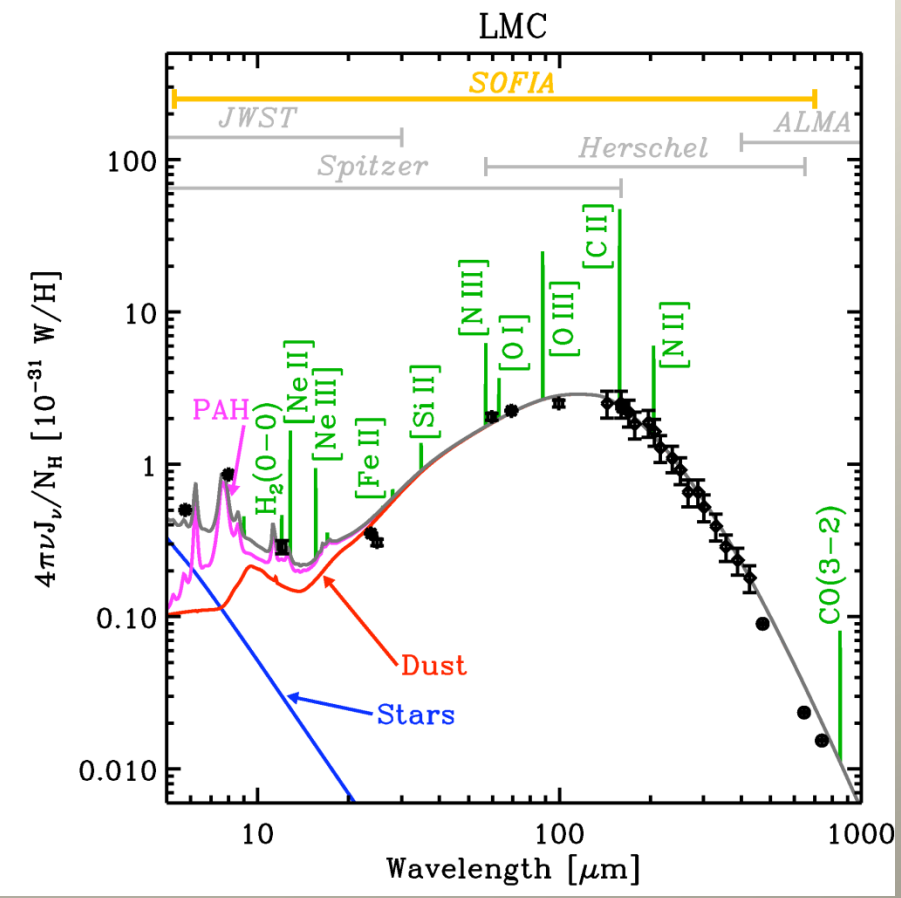
The SOFIA Observatory Capabilities

Erick Young

SOFIA Science Center

Scientific Rationale for SOFIA

- The scientific rationales for SOFIA and the Far-Infrared Surveyor share the same foundation.
- Most of the luminosity of star formation regions, external galaxies, and cooler objects in the universe is in far-IR and Sub-mm dust emission
- The most important emission lines responsible for the energy balance of the Interstellar Medium are in the far-infrared

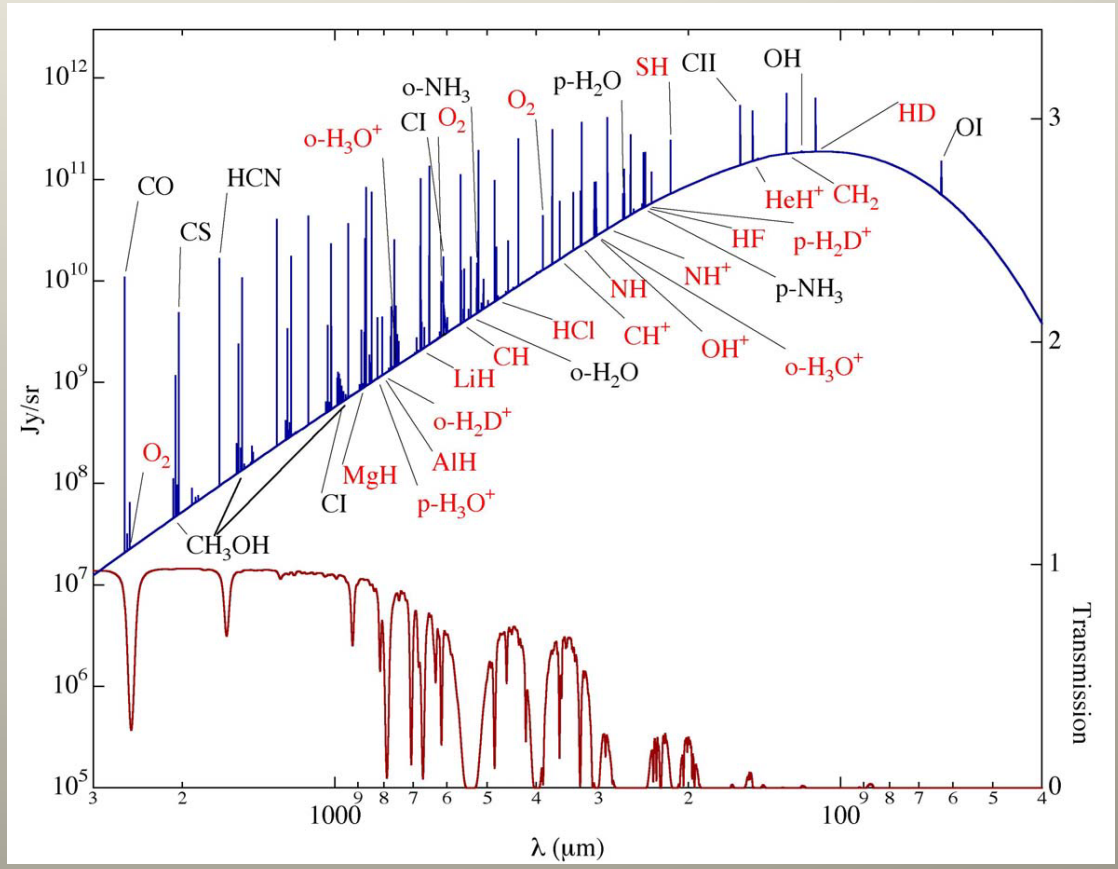


The spectral energy distribution of the entire LMC, based on data from Spitzer, IRAS and FIRAS (Bernard et al. 2008). SEDS are fitted with the dusty PDR model of Galliano et al. (2008).
Figure courtesy of Galliano.

