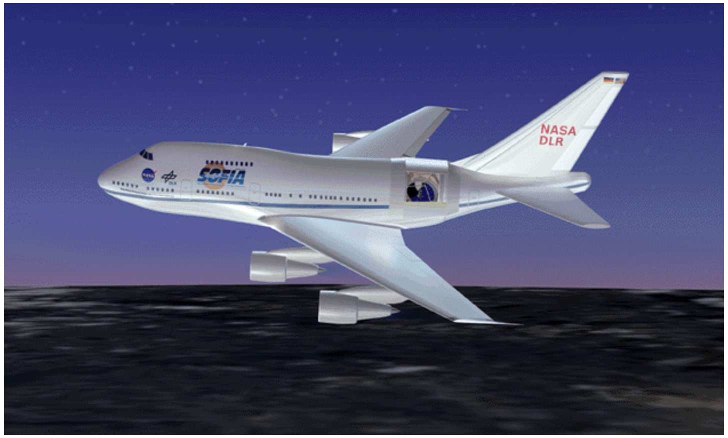
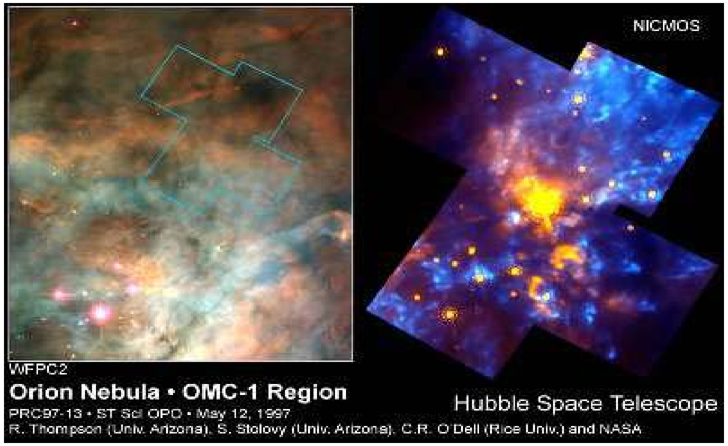
The Stratospheric Observatory for Infrared Astronomy (SOFIA)





by

R. D. Gehrz[1] and E. E. Becklin[2]

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[2]SOFIA Chief Scientist, Universities Space Research Corporation, NASA Ames Research Center

SPIE Astronomical Instrumentation, Marseille, France, June 27, 2008

Outline

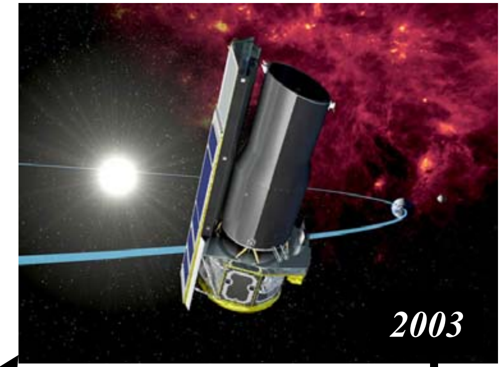
- SOFIA Heritage and Context
- SOFIA Facility Status Report
- SOFIA's Science Capabilities
- Research with SOFIA
- SOFIA Schedule
- Opportunities for International Collaboration on SOFIA
- Summary

SOFIA's Heritage and Context

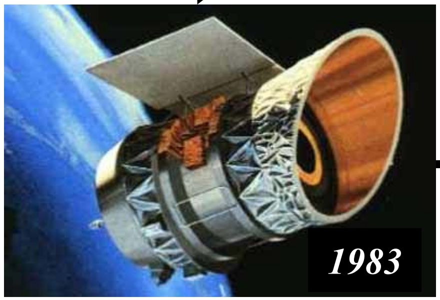
The History of Air and Space Infrared Astronomy

NASA Lear Jet Observatory

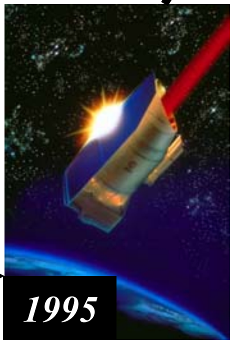
NASA Kuiper Airborne Observatory (KAO)



NASA Spitzer Space Telescope



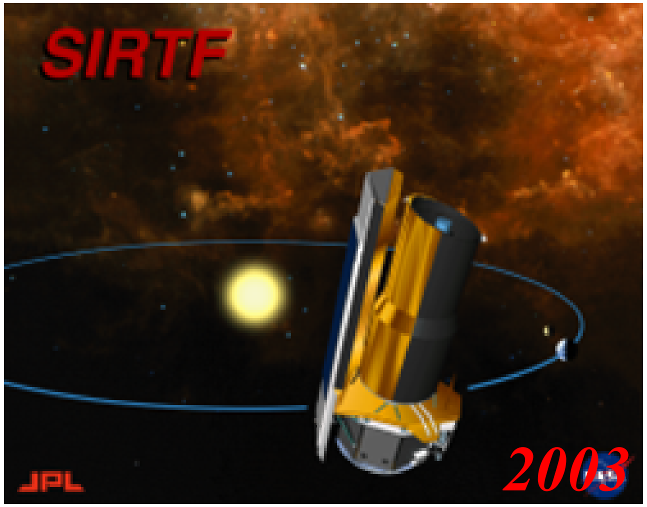
NASA Infrared Astronomical Satellite (IRAS)

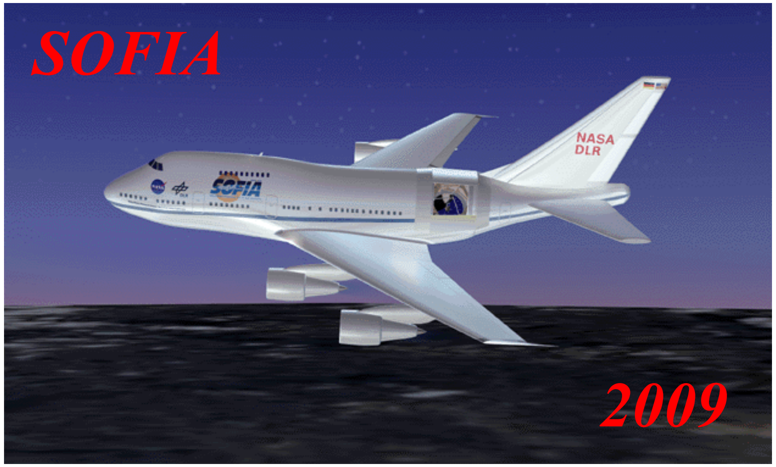


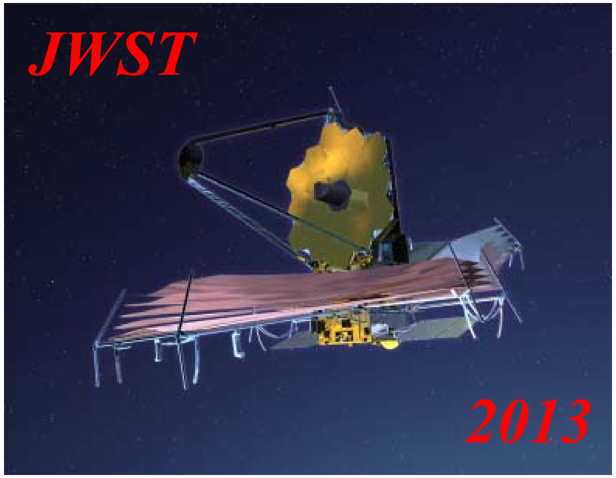
ESA Infrared Space Observatory (ISO)

NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA)

