
SOFIA
NASA
DLR
N747NA
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850

SOFIA

Stratospheric Observatory For Infrared Astronomy

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Outline of Material

- Overview of SOFIA
- Progress to Date
- Instruments
- Science
- Schedule and Science Opportunities

OVERVIEW

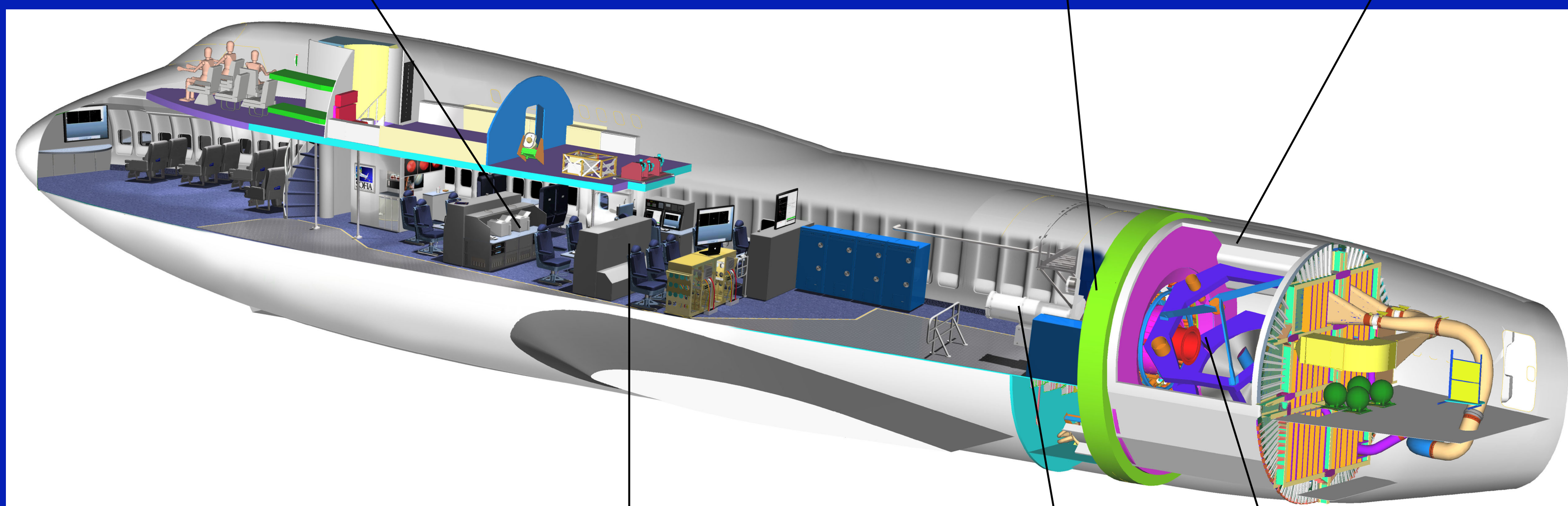
Overview of SOFIA

- SOFIA is 2.5 m telescope in a modified B747SP aircraft
  - Optical-mm performance
  - Obscured IR (30-300 μm) most important
- Joint Program between the US (80%) and Germany (20%)
- First Science 2010 (NASA, DLR, USRA, DSI)
- Designed for 20 year lifetime

Overview of SOFIA (Cont)

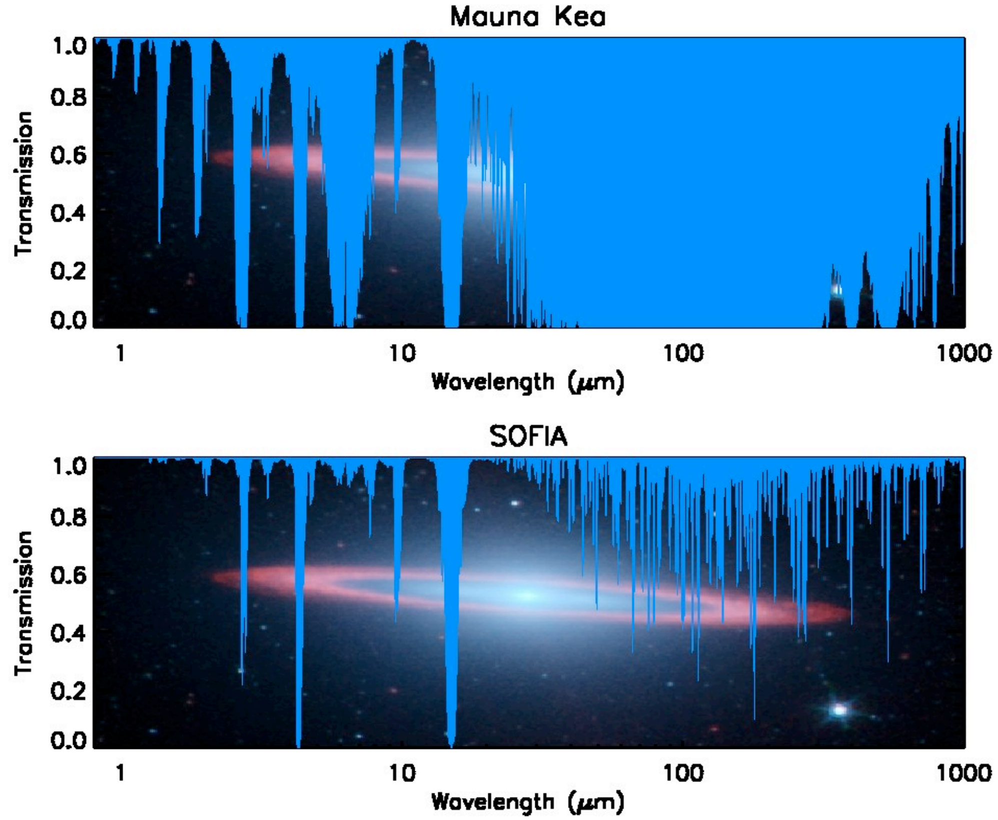
- Operating altitude
  - 39,000 to 45,000 feet (12 to 14 km)
  - Above > 99% of obscuring water vapor
- World Wide Deployments
- Ramp up to ~1000 science hours per year
- Build on KAO Heritage with improvements (Facility Inst., Science Support)
- Science flights to originate from Palmdale ….Aircraft operation by NASA Dryden Research Center (DFRC)
- Science Center is located at NASA Ames Research Center

SOFIA — The Observatory



Why SOFIA?

- Infrared transmission in the Stratosphere very good: >80% from 1 to 1000 microns
- Instrumentation: wide complement, rapidly interchangeable, state-of-the art
- Mobility: anywhere, anytime
- Long lifetime
- Outstanding platform to train future Instrumentalists
- Near Space Observatory that comes home after every flight



PROGRESS TO DATE

SOFIA Makes Its First Flight!

