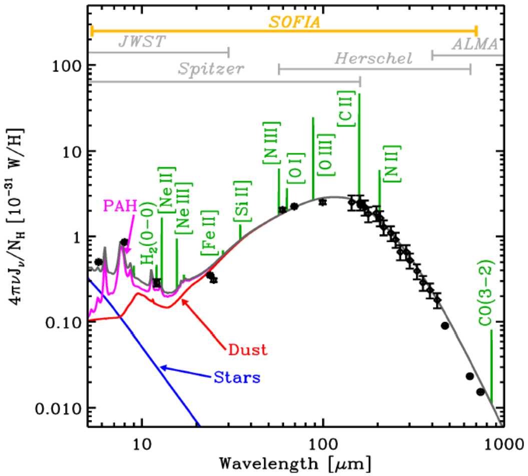
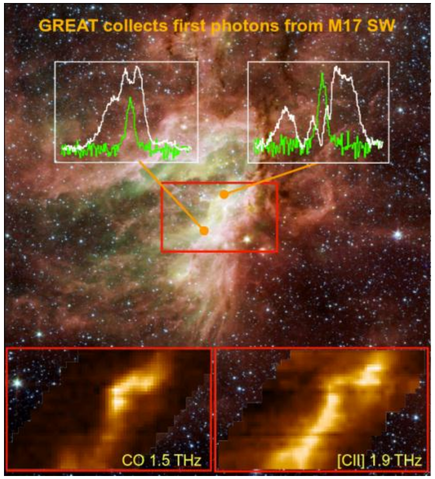
Molecular Spectroscopy with the Stratospheric Observatory for Infrared Astronomy (SOFIA)





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Outline

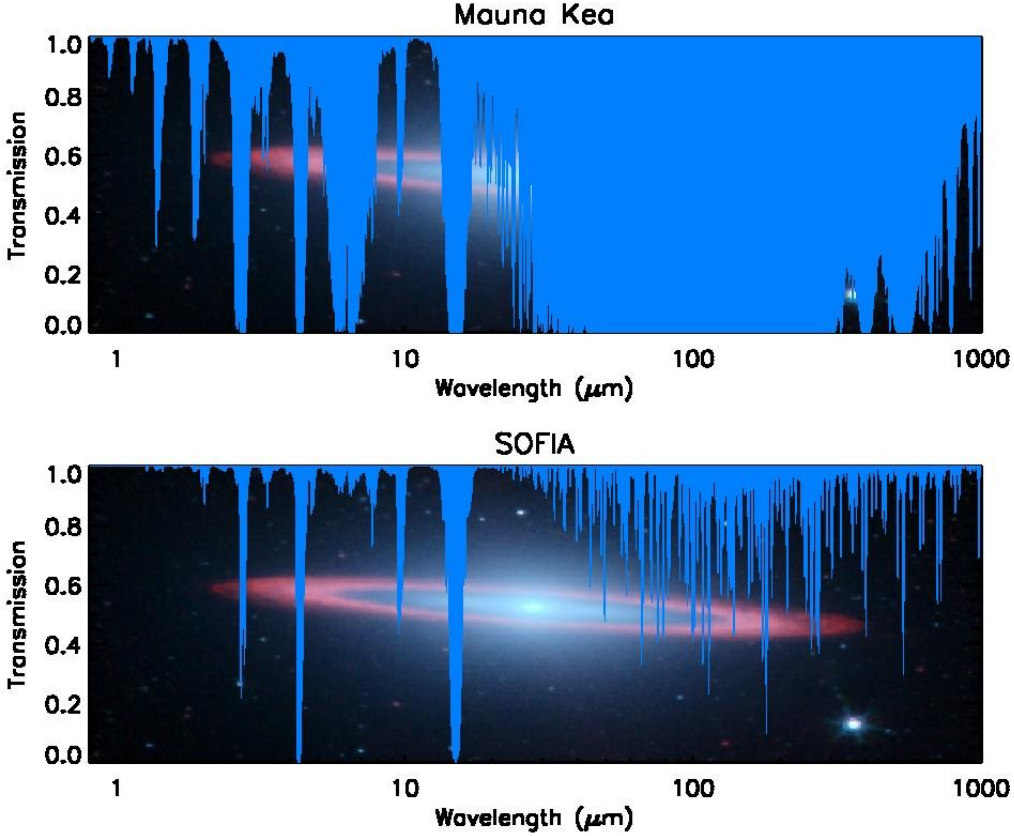
- *SOFIA Facility Overview*
- *How SOFIA Studies the Chemical Evolution of the Universe*
- *Molecular Spectroscopy with SOFIA*
- *Early Molecular Spectroscopy Results with SOFIA*
- *Future Molecular Spectroscopy with SOFIA*
- *Summary*

SOFIA Overview

- *2.5 m telescope in a modified Boeing 747SP aircraft*
  - *Imaging and spectroscopy from 0.3 μm to 1.6 mm*
- *Operational Altitude*
  - *Up to 45,000 feet (12 to 14 km); above > 99.8% of obscuring water vapor*
- *Joint Program between the US (80%) and Germany (20%)*
  - *20 year design lifetime –can respond to changing technology*
  - *Science at NASA-Ames; Flights at NASA 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*

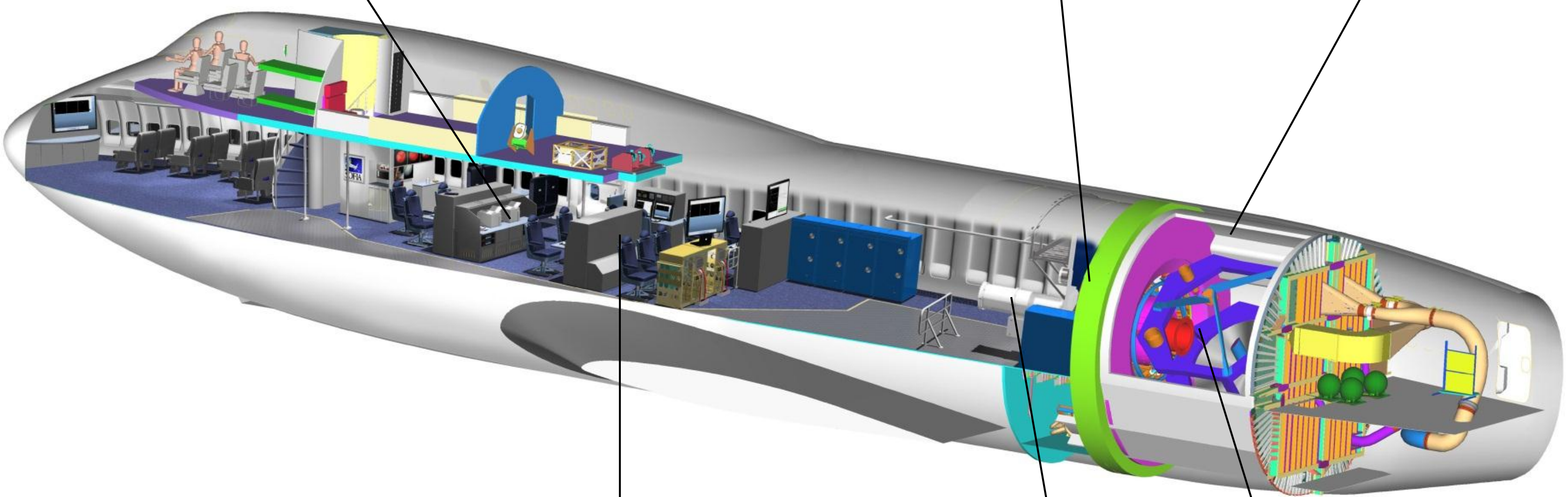


The SOFIA Observatory

open cavity (door not shown)

