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The SOFIA Science Vision

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Outline

- Why we need a new Science Vision
- Overview of the Science Themes
- Key Science Identified in the Science Vision
- How to use the Science Vision and Summary

Why the Need for New Science Vision?

- We have decided to look at and update our SOFIA Science Case in the post Spitzer, contemporary Herschel era.
- We were looking for a small set of potential SOFIA projects:
  - Immediately recognizable as answering, or instrumental in answering, very important outstanding astrophysics questions
  - Not a list of everything SOFIA could do, but instead a short list of key science investigations
  - The SOFIA data are essential – not just supplementary

Science Vision Working Group

- Co-chaired by Tom Roellig and Eric Becklin
- Meet weekly at ARC with USRA and NASA scientists to coordinate efforts starting in Feb 2008.
- Identified four organizational science themes and selected chairs for each of these themes. Also selected Co-Chairs within the ARC SOFIA Science team.
- Panel chairs were responsible for identifying the rest of their panel.
- In all there were was an international team of over 40 scientists that contributed to the New Science Vision document.

Products

- A concise, clearly written, well documented and potentially peer reviewed Science Vision publication, not more that 100 pages in length, that conveys the compelling scientific contributions of SOFIA, and its complementary and extending role for existing and planned space and ground-based IR observations.

- Written for a general astronomy audience.

- Incorporating Science enabled by possible future instrumentation. (< 25% of the length of the Science Vision document).

- Executive summary of the above paper; (Note: the first Executive Summary was re-named "The Case for SOFIA" and is a 16 page document for the non-astronomers and is available

- A synopsis of the Science Vision of no more than 16 PowerPoint slides for use by the general astronomy community.

The Five Chapters of the SOFIA Science Vision

I. Introduction
Bob Gehrz, Dan Lester, Tom Roellig, Eric Becklin

II. The Formation of Stars and Planets
Neal Evans (Chair), Jim DeBuizer (Deputy)

III. The Interstellar Medium of the Milky Way
Margaret Meixner, Xander Tielens (Co-Chairs)

VI. Galaxies and the Galactic Center
Gordon Stacey (Chair), Bill Vacca (Deputy)

V. Planetary Science
Jeff Cuzzi, (Chair), Dana Backman (Deputy)

Introduction and Key Aspects of SOFIA

- SOFIA has a Unique wavelength coverage for Imaging and Spectroscopy from 28 to 60 microns over in the next 10 to 15 years. In this range, the Imaging is the best that can presently be obtained.