SOFIA in the Palmdale Hanger

SOFIA with 100% Open Door

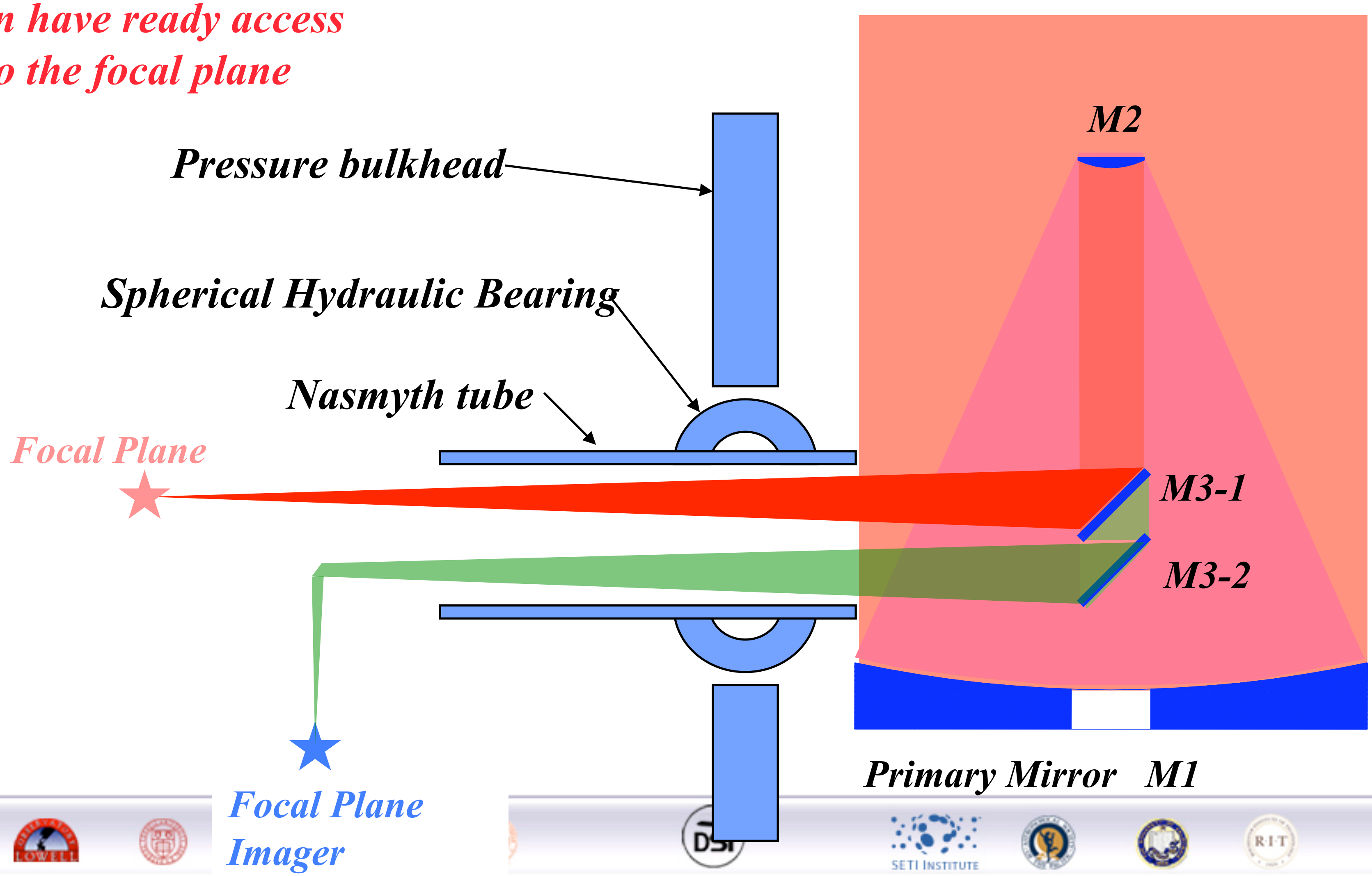
Recent Flights with Significance

- 18 Dec 09: 100% open door at 15,000 ft; No measureable acoustics and no extra drag.
- 15 Jan 10: Telescope Activation with door closed at 43,000ft; All aspects of the telescope preformed to spec.
- 12 Feb 10: Open Door landing (40%) with no major problems.