Educators work station

pressure bulkhead



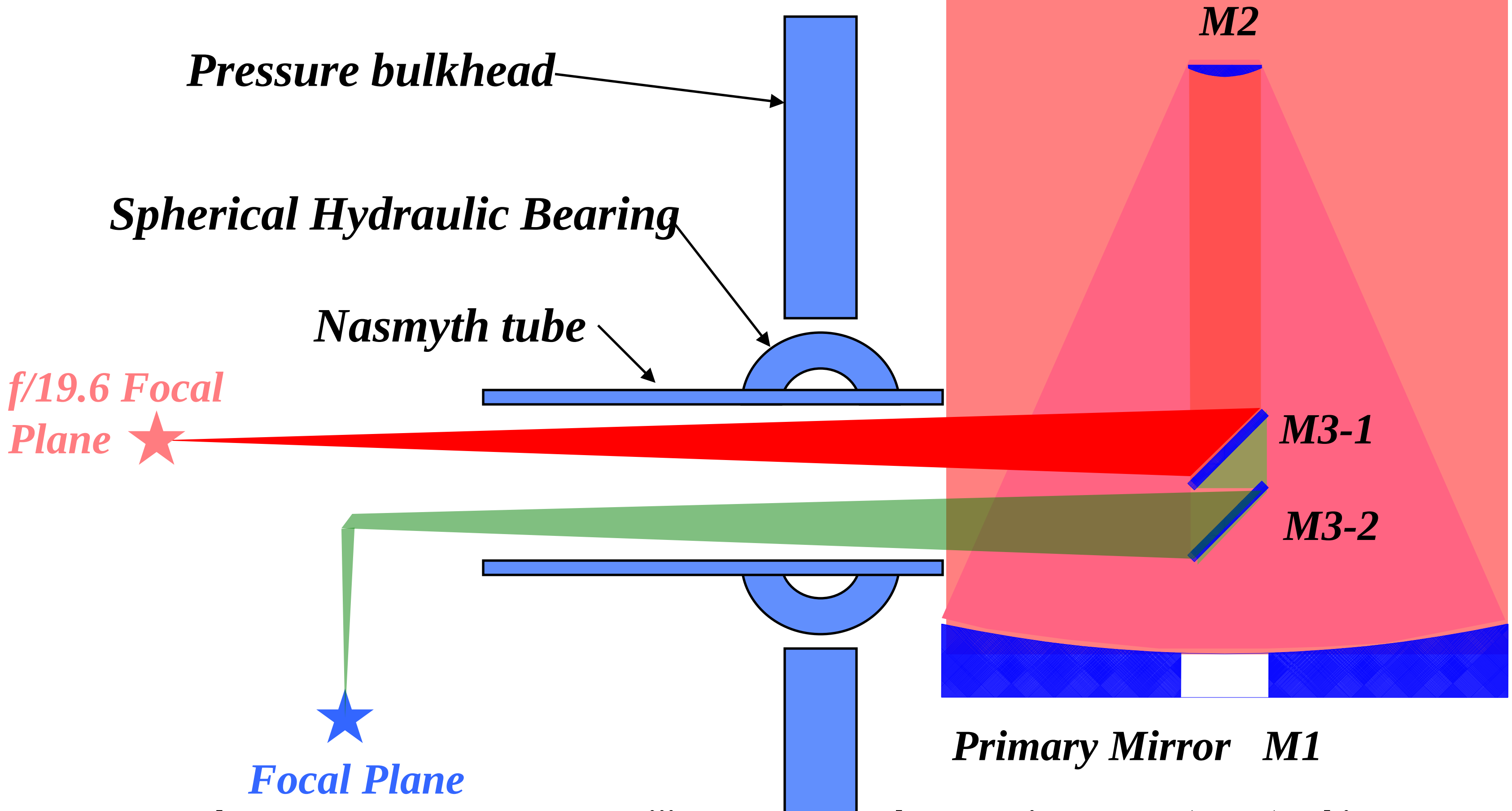
scientist stations, telescope and instrument control, etc.