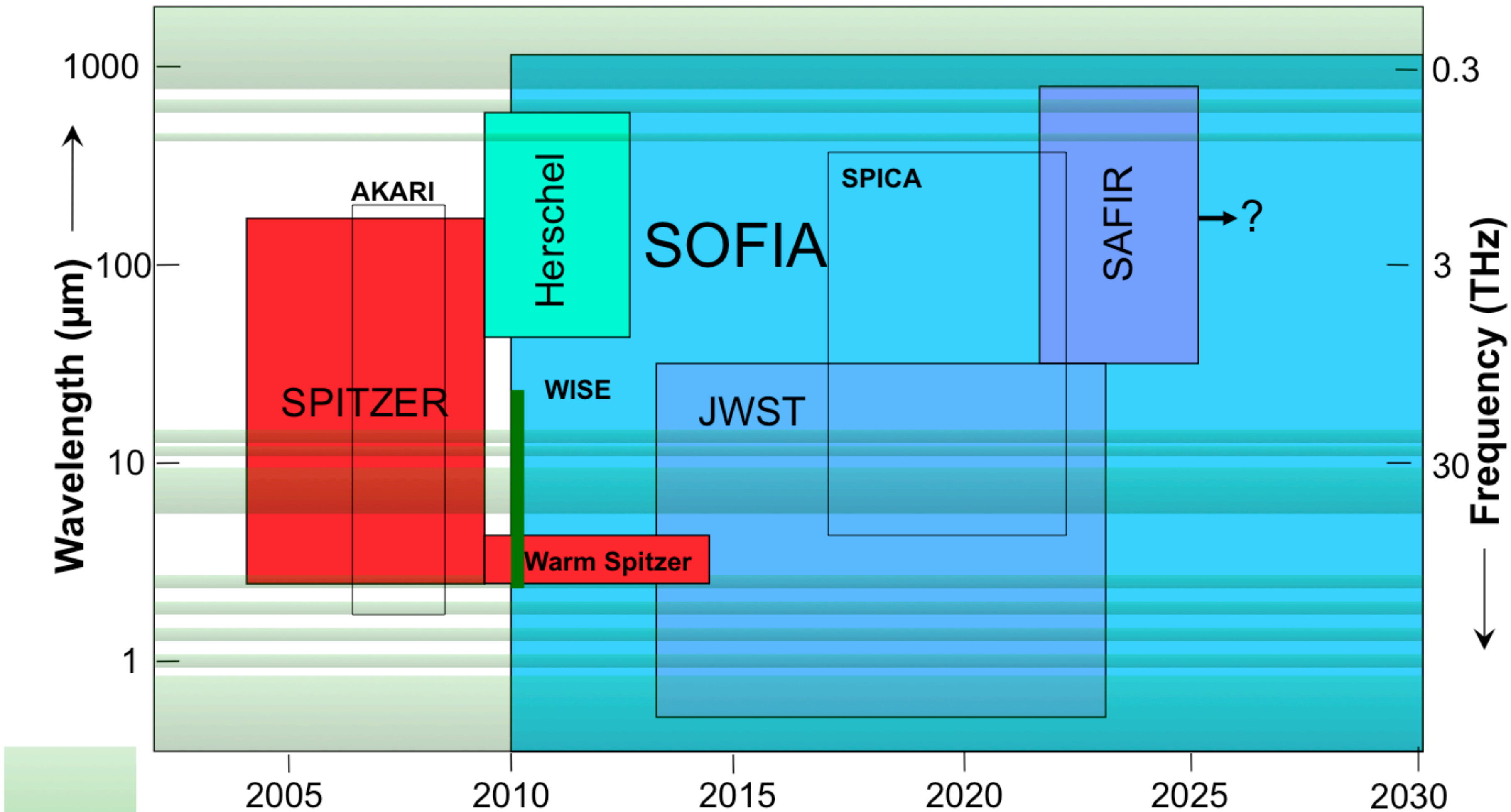
- SOFIA's biggest strength is in High Resolution Spectroscopy
  - In the 5 to 150 micron region SOFIA has ability to make observations with enough resolution to see Doppler motions in the Km/sec velocity range.
  - The Spectral Resolution is enough to separate different molecules and thus study Chemistry is space.

- SOFIA can observe objects such a Comets and Venus relatively close to the Sun.

- 20 year lifetime allows special long to projects to be completed

- Advanced Instrumentation can allow the Observatory to reinvent itself every few years and take advantage of technology improvements

