



# Spitzer and SOFIA

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14 October 2009



# Some Areas where Spitzer has set the Stage for SOFIA (1/2)



| Spitzer Area   | SOFIA Opportunity  | Comments   |
|--|--|--|
| Protostellar/protoplanetary disk spectroscopy of potentially biogenic molecules                      | Higher resolution for mass determination, isotopic studies   | Many species not accessible from ground; wavelength too short for Herschel. What can ALMA do?  |
| Spatial, spectral dissection of nearby spiral galaxies, including the Magellanic clouds              | Spectroscopy of active and quiescent regions of the ISM; isotopic abundance gradients; higher resolution imaging, etc.         | Spectra from 5-60um – H <sub>2</sub> , fine structure lines, CO, etc. may be SOFIA niche. Higher resolution imaging longward of ~50um may not compete well with Herschel |
| Comets – dust and gas phase studies, including mineralogy and comparison to exoplanet system studies | Gas phase and solid state spectroscopy of all bright comets; approach closer to sun; draw connections to exoplanetary material | Mid-IR key for mineralogy – many molecules of interest not easily accessible from the ground   |
| Debris Disk photometry, imaging, and phenomenology.  | Imaging studies of highest surface brightness systems  | SOFIA imaging suffers from lower surface brightness sensitivity – may be worth looking at brightest cases, particularly shortward of ~50um                               |
| Transit/eclipse photometry of exoplanets – a major discovery area for Spitzer                        | Unclear but should be tried to get access to full wavelength range   | Spitzer's high stability enabled this; see Mark Swain for SOFIA possibilities<br>mww-2 – 10/14/2009  |

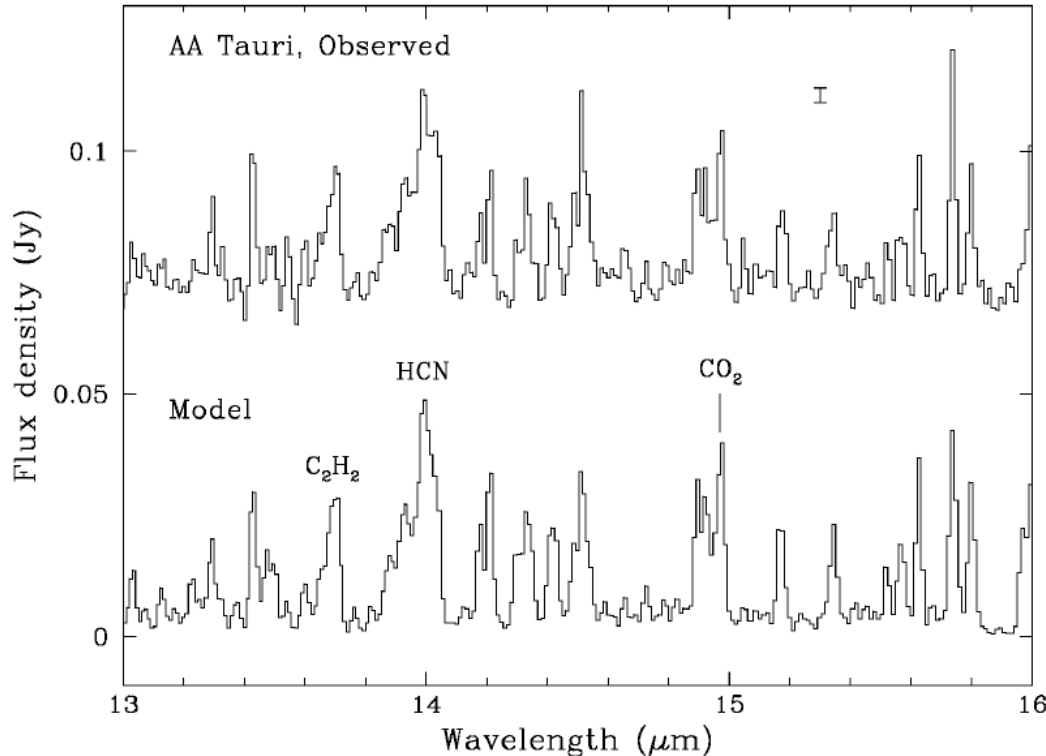


# Some Areas where Spitzer has set the Stage for SOFIA (2/2)



| Spitzer Area   | SOFIA Opportunity  | Comments   |
|--|--|--|
| Mapping and cataloging the infrared emission from the galactic plane from 3.6 to 70um  | Systematic but targeted studies of IR dark clouds, filament polarimetry, young clusters, etc. See comment in last line below   | Here Spitzer data could enable many, many projects. SOFIA's resolution could be critical in complex regions; polarimetry probably best example of something unique to SOFIA. Spitzer data will allow study of regions and problems other than bright cloud cores |
| PAH phenomenology  | Higher resolution spectroscopy may be informative; search for C60 lines as well  | Try looking with higher spatial and spectral resolution in a range of environments. Need to pose the PAH question carefully to gain understanding. Higher resolution spectra important for 7-9um C60 lines.  |
| Low mass star formation has been very systematically studied by Spitzer – time scales, protostellar mineralogy, disk dissipation, etc. | High mass star formation studies to complement Spitzer's work on low mass stars. Spitzer has not done much mapping of the really bright FIR sources studied from KAO | Specific studies could include study of UC HII regions, use SOFIA's resolution to sort out complex structures, searching for circumstellar disks, etc. Note that studying high mass star formation was part of initial GLIMPSE motivation                        |
| Massive archive of everything from NEOs to galaxies producing reionization to the IR background  | Systematic programs including dozens of objects; may influence science utilization model   | Exploitation of archive [and later that of Herschel] will continue to reveal science questions uniquely accessible to SOFIA  |

# Organic Molecules in a Protoplanetary Disk



## Model Fit Shows:

- Gas at temperature ~400-600K
- Emitting region a few astronomical units in size
- Abundances relative to CO increased by order of magnitude