Importance of Far IR / Sub-mm -2

- Most of the key atomic and molecular tracers of the interstellar medium are in the Far Infrared and Sub-mm

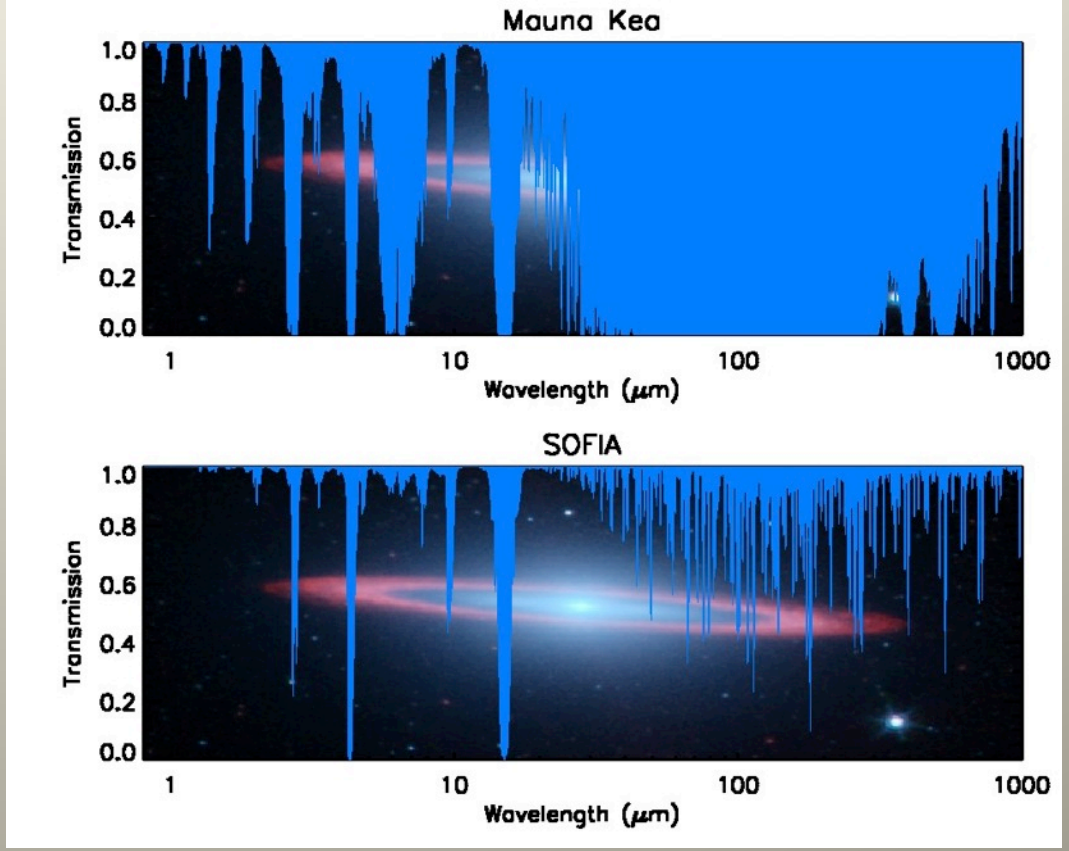
Molecular Cloud Spectrum



Ted Bergin, 2008

Motivation for SOFIA

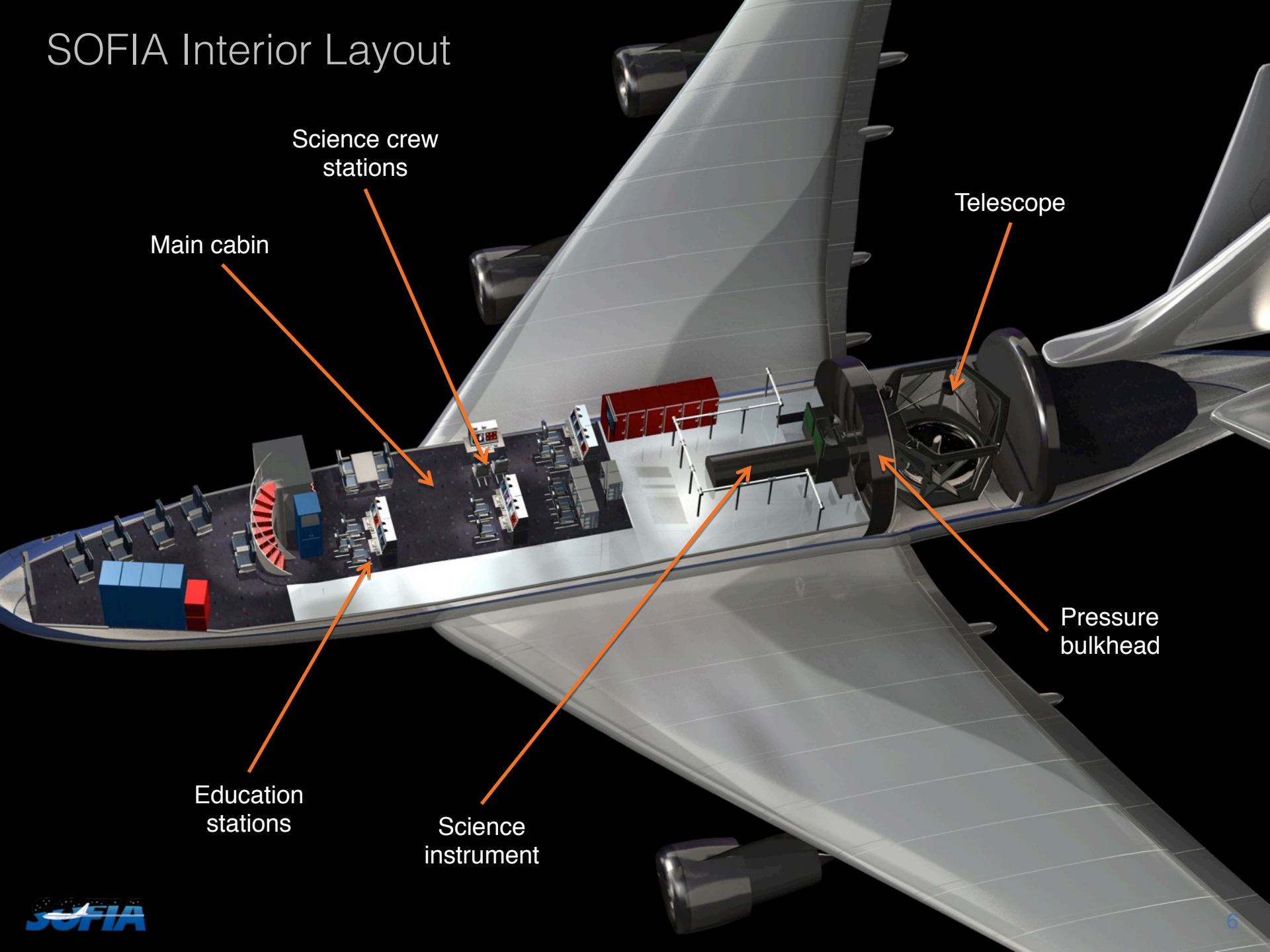
- The infrared is a key part of the spectrum for studying young stars, galaxies, planets, and the interstellar medium.
- The Earth's atmosphere is opaque to large parts of the infrared wavelength range. Water vapor absorbs much of this radiation.
- Go to a place where there is much less water vapor.