SOFIA and Major IR Imaging/Spectroscopic Space Observatories



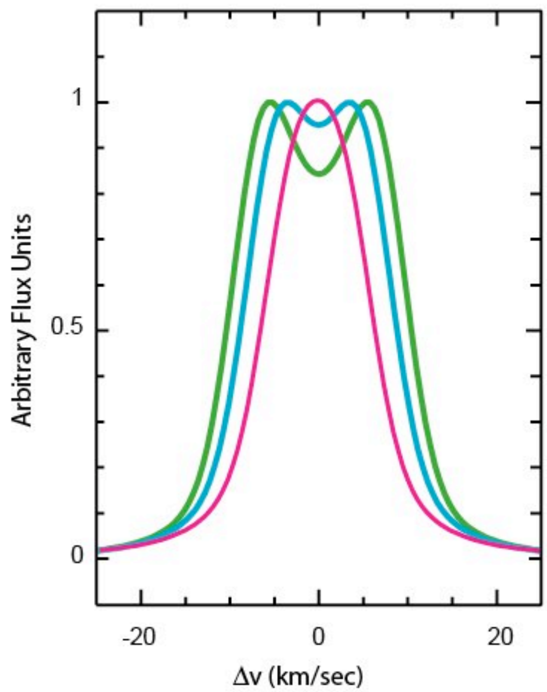
Ground-based Observatories

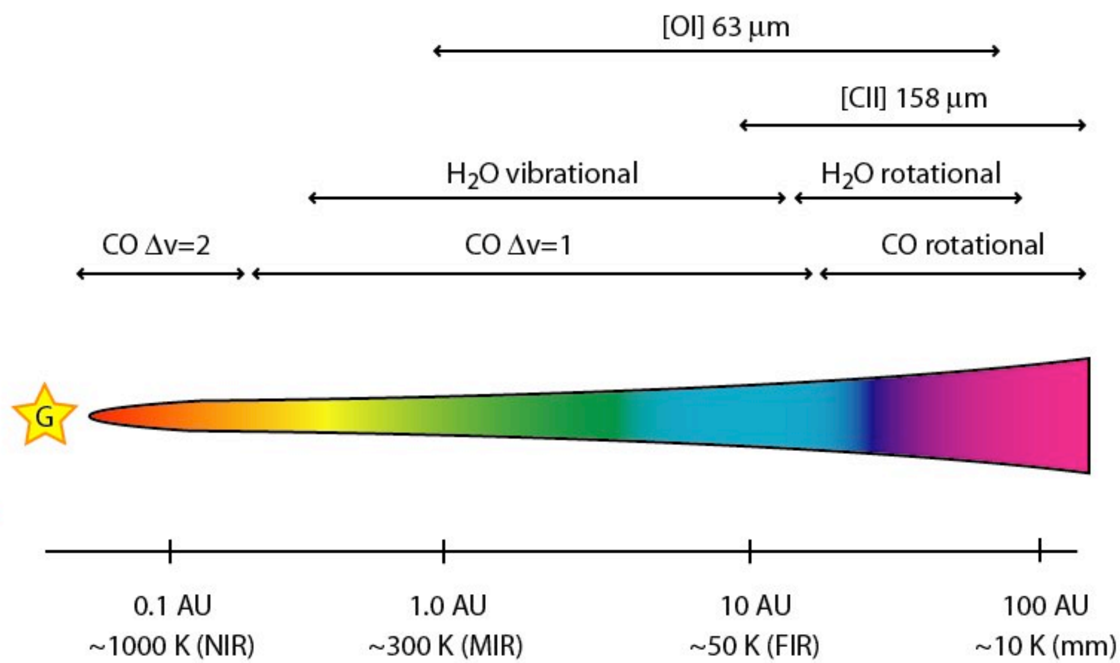
The Formation of Stars and Planets

- Disks of Rotating Material are a key to both how Stars and especially Planets form.

- SOFIA's High Spectral Resolving power is key to understanding the Disks and the material in the Disks that form Planets.
  - Planets are forming out of the Dust and Gas in the Disk
  - Chemistry is taking place building the materials of Life.
  - Looking at other Forming Stars and Planets gives us clues how formation occurred in our own Solar System

How does the chemistry of disks vary with radius?





- *High spectral resolution can determine where species reside in the disk; small radii produce double-peaked, wider lines.*
- *Observing many sources at different ages in this way will trace the disk chemical evolution*

Astrochemistry in Star Forming Regions

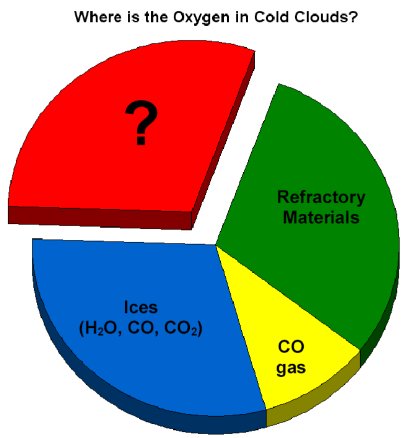
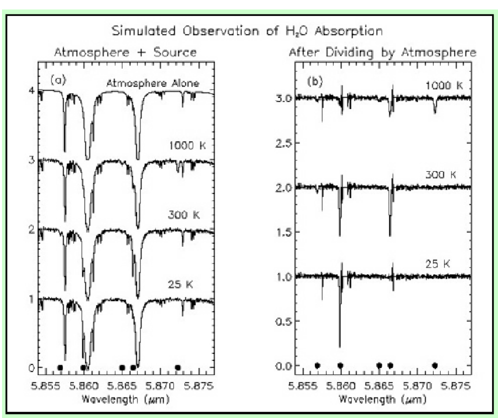