THE TELESCOPE

Nasmyth: Optical Layout

Observers in pressurized cabin have ready access to the focal plane

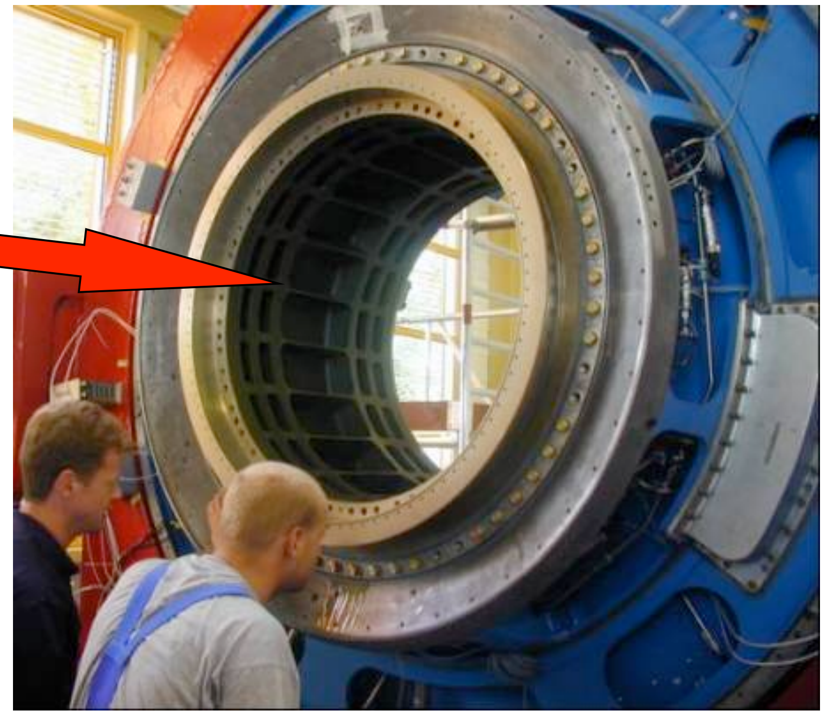


Rotation Isolation Subsystem

Spherical Bearing

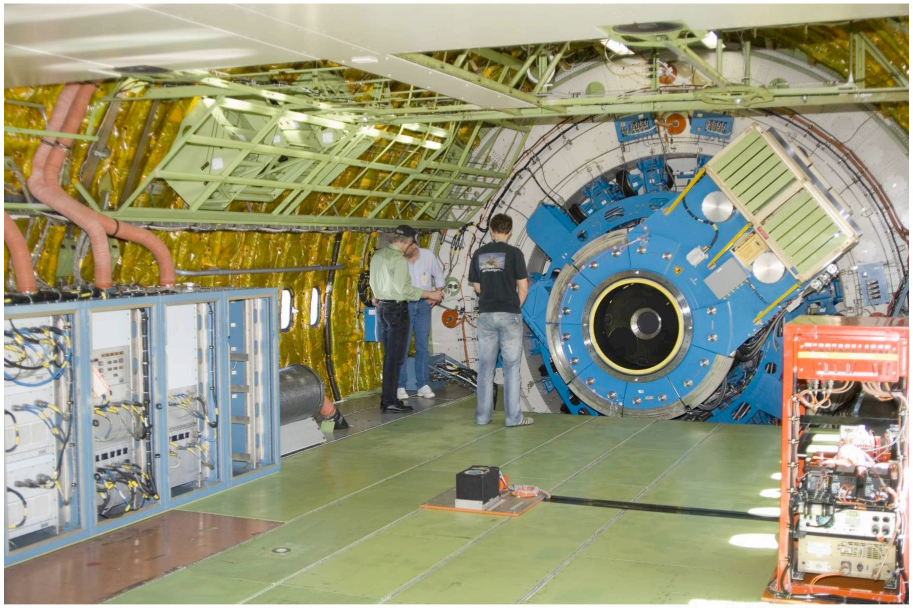
The Bearing Sphere on the Nasmyth Tube

“First Oil“



Major Physical Installations Completed

Main Deck, Looking Aft at Instrument Interface

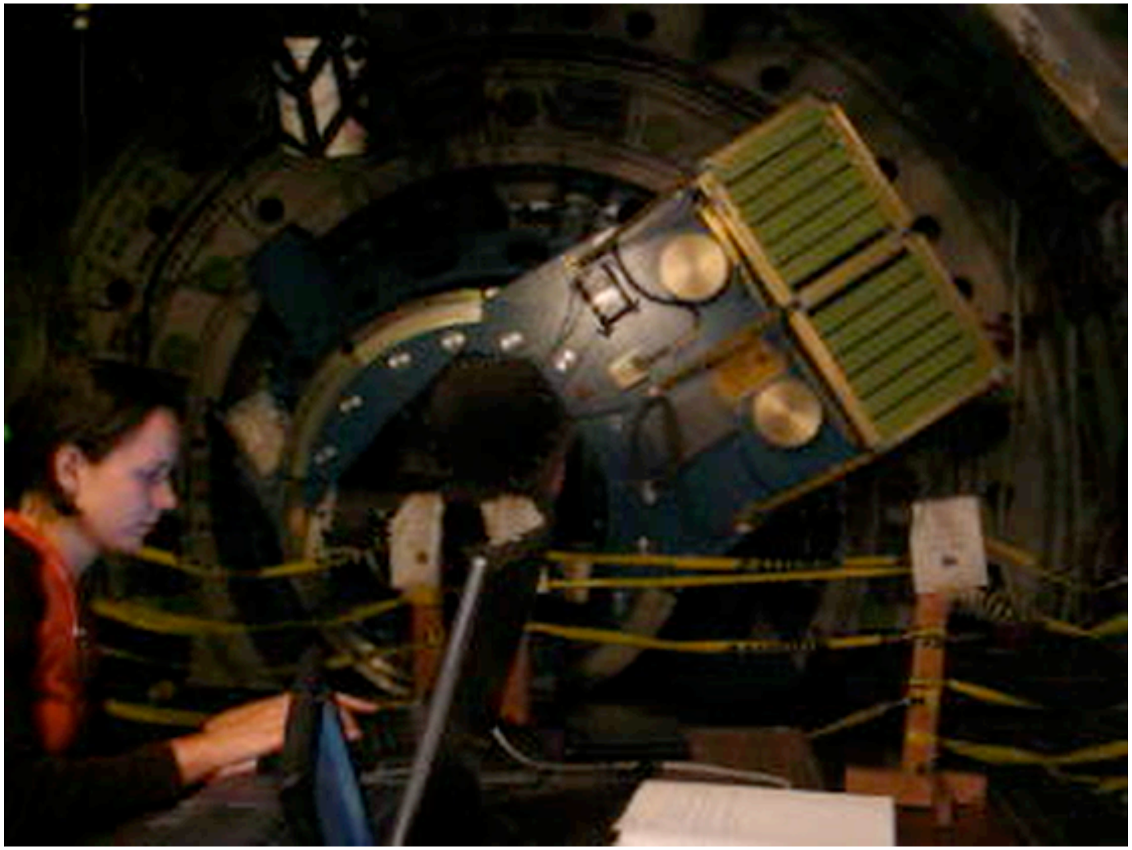


NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED07-0078-033 Date: April 25, 2007 Photo By: Tony Landis

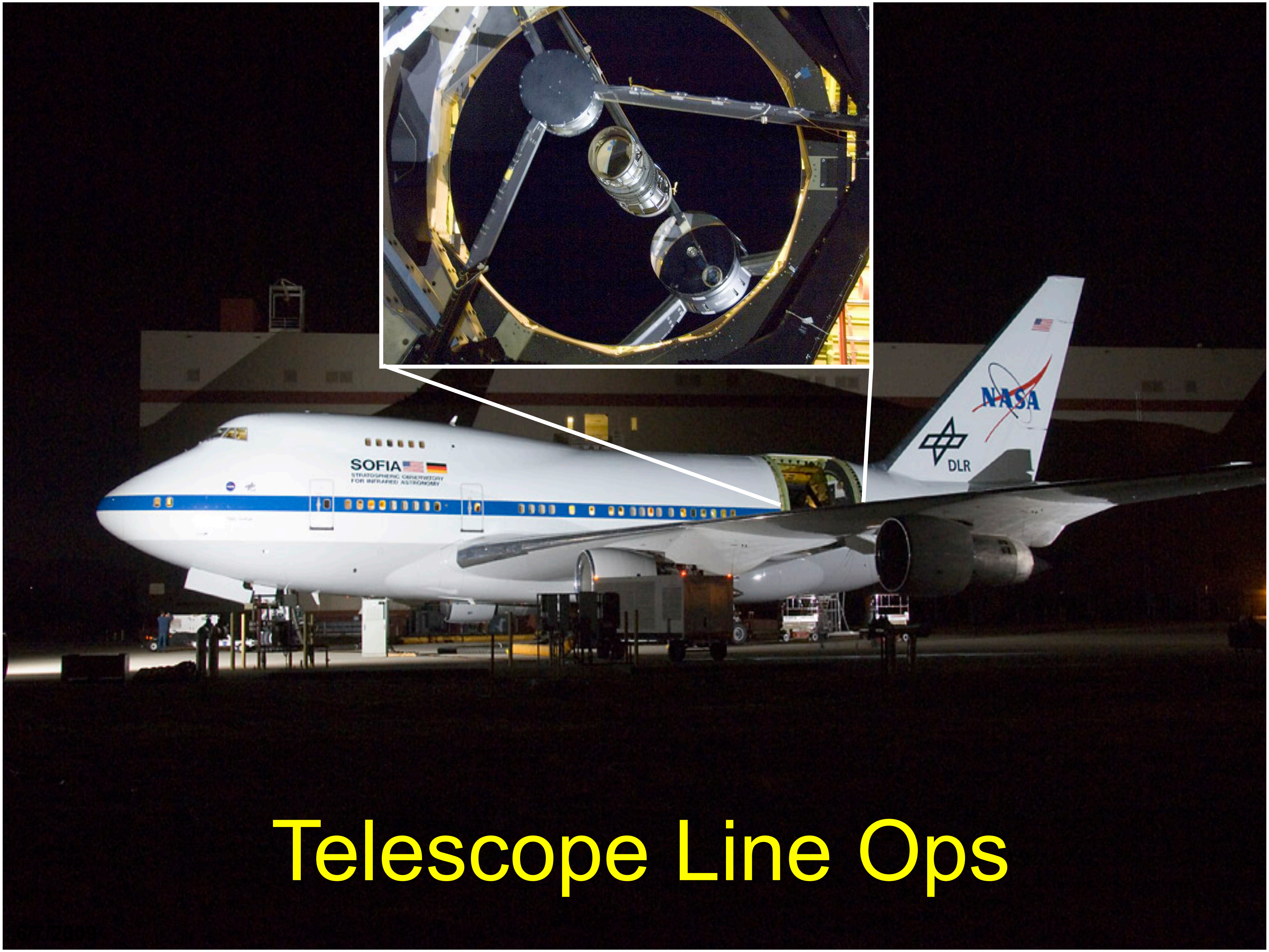
Technicians check out the mounting structure of the infrared telescope installed in NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA).

