Extrasolar planetary systems

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Abstract. We present a statistical analysis of the physical and dynamical characteristics of the extrasolar planets, which have been detected to date by radial velocity surveys. The recent observational possibilities for determination of the kinematics of planetary systems are analyzed also.
Key words: planetary systems: characteristics - planetary systems: dynamics - planetary systems

Извънслънчеви планетни системи
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Ние представяме е статистически анализ на фозочните и динамични характеристики на извънслънчевите планети, открити напоследък чрез обзори на лъчеви скорости. Анализирани са и възможностите да определяне на кинематиката на планетните системи.

1 Introduction

During the last ten years the presence of planets around nearby stars is observational fact. The first efforts to discover such objects lead far in the history of astronomy. Huygens (1698) talk about such a phenomenons even in 17 century. But the experiences of observation are unsuccessful because of the limited possibilities of the observational technique. The first extrasoalar planet system - 51 Pegasi b - round Solar-type-star in the constellation Pegasus is discovered in 1995. This Jupiter-mass companion was detected by Eshelle spectrograph at 3-m telescope [Mayor M. at al. 1997]. At the prime now discovery to today are known 170 planetary systems, 198 planets and 20 multiple planet systems classified in catalogues. Six catalogues are known. One of the most complete and exact on own essence is the catalogue of Jean Schnaider [2006]. In this catalogue a explanation in brief of physical and dynamical characteristics of stars and theirs planetary companions are given in detail, as well as the methods and the technique needed for their research.

2 A studies implement

2.1 Systematic and analysis of extrasolar planet characteristics

The dynamical and physical characteristics of planets bearing stars are analyzed. The analysis is made on the basis of all discovered planetary systems to 2006 including. We find that, in increase of the number of the planetary systems, increase the number of planets:

- With short orbital periods less than 10d (Fig.1), as planets with many short periods ($P < 3$d) predominate among them. The planet companions with $P > 365$d are detected also.

- The mass distribution of planets (Fig.2) rises strongly toward low masses $M \sin i \leq 2M_j$

The planetary orbits have high eccentricities (e) and small semimajor axis (a). A planet compounds with $e > 0,1$ and $a < 1$AU are more often detected. In particularity, the many planets reside mainly in strong eccentric orbits (Fig.3), the number of planets increases for semimajor axis less than 0,1AU(Fig.4). But all known extrasolar planets (except four of them) are observed at orbital distance below 4AU. Semimajor axis

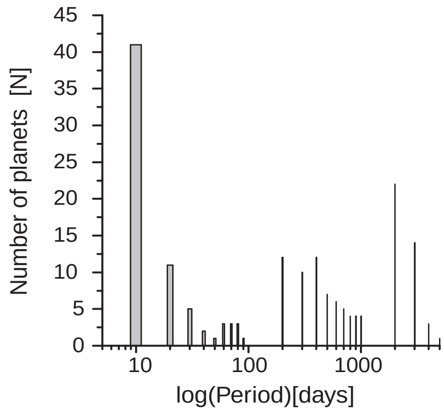

Fig. 1. *Period Distribution*

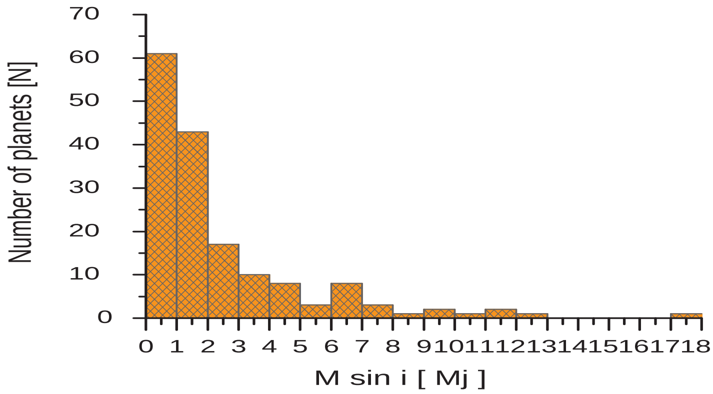

Fig. 2. *Mass distribution of extrasolar planets*

distribution in the interval of 0 to 1AU is shown in Figure 5, showing areas, indicating a paucity or lack of planets at that distances. The structure of this distribution is very much like to the distribution of the semimajor axis in the asteroid belt of the Solar system (Fig.6). This circumstance put a question: is it possible this structure to be indication of the existence of resonance in the motion of extrasolar planetary systems?