TELESCOPE

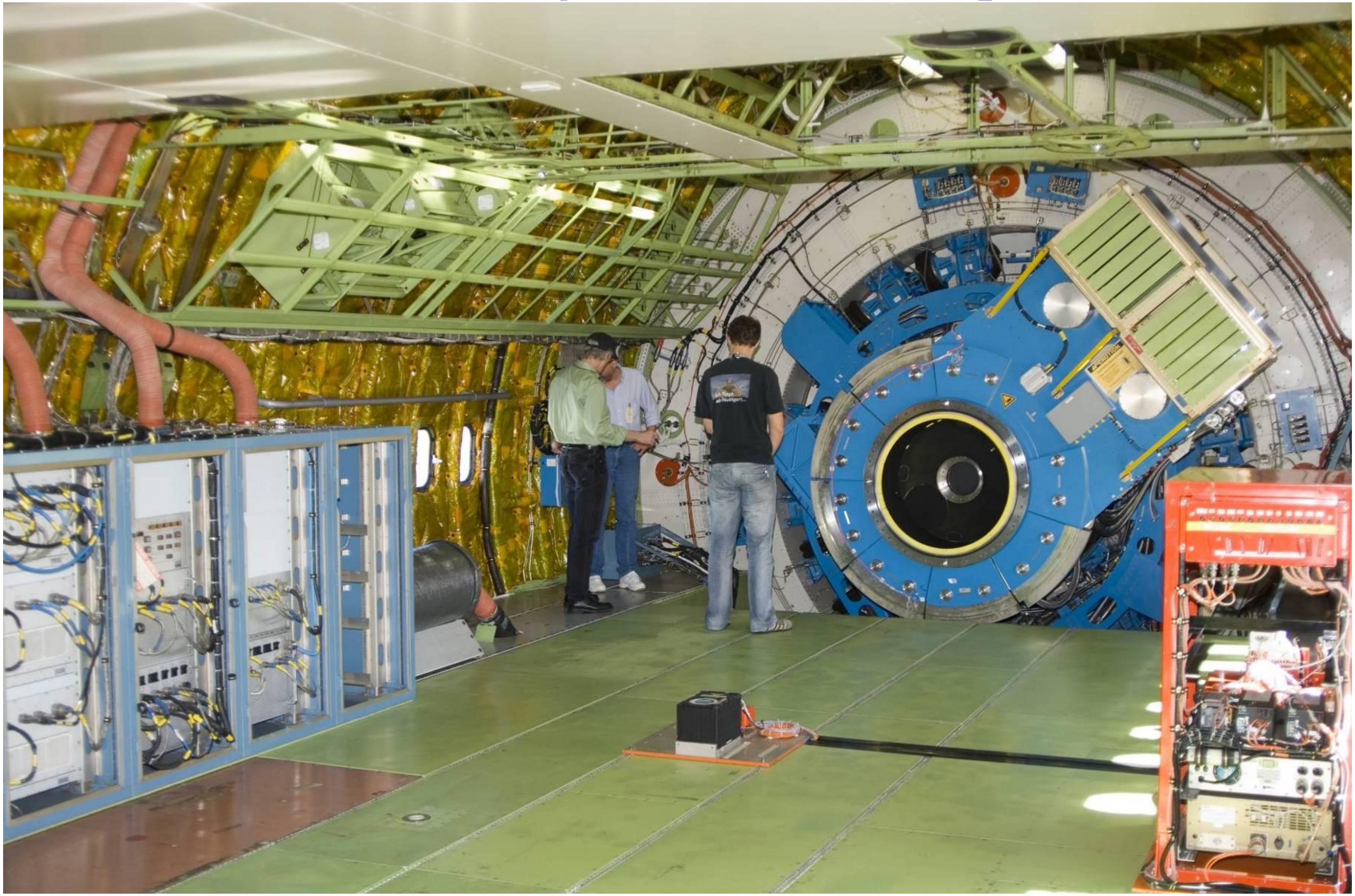
scientific instrument

Nasmyth: Optical Layout

Observers in pressurized cabin have ready access to the focal plane



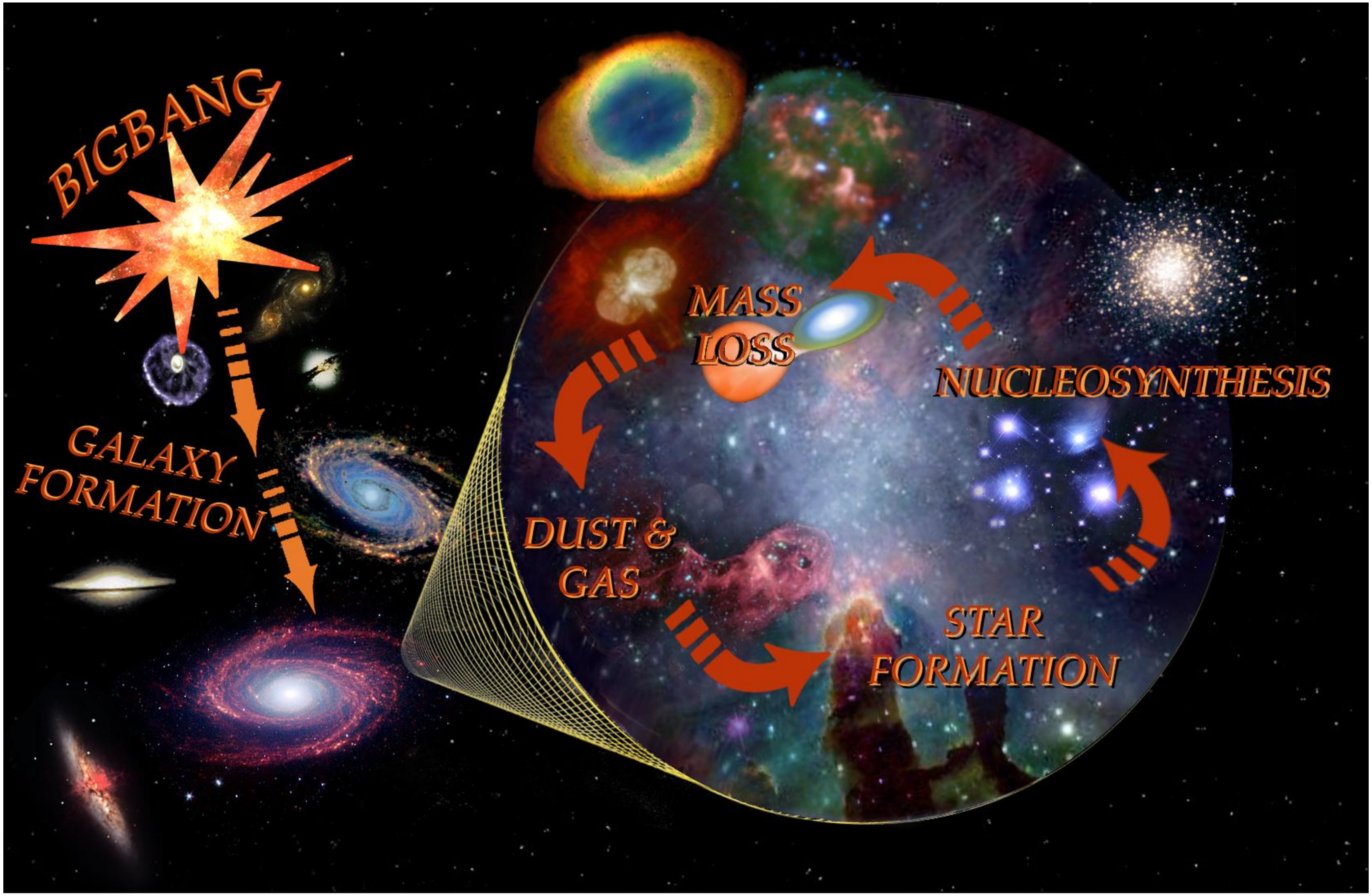
Back End of the SOFIA Telescope



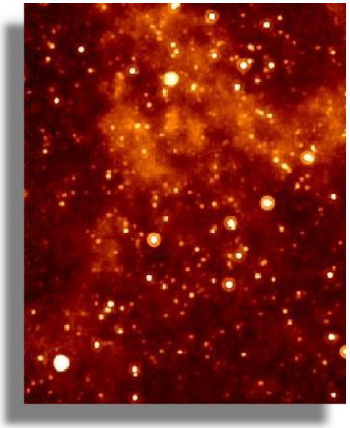
SOFIA Airborne with Door Open!

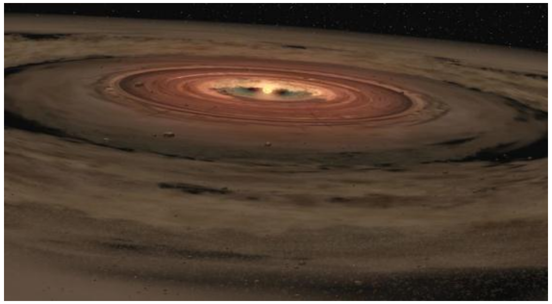
NASA's Stratospheric Observatory for Infrared Astronomy 747SP on Dec. 18, 2009. (NASA Photo / Carla Thomas)

