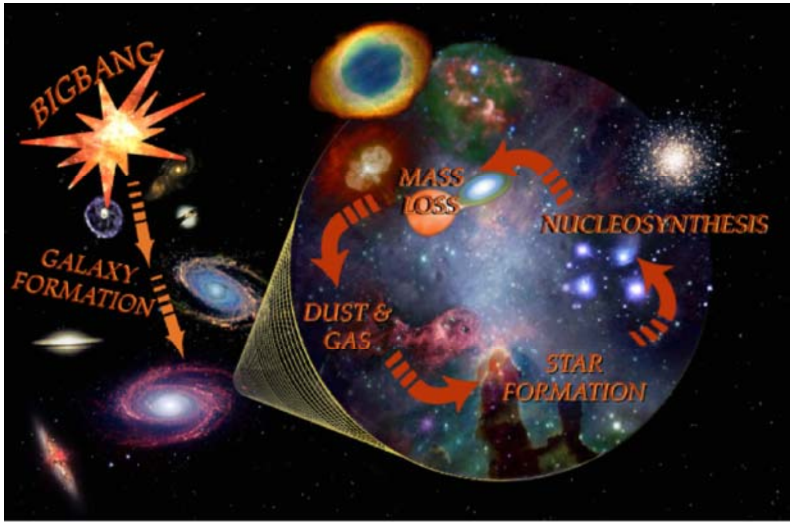
The Stratospheric Observatory for Infrared Astronomy (SOFIA)



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This talk is at: *http://www.sofia.usra.edu/Science/speakers/index.html*

Outline

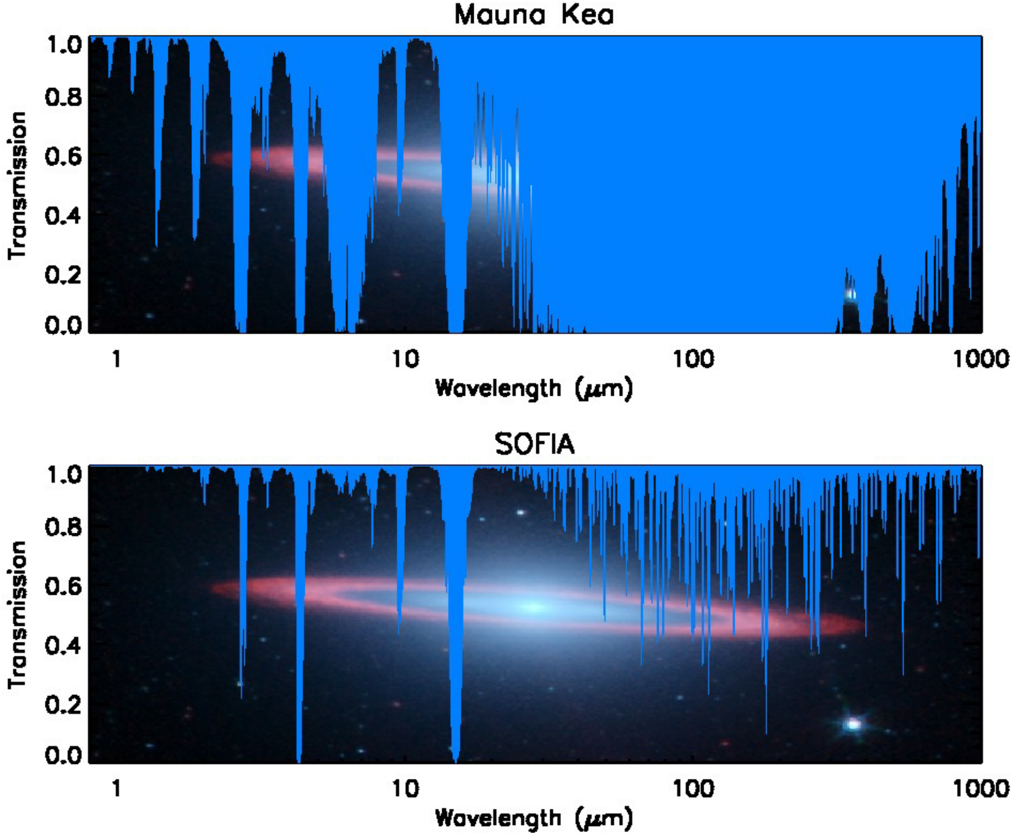
- *Description, Status Report, and Performance Specifications*
- *First-Light and Early Science Images*
- *Early and Basic Science Calibration Information*
- *General Investigator (GI) and Instrumentation Opportunities*
- *Summary*

SOFIA Overview

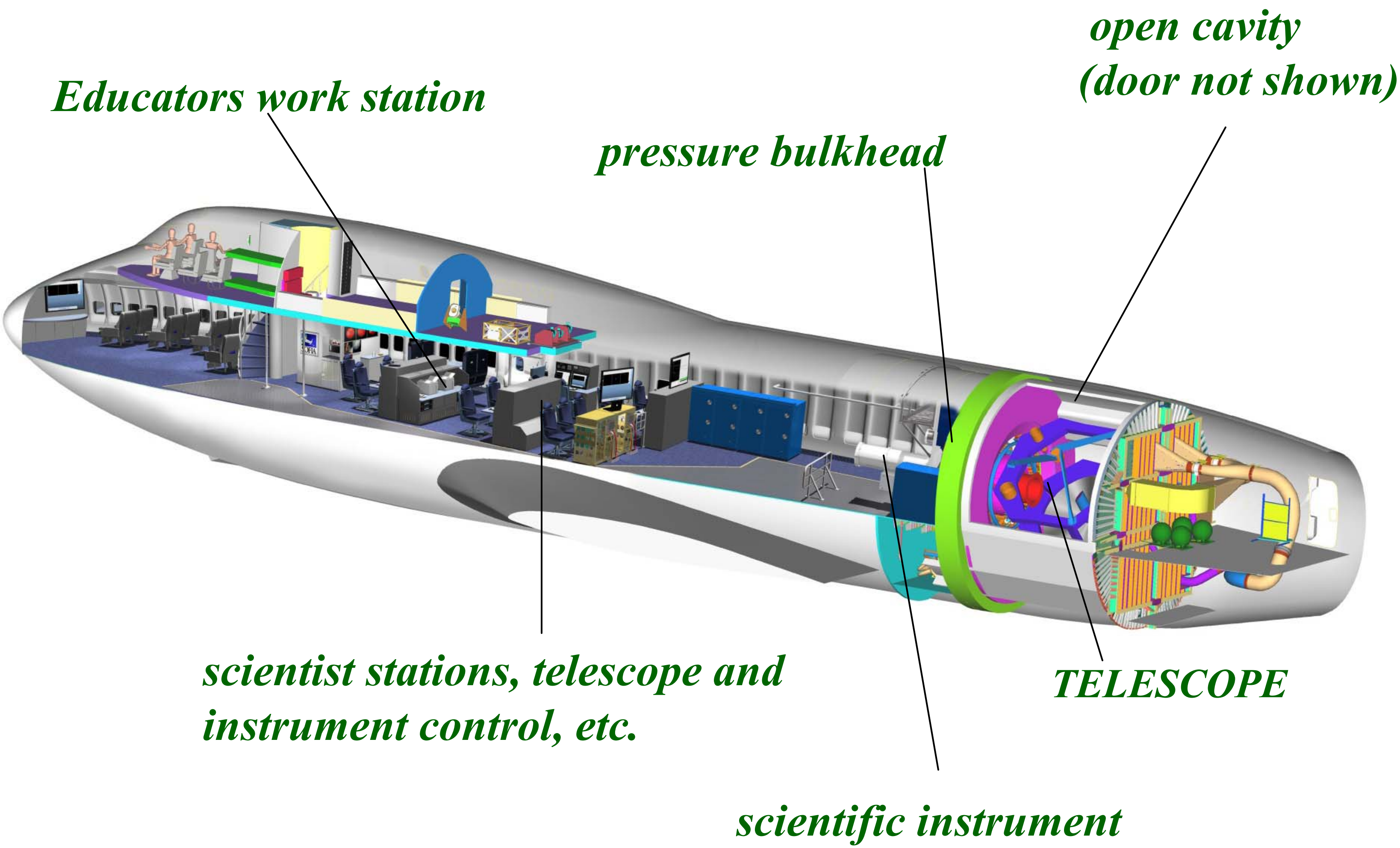
- *2.5 m telescope in a modified Boeing 747SP aircraft*
  - *Imaging and spectroscopy from 0.3 μm to 1.6 mm*
  - *Emphasizes the obscured IR (30-300 μm)*
- *Operational Altitude*
  - *39,000 to 45,000 feet (12 to 14 km)*
  - *Above > 99.8% of obscuring water vapor*
- *Joint Program between the US (80%) and Germany (20%)*
  - *First Light images were obtained on May 26, 2010*
  - *20 year design lifetime –can respond to changing technology*
  - *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*

