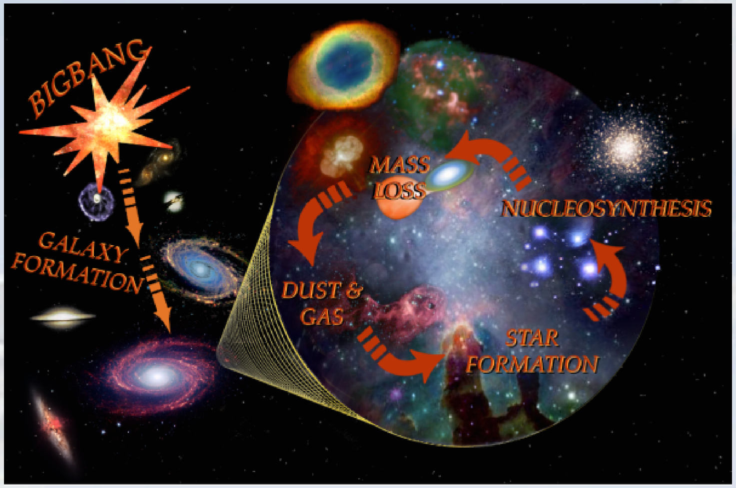
SOFIA - Science Vision and Current Status



Scott Horner

SOFIA Instrument Scientist

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http://www.sofia.usra.edu

Outline

- *SOFIA introduction*
- *SOFIA science vision*
- *SOFIA status*

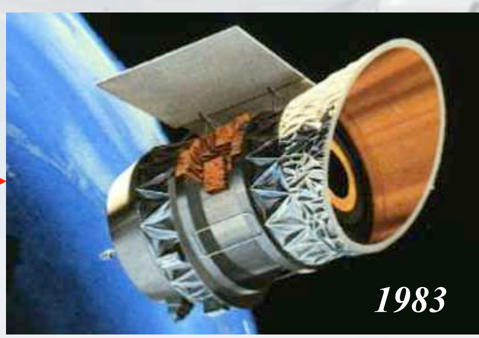
The History of Flying Infrared Observatories

NASA Lear Jet Observatory

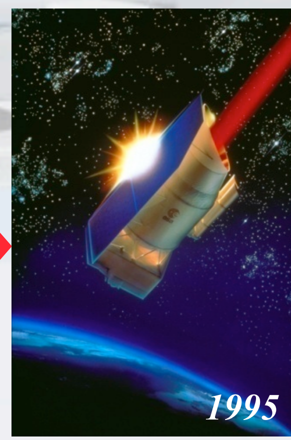
NASA Kuiper Airborne Observatory (KAO)

NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA)

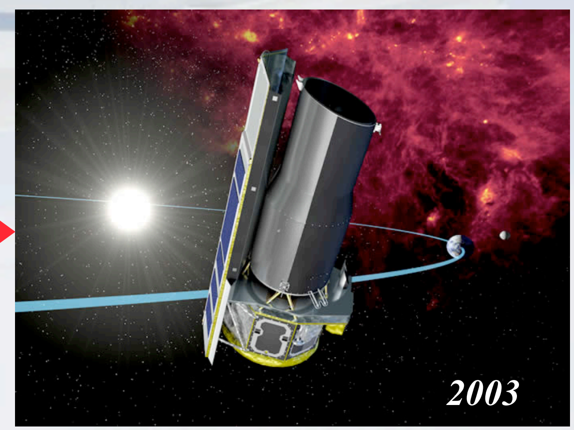
Science objectives



NASA Infrared Astronomical Satellite (IRAS)



ESA Infrared Space Observatory (ISO)



NASA Spitzer Space Telescope

SOFIA Overview

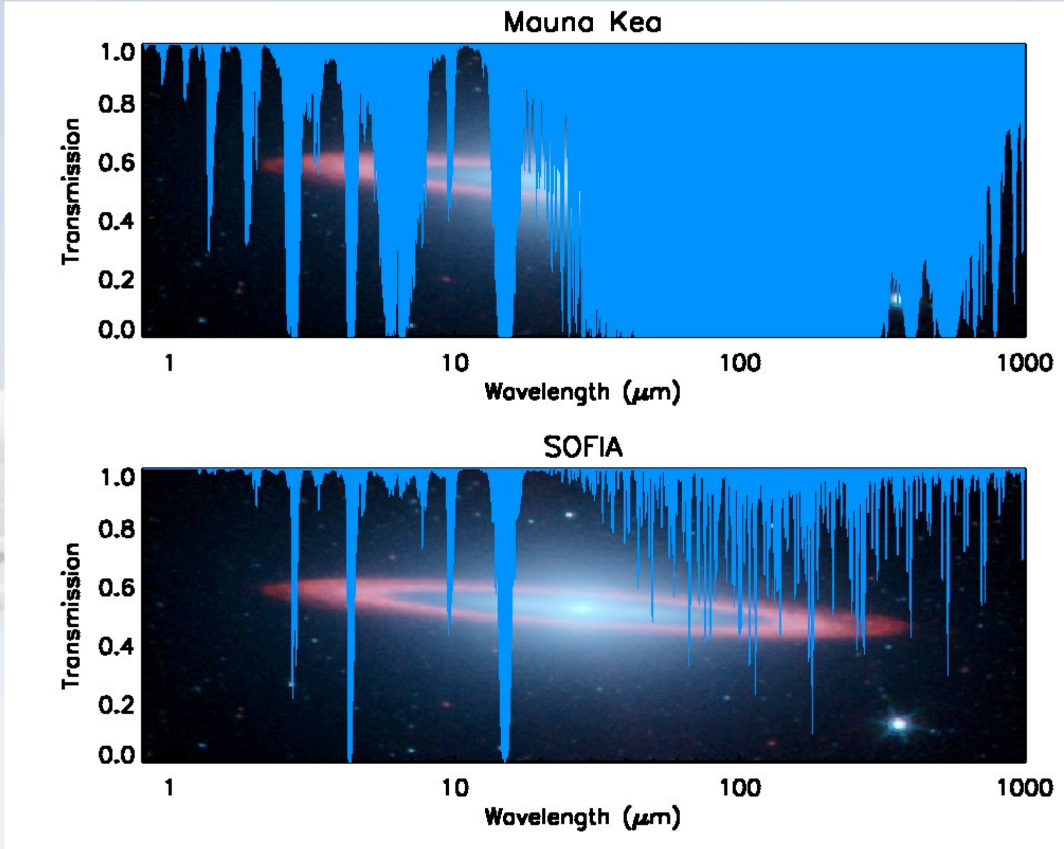
- *2.5 m telescope in a modified Boeing 747SP aircraft*
  - *Imaging and spectroscopy from 0.3 μm to 1.6 mm*
  - *Emphasizes the obscured IR (30-300 μm)*

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

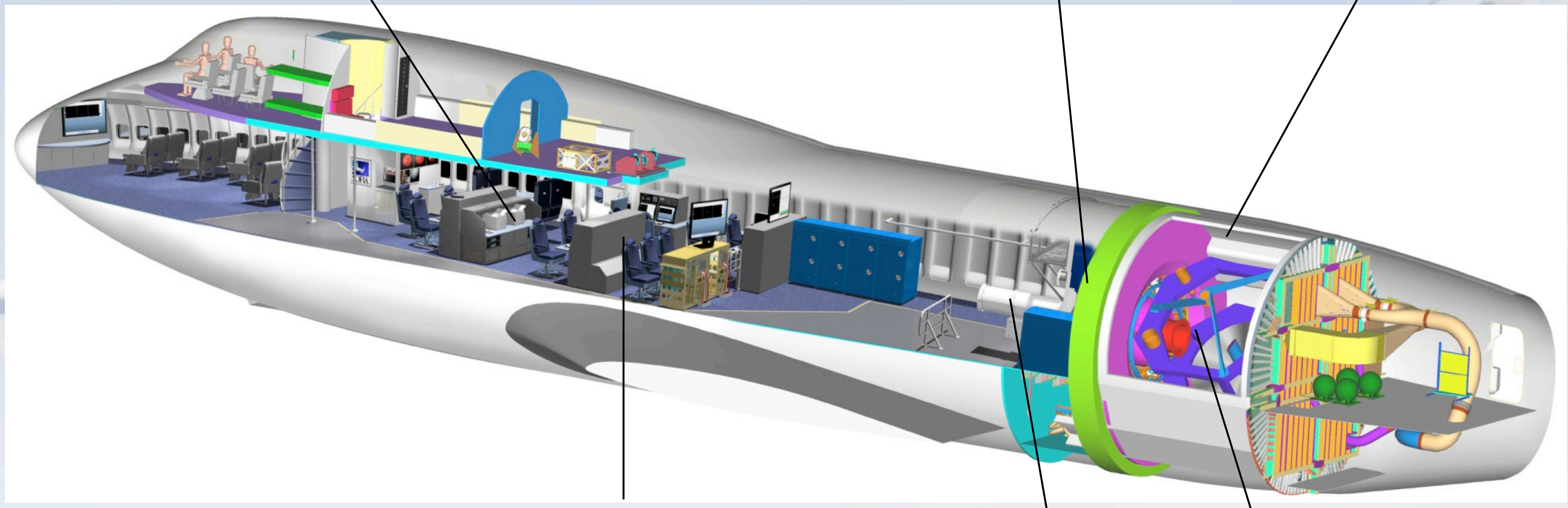
- *Joint Program between the US (80%) and Germany (20%)*
  - *First Light in 2010*
  - *20 year design lifetime –can respond to changing technology*
  - *Ops: Science at NASA-Ames; Flight at Dryden FRC (Palmdale- DAOF)*
  - *Deployments to the Southern Hemisphere and elsewhere*
  - *>120 8-10 hour flights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

