On Some General Regularities of Formation Planetary Systems.

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J.Wheeler's geometrodynamic concept have been used, in which space continuum is considered as a topologically non-unitary coherent surface admitting the existence of transitions of the input-output kind between distant regions of the space in an additional dimension. This model assumes the existence of closed structures (micro- and macrocontours) formed due to the balance between main interactions: gravitational, electric, magnetic, and inertial forces. It is such macrocontours that have been demonstrated to form—independently of their material basis — the essential structure of objects at various levels of organization of matter. On the basis of this concept in this paper basic regularities acting during formation planetary systems have been obtained. The existence of two sharply different types of planetary systems has been determined. The dependencies linking the masses of the planets, the diameters of the planets, the orbital radii of the planet, and the mass of the central body have been deduced. Formation of low-density planets was explained. The possibility of formation Earth-like planets near brown dwarfs has been grounded. The minimum mass of the planet, which may arise in the planetary system, has been defined.

1 Introduction

Wheeler's geometrodynamic concept, in which microparticles are considered as vortical oscillating deformations on a non-unitary coherent surface and the idea about transitions between distant regions of space in the form of Wheeler's "wormholes", made it possible to substantiate the existence of closed structures (micro- and macrocontours) acting at various levels of organization of matter [1-3].

These contours are material, based on the balance between main interactions: electrical, magnetic, gravitational, and inertial forces. They are not associated to the specific properties of the medium; they determine the important properties of objects and allow using of analogies between objects of different scales.

Such approach allows using a model that best are independent of the properties of an object or medium. In this paper the concept is used to establish some of the basic laws of the formation of planetary systems. Here, as in paper [2], there is no need to consider the nature of the cosmological medium, i.e. protoplanetary nebula, from which the planets formed, and other specific features of the process. Idea of the planetary system consisting of some amount of macrocontours, from which planets formed, and the contours of a higher order integrating the planets and a central body was enough to get the general regularities.

2 Initial premises

As was shown earlier [1], from the purely mechanistic point of view the so-called *charge* only manifests the degree of the nonequilibrium state of physical vacuum; it is proportional to the momentum of physical vacuum in its motion along the contour of the vortical current tube. Respectively, the *spin* is proportional to the angular momentum of the physical vacuum with respect to the longitudinal axis of the contour, while the *magnetic interaction* of the conductors is analogous to the forces acting among the current tubes. It is given that the elementary unit of such tubes is a unit with the radius and mass equal to those of a classical electron (r_e and m_e).

It should be noted that in [1, 2] the expressions for the electrical and magnetic forces are written in a "Coulombless" form with charge replaced by electron limiting momentum.

In this case, the electrical and magnetic constants (ε_0 and μ_0) are expressed as follows:

$$\varepsilon_0 = m_e / r_e = 3.33*10^{-16} \text{ kg/m}, \quad (1)$$

$$\mu_0 = 1/(\varepsilon_0 c^2) = 0.0344 \ \mathrm{N}^{-1}, \tag{2}$$

where c is the velocity of light.

Thus, the electric constant ε_0 makes sense the linear density of the vortex tube current, and the magnetic constant μ_0 makes sense the reciprocal value of the interaction force between two elementary charges.

In [2] the relative comparison of various interactions have been carried out and the basic relationships were obtained, some of which are necessary for the understanding of thise article.

1. *The balance of electric and magnetic forces* gives a geometric mean - a characteristic linear parameter that is independent of the direction of the vortex tubes and the number of charges:

$$R_s = (r_0 L)^{1/2} = (2\pi)^{1/2} c*[\mathrm{sec}] = 7.52*10^8 \ \mathrm{m}, \tag{3}$$

   - a magnitude close to the Sun radius and the sizes of typical stars, where r_0, and L are the rotary radius or the distance between the vortex tubes (thread) and their length.
2. *The balance of gravitational and inertial (centrifugal) forces* gives the maximum gravitational mass of the object satisfying the condition (3):

$$M_m = R_s c^2/\gamma = f R_s \varepsilon_0 = 1.01*10^{36} \ \mathrm{kg}. \tag{4}$$

