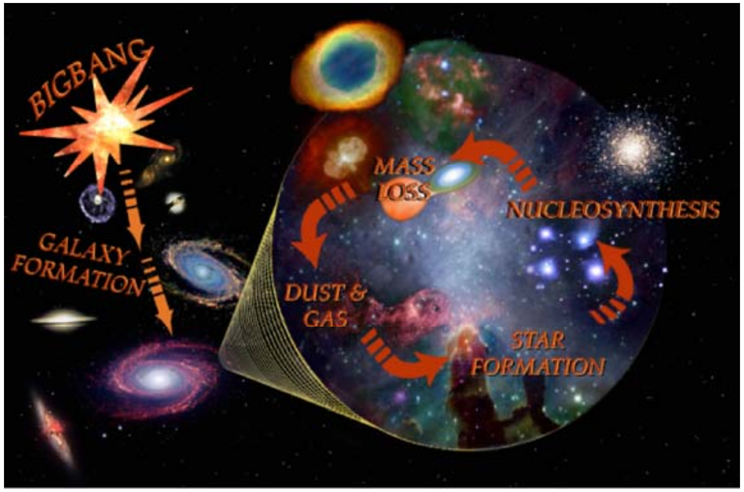
SOFIA's New Science Vision



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http://www.sofia.usra.edu

Outline

- *The SOFIA New Science Vision Activity*
- *Producing the SOFIA New Science Vision Report*
- *Blue Ribbon Panel Review of the Report*
- *Outline of the SOFIA New Science Vision Report*
- *SOFIA Science New Vision Report science highlights*
- *Summary*

Why the Need for New Science Vision?

- *In some recent presentations to scientific review groups, including high-level NASA advisory groups, we have received comments that can be paraphrased as: "The SOFIA science case that you have presented is useful, but does not rise to the level that justifies the costs of SOFIA."*

- *Cost per science observing hour for SOFIA is very high, even compared to expensive space missions like HST, Spitzer, Chandra. The cost relative to science realized is NASA's foremost project evaluation metric - therefore we need to emphasize the most clearly important and unique aspects of the SOFIA science case*

A New Science Vision for SOFIA

- The original science case for SOFIA was articulated more than fifteen years ago
  - Astronomical science has progressed
  - SOFIA science projects will now build on the Spitzer results
  - Science goals for SOFIA and the soon to be launched Herschel mission need to be coordinated
- Need to develop a small set of “killer” SOFIA projects
  - Immediately recognizable as answering, or being instrumental in answering, fundamental astrophysics questions
  - A a short list of compelling SOFIA science investigations
  - Projects where SOFIA data are essential and not just supplementary

SOFIA Science Vision Products

- *New SOFIA Science Vision Publication that is:*
  - *Concise, well documented, and clearly written for a general audience*
  - *Peer reviewed*
  - *Conveys the compelling scientific contributions of SOFIA*
  - *Justifies SOFIA's complementary and extended roles for existing and planned space and ground-based IR observatories*
  - *75% or more of the science enabled by first generation instruments*
- *Executive summary of the SOFIA Science Vision*
- *A 16 Slide PowerPoint synopsis of the SOFIA Science Vision for presentations to high-level committees and the community*

SOFIA New Science Vision Working Group

- *Co-Chairs were Eric Becklin and Tom Roellig*
- *Weekly meetings at ARC with USRA and NASA scientists to coordinate efforts*
- *Four science theme panels and chairs were identified:*
  - *Formation of Stars and Planets*
  - *The Interstellar Medium of the Milky Way*
  - *Galaxies and the Galactic Center*
  - *Planetary Science*
- *Panel chairs solicited panel members*
- *An international team of over 40 scientists contributed to the New Science Vision document*

Peer Review: Blue Ribbon Board Charter

Does the New Science Vision document successfully

- *Reflect important science investigations that command wide interest within the astronomical community?*
- *Articulate a unique role for SOFIA in attacking these investigations?*
- *Show that the SOFIA observations are feasible with present and anticipated SOFIA instrumentation?*
- *Indicate how the SOFIA results will complement and enhance the discoveries from other observatories and missions?*

The Blue Ribbon Board Meeting

- *A draft of the New Science Vision document was generated and submitted to the Blue Ribbon review board on October 19, 2008*

- *Blue Ribbon board met at ARC on October 28, 2008 Members and their assigned science areas were:*

John Mather (GSFC), Chair
Michael Brown (Caltech), solar system
Steve Kahn (Stanford), galactic center
Gillian Knapp (Princeton), star formation
William Mathews (UCSC), galactic center
Gary Melnick (CfA), ISM
Marcia Rieke (Arizona), nearby galaxies
Hans-Peter Röser (Stuttgart), star formation
Michael Werner (JPL/Caltech), ISM

- *The Blue Ribbon board report received on December 4, 2008*

Activities Since the Blue Ribbon Review

- *Produced a close-to-the-final version revised taking account of the Blue Ribbon Board's comments, including an executive summary*
- *Submitted the revised version to our Blue Ribbon Boars for a final review (Note that the length has grown from 50 to 136 pages)*
- *Received Board responses by 4/15/09*
- *Responses were universally favorable, with only a few relatively minor suggested changes*
- *Created a separate document, "The Case for SOFIA"*
  - *Originally written for NASA HQ*
  - *Very popular with the lay public as well*
  - *1,800 copies printed to date, 1,300 distributed*

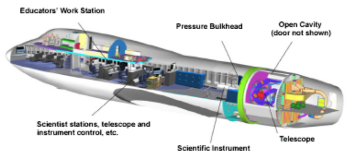
Concluding the Vision Report Activity

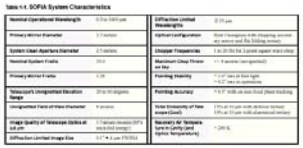
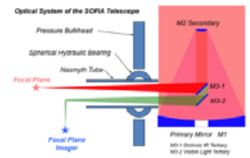
- ***Final revisions, proofreading, NASA Headquarters approval, and printing were concluded during the week of May 11, 2009***
- ***The final printed version was presented at the SOFIA Science Council meeting May14 – 15, 2009***
- ***The printed version will be sent out widely and distributed at the AAS meeting in Pasadena***
- ***The remaining task is to incorporate the content into a PowerPoint slide set***

Table of Contents of "The Science Vision for the Stratospheric Observatory for Infrared Astronomy"

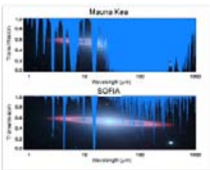
Chapter 1: Introduction

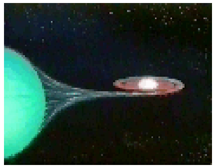
- *Facility overview*



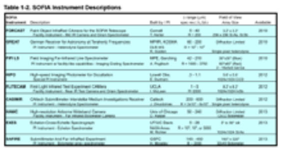
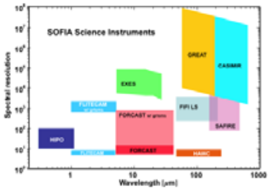



