Appendix

The lonely Moon, double asteroids, and multiple collisions

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Space collisions, of which the fall of the Chelyabinsk bolide to Earth is an example, are a catalyst of planetary evolution. Without considering the process of multiple collisions, it is impossible to understand the key issues of celestial arrangement; in other words, the origin of asteroids and the natural satellites of planets, including the Moon.

How did the Moon appear? This issue has concerned astronomy for over 2,500 years, and begins with the question: *Where did the matter, from which the Moon formed, come from?*

A related question has not been puzzled over for quite as long, a mere 200 years: *How did the belt of asteroids appear between Mars and Jupiter and why did the belt of asteroids not shape into a planet?*

It has been found that the asteroid belt did not accumulate into a planet because its current weight is only equal to the weight of our Moon, or 0.05 percent of Earth's mass. Therefore, the question about the origin of the asteroid belt can be reformulated: *Where did 99.9 percent of the original matter of the asteroid belt go to?*

The problem of the asteroid matter seems to be opposite to that of the source of matter for the formation of the Moon, but in reality, these are two closely related questions. The significant moment in this confusing story was the discovery of double asteroids, or asteroids with natural satellites, i.e. moons (see Fig. 14.1 top left in Chapter 14, the asteroid Ida with the natural satellite Dactyl. This photograph shocked experts). From this, a new question arose: *How did the moons of asteroids, or double asteroids, appear?* This question shed some unexpected light on the problem of the formation of the Moon and the asteroid belt.

However, let us return to square one. Until 1610, the Moon was believed to be unique; there were no other natural satellites known in the Solar System. Then, 400 years ago, Galileo Galilei looked into his telescope and observed four new

N. Gorkavyi et al. (eds.), *Chelyabinsk Superbolide*, Springer Praxis Books,
https://doi.org/10.1007/978-3-030-22986-3

moons near Jupiter, beginning a new age of research into the Solar System. The Moon was no long a unique phenomenon, but in spite of the rapid growth in the number of discovered moons, the Moon did keep some of its exclusivity: all the new moons discovered were only found near the gas giants Jupiter, Saturn, Uranus, and Neptune, with the exception of the two tiny satellites of Mars, Phobos and Deimos. They were the only rivals to our Moon as satellites of planets with a solid surface and were only discovered relatively recently, in 1877. In terms of the relative mass (mass of the satellite divided by the mass of the planet), our Moon surpassed all the other known moons of the Solar System.

Its reputation as a unique natural satellite, different from any other, brought about a unique origin model for the Moon: the theory of a mega-impact. The theory was proposed by the Canadian geologist Reginald Daly in 1946 and was later given a second life in a 1975 article by American scientists Bill Hartmann and Donald Davis. According to this theory (see its present-day discussion in *Origin of the Earth and Moon* [1]), the huge planet Theia collided with Earth 4.5 billion years ago. Theia was a similar size to Mars (diameter about 7,000 km) and as a result of this truly unique event, some splinters from the collision went into an orbit around Earth, or more accurately, into an orbit as the new body resulting from the merging of Earth and Theia.

Although this model became almost universally accepted, geochemists J.H. Jones and H. Palme opposed the mega-impact theory [2, 3]. The geochemical conclusions from the catastrophe model were:

a) the Moon must have approximately the same chemical composition as Earth's mantle;
b) the Moon must have no core;
c) the Moon that was born from Earth must be younger than Earth;
d) as a result of the mega-impact, there should have been melting of the Moon and Earth. Thus, Earth and the Moon must have had oceans of liquid magma;
e) that the Moon is lacking in volatile elements is a consequence of the heating of Earth's matter thrown into orbit upon the mega-impact.

In reality, according to the data of these geochemists, the picture is somewhat different:

a) the chemical composition of the Moon is notably different from that of Earth. In particular, the iron content in the Moon proved to be 1.5–2 times higher than in Earth's mantle;
b) the Moon has a significant core (1–3 percent by mass, or 300–400 km in radius, which is about 20 percent of the Moon's radius of 1,738 km);
c) the Moon is older than Earth or, more correctly, the Moon's core appeared earlier than Earth's core;

d) the Moon was relatively cold and had been only partially flooded with magma. Geochemical data also refuted the existence of an ocean of molten mantle on Earth. For example, the contemporary mantle of Earth is notably less differentiated than it would have been if an ancient molten magma ocean had existed;
e) the content of volatile elements on the Moon does not support the mega-impact model. Their content cannot be derived from Earth's mantle by heating [2].

