1. Science aim/goal (provide a high-level statement in 140 characters or less):
Determining the distribution of D/H values in comets will reveal their thermo-chemical history and determine their role in delivery of water to the early Earth.

2. (i) Scientific Importance:
Prior to Herschel, comets seemed to exhibit enrichment consistent with a formation temperature around 30 K. Herschel has detected water in short period comets with a terrestrial D/H, prompting some to suggest that ocean water was delivered by ecliptic comets. However, the sample is extremely limited and more observations are necessary, as Rosetta measurements suggest significant variations. A survey of FIR measurements of the D/H isotopic ratio of water in comets is necessary to determine the primordial conditions of our Solar System and probe the origins of Earth's water in a comprehensive manner.To reach the next level of understanding, we require the D/H in a much larger sample of comets to assess whether there is a continuum of values or several distinct populations (Oort Cloud versus Kuiper Belt), with important implications for supply of volatiles to the inner solar system (Encrenaz 2008).

(ii) Measurements Required:
Spectroscopy from 50-600 μm is a key capability of a far-IR space telescope, opening up the study of water and its isotopes in various bands. The 500-600 μm range allows the measurement of H_2O (539 μm), HDO (589 μm), $H_2{}^{17}O$ (543 μm) and $H_2{}^{18}O$ (547 μm) (Hartogh et al 2009) with heterodyne instrumentation at high spectral resolution. Stronger water, and HDO, lines continue to shorter wavelengths (50-250 μm), see Figures 2 and 3. Far-infrared lines of HCN and CO, including isotopes are also prevalent at 100-500 μm. Spectral resolution of ~1e5 at 100 microns at high sensitivity will enable the detection of H_2O and HDO at lower wavelengths for fainter comets. Follow-up observations at heterodyne wavelengths (R≥1e6) will enable resolved line profiles for brighter comets and can provide insight into dynamics and outflow properties of a given target.

(iii) Uniqueness to 10μm to few mm wavelength facility:
The measurements possible in the far-IR will permit unique science. Low energy water lines, including isotopes, are for the most part not observable from the Earth due to atmospheric water. These fundamental and strong transitions of water (including isotopologues) can answer this question due to the low temperature of comets throughout their orbit.

(iv) Longevity/Durability:
A far-IR telescope will complement with other large facilities that will exist in 2025 to 2030. Ground-based optical facilities in the 30-40m class will provide revolutionary capability at optical and near-infrared wavelengths. The JWST instrument range extends only to 28 μm, while ALMA commences at ~300 μm, leaving a significant gap in the far-infrared. After the expected end of JWST operations around ~2028, no mid- to far-infrared telescope is currently scheduled to be operational, leaving an even wider gap between near-IR and sub-mm capabilities. A large far-IR telescope will provide unique and critical science addressing key questions of solar system formation and evolution.

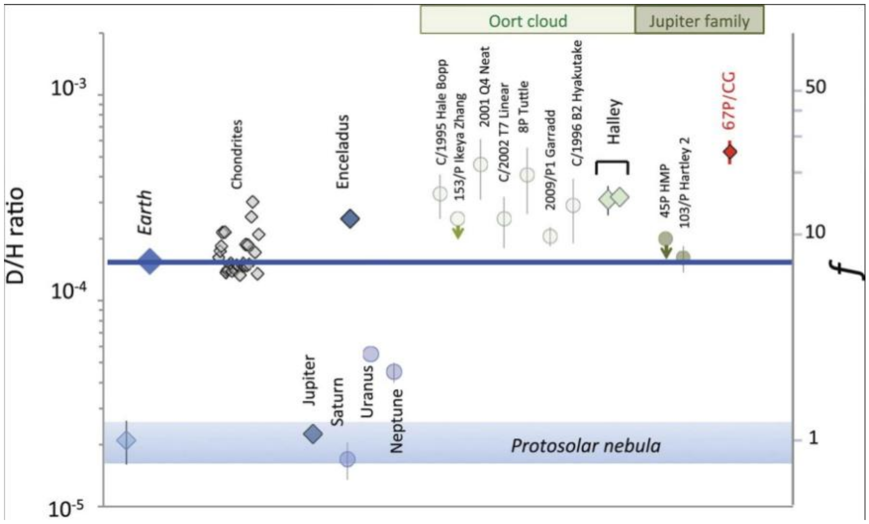

Figure 1: D/H measurements in comets, from Altwegg, K. et al. 2015. (Science 347, 1261952). A larger statistical sample of targets are needed to determine the origin of Earth's ocean and measure the dispersion of this ratio in both dynamic families.

4. Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	50-250	50-600	See Figures 2 and 3
Number of targets		50	100	Includes comets from both dynamic families at various heliocentric distances.
Survey area	deg.^{2}			Single point targets
Angular resolution	arcsec	30	10	At 550 GHz
Spectral resolution	$\Delta\lambda/\lambda$	1E5	1E6	
Bandwidth	Micron	50	100	Cover both isotopes
Continuum Sensitivity (1 σ)	μJy			
Spectral line sensitivity (1 σ)	W m^{-2}	2E-21	1E-22	This gives us detections of HDO in comets with Q(H2O) ~ 2E22 s-1. Provides detections of >30 targets known to date.
Signal –to-noise	σ	5	10	
Dynamic range				
Field of Regard				Ecliptic access for most comets. JWST FOR is reasonable.
Cadence				
Any other requirement				Moving target tracking (≥ 60 mas/s)

5. Key references: (Optional, at most three, reviews preferred)

Encrenaz, Th., "Water in the Solar System", Ann. Rev. Astron. Astrophys. 2008. 46:57–87.

Hartogh, P. et al.: "Water and related chemistry in the solar system. A guaranteed time key programme for Herschel," Planetary and Space Science 57 (2009) 1596–1606

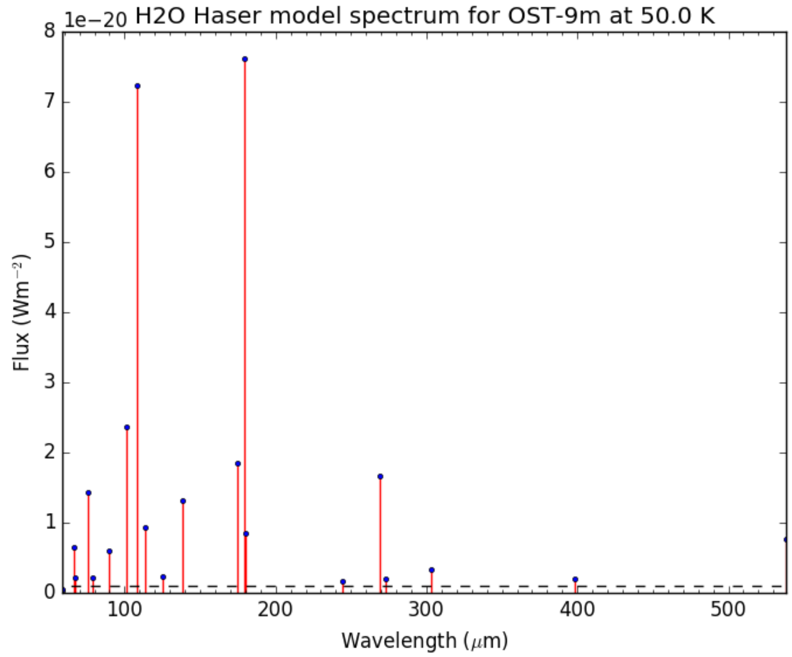

Figure 2: Simulated cometary H2O spectra for a 9m single aperture. Sensitivity 10^{-21} W/m^2 - 5 sigma spectral line and R~1e5.

