National Aeronautics and Space Administration

Water Formation and Heritage Across Cosmic Time

Principal Investigator: Robert West (322); Co-Investigators: Paul Goldsmith (326), Yasuhiro Hasegawa (326), Youngmin Seo (326), Karen Willacy (326)

Program: FY21 R&TD Strategic Initiative   **Strategic Focus Area: The Science of Water in the Universe**

Objectives

The overarching objective of this study is to 'follow the water trail' across space and time, from the earliest times to the foirmation of planetary systems, to exoplanets. Specific objectives are to understand the distribution, isotopic composition, and evolution of water in several key astrphysical environments (dense cores, protostellar disks, planetary systems, and exoplanets, with attention to habitability).

Background

This task is one of two, covered under the Strategic Focus Area The Science of Water in the Universe. In this task we study water in a variety of astrophysical environments leading to our own planet Earth. We cover a wide range of temporal and spatial scales, from galaxies to interstellar cloud cores, to protoplanetary disks, to exoplanets, and the formation and evolution of planetary systems. This last sub-task ties together several of the others and connects to our sister task led by Dariusz Lis, whose team focusses on comets and processes in our solar system. A common thread throughout both of these tasks involves the deuterium-to-hydrogen ratio. This ratio is key for probing, among many other things, the origin of the earth's water, from possible cometary or asteroidal impacts during late-stage formation of the earth.

Approach and Results

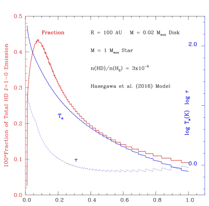
We have four sub-tasks: (1) To use observations of HD emission to measure the mass of protostellar disks, lead by Paul Goldsmith, (2) To use computer codes to model the chemistry inside dense cores and protostellar disks, and to model emission features that can be used to guide observations, lead by Karen Willacy and Youngmin Seo, (3) to calculate the polarization signature of light reflected from an exoplanet to determine sulfuric acid concentration in cloud droplets and to infer from that the ability of organisms to survive in the clouds or in an acidic lake or ocean, lead by Robert West, and (4) to model formation mechanisms for planetary systems to understand the construction of planets from the initial gas, dust, pebbles, and planetesimals, and to understand the distribution and transport of water and deuterium fractionation at the various stages, lead by Yasuhiro Hasegawa. Each of these heavily invests in computer modeling, and each has a goal to determine what types of observations would best address future advances for these topics. For example, in the case of the polarization signature of directly-observed exoplanets, we computed expected signal-to-noise ratio for a notional HabEx mission to determine under what circumstances such a mission would be able to make a meaningful assessment of the ability of life to exist, based on the acidity of the cloud drops retrieved from polarization data.

Significance/Benefits to JPL and NASA

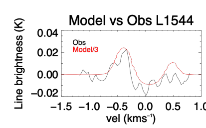
Our efforts lay the science groundwork for Flagship and smaller missions now under consideration by NASA and the science community, and for JPL-led Discovery or Midex mission concepts. One example is "Source", a 7X, MIDEX/PROBE; 4X DISCOVERY mission concept. Our objectives strongly intersect with those of the NASA flagship Origins mission concept, and various aspects of HabEx and other mission concepts. We also show pathways to proposals and analyses of observations from JWST and SOFIA.

Publications

Two papers in preparation

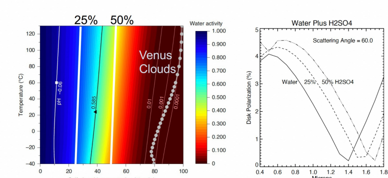


Shown here are model results for a radiative-transfer calculation of a simulated protostellar disk, using HD as a tracer. Antenna Temperature (that would be observed by future interferometer resolving disk structure) declines rapidly with radius (BLUE CURVE). Due to disk area increasing with r, the FRACTION of the total signal shows clear peak at around 10 AU (RED CURVE) This is the region that is primarily being sampled by current unresolved data There is significant issue with the HD line being optically thick in inner portion of disk (DOTTED BLUE CURVE) – observations are NOT picking up all the HD in this region. Scales for the blue curves are on the right.



Results of a chemistry model (red curve) for water in core L 1544 are shown along with Herschel observations. The curves are differences relative to the dust continuum. Although the profile shapes show moderately good agreement, refinement is needed. Water abundance in outer regions is too high - probably due to desorption being too efficient (in the model) at returning ices to gas.

Water Activity and Polarization of a Directly Imaged Exoplanet
A planet covered by optically thick clouds: Habitable?



Life as we know it cannot survive acid concentrations higher than the white square or black triangle, at their respective temperatures. Polarization measurements of a directly-imaged exoplanet might discriminate, provided signal/noise is sufficiently high. Left panel from Hallsworth et al., 2021.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Robert.A.West@jpl.nasa.gov

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