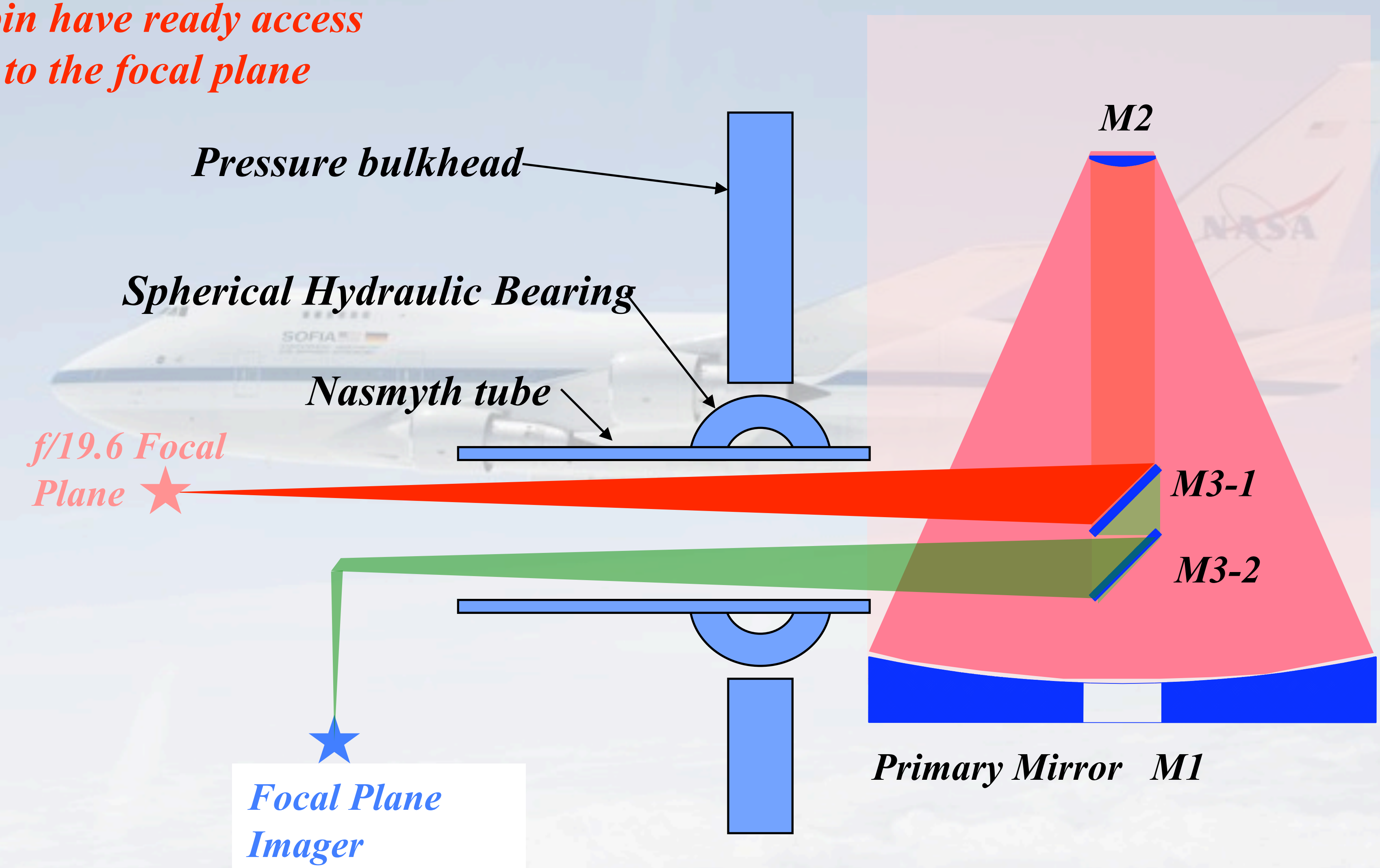


The SOFIA Observatory



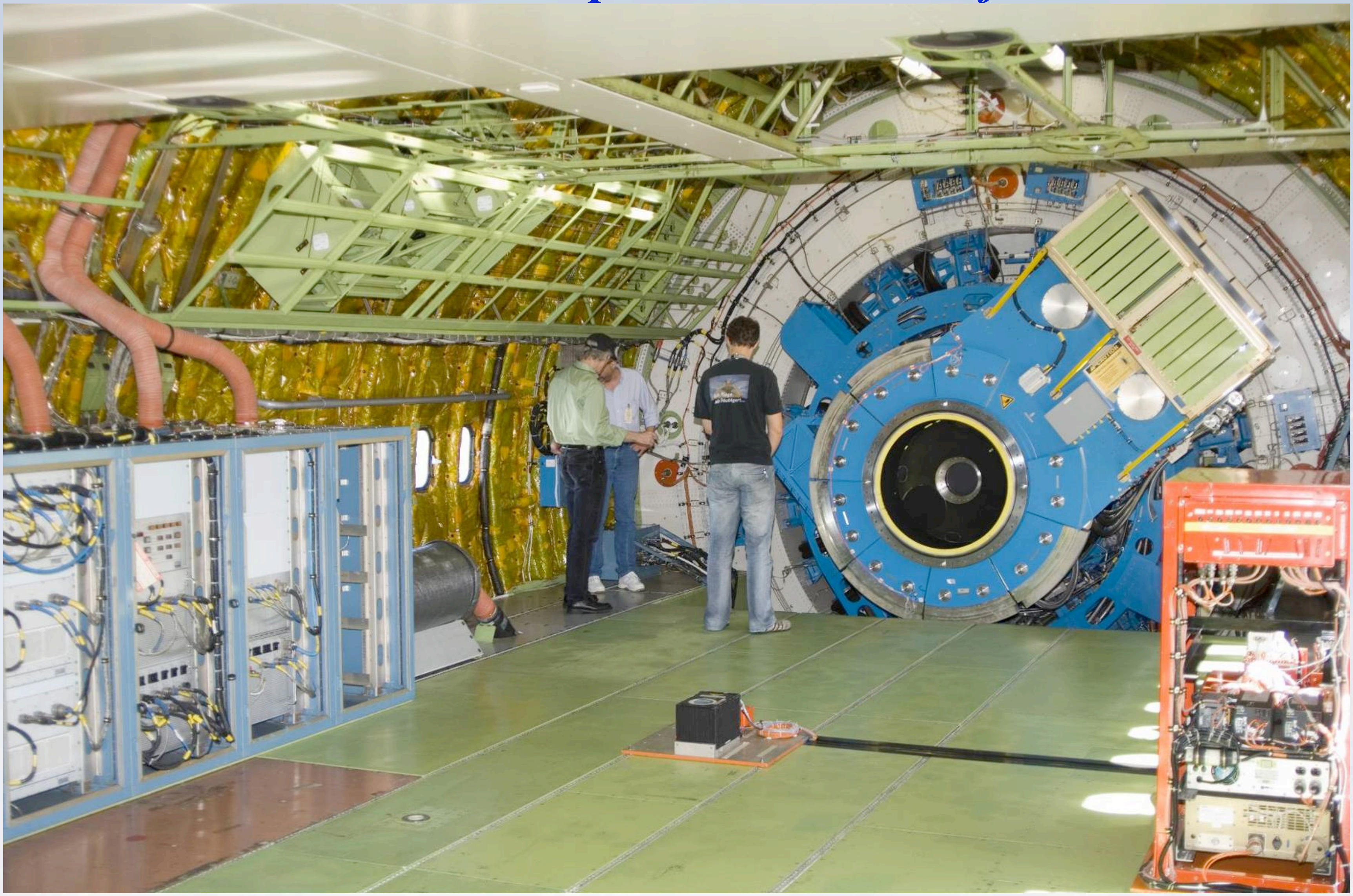
Nasmyth: Optical Layout

Observers in pressurized cabin have ready access to the focal plane

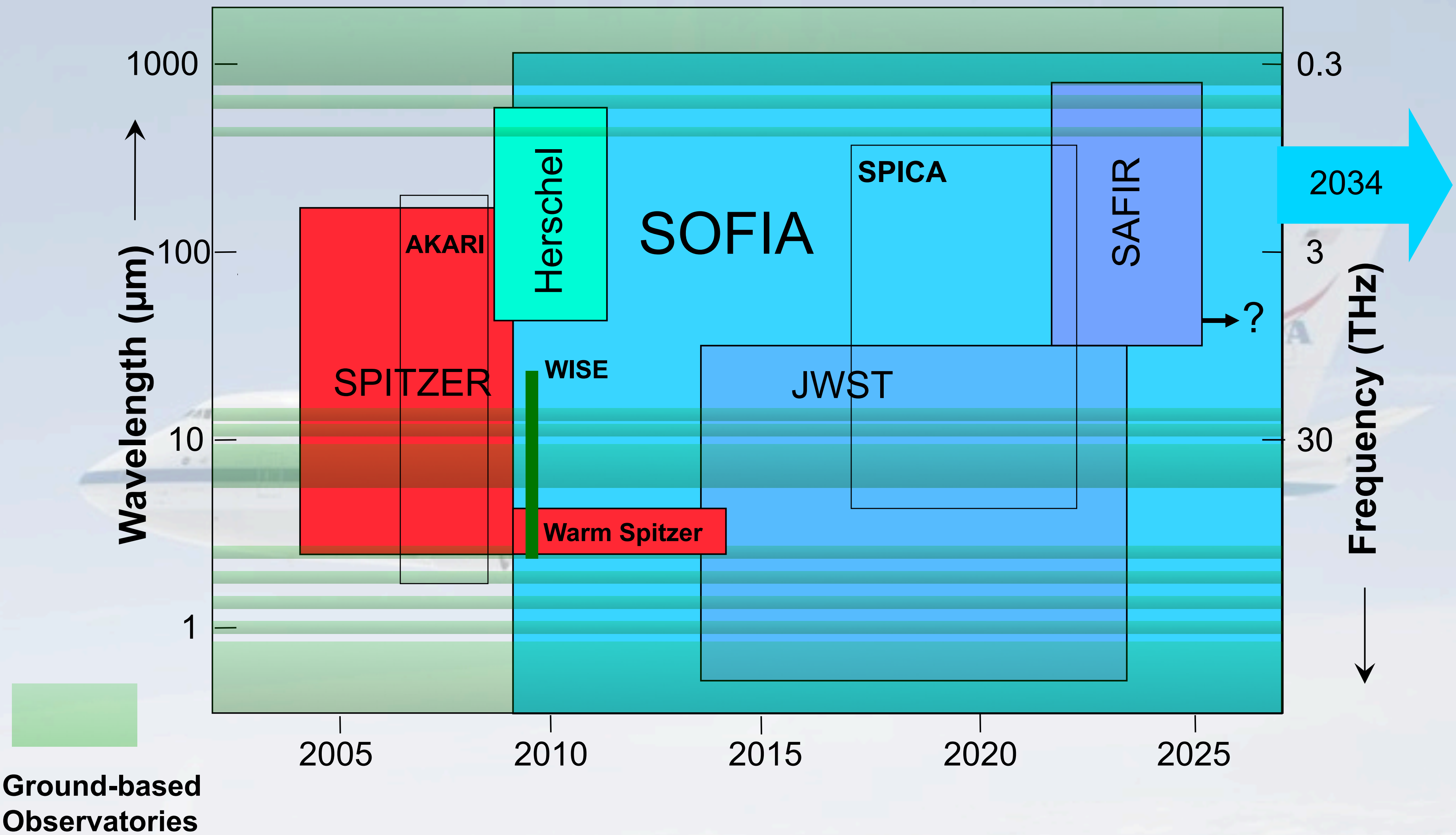


Primary Mirror Installed Oct. 8, 2008

SOFIA Telescope instrument interface



SOFIA and Major IR Imaging/Spectroscopic Space Observatories



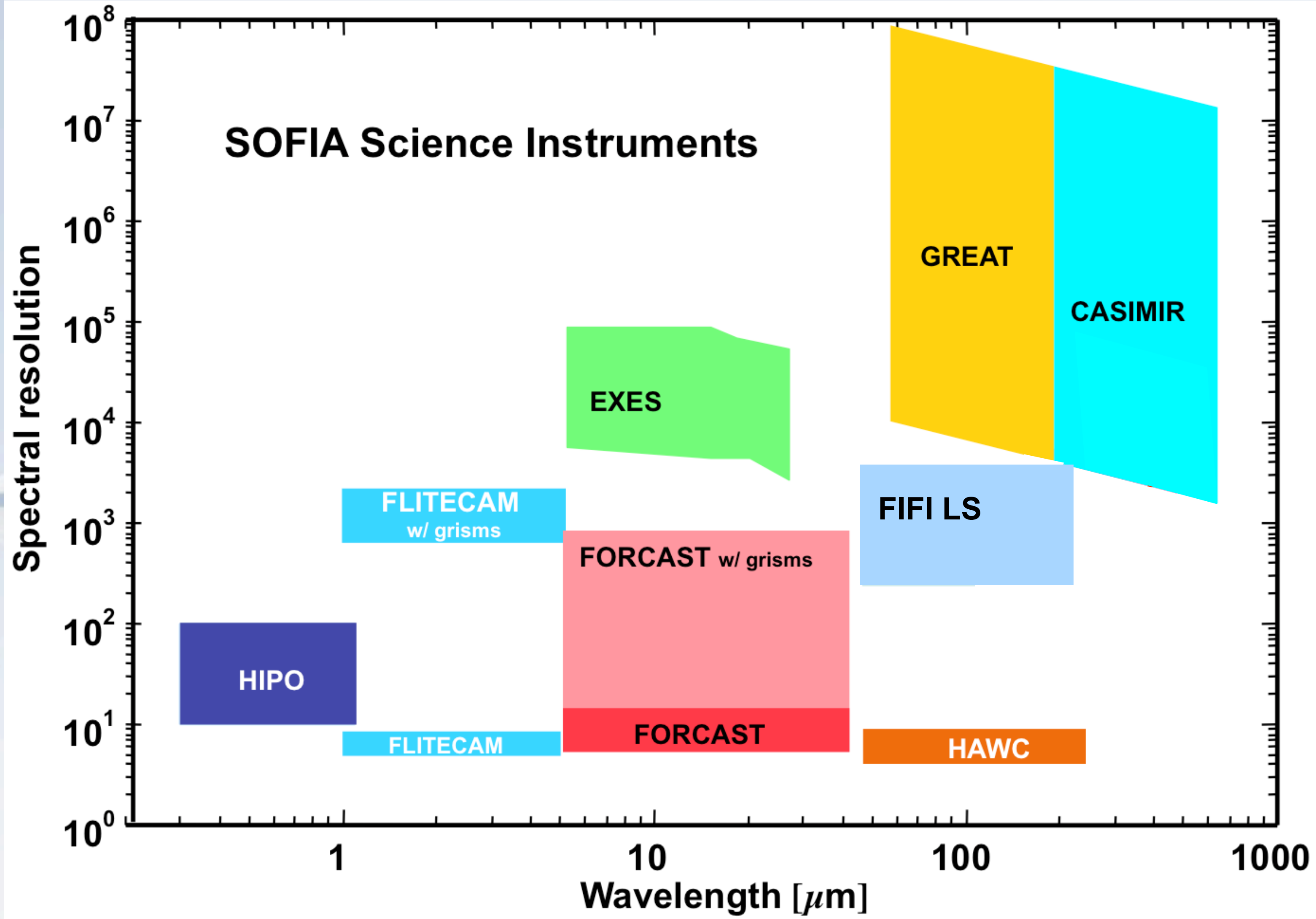
SOFIA's First-Generation Instruments

Instrument	Type	λ (μm)	Resolution	PI	Institution
HIPO	fast imager	0.3-1.1	filters	E. Dunham	Lowell Observatory
FLITECAM	imager/grism	1.0-5.5	filters/R~2000	I. McLean	UCLA
FORCAST	imager/grism	5.6-38	filters/R~2000	T. Herter	Cornell
GREAT	heterodyne receiver	62-65 111-120 158-187 200-240	R~10^4-10^8	R. Güsten	MPIfR
CASIMIR	heterodyne receiver	250-264 508-588	R~10^4-10^8	J. Zmuidzinas	CalTech
FIFI-LS	imaging grating spectrograph	42-110 110-210	R~1000-2000	A. Poglitsch	MPE
HAWC	imager	40-300	filters	D. A. Harper	Yerkes Observatory
EXES	imaging echelle spectrograph	5-28.5	R~3000-10^5	M. Richter	UC Davis