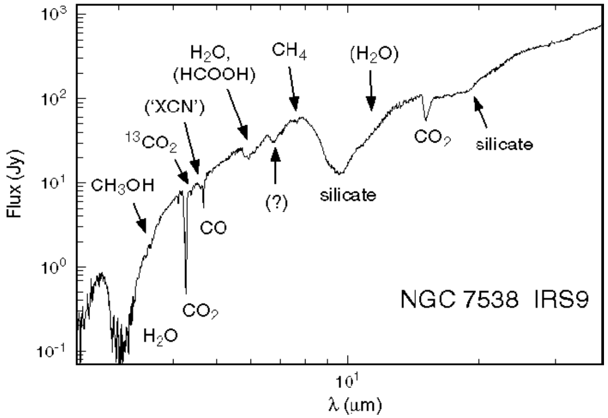
SOFIA Studies the Chemical Evolution of the Universe



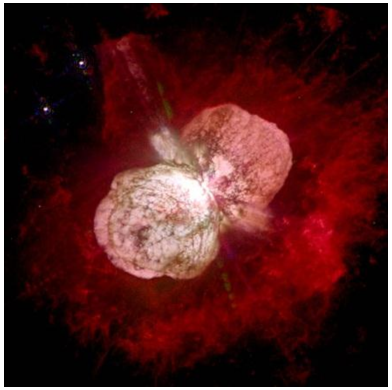
Studying the Physics and Chemistry of Stellar Evolution with SOFIA

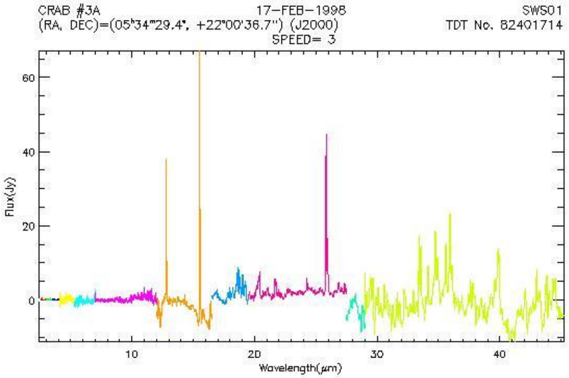






Gas and molecules in the formation of stars, planets, and life





Gas and molecules in the winds and remnants of evolved and dying stars

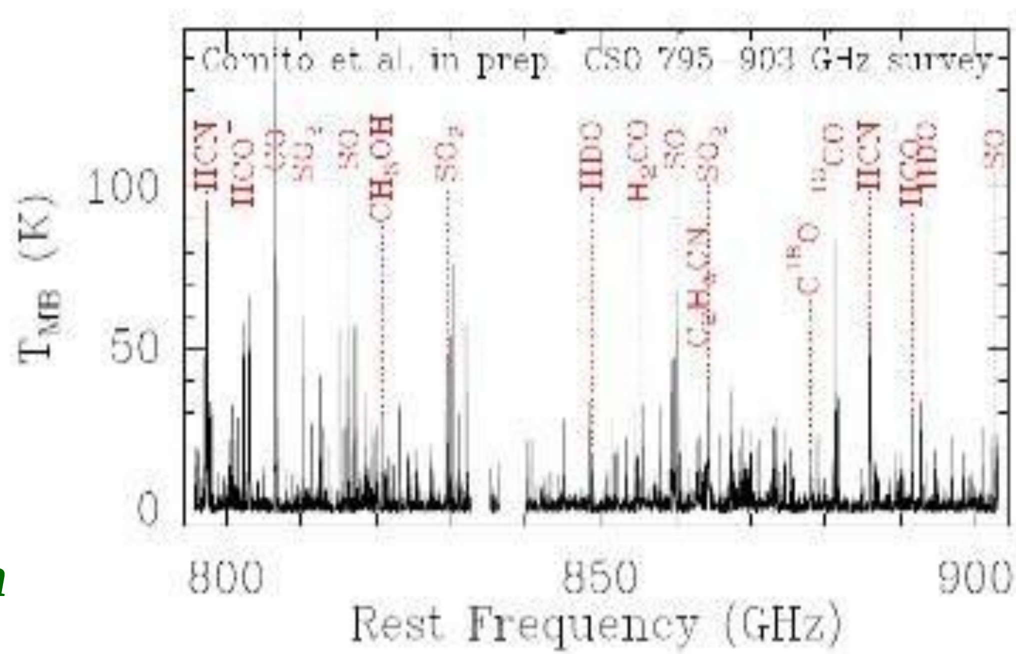
AnalytiX-2012, March 24, 2012, Beijing International Convention Center (BICC), China

R. D. Gehrz

Astrochemistry with SOFIA

SOFIA is an excellent observatory for studying chemistry in space

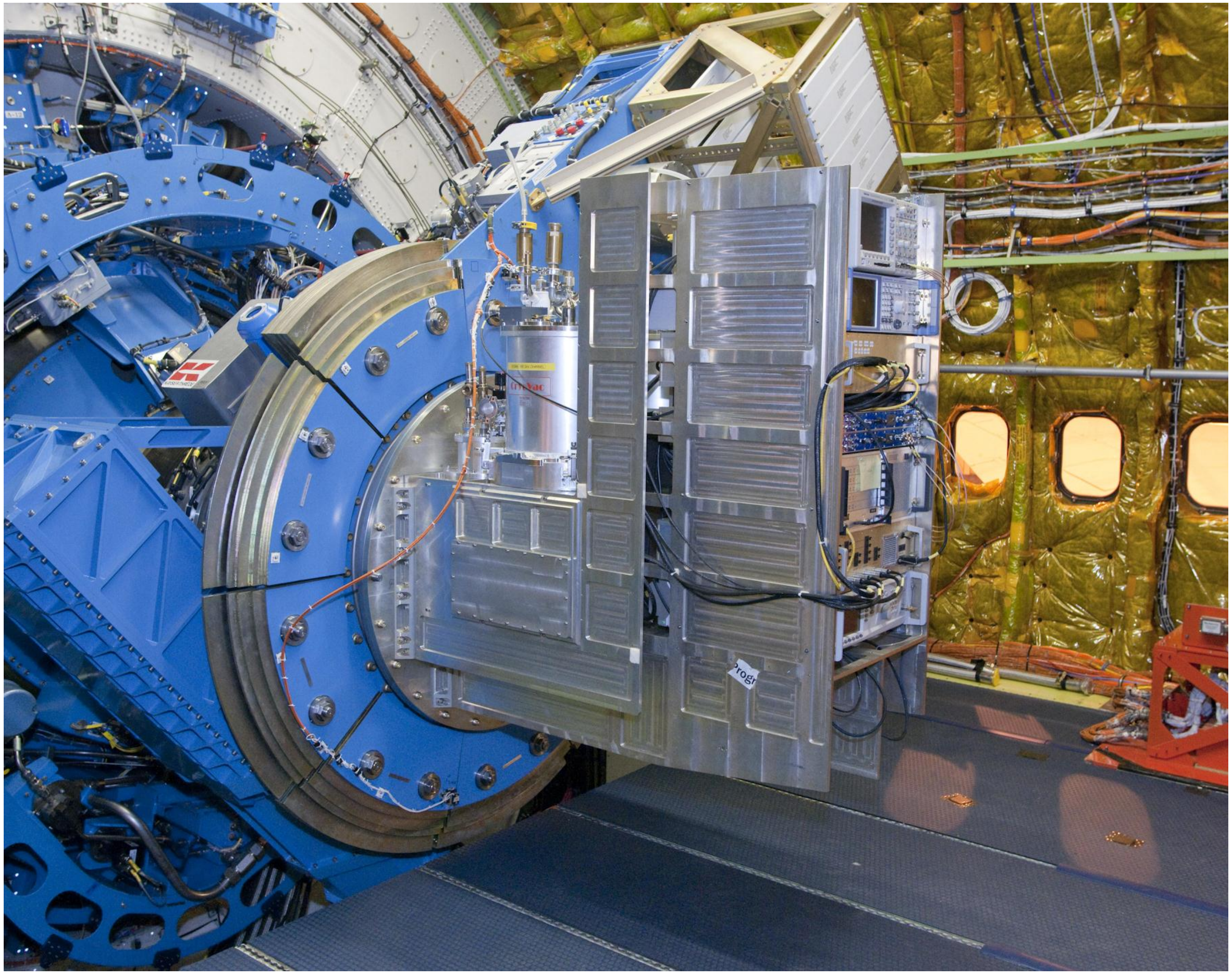
- *Many ground state molecular lines in the IR and sub-mm*
- *Light molecules like H_2, HD, H_2O, and other hydrides have lines at these wavelengths*
- *The fullerene (C_{60}) has 4 IR lines in SOFIA's bands*
- *SOFIA has the necessary high spectral resolution over this spectral region*



