The Infrared Universe as Seen by Spitzer……and Beyond

February 20, 2007

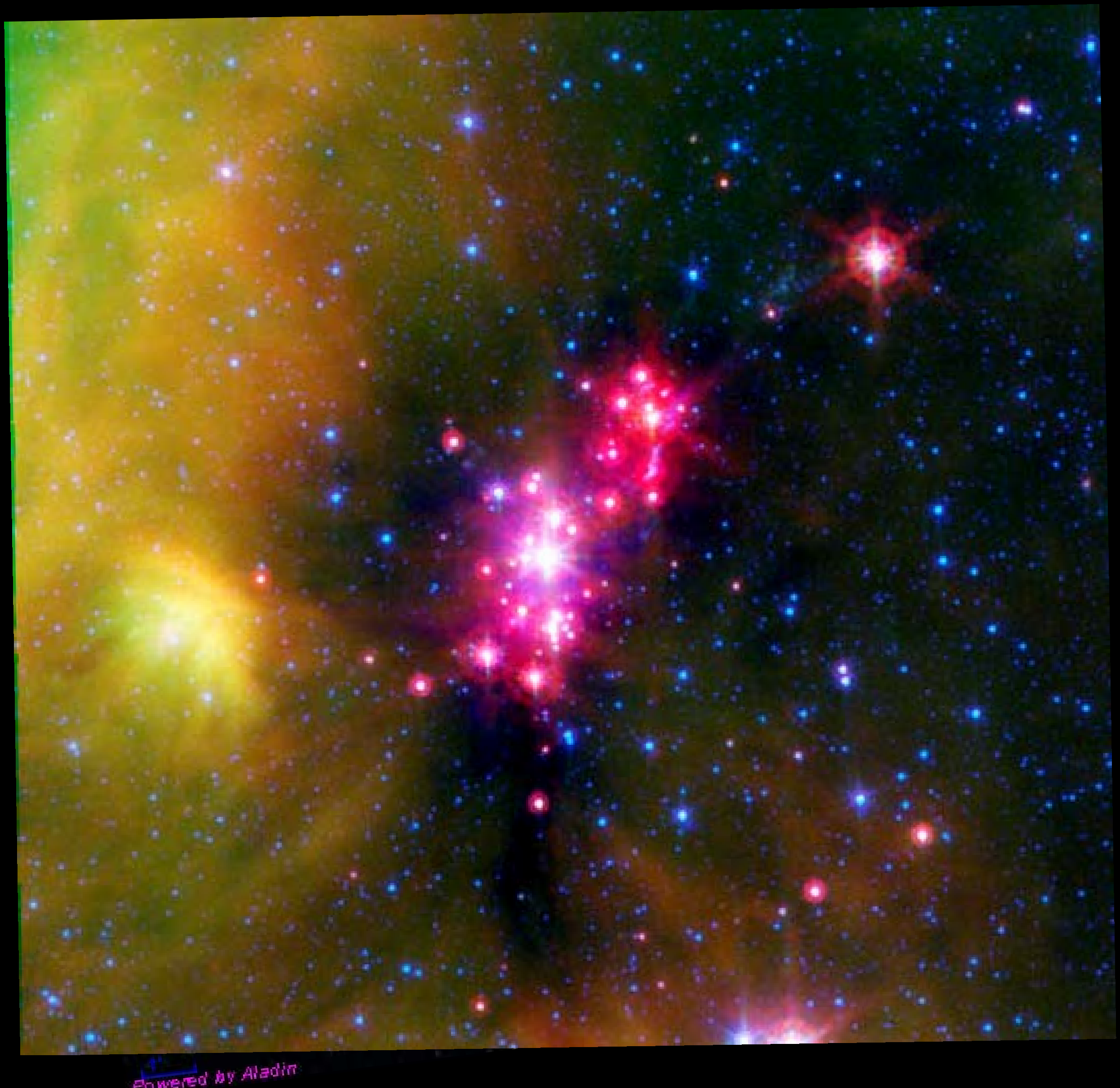
Presented to the Herschel Open Time Key Project Workshop

