COMETS AND THE ORIGIN OF EARTH'S WATER

DAREK LIS

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

PRIMA COMMUNITY WORKSHOP
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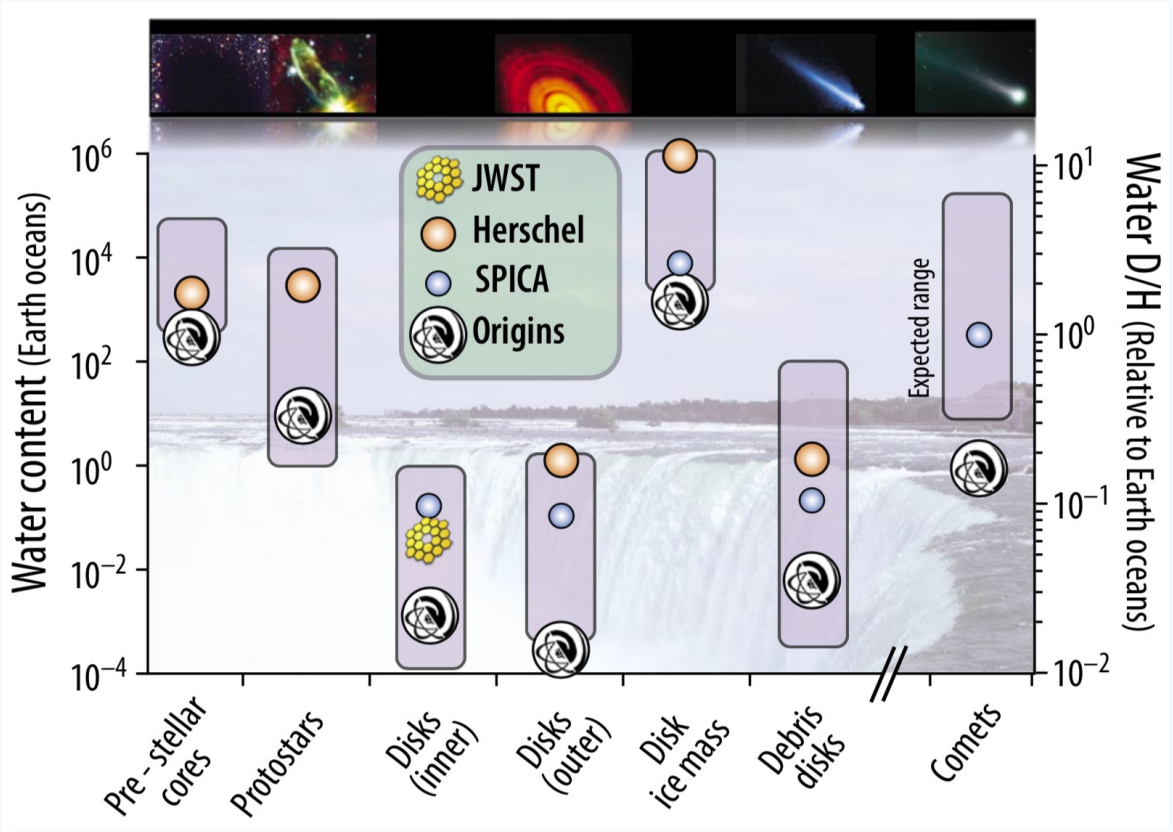
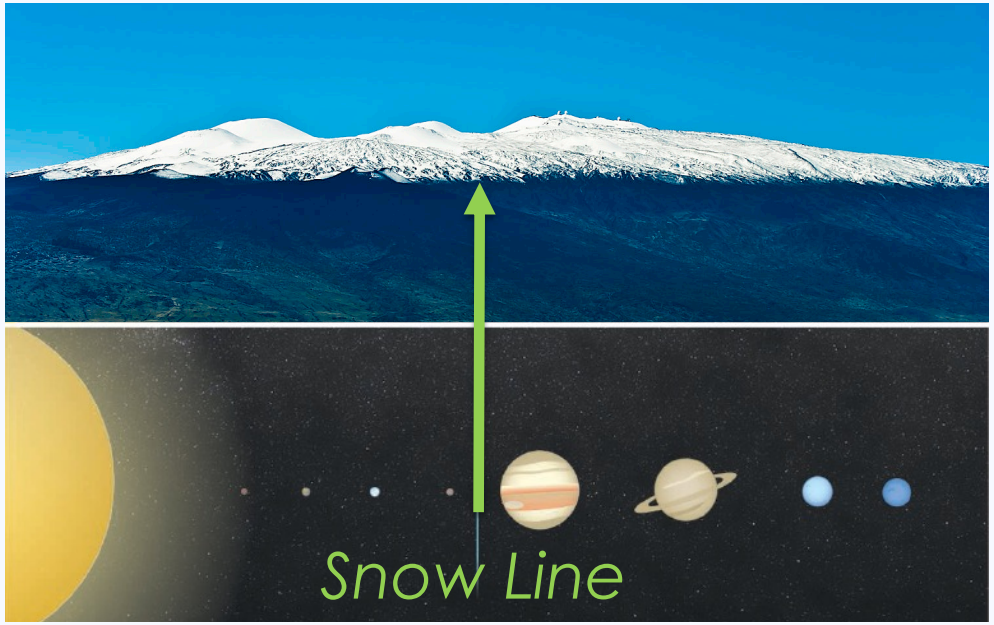