SOFIA
Stratospheric Observatory for Infrared Astronomy

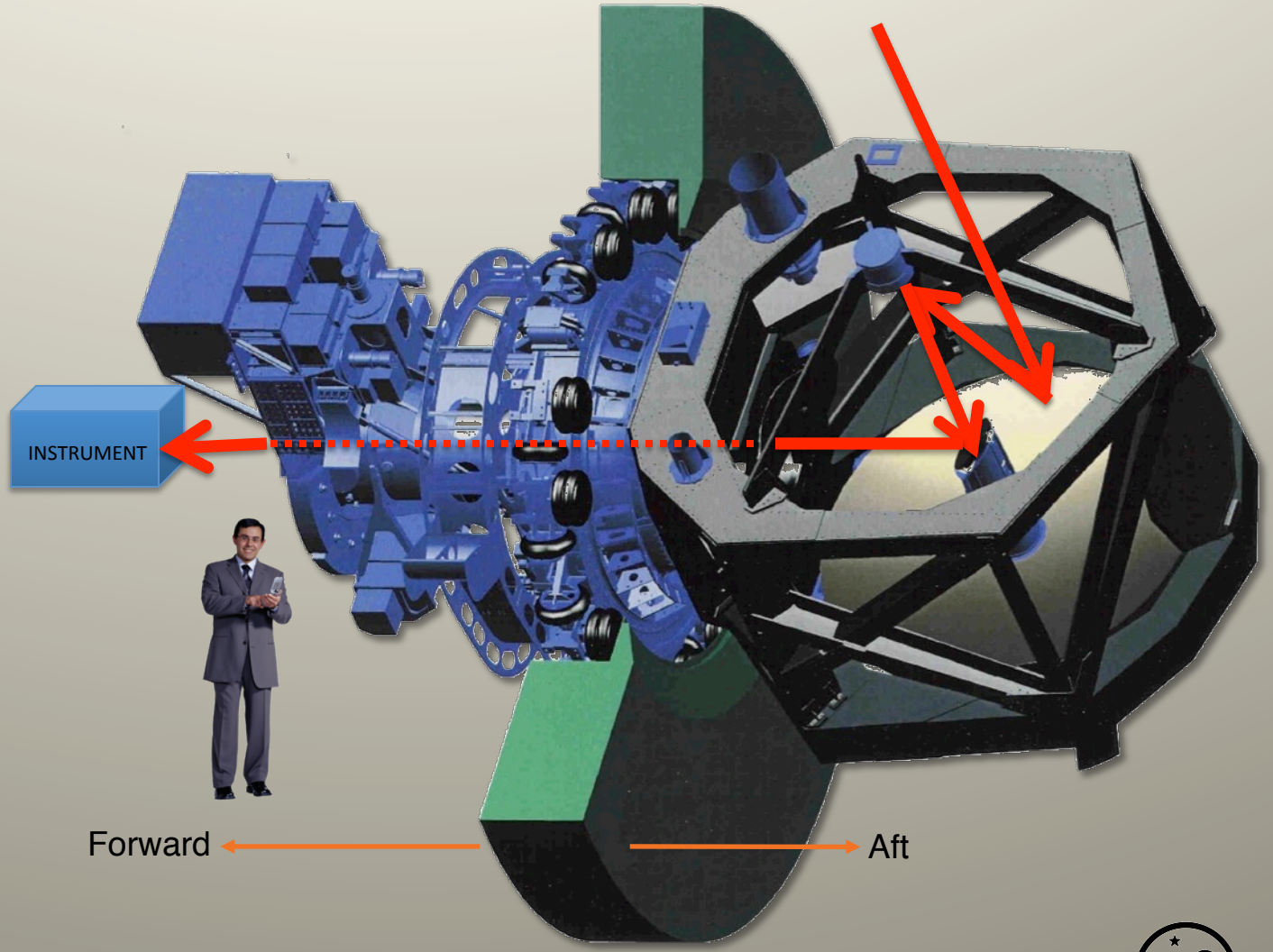
- Collaboration between NASA and DLR
- Highly modified 747-SP aircraft with a 2.7-m telescope
- Flies up to 13.7 km (45,000 feet), above 99.9% of the water vapor in the atmosphere
- Suite of infrared imagers and spectrometers
- Provides access to the infrared to the worldwide astronomical community

SOFIA Interior Layout



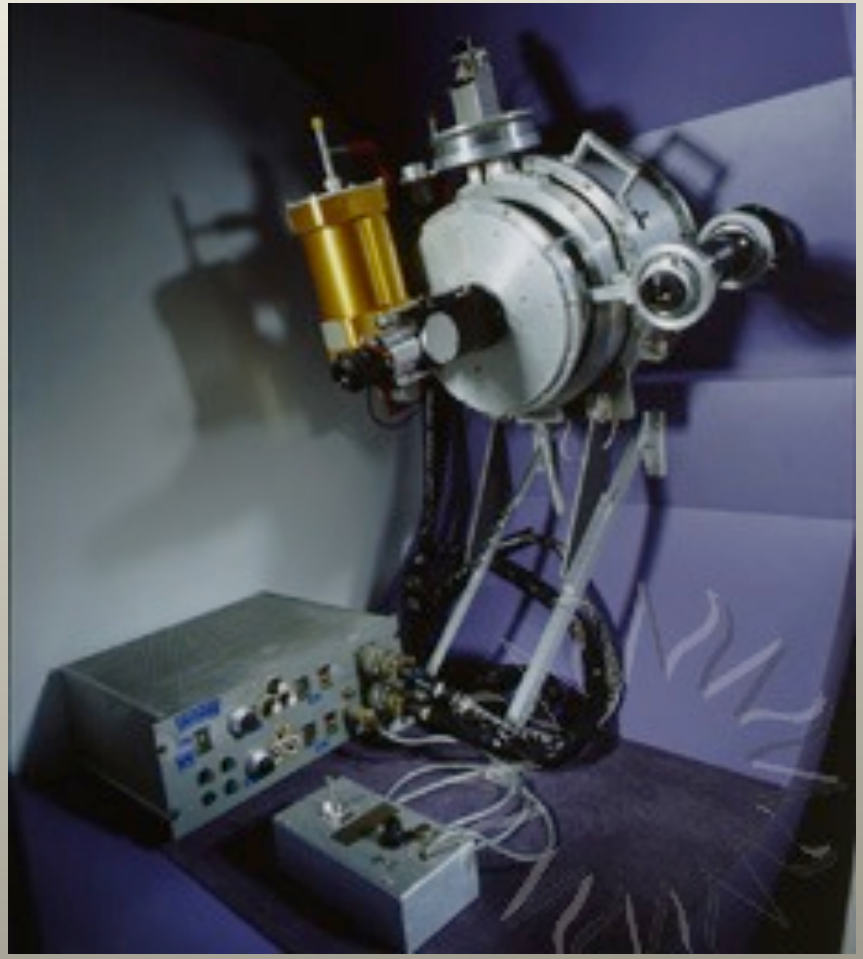
THE SOFIA TELESCOPE

- The telescope is a major contribution from Germany
- 2.7 meter diameter mirror
- Wavelength: 0.3 to 1,600 microns
- Installed weight: 17 metric tons

