A Mission to Study Water in the Local Universe

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Background:
Beyond its obvious biogenic importance, water is of great interest in many astronomical situations. It is an important coolant of warm interstellar clouds and is a significant reservoir of oxygen in the interstellar medium. It is a valuable tracer of the motions of interstellar clouds associated with forming stars including OUTFLOWS and COLLAPSE. It is a tracer of the thermo-chemical history of cloud material via the H_2O ortho-para ratio. Finally, water is a critical source of information on the origin of the Earth's oceans from icy objects in the solar system.

Project Goals:
Observing water in the local universe requires high spectral resolution: the line widths may be less than 1 km/s in comets and dense cloud cores. Thus, a heterodyne system is needed. A variety of rotational transitions is available, so that one goal is to choose a set of lines that allows determination of critical parameters, but covers a wide range of targets. A heterodyne receiver will itself be cryogenically cooled to minimize noise, but the temperature of the telescope and associated optics (unlike the case for broadband photometry and low-resolution spectroscopy) is not critical. Thus, we can contemplate a large, ambient temperature telescope to maximize sensitivity and angular resolution, coupled to a multiband receiver covering key spectral lines of water and deuterated water, the latter being necessary for study of cometary water and its relationship to water on the Earth's surface.

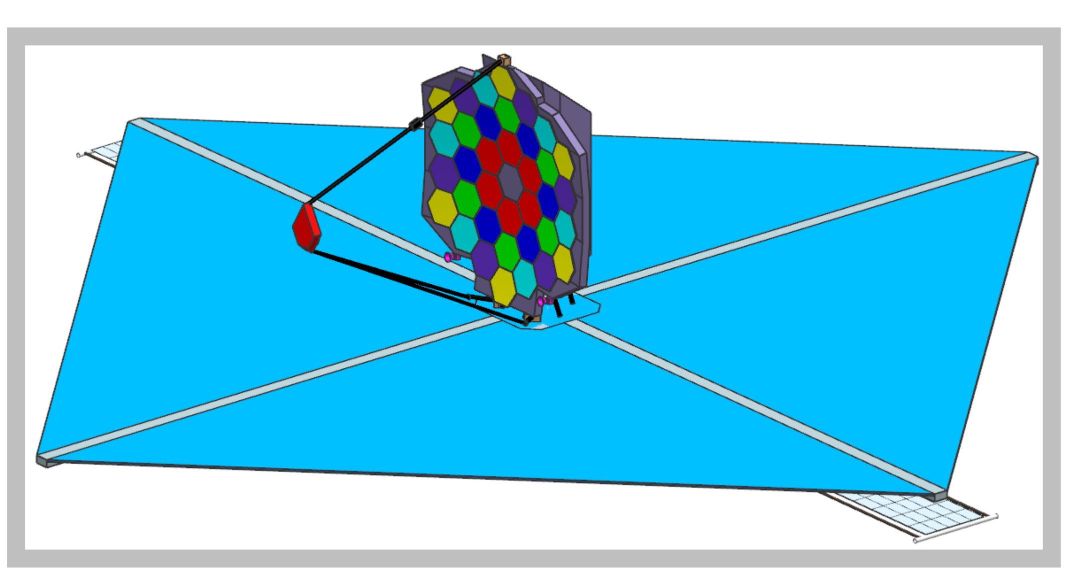
(1) Telescope and Mission
We have developed a concept for a relatively lightweight 36-segment 6m diameter telescope that can be folded and fit into the shroud of a Falcon 9 Heavy, with direct launch to L2. The overall surface accuracy is 10 µm rms. A LEOstar-3 bus with upgraded dual startrackers gives 1" pointing accuracy appropriate for 12.5" FWHM beam width at 1 THz (λ = 300 µm). An enhanced propulsion system for orbital insertion and orbit maintenance is required. The total spacecraft mass is 7000 kg, but this should be reduced by design optimization.