- *Unique capabilities*

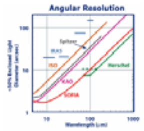


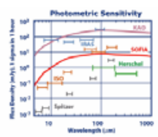



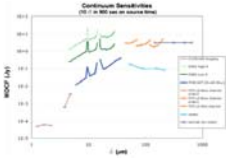
- *First generation instruments*

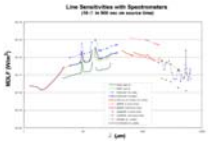



- *Spatial resolution and sensitivity*

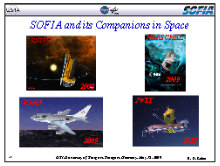


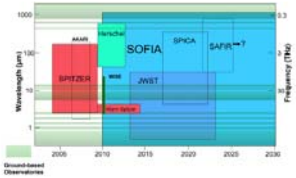






- *SOFIA and other missions*

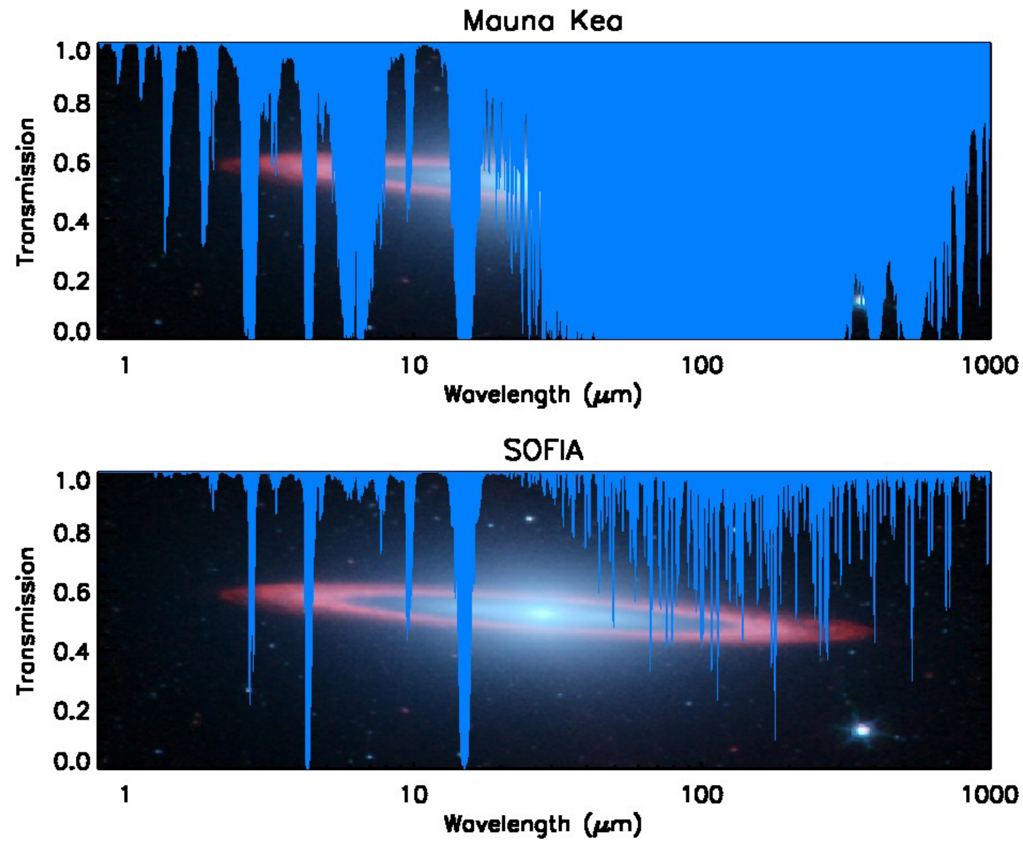




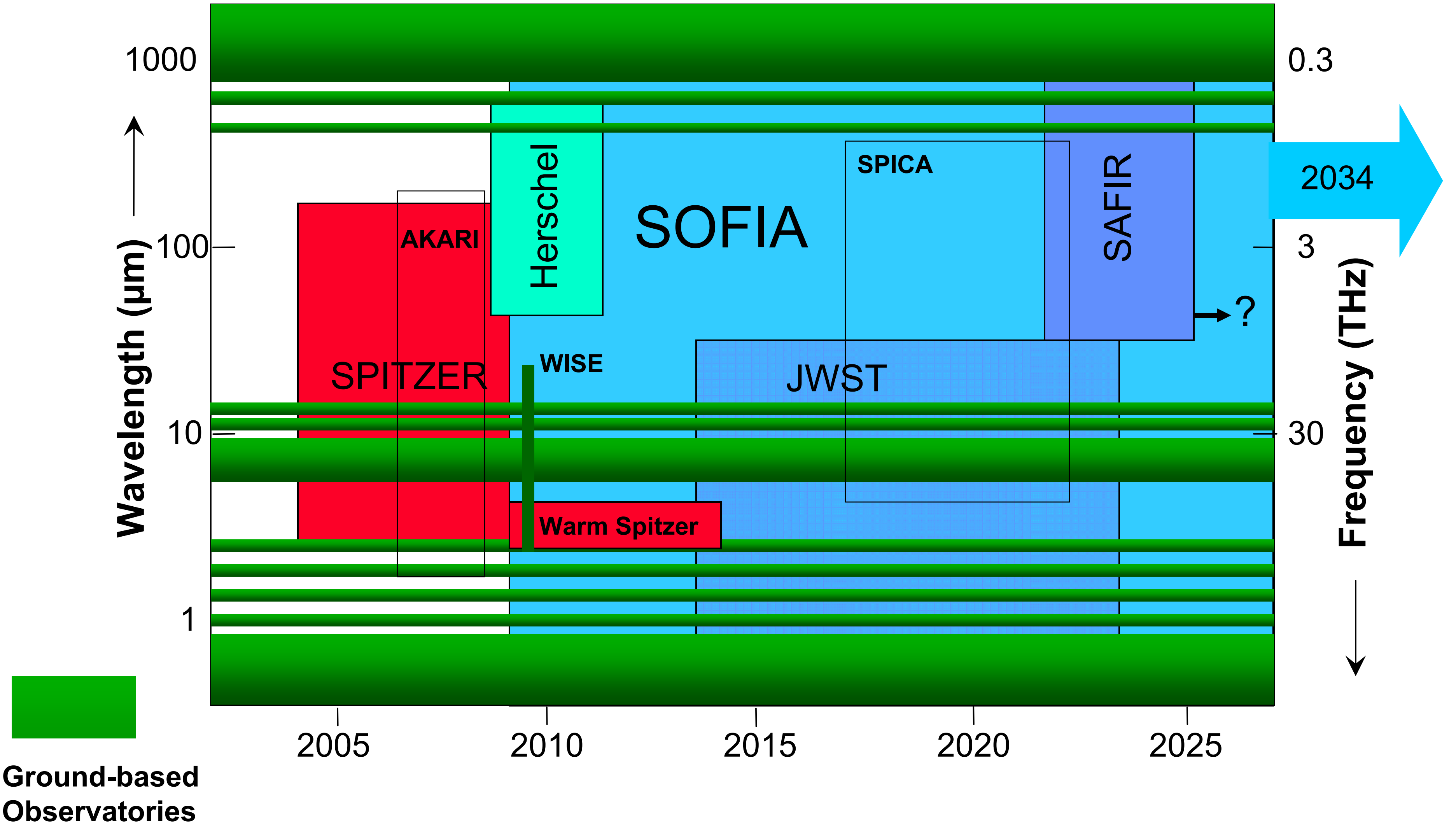
- *Instrument, Technology, and E & PO*


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*



SOFIA and Major IR Imaging/Spectroscopic Space Observatories



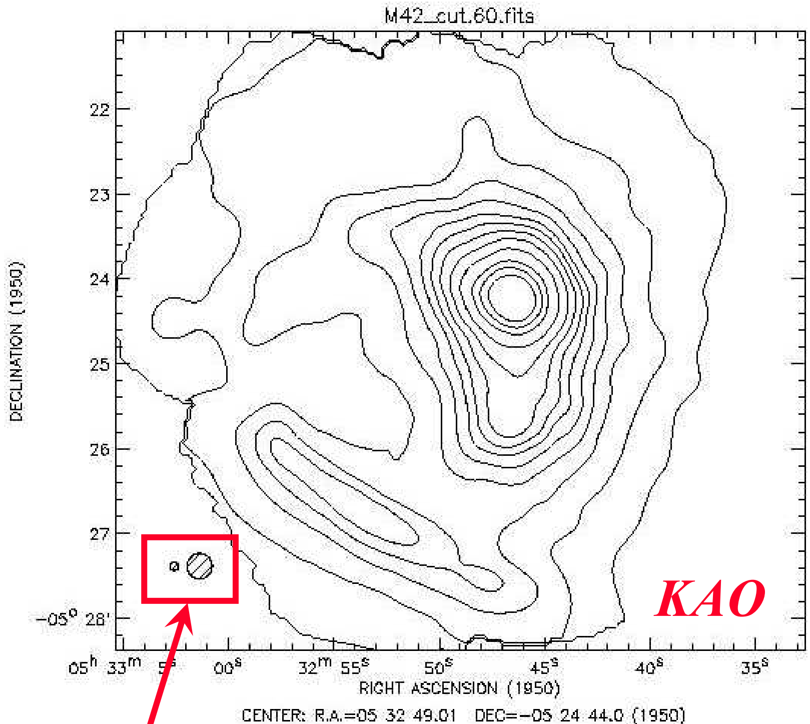
Key Astrophysics Questions for SOFIA

Chapter 2: The Formation of Stars and Planets

- *The Formation of Massive Stars*
- *Understanding Proto-planetary Disks*
- *Astrochemistry in Star Forming Regions*

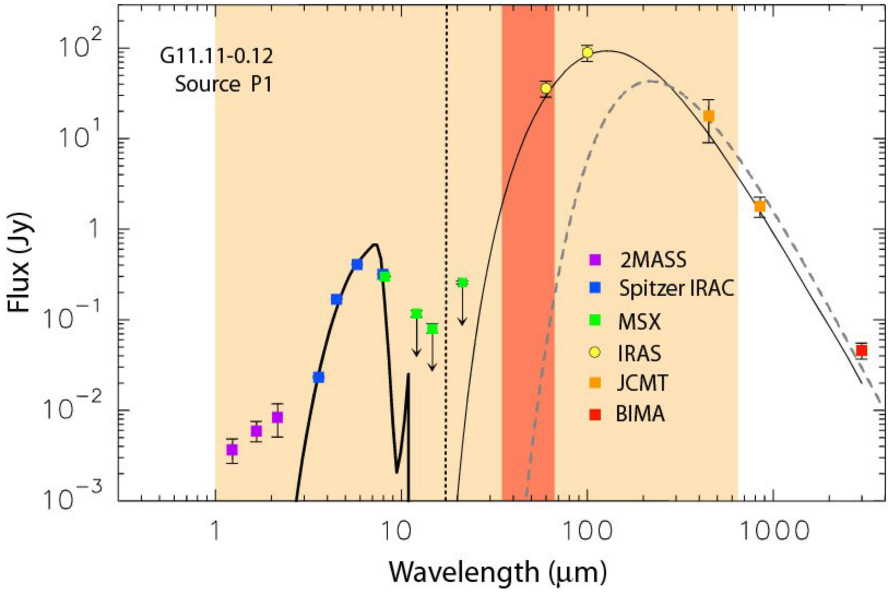
SOFIA and Regions of Star Formation

How will SOFIA shed light on the process of star formation in Giant Molecular Clouds like the Orion Nebula?

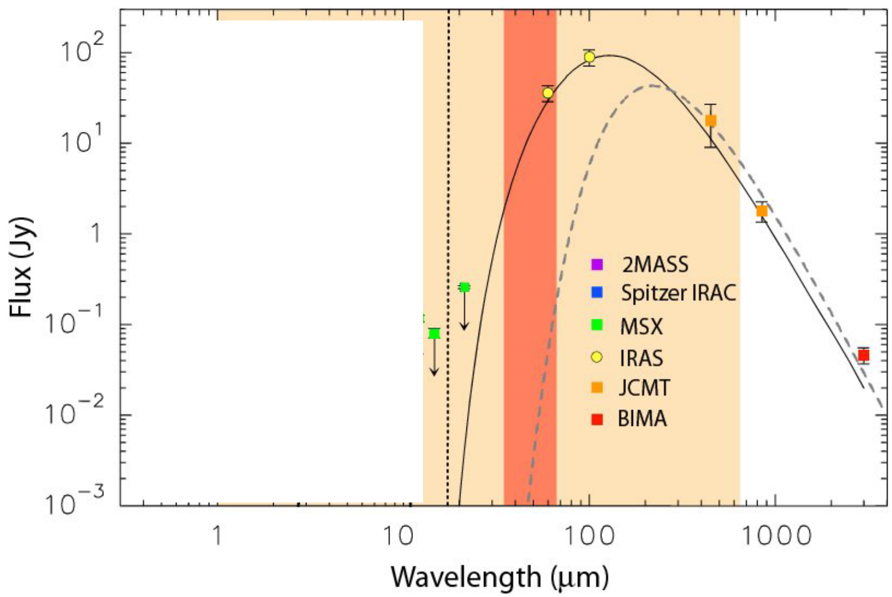


With 9 SOFIA beams for every 1 KAO beam, SOFIA imagers/HI-RES spectrometers can analyze the physics and chemistry of individual protostellar condensations where they emit most of their energy and can follow up on HERSCHEL discoveries.