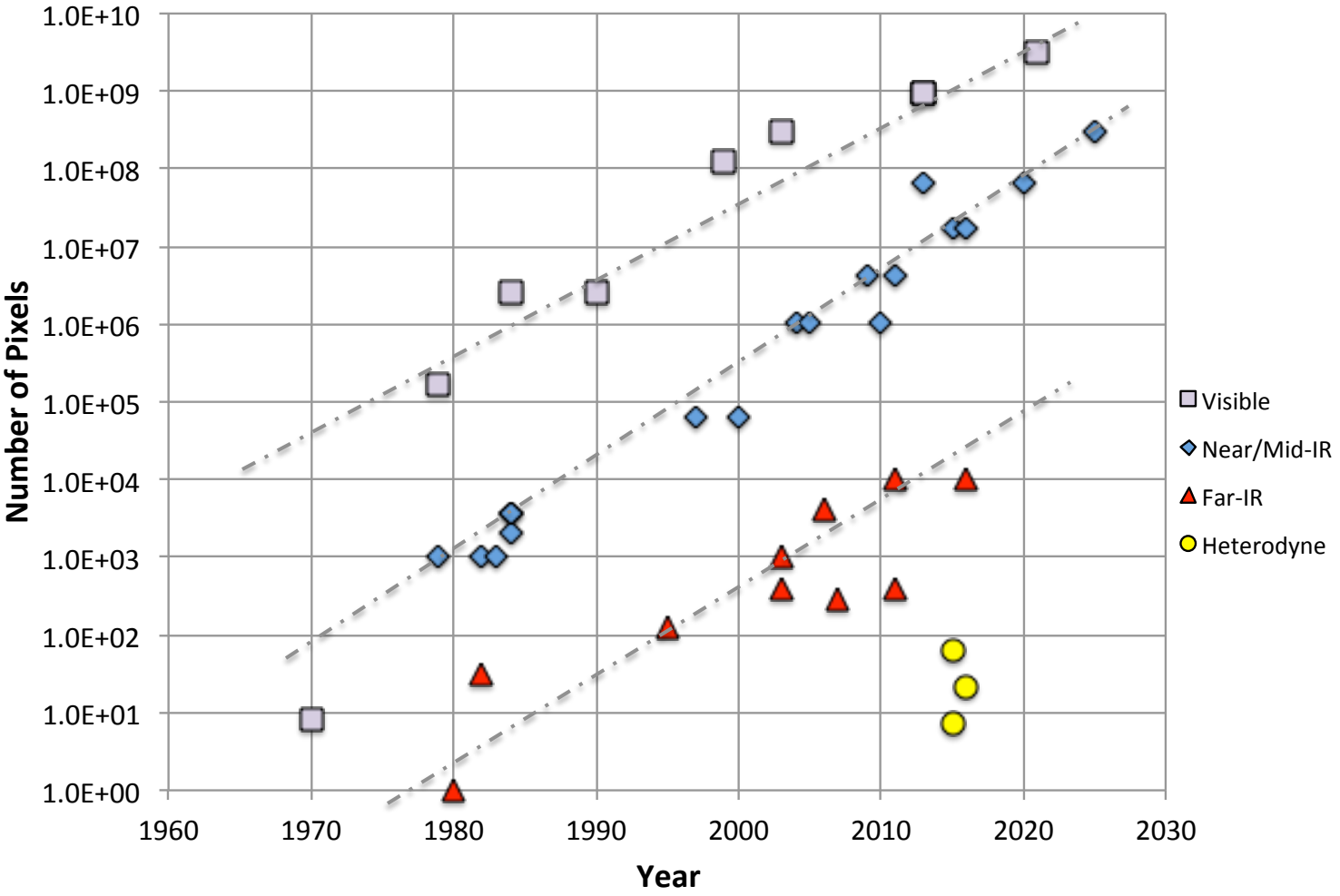


That Was Then

- Frank Low's Far-IR Photometer on Lear Jet mid-1960's
- Single-pixel germanium bolometer
- 2-Liter liquid helium cryostat

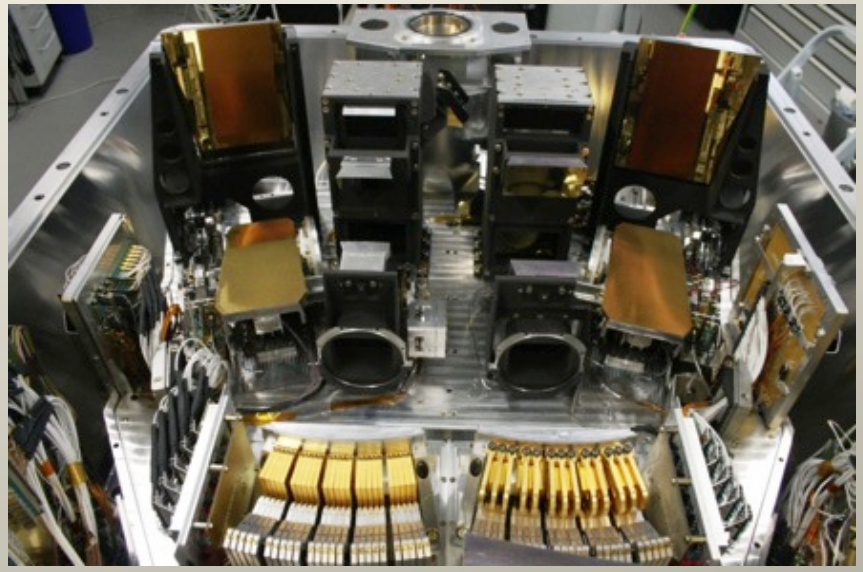


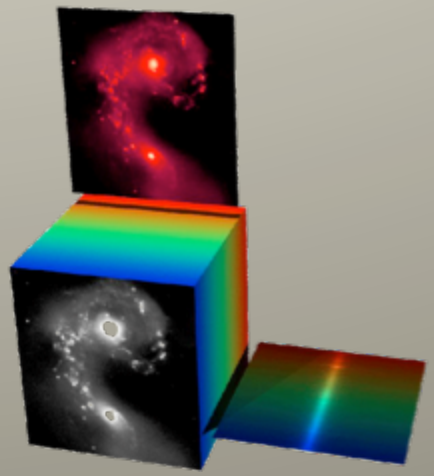
Growth in Astronomical Sensors



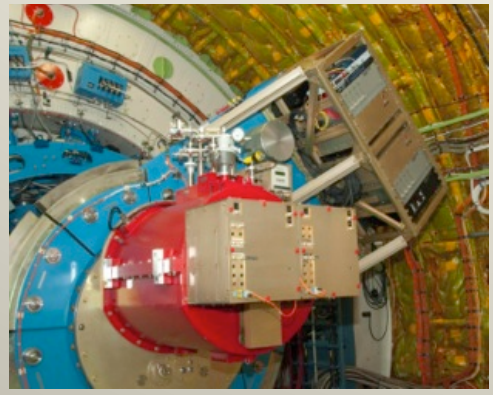
FIFI-LS

- **F**ield-**I**maging **F**ar-**I**nfrared **L**ine **S**pectrometer
- Alfred Krabbe (University of Stuttgart) PI
- Two-Channel Integral Field Spectrometer
  - 51-120 μm and 115-203 μm
    - 5x5 Spatial Pixels
    - Each pixel has 16 spectral detectors
- Resolving Power 500-2000