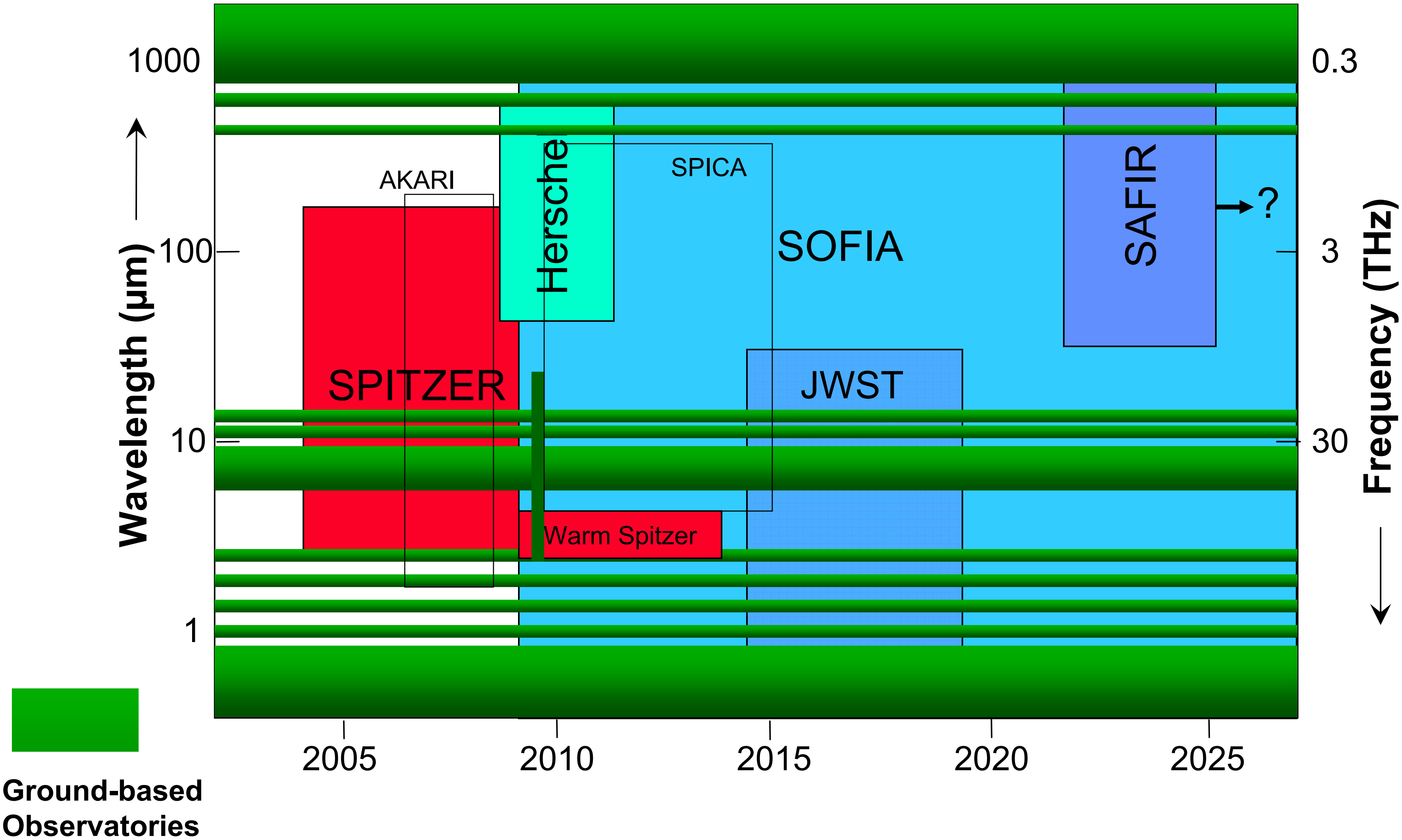
SOFIA and its Companions in Space



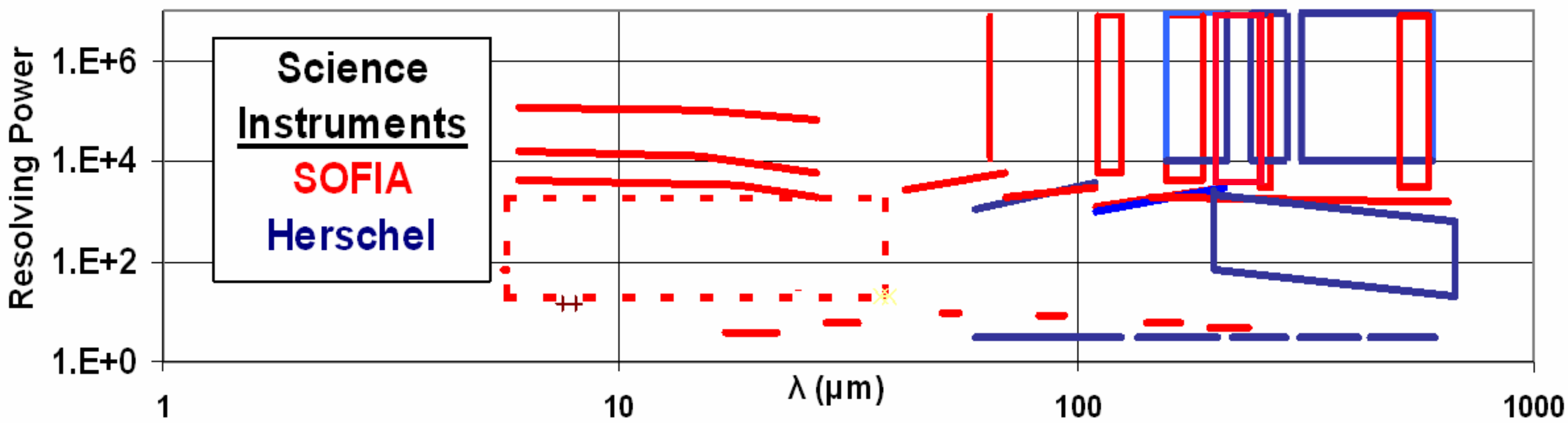




SOFIA and Major IR Imaging/Spectroscopic Space Observatories



SOFIA and Herschel: Compilemtarity, Synergism



A comparison between SOFIA First Generation SIs and Herschel SIs

- *Similar instrumentation at relatively unexplored long wavelengths*
- *SOFIA will complement and supplement Herschel observations*
- *SOFIA's long life and accessibility will encourage the development and application of new technologies*

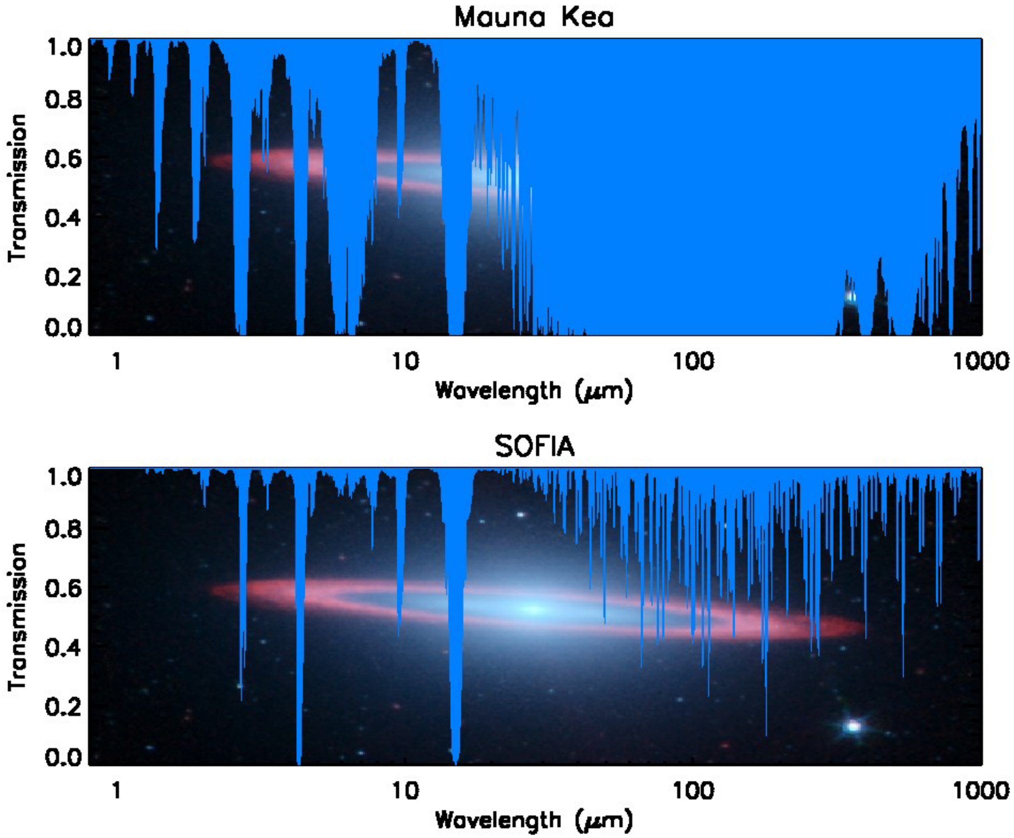
SOFIA Status Report

SOFIA Overview

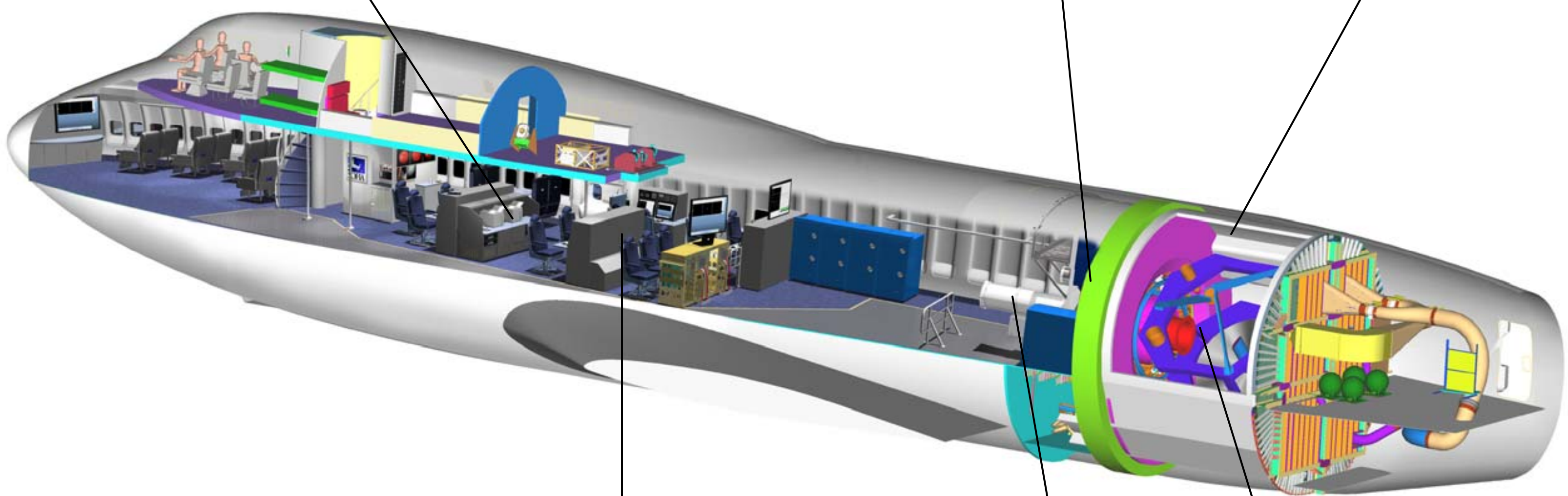
- *2.5 m telescope in a modified Boeing 747SP aircraft*
  - *0.5 μm to 1.6 mm*
  - *Emphasizes the obscured IR (30-300 μm)*
- *Service Ceiling*
  - *39,000 to 45,000 feet (12 to 14 km)*
  - *Above > 99.8% of obscuring water vapor*
- *Joint Program between the US (80%) and Germany (20%)*
  - *First Light Science in 2009*
  - *20 year design lifetime*
  - *Ops: Science at NASA-Ames; Flight at Dryden FRC (Palmdale- Site 9)*
  - *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*

