Stratospheric Observatory for Infrared Astronomy

William T. Reach

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SOFIA Overview
Why Infrared

- Thermal radiation
- Absorbed sunlight is re-emitted at peak wavelength 13, 19, 30, 43, 60, 40 microns by solid bodies at distances 1, 2, 5, 10, 20, 85 AU from the Sun
- Vibrationally excited molecules
- Atmospheric transmission
  - Thermal structure by imaging at different wavelengths
  - Chemistry and dynamics from molecular line shapes

IRTF/Wesley/Kazumoto/Go

Spectral radiance, W/(m² µm sr)

Wavelength, µm
Infrared transmission above the stratosphere very good because we fly above 99.8% of water in the Earth’s atmosphere

Transmission >80% from 1 to 1000 microns

Instrumentation: we deploy a wide complement, rapidly interchangeable, state-of-the-art instruments, and we provide a test-bed for new instrumentation
SOFIA Quick Facts

• SOFIA is 2.5 meter telescope in a modified B747SP aircraft
  – Optical-mm performance
  – Obscured IR (30-300 microns) most important
• Joint US (80%) and German (20%) program
• Designed for 20 year lifetime
• Operating altitude
  – 39,000 to 45,000 feet (12 to 14 km)
  – Above > 99% of obscuring water vapor
• World Wide Deployments
• Home base: Palmdale, CA. (NASA/Armstrong)
• Science Center: Mountain View, CA (NASA/Ames)
• Deutsches SOFIA Institut (DSI): Stuttgart, Germany
The SOFIA Observatory

Telescope and Optical Layout

Telescope Performance

- SOFIA telescope was built in Germany and contributed by DLR
- Image quality depends on wavelength
  - Diffraction: $\lambda$(microns)/10
  - Jitter of telescope
  - Shear layer turbulence
  - Other effects
- Measured performance
  - diamonds
- Expected performance
  - Active mass dampers
  - Goal
    - Solid line
- Ultimate goal
  - Dotted line

![Graph showing Image FWHM (arcsec) vs. Wavelength (um)]
SOFIA Science Instruments

• Facility Science Instrument
  – Developed by contract and delivered to Project
  – Offered to all proposers
  – Operated by the science center

• Principal Investigator Science Instrument
  – Developed by contract and retained by contractor
  – Offered to all proposers
  – Operated by the PI team

• The 3\textsuperscript{rd} Generation Call for a new SOFIA instrument
  – Downselect to 1 or 2 for a detailed “Phase A” study starting 1/2016
  – Looking for one new facility-class science instrument delivered 2018
Quick tour of possibilities
Terrestrial Planets

Mercury: not visible

Venus: atmosphere composition, dynamics (winds, temporal variation) [EXES]

Mars: atmosphere composition (methane, D/H); dynamics
Outer Planets

- Jupiter
- Saturn
- Uranus
- Neptune

All:
- Convection in troposphere (FORCAST),
- convection in stratosphere (EXES),
- weather (FORCAST),
- atmosphere chemistry including exosphere (GREAT, EXES),
- heat output (FORCAST, FIFI LS, HAWC+)
Moons

• **Titan atmosphere** [EXES, GREAT]
  - prebiotic molecules
  - out-of-equilibrium species tracing hot chemistry

• **Moons with subsurface oceans**
  - Radiometry for energy balance [FORCAST, FIFI LS, HAWC+]
  - temporal and phase-angle changes due to surface features [”]
Small Bodies

Dwarf Planets
- Occultations [HIPO/FLIPO] for diameters, rings, atmosphere search, haze
- Radiometry [FORCAST]: diameter, thermal properties
- Surface composition [FORCAST & FLITECAM grism]