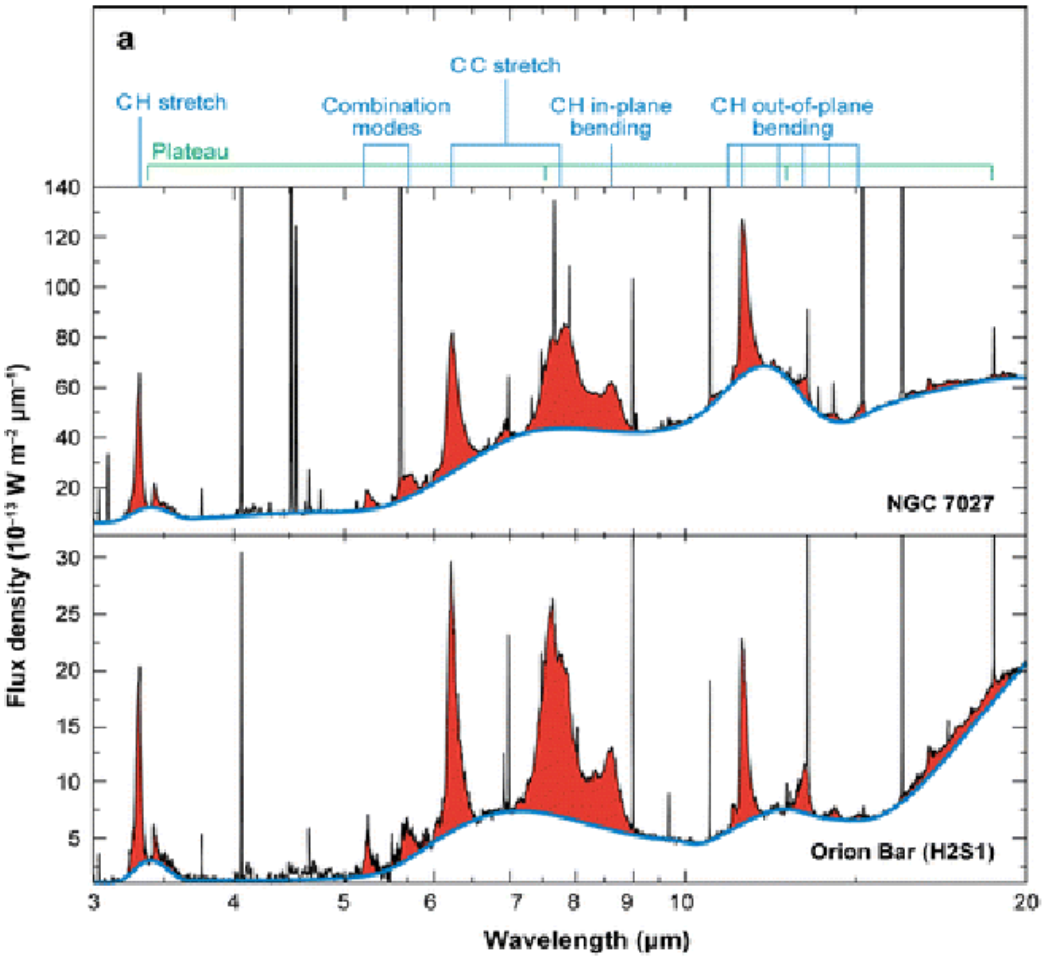
Figure 2-6. *A pie chart showing the oxygen budget in cold clouds. Almost 1/3 of the oxygen is unaccounted for.*

- ***SOFIA is the only mission that can provide spectrally resolved data on the 63 and 145 μm [OI] lines to shed light on the oxygen deficit in circumstellar disks and star-forming clouds***



- ***SOFIA has the unique ability to spectrally resolve water vapor lines in the Mid-IR to probe and quantify the creation of water in disks and star forming environments***

ISM: Emission from PAH Rich Objects

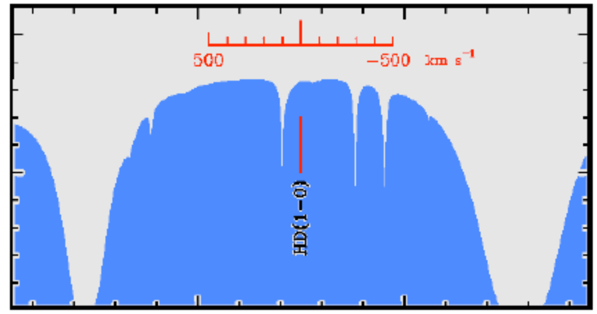


Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)

- ***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***

ISM: 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.