Sources Embedded in Massive Cloud Cores

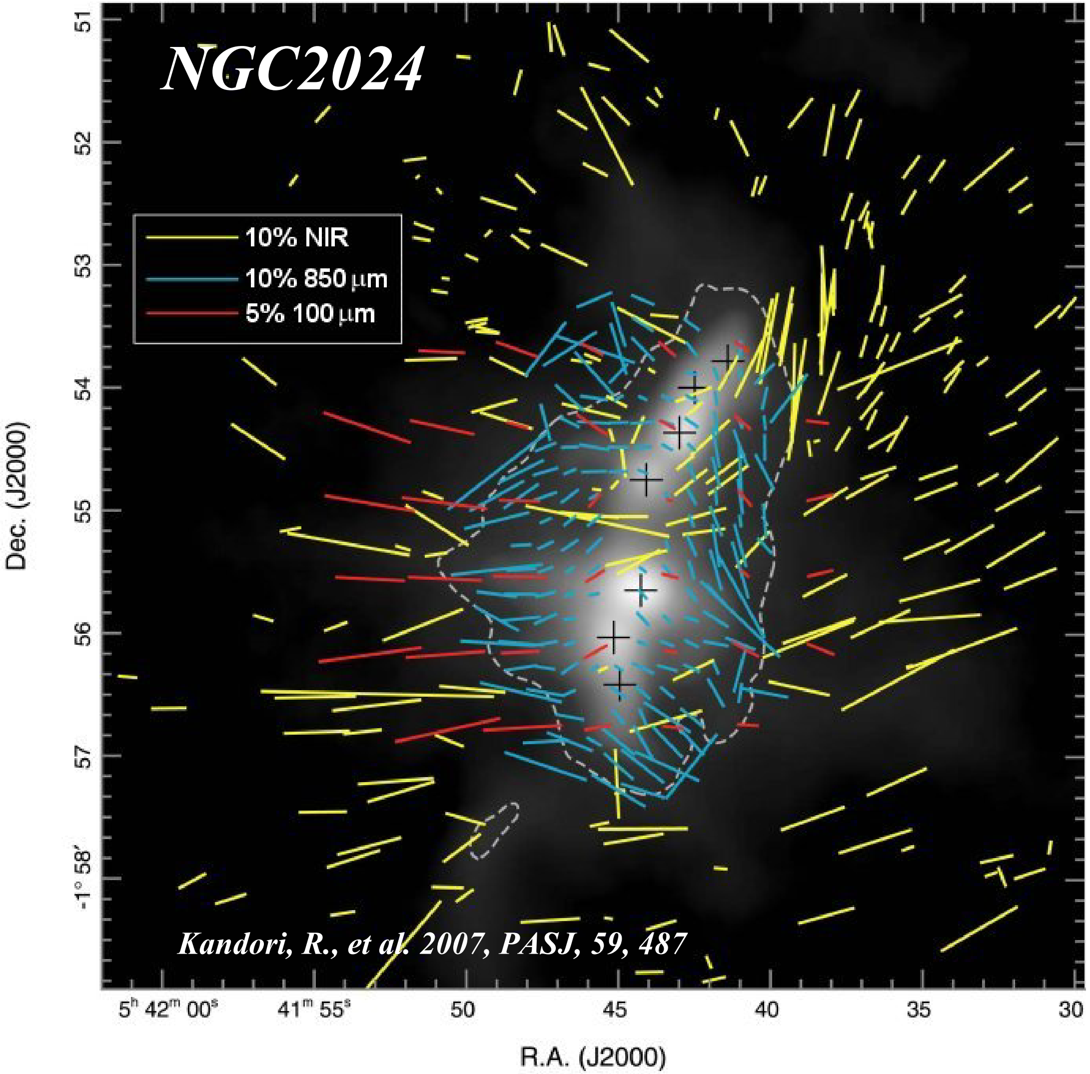


- *In highly obscured objects, no mid-IR source may be detectable*



- *20 to 100 microns can provide a key link to shorter wavelengths*

Magnetic Fields in Massive Star Forming Regions

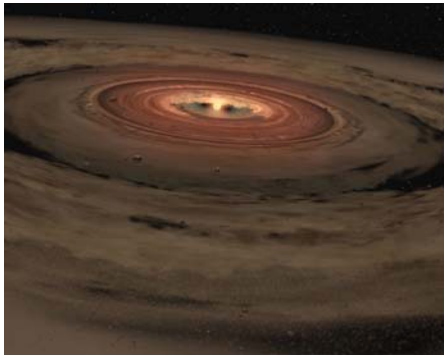


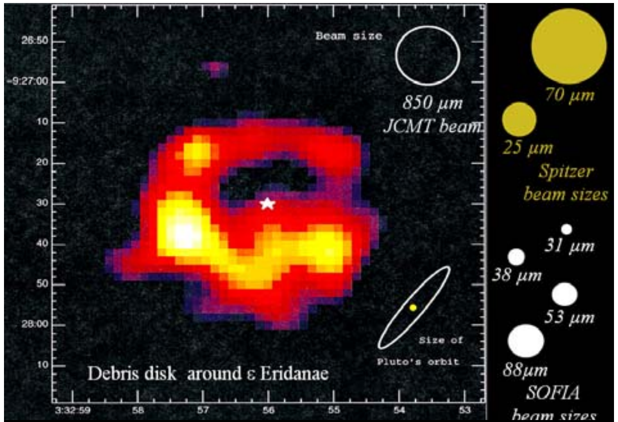
- *Within the dashed contour, NIR and sub-mm disagree on field direction. NIR probes outer low density material. FIR will probe warm, dense material*
- *A polarimetric capability for HAWC is being investigated*

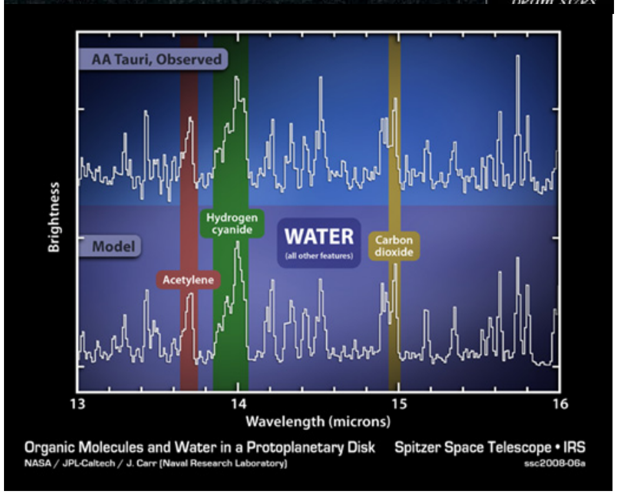
IRSF/SIRIUS and JCMT/SCUBA data

SOFIA and Extra-Solar Circumstellar Disks

What can SOFIA tell us about circumstellar disks?



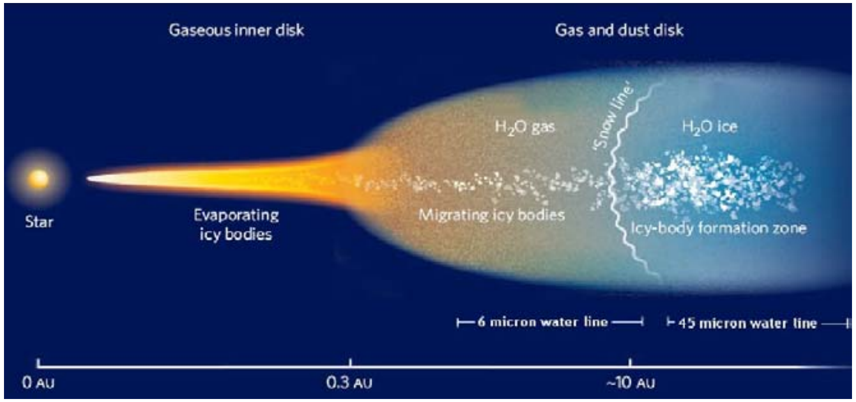




- *SOFIA imaging and spectroscopy can resolve disks to trace the evolution of the spatial distribution of the gaseous, solid, and icy gas and grain constituents*
- *SOFIA can shed light on the process of planet formation by studying the temporal evolution of debris disks*

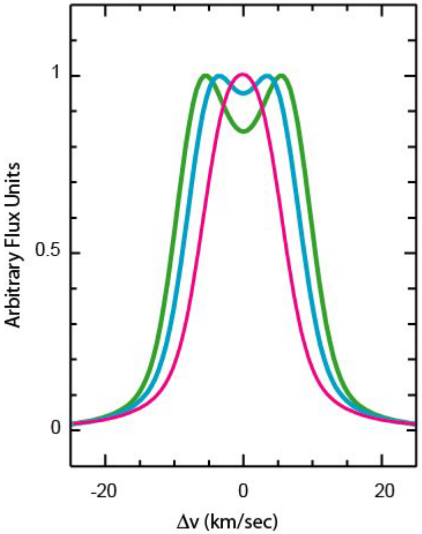
The chemistry of disks with radius and Age

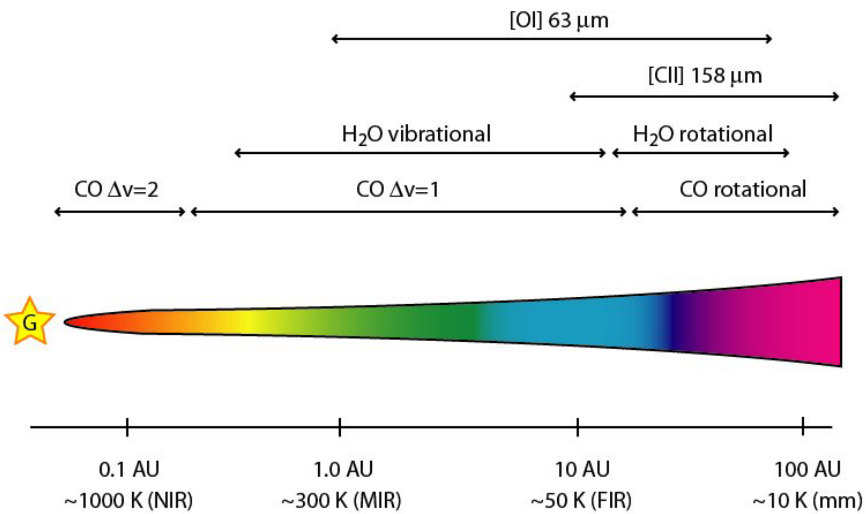
- ***High spatial and spectral resolution can determine where different species reside in the disk***



- ***small radii produce double-peaked, wider lines.***

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





Astrochemistry in Star Forming Regions

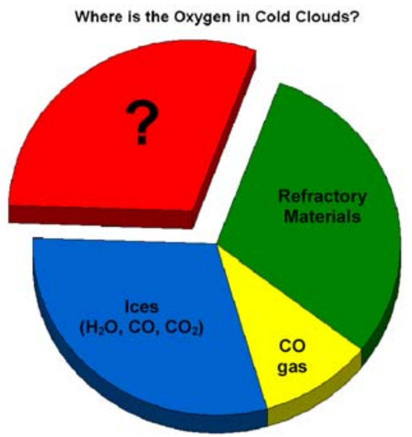
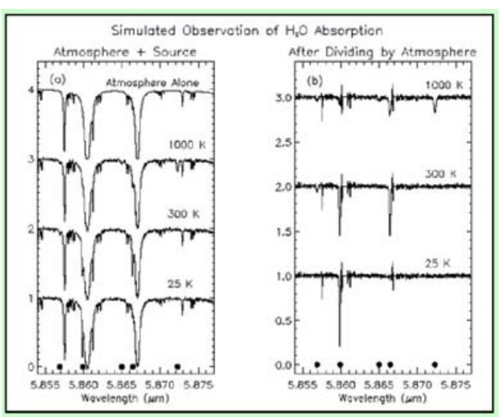


Figure 2-6. A pie chart showing the oxygen budget in cold clouds. Almost 1/3 of the oxygen is unaccounted for.