Telescope Installed

Telescope in Action



March 2008 Ground Test in Palmdale



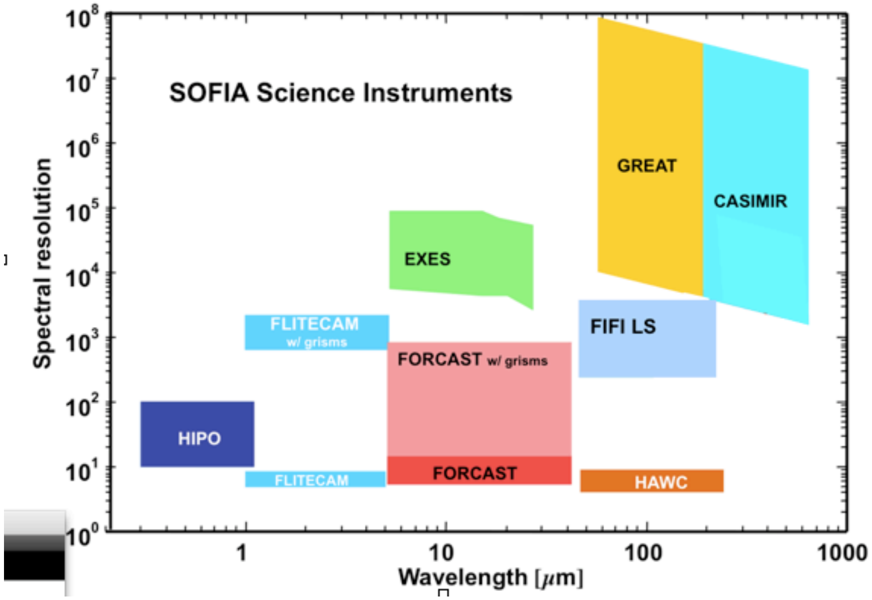
Telescope Line Ops

INSTRUMENTATION

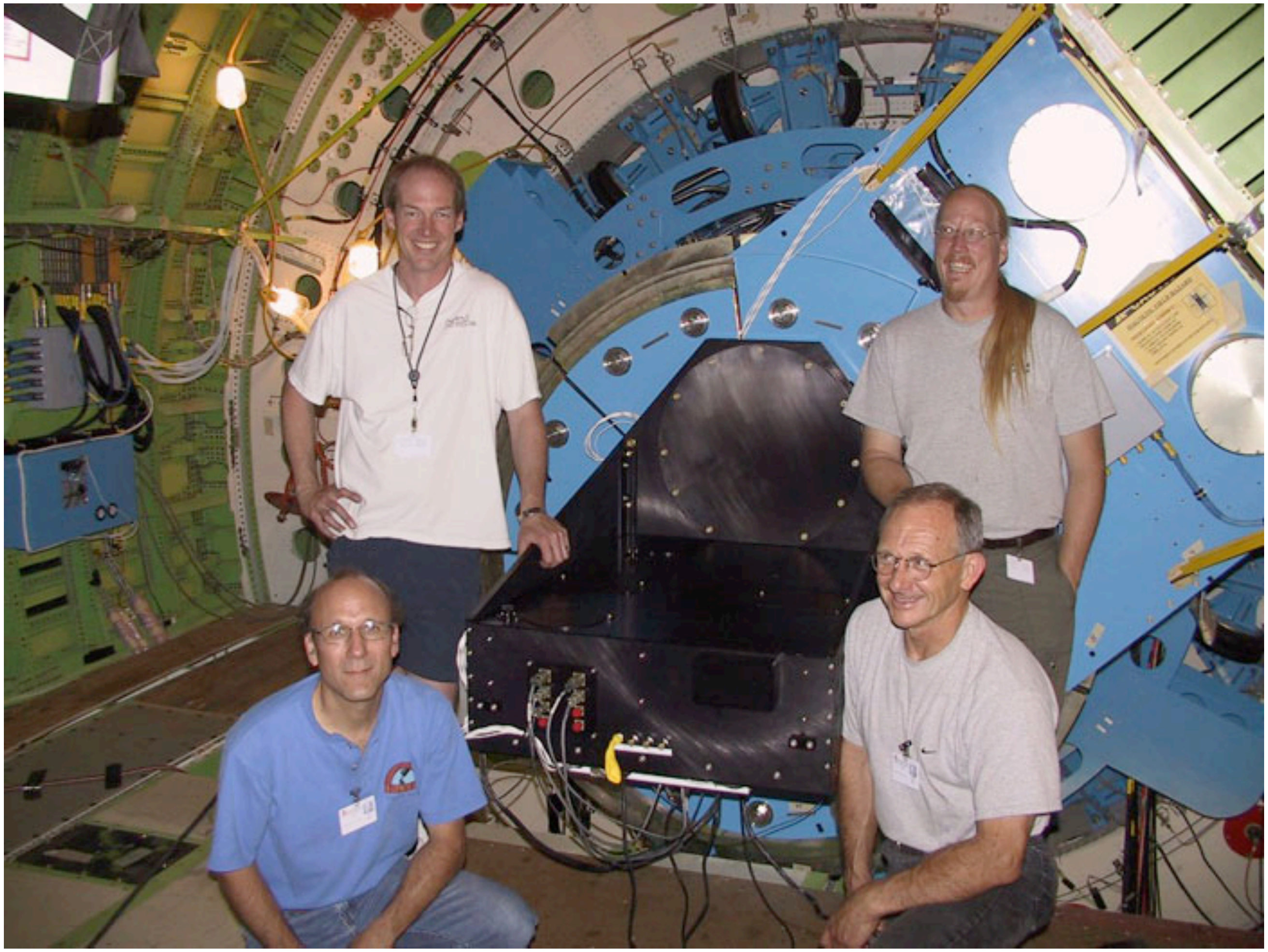
SOFIA's Instrument Complement

As an airborne mission, SOFIA supports a unique, expandable instrument suite

- SOFIA covers the full IR range with imagers and low to high resolution spectrographs
- 5 instruments at Initial Operations; 8 instruments at Full Operations.
- SOFIA will take full advantage of improvements in instrument technology. There will be one new instrument or major upgrade each year.
- Will support both Facility Instruments and PI Class Instruments



HIPO as a Test Instrument

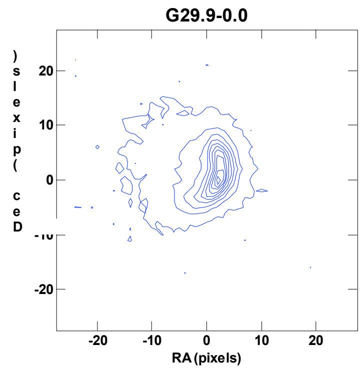


FORCAST: Mid-IR Imager

G29.9-0.0

PI: T. Herter (Cornell Univ.)
herter@astrosun.tn.cornell.edu

Detectors: Dual channel
256 x 256 arrays;
5 – 25 μm (Si:As)
20 – 40 μm (Si:Sb)
Field of View: 3.2’ x 3.2’

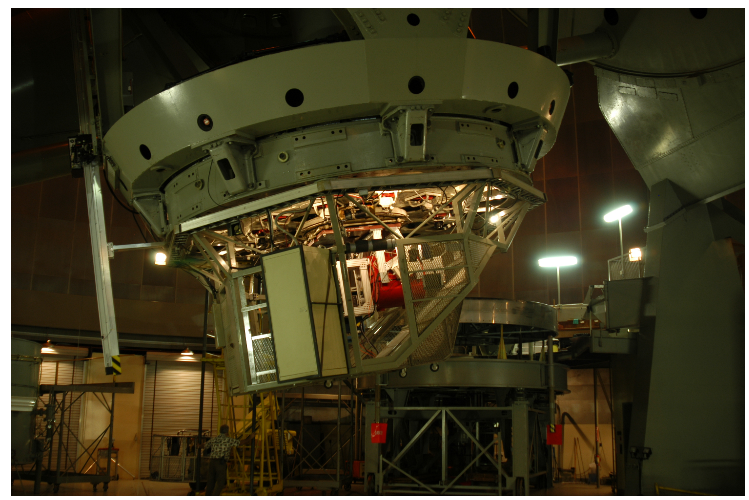


10.6 μm ($\Delta\lambda$ = 0.23 μm) image and contour map of the cometary HII region G29.9-0.0 made with FORCAST. RA and Dec are in pixels (~ 0.5”/pixel).

Science: Thermal and narrow band imaging

Targets: Circumstellar disks, Galactic Center, Galactic and extragalactic star formation

NB: Diffraction Limited > 15 microns;
Grism upgrade funded (Ennico et al.)



FORCAST at Palomar Summer 2006

GREAT: Heterodyne Spectrometer

PI: R. Guesten, Max-Planck Institut, Bonn
guesten@mpifr-bonn.mpg.de

Detector: dual channel mixer (HEB);
60 – 200 μm (2 – 5 THz)

Field of View: single element

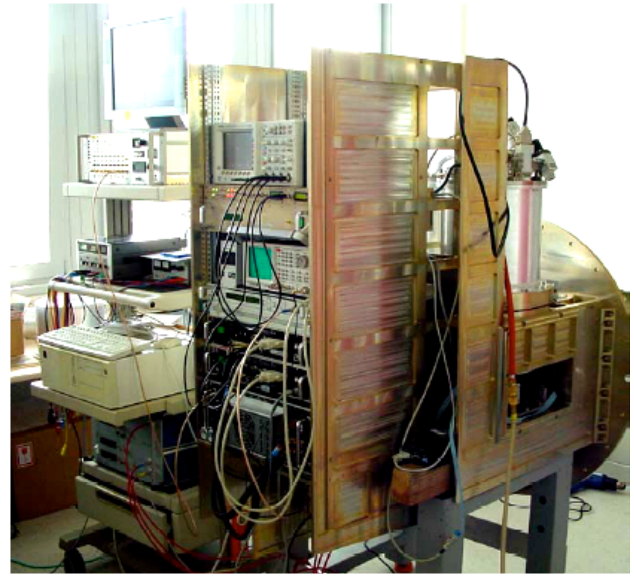
R= 10^6 -> 10^8

Science: Spectroscopy of CII (158 μm), and HD (112 μm)

Targets: Galactic and extragalactic ISM, circumstellar shells

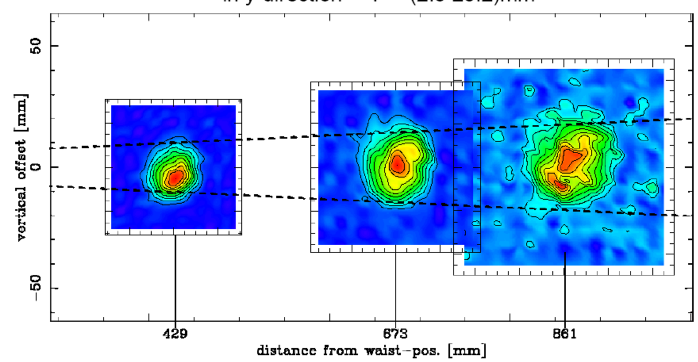
NB: T_S ~ 2500 K at 158 μm

High frequency upgrade at 4.7 THz expected for OI (63 μm).



