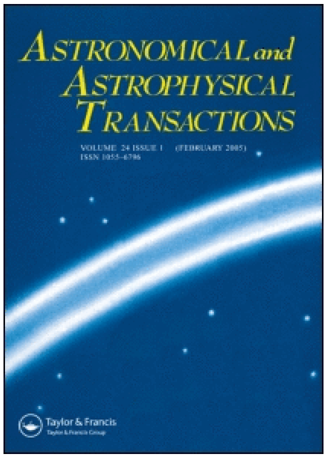

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The origin of the asteroid main belt: Synthesis of mutually exclusive paradigms

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THE ORIGIN OF THE ASTEROID MAIN BELT: SYNTHESIS OF MUTUALLY EXCLUSIVE PARADIGMS

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An origin of the asteroid main belt (MB) is usually considered in the framework of either (1) Olbers hypothesis on breaking of a small planet Phaethon, or (2) a hypothesis on a planet which failed to be accumulated in the protoplanetary cloud due to the Jovian perturbations with subsequent collisional evolution of its embryos. Both hypotheses have their own shortcomings. The possibility of explosion of the ice electrolysis products dissolved in icy envelopes of distant planets, which was suggested recently, apparently poses the Olbers hypothesis on a firm basis and explains a variety of the asteroid MB features especially if one takes into account a success of this approach in explaining and predicting properties of other minor body groups. However, gasdynamic calculations revealed that a non-central explosion of the envelope of a $M = 0.2M_{\rm moon}$ planet produces numerous not very big (up to $\sim$ 50 km) icy fragments – the future C-asteroids, but does not destroy its rocky core. To overcome this difficulty, we call attention to a high probability for Phaethon to have a satellite which was lost in the explosion. Its subsequent hypervelocity collision with the rocky core left led to the appearance of large (> 100 km) and numerous rocky bodies. Thus, as is often the case, the truth appears to lie between the extremes and such a synthesis combines the benefits of the both approaches.

KEY WORDS Origin of asteroids, collisions, explosion of a planet

1 INTRODUCTION

The asteroid MB origin is not yet understood. The widespread assumption on non-accumulated planet in the standard nebular hypothesis context is appealing with its simple explanation of the S–M–C asteroid distribution vs. the Solar distance as being due to volatiles' driving away into a distant zone of their condensation. However, in order to explain a large velocity dispersion of asteroids, one has to refer to a new hypothesis invoking large perturbing bodies arriving from the Jupiter accumulation zone (Safronov, 1969); it is unclear also how to explain the high orbital tilt ($\approx 35°$) of large Pallas (Whipple *et al.*, 1972), why the MB is bounded by 3.2 AU where Jovian influence is negligible (Lecar and Franklin, 1973), etc.

Prevailing during 150 yrs, the Olbers hypothesis regarding asteroids as a product of breaking of a moon-like planet – Phaethon, was rejected as no clear physical reason of the disruption was found. However, such a mechanism was suggested by Drobyshevski (1980). This is the volumetric electrolysis of dirty ices (Drobyshevski *et al.*, 1995) composing massive envelopes of Ganymede-type distant moon-like bodies (where the ice-to-rock ratio is about 1). When the electrolysis products, $2H_2+O_2$, accumulate up to 15–20 wt.% as a solid-state solution in the ice containing also $\sim 10\%$ organics, a heavy meteoroid impact is able to initiate a detonation of the solution. The energy of the envelope explosion is sufficient to destroy a planet with $M < 0.5M_{\rm moon}$ (Drobyshevski, 1986) or to shed off a part of the envelope from a greater body in the form of the outermost ice fragments, water vapors, sand, etc.

The icy fragments (= comet nuclei) are saturated with $2H_2+O_2$ also and, under certain conditions, are capable of new explosions, burning, etc. In this way we succeeded both in explaining the origin and properties of the most of the inner Solar system minor bodies (the SP comets, the Trojans, the small satellites of Mars and Jupiter, the Saturn rings, etc.) and related bodies (difference in the structure and topography of the Galilean satellites, the strength of ancient magnetic fields of giant planets and the Solar wind, etc.), and in offering numerous predictions many of which were confirmed later (Titan's atmospheric composition and the population of the Saturn rings, burning and distant outbursts of the SP comets, etc.) or are awaiting their verification (an excessive thermal flux from Titan due to freezing its water ocean after recent envelope explosion, ~ 1 km thickness of icy crust on its surface, and so on) (see Drobyshevski, 1989 and ref erences therein). The New Explosive Cosmogony (NEC) of minor bodies does not encounter any substatial criticism (Drobyshevski, 1995a).

2 ON CONSEQUENCES OF THE EXPLOSION OF A PLANETARY ICY ENVELOPE: THE IMPOSSIBILITY OF THE CORE BREAK-UP AND OTHER PROBLEMS

Two-dimensional gasdynamic calculations of non-central axisymmetric explosion of a planet with $M = 0.2M_{\rm moon} \approx 1M_{\rm pluto}$ at $M_{\rm rock} = 0.08M_{\rm moon}$ have shown (Drobyshevski *et al.*, 1994) that the body loses a somewhat more than a half of its original mass. The known remoteness of C-bodies from the Sun (originally, the dirty ice fragments), when compared to other asteroid types, can be caused by selfgravity provided the explosion was originally initiated in the planet's trailing hemisphere. In this case the icy envelope fragments of the leading hemisphere get a greater speed-up in smaller gravitational pull due to preceding explosive fly apart of the other hemisphere matter. This removes the main argument against the Olbers hypothesis.

