Stratospheric Observatory for Infrared Astronomy Capabilities for Observations of Moons

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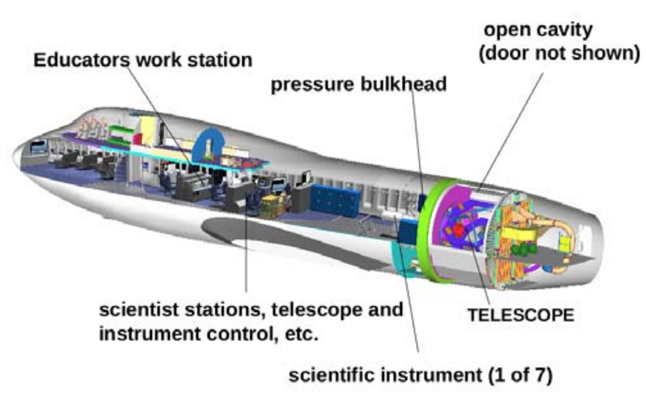
ABSTRACT

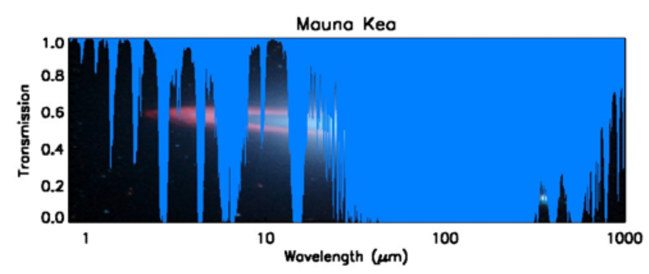
The Stratospheric Observatory For Infrared Astronomy (SOFIA) is a joint US/German effort to fly a 2.5 meter telescope on a modified Boeing 747SP aircraft at stratospheric altitudes, where the atmosphere is largely transparent at infrared wavelengths. It offers the convenient accessibility of a ground-based observatory coupled with performance advantages of a space-based telescope. Its portability will enable specialized observations of transient and location-specific events. Particularly relevant to this symposium is its ability to observe large moons without saturation of the detectors or straylight from the planets - phenomena that affected many spaceborne observatories.

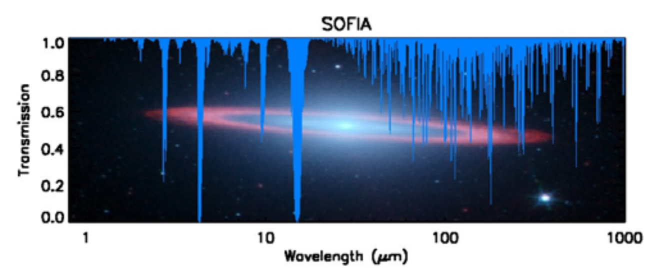
SOFIA's first generation instruments cover the spectral range from 0.3 to 240 microns and have been designed with planetary science in mind. The High-speed Imaging Photometer for Occultations (HIPO) is perfectly suited for occultations of stars by Solar System Objects, with SOFIA flying into the predicted shadows and characterizing the occulting object's atmosphere by means of a highly accurate light curve. The First Light Infrared Test Experiment CAMera (FLITECAM) offers imaging and moderate resolution spectroscopy at wavelengths between 1 and 5 microns that will be of use for the study especially of those moons, which have not been observed with NIMS on Galileo or VIMS on Cassini. The Faint Object infraRed CAmera for the Sofia Telescope (FORCAST) enables imaging and low-resolution spectroscopy at longer wavelengths than FLITECAM. It will, among other things, give access to the thermal emission of the Galilean satellites and shed light on their chemical composition and unique, radiation-induced reactions on the surface. By repeating the measurements from Voyager and the Infrared Space Observatory with better signal-to-noise ratio, vital information on the evolution of these moons can be gained. An instrument that will become available in the future is the Echelon cross Echelle Spectrograph (EXES). It will provide high-resolution spectral data between 5 and 28 microns that can for example be used to search for complex hydrocarbons and nitriles in Titan's stratosphere, benefiting from the lack of atmospheric interference by telluric water and carbon dioxide.

SOFIA's first light flight occurred in May, 2010, and the Cycle 1 observing program is scheduled to begin in October, 2012. The Program selected two new instrumentation proposals in the spring of 2012, and regular calls for observing proposals will be issued each autumn. SOFIA is expected to make some 120 science mission flights each year when fully operational in 2014.

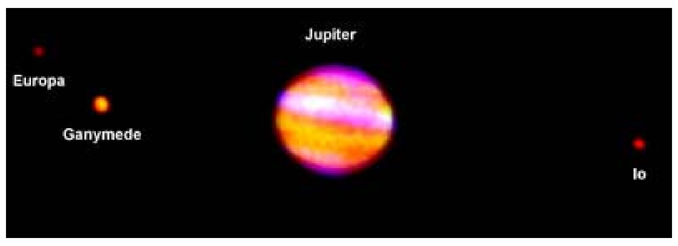
The Observatory







SOFIA and the Galilean Moons



SOFIA image of Jupiter and three of the Galilean moons composed of multiple frames taken at wavelengths of 5.4, 24, and 37 microns with the FORCAST infrared camera.

