Advances in Plasma Astrophysics
Proceedings IAU Symposium No. 274, 2010
A. Bonanno, E. de Gouveia Dal Pino, & A. G. Kosovichev, eds.

doi:10.1017/S174392131100665X

Development of the PFO–CFO hypothesis of solar system formation: Why do the celestial objects have different isotopic ratios for some chemical elements?

Elena A. Kadyshevich[1] **and Victor E. Ostrovskii**[2]

[1]Obukhov Institute of Atmospheric Physics RAS
Pyzhevskii str. 3, Moscow, 119017 Russia
email: kadyshevich@mail.ru

[2]Karpov Institute of Physical Chemistry,
Vorontsovo Pole str. 10, Moscow, 105064 Russia
email: vostrov@cc.nifhi.ac.ru

Abstract. The Solar System formation PFO–CFO hypothesis is developed in the direction of creation of a phenomenological model focused on solution of a number of paradoxes and answering to a number of mysterious questions under the same cover. For explanation of the events and processes that occurred over the period from the middle ages of the pre-solar star to the Solar System formation, original approaches are applied.

Keywords. Sun: evolution, solar system: formation, planets and satellites: formation

1. Introduction. Statement of the problem

The results of the Solar System (SS) observations lead to some paradoxes and require answers to a number of principle questions.

The most important paradoxes are as follows. (1) Any isolated star early in its life is electrically neutral, and its electron and proton amounts are equal. As neutronization of a star proceeds, its electron and proton amounts decrease to the same degrees. Thus, at the stage of full neutronization, the collapsed neutron stars should have no electrons and should have zero magnetic moment. Meanwhile, the measured magnetic moments of neutron stars are extremely high. Why is it so? (2) If the SS is the product of explosion of the pre-solar star, what is the mechanism of the transfer of the major portion of the star angular momentum to the planets, and, if the angular momentum was received from any other source, what is its nature? (3) If the SS is the product of explosion of the pre-solar star, why is the total mass of all SS planets less than the Sun mass by a factor of almost 1000? (4) The fourth paradox was recently formulated by the US National Research Council: "If only one nebula is the progenitrix for the SS, why are the planets principally different?" Solution of this paradox was qualified as the most important astrophysical problem (http://books.nap.edu/openbook.php?record_id=12161&page=9).

Some of the questions are as follows. (1) What is the nature of the 11-year solar-activity cycle, and is there a causal relationship between the variations in the solar activity and solar magnetic moment? (2) What is the mechanism of formation of chemical elements, including the heavy ones? (3) Why do the SS celestial objects contain chemical elements in different isotopic compositions? (4) Why is the corona temperature much higher than the photosphere temperature? (5) Why are most of the biggest celestial bodies located within a space belt along the ecliptic plane? (6) Can the Earth's localizations of minerals result from any space processes? (7) Were the terrestrial planets melted at the initial step of their origin?

Some of these paradoxes and questions are quite mysterious. Most of them have hypothetical solutions (e.g., Basu *et al.* 2009; Guerrero & de Gouveia Dal Pino 2008; Bonanno *et al.* 2008; Erdelyi & Ballai 2007). However, there is no hypothesis that could consider all them under one cover. In astronomy, there are a number of brilliant physico-mathematical works that give numerical values of different parameters, lead to definite limitations, and put lids on different phenomena. Meanwhile, some processes, phenomena, and states of matter, for which these parameters are calculated, are hypothetical and the values of the parameters can not be verified. When discussing the problems of solar interior, we should take into account that there are no knowledge on the properties of the matter and energy in very dense and hot media when the translational terms are degenerated and the entire giant energy of the matter is concentrated in the electron energy and in the oscillatory and rotational energy of nucleons, interactions between which in similar media can not be realized and studied under real conditions. On frequent occasions, calculations are based on some model notions, which are applicable until observational data indescribable by the conclusions from these notions are collected.

This stimulates new competitive phenomenological models. Below, we consider an original model explanation for a wide circle of the phenomena of the SS formation era and of the present epoch. Many of its components are available for subsequent testing.

