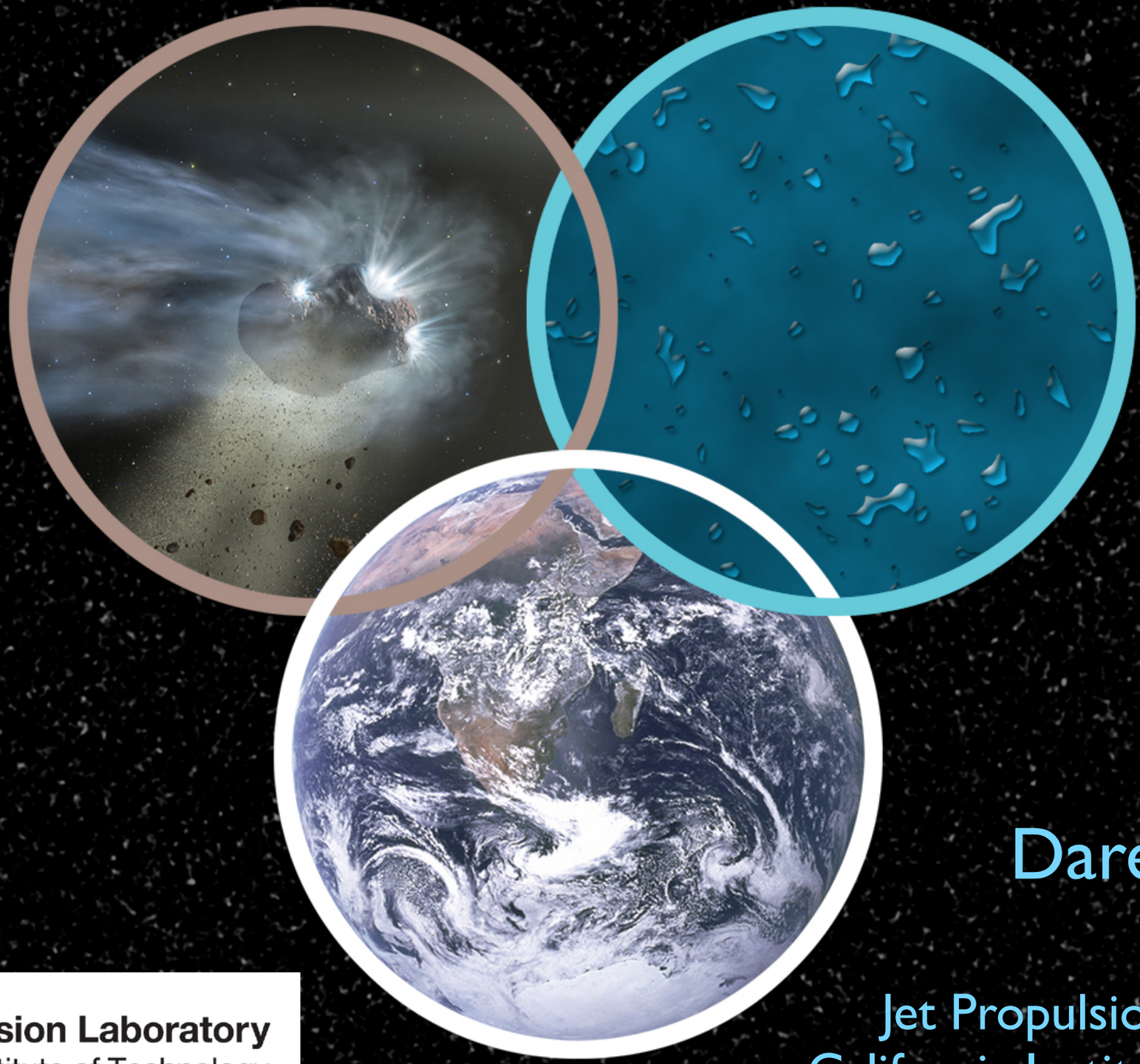
Isotopic Ratios in Cometary Water



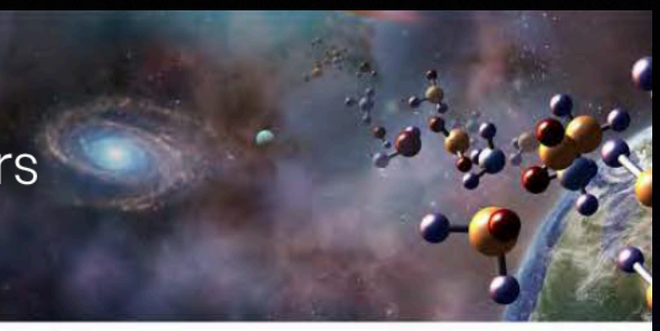
Darek Lis

Jet Propulsion Laboratory
California Institute of Technology

ESA 2050 Workshop, June 14, 2019

Jet Propulsion Laboratory
California Institute of Technology

ORIGINS Space Telescope | From first stars to life



SCIENCE DRIVERS FOR MISSION DESIGN

HOW DOES THE UNIVERSE WORK?

How do galaxies form stars, make metals, and grow their central supermassive black holes from reionization to today?

Using sensitive spectroscopic capabilities of a cold telescope in the infrared, Origins will measure properties of star-formation and growing black holes in galaxies across all epochs in the Universe.

HOW DID WE GET HERE?

How do the conditions for habitability develop during the process of planet formation?

With sensitive and high-resolution far-IR spectroscopy Origins will illuminate the path of water and its abundance to determine the availability of water for habitable planets.

ARE WE ALONE?

Do planets orbiting M-dwarf stars support life?

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NASA/Origins

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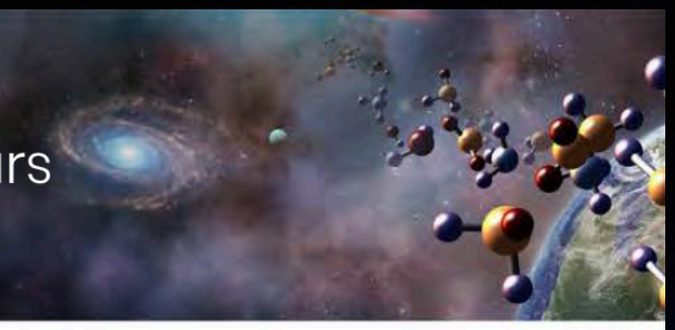

