upsilon And are 246° and 259°, each with an uncertainty of 4°. Dynamical calculations show that this coincidence likely implies that planets c and d reside in a secular resonance in which $\Delta\omega$ librates about 0 with an amplitude of $\sim 30°$ (Chiang, Tabachnik, & Tremaine 2001; Lissauer & Rivera 2001).

Such a secular resonance opens the question of dynamical origin. Gentle migration of the two planets into this delicate resonance is required rather than deep scattering. Models to achieve this gentle settling invoke migration in a viscous disk and possible excitation of the eccentricity of the outer planet, d, by the disk. Secular interactions between planets c and d could have allowed exchange of eccentricities between the two planets (Chiang & Murray 2002).

3.2. GJ 876

GJ 876 has spectral type M4V and mass 0.35 $M_\odot$, making it the lowest mass star with an extrasolar planet. Its measured velocities can be fit (albeit inadequately) with a model of two planets orbiting in simple (independent) Keplerian motion around the star (Marcy et al. 2001), as shown in Figure 7. The orbital periods are 30.1 and 61.0 days, indicating the possibility of a gravitational interaction between the planets leading to a dynamical resonance. Such a 2:1 mean–motion resonance indeed is indicated by simulations of the two-planet system that include the planet-planet interactions (Rivera & Lissauer 2001; Lee & Peale 2002). The planets will librate about this 2:1 ratio of orbital periods indefinitely. The establishment of this resonance may have involved convergent migration as the outer planet migrated toward the inner one, pushed together by book–end gas, allowing them to settle into a 2:1 resonance (Lee & Peale 2002).

The two planets orbiting GJ 876 perturb each other on a time scale of years, and the effects are detectable in the existing measurements. Figure 7 shows the best fit to the velocities achievable with a model that includes two independent Keplerian orbits. The value of $\sqrt{\chi^2}$ is 2.4, and the RMS of the residuals is 12 m s^{-1}, both indicating that the fit is inadequate.

A model that includes the planet–planet interactions lowers the value of $\sqrt{\chi^2}$ from 2.4 to 1.5 over the model that does not include perturbations (Rivera & Lissauer 2001; Laughlin & Chambers 2002). Moreover, the planets cannot be arbitrarily massive, as the perturbations are modest in magnitude (roughly 10 m s^{-1} during several years). Thus the orbit plane cannot be arbitrarily face-on, and simulations limit the value of $\sin i$ to be 0.5–0.8 (Rivera & Lissauer 2001; Laughlin & Chambers 2002). Recent astrometric measurements of the wobble of GJ 876 find an orbital inclination for the outer planet of 84° ± 10°, implying a mass of 1.89 ± 0.34 $M_{\rm JUP}$ (Benedict et al. 2002).

3.3. 55 Cancri

The G8 main sequence star 55 Cnc revealed a velocity periodicity of 14.6 d and $M \sin i = 0.9$, but also revealed a trend in the velocity residuals to the Keplerian fit (Butler et al. 1997). These velocity residuals rose from 1989 until 1996, declining thereafter. Intense monitoring (especially by DAF during the past four years) reveals that a minimum in the velocity residuals has been reached, indicating closure of the outer orbit (Marcy et al. 2002). The raw velocity measurements for 55 Cnc are shown in Figure 8.

