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Orbital and Physical Characteristics of Extrasolar Planets Systems

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Abstract. The article presents part of the researches on extrasolar planets, which we recently performed. This newly discovered phenomenon attracted many astronomers 'attention over the past years. More than 170 planets systems have been already mapped and a significant quantity of observation material has been accumulated. These results allow us to build quite reasonable statistical analyses. Besides, The perspective to shortly perform observations of this phenomenon from the National Astronomy Observatory in Rozen is an additional boost for us to invest more effort in our researches.

Our analysis is based on observations and on data, catalogued in 2006. Our main goal was to survey planet system' distribution as a function of their orbital and physical characteristics.

1 Introduction

The new observations definitely show that more and more are the planets outside of the Solar system. This circumstance gives enough reasons the obtained observational data to be analyzed statistically with respect to their orbital characteristics. This problem has been thoroughly investigated since the first discoveries of extrasolar planetary systems [1,2]. The analysis has been reiterated with the increase of the number of planets with the purpose to reject or confirm the results obtained previously. Precisely to this end, here we will discuss and analyze the dynamical and physical characteristics of the discovered and observed up to now extrasolar planet systems. The obtained results are compared with the previously received ones. For our analysis, we use the recent data in the Jan Schnaider's catalog [3]. If one takes into account that the content of the catalog shows an enormous diversity of masses and orbital parameters and the fact that all of them are discovered by the radial velocity method, one finds a good reason for the respective analysis.

2 The Orbital Elements Distribution

To the very time of the detection of the first extrasolar planet system, our concept was based only upon the study of the Solar system structure. As is well known, the later has been formed around a main sequence star (The Sun) of late spectral type-G2V. According to the statistical analysis of the observed stars, the extrasolar planet systems are formed around stars of late spectral type – F, G, K and M. This conclusion is confirmed by the examinination of spectral types distribution of the new systems.

In Figure 1, the number of planets as function of the spectral type of the stars is plotted. The parent-stars, around which the planets are observed, are cold stars of late spectral type. In the stars' spectra, the strongest spectral lines are the ones of the lines H and K of CaII, due to the large calcium content in the star-matter. It is seen from the histogram that the observed planets are mainly around stars of spectral type G (stars with low luminosity and low temperature). More concretely, they belong to the spectral subtypes GO to G9. These results lead the conclusion that the planet systems are mainly formed around solar-type stars. Moreover, the planetary companions to the main-sequence stars are the most ones. Only three of them (HD 117618; HD 121504; HD 20782) are analogous to the Sun. Planet systems belonging to stars-subgiants are considerably more rare, and the ones belonging to giants and bright giants are most rarely observed.

For the present, including year 2006, these are the results, obtained from the observations. It is most likely that they will be confirmed by the further observations.

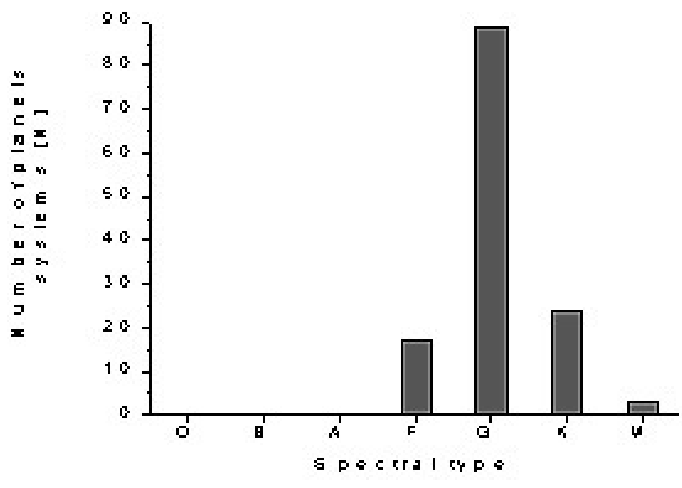

Figure 1. The parent stars of planet systems distributions about spectral types.