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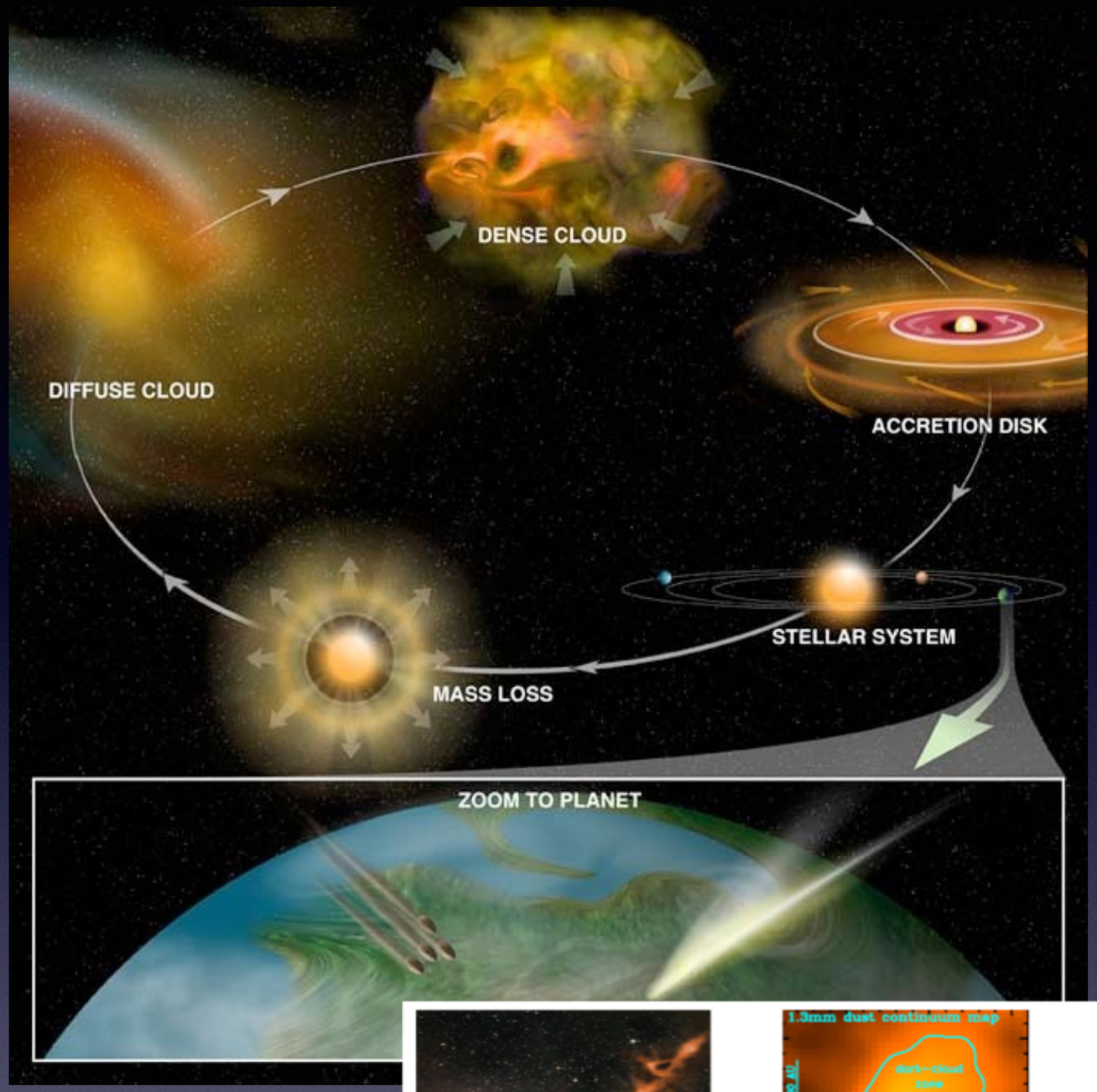
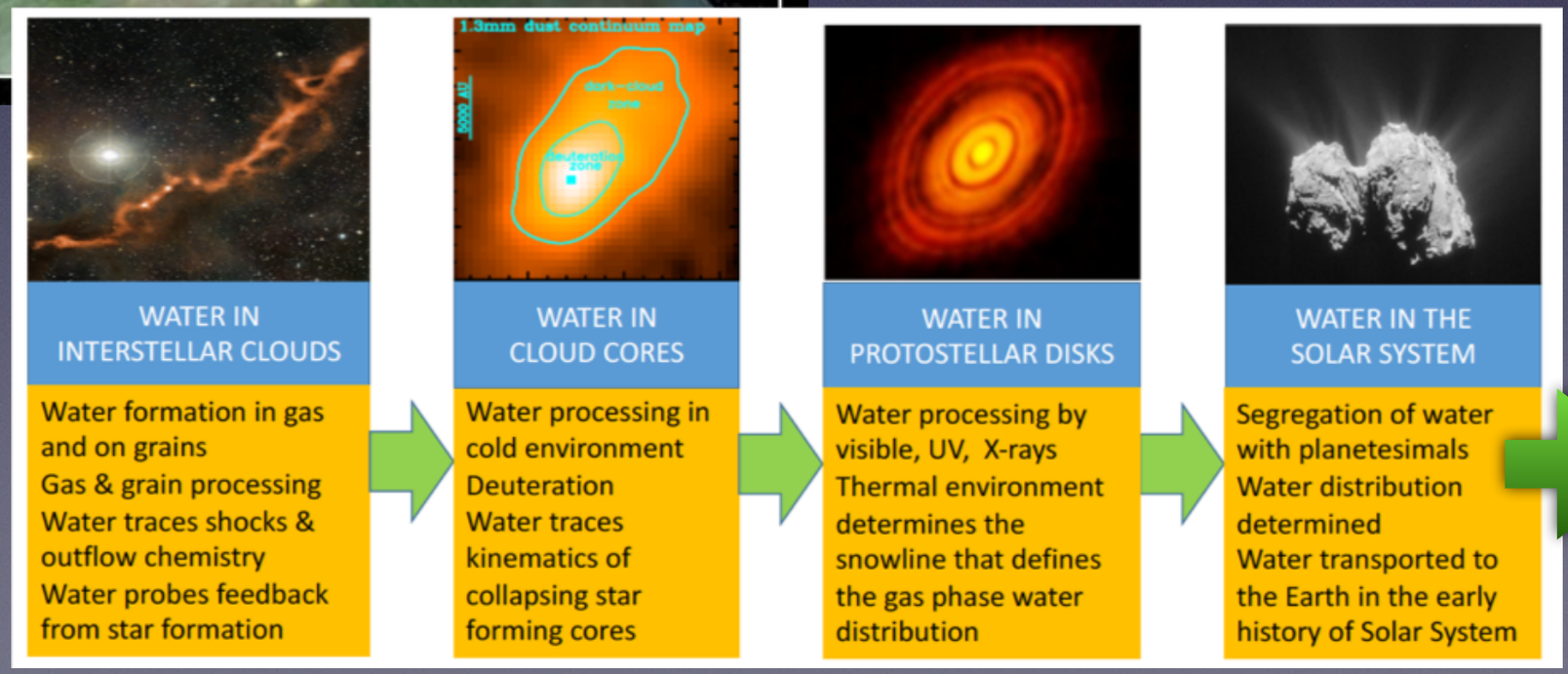
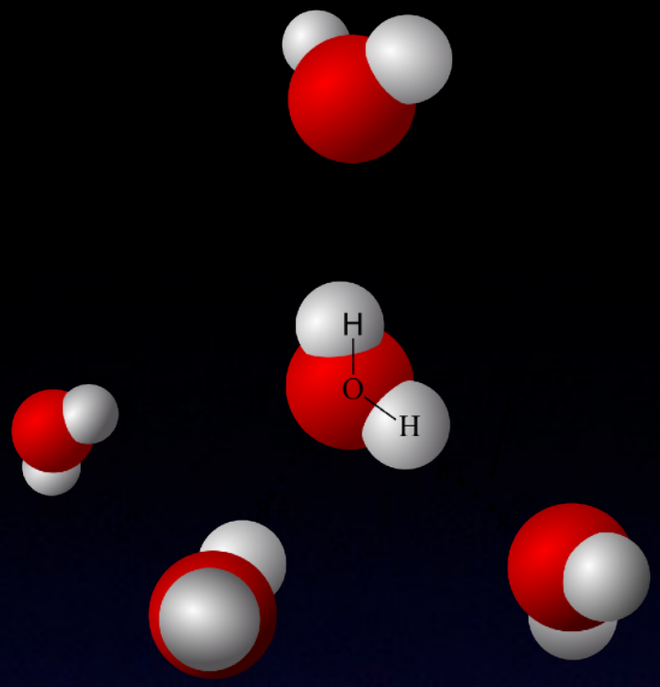
Cosmic Inheritance of Water