Michael Werner, Spitzer Project Scientist

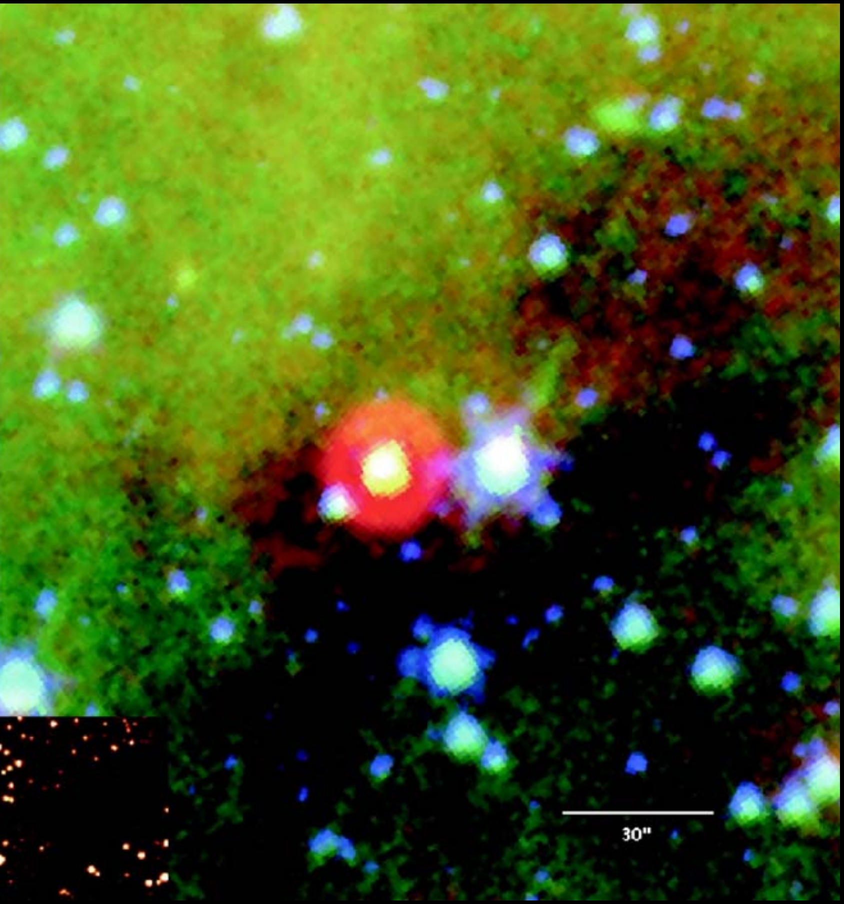
JPL/Caltech

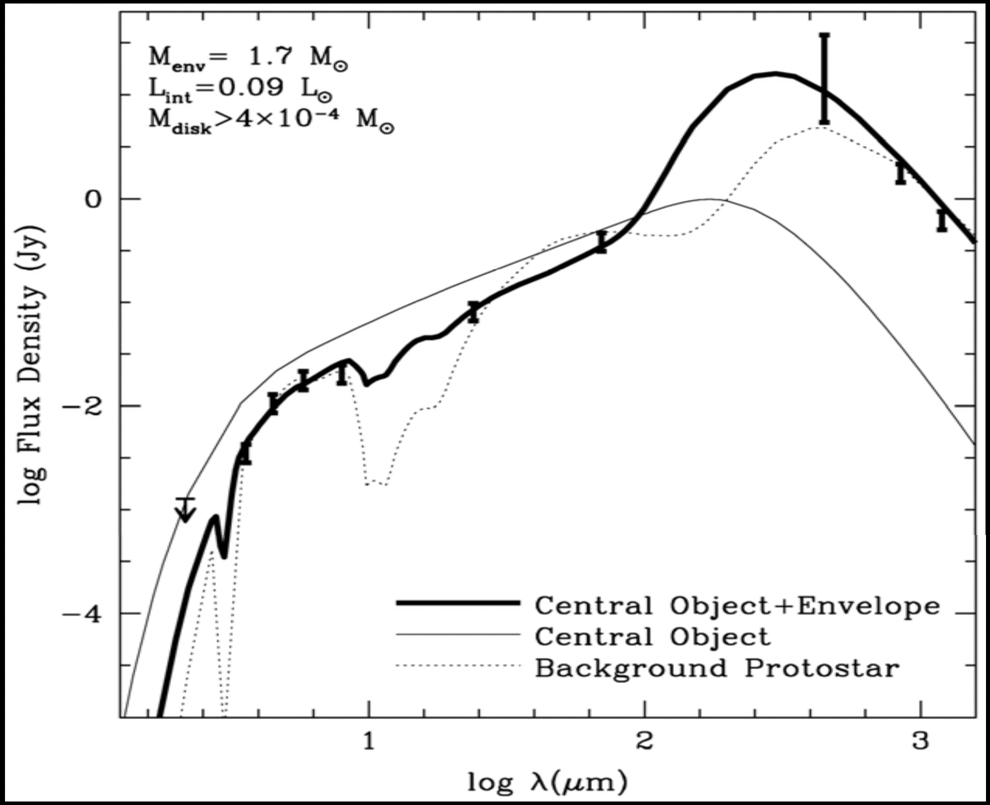
The Holly Berry Cluster [NOT the Halle Berry cluster] in Serpens

