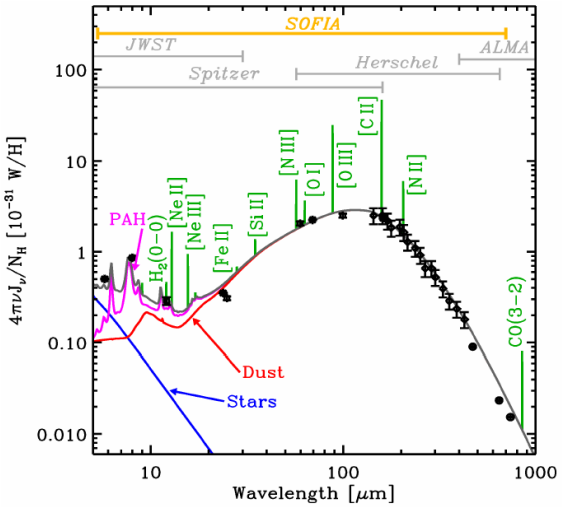
Infrared Spectroscopic Studies of the Physics and Chemistry of Stellar Evolution with the Stratospheric Observatory for Infrared Astronomy (SOFIA)



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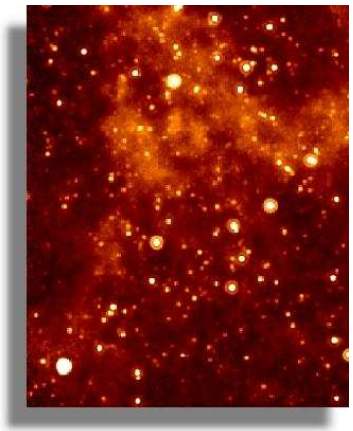
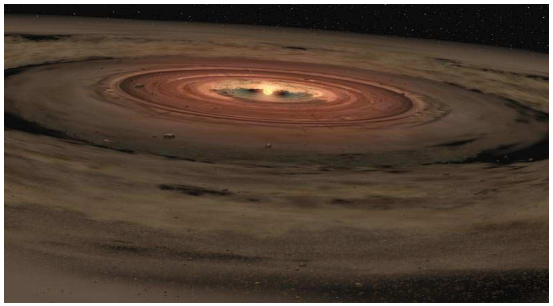
This talk is at: *http://www.sofia.usra.edu/Science/speakers/index.html*

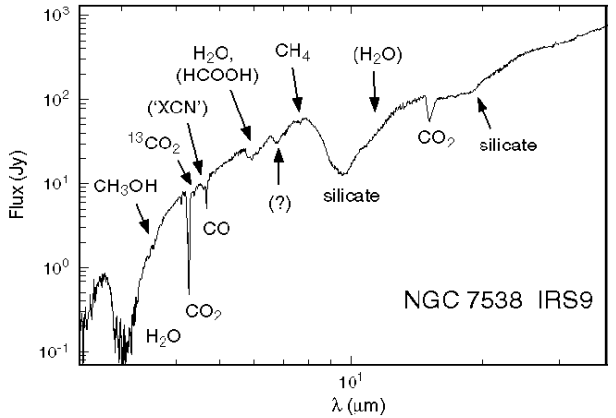
Outline

- ***SOFIA and the Chemical Evolution of the Universe***
- ***Science addressed by Infrared Spectroscopy with SOFIA***
- ***Summary***

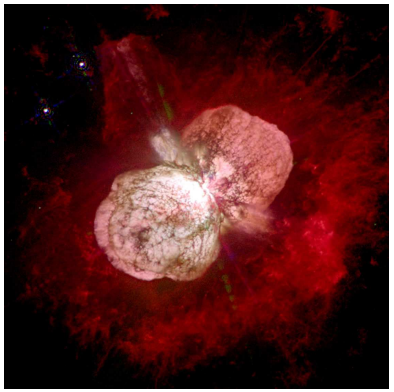
Studying the Physics and Chemistry of Stellar Evolution with SOFIA

