FIR Solar System Science Questions

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Solar System Sub-Group

- 29 International Members
- Advise on Science Goals, Capability Requirements, Complementary Science
- 2 meetings to date

Anderson	Carrie	GSFC
Arenberg	Jon	NGC
Bauer	Gerbs	JPL
Bergin	Ted	U. Mich
Bjoraker	Gordon	GSFC
Cordiner	Martin	CUA
de Pater	Imke	Berkeley
Ennico	Kim	Ames
Fletcher	Leigh	Leicester
Gerakines	Perry	GSFC
Gurwell	Mark	CfA
Hesman	Brigette	Umd
Leisawitz	David	GSFC
Lillie	Charles	Lillie Consulting
Lis	Darek	Caltech
Livengood	Timothy	UMd
Milam	Stefanie	GSFC
Moullet	Arielle	NRAO
Nixon	Conor	GSFC
Orton	Glenn	JPL
Padget	Deborah	GSFC
Palumbo	Ernesto	IAPS-INAF
Pontoppidan	Klaus	STScI
Reach	Bill	USRA
Santos Sanz	Pablo	IAA
Stansberry	John	STScI
Su	Kate	UAz
Sylvestre	Melody	Bristol
Unwin	Stephen	JPL

My expectations for the STDT are to consider an observatory that address key science objects for all communities (including the solar system) that is complementary to current/future observatories (ALMA, JWST)

Solar System Key Science: Water, time-variable, and composition studies

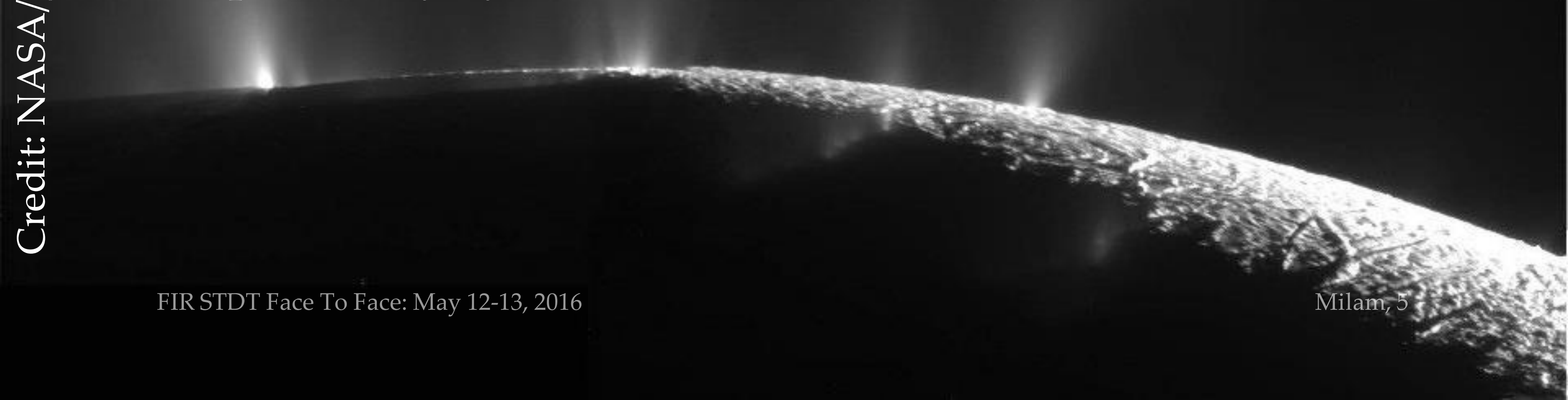
- D/H and other volatile isotope ratios in small bodies and planetary atmospheres.
- Search for water across the Solar System
- Compositional studies
- Solar System targets are ideal for appealing to the public and provide a tremendous asset to astrophysics missions.
- Most objects are extended and bright – may cause saturation issues.
- Moving targets with rates of motion up to >100 mas/s
- Targets themselves or other phenomena (storms, impact events, etc) are often variable or short lived.
- High Spectral Resolution required for many targets (R>10,000).

Key Science Questions

- Comprehensive Questions for community?
- Relevant in 15 years post-JWST and post-WFIRST (and other facilities) and cannot be done between now and then?
- Transformative Science?

Key Questions 1: Water

Where is the water in the Solar System?
Observations of water in planets, satellites, and small bodies can help determine the distribution of water in the presolar disk, the origin of small bodies, as well as provide a tracer for planetary activity, potential sites for extraterrestrial biology, and offer insight into the nature of water in other planetary systems.



