Sources of primordial matter in the asteroid belt

M. Delbo'[1*]

[1]*Université Côte d'Azur, CNRS–Lagrange, Observatoire de la Côte d'Azur, France,*

Abstract
Asteroids are numerous small bodies orbiting the sun with heliocentric distances mainly between that of Mars and Jupiter. They have diverse compositions, ranging from metallic [27], to rocky, to carbonaceous [13], to water- [7, 25] and organic-rich [4]. These last categories include objects that compositionally may form a continuum with comets [10], which also contain important amount of water ice [9, 5, 23], organics [3] and other volatile compounds [20, 17]. The volatile-rich composition indicates that these bodies formed in the cold regions of the protoplanetary disk [19], probably much farther away than one astronomical unit from the Sun. Some of these bodies might also contain matter that formed before our Sun was born, in the interstellar medium

Asteroids and comets have impacted [11] our planet (and many other bodies including the sun [8]) all along the history of our solar system. Therefore, they are carriers of water and other volatile and organic compounds, which are the basic ingredients for life on Earth. In particular, impacts between asteroids within the main belt create families [21] of smaller fragments, which can become Earth-crossers [18] and impact our planet [11]. This process has been going on at least during the last 4 Gyr [6]. This time corresponds to the age of the oldest known family of asteroid fragments [6].

But earlier than that epoch the structure of our solar system was different than the one we know today [28, 29, 1]. Large asteroids were more numerous than they are at present, and Earth was struck very frequently [22]: indeed, our planet formed in one of the most fiery environment of the young solar system. It is during these stages of Earth formation that small bodies brought most of their volatile materials [24].

I will review current information about the physical properties of asteroids and comets that highlight the importance of these bodies as carriers of organics and volatiles materials across the solar system. Spectroscopy, by which we analyse the surface composition, indeed revealed water [25, 26, 2, 13] and organics on asteroids (and of course on comets). Another important piece of information about the composition of minor bodies come from meteorites [16]. Although these objects constitute a very limited sample of asteroid, and to less extend, cometary materials, they reveal the presence of water [12] and complex organic molecules. Further information will be obtained by NASA's OSIRIS-REx [15, 14] and JAXA's Hayabusa2 space missions, which will return to Earth samples of fresh materials from low-albedo and likely organic-rich asteroids.

References

[1] Bottke, W. F., Vokrouhlicky , D., Minton, D., Nesvorny , D., Morbidelli, A., Brasser, R., Simonson, B., and Levison, H. F. (2012). An Archaean heavy bombardment from a destabilized extension of the asteroid belt. Nature, 485, 78–81.
[2] Campins, H., Hargrove, K., Pinilla-Alonso, N., Howell, E. S., Kelley, M. S., Licandro, J., Moth´e-Diniz, T., Fern´andez, Y., and Ziffer, J. (2010). Water ice and organics on the surface of the asteroid 24 Themis. Nature, 464, 1320–1321.
[3] Capaccioni, F., et al. (2015). The organic-rich surface of comet 67P/Churyumov-Gerasimenko as seen by VIRTIS/Rosetta. Science, 347, 628
[4] De Sanctis, M. C., et al. (2017). Localized aliphatic organic material on the surface of Ceres. Science, 355, 719–722.
[5] Delbo, M. (2017). Comets: Exposing the icy interior of 67P. Nature Astronomy, 1, 126.
[6] Delbo, M., Walsh, K., Bolin, B., Avdellidou, C., and Morbidelli, A. (2017). Identification of a primordial asteroid family constrains the original planetesimal population. Science, 357 1026–1029.
[7] DeMeo, F. E., Alexander, C. M. O., Walsh, K. J., Chapman, C. R., and Binzel, R. P. (2015). The Compositional Structure of the Asteroid Belt. in Asteroids IV (P. Michel, et al. eds.) University of Arizona Press, Tucson., pages 13–41.
[8] Farinella, P., Froeschlè, C., Froeschlè, C., Gonczi, R., Hahn, G., Morbidelli, A., and Valsecchi, G. B. (1994). Asteroids falling into the Sun. Nature, 371(6):314–317.
[9] Fornasier, S., et al. (2016). Rosetta's comet 67P/Churyumov-Gerasimenko sheds its dusty mantle to reveal its icy nature. Science, 354,1566–1570.
[10] Gounelle, M. (2011). The asteroid–comet continuum: In search of lost primitivity. *Elements*.
[11] Harris, A. W., Boslough, M., Chapman, C. R., Drube, L., and Michel, P. (2015). Asteroid Impacts and Modern Civilization: Can We Prevent a Catastrophe? in Asteroids IV (P. Michel, et al. eds.) University of Arizona Press, Tucson., pages 835–854.
[12] Krot, A. N., et al. (2015). Sources of Water and Aqueous Activity on the Chondrite Parent Asteroids. in