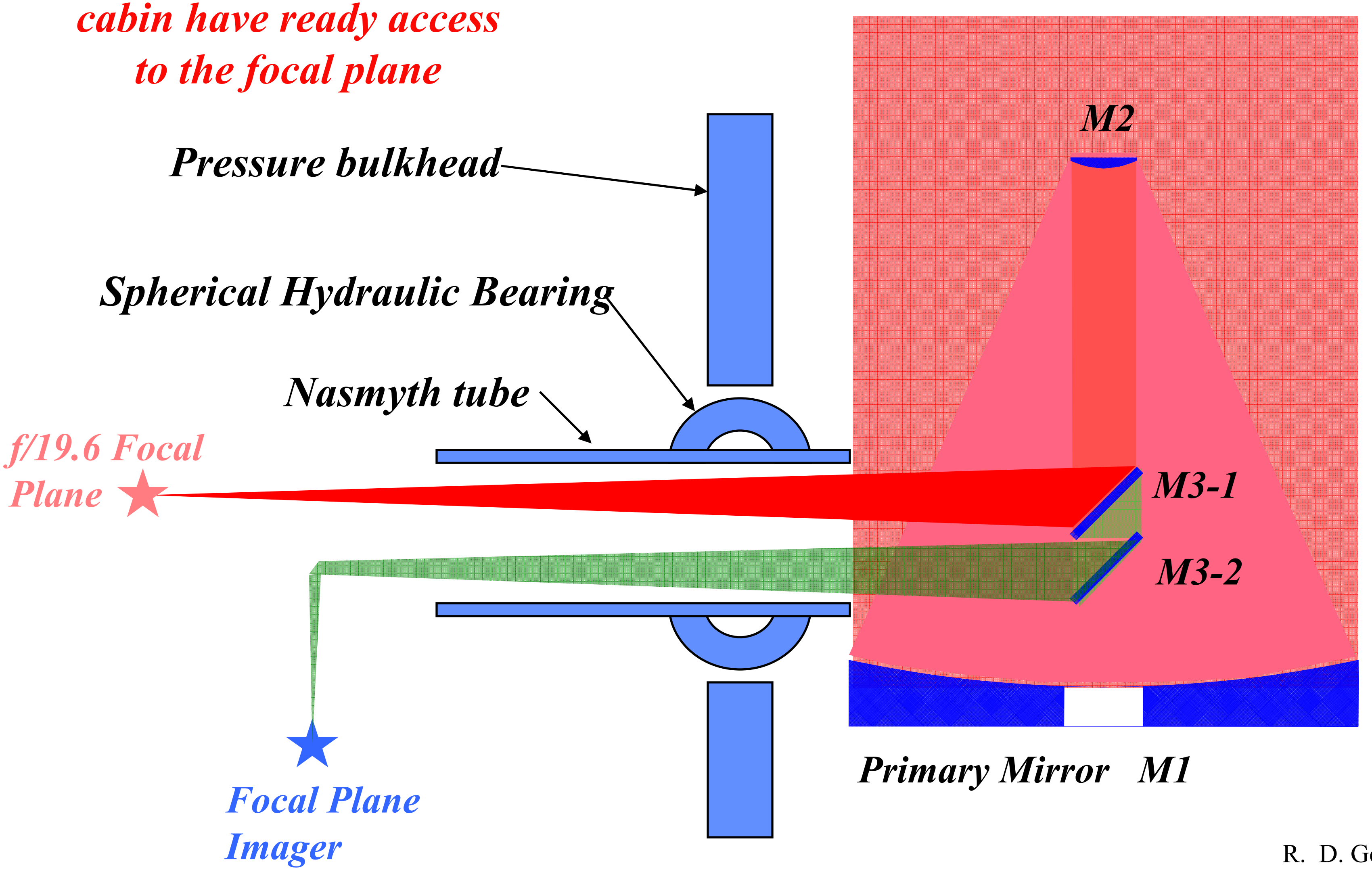


The SOFIA Observatory

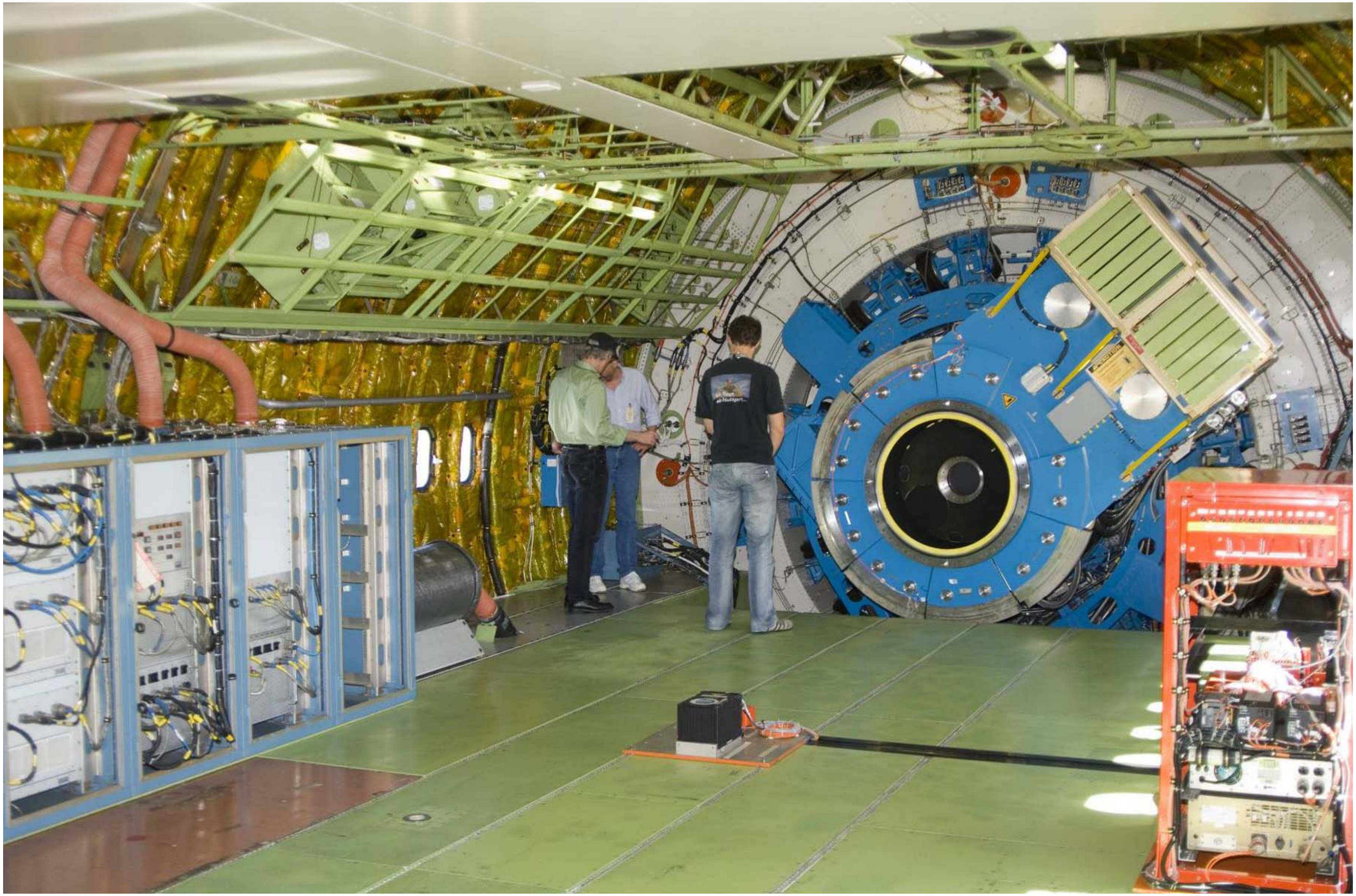


Nasmyth: Optical Layout

Observers in pressurized cabin have ready access to the focal plane



Back End of the SOFIA Telescope

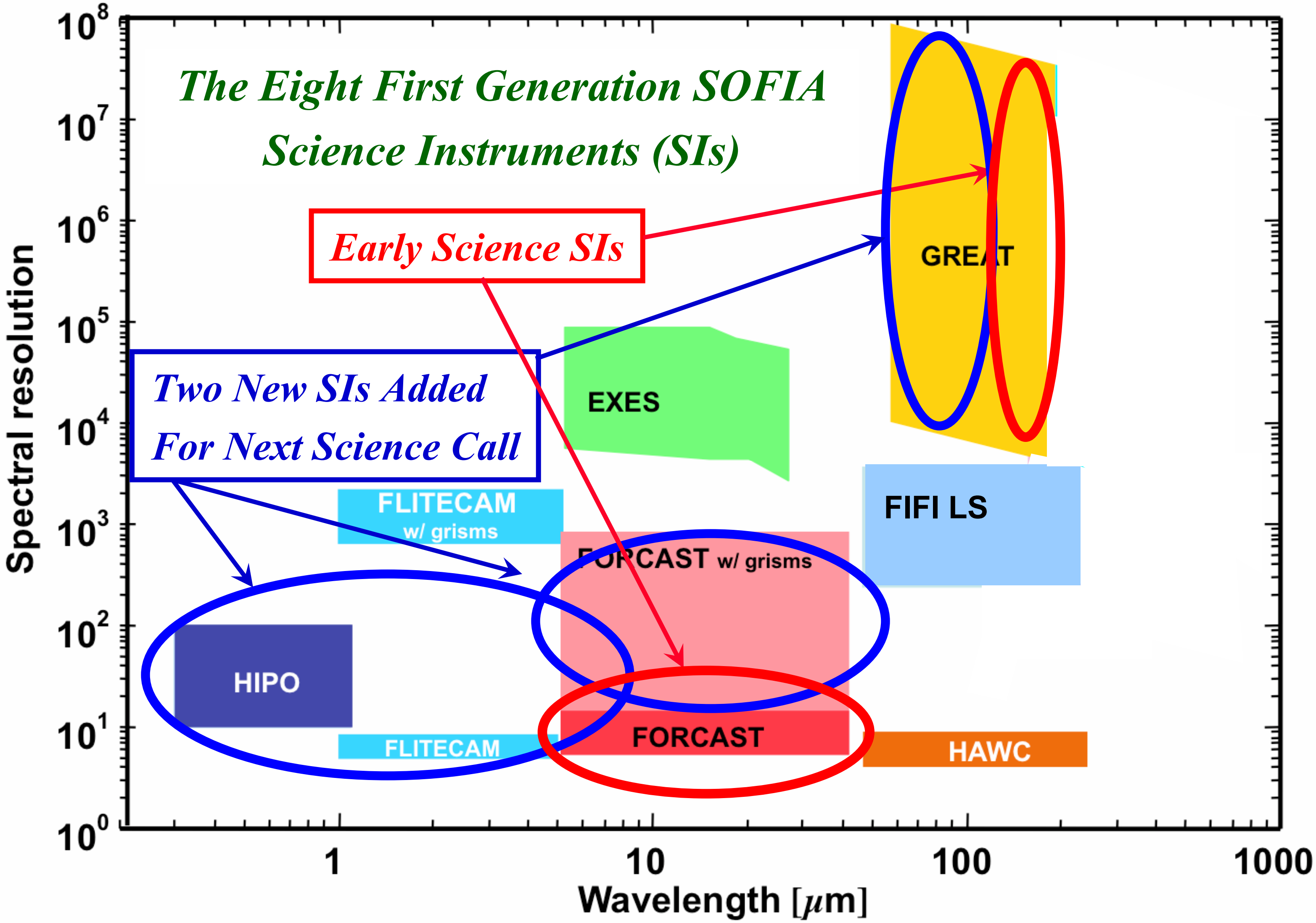


SOFIA Airborne with Door Open!

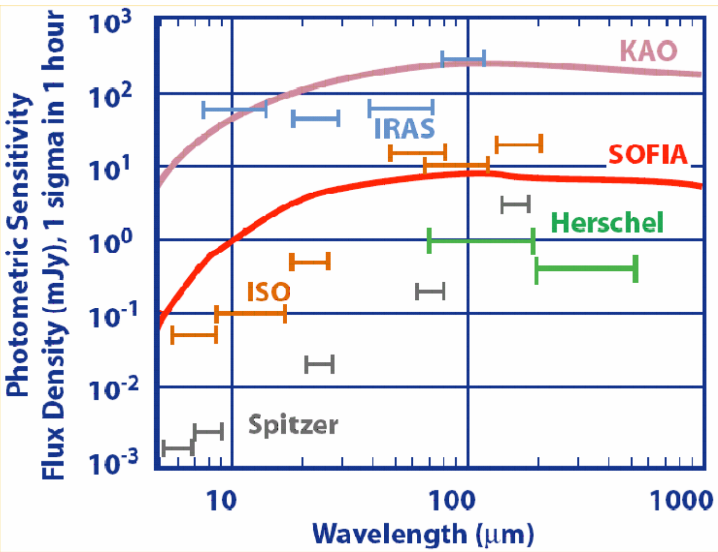
NASA's Stratospheric Observatory for Infrared Astronomy 7[redacted]on Dec. 18[redacted]. (NASA Ph[redacted]Carla Tho[redacted]