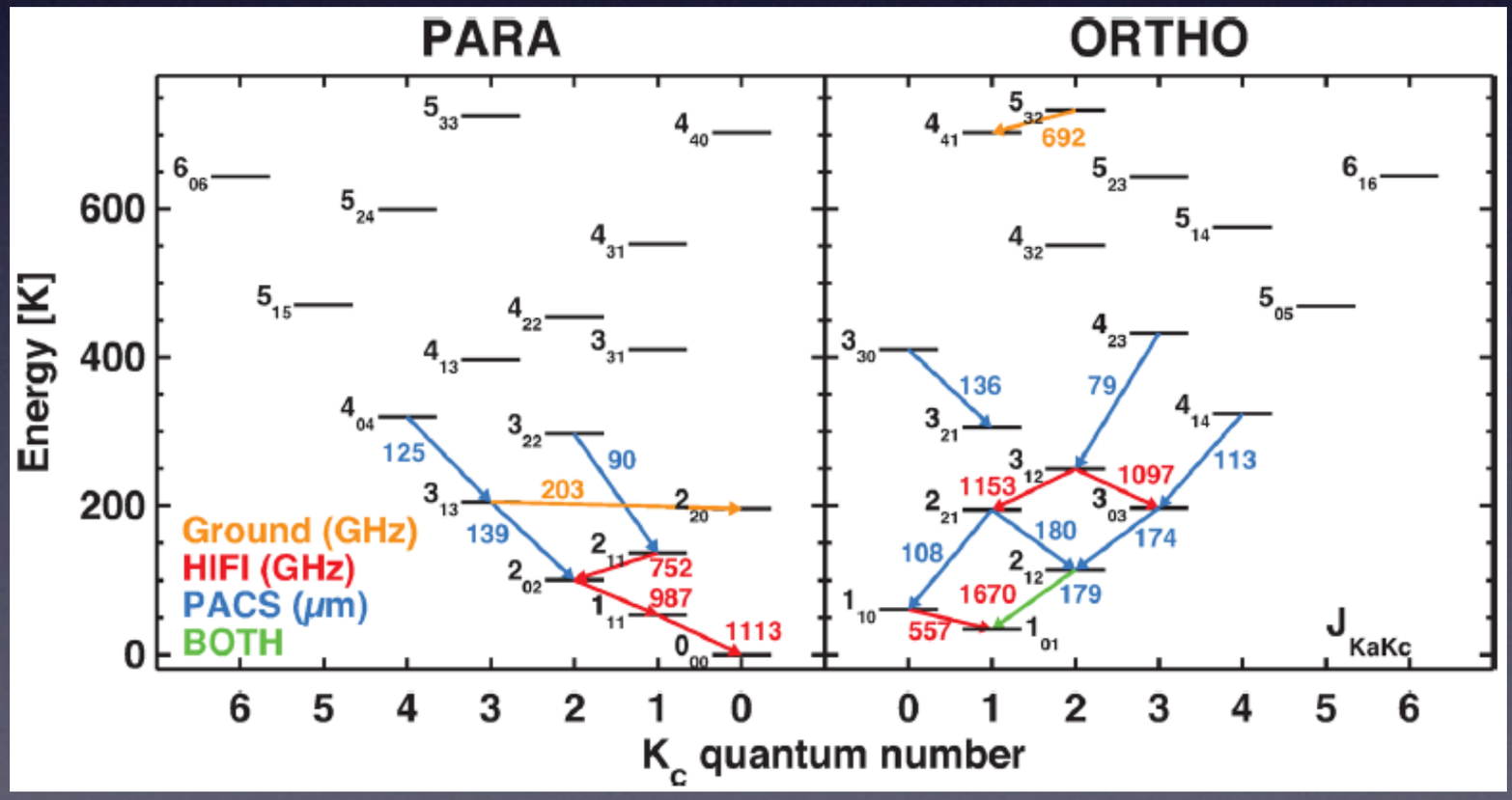


Images: NRAO/NASA

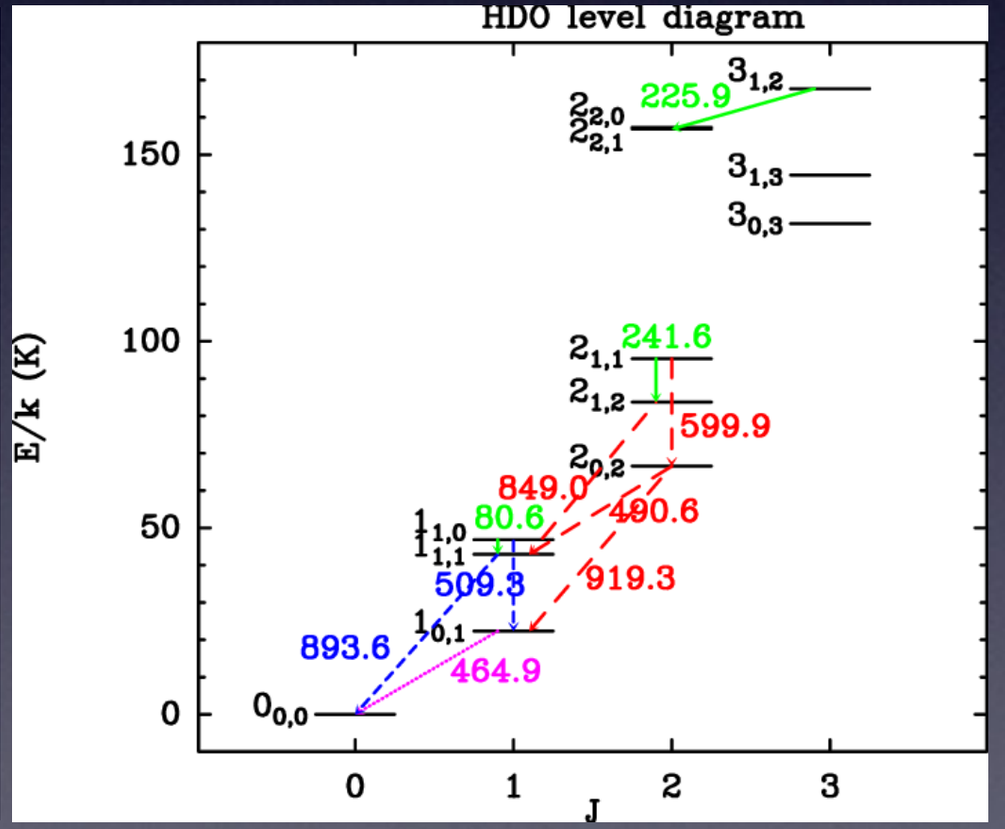


Observations of Cold Water

- Atmosphere opaque at the frequencies of the low-energy water lines
- Even SOFIA cannot observe cold water, but it can observe water-18 and HDO