The Holly Berry Cluster in Serpens

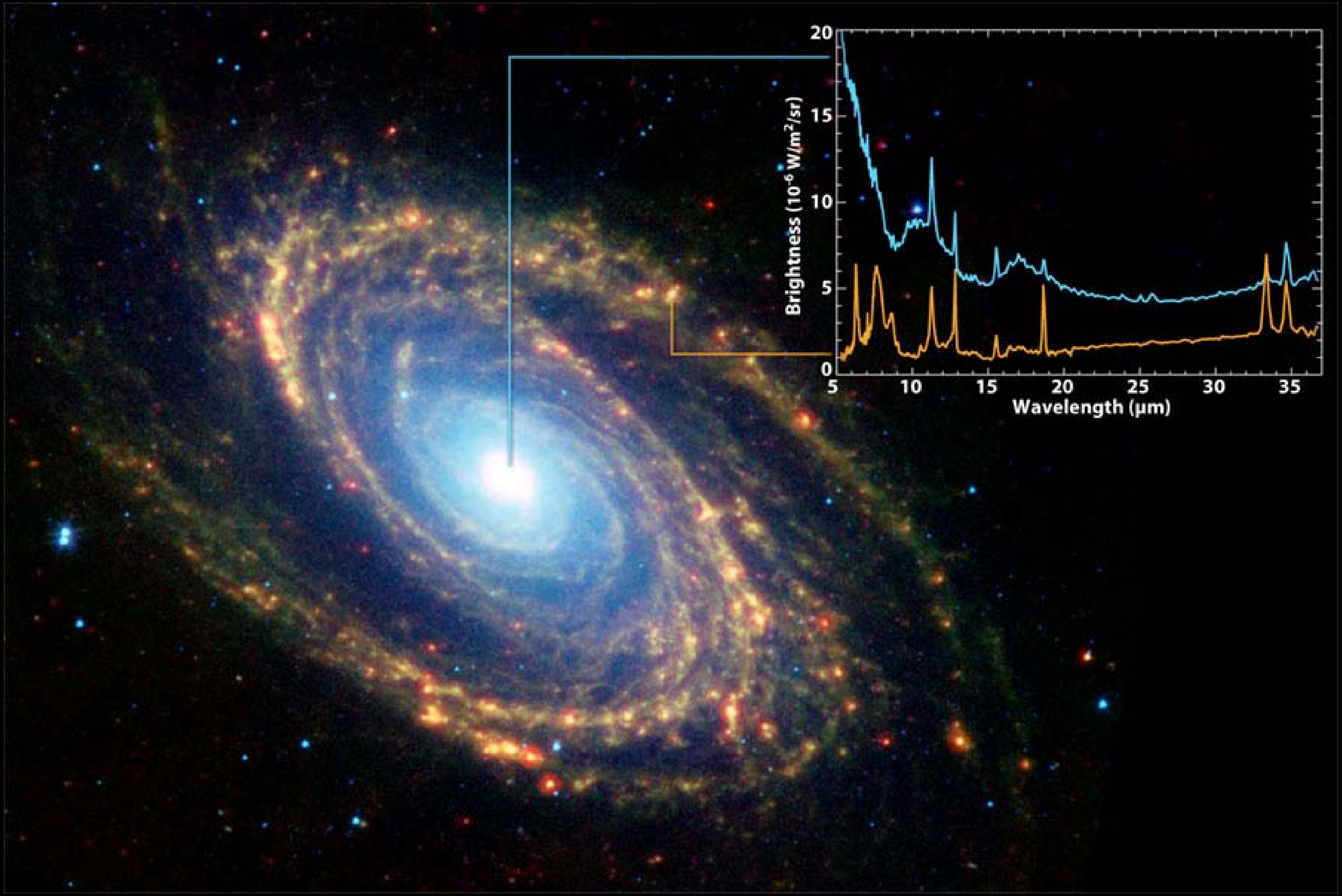


Candidate Young (Sub-)stellar Object in a “Starless Core” L1014

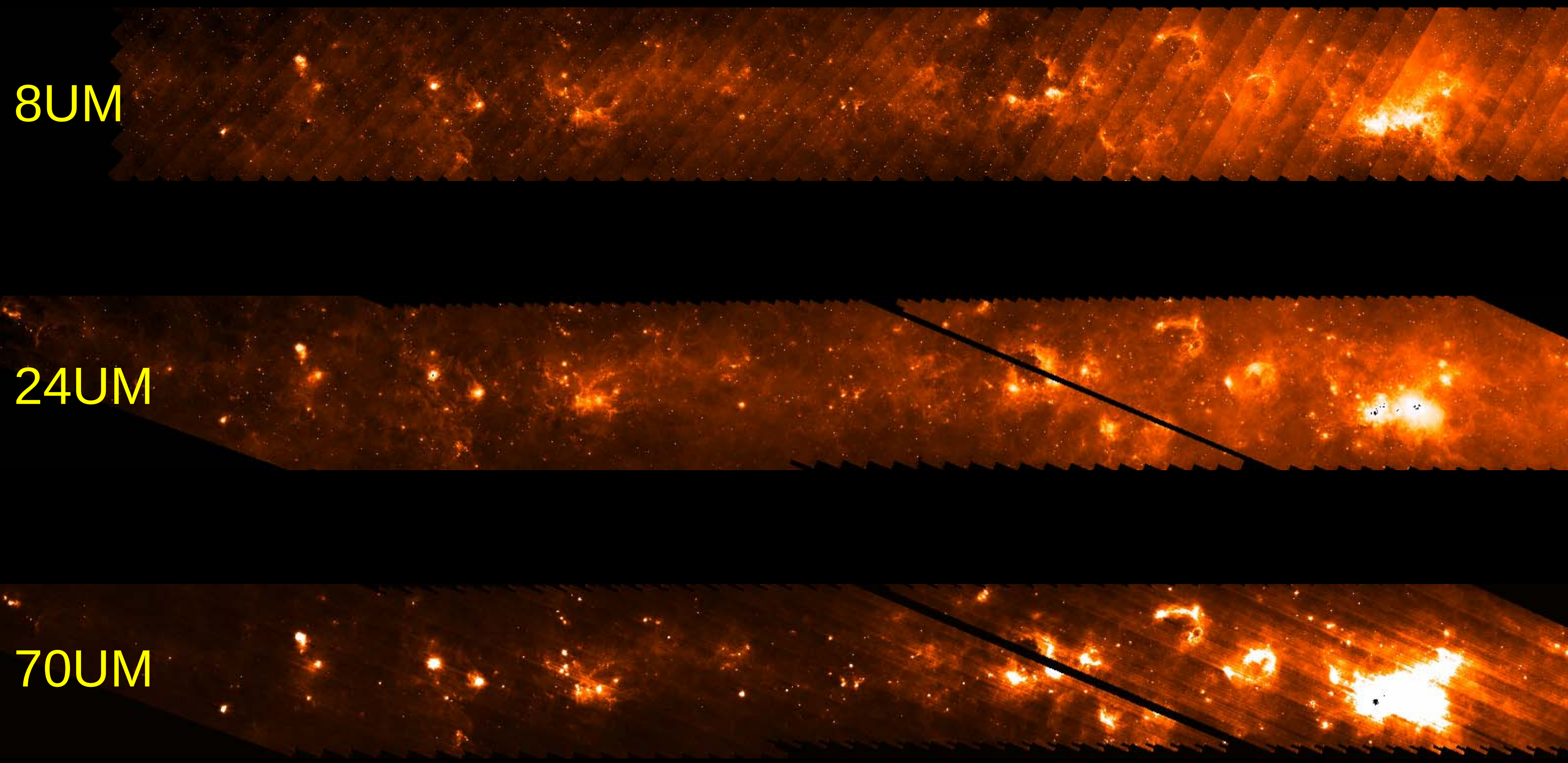




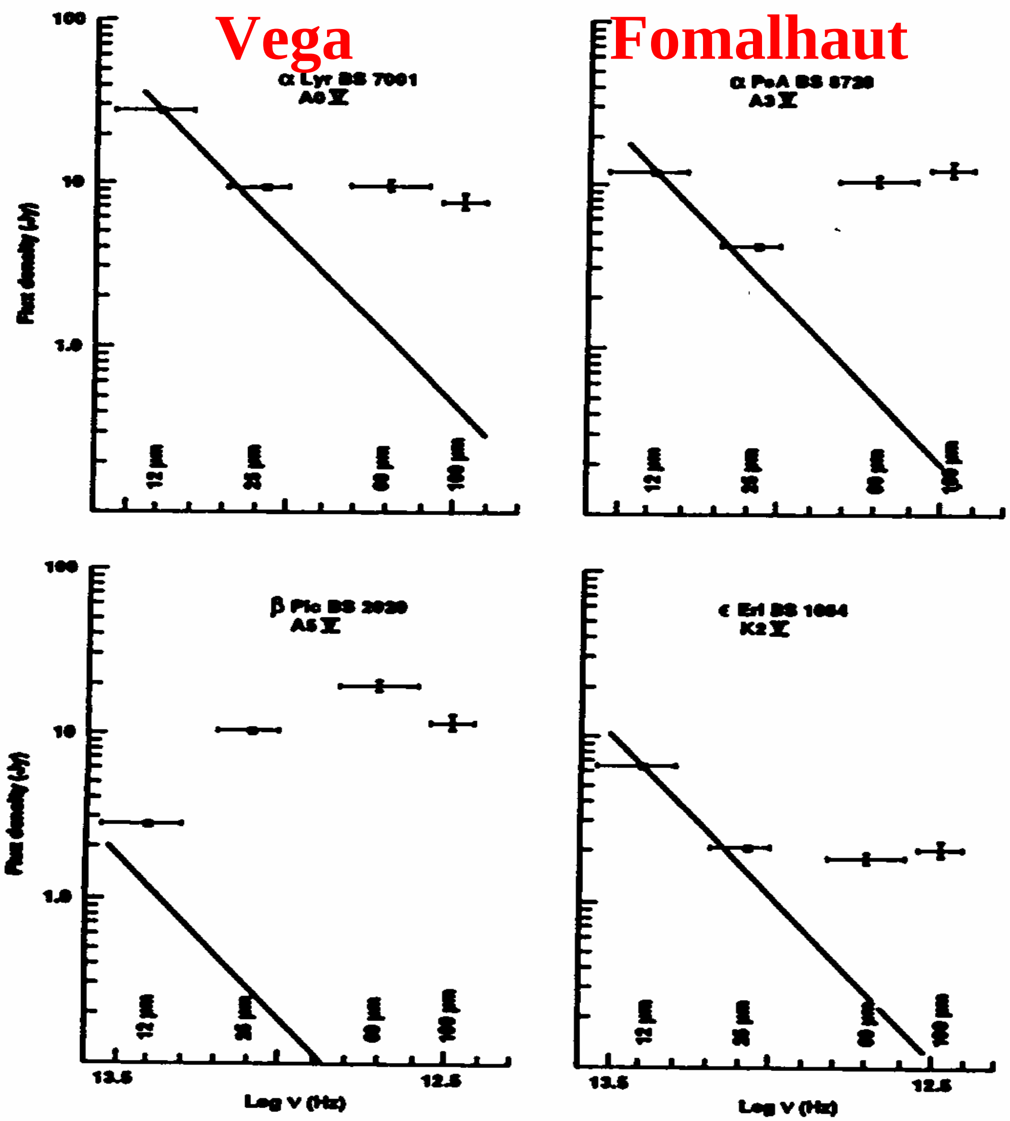
Detailed Spitzer Studies of Nearby Galaxies Like M81 Inform Interpretation of Deep Surveys



