SOFIA - Science Vision and Current Status

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Outline

• SOFIA introduction
• SOFIA science vision
• SOFIA status
The History of Flying Infrared Observatories

- NASA Lear Jet Observatory (1967)
- NASA Kuiper Airborne Observatory (KAO) (1974)
- NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA) (2009)
SOFIA Overview

- 2.5 m telescope in a modified Boeing 747SP aircraft
  - Imaging and spectroscopy from 0.3 µm to 1.6 mm
  - Emphasizes the obscured IR (30-300 µm)

- Service Ceiling
  - 39,000 to 45,000 feet (12 to 14 km)
  - Above > 99.8% of obscuring water vapor

- Joint Program between the US (80%) and Germany (20%)
  - First Light in 2010
  - 20 year design lifetime –can respond to changing technology
  - Ops: Science at NASA-Ames; Flight at Dryden FRC (Palmdale- DAOI)
  - Deployments to the Southern Hemisphere and elsewhere
  - >120 8-10 hour flights per year
The Advantages of SOFIA

- Above 99.8% of the water vapor
- Transmission at 14 km >80% from 1 to 800 µm; emphasis on the obscured IR regions from 30 to 300 µm
- Instrumentation: wide variety, rapidly interchangeable, state-of-the-art – SOFIA is a new observatory every few years!
- Mobility: anywhere, anytime
- Twenty year design lifetime
- A near-space observatory that comes home after every flight
The SOFIA Observatory

Educators work station

pressure bulkhead

open cavity (door not shown)

scientist stations, telescope and instrument control, etc.

TELESCOPE

scientific instrument (1 of 8)
Observers in pressurized cabin have ready access to the focal plane.
SOFIA Telescope instrument interface
**SOFIA and Major IR Imaging/Spectroscopic Space Observatories**

- **Wavelegth (µm)**: 0.1, 1, 10, 100, 1000
- **Frequency (THz)**: 0.3, 3, 30

- **2005 - 2010**
  - SOFIA
  - Herschel
  - SPITZER
  - AKARI
  - WISE
  - Warm Spitzer

- **2015 - 2020**
  - SOFIA
  - SPICA
  - JWST

- **2025 - 2030**
  - SAFIR

- **Ground-based Observatories**

- **2034**
### SOFIA’s First-Generation Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Type</th>
<th>λ (μm)</th>
<th>Resolution</th>
<th>PI</th>
<th>Institution</th>
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<tbody>
<tr>
<td>HIPO</td>
<td>fast imager</td>
<td>0.3-1.1</td>
<td>filters</td>
<td>E. Dunham</td>
<td>Lowell Observatory</td>
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<td>FLITECAM</td>
<td>imager/grism</td>
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<td>filters/R~20000</td>
<td>I. McLean</td>
<td>UCLA</td>
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<td>heterodyne receiver</td>
<td>62-65 111-120 158-187 200-240</td>
<td>R~10^4-10^8</td>
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<td>MPIfR</td>
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<td>CASIMIR</td>
<td>heterodyne receiver</td>
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<td>imaging grating spectrograph</td>
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<tr>
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<td>EXES</td>
<td>imaging echelle spectrograph</td>
<td>5-28.5</td>
<td>R~3000-10^5</td>
<td>M. Richter</td>
<td>UC Davis</td>
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* Facility-class instrument
** Developed as a PI-class instrument, but will be converted to Facility-class during operations
Instrument R/λ graph

SOFIA Science Instruments

- **SOFIA**
- **GREAT**
- **CASIMIR**
- **EXES**
- **FIFI LS**
- **FORCAST** with grisms
- **FORCAST**
- **FIPE**
- **HAWC**

Spectral resolution

Wavelength [μm]
SOFIA and Regions of Star Formation

How will SOFIA shed light on the process of star formation in Giant Molecular Clouds like the Orion Nebula?

With 9 SOFIA beams for every 1 KAO beam, SOFIA imagers/HI-RES spectrometers can analyze the physics and chemistry of individual protostellar condensations where they emit most of their energy and can follow up on HERSCHEL discoveries.
Sources Embedded in Massive Cloud Cores

- In highly obscured objects, no mid-IR source may be detectable

- 20 to 100 microns can provide a key link to shorter wavelengths
SOFIA and Extra-Solar Circumstellar Disks

What can SOFIA tell us about circumstellar disks?

- SOFIA imaging and spectroscopy can resolve disks to trace the evolution of the spatial distribution of the gaseous, solid, and icy gas and grain constituents.

- SOFIA can shed light on the process of planet formation by studying the temporal evolution of debris disks.
The chemistry of disks with radius and Age

- High spatial and spectral resolution can determine where different species reside in the disk.

- Small radii produce double-peaked, wider lines.

- Observing many disks at different ages will trace disk chemical evolution.
Astrochemistry in Star Forming Regions

• SOFIA is the only mission that can provide spectrally resolved data on the 63 and 145 $\mu$m [OI] lines to shed light on the oxygen deficit in circumstellar disks and star-forming clouds.

