Tracing Water from Interstellar Clouds to Ocean Worlds

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Program: R&TD

Project Objective:

The overarching objective is to open up a new area of research at JPL – studying the connection between chemical processes in the interstellar medium (ISM) and critical aspects of habitable planet formation. A particularly important aspect is tracing the "water trail" from interstellar clouds, to dense cores, protostellar disks, and primitive Solar System bodies, such as comets.
A broad and unified approach will lead to important insights in understanding how water was delivered to the primitive Earth. The rapidly growing field of exoplanet atmospheric studies makes this connection important for other planetary systems.

FY18/19 Results:

D/H ratios in cometary water varies between 1 and 3 times the Earth's ocean value (Fig. 1). Today, SOFIA offers the most sensitive platform to study water through observations of the low-energy rotational lines of optically thin water isotopologues in the FIR. The recent finding that hyperactive comets have a terrestrial D/H ratio in water (Fig. 2) has renewed interest in comets as a possible source of Earth's water. Hyperactive comets require a secondary source of water vapor in the coma, explained by the presence of subliming icy grains expelled from the nucleus. The reason why hyperactive comets have low D/H ratios is not clear. However, one possible interpretation is that isotopic properties of water outgassed directly from the nucleus and icy grains may be different, due to fractionation effects at sublimation. In this case, many comets may share the same Earth-like D/H ratio in water, with profound implication for the early Solar System and the origin of the Earth's oceans.
A study of a future space mission, named *Source*, in preparation for the 2021 MIDEX call, is currently under way. A kick-off science workshop took place in August, 2019, ahead of the "*Water in the Universe*" meeting organized by the Astrochemistry Subdivision of the American Chemical Society in San Diego. *Source* will allow accurate measurements of the D/H ratio, as well as O isotopic ratios, in ~45 comets over its 3-year mission lifetime.

Benefits to NASA and JPL (or significance of results):

Water is a central theme of NASA's vision. "*Building new worlds*", specifically "*What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets*" is one of the broad crosscutting science themes by the Planetary Science Decadal Survey *Vision and Voyages*. Understanding "*How the conditions for habitability develop during the process of planet formation*" is one of the three overarching themes identified by the Origins Space Telescope study team in preparation of the ongoing 2020 Astrophysics Decadal Survey. This project directly addresses these science themes as well as the JPL quests "*Understand how our Solar System formed and how it is evolving*", and because liquid water is a requirement for life, "*Understand how life emerged on Earth and possibly elsewhere in the Solar System*." In will enable cutting-edge observing proposals for existing NASA facilities (SOFIA) and support future observing (JWST), as well as future mission proposals.
Vision and Voyages explicitly identified "*determining the deuterium/hydrogen and other crucial isotopic ratios in multiple com*ets" as key measurements for understanding Solar System beginnings. Such measurements can be carried out in a handful of individual objects with sample return or through in-situ exploration. However, only remote sensing allows studies of a statistically significant sample of comets. A wide range of possible missions, on different time scales, is currently under discussion, from a smallsat to a nearby comet, to a Discovery or Explorer class remote sensing space telescope that would provide a statistically significant set of cometary isotopic ratio measurements.