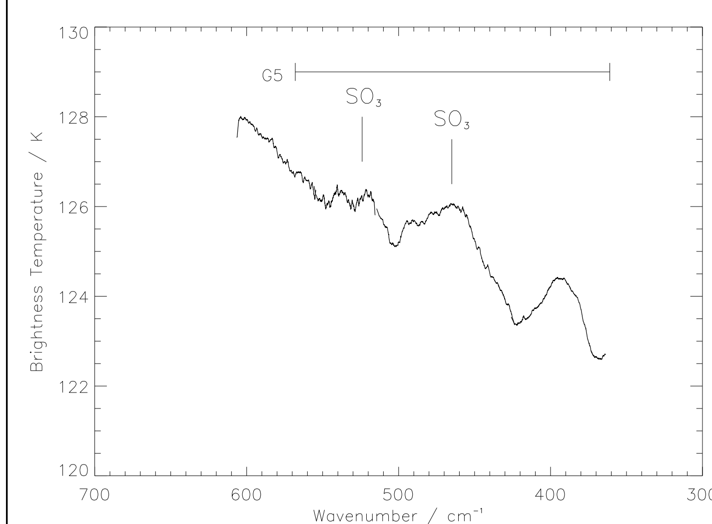
FORCAST, [1], will be able to perform grism spectroscopy at a resolution of R = $\lambda/\Delta\lambda$ = 90 - 300 with coverage from 5 - 37 μm (2000 - 270 cm^{-1}). Spectroscopy will be carried out by chopping and nodding either on-slit or off. This capability will be well suited to address questions about the surface composition of the Galilean moons, for example:

- What other molecules apart from sulfur dioxide are present in **Io**'s global frost [2]?
- Did carbonic acid and carbonates form on **Europa**, and what is the relevance of its surface chemistry for astrobiology?
- What are the differences and similarities between **Ganymede** and its neighbors? Thanks to its long operational lifetime, SOFIA may be a bridge to the arrival of JUICE in the Jovian system.
- Is carbon or sulfur the key element in the chemical reactions on the surface of **Callisto** [3]?

The Thermal Infrared Emission

In this column we show unpublished spectra from the Infrared Space Observatory. They demonstrate the presence of features in the thermal infrared, to which we provide tentative identifications. The wavelength ranges, where SOFIA can contribute data with better signal-to-noise ratios, are marked in the plots.

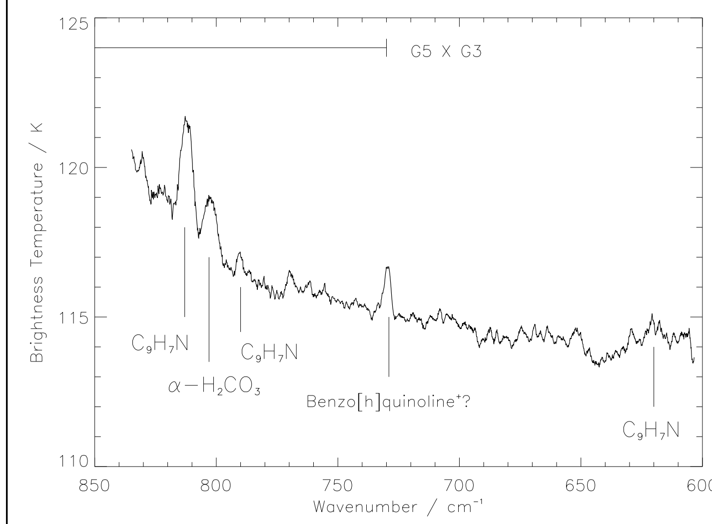
Io



The spectrum of Io between 610 and 360 cm^{-1} (16.4 - 27.8 μm) with features of SO_3 labeled with vertial lines, and the range of the FORCAST low-resolution G5 grism indicated with a horizontal line

Sulfur trioxide could make a significant contribution to the emission flux.