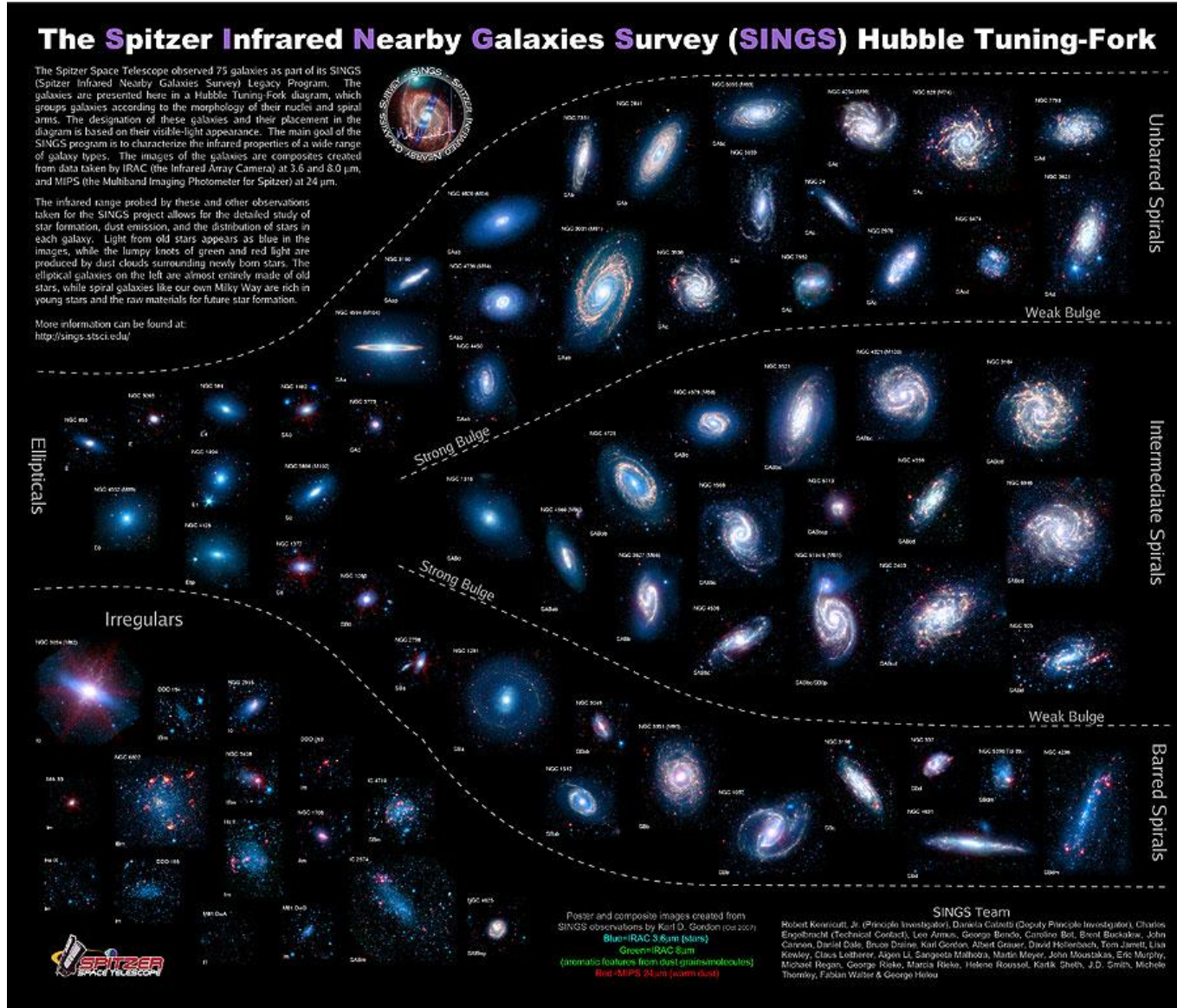
Perhaps we are seeing buildup of organic material in inner regions of a young solar system

## The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0  $\mu\text{m}$ , and MIPS (the Multiband Imaging Photometer for Spitzer) at 24  $\mu\text{m}$ .

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at: <http://sings.stsci.edu/>



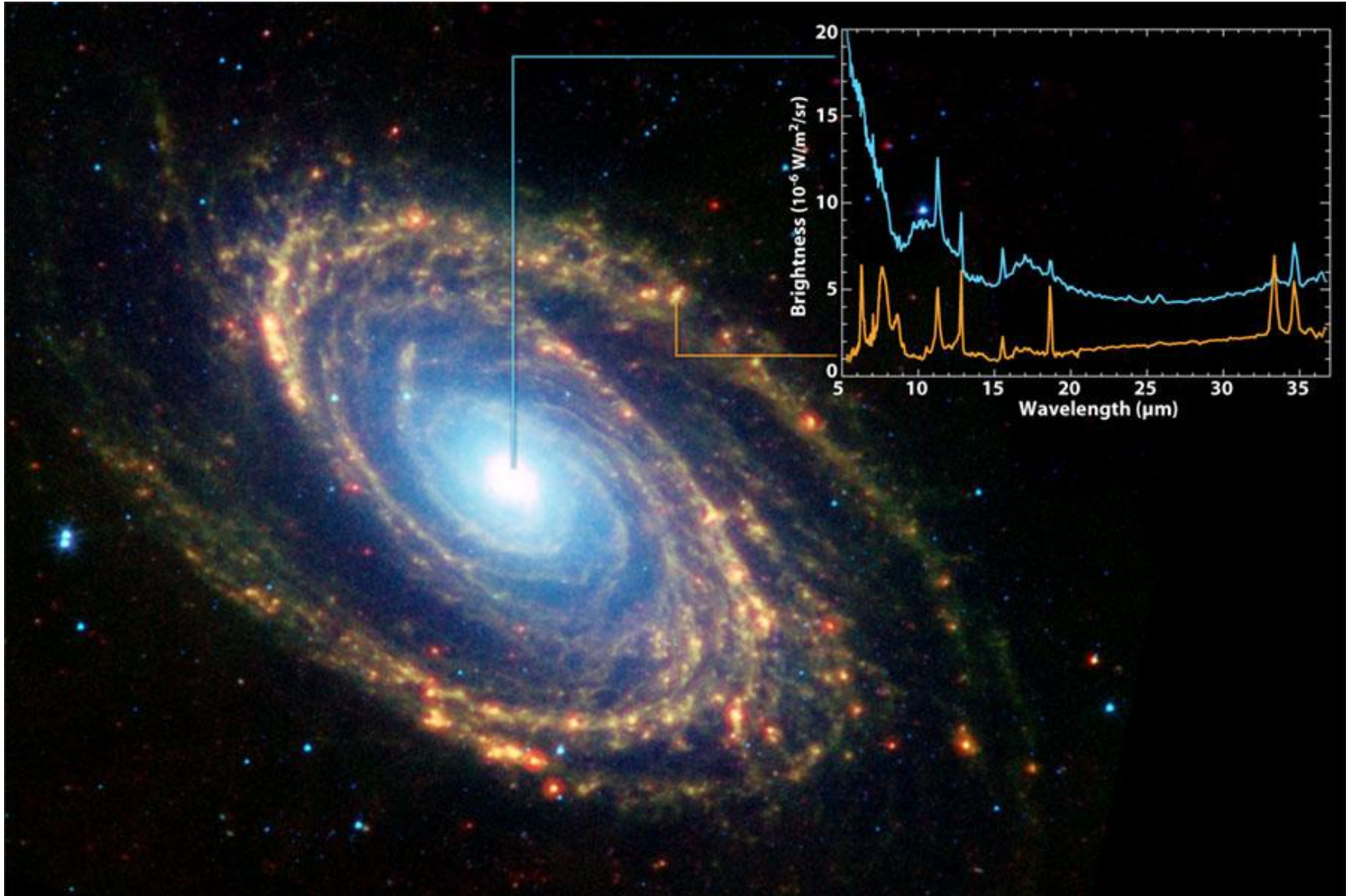
Poster and composite images created from SINGS observations by Karl O. Gordon (pi2202)   
**Blue**=IRAC 3.6  $\mu\text{m}$  (stars)   
**Green**=IRAC 8  $\mu\text{m}$  (aromatic features from dust grains/molecules)   
**Red**=MIPS 24  $\mu\text{m}$  (warm dust)