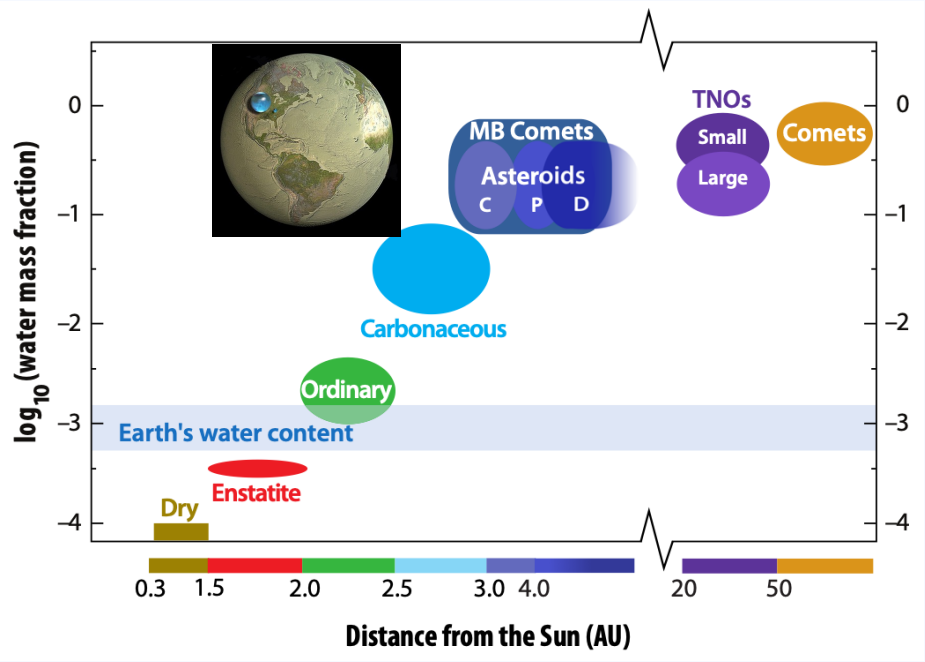
Overarching goals: Understand the origin of Earth's water and its habitability. In a broader context, understand whether Earth-like planets are common in other exoplanetary systems.

ORIGINS Space Telescope

WATER IN THE SOLAR SYSTEM

- Water mass fraction increases with distance from the Sun.
- "Textbook model": temperature in the terrestrial planet zone too high for water ice to exist.
- Water and organics had to be delivered later by impacts of comet- or asteroid-like bodies.

