Solar System Science for SOFIA

Dale P. Cruikshank
NASA Ames Research Center

Asilomar, June 7-8, 2010
Solar System science in the SOFIA science vision document, 2009

- Primitive bodies
  - Trans-Neptunian objects (TNOs), centaurs and asteroids
    - Atmospheres of TNOs from stellar occultations
    - Comets—mineralogy, water, organic molecules

- Extrasolar planetary material

- Giant planets
  - Global studies, atmospheric chemistry, spatial/temporal variations

- Venus
  - Atmospheric structure, chemical and isotopic composition

- Titan, a prebiological organic laboratory
  - Atmospheric chemistry
Occultations of stars by Trans-Neptunian Objects (TNOs) with SOFIA

- **Objectives**
  - Establish accurate diameters
  - Probe for atmospheres
  - Search for close companions

- **Approach**
  - Target brightest TNOs
  - Observe from optimum locations
  - Make simultaneous optical/IR observations with HIPO and FLITECAM

- **Prediction Strategy**
  - Improve orbits for the largest (~30) KBOs
  - Maintain list of possible events
  - Refine astrometry for the best possibilities
  - Select events to observe (error ≤ 1500 km)
  - Final prediction refinement in flight?
The ices of Triton and Pluto

$N_2$, $CH_4$, $H_2O$, $CO$, ($CO_2$)
Trans-Neptunian Objects: Spectral evidence for thin atmospheres

- CH$_4$ ice bands shifted in wavelength
  - Indicates that CH$_4$ occurs in an N$_2$ matrix
- Presence of the 2.15- µm N$_2$ ice band
  - The $\beta$-phase of N$_2$ implies that T > 36 K
- Therefore, the “high” temperature implies an atmospheric pressure of several microbars of N$_2$
- Occultation lightcurves from SOFIA can give information on atmospheric structure and presence of haze layers
Comet spectra and protoplanetary and debris disks compared

Lisse et al., 2008
Jupiter is a changing planet …

Disappearance of the South Equatorial Belt, 2009-2010

Impact scar in the atmosphere, 2009
Neptune’s pressure-induced $\text{H}_2$ spectrum

Key: ■ ISO SWS, ♦ Orton’s model, + Spitzer IRS LH
The atmospheres of Saturn, Uranus and Neptune are seasonally variable.

The 20-year lifetime of SOFIA corresponds to the transition of Uranus from equinox to solstice.
An outstanding problem:
Methane on Mars?

A problem for EXES at high spectral resolution and smaller telluric CH$_4$ column abundance

The CH$_4$ detection is based on a doppler-shifted Mars lines seen on the wings of lines in the telluric CH$_4$ band at 3.35 $\mu$m

Mumma et al., 2009
Recent Discoveries, 2.5-5 \( \mu \text{m} \) –
\( \text{H}_2\text{O} \) ice and Organic Solids on an Asteroid

\( \text{H}_2\text{O} \) ice coating on surface grains, asteroid 24 Themis

“Main Belt” comets may have near-surface ice

Organic signatures on 24 Themis after removal of \( \text{H}_2\text{O} \) ice band:
Green = PAHs
Violet = Asphaltite
Blue = Carbonaceous meteorite

Rivkin et al., Campins et al. 2010
Recent Discoveries, 2.5-5 µm – Carbonate minerals on an asteroid reveal a history of liquid water

The asteroid parent bodies of carbonaceous meteorites were also altered by liquid H₂O
Spectroscopy of Trans-Neptunian Objects 0.5-2.5 $\mu$m

Colors range from neutral to red, both with and without H$_2$O ice.
Importance of Extending Spectral Coverage to 5 μm

Triton spectrum
2.5 - 5 μm (Akari)
AKARI spectrum with grism. Resolution $\lambda/\Delta\lambda = 135$
(Preliminary version of the figure)
Isotopes in Ices

- $^{13}$CO on Triton
- O and S isotopes in SO$_2$ on Io
- Isotopes in CO$_2$
Trojan asteroid 624 Hektor and two comets. All show similar mineral emission features (primarily olivine)
Other primitive asteroids (C, P, and D types) having no diagnostic mineral bands in the near-IR, show mineral emission bands with differing detailed structures.

5 – 25 µm emission spectra may be the only way to determine their compositions.
6.2-µm Emission Feature on Asteroids *(Spitzer spectra)*

Most asteroids show an emission feature at 6.2 µm that is presently unidentified.

May be **hydrinous silicates, organics, or carbonates**. It is seen on asteroids showing no other evidence of hydration or organic materials.
The region 2.5 - 5 µm is especially rich in molecular bands in ices and organic solids.

The region > 5 µm is especially valuable for mineral identification, surface thermal properties, and comparisons of Solar System bodies to other sources.
Summary - II

- High-speed photometry is well addressed by HIPO
- High-resolution spectroscopy for Solar System bodies is well in hand in the first generation SOFIA instruments
- Low-resolution ($R = 100 – 1000$) spectra measured simultaneously in a broad spectral range (2.4 - 25 µm) are needed
  - Many small bodies can be observed
  - This spectral region includes reflected sunlight and thermal emission regions
  - Opens previously unobserved spectral regions of great importance in understanding origin and evolution of Solar System bodies.
  - High sensitivity more important than spectral resolution