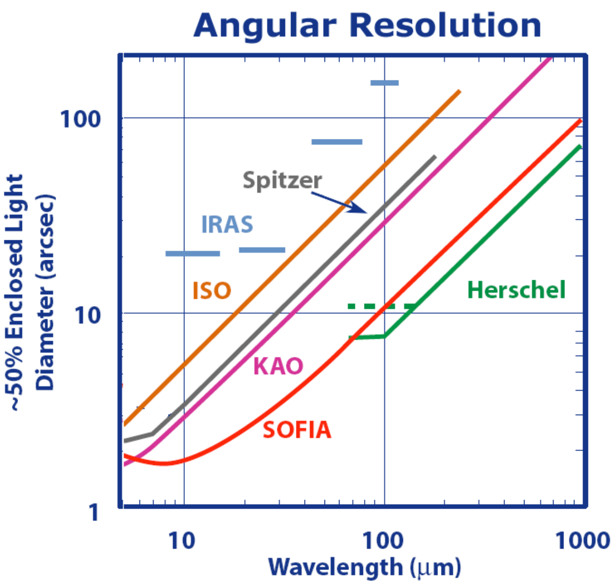
Door_Test Door_Open

SOFIA First Generation Spectroscopy



Photometric Sensitivity and Angular resolution





SOFIA is as sensitive as ISO

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

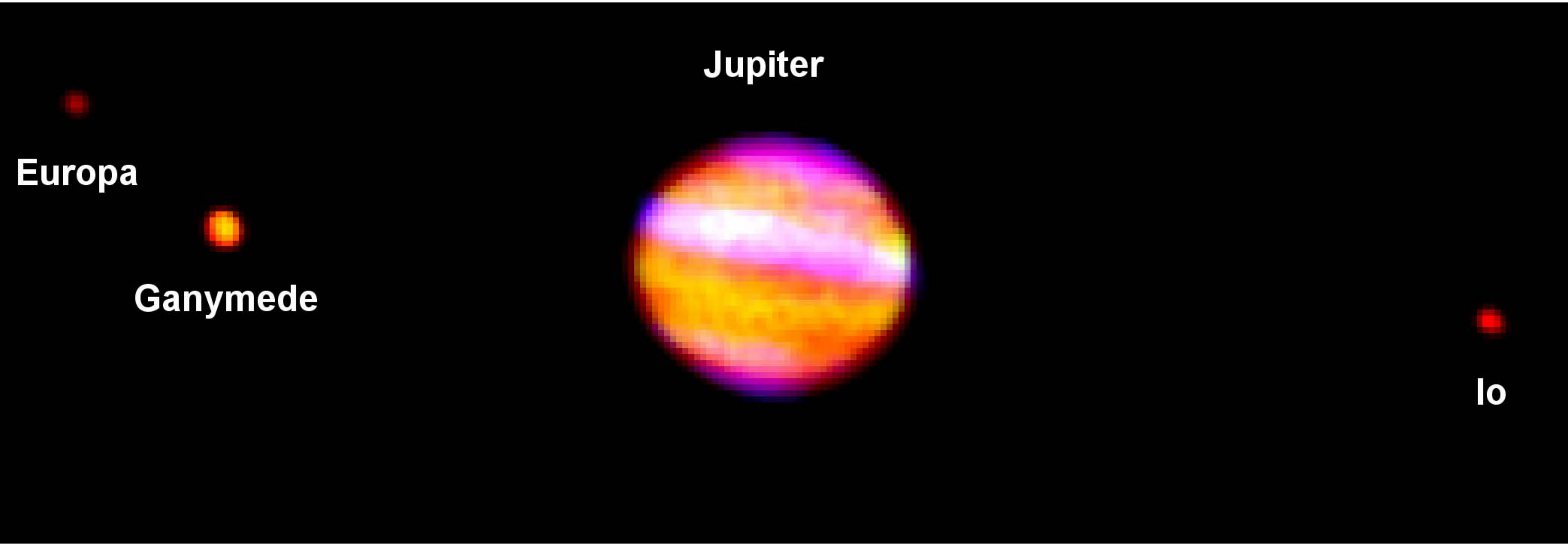
SOFIA First Light and Early Science

The First Light and Early Science with FORCAST

The FORCAST Team

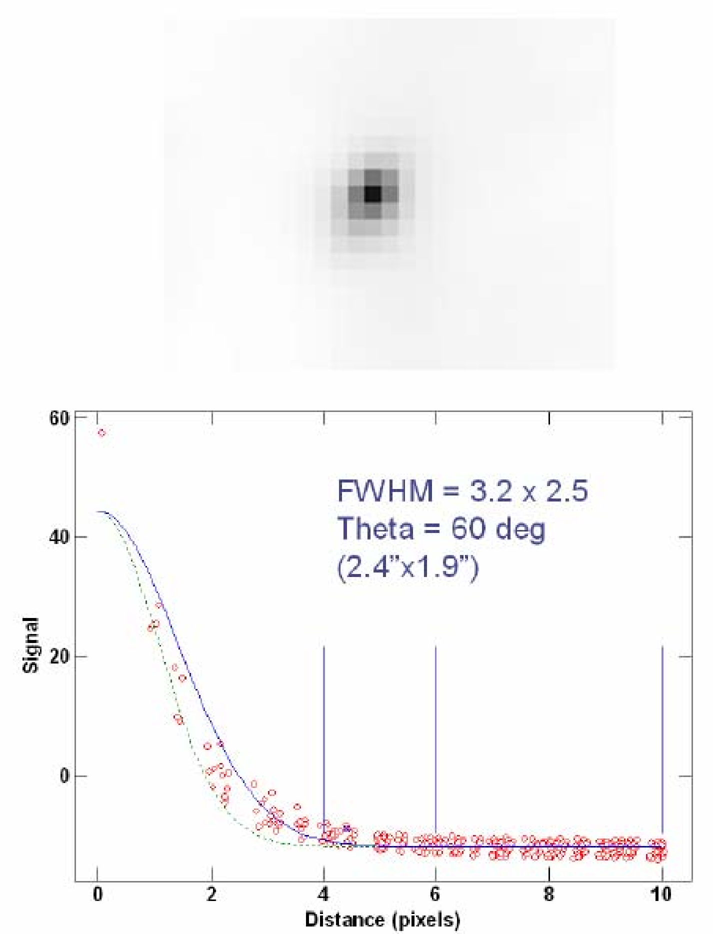
The DSI Telescope Assembly and Mission Operations Team in action during the First Light Flight