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

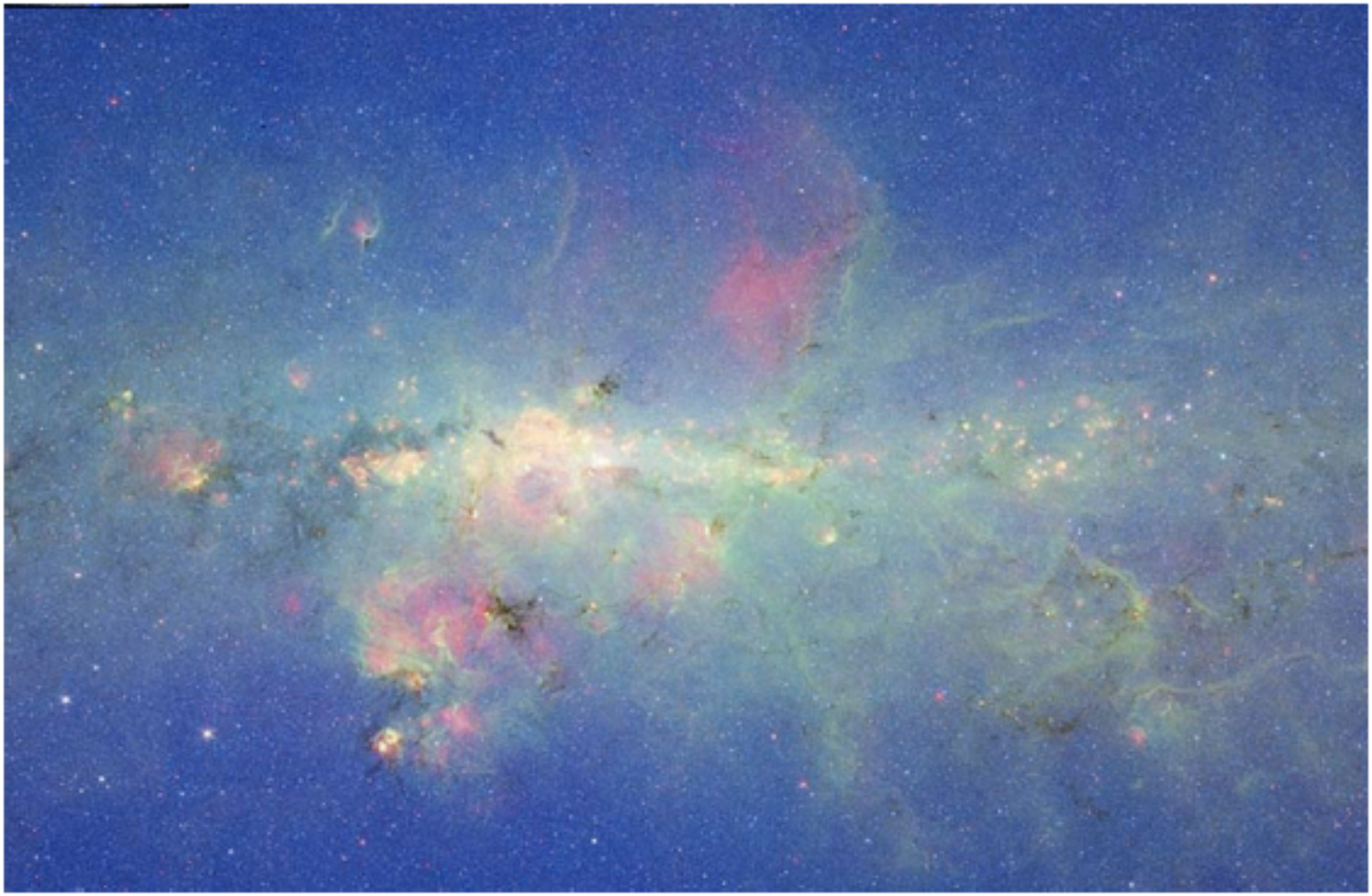
As pointed out by Bergin and Hollenbach, HD gives the cold molecular hydrogen.

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.