- ***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***

Key Astrophysics Questions for SOFIA

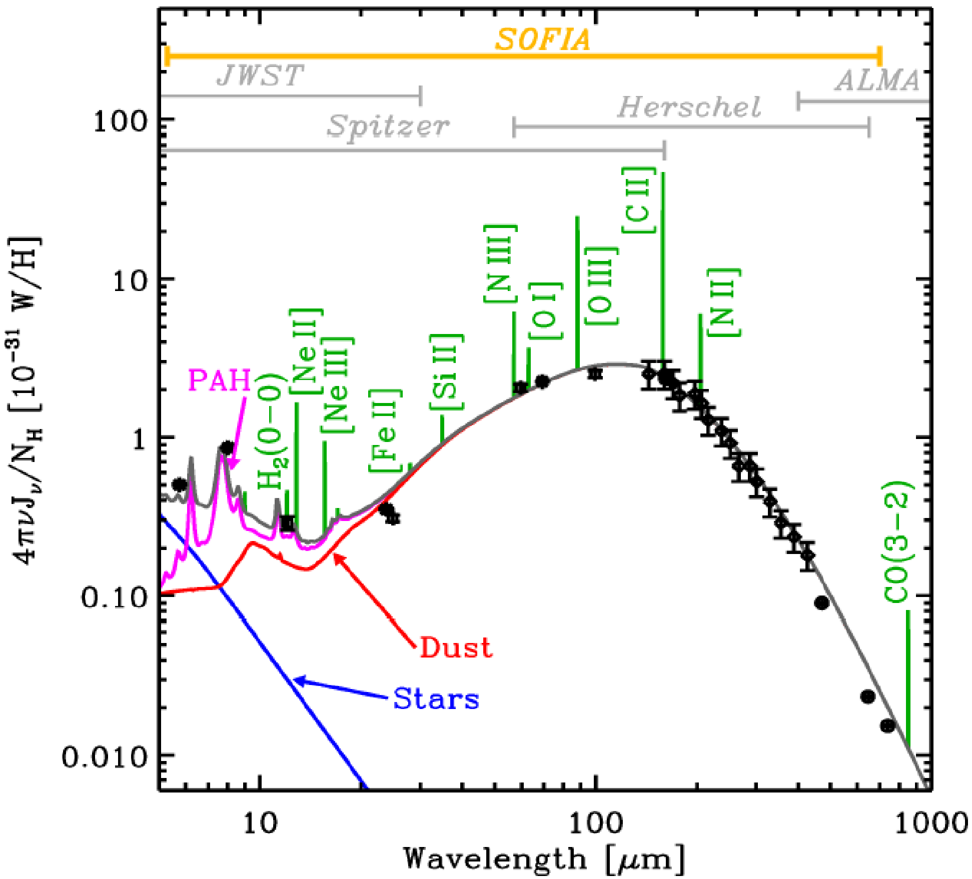
Chapter 3: The Interstellar Medium of the Milky Way

- Massive Stars and the ISM: Photodissociation Regions (PDRs)
- The Diversity and Origins of Dust in the ISM: Evolved Star Contributions
- The Role of Large, Complex Molecules in the ISM: Identification of PAHs
- Deuterium in the ISM: Constraints from HD

Related Objects of Opportunity

- Eruptive Variable Stars, Classical Novae, and Supernovae,

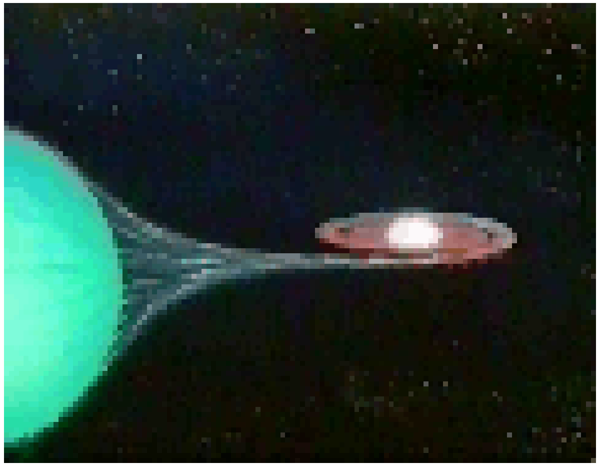
Thermal Emission from ISM Gas and Dust



Spectral Energy Distribution (SED) of the entire LMC (courtesy of F. Galliano)

- *SOFIA is the only mission in the next decade that is sensitive to the entire Far-IR SED of a galaxy that is dominated by emission from the ISM excited by radiation from massive stars and supernova shock waves*
- *The SED is dominated by PAH emission, thermal emission from dust grains, and by the main cooling lines of the neutral and ionized ISM*

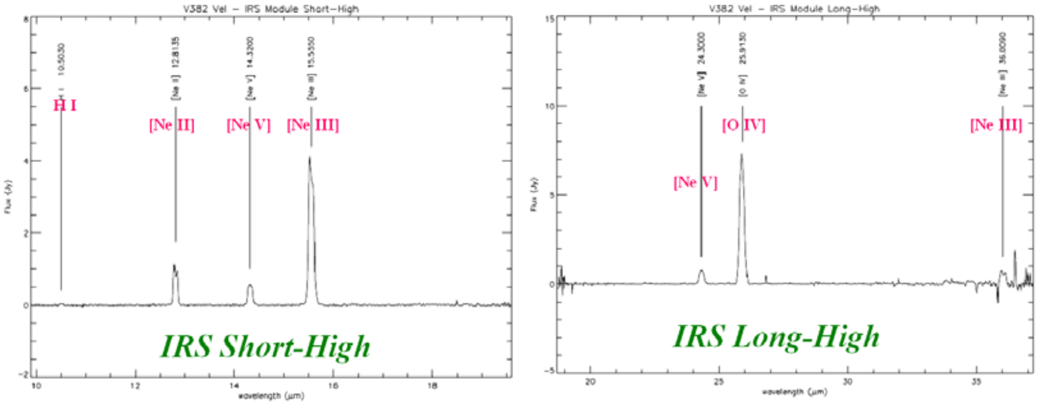
SOFIA and Classical Nova Explosions



What can SOFIA tell us about gas phase abundances in Classical Nova Explosions?

Spitzer Spectra of Nova V382 Vel

R. D. Gehrz, et al. 2005, ApJ, in preparation [PID 124]

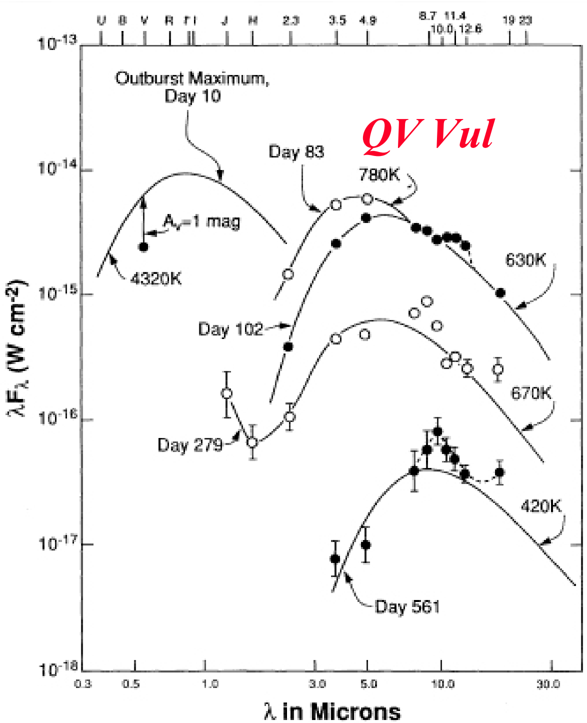


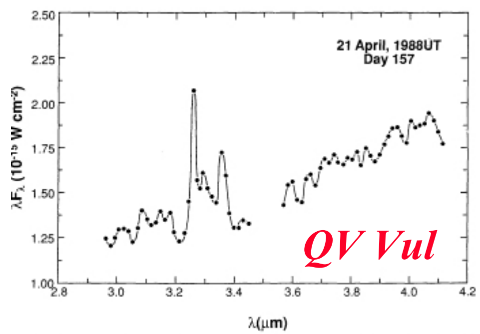
- Gas phase abundances of CNOMgNeAl
- Contributions to ISM clouds and the primitive Solar System
- Kinematics of the Ejection

SOFIA and Classical Nova Explosions

What can SOFIA tell us about the mineralogy of dust produced in Classical Nova Explosions?

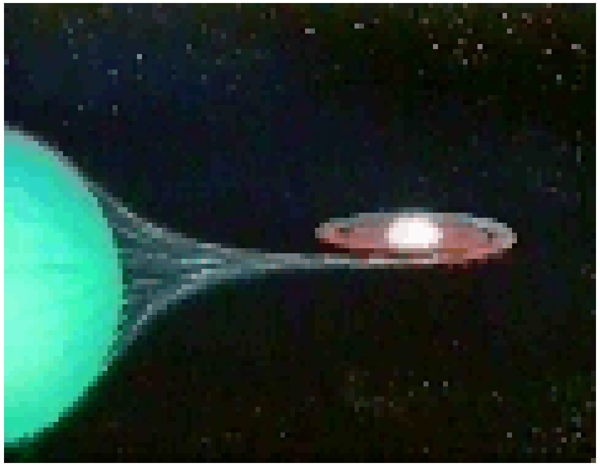
Gehrz et al. 1992 (Ap. J., 40, 671)





QV Vul formed four types of stardust:

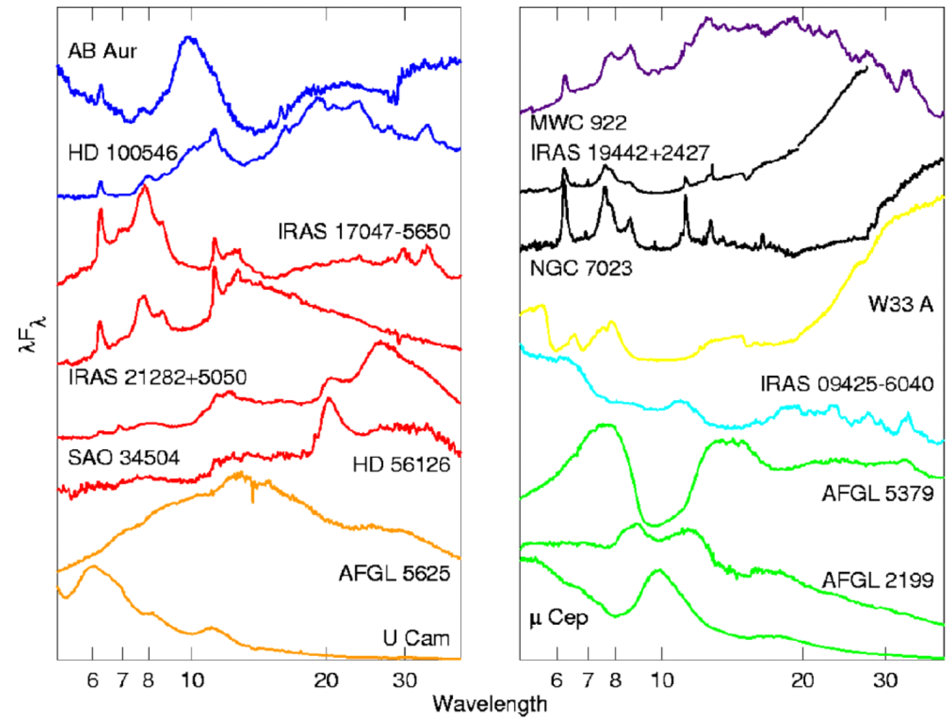
- *Amorphous carbon*
- *SiC*
- *Amorphous silicates*
- *Hydrocarbons*



- *Stardust formation, mineralogy, and abundances*
- *SOFIA's spectral resolution and wavelength coverage is required to study amorphous, crystalline, and hydrocarbon components*
- *Contributions to ISM clouds and the Primitive Solar System*