Mipsgal and Glimpse Images of a 20 Degree Swath of the Galactic Plane



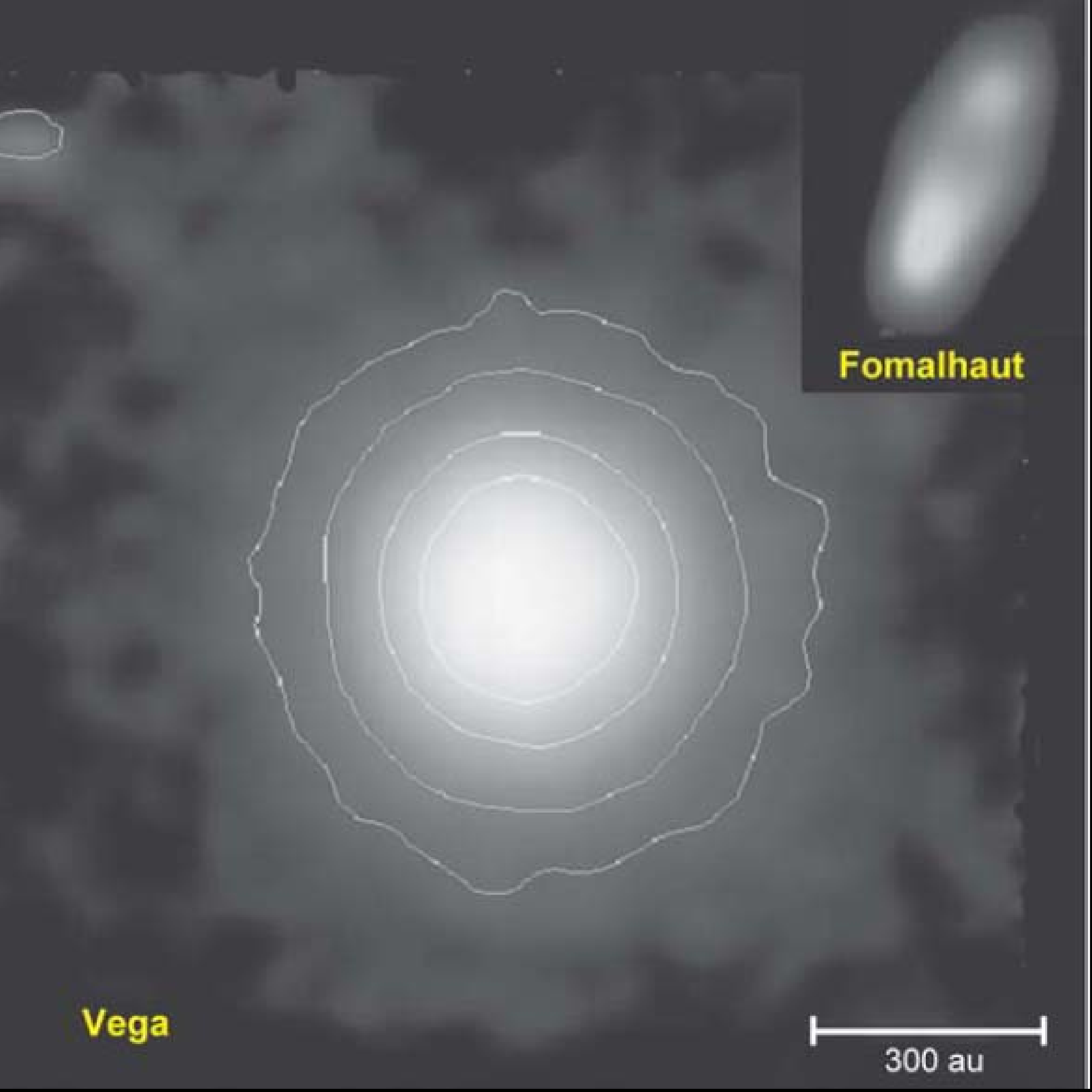
DEBRIS DISKS AND THE FORMATION OF PLANETS
A Symposium in Memory of Fred Gillett



Edited by

Larry Caroff, L. Juleen Moon, Dana Backman and Elizabeth Praton

IRAS and ISO set the stage for Spitzer studies of debris disks, important signposts of planetary system formation.



