National Aeronautics and Space Administration

Tracing Water from Interstellar Clouds to Ocean Worlds

Principal Investigator: Dariusz Lis (326)

Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Tracing Water from Interstellar Clouds to Ocean Worlds
Strategic Initiative Leader: Paul F Goldsmith

Objectives: The overarching scientific objective of this task is to study the origin of the Earth's water in the context of inheritance from the protoplanetary disk, from which the Solar System formed, and to understand the origin of water in that disk (Figure 1). If the process operates universally, habitable planets like the Earth may be common in the Universe.

Background: Measurements of the isotopic composition of cometary water provide important constraints on the origin of Earth's oceans. Isotopic composition (D/H) of the inner Solar System (Asteroid belt) is well determined from measurements in meteorites. Comets are best tracers of the present day outer Solar System, because they have atmospheres that can be studied using remote sensing techniques. However, only 4 *accurate* space measurements of the D/H ratio in comets have been obtained over the past 35 years. A statistical study comparing the isotopic composition the Oort cloud and Kuiper belt with that of the Asteroid belt is needed to test Solar System formation models combining chemistry and dynamics caused by giant planet migration. The discovery that hyperactive comets have terrestrial D/H ratios has further renewed interest in such measurements. These comets require a secondary source of water in their coma, explained by the presence of icy grains, suggested to be pristine tracers of the bulk isotopic composition of the nucleus. Future JPL-led missions, such as the Astrophysics Probe PRIMA, or the SIMPLEx concept WISPER, will study variations in the isotopic composition within the coma of a hyperactive comet. Observing programs to utilize JWST to gain insight into the different stages of the water trail are equally important (Figure 2).

Approach and Results: Cometary lines are heavily spectrally diluted at the expected spectral resolution of the PRIMA direct detection spectrometer, R=5000(λ/112 μm). Past experience with similar space-based instruments suggests that weak lines with a line-to-continuum (L/C) ratio of ~1% should be detectable, while weaker lines may not be. Herschel/PACS observations of the dust continuum emission in comets together with models of the HDO line emission suggest a L/C ratio of 3 – 4 % and 1 – 2 %, respectively, for the bright HDO lines around 120 and 180 μm, at the PRIMA spectral resolution. The L/C ratio thus not appear to be a confounding factor for D/H measurements with PRIMA.
Furthermore, simulations of the FIR spectra of known cometary species show that line confusion is also not a confounding factor, except for the longest wavelength, 234 μm HDO line, with in nearby comets may be blended with methanol emission. Additional simulations including the actual wavelength response of the PRIMA medium-resolution spectrometer are in progress.
The fact that hyperactive comets typically have terrestrial D/H ratios may imply that water outgassing directly from the nucleus is affected by chemical fractionation processes. Sublimating icy grains in the coma may be more pristine and representative of the isotopic composition of the nucleus. Ground-based observations of comet Wirtanen with SOFIA and ALMA provide some evidence for variations in the D/H ratio with the field of view. However, measurement uncertainties are large and the results are inconclusive. WISPER, with a 100 km FoV at 30,000 km from the nucleus, will be able to measure the D/H ratio *as a function of distance from the nucleus* in a hyperactive comet and determine uniquely whether water outgassed from the nucleus and the icy grains has the same isotopic composition.

Significance/Benefits to JPL and NASA: New observational capabilities for advancing our understanding of various aspects of the water trail are, or will soon be available. JWST spectra provide information about the water content and composition of interstellar ices (Figure 2). Future JPL-lead missions, such as PRIMA or WISPER, will offer unparalleled opportunities to study the isotopic composition of comets. This Strategic Initiative puts JPL in a forefront position to lead new missions, develop new instruments, and to exploit a range of existing and upcoming facilities.