First Light on May 26, 2011 UT: We demonstrated diffraction limited imaging capability at 30 microns

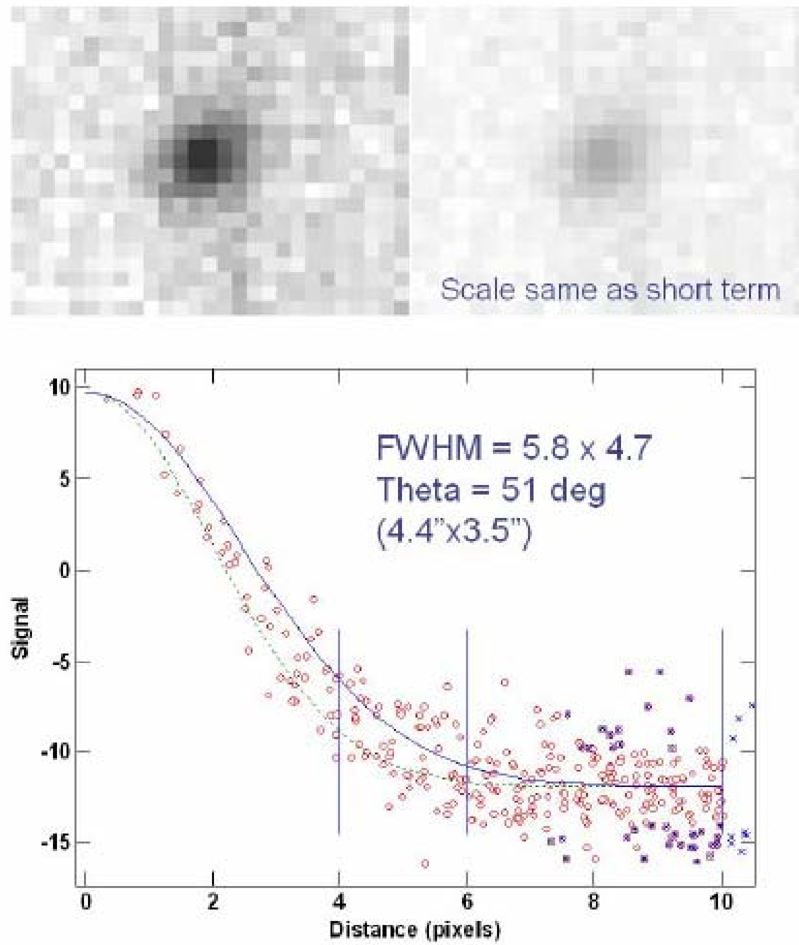


Red = 37.1 μm, Green = 24.2 μm, Blue = 5.4 μm

PSF and Jitter from Images of γ Cygni

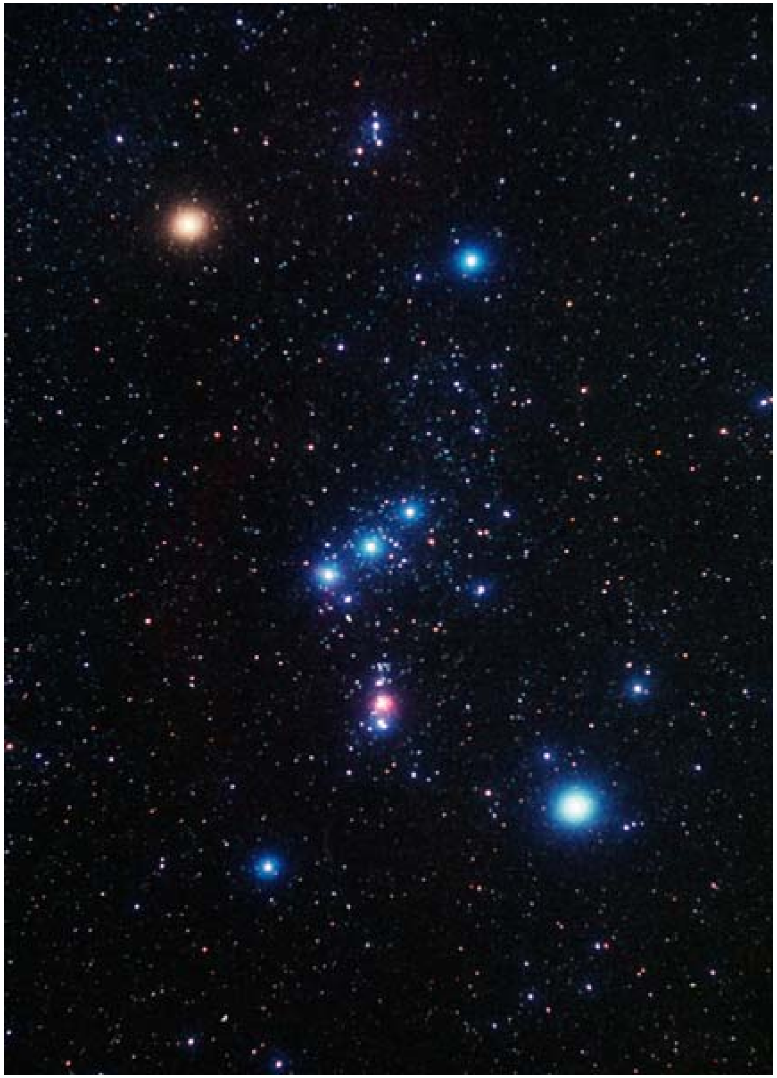


2,800 2.5 ms images shifted and co-added



Same data w/o shift and add

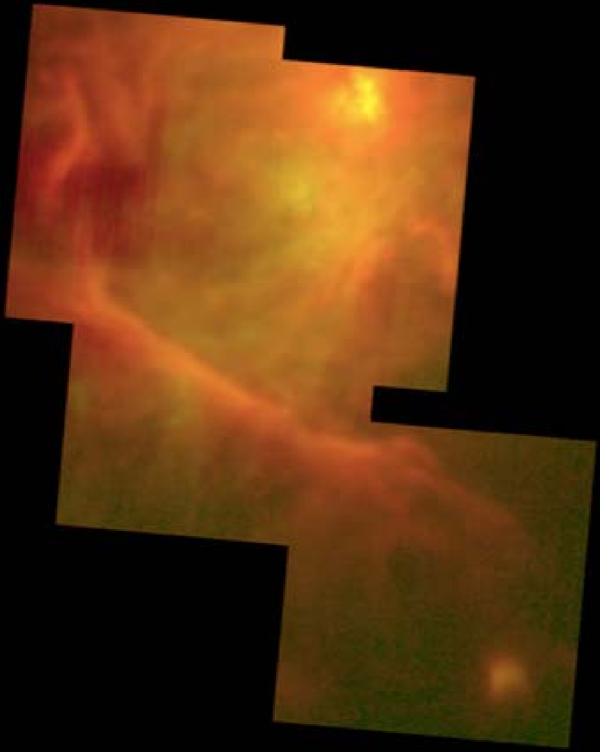
SOFIA Early Science: Star Formation in Orion