Theoretical beam-width @ focal plane: 2.55mm

Measured in x-direction : (2.2 ±0.2)mm
in y-direction : (2.5 ±0.2)mm



Successful lab demonstration of GREAT in Oct 2005

FIFI-LS: Far-IR Spectrometer

PI: A. Poglitsch, Max-Planck Institut, Garching
alpog@mpe.mpg.de

Detectors: Dual channel 16 x 25 arrays;
42 – 110 μm (Ge:Ga)
120 - 210 μm (Ge:Ga stressed)

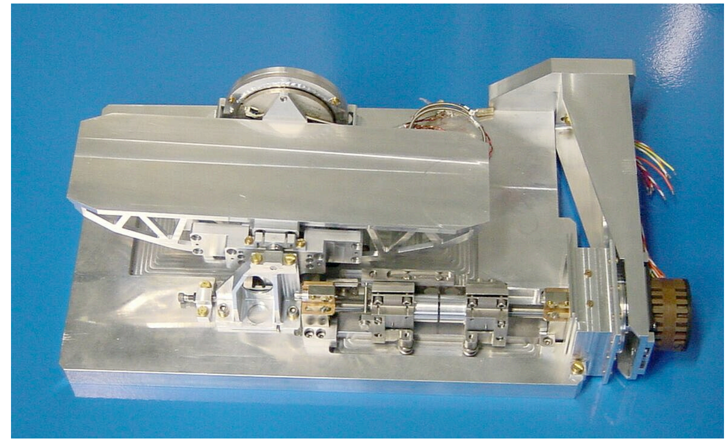
Field of View: 30” x 30” (blue), 60” x 60” (red)

R= 1500 - 6000

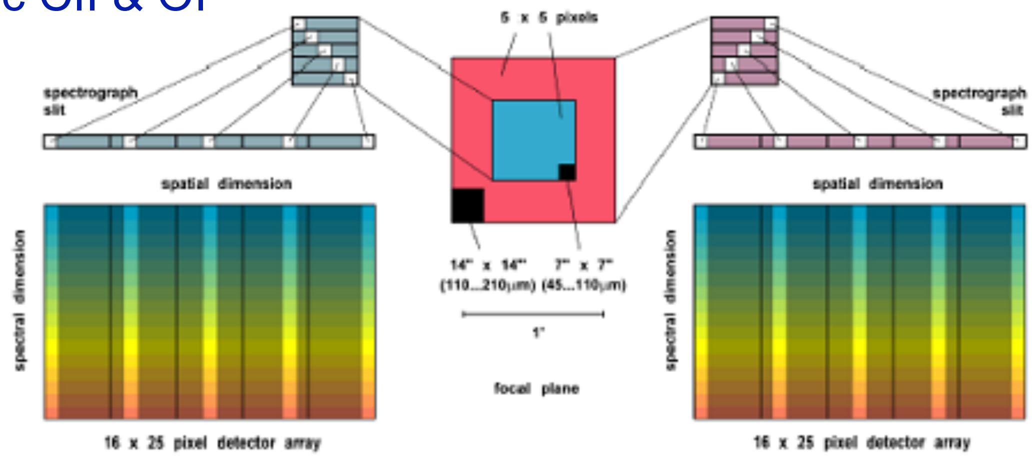
Science: Imaging of extragalactic CII & OI

Targets: Extragalactic imaging

NB: Imaging array is 5 x 5 pixels



Grating drive & support optics integration with flight cryostat in 2006



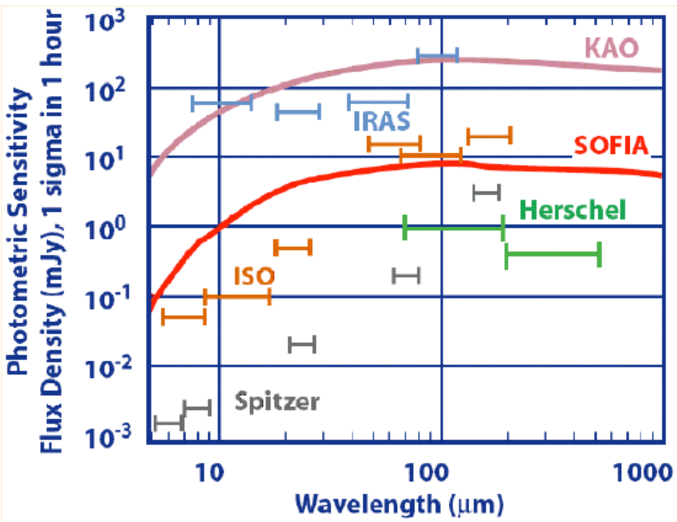
On sky orientation of ‘blue’ and ‘red’ channels

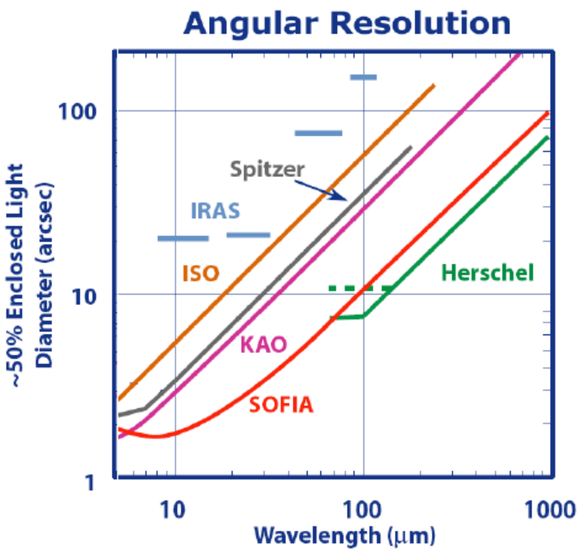
SCIENCE

Science Capabilities

- Because of large aperture and better detectors, sensitivity for imaging and spectroscopy similar to the space observatory ISO
- 8x8 arcmin Field of View allows use of very large detector arrays
- Image size is diffraction-limited beyond 25 μm, making it 3 times sharper than the space observatory Spitzer at these wavelengths

Photometric Sensitivity and Angular resolution



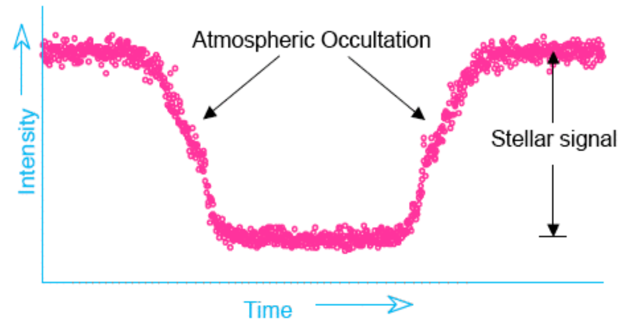


SOFIA is as sensitive as ISO

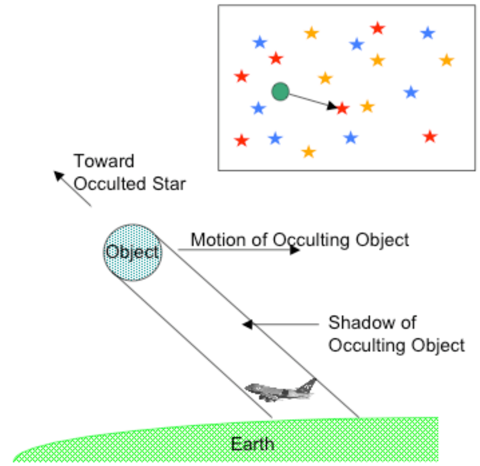
SOFIA is diffraction limited beyond 25 µm (θmin ~ λ/10 in arcseconds) and can produce images three times sharper than those made by Spitzer

Occultation astronomy with SOFIA

SOFIA will determine the properties of Dwarf Planets in and beyond the Kuiper Belt



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



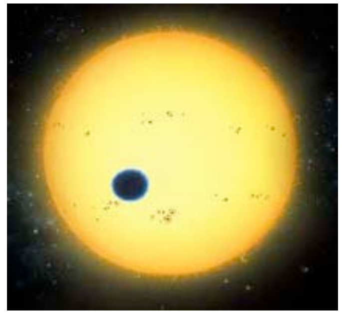
•SOFIA can fly anywhere on the Earth, allowing it to position itself under the shadow of an occulting object.