* *Facility-class instrument*

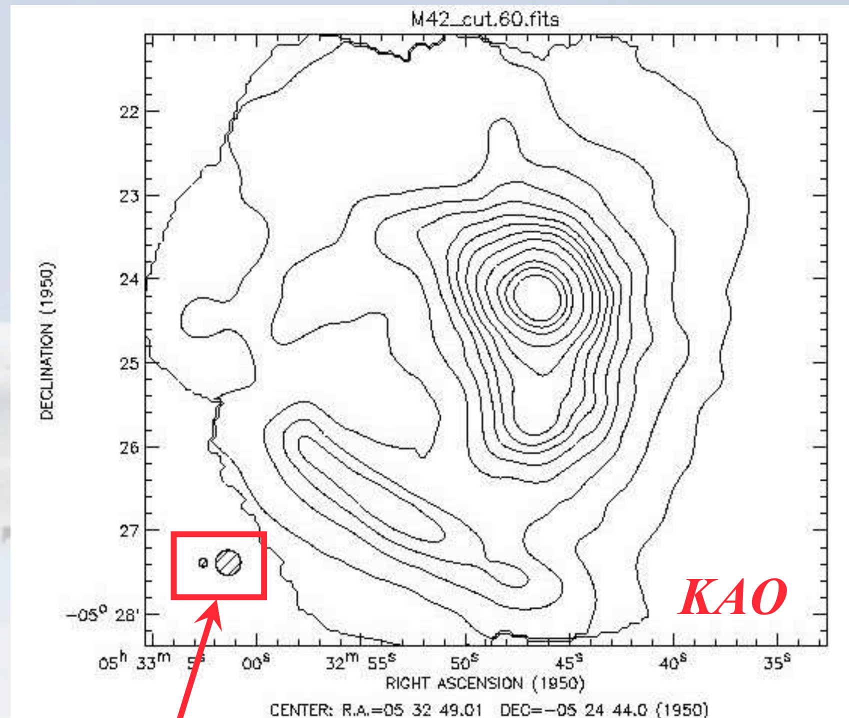
** *Developed as a PI-class instrument, but will be converted to Facility-class during operations*

Instrument R/λ graph



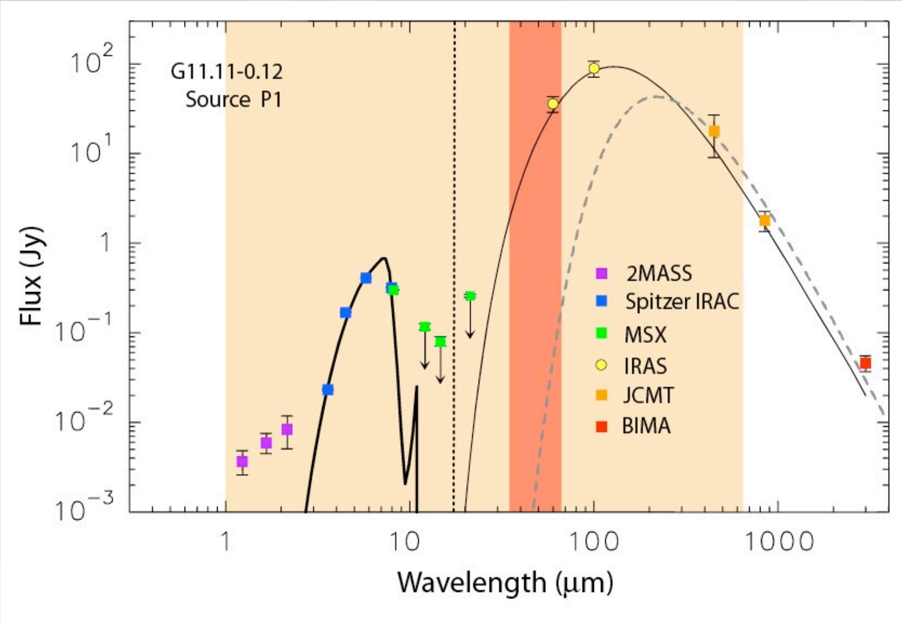
SOFIA and Regions of Star Formation

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

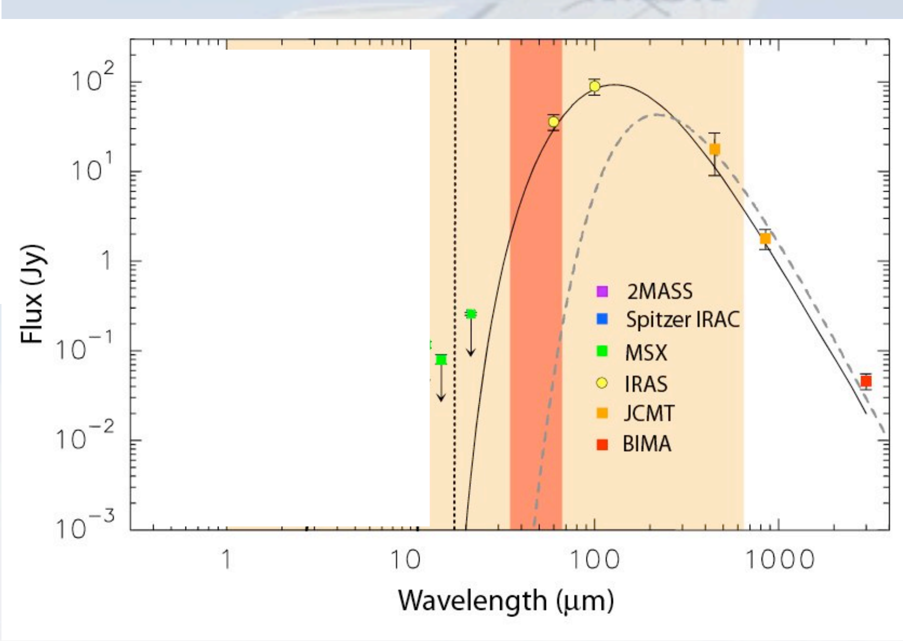


With 9 SOFIA beams for every 1 KAO beam, SOFIA imagers/HI-RES spectrometers can analyze the physics and chemistry of individual protostellar condensations where they emit most of their energy and can follow up on HERSCHEL discoveries.

Sources Embedded in Massive Cloud Cores

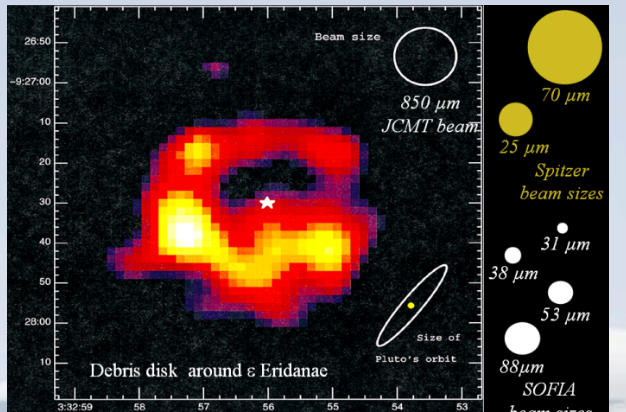


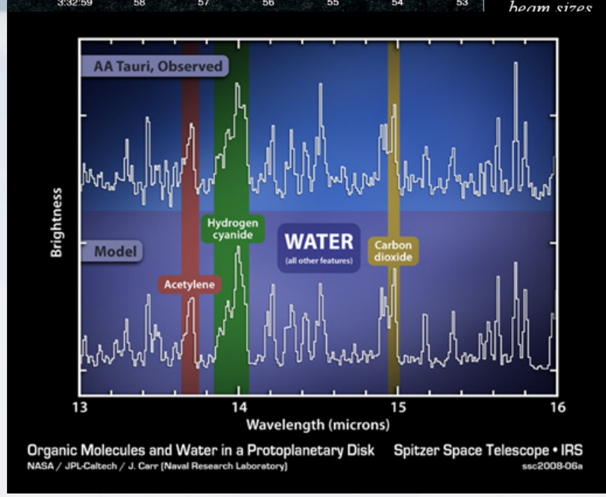
- *In highly obscured objects, no mid-IR source may be detectable*
- *20 to 100 microns can provide a key link to shorter wavelengths*

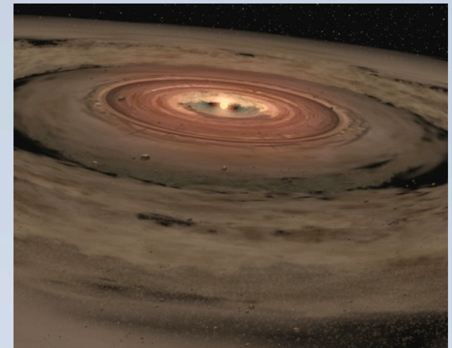


SOFIA and Extra-Solar Circumstellar Disks

What can SOFIA tell us about circumstellar disks?



