SOFIA Stratospheric Observatory for Infrared Astronomy

Science Operations of an Airborne Observatory

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What is SOFIA?

SOFIA

Stratospheric Observatory for Infrared Astronomy

What is SOFIA?

SOFIA Stratospheric Observatory for Infrared Astronomy

SOFIA is a joint U.S./German project:

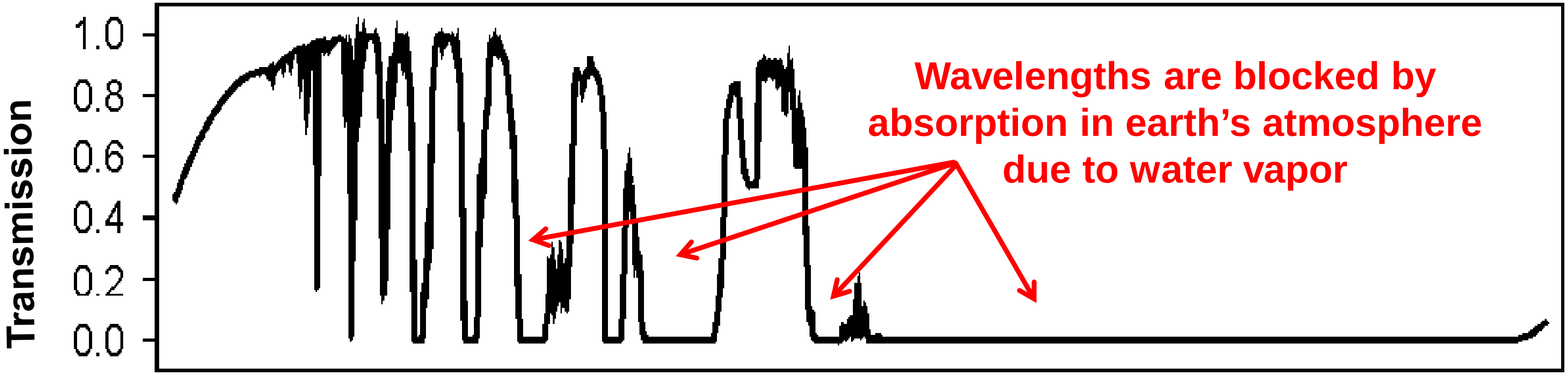
- 80% NASA (National Aeronautics and Space Administration)
- 20% DLR (German Aerospace Agency)

SOFIA science missions are executed by:

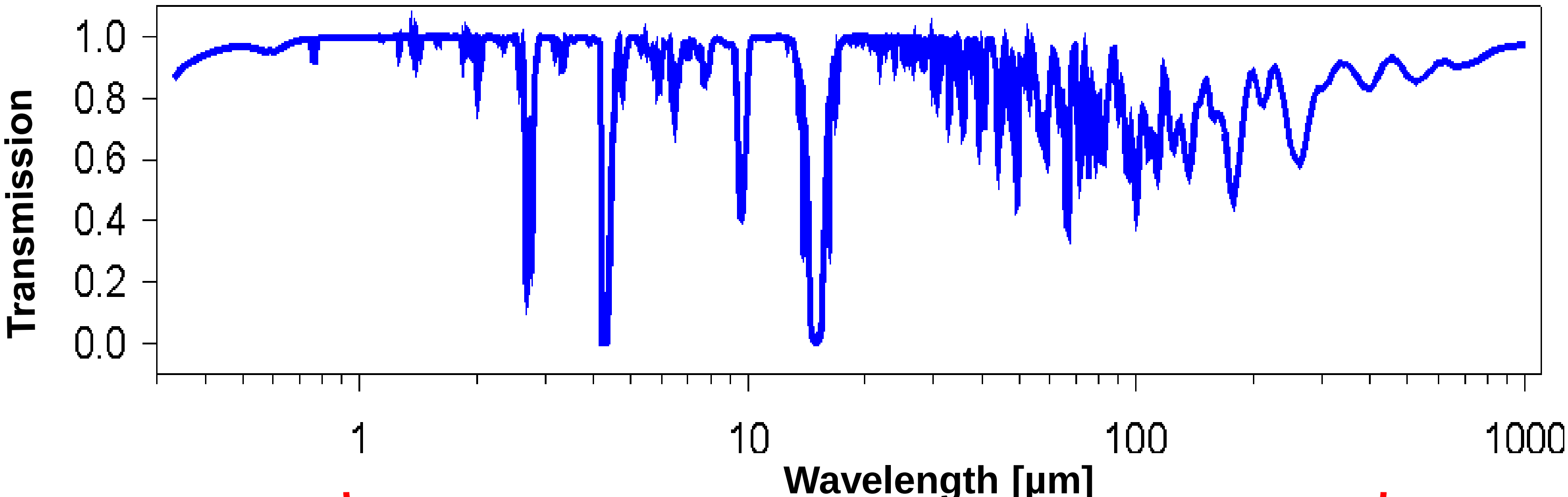
- USRA (Universities Space Research Association)
- DSI (German SOFIA Institute)

Costs and Observing Time are shared by the United States (80%) and Germany (20%).

A) from ground based telescopes:



B) from SOFIA in 45.000 ft (13,7 km) altitude:

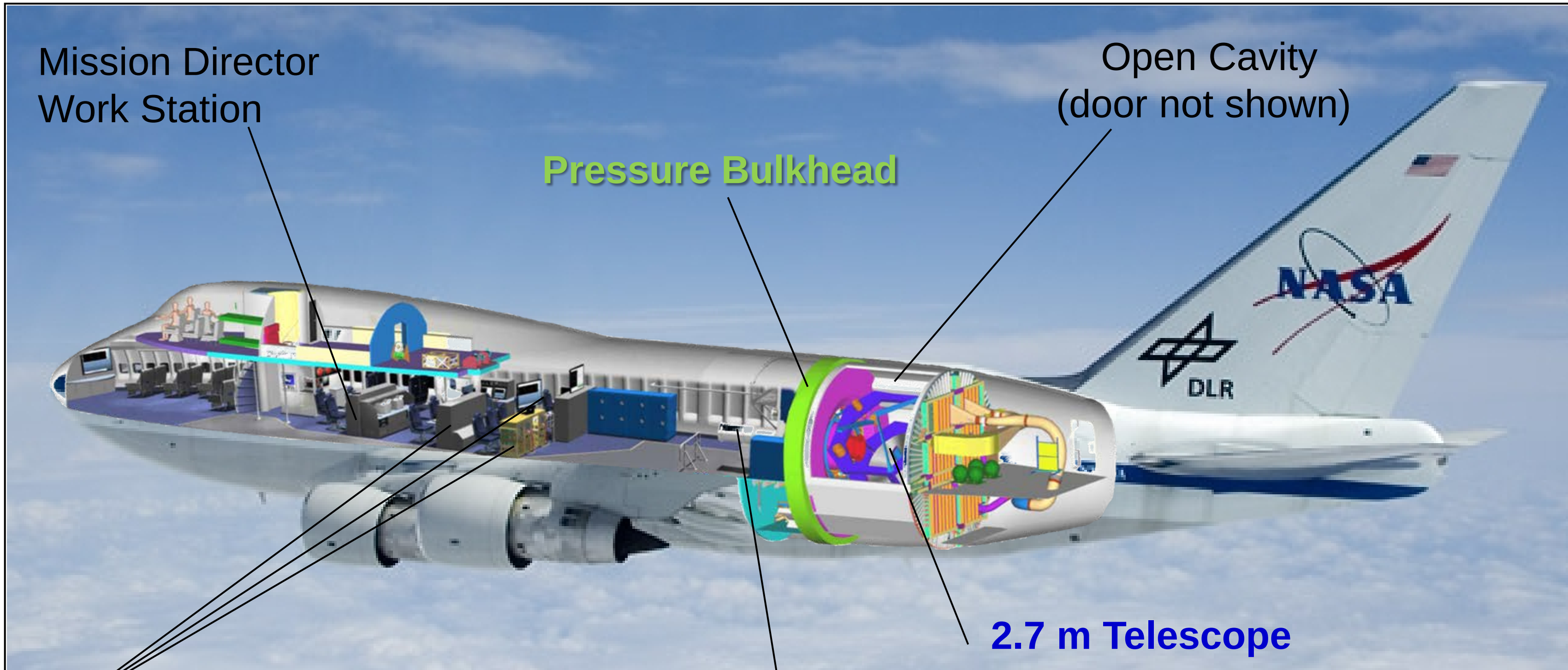


SOFIA observes the Near-, Mid- and Far-InfraRed (1 to 300 µm)

The Observatory

From the basic airplane Boeing 747SP…

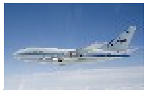
… to the airborne observatory SOFIA.



VLT Construction

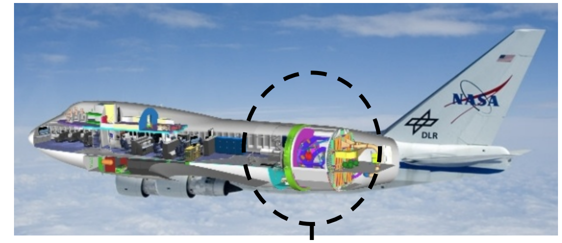
http://www.eso.org/public/archives/images/screen/eso9414b.jpg

The Telescope



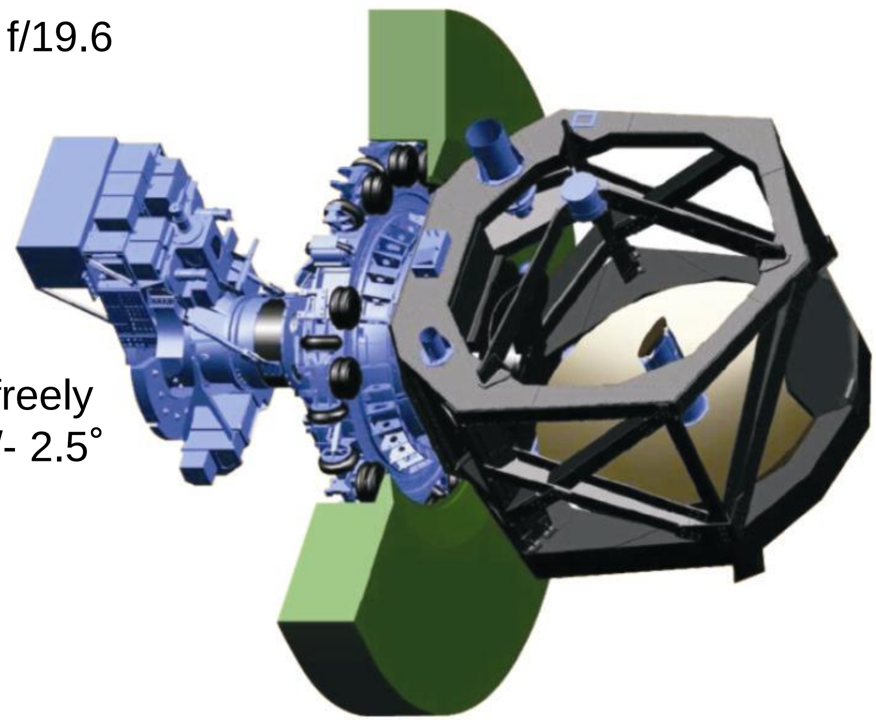
Stratospheric Observatory for Infrared Astronomy