2. The advanced Solar System formation PFO–CFO hypothesis

General provisions. The PFO–CFO hypothesis of the SS formation is considered in a general way in the papers by Kadyshevich & Ostrovskii (2010a,b); Kadyshevich (2009a,b); Ostrovskii & Kadyshevich (2009a,b); Ostrovskii & Kadyshevich (2008); Ostrovskii & Kadyshevich (2007). The main goal of the previous version of this hypothesis consisted in solution of the paradox (4) in its wording given in Section 1. The title "PFO–CFO hypothesis" reflects its central idea that the cold celestial objects formed from light elements through physical processes, such as condensation, physical adsorption and absorption, aggregation, occlusion, etc., and are the Physically Formed Objects (PFO) and the warm celestial objects formed mainly from medium-weight elements through chemical syntheses and are the Chemically Formed Objects (CFO). This paper is aimed at more extensive consideration of the processes that proceeded in the pre-solar star and initiated the SS formation phenomenon. The pre-solar star history is considered as the typical history of transformations of the stars similar to this star in the age and size. We proceed from the following starting positions. The SS represents an electrically neutral system that originated on the basis of a pre-solar star, which was formed, apparently, from an object similar to a medium-size red giant. The middle-aged mother star was similar in its principal characteristics to the present Sun: it consisted of a core, a radiation zone, a convection zone, and outer zones. (Therefore, below, we alternate the consideration of the middle-aged pre-solar star with the consideration of the present Sun.) The star was compressing under the gravity forces; therewith, its body and surface temperatures increased steadily. The degree of compression heightened inward along the radius. The pre-solar star core and radiation zone consisted (similarly to the Sun) of a non-atomized unstructured p–n–e dense-plasma matter which is unknown under the Earth's conditions. The principal physical specificity of this matter consists in the fact that each its mass unit possesses an enormous kinetic energy realized in rotational and vibrational degrees of freedom with no translational component; similar analogs are unknown under the Earth's conditions, and the physical laws accessible for them can be only objects

https://doi.org/10.1017/S174392131100665X Published online by Cambridge University Press

of guesses. The degree of matter compression in the core was higher than that in the radiation zone. In the core and in the radiation zone, processes of neutronization and of ionization of the p–n–e matter proceeded. We assume that the notion (see the book by Bisnovatyi-Kogan (2001)) on the necessity of extremely high degrees of compression for neutronization is inapplicable to the hot p–n–e systems with low neutron and electron concentrations for the following reasons. (1) The number of neutrons is greater than that of protons in the atomic nucleus of all stable and radioactive chemical isotopes (except protium); therewith, the bigger are the atomic nuclei, the higher is the n/p ratio (e.g., Greiner & Zagrebaev 2006, Fig. 1). This means that such a situation is thermodynamically preferential. (2) Neutronization is the exothermic process, and the entropy change is insignificant; this fact confirms that neutronization can proceed with no external energy. (3) Statements of some authors about the necessity of an external energy for this process relates to the energy barrier, i.e., to the rate of neutronization but not to its possibility; in addition, they relate to isolated atoms but not to the p–n–e matter where the potential barriers can be much lower. Note also that this process can proceed by tunneling. Bearing on this conclusions, we take that neutronization proceeded in the core and in the radiation zone. We don't understand the authors who take that neutronization begins deep in stars at a density of about 10^6 g/cm^3 and at a temperature of about 10^6 K; the point is that, in the process of compressing and heating, this matter should lose (as a result of thermal ionization) the major portion of its electrons necessary for neutronization.

Similarly to the authors of the widely distributed hypotheses (e.g., Caroll & Ostlie 2006), we assume formation of the degenerate electron gas, but we see its origin in thermal ionization of the p–n–e matter. Namely, the p–n–e matter is characterized by a potential of thermal ionization and, thus, it is capable of emitting electrons at any definite temperature. Compression of the p–n–e matter is accompanied by the thermal ionization starting with a temperature level, which can be dependent on the p–n–e composition. This ionization process has its analog in the process of ionization of weakly-ionized plasma. The degree of ionization of such plasma depends on the temperature, density, and ionization energies of the atoms (Saha 1921). We believe that ionization of the n–p–e matter proceeds in dense layers and leads to separation of the electrons from the stratum with formation of an electron-gas "pillow" between the star core and the radiation zone. In the Saha process, the Debye length is large. However, in the star core, the outflow of the electrons from the reaction zone and consumption of a portion of the electrons for neutronization should stimulate ionization. We assume that, in rather hot and dense media, neutronization is attendant with ionization and, apparently, some of the acts of ionization are conjugated with acts of neutronization, the conjugation proceeding by tunneling. The deeper is located a layer of the p–n–e matter, the higher is its temperature. The electron-gas layer is located over the field of the ionization temperature and compensates the pressure of the overlying layers of the radiation zone. Thus, the field of the ionization temperature demarcates the core from the radiation zone and the degenerate electron gas accumulates in this field and forms a "pillow" between the zones. Just this pillow is the cause of a significant difference between the Sun-core rotational speed and the Sun radiation zone rotational speed and of the mysterious 11-year cycles of solar activity. The difference between the rotational speeds is discovered recently by the SOHO mission (Garcia *et al.* 2007). The 11-year cycles are explained by us as follows. In the course of any era, the depth of electron-gas burial and the rate of its formation as a result of thermal ionization of the p–n–e matter are approximately constant. The 11-year cycles are of hydraulic nature and are determined by the time period in which the increment of the electron-gas pressure becomes sufficient for overcoming the pressure of the radiation-zone superstratum. When passing through the radiation zone, the electron-gas