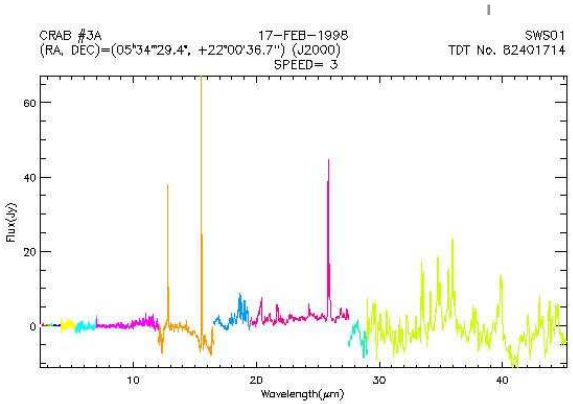






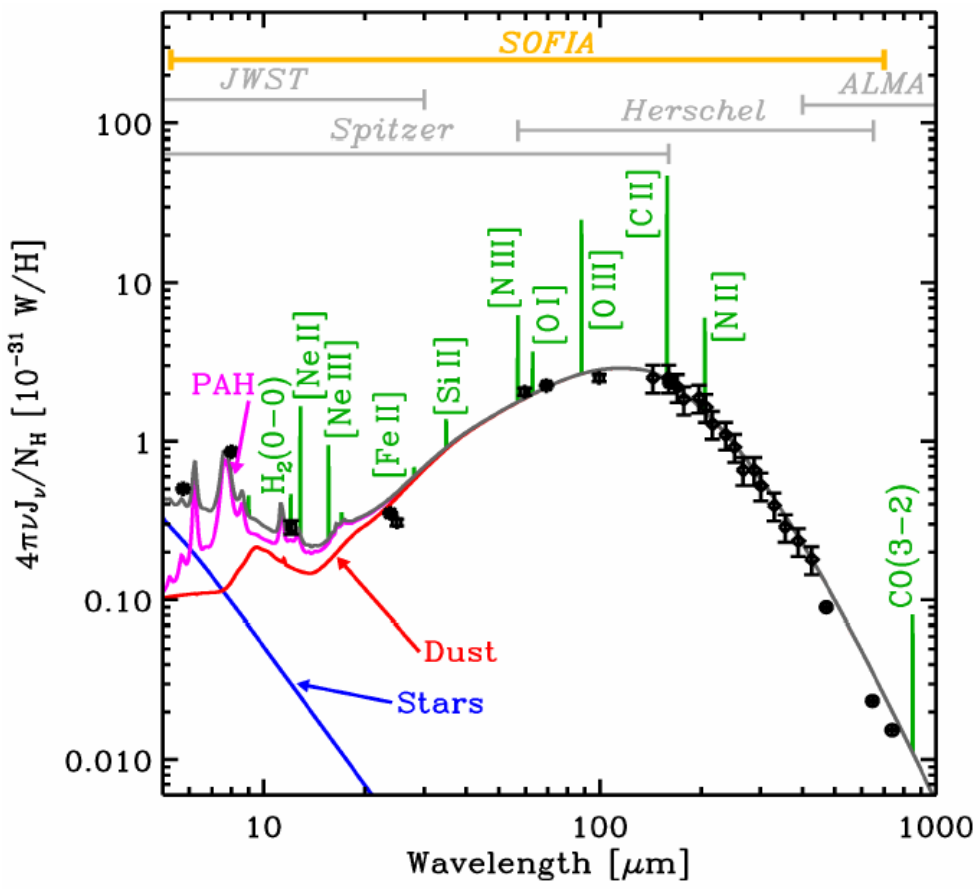
The formation of stars and planetary systems





The winds and remnants of evolved and dying stars

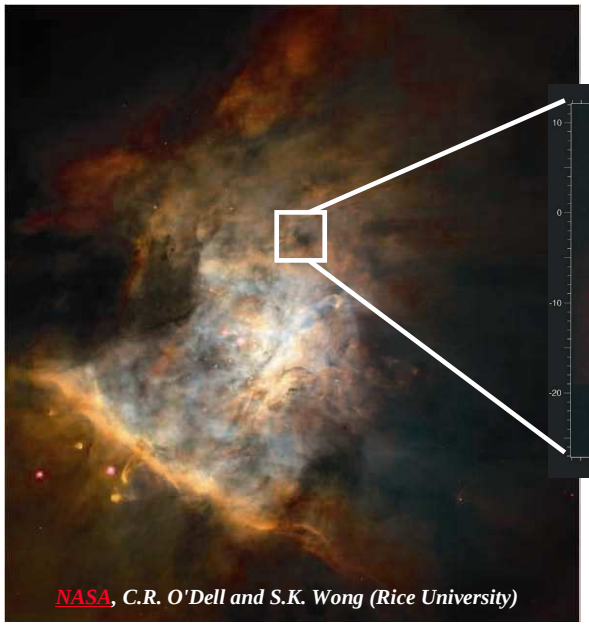
Emission from Gas and Dust in Star Forming Clouds

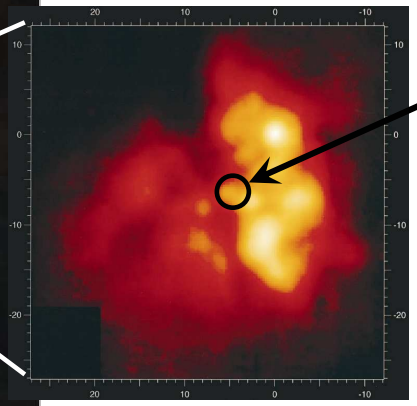


Spectral Energy Distribution (SED) of the entire LMC (courtesy of F. Galliano)