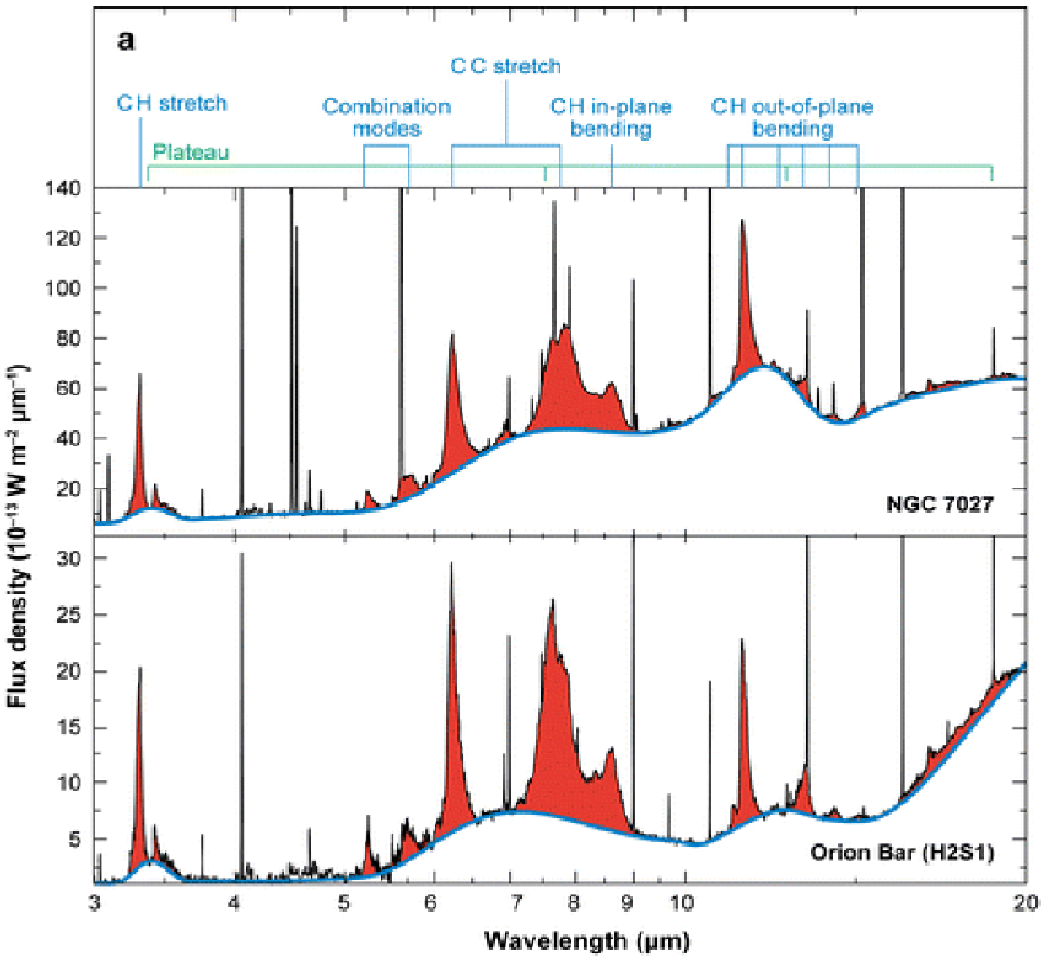
SOFIA Will Study the Diversity of Stardust

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

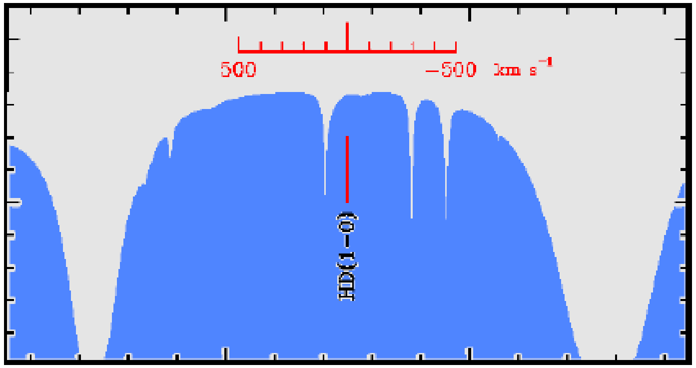


Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)

- ***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***

SOFIA Observations of ISM HD

- The 112 μm ground-state rotational line of HD is accessible to GREAT
- ISO detection of SGR B shows that HD column densities of ~ $10^{17} - 10^{18}$ cm^{-2} can be detected
- All deuterium in the Universe was originally created in the Big Bang
- D is destroyed by astration in stars
- Therefore, D abundance probes the ISM that has never been cycled through stars



Atmospheric transmission around the HD line at 40,000 feet

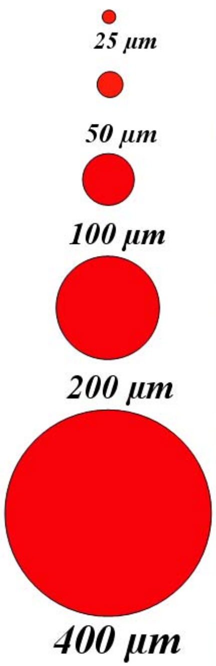
- 112 μm observations of HD can be used to determine ISM H/D abundances
- Cold HD (T<50K) is a proxy for cold molecular Hydrogen,
- The 112 μm line can be used to map the Galactic distribution of cold molecular gas just as 21 cm maps the distribution of neutral hydrogen

Key Astrophysics Questions for SOFIA

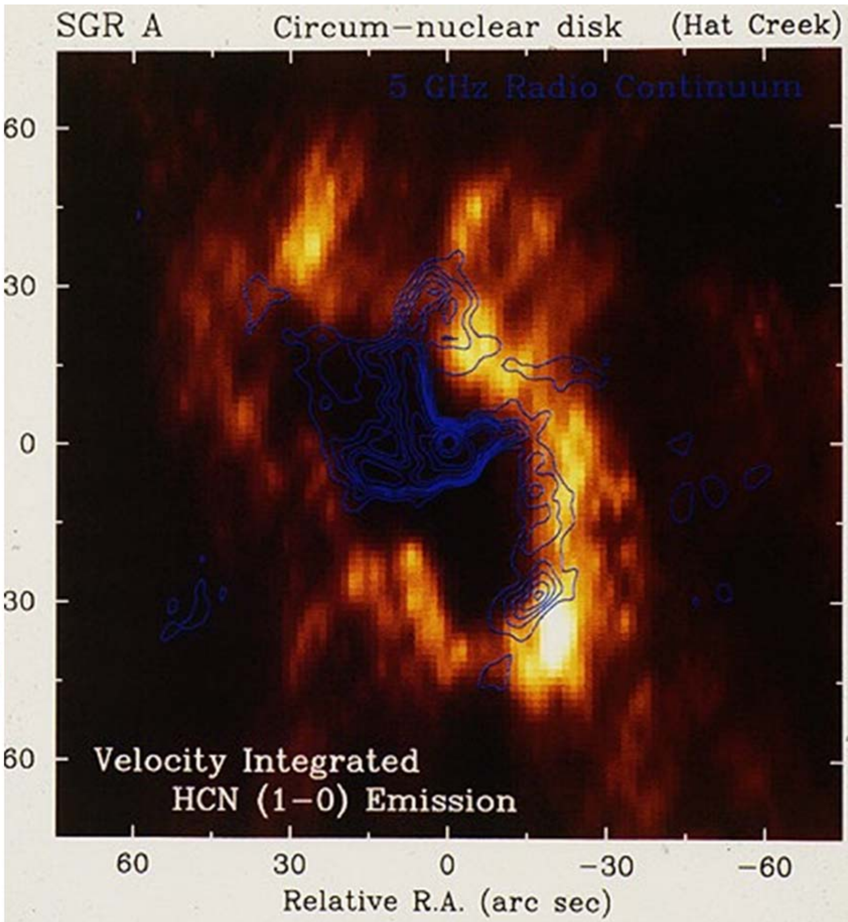
Chapter 4: Galaxies and the Galactic Center

- *The Galactic Center: Warm Clouds and Strong Magnetic Fields*
- *The Interstellar Medium and the Star Formation History of External Galaxies*
- *Tracing the Universe's Star Formation History with Far-IR Fine Structure Lines*

SOFIA and the Black Hole at the Galactic Center



SOFIA beams



- *SOFIA imagers and spectrometers can resolve detailed structures in the circum-nuclear disk at the center of the Galaxy*
- *An objective of SOFIA science is to understand the physical and dynamical properties of the material that feeds the massive black hole at the Galactic Center*

The ISM and Star Formation in External Galaxies

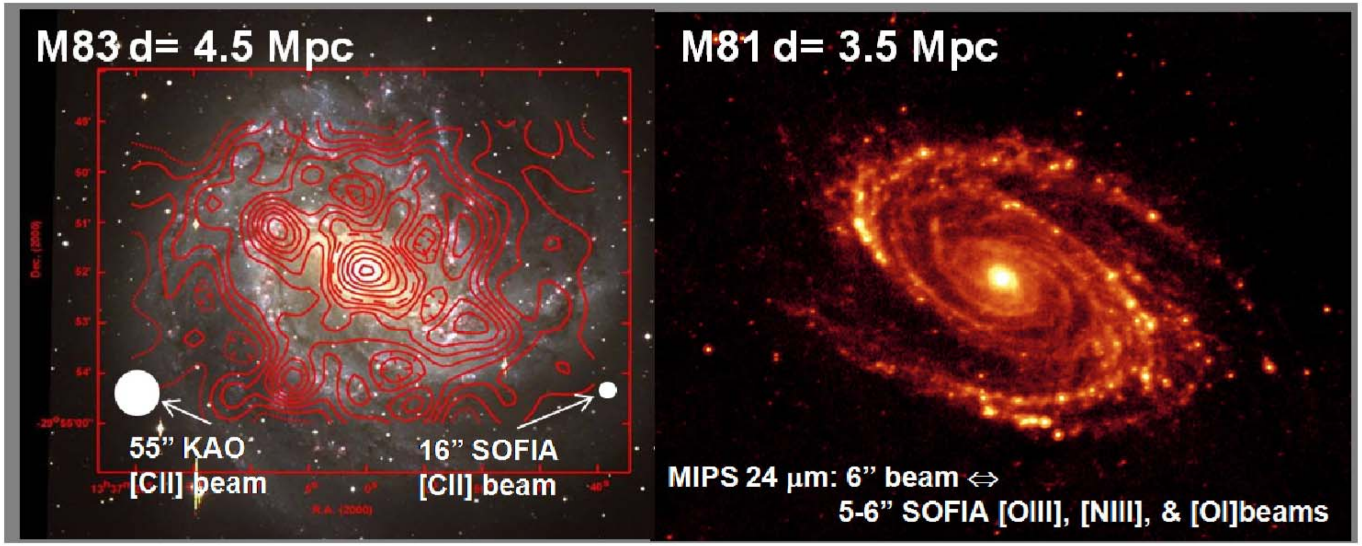
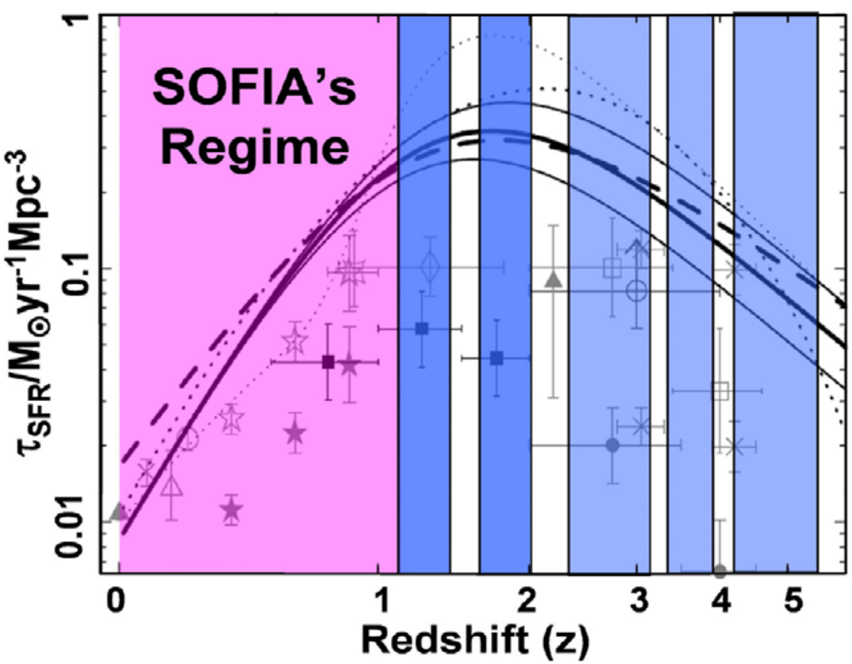