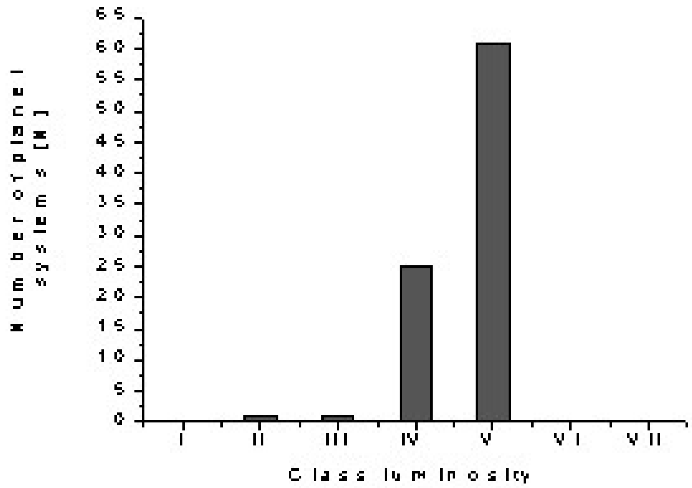

Figure 2. The parent stars of planet systems distributions about luminosity classes.

2.1 The Period Distributions

The periods vary from days up to several years. It is seen from histogram (Figure 3), that about 54% of total number are planets with periods less than 365 days and about 45% are planets with large periods ($P \geq 1$ yr.). The number of planets orbiting with short periods ($P < 10$ days) is increased considerably (about 24%)

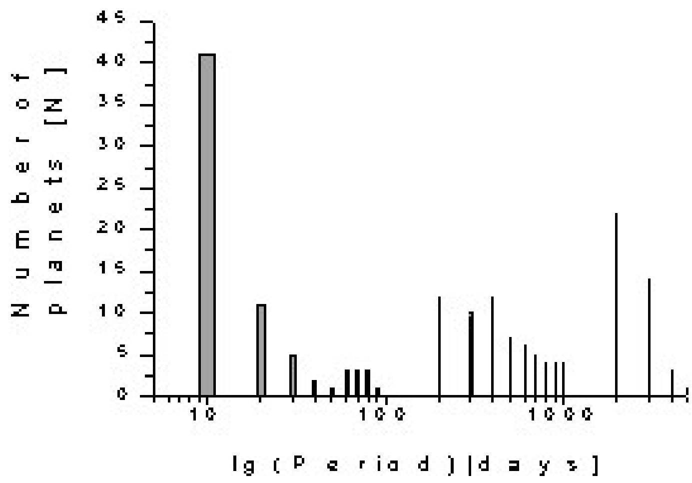

Figure 3. Period distribution of all discovered extrasolar planets including 2006 yr.

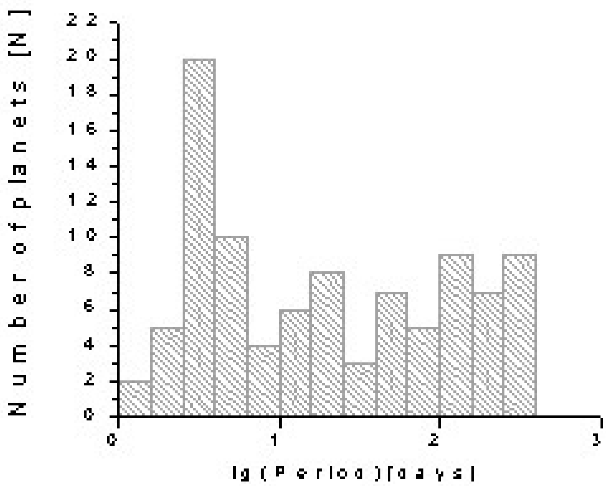

Figure 4. Distribution of period as a function of a number of planets with P < 365 day.