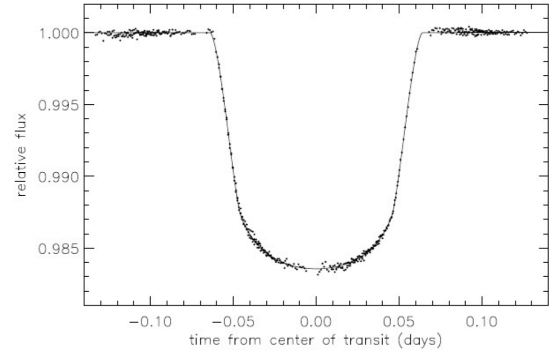
•Occultation studies with SOFIA will probe the sizes, atmospheres, and possible satellites of newly discovered planet-like objects in the outer Solar system.

•The unique mobility of SOFIA opens up some hundred events per year for study compared to a handful for fixed observatories.

Extrasolar Planet Transits

SOFIA will determine the properties of new extrasolar planets by use of transits with HIPO and FLITECAM working together





Artist concept of planetary transit and the lightcurve of HD 209458b measured by HST revealing the transit signature

Today over 300 extrasolar planets are known, and over 50 transit their primary star

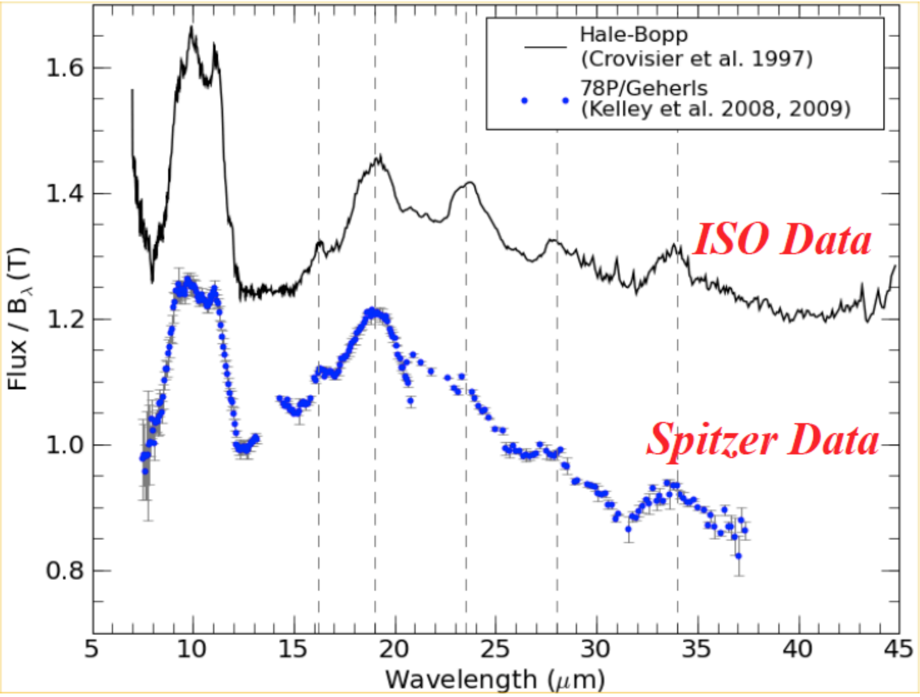
SOFIA will fly above the scintillating component of the atmosphere and will provide the most sensitive freely pointing observatory for extrasolar planetary transits after HST and before JWST.

SOFIA's HIPO and FLITECAM instruments can observe with high signal-to-noise the small variations in stellar flux due to a planet transit and

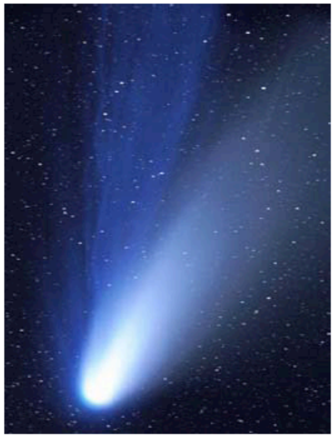
- Provide good estimates for the mass, size and density of the planet
- Will be able to probe the composition of the planetary atmospheres

SOFIA and Comets: Mineral Grains

What can SOFIA observations of comets tell us about conditions in the protosolar disk?



The vertical lines mark features of crystalline Mg-rich crystalline olivine (forsterite)

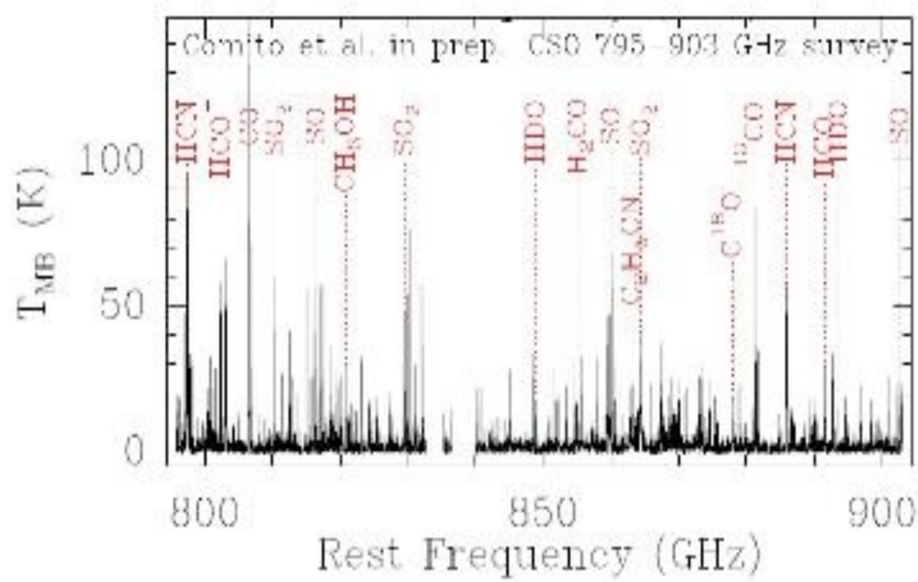


- *Comet dust mineralogy: amorphous, crystalline, and organic constituents*
- *Comparisons with IDPs and meteorites*
- *Comparisons with Stardust*
- *Only SOFIA can make these observations near perihelion*

Astrochemistry

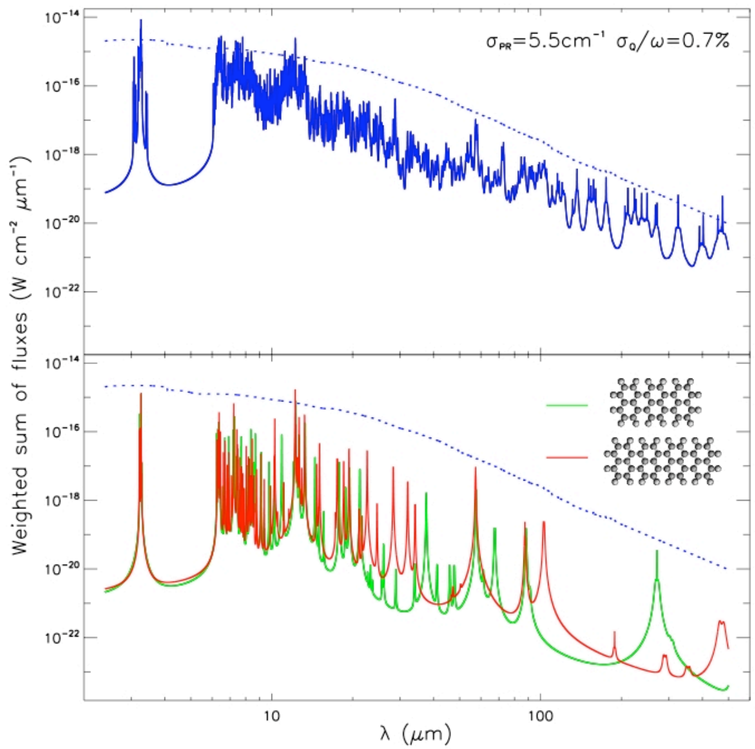
SOFIA is a good observatory to study chemistry in space

- Many ground state molecular lines in IR or submillimeter
- Need high spectral resolution throughout which SOFIA has.
- As sensitive as CSO, but much larger wavelength range is accessible.
- Frequencies above 1.9 THz not seen by Herschel. (Also 1.25-1.41 THz)
- Light molecules: Molecular hydrogen, HD, water, other hydrides in IR and submillimeter
- The fullerene, C_{60}, has 4 IR lines in SOFIA's bands