Asteroids IV (P. Michel, et al. eds.) University of Arizona Press, Tucson., pages 635–660.
[13] Küppers, M. (2017). Dwarf planet Ceres and the ingredients of life. Science, 355: 692–693.
[14] Lauretta, et al. (2014). The OSIRIS-REx target asteroid (101955) Bennu: Constraints on its physical, geological, and dynamical nature from astronomical observations. Met. & Pl. Science, 113.
[15] Lauretta, D. S., et al. (2012). The OSIRIS-REx Mission : Sample Acquisition Strategy and Evidence for the Nature of Regolith on Asteroid (101955) 1999 RQ36. Asteroids, Comets, Meteors. Proceedings IAU Symp. N. 229, 2005 D. Lazzaro, S. Ferraz-Mello & J.A. Fernandez, eds, 1667 6291.
[16] Libourel, G., Michel, P., Delbo, M., Ganino, C., Recio-Blanco, A., de Laverny, P., Zolensky, M. E., and Krot, A. N. (2017). Search for primitive matter in the Solar System. Icarus, 282:375–379.
[17] Marty, B., et al. (2017). Xenon isotopes in 67P/Churyumov-Gerasimenko show that comets contributed to Earth's atmosphere. Science, 356(6):1069–1072.
[18] Morbidelli, A. and Vokrouhlicky D. (2003). The Yarkovsky-driven origin of near-Earth asteroids. Icarus, 163, 120–134.
[19] Morbidelli, A., Walsh, K. J., O'Brien, D. P., Minton, D. A., and Bottke, W. F. (2015). The Dynamical Evolution of the Asteroid Belt. in Asteroids IV (P. Michel, et al. eds.) University of Arizona Press, Tucson..493–507.
[20] Mumma, M. J. and Charnley, S. B. (2011). The Chemical Composition of Comets—Emerging Taxonomies and Natal Heritage. Annual Review of Astronomy and Astrophysics, 49:471–524.
[21] Nesvorny D., Broz, M., and Carruba, V. (2015). Identification and Dy- namical Properties of Asteroid Families. in Asteroids IV (P. Michel, et al. eds) Univ. of Arizona Press, Tucson., 297–321.
[22] Nesvorny D., Roig, F., and Bottke, W. F. (2017). Modeling the Historical Flux of Planetary Impactors. The Astronomical Journal, 153, 103.
[23] Pajola, M., et al. (2017). The pristine interior of comet 67P revealed by the combined Aswan outburst and cliff collapse. Nature Astronomy, 1, 92.
[24] Raymond, S. N. and Izidoro, A. (2017). Origin of water in the inner Solar System: Planetesimals scattered inward during Jupiter and Saturn's rapid gas accretion. Icarus, 297, 134–148.
[25] Rivkin, A. S., Campins, H., Emery, J. P., Howell, E. S., Licandro, J., Takir, D., and Vilas, F. (2015). Astronomical Observations of Volatiles on Asteroids. in Asteroids IV (P. Michel, et al. eds.) Univ. of Arizona Press, Tucson., 65–87.
[26] Rivkin, A. S. and Emery, J. P. (2010). Detection of ice and organics on an asteroidal surface. Nature, 464, 1322–1323.
[27] Shepard, M. K., Clark, B. E., Ockert-Bell, M., Nolan, M. C., Howell, E. S., Magri, C., Giorgini, J. D., Benner, L. A. M., Ostro, S. J., Harris, A. W., Warner, B. D., Stephens, R. D., and Mueller, M. (2010). A radar survey of M- and X-class asteroids II. Summary and synthesis. Icarus, 208, 221–237.
[28] Tsiganis, K., Gomes, R., Morbidelli, A., and Levison, H. F. (2005). Origin of the orbital architecture of the giant planets of the Solar System. Nature, 435, 459–461.
[29] Walsh, K. J., Morbidelli, A., Raymond, S. N., O'Brien, D. P., and Mandell, A. M. (2011). A low mass for Mars from Jupiter's early gas-driven migration. Nature, 475, 206–209.

Short Summary

There will be a review of the current information about the physical properties of asteroids and comets that highlight the importance of these bodies as carriers of organics and volatiles materials across the solar system.