### SINGS Team

Robert Kennicutt, Jr. (Principal Investigator), Daniela Calzetti (Copyy Principle Investigator), Charles Engelbracht (Technical Contact), Leo Armus, George Bendo, Carolina Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Robert Gruen, David Hollenbach, Tom Jarrett, Lisa Kewley, Steve Lohriver, Ajay Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Karik Sheh, J. D. Smith, Michele Thornley, Fabian Walter & George Helou



# Spitzer Data on M81 with All Three Instruments

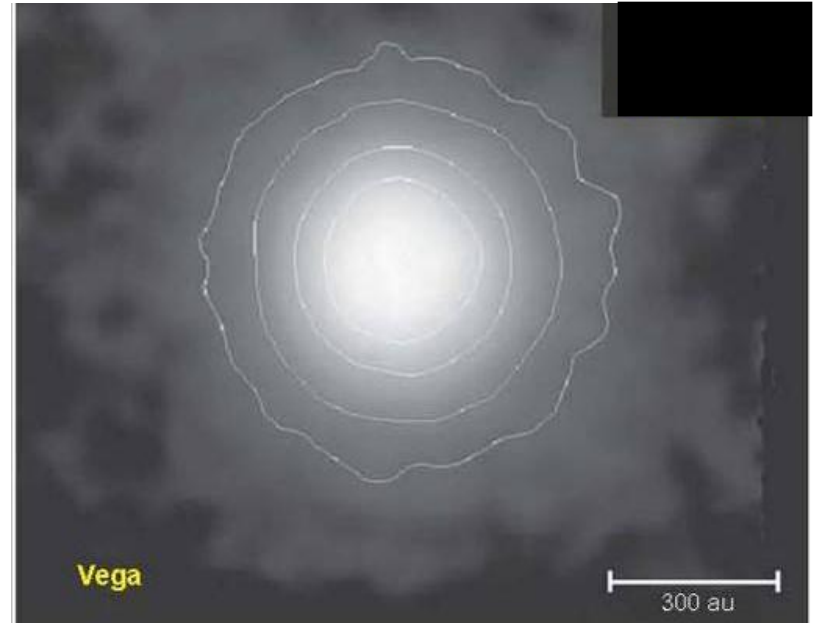
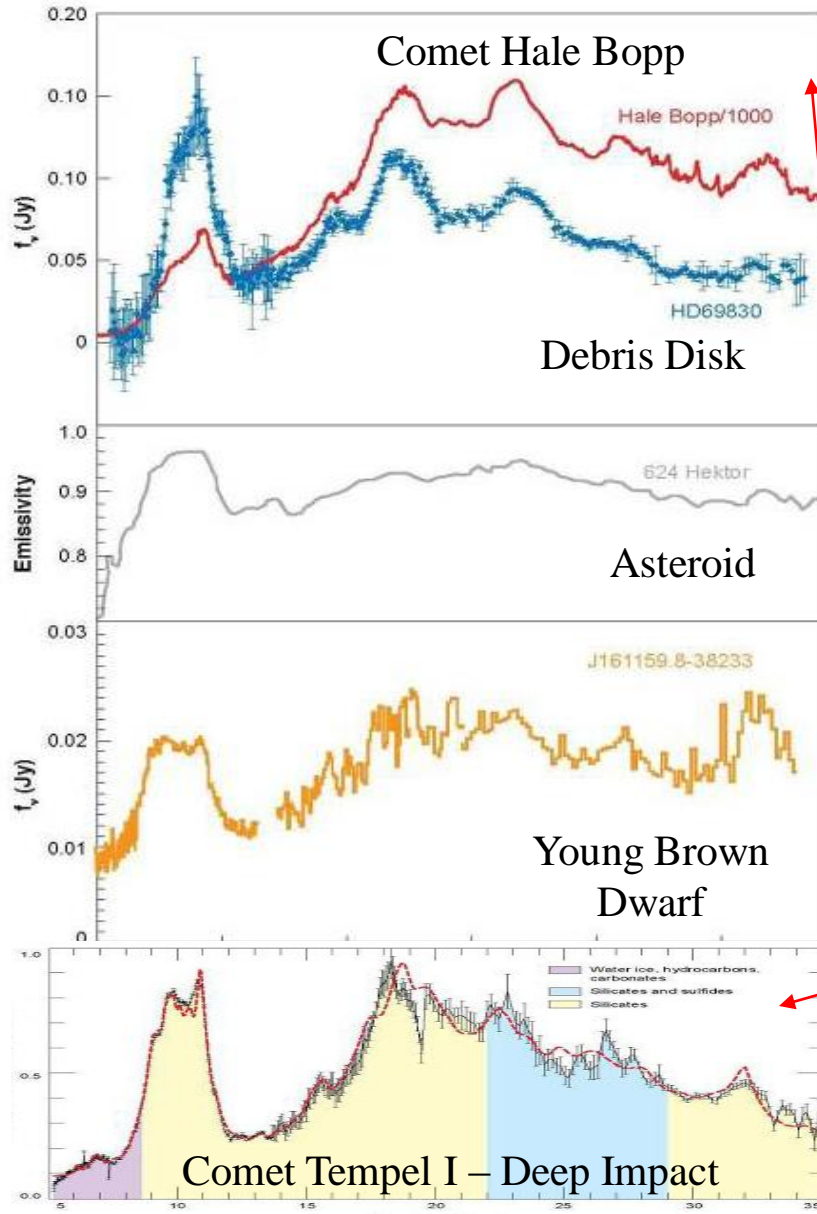