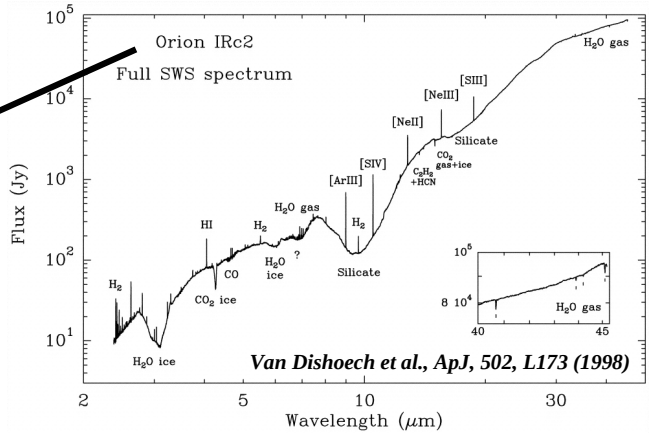
- *SOFIA is the only mission in the next decade that is sensitive to the entire Far-IR SED of a galaxy that is dominated by emission from the ISM excited by radiation from massive stars and supernova shock waves*
- *The SED is dominated by PAH emission, thermal emission from dust grains, and by the main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

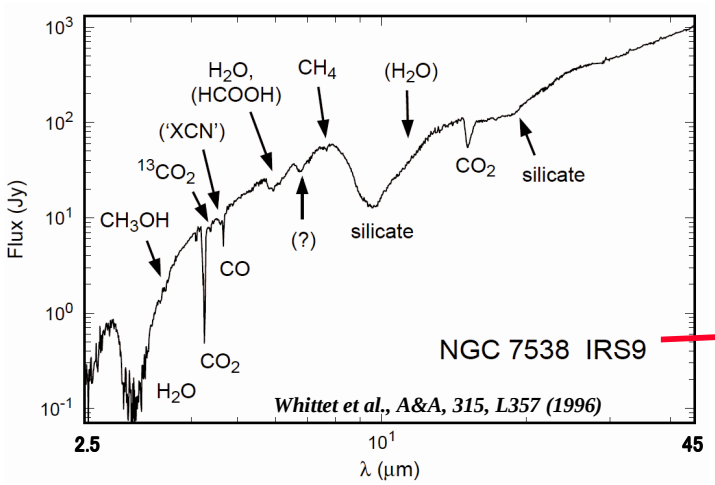
Sources Embedded in Massive Cloud Cores

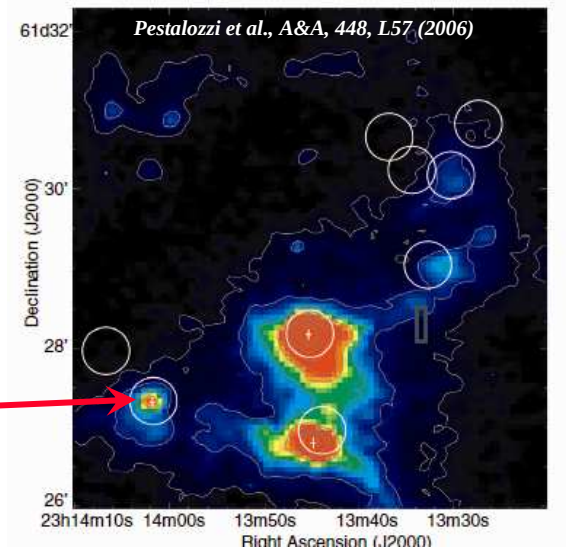




Gezari, Backman, and Werner, ApJ 509, 283 (1998)

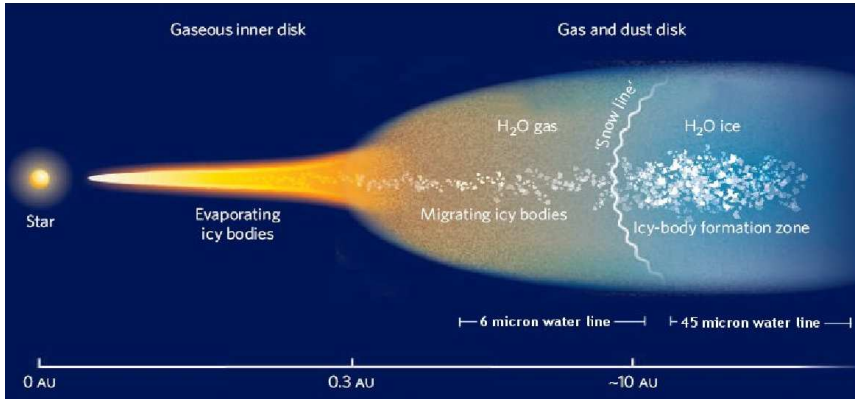






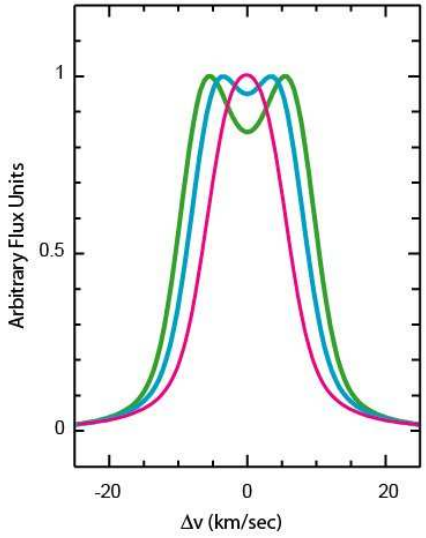
The chemistry of disks with radius and Age