SOFIA

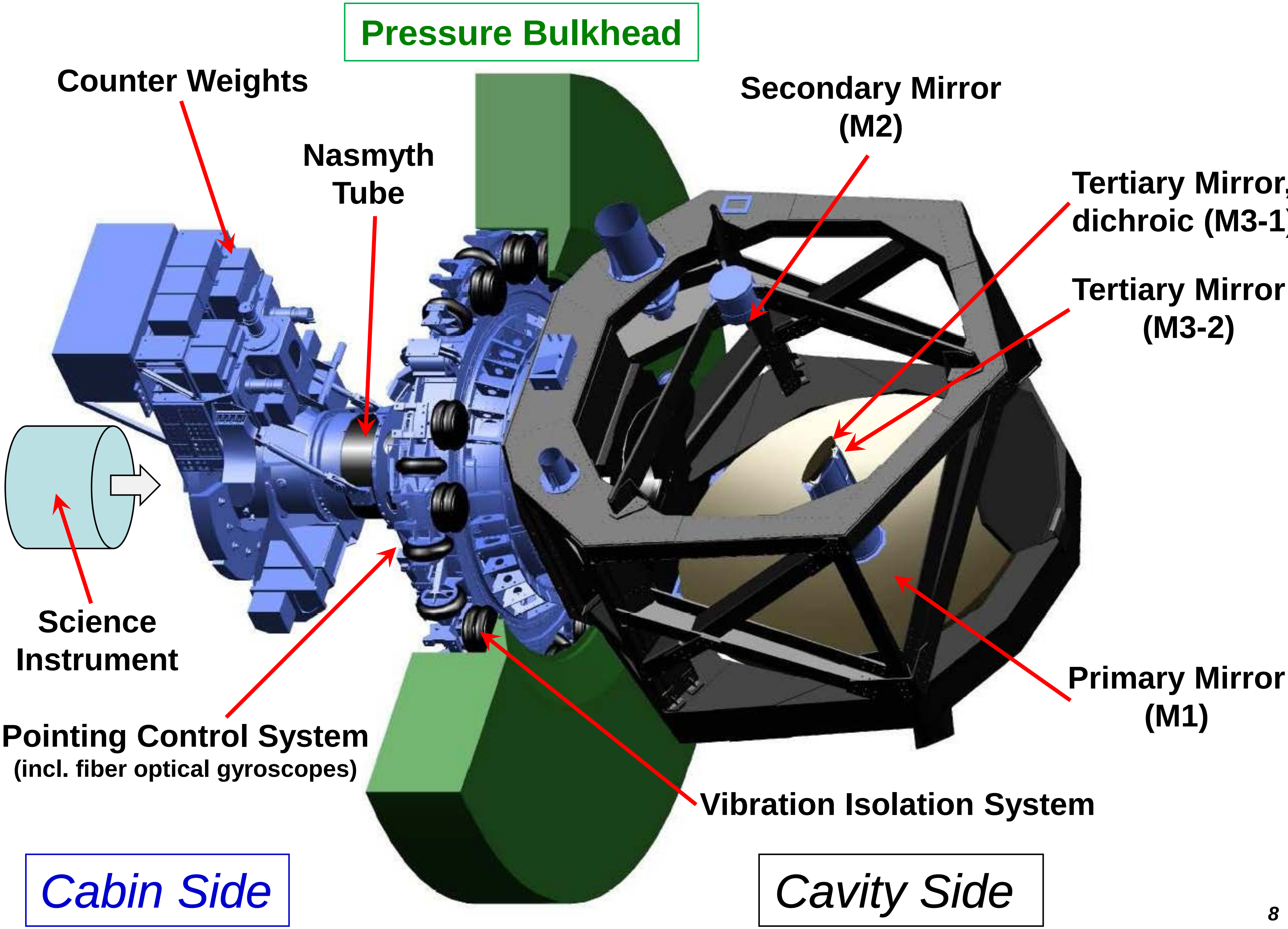


The SOFIA Telescope:

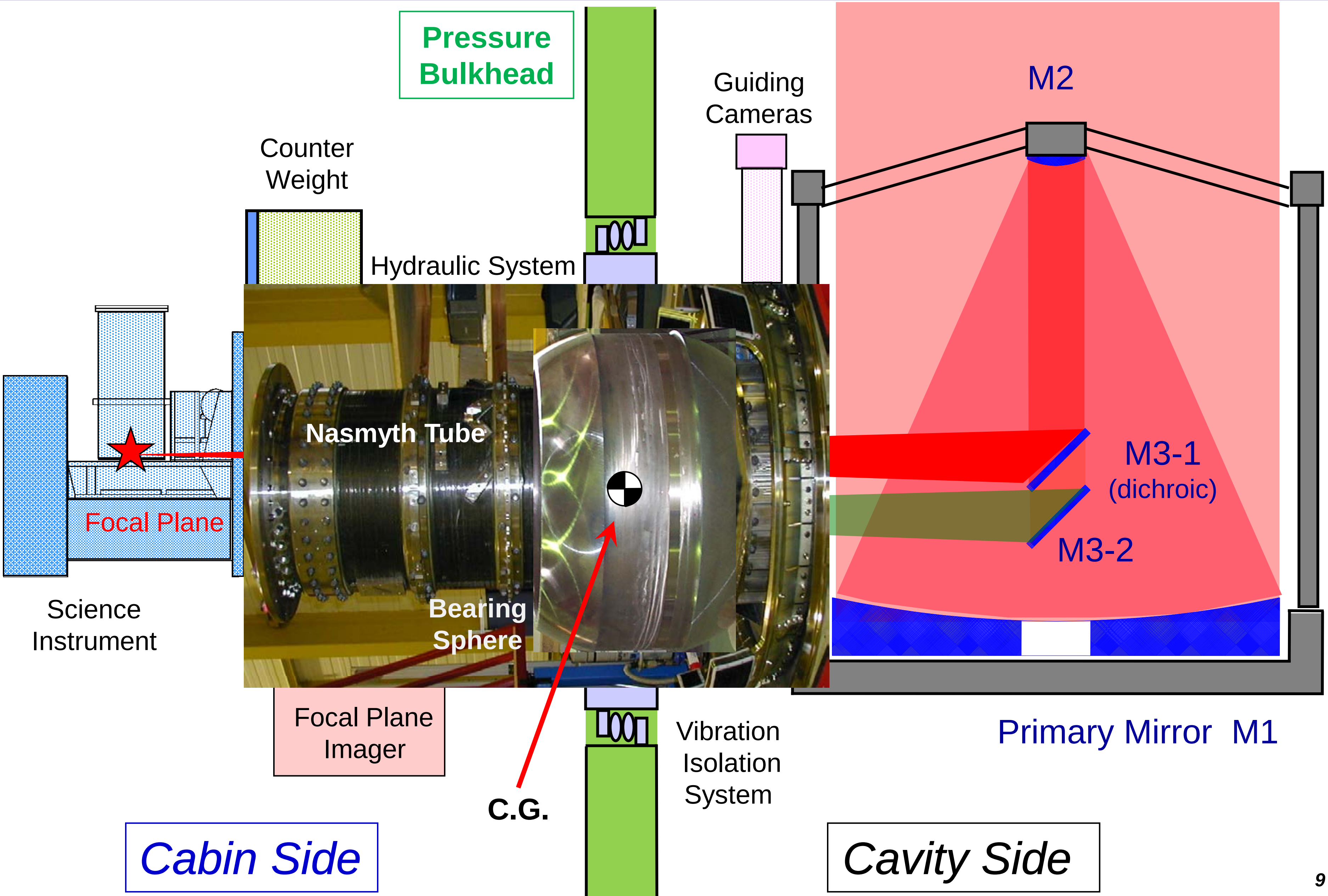
- „Cassegrain with Nasmyth Tube“, f/19.6
- Primary Mirror Ø = 2.7 m
- effective aperture Ø = 2.5 m
  (to allow un-vigneted chopping)
- Mass ~17 t
- Spherical bearing allows to move freely
  in all three axes (EL, XEL, LOS) +/- 2.5°
- Inertial stabilized by Fiber Optical
  Gyroscopes (FOG)
- Pointing stability: 0.2 arcsec rms
- Elevation range: 23° – 58°
  (view limited by door system)