3. *The balance of magnetic and gravitational forces* also results in a geometrical mean:

$$(r_0 L)^{1/2} = (\varepsilon / f)^{1/2} R_s, \tag{5}$$

   where the ratio of the products $\varepsilon = (z_{g1} z_{g2})/(z_{e1} z_{e2})$ is an *evolutionary parameter*, which characterizes the state of the medium and its changes, as the mass carriers become predominant over the electrical ones and, as a matter of fact, shows how the material medium differs from vacuum, f - is the ratio of electrical-to-gravitational forces, which under the given conditions is expressed as follows:

$$f = c^2/(\varepsilon_0 \gamma) = 4.16*10^{42}, \tag{6}$$

   where γ is the gravitational constant. In the general case, expression (5) gives a family of lengthy contours consisting of contra-directional closed vortex tubes (*mg-contours*).
4. The vortex tubes can consist, in their turn, of a number of parallel unidirectional vortex threads, whose stability is ensured by the *balance of magnetic and inertial forces* forming *mi-zones*.
5. Structurizations of the primary medium, where there is more than one pair of balanced forces, results in complication an originally unstructured mass by forming in it local *mi*-zones. In particular, the number of *mi*-zones in the object of arbitrary mass M_i will be:

$$z_i = M_m / M_i^{\ 1/4}. \tag{7}$$

3 Planetary systems

Let us assume there is a cloud of the originally protoplanetary material having an evolutionary parameter ε, in which a planetary system with a central mass M_0 and planets with a mass m_p on a radius r_p, with a rotary velocity v_0 is being formed. Let us assume that the central body is a point-like mass, and the mass of the planet is formed of contours of total number z_p and axis sizes d_p x l_p.

Then the mass of the planet can be expressed as the total mass of contours:

$$m_p = z_p \varepsilon \varepsilon_0 l_p. \qquad (8)$$

The characteristic size of the *mg*-contour by analogy to (5):

$$(l_p d_p)^{1/2} = (\varepsilon / f)^{1/2} R_s. \qquad (9)$$

Suppose the number of *mg*-contours constituting the mass of the planet is proportional to the distance to the central body, i.e. a planet contour is *a structural unit for the contour of higer order* that integrates planet with the central body

$$z_p = r_p / d_p. \qquad (10)$$

This is true for a flat homogeneous disk of the initial nebula, where the *mg*-contour is *one-dimensional*, but in general, density of medium may be different and, of course, decrease toward the periphery. The protoplanetary disk may have a local rarefaction or condensation, i.e. have sleeves or be *flatspiral*. Therefore, in general, we have:

$$z_p = (r_p / d_p)^n, \qquad (11)$$

where the coefficient n reflects the “packaging” of contours in the model object (planet).

The orbital velocity of the planet can be expressed from the balance of centrifugal and gravitational forces:

$$v_0 = (\gamma M_0 / r_p)^{1/2}. \qquad (12)$$

On the other hand, we can use the analogy of the Bohr atom, where in the proton-electron system the orbital velocity of the electron at the radius of r_i is equal to

$$v_0 = c\,(r_e / r_i)^{1/2}. \qquad (13)$$

Then for the contour integrating the planet with the central body, taking the parameter l_p as the unit of length, an analogous relation can be written:

$$v_0 = c\,(l_p / r_p)^{1/2}. \qquad (14)$$

The number of *mg*-contour z_0 for the stable state of the object, as given in [2], should be taken equal to the number of *mi*-zones:

$$z_p = z_i = (M_m / m_p)^{1/4}. \qquad (15)$$

Share further the dimensionless parameter: $M = M_0 / M_m$, $m = m_p / M_m$, $v = v_0 / c$, $r = r_p / R_s$, $l = l_p / R_s$, $d = d_p / R_s$, and $z = m^{-1/4}$. Taking into account (8-15), after transformations we obtain expressions describing the dependence of the planet mass on its orbit radius and mass of the central body:

$$m = (rM^2)^{4n/(5n-1)}, \qquad (16)$$

proportions of *mg*-contour

$$d = m^{5/4} / M^2, \quad l = M, \qquad (17, 18)$$

and the value of the evolutionary parameter

$$\varepsilon = f\, m^{5/4} / M\,. \qquad (19)$$

However, this model also admits a second case of orientation of *mg*-contour according to another to its axis. In this case an expression for z_p analogous to (11) can be written:

$$z_p = (r_p / l_p)^k\,; \qquad (20)$$

then relation *m(r)* taking into account (15), (18), (20) will look as follows:

$$m = (M / r)^{4k}\,. \qquad (21)$$

In this variant the emerging masses of planets quickly decrease to the periphery of the protoplanetary disk, and it can be assumed that such initial nebulae are *lenticular in nature*. We call planets corresponding relations of (16) and (20) as *Type I planets* and *Type II planets*, accordingly