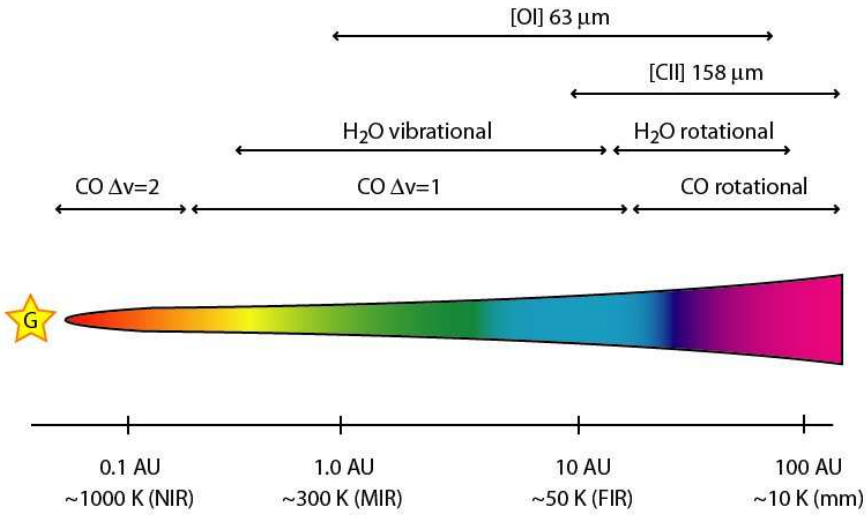
- *High spatial and spectral resolution can determine where different species reside in the disk*



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

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

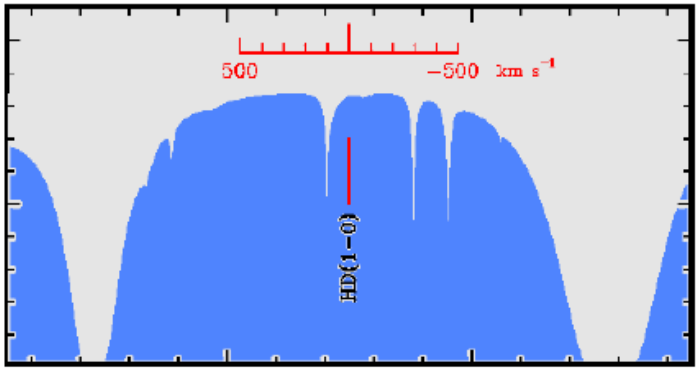




SOFIA Observations of ISM HD

- *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

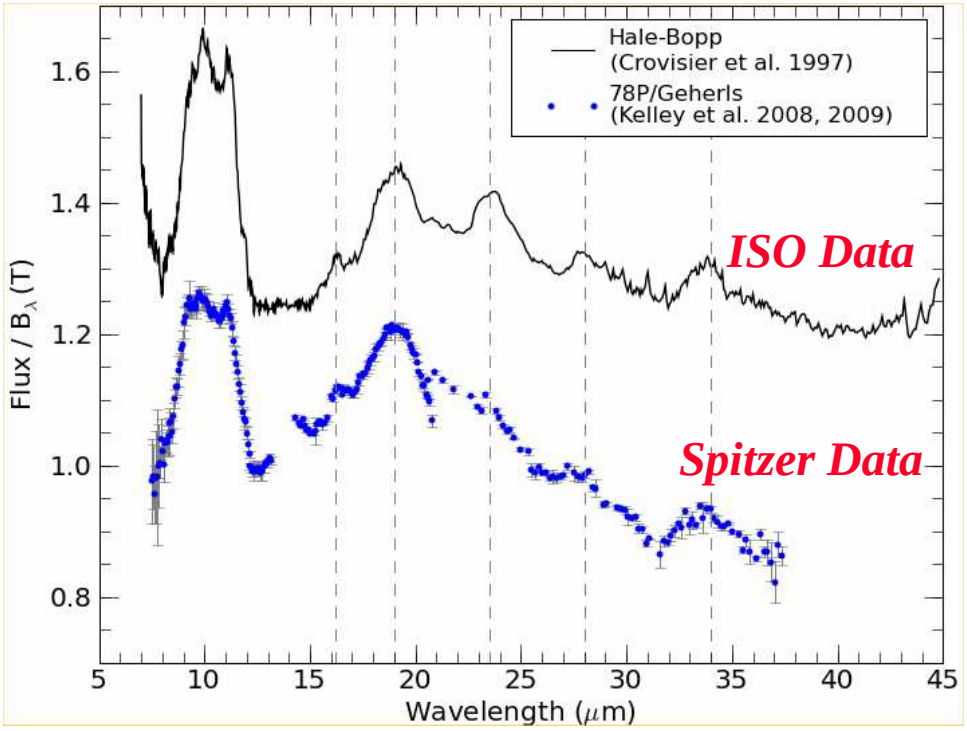
- *112 μm observations of HD can be used to determine ISM H/D abundances*
- *Cold HD (T<50K) is a proxy for cold molecular Hydrogen,*
- *The 112 μm line can be used to map the Galactic distribution of cold molecular gas just as 21 cm maps the distribution of neutral hydrogen*