https://doi.org/10.1017/S174392131100665X Published online by Cambridge University Press

flows enrich themselves with the p–n–e matter, and the rather powerful ones cross the photosphere–chromosphere boundary. Some narrow channels are passable for electrons always or almost always, but their traffic capacity in the present era is less than the inflow of the core electrons to the electron layer. Between the events of maximum solar activity, the quantity of "working" narrow and medium channels for the electron outflow depends of the electron-gas pressure. The spots are caused by these flows, and the opposite polarities of the observable local magnetic fields in the photosphere are caused by the quantitative relations between electrons and positive ions in the powerful flows. The Sun's global magnetic field variations are, apparently, caused by the periodic alternation in the nature, amounts, and polarity of the charge-carrier particles (e.g., electrons and metal ions) in the global flows of electric current. The compression and warming-up increased the rotational speed of the star and its kinetic energy; the last tendency revealed itself to the utmost along the equatorial belt of the star.

The mechanism of formation of chemical elements. We assume that atoms of chemical elements originated and originate now not within the star core but over the space in the outer vicinity of the radiation-zone boundary as a result of tangential sputtering of radioactive unstructured nanodrops (NDs) of the star matter from the radiation-zone–convective-zone boundary. Outside this boundary, the energy of the NDs is mainly realized in the translational movement. In the beginning, these NDs were minimum in their sizes, composed predominantly of 1, 2, 3 nucleons, and increased in size as the star rotational speed increased. Continuous increasing in the rotational speed was initially caused by the gravity densification of the star matter and then was also caused by its neutronization. The ND flows occurred predominantly in the vicinity of the equatorial belt, i.e., in the field, where the rotational speed was maximal. The size of the NDs steadily increased with the rotational speed. The unstructured NDs, after their isolation from the unstructured star matter, quickly formed radioactive atoms and then steadily transformed to the stable atoms of corresponding sizes. As a result of radioactive decays, the atoms got additional impulses and formed, depending on their energy, convection zone, photosphere, chromosphere, or corona. The convection zone temperature is rather low because a significant portion of atoms passed it before their decays, and the corona atoms are very hot because they underwent several decays or collided in the convection zone with hot atoms and captured a portion of their energy. Therefore, the corona is populated with the most energetic atoms. Thus, the angular momentum of all SS atoms or of the planetary system as a whole is not limited by the momentum taken from the star but represents its sum with a contribution obtained from radioactive decays.

The major components of the mechanism of the initial period of planet formation. According to the PFO–CFO hypothesis, the SS originated as a result of the loss of some mass by the pre-solar star with no effect of other objects or phenomena. Apparently, only the phenomenon of the so-called isotopic anomalies was proposed by advocates of the effect of outside events on this process. We will show that the isotopic anomalies are explainable on the basis of our concept.

With time, the star core and radiation zone compressed and their rotational speed rose. Therewith, the ND flows over the equatorial region intensified and the ND sizes increased. At each rotational speed, a definite size of the NDs prevailed. The flows formed clouds, which flowed away from the star when their energy obtained from the star and from the radioactive decays became sufficient. The lighter were the atoms, the farther flowed the clouds into the cold space regions. The difference in the rotational speeds of the star core and the star radiation zone increased progressively, and the radiation-zone pressure on the electron-gas layer heightened. Under some critical conditions, the radiation zone was destroyed as a result of a restricted explosion. Namely, the radiation zone was separated from the star core, divided into clouds of radioactive NDs, and the blockade of the electron-gas layer was called off. These processes liberated a huge amount of energy as a result of depression of the system and formation of atoms and their radioactive decays and led to formation of a magnetic field around the core on the basis of liberated electron gas. Apparently, these processes could not lead to dramatic transformations of the core. After this event, almost all newly formed radioactive heavy elements returned to the core before long and only a small portion (about 0.11%) of the pre-solar star mass transformed to the SS celestial bodies. Their retrieval led to formation of a rather loose radioactive stratum that initiated chain fission reactions. The stratum transformed progressively to the p–n–e mass under the action of the heat of these reactions and gravity, its luminosity increased, and we obtained our Sun in all its glory.