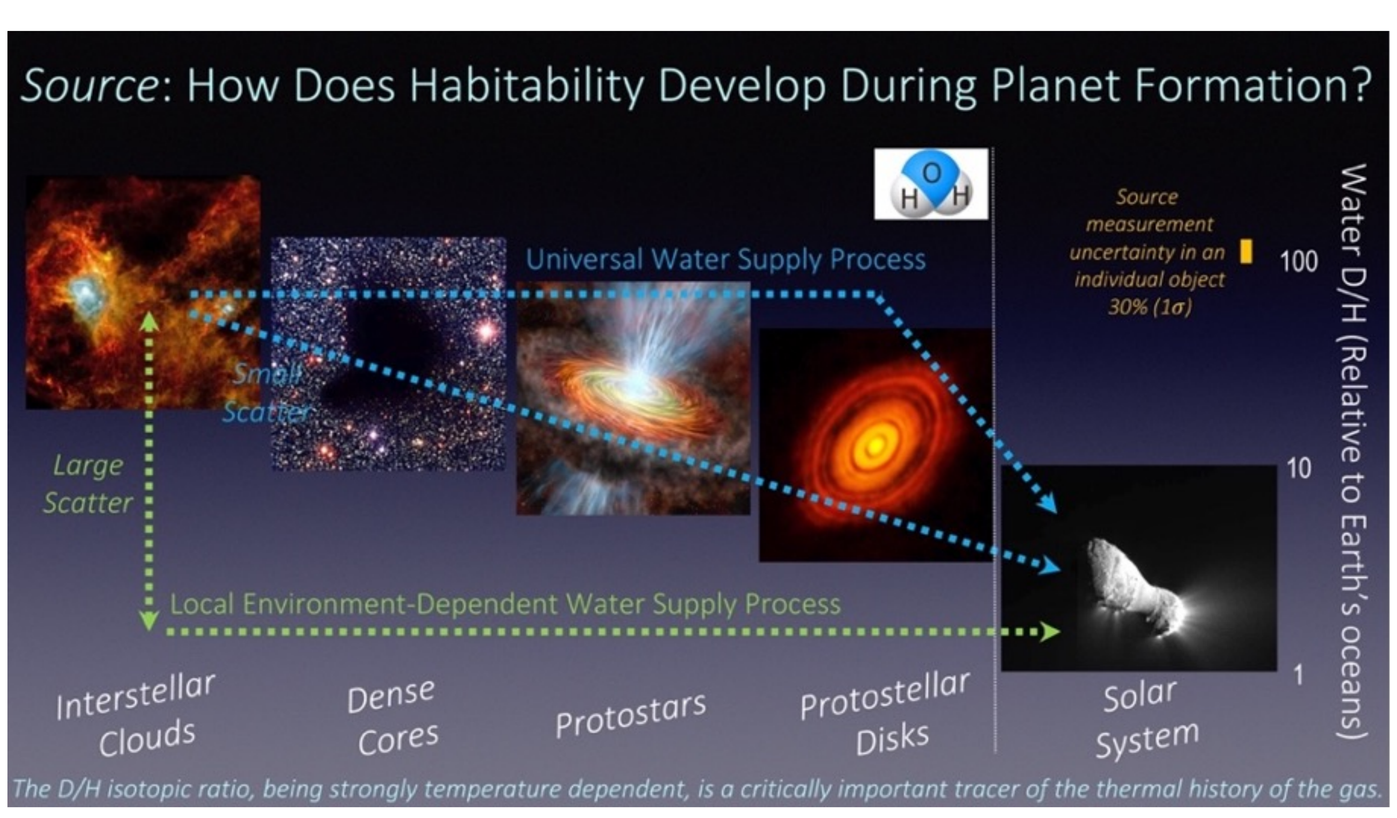

Figure 1. Schematic of the phases of the water trail. We must understand the steps indicated here to determine how water from interstellar clouds is delivered to habitable planets such as the Earth.