In view of the fact more than systems have one planet, it is difficult to give an answer of this question. However, the orbital resonance is observed sometimes at the multiple-planet systems. For instance, the systems Gl 876, HD 82943 and 55Cnc are in the 2:1 and 3:1 resonance [Ji J.H. et al.2002], [Gozdziewski K. et al 2001], [Kinoshita H. et al 2003]. Furthermore, as Figure 7 shown, the more parent - stars are solar-type stars and thear masses are of the order of the Sun-mass. The mean mass of observed stars is $1,2M_{\odot}$. Therefore, the structure of gravity fields of detected planetary systems ought to be similar each to other. This is another circumstance which suggests the existence of resonance. And we adopt that noted facts corroborate the hypothesis for resonance structure of discovered extrasolar planet systems to date.

- The discovered extrasolar planets are formed mainly round stars of late spectral types - F, G, K and M, as the biggest number of planets is round the stars of G type (Fig.7). This observational fact is confirmed repeatedly with increase of number of planets systems. Thus, the formation processes of planets are dependent on specific physical conditions of the star and the stellar dick.

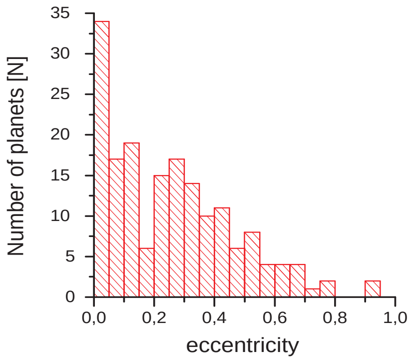

Fig. 3. *Eccentricity as a function of number of planets*

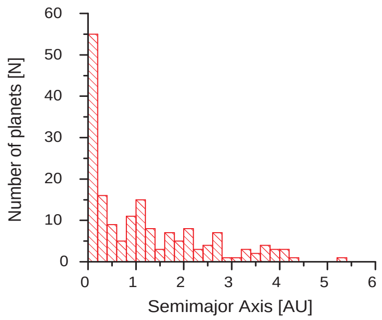

Fig. 4. *Distribution of semimajor axis for all known planet candidates. Many of observed stars have planets whit* $a < 0,1AU$

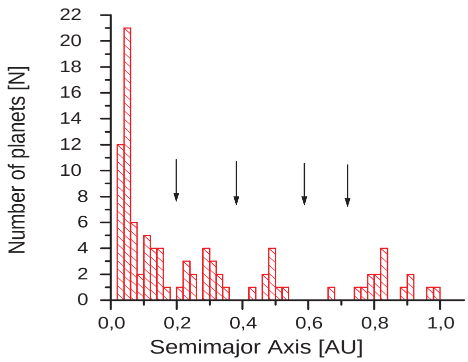

Fig. 5. *Semimajor axis distribution in the interval of 0 to 1AU*

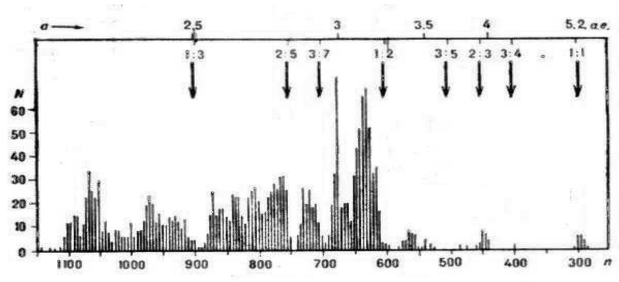

Fig. 6. *Distribution of asteroid ring*

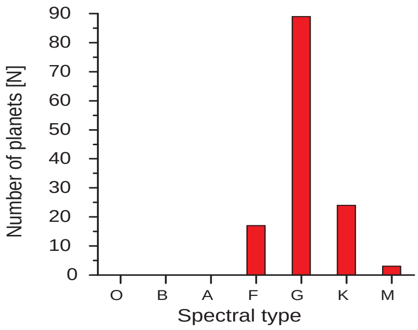

Fig. 7. *Spectral type of parent-stars vs. known exoplanets*

The planet - bearing stars are systematically metal-rich. As show Figure 8, the number of planets rises rapidly with stellar metallicity [F/H]$\geq +0,2$. But planetary frequency around stars with [F/H]$> +0,3$ strongly decreases. It is not clearly quite, these effects if due to the selection of observational stars or certain physical objective laws. The