# IRAC/MIPS Image of LMC; Significant IRS Studies Also Done



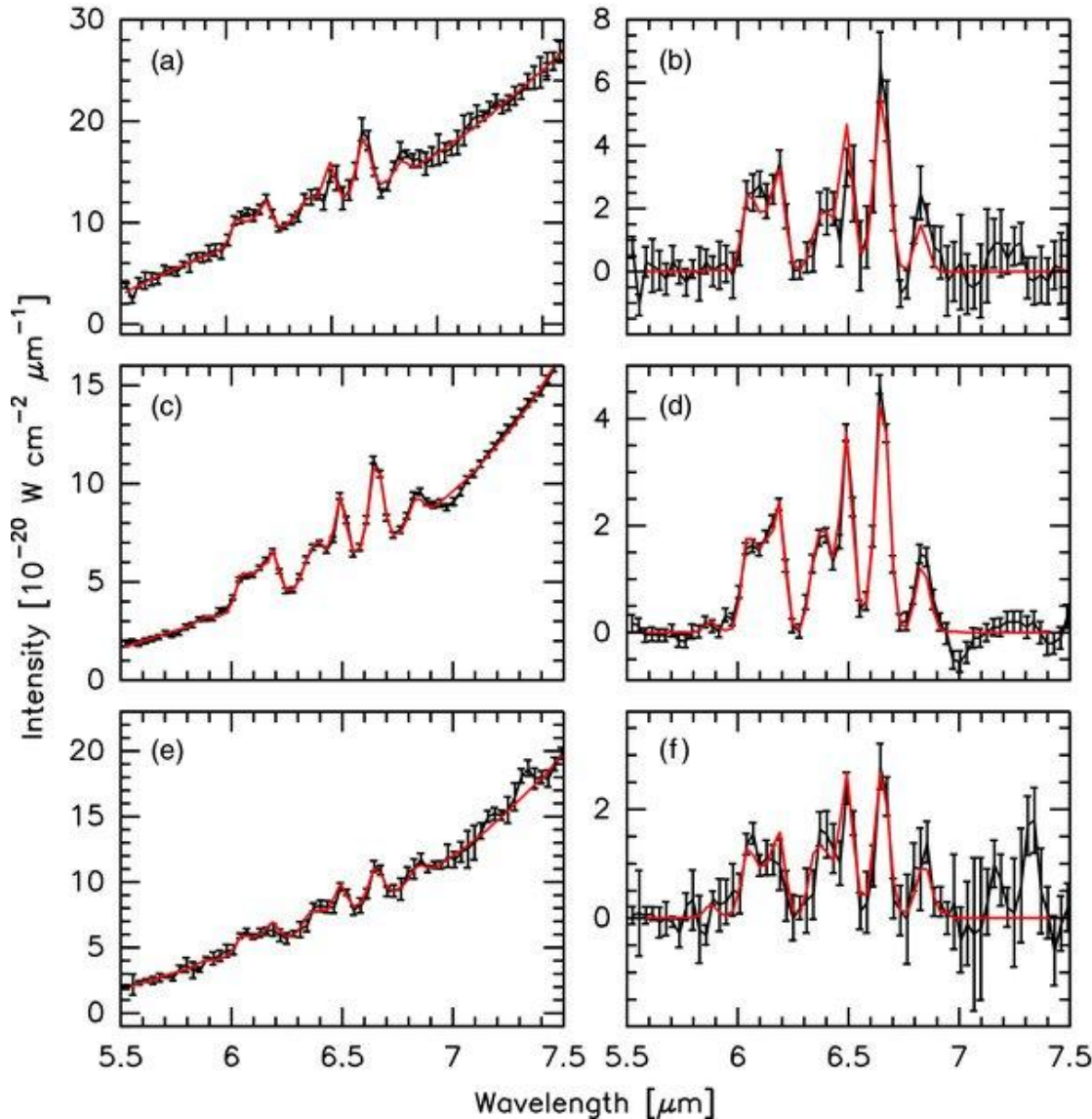
Large Magellanic Cloud Spitzer Space Telescope • IRAC • MIPS  
NASA / JPL-Caltech / M. Meixner (STScI) & the SAGE Legacy Team ssc2006-17b



Silicate mineralogy strikingly similar in our own solar system and in extrasolar planetary systems



# Gas Phase Studies Should Also be Possible for Comets



- This is data from Woodward et al on H<sub>2</sub>O in a comet

# Can SOFIA Image the Vega Disk at 70um?

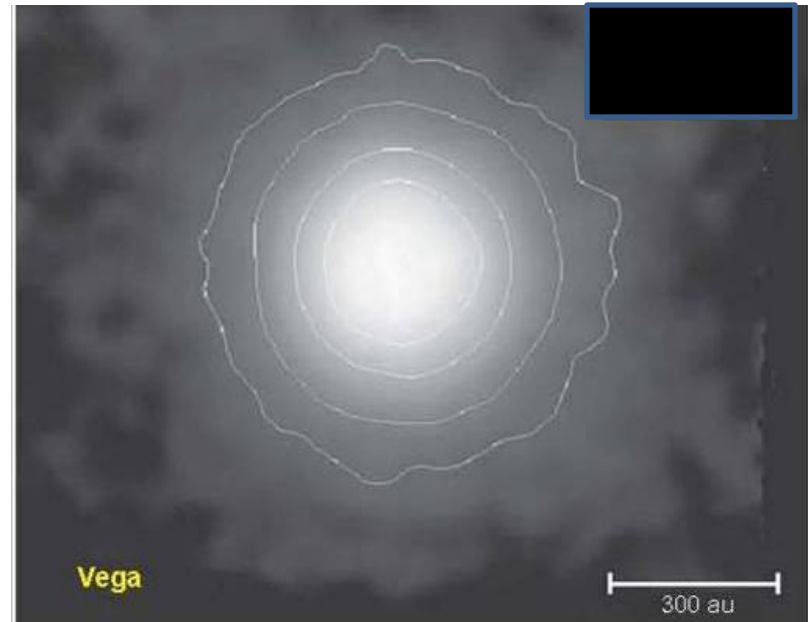
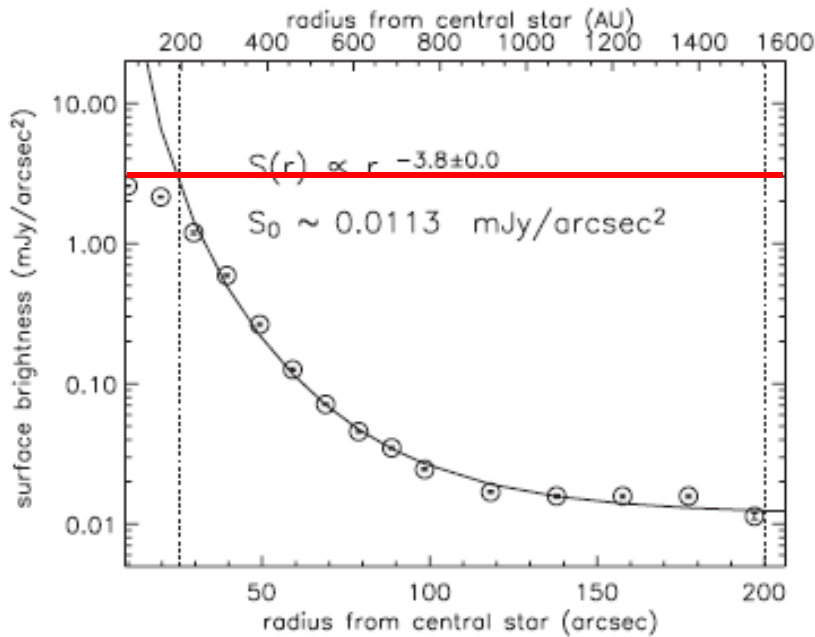


FIG. 7.—Radial profile of the Vega disk at 70  $\mu\text{m}$ . A power law plus a constant background are used to fit the data points between the two dotted lines. The distribution is found to be consistent with an  $r^{-3.8}$  power law.