20 (Green) and 37 (Red) Micron Data of Orion Nebula

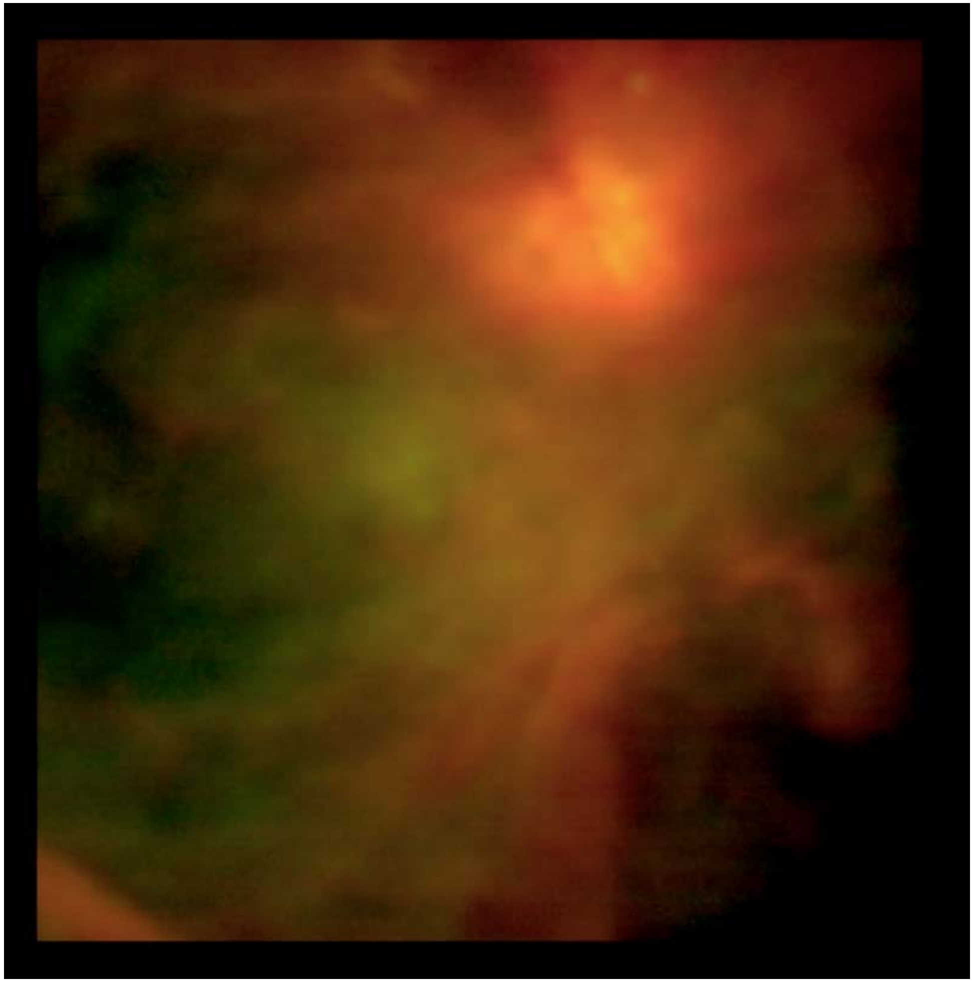
Visible light
(HST, C. O'Dell and S. Wong)

Near infrared
(ESO, M. McCaughrean)



SOFIA mid infrared
(SS02)

SOFIA Early Science Images



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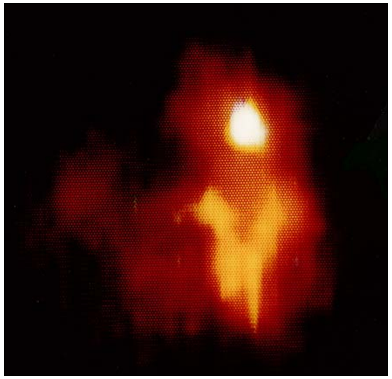