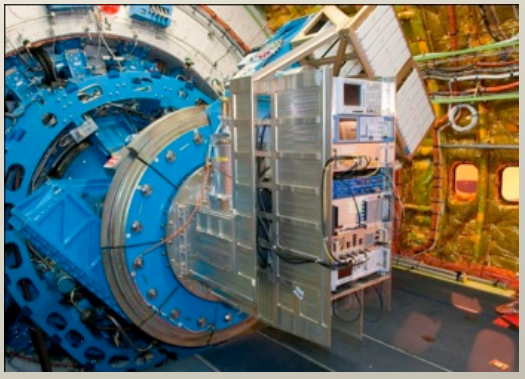


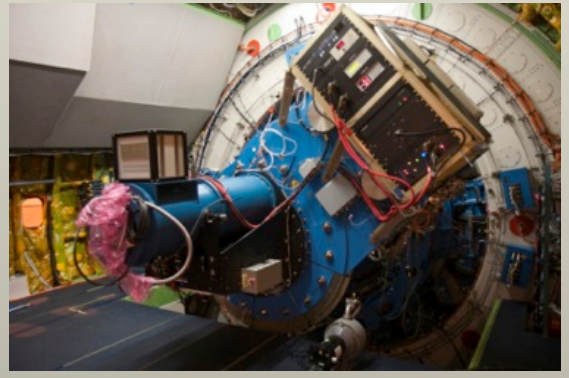
SOFIA Instrument Complement



FORCAST
Mid-IR Camera

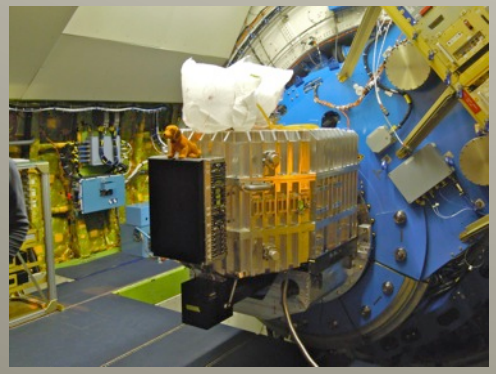
GREAT
Heterodyne spectrometer





FLITECAM
Near IR Camera

HIPO
Occultation Photometer

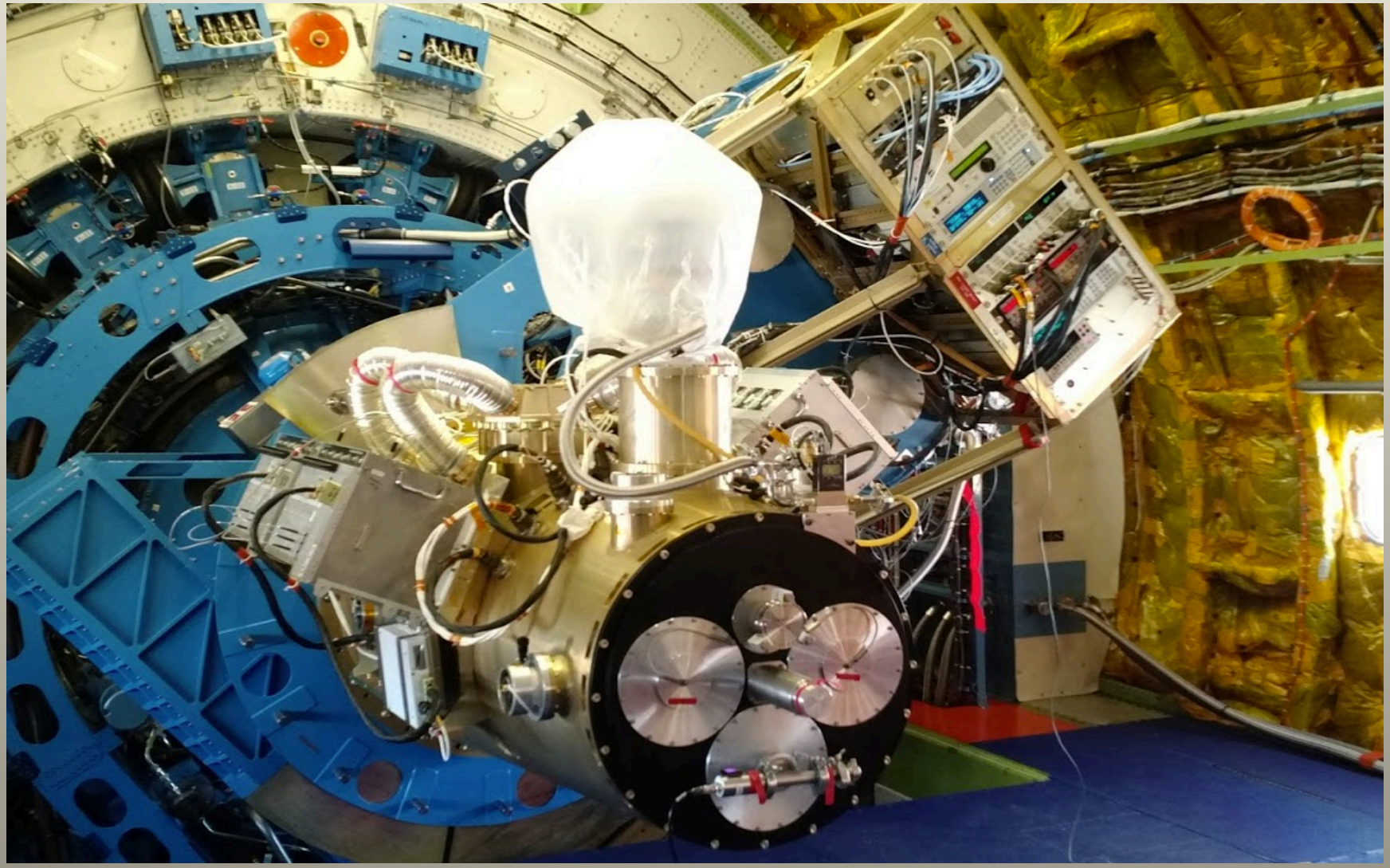


FIFI-LS
Integral Field Spectrometer

EXES
High Resolution IR Spectrometer

And coming soon: HAWC+

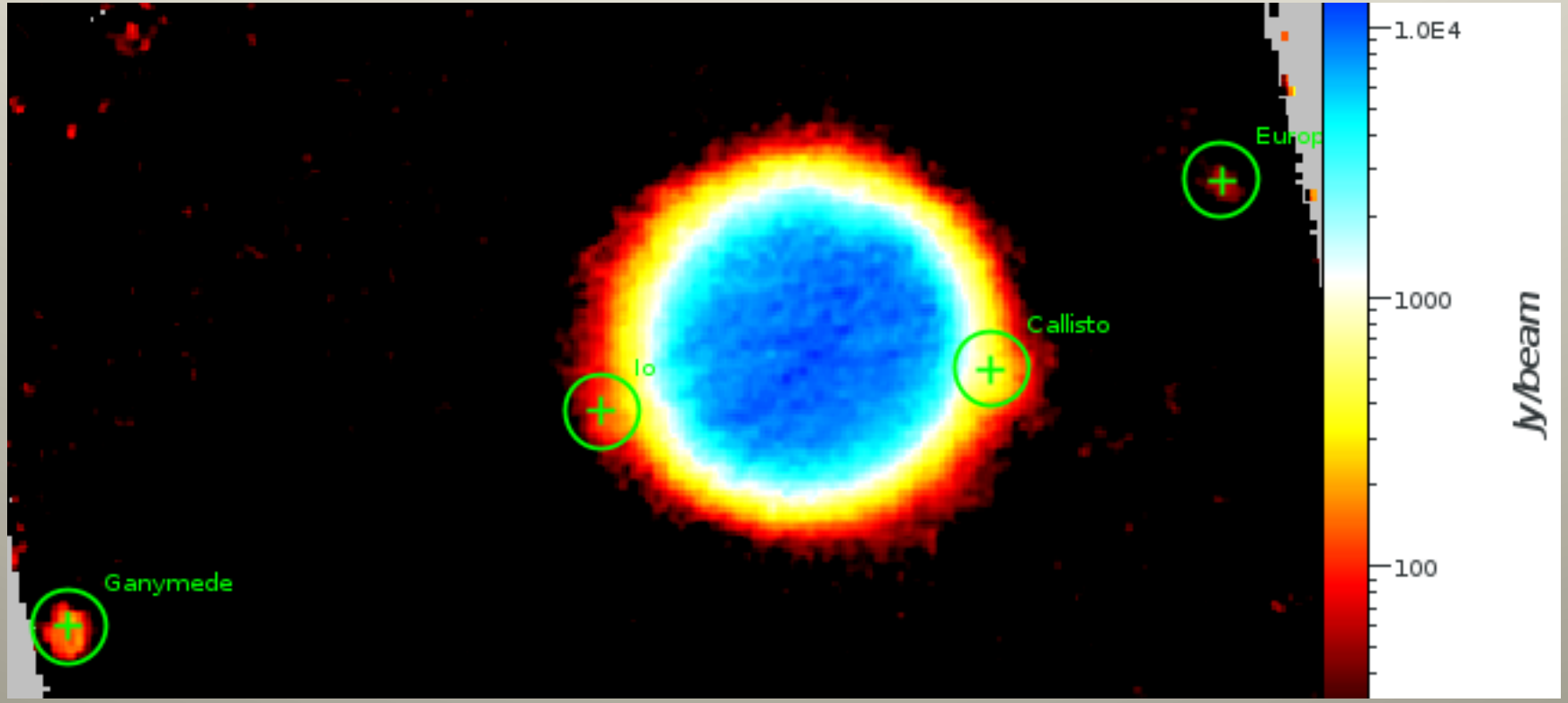
HAWC+ During Commissioning Series



USRA

DSI

HAWC+ First Light



April 27, 2016

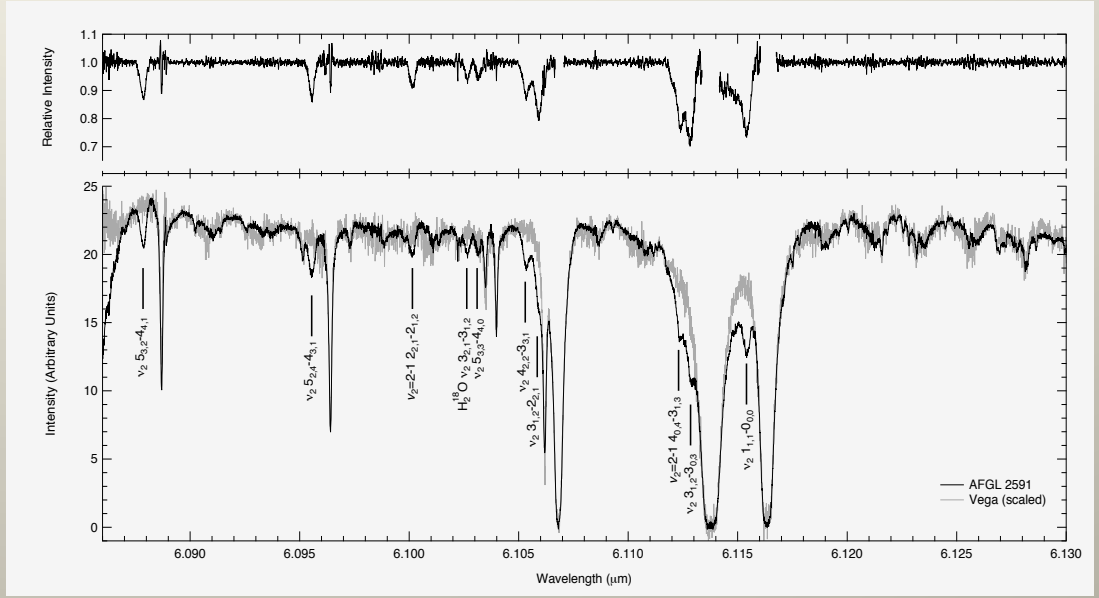
Jupiter and family at 53 μm

SOFIA Instrument Complement

Instrument	Description	Coverage
EXES (Echelon-Cross- Echelle Spectrograph)	High Resolution ($R > 10^5$) Echelle Spectrometer	5 – 28 μm
FIFI-LS (Field Imaging Far-Infrared Line Spectrometer)	Dual Channel Integral Field Grating Spectrometer	42 – 110 μm 100 – 210 μm
FLITECAM (First Light Infrared Test Experiment CAMera)	Near Infrared Imaging Grism Spectroscopy	1 – 5.5 μm
FORCAST (Faint Object infraRed CAmera for the SOFIA Telescope)	Mid-IR Dual Channel Imaging Grism Spectroscopy	5 – 25 μm 25 – 40 μm