Galaxies and the Galactic Center

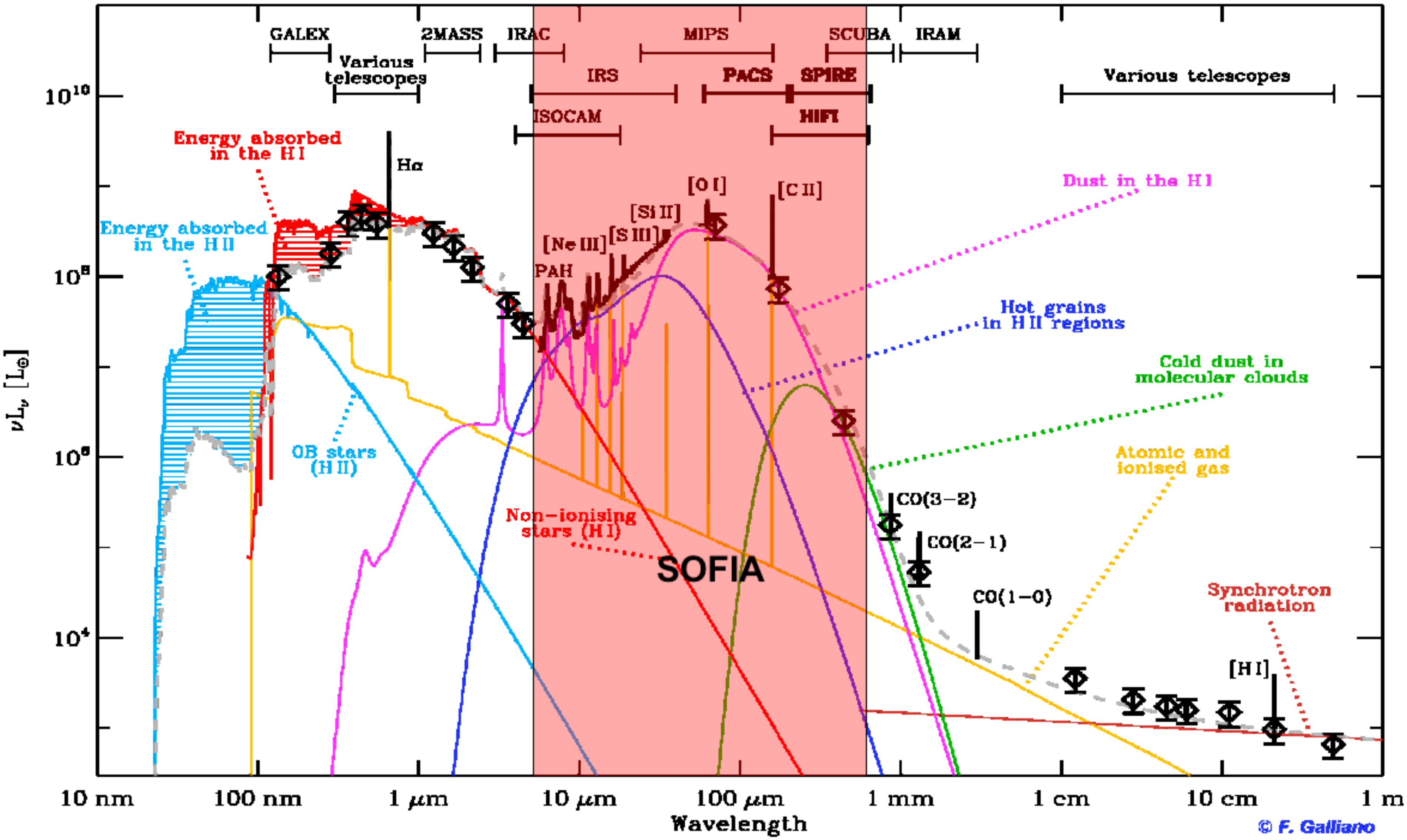
- The Central Region of our Galaxy is a very special place with many critical studies related to the Massive Black Hole and other phenomena
  - What is the relationship of Star Formation and the MBH
  - Is the region heated by X-rays, Cloud-Cloud collisions or uv photons from stars.



Nearby Galaxies

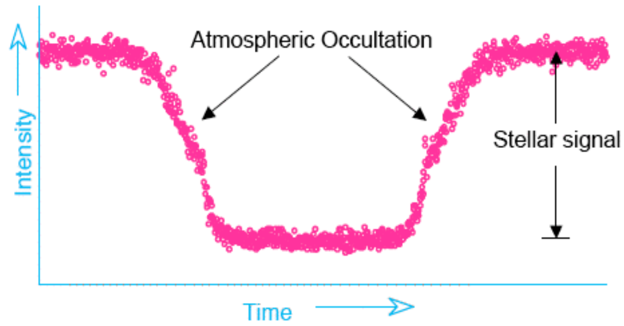
- SOFIA's strength is understanding the material between the stars in Nearby Galaxies
  - 9 octaves of wavelength coverage (1 to 700 μm) that covers the peak of dust distribution in galaxies
  - The high angular resolution allows separation of the spiral arm inter-arm regions
  - Host of diagnostic lines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