70um Images of Vega and Fomalhaut show strikingly different structure. Debris disks are not one size fits all.

Circumstellar dust around main sequence A stars varies stochastically with time, reminding us that the Earth grew up in a dangerous neighborhood.

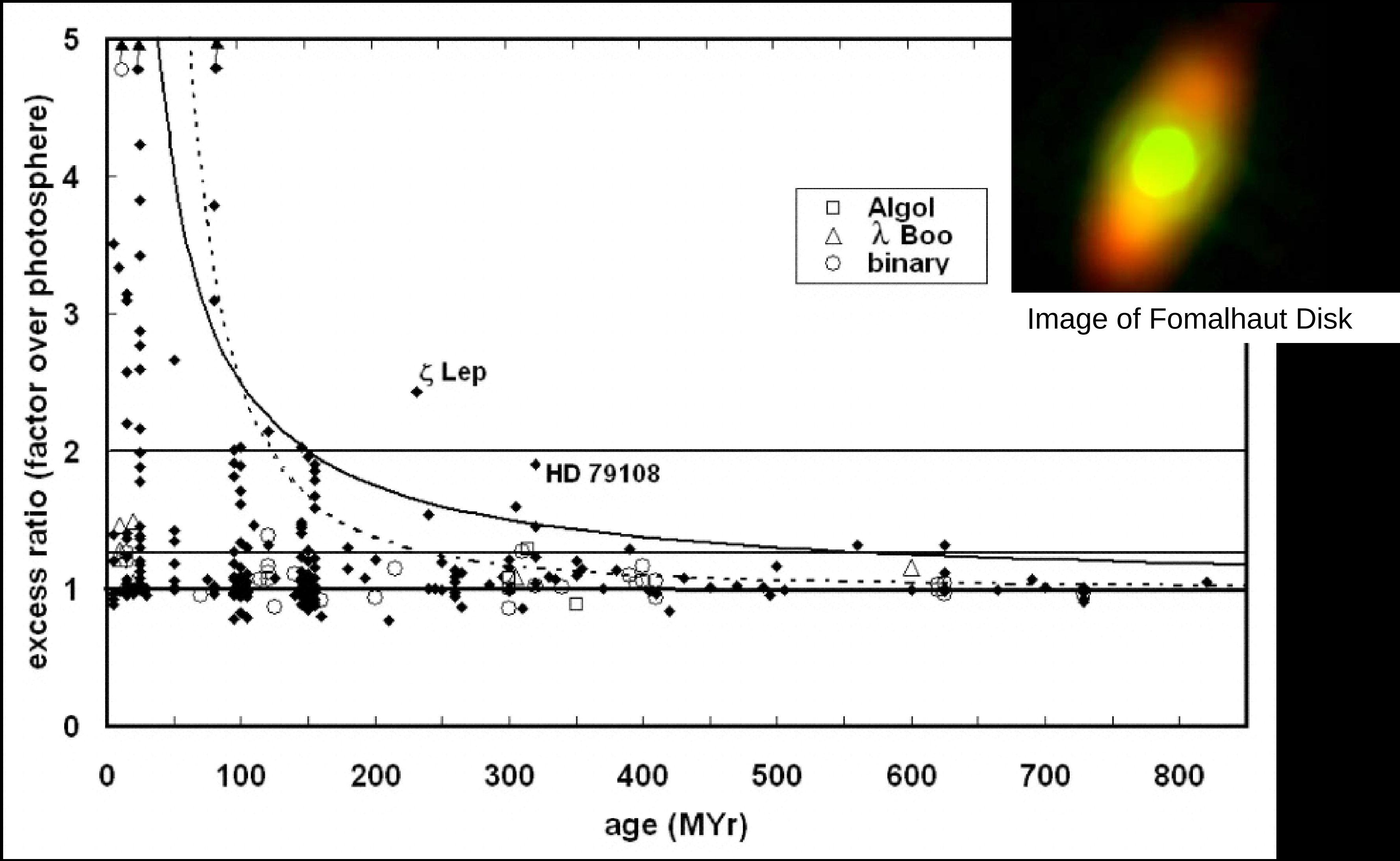
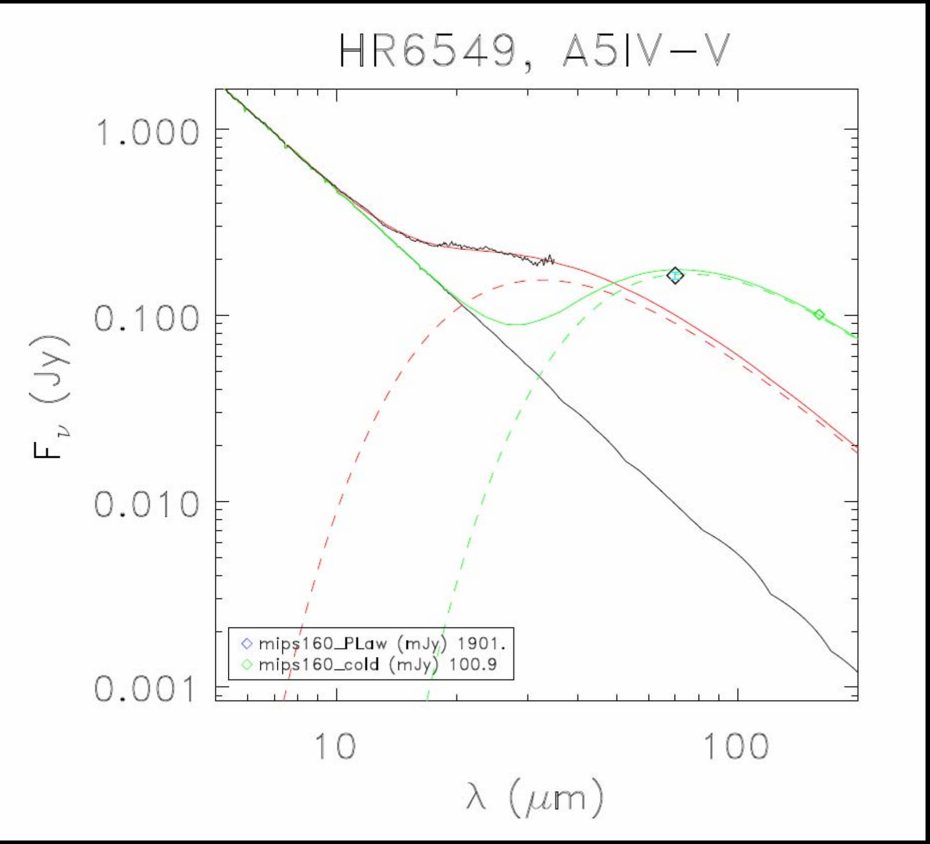
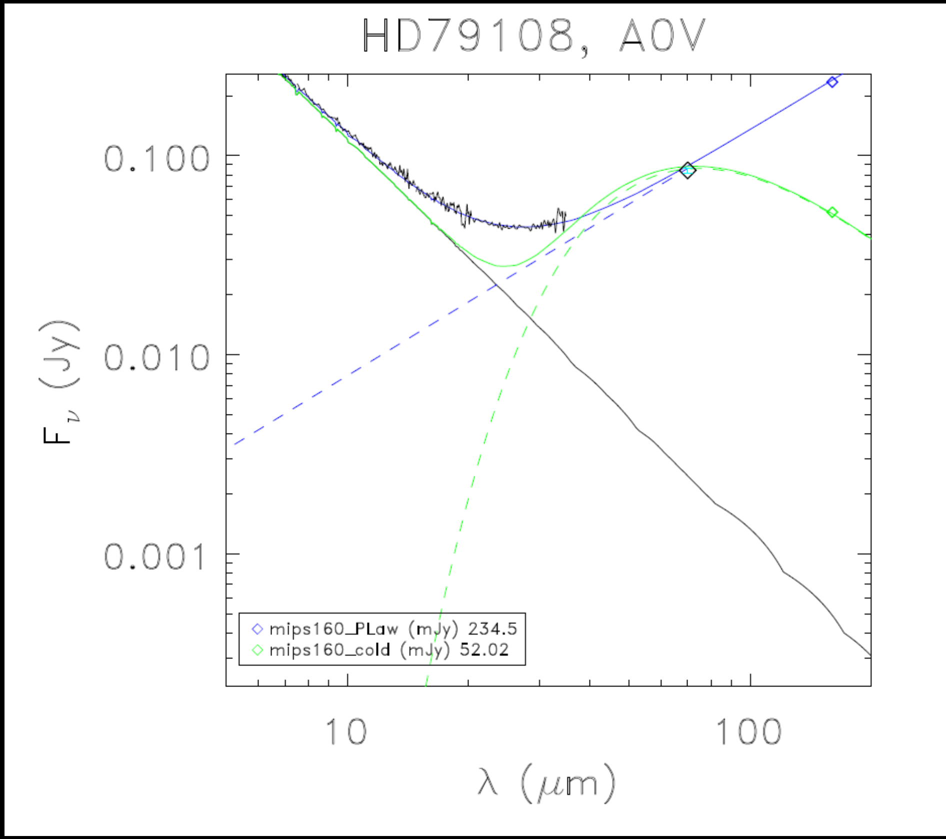
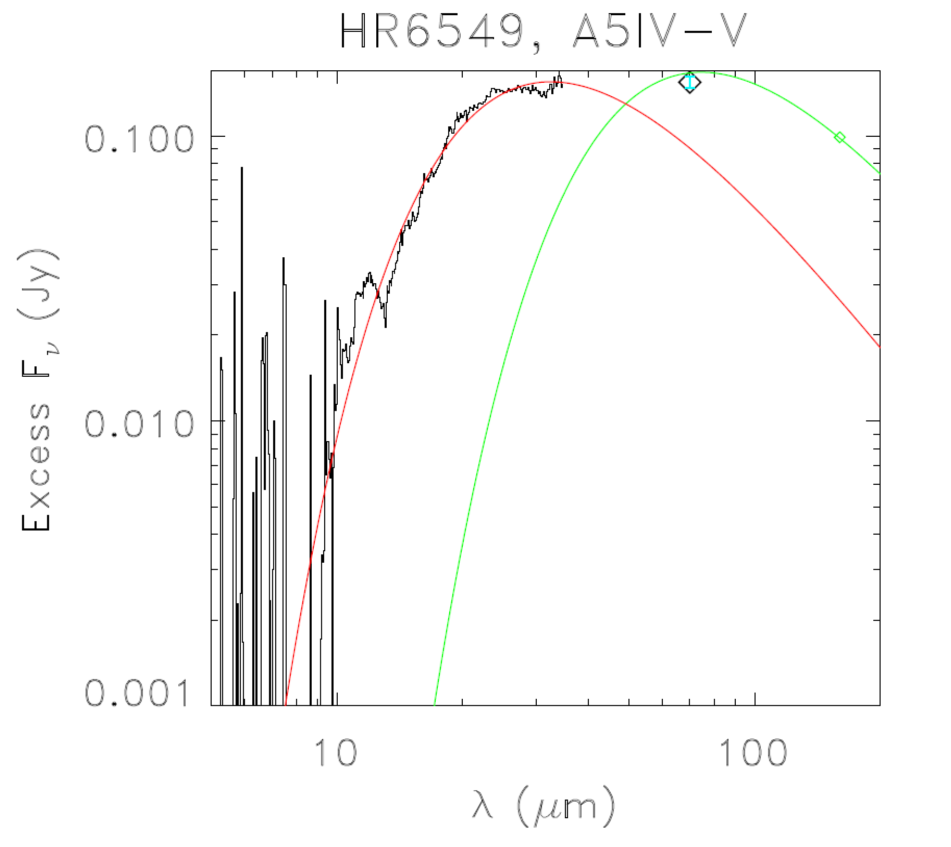