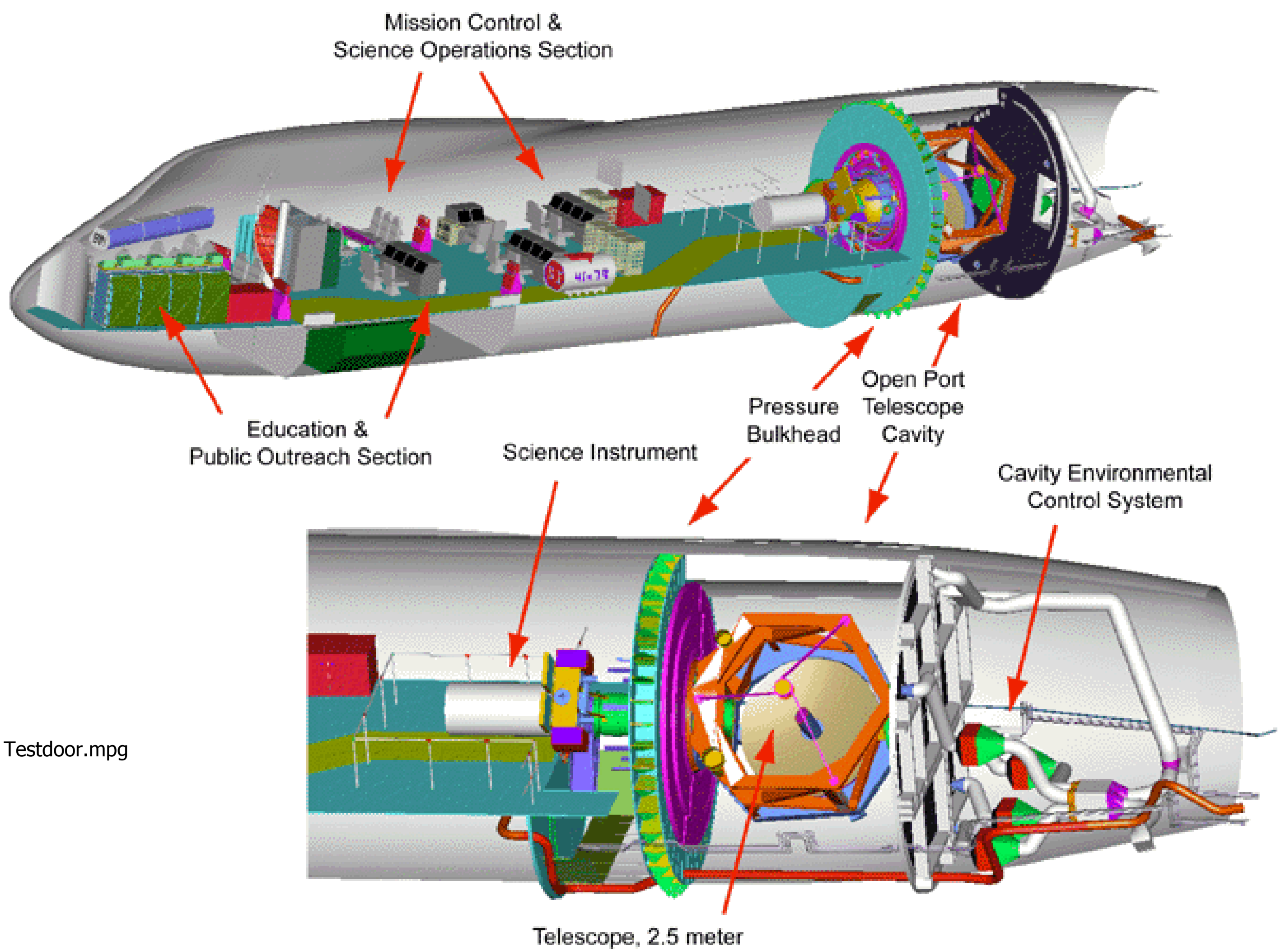


SOFIA — The Observatory



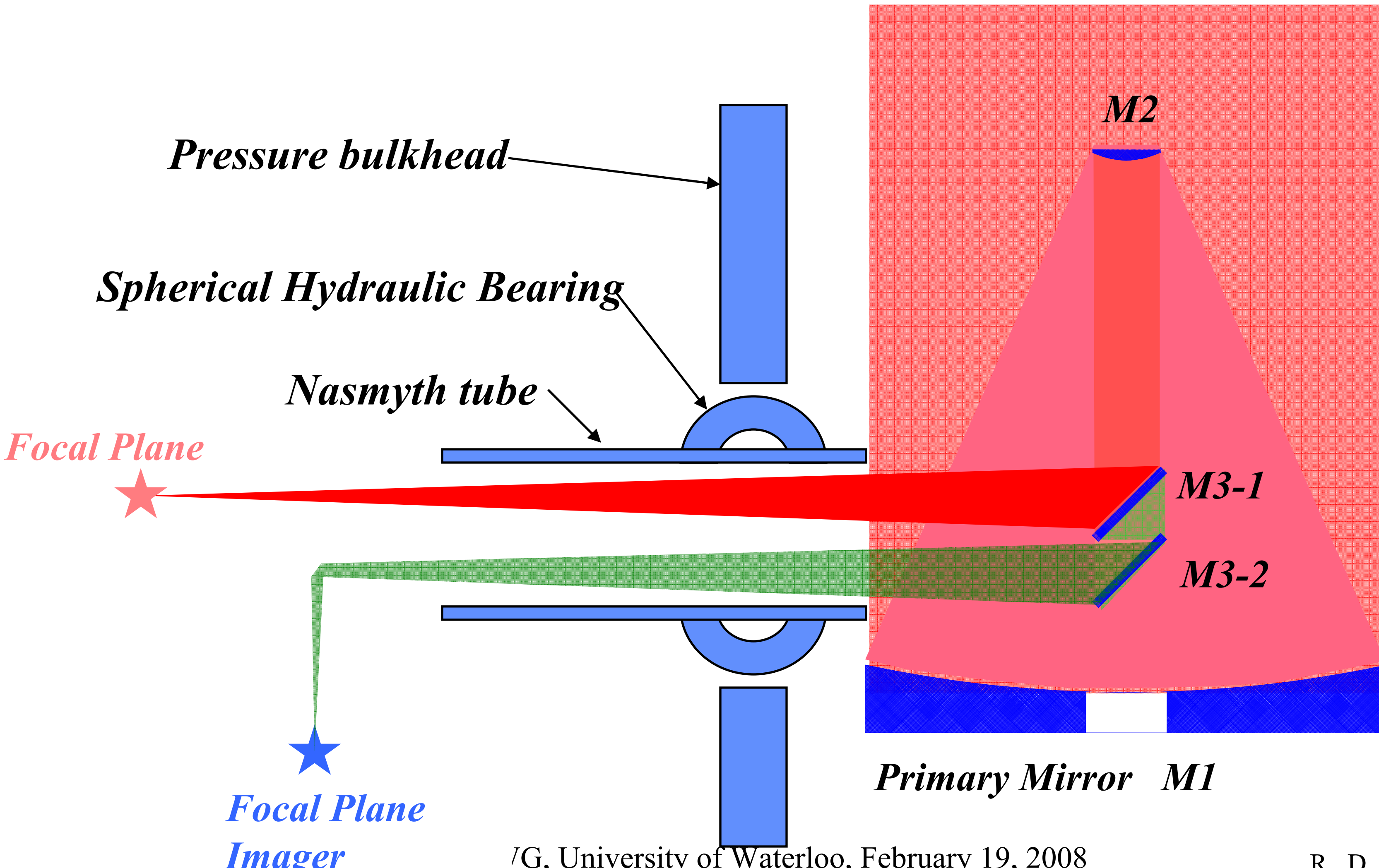
Layout of Personnel and Accomodations

(upper deck not shown)