But the criticism from space chemists was ignored, and the theory, none of whose suppositions were true, still remains almost universally accepted.

Different variations of the giant impact theory seem to have provided solutions to the problem of increased iron content in the Moon's rocks. According to these new theories, 80 percent of the Moon's matter originated from the collision with Theia. If that were true, however, then the isotopic composition of the Moon would differ significantly from that of Earth (all space bodies have individual isotopic composition). Various groups of space chemists conducted analyses of the lunar minerals brought back from the Moon by the Apollo expeditions and found that the isotopic composition matched almost exactly with that of the Earth.

In order to explain this isotopic similarity, supporters of the mega-impact theory began to propose ever more catastrophic models, in which the mass of Theia increased from 10–20 percent to 30–45 percent of Earth's mass [3]. This configuration better fitted the isotopic similarity, but raised a new problem of excessive angular momentum and did not address the existing problem of the absence of any signs of global melting on Earth.

In contrast, researchers who addressed the problem differently, by considering that the mass of Theia was actually less than ten percent that of Earth, solved the problem of the isotopic composition easily, because it would have been mostly matter from Earth rather than Theia that would have been thrown out to form the Moon in the event of a collision. Of course, if the mass of the impactor is less, the problem of the angular momentum deficit of the resulting Moon-Earth system arises. Scientists tried to overcome this problem by assuming that Earth's rotation was very rapid before the mega-impact [4]. But does this not all suggest that too many assumptions are being made in order to save the mega-impact theory? Perhaps it would be better to wait until scientists overcome the intellectual barrier of the 'one-collision hypothesis' and instead consider several collisions of not very large bodies, which would not change the solution of the isotopic problem but would make it easier to solve the angular momentum problem.

The solution to the problem of the formation of the asteroid belt is equally deplorable: over the past two hundred years, not a single model has been suggested that would clearly explain what happened to the majority of the mass from the asteroid belt.

Since 1978, there has been a chain of events that, sooner or later, will change the established paradigm of a catastrophic birth of our Moon. Charon, a moon of Pluto, the small, cold dwarf planet on the edge of the Solar System, was discovered in 1978. In terms of relative mass (12 percent of Pluto's mass), Charon far outstrips the Moon (1.2 percent of Earth's mass) and has thus deprived the Moon of its last unique characteristic (in terms of absolute mass, several satellites have been found around the giant planets which exceed that of the Moon).

In 1988, a group of astronomers led by V.V. Prokof'yeva-Mikhailovskaya from the Crimean Astrophysical Observatory began observations of the apparent magnitude of asteroids. The characteristic variability recorded for the asteroid 87 Sylvia proved that the asteroid had a moon, and this was stated in a publication in 1992 **[5]**. The Crimean astronomers also found signs of duality with other asteroids, but nobody believed them. Asteroids were considered to be splinters; debris at the location of a planet that failed to form. The notion of satellites around asteroids was considered laughable.

The laughter stopped instantly when the interplanetary station Galileo took photographs of the moon Dactyl around the asteroid Ida. As of April 2015, 270 moons of asteroids and transneptunians (large bodies beyond Neptune; Pluto is now considered to be a transneptunian object) have been discovered. The asteroid 87 Sylvia was found to have two moons and there are now several known triple asteroid systems. Pluto was found to have four more moons in addition to Charon, and became the first sextuple system of the asteroid type.

According to assessments by astronomers-observers, about 15 percent of asteroids have moons. This means that there is a rather regular, often realizable scenario for the formation of moons near small planets with a solid surface. How can this scenario be combined with the giant mega-impact theory for our own Moon? Perhaps the Moon was formed in a similar way to other moons and is not actually unique?

Many asteroids, for example, Itokawa (and even the Churyumov-Gerasimenko comet, see Fig. 14.1 bottom right, Chapter 14), have a dumbbell form, or that of two agglutinated bodies. Apparently, in such cases, they are formed by the slow approach and attachment of the former moon and the primary body. Such non-destructive attachment between the asteroid and its moon is only possible if the orbital velocity of the moon is low, i.e., if the asteroid has a low mass. In the case of large asteroids, the merging of the moon with the central body would occur at a high velocity and end with the complete destruction of the moon. If the moon followed a circular orbit and the asteroid itself was large and quasi-spherical, the tangential collision of the moon would have left a long fossa (trench) on the surface of the primary body. Of note is that the large, fast-rotating asteroid Vesta (with an average diameter of 525 km) was found to have no moons, although two series of giant fossae were found on it – one in the equator area (Divalia Fossae Formation) and the other at 30°N (Saturnalia Fossae Formation). The fossae reach 300–400 km in length, 10–20 km in width, and up to 5 km in depth.