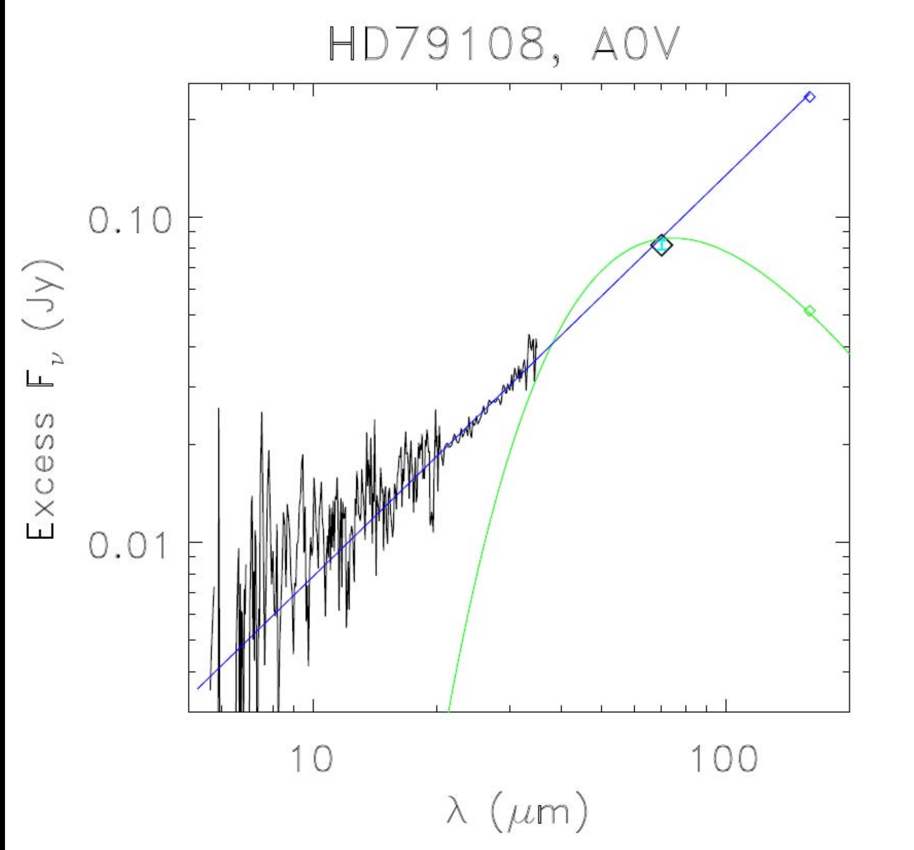
Image of Fomalhaut Disk

IRS Spectra and 70um photometry extend 24um measurement inward and outward





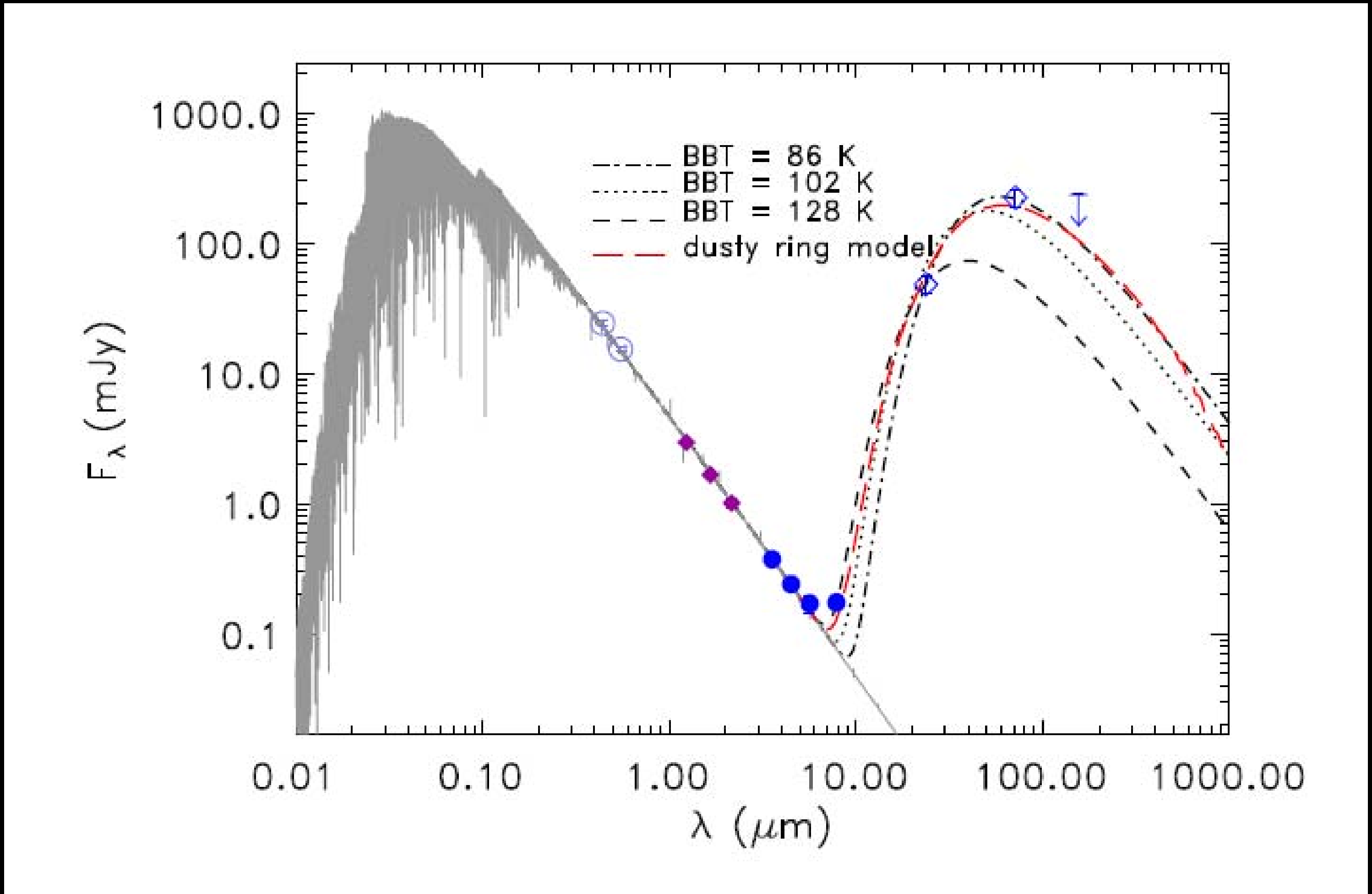




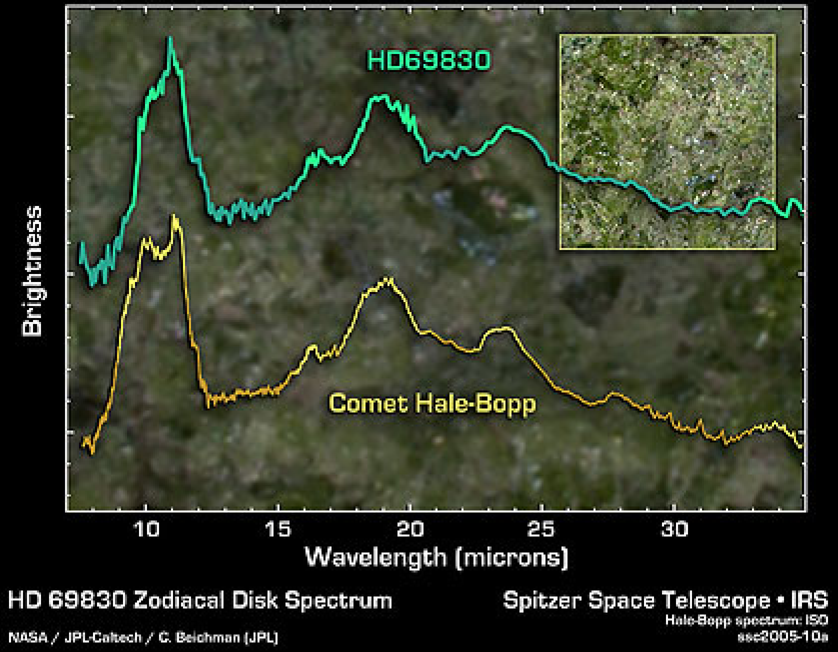
In IRS data, infrared excess can show either power law or blackbody spectral shape. Power law may extends at least to 70um