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Extrasolar planets

M. Barbieri[1] and R. U. Claudi[1]

Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy e-mail: mauro.barbieri@pd.astro.it

Abstract. In the last 10 years about 150 extrasolar planets have been discovered using ground based Doppler survey. Most of the planets have masses below the Jupiter masses. Here we present the physical and orbital characteristics of these newly discovered planetary systems.

Key words. Planetary systems

1. Introduction

Since the discovery of the first extrasolar giant planet in 1995 reported by Mayor & Queloz (1995), the number of known extrasolar planets (ESP) have been steadily increased up to about 150. The continuously increasing number of extrasolar planets is due to the increased number of monitored stars and in refinement in the detection techniques. Most of the known ESP have been discovered using high precision radial velocity measurements of the hosts stars. With this technique it is possible to determine the product between the mass of planets and the sine of the inclination of the orbital plane respect to the line of sight. From the analysis of the radial velocity measurements it is possible to determine the orbital period and eccentricity of unseen planets. For a few number of planets the transit in front of the disk of the parent star has been observed. These transiting planets offer the unique opportunity to infer the radius and hence the density of the planets.

The observed orbital and physical characteristics of these planets are very dissimilar from those of giant planets in the Solar System. These characteristics and some possible interpretations of this observational panorama are discussed in this paper. The data shown in the figures are taken from *Extrasolar Planet Encyclopedia* (Schneider 2005) as of January 2005.

Send offprint requests to: M. Barbieri

2. Characteristics of the extrasolar planets

2.1. Mass distribution

The mass distribution of ESP (Fig. 1) is a decreasing function of the mass and most of the planets have masses below 2 M_{jup}. This distribution is modeled as a power–law :

$$dn \propto M^{-\alpha} dM \qquad (1)$$

with $\alpha = 1.1 \pm 0.1$ (Heacox 1999; Stepinski & Black 2001; Zucker & Mazeh 2001; Tabachnik & Tremaine 2002). At high mass regime, over 10 M_{jup} there is a lack of objects, this zone is called the *brown dwarf desert* (Marcy & Butler 2000).

Although the radial velocities technique can provide only the value $M \sin i$, the undeter-

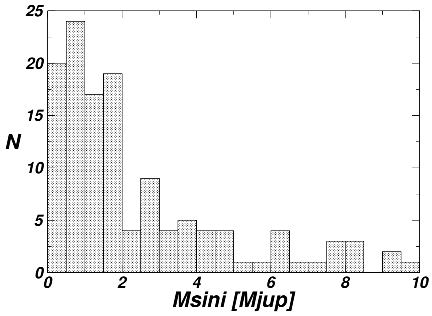

Fig. 1. Mass distribution of the extrasolar planets.

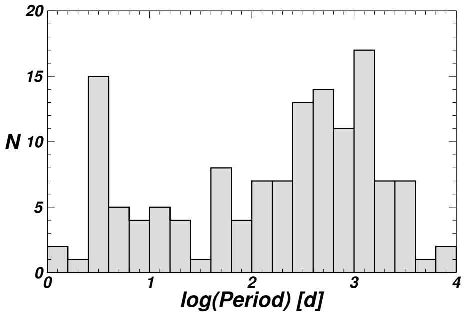

Fig. 2. Period distribution of the ESP.

minated value of inclination could not change significantly the shape of the mass distribution. From statistical considerations (Fischer et al. 2005) the authors calculated that about 86% of these planets have inclination such that the measured masses are within factor of two of the true mass.

2.2. Period distribution

As first approximation, the period distribution of ESP can be described by a power law:

$$dn \propto P^{-\beta} dP \tag{2}$$

with $\beta = 0.73 \pm 0.06$ (Tabachnik & Tremaine 2002). While other authors (Heacox 1999; Stepinski & Black 2001; Mazeh & Zucker 2002) find a steeper value, $\beta \approx 1$. Following Tremaine & Zakamska (2004) this discrepancy could arise from the incorrect weightening of the selection effects in the different analysis. In Fig. 2 the distribution of period for the ESP is shown. The peak at short periods is interpreted (Udry, Mayor & Queloz 2003) as the result of pile up of low mass planets, migrating inwards, halted by the tidal forces in proximity of the central star. These planets are called *hot Jupiters*.