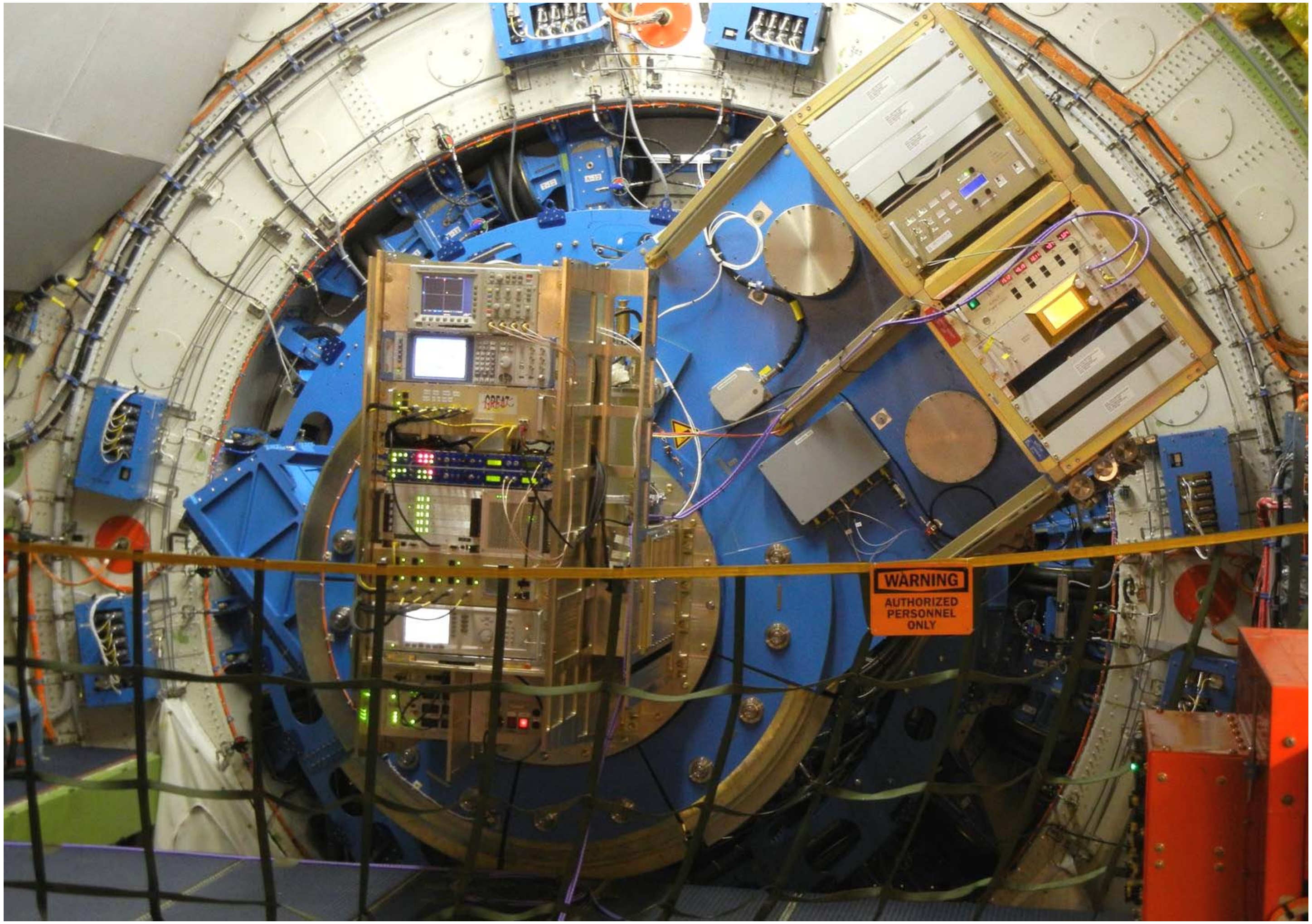
Red = 20 μm

Green = 12 μm

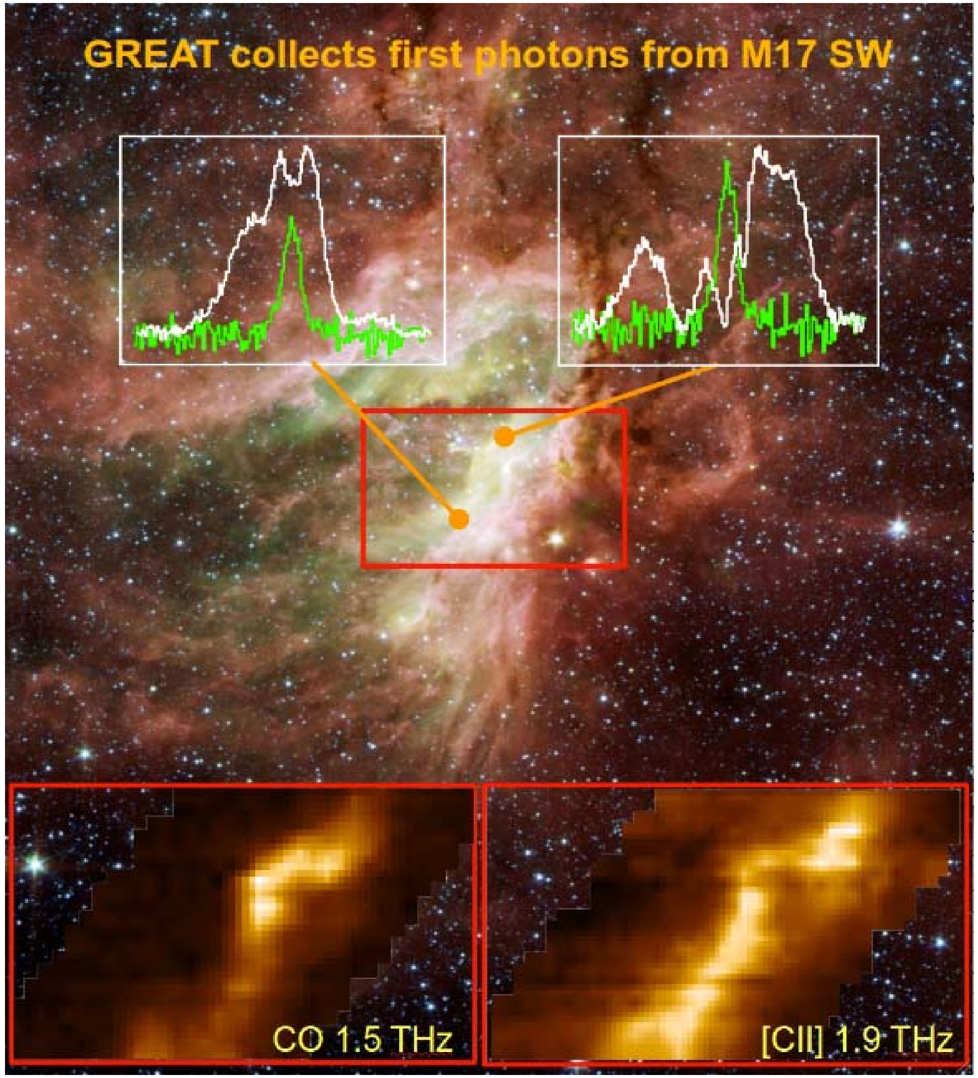
Blue = 11 μm

Wyoming Infrared Image from Herzog et al., 1980, Sky and Telescope, 59, 18

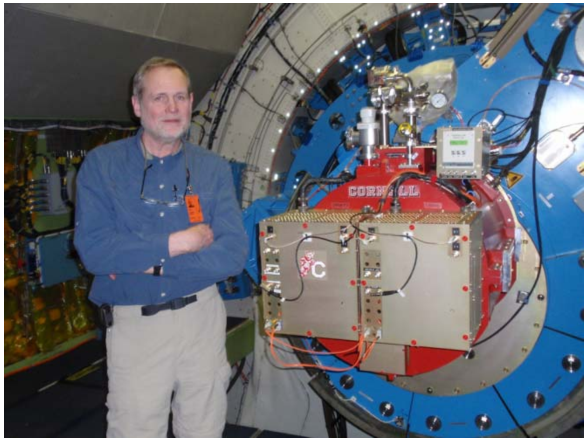
Early Science with GREAT installed on SOFIA

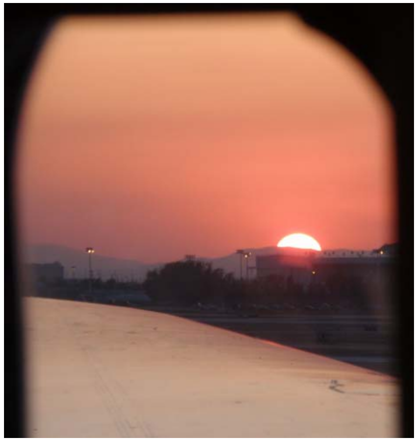


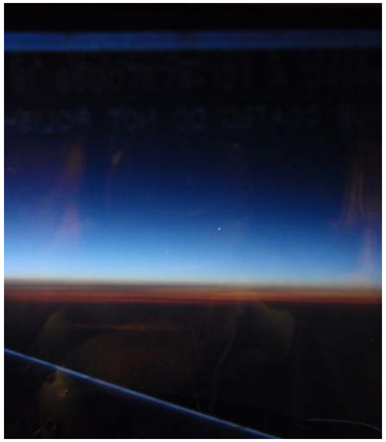
Early Science with GREAT (White CII, Green CO)



May 5, 2011: First Basic Science Guest Investigator







SOFIA Calibration

Calibration standards

- *At present we rely on modeling work done and validated by Herschel.*
- *At present we also rely heavily on other modeling work:*
  - *Atmospheric models by R. L. Kuruzc*
  - *Stellar models by the "Leeuwen group" (L. Decin)*
  - *Models of planets and planetary moons (R. Moreno)*
  - *Asteroids, ThermoPhysical models with shape information by Th. Müller (Garching)*
  - *Secondary calibrators (TBD)*

FORCAST Calibration: Stellar Calibrators

- *Bright, well studied stars, with well determined physical properties (Size, T_{eff}, Surface gravity, metallicity, brightness etc.)*

- *The primary calibrators for FORCAST Basic science have all been modeled for Herschel by the Leeuwen group (L. Decin) using state of the art atmospheric models (MARCS,TURBOSPECTRUM) and validated by Herschel.*

- *We have used these models to predict what flux densities FORCAST sees in each filter (including instrument throughput, filter characteristics and atmospheric transmission)*

Calibrating GREAT: Planets and Small Bodies

- *Mars: We will use the model adopted by Herschel. It is available on the web at:*
  - *http://www.lesia.obspm.fr/perso/emmanuel-lellouch/mars/*
- *Uranus and Neptune are primary calibrators. We will use independent models by R. Moreno and again G. Orton, and ESA2 models (available as FITS and ascii files).*
- *Other planets and planetary moons also modeled by Moreno*
- *Asteroids: Modeled by Th. Müller on request*

Next Call for Science

- October 2011 — Next Call for GI Science Proposals
- January 12, 2012 — Next Science Proposals Due
- Summer 2012 — Next Science Flight Series Begins
- SIs Available:
  - GREAT
  - FORCAST (with grisms)
  - HIPO
  - FLITECAM (with grisms)

2nd Generation Science Instruments

- *First Solicitation released on July 9, 2011*
- *Proposals due on October 7, 2011*
- *Selections announced: Late 2011*
- *Contracts initiated: Early 2012*
- *$1 M in FY2012, $3 M in FY2013, $5 M @ in FY2014-FY2018*
- *There will be additional calls every three years*

Summary

- *The Program is making progress!*
  - *Flight envelope testing is completed*
  - *Science flights have begun*
- *SOFIA will be one of the primary observational facilities for far-IR and submillimeter astronomy for many years*

Our Web site: <u>*http://www.sofia.usra.edu//*</u>

This talk: <u>*http://www.sofia.usra.edu/Science/speakers/index.html*</u>

Backup

Calibration standards

- *At present we rely on modeling work done and being validated by Herschel.*
- *We also use models by M. Cohen, atmospheric models by R. L. Kuruzc, and other models:*
  - *Stellar models by the "Leeuwen group" (L. Decin)*
  - *Models of planets and planetary moons (R. Moreno)*
  - *Asteroids, ThermoPhysical models with shape information by Th. Müller (Garching)*
  - *Secondary calibrators (TBD)*

Basis Science Calibration Plan

- *Two instruments for Basic Science*
  - *FORCAST (8 flights)*
  - *GREAT (4 US flights)*
- *The observatory (i.e. the SMO) is responsible for ensuring that the data are well calibrated.*
  - *For basic science well calibrated means a goal of $\leq$ 20% accuracy in flux calibration*

Calibration standards

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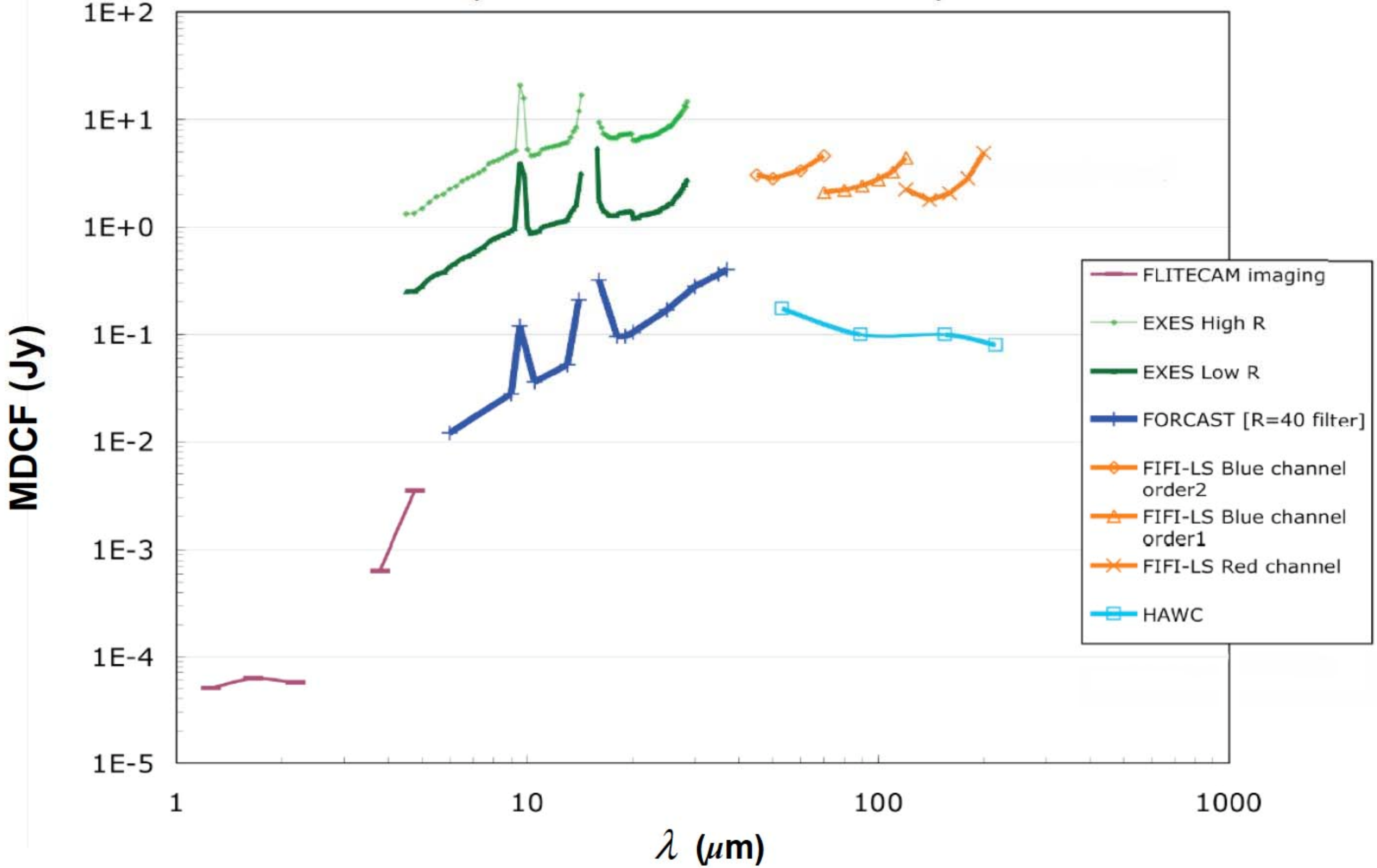
SOFIA's First-Generation Instruments