Galaxy Spectral Energy Distribution (SED)

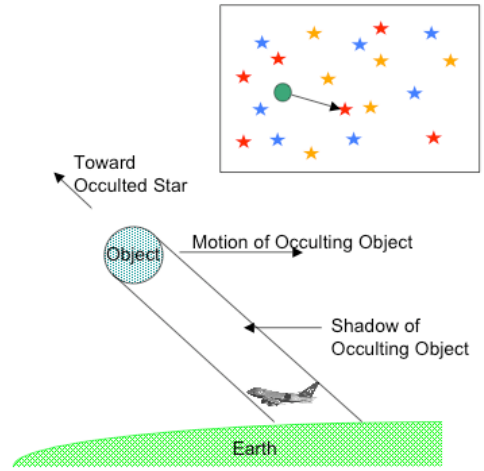


Occultation astronomy with SOFIA

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

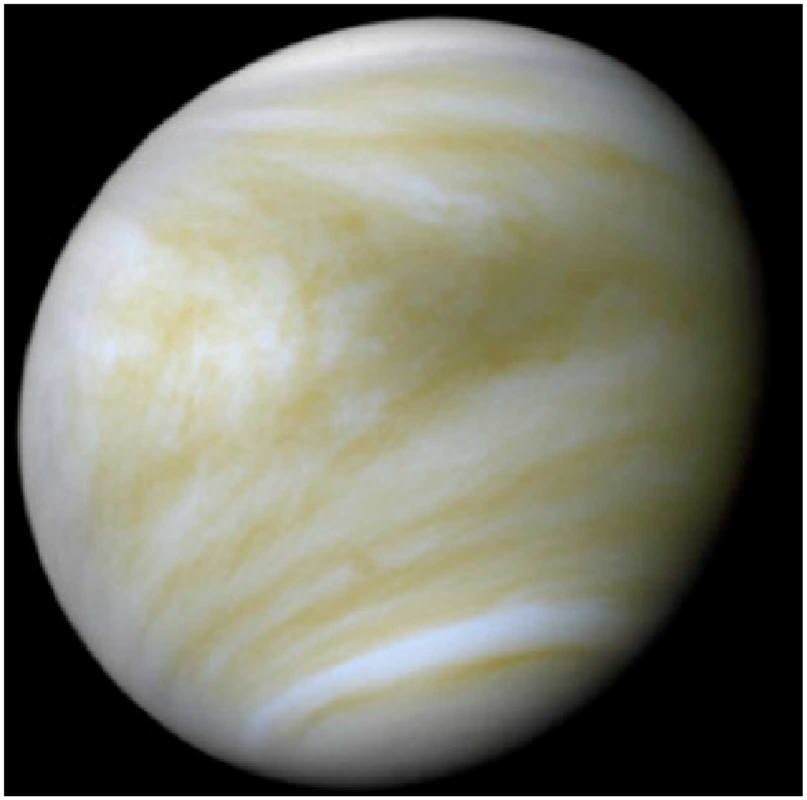


- SOFIA can fly anywhere on the Earth, allowing it to position itself under the shadow of an occulting object.

- 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.

SOFIA and Venus: Earth's Neglected Sibling



NASA **Pioneer Venus** *UV image of Venus*

- ***The chemistry and dynamics of Venus's atmosphere are poorly understood***
- ***High resolution spectrometer on the Venus Express failed***
- ***Pointing constraints prevent our major space observatories from observing Venus***
- ***Sofia has the spectrometers and the sunward pointing capability to play a discovery-level role in our understanding of Venus's atmosphere***

How to Use the Science Vision

- Read the SOFIA Science Vision, including the tables of observations and the graphs of sensitivity to get an idea of what can be done with SOFIA.
- Share and Discuss the Science Vision with your colleagues
- Use the examples in the Science Vision to consider projects in your favorite area of astrophysics
- For Basic Science, FORCAST Imaging and Limited GREAT Spectroscopy will be available. Keep abreast of developments through our website
- Apply for time on SOFIA through the Basic Science Call and other future calls