In Fig. 3 we plot the period distribution for three arbitrary mass regimes:

1. low mass planets with $M \sin i \leq 0.75\ M_{jup}$,
2. intermediate mass planets with $0.75 < M \sin i \leq 4\ M_{jup}$,
3. high mass planets with $M \sin i > 4\ M_{jup}$.

Low mass planets tends to have short orbital periods. These planets induce small variations on radial velocities when they are too far from the parent star. As a consequence these planets are hardly observable at large distance. On the contrary they are easily observable at short periods. Intermediate and high mass planets tend to have long periods while some planets reside onto Jupiter–like orbits. The interesting feature of these distributions is that there is a lack of high mass planets with orbital periods shorter than 100 days (Zucker & Mazeh 2002). In spite of the possibility to be easily detected with radial velocity method for the large reflected displacement induced on the stellar companion fewer massive planets are discovered.

2.3. Eccentricity distribution

The eccentricities are the most remarkable orbital parameter of ESP. Eccentricities values range between 0 up to 0.93 (Fig. 4), with a mean value 0.26, greater than any eccentricity of the Solar System planets.

The peak at low eccentricities could originate because of the tidal circularization of eccentric orbits (Fischer et al. 2005) over a time scale shorter than 10^9 years (Terquem et al. 1998). Another explanation (Marcy & Butler 1998) is that a planet born in a nearly circular orbit, migrates inward maintaining inalterated eccentricity. On the other hand two or

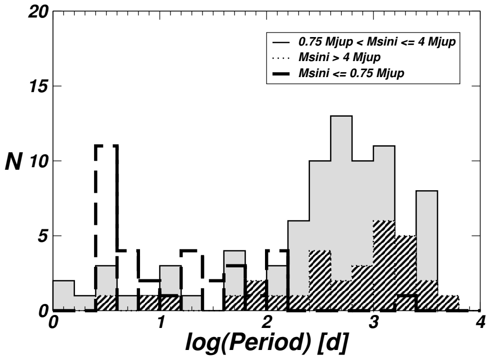

Fig. 3. Period distribution of the ESP for three mass regimes. Dashed line: low mass planets with $M \sin i \leq 0.75\ M_{jup}$. Filled histogram: intermediate mass planets with $0.75 < M \sin i \leq 4\ M_{jup}$. Hatched histogram: high mass planets with $M \sin i > 4\ M_{jup}$.

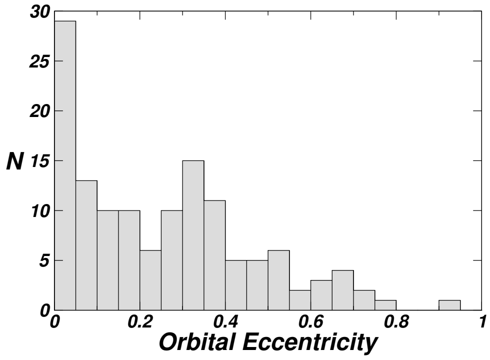

Fig. 4. Eccentricity distribution of the ESP.

more planets could interact gravitationally and shift themselves in more internal orbits within the protoplanetary disk. The subsequent interaction with the disk could circularize the orbit (Marcy & Butler 1998).

On the other side the origin of high eccentricities is presumably due to the dynamical interactions acting during the phase of planetary formation. Various mechanisms were proposed to explain such a behavior

1. tidal interaction between the protoplanet and the disk (Goldreich & Tremaine 1980; Lin et al. 1996; Bryden et al. 1999)
2. gravitational scattering between the planets (Rasio & Ford 1996; Weidenschilling & Marzari 1996; Levison et al. 1998; Marzari & Weidenschilling 2002)
3. gravitational scattering due to the presence of a companion star (Marzari et al. 2005)
4. resonant gravitational interactions between planets and planetesimals. (Murray & Holman 1997; Murray et al. 2001; Chiang et al. 2002)

In Fig. 5 the orbital semimajor axis versus the eccentricity are plotted. A zone of avoidance is present at short period and high eccentricities. This could be due to the strong tidal interaction between planet and star leading to the circularization of the orbits. In the same figure the three different regimes of masses for the ESP are presented. No strong correlation between semimajor axis, eccentricities and mass are evident from this plot.