The mineral matrix contained in ice can include interstellar grains as well, which remain intact in the unexploded fragments thus explaining their known occurrence in meteorites. Chondrules are formed of this matrix during the explosion under the high temperature action. Later on, the dispersed matrix particles are captured by other fragments and in subsequent collisions they retain on the largest bodies imparting them the observable modern C-appearance. Evidence of thermal metamorphism is found on the C, G, B, and F asteroids (Hiroi *et al.*, 1993) and in meteorite organics (Morgan *et al.*, 1991). The coherent magnetization of Gaspra also favors that it is not a pile of primitive lumps but is a part of large metamorphosed body (Kivelson *et al.*, 1991). Similarly, detection of Li in a plume after P/Shoemaker–Levy 9 only L-fragment infall onto Jupiter (West, 1994) favors not agglomeration of primitive ice-containing condensate in rather locally homogeneous and turbulized preplanetary medium, but aqueous wash-out of salts from rocks with their subsequent concentration in frozen up ice in the planetary body (Drobyshevski, 1995c, 1996b).

The calculations also showed that, due to a cumulative jetting effect in a region opposite to the detonation ignition point, fragments could be ejected at velocities corresponding to an 8° orbital tilt. It is clear that more calculations are required for further refinement of this idea. This concerns especially the water equation of state, the initial matter and $2H_2+O_2$ distribution in the body, etc.

However, one can see three problems not so simple to solve when remaining within the conceivable assumptions on the chemical 2D explosion of Phaethon:

(1) In spite of the total energy excess, which is seemingly enough to break-up the planet totally, the 2D explosion hydrodynamics is such that it is difficult to disintegrate the Phaethon's rocky core.

(2) The explosion is able to expel, as unexploded fragments, an envelope of $\sim$ 50 km thick, not much more. This is confirmed by crater sizes on Galilean satellites, the craters having been created by their explosion fragments. Meanwhile, there are $\sim$ 200 asteroids of $>$ 100 km, dia (the greatest ones are Ceres 1000 km. Pallas 580 km, and Vesta 520 km) (Zellner, 1979). One can relate Phaethon's explosion with the heavy Imbrium bombardment of inner planets 3.9 Byr ago with impactors of $\sim$ 100 km in size. The avalanche-like impact selfdestruction of Mercurian silicate mantle (Drobyshevski, 1992, 1996a) was hardly able to supply fragments of $\phi >$ 10 km.

(3) The orbital tilt of large Pallas is too great to be produced even in directed chemical explosion.

3 ON A POSSIBILITY AND NEED FOR A SYNTHESIS OF THE TWO PARADIGMS

If one takes into account an undoubtedly crucial role of the collisional evolution of the MB (as a result its modern mass is about 1/5 the initial value – Farinella *et al.*, 1985), it makes sense to combine the two approaches opposed to each other up to now, viz. the breaking up of one planet and the collisional evolution of several large planetoids. As a basis for such unification could be an assumption on Phaethon having rather large Charon–type satellite (i.e. it was a Pluto–like system). Binary planets are a rather common occurrence in the Solar system, especially if one considers the Sun–Jupiter system as a limiting case of a close binary star (Drobyshevski, 1978, 1995b). These are the Earth–Moon, Pluto–Charon, and possibly, Venus–Mercury pairs (Drobyshevski, 1992, 1996a).

The "close binary" cosmogony supposes an occurrence of numerous moon–like and more massive bodies emerging from the proto–Jupiter, filling the space in the Sun–Jupiter system and interacting mainly gravitationally with each other. The interactions included mutual high–velocity collisions and also break–ups. So, quite naturally, numerous primeval "asteroid" belts could occur as between Mars and Jupiter as between other planets. These belts of fragments, including that containing the surviving Pluto–like Phaethon system on a rather stable orbit between Mars and Jupiter, were unstable due to planetary perturbations and dissipated gradually to a variable degree. The rate of dissipation of such a primeval asteroid belt, with the Phaethon system imbedded into it, has to be investigated in the spirit of the classical work of Lecar and Franklin (1973). At this stage nobody can exclude retaining some primeval asteroids up to the moment of Phaethon's explosion.

Then, in the explosion of Phaethon, the satellite could be lost and go into its own path around the Sun. It is easy to show that the loss of a satellite occurred if the system total mass decreases more than by a factor of two in the explosion, that is just close to the calculated case (Drobyshevski *et al.*, 1994) of the Pluto–like planet explosion. On the other hand, when basing on just–mentioned "close binary" cosmogony, the initial orbit of Phaeton could well have substantial eccentricity and inclination initially. So, after many revolutions around the Sun, the satellite collided, at a velocity of $\sim V_{\mathrm{orb}}/3 = 6$ km/s, with the remnant of the Phaethon's core (the future Ceres, possibly). Such a collision energy exceeds by far any chemical energy. As a result, several large asteroids originated, including Pallas on its highly inclined orbit and metallic and rocky bodies. So, our approach incorporates Chapman's (1976) hypothesis on a collisional break–up of a large asteroid in that epoch.

The further evolution of this high–velocity–dispersion ensemble was developing along the rather well known collisional scenario (e.g. Farinella *et al.*, 1985), with due regard for the subsequent explosions (and burning out) of the ice fragments which were saturated initially with $2H_2+O_2$ in the parent Phaethon.

It is highly improbable to reject such a contribution of the chemical explosive evolution, as well as Phaethon's explosion itself, if one takes into account gains of NEC in explanation of features of not only different small body groups, but the MB asteroids, properly (the S–M–C distribution vs. the Sun distance, the determination of the ancient Solar wind parameters needed for providing the explosion which are in agreement with other subsequent (Bohigas *et al.*, 1986) estimates, etc.).

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