The actual data relating to the planets in extrasolar planetary systems having three or more planets plotted on diagrams in the coordinates of *r - m*, where *r* - the size of the major semiaxis, (Fig. 1-3). The results of the site *http://www.allplanets.ru/index.htm* have been used. The numbers in the figures correspond to the position of the experimental points and point to the sections of the catalog of extrasolar planets.

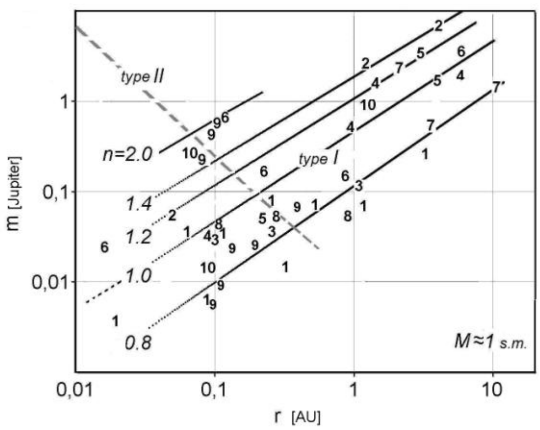

Fig. 1: Dependence of the mass of Type I planets on their orbital radius at $M \approx 1$ s.m. 1- HD10180, 2 - D125612, 3 - HD134606, 4 - HD160691, 5 - HD204313, 6 - HD75732, 7 - HD95128, 8 - HD31527, 9, 10 - KOI.

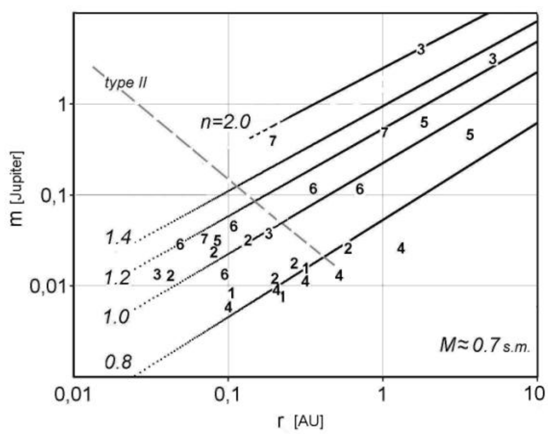

Fig. 2: Dependence of the mass of Type I planets on their orbital radius at $M \approx 0.7$ s.m. 1- HD20794, 2 - D40307, 3 - GJ676A, 4 - HD10700, 5 - HD181433, 6 - KOI 701, 7 - HIP57274.

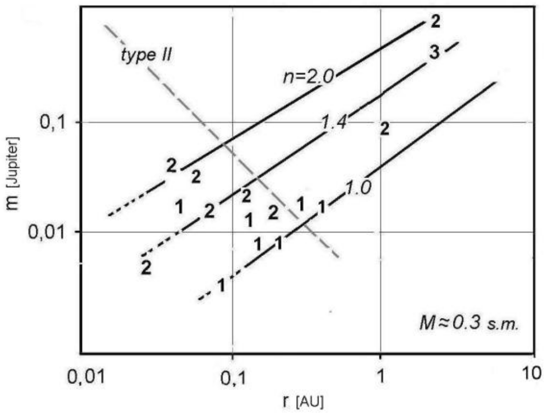

Fig. 3: Dependence of the mass of Type I planets on their orbital radius at $M \approx 0.3 \ldots 0.4$ s.m. 1 - GJ, 2 - Gliese, 3 - OGLE.

