

Glaciopanspermia: Seeding the Terrestrial Planets with Life?

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Terrestrial planets: habitable zones

We consider the possibility that within the next decade life may be detected on other planetary bodies. Both Mars and Venus hold some promise: While life may be present as lithoautotrophs in the Martian deep subsurface, it may also have adapted to the Martian surface environment by developing an antifreeze [1]. In contrast, Venus' surface is inhospitable, but the thick Venus atmosphere has a habitable zone [2]. Therefore, it may well turn out that the three terrestrial planets all carry life.

Life: place of origin

The question whether life originated on Earth or elsewhere in the solar system has no obvious answer, since the Earth was probably sterilized during the LHB, about 700 My after the formation of the solar system. Seeding by lithopanspermia is a definite possibility [3], but the question remains what place in the solar system could have been the origin. As liquid water appears to be advantageous for evolving complex organic chemistry, we consider planetary bodies which have or have had an ocean early in the history of the solar system. These are the terrestrial planets and a number of icy bodies of the solar system.

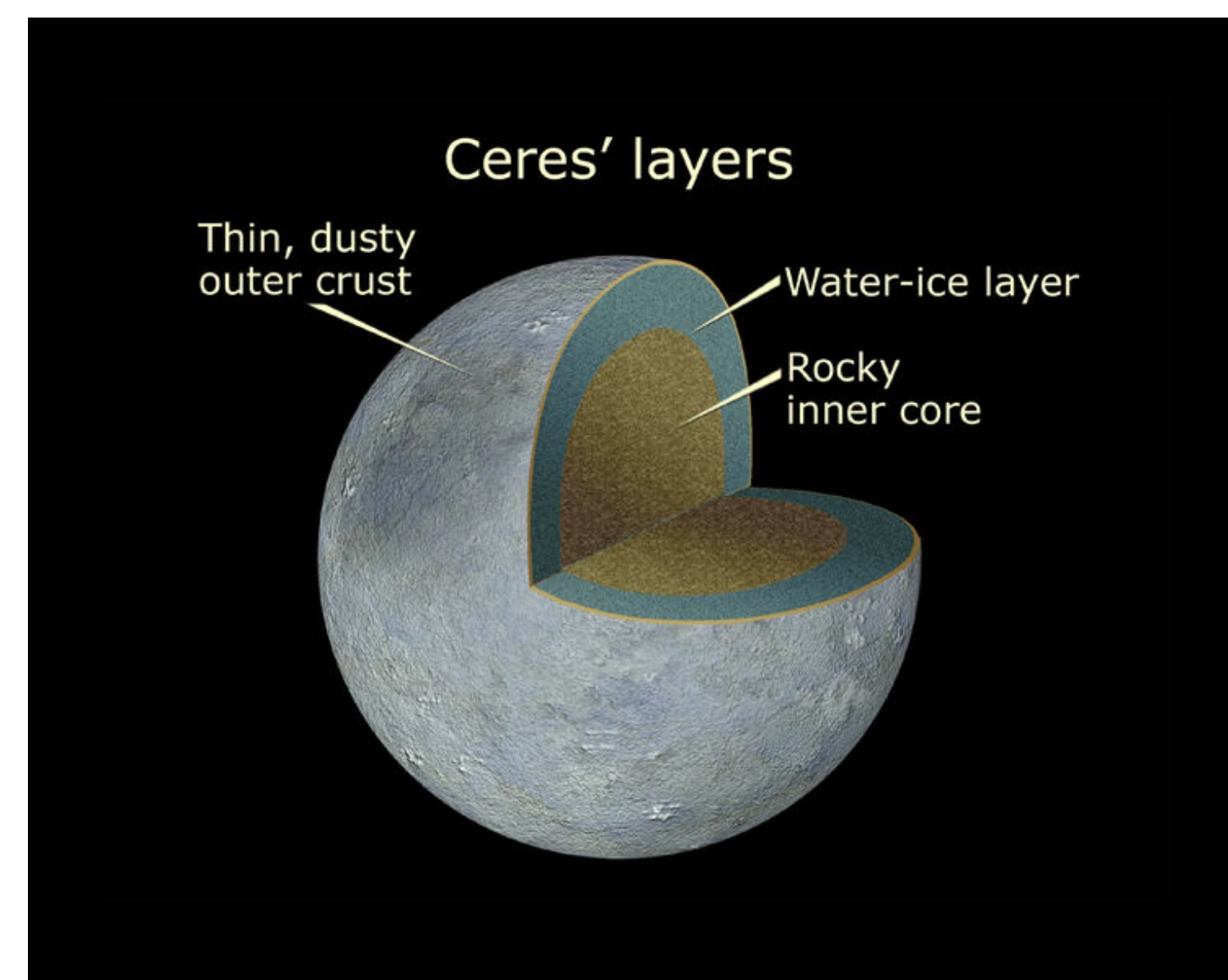
Lithopanspermia

Possible sources of life for lithopanspermia include Earth itself (before LHB), Mars, Venus (if it had a more benign climate than today) and the icy bodies further out in the solar system. The mechanics of lithopanspermia entail the problems of impact ejection, preservation during transfer and arrival. The ejection of pieces of the surface into space requires achieving at least the escape velocity of the parent body. Preservation during travel from the parent body to the seeded "child body" appears to be a lesser problem. The arrival of spore-bearing meteorites is a more severe problem for airless bodies like the moon, because of the shock upon arrival, than for the terrestrial planets where meteorites may survive through aerobraking.