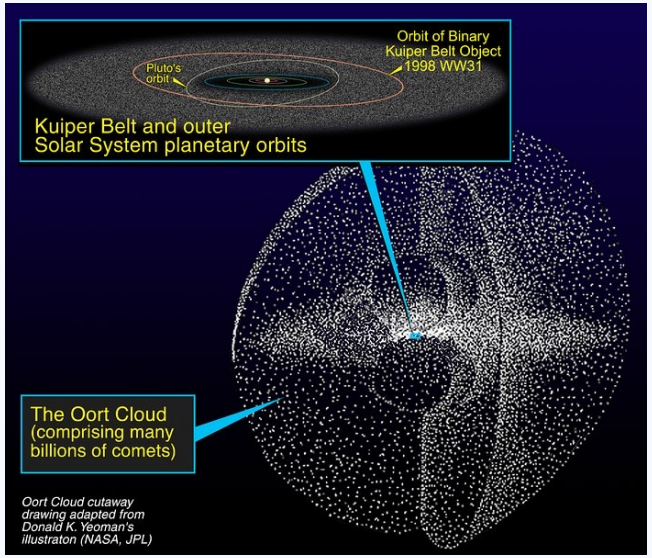


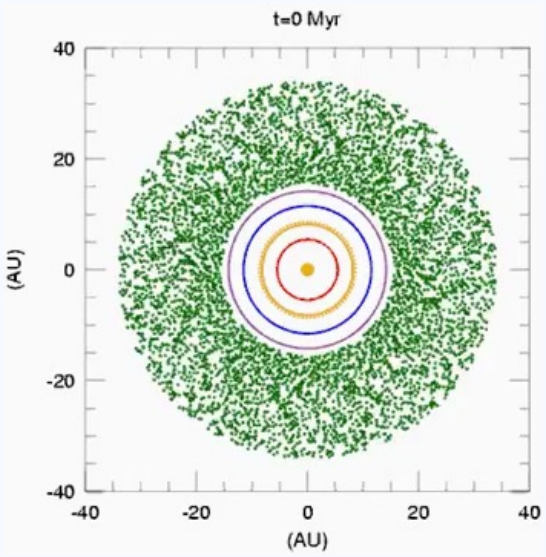


- Alternative: water survived, incorporated into olivine grains or through oxidation of an early H atmosphere by FeO in the magma ocean.
- Volatiles on Earth and the other terrestrial planets appear to have been heterogeneously sourced from different Solar System reservoirs.
- Late accretion of chondritic and cometary materials is an important stage.

van Disoecck et al. 2014 *Broadley et al. 2022* *Woo, Morbidelli et al. 2023*

WHY STUDY COMETS?

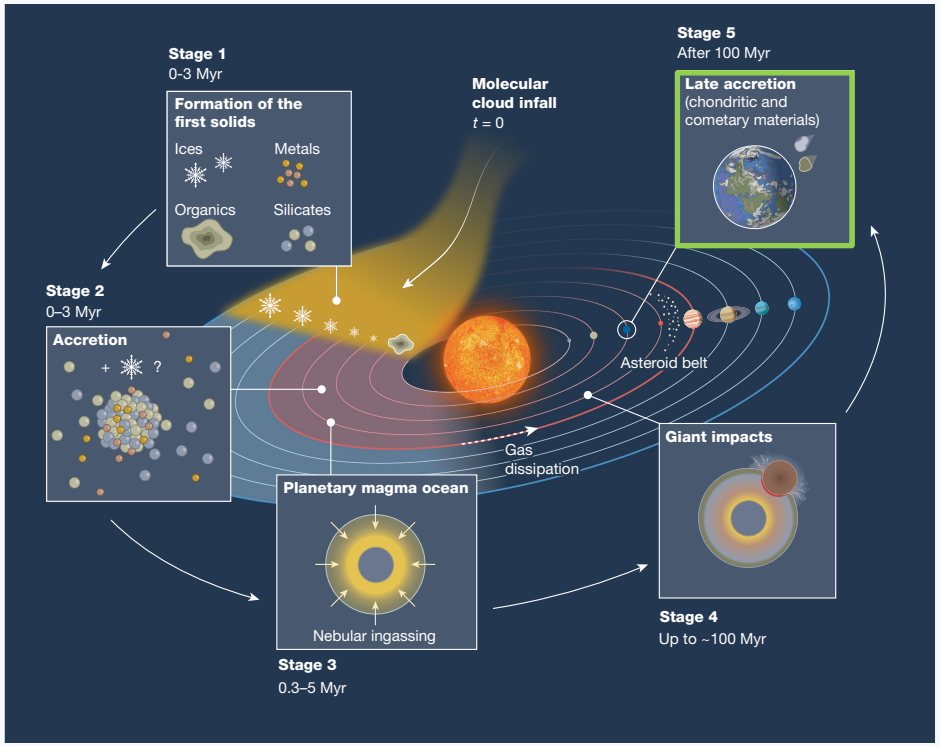




- Comets are tracers of the present day outer Solar System that can be studied using remote sensing techniques (atmospheres)
- Compare isotopic composition of the outer Solar System (Kuiper belt, Oort cloud) with the inner Solar System (Asteroid Belt)
- Compare composition of different dynamical groups, look for correlations with physical parameters
- Quantitative constraints on the dynamical/chemical models of the early Solar System

- Focus on D/H because the observed variations are large, a factor of 3. The required accuracy of the individual measurements is much more forgiving than for other isotopic ratios.