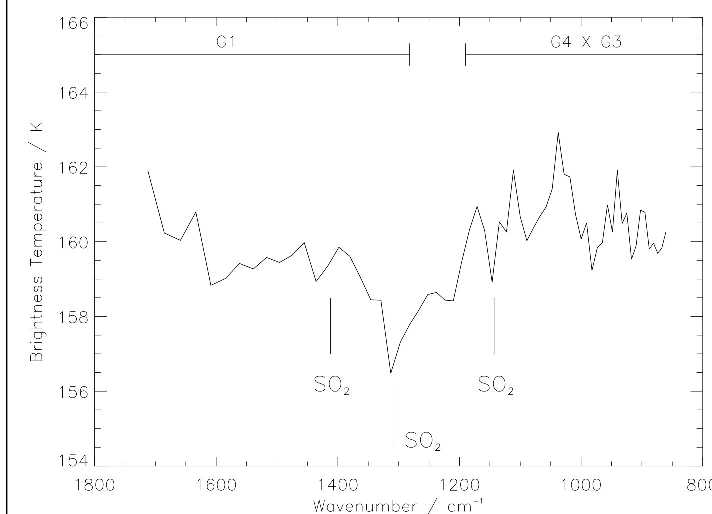
Europa



The spectrum of Europa between 840 and 600 cm^{-1} (11.8 - 16.7 μm) with the predicted locations of Quinoline (C_9H_7N) features labeled, and the range of the FORCAST moderate-resolution cross-dispersed G5 $\times$ G3 grism indicated with a horizontal line; the EXES instrument will cover this entire range at high resolution.

Quinoline is a polycyclic aromatic nitrogen heterocycle, which is related to nucleobases and has been detected in meteorite extracts [4].

Callisto

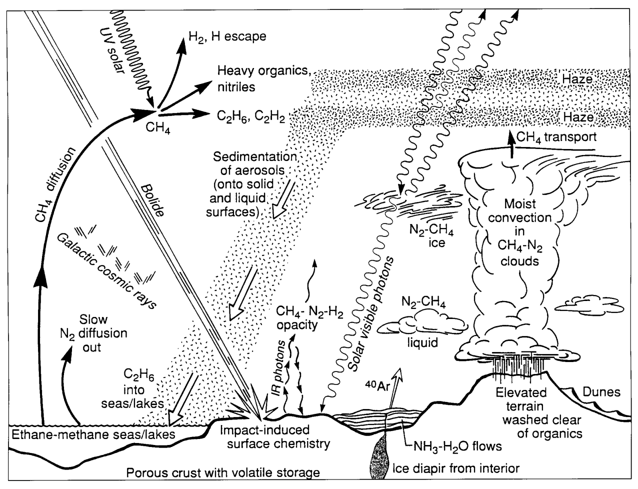


The spectrum of Callisto between 1720 and 860 cm^{-1} (5.8 - 11.6 μm) with the locations of SO_2 bands indicated with vertical lines and the ranges of FORCAST grisms shown as horizontal lines.

How significant are the local minima at the positions of the three strongest SO_2 bands in this wavenumber range [5]?

SOFIA and Titan

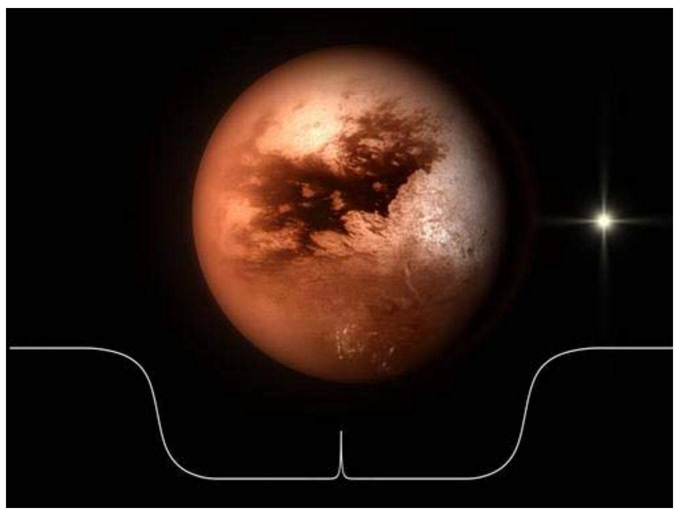
The mid-infrared wavelength coverage of EXES on SOFIA enables the search for and quantitative studies of organic and other molecules in Titan's rich and evolving atmosphere beyond the capabilities of spacecraft and ground-based observatories. We mention here in particular CH_3 at 16.5 μm (606 cm^{-1}), C_6H_2 at 16.1 μm (621 cm^{-1}), and crotonitrile at 13.7 μm (730 cm^{-1}). The existence of these molecular species on Titan has been predicted by models of its atmosphere. Major atmospheric constituents such as methane, carbon monoxide, and prussic acid can of course be studied and monitored as well.



Titan's atmosphere

Other Moons and Rings

Triton is too cold and too close to Neptune for spectroscopy with SOFIA. Observations of the water close to Enceladus are not possible, either, because the relevant lines are strongly excited in the Earth's atmosphere and overpower moon and torus. Rings are too faint or too close to their planet for direct observation. As SOFIA can reach any place on Earth, however, stellar occultations are an interesting option.



Simulated light curve during Titan occultation event

References

[1] T.L. Herter et al. 2012, Astrophysical Journal Letters, **749**, L18

[2] R.K. Khanna et al. 1995, Icarus **115**, 250

[3] R.E. Johnson et al. 2004, Jupiter, 485

[4] M.P. Bernstein et al. 2005, Astrophysical Journal, **626**, 909

[5] D.B. Nash & B.H. Betts 1995, Icarus **117**, 402