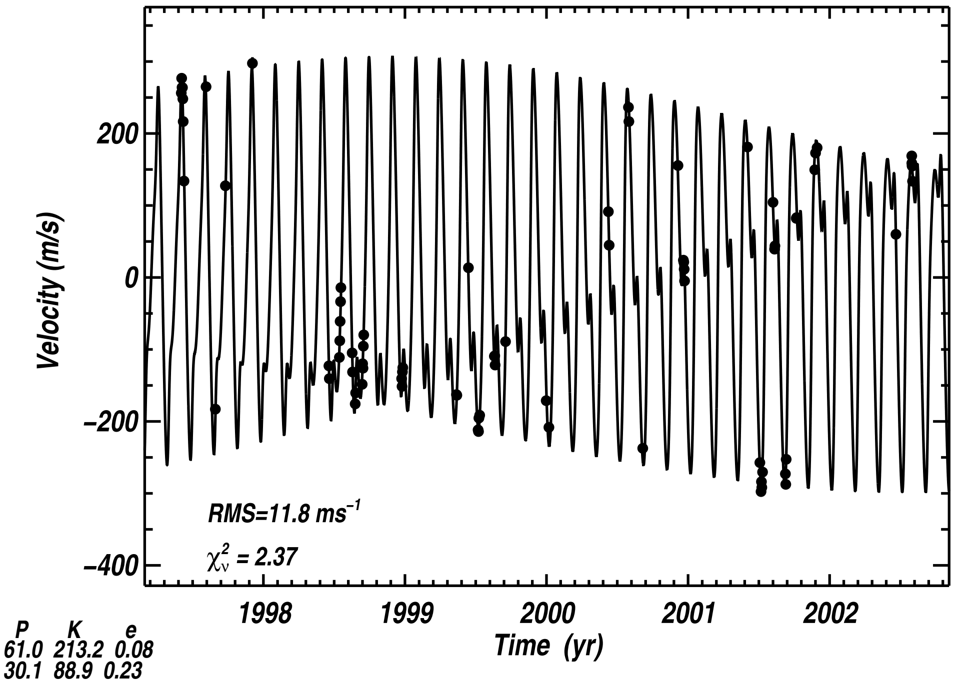

Figure 7. Velocities and two–Keplerian fit for GJ 876. The high value of χ^2 and RMS are a result of planet–planet interactions.

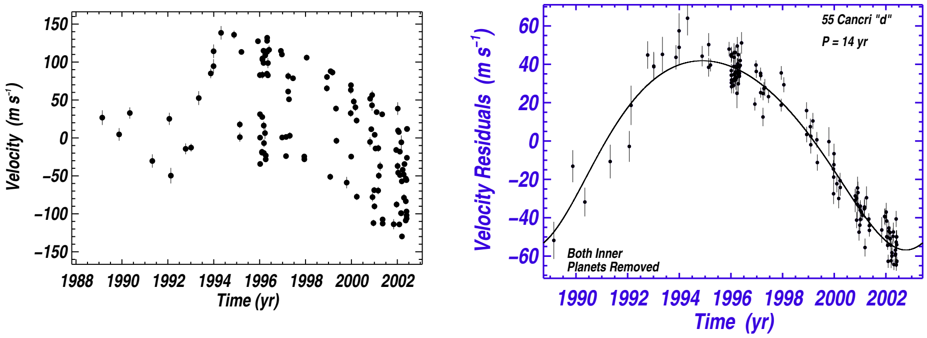

Figure 8. Three planets orbiting 55 Cancri. Left: Raw velocities versus time. Right: The best three–planet fit to the velocities, after subtracting the inner two planets. The third planet resides at ~ 6 AU in a nearly circular orbit.

The 55 Cancri system clearly has an outer planet at nearly 6 AU, as shown in Figure 8 (right). A two–planet fit to 55 Cancri leaves residuals that exhibit a periodicity of 44 days, possibly caused by a third planetary companion. However, the rotation period of the star is 35–42 days, as shown by Henry et al. (2000) from periodicities in the Ca II H&K line. Thus a danger exists that the 44–day period in the velocities may be caused by stellar surface inhomogeneities which rotate into and out of the view across the hemisphere. Greg Laughlin has shown that the "middle" planet, if real, not only would be stable against the perturbations of the other two planets, but also would reside near a 3:1 resonance with the inner planet of period 14.6 d.

The outer planet, 55 Cnc d, is the first extrasolar planet discovered to orbit beyond 5 AU from its star. Indeed, with a nearly circular orbit ($e < 0.2$) it is clearly the extrasolar planet most reminiscent of our Jupiter at 5.2 AU. However, 55 Cnc d has a large mass, at least 4 $\mathrm{M_{JUP}}$, and the architecture of the 55 Cnc system as a whole, with its two inner jupiter–mass planets, clearly differs from that of our solar system. The inner two giant planets apparently suffered significant migration, but not so for the outer one. Interestingly, N-body simulations by G. Laughlin (Marcy et al. 2002) show that a terrestrial–mass planet would be stable in orbit between 55 Cancri c and d, making this star a good candidate for direct imaging.

The three planetary systems described above, Upsilon And, GJ 876, and 55 Cnc are among 10 multi–planet systems known to date (see `http://exoplanets.org`). Among these is HD 82974 which also reveals a 2:1 resonance (ESO Press Release 07/01). These four systems show signs of resonances currently, and presumably mean-motion and secular resonances constrain the plausible dynamical evolution that could lead to these confined states. The remaining multi–planet systems are not in obvious resonances and seem to reside in a different class.

4. Hierarchical Planetary Systems

Among the 10 multi–planet systems known to date, 6 consist of two planets in widely separated orbits. Two such cases are HD 37124 and HD 12661.