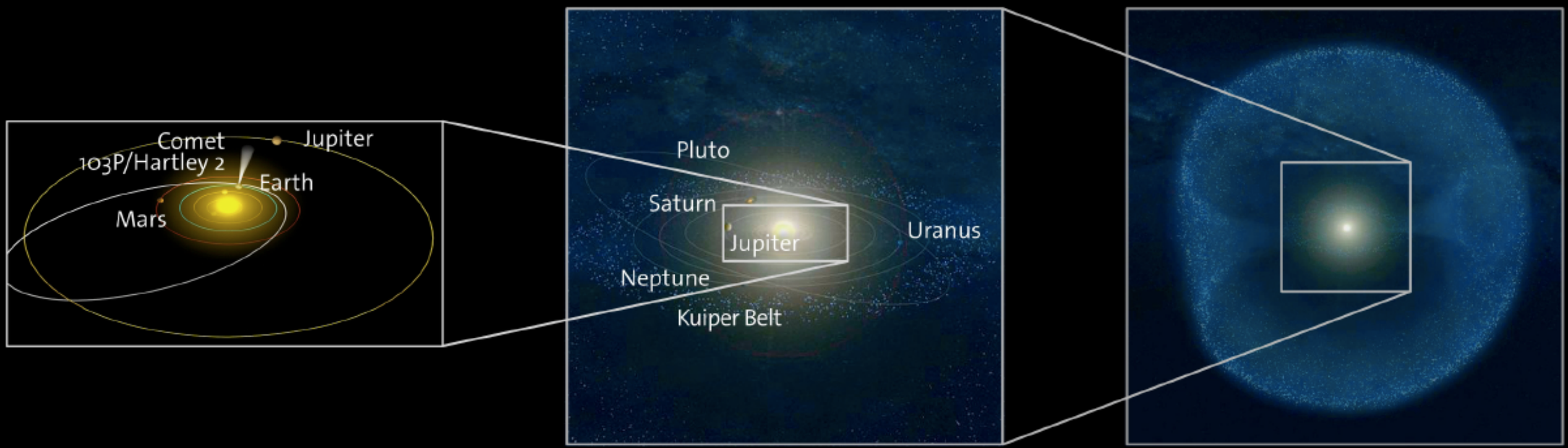


van Dishoeck et al. 2013



Coutens et al. 2014

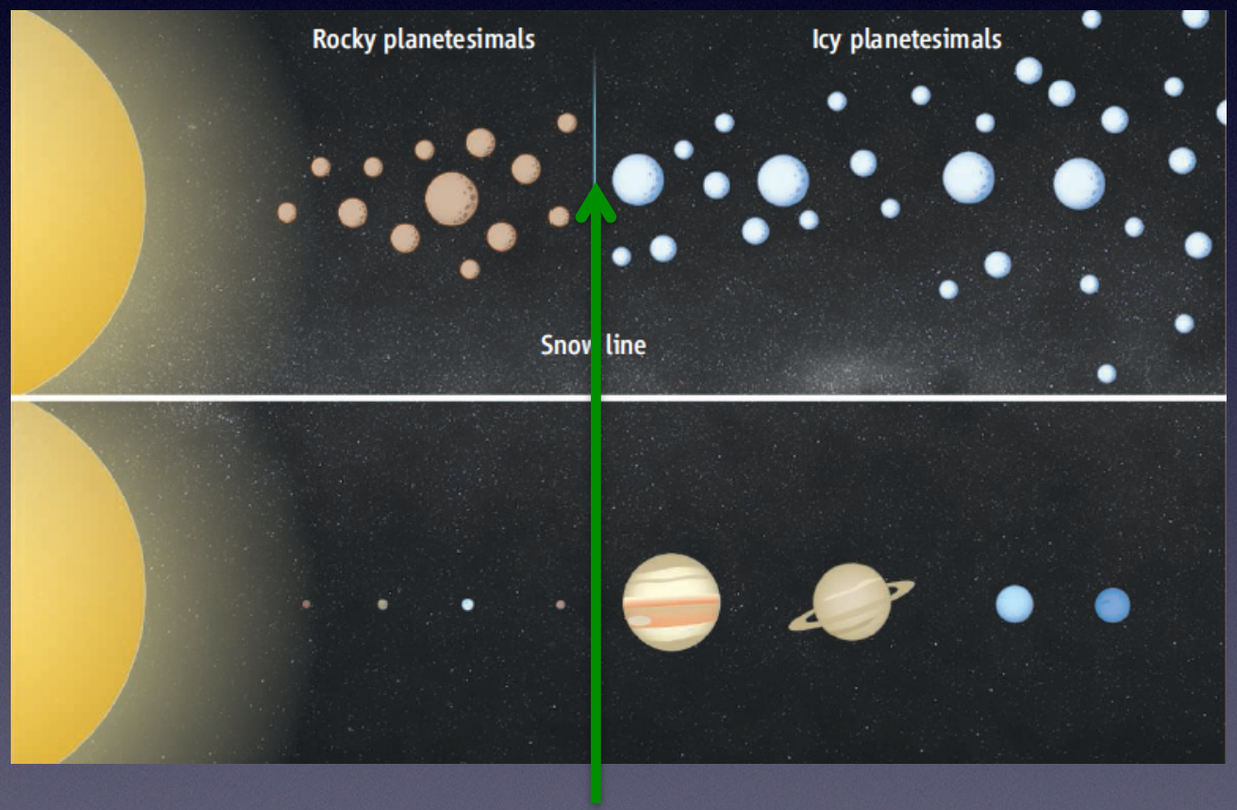
Comets



- Comets are among the most primitive bodies formed before planets and asteroids
- *Jupiter Family comets* originate in the Kuiper Belt, or associated scattered disc, beyond the orbit of Neptune

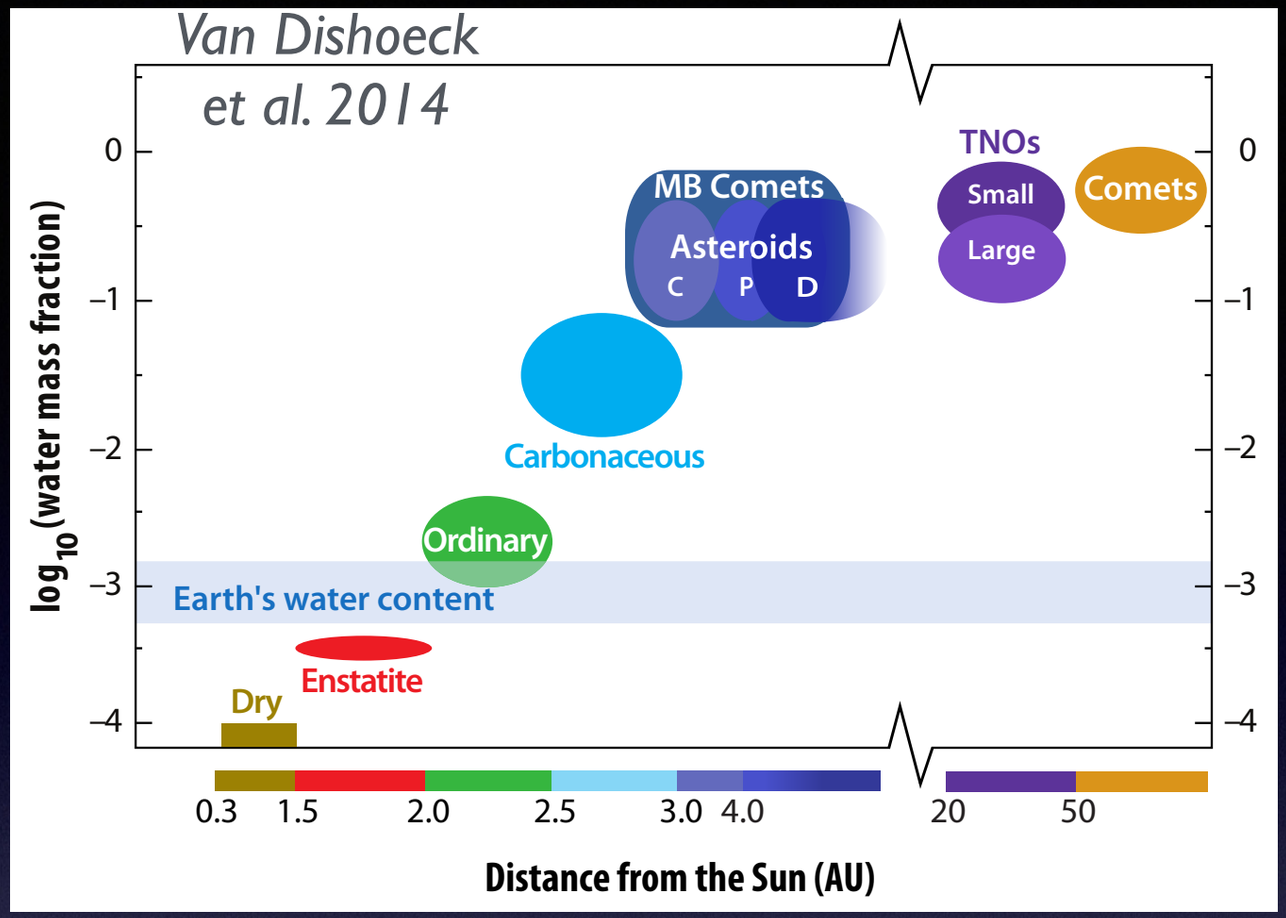
- *Long-period comets* come from the Oort cloud, but formed in the Jupiter-Neptune region
- Sent toward the Sun by gravitational perturbations from the outer planets or nearby stars, or due to collisions