FPI+ (Focal Plane Imager Plus)	Visible light high speed camera	360 – 1100 nm
GREAT, upGREAT (German REceiver for Astronomy at Terahertz frequencies)	High resolution ($R>10^6$) heterodyne spectrometer; multi-pixel spectrometer	1.25 – 1.52 THz 1.81 – 1.91 THz 4.74 THz
HAWC+ (High-resolution Airborne Wideband Camera-Plus)	Far-Infrared camera and polarimeter	Five ~20% bands at 53, 63, 89, 154, & 214 μm.

EXES Detects H_2O in the AFGL 2591 Star Forming Region

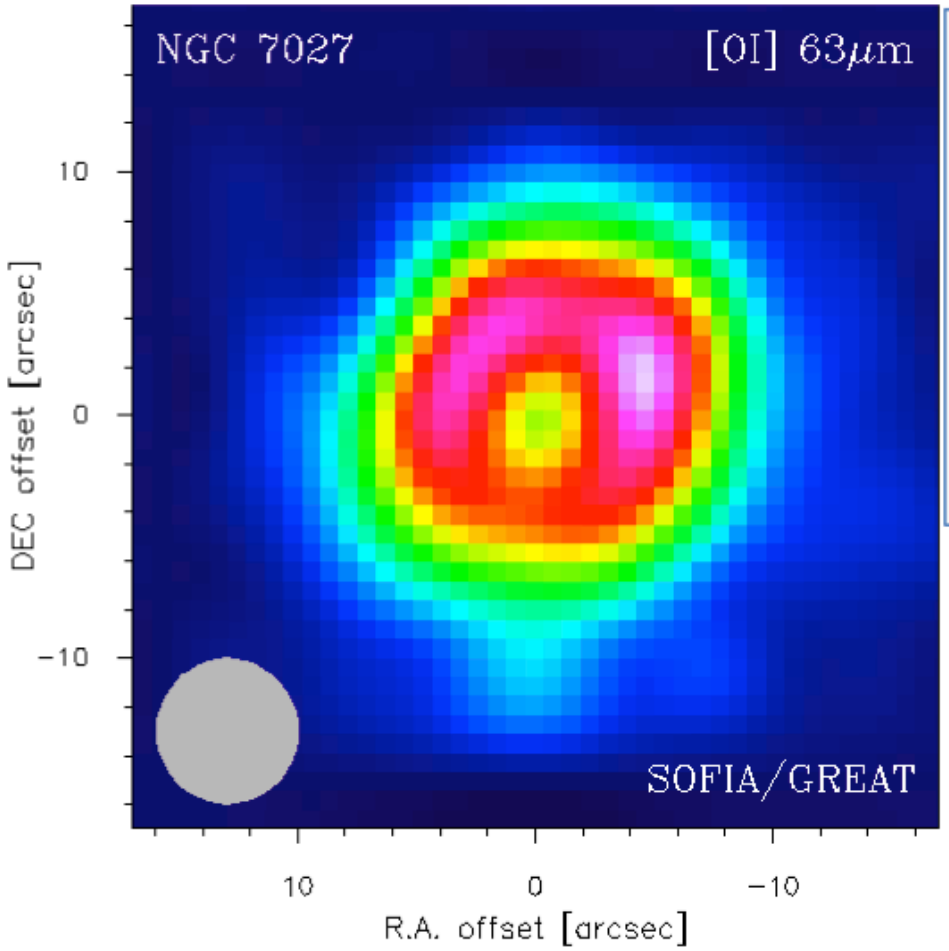
- Water is one of the key components of the interstellar medium and protostellar environments.
- Most observations of H_2O (even from space) have been of ***emission*** from excited (hot) water.
- The important and dominant low excitation levels are best observed in ***absorption*** against a background source.
- Absorption observations require high spectral resolution– uniquely provided in the mid-IR by EXES
- First spectrally resolved observations of ν_2 lines from H2O and $H_2{}^{18}O$.
- Water column density in outflow much higher than previously inferred.