Science with the German REceiver for Astronomy at Terahertz frequencies (GREAT)

- PI: R. Güsten, Max-Planck Institut, Bonn (guesten@mpifr-bonn.mpg.de)
- Detector: dual channel hot-electron bolometer (HEB):
  - 1.25 - 1.50 THz (240 - 200 μm)
  - 1.82 - 1.92 THz (165 - 155 μm)
  - 2.50 - 2.70 THz (120 - 110 μm)
- Single pixel, $R = \lambda/\Delta\lambda \sim 10^6$ to 10^8
- Science: Spectroscopy of CII (158 μm), HD (112 μm) , and OI (63 μm), light molecules

GREAT on the SOFIA Telescope



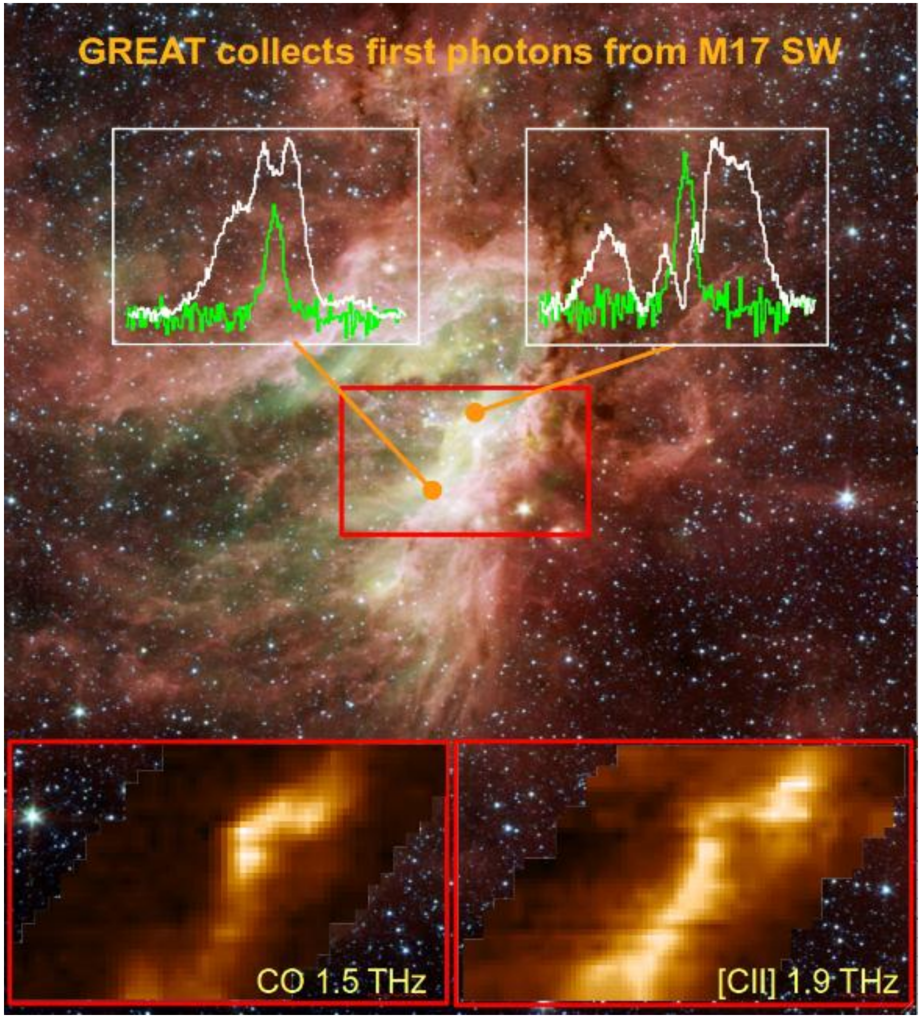
Recent Spectroscopic Observations with GREAT on SOFIA

A Case Study of Star Formation: M17SW

NASA/JPL-Caltech/Spitzer image

- *Molecular cloud contains 10^4 $M_\odot$ of gas*
- *Cloud is illuminated by a young star cluster with a luminosity of more than 10^6 $L_\odot$*
- *Radiation from the cluster ionizes and compresses the gas*
- *GREAT spectroscopy can reveal both the radiative compression that might trigger star formation and the heating that will disperse some regions of the cloud*
- *GREAT spectra can therefore predict the future of star formation activity in the molecular cloud*

First Science with GREAT (White CII, Green CO)