SEARCHING FOR CARBON RINGS

- SOFIA can measure all vibrational modes of interstellar Carbon Rings PAHs:
- Moderate resolution (R=200-1000) spectroscopy from 5-200 μm is a key to finding the large carbon molecules. It is best done with an advanced instrument that works over the entire wavelength range.
- High resolution follow up using GREAT & CASIMIR can resolve P-Q-R branch structure of lowest vibrational transitions



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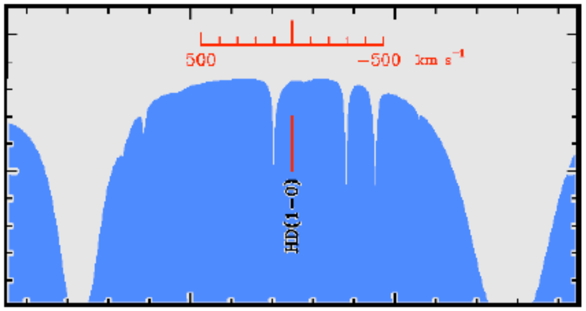
Cold Molecular Hydrogen using HD

SOFIA will study deuterium in the galaxy using the ground state HD line at 112 microns. This will allow determination the cold molecular hydrogen abundance.



Atmospheric transmission around the HD line at 40,000 feet

Deuterium in the universe is created in the Big Bang.

Measuring the amount of cold HD (T<50K) can best be done with the ground state rotational line at 112 microns accessible with SOFIA.

Detections with ISO means a GREAT high resolution spectroscopic study possible.

As pointed out by Bergin and Hollenbach, HD gives the cold molecular hydrogen.

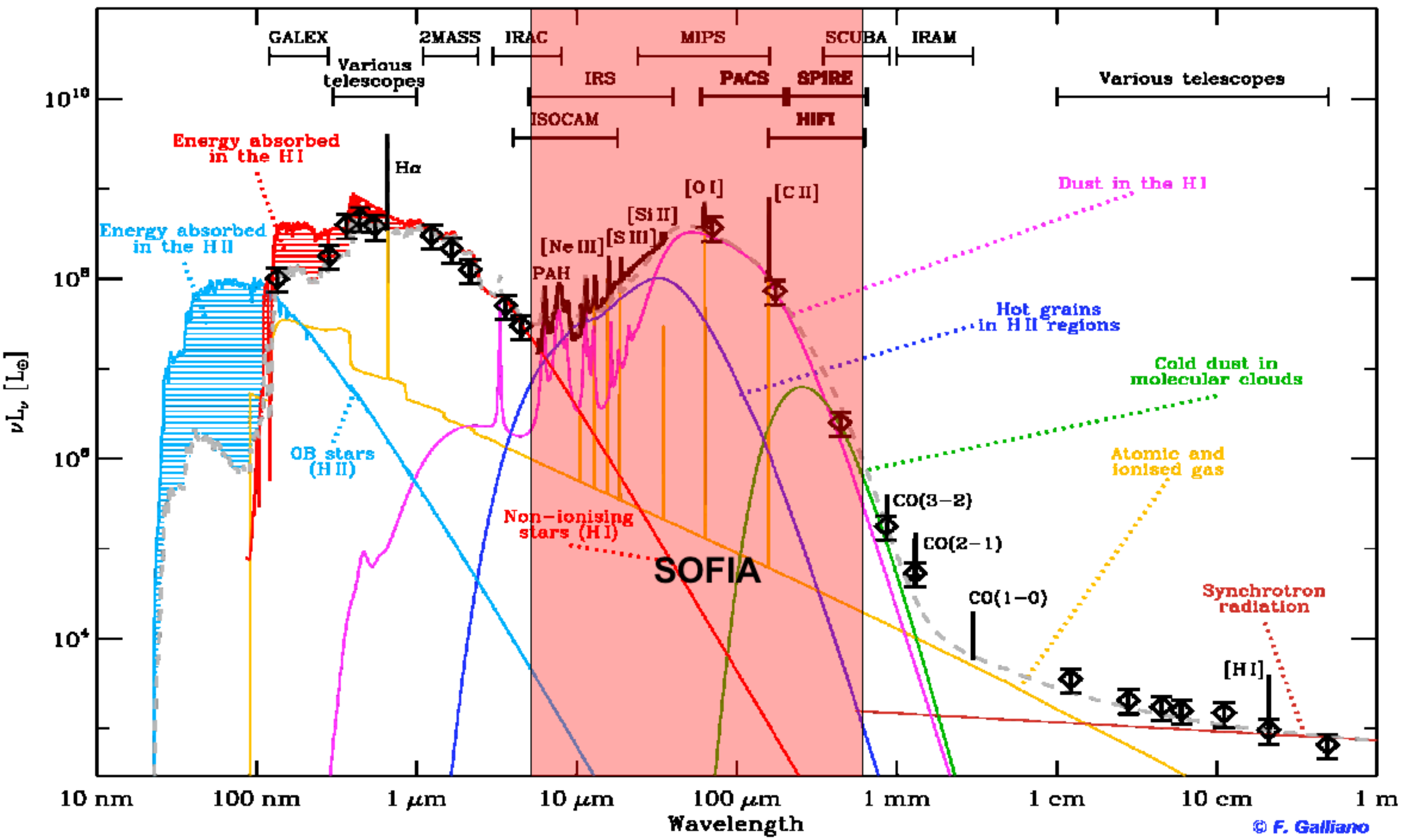
HD has a much lower excitation temperature and a dipole pole moment that almost compensates for the higher abundance of molecular hydrogen.

In the future could be used much like the HI 21cm maps but for cold molecular gas.

Nearby Galaxies

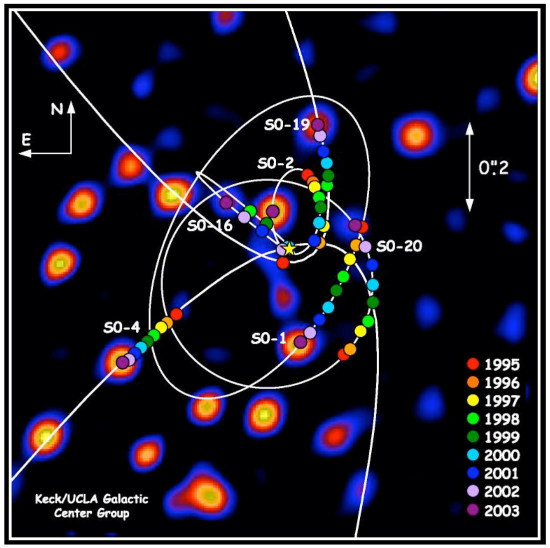
- SOFIA's strength is understanding the material between the stars in Nearby Galaxies
  - 9 octaves of wavelength coverage (1 to 700 μm) that covers the peak of dust distribution in galaxies
  - Host of diagnostic lines from 5 to 60 μm, including (post Spitzer) SOFIA-unique lines with FORCAST and FIFI-LS

Galaxy Spectral Energy Distribution (SED)



Star Formation in the Center of the Galaxy in the Presence of a Massive Black Hole

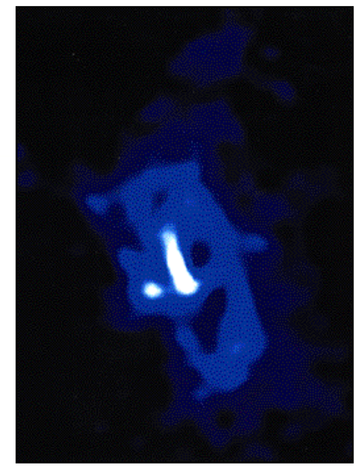
SOFIA will help determine how
Stars form in the presence of
a Massive Black Hole



Astronomers at ESO and Keck have detected fast moving stars revealing a 4 x 10^6 solar mass black hole at the Galactic Center

One of the major discoveries of the KAO was a ring of dust and gas orbiting the very center of the Galaxy at r=1pc

Young newly formed stars have also been found orbiting the black hole within 1000au



- Did these young massive stars form in the ring of dust and gas?
- If so, how do they get so close to the black hole?
- Can we detect Sgr A* in a flared event?
- SOFIA with its high angular and spectral resolution is well place to help answer these questions over the next 20 years

Schedule & Future Opportunities

SOFIA Schedule (Major Milestones)