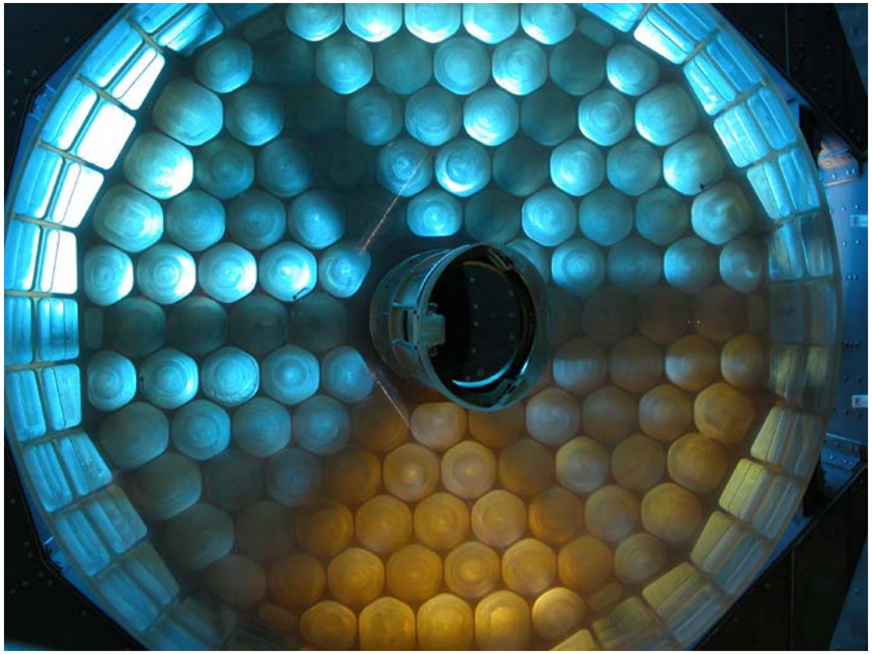


Testdoor.mpg

Nasmyth: Optical Layout



The Un-Aluminized Primary Mirror Installed

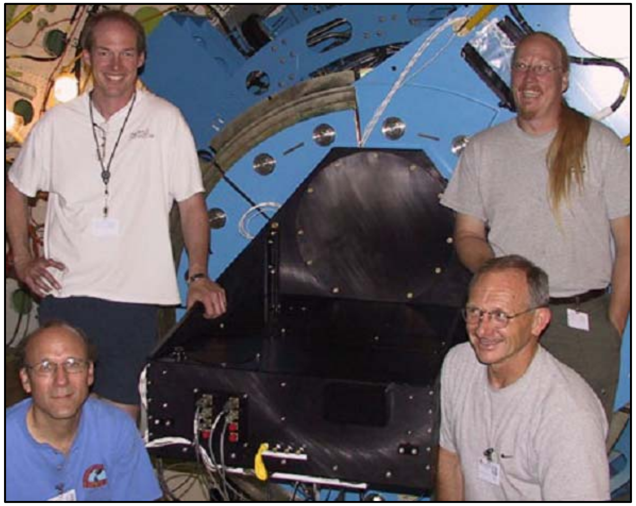


SOFIA Airborne!

26 April 2007, L-3 Communications, Waco Texas: SOFIA takes to the air for its first test flight after completion of modifications

SOFIA_FirstFlight-VNF.mp4

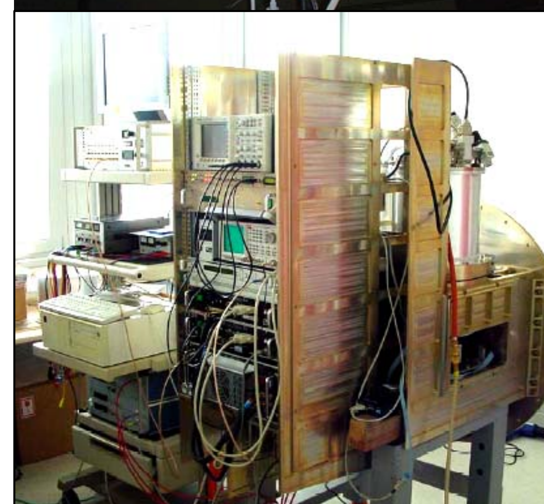
Four First Light Instruments



Working/complete HIPO instrument in Waco on SOFIA during Aug 2004

Working/complete FLITECAM instrument at Lick in 2004/5

Working FORCAST instrument at Palomar in 2005



Lab-picture of GREAT equipped with the KOSMA 1.9THz channel

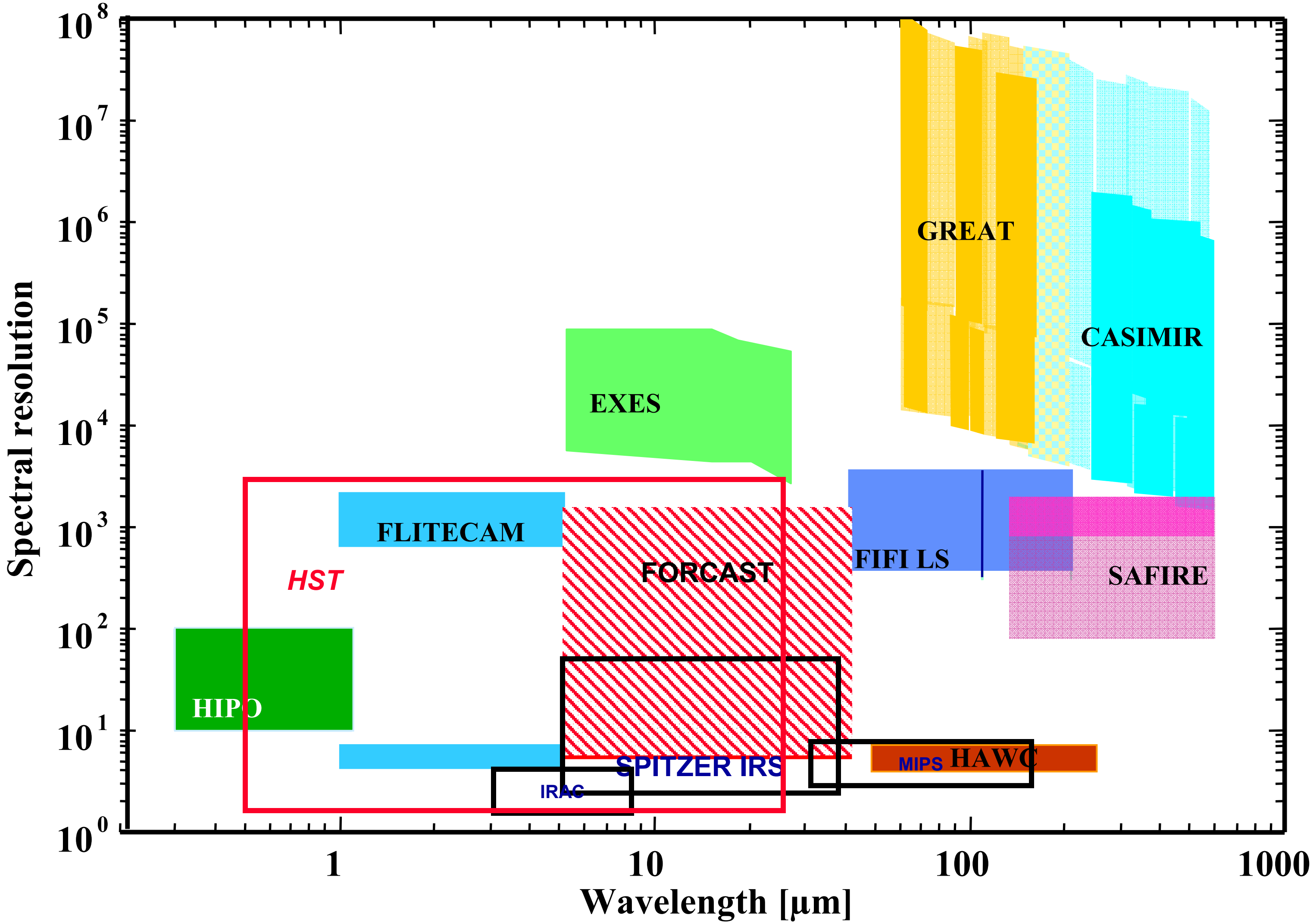
Successful lab demonstration of GREAT in July 2005