Figure 4-4. *(left) KAO [CII] map of M83 (d=4.5 Mpc) (contours, 55" beam) superposed on an optical image (Geis et al., in prep.). (right) MIPS 24 µm (6" beam) continuum image of M81 (d=3.5 Mpc). SOFIA can image nearby galaxies in the [OIII] 52 µm, [NIII] 57 µm, and [OI] 63 µm lines at a spatial resolution comparable to that of the Spitzer 24 µm image.*

- ***SOFIA observations of Far-IR lines can be conducted at unprecedented spatial resolution***
- ***ISM abundances and physical conditions can be studied as a function of location and nucleocentric distance***

The Star Formation History of the Universe



The co-moving history of star formation in the Universe (Smail et al. 2002) comparing SOFIA capabilities (pink) with existing data (symbols) and capabilities of ground-based observatories (blue).

- *[CII] emission and the Far-IR continuum trace the physical extent and ages of starburst episodes with redshift*
- *SOFIA can detect [CII] in the redshift range z = 0.25 to 1.25*
- *This range covers most of cosmic history back to the time when the star formation rate per unit volume had peaked*
- *SOFIA can determine whether starbursts at z = 1 were galaxy-wide or spatially confined*

Key Astrophysics Question for SOFIA

Chapter 5:Planetary Science

- *Primitive Bodies*
- *Extra-Solar Planetary Material*
- *Giant Planets*
- *Venus: Earth's Neglected Sibling*
- *Titan: a Pre-biological Organic Laboratory*

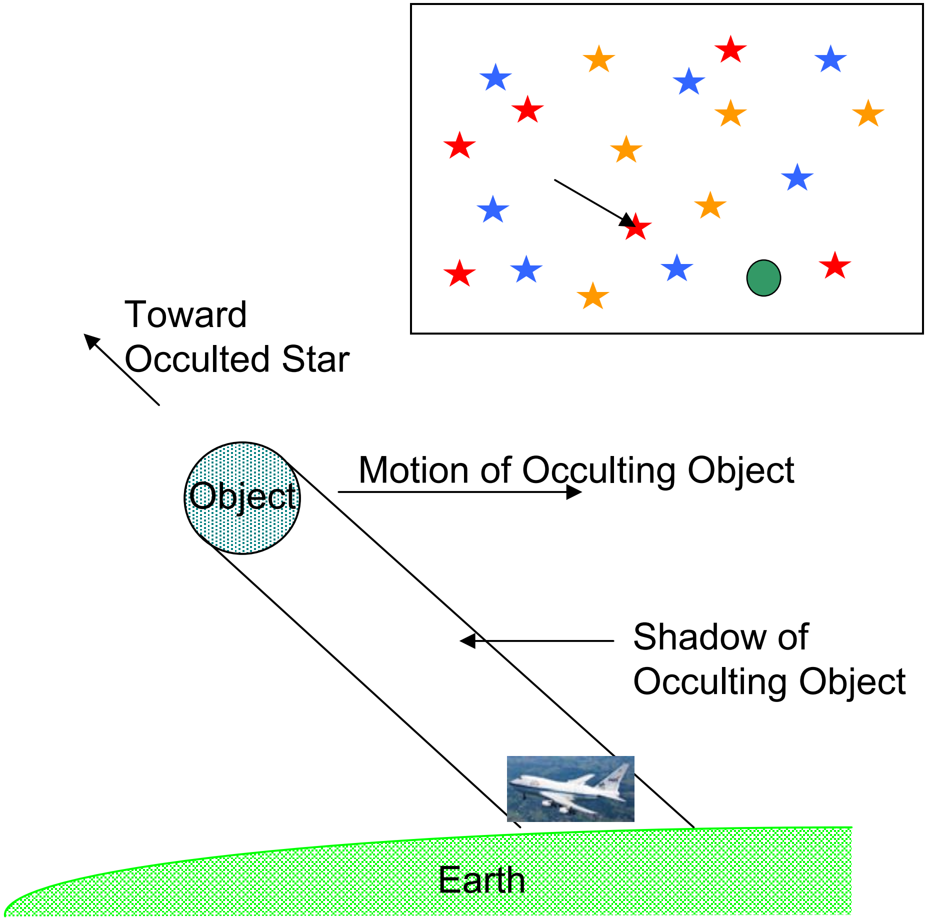
Related Objects of Opportunity

- *Bright Comets, Occultations, Transits of Extra-Solar Planets*

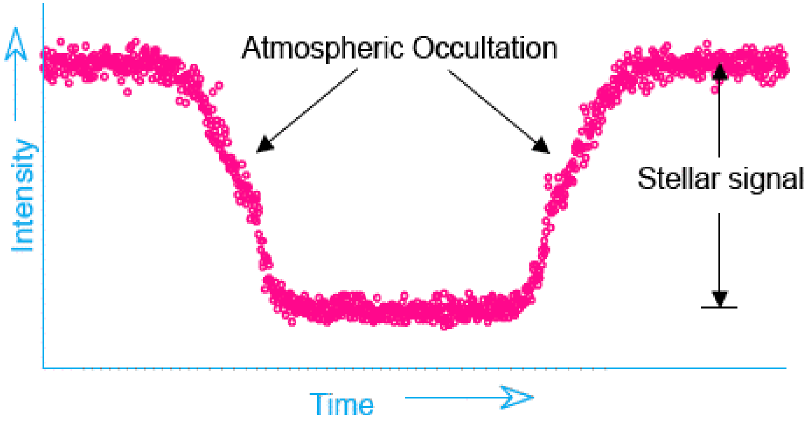
Occultation Astronomy with SOFIA

How will SOFIA help determine the properties of small Solar System bodies?

- *Occultation studies probe sizes, atmospheres, satellites, and rings of small bodies in the outer Solar system.*
- *SOFIA can fly anywhere on Earth to position itself in the occultation shadow. Hundreds of events are available per year compared to a handful for fixed ground and space-base observatories.*

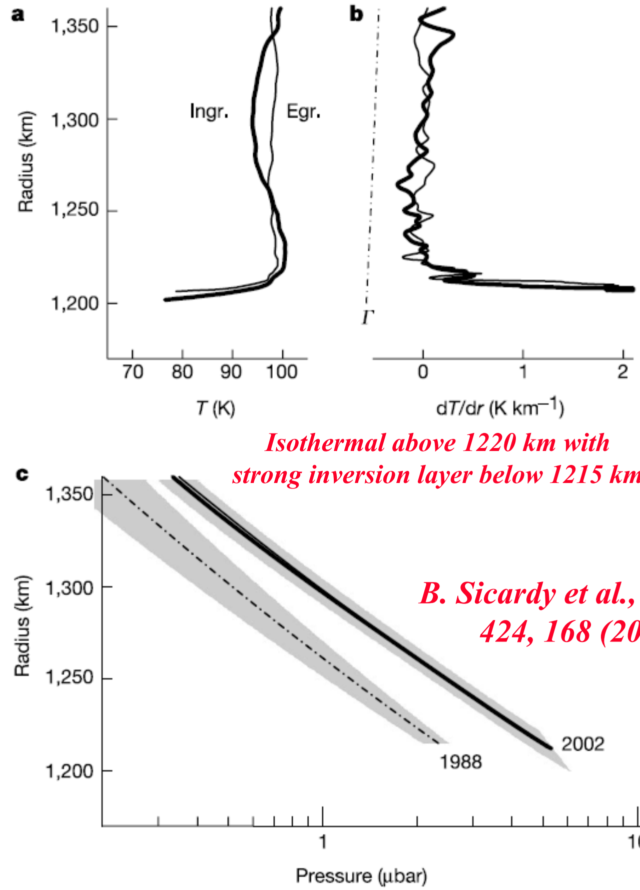


Occultations and Atmospheres



This occultation light curve observed on the KAO (1988) probed Pluto's atmosphere

J. L. Elliot et al., Icarus 77, 148-170 (1989)



Isothermal above 1220 km with strong inversion layer below 1215 km

B. Sicardy et al., Nature, 424, 168 (2003)

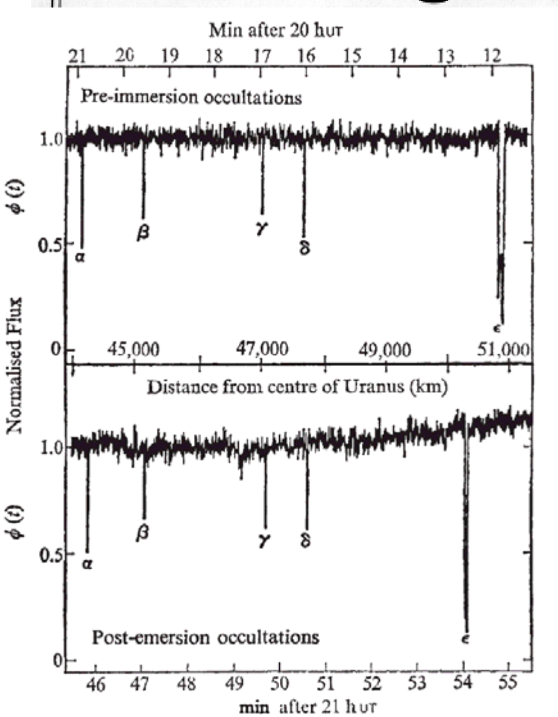
Figure 2 Temperature and pressure profiles of Pluto's atmosphere derived from the inversion of the P131.1 light curve. This inversion[17] assumes a spherically symmetric and transparent atmosphere. It first provides the atmospheric refractivity profile, then the density profile for a given gas composition, and finally the temperature profile, assuming an ideal gas in hydrostatic equilibrium. We assume for Pluto a pure molecular nitrogen[6] atmosphere,

Occultations: Rings and Moons

Uranus' Rings: The Story of a Discovery

— Sun Photo by Liz Werner

THE TEAM: Researchers Edward Dunham (l.), James Elliot, and Douglas Mink examine the unexpected signal pattern produced on the charter recorder by the outermost ring of Uranus.