• SOFIA has the unique ability to spectrally resolve water vapor lines in the Mid-IR to probe and quantify the creation of water in disks and star-forming environments.
SOFIA is the only mission in the next decade that is sensitive to the entire Far-IR SED of a galaxy that is dominated by emission from the ISM excited by radiation from massive stars and supernova shock waves.

The SED is dominated by PAH emission, thermal emission from dust grains, and by the main cooling lines of the neutral and ionized ISM.
**SOFIA Will Study the Diversity of Stardust**

- **Herbig AeBe**
- **Post-AGB and PNe**
- **Mixed chemistry post-AGB**
- **C-rich AGB**
- **O-rich AGB**
- **Mixed chemistry AGB**
- **Deeply embedded YSO**
- **HII region reflection nebulae**

- ISO SWS Spectra: stardust is spectrally diverse in the regime covered by SOFIA
- Studies of stardust mineralogy
- Evaluation of stardust contributions from various stellar populations
- Implications for the lifecycle of gas and dust in galaxies
Thermal Emission from PAH Rich Objects

- A key question is whether portions of the aromatic population of PAHs are converted to species of biological significance.

- Far-IR spectroscopy can constrain the size and shape of PAH molecules and clusters.

- The lowest lying vibrational modes ("drumhead" modes) will be observed by SOFIA’s spectrometers.

Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)
SOFIA and the Black Hole at the Galactic Center

- **SOFIA imagers and spectrometers can resolve detailed structures in the circum-nuclear disk at the center of the Galaxy**

- **An objective of SOFIA science is to understand the physical and dynamical properties of the material that feeds the massive black hole at the Galactic Center**
SOFIA observations of Far-IR lines can be conducted at unprecedented spatial resolution

ISM abundances and physical conditions can be studied as a function of location and nucleocentric distance
This occultation light curve observed on the KAO (1988) probed Pluto’s atmosphere

J. L. Elliot et al., Icarus 77, 148-170 (1989)

Isothermal above 1220 km with strong inversion layer below 1215 km

SOFIA and Comets: Protoplanetary Disks

What can SOFIA observations of comets tell us about the origins of our Solar System and other solar systems?


- The similarities in the silicate emission features in HD 100546 and C/1995 O1 Hale-Bopp suggest that the grains in the stellar disk system and the small grains released from the comet nucleus were processed in similar ways.
SOFIA and the Gas Giant Planets

- SOFIA’s unique capabilities of wavelength coverage, high spatial resolution, and long duration will open new windows of understanding of the giant planets through studies of their atmospheric compositions, structures, and seasonal and secular variability.

- These studies may enhance our understanding of the atmospheres of large, extra-solar “hot Jupiters”.

The IR spectrum of Neptune (Orton et al. 1987)

Varying thermal emission across the face of Jupiter showing beam sizes for FORECAST (NASA IRTF image)
SOFIA and Venus: Earth’s Neglected Sibling

- The chemistry and dynamics of Venus’s atmosphere are poorly understood.

- High resolution spectrometer on the Venus Express failed.

- Pointing constraints prevent our major space observatories from observing Venus.

- Sofia has the spectrometers and the sunward pointing capability to play a discovery-level role in our understanding of Venus’s atmosphere.
SOFIA and Extra-solar Planet Transits

How will SOFIA help us learn about the properties of extra-solar planets?

- More than 268 extra-solar planets; more than 21 transit their primary star
- SOFIA flies above the scintillating component of the atmosphere where it can detect transits of planets across bright stars at high signal to noise

- Transits provide good estimates for the mass, size and density of the planet
- Transits may reveal the presence of, satellites, and/or planetary rings

HD 209458b transit:
- a) artist’s concept and
- b) HST STIS data
## Segment 2 – Tracking dates

### 2010

<table>
<thead>
<tr>
<th>SS1 H/W Install/Checkout</th>
<th>Door Open/TA @ 23 deg</th>
<th>TA Misalignment (daytime)</th>
<th>Install/Checkout</th>
<th>FORCAST Mini Line Ops</th>
<th>TA Characterization/First Light attempt</th>
<th>Data Analysis</th>
<th>Briefings</th>
<th>Observatory Checkout</th>
<th>FORCAST Line Ops</th>
<th>TA Flight Prep</th>
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### Line Ops Prep

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<th>Data Analysis</th>
<th>TA @ 30</th>
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### TA Characterization

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### GREAT Line Ops

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<td>Holiday</td>
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Created 3/9/2010
Schedule Reference: SOFIA_IMS100311Mt.mpp

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**Color Key:**
- **Science Flight**
- **Platform Flight**
- **TA Flight**
- **Ground Testing**
- **Data Analysis**
- **Contingency Flight**
SOFIA: Science For the Whole Community

- Planetary Atmospheres
- Chemistry of the cold ISM
- Dynamics of collapsing protostars
- Dynamics of the Galactic Center
- Velocity structure and gas composition in disks and outflows of YSOs
- Composition/dynamics/physics of the ISM in external galaxies
- PAH & organic molecules
- Nuclear synthesis in supernovae in nearby galaxies
- Composition of interstellar grains
- Debris Disk Structure
- Luminosity and Morphology of Star Formation Galactic and Extra-Galactic Regions
- KBOs, Planet Transits
- Comet Molecules