Observing Comets with SOFIA

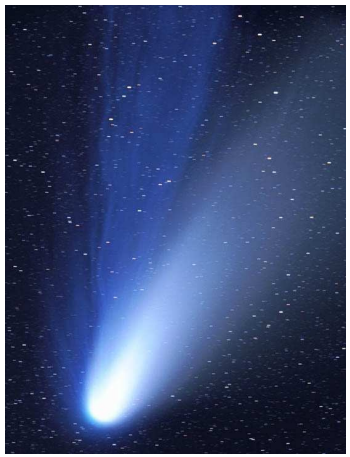
- *Comet nuclei are the Rosetta Stone of the Solar System and contain a frozen record of the contents and physical conditions of the primitive Solar Nebula*
- *Comet nuclei, comae, tails, and trails emit primarily at the thermal IR wavelengths accessible with SOFIA*
- *IR Emission features from grains, ices, and molecular gases 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)

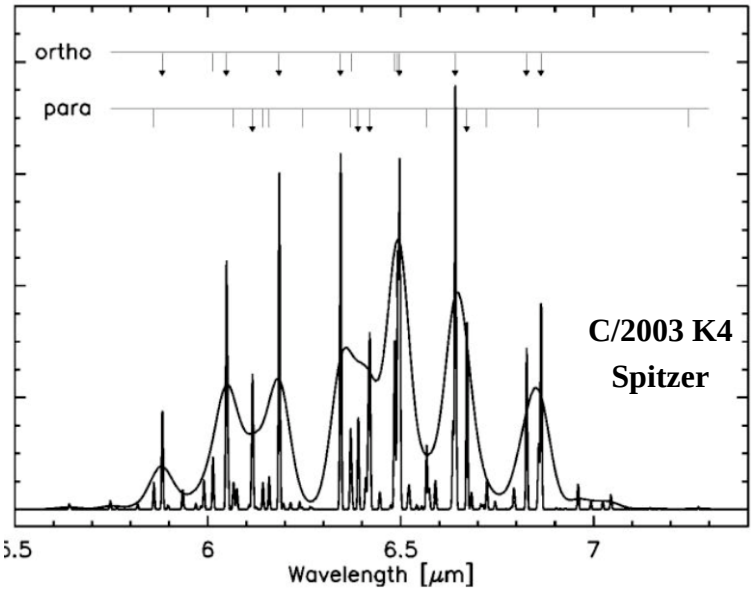


- ***Comet dust mineralogy: amorphous, crystalline, and organic constituents***
- ***Comparisons with IDPs and meteorites***
- ***Comparisons with Stardust***
- ***Only SOFIA can make these observations near perihelion***

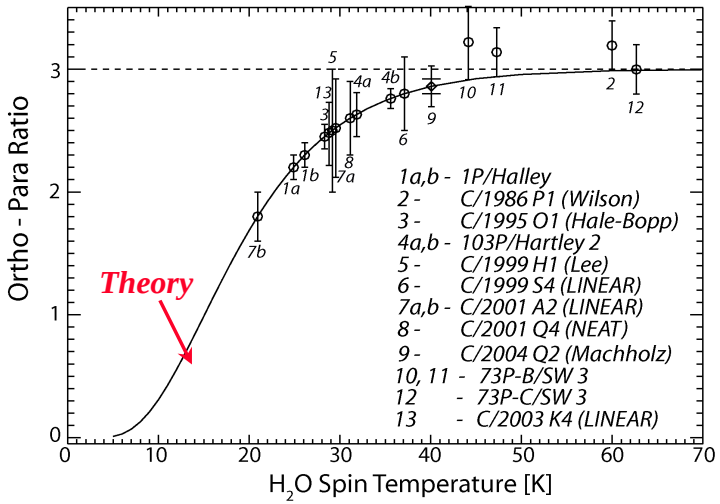
SOFIA and Comets: Gas Phase Constituents

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

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



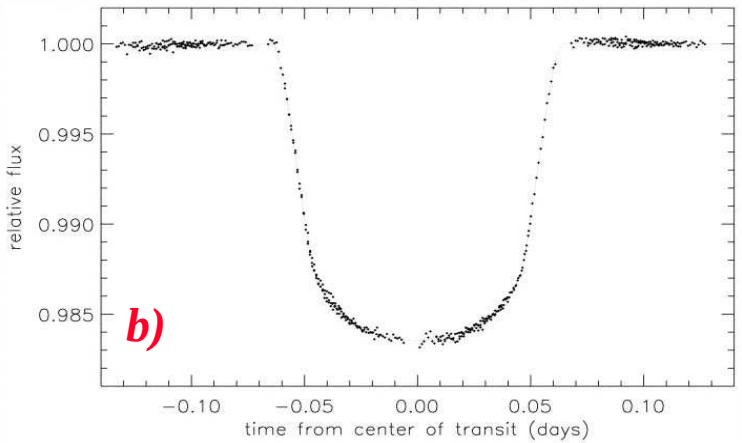
B. P. Bonev et al. 2007, ApJ, 661, L97



- *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 Extra-solar Planet Transits