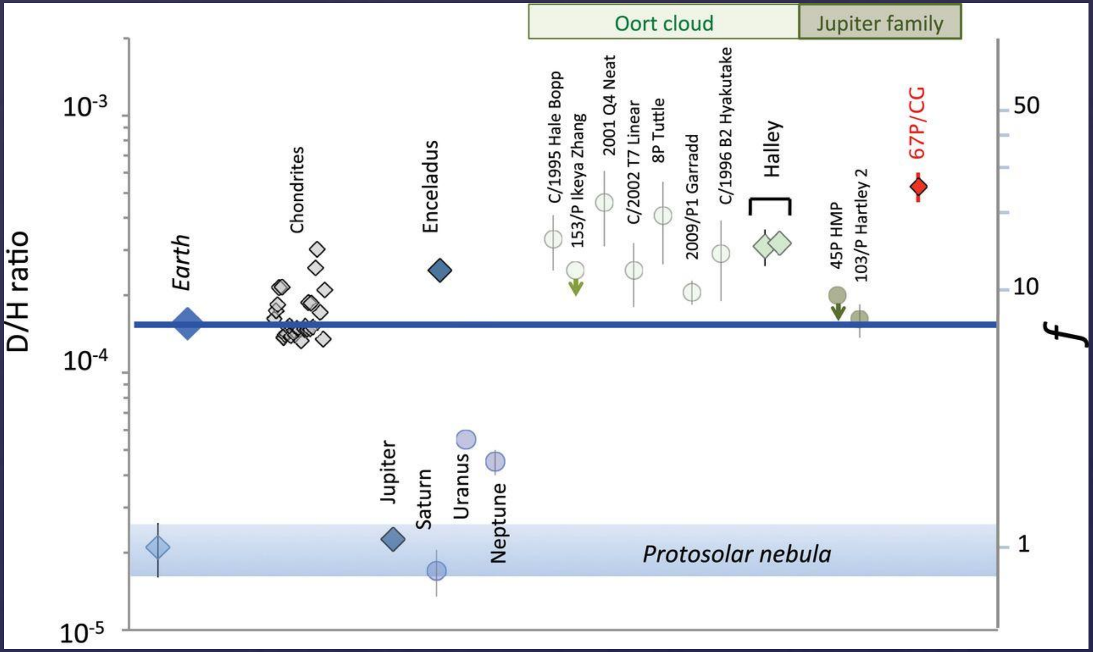
Credit: NASA/JPL.

Key Questions 1: Water

- What can we learn about subsurface oceans in the Solar System using remote H_2O observations?
- What drives activity (outgassing/plumes) from icy moons, comets etc.?
- How do observations of extrasolar protoplanetary and debris disks enrich our understanding of the formation and evolution of the solar system, and vice versa? (a) Giant planet formation and migration (b) Tapping the water reservoir to make “ocean worlds” (c) Understanding how to read the D/H tea leaves (d) On what timescale does the gas dissipate?

Key Questions 2: Isotopes

What is the distribution of volatile isotopes (H, C, N, and O) across the Solar System?



Can we determine the origin of water in the solar system from isotopic evidence in small bodies? Can statistical studies of volatile isotopes reveal the origin of volatiles to terrestrial bodies?

Key Questions 2: Isotopes

- What is the statistical distribution of D/H values (in H_2O) in Oort Cloud comets, Jupiter Family comets (and main belt comets / active asteroids)? The answer to this question is crucial as a probe of the thermo-chemical history of these bodies as well as determining their possible role in exogenous delivery of materials to the early Earth. Could we finally explain the mechanism of water delivery to Earth ?
- What does the oxygen isotope ratio tell us about the origin of water on Earth?
- D/H ratio in atmospheres of giant planets from Far-IR HD lines at 89, 178, 265, 351 cm^{-1}.
- What do the oxygen and nitrogen isotopic ratios tell us about the solar system formation and evolution?

Key Questions 3: Characterization

What is the surface and atmospheric composition of solar system bodies, what form does the organic matter take, and how is it distributed or influenced within a given target?

Compositional studies of the outer solar system, including seasonal or geological variability, can help constrain models of solar system formation. Study atmospheric chemistry and provide case studies for exoplanets.