• First Re-Flight	Occurred April '07
• Closed Door Testing	Finished Jan 08
• Mirror Coated	Summer 08
• Door Drive Delivered	Spring 09
• Open Door Flights at Palmdale	Winter 10
• First Light and Heat	April 10
• First Science	Fall 10
• Next Instrument call	2011

Observer Opportunities

- Selection for Community support of Early Short Science with FORCAST and GREAT has been made. Paul Harvey (UC Boulder), Mark Morris (UCLA) for FORCAST, David Neufeld (JHU)
- The Call for more extended observing (~15 Flights) in Basic Science in CFY 2010 with FORCAST and GREAT is now available on the SOFIA website. Proposals due 31 May.
- Future calls every year with additional instruments
- Open Observatory with Facility Instruments

Next Call for New Instruments

- The next call for instruments will be after First Science ~CY '11. A workshop in 2010 June 6,7 and 8 in Monterey CA.
- 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

Summary

- Program making progress!
  - Aircraft structural modifications complete
  - Telescope installed, several instruments tested on ground observatories.
  - Full envelope flight testing with closed door. Aircraft at Palmdale.
  - Major subsystems are installed (Door motor drive, coated primary mirror)
  - First Door Open was a success
  - First science in 2010
- SOFIA will be one of the primary facilities for far-IR and sub-millimeter astronomy for many years

Back-up

Instrument/ Location	PI	Instrument Type
HIPO/Lowell	Dunham	.3-1.1 μm High Speed Occultation Camera
FLITECAM**/ UCLA	McLean	1-5.5 μm Infrared Camera and IR channel for HIPO
FORCAST**/ Cornell	Herter	Faint Object Infrared Camera. Simultaneous Dual channel observations (5-25 μm & 25-40 μm)
GREAT/MPI-Bonn	Güsten	Hi resolution ($R > 10^6$) Heterodyne Spectrometer 3 bands - 1.6-1.9 THz; 2.4-2.7 THz; 4.7 THz
FIFI-LS**/ MPI Garching	Poglitsch	Dual Channel (42-110 μm ; 100-210 μm) Grating Spectrometer
HAWC**/ UChicago	Harper	High Angular resolution 4 channel Camera @ 50 μm, 100 μm, 160 μm, 200 μm
CASIMIR/ Caltech	Zmuidzinas	Hi resolution ($R \sim 10^6$) Heterodyne Spectrometer 500-2000 GHz
EXES/UT,UC	Richter	5-28 μm-High resolution grating spectrometer (R>100,000)
Davis, Ames		

** Facility Instruments

SOFIA and Spitzer

- SOFIA will become operational after Spitzer runs out of cryogens. The science impact of not being contemporary is small: Spitzer is a high sensitivity imaging and low resolution spectroscopy mission. SOFIA is a high spectral and high angular resolution mission.
- As it now stands, the two observatories are very complementary and now that Spitzer has run out of cryogens, SOFIA will be the only observatory working in the 28 to 60 micron region for over 10 years: Comets, Supernovae, Variable AGN, other discoveries.

SOFIA and Herschel

* SOFIA will now start after Herschel
- Joint calibration work is on going
- For the years of overlap, SOFIA will be only program
  - with 25 to 60 micron capability
  - with high resolution spectroscopy in the 60 to 150 micron region
- When cryogens run out in Herschel in early 2013. SOFIA will be only NASA mission in 25 to 600 micron region for many years
  - Important follow-up
  - Advanced instrumentation will give unique capabilities to SOFIA: Polarization, Heterodyne Arrays, Heterodyne Spectroscopy at 28 microns (ground state of molecular hydrogen), and other interesting astrophysics lines
- Both missions are critically important and complementary

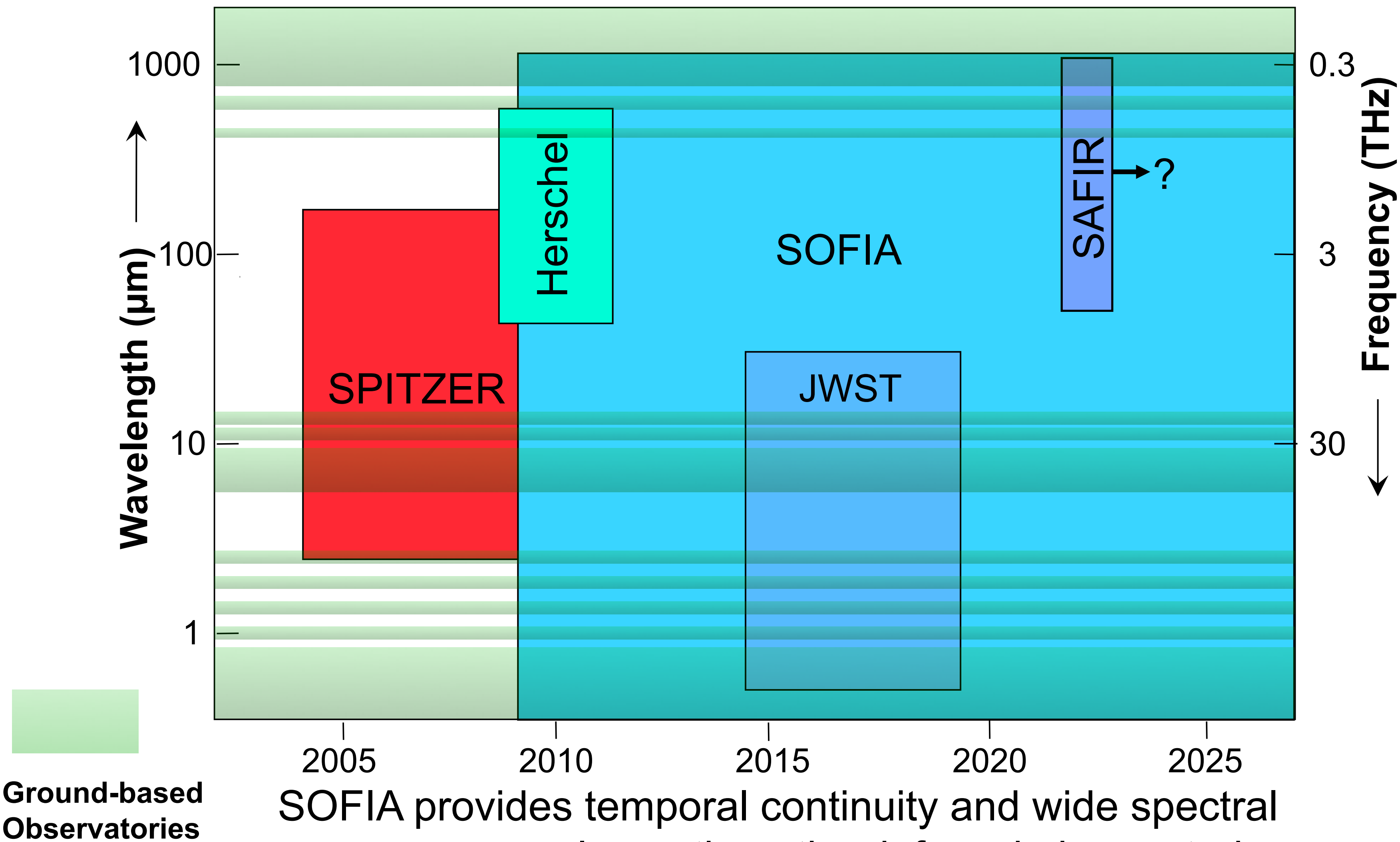
SOFIA and JWST

- SOFIA is very complementary to JWST
- Before JWST is deployed and after Spitzer cryogens run out , SOFIA is only mission with 5 to 8 micron capabilities
  - important organic signatures
- After JWST is launched SOFIA is the only mission to give complementary observation beyond 28 microns and high resolution spectroscopy in 5 to 28 micron region

SOFIA and WISE

- WISE is a very sensitive all sky survey in the 3.3 to 23 micron region which launched in Dec 09.
- SOFIA can provide a number of important follow up observations.
  - Very red sources seen only at 23 microns can be followed up at 38 microns with FORCAST on SOFIA and spectra can be obtained with EXES on SOFIA for the brightest 23 micron sources not seen by IRAS.
  - Nearby cold Brown Dwarfs discovered by WISE can be followed up with the FLITECAM GRISM and EXES.

Infrared Space Observatories



SOFIA provides temporal continuity and wide spectral coverage, complementing other infrared observatories.

SOFIA First Generation Spectroscopy