

Discovery of the Nature of Separation of Ice Bodies of the Visible Dense Rings of Saturn, Predicted by J. C. Maxwell in 1856, and How It Helps Solve Unsolved Problems of Purely Gravitational Models of Their Origin

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Abstract

Cassini measurements suggest that ice bodies of Saturn's visible dense rings have diamagnetic properties. Recently, JWST confirmed the existence of water around forming planets and showed that the magnetic field plays an important role in the formation of planets. It follows that Saturn's visible dense rings could arise from the ice bodies of a protoplanetary cloud the radius of the Roche limit under the mutual action of a diamagnetic expulsion force created by Saturn's magnetic field, together with the action of Saturn's gravitational and centrifugal forces. As a result, the Kepler's orbits of the ice bodies of the protoplanetary cloud move into the plane of Saturn's equator and origin highly compressed stable system of the visible dense rings with separate individual ice bodies. With the same orientation of magnetic moment of ice bodies, their repulsion and separation occur due to their magnetization by Saturn's magnetic field. Ice bodies are also attracted to each other due to their own gravity. At the balance of the both forces, the ice bodies remain at an equilibrium distance between them. This provides important evidence of the nature of J. C. Maxwell's discovery in 1856 that the visible dense rings of Saturn are not continuous, but composed of individual bodies. This theory can provide an explanation of the origin of Saturn's visible dense rings and their structure observed by Cassini probe in 2004-2017. It could also improve purely gravitational models of the origin of Saturn's visible dense rings, which can only show how additional ice could penetrate the visible dense rings, and cannot explain convincingly their origin and structure.

Keywords

Saturn's Visible Dense Rings, Origin of Saturn's Visible Dense Rings, Diamagnetism of Ice in Space, Saturn's Magnetism

1. Introduction

Existing purely gravitational models of the origin of Saturn's visible dense rings of Saturn are not able explain convincingly their origin and observed features [1]-[10]. These include their stability and strong flatness at Saturn's equator, their fine structure, and equilibrium separation of ice bodies within their entire system. Cassini measurements concluded that the ice bodies of the visible dense rings have diamagnetic properties [11] [12] and the ratio of deuterium and hydrogen isotopes in them is the same as that of Earth's ice [13]. Recently, JWST confirmed the existence of water around forming planets [14] and showed that the magnetic field plays an important role in the formation of planets [15].

It follows that visible dense rings could arise from ice bodies of a protoplanetary cloud the size of the Roche limit under the mutual action of the force of diamagnetic expulsion created by Saturn's magnetic field, together with the action of its gravitational and centrifugal forces. As a result, the Kepler's orbits of the ice bodies of the protoplanetary cloud move into the plane of Saturn's equator and origin stable system of the visible dense rings with separate individual ice bodies. This provides important evidence of the nature of J. C. Maxwell's discovery in 1856 that the rings of Saturn are not continuous, but consist of individual bodies. This theory provides an explanation of the origin of a highly compressed disk of Saturn's visible dense rings at its equator and their structure observed by Cassini probe in 2004-2017. It may also improve existing purely gravitational models of the origin of Saturn's visible dense rings, which can only show how additional ice could penetrate the visible dense rings, and cannot explain convincingly their origin and structure.

2. Magnetic Anisotropic Accretion as Additional Process to Gravitational Accretion in the Origin of Saturn's Visible Dense Rings at Its Equator. The Tchernyi-Kapranov Effect

G. Kuiper proposed the bodies of visible dense rings made up of ice. The Cassini space probe discovered that they consist of 90% - 95% water ice [8] [9]. The Cassini measured the ratio of the heavy and light hydrogen isotopes of the ice of visible dense rings is the same as of ice on the Earth [13]. Then we can choose Earth's ice XI which is stable below 73K and it is diamagnetic [11] [12]. Saturn has a spherically symmetric gravitational field and an axisymmetric magnetic field with magnetic equator. For Saturn magnetic equator coincides with geographical one [16]. In the region where visible dense rings are located, Saturn's magnetic field is stable and its dipolar component predominates [17].

Because JWST confirmed existence water around forming planets [14], we can use the classical theory of the small nebula by V. Safronov [1] to study the process of the origin of Saturn's visible dense rings. Contribution of Saturn's magnetic field through the action of diamagnetic expulsion force we call as Magnetic Anisotropic Accretion (The Tchernyi-Kapranov effect) [18]-[22]. It works together with gravitational accretion in origin of visible dense rings.

Interaction of Saturn's magnetic field with diamagnetic ice bodies of the protoplanetary cloud creates a force diamagnetic expulsion. Under the action of this force together with the action of Saturn's gravitational force and centrifugal force, all orbits of ice bodies begin to shift to the plane of the magnetic equator, where the total energy of the diamagnetic ice bodies is minimal due to minimum value of their magnetic energy.

As a result, all the orbits of ice bodies in the protoplanetary cloud which has a Roche limit radius move to the Saturn's equator plane, and create highly compressed flat structure of the visible dense rings due to the mutual action of Saturn's gravity and its magnetism. This process is on **Figure 1**.