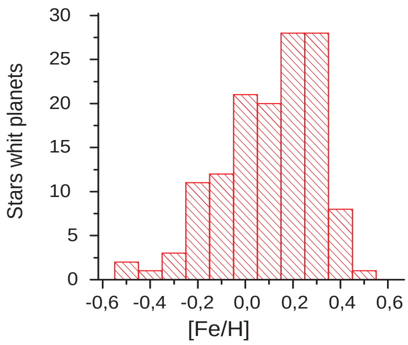

Fig. 8. *Metallicity diagram for stars with planets*

dynamical and physical characteristics of extrasolar planets are examined for any relationship between them. Our results suggest that there is relation only between the mass of planets and its orbital periods. In Figure 9 seems to be an absence of high-mass planetary companions ($M \sin i \leq 2M_j$) orbiting in many short period ($P < 10$d) trajectories. To estimate quantitatively the statistic significance of the high-mass-short-period absence we consider the mass - period correlation coefficient of the sample of planets in the interval of 1d to 10d. The resulting value was 0,3. This value means there is a moderately correlation in the planet population. Sash a correlation between the planets with the periods in the range of 10d to 100d and its masses also is evident.

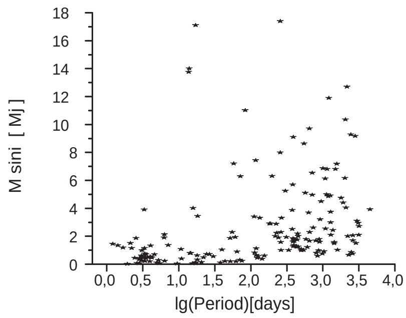

Fig. 9. *Mass plotted against period*

2.2 Effect of indistinguishable

The effect of indistinguishable between the planet systems and close binary star systems appears when they moving in the plain perpendicular or nearly perpendicular to the line of sight.

It is well known that the motion of a close binary system in a plaine perpendicular of the line of sight cannot be detected by spectroscopic and photometric observations. In this case, such system is consider as single star and the planet systems can't defined as so.

However, the plaine of motion when is nearly perpendicular of line of sight the variations of radial velocity have small amplitudes. Hence, the velocity amplitudes of these two types of system (close binary system and planet system) are commensurable and they are indistinguishable from one another.

To obtain rough quantitative estimate, we used the theoretical model of close binary system described in Trifonova at al. [2004]. Note, that the model consist of star with spherical symmetry in the distribution of the mass and star with breached spherical symmetry. For the purpose using the relation between the amplitude (K) and potential of gravity U of the system, i.e.

$$K = \frac{fM}{na^2} \left(\frac{a}{r}\right)^2 A^*_{20} 6\sqrt{5} \cos^2 i' \sin i',$$

where f is the constant of gravity, M is the mass of the deformed star, A^*_{20} is the second zonal harmonics in the potential, a is the equatorial radius of the star with breached spherical symmetry and $n = \frac{2\pi}{P}$ - mean motion.

The results of the calculations are given in the Table 1.

Table 1. Values of model amplitude

$i'(^o)$	K(m/s)
0	0
1	37.9
2	75.8
3	113.4

In the Fig.10 are plotted the amplitude distribution for known planet systems. As seen from Figure, the discovered planet systems with amplitudes in the interval from 30m/s to 40m/s are multitudinous. The comparison between the velocity amplitude of these systems and the model amplitude at $i' = 1^o$ shows that they are of the same order. Hence, could be expected that extrasolar planetary systems can't be distinguished of close binary systems only to radial velocity amplitude in some cases.