Once upon a time the Earth accreted dry



Snow Line

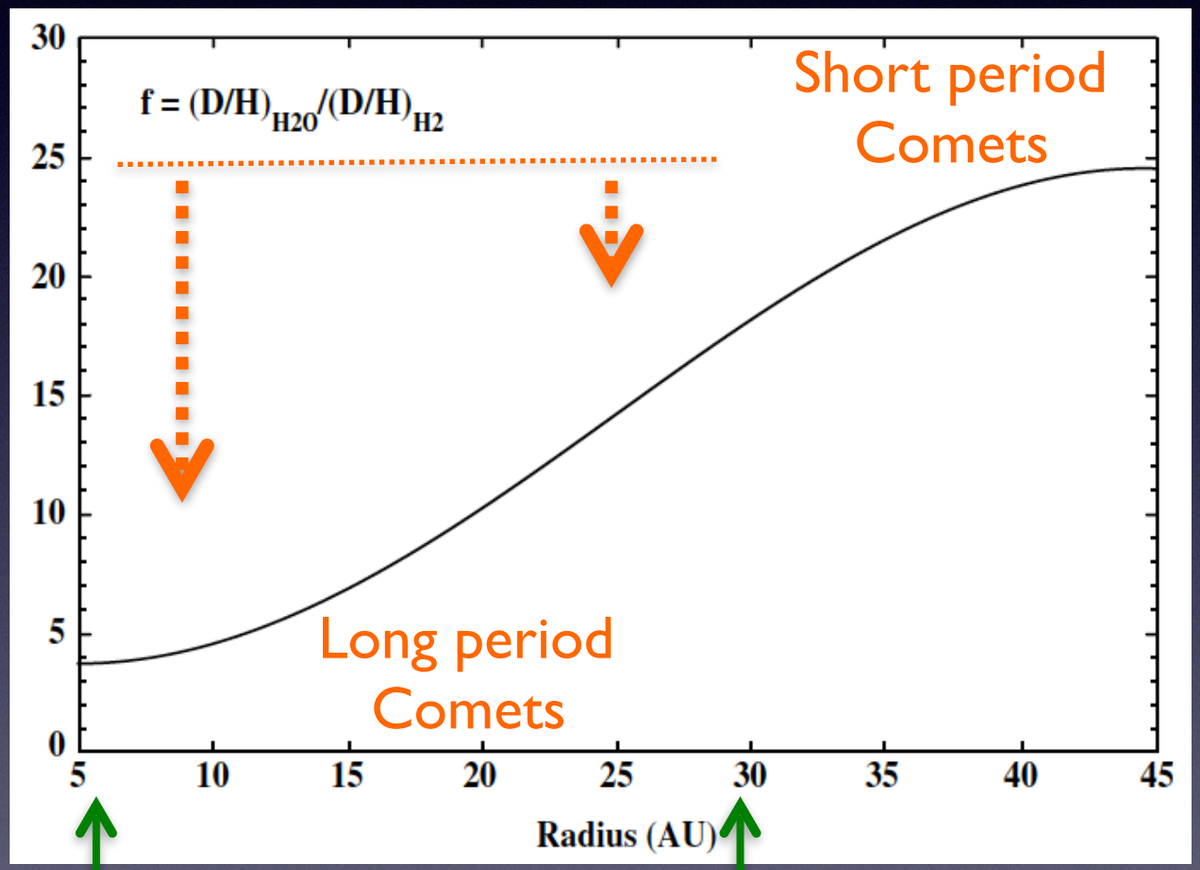
Akeson 2011



- "Building blocks" of terrestrial planets:
  - Temperature at 1 AU was too high for water ice to exist in the accretion disk
  - Earth accreted dry
  - Water, and organics, were most likely delivered by external sources, similar to today's comets or asteroids
- D/H ratio: forensic "isotopic fingerprinting"

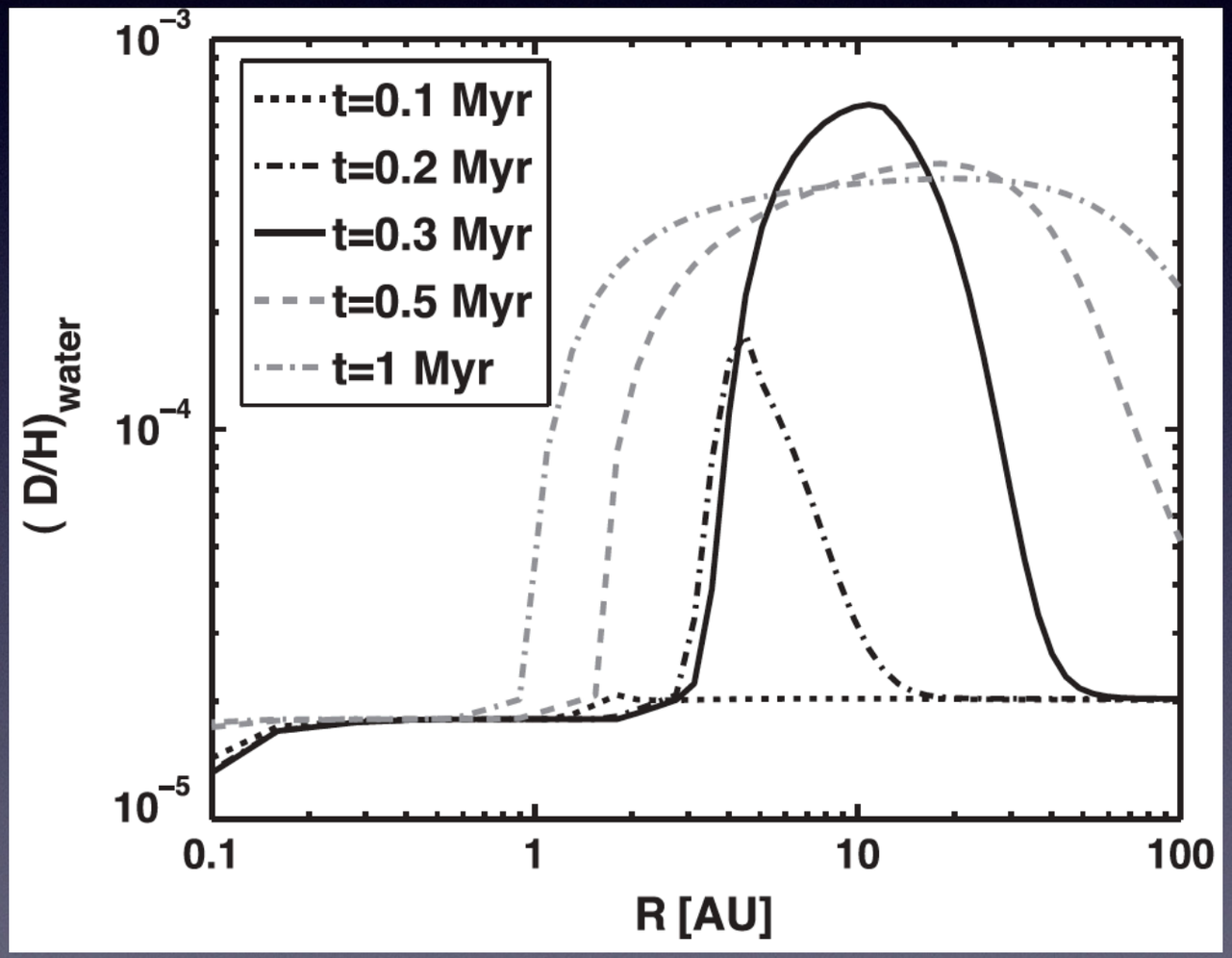
"Textbook" D/H in Water in the Solar Nebula

- Variations in the D/H ratio: progressive isotopic exchange reactions between HDO and H_2
- Water was initially synthesized by interstellar chemistry with a high D/H ratio (>7.2×10^{-4}; highest value measured in clay minerals)
- The D/H ratio in the solar nebula then gradually decreased with time
- Turbulent mixing of grains condensed at different epochs and locations in the solar nebula ➟ D/H gradient