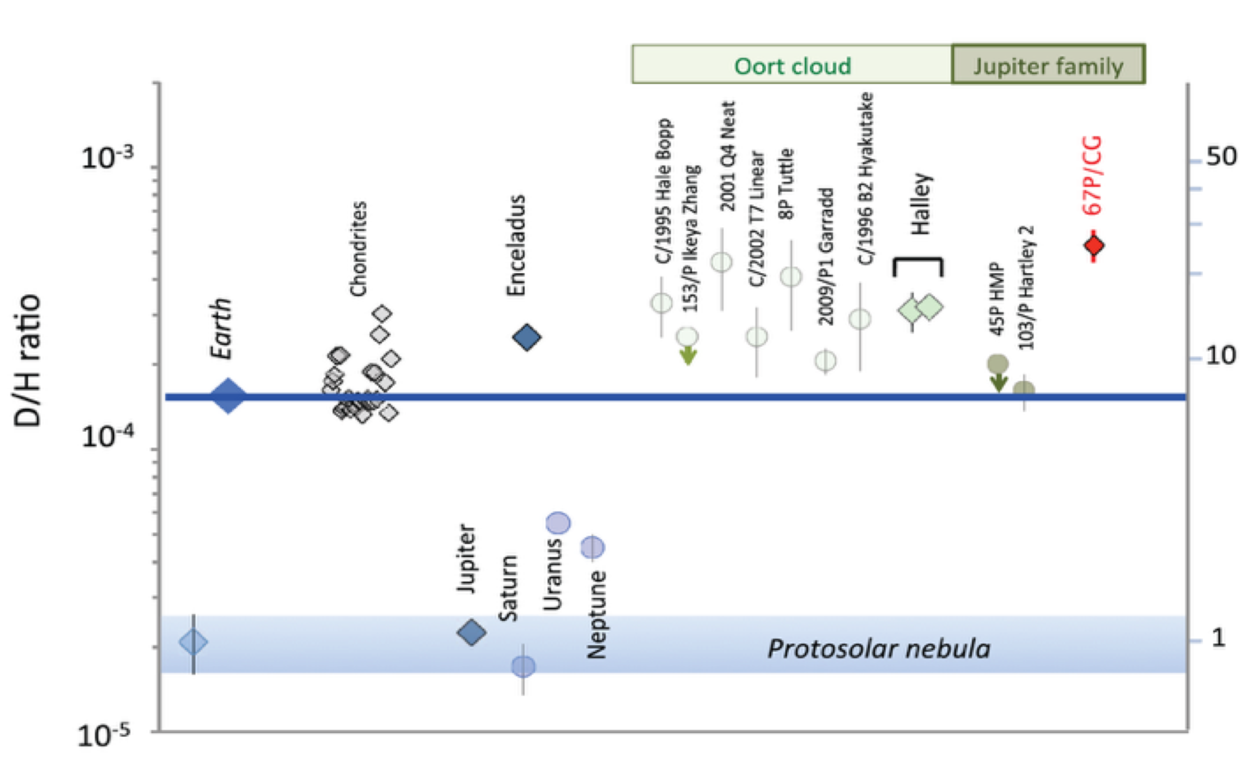
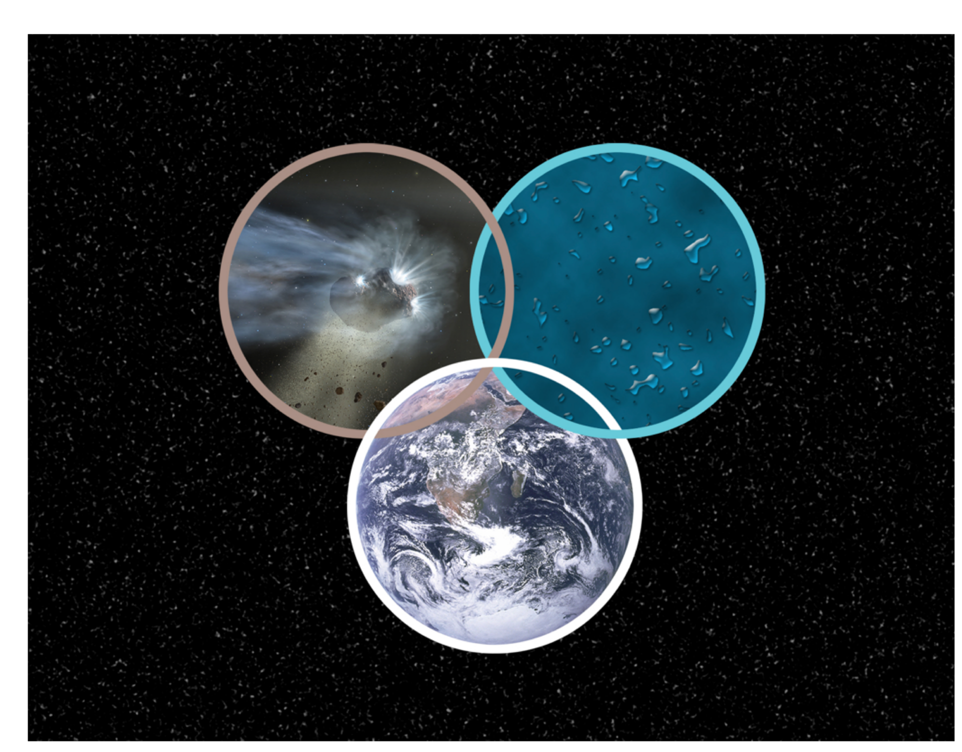


Fig. 1 – D/H ratio in the Solar System. The protosolar nebula value in H_2 is 2.1×10^{-5}, close to the Big Bang value of 2.5×10^{-5}. The Earth's ocean value in water, VSMOW, is 1.5576×10^{-4}. Cometary D/H values in water show a scatted between 1 and 3 times VSMOW. (From the *Origins Space Telescope* Mission Concept Study Report.)