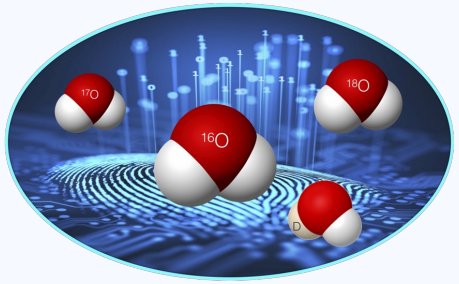
Multiple stages of volatile incorporation



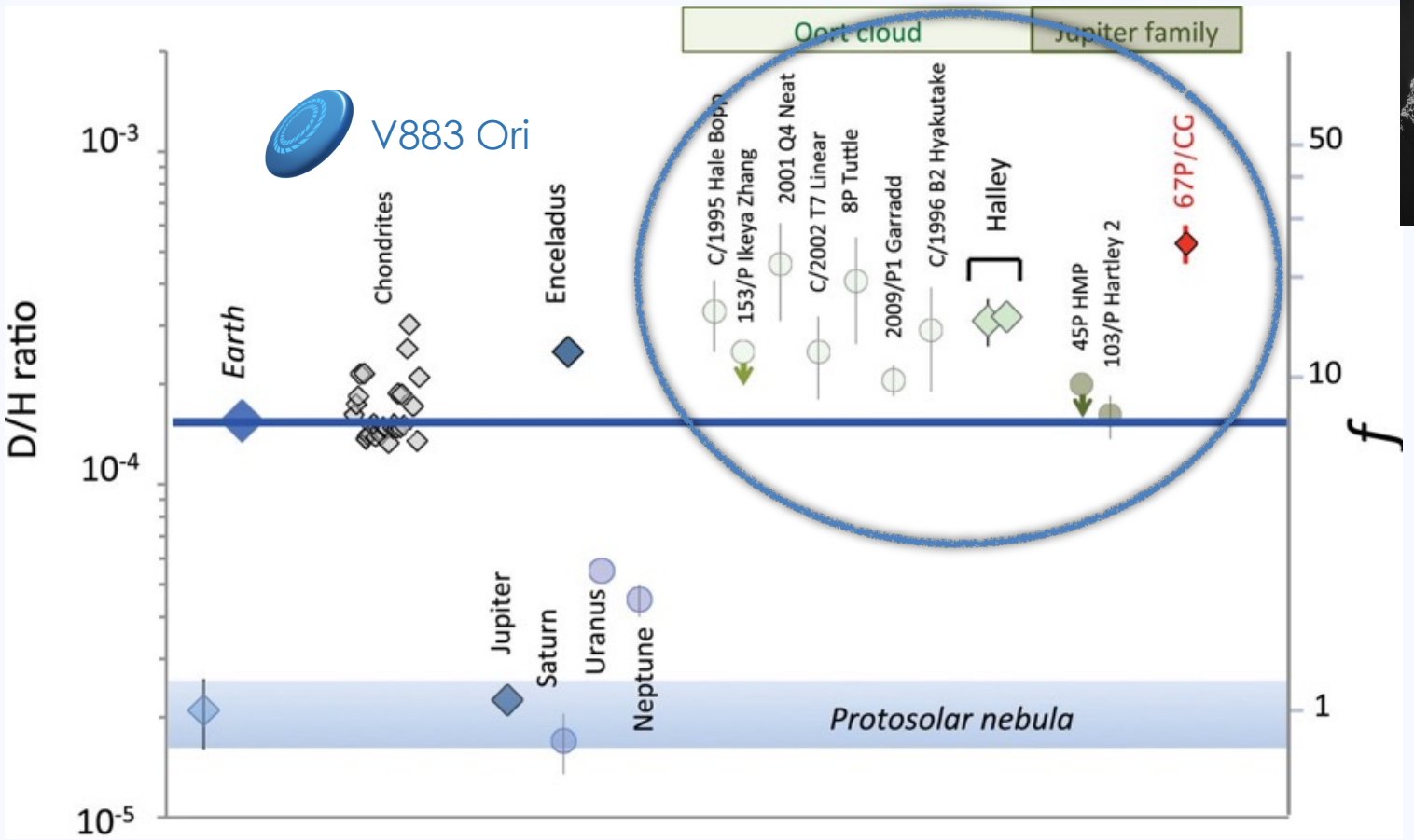
Cometary bombardment described by the Nice model