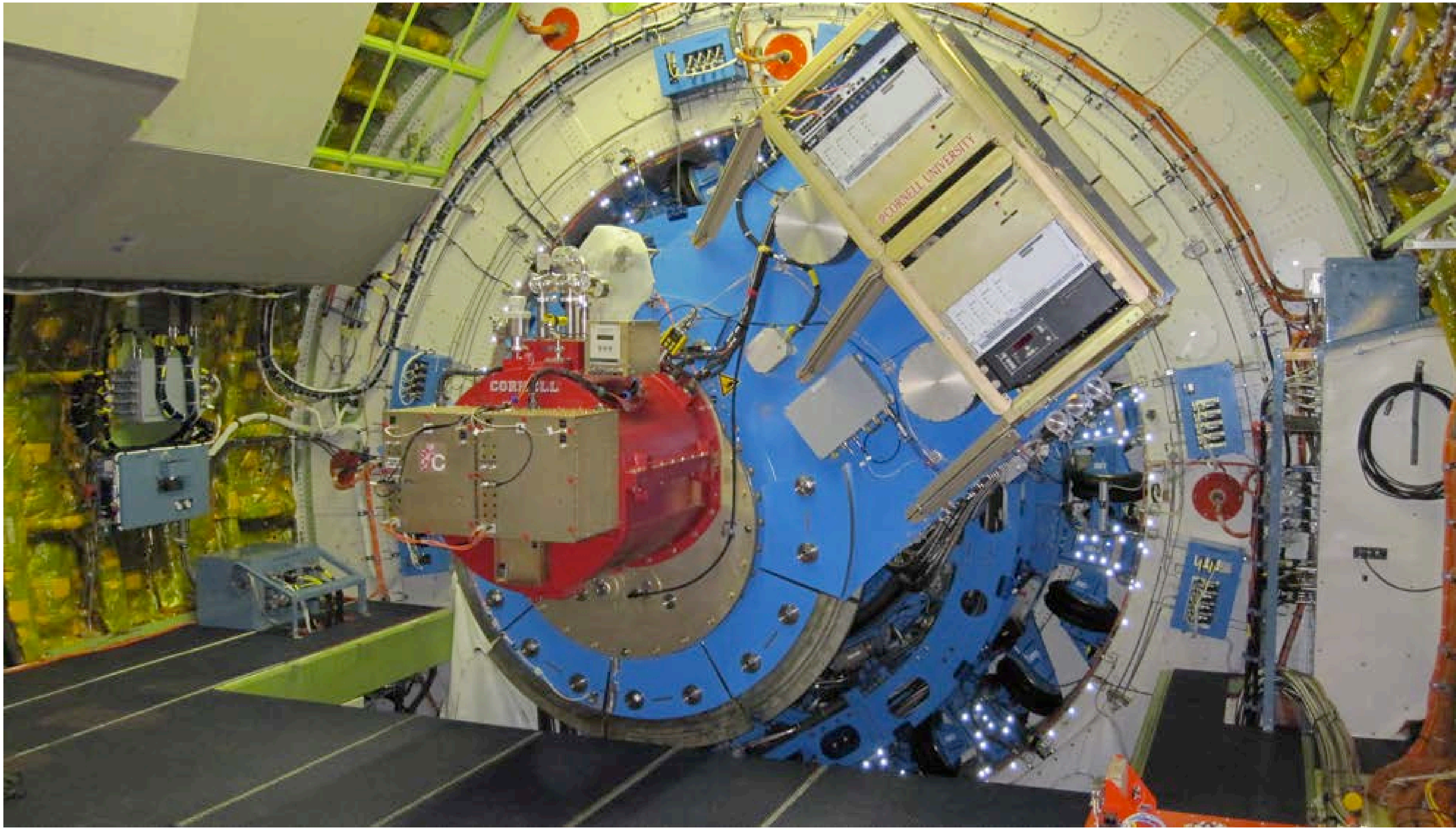
The Telescope



Optical Path



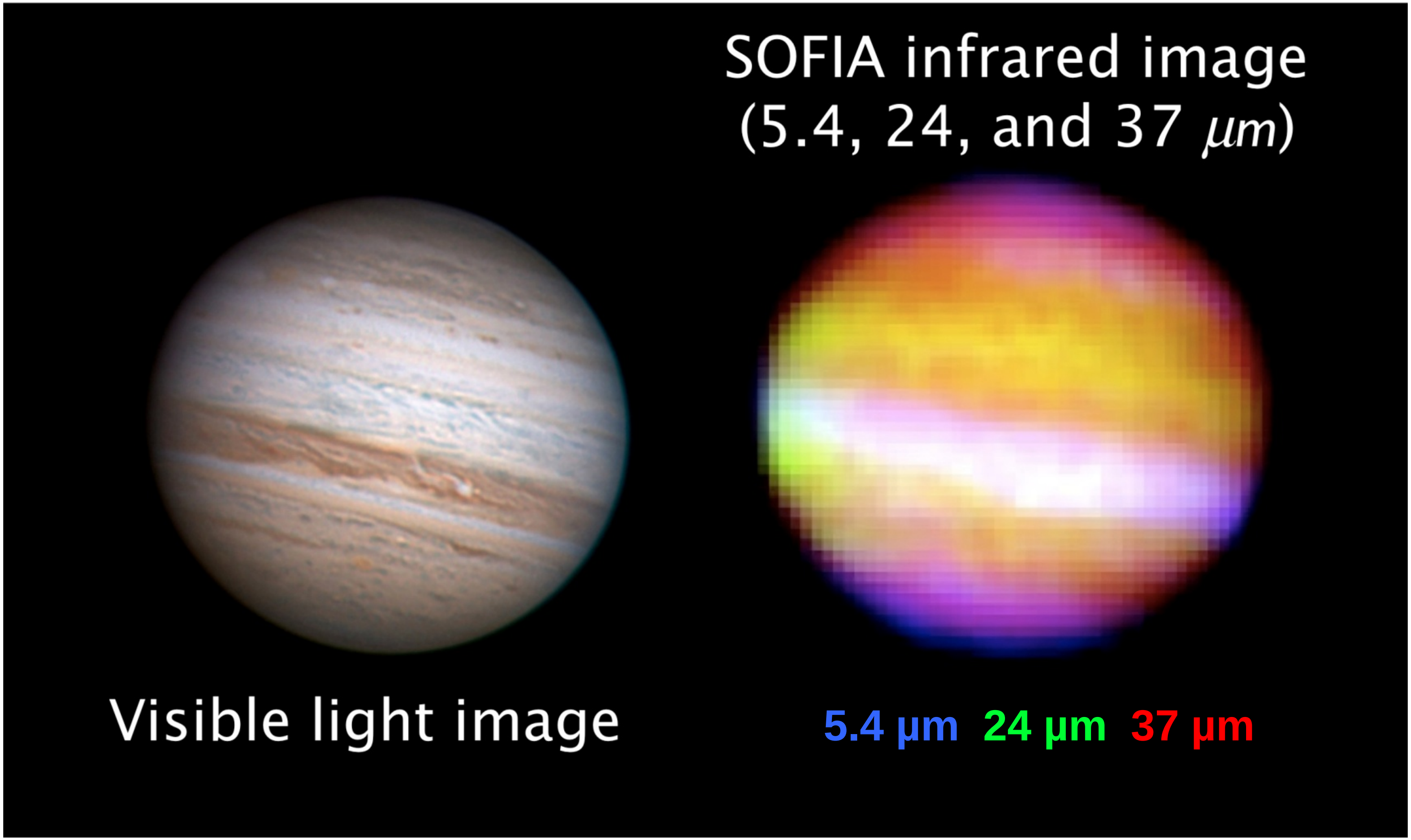
FORCAST (Faint Object infraRed CAmera for the SOFIA Telescope)



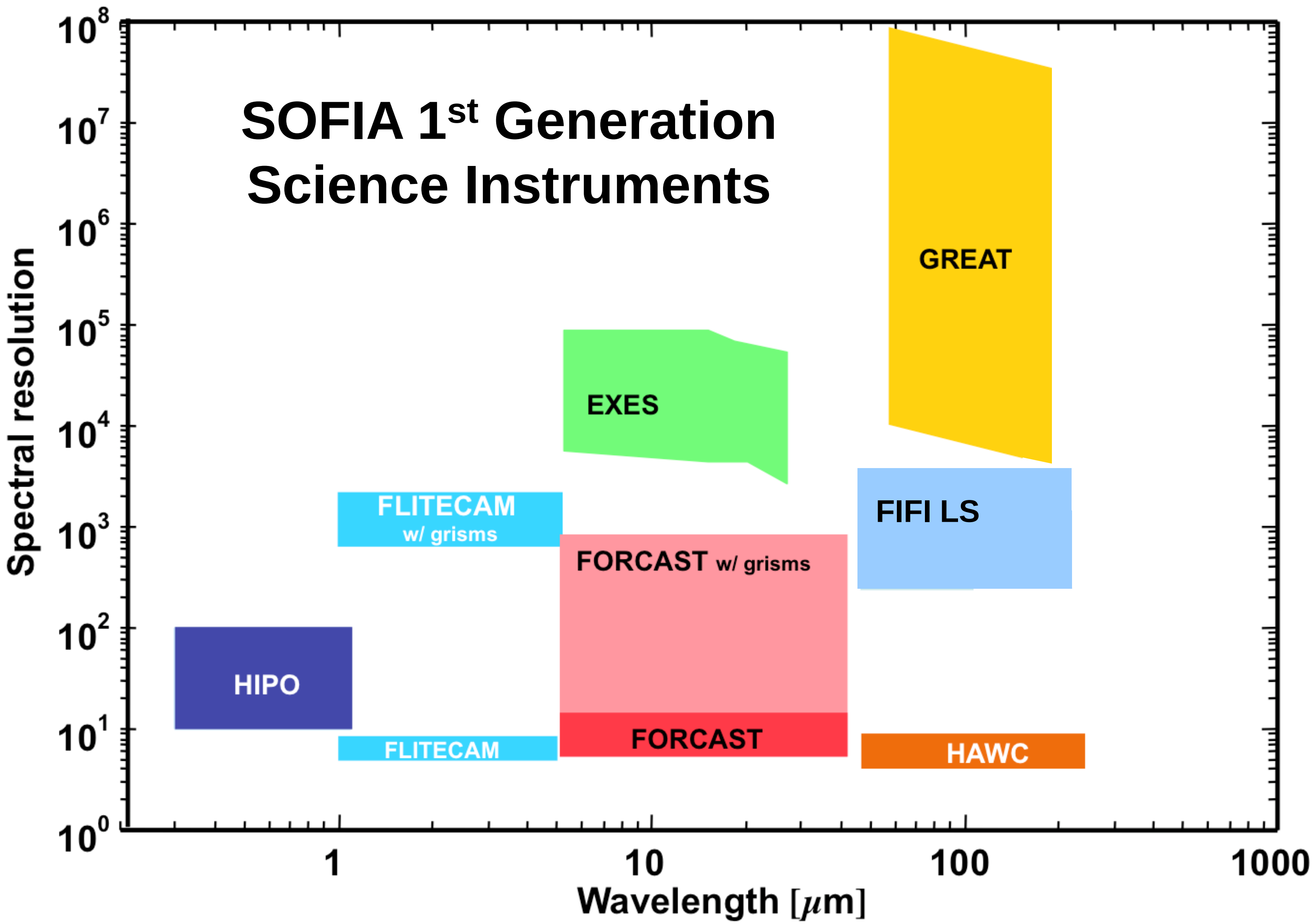
Principal Investigator: Dr. Terry Herter, Cornell University, Ithaca, New York

λ = 5-25 μm & 25-40 μm FOV: 3.2‘ x 3.2‘ Spectral resolution: 5.7-250

First Light (26.Mai 2010)



Instrument R/λ graph



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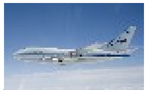
1^{st} Generation Science Instruments