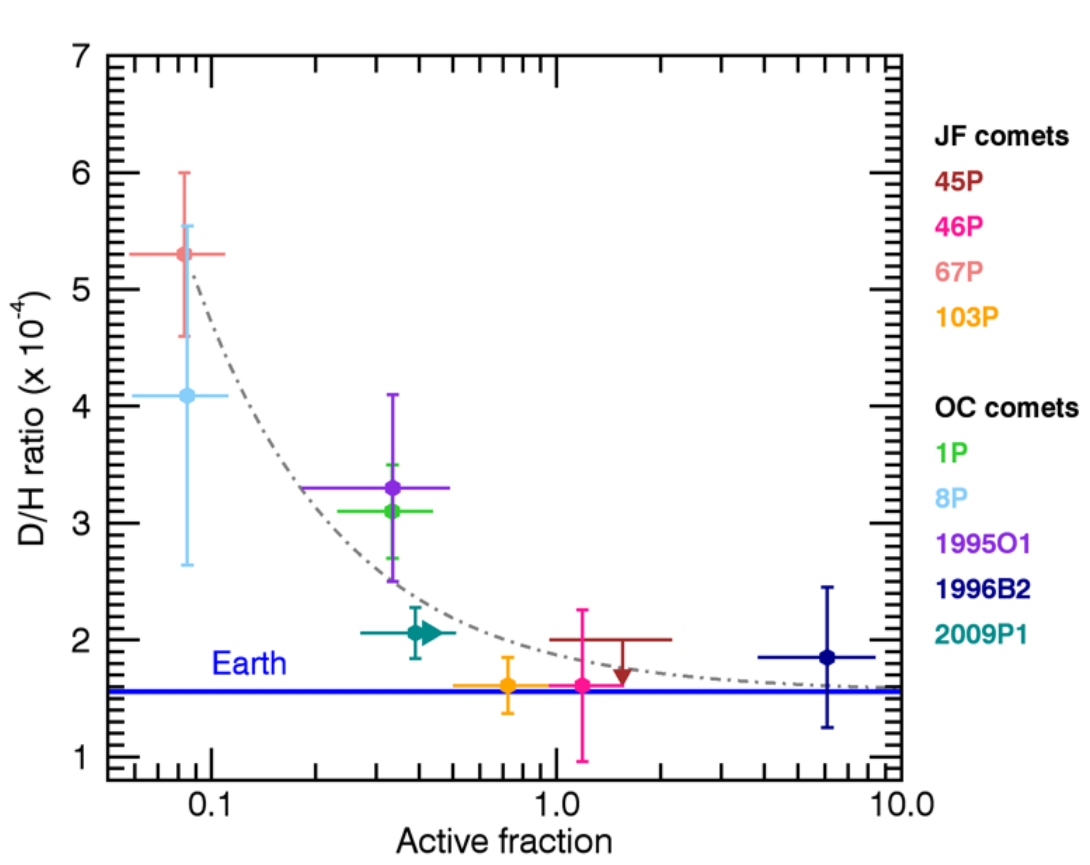


Fig. 2 – D/H ratio in cometary water as a function of the cometary active fraction. Hyperactive comets with active fractions above ~0.5 have D/H ratios in water consistent with VSMOW. (From Lis et al. 2019.)

Publications:

Terrestrial deuterium-to-hydrogen ratio in hyperactive comets. Lis, D.C., et al., A&A, 625, L5 (2019).
The water line emission and ortho-para ratio in the Orion Bar photon-dominated region. Putaud, T., et al., A&A in press, arXiv:1908.0268 (2019).
D/H ratio in water and the origin of Earth's oceans. Lis, D.C., et al., BAAS, 51, 3, 111 (2019).
The trail of water and the delivery of volatiles to habitable planets. Pontoppidan, K., et al., BAAS, 51, 3, 229 (2019).
ALMA autocorrelation spectroscopy of comets: The HCN/H13CN ratio in C/2012 S1 (ISON). Cordiner, M.A., et al., ApJ, 870, L26 (2019).

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