(Figure 4), as well the number of planets with shorter periods (P $\leq$3 days) (about 15%). It is evident that there exists slight difference with the results obtained, in comparison with the 2005 yr data (about 20% for P < 10 days and about 13% for P $\leq$3 days). The use of the present observational technique obviously allows one to detect mainly planetary companions with small periods.

2.2 The Mass Distribution

The results of the mass distribution (Figure 5) shows unambiguously, that more of the observed planets are those, which masses are less or about the mass of the

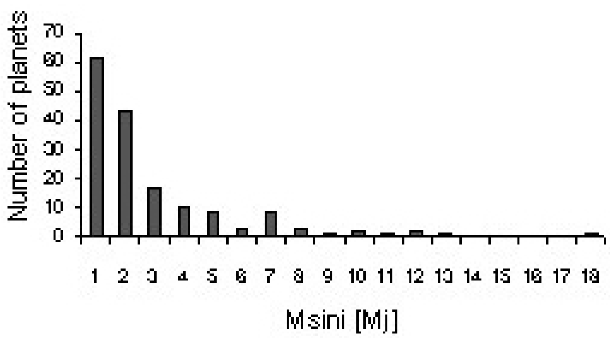

Figure 5. Distribution of minimum masses for currently discovered planetary companions.

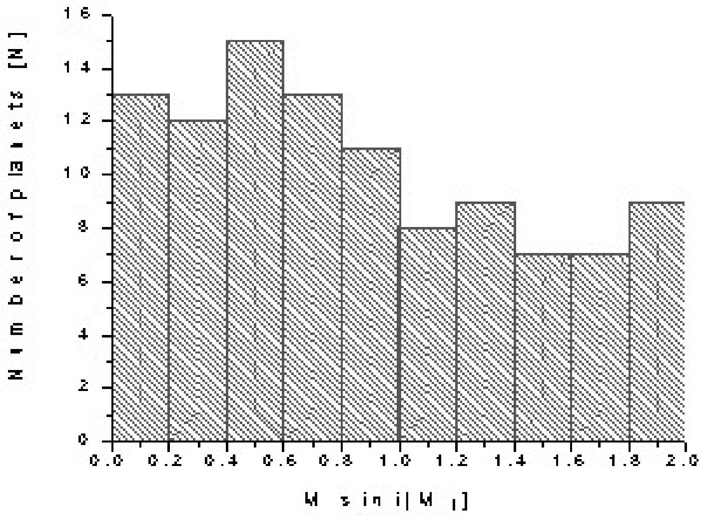

Figure 6. Distributions of exoplanet masses from 0 to 2.

Jupiter. Many planetary companions with masses in the interval 0–10M_j have been detected. It has been established that there exist a relatively large number of planets with masses far below 2M_j (Figure 6). It may be seen clearly from the graph, the presence of companions with fairly large masses (over 12M_j). These are the companions with masses 12.7M_j and 17.1M_j around the stars HD 38529 and HD 168443.

2.3 Semimajor Axis Distributions

The semimajor axis of the orbits of the extrasolar planets varies in the interval from 0.0225 to 5 AU. Only one of the companions rounds in an orbit with $a = 5.257$ AU around the star 55Cnc. For the present, this is the only case, corresponding to the traditional paradigms of giant planetary formation, which are formed and rounds far away from theirs stars [4]. The number of planets considerably increases compared to these with small value of the semimajor axis. The most planets detected are with $a < 1$ AU. Among them, the so-called "Hot Jupiters"-planets whose orbits have $a < 0.1$ AU predominate.

The obtained results for the distribution of semimajor axis from the statistical data up to 2004 yr were quite different – the distribution was increasing to planets of great values of semimajor axis. The greatest was the number of planetary companions with semimajor axis in the interval from 1 to 5 AU.