The solar nebula composed of the pre- and post-explosion clouds that flowed away from the star core near the ecliptic plain, progressively cooled, and could come apart or mix. Therewith, the earlier they were born and the lighter atoms they contained, the farther from the core they advanced; therefore, the clouds composed of light atoms could not mix with the clouds composed of heavy atoms.

PFO formation started, when the nebula began to collapse after its outer H_2 and He clouds cooled to the H_2 condensation temperature. Hydrogen droplets absorbed light Li, Be, B, LiH, and BeH atoms and molecules, which formed the agglomerate cores. Steadily, the agglomerates increased in size as a result of their competition with each others for the mass and gravitational attraction. Obeying the law of conservation of the angular momentum, the nebula collapsed as a whole because its objects were bound by gravity forces. Heavy atoms and hydrides remained in that nebula section where the temperature was too high for physical absorption processes and the temperature and concentrations of atoms and molecules were too low for chemical reactions. The system progressively decreased in its volume as a result of the condensation processes and under the action of the gravitational attraction. Meanwhile, the activity of the pre-solar star core began to increase. The less was the distance from the Sun, the greater was the degree of compression and the higher was the temperature. These trends initiated chemical reactions over the warm region of the nebula. As the gravity compressing of the space matter increased, chemical combination reactions exponentially accelerated. These reactions stimulated localizations of the substances and reaction heat and initiated compressible vortexes, within which hot cores originated, and triggered the process of CFO formation. The reaction heat was capable of melting the cores. In the vicinities of the giant vortexes, low-pressure and gravitational attraction zones arose. The occurrence of such zones stimulated flows of light cold vaporous and gaseous substances and asteroid-like agglomerates from the outer space and flows of asteroid-like agglomerates of not so light substances from the intermediate regions of the space to the hot cores. The flows precipitated over the hot core surfaces of the CFO and cooled these surfaces. The "spherical thermoses" obtained as a result of these precipitation processes steadily became the young terrestrial planets and their satellites. The following period of the planet formation is detailed in the above-cited preceding version of the PFO–CFO hypothesis.

Why do the celestial objects have different isotopic ratios for chemical elements? We return to the period of the SS formation just before the explosive disruption of the presolar radiation zone. The n/p ratio of the radiation-zone matter progressively increased, matter consolidated, rotational speed increased, and atomized clouds composed of more and more heavy radioactive atomic nuclei floated away from the star. The ND nucleon number gradually increased. The NDs of any definite composition left the star when the centrifugal force came up with the force of bond between these NDs and the star body. The before-explosion emission, which consisted of low- and moderate-sized atoms, was

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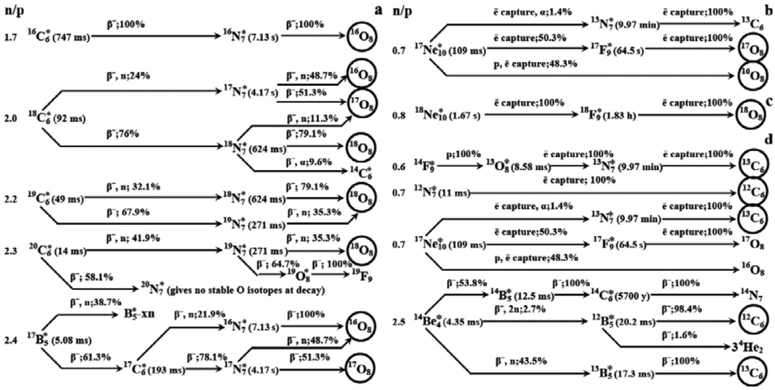

Figure 1. Possible ways of formation of stable O-isotopes (a, b, c) and C-isotopes (d) from nanodrops; stable isotopes are encircled, radioactive isotopes are marked by asterisks, arrows show the directions of the reactions; the n/p values for the source nanodrops, the half-life, and the types and percentages of the radioactive decays are indicated.

multi-cloud. The isolated NDs transformed quickly to the corresponding radioactive atoms and then step by step transformed to the stable atoms; this process began just after isolation of NDs from the radiation-zone p–n–e mass.