SOFIA Science Capabilities

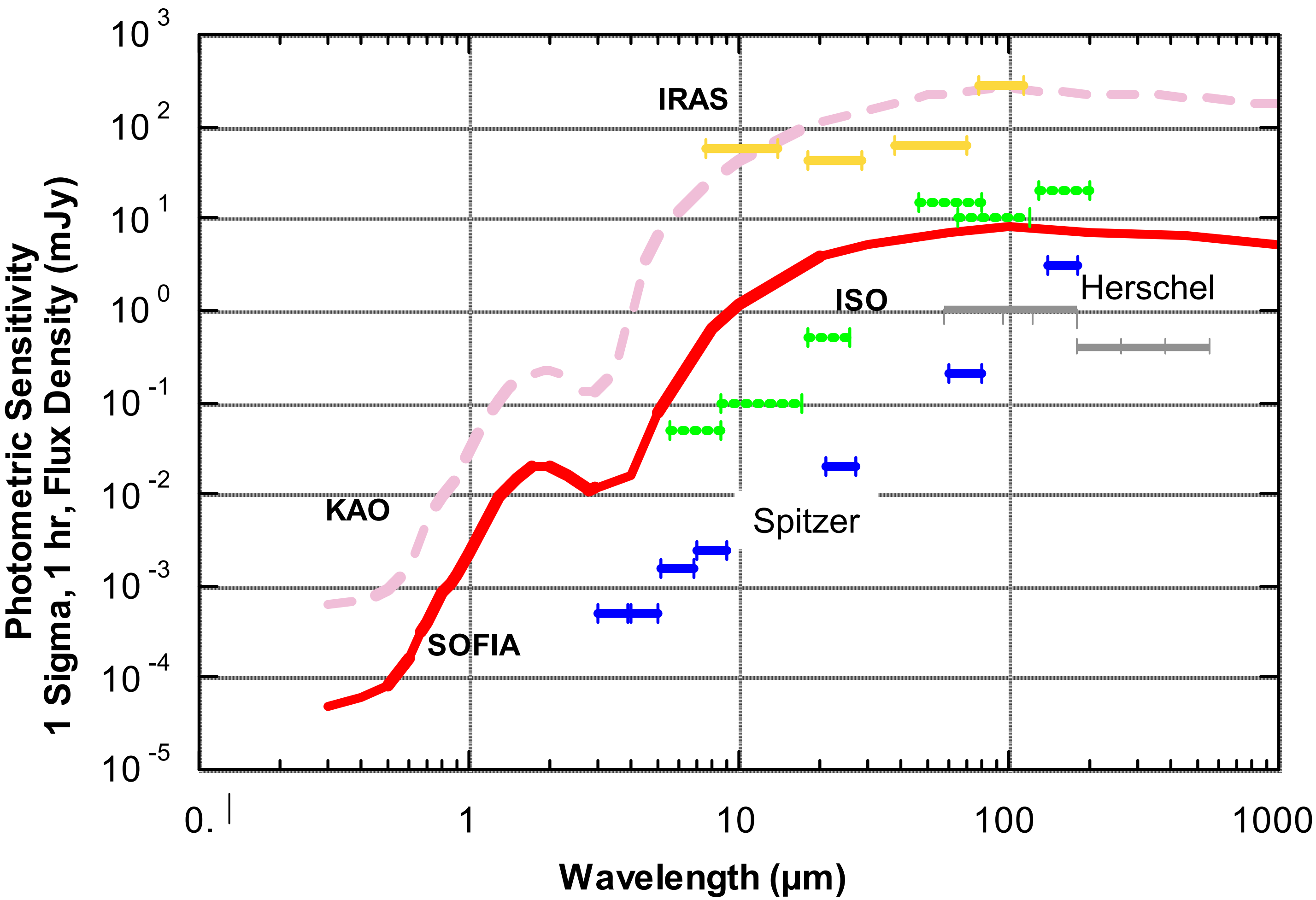
SOFIA's Unique Science Capabilities

- *SOFIA is diffraction limited beyond 25 µm ($\theta_{min} \sim \lambda/10$ in arcseconds) and can produce images three times sharper than those made by Spitzer*
- *SOFIA's large aperture enables high resolution spectroscopy ($R = \lambda/\Delta\lambda = 10^3 - 10^8$)*
- *SOFIA's 8 arcmin diameter FOV allows use of very large detector arrays.*
- *Large aperture and better detectors give SOFIA sensitivity for imaging and spectroscopy similar to that of space observatory ISO*
- *SOFIA can respond rapidly to temporal events and track them*
- *SOFIA can adapt to new technologies*

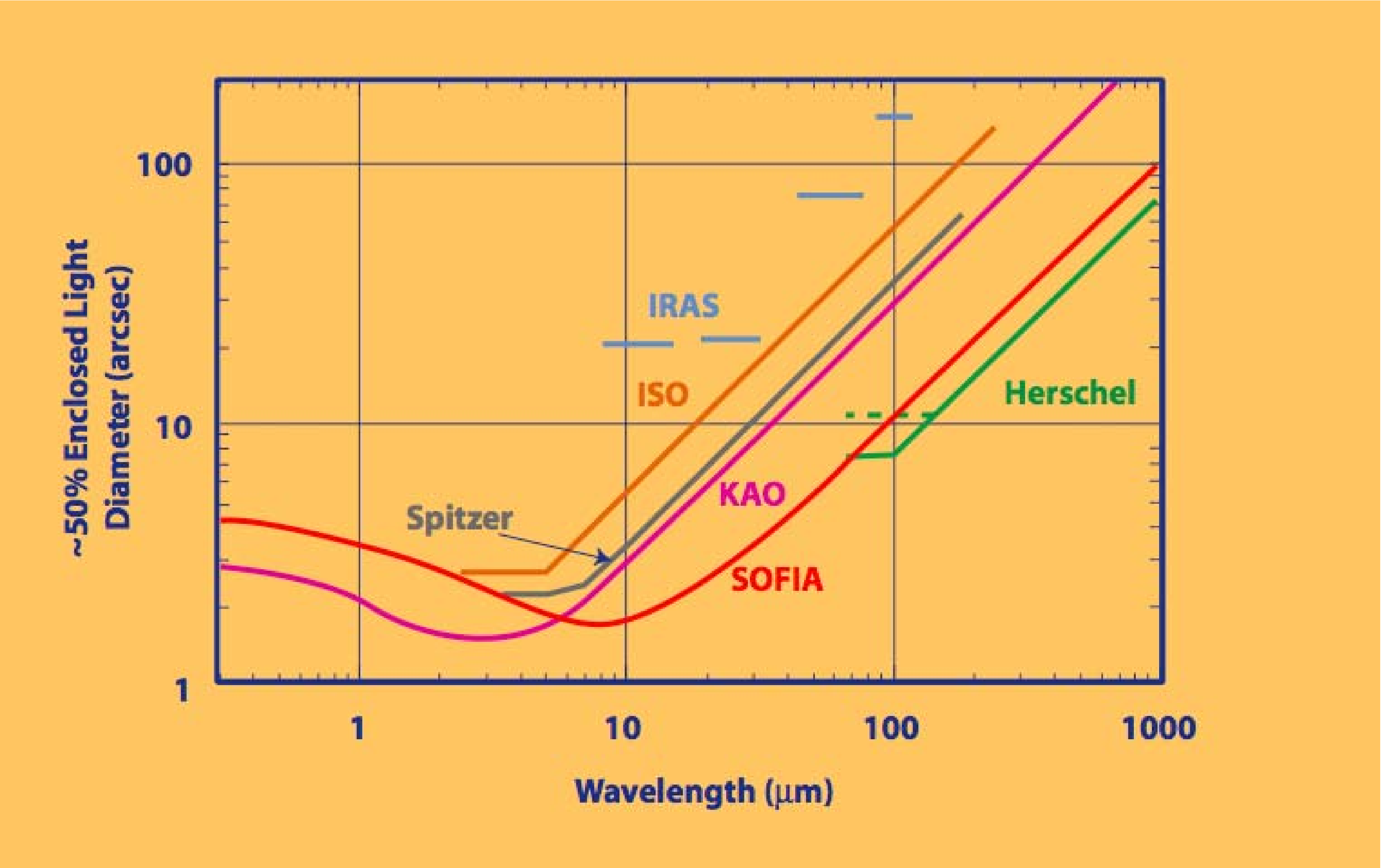
SOFIA First Generation Spectroscopy



Photometric Sensitivity

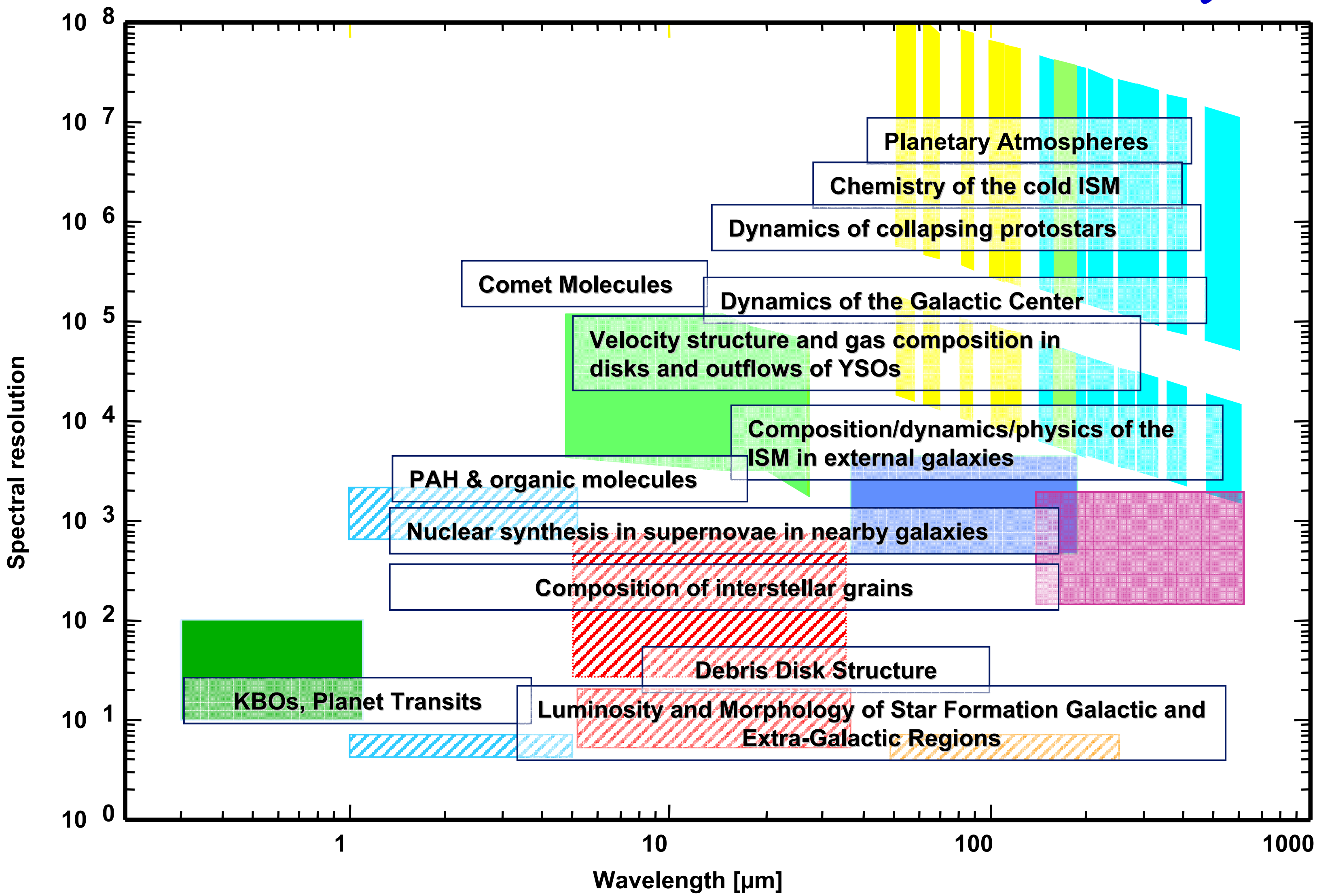


Angular Resolution



Research with SOFIA

SOFIA: Science For the Whole Community



R. D. Gehrz

SOFIA Addresses Key Science Questions

Stellar Astrophysics

- How does the ISM turn into stars and planets?
- How do dying stars enrich the ISM? What becomes of their ashes?