As is seen in Figure 7, at the obtained distribution minimums are observed, in which there are mach less or generally lacking planets with given value of the

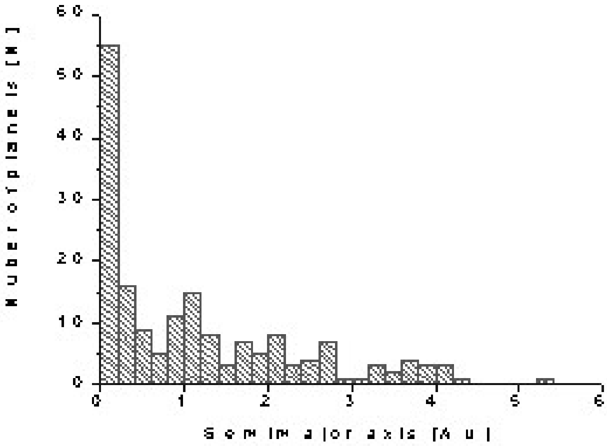

Figure 7. Distribution of planets as a function of semimajor axis.

semimajor axis. That is probably an indication for the presence of resonance effects in the planet systems dynamics. The distribution obviously suggests that there are no planets in these regions or in such distances from the stars.

To analyze the distribution structure shown in Figure 7, let us separately consider the distribution of planets in two single intervals: from 0.02 to 1 AU and from 2.0 to 3.6 AU. The results are show in Figures 8 and 9. It is evident that there exist well-defined areas in which planets are lacking. This fact points out almost unambiguously to the resonant character of the planet orbits.

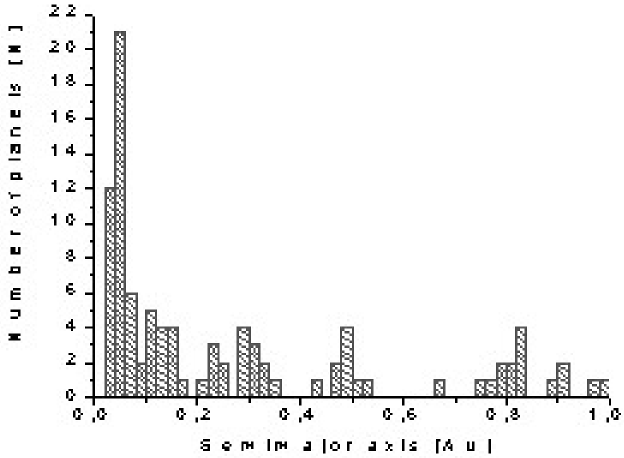

Figure 8. Distribution of semumajor axis in the interval of 0 to 1 AU.

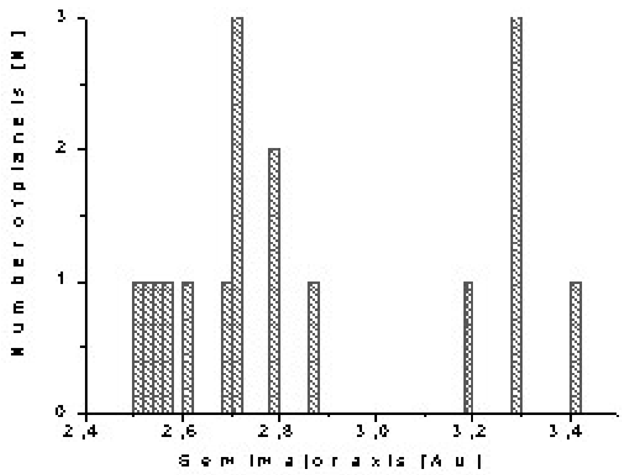

Figure 9. Distribution of semumajor axis in the interval of 2.5 to 3.5 AU.

Of course, it may be due to the observational selectivity, but such affirmation is too suspicious. The resonant nature is shown especially clear in Figure 8. As is well known, similar structure is observed in the Solar system. For clarity, the structure of the asteroid ring is presented in Figure 10.