Figure 1 gives the available data (Tuli 2005; Audi *et al.* 2003) on all possible chains of radioactive decays that can lead to ^{16}O, ^{17}O, ^{18}O (a, b, c) and ^{12}C, ^{13}C (d) formation. The ways of formation of these elements are considered as examples. The side isotopes that form in these chains are also given. In each cloud, O-isotopes are of a specific origin and of a specific isotopic ratio, both depending on the ND size and nuclide composition in the period of ND formation. Later, the O-containing clouds could mix with other clouds and with each other and form minerals with different ^{16}O/^{17}O/^{18}O ratios. The most active mixing proceeded during vortex processes of formation of the hot planets.

An analysis of the data of the figure in the context of the PFO–CFO hypothesis led us to the following general conclusions. Each of the elements was presented in several clouds formed at different n/p ratios characteristic for the outer surface of the radiation zone. Each element in any one cloud after termination of radioactive decays could be presented by one isotope or by several isotopes. The relative amounts of the stable isotopes formed from any one source radioactive isotope can be calculated but no quantitative data on the relative powers of different flows from the star are available. Each of the clouds and the secondary clouds resulted from full or partial mixing of the primary clouds participated in further chemical reactions and in agglomerations. In each such a process, the isotopic compositions of the products were determined by the isotopic compositions of the clouds that were initial ones for this process.

Relative to carbon, the following conclusions can be made. Carbon could be obtained from four sources: ^{14}F*, ^{17}Ne*, ^{12}N*, and ^{14}Be*. ^{13}C is a small admixture to ^{12}C, we conclude that the ^{12}N* flow was most powerful. Apparently, three carbon-containing clouds participated in formation of the SS. They are: α-cloud (100% ^{13}C) formed at n/p = 0.6 from the ^{14}F* flow; β-cloud (a mixture of ^{12}C, ^{13}C, ^{16}O, and ^{17}O, where (^{17}O/^{13}C) = 36.0) formed at n/p = 0.7 from the low-power ^{17}Ne* flow and high-power ^{12}N* flow (apparently, β-cloud is the main contributor to the Earth's carbon and ^{17}O); and γ-cloud formed at n/p = 2.5 and composed of the mixture of (^{14}N/^{13}C/^{12}C/^{4}He) = 1/0.81/0.048/0.0055 and of (^{12}C/^{13}C) = 1/0.059 (apparently, γ-cloud along with β-cloud played an important role in formation of some cold celestial objects such as Saturn and

Titan). It is impossible to exclude the occurrence of SS objects in which the entire C is obtained from the flow of ^{14}F* and carbon is all-^{13}C.

Oxygen could be obtained from the flows of ^{17}Ne* (n/p = 0.7), ^{18}Ne* (n/p = 0.8), ^{16}C* (n/p = 1.7), ^{18}C* (n/p = 2.0), ^{19}C* (n/p = 2.2), ^{20}C* (n/p = 2.3), and ^{17}B* (n/p = 2.4). It is impossible to exclude the existence of the celestial objects that contain oxygen only in the form of ^{16}O or in the form of ^{18}O. The maximum content of ^{17}O in the mixture with ^{16}O can be 51%. Different ^{16}O/^{17}O/^{18}O compositions are possible as a result of mixing of several flows. For our consideration, the cloud formed by the ^{17}Ne* and ^{18}Ne* flows is of principal interest. Such a cloud should have ^{18}O twice as much as ^{17}O if the powers of these two flows are equal. Apparently, this condition is satisfied because the n/p ratios and the sizes of the source NDs in these flows are rather close. This means that additions of portions of this cloud to the cloud, on the basis of which SMOW was formed, contributed to ^{18}O twice as much as to ^{17}O in the resulted clouds and in the products of their subsequent chemical reactions. These reactions led to formation of different mineral localizations, each of which contained different additions of ^{18}O and ^{17}O relative to the SMOW isotopic content, but, in all localizations, the ^{18}O addition was twice as large as the ^{17}O addition. Just such a relation is observed for different minerals over the Earth and Moon (Clayton 1993).

3. Conclusion

The dense p–n–e matter is scarcely realizable at the Earth. Only specialized analyzing of astronomic data and new phys.-math. studies are capable of testing our hypothesis.

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