A moon should rotate around Vesta (near its surface) at a speed of 900 km/h. If its orbital rotation is prograde (coincides with the direction of the asteroid's own rotation), the moon will move with a speed of about 600 km/h relative to Vesta's surface. Assessments show that a moon with a mass a thousand times lower than that of Vesta, with the same density and a diameter of about 50 km, has enough kinetic energy before stopping (or full destruction) to make a canyon 5 km deep, 10 km wide, and 1,000 km long even in strong granite, with a specific crushing energy of about 10^9 erg/cm^3. Such a moon could leave a fossa, in a material comparable with ice in terms of strength (10^8 erg/cm^3), of 10,000 km long (or a shorter but deeper fossa). The two series of grooves mean that Vesta swallowed two moons, whose orbits were inclined to each other. Imagine a moon that flies above the asteroid's surface at a speed of a turbojet airplane and crushes mountains several kilometers high – an impressive sight.

Another criteria is that of a more gentle attachment of a moon to an asteroid, assuming that the moon in this case has little energy and is incapable of digging a canyon (or crater) larger in volume than the moon itself. Thus, the conditions for forming a dumbbell asteroid would include a restricted orbital velocity of the moon V: $V^2 < 2E_v / \rho$, where E_v is the specific volumetric energy of the asteroid's destruction, and ρ is the moon's density. This velocity is about 100 m/sec. Consequently, fast-rotating asteroids of up to several hundred thousand kilometers can have equatorial grooves, the footprints from the falls of their moons. For an asteroid with a diameter less than one hundred kilometers, merging with the moon must result in the formation of a dumbbell shape.

Vesta's lack of moons has actively been discussed in specialist literature and popular journals. Journalist Jeff Hecht asked one of the authors of this appendix why Vesta has no moons. Having heard a hypothesis about Vesta engulfing its moons, he cited this hypothesis in an article on May 30, 2015, entitled: "Vesta has no moons—is it unlucky or did it eat them?" **[6]**

The process of moons and asteroids merging means that asteroids with moons could have been more numerous, possibly as much as half of the asteroid population. Perhaps only slowly-rotating asteroids and planets – such as Venus and Mercury – did not have moons? Freshly-formed asteroids involved in strong collisions might also not have had sufficient time to acquire a moon.

In 1995, Prokof'yeva-Mikhailovskaya, Tarashchuk, and Gorkavyi wrote a review in *Physics Physics-Uspekhi*, in which, apart from describing the observational data of the Crimean astronomers, the dynamic stability of the orbits of the moons of asteroids that are located within the Hill sphere of their primary bodies was shown **[7]**. However, the reasons for the formation of relatively large moons around small asteroids with weak gravity remains unclear so far. The formation of our own Moon – comparatively large in relation to Earth – presented a similar problem, but the mystery of small moons near small asteroids was most complicated.

Between 2004 and 2007, Gorkavyi proposed a single model for the formation of our Moon and those of the asteroids [8, 9]. According to this model, the Moon grew out of the regular circumplanetary cloud, whose mass multiplied due to a ballistic transfer of matter from Earth's mantle (see Fig. A.1). This transfer is similar to that used by the mega-impact theory, but in this model it occurs as several less catastrophic events rather than one mega-impact.