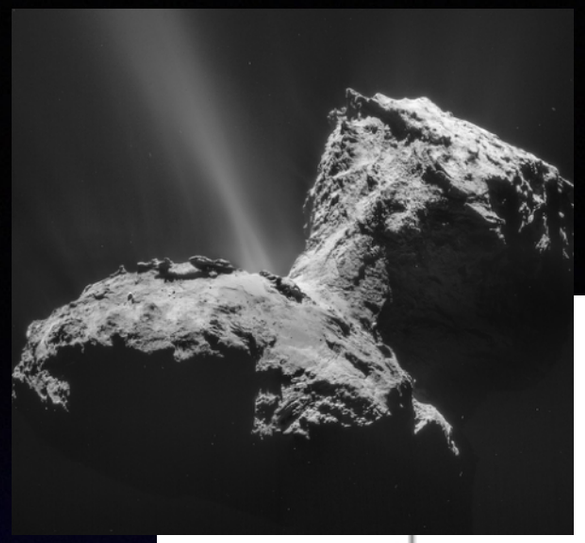
Horner et al. 2007

Other D/H Models

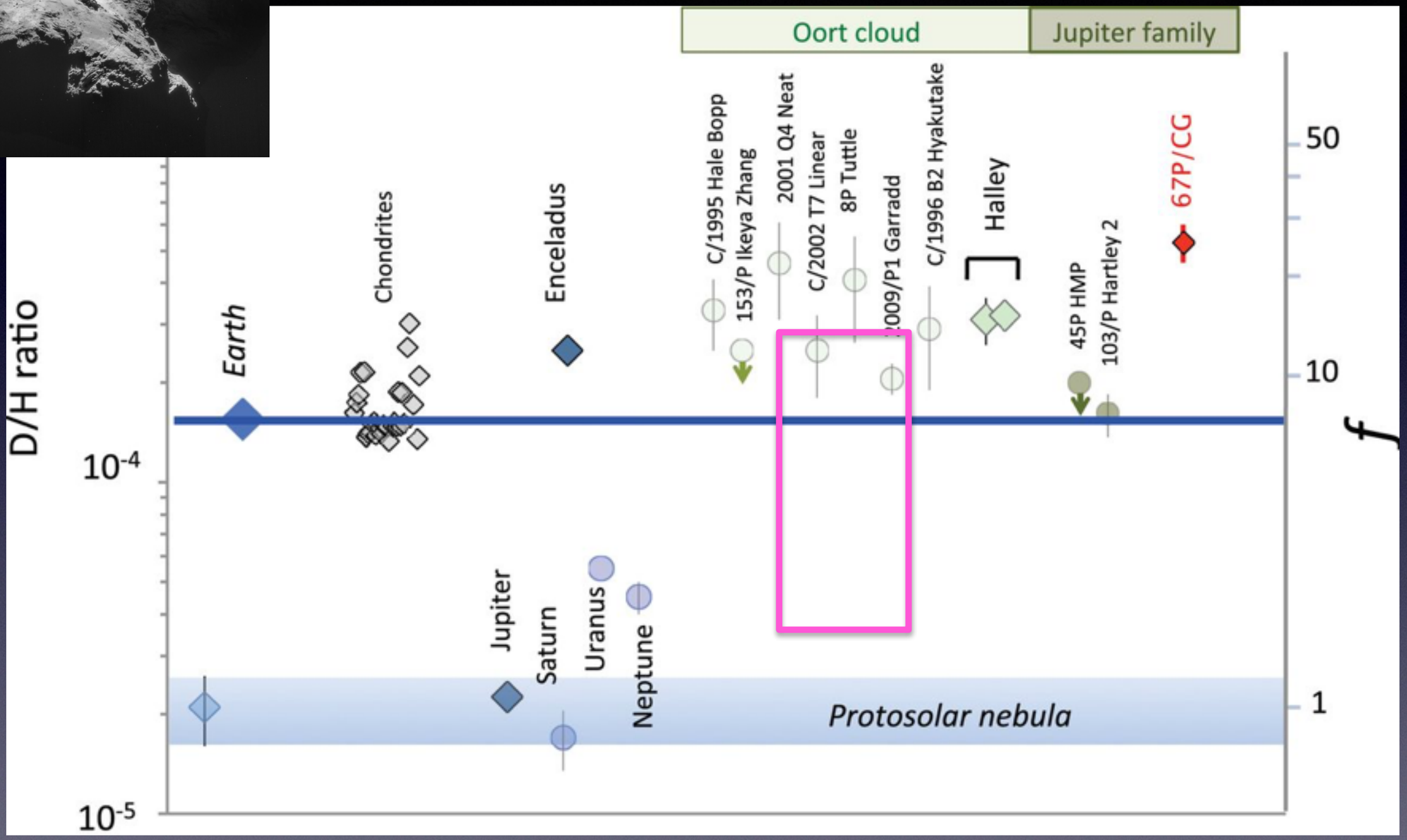


- A coupled dynamical and chemical model
- D/H may *decrease* in the outer regions
- Water thermally processed in the inner disk transported outward

Yang et al. (2013)



D/H Observations



- Variations between one and three times VSMOW
- No trends with physical or dynamical parameters

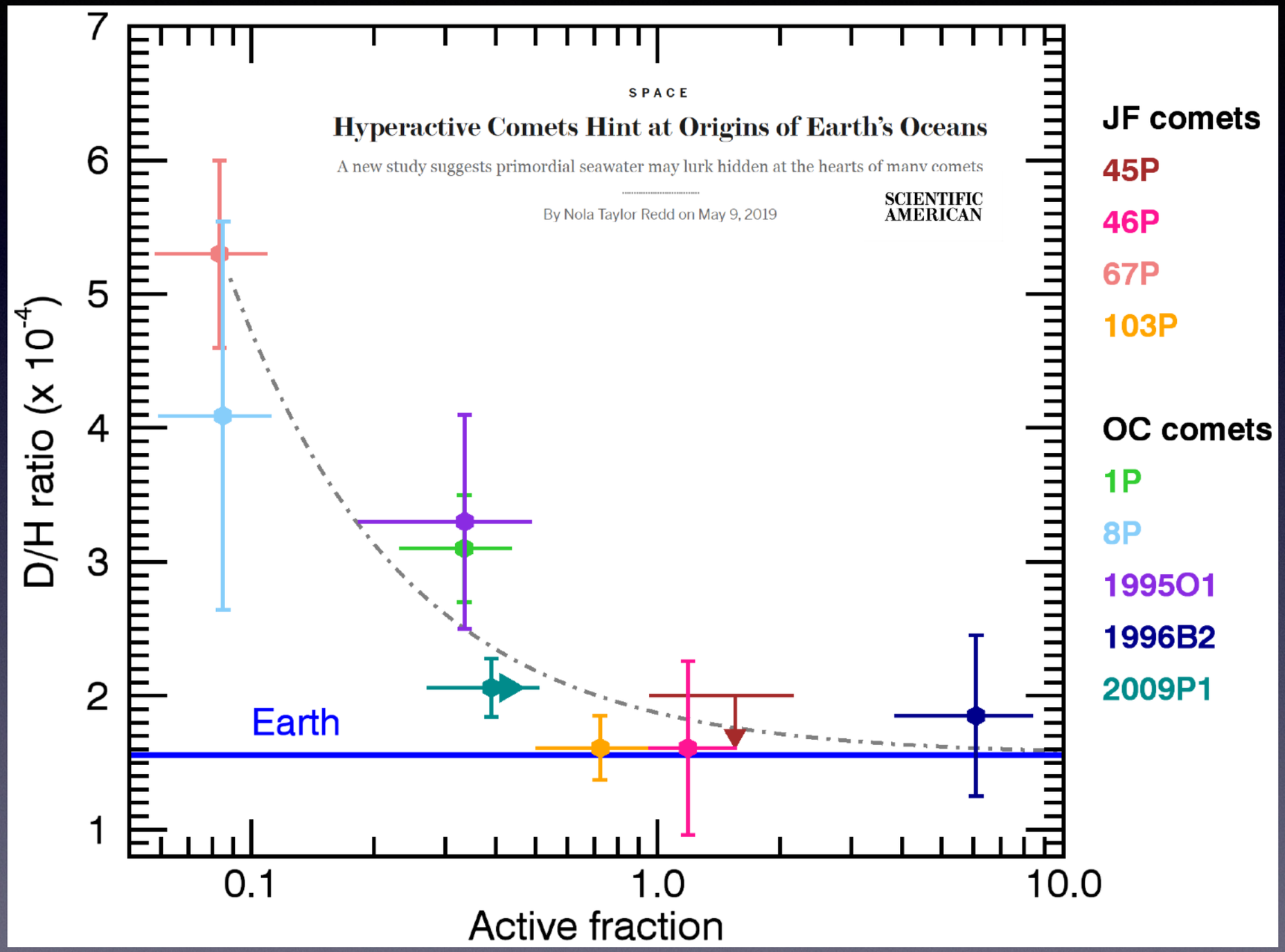
ORIGINS Space Telescope

Hyperactive Comets

- SOFIA observations of comet Wirtanen, December 2018
- Jupiter-family comet, orbital period 5.4 years
- Original target of the *Rosetta* mission