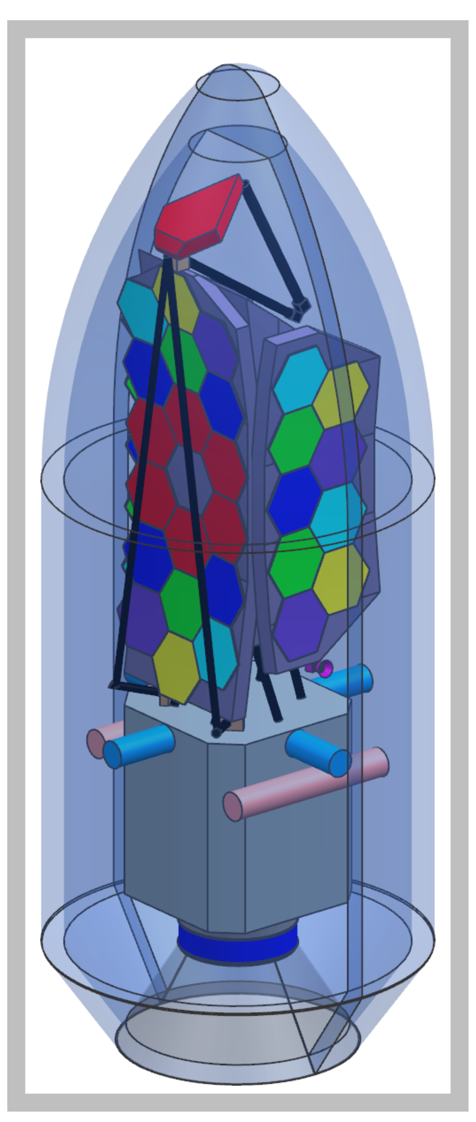
Important Transitions of H_2O

Freq (GHz)	Transition	Species
547.7	$1_{10} – 1_{01}$	(o-18)
552.0	$1_{10} – 1_{01}$	(o-17)
556.9	$1_{10} – 1_{01}$	(o-16)
987.9	$2_{02} – 1_{11}$	(p-16)
994.7	$2_{02} – 1_{11}$	(p-18)
1107.2	$1_{11} – 0_{00}$	(p-17)
1113.3	$1_{11} – 0_{00}$	(p-16)

Important Transitions of HDO

Freq (GHz)	Transition
509.3	1_{10} - 1_{01}
599.9	2_{11}- 2_{02}
893.6	1_{11}- 0_{00}
919.3	2_{02}- 1_{01}
1009.9	2_{11}- 1_{01}