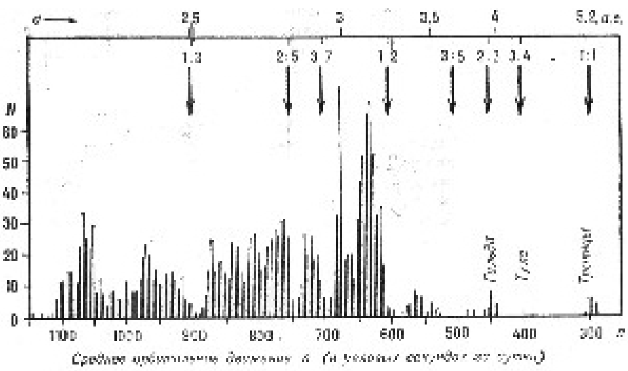

Figure 10. Distribution of asteroid orbits.

2.4 Eccentricity Distribution

The extrasolar planets generally follow eccentric trajectories ($\ddot{a} > 0,1$) (Figure 11). If we look at the eccentricities of the planetary companions, we can see that they are spread through values that go from zero to 0.9 for planets orbiting the stars HD 80606 and HD 20782. One part of them (about 10%), rounds in

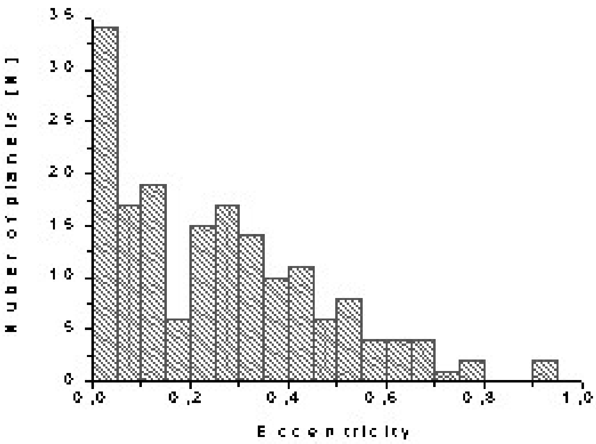

Figure 11. Distribution of eccentricity.

circular orbits ($\ddot{a} = 0$), about their stars and another part have nearly circular orbits ($\ddot{a} < 0.07$), similar to the planets in the Solar systems.

It is evident from the analysis made that more and more giant planets are detected, which follow strongly eccentric trajectories. The number of planets whose orbits are similar to the orbits of the gas giants in our Solar system increase respectively, but it is much smaller.

3 Examining of Statistical Correlations

In view of the objective study of some dependencies in the planet dynamics, we present below the results of our statistical analysis.

3.1 The mass-period correlation

The distribution of planets in the diagram mass–period is given in Figure 3. The most of the planetary companions have masses less than 2M$_j$ with periods in the interval from days to years.

A remarkable special feature in this distribution is the absence of planets with large masses ($M sini >$ 2M$_j$) and short periods (P <10 days). The statistical signification of this relation is quantified by the obtained correlation coefficient R, which takes value of 0.3. This coefficient suggests a moderate positive correlation. Such correlation exists also in the relation mass - periods in the interval from 10 to 100 days ($R = 0.4$). The relation decreases with the significant increase of the period. In the periods ranging above 100 days to years the correlation is small ($R = 0.2$).

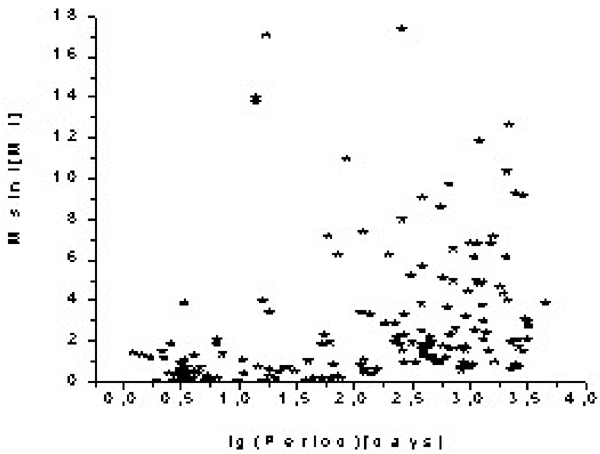

Figure 12. The mass as a function of period.