The velocity distribution of impact ejecta falls off steeply, which draws attention to bodies with lower escape velocities. For icy moons, the ejecta have to escape not only the moon, but also the gravitational well of their planet (viz. Europa). Moreover, the ejecta have to reach the target planet, possible by gravitational slingshot effects, but more likely with an extra velocity increase sufficient for a Hohmann transfer orbit. Possible parent bodies for lithopanspermia are listed in the Table.

Icy bodies

The icy bodies have been considered as abodes of life, with emphasis on Europa, which still has an ocean, preserved by tidal energy absorption. Impact ejecta from the icy bodies are in a prominent position to reach a transfer orbit to one of the terrestrial planets. The table shows that the moons of Jupiter and Saturn are at a disadvantage because of the gravitational well of these planets. If we ignore Triton and Pluto and other KBOs, an interesting candidate is the dwarf planet Ceres.



Originating planetary body	In orbit around:	Escape velocity (km/s)	Total Δv (km/s) for transfer to:		
			Venus	Earth	Mars
Venus	Sun	10.46	0	10.80	11.94
Earth	Sun	11.19	11.46	0	11.57
Mars	Sun	5.03	6.93	5.68	0
Ceres	Sun	0.51	6.40	4.88	2.86
Europa	Jupiter	2.03	8.95	8.27	7.40
Ganymede	Jupiter	2.74	8.45	7.72	6.79
Eceladus	Saturn	0.24	7.98	7.55	6.96
Titan	Saturn	2.64	6.96	6.47	5.77
Triton	Neptune	1.46	4.85	4.67	4.41
Pluto	Sun	1.20	4.02	3.88	3.65

Table: Transfer of impact ejecta from past or presently ocean-bearing planetary bodies to Venus, Earth or Mars. (Transfer via Hohmann ellipse)

Ceres: life?

Can Ceres' crust be considered to possibly contain viable spores? The crustal material has been subject to impact gardening and addition of chondritic material. The gradual freezing of the ocean and thickening of the icy crust has probably led to icy volcanism with material from the ocean being deposited on the surface. The spectroscopic detection of phyllosilicates seems to confirm this [4]. Furthermore, the surface temperature of Ceres is in spots as high as 239 K, sufficient for life in brine-filled channels in its dirty ice crust to survive even until today. Such life might employ photosynthesis or compounds such as oxidants created by radiation for energy and possibly hydrogen peroxide as an antifreeze [1].

Although the origin of life per se is a process rife with speculation, Ceres cooled early in the history of the solar system because of its distance from the sun and its smaller size, compared with the terrestrial planets. Thus, life may have evolved early on Ceres.