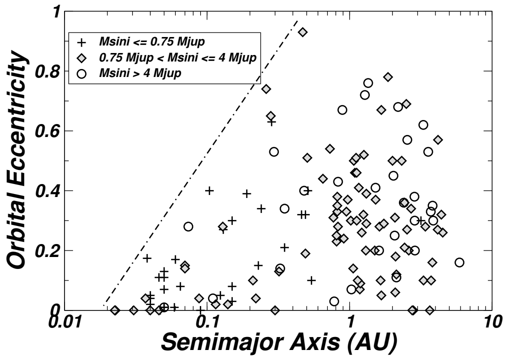

Fig. 5. Semimajor axis versus eccentricity for the ESP. Plus: low mass planets with $M \sin i \leq 0.75\ M_{jup}$. Diamond: intermediate mass planets with $0.75 < M \sin i \leq 4\ M_{jup}$. Circles: high mass planets with $M \sin i > 4\ M_{jup}$.

Table 1. Characteristics of transiting ESP.

Name	P day	M M_{jup}	R R_{jup}	ρ g·cm^{-3}
OGLE-TR-56b	1.20	1.45 ± 0.23	1.23 ± 0.16	1.00 ± 0.30
OGLE-TR-113b	1.43	1.35 ± 0.22	1.09 ± 0.10	1.00 ± 0.40
OGLE-TR-132b	1.69	1.19 ± 0.13	1.13 ± 0.08	1.02 ± 0.33
TrES-1b	3.03	0.75 ± 0.07	1.08 ± 0.18	–
HD 209458b	3.52	0.69 ± 0.05	1.40 ± 0.17	0.31 ± 0.07
OGLE-TR-111b	4.02	0.53 ± 0.11	1.00 ± 0.13	0.61 ± 0.39
OGLE-TR-10b	3.10	0.57 ± 0.12	1.24 ± 0.09	0.38 ± 0.10

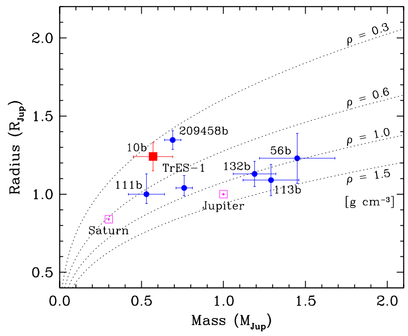

Fig. 6. The mass–radius relation for transiting ESP. Jupiter and Saturn are included for reference, as well as the dotted lines of constant density. Figure taken from Konacki et al. (2005).

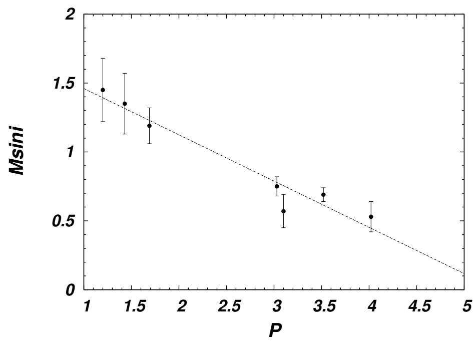

Fig. 7. Mass–period diagram for the transiting ESP. The dashed line is the best linear fit: $M = (-0.336 \pm 0.038) \times P + (1.796 \pm 0.105)$

2.4. Planetary radii and densities

Only seven ESP (Tab. 1) are known to transit the disk of parent star. The radii of some planets (especially) HD 209458b and OGLE-TR-10b are very large compared to the model of a Jupiter–like planet of the same mass of these planets. Two interpretations have been proposed to explain these large radii: 1) Bodenheimer et al. (2001) argue that these planets receive heat from interior tidal heating through ongoing orbital circularization, 2) Guillot & Showman (2002) suggest that strong insolation–driven weather patterns on the planet are leading to some conversion of kinetic wind energy into thermal energy at pressures of tens of bars.

There is an apparent difference in mass–radius diagram between long period planets and short period planets (Fig. 7). Long period planets have small masses, while short period planets have masses a factor 2 heavier than long period planets (Konacki et al. 2005). The data are consistent with a linear fit (Mazeh et al. 2005).

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