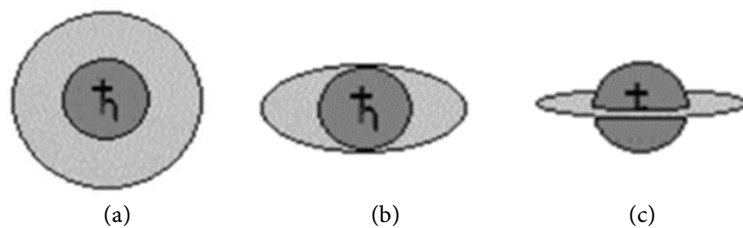


Figure 1. Collapse of Saturn's protoplanetary cloud which has a Roche limit radius and filled with diamagnetic ice bodies into a disk of visible dense rings after the mutual action of Saturn's gravitational and magnetic fields on ice bodies of the protoplanetary cloud: from a to b to c.

As a result, all ice bodies find themselves inside a three-dimensional magnetic well in the plane of Saturn's magnetic equator, which coincides with the geographic equator [16]. The ice bodies form a highly compressed flat disk-shaped structure of Saturn's visible dense rings. For ice bodies moving in orbit, acting on them gravitational force is balanced by centrifugal force and the force of diamagnetic expulsion.

We solved dynamic problems of the movement of a sole diamagnetic spherical ice body in the gravitational and magnetic fields [18] [22]. For the constant orbital radius, the solution reduced to an equation for the azimuthal angle θ of the ice body motion:

$$\ddot{\theta} + \dot{\theta}^2 \cot \theta - (A + B \cos^2 \theta) \cot \theta = 0. \quad (1)$$

where A and B are the constants related to the gravitational and magnetic forces, respectively. B also includes the Clausius-Mossotti factor for magnetic spheres, which depends on the environment of ice body. The important thing is that the Coriolis force does not act at the equator of the planet.

The analytical solution of (1) equal to $\theta = \pi / 2$ shows that all the stable orbits of ice bodies trapped in the equatorial plane. Gravitational force acting on orbiting ice body counterbalanced by centrifugal force and the force of diamagnetic expulsion. This fact was established during several research missions to Saturn.

3. Separation of Ice Bodies in the Saturn’s Visible Dense Rings

J. C. Maxwell proved in 1856 the fact that the visible dense rings along the orbit are not continuous, but consist of individual bodies [23]. In the magnetic field of Saturn, the bodies of diamagnetic ice acquire their own magnetization, opposite in sign to the magnetic field of Saturn. This leads to their repulsion and separation due to the magnetic force. In addition, the bodies are attracted to each other due to the gravitational force. When the gravitational force and the magnetic repulsion force are equal, an expression for the equilibrium distance r_0 between the ice bodies is [24] [25]:

$$r_0 = \left(\frac{R}{r_{sp}} \right)^3 \frac{m_s}{M_p} \frac{\mu - \mu_0}{\mu + 2\mu_0} \sqrt{\frac{3\mu_0}{4\pi G}} \tag{2}$$

where μ and μ_0 are magnetic permeability of the ice body material and free space, respectively; R is the ice body radius, r_{sp} is the radial distance between the centers of Saturn and the spherical ice body, M_p is the mass of ice body with magnetic moment m_p , m_s is the magnitude of magnetic moment of Saturn, G is the gravitational constant. This is shown schematically in **Figure 2**.

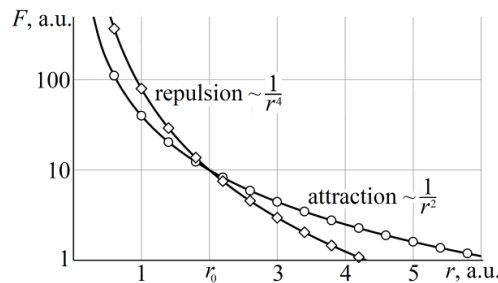


Figure 2. Dependence of the repulsion and attraction forces of ice bodies on distance between them.

4. Conclusions

In the present theory, there is no rejection of various gravitational and any other theories of the origin of Saturn’s visible dense rings. We have considered only additional contribution of Saturn’s magnetism to the visible dense rings origin process due to diamagnetism of ice bodies and try to apply it to an explanation of the peculiarities observed by Cassini in visible dense rings. It has been shown that the magnetization of diamagnetic ice bodies of the protoplanetary cloud and the effect process of magnetic anisotropic accretion (the Tchernyi-Kapranov effect) with the action of the force of diamagnetic expulsion extends our knowledge of nature of the origin of Saturn’s dense rings. This could also complement gravitational

models, which in principle are unable to explain the separation of ice bodies in visible dense rings.

J. C. Maxwell, the founder of the theory of electromagnetism, was close to a final solution to the problem of the origin of Saturn's visible dense rings when in 1856 he proved that the orbits of the rings were not continuous, but consisted of individual bodies. However, he was unable to determine the force that holds bodies in visible dense rings apart from each other, since in his time it was not known that the rings are mainly composed of ice and that ice has diamagnetic properties. The Cassini probe received information that individual bodies of visible dense rings consist mainly of diamagnetic ice only 150 years later during its mission around Saturn in 2004-2017.

It is now clear that discussions about the age of Saturn's rings will only become valid if they initially take into account not only the influence of Saturn's gravity, but also the role of Saturn's magnetic field. It allows us to explain phenomena in the visible dense rings observed by the Cassini probe, such as the origin of their stable, highly compressed flat structure at the equator of Saturn, and calculate the equilibrium distance between ice bodies in the dense rings.

Taking into account Saturn's magnetism suggests that the age of the visible dense rings may be almost the same as the age of Saturn's magnetic field. This coincides with the conclusion of [10] that Saturn's visible dense rings may be as old as the entire Saturn's system.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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