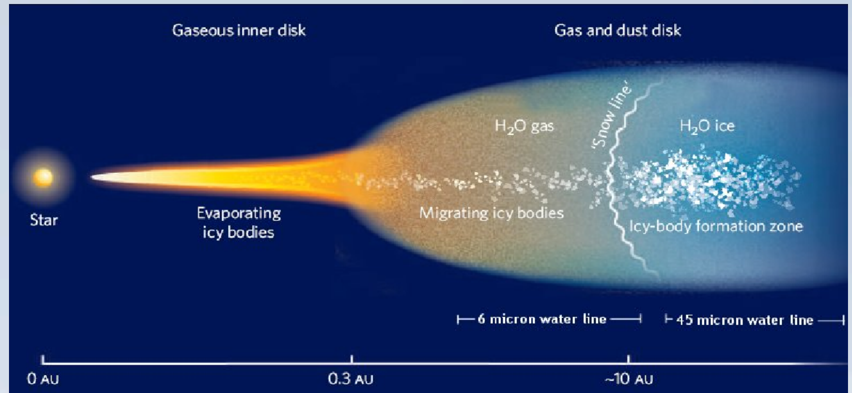




- *SOFIA imaging and spectroscopy can resolve disks to trace the evolution of the spatial distribution of the gaseous, solid, and icy gas and grain constituents*
- *SOFIA can shed light on the process of planet formation by studying the temporal evolution of debris disks*

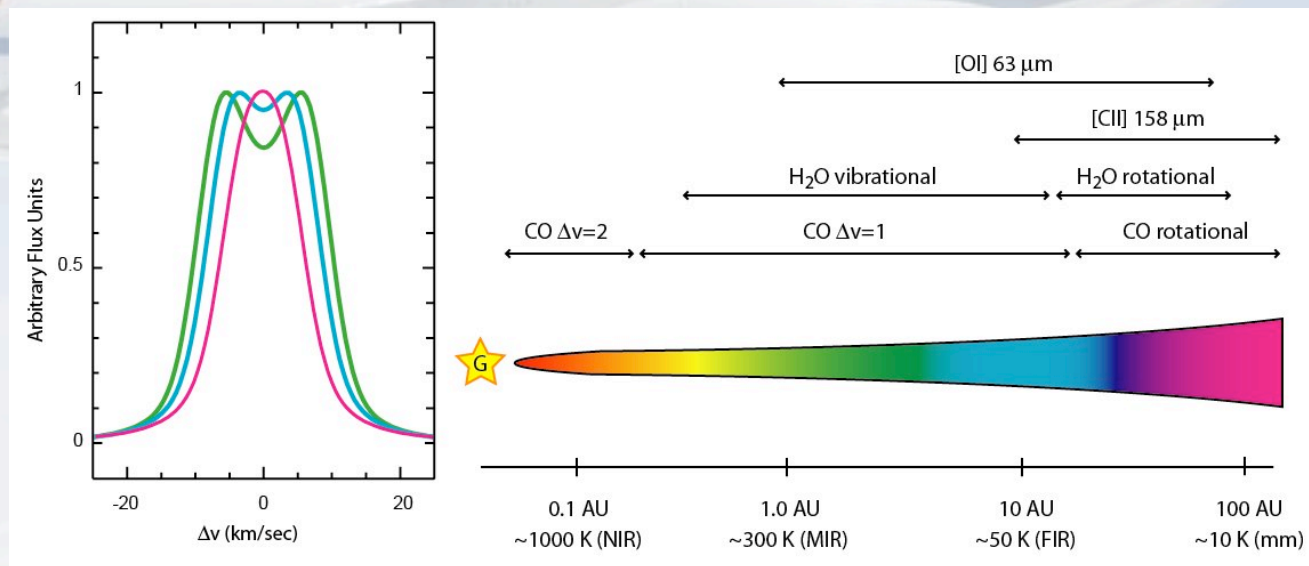
The chemistry of disks with radius and Age

- ***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

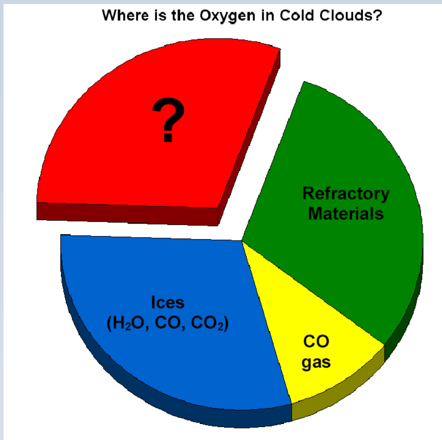
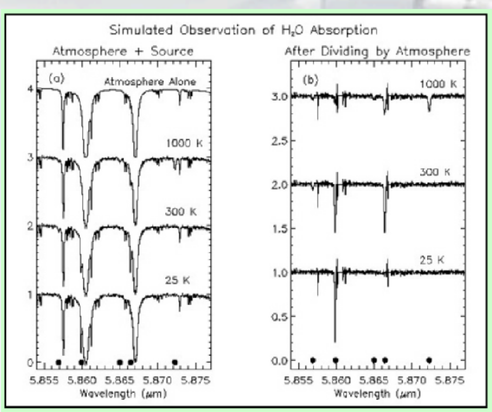


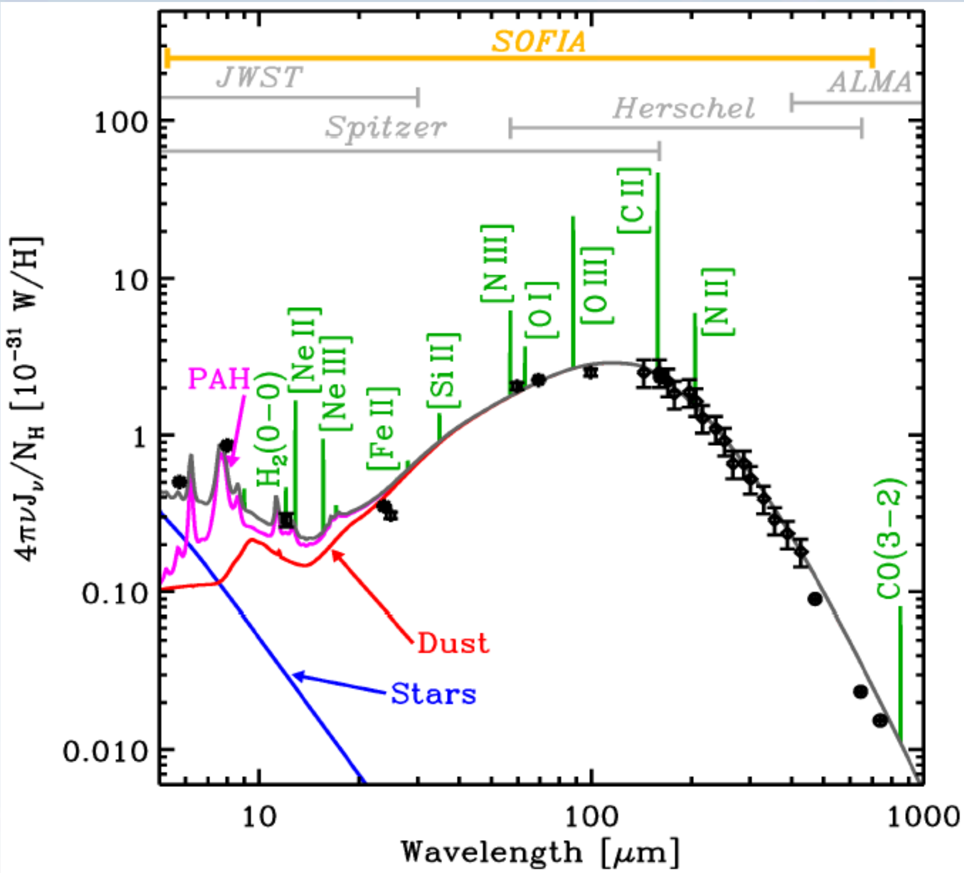
Figure 2-6. *A pie chart showing the oxygen budget in cold clouds. Almost 1/3 of the oxygen is unaccounted for.*