The calculated dependences *m(r)* according with forrmula (16) converted to coordinates expressed in the masses of Jupiter and astronomical units by multiplying *m* by M_m / 1.87*10^{27} and *r* by R_c / 1.5*10^{11}. These dependencies correspond to the period of planet formation, but several isolines *n* are shown, because the conditions of formation of the planets and their further evolution is unknown. A large range of values is present on this and others diagrams; in this case it is inevitable. However, the dependence of the masses of extrasolar planets on their orbital radii and on the masses of central stars is revealed quite clearly in agreement with the expression (16). These regularities, i.e. increas in the mass of planets with increasing distance to the central star and with increasing the mass of central stars, also confirmed in [4 - 7] and others.

Types II planets do not fit into this pattern. In (Fig. 1-3) they would be located near the dashed line. They have masses typically of the order of the mass of Jupiter and greater than one and are in orbits close to the central star (hot Jupiters).

Figure 4 shows the actual data on extrasolar Type II planets, which are in agreement with the expression (21) at a coefficient *k*, whose value differs very little from 1/3. When comparing (11) and (20), given that $k \approx 1/3$, one comes to the conclusion that in this case *mg*-contour is *a three-dimensional* element. With decreasing the density of medium towards the periphery of the disc the dimension of *mg*-contour can be reduced.

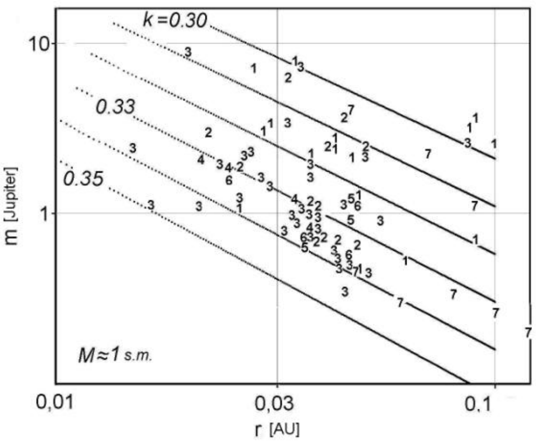

Fig. 4: Dependence of the mass of Type II planets on their orbital radius at $M \approx 1$ s.m. 1 - CoRoT, 2 - HAT-P, 3 - WASP, 4 - TrES, 5 - XO, 6 - OGLE, 7 - HD.

These planets are mainly found in singl-planet systems. The existence of systems of this type was unexpected for astrophysicists. It is supposed that their formation or dynamical history occurred in another way when the planets were formed on the periphery of the initial disc and then migrated to closer orbits [8]. In the framework of the proposed model the existence of such planetary systems *is natural*. Moreover, this situation by Type II occurs in systems of the planetary satellites, such as Earth-Moon, Neptune-Triton, and Pluto-Charon.

Figure 5, taken from [9], shows a large array of data on extrasolar planets in the coordinates r - m (star masses are different). In order to confirm the obtained regularities isolines $m(r)$ by (16) and (21) at M = 1 s.m. superimposed on the diagram; they just pass through areas, where the planets are at the most grouped. Moreover, the model allows us to explain the presence of the large number of massive planets and indicate the area, where they are concentrated.

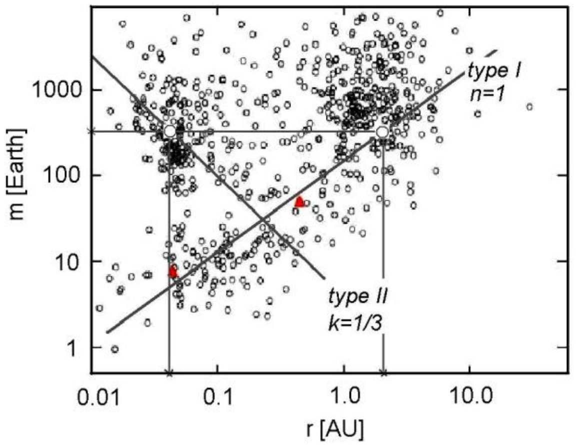

Fig. 5: The calculated dependence *m(r)* on the background of distribution of all known extrasolar planets in the semimajor axis-mass parameter spaces. Triangles represent the planets of the system GJ 221. The masses shown in masses of the Earth.