This occultation light curve observed on the KAO in 1977 shows the discovery of a five ring system around Uranus

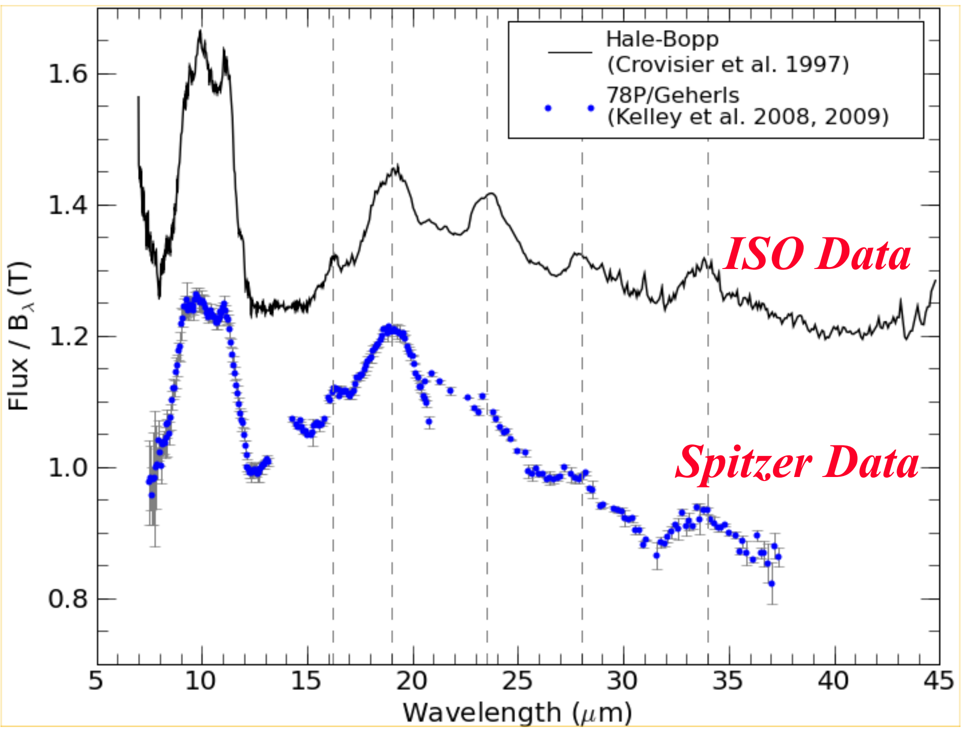
J. L. Elliot, E. Dunham, and D. Mink, Nature 267, 328-330 (1977)

Observing Comets with SOFIA

- *Comet nuclei are the Rosetta Stone of the Solar System and their ejecta reveal the contents and physical conditions of the primitive Solar Nebula when they are ablated during perihelion passage*
- *Comet nuclei, comae, tails, and trails emit primarily at the thermal IR wavelengths accessible with SOFIA*
- *Emission features from grains, ices, and molecular gases occur in the IR and are strongest when comets are near perihelion*
- *SOFIA has unique advantages: IR Space platforms like Spitzer, Herschel, and JWST) cannot view comets during perihelion passage due to pointing constraints*

SOFIA and Comets: Mineral Grains

What can SOFIA observations of comets tell us about the origin of the Solar System?



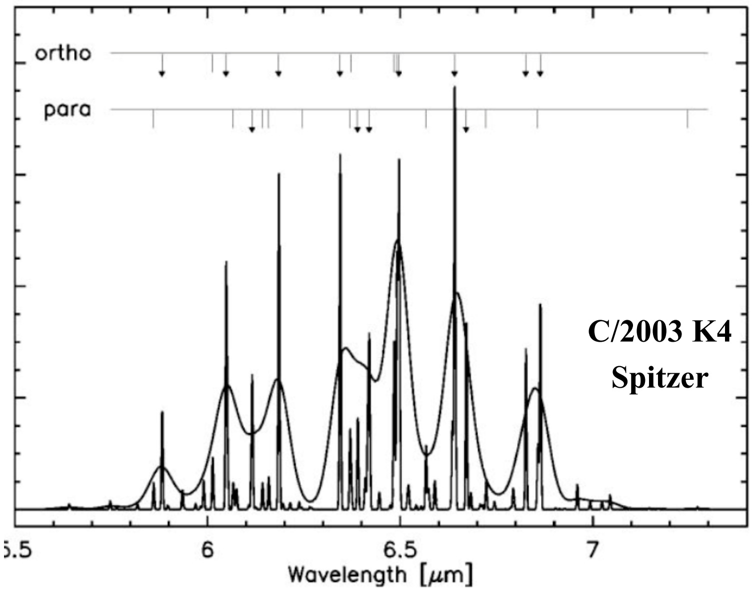
The vertical lines mark features of crystalline Mg-rich crystalline olivine (forsterite)

- ***Comet dust mineralogy: amorphous, crystalline, and organic constituents***
- ***Comparisons with IDPs and meteorites***
- ***Comparisons with Stardust***
- ***Only SOFIA can make these observations near perihelion***

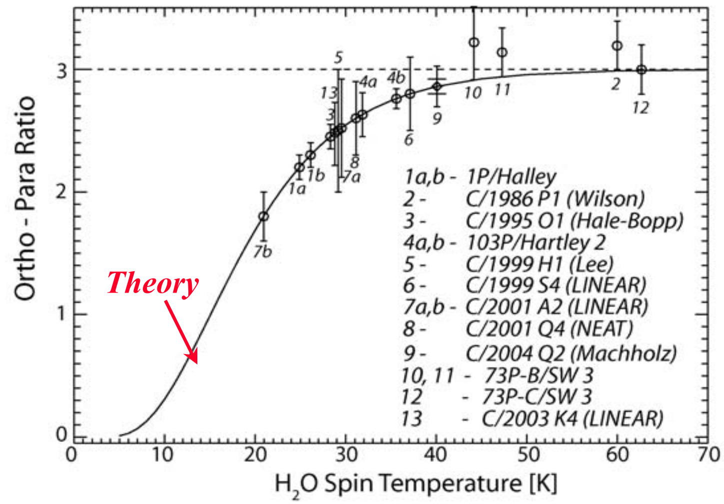
SOFIA and Comets: Gas Phase Constituents

What can SOFIA observations of comets tell us about the origin of the Solar System?

C. E. Woodward et al. 2007, ApJ, 671, 1065



B. P. Bonev et al. 2007, ApJ, 661, L97



- *Production rates of water and other volatiles*
- *Water H_2 ortho/para (parallel/antiparallel) hydrogen spin isomer ratio gives the water formation temperature; a similar analysis can done on ortho/para/meta spin isomers of CH_4*
- *Only SOFIA can make these observations near perihelion*

SOFIA and Comets: Protoplanetary Disks

What can SOFIA observations of comets tell us about the origins of our Solar System and other solar systems?

ISO Observations — Adapted from Crovisier et al. 1996, Science 275, 1904 and Malfait et al. 1998, A&A 332, 25

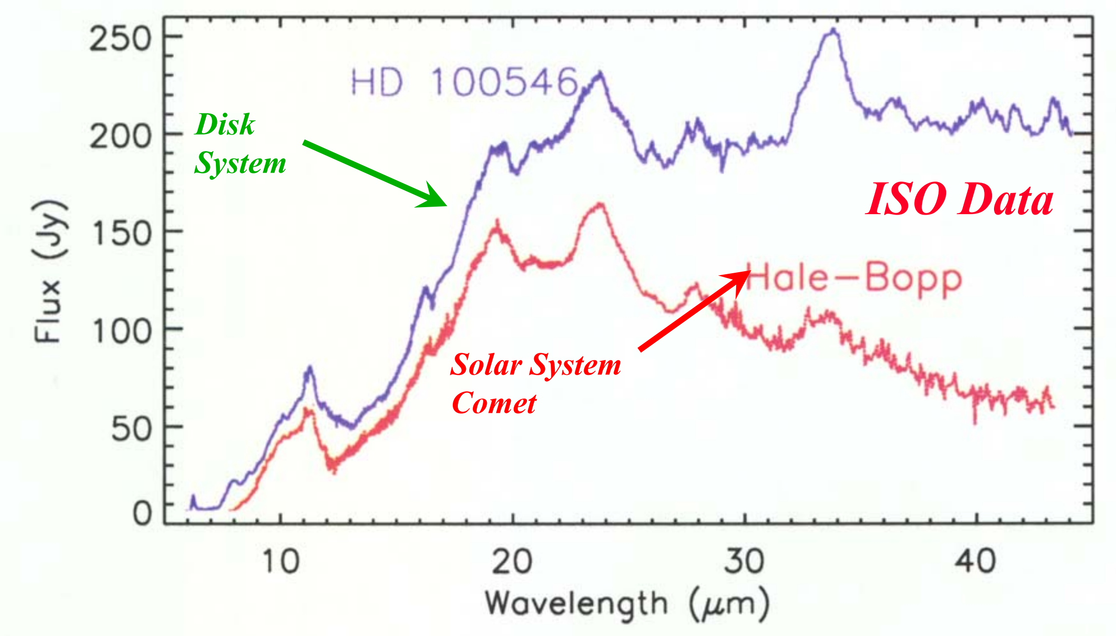
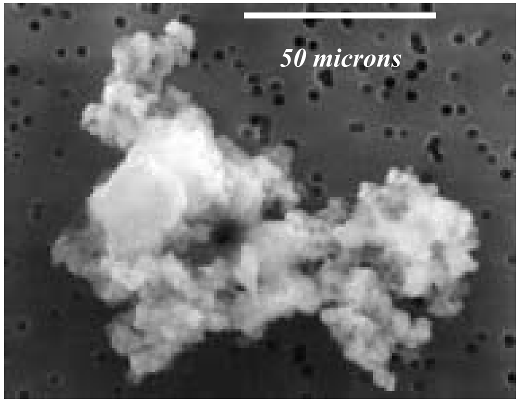
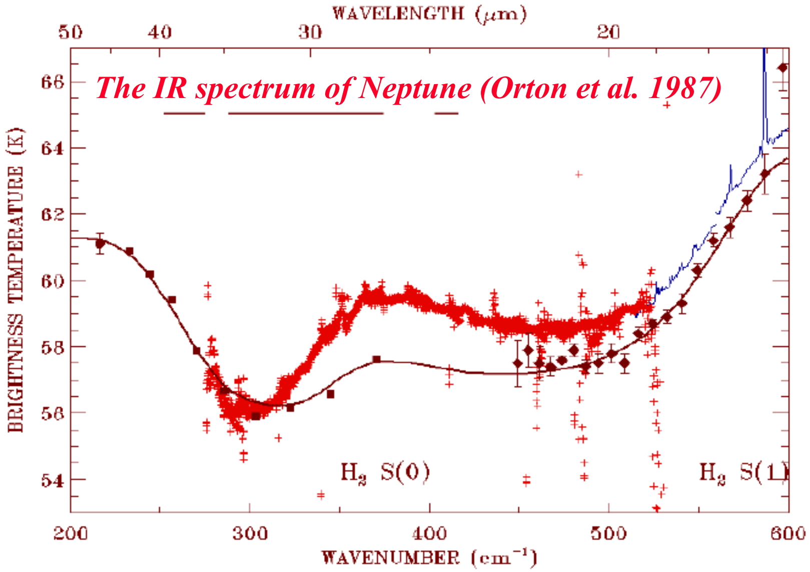


Image of Solar System IDP (Interplanetary Dust Particle)