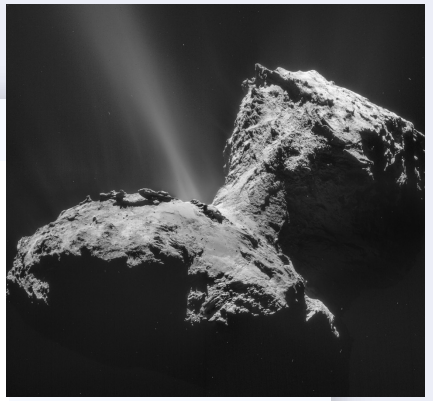
Broadley et al. 2022

D/H RATIO IN THE SOLAR SYSTEM



Unique Fingerprint

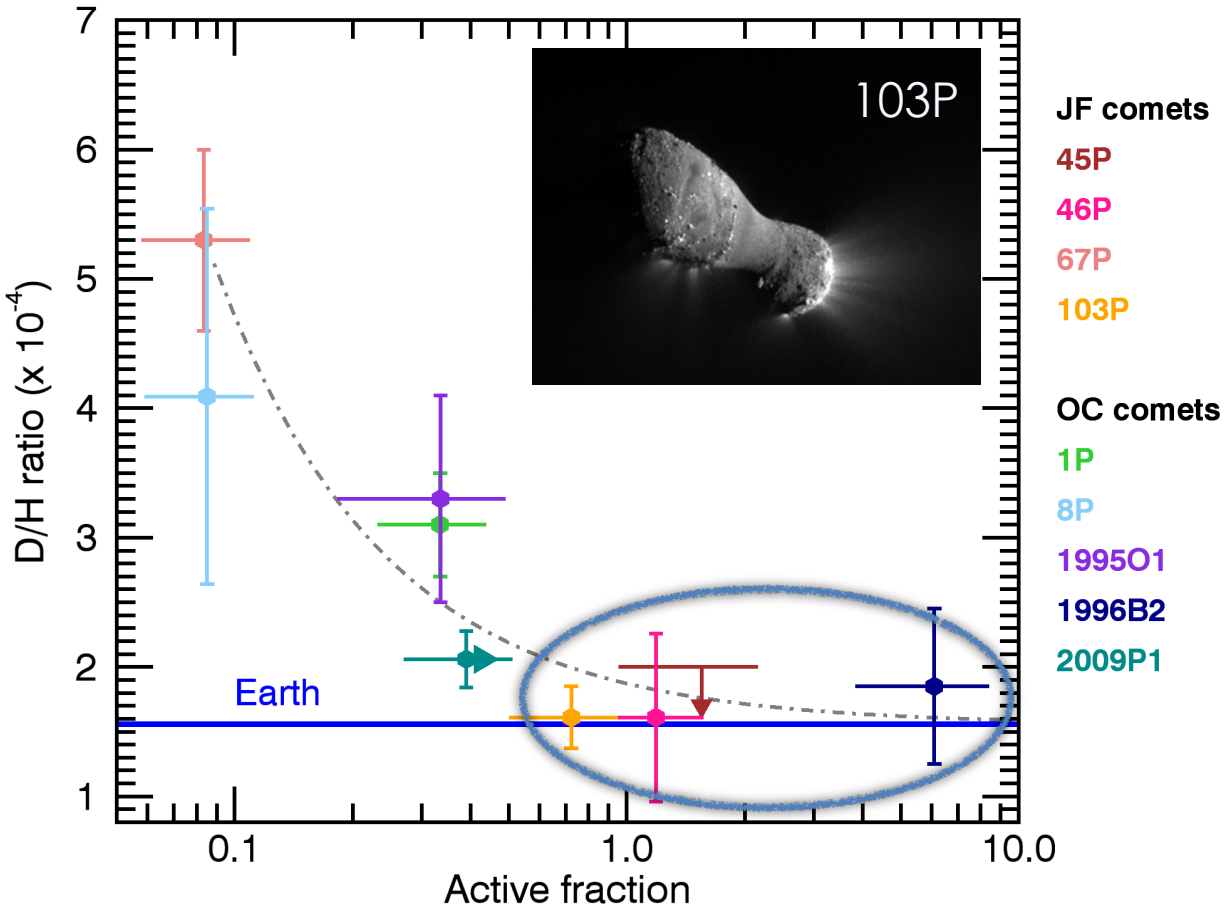




- Comets: variations between one and three times the terrestrial value, both in long-period and short-period comets

Altwegg et al. 2015
Tobin et al. 2023

TERRESTRIAL D/H RATIO IN HYPERACTIVE COMETS



Comets with high active fractions typically have terrestrial D/H ratios.