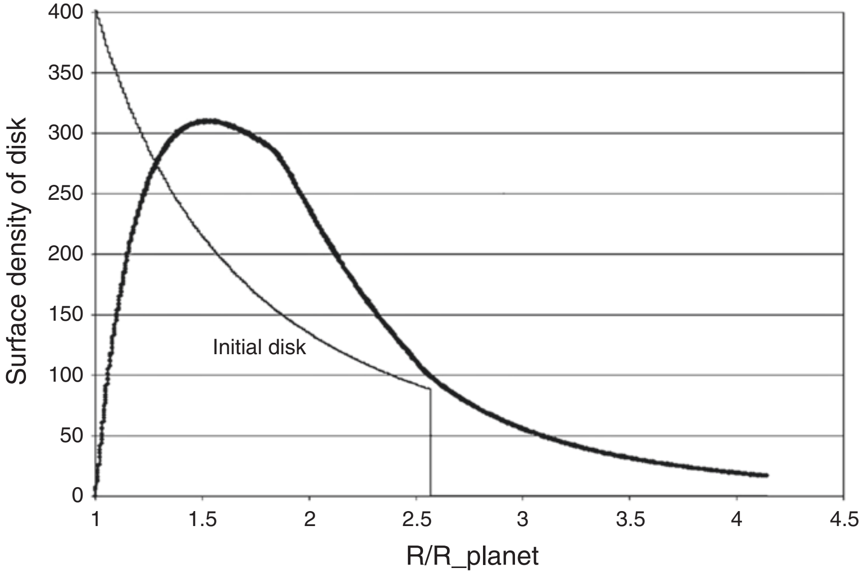

Figure A.1: The density of the circumplanetary disk around the Earth grows because of the ballistic transfer of the ejecta from Earth's surface.

Taking into account the results obtained by the authors in other works focused on analytical and numerical research of the dust cloud dynamics, a general picture of the origin of the asteroid belt, the moons of asteroids, and our own Moon can be drawn [10–12].

Asteroids lose their mass under micrometeorite bombardment. According to the experimental data of Japanese researchers, the asteroid Itokawa, which moves between Earth and Mars, loses many dozen centimeters of its surface layer over a million years [13]. Over 4.5 billion years, such loss would amount to a layer of 2–3 km. Taking into account that the micrometeorite bombardment is more intensive in the zone of the asteroid belt and that the dust cloud density must have been much higher in the past, it can be concluded that asteroids can lose dozens and even hundreds of kilometers of their surface layers.

Where did all that mass, which turned into splinters and dust, go? If the asteroid belt was a closed system, nothing would happen; the dust would leave the surface of the asteroids and return without changing the general mass of the asteroid belt. However, in reality the asteroid belt is open to influence: it is lit by the Sun. The Sun's rays create sufficient light pressure for the finest newly-formed dust grains of submicron size to be thrown out of the Solar System. Larger dust grains, of 1 micron, are thrown into elliptical orbits immediately after their formation and approach Jupiter at their apocenters. Jupiter in turn treats them bluntly, throwing them in all directions at colossal speeds. Numerical calculations by the authors show that 50 percent of such dust grains are thrown out of the Solar System into interstellar space [9, 10]. Jupiter, together with the solar pressure, works as a giant vacuum cleaner that removes fine dust from the asteroid belt. Larger dust particles, which do not reach Jupiter's orbit and escape its 'gravitational kick', are affected differently and drift slowly to the Sun under the influence of the Poynting-Robertson effect. This effect makes a particle, which moves along the orbit in the media of solar wind quanta, lose its angular momentum (similarly, a man running during a vertical rain shower is hit in the face by raindrops due to his own speed) and crawl towards the Sun. This also decreases the asteroid belt mass.

The Sun and Jupiter are the 'thieves' that quietly and discreetly stole the main mass of the asteroid belt, preventing the material from forming a full-scale planet. Data from the asteroid Itokawa suggest that such a process is highly efficient.

Each asteroid was gradually reduced over cosmological time, sending dust flows in all directions that, by its total mass, exceeded its current residue. From the point of view of Ilya Prigozhin's concept of self-organization, this is a typical open system prone to the formation of structures. A reducing asteroid creates a space of opportunity around itself.

Moons are self-organizing structures that grow by feeding on the dust flying from asteroids. In fact, it is sufficient to create quite a small seed disk around an asteroid (the creation of such a disk from particles passing around planets was discussed in detail in the monograph *Terrestrial planets: origin and early evolution* [14]) and this begins to intercept the flying matter efficiently as it sorts: the retrograde bodies (in terms of their rotation relative to the disk rotation) are thrown to the planet and the prograde particles are captured by the disk, increasing its mass [9].

Numerical calculations showed that even with isotropic bombardment of an asteroid by micrometeorites, a prograde disk (i.e. a disk rotating in the same direction as the asteroid itself) grows around it; such a disk has its peak density not far from the central body. As shown by research into the available observations, the main mass of the moons of asteroids is situated in the orbits equal to 3–4 radii of the central body (Fig. A.2).