Planetary Science

- What are dwarf planets? How do they relate to solar system formation?
- Are biogenic molecules made in space? Are they in other solar systems?

Extragalactic Astrophysics

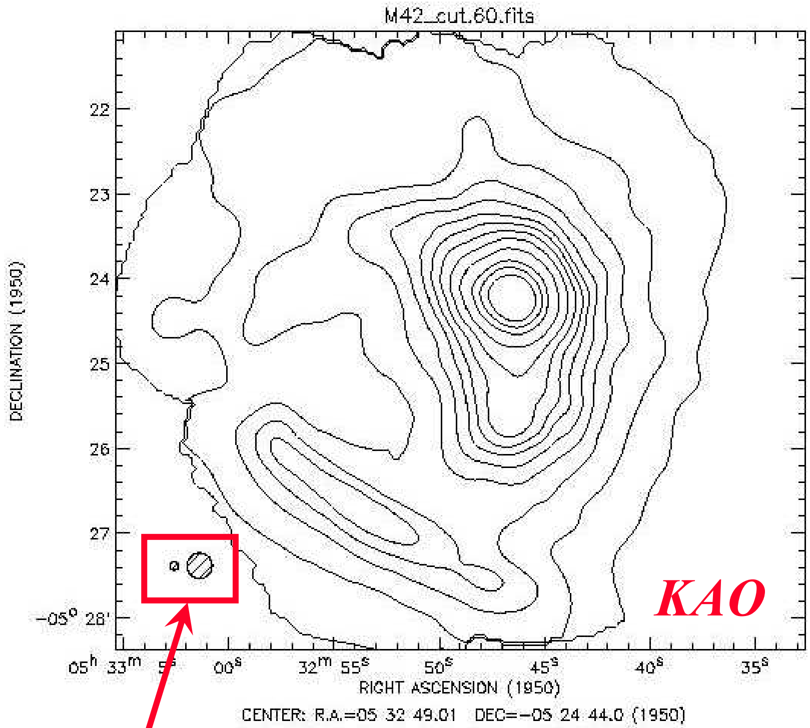
- What powers the most luminous galaxies? How do they evolve?
- What is a massive black hole doing at the center of our Galaxy?

SOFIA Science: Targets of Opportunity

- ***Bright Comets***
- ***Eruptive variable stars***
- ***Galactic and LMC/SMC classical novae***
- ***Supernova in our galaxy or other nearby galaxies***
- ***Eclipses and Occultations***

SOFIA and Regions of Star Formation

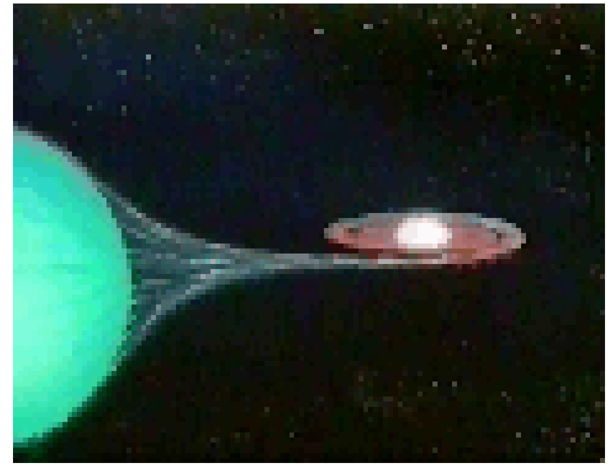
How will SOFIA shed light on the process of star formation in Giant Molecular Clouds like the Orion Nebula?



With 9 SOFIA beams for every 1 KAO beam, SOFIA imagers and spectrometers will be able to observe protostellar condensations where they emit most of their energy with unprecedented spatial detail.

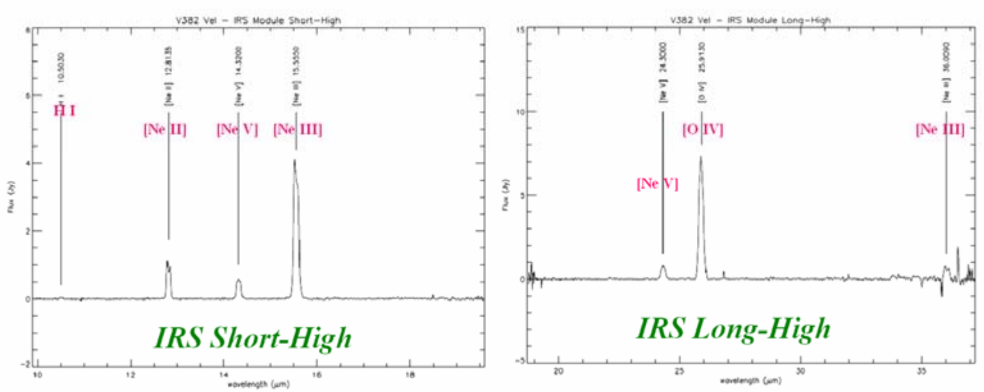
SOFIA and Classical Nova Explosions

What can SOFIA tell us about Classical Nova Explosions?



Spitzer Spectra of Nova V382 Vel

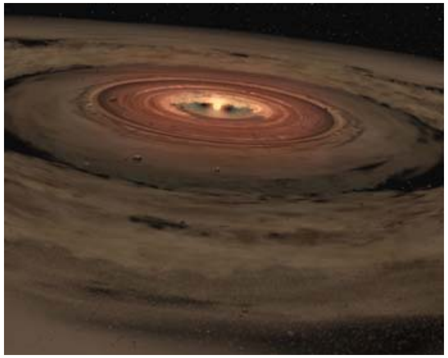
R. D. Gehrz, et al. 2005, ApJ, in preparation [PID 124]

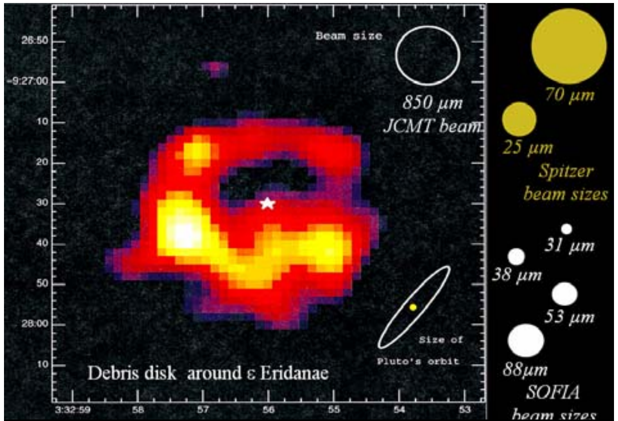


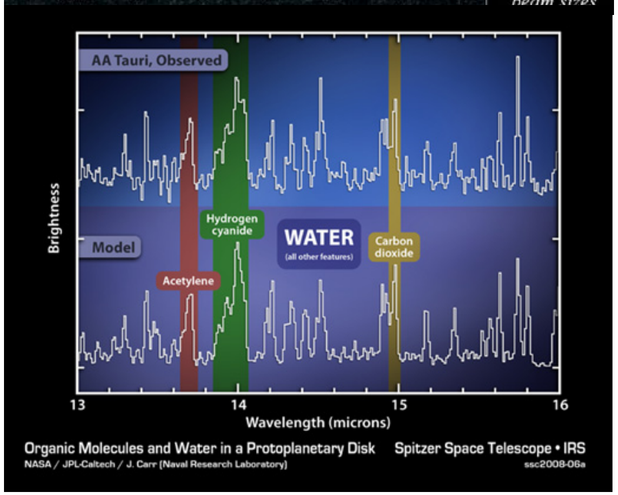
- *Gas phase abundances*
- *Stardust formation and mineralogy, and abundances*
- *Contributions to ISM clouds*
- *Kinematics of the Ejection*

SOFIA and Extra-solar Debris Disks

What can SOFIA tell us about debris disks?



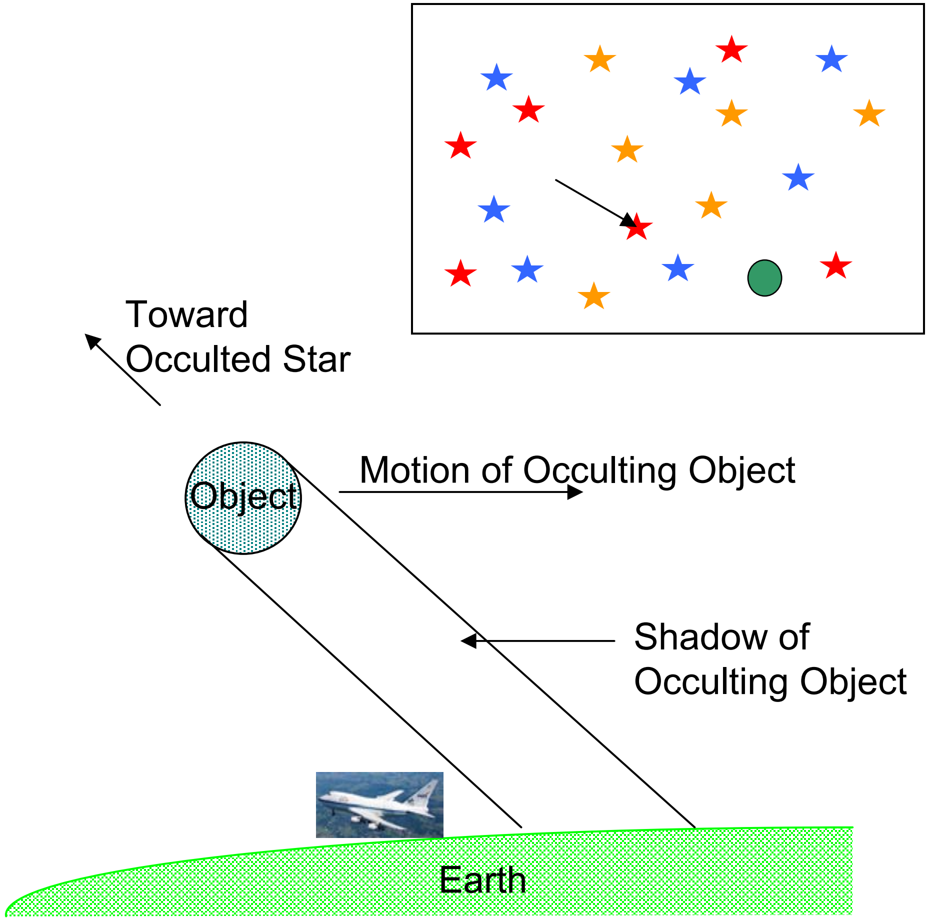




- *SOFIA imaging and spectroscopy can resolve disks to trace the evolution of the spatial distribution of the gaseous, solid, and icy gas and grain constituents*
- *SOFIA can shed light on the process of planet formation by studying the temporal evolution of debris disks*