Furthermore, Ceres (1) is a differentiated body with a rocky core and an icy mantle, possibly still partly liquid, with a depth of more than 100 km; (2) may have or have had hydrothermal vents at its rocky core [5] and thus life may have evolved early; (3) has not been damaged much during the LHB, as it kept its icy mantle; (4) its impact ejecta need only a small Δv to transfer to Earth or Mars, and (5) is relatively accessible to further research.

Other icy bodies

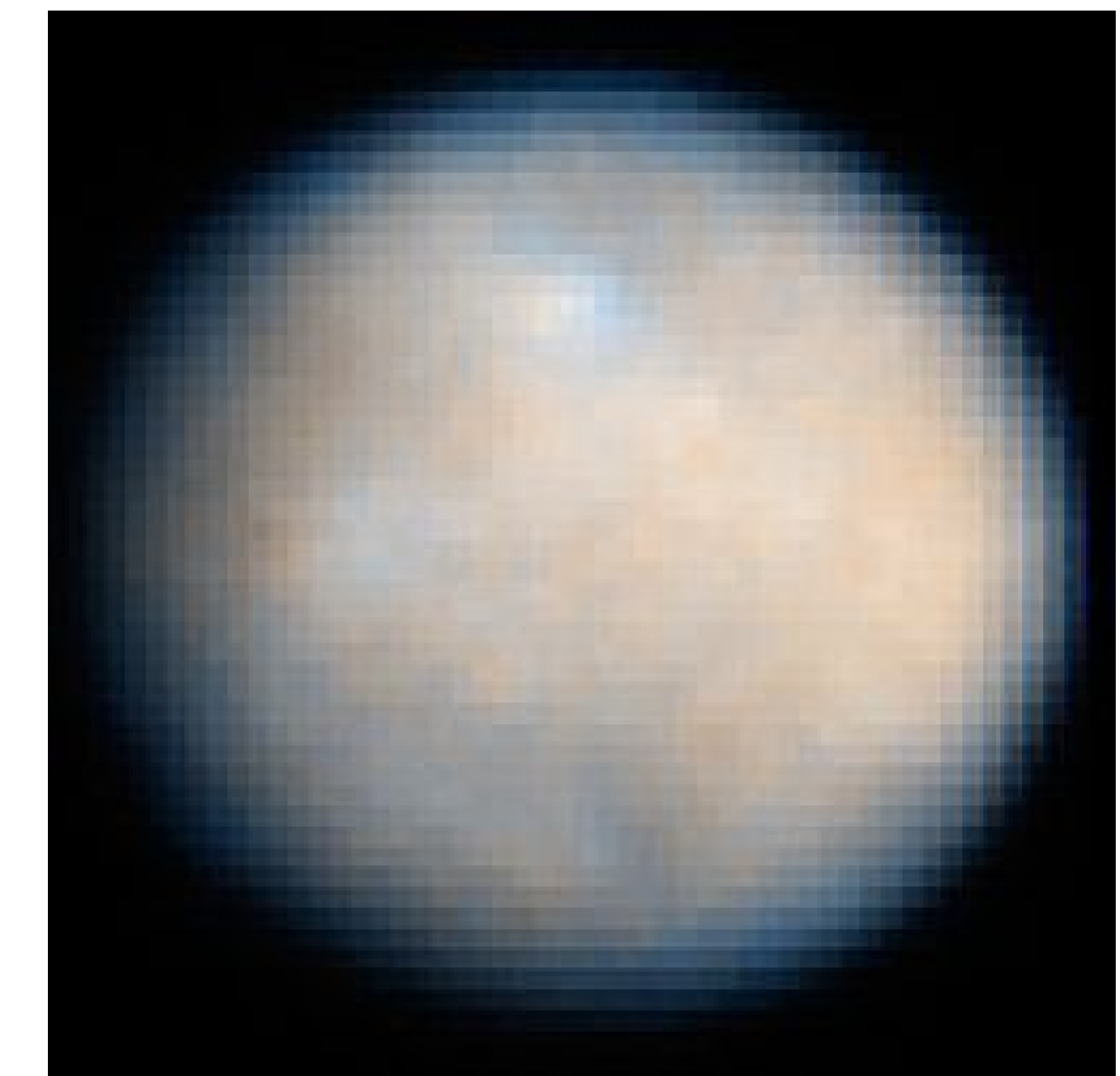
In contrast, other icy bodies are less likely candidates: Vesta is the second most massive asteroid after Ceres and although it appears to be solid rock (density $3.4 \text{ g} \cdot \text{cm}^{-3}$), Vesta may have had an icy mantle before a major impact occurred. The moons of Jupiter and Saturn are situated in the gravitational potential well of their planet and to escape it extra energy is needed, see Table.