Continuum Sensitivity

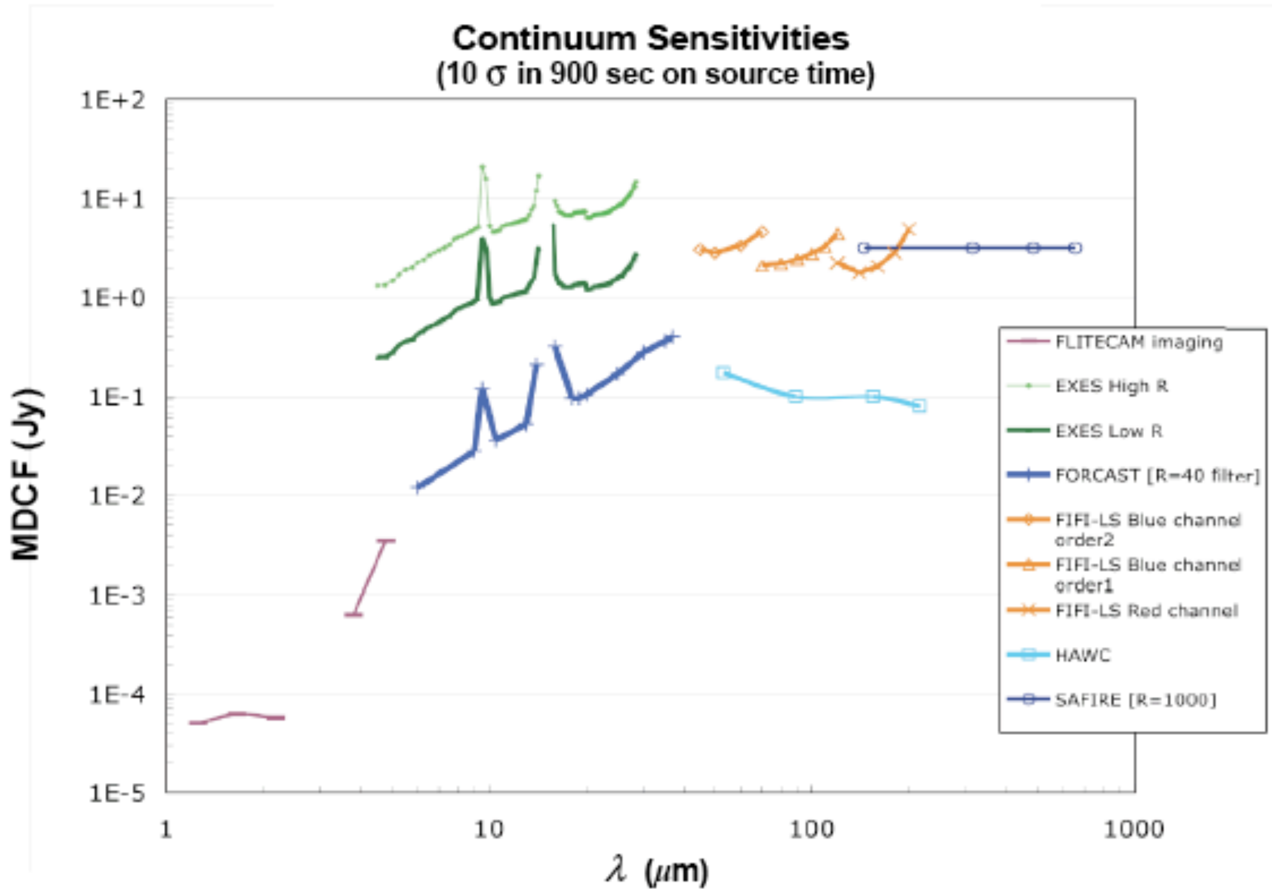


Figure 1-9. The continuum sensitivity of SOFIA instruments expected at the time of full operational capability. Shown is the 10 σ minimum detectable continuum point source flux densities (MDCF) in Janskys for 900 seconds of integration on source. Observing and chopper efficiency have not been included.

Summary

- The science case for SOFIA has been looked at in the post-Spitzer era.
- A document that highlights some of the best SOFIA science has been produced.
- The document has been reviewed by a Blue Ribbon Panel headed by John Mather.
- The finished product is available at our USRA SOFIA web site: http://www.sofia.usra.edu/Science/docs/SofiaScienceVision051809-1.pdf, Astro Ph http://arxiv.org/abs/0905.4271 , and in hard copy at this AAS meeting