Occultation Astronomy with SOFIA

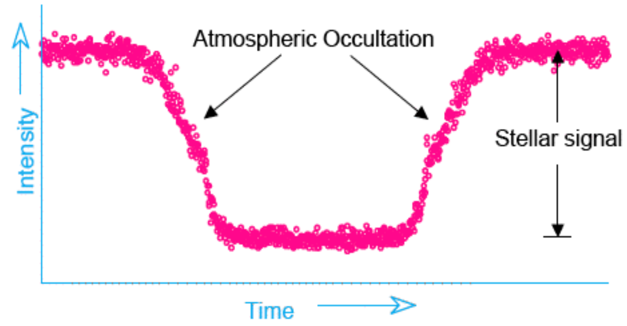
- An occultation occurs when solar system object passes between an observer and a star. The star acts like a tiny probe as it sets behind the planet's limb
- SOFIA can fly anywhere on the Earth, allowing it to position itself under the shadow of an occulting object



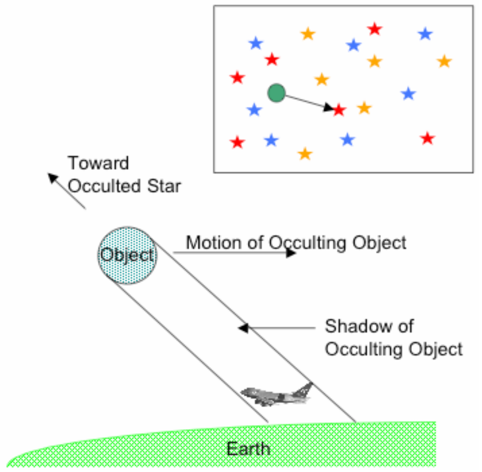
Occultation astronomy with SOFIA

How will SOFIA help determine the properties of Dwarf Planets in and small bodies in the Solar System?

- *Occultation studies with SOFIA will probe the sizes, atmospheres, and possible satellites of newly discovered planet-like objects in the outer Solar system.*



Pluto occultation lightcurve observed on the KAO (1988) probes the atmosphere

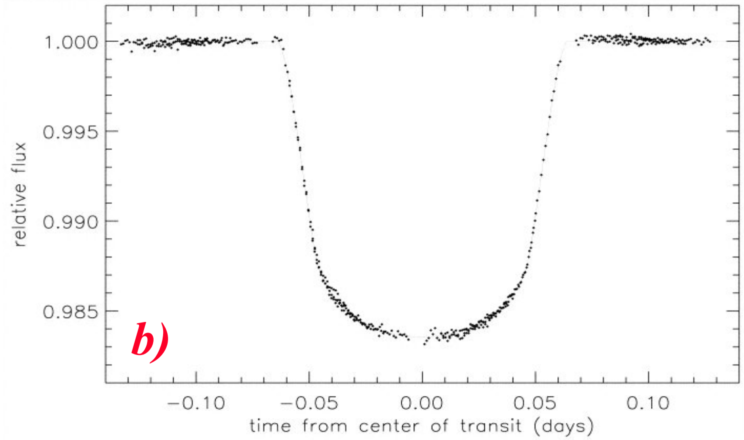


- *The unique mobility of SOFIA opens up some hundred events per year for study compared to a handful for fixed ground and space-based observatories.*

SOFIA and Extra-solar Planet Transits

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

- More than 200 extra-solar planets, some of which 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

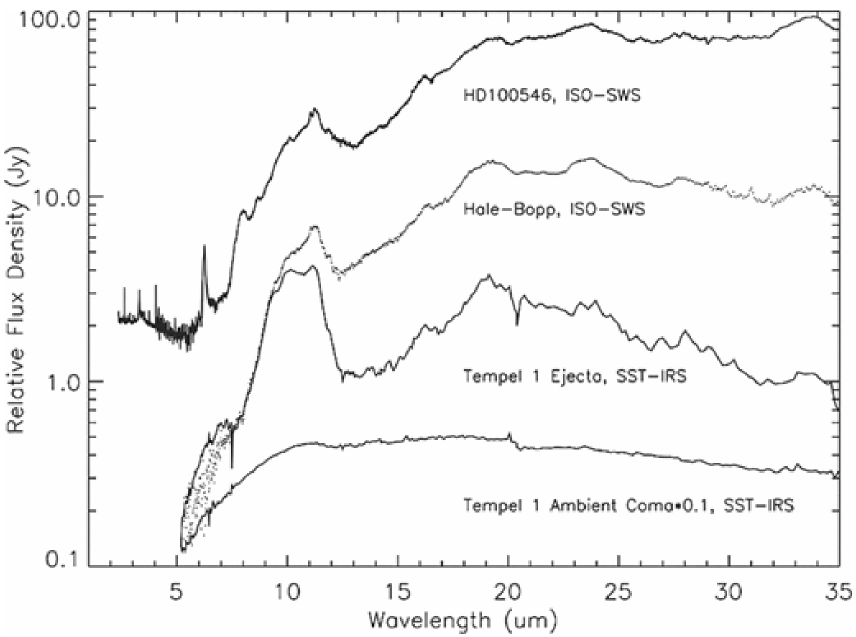


HD 209458b transit:
a) artist's concept and
b) HST STIS data

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

SOFIA and Comets during Perihelion Passage

What can SOFIA tell us about The origin of the Solar System for studies of comets at perihelion passage?



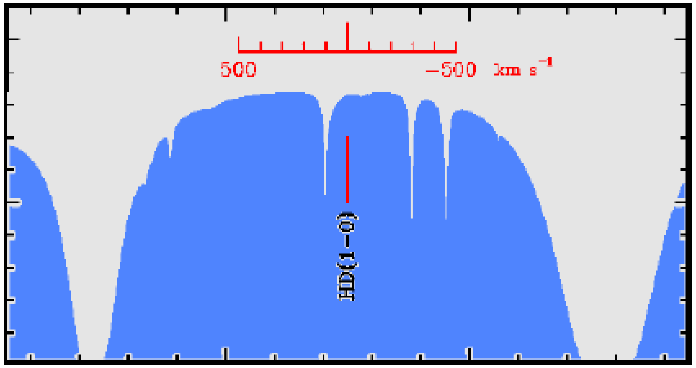
NASA/UM C. M. Lisse et al., Science 313, 635 (2006)

- *Comet dust mineralogy and physical properties*
- *Comparisons with IDPs*
- *Comparisons with meteorites*
- *Comparisons with Stardust*
- *Only SOFIA can get these observations*

Cold Molecular Hydrogen using HD

How can SOFIA be used to study the cold molecular hydrogen abundance in the Galaxy using the 112 μm ground-state HD line?

- Deuterium is created in the Big Bang.
- Cold HD (T<50K) is a Proxy for cold molecular Hydrogen
- Cold HD can best be mapped in the 112 μm ground-state rotational line