- ***SOFIA is the only mission that can provide spectrally resolved data on the 63 and 145 µm [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***

Thermal Emission from ISM Gas and Dust



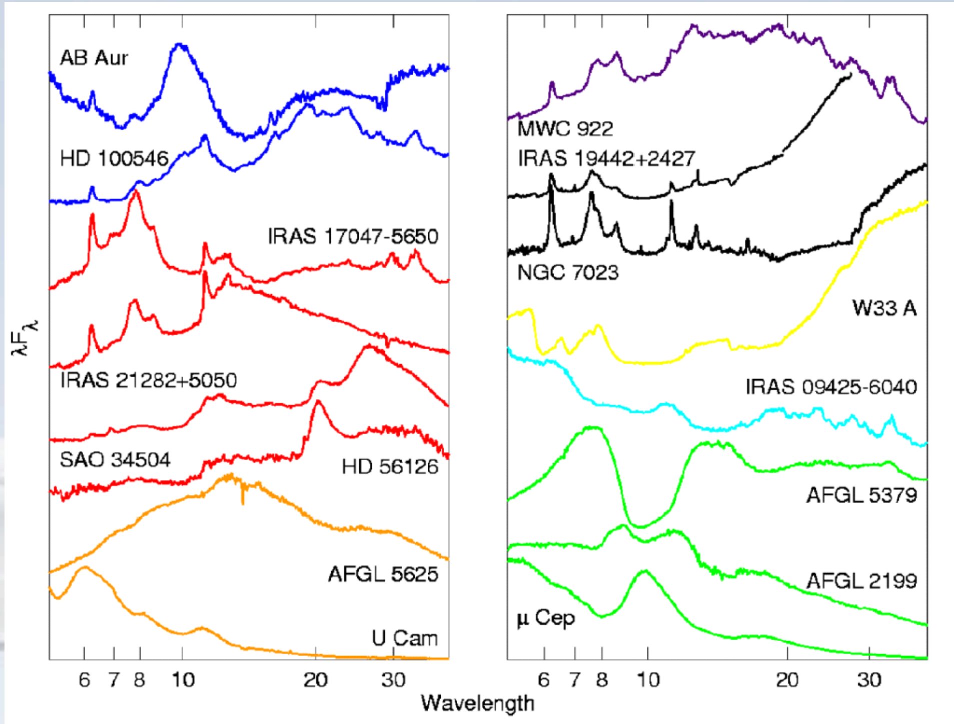
Kandori, R., et al. 2007, PASJ, 59, 487

Spectral Energy Distribution (SED) of the entire LMC (courtesy of F. Galliano)

- *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*

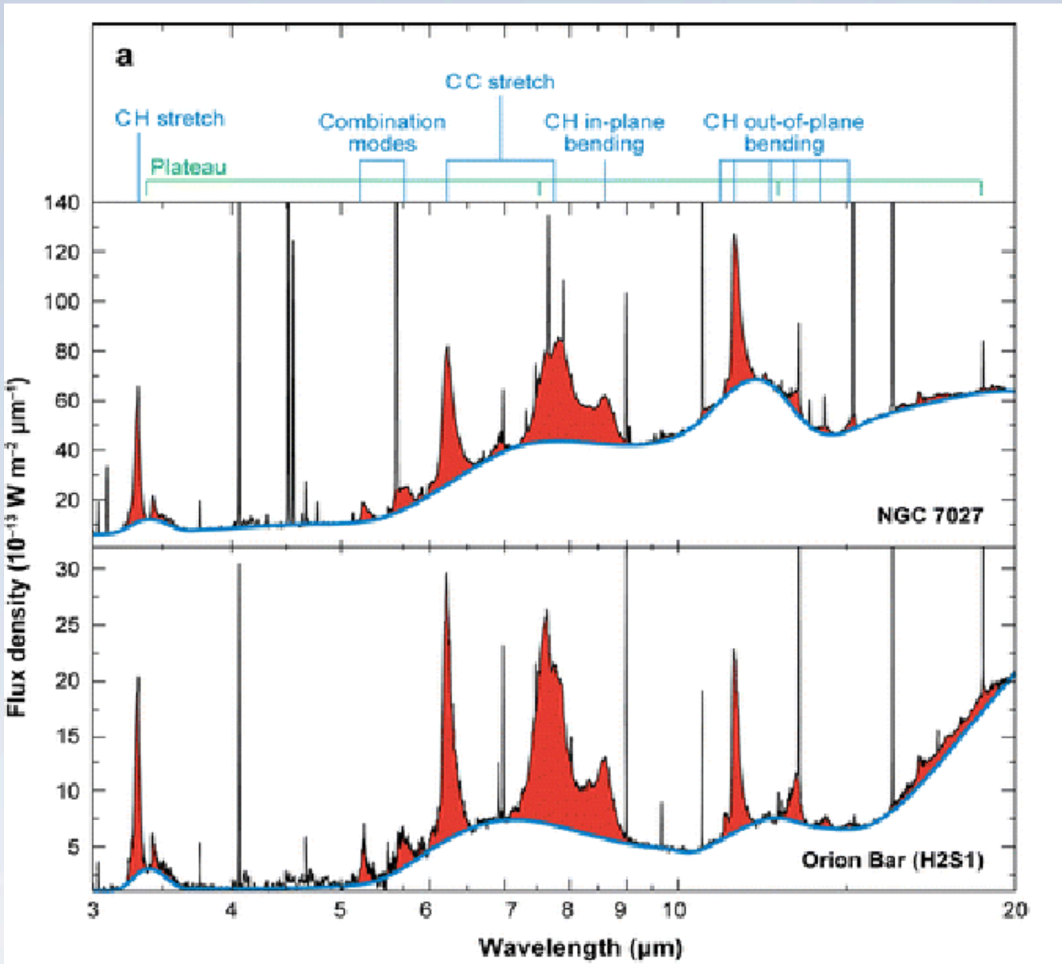
SOFIA Will Study the Diversity of Stardust