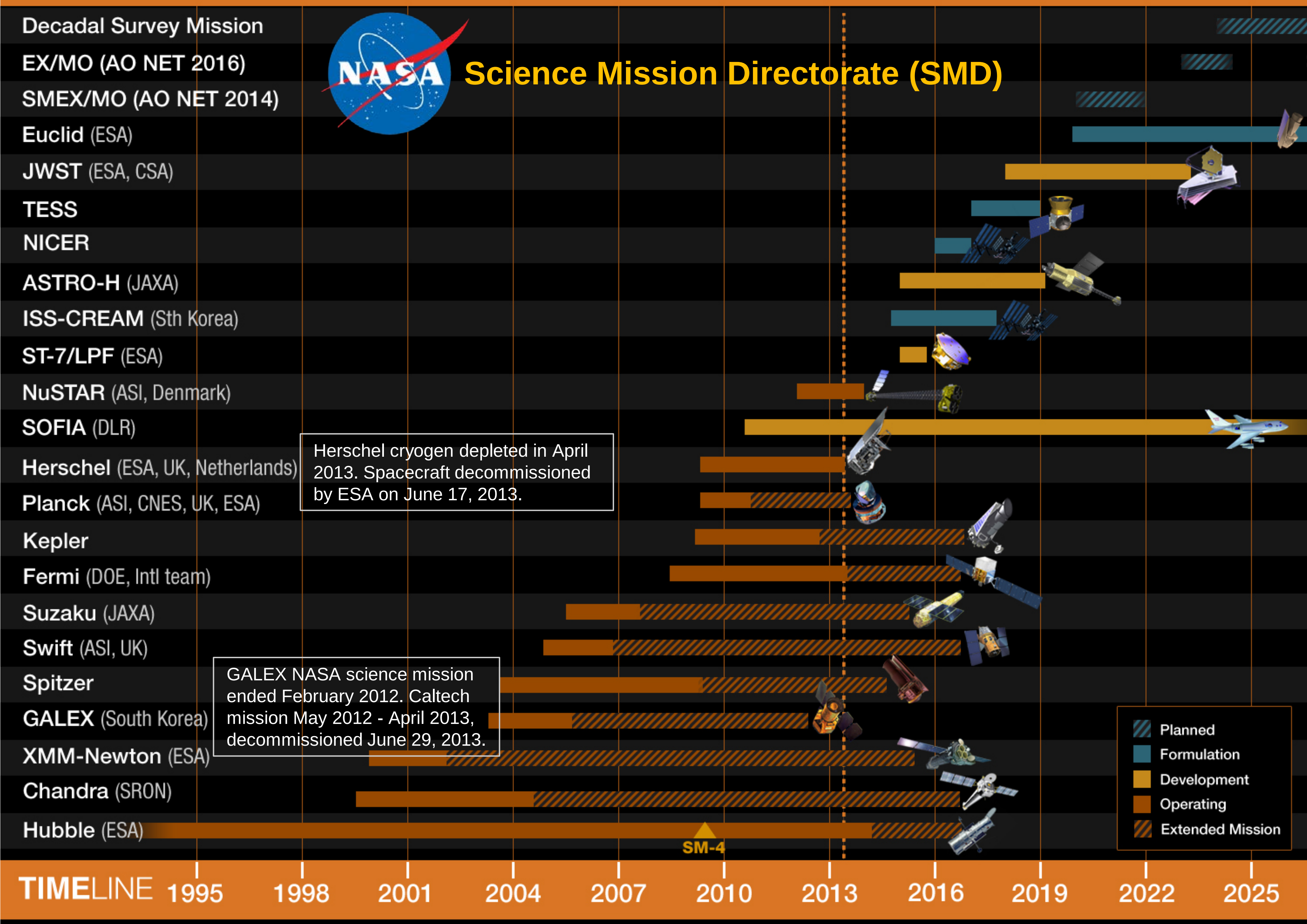
Stratospheric Observatory for Infrared Astronomy

SOFIA

Name	Meaning	Description	PI	Institution	Country	Wavelength [µm]	Spectral Resolution	1^{st} (F)Light on SOFIA
FORCAST	**F**aint **O**bject Infra**R**ed **Ca**mera for the **S**OFIA **T**elescope	Mid-Infrared camera and grism spectrometer	T. Herter	Cornell University, Ithaca, NY	USA	5 – 40	5.7 – 250	2010
GREAT	**G**erman **Re**ceiver for **A**stronomy at **T**erahertz Frequencies	2-Chanel heterodyne spectrometer	R. Güsten	MPIfR, Max-Planck Institut für Radioastronomie, Bonn	Germany	60 – 240	10^6 – 10^8	2011
FLITECAM	**F**irst **Li**ght **I**nfrared **T**est **E**xperiment **Cam**era	Near-Infrared camera and grism spectrometer	I. McLean	UCLA Division of Astronomy and Astrophysics, Los Angeles, CA	USA	1 – 5.5	1000 – 2000	2011
HIPO	**H**igh-speed **I**maging **P**hotometer for **O**ccultation	CCD imaging photometry at visual / NIR wavelengths	T. Dunham	Lowell Observatory, Flagstaff, Arizona	USA	0.3 – 0.6 0.4 – 1.1		2011
EXES	**E**chelon-**Cross**-**E**chelle **S**pectrograph	High resolution Mid-Infrared echelon (slit) spectrometer	M. Richter	UC Davis, built at NASA Ames Research Center	USA	5 – 28	3000, 10^4, 10^5	2014
FIFI-LS	**F**ield **I**maging **F**ar-**I**nfrared **L**ine **S**pectrometer	spatial and spectral slit spectroscopy 2 wavelengths	A. Krabbe	Univ. of Stuttgart, Stuttgart	Germany	42 – 110 110 – 210	1000 – 3750	2014
HAWC+	**H**igh-resolution **A**irborne **W**ideband **Ca**mera	Far-Infrared bolometer camera (and polarimeter)	D. Dowell	JPL, Pasadena, CA	USA	50 – 250		2015

Astrophysics Missions timeline

Last updated: June 29, 2013



Observing Cycles

Calendar year 2013: Observing Cycle 1 (278 Research Hours)
Calendar year 2014: Observing Cycle 2 (335 Research Hours)
and so on… (increasing up to full ability of ~1000 Research Hours each year)

SOFIA Observing Cycles are in coincidence with the calendar year.

Call for Proposals (CfP)

There will be a separate U.S. and German Proposal Call released in each spring, ideally supported by a "SOFIA CfP Workshop":

- U.S. Call for Proposals by USRA (worldwide open, German PIs excluded)
- German Call for Proposals by DSI (for German PIs only)

There will be a "SOFIA Observer's Handbook" online for each cycle:

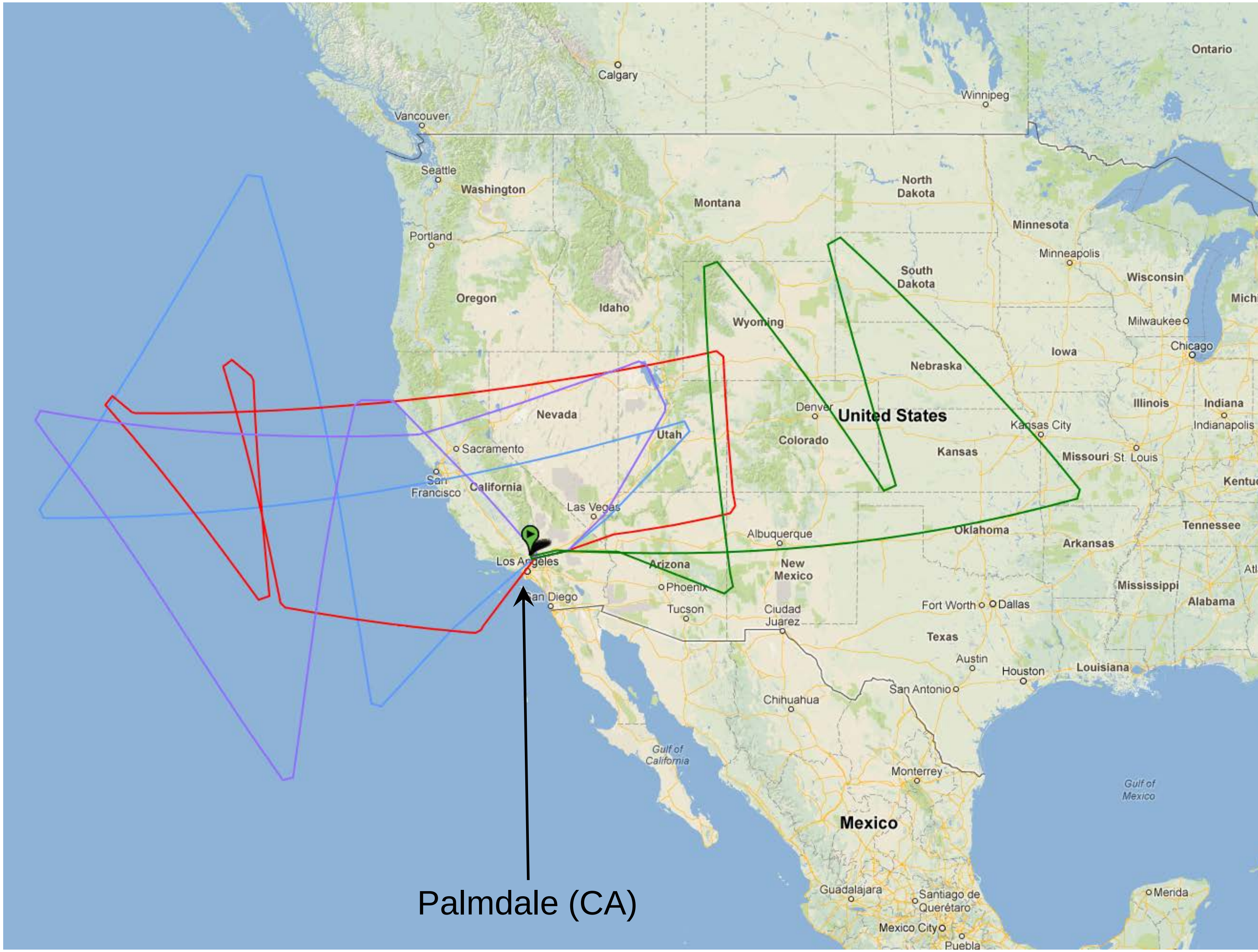
www.sofia.usra.edu/Science/proposals/cycle1/SOFIA_Observers_Handbook_v1.3.1.pdf
www.sofia.usra.edu/Science/ObserversHandbook/ObsHandbook-Cy2.pdf

Observation Scheduling and Flight Planning

Facts to be considered (unlike on ground-based observatories):

- The telescope looks out of the port side of the aircraft.
  → the azimuth of the target dictates the aircraft heading.
- Restricted air space needs to be avoided.
- Object to be observed needs to be in the elevation range of 23° – 58° .
  → observing a target that culminates above 70° (~11 hrs above 23°)
  → night is split into two observing windows of only ~3 hours.
- Because the aircraft is moving, the observatory's longitude and latitude are changing constantly.
  → Flight planning can be used to adjust targets elevation.
- After an observing night, SOFIA needs to return to the airport it departed from: Palmdale (CA) or Christchurch (NZ).
  → Minimization of dead legs.
- Minimize down time due instrument swaps.