In [2] it is shown that for the central star there is a period of evolution when the number of *mg*-contours is equal to the number of *mi*-zones, which should correspond to the most *stable or balanced state*. It is this period is most favorable for the formation of the most massive planets. In this case, the evolutionary parameter ε receives the expression:

$$\varepsilon = f M^{11/12}. \qquad (22)$$

Then, as it follows from (19) and (22),

$$m = M^{23/15}. \qquad (23)$$

For the mass of the Sun $M = 2*10^{-6}$. Then $m_p = (2*10^{-6})^{23/15} M_m$ or $1.85*10^{27}$ kg, which is almost exactly the mass of Jupiter. Depending on the type of planetary system this mass can arise in orbit size of 0.038 au (hot Jupiters), or 2.3 au (cold Jupiter), (Fig. 5). More massive stars give rise greater mass of the planet.

Figure 6 shows the dependences of *m(r)* by (16) at different n and by (21) at k = 1/3 as well as the position of the planets in the solar system. Decrease in the value of index n with increasing radius and decreasing density of protoplanetary disk is interpreted by expression n - (n -0.4) r / 50, assuming that the disk was limited of radius 50 au wherein n was reduced to a value 0.4 at the periphery.

In general, the initial protoplanetary cloud of the solar system would fit the flat model at $n \approx 1$ if it is assumed that the small planets were formed close to the Sun, but later moved to a more distant orbit uder the influence of massive planets that were formed later. Detection of Earth-like planets that are very close to the central star [10, 16] confirms this assumption. It is also possible that the initial cloud had a low density on the orbits where small planets have been formed.

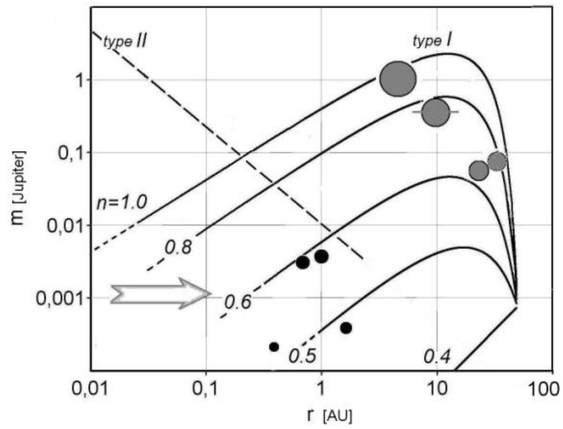

Fig. 6: Dependence of the mass of the solar system planets on their orbital radius.

4 On the parameters of the planets

For Type I planets calculations show that $d >> 1$, i.e. a *mg*-contour is actually a one-dimensional structure and when "packing" it in a volume ratio of linear dimensions, i.e. ratio of the diameters of planets averaged over density, taking into account (17), must meet the relationship:

$$D = d^{1/3} = m^{5/12} M^{-2/3}. \tag{24}$$

These parameters are here dimensionless and can be expressed as, for example, the parameters of Jupiter and the Sun.

Figure 7 shows the dimensionless dependence *D(m)* by (24) for Type I planets reduced to the parameters of Jupiter and mass of the Sun. The planets of the solar system are located along a solid line. It also shows the position of the six planets of the sistem Kepler-11 having an intermediate density [11], which generally corresponds to the calculated dependence.

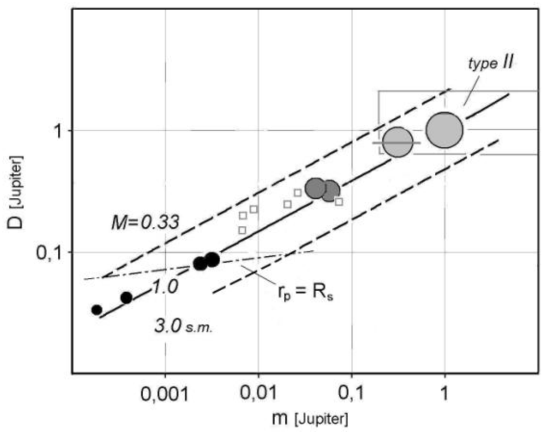

Fig. 7: The dependence of the diameter of the planets on their mass for Type I planets. The squares marked planets of the system Kepler-11. Rectangle roughly bounded region of massive Type II planets at $M \approx 1$. Dash-dot line shows the boundary of the minimum planetary masses, determined from the condition $r_p = R_s$ at $n=1$.