Emit more water molecules than can be expected given the size of the nucleus.

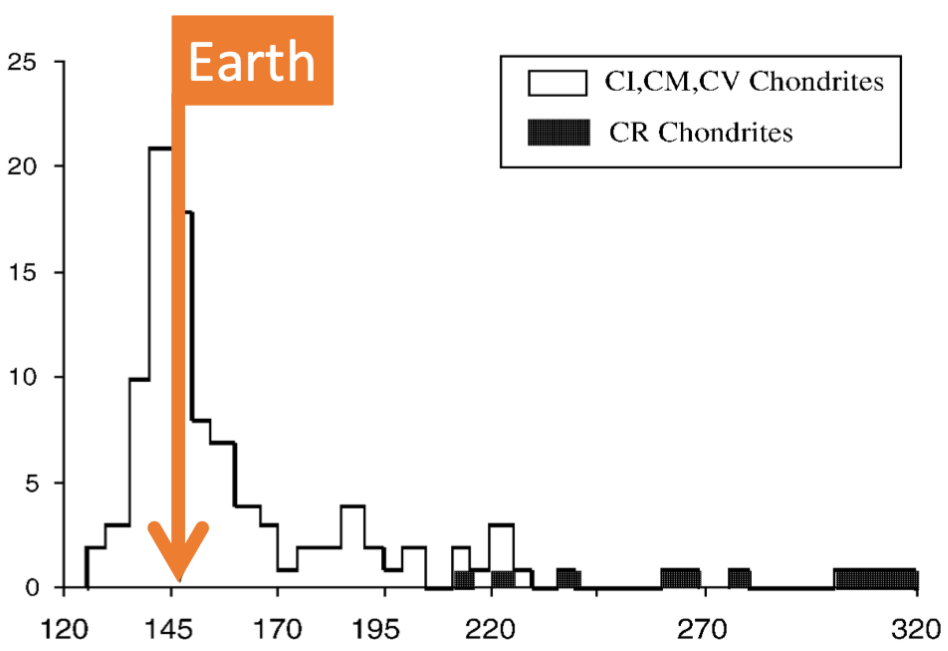
Presence of sublimating water-ice-rich grains in the coma.

Archetype 103P/Hartley 2 studied by Deep Impact — both icy grains and water overproduction were observed.

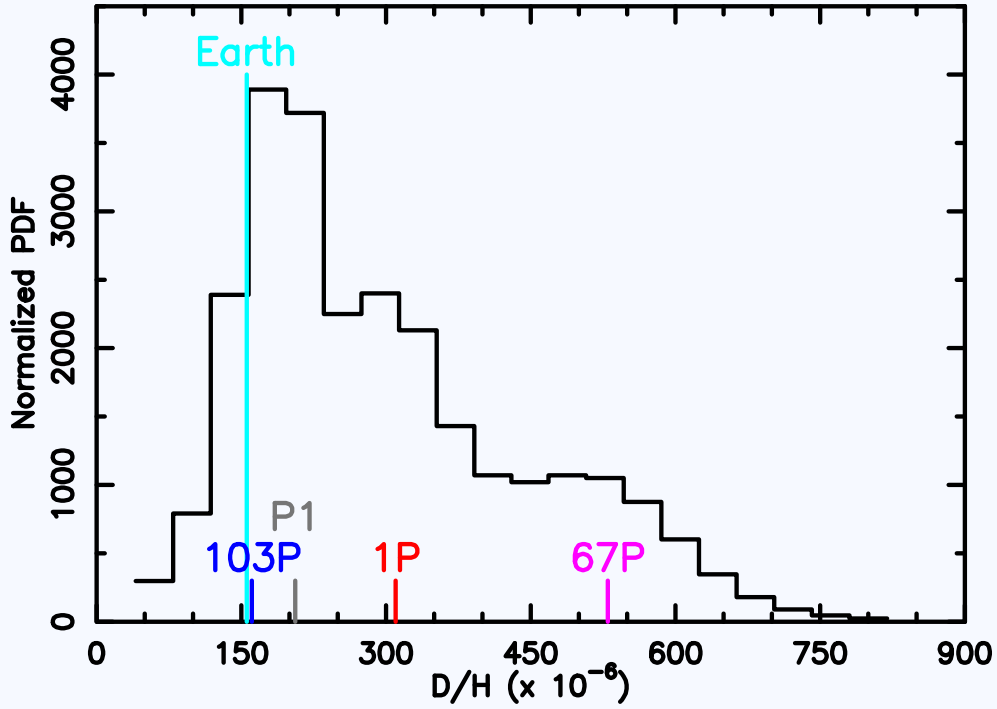
Sublimating icy grains may be more pristine and more representative of the bulk composition of the nucleus.