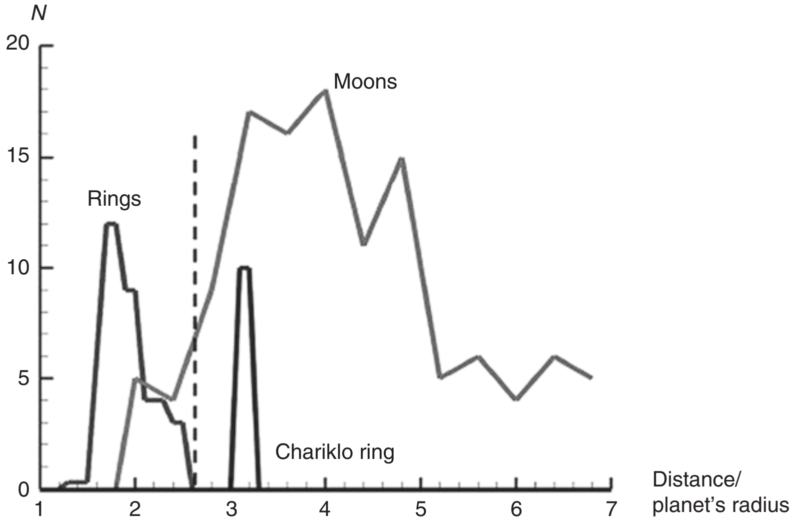

Figure A.2: Distribution of planetary rings, moons of asteroids, and the Chariklo ring (the altitude of its peak is selected arbitrarily) by their distance from the planet. The dotted line means the outer borderline of planetary rings. It follows from this image that the Chariklo ring is a proto-moon disk rather than a planetary ring.

The rings recently discovered near the Centaur-class asteroids Chariklo and Chiron were announced as planetary rings; however, in reality these are proto-moon discs situated at a distance of exactly three radii from the asteroid, in contrast to planetary rings that are limited to a maximum radius of 2.6 (Fig. A.2).

How is the formation of our Moon different from the formation of the moons of asteroids? Actually, it does not differ in any principle respect. Micrometeorites and meteorites collide with an asteroid's surface at a colossal speed and throw flows of friable surface matter from it. These flows have much slower speeds (about 10 m/sec as shown by laboratory experiments **[15]**). In the case of the Moon, such micrometeorites and meteorites are replaced by larger bodies (planetesimals) from dozens of kilometers up to 1,000 km. However, even 1,000-km planetesimals are hundreds of times lighter than Theia, meaning that the Moon appeared as a result of multiple moderate collisions, not a single catastrophic impact. The matter from Earth's mantle was gradually thrown to orbit, to the proto-moon disk from which the Moon later formed, without the need for Earth to melt and without a unique mega-impact. The fact that the Moon formed quite near Earth and later moved to a distance equal to 60 Earth radii has been known for some time (the Moon is currently moving away from Earth at a speed of 4 cm per year).

One intriguing question is whether Earth had smaller, outer moons like those of Pluto. If so, then, the moving Moon must have engulfed its smaller brothers.

Thus, we have proposed a model that explains the three key problems of current planetology at once: the asteroid belt formation (or its mass loss); the appearance of multiple moons around asteroids (that were formed using the lost mass), and the birth of the Moon. This model does not require any unique events and, in the final analysis, better agrees with the geochemical data than the theory of a catastrophic mega-impact. This multi-impact model unites the most important and significant moments of the mega-impact theory (throwing Earth's mantle matter to space upon collision with a large body) and the accretion model (existence of a long-lived proto-satellite disk) and removes the difficulties of both concepts.

The authors have learned relatively recently that the theory of the Moon's origin as a result of a number of smaller impacts has also been developed independently by the Moscow cosmogonic group of Safronov-Ruskol-Vityazev-Pechernikova (see the history of this model in review [16]). This group also used the theory to develop the model of the Moon's formation by accretion. According to the calculations of the Moscow specialists, the maximum size of bodies falling to Earth did not exceed one percent of Earth's mass, meaning they were of 'Lunar', rather than 'Martian' size. This immediately renders the mega-impact model unrealistic.

An article by Gaftonyuk and Gorkavyi studied the patterns of the double asteroid database, which had already provided rather rich data [17]. It showed that the probability of a moon's existence grows with the increased rotation speeds of asteroids. Additionally, all the discovered moons rotate in the same direction as their central body and lie close to the plane of its equator. Thus, the moon systems of asteroids are regular and similar to those of the large planets.