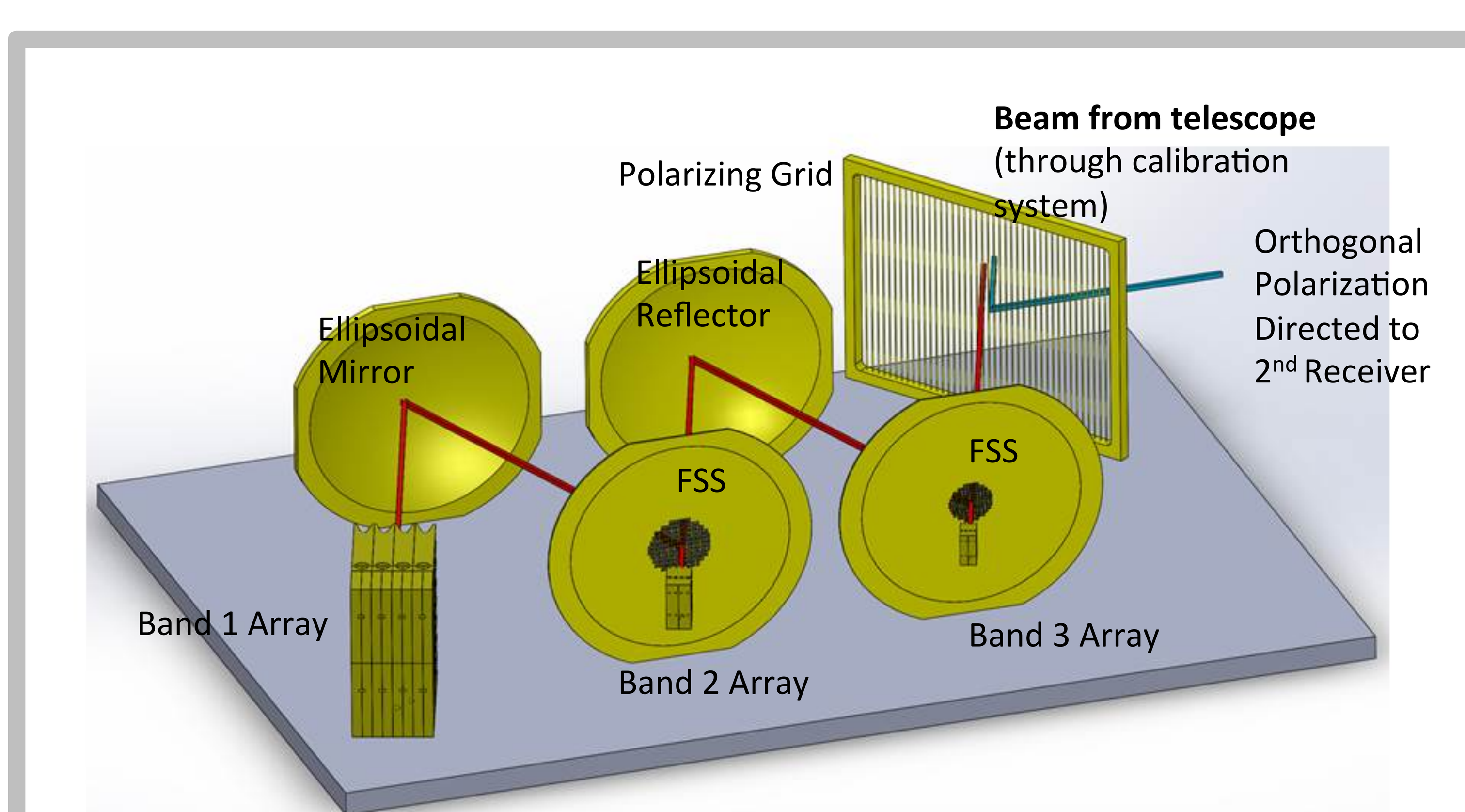




Right: Folded telescope in launch shroud. The spacecraft bus is below the telescope with the furled sunshield shown schematically by blue & pink bars; Above: deployed telescope with 20m-sized single-layer sunshield. The spacecraft bus is below the sunshield.

(2) Receiver
Two key concepts for the receiver are (1) to observe multiple bands simultaneously, and (2) to have modest-sized arrays in each band to increase speed of imaging extended sources. Together these dramatically increase the ability to determine conditions in sources since multiple transitions are generally required to determine excitation conditions and sources are extended. This applies to comets as well as interstellar clouds. In this receiver concept we use a series of frequency selective surfaces (FSS) which transmit frequencies above a cutoff and reflect lower frequencies. The optical system first separates two linear polarizations and then images beams coupling to the individual feedhorns. The arrays have 16 to 64 pixels each.

(3) Spectrometer
Multipixel submillimeter heterodyne spectrometers are demanding in terms of spectrocopic analysis. Herschel HIFI type systems will not be adequate due to excessive power and mass requirements. A collaboration between JPL and UCLA is developing a series of custom ASIC VLSI CMOS spectrometer chips. We anticipate having a 1024 channel 1.5 GHz bandwidth unit by mid 2016 and yet more capable units subsequently. The power consumption per spectrometer is < 400 mW including 7 bit ADC, FFT, accumulator, and interface. Thus 100 spectroscopic pixels operating simultaneously will require < 40 W of power.



Above: Schematic of three-band receiver using two FSS for band separation. The concept can be extended to more bands as the highest-frequency band is dropped first, and thus suffers minimum loss.