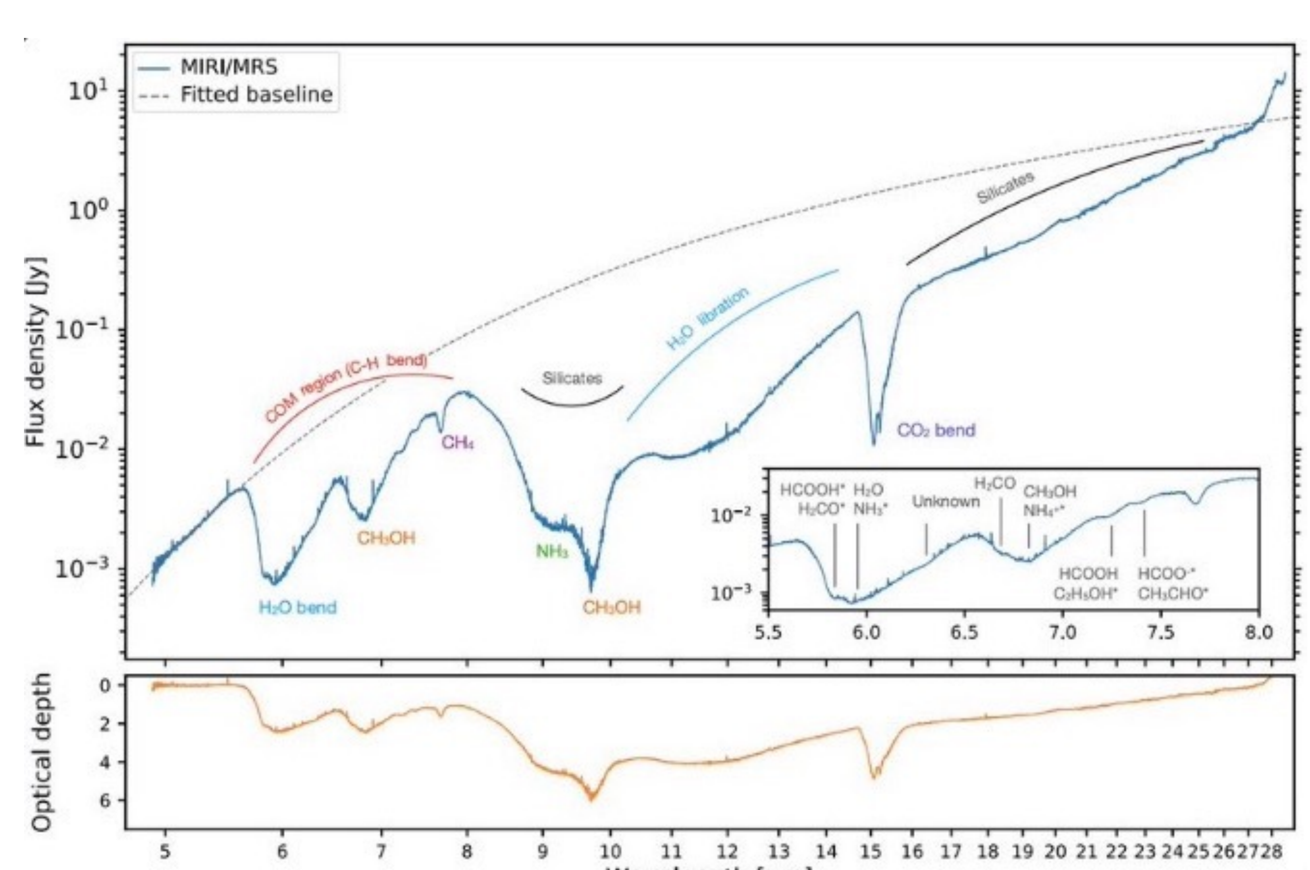

Figure 2. JWST MIRI MRS spectrum of ice features toward a very young protostar (K. Pontoppidan via Twitter)

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#22-4881
Poster Number: RPC#R18011

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Publications (FY'22):

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PI/Task Mgr. Contact Information:

Email: Dariusz.C.Lis@jpl.nasa.gov