In terms of relative mass, the Moon is in the middle of the distribution of moons of solid bodies. The Moon stopped being a unique body in the planetological sense because many analogs for it have been discovered over time. Until recently, there were eight or nine planets in the Solar System and a lot of space debris. Now, we have millions of planets in our system, with their own origins, histories, and moons. Therefore, the models of moon formation near solid planetoids, including the Moon near Earth, must be unified to explain the formation of both the moons of asteroids and our own Moon. Any theory of the Moon's formation that cannot explain the formation of the moons of asteroids is morally outdated, even if it has been suggested quite recently.

The mega-impact model of the Moon's formation is also connected with the significant issue of the origin of Earth's oceans. Where would the water have come from?

Tobi Owen, a Hawaiian astronomer and specialist in the origin of Earth's hydrosphere, postulated three possible sources of Earth's oceans in his interview with *Scientific American* of October 21, 1999: 1) Water that was contained in the asteroids (planetesimals) that agglutinated in the past to form the planet Earth. (This is, of course, a realistic source, because the primary bodies contained a lot of moisture.); 2) Water that was delivered to Earth during subsequent falls of asteroids and meteoroids such as carbonaceous chondrites from the asteroid belt; 3) Water from the comets that hit Earth infrequently [1].

In principle, asteroids and comets as sources of Earth's water are realistic. The question is how much water has been delivered this way. Space chemists researched this issue and observed that if water had been delivered to Earth by meteorites, which contain a lot of the inert gas xenon, then Earth's atmosphere would likely have contained ten times more xenon than it does. As the inert gas xenon does not engage in chemical reactions, its quantity has not changed since the time of Earth's formation. Thus, the 'meteoritic hypothesis' of the origin of Earth's oceans is unlikely. Space chemists also criticized the 'comet hypothesis', because the deuterium/hydrogen ratio in cometary ice is twice as high as in Earth's oceans. Relatively recent measurements taken by Rosetta near the Churyumov-Gerasimenko comet indicated that the deuterium/hydrogen ratio in that comet was three times higher than in Earth's water, so any relationship between comets and Earth's oceans is not confirmed [18]. In their article 'Oceans from Heaven' in *Scientific American* of March 2015, D. Jewitt and E. Young suggested that there is "no simple solution" to the choice between the comet hypothesis and the meteoritic hypothesis for the origin of oceans. However, why are researchers not happy with the first hypothesis, the simplest and most logical among the possibilities that were enumerated by Owen?

It is because the mega-impact model, which only creates the Moon with great difficulty, also deprives Earth of its oceans. As Jewitt and Young noted: "The energy of this global-scale impact would have swept away much of the atmosphere, flash-boiled any watery oceans and produced an ocean of magma hundreds of kilometers deep. Regardless of whether Earth formed wet or dry, the devastating blow of this Moon-forming impact must have cleansed our planet of nearly all its primordial water."

Having adopted the mega-impact catastrophic theory, scientists started racking their brains to devise sophisticated scenarios for returning the oceans to Earth. There is no need to rack one's brains, but there is a need to break stereotypes.

For any young scientists reading, catastrophism is a true sign of the scientific inadequacy of a theory. A theory based on the assumption of a rare event is inherently not good, because it has a low probability. What is worse is that a catastrophic event provides many free parameters for a model which on the one hand allows easy adaptation of a parametric model to the observed phenomenon, but on the other hand drastically decreases the scientific value of such a flexible model.

Catastrophic models have a low prediction value, because they are not applicable to other physical systems and cannot say anything about them. As a rule, catastrophic theories are debunked over time; if they have not been debunked so far, it simply means that not enough time has passed and that some of the proponents of the old model remain to defend it.

Let us consider Jupiter's irregular moons and the theory of the accidental capture by Neptune of its moon Triton, which has a retrograde orbit, as examples of the catastrophic formation model. According to the first model, the group of prograde (rotating in the same direction as the planet) and retrograde moons of Jupiter appeared due to the accidental collision of two large asteroids on head-on trajectories.

In 1993–95, the authors developed a numerical model to analyze the capture of small asteroids near a giant planet **[19]**. The model took into account the existence of a disc of prograde particles orbiting around the planet, and of collisions between particles of this disc and asteroids flying by. All the typical trajectories of passing asteroids were studied and hundreds of thousands of the splinter trajectories that formed from the collision of particles and asteroids were calculated, with different assumptions of their masses. The model was used for the systems of the three giant planets Jupiter, Saturn, and Neptune.