Data points are radial profile for Vega disk from Su et al. Red line is estimated 10 sigma, 900 s. surface brightness sensitivity of SOFIA based on 100 mJy photometric sensitivity

# JPL A Few Words from Our Sponsor



## Reionization to Exoplanets: Spitzer's Growing Legacy

**Location: Hilton Hotel, Pasadena, CA 26-28 October 2009**  
**Registration Deadlines: Early 15 August 2009 • Late 16 October 2009**  
<http://ssc.spitzer.caltech.edu/mtgs/spitzer2009>

**Topics:**

- The Early Universe
- The Dusty Universe
- The Galaxy
- Star Formation
- Exoplanets

**Invited Speakers:**

|                |              |               |
|----------------|--------------|---------------|
| B. Benjamin    | N. Evans     | C. Maraston   |
| A. Burrows     | G. Fazio     | P. McCarthy   |
| D. Calzetti    | R. Genzel    | J. Najita     |
| P. Capak       | L. Hartmann  | S. Raymond    |
| D. Charbonneau | L. Hernquist | G. Rieke      |
| M. Dickinson   | J. Houck     | A. Sargent    |
| B. Draine      | H. Knutson   | R. Somerville |
| R. Ellis       | G. Laughlin  | G. Tinetti    |
|                | C. Lisse     |               |

**SCIENTIFIC ORGANIZING COMMITTEE:** M. Werner (JPL) • B. T. Soifer (SSC/Caltech) • J. Stauffer (SSC)  
 R. Benjamin (Univ of Wisconsin-Whitewater) • T. Bergin (Univ of Michigan) • R. Blandford (Stanford) • D. Calzetti (Univ of Massachusetts)  
 D. Charbonneau (Harvard) • R. Ellis (Caltech) • C. Lisse (Johns Hopkins Univ) • E. Van Dishoeck (Leiden Univ)

**LOCAL ORGANIZING COMMITTEE:** P. Ogle (SSC) • P. Patterson (IPAC) • G. Bryden (JPL) • M. Castillo (IPAC) • J. Colbert (SSC) • A. Dean (SSC)  
 S. Fajardo-Acosta (SSC) • J. Howell (SSC) • E. Kennedy (IPAC) • S. Laine (SSC) • H. Mycroft (IPAC) • R. Scholey (IPAC) • E. Scire (SSC)  
 H. Seibly (IPAC) • K. Sheth (SSC)

Frank Low

speakers

Chas Beichman  
 Bill Hoffmann  
 Don McCarthy\*  
 George Rieke  
 Peter Strittmatter

Mike Werner  
 Erick Young \*TBC

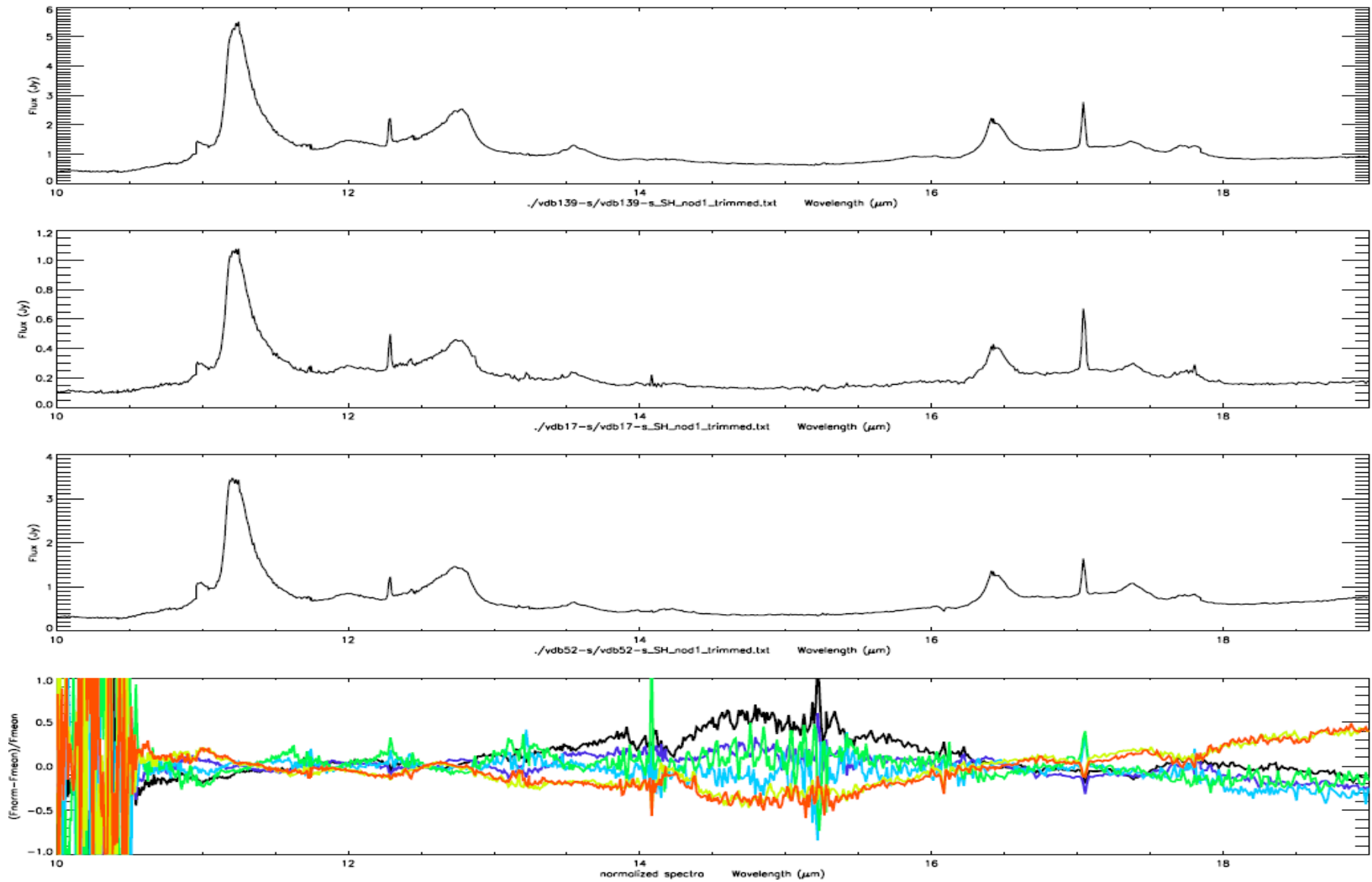
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 Develop-  
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 Infrared  
 Astronomy