Flight Paths



Stratospheric Observatory for Infrared Astronomy

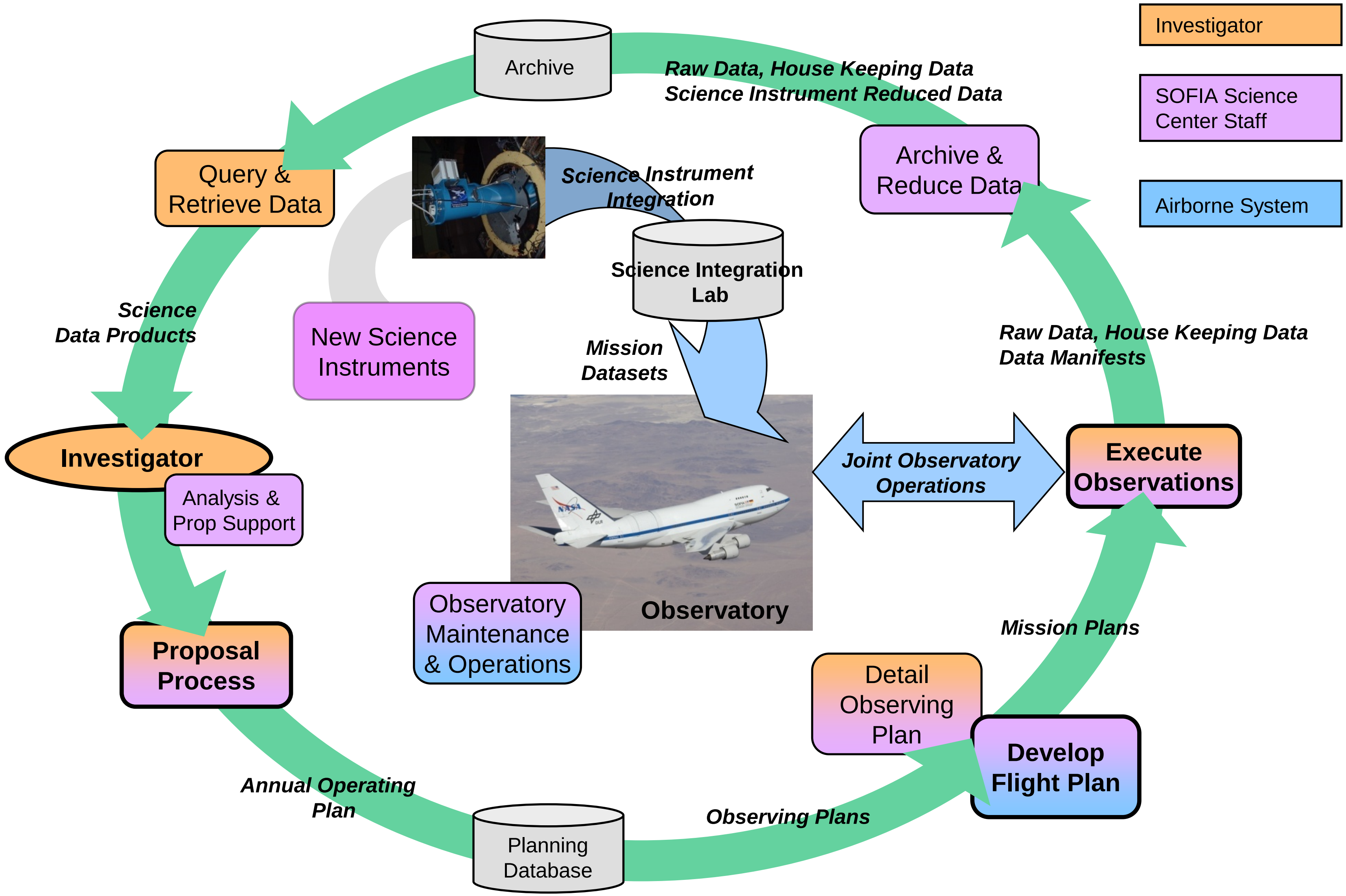
SOFIA

Flight Paths

SOFIA Stratospheric Observatory for Infrared Astronomy

Geographic Distribution of SOFIA Science Flights (2010-2011)

Data Cycle System



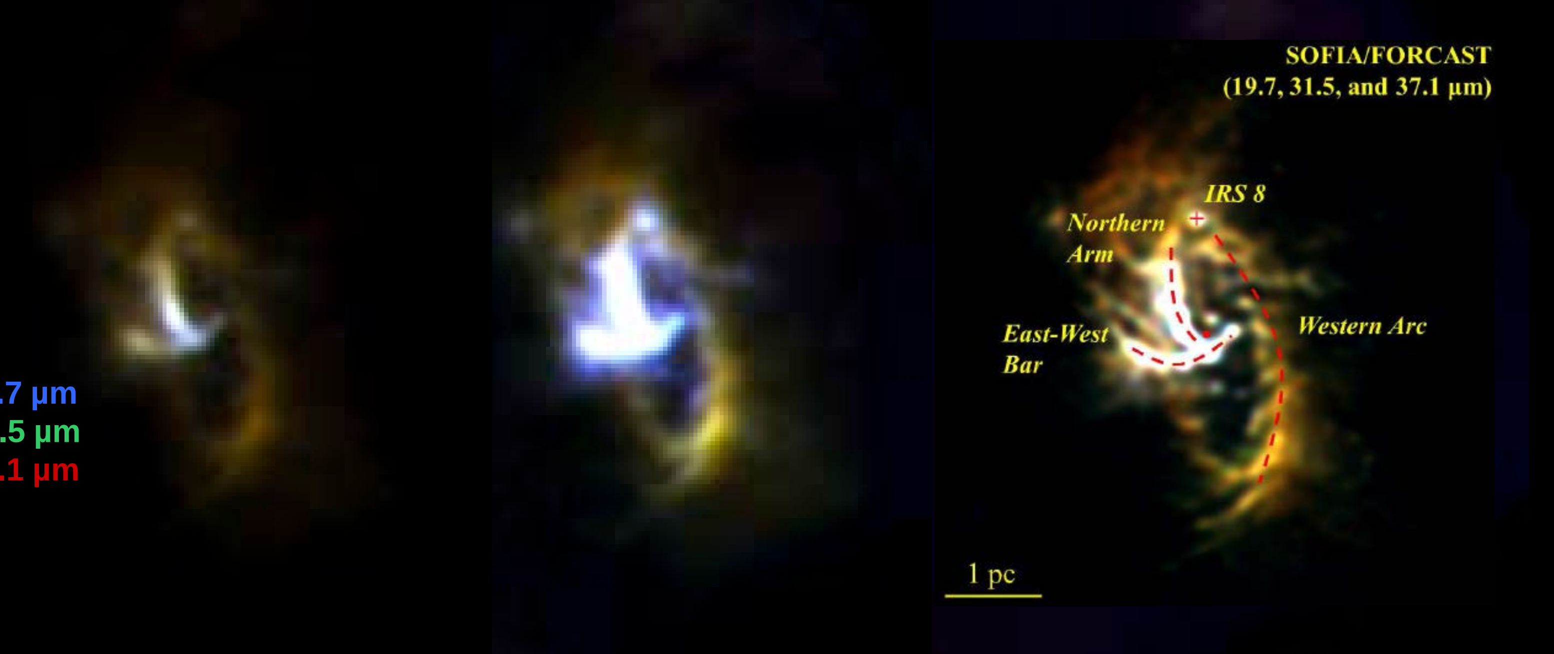
Tools for Annual Lifecycle

Stratospheric Observatory for Infrared Astronomy

SOFIA

Sgr A*- CND

Multicolor image of the **c**ircum**n**uclear **d**isk (CND) at the Galactic Center



blue 19.7 µm
green 31.5 µm
red 37.1 µm

Brightness varies from left (central structures) to right (to emphasize CNR)

- Almost perfect ring R~ 1.5 pc around the 4•10^{6} M$_{\odot}$ Black Hole
- Thickness/Diameter only ~ 1/10; inclination wrt plane of sky 67º
- Color gradient across ring: Internal heating source
- Probably by young stars interior to the ring

FORCAST: T. Herter, M. Morris et al. 2012

R. M. Lau, T. L. Herter, M. R. Morris, E. E. Becklin, J. D. Adams
SOFIA/FORCAST Imaging of the Circumnuclear Ring at the Galactic Center
The Astrophysical Journal, Volume 775, Number 1

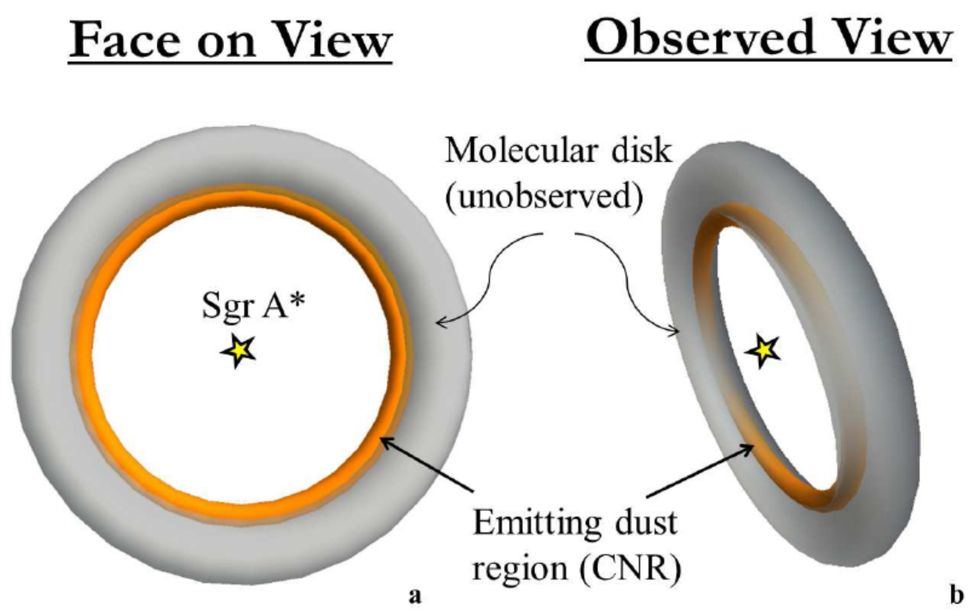


Fig. 4.— Schematic diagram of the geometry of the Circumnuclear Ring (CNR). The diagram illustrates that the CNR is the illuminated inner edge (orange) of a larger disk of cool dust and gas (grey) unobserved at our wavelengths. The face on view model (a) shows the ring-like structure of the CNR centered on Sgr A*. The observed view model (b) is the same model as (a) inclined by 67° with respect to the plane of the paper and rotated to align with the observed CNR in equatorial coordinates. The north and south regions of the CNR are brightened in (b) to reflect the effect of the inclination increasing the column density of the emitting dust along lines of sight at those regions.