Velocities from 1997–2000 for HD 37124 revealed a planet with a period of 155 d and $M \sin i = 1.0$ (Vogt et al. 2000). But subsequent velocity measurements in 2001 and 2002 (Butler et al. 2002b) revealed an outer planet (P = 1500±300 d) in addition to the inner one (see Figure 9). The best–fit eccentricity of the outer planet is formally near $e = 0.7$, but the value of χ^2 remains insignificantly different for e = 0.4–0.8. However, dynamical simulations by one of us (DAF) and by Greg Laughlin suggest that the higher eccentricities can be excluded due to the resulting unstable orbit. For $e > 0.7$, the outer planet approaches the inner one too closely resulting in subsequent ejection of one of them. From these dynamical considerations, the outer planet probably has an eccentricity less than ~ 0.55. This system typifies a growing number of multiple–planet systems in which dynamical considerations impose constraints on the plausible orbits.

We introduce the classification "hierarchical" for widely separately double–planet systems. We define hierarchical planetary systems as those in which the ratio of orbital periods is greater than 5:1. Such systems are unlikely to be

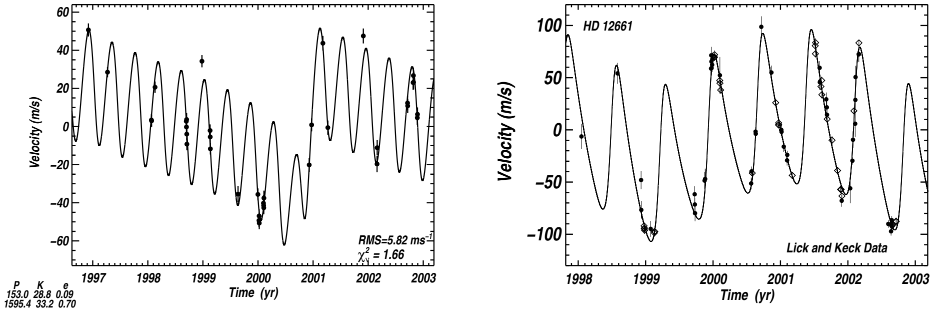

Figure 9. "Hierarchical" double–planet systems HD 37124 (left) and HD 12661 (right). The velocities are fit with a double–Keplerian model (solid line). The widely separated periods render these systems "hierarchical" (see text). For HD 12661, the velocities are from Keck (diamonds) and Lick (dots).

actively engaged in mean–motion or secular resonances. In hierarchical systems, neither the orbital parameters, nor linear combinations thereof, are likely to circulate or librate about some value. Indeed, their periods are so disparate that interactions affect the motions only on time scales that are long compared to the orbital periods.

For HD 37124, the periods are 155 and 1500 d, clearly representing the hierarchical class of double planets. While they don't interact strongly now, one wonders if the two planets have ever interacted strongly in their past. Any past close encounter would have resulted in large orbital eccentricities, but such is not the case. These two planets have nearly equal values of $M \sin i$, and the inner planet has $e = 0.1$, nearly circular, indicating that it did not suffer a close scattering as its last dynamical event. But the outer planet has a large eccentricity of $e = 0.4$–0.5, leaving a mystery of its origin if not by a close scattering. One might wonder if slow exchange of eccentricity may be occurring between the two planets via the Kozai resonance (Kozai 1962). Of course, the orbital inclinations are unknown but are necessary to definitively anticipate any interactive dynamics.

Another "hierarchical" double–planet system is HD 12661, with two planets having periods of 260 and 1407 d. Figure 9 shows the current best two–planet fit, using velocity measurements from both Lick and Keck observatories (Fischer et al. 2003). A resonance is unlikely to be currently active in this system. With eccentricities of 0.3 and 0.2, it remains possible that interactions played a role in shaping their current orbits and that an ongoing interaction actively causes an eccentricity exchange (Holman et al. 1997; Chiang et al. 2002).

5. Eccentricities and Resonances Among Single and Multiple Planets

High orbital eccentricities are common among single planets and resonances are common among multiple–planet systems. One wonders if there is a connection between these two unexpected properties. Are eccentricities pumped in single planets by a different mechanism than in multiple–planet systems? To investigate this, one may compare the eccentricity distributions among single and multiple–planet systems.

Figure 2 shows orbital eccentricity vs. semi-major axis for all 97 securely known planet systems, showing with asterisks those planets that reside in multiple planet systems. There are 22 such planets, residing in 10 multiple systems, two of which are triple. *The distribution of orbital eccentricities among the planets in multi–planet systems is indistinguishable from that of the single planets.* Moreover, the distribution of semi-major axes of planets within multi–planet systems is indistinguishable from that of the single planets shown.