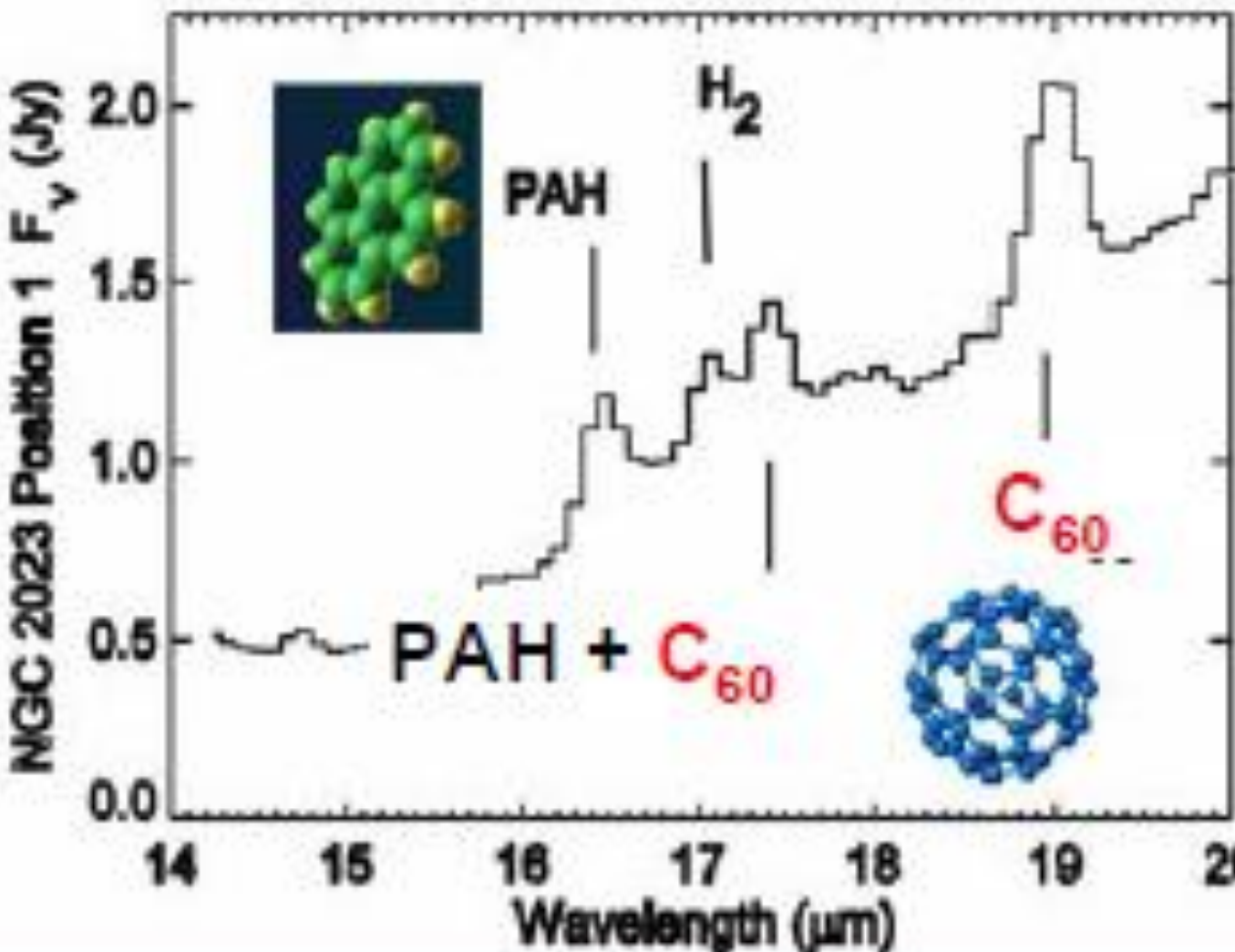
1:30-4:15  
 28 October  
 California  
 Ballroom

Pasadena Hilton  
 reception following



# A Spitzer PAH Puzzler: Bright Sources Have Identical Spectra





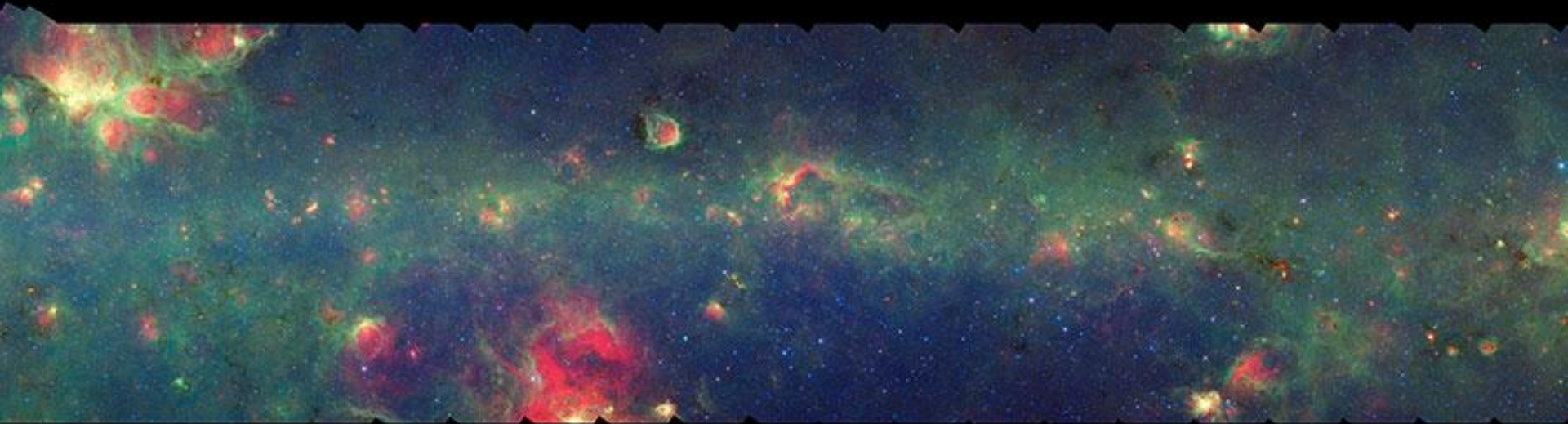
Shorter wavelength lines at 7 and 8.5 $\mu\text{m}$  should be detected to confirm identification; SOFIA can help to tease these out of the PAH forest