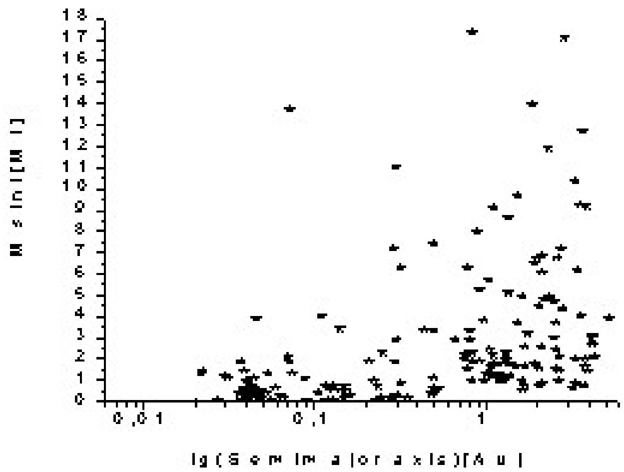

Figure 13. Mass vs. Semimajor axis.

3.2 The mass-semimajor axis relation

The graph in Figure 14 shows a quantitative equivalence between the mass and semimajor axis ($R = 0.1$). The substellar companions with low masses are observed mainly close to the stars ($\dot{a} < 0.2$ AU). A presence is ascertained of planets with low and large masses when the distance from stars increases. Therefore, as the statistics shows, the planets with mostly large masses ($Msini > 2\mathrm{M}_j$) is most probably to be detected at distances approximately 1 AU and beyond 1 AU.

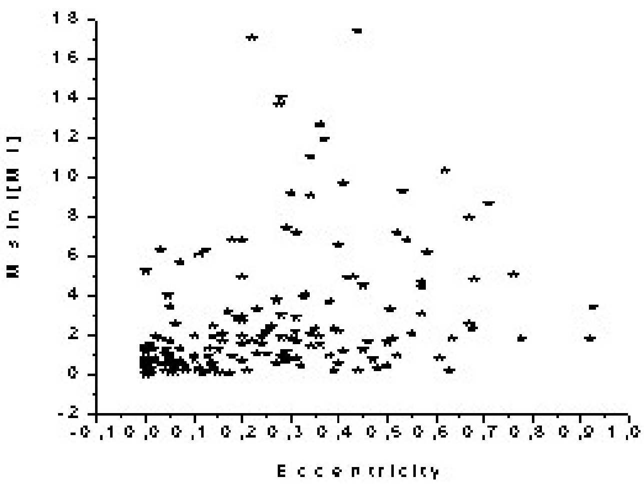

Figure 14. $M \sin i$ vs. orbital eccentricity for all know planetary companions in the range $e = 0$–0.9.

As is seen from the distribution, this does not exclude the possibility such planets to be close and very close to their stars, but at present, they are a few.

3.3 Mass–eccentricity relation

Most of the planets reside in strongly eccentric trajectories with $\ddot{a} > 0.1$, independently of their masses. Figure 15 shows $Msini$ versus orbital eccentricities which exhibits no obvious trend. This suggests that eccentricity is low correlated ($R = 0.1$) with planet mass. Apparently, substellar companions having mainly low masses (*M sin i*<2M$_j$) reside in circular ($\ddot{a} = 0$) and nearly circular orbits ($\ddot{a} < 0.1$), but planets with large masses reside in such orbits as well.

3.4 Eccentricity–period relation

The obtained configuration in Figure 12 exhibits a low statistical relation ($R = 0.1$) between the period and eccentricity. The following specific features may be noted:

- a planet candidate with period larger than 10 days mainly have eccentric ($\ddot{a} > 0.2$) orbit. It is mostly the case when such orbits are found for companions with long period. The planets with nearly circular orbits and with long periods are just a few.
- a lack of planet giants with short periods (P <4 day) and large eccentricities.