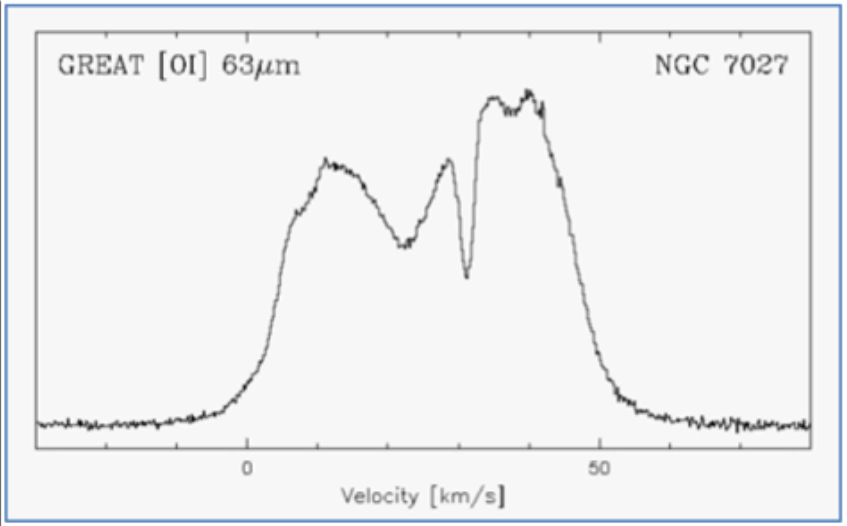


(A) Spectrum of AFGL 2591 divided by standard star spectrum showing residual water in disk of young star.
(B) Spectra of young star AFGL 2591 and standard star Vega. Most of the deep absorptions are due to H_2O in the Earth's atmosphere, but blue-shifted H_2O is present in the young star spectrum.

Indriolo et al. (2015)

GREAT 4.7 THz First Light



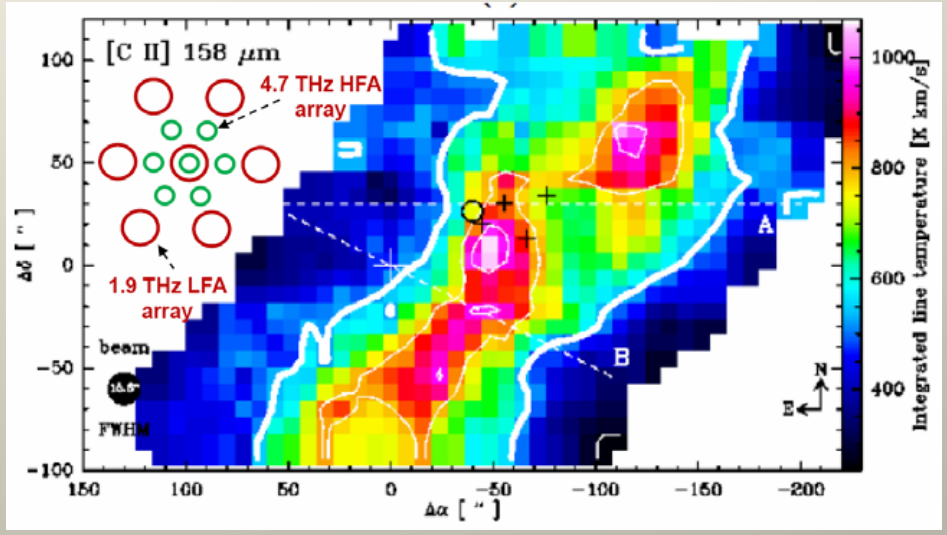


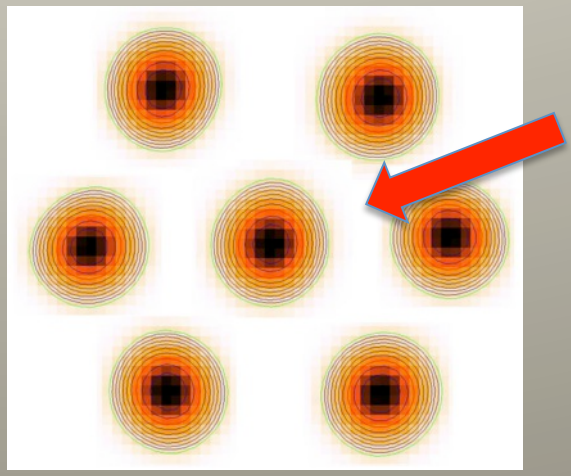
Velocity resolved observations allow study of gas dynamics in objects.

(Rolf Güsten & the GREAT Team)

SOFIA is a Platform for New Technology: upGREAT

- upGREAT an enhancement of the GREAT heterodyne instrument developed by Rolf Güsten and collaborators.
- The instrument was commissioned in May 2015
- Compact heterodyne arrays
  - 7 pixels x 2 polarizations @ 1.9 THz
  - 7 pixels @ 4.7 THz [O I] (ready in 2016)
- Maps ***more than an order of magnitude faster*** than the previous instrument

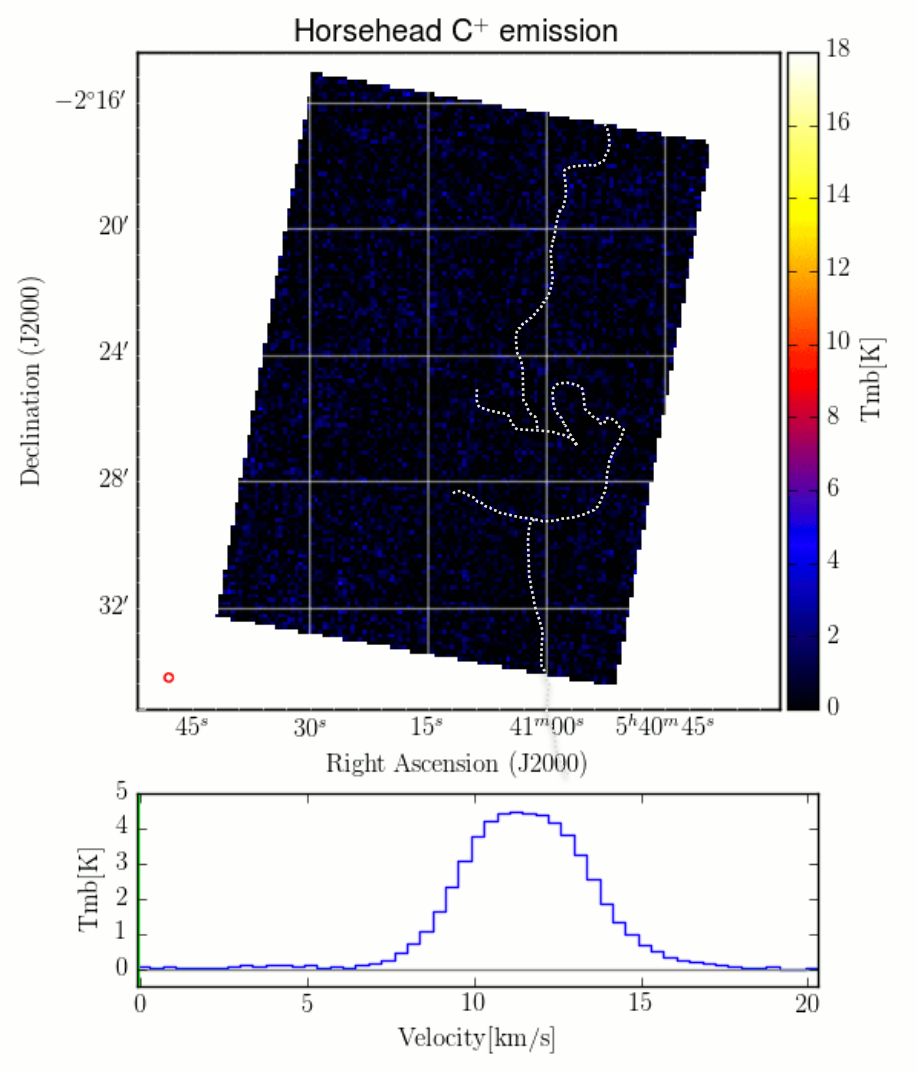




What was one beam on the sky is now seven beams

Measured upGREAT beam profiles

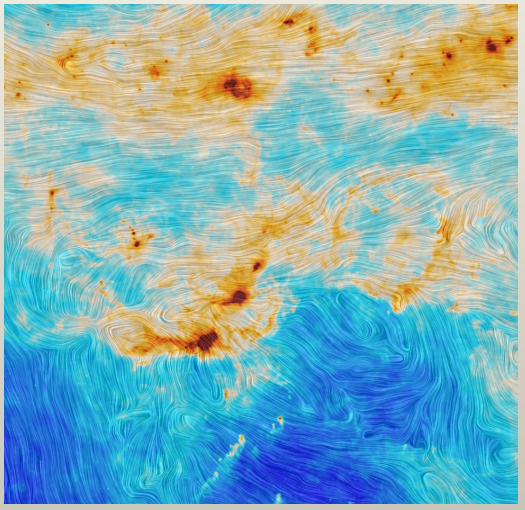
DDT Demonstration Observation upGREAT [C II] Map