- *There are 358 extra-solar planets; more than 59 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*



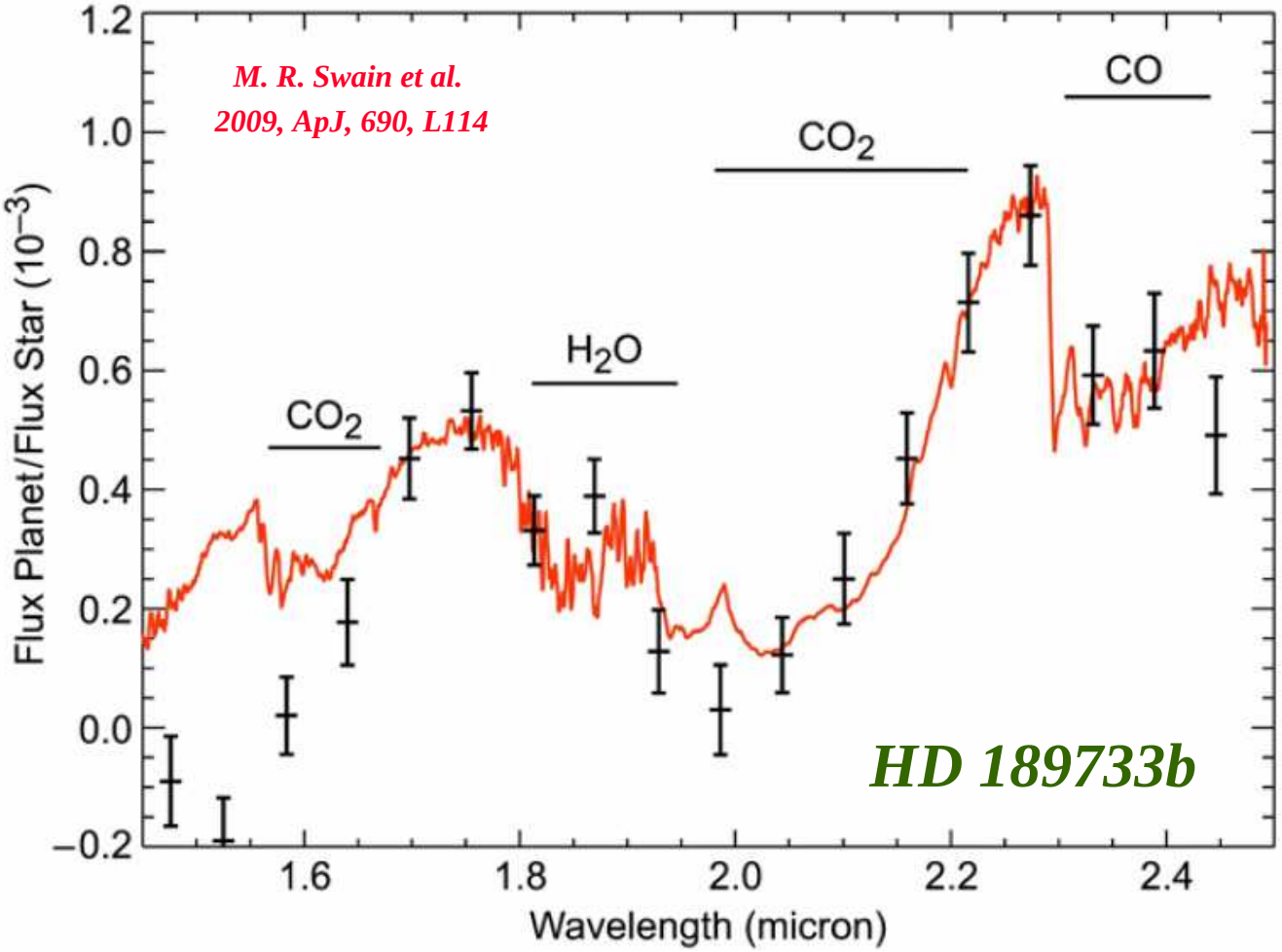
HD 209458b transit:

a) artist's concept and

b) HST STIS data

- *Transits provide estimates for the mass, radius and density of the planet*
- *Transits can reveal the presence of, satellites, and/or planetary rings*
- *Spectroscopic observations can reveal the presence and composition of an atmosphere*

Detection of Biogenic Molecules in Extrasolar Planetary Atmospheres by the transit Method