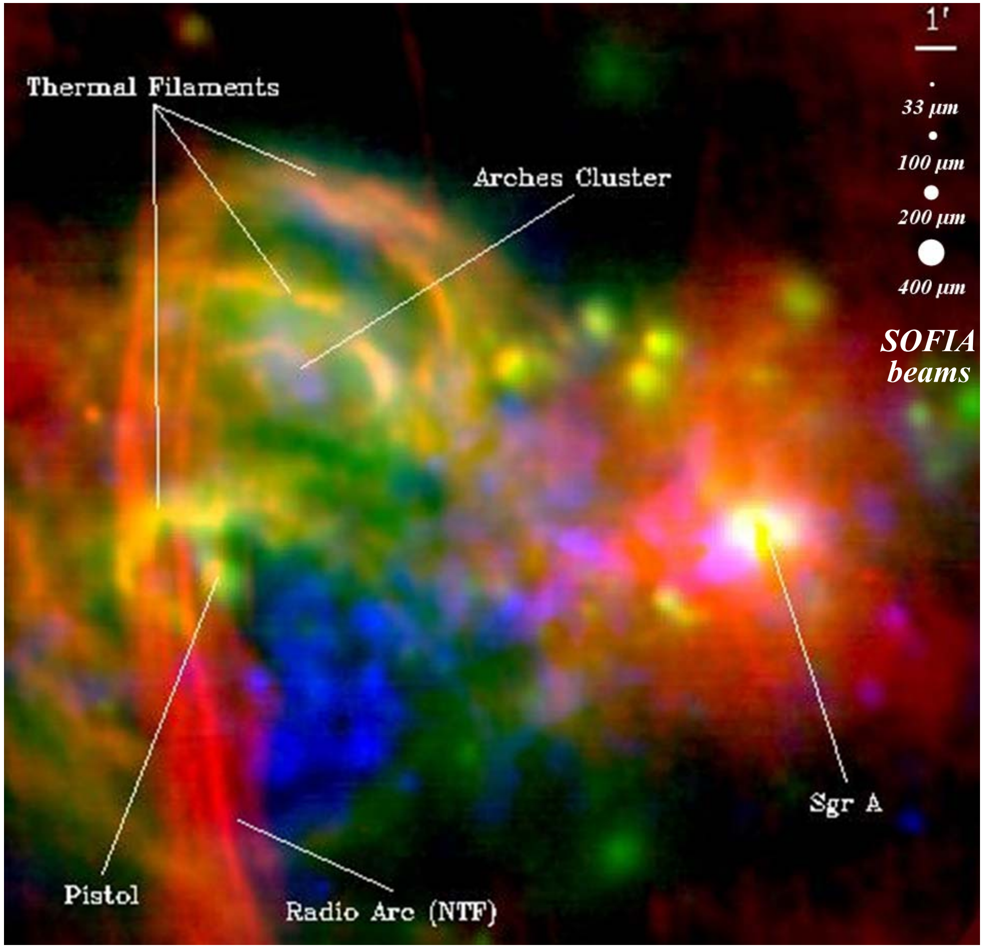


Atmospheric transmission around the HD line at 40,000 feet

- A GREAT high resolution spectrometer study is possible given ISO detection
- This technique could be used to map the Galactic distribution of cold molecular gas the way that 21 cm is used to map the distribution of neutral hydrogen

SOFIA and Activity in Galactic Nuclei

What can SOFIA see at the center of our Galaxy?

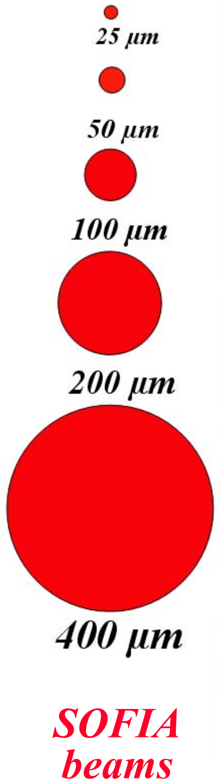


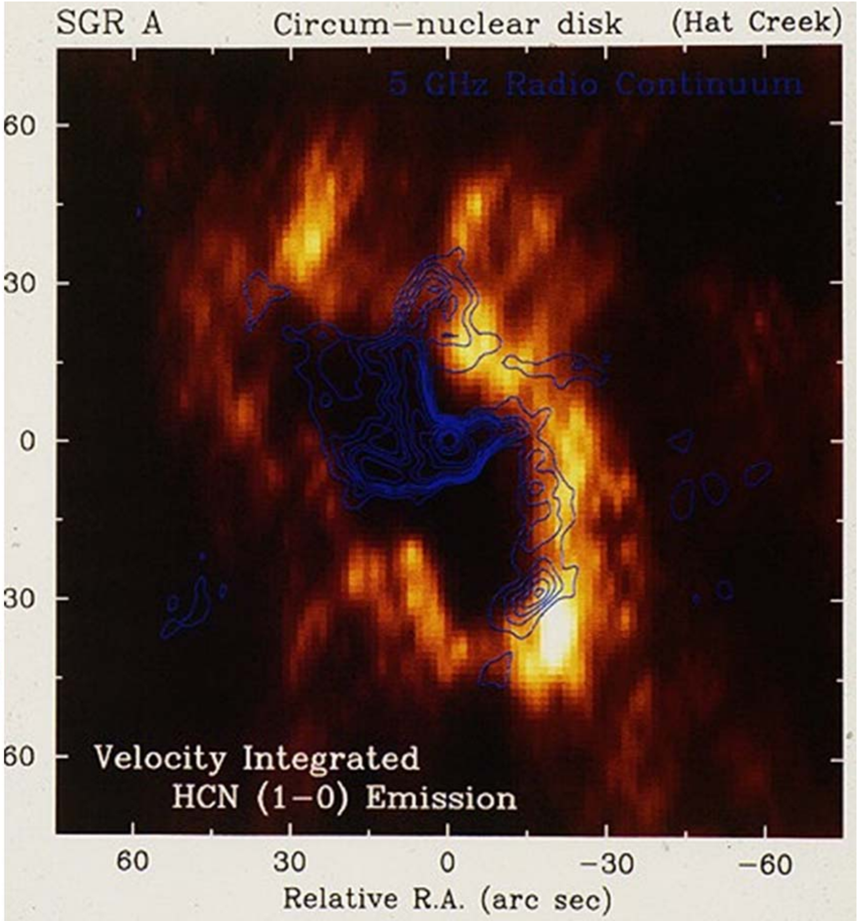
Red, 90 cm radio; green, mid-IR; blue, X-ray: Daniel Wang et al., University of Massachusetts HST OBSERVING PROGRAM 11120.

- *SOFIA imagers and spectrometers can resolve important structures at the center of the Galaxy*
- *An objective of SOFIA science is the identification of the stellar sources that excite and support the thermal arches near the Galactic Center*

SOFIA and the Black Hole at the Galactic Center

How will SOFIA study the massive 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 to understand the physical and dynamical properties of the material that feeds the massive black hole at the Galactic Center*

Schedule

SOFIA Schedule (Major Milestones)

• First Re-Flight	Occurred April '07
• Ten Closed Door Flights	Finished Dec '07
• Door Drive Delivered	Spring '08
• Mirror coated and ground tests	Spring/Summer 08
• Open Door Flights at Palmdale	Fall '08
• First Science	'09
• Next Instrument call	'10

Early US General Observer Opportunities

- First call Early Science proposals this year
  - Early Short Science Aug '08 with PI's
  - Early Basic Science Dec '08 GO's
- Early Short Science with FORCAST and GREAT
  - Special call for participation with PI's
  - Very limited flights (~3)
  - GO's will not fly
- Early Basic Science also with FORCAST and GREAT
  - Longer period (~15 Flights)
  - More capabilities
  - Call will be for GO Science and GO participation

Early Science with SOFIA

- *The aircraft has flown in April 2007 and is now at NASA Dryden FRC for flight certification tests*
- *Early Science is expected to occur in 2009*
- *Two instruments have been selected for Early Science*
  - *FORCAST: a US 5-40 μm imager*
  - *GREAT: a German heterodyne 60 to 200 μm Spectrometer*
  - *Both have been tested in the lab or on a telescope*

Next Call For New Instruments

- *The next call for instruments will be at First Science ~ FY '10*
- *We are considering:*
  - *New science instruments, both FSI and PSI*
  - *Studies of instruments and technology*
  - *Upgrades to present instruments*
- *There will be additional calls every 3 years*
- *There will be one new instrument or upgrade per year*
- *Approximate funding for new instruments and technology is ~\$10 M/yr*

Partnership Opportunity on SOFIA

- ***NASA is funding 80% of the program and the German space agency (DLR) is funding 20% of the program***

- ***The NASA Science Mission Directorate is open to considering proposals for participation as a partner in the United States's share of the operations phase of the SOFIA Mission by domestic and international governments, agencies, universities, organizations, and research foundations***

Summary

- *The Program is making progress!*
  - *Aircraft structural modifications complete*
  - *Telescope installed, several instruments tested on ground observatories*
  - *Full envelope closed door flight testing is complete.*
  - *door motor drive, coated primary mirror are being installed during summer of '08*
  - *First science will be in early '09*
- *SOFIA will be one of the primary observational facilities for far-IR and submillimeter astronomy for many years*

Backup

The Initial SOFIA Instrument Complement

- HIPO: High-speed Imaging Photometer for Occultation
- FLITECAM: First Light Infrared Test Experiment CAMera
- FORCAST: Faint Object InfraRed CAmera for the SOFIA Telescope
- GREAT: German Receiver for Astronomy at Terahetz Frequencies
- CASIMIR: CAltech Submillimeter Interstellar Medium Investigations Receiver
- FIFI-LS: Field Imaging Far-Infrared Line Spectrometer
- HAWC: High-resolution Airborne Wideband Camera
- EXES: Echelon-Cross -Echelle Spectrograph
- SAFIRE: Submillimeter And Far InfraRed Experiment

USRA NASA DLR SOFIA

SOFIA's 9 First Generation Instruments

Instrument *	Type	ΛΛ (μm)	Resolution	PI	Institution
HIPO %	fast imager	0.3 - 1.1	filters	E. Dunham	Lowell Obs.
FLITECAM %	imager/grism	1.0 - 5.5	filters/R~2E3	I. McLean	UCLA
FORCAST	imager/(grism?)	5.6 - 38	filters/(R~2E3)	T. Herter	Cornell U.
GREAT ¤	heterodyne receiver	158 - 187, 110 - 125, 62 - 65	R ~ 1E4 - 1E8	R. G□sten	MPIfR
CASIMIR ¤	heterodyne receiver	250 -264, 508 -588	R ~ 1E4 -1E8	J. Zmuidzinas	CalTech
FIFI LS ¤	imaging grating spectrograph	42 - 110, 110 - 210	R ~1E3 - 2E3	A. Poglitsch	MPE
HAWC ¤	imager	40 - 300	filters	D. A. Harper	Yerkes Obs.
EXES	imaging echelle spectrograph	4.5-28.3	R ~ 3E3 - 1E5	J. Lacy	U. Texas Austin
SAFIRE ¤	F-P imaging spectrometer	150 - 650	R ~ 1E3 - 2E3	H. Moseley	NASA GSFC

** Listed in approximate order of expected in-flight commissioning*

% Operational (August 2004)

§ Uses non-commercial detector/receiver technology