Key Questions 3: Characterization

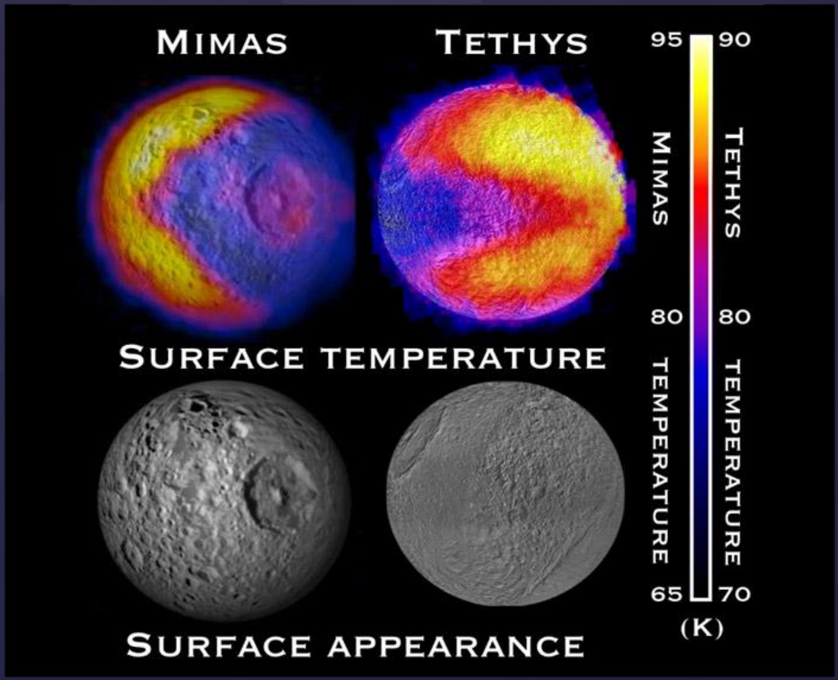
- What are the distributions of H_2O, CO, HCN, CH_4, NH_3 etc. in the atmospheres of planets, moons and other Solar System bodies? Eg.: abundance studies of Pluto, Triton, Neptune, Uranus, Titan from far-IR rotational lines, including spatial and temporal variations. What can these species tell us about atmospheric structure, chemistry, climate and origin?
- Living Solar System objects: probing dust and volatile release from large and primitive Asteroids, Comets, KBOs – Statistical survey of small bodies.
- Characterize Planet 9. What does that tell us that we didn't already know about the solar system?
- Probe solar system and exo-planets in molecules that are inaccessible from ground -- H_2O, C_2H_2, NH_3, etc -- hydration, gases, ices. How widespread are molecules useful or essential (water) to life, and where can they be found?

Key Questions 3: Characterization

- What is the He/H_2 ratio in Uranus and Neptune? This should be able to be determined from the shape of the far-infrared spectrum, coupled with shorter-wavelength observations of from SOFIA/FORCAST out to 35 microns or ground-based observations out to 25 microns.
- Methane in the solar system atmospheres - where is it, how is it distributed.
- Acquire unbiased statistical distributions of small-body orbits throughout the Solar System and compare to composition -- what comes from what, and from where?
- What is the content of gases escaping Enceladus and Ceres (+ Europa)?

Key Questions 4: Thermal

Determine the thermal structure, endo- and exogenic heating, inertia of small bodies, and atmospheric effects using reflected sunlight combined with thermal measurements. Statistically measure thermophysical properties of small bodies to help understand their origins, endogenic heat fluxes, and surface alteration by their external plasma environments.



Key Questions 4: Thermal

- What's cooling Pluto? Is this cooling important for other thin, sublimation atmospheres? [Upper atmosphere is cold, much colder than expected...no obvious coolant yet identified]
- What is the magnitude (and possible source) of internal heating in solar system and exoplanet bodies? Compare actual radiant energy to estimated short-wavelength heating.
- For Giant Planet systems, the key goal would be unraveling the thermal structure, chemistry and dynamics of planetary atmospheres; as well as mapping thermal emission from planetary satellites and small bodies to understand their origins, endogenic heat fluxes and surface alteration by their external plasma environments. For Uranus and Neptune, in particular, such models will also be useful to create standard calibration sources; this is a useful follow-on to Herschel and - to a lesser extent - Planck.

Key Questions 4: Thermal

- What is the total bolometric output of Uranus: is it truly representative of an atmosphere without an internal heat source.
- What are the Far IR/thermal emission characteristics of KBOs down to the 50 km size, and what is the size distribution of the outer solar system populations down to these sizes.
- Detection, light-curves, thermal inertias of airless moons.

Key Questions: Other

- Broad question - what about the giant planets and ice giants - is there frontier information?
- Planetary rings new discoveries (e.g. Mars Torus) and detailed studies

Essential Requirements for Solar System Studies

- Temporal Coverage: regular, repetitive observations
- Spatial Resolution: provide global and spatial studies
- Moving Targets: Track rates of motion > 60 mas/s
- Sensitivity: extended bright objects vs small faint targets – require a large dynamic range on sensitivity
  - Detection of new/minor species and isotopes
- Spectral Resolution
  - Isotopes (H, C, N, O), H_2, H_2O, CH_4, NH_3, CO_2, etc.
- Compete with Spacecraft: complementary observations to flybys, orbiters, landers, and rovers.
- Calibration: unique to Solar System objects (often used as calibrators).

Summary

- 4 major key questions: Water, Isotopes, Characterization, Thermal
- The dynamic nature of MOST Solar System objects makes these 4 themes/questions relevant regardless of past/current/future observations.
  - Statistical studies are needed for small bodies that cannot be done with current/future missions (more is always needed!).
  - Weather, seasonal, impact, etc events should be observed routinely.
- LOCAL-truth for Exoplanets and Planetary Formation.