SOFIA Will Study the Diversity of Stardust

Herbig AeBe

Post-AGB and PNe

Mixed chemistry post-AGB

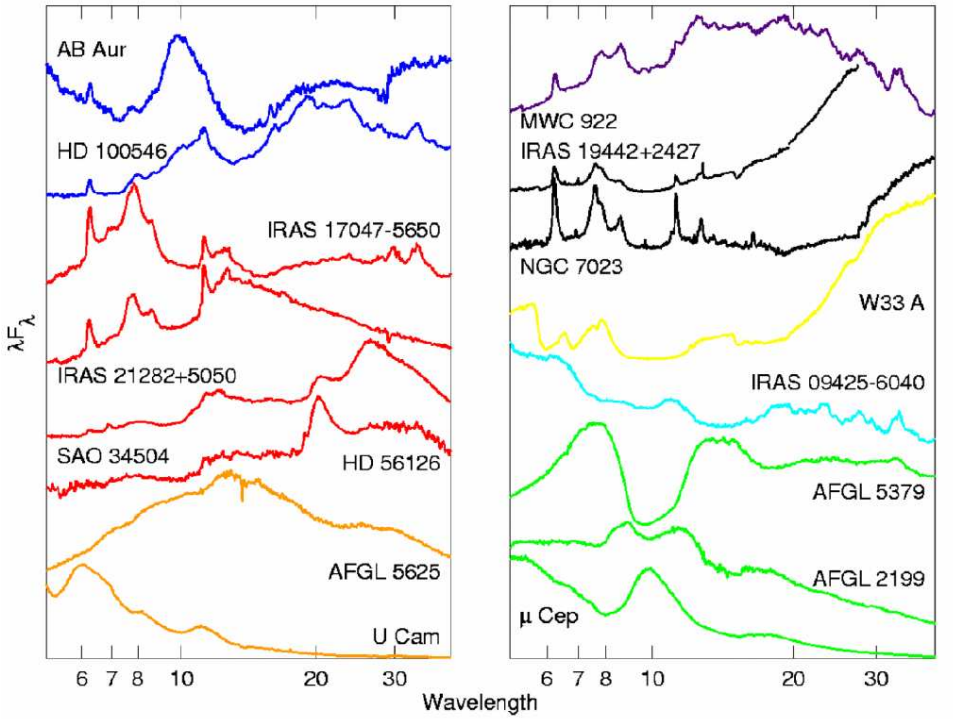
C-rich AGB

O-rich AGB

Mixed chemistry AGB

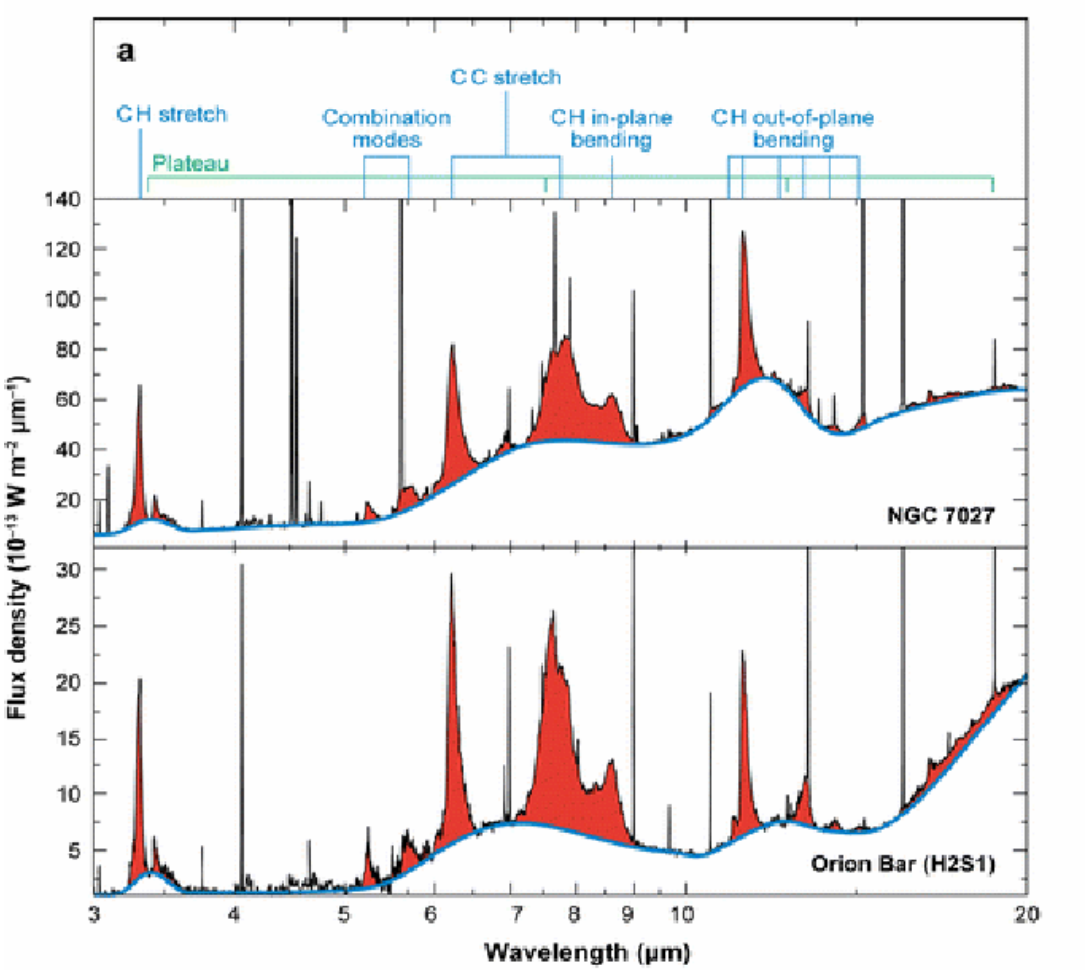
Deeply embedded YSO

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

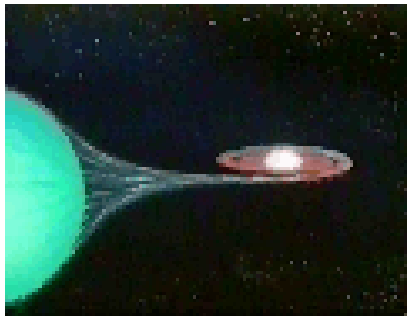


Vibrational modes of PAHs in a planetary nebula and the ISM (A. Tielens 2008)