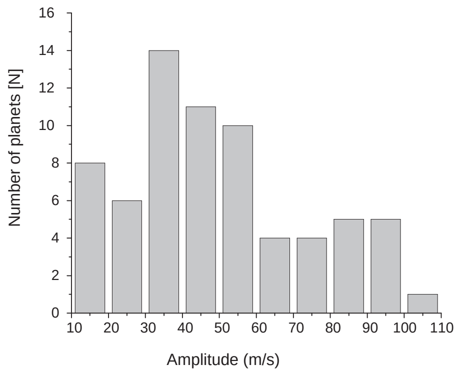

Fig. 10. *Distribution of velocity amplitudes of planet systems*

2.3 An analysis of the accuracy by which determined the orbits of planetary systems

In this subsection we analyze the accuracy of determination of orbital elements of discovered planet systems. This is made with the purpose to reach absolute accuracy in orbits determination. Two statistical estimates are made:

-An estimate of accuracy, by which the observed radial velocities are determined after corresponding astronomical corrections.

-An estimate of accuracy of mathematical model derived by authors of this paper.

We also present here, an analysis of the errors related to the applied model. With regard to this is supposed that:

a) the observations of radial velocities are accurate and they are even distributed in time.

b) the approximation of observed values of the radial velocity is completed by two models as use the method of the least squares.

It's made to be separate the observed errors from ones of the approximation. Thus, we have a better notion of real accuracy of determination of orbital elements. In the presence of two and more planets, the motion of system differs significantly from Kepler's motion. For this case the described approach is especially needed. These estimates characterize the model's effectiveness. In the present article two models is used: the model obtained by authors Petkova at al. (Model I [2006]) and the classical model (Model II). They are defined by the expressions:

$$V_r = KD\cos(\upsilon + \omega)\,, \qquad (ModelI)$$

where

$$D = \sqrt{1 + e^2 + 2e\cos\upsilon}$$

and

$$V_r = K\Big[\cos(\upsilon + \omega) + e\cos\omega\Big], \qquad (ModelII)$$

here, $K = \frac{na\sin i}{\sqrt{1-e^2}}$ is the of radial velocity amplitude, ω - argument of periastron, υ - true anomaly, a - semimajor axis, e - eccentricity.

As seem from expressions, the models depend on four parameters - P, a, e,ω. However, the co-determination of parameters leads to serious difficulties. It is due to large difference in orders of ones. This difference is reason that the determinant of system is vanishing and unsteady solution is obtained. To perform the statistic processing, the unknown impose to be determined separately. In the combination of e with ω which they are in the some order is obtained the best estimation. This is confirms of small mean statistic errors by which are determined the orbital elements and the radial velocity.

For illustration is given a numerical example. For the aim, we use the observation and orbital parameters of planet systems HD 23596 provided by Perrier et al. [2003]. As a zero-values of unknowns are accept:

$$e_0 = 0.269, \qquad \omega_0 = 274.1^o$$

The corrections of approximate values in two models are obtained, namely:

Model I		Model II	
$de = -0.026$	$m_e = \pm 0.056$	$de = 0.082$	$m_e = \pm 0.037$
$d\omega = -0.029$	$m_\omega = \pm 0.019$	$d\omega = 0.052$	$m_\omega = \pm 0.023$
$m_{V_r} = \pm 0.002 km/s$		$m_{V_r} = \pm 0.003 km/s$	

As seem from the obtained results the models in the concrete example are equivalents. The results are illustrated in Figure 11 and Figure 12. They present the radial-velocity curve for HD 23596.

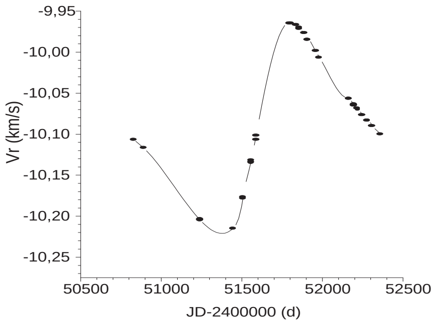

Fig. 11. *The radial-velocity curve for HD 23596 versus time (Model I)*

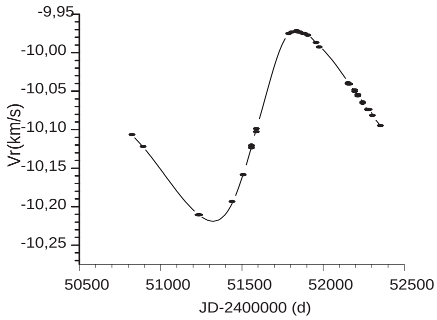

Fig. 12. *The radial-velocity curve for HD 23596 versus time (Model II)*

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