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

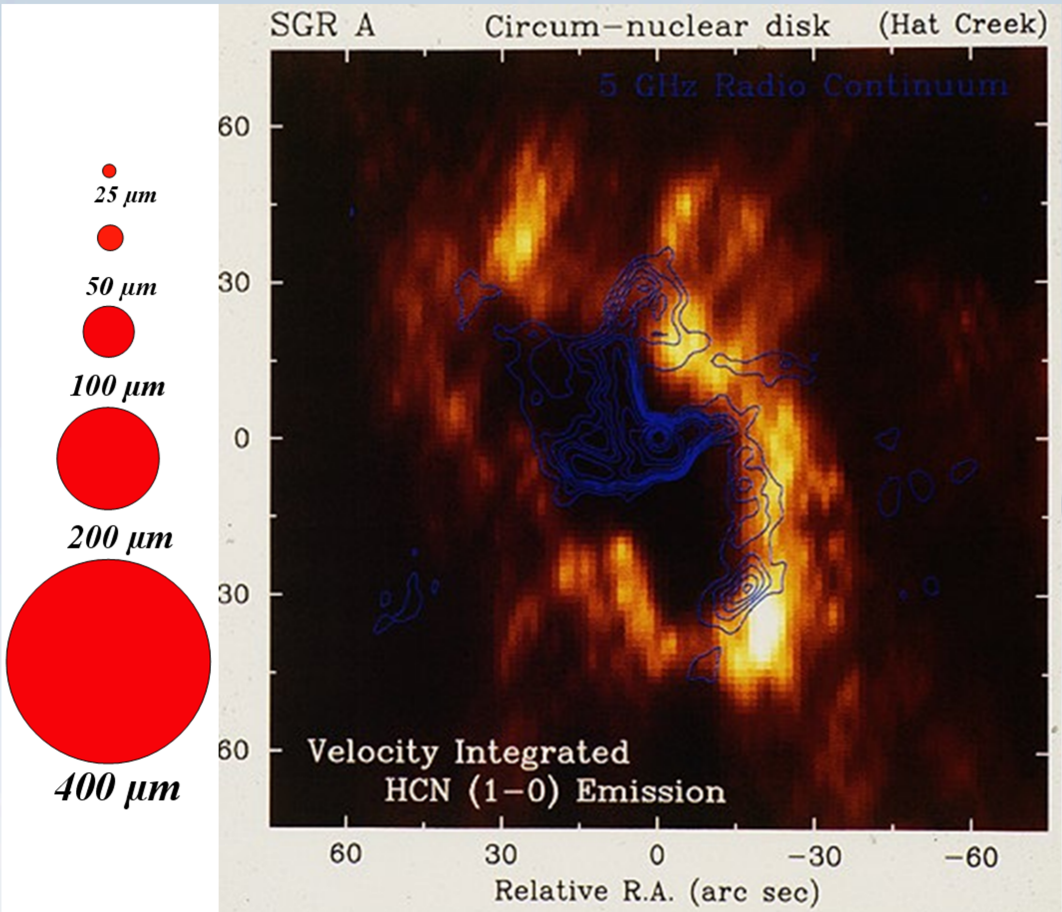
Thermal Emission from PAH Rich Objects



Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)

- *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*

SOFIA and the Black Hole at the Galactic Center



SOFIA beams

- *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*

The ISM and Star Formation in External Galaxies

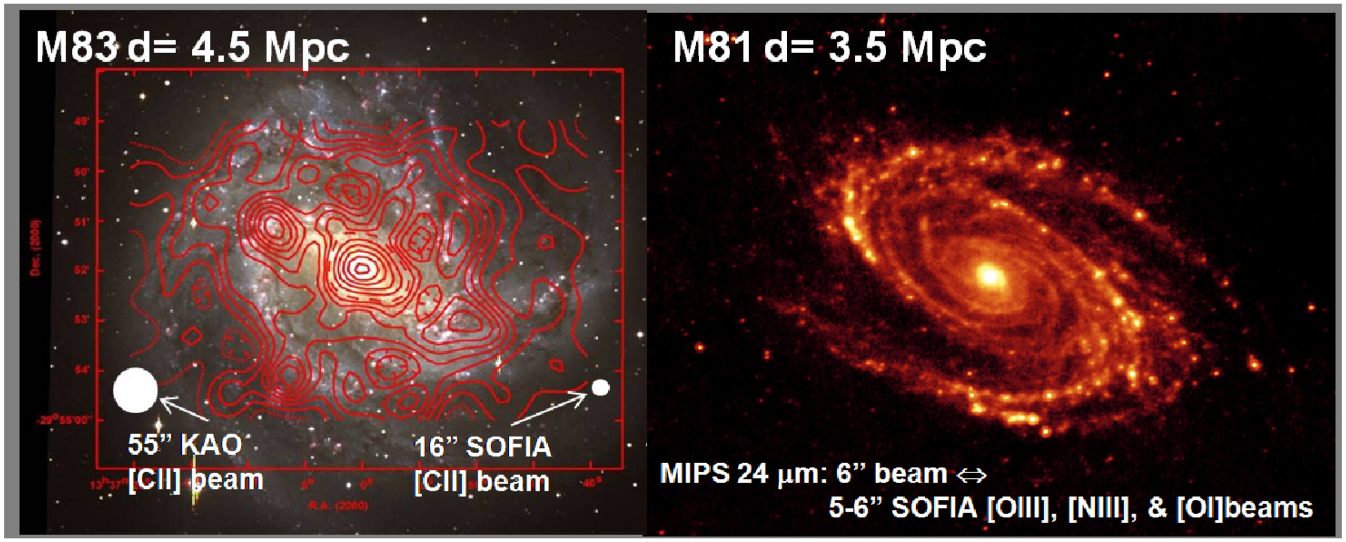
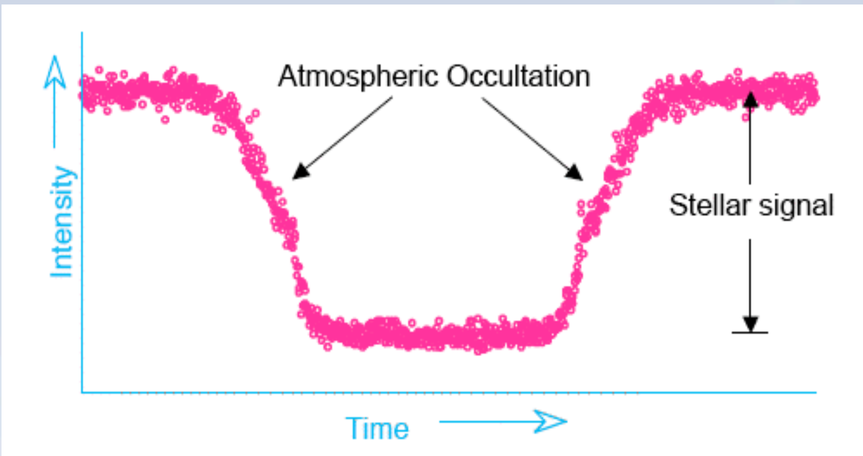


Figure 4-4. *(left) KAO [CII] map of M83 (d=4.5 Mpc) (contours, 55" beam) superposed on an optical image (Geis et al., in prep.). (right) MIPS 24 μm (6" beam) continuum image of M81 (d=3.5 Mpc). SOFIA can image nearby galaxies in the [OIII] 52 μm, [NIII] 57 μm, and [OI] 63 μm lines at a spatial resolution comparable to that of the Spitzer 24 μm image.*

- ***SOFIA observations of Far-IR lines can be conducted at unprecedented spatial resolution***

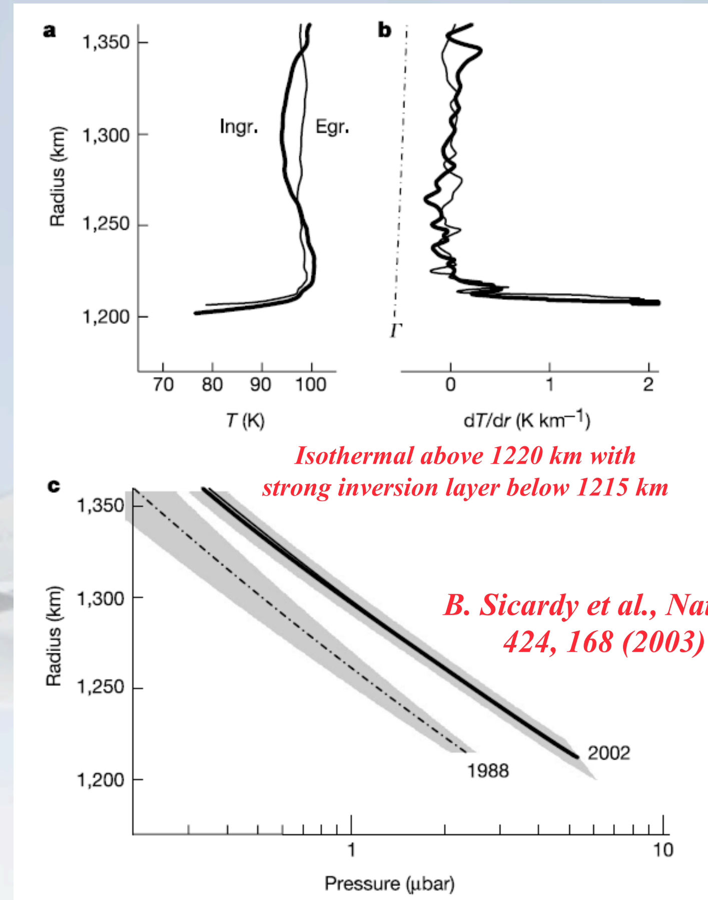
- ***ISM abundances and physical conditions can be studied as a function of location and nucleocentric distance***

Occultations and Atmospheres



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

B. Sicardy et al., Nature, 424, 168 (2003)

Figure 2 Temperature and pressure profiles of Pluto's atmosphere derived from the inversion of the P131.1 light curve. This inversion[17] assumes a spherically symmetric and transparent atmosphere. It first provides the atmospheric refractivity profile, then the density profile for a given gas composition, and finally the temperature profile, assuming an ideal gas in hydrostatic equilibrium. We assume for Pluto a pure molecular nitrogen[6] atmosphere,