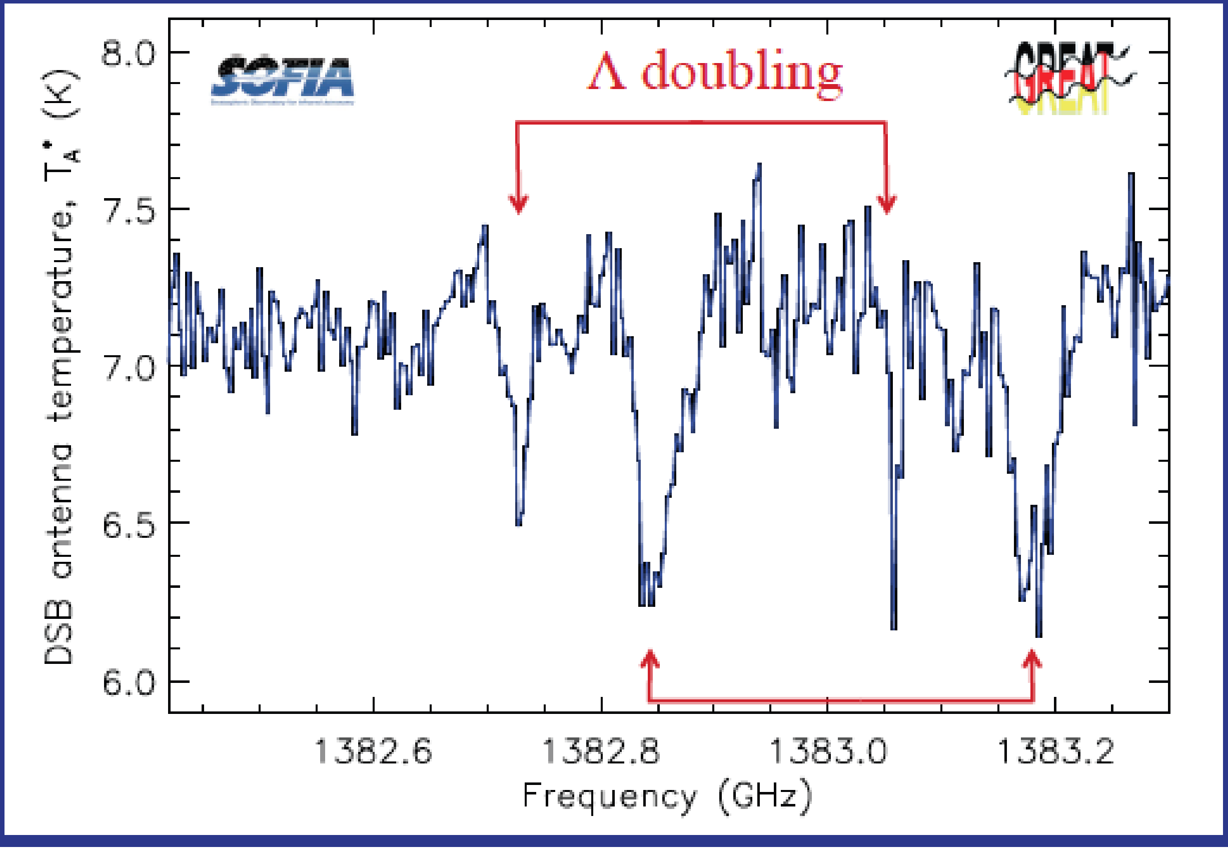
Spectra and spectral maps: GREAT Team/NASA/DLR/USRA/DSI; Background IR image: NASA/JPL-Caltech/Spitzer

- ***CII traces the ionization front of the Photo-dissociation Region (PDR)***
- ***High J CO emission is from compressed molecular gas where triggered star formation is occuring***

Discovery of SH (Mercapto radicals) in Interstellar Space by Neufeld et al.

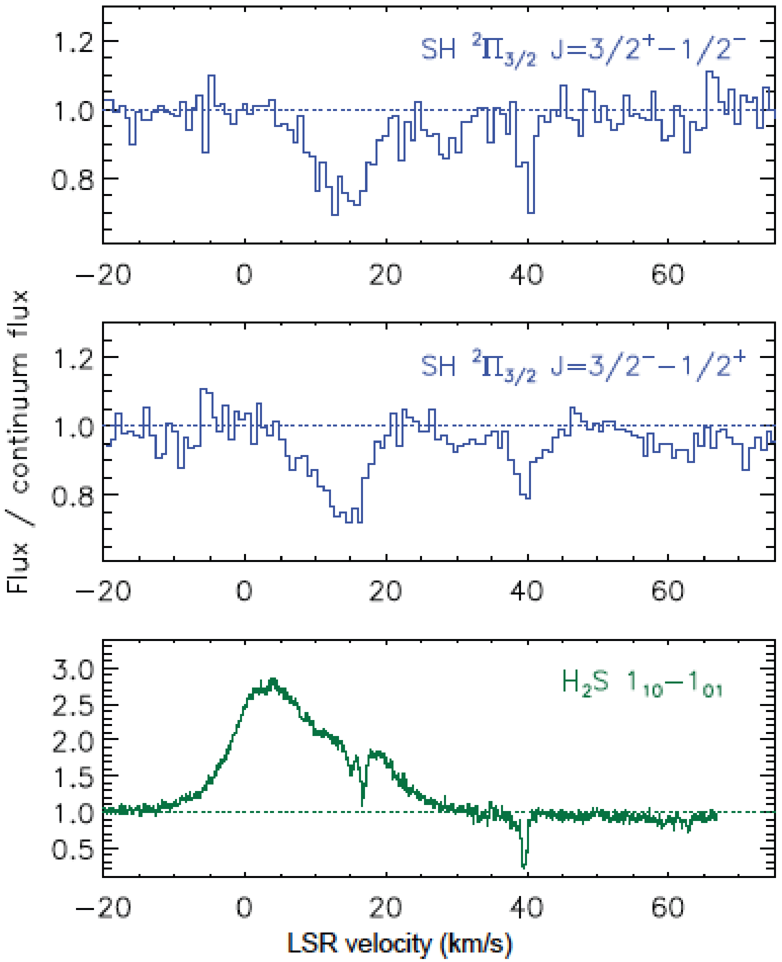
- *SH is one of the simplest Hydrides not yet detected in the ISM*
- *Its ground state rotation line at 1.383 THz (217 microns) shows Lambda-type doubling (nuclear rotation-electron spin interaction), so it is easy to identify*
- *W49N intersects several molecular clouds in it own and another spiral arm that cause absorption of the continuum.*

Mercapto radicals were clearly detected in absorption toward W49N



SH

with H_2S from the IRAM 30m



- ***The implied diffuse cloud abundance ratio, $SH/H_2 \sim 10^{-8}$, suggests the presence of gas temperatures ~1000K***