Averaged line profile over mapped region. Smoothed to 0.76 km/s velocity resolution

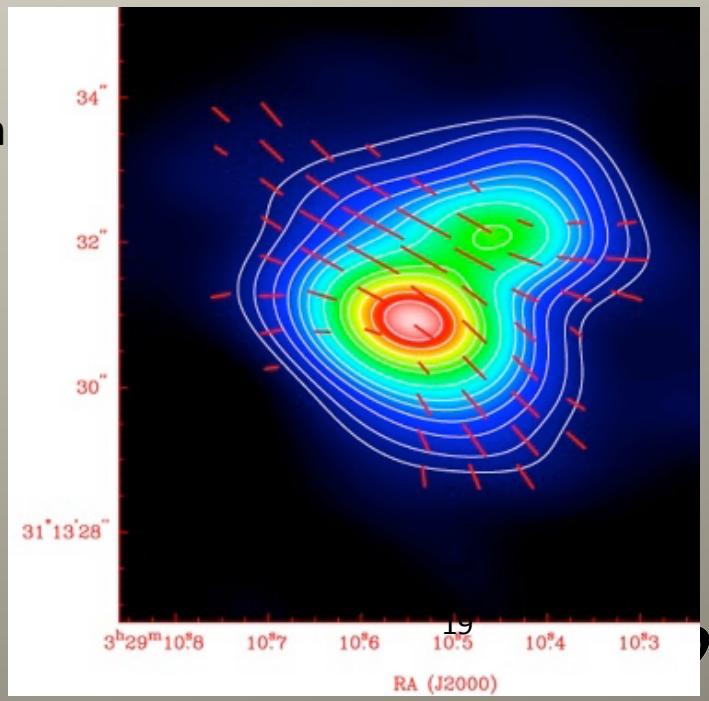
HAWC+ Will Enable Magnetic Field Studies at Key Angular Scales

HAWC+ Bridges the angular scale between PLANCK and interferometers such as SMA and ALMA



Magnetic field map of Orion molecular cloud overlaid on dust emission

Planck Collaboration
Marc-Antoine Miville-Deschênes



Magnetic Field vectors in NGC1333 IRAS 4A observed with the Submillimeter Array overlaid on dust emission

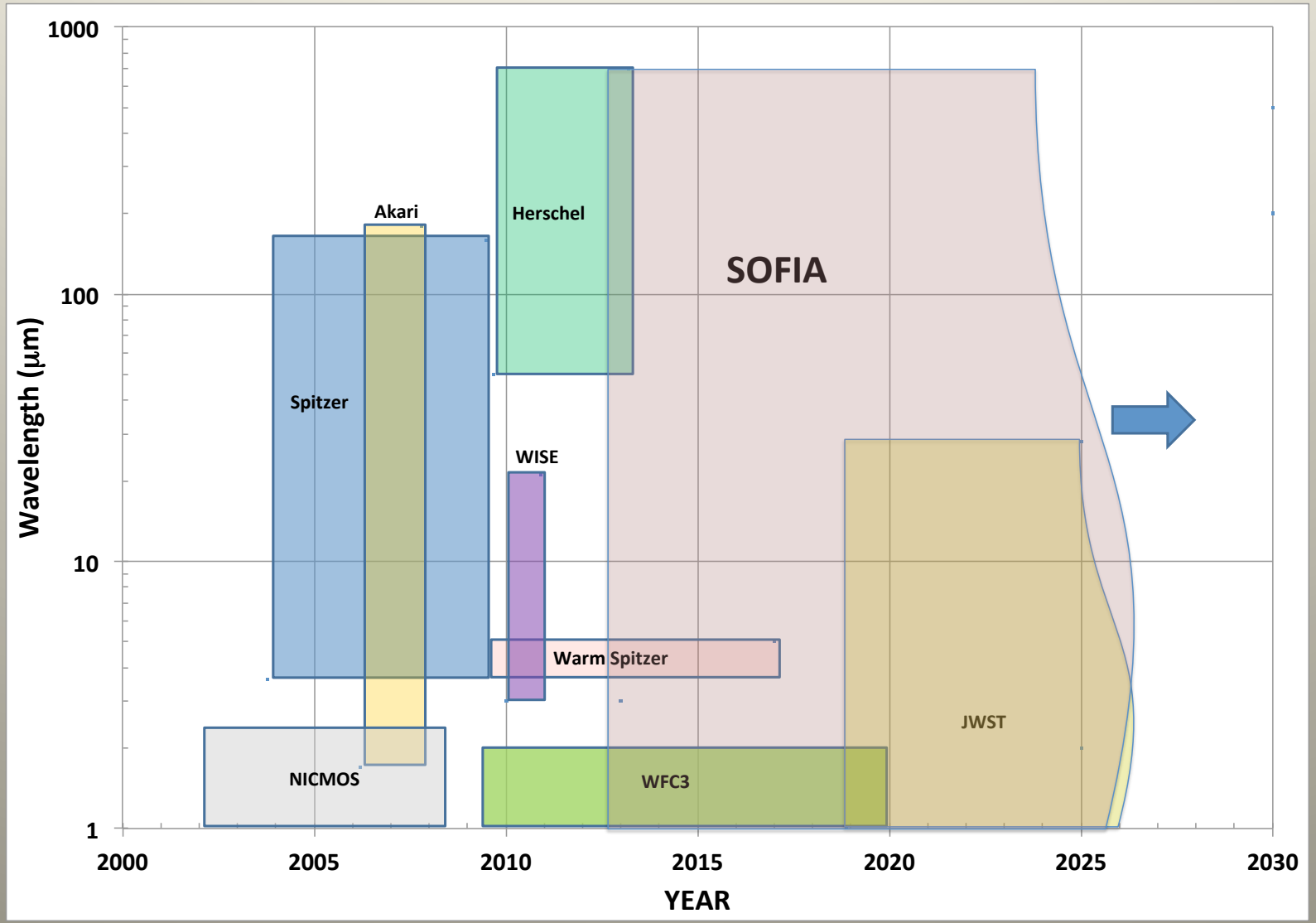
Girart 2006

Key SOFIA Capabilities

- Mid- and Far-Infrared Imaging
- Mid and Far-Infrared Spectroscopy
- Velocity-resolved Heterodyne Spectroscopy
- Polarimetry

- Long potential lifetime

Infrared Mission Coverage



Summary

- SOFIA is a 2.7-m aperture airborne telescope that provides the world astronomical community with access to wavelengths obscured by water vapor, particularly in the infrared and sub-millimeter
- SOFIA has a wide array of scientific instruments with imaging and spectroscopic capabilities
- SOFIA is able to deploy to distant locations, particularly the Southern Hemisphere as required by the science
- SOFIA is operational and producing important science in a many astronomical areas.

https://www.sofia.usra.edu