**JPL**

IRAC/MIPS Survey of

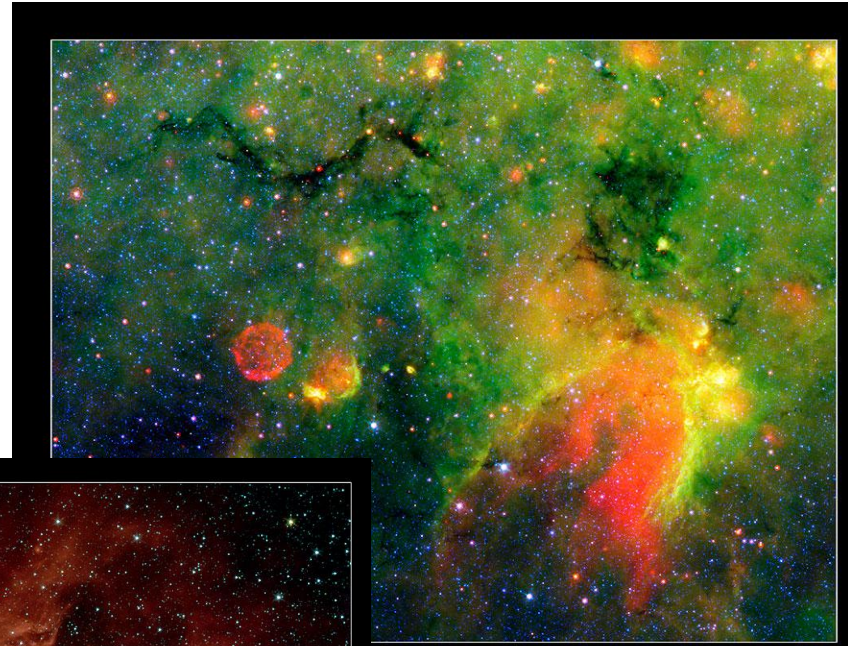
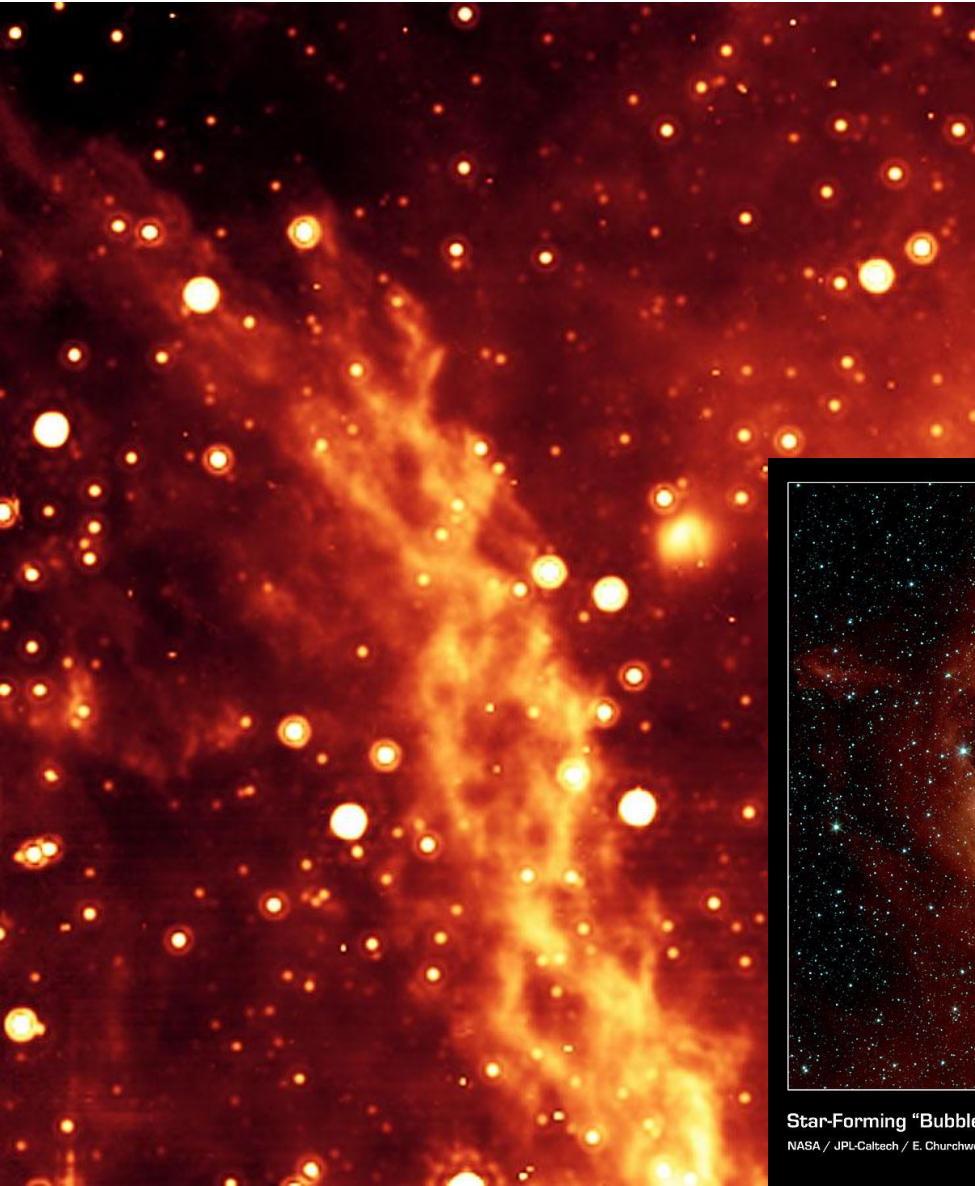