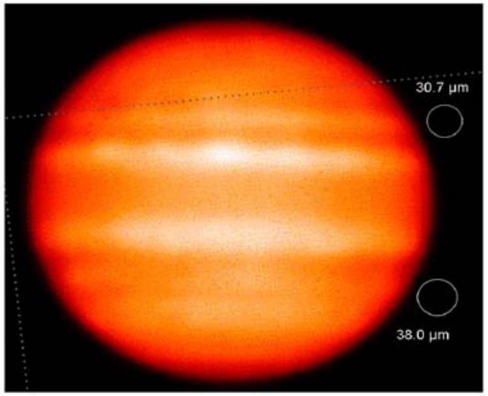


- *The similarities in the silicate emission features in HD 100546 and C/1995 O1 Hale-Bopp suggest that the grains in the stellar disk system and the small grains released from the comet nucleus were processed in similar ways*

SOFIA and the Gas Giant Planets

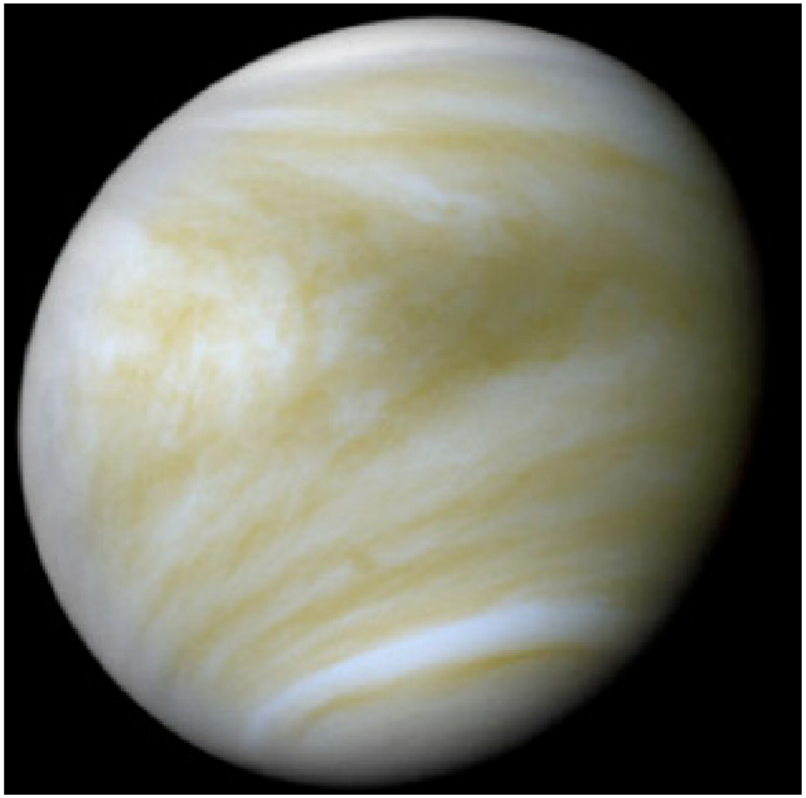


Varying thernmal emission across the face of Jupiter showing beam sizes for FORECAST (NASA IRTF image)



- SOFIA's unique capabilities of wavelength coverage, high spatial resolution, and long duration will open new windows of understanding of the giant planets through studies of their atmospheric compositions, structures, and seasonal and secular variability
- These studies may enhance our understanding of the atmospheres of large, extra-solar "hot Jupiters"

SOFIA and Venus: Earth's Neglected Sibling



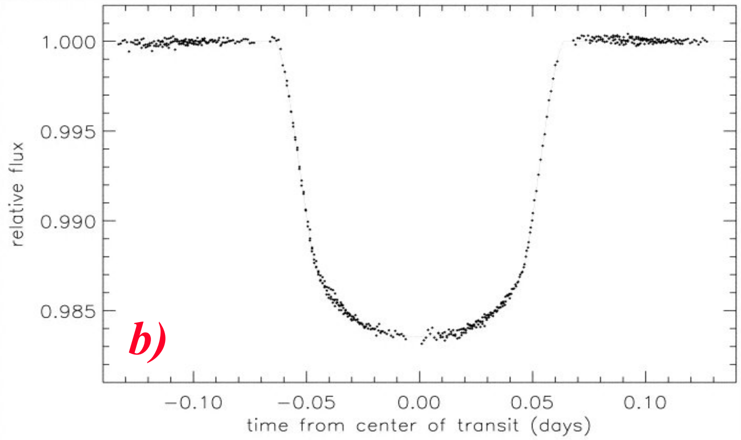
NASA **Pioneer Venus** *UV image of Venus*

- ***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***

SOFIA and Extra-solar Planet Transits

How will SOFIA help us learn about the properties of extra-solar planets?

- More than 268 extra-solar planets; more than 21 transit their primary star
- SOFIA flies above the scintillating component of the atmosphere where it can detect transits of planets across bright stars at high signal to noise



HD 209458b transit:

a) artist's concept and

b) HST STIS data

- Transits provide good estimates for the mass, size and density of the planet
- Transits may reveal the presence of, satellites, and/or planetary rings

Summary

- *The New Science Vision Report for SOFIA is now in print and will be released on June 7, 2009 at the 214th Meeting of the American Astronomical Society in Pasadena, CA*

- *SOFIA is expected to address epic scientific questions for more than a decade*

- *See our the SOFIA website at:*

  http://www.sofia.usra.edu/

Backup

The Initial SOFIA Instrument Complement

- ***HIPO: High-speed Imaging Photometer for Occultation***
- ***FLITECAM: First Light Infrared Test Experiment CAMera***
- ***FORCAST: Faint Object InfraRed CAmera for the SOFIA Telescope***
- ***GREAT: German Receiver for Astronomy at Terahetz Frequencies***
- ***CASIMIR: CAltech Submillimeter Interstellar Medium Investigations Receiver***
- ***FIFI-LS: Field Imaging Far-Infrared Line Spectrometer***
- ***HAWC: High-resolution Airborne Wideband Camera***
- ***EXES: Echelon-Cross -Echelle Spectrograph***
- ***SAFIRE: Submillimeter And Far InfraRed Experiment***

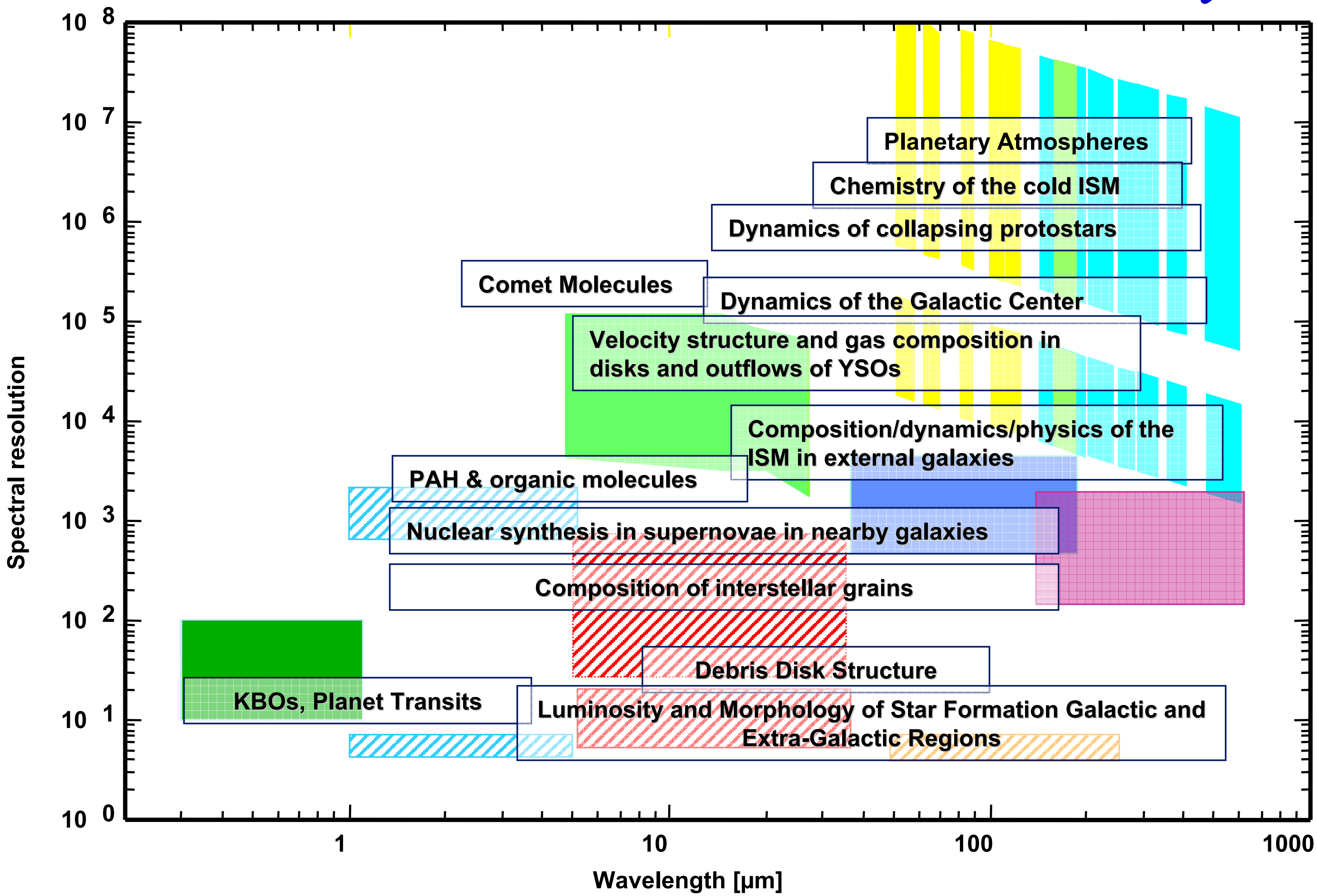
SOFIA's First-Generation Instruments

Instrument	Type	λλ (μm)	Resolution	PI	Institution
HIPO (Available 2010)	fast imager	0.3 - 1.1	filters	E. Dunham	Lowell Obs.
FLITECAM * (Available 2010)	imager/grism	1.0 - 5.5	filters/R~2000	I. McLean	UCLA
FORCAST * (Available 2009)	imager/(grism?)	5.6 - 38	filters/(R~2000)	T. Herter	Cornell U.
GREAT (Available 2009)	heterodyne receiver	62 - 65 111 - 12 158 - 187 200 - 240	R ~ 10^4 - 10^8	R. Güsten	MPIfR
CASIMIR (Available 2011)	heterodyne receiver	250 -264, 508 -588	R ~ 10^4 -10^8	J. Zmuidzinas	Caltech
FIFI LS ** (Available 2009)	imaging grating spectrograph	42 - 110, 110 - 210	R ~1000 - 2000	A. Poglitsch	MPE
HAWC * (Available 2011)	imager	40 - 300	filters	D. A. Harper	Yerkes Obs.
EXES (Available 2011)	imaging echelle spectrograph	5 - 28.5	R ~ 3000 - 10^5	J. Lacy	U. Texas Austin
SAFIRE (Available 2012)	F-P imaging spectrometer	150 - 650	R ~ 1000 - 2000	H. Moseley	NASA GSFC

** Facility-class instrument*

*** Developed as a PI-class instrument, but will be converted to Facility-class during operations*

SOFIA: Science For the Whole Community



DSI, University of Stuttgart, Stuttgart, Germany, May 18, 2009

R. D. Gehrz