It is interesting to note that the expression (24) obtained solely on the basis of general provisions and being adequate to a wide range for Type I planets, in fact, coincides with the analogous dimensionless dependence derived by the authors in the paper [7]. However, this dependence was obtained by the authors by solving the equation of state, which describes the relationship between density, pressure, and temperature for the substance under conditions of thermodynamic equilibrium. The position of the terrestrial planets corresponds exactly to the general trend and confirms the assumption that these planets were formed by Type I near the Sun.

During evolution first planets were formed when ***the orbital angular momentum of the planet is compared to the rotational angular momentum of the central body***. Let us compare the corresponding expression: to the central body derived in [2] and, referring to (10), (12), (17), and (19), at $n = 1$, analogous one to the planet:

$$M(\varepsilon / f)M_m cR_s = M^{7/10}(\varepsilon / f)^{6/5}M_m cR_s . \quad (25)$$

As follows from (25):

$$\varepsilon = f M^{3/2}, \quad (26)$$

and then one can obtain:

$$m = M^{2}, \quad r = 1. \quad (27, 28)$$

Radius $r_p = R_s$ is the natural limit for *the minimum masses of Type I planets*. The outer planets, whose mass is greater, have the orbital angular momentum *greater* than the rotational angular momentum of the central star. With $M = 1$ s.m. $m_{pmin} = 4{*}10^{-12}M_m = 4{*}10^{24}$ kg, which just corresponds to the average mass of the terrestrial planets. Thus, in this model the existence of Earth-like planets near the central star is natural.

By analogy, for Type II planets one can obtain the relations similar to (25-28) at $k = 1/3$:

$$M(\varepsilon / f)M_m cR_s = M^{3/2}(\varepsilon / f)^{1/2}M_m cR_s , \quad (29)$$

$$\varepsilon = f M, \quad m = M^{8/5}, \quad r = M^{-1/5}, \quad (30, 31, 32)$$

which determine their specific mass and orbital radius. At $M = 1$ s.m. $m_p = 7.6{*}10^{-10}M_m = 7.6{*}10^{26}$ kg or 0.4 Jupiter's mass, $r_p = 13.8\ R_s = 1.03{*}10^{10}$ m or 0.07 au. The inner planets with a greater mass have angular momentum that *is less* than that of the central star.

The size of the planets of type II can be estimated by the value of the orbital radius, having on a *m*g-contour, *r/z*. Keeping in mind the expression $z = m^{-1/4}$, and expressing r from (21) at $k = 1/3$, we obtain (in the parameters of the Sun and Jupiter):

$$D \sim M / m^{1/2}. \quad (33)$$

There is a need additionally to take account the fact that the unit *mg*-contour is in this case not one-dimensional, and the mass of the model object is proportional to the parameter ε, formula (8). Thus, the relation (33) should be supplemented. Using (19) and moving from the mass ratio to the ratio of linear sizes the final expression gets the following forms:

– in the case of a three-dimensional *mg*-contour

$$D = (M / m^{1/2})\ (m^{5/4}M^{-1})^{1/3} = M^{2/3}/m^{1/12}. \quad (34)$$

– for the less dense medium, in the case of two-dimensional *mg*-contour, formula (34) takes the form:

$$D = (M/m^{1/2})\,(m^{5/4}M^{-1})^{1/2} = M^{1/2}\,m^{1/8}. \qquad (34a)$$

The obtained dimensionless relationships are generally in agreement with the actual laws. Figure 8 shows the dependence of *D*(*M*), and Figure 9 shows the dependence of *D*(*m*) calculated from formulas (34) and (34*a*) at different *M*, which are for illustrative purposes superimposed on the chart taken from the article [12].

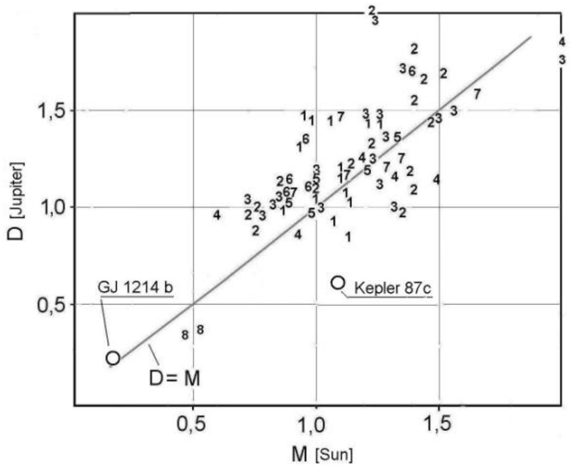

Fig. 8: The dependence of the diameter of the planets on the mass of the central star (masses of the planets are different). 1 - CoRoT, 2 - HAT-P, 3 - WASP, 4 - KOI, 5 - XO, 6 - TrES, 7 - OGLE, 8 - GJ.