R. M. Lau, T. L. Herter, M. R. Morris, E. E. Becklin, J. D. Adams
SOFIA/FORCAST Imaging of the Circumnuclear Ring at the Galactic Center
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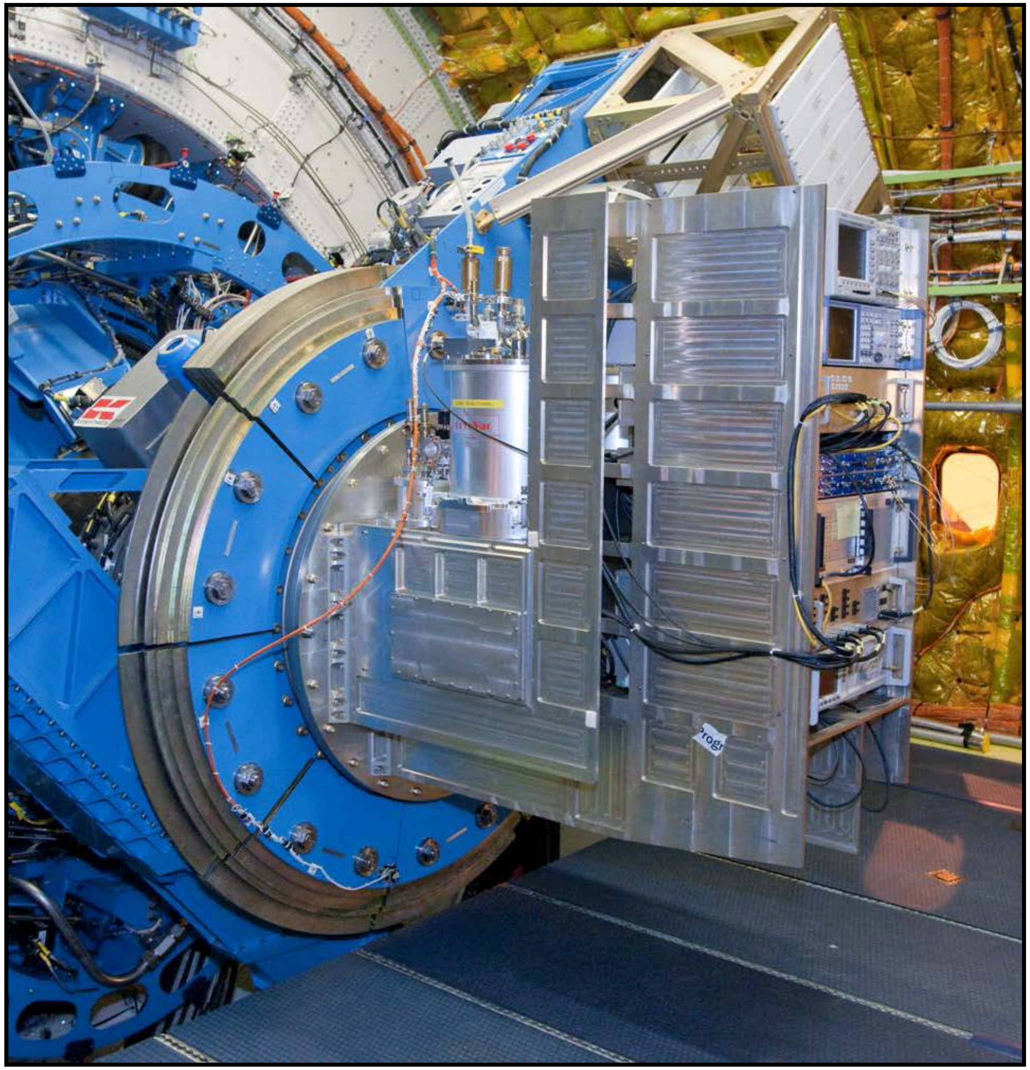
GREAT (**G**erman **RE**ceiver for **A**stronomy at **T**erahertz frequencies)



Heterodyne Spectrometer

PI: R. Güsten, guesten@mpifr.de
Max-Planck Institut für Radioastronomie

Detector: dual channel mixer (HEB);
60 – 240 µm (1.25 – 5 THz)

Resolving power = 10^8

Targets: Galactic and extragalactic ISM, circumstellar shells

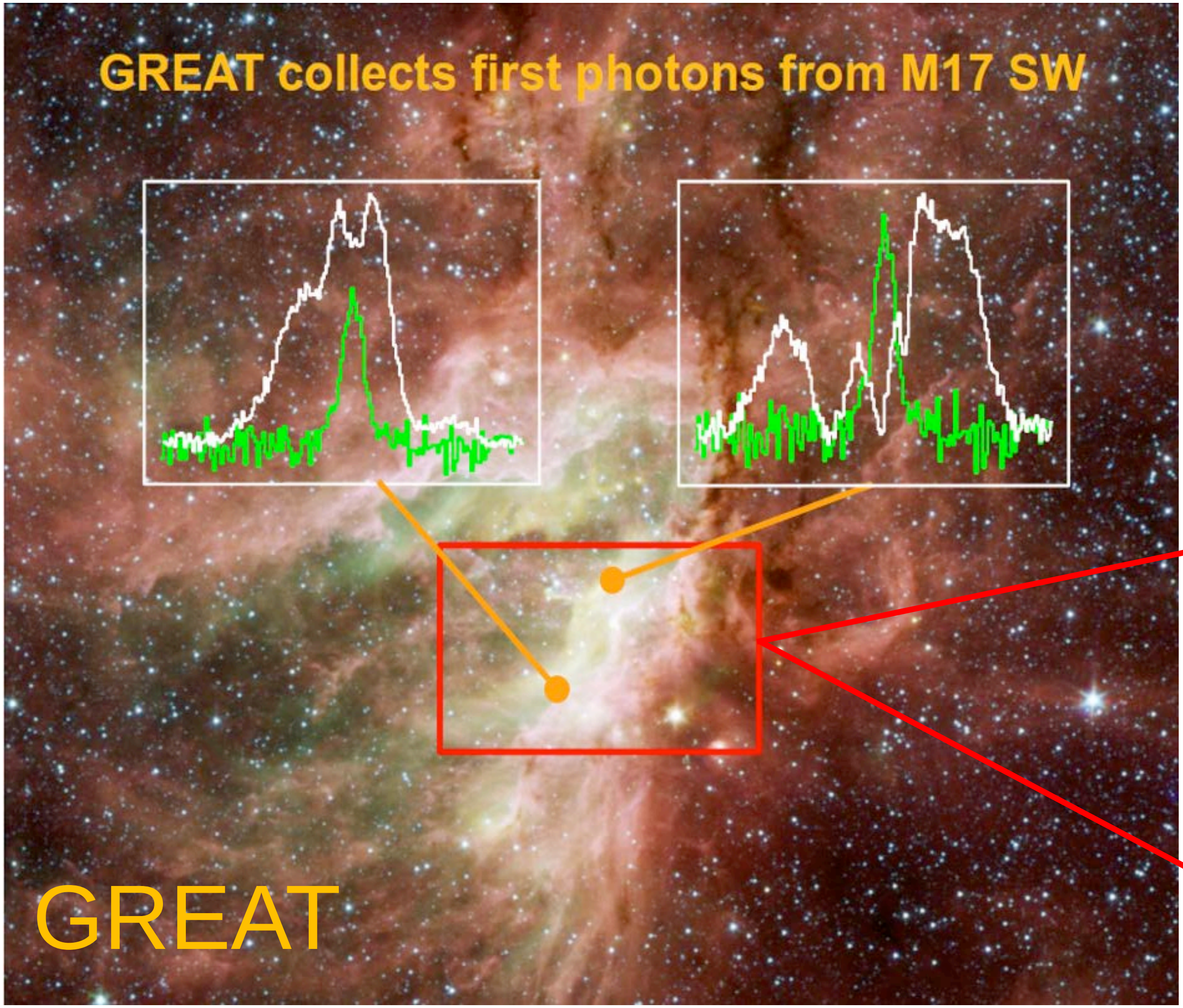
Channels	Astronomical lines
1.25-1.50 THz :	[NII], CO, (13)CO, HCN, H2D+
1.82-1.92 THz :	[CII], CO
2.4-2.7 THz:	HD, OH(2P3/2), CO, (13)CO

System temperature T~1500 K at 158 µm

High frequency upgrade at 4.7 THz expected in Oct 2013 for OI (63 µm).

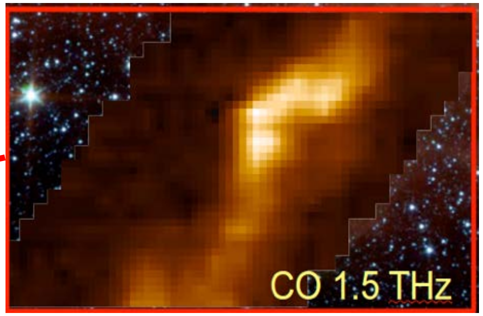
In 2015: upGREAT with 14 pixels at 1.9 THz and 7 pixels at 4.7 THz

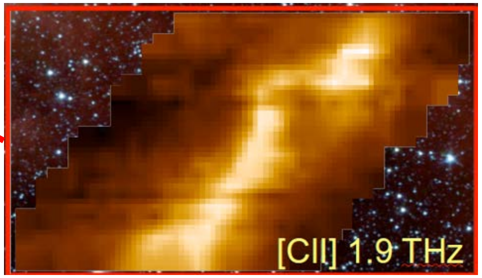
Mapping of [CII] and CO in molecular cloud M17 SW



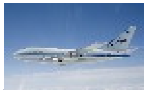
molecular mass:
~10^4 M_{Solar}

- [CII]
- CO





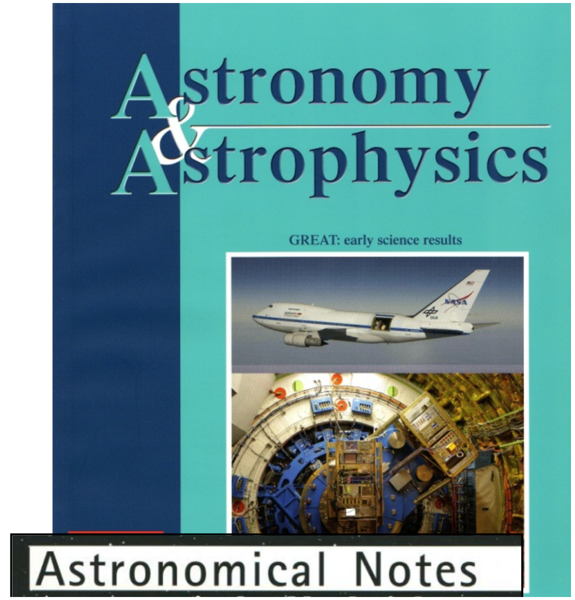
http://www.dsi.uni-stuttgart.de/aktuelles/news/news_0013.html



Early Science with GREAT:

➔ 22 GREAT Papers

➔ A&A Vol. 542 Special Issue (June 2012)