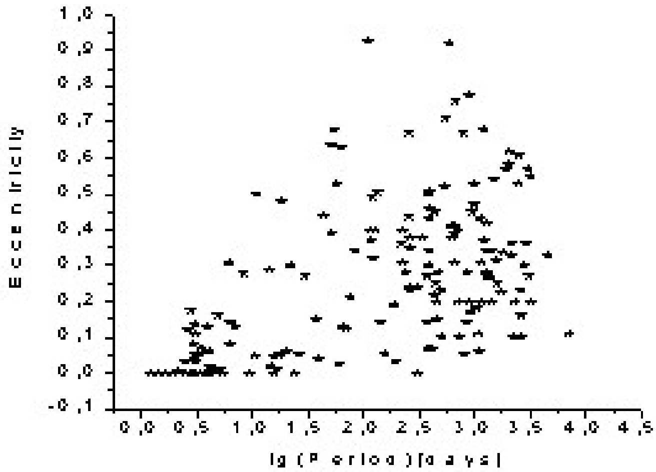

Figure 15. Eccentricity-lg P diagram for planetaryobjects.

3.5 Eccentricity-semimajor axis relation

The eccentricity moderately correlates with semimajor axis (Figure 17). The obtained coefficient of correlation has value $R = 0.3$. The functional dependence is defined by the presence of planets with large eccentricities and long orbital radius, and respectively of planets with low eccentricities and small orbital radius. However, the orbits with $\ddot{a} > 0.1$ have small semimajor axis as well as orbits with low eccentricities have large radius.

3.6 The planet–metallicity correlation

It may be affirmed with certainty that the chemical structure of the stars is a distinguishing feature for availability of planets. The distribution of discovered stars with planets as increasing function of the metallicity [Fe/H] is shown in Figure 12. Approximately 30% of the observed stars with [Fe/H]$\geq$0.2 have planets. But as the graph shows, the number of planet-bearing stars which have metallicities [Fe/H]$\geq$0.3 sharply decreases. This peculiarity in the distribution may be due to either the small number of stars with similar chemical composition, or probably the planets forms around stars with metal definite metal content. The planetary companions bearing stars with low metal content have been detected rarely (0.5<Fe/H<0.0).

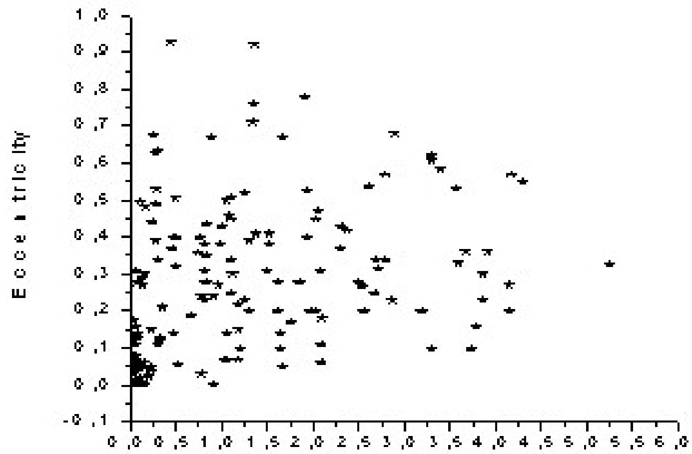

Figure 16. Eccentricity versus Semimajor axis.