(http://www.sofia.usra.edu/Science/instruments/)

see also Gehrz et al. 2011 (arXiV:1102.1050)

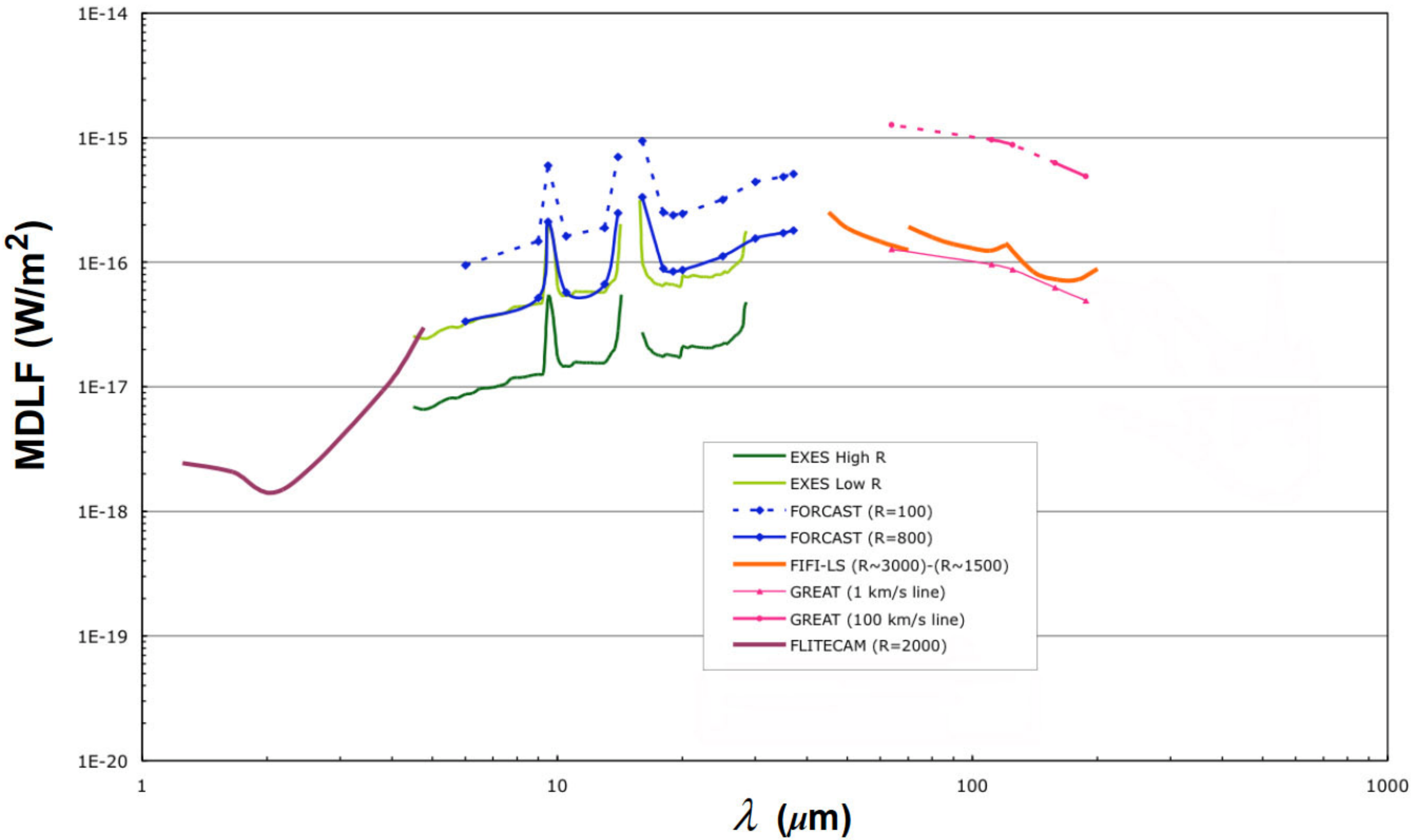
Instrument	Type	λλ (μm)	νν (THz)	Resolution	PI
FORCAST (in operation)	imager / (grism)	5.4 - 37	8.1 - 56	filters / (R~2000)	T. Herter / Cornell U.
GREAT (H-Freq.) (M-freq. -- June 2011) (L-freq.'s -- operating)	heterodyne spectrometer	(62 - 65) (110 - 125) 156 - 165 200 - 240	(4.6 - 4.8) (2.4 - 2.7) 1.82 - 1.92 1.25 - 1.50	$R \sim 10^4 - 10^8$	R. Güsten / MPIfR
HIPO (summer 2011)	fast imager	0.3 - 1.1		filters	E. Dunham / Lowell Obs.
FLITECAM (summer 2011)	imager / (grism)	1.0 - 5.5		filters / (R~2000)	I. McLean / UCLA
FIFI-LS	imaging grating spectrograph	42 - 110 110 - 210	2.7 - 7.1 1.4 - 2.7	R ~1000 - 2000	Poglitsch,Krabbe /MPE,IRS
EXES	imaging echelle spectrograph	4.5 - 28.4	10.6 - 67	$R \sim 3000 - 10^5$	M. Richter / UC-Davis
HAWC	imager	45 - 270	1.1 - 6.6	filters	D. A. Harper / U. Chicago

Continuum Sensitivities
(10 σ in 900 sec on source time)