Lis et al. 2019

D/H DISTRIBUTION: INNER VS. OUTER SOLAR SYSTEM



D/H in the inner Solar System relatively well constrained by measurements in meteorites (100+ measurements).



D/H in the outer Solar System poorly constrained – 10 measurements in comets, only 4 accurate (8-10%, 1σ).

Need a statistical study to make a meaningful comparison!

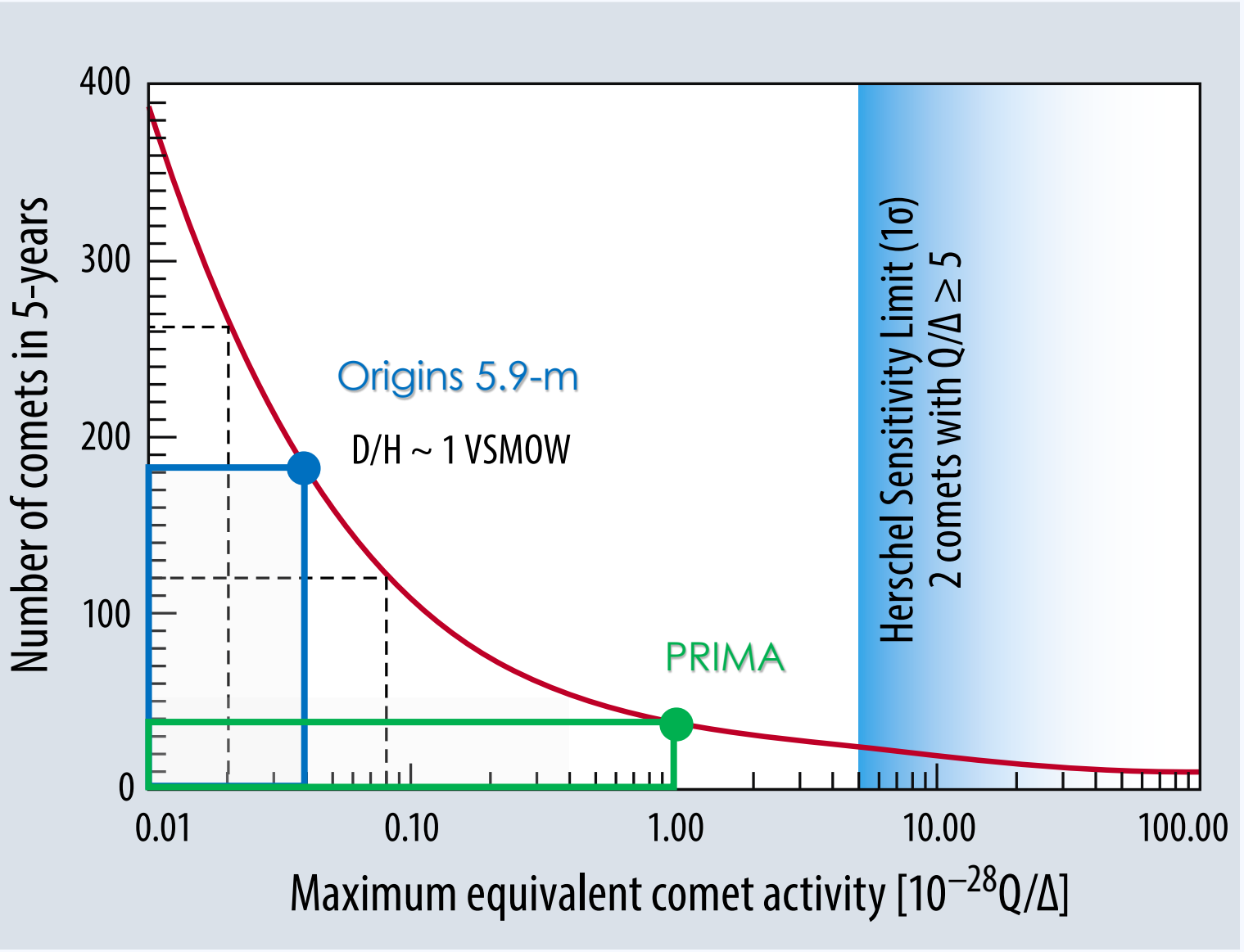
Alexander 2006

WHAT CAN PRIMA DO?