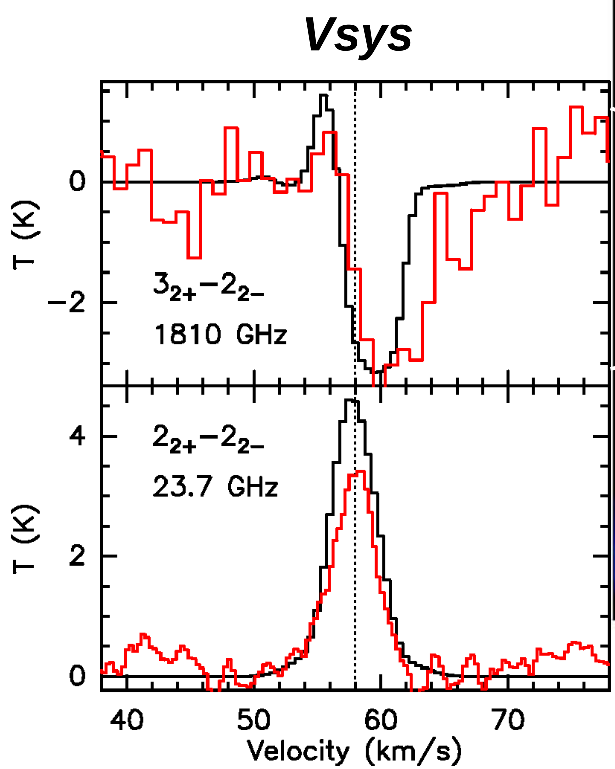
Other GREAT Results

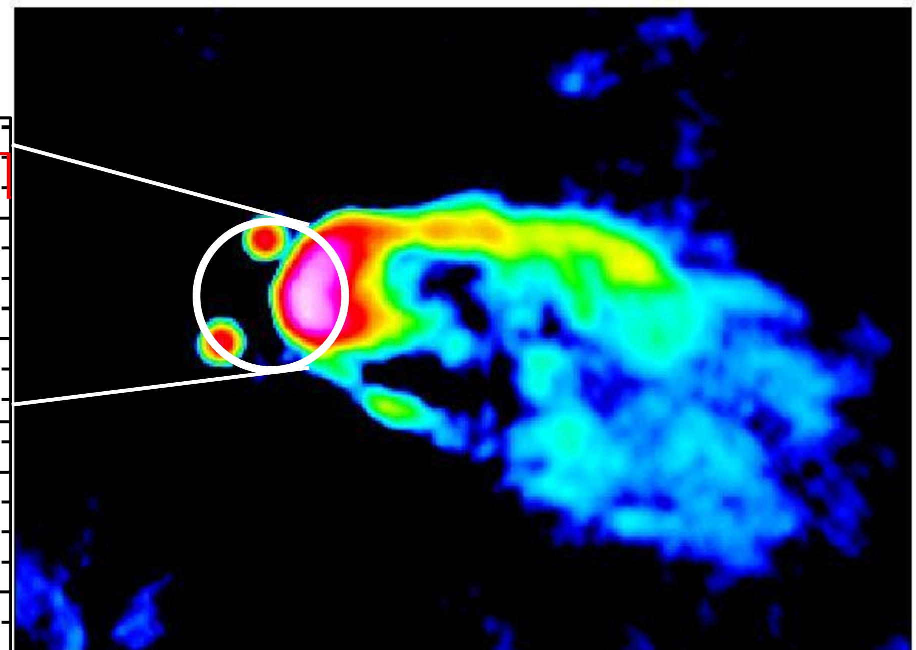
- ***In-fall of Material in a Star-forming Cloud by Wyrowski et al.***
- ***First Detection of OD in the Interstellar Medium (ISM) by Parise et al.***

GREAT Science Results: probing infall

Probing in-fall in a protostellar cloud with ammonia absorption against dust continuum

- ***UCHIIR G34.3: red-shifted ammonia (NH_3) absorption detected***
- ***modeled with in-falling envelope***

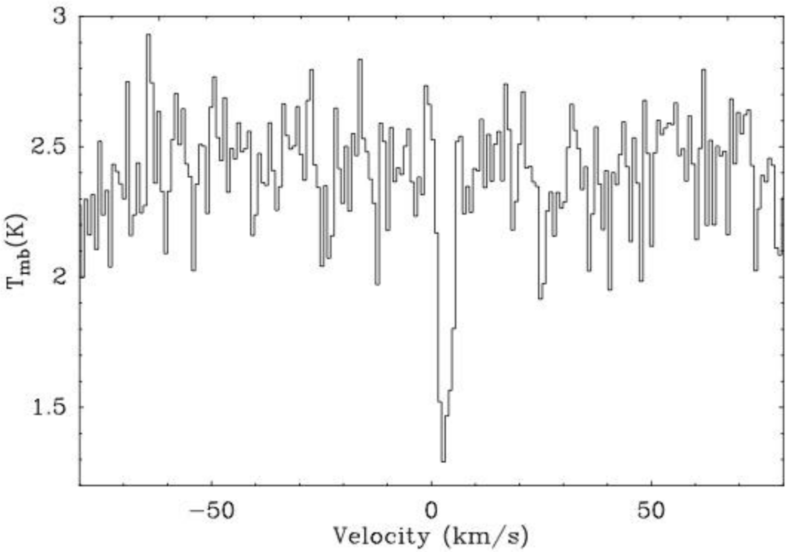




G34.26+0.15 VLA 3.6cm

Detection of OD towards the low-mass protostar IRAS16293

- *Detection of the OD ground state line at 1.39 THz in absorption towards the line-of-sight of a low-mass protostar.*
- *First detection of OD outside of the solar system.*



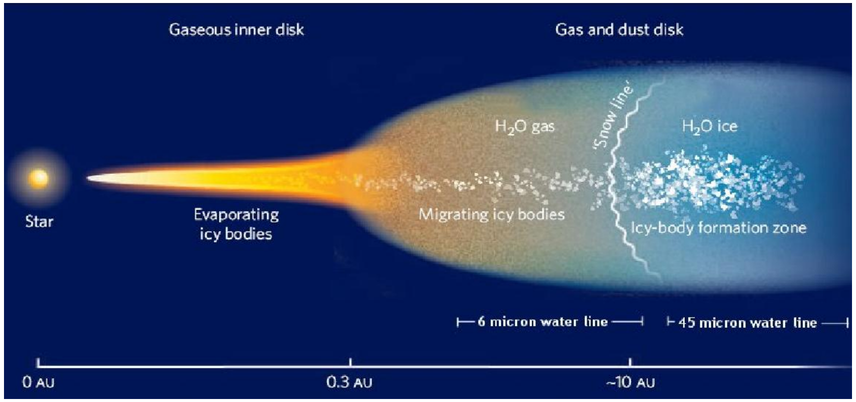
High OD abundance suggests a higher than predicted OH fractionation

B. Parise - AAS SOFIA Splinter 09.01.2012

Future Spectroscopic Science with SOFIA

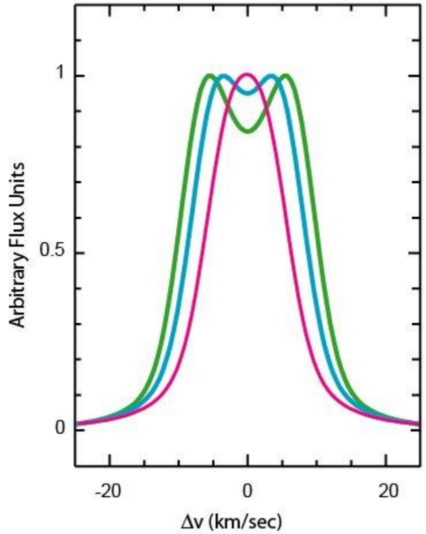
The chemistry of disks with radius and Age

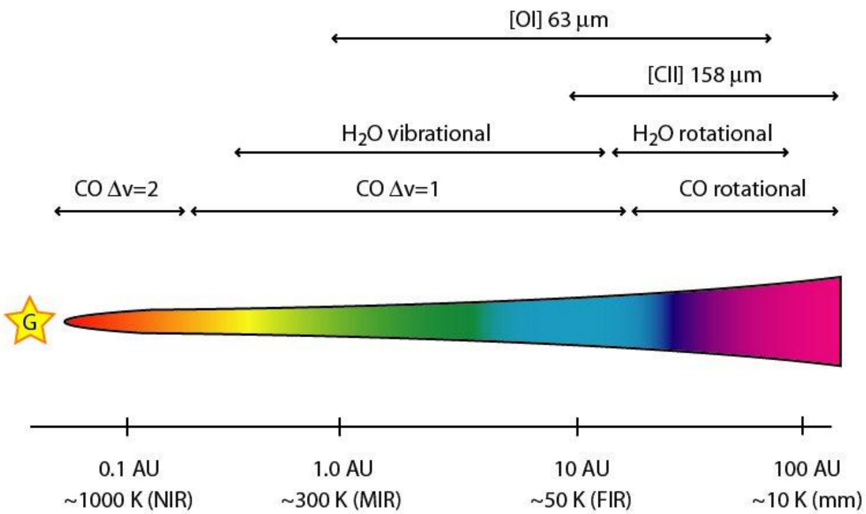
- High spatial and spectral resolution can determine where different species reside in the disk



- small radii produce double-peaked, wider lines.