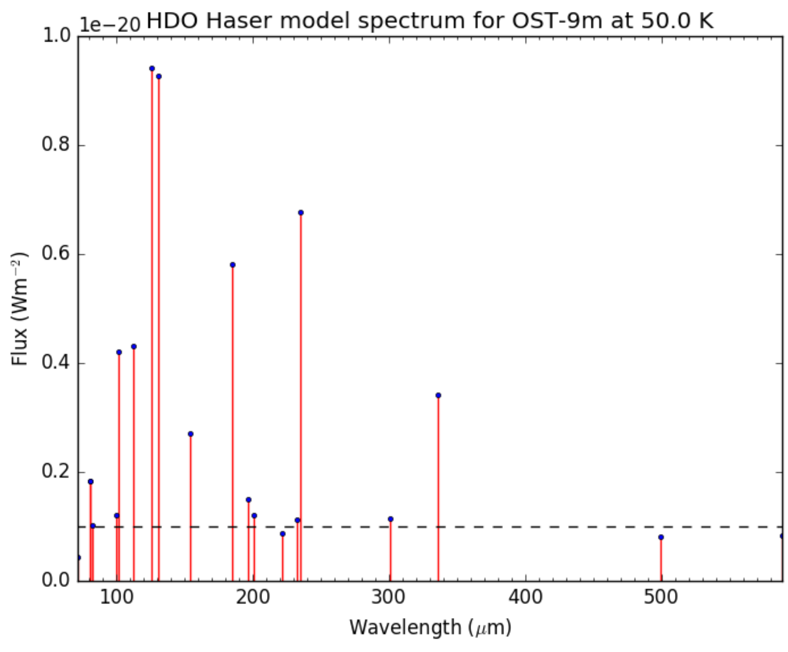

Figure 3: Same as Figure 2, but for HDO.

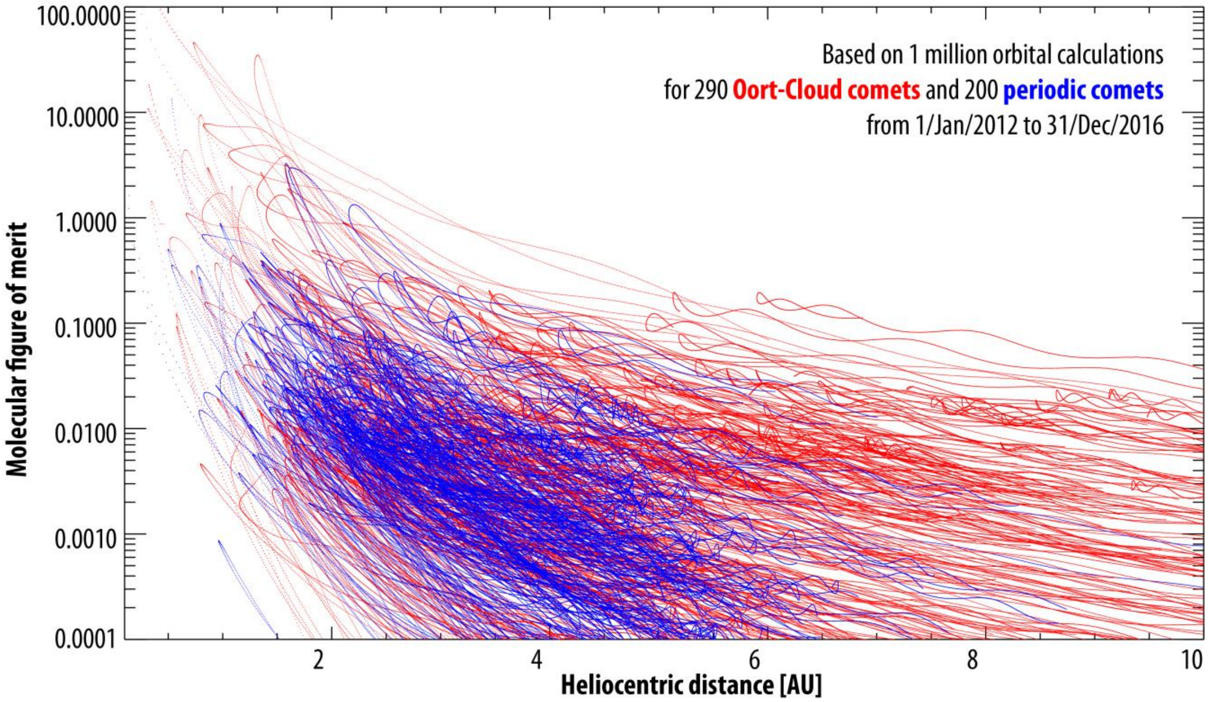

Figure 4: With a 9m aperture (2e-21 W/m^2) we can observe nearly ALL short and long period (Oort-Cloud) comets at multiple epochs with a FOM ≥ 0.001. NOTE: Figure of Merit (FOM) = [30.68 + 1.23 log10 (Delta) - 0.25mV Q(H2O)/Δ(AU)*10^{28}]/Delta.