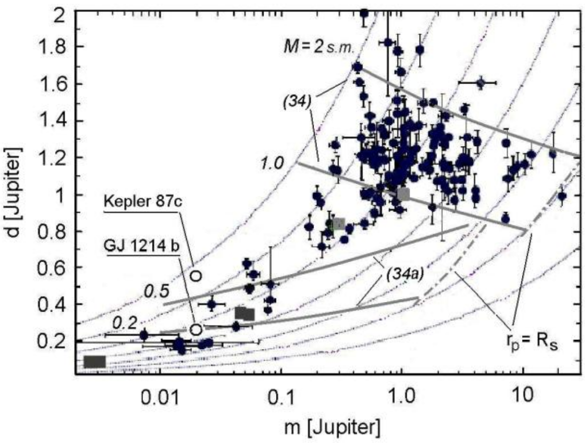

Fig. 9: The calculated dependences *D(m)* of Type II planet on the background of distribution of known transit extrasolar planets in the planet mass-radius spaces. Gray squares shows the planets in the solar system. Dotted lines are lines of equal density - 0.1, 0.3, 0.9, 3.0, 9.0, 25.0, and 100 g/cm^3. Dash-dotted line limits the maximum masses of the planets, k = 1/3.

In particular, it becomes clear both the existence of planets with similar sizes but sharply differing masses and having the same mass at various sizes. Planets with a relatively small mass, for example, GJ 1214b [13], Kepler-87c (they are shown in Fig. 8 and 9), and others, formed probably by type II; their diameters varied greatly and correspond to the values, which are calculated by the option (34*a*).

The densities of Type I and Type II planets through their mass and the mass of a star in dimensionless units (in units of the Jupiter's mass and the Sun's mass), having in mind that $\rho \sim mD^{-3}$, have radically different character and can be expressed as follows:

$$\rho_1 = m^{-1/4} M^{2}, \quad \rho_2 = m^{5/4} M^{-2}, \quad \rho_{2a} = m^{5/8} M^{-3/2}. \qquad (35, 36, 36a)$$

Of course, obtained dependences are not precise or definitive. They only reflect *the general trends* uniting the diameter of the planet to its mass and the mass of stars in the period of the formation of planetary systems. As follows from (21) and (36) Type II planet masses decrease with increasing distance from the central star as well as their density decreases. This is illustrated by the planet Kepler 87c having a very low density with its orbital radius of 136 R_s or 0.68 au. Even more striking instance - is the planets of Kepler-51 system. Formulas (36) and (36*a*) explain such a low density of these planets. Formation of Type II planets in more remote orbits it is unlikely, and the massive main planet, the less likely others planets are formed [8].

Low-mass rocky planets of type II can not be formed near Sun's mass stars and others having greater masses, but, as follows from (36), their formation is possible in the system of dwarf stars when $M < 1$ s.m. Indeed, another test of the correctness of the presented model may serve determination the masses of stars, at which planets with masses and sizes like the Earth can be formed. Let their mass is in the range from 0.001 ... 0.01 Jupiter's mass and the density is 3 ... 5 Jupiter's density. Then for the Type I planets formula (35) gives: M = 0.73 ... 1.26 s.m. and for Type II planets formulas (36) and (36*a*) give: M = 0.006 ... 0.032 and 0.019…0.07 s.m. The first solution is obvious and corresponds to the stars with a mass close to the mass of the Sun and the second solution just corresponds to the very low-mass stars - *brown dwarfs*.

This prediction proved to be correct. Indeed, recent observations have shown that is quite possible the formation of Earth-like planets around of brown dwarfs and there may be created suitable conditions for emergence of life [14]. These types of planetary systems even more preferable since no need planets to migrate to more distant (as in the case of the Earth) and the suitable masses of the brown dwarfs vary within a more wide range. The question arises whether there are conditions under which the formation of planets in the evolution of both types is equally probable?

