A THz Space Mission to Probe the Trail of Water

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We present a concept for a submillimeter spectroscopic mission to probe the trail of water from the interstellar medium to habitable planets. Water is an essential ingredient for life as we know it, and understanding how water is transported to planets in forming planetary systems is a fundamental question that we need to answer in order to understand how ocean worlds evolve throughout the universe. The water in habitable planets came from the protoplanetary disks out of which they formed, but a variety of obstacles make it impossible at the present time to determine observationally the distribution of water within such disks. Thus, we need to trace the water trail and understand the dense cores in which water can be formed, and how these regions evolve to become disks. And, we need to understand how the chemistry in disks evolves, and how material is transported within a disk, in order to determine the availability of water in different regions within them.

Observing gas-phase water in the local universe requires high spectral resolution because line widths may be less than 1 km/s in comets and dense cloud cores and a resolution of 0.1 km/s is compulsory. Thus, to study the water trail we need a heterodyne system, which is cryogenically cooled to minimize noise. To follow the water trail, we can consider a relatively large, ambient temperature telescope to maximize sensitivity and angular resolution, coupled to a multiband receiver covering key spectral lines of water and its isotopologues. A large survey of the submillimeter transitions of water vapor in conjunction with studies of water ice using JWST and SPHEREx will revolutionize our understanding of the role of water, its distribution, and key ISM processes. The required submm observations will not be possible with either the ESA/JAXA mission SPICA or the Astro2020 Decadal Study mission Origins Space Telescope (Origins) as developed by NASA, which in its current version includes a heterodyne instrument only as a possible up-scope option.

Three attributes for the receiver are: (1) to observe multiple bands simultaneously, (2) to have maximum sensitivity, and (3) to have spectral resolution ~0.1 km/s. The optical system first separates two linear polarizations, then separates the bands with frequency selective surfaces, and finally images beams coupling to the individual mixer feedhorns. We report on studies of a number of designs for a telescope of diameter between 2m and 7m. To observe lines between 500 GHz and 1200 GHz requires a surface accuracy of 13 microns *rms* or better. A number of advances have improved the ability to observe water in a wide range of sources including dense cores, protostellar disks, comets, and other minor objects in the solar system. These include 1) improved SIS receiver performance and design relative to what was available for Herschel/HIFI, 2) frequency-multiplied local oscillator chains that can now readily supply with significant tunability, and 3) CMOS ASIC digital spectrometers offer multi-GHz bandwidth per pixel with very low power consumption. These technical developments make a scientifically compelling Water Mission feasible and affordable.