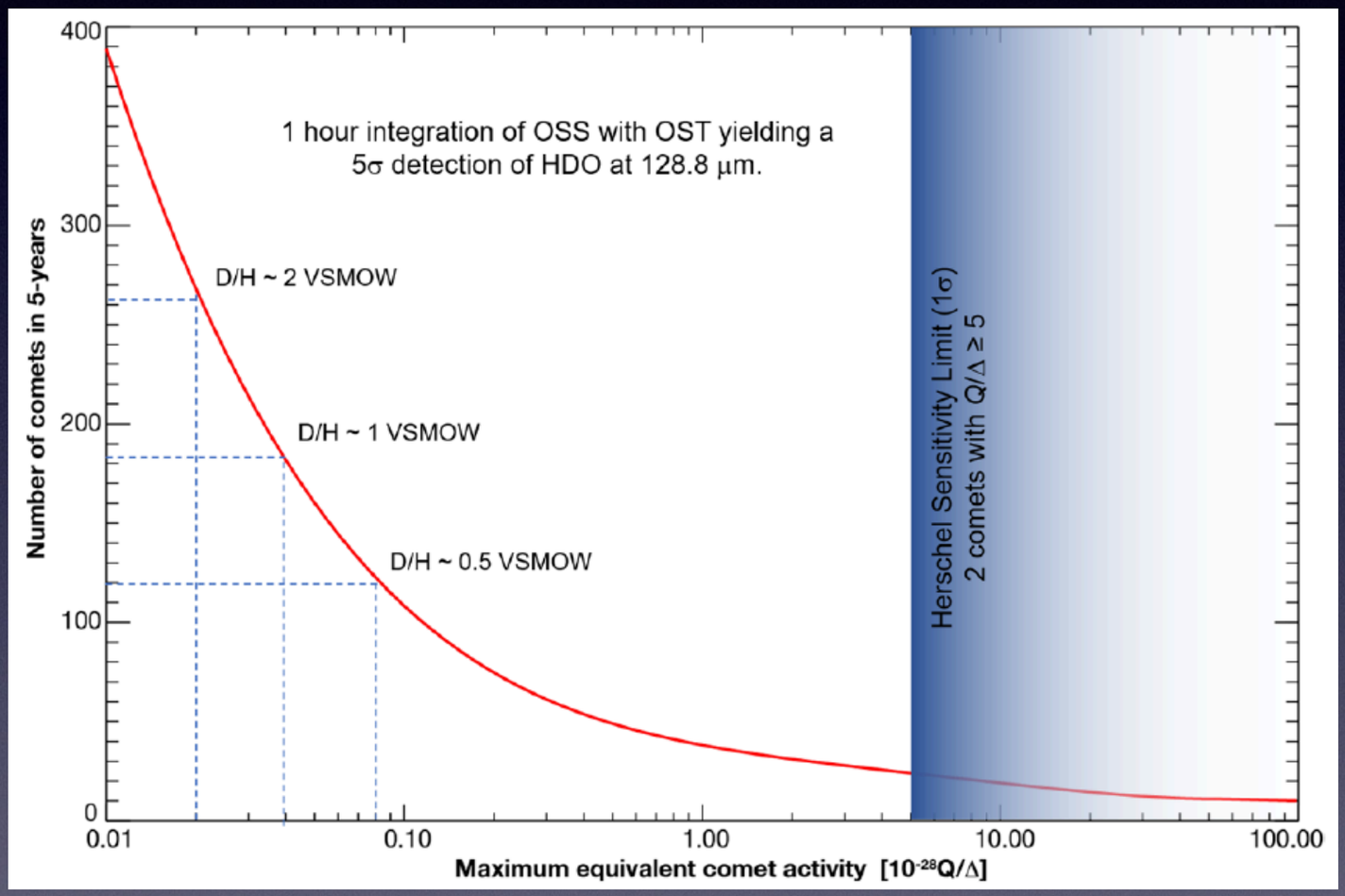
- Emit more water molecules that can be expected given the size of the nucleus
- Presence of sublimating water-ice-rich particles in the coma
- Archetype 103P/Hartley studied by Deep Impact — both icy grains and water overproduction were observed
- Active fraction: ratio of the active surface area to the total nucleus surface

D/H vs. Active Fraction

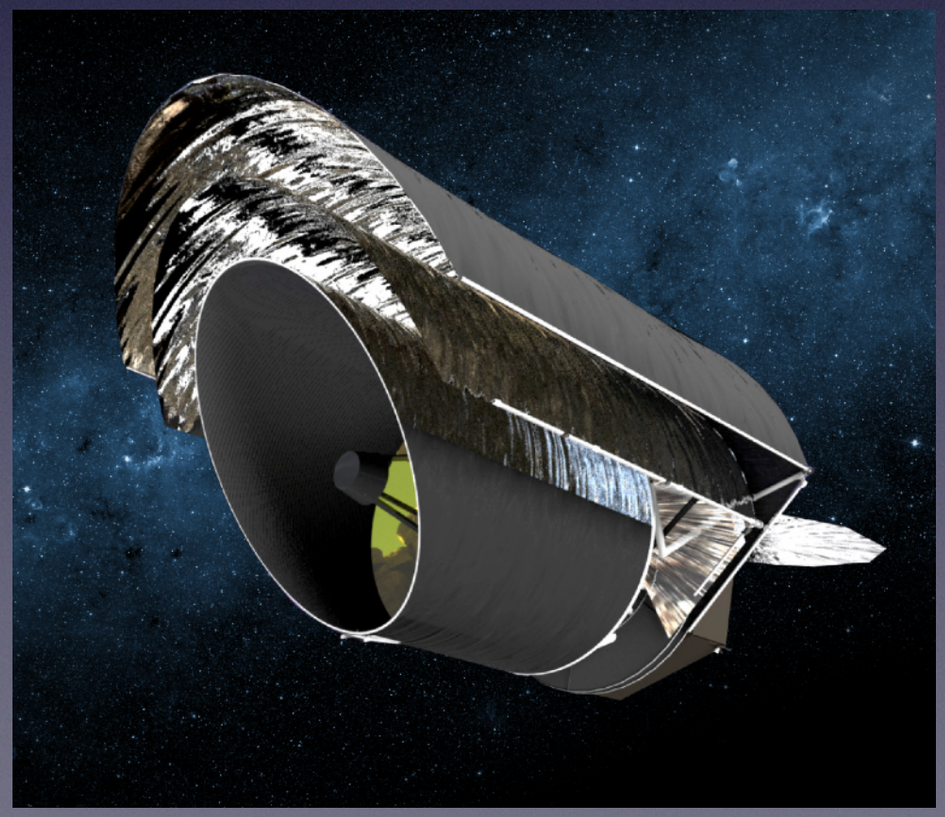


- Comets with active fraction above 0.5 typically have terrestrial D/H ratios
- Large reservoir of ocean-like water in the outer Solar System

Where Do We Go from Here?