<u>Discovery</u> of interstellar <u>mercapto radicals (SH)</u>

D. A. Neufeld et al.

Detection of OD towards the <u>low-mass protostar</u>

B. Parise et al.

Confirmation of <u>transient nature of the circum-nuclear disk</u>

M. A. Requena-Torres et al.

<u>Globules and pillars</u> seen in the [CII] 158 μm line with SOFIA

N. Schneider et al.

<u>Ammonia absorption</u> as a probe of infall in high-mass star forming clumps

F. Wyrowski et al.

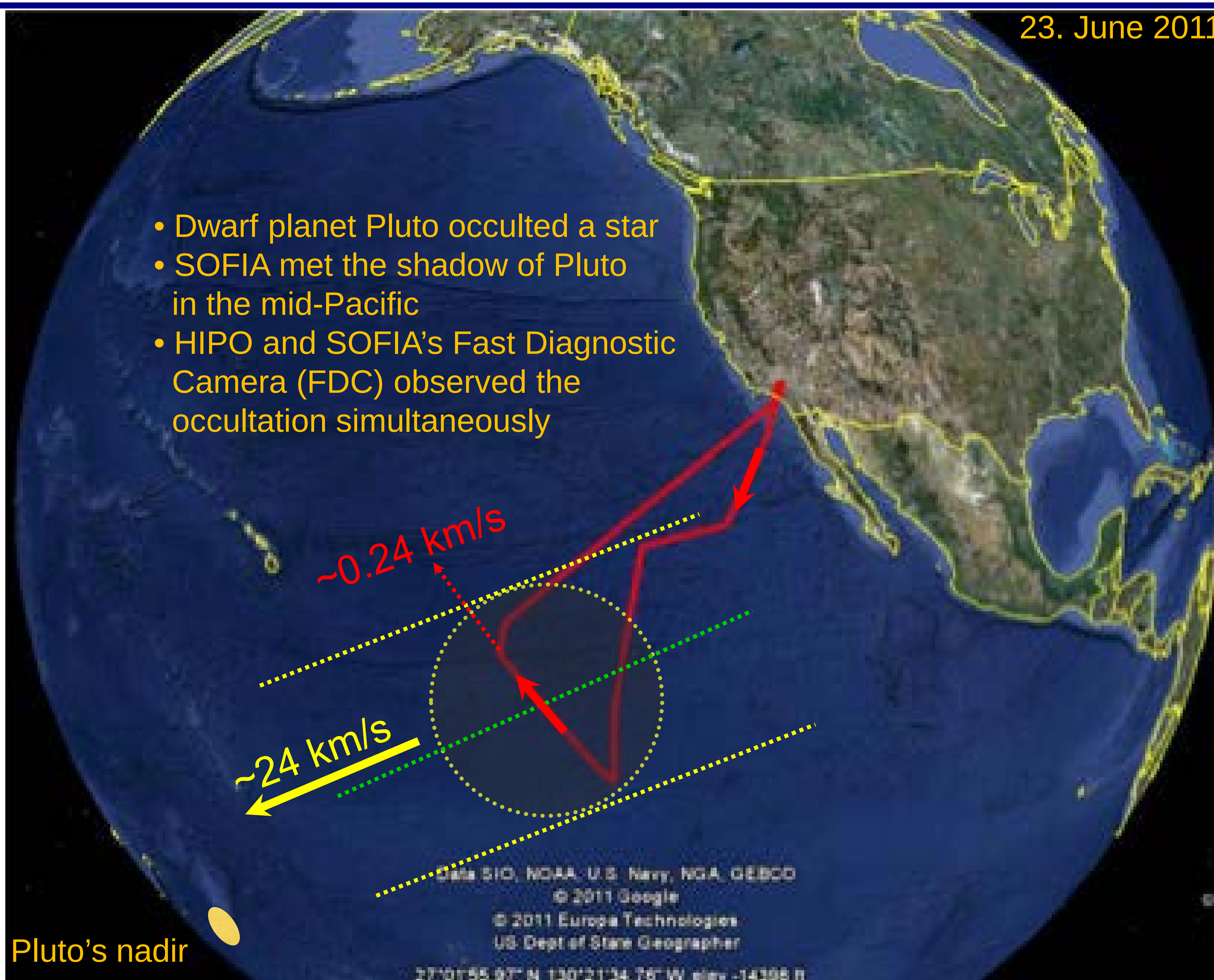
The <u>structure of hot gas</u> in Cepheus B

B. Mookerjea et al.

Pluto Occultation

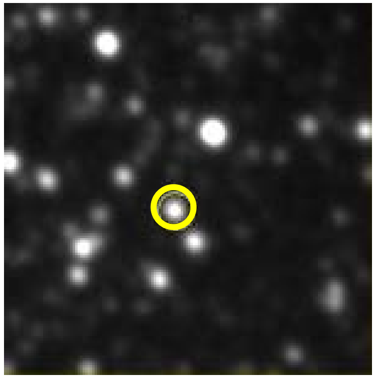
23. June 2011

- Dwarf planet Pluto occulted a star
- SOFIA met the shadow of Pluto in the mid-Pacific
- HIPO and SOFIA's Fast Diagnostic Camera (FDC) observed the occultation simultaneously

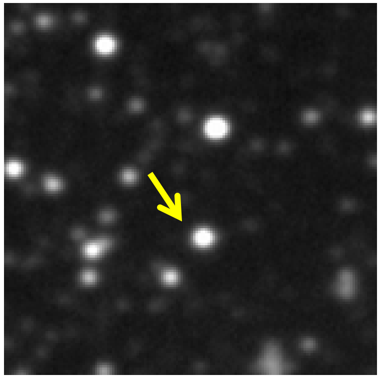


Dunham, Wolf et al. 2012

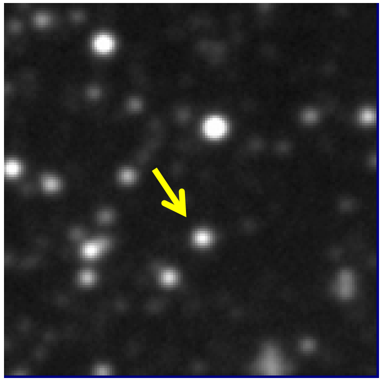
Image sequence from the FDC:



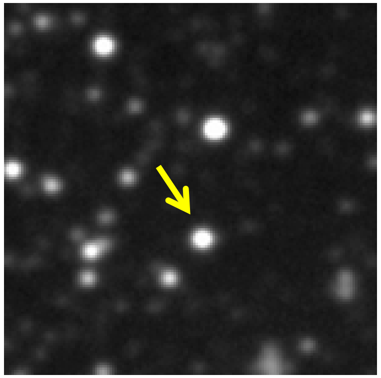
Pluto (circled) is 13” from the star, 200 min. before the occultation



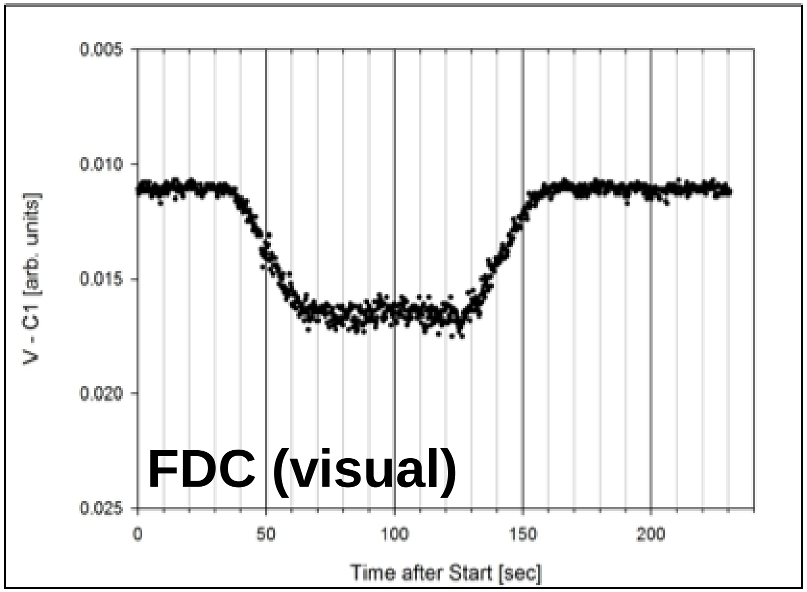
Just before occultation: Pluto and star merged, combined light

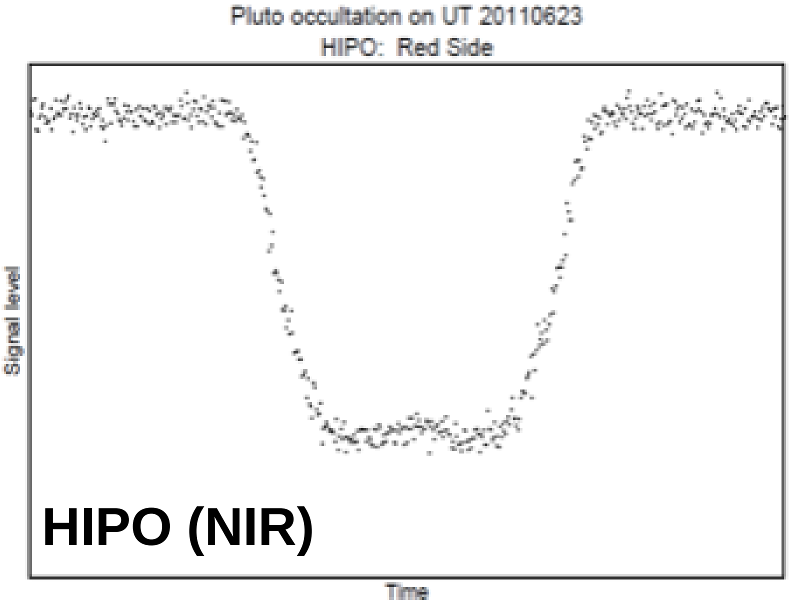


During occultation: Pluto and star merged, only Pluto light seen



After occultation: Pluto and star merged, combined light





Dunham, Wolf et al. 2012

Pluto Occultation

SOFIA's mobility was crucial for this successful observation:

- duration of occultation ~120 sec
- central line reached <50 km

Results published last week:

M. J. Person, E. W. Dunham et al.

The 2011 June 23 stellar Occultation by Pluto: Airborne and Ground Observations

The Astronomical Journal, 146:83 (15pp), 2013 October

discussing:

- Astrometry and Prediction of the Occultation
- Data and Light Curves measured
- Pluto's Atmosphere structure
- Evolution of Pluto's Atmosphere as Pluto gets more distant from the sun

1st Southern Hemisphere Deployment
Christchurch (NZ)
July 12th – August 3rd 2013
with GREAT