Surprisingly, it was found that all small asteroids are captured in quite specific zones near each planet, which are determined by the different geometry of the trajectories of the oncoming bodies. These zones are different for prograde and retrograde asteroids, and are where the real groups of retrograde and prograde irregular moons are located. Thus, the position of external moons that were considered to be irregular for a long time was found to be compliant with stringent celestial-mechanical regularities. The model explained the existence of Jupiter's outer moons including the retrograde group Pasiphae, Saturn's retrograde moon Phoebe, and Neptune's big retrograde moon Triton. The diversity of the moon systems of Jupiter, Saturn and Neptune proved to be connected to changes in only one significant parameter of the model – the evolution duration. Increasing evolution durations resulted in the formation of ever more massive retrograde moons. Therefore, Saturn has more such moons than Jupiter, and Neptune's retrograde moon bodies dominated over prograde bodies and formed the giant retrograde Triton.

The article made a conclusion, based on the model for Saturn, that the planet had an undiscovered group of outer retrograde moons at twice the distance of the

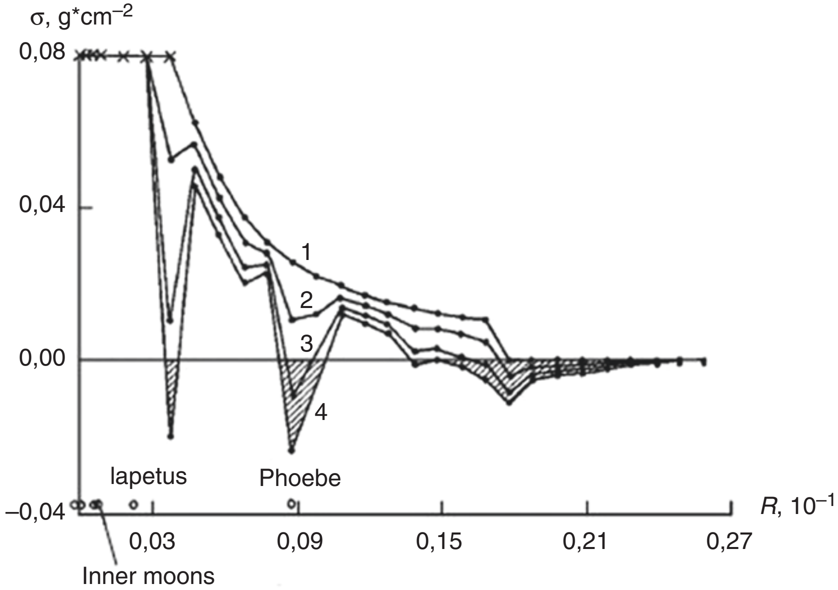

Figure A.3: The original density profile (1) of the prograde near-planet disk evolves due to the capture of retrograde asteroids and their fragments (profiles 2–4) up to the zone where retrograde moons dominate (shaded zones below the axis). One such zone happens to be around the orbit of Phoebe, while the other, outer zone contained no known moons in 1995. A whole group of retrograde moons of Saturn were discovered in that zone some years later.

orbit radius of the retrograde Phoebe (13 million km), similar to Jupiter's outer group Pasiphae (Fig. A.3). The prediction of the existence of this outermost group of retrograde moons was confirmed several years later: 25 retrograde moons of Saturn were discovered over 2000–2007, at a distance of 18–24 million km.

In 2001, the authors made an additional prediction, based on their 1995 calculations, that Nereid, the outermost moon of Neptune at that time, was the largest of the prograde moons in a group of outer moons, which would consist of a mixture of moons with prograde and retrograde orbits and with the retrograde moons dominant **[20]**. This prediction was confirmed with the discovery of two prograde and three retrograde moons of Neptune beyond Nereid's orbit in 2002–2003.

Thus, developments in science have systematically expelled catastrophic models, replacing them with theories that are based on regular rather than accidental phenomena.

The concept of the formation of the Moon, double asteroids, and the asteroid belt itself through multiple systematic space collisions contains a lot of little-studied and unclear phenomena, which is exactly why it presents a great opportunity for young scientists and postgraduates, including those from Chelyabinsk State University, to apply their abilities.

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