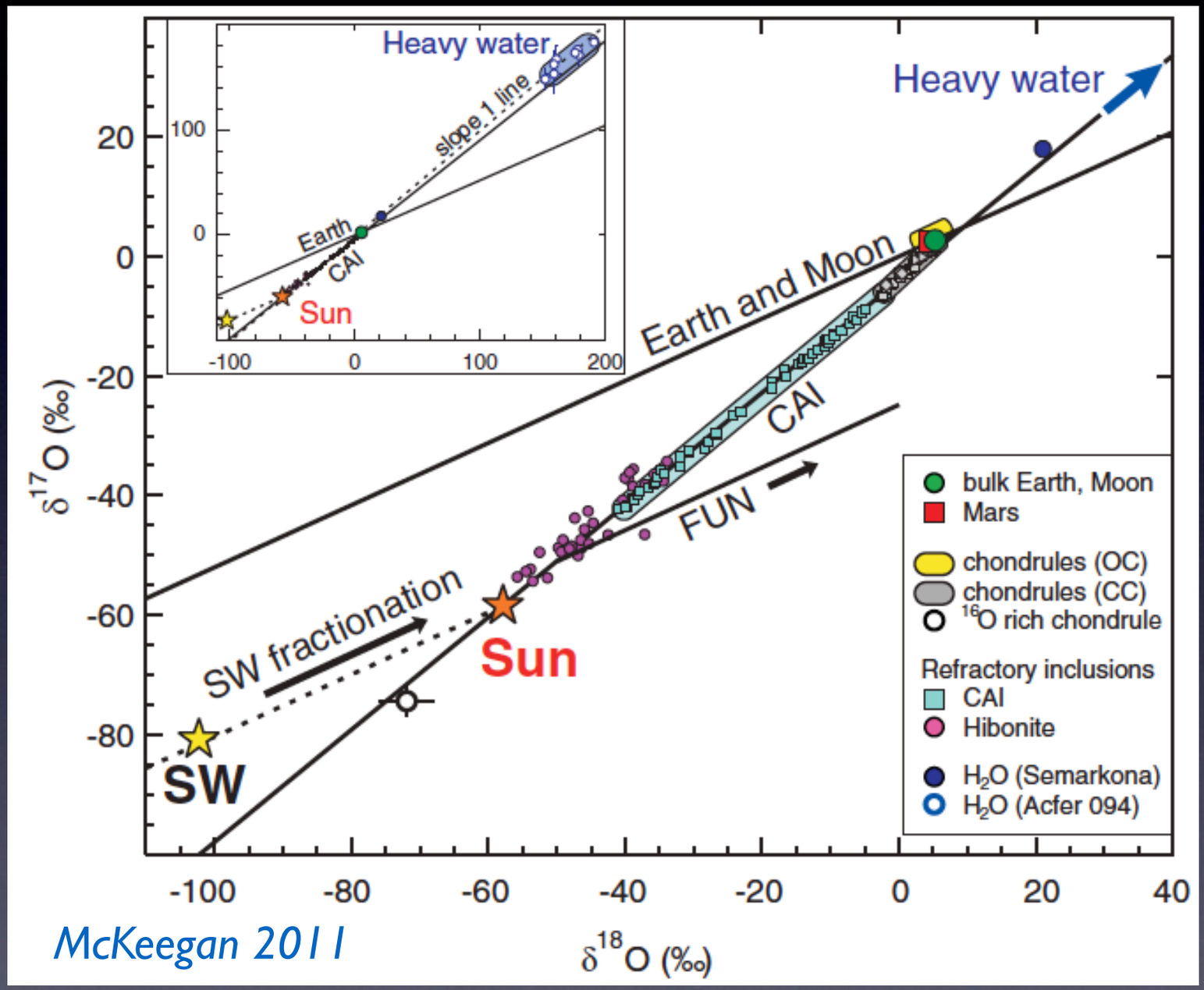


- Figure of Merit (FOM) = $Q(H_2O)/\Delta$(au)
- Wirtanen: $7.7\times10^{27}s^{-1}/0.08$ au$=1\times10^{29}$
- Expect ~1 measurement per year with SOFIA
- *Origins* or a dedicated mission needed to measure D/H ratio in a large sample of comets



NASA, Origins

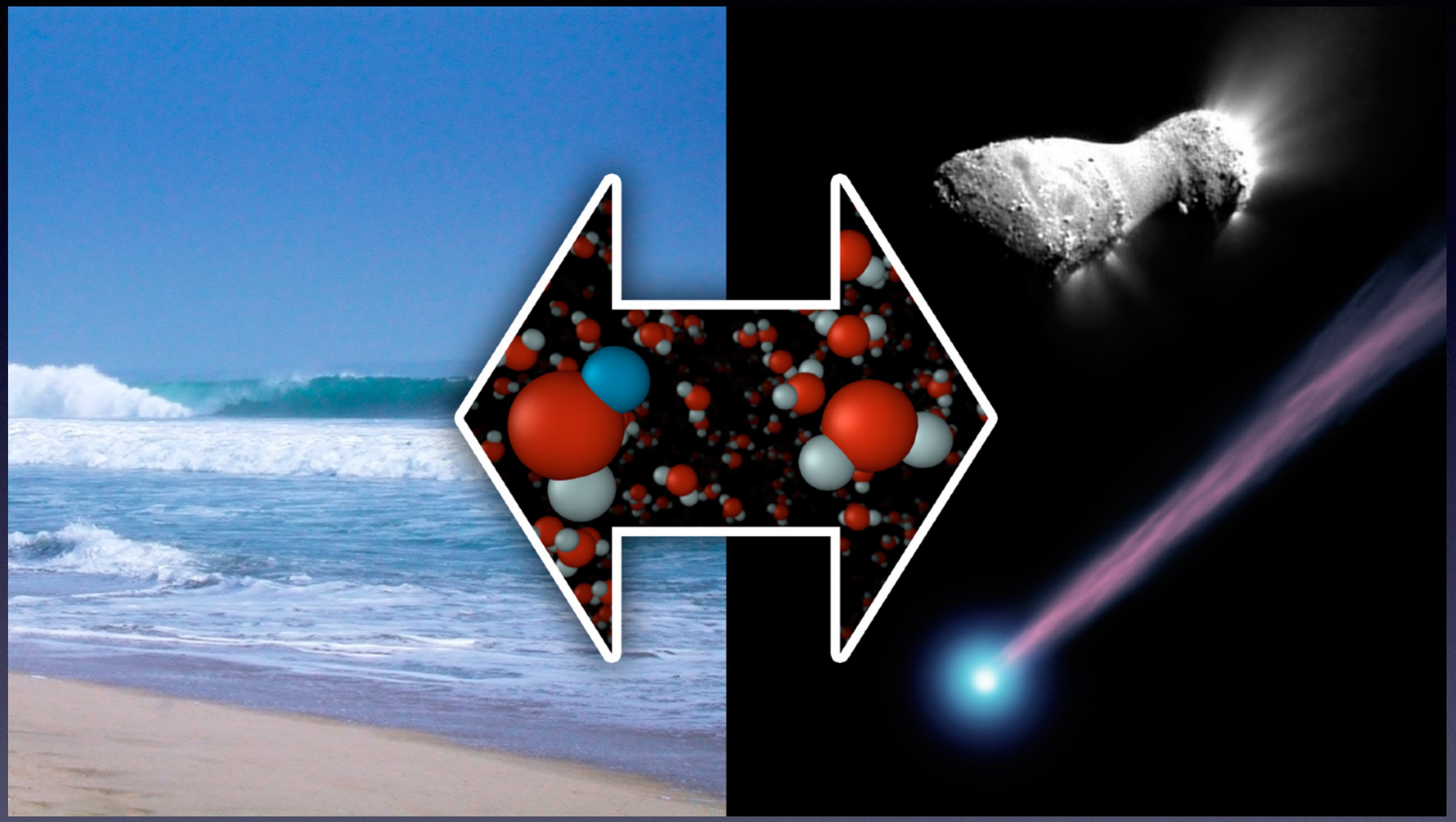
Oxygen Isotopic Ratios



McKeegan 2011

- Expect mass dependent fractionation: fractionation of $^{17}O/^{16}O$ half of that of $^{18}O/^{16}O$
- Mass independent fractionation observed — why?

Summary



- Measurements of isotopic ratios in a large sample of comets, including Main Belt comets, are key for understanding the origin of Earth's water
- With a long term, focused program, SOFIA can double the number of existing D/H measurements during its lifetime
- *Origins* or a dedicated Discovery or Probe class mission is needed to provide a statistically significant sample

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