It is logical to assume that in the initial period there had been rarefied initial spherical cloud around the central body, which is then transformed into or flatspiral disk, or lenticular in shape, from which Type I planets or Type II planets, respectively, have been formed. Hypothetically, this would correspond to the initial state of complete equality of conditions of planets formation in both types, i.e. $l = d = M$, $n = k$, masses of planets by (16) and (21) are equal.

Having in mind (16), (17), (21), we find:

$$n = k = 0.2\ (lg(rM^{2}) / lg(M / r) + 1), \qquad (37)$$

$$m = M^{12/5}. \qquad (38)$$

Thus, this mass depending on the coefficient n may occur at any orbit (Fig. 10). The size of the planet in this case is uncertain since dependences (24) and (34) are here incorrect. One can specify the maximum size of an object if *mg*-counters are packaged in a linear structure, $D_{max} = zl$. Since $z = m^{-1/4}$ and $l = M$, using (38), we obtain:

$$D_{max} = M^{2/5}. \qquad (39)$$

Convergence coefficient values of n and k indicates a decrease formally in the density of medium in any variant evolution that, obviously, corresponds to the moust low mass. The average value of the coefficient equal to 0.5 at M = 1 s.m. corresponds to the orbital radius of 0.07 au, which coincides with the specific radius for Type II planets.

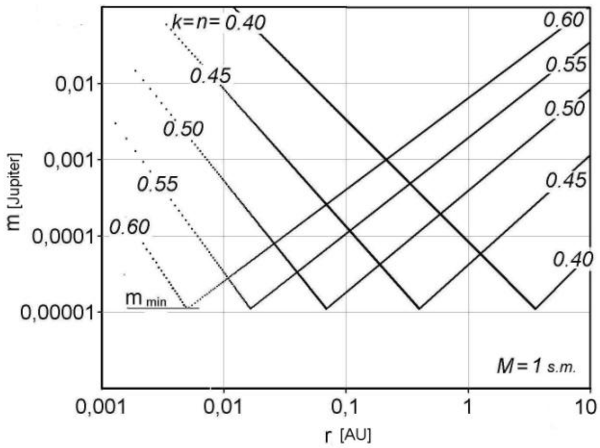

Fig. 10: Dependence of the mass of the planets on their orbital radius at $l = d$.

For the mass of the Sun, $m_{plim} = 2.1*10^{-14} M_m = 2.1*10^{22}$ kg, $D_{pmax} = 0.0053\, R_s = 3.9*10^6$ m. It is unknown whether such planets form in reality. In any case, in the solar system there are no regular planet's masses less than m_{plim}, except Pluto having a similar mass of $1.3*10^{22}$ kg, the status of which is uncertain. The same can be said of the satellite systems of the major planets. Masses less settlement not observed to date also among extrasolar planets.

The existence of lowest masses for the planets formed and, accordingly, their lowest diameters explains fact of rapid decrease of the planets having a small radius as well as existence of a maximum of planetary radii specified in [15].

5 Conclusion

Planetary systems can be quite diverse as their structure depends on the initial composition of the protoplanetary cloud, mass and type of stars, formation history of the planetary system, and the random factors. Nevertheless, there are some general patterns.

There are two types of planetary systems. In the sistem of the first type planets are formed from flatspiral protoplanetary cloud. Masses of Type I planets increase to the periphery passing through their maximum (cold Jupiters) that occur in the distance from the center in the local condensations of the medium (the sleeves, spirals), supposedly, in later periods of the evolution. Earth-like planets are formed near the central star and maybe can migrate to the more remote orbits.

In the second type of planetary systems planets are formed from a protoplanetary cloud lenticular or elliptical type. The masses of Type II planets decrease to the periphery of the disc. Massive planets (hot Jupiters) are formed in condensations near the central star; the formation of other planets in more distant orbits is unlikely and they have a low density. Low-mass rocky planets in these systems can be formed only at low-mass stars (brown dwarfs).

The possibility of the formation of Earth-like planets in the planetary systems of brown dwarfs has been predicted.

The regularities among the masses, sizes, orbital radii of the planets and masses of the central stars have been obtained.

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