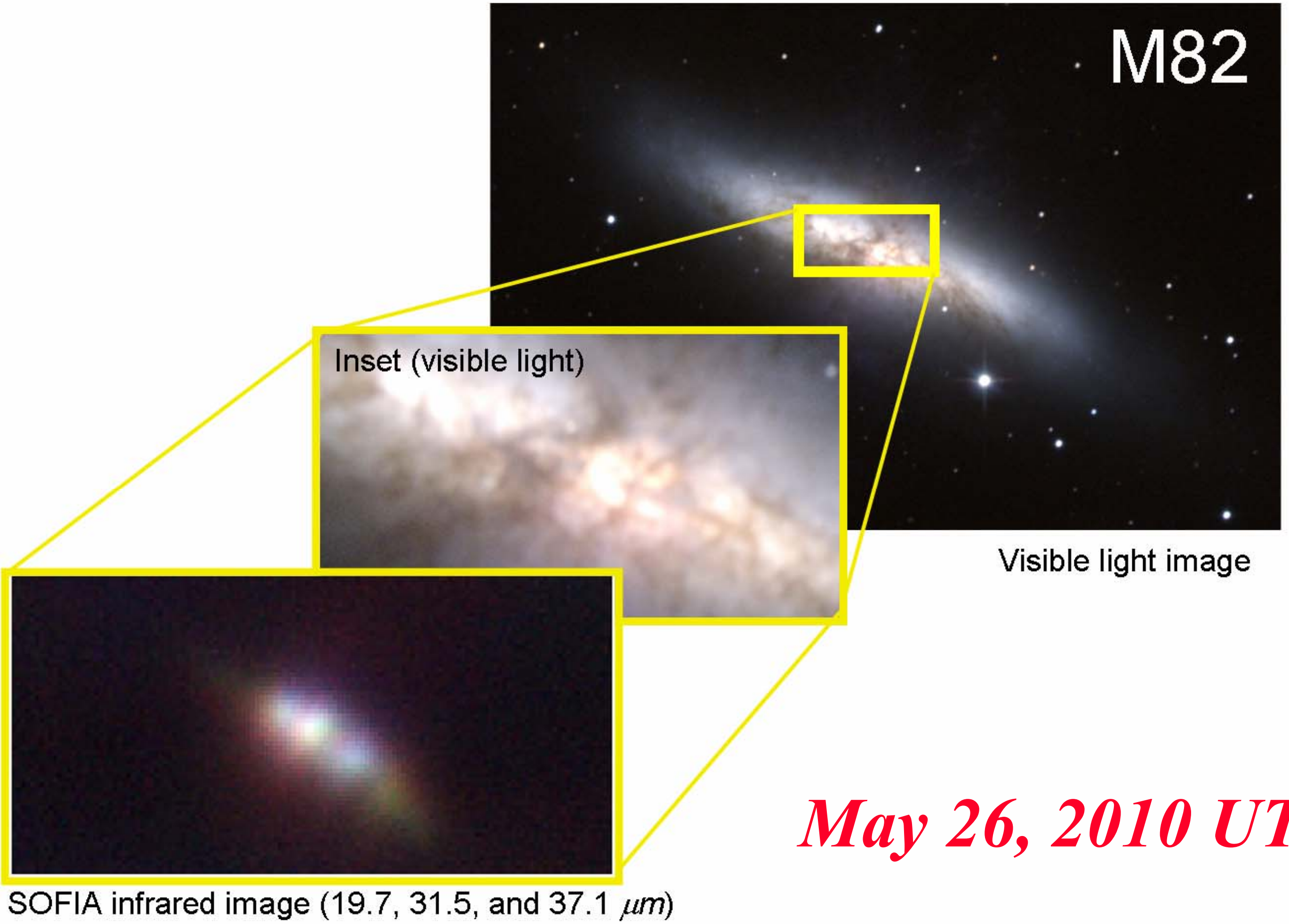


Line Sensitivities with Spectrometers

(10 σ in 900 sec on source time)

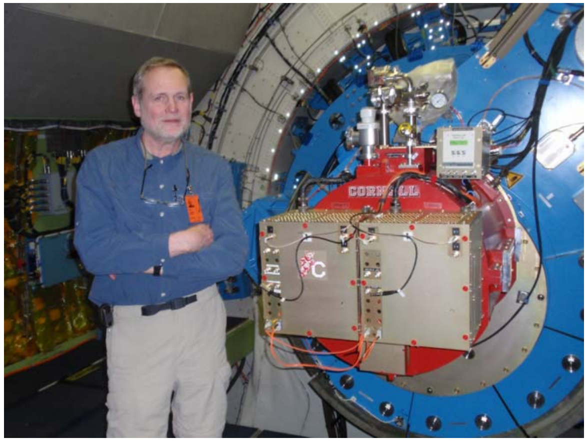


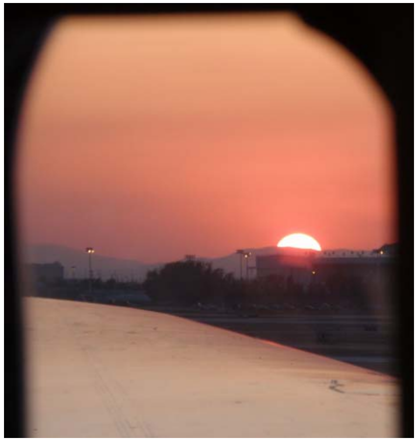
SOFIA's FORCAST First-Light Images: M82

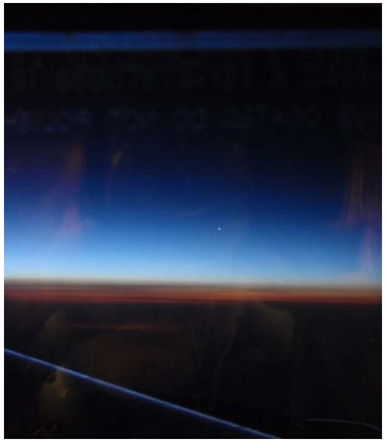


May 26, 2010 UT

May 5, 2011: First Basic Science Guest Investigator



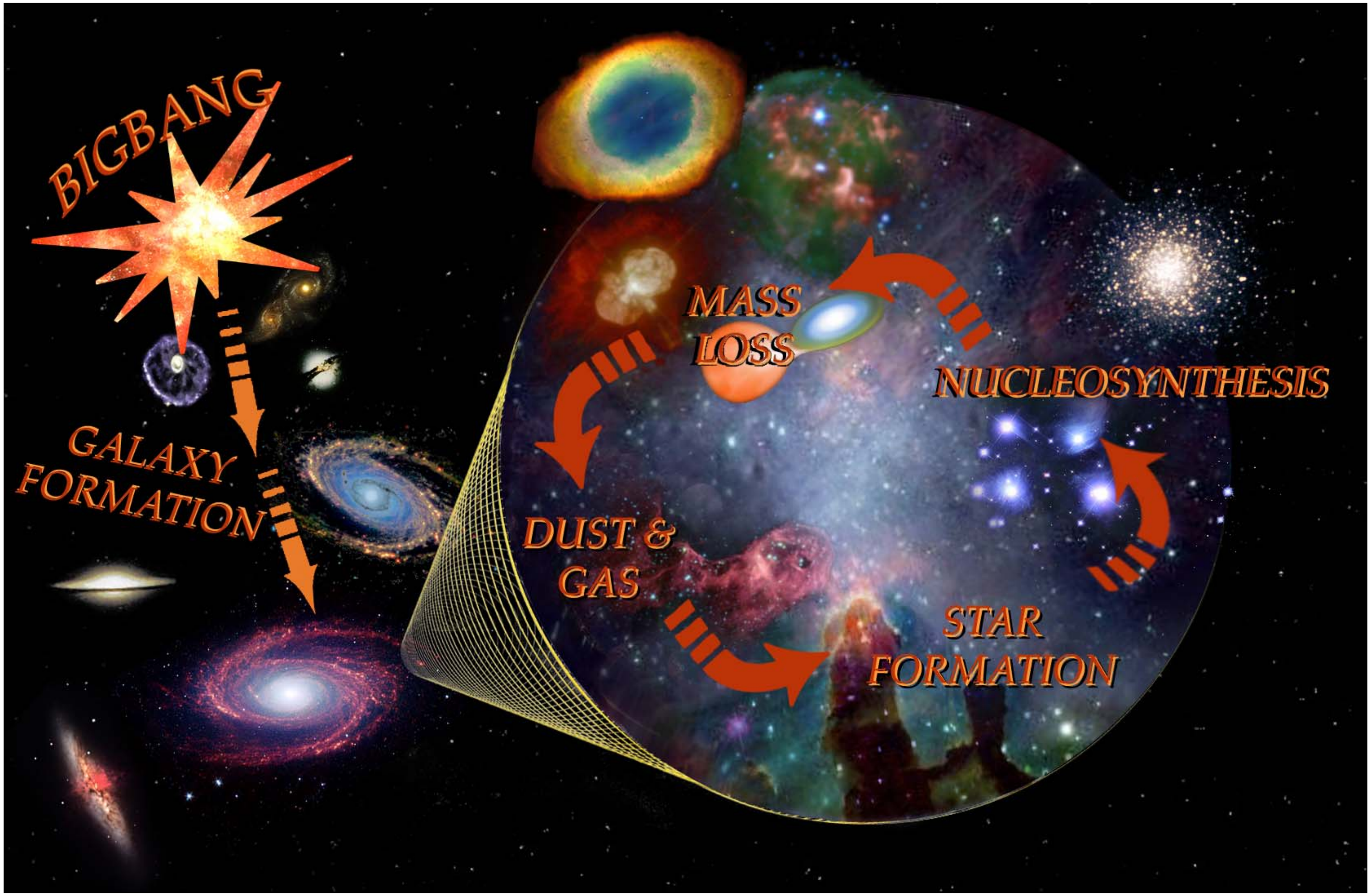




Calibration Planning: Process

- In preparation for Basic Science the SOFIA Calibration Scientist and the Instrument scientist sets a calibration strategy for each instrument
  - Number of calibrator observations per flight (≥3 for FORCAST; GREAT largely self-calibrating and can only use planets for flux calibration)
  - List of approved calibration targets
- The Calibration Scientist, together with the Instrument Scientists estimates how much time is needed for the calibrator legs
- As each flight is laid out, the Flight Planner in cooperation with the Calibration and Instrument Scientists implements the calibration strategy
- The Instrument Scientist reviews the submitted Flight Plans for adherence to the strategy and planning
  - Consults with the Calibration Scientist, as needed.

SOFIA and the Chemical Evolution of the Universe



Primary calibrators

Star	Spectral type	M_{bol} (mag)	Flux density (37 μm) [Jy]
Sirius (α CMa)	A1V	1.33	10.8
α Boo*	K2 IIIp	-0.90	55.3
α Cet*	M2 III	-3.09	17.4
α Tau*	K5 III	-1.72	50.3
β And*	M0 III	-3.14	19.9
β Peg	M2.5 III	-3.34	30.4
γ Dra*	K5 III	-2.07	11.7
ι Aur	K3 II	-2.4	??
σ Lib	M3/M4 III	-3.6	15.4
β UMi	K4 III	-1.71	9.8

GREAT Low Frequency Bands: ESA2 Saturn Model