the Galactic Plane: Grist for SOFIA's Mill

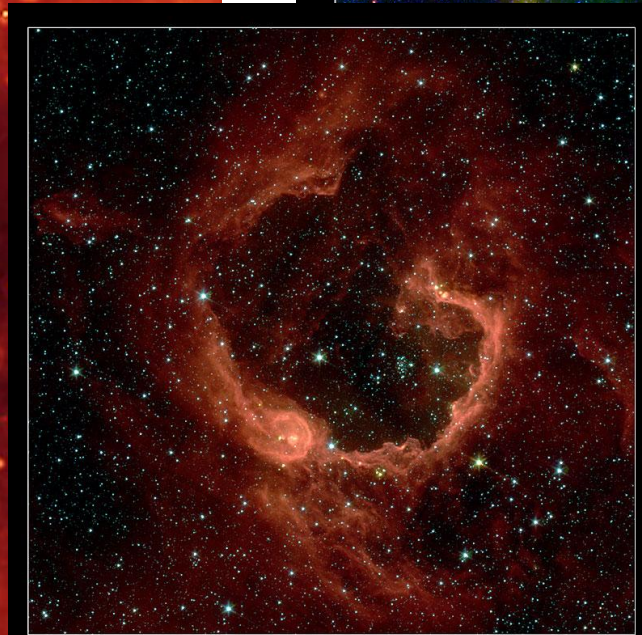




# Structures Like These Cry Out for Polarimetric Exploration



Galactic Plane Spitzer Space Telescope • IRAC • MIPS  
ssc2006-20a

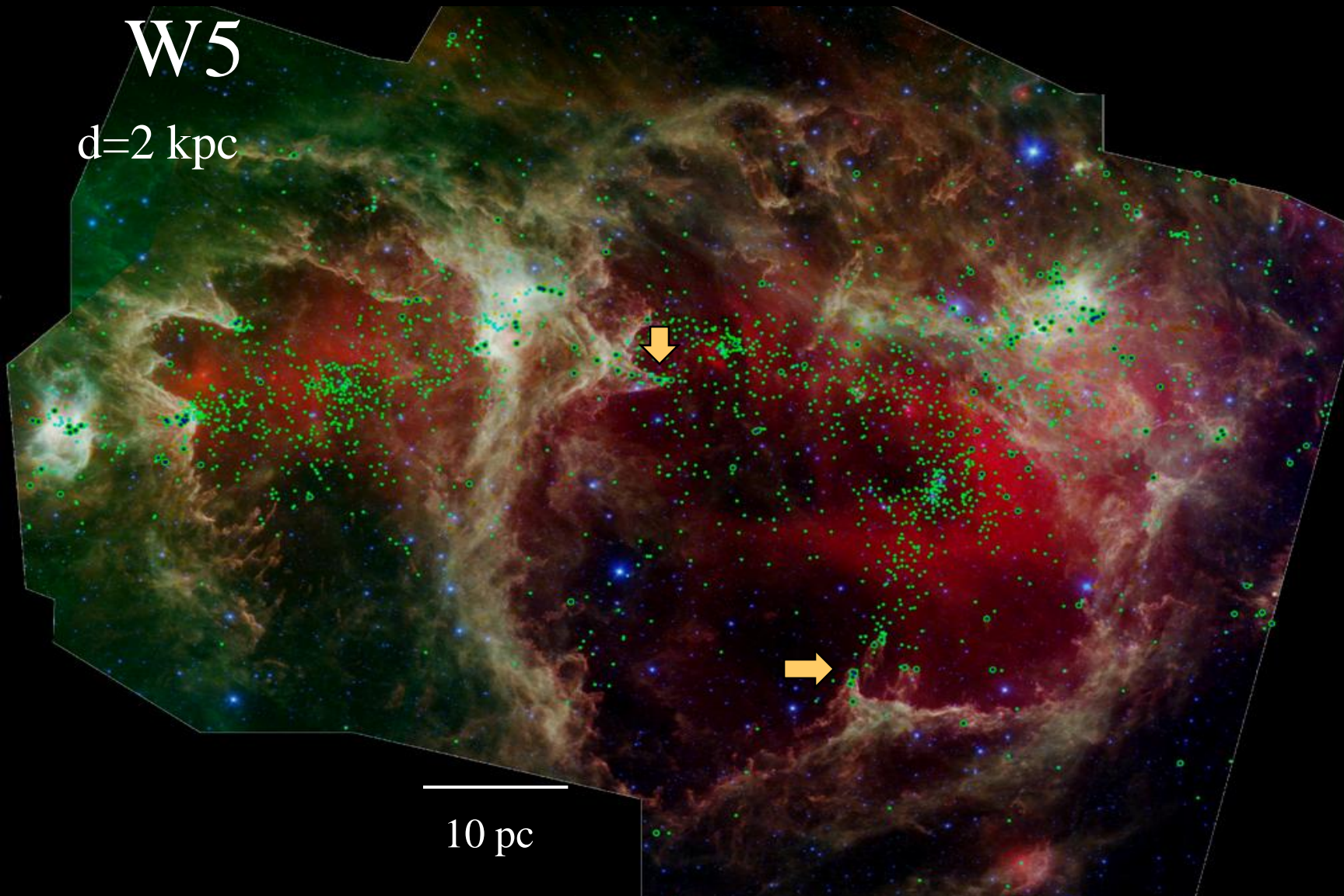


Star-Forming "Bubble" RCW 79 Spitzer Space Telescope • IRAC  
NASA / JPL-Caltech / E. Churchwell (University of Wisconsin-Madison) sig05-001

Small Green Circles: IR-ex sources, Big Green/Blue Circles: Protostars

W5

d=2 kpc



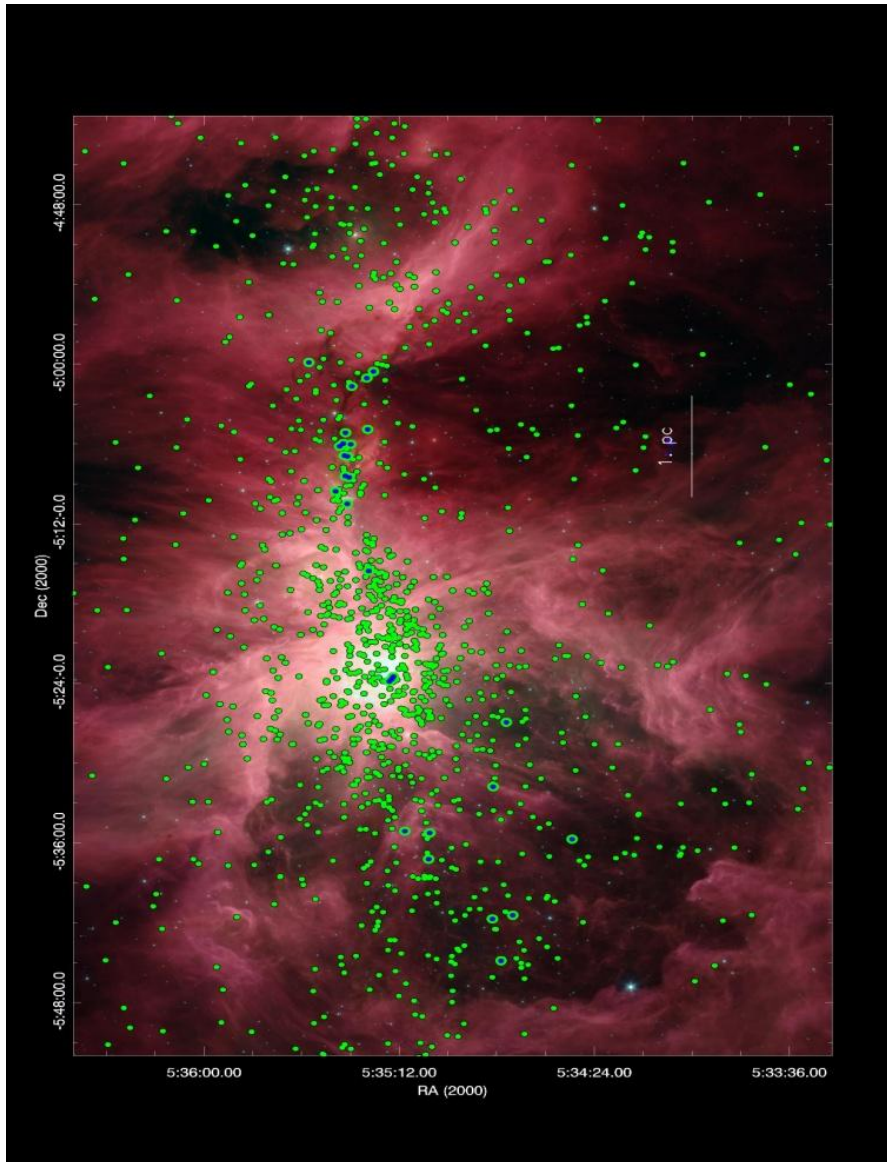
10 pc

24, 8, 4.5 **Large Scale Patterns of Low Mass Star Formation Studied by Spitzer**

Koenig et al.



# Low Mass Protostars Seen In Orion



Can SOFIA make equivalent progress in studying high mass star formation?