Furthermore, the plutoids, and also Triton, deliver ejecta which, coming from the outer reaches of the solar system, involve a relatively high inclination and a high relative speed when reaching Venus, Earth or Mars. Thus, the spores from ejecta have a low probability of reaching the surface of one of the inner planets intact.

"Glaciopanspermia"

Impact ejecta from Ceres, for a substantial part consisting of ice – hence glaciopanspermia – will be subject to evaporation of volatiles, like comets are (see [6], p.373), although the material may well have a more compacted structure than that of a comet. The evaporation process will have the effect of a relatively short lifetime, dependent on the size and structure of the ejecta.

Another side of the same coin is that spores or spore-containing particles may have been loosened by the evaporation of the ice. These may enter the atmospheres of the terrestrial planets as micrometeorites, which may well mean that glaciopanspermia is an effective way of transporting life.



Ceres as seen by Hubble Space Telescope (ASC)

Conclusion

The seeding of the terrestrial planets from Ceres is a hypothesis that can be tested by, first, the detection of life in the crustal layers of Ceres, and secondly, a commonality of Cerean life with Terran and possible Martian and Venusian life. Third, spores of life from the Cerean ocean may be, or have been, ejected by icy volcanism. Fourth, biomarkers of Cerean life might be found in the ices at the Moon's poles and on the surface of other main belt asteroids, as there the arrival of ejecta from Ceres may have taken place at low velocity. The future exploration of the Moon's polar regions may shed more light on this, while the Dawn mission may give indications of the past and present habitability of Ceres. Icy volcanism may still occur on Ceres, as the continuing freezing of the ocean increases the total volume.

Further exploration of Ceres is called for, pending the 2015 Dawn mission results, to search on the surface of Ceres, particularly close to locations of icy volcanism, for organics, the spectrum of organic macromolecules [7] and for biogenic hydrogen peroxide.

References

- [1] Houtkooper, J.M., and Schulze-Makuch, D. (2007) A possible biogenic origin for hydrogen peroxide on Mars: the Viking results reinterpreted. *International Journal of Astrobiology* 6: 147-152.
- [2] Schulze-Makuch, D., Grinspoon, D. H., Abbas, O., Irwin, L. N., and Bullock, M. A. (2004) A Sulfur-Based Survival Strategy for Putative Phototropic Life in the Venusian Atmosphere. *Astrobiology*, 4(1), 11-18.
- [3] Horneck, G., Stöffler, D., Ott, S., Hornemann, U., Cockell, C.S., Moeller, R., Meyer, C., de Vera, J.-P., Fritz, J., Schade, S., and Artemieva, N.A. (2008) Microbial Rock Inhabitants Survive Hypervelocity Impacts on Mars-Like Host Planets: First Phase of Lithopanspermia Experimentally Tested. *Astrobiology* 8: 17-44.
- [4] Castillo-Rogez, J.C., McCord, T.B., and Davies, A.G. (2007). Ceres: Evolution and present state. *Lunar and Planetary Science XXXVIII*: 2006-2007.
- [5] Rivkin, A.S., Volquardsen, E.L., and Clark, B.E. (2006). The surface composition of Ceres: Discovery of carbonates and iron-rich clays. *Icarus* 185: 563-567.
- [6] de Pater, I. and Lissauer, J.J. (2001). *Planetary Sciences*. CUP, Cambridge, UK.
- [7] McKay, C. P. (2004) What is life - and how do we search for it in other worlds? *PLoS Biol.* 2(9): e302. p.1260-1263.