JPL'S CAPABILITIES FOR ICE PHYSICS EXPERIMENTATION WITH PLANETARY APPLICATIONS.

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Introduction: The interpretation of data obtained by planetary missions relies on models of the physical properties of astromaterials. In the case of ices, many of the compounds identified on planetary surfaces and suggested by cosmochemical models do not occur naturally on Earth It is therefore necessary to conduct experiments using synthetic samples and specific equipment to reproduce the environmental conditions specific to icy bodies. The JPL Ice Physics Laboratory (http://scienceandtechnology.jpl.nasa.gov/research/facilities/ices) has developed several cryogenic facilities, devoted to the measurement of planetary ice physical properties, to support geophysical modeling and mission data interpretation. We present here the experimental facilities developed to date and the applications envisioned for these facilities.

Physical measurements: Table 1 lists the facilities available at the Ice Physics Laboratory. The measurements fall into four families.

Mechanical/Rheological properties: A good understanding of the mechanical properties of ices is essential to build realistic geophysical models of the evolution and transport of matter and heat in icy bodies. The *Planetary Tides Simulation Facility* investigates the visco-elastic and anelastic properties of solid ice samples, to bring new constraints on the role of tidal dissipation on the evolution of icy satellites, particularly via the development of a new model that includes anelasticity [1,2]. The cryogenic viscometer is devoted to studying the flow properties (viscosity, thixotropy, yield stress) of aqueous mixtures, partially frozen under their liquidus, in order to provide data useful to interpret the geomorphological features associated to the possible flow of such slurries on Titan's surface [e.g., 3] and/or within the icy shell and at the ice-ocean interface.

Thermal and thermodynamic properties: The mechanical properties depend largely on sample nature, stress and temperature. It is thus also crucial to have reliable models of the thermal structure of icy bodies to understand their evolution. Furthermore, most icy bodies do not contain only water ice, but also hydrates, volatiles, and aqueous components (e.g., ammonia) that affect the stability of each phase [e.g., 4]. A high-pressure cryogenic calorimeter has been recently developed to investigate the phase behavior of chemical systems with H_2O, N_2, CO_2, CH_4, and compounds in solution (e.g., NH_3). Although the thermal conductivity of water ice is fairly well known down to low temperatures, thermal data on other phases of interest are scarce. A new cryogenic thermal conductivity setup is now available and is being used to fill in this data gap.

Dielectric properties: Radar instruments, and most recently Radar Sounding instruments, are among the most widely used to study the surface morphology and subsurface of planetary bodies. However, the lack of a database of dielectric measurements for frozen materials and organics covering a wide range of frequencies hinders data interpretation. Two facilities have been developed to remedy this issue with the literature and help with the interpretation of planetary Radar data.

Interactions between liquid hydrocarbons and icy substrates: Titan has a dense atmosphere and a hydrocarbon cycle, with lakes that form from precipitation of methane, ethane, and other products of the atmospheric chemistry. Titan's surface is expected to consist of water ice or clathrate hydrates, probably with some porosity. A cryogenic chamber allows investigating the interactions between the liquid precipitates and the surface: wetting, absorption in the ice, etc [5].

Sample synthesis and characterization: The physical properties investigated in the Ice Physics Laboratory strongly depend on sample composition and microstructure. Accordingly, a significant effort has been allocated to developing the *Ice Factory*, which regroups all the equipment needed to produce and characterize frozen samples [6]. Table 2 describes the analytical techniques available to us at JPL to conduct this crucial, initial step of the experiments. Future studies will include more complex sample compositions, with silicates and organics mixed with ices.

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References: [1] Castillo-Rogez J.C. et al. (2011) *JGR, 116,* E09008. [2] Castillo-Rogez J.C. et al. (2012) *LPS XLIII,* this meeting. [3] Zhong F. et al. (2009) *Icarus, 202,* 607-619. [4] Fortes A.D. and Choukroun M. (2010) *Space Sci. Rev., 153,* 185-218. [5] Sotin C. et al. (2009) *LPS XL,* Abstract #2088; Sotin et al., in prep. [6] Choukroun M. et al. (2011) *Microscopy and Analysis, 25*, 5-7.

Table 1. Characteristics of the experimental facilities and ongoing research at the JPL Ice Physics Laboratory.

Experiment	Measurement	Conditions	Samples (to date)	Applications
Planetary Tides Simulation Facility	Visco-elastic properties, attenuation	Stress: 0.05-4 MPa Temp.: 150-300 K	Solid ice, hydrates, clathrate hydrates	Rheology of ices, tidal heating modeling of icy bodies
High-pressure calorimeter	Phase diagrams, thermodynamic properties	Temp.: 80-400 K Pressure: 0-10 MPa	Clathrate hydrates in aqueous solutions	State of volatile-bearing ices and cryovolcanism
Thermal conductivity setup	Thermal conductivity	Temp.: 90-300 K	Solid ice, hydrates, clathrate hydrates	Thermal modeling of icy satellites
Cryogenic viscometer	Rheology of slurries (solid-liquid binary mixtures)	Temp.: 150-300 K	Aqueous solutions (methanol, ammonia, sulfates)	Cryovolcanism on Titan, slurries at internal ice-ocean interfaces
Titan chamber	Wetting of ices by liquid hydrocarbons	Temp.: 80-300 K Pressure: < 1 bar N_2	Substrate: ice, clathrate hydrates Liquids: methane, ethane, etc.	Physical interactions between Titan's bedrock and lakes
Cryogenic microwave setup	Dielectric properties of liquids/solids	Temp.: 80-300 K Frequency: 13.78 GHz	Liquid hydrocarbons, ice/hydrates	Modeling and interpretation of Cassini Radar data on Titan's lakes
Dielectric setup	Dielectric properties (solid materials)	Temp.: 150-273 K Frequency: 1-100 MHz	Ice, hydrates, mixed with rock	Interpretation of ground-penetrating RADAR
Ice Factory	Sample synthesis and characterization	Cold room: 210-350 K; Freezers: 240 and 190 K; Compaction to 150 MPa	Solid water ice (50 μm to 1 mm grain size), clathrate hydrates, hydrated sulfates	Synthesis of planetary ice analogs with controlled composition and microstructure for the physical measurements.

Table 2. Analytical facilities available to the Ice Physics Lab at JPL for cryogenic sample characterization.

Analytical technique	Characteristics	Samples tested to date	Conditions	Application/Resolution
Optical microscope + Linkam cryostage	Transmitted and reflected, polarized or crossed-polarized illumination	Sections of ice, hydrates, clathrates	77-580 K, with N_2 purge	Microstructure analysis, down to <1 μm
LabRam imaging Raman spectrometer + Linkam cryostage	532 and 633 nm laser sources, with automated XYZ stage for imaging	Sections of ice, clathrates, hydrates, liquid hydrocarbons	77-580 K, with N_2 purge	Composition and microstructure, spectral resolution < 1 cm^{-1} from 50-4000 cm^{-1}
Cryogenic Scanning Electron Microprobe	10 kV accelerated electrons, secondary electron imaging, with X-ray spectrometer	Ice, clathrates, hydrates	77-300 K, under high vacuum	Microstructure analysis with a resolution up to 100 nm, and composition from ~ 0.5-1%