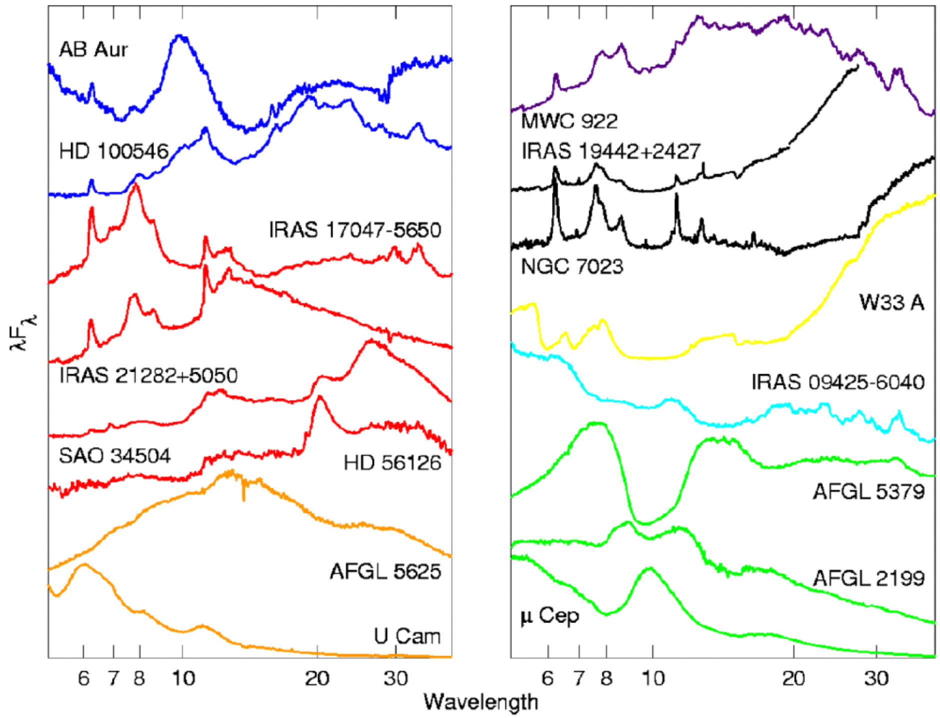
- Observing many disks at different ages will trace disk chemical evolution





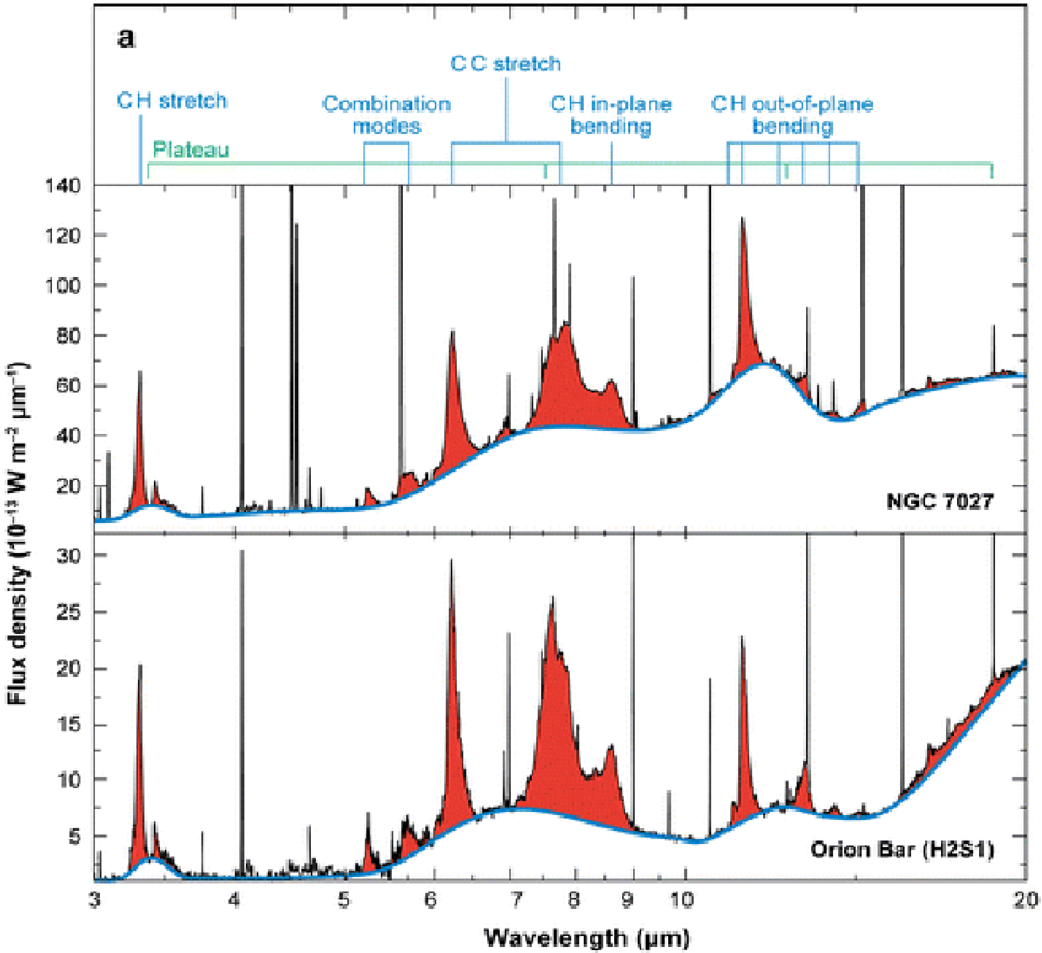
SOFIA Will Study the Diversity of Stardust

Herbig AeBe
Post-AGB and PNe
Mixed chemistry post-AGB
C-rich AGB
O-rich AGB
Mixed chemistry AGB
Deeply embedded YSO
HII region refection nebulae



- *ISO SWS Spectra: stardust is spectrally diverse in the regime covered by SOFIA*
- *Studies of stardust mineralogy*
- *Evaluation of stardust contributions from various stellar populations*
- *Implications for the lifecycle of gas and dust in galaxies*

Thermal Emission from PAH Rich Objects



Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)

- ***A key question is whether portions of the aromatic population of PAHs are converted to species of biological significance***
- ***Far-IR spectroscopy can constrain the size and shape of PAH molecules and clusters.***
- ***The lowest lying vibrational modes ("drumhead" modes) will be observed by SOFIA's spectrometers***

SUMMARY

- *Early molecular spectroscopy with GREAT on SOFIA is producing interesting results.*

- *SOFIA will be a premier facility for far-IR and submillimeter spectroscopy for many years*

Our Web site is *http://www.sofia.usra.edu/*

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