SOFIA and Comets: Protoplanetary Disks

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

ISO Observations — Adapted from Crovisier et al. 1996, Science 275, 1904 and Malfait et al. 1998, A&A 332, 25

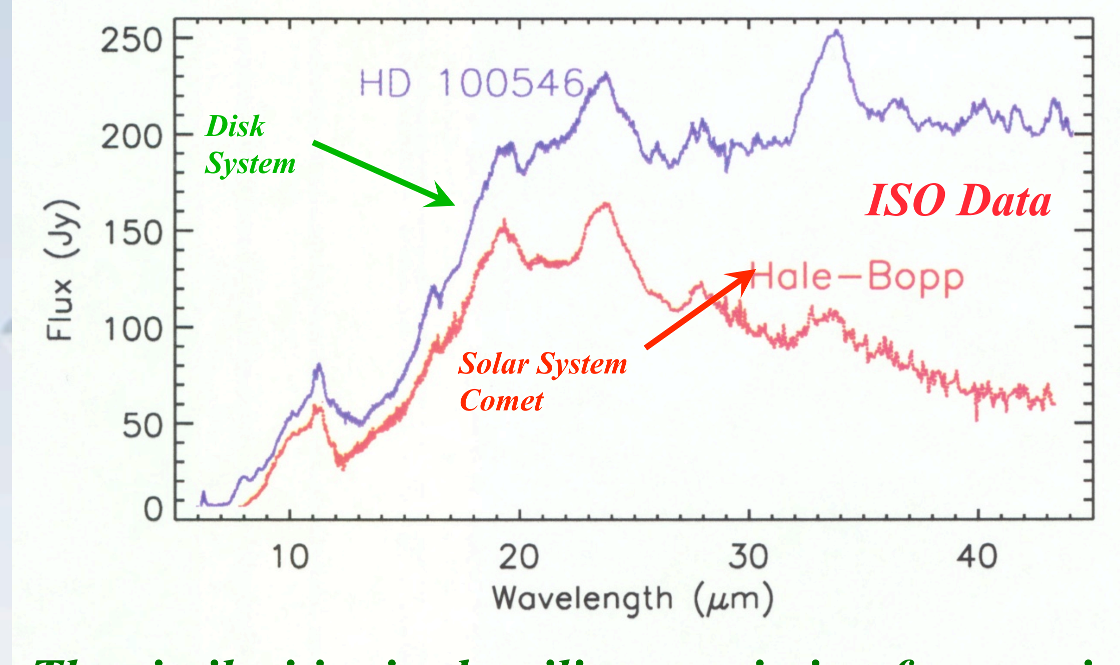
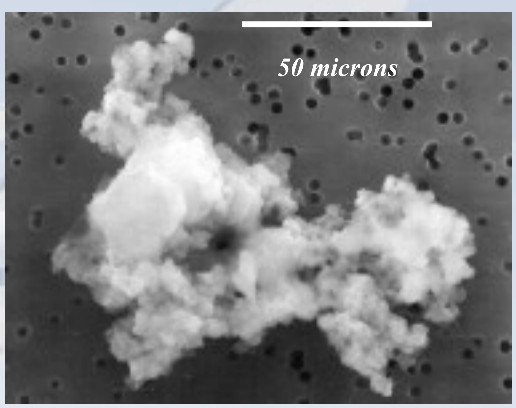
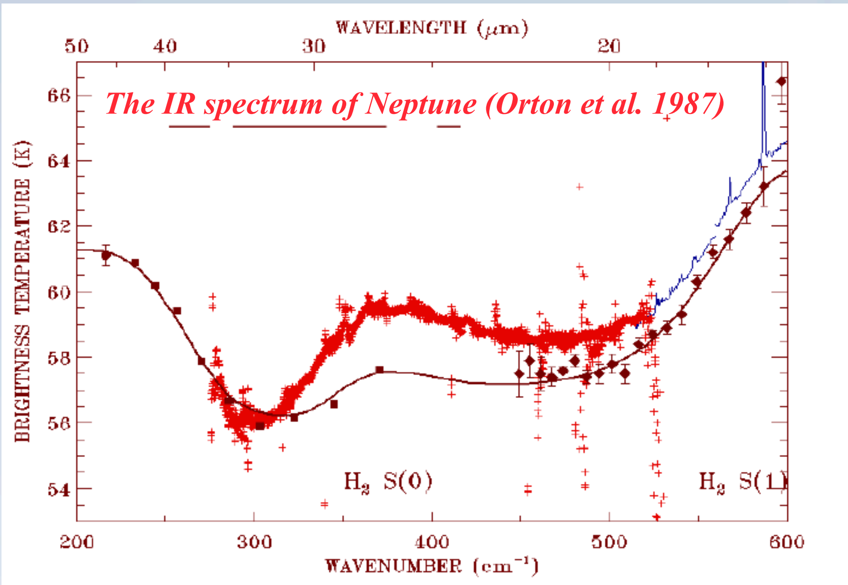


Image of Solar System IDP (Interplanetary Dust Particle)

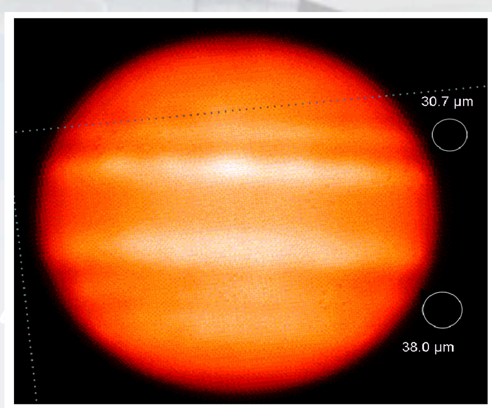


- ***The similarities in the silicate emission features in HD 100546 and C/1995 O1 Hale-Bopp suggest that the grains in the stellar disk system and the small grains released from the comet nucleus were processed in similar ways***

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*



Varying thernmal emission across the face of Jupiter showing beam sizes for FORECAST (NASA IRTF image)

- *These studies may enhance our understanding of the atmospheres of large, extra-solar "hot Jupiters"*

SOFIA and Venus: Earth's Neglected Sibling

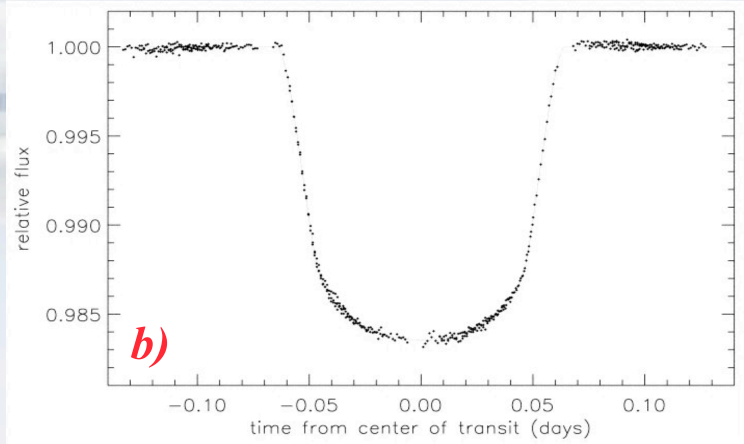
NASA **Pioneer Venus** *UV image of Venus*

- ***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*



HD 209458b transit:

a) artist's concept and

b) HST STIS data

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

Segment 2 – Tracking dates

2010

TA Misalignment (daytime) | *TA Characterization/ First Light attempt*

SS1 H/W Install/Checkout | Door Open/TA @ 23 deg | Install/ Checkout | FORCAST Mini Line Ops | Data Analysis | Briefings | Observatory Checkout | FORCAST Line Ops | TA Flight Prep

M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M

March | April | May

Line Ops Prep

Door Open/TA @ 40 | Data Analysis | TA @ 30 | Systems Prep | SE01-005 Testing | SE01-004 Testing | SE01-003 Testing

T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T

May | June | July | August

TA Characterization | *ISF*

FORCAST Line

SE01-003 Testing | Flight Prep | CST | Observatory Prep | SS #1

W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W T F M T W

August | September | October | November

GREAT Line Ops | Prep | Envelope Expansion #2

T F M T W T F Holiday M T W T F M T W T F M T W T F Holiday M T W T F M T W T F M T W T F M T W T F M T W T

November | December | January

Science Flight
Platform Flight
TA Flight
Ground Testing
Data Analysis
Contingency Flight

Created 3/9/2010
Schedule Reference: SOFIA_IMS100311Mt.mpp

SOFIA: Science For the Whole Community