Comets
- Dust and gas composition from outgassing [GREAT, FORCAST]
- Mineralogy (Fe/Mg silicates) [FORCAST grism]
- Origin of terrestrial water (D/H, ortho/para) [GREAT]
More details on a few potential projects
• Visibility conditions on mid-Feb 2017:
  – 40 degree solar elongation
  – 40” angular size
  – but only visible in early evening for <1 hr
• Molecules already observed with TEXES
  – CO₂, HDO and SO₂
  – Detectability of lines depends critically on Doppler shift
• Other molecules remain uncharacterized
  – no access to infrared outside Earth’s atmosphere, while Venus has many of same gases as Earth
  – Isotopic ratios trace chemical history; why were Venus’ oceans lost?
• Dynamics
  – Vertical distribution of SO, SO₂ related to cycling
  – Winds
  – Factor of 5-10 temporal variation in SO₂ (Encrenaz et al 2012)
• CYCLE 4 project accepted
  – Constantine Tsang (SWRI) “Venus Atmosphere: D/H Ratio from H₂O and HDO Measurements”
SOFIA spectroscopic slits were stepped across the disk of Jupiter to make spectral maps.

With EXES at high spectral resolution: lib-brightened, narrow, stratospheric H$_2$ line.

With FORCAST at moderate resolution, measure pressure-broadened H$_2$

Para/Ortho state ratio, paired with CH$_4$ temperature, measures mixing rate in the atmosphere, because the rate of para/ortho conversion is known.
Pluto’s Atmosphere

- 2011 Jun 23 event
Pluto’s Atmosphere

- Person et al. 2013 AJ
Pluto’s Atmosphere

2015 Jun 29 event

A. Bosh (Monday 4pm)
- Haze in Pluto's atmosphere: Results from SOFIA and ground-based observations of the 2015 June 29 Pluto occultation
Proposing to observe with SOFIA

- **Annual proposal calls (issued April, due June)**
  - Observing period March-February
  - Approximately 800 research hours per year
  - Phase I proposals
    - Scientific & technical justification, Targets & durations
  - Selection based on time allocation committee of peers
  - Phase II (accepted projects)
    - Observation details entered with S-Spot, Annual observing schedule

- **Flight series**
  - Typically 1-3 week flight series with single science instrument
  - Rolling flight series flight plans
  - Guest investigators (1-2/flight) invited to monitor & tweak in real time

- **Data reduction**
  - Level 2 data processing pipeline: FITS files with artifacts removed
  - Level 3 calibrated data: readily useable files in physical units
  - Processing performed by science center (facility) or instrument team (PI)
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<td>17- to 37-micron Photometry and Spectroscopy of Uranus and Neptune</td>
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<td>Glenn Orton (JPL)</td>
<td>Jupiter's Stratospheric HCN, Hydrocarbon and Temperature Fields</td>
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<td>Charles Woodward (U. Minn.)</td>
<td>A Tale of Two Comets - The FORCAST Story</td>
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<td>Mineralogical Evolution in Extreme Debris Disks</td>
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<td>Therese Encrenaz (Paris Obs)</td>
<td>A map of D/H on Mars using EXES aboard SOFIA</td>
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<td>Andrew Rivkin (JHU/APL)</td>
<td>Characterization of OH and H2O in Asteroids</td>
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<td>Unusual material orbiting the dustiest main sequence A-type stars</td>
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<td>Joseph Adams (SOFIA/USRA)</td>
<td>The Dust Production Rate in the Fomalhaut Debris Disk</td>
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<td>Venus Atmosphere: D/H Ratio from H2O and HDO Measurements</td>
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<td>Shohei Aoki (IAPS Italy)</td>
<td>Verification of CH4 on Mars and investigation of its temporal and spatial</td>
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<td>variations by SOFIA/EXES</td>
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<td>Miriam Rengel (MPIfSS)</td>
<td>Investigating the composition of Titan's stratosphere with SOFIA: time</td>
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<td>variability &amp; intriguing unidentified signatures</td>
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<td>Inseok Song (U. Georgia)</td>
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<td>Juergen Wolf (DSI/SOFIA)</td>
<td>Stellar Occultations by Trans-Neptunian Objects and Centaurs</td>
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