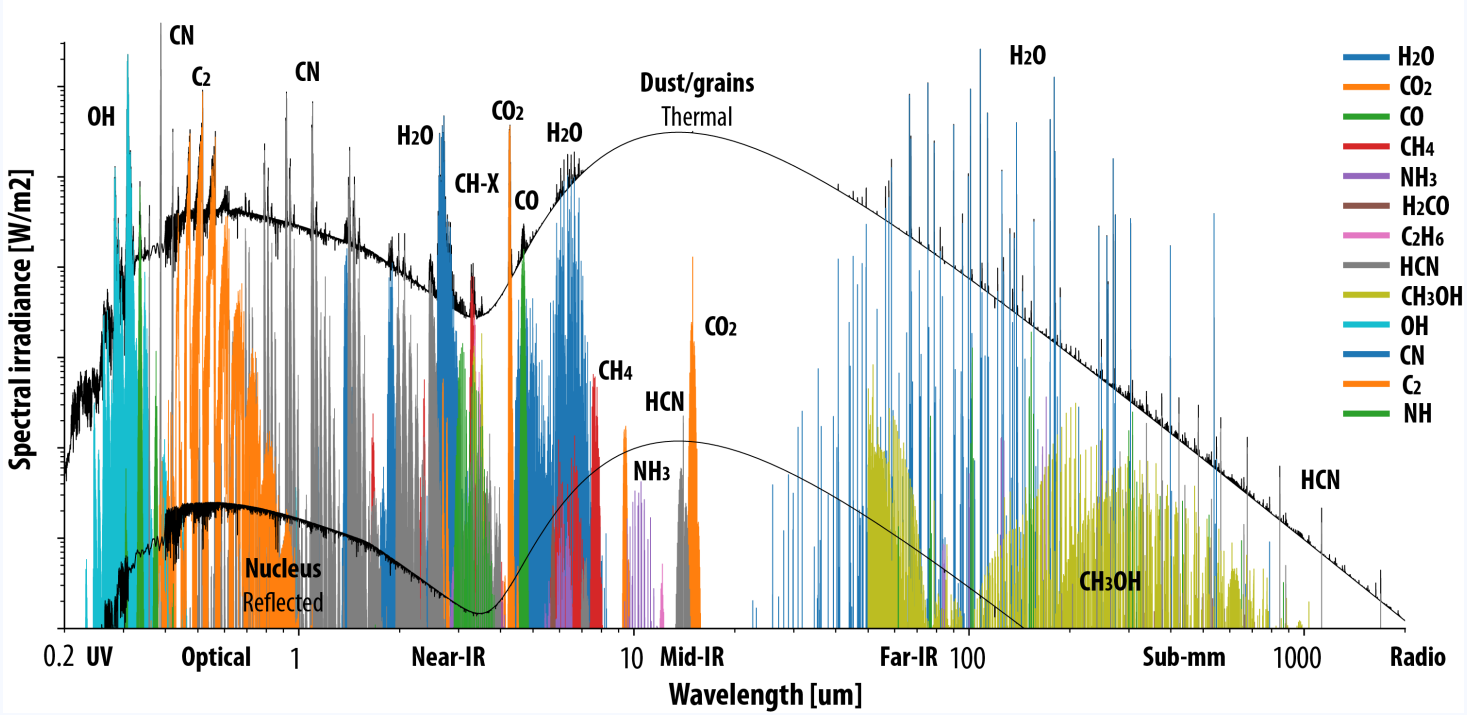
Use *Origins* calculations for the number of comes vs. equivalent comet activity (FoM=$10^{-28}Q/\Delta$).

FoM=1 (fiducial model): 35 – 40 comets in a 5 year mission. Line flux detection limit 5 x 10^{-20} W/m^2 @ 234.6 μm.

Using the latest CBE sensitivity, this corresponds to about 20 h per target, or 150 h per year.



POTENTIAL CONFOUNDING FACTORS



Line Confusion

- Blending with nearby lines (e.g., methanol)
- Interference from bright water lines leaking through the sidelobes of the FTS response

Line-to-Continuum Ratio

Both depend on the spectral resolution of the FTS.

Preliminary calculations suggest that R~5000 is sufficient.

Planetary Spectrum Generator

Jet Propulsion Laboratory
California Institute of Technology