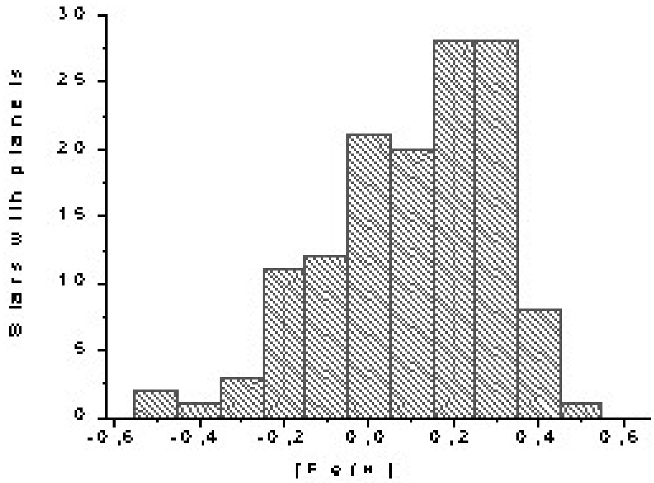

Figure 17. The planet-metallicity correlation. Apparently, planet-bearing stars are rich in heavy elements.

4 Conclusions

On the basis of the larger numbers of observations (176 Planets), a remarkable statistical features are determined. The basic conclusions made in this paper are the following:

- Adding of newly discovered planet systems confirm the conclusion that the stars with planets are cold stars of late spectral type – F, G, K and M. The majority of them are main-sequence stars – solar-type stars (Figures 1 and 2);

- The detected planets have periods in range of days to years (Figures 3 and 4). With the increasing number of discoveries, mainly increases the number of short-period planets with (P <10 day). Among them predominate the companions with very short periods (P<3 day) (the observed minimum period is 1,211 day). The number of planetary candidates with long periods is comparatively small. These results are identical with the results obtained by statistical analysis of the planets discovered up to 2004yr. [2, 5–7].

- The distribution of exoplanet masses increases for decreasing planet masses (Figure 5). It is ascertained relatively large number of planets with very low masses ($M \sin i \leq 0{,}2\mathrm{M}_j$) (Figure 6). The same conclusion has been made also by the authors of [6–10];

- The previous analyses established that the number of planets increases with the distance from star [1, 9, 11, 12]. The present analysis shows that the distribution of semimajor axis increases considerably to planets, which orbits with $\grave{a}$<1AU. Among them are many of the co-called "Hot Jupiters" – planets, whose orbits have $\grave{a}$<0,1AU (Figure 7);

- The distribution of planets as a function of the semimajor axis clearly shows the availability of dynamical resonance in the planet orbits (Figure 7). The impression for the presence of this effect become stronger from the distributions illustrated in Figures 8 and 9 as compared to our results with distribution of asteroid orbits shown in Figure 10 [13]. This problem will be discussed in detail in our next paper;

- The eccentricity distribution of planets is very interesting. Many of them follow eccentric trajectories in comparison with the orbits of gas giant planets in the Solar system. This special feature has been found in the first statistical analyses made [6, 7, 12, 14] and is confirmed by the presence analysis too

- In spite of some distinctions with the prevailing examinations [15–18], the metallicity of the stars increases with the presence of planets.

- According to the previous analyses the planets' masses correlate with period. This correlation quantifies the lack of planets with large masses ($M \sin i$>2M$_j$) and short periods (P <40 day) [2, 7, 19–22] as well as planets with low masses and long periods [23]. In this paper we found that periods of planets in range of 1 day to10 days and from 10 to 100 days moderately correlate with planets' masses. We only observe a lack of companions with large masses (M sin i>2M_j) and periods less than 10 days. The mass-period relation for planets with periods above100 days is weak.

- Planets with large masses are detected very rarely close to the star ($\grave{a}$<0,2AU). This conclusion was made also in a previous work, based on the analysis of smaller number of planets, as well as it was noted that such planets will be observed rarely at distances above 1AU [12, 24–26]. Contrary to this observation, orbits of giant planets with large masses mainly have large semimajor axes (a=0,3-5AU). The correlation analyses suggest weak dependence.

- The eccentricity correlates with the mass, period and semimajor axis according to the statistical examinations. [5, 12, 14, 19–21, 26]. This relation is considerable mostly between the eccentricity and semimajor axis [9,26]. The analysis of very large number of discovered planets also exhibits moderate correlation for these two last orbital elements. The eccentricity- mass and eccentricity-period correlations are small.

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