The similarity in the eccentricities and semi-major axes of single planets and multiple–planets suggests that the origin of the eccentricies may be qualitatively similar. A similar mechanism is remarkable, because the planets in multi–planet systems are definitely perturbed by each other, as seen dynamically in the GJ 876 system (Rivera & Lissauer 2002).

Distinct mechanisms have been proposed to explain the orbital eccentricities, namely planet–planet interactions and planet migration leading to resonance capture (Marzari & Weidenschilling 2002; Ford, Rasio & Yu 2003; Lee & Peale 2001; Chiang & Murray 2001; Chiang, Fischer, & Thommes 2002). Goldreich & Sari (2002) also consider planet–disk interactions, as does Chiang (2003).

A comprehensive model for orbital eccentricities may involve several combinations of pumping processes acting simultaneously or in series. One such scenario involves two or more planets migrating in a viscous disk at different rates, depending on the neighboring gas in the disk. Such differential migration allows them to capture each other in mean–motion resonances. The resonant interactions can pump the eccentricities of both planets up to values as high as 0.7 (Lee & Peale 2002; Chiang 2003), as observed.

The growth in eccentricities, especially as the disk dissipates, can render the two orbits unstable as close passages occur. In deep resonances, the planets may be immune to such instabilities (Thommes, personal communication, 2002). But in weaker resonances, or under the action of additional perturbers, the system could become chaotic within a stellar lifetime. Such a scenario might lead to the marginally unstable conditions invoked by Rasio & Ford (1996) and by Marzari & Weidenschilling (2002). Ford, Rasio & Yu (2003) have shown that close passages often lead to ejection of the less massive planet, leaving one behind. This sequential set of processes provides a natural explanation for the resonances and eccentricies observed among multiple–planet systems and for the eccentricities observed in single planets. Single planets may represent the survivors of multiple–planet progenitors.

A selection effect may play a role in the high eccentricities observed among the *single* extrasolar planets discovered to date. Most known extrasolar planets reside within 3 AU due to the limited duration ($\sim$ 10 yr) of the Doppler surveys. Thus the planets detected to date may represent a subset that ended up within 3 AU. Giant planets within 3 AU may represent the survivors of scattering events in which the other planet was ejected, carrying away energy from the surviving planet.

During the next decade, Doppler searches will be able to detect jupiters in orbits from 3–6 AU. Their orbital eccentricities will shed light on their dynamical history as well as on the prevalence of giant planets in circular orbits with no giant planets inward of them. It seems likely to us that the solar system analogs are yet to be revealed, and they could be even more numerous than the planetary systems found to date.

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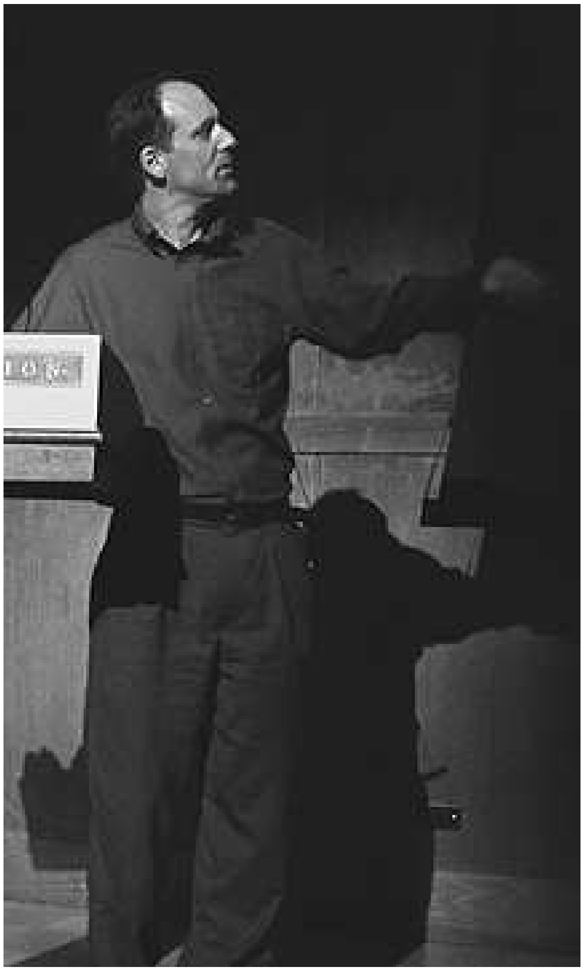

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