- *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*

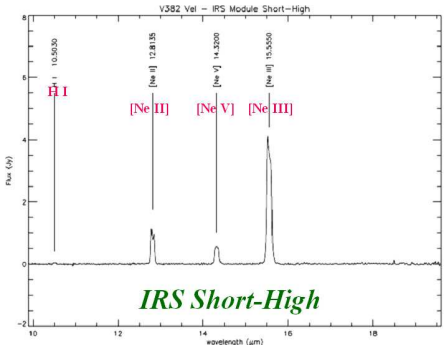
SOFIA and Classical Nova Explosions

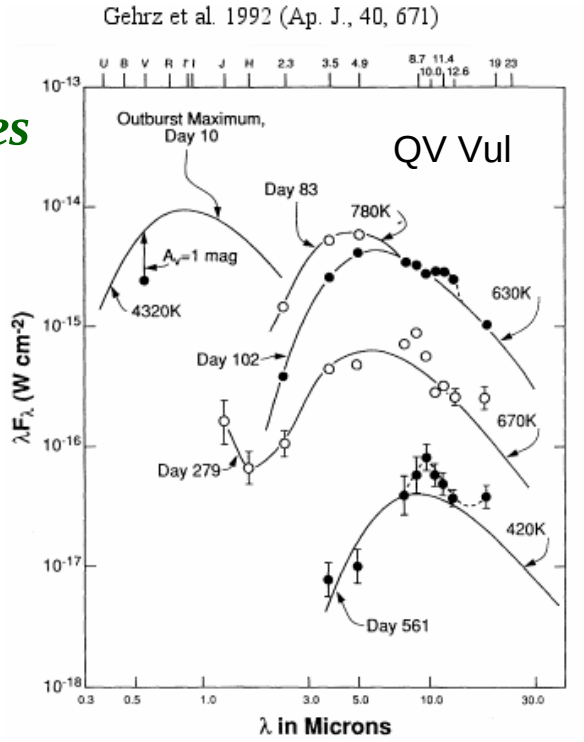
What can SOFIA tell us about gas phase abundances and dust minerology in classical nova explosions?



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

Nova V382 Vul, *Spitzer*





- ***Gas phase abundances of C, N, O, Mg, Ne, Al***
- ***SOFIA's wavelength and spectral range enables coverage of all forbidden lines and features of astrophysical dust components***
- ***Kinematics of the ejection***
- ***Contributions to ISM clouds and primitive solar system***

Summary

- *SOFIA will be a premier facility for far-IR and submillimeter spectroscopy for many years*
- *It will be especially effective for studies of the physics and chemistry of many stages in the process of stellar evolution:*
  - *Regions of star formation and ISM clouds*
  - *Luminous young stellar objects*
  - *Proto-planetary disks*
  - *Comets and planetary atmospheres*
  - *The winds of evolved stellar systems*

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

Backup

Astrochemistry in Star Forming Regions

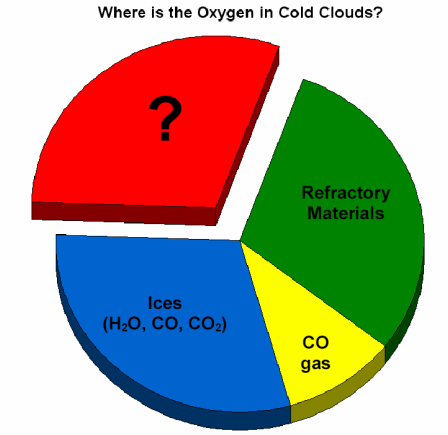
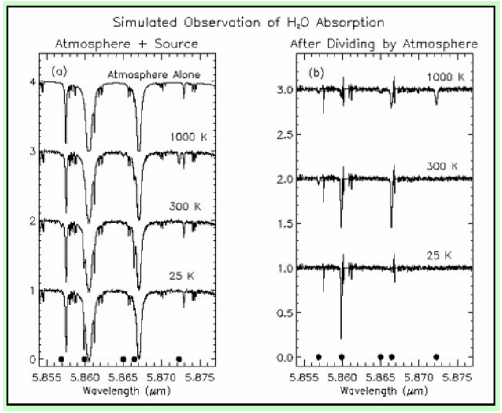


Figure 2-6. *A pie chart showing the oxygen budget in cold clouds. Almost 1/3 of the oxygen is unaccounted for.*



- ***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***