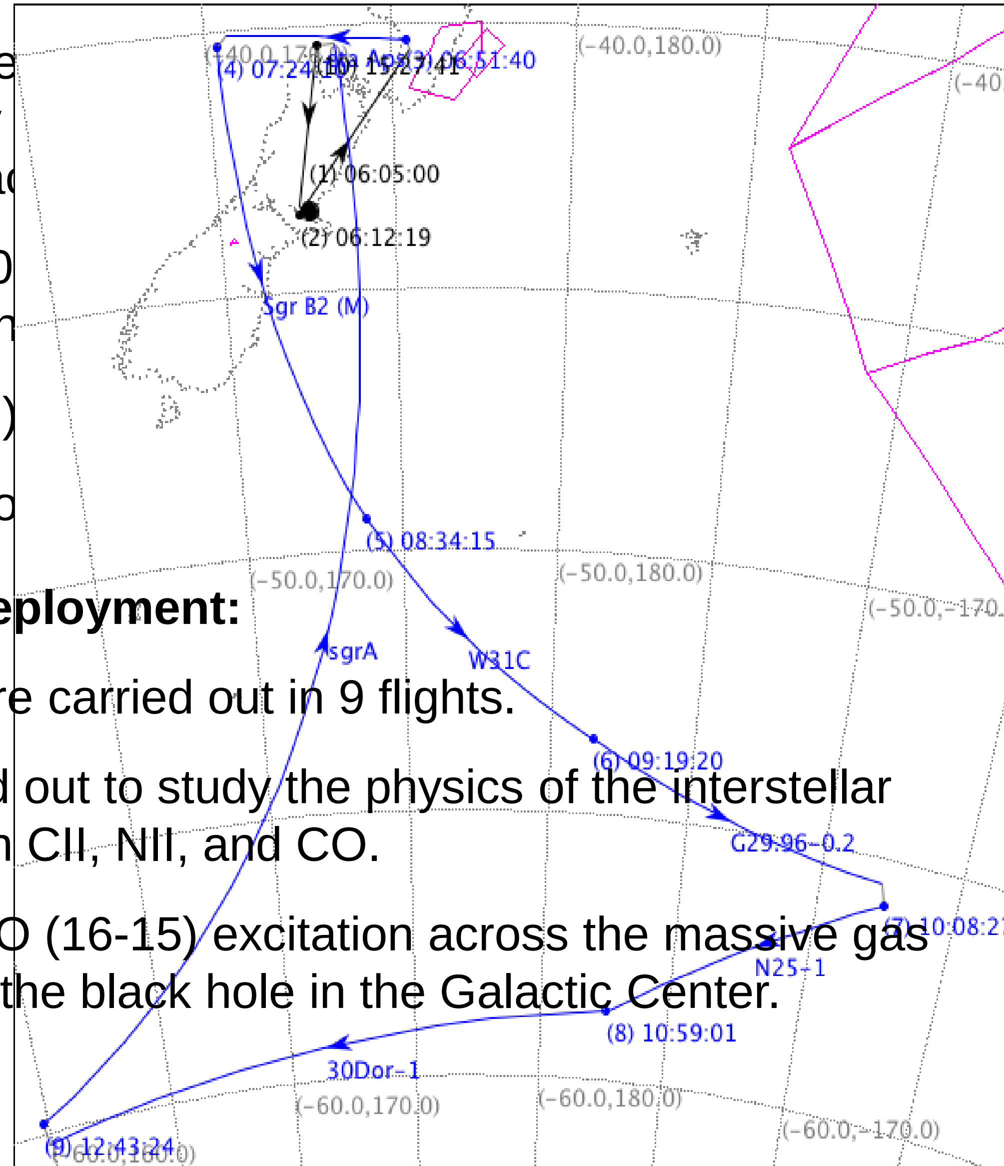
SOFIA Stratospheric Observatory for Infrared Astronomy

Why Southern Hemisphere Deployment?

- To observe key regions that are
  Palmdale: The Southern Milky
  Magellanic Cloud and the Galac
- Prominent targets like NGC360
  optical, but for which we have n
- Better (longer, higher elevation)
- Water vapor at LOS is <5 micro

Observations during the NZ deployment:

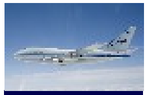
- In total 25 science projects were carried out in 9 flights.
- 7 science projects were carried out to study the physics of the interstellar gas in the Magellanic Clouds in CII, NII, and CO.
- CO (11-10), CO (13-12) and CO (16-15) excitation across the massive gas disk rotating around & feeding the black hole in the Galactic Center.



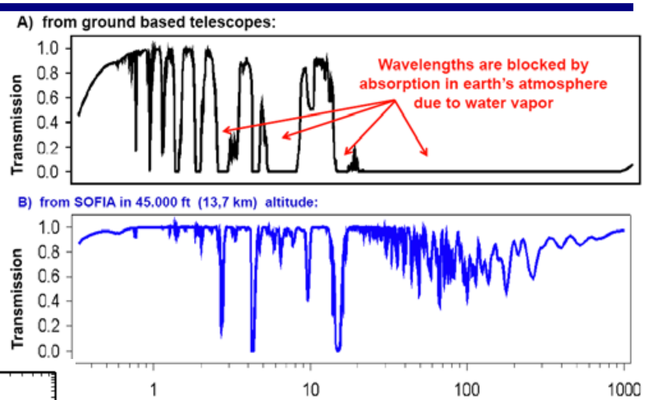
Summary: Why SOFIA?

SOFIA

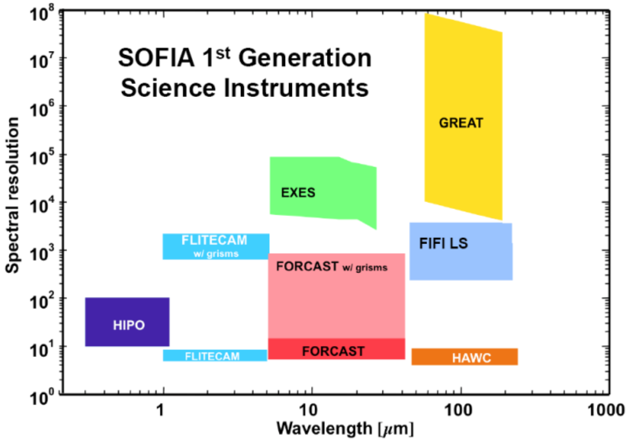
Stratospheric Observatory for Infrared Astronomy



Infrared transmission:
in the Stratosphere the transmission is
>80% for wavelengths from 1 to 1000 µm

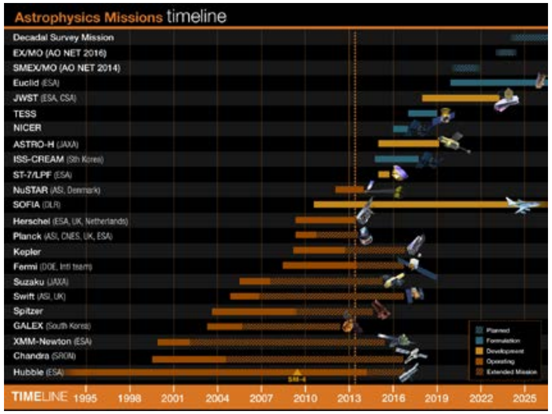


Instrumentation:
wide complement
rapidly interchangeable
state-of-the art

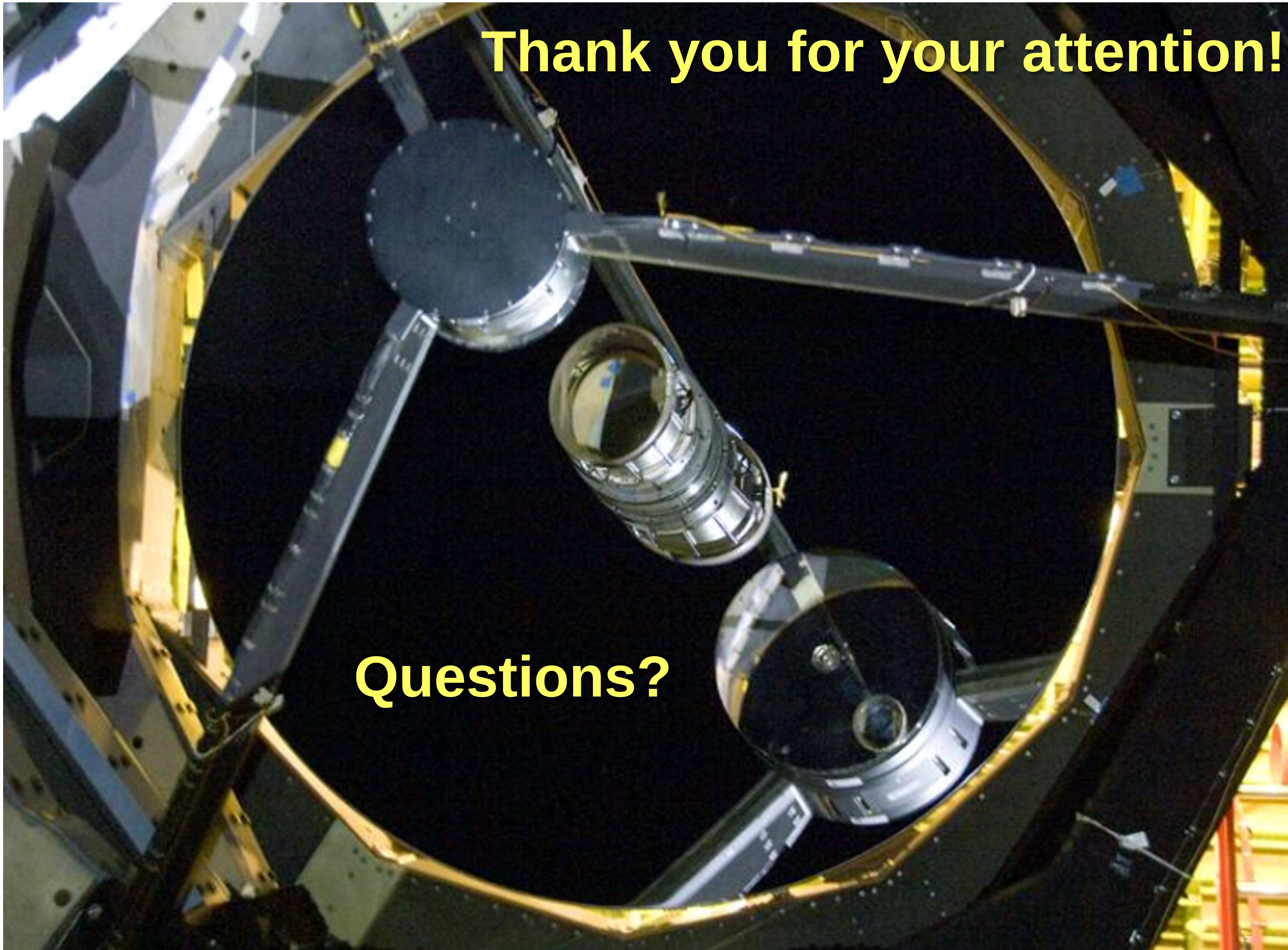


Global Mobility:
SOFIA can observe anywhere, anytime, on short notice

Lifetime:
SOFIA is built for 20 years and will be one of the primary facilities for FIR and sub-mm astronomy for many years



Thank you for your attention!



Questions?

More Information about SOFIA can be found…

NASA homepage:
http://www.nasa.gov/mission_pages/SOFIA

USRA homepage:
http://www.sofia.usra.edu
http://www.sofia.usra.edu/Science

DSI homepage:
http://www.dsi.uni-stuttgart.de

Other:
http://www.youtube.com/user/SOFIAObservatory
http://de.flightaware.com/live/flight/NASA747