revealing large amounts of cold material at large distances from the star. At the shortest wavelengths, excess often can be traced down to 10um, probing the asteroidal/habitable zone

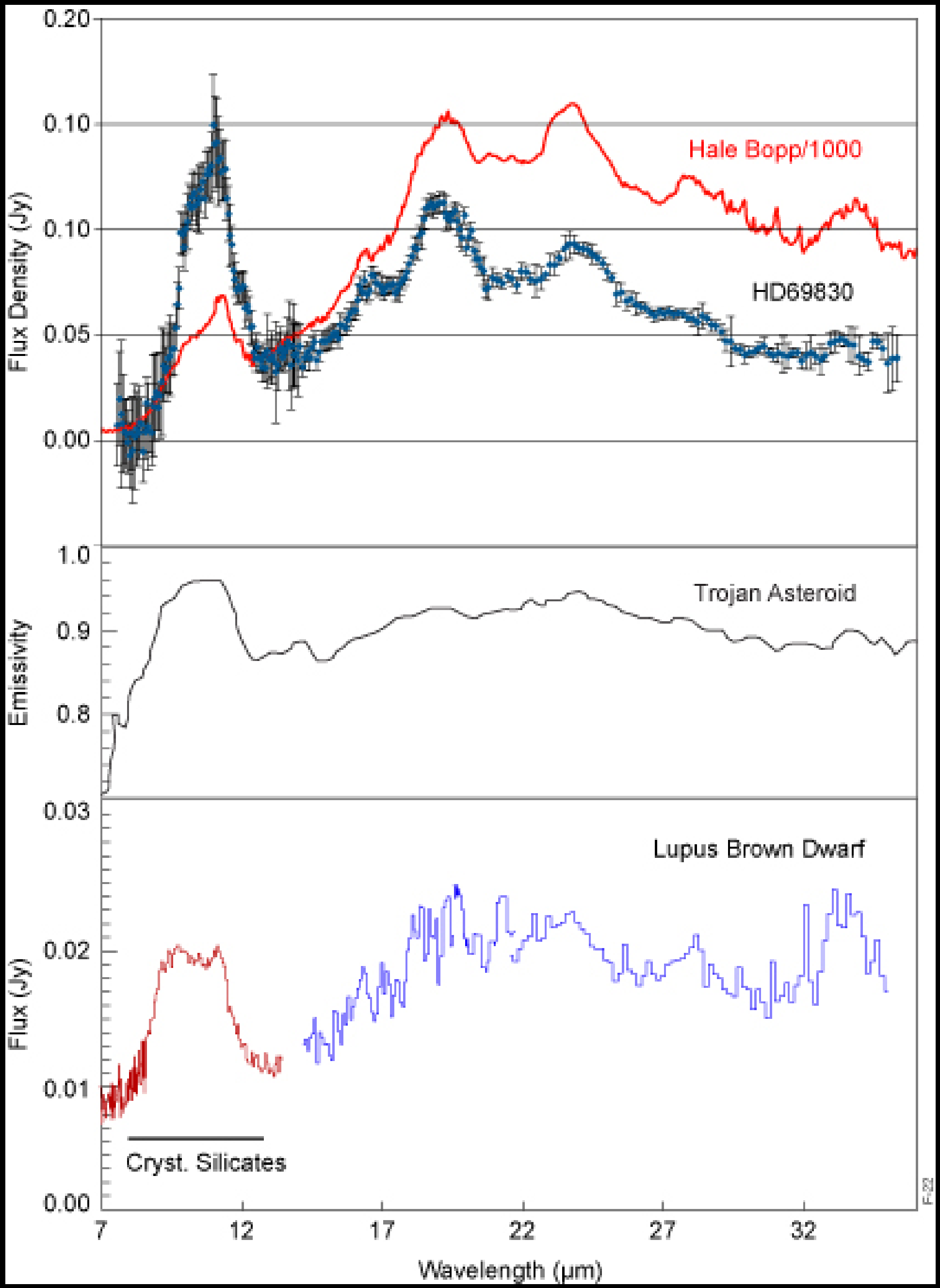
The central star of the Helix Nebula, a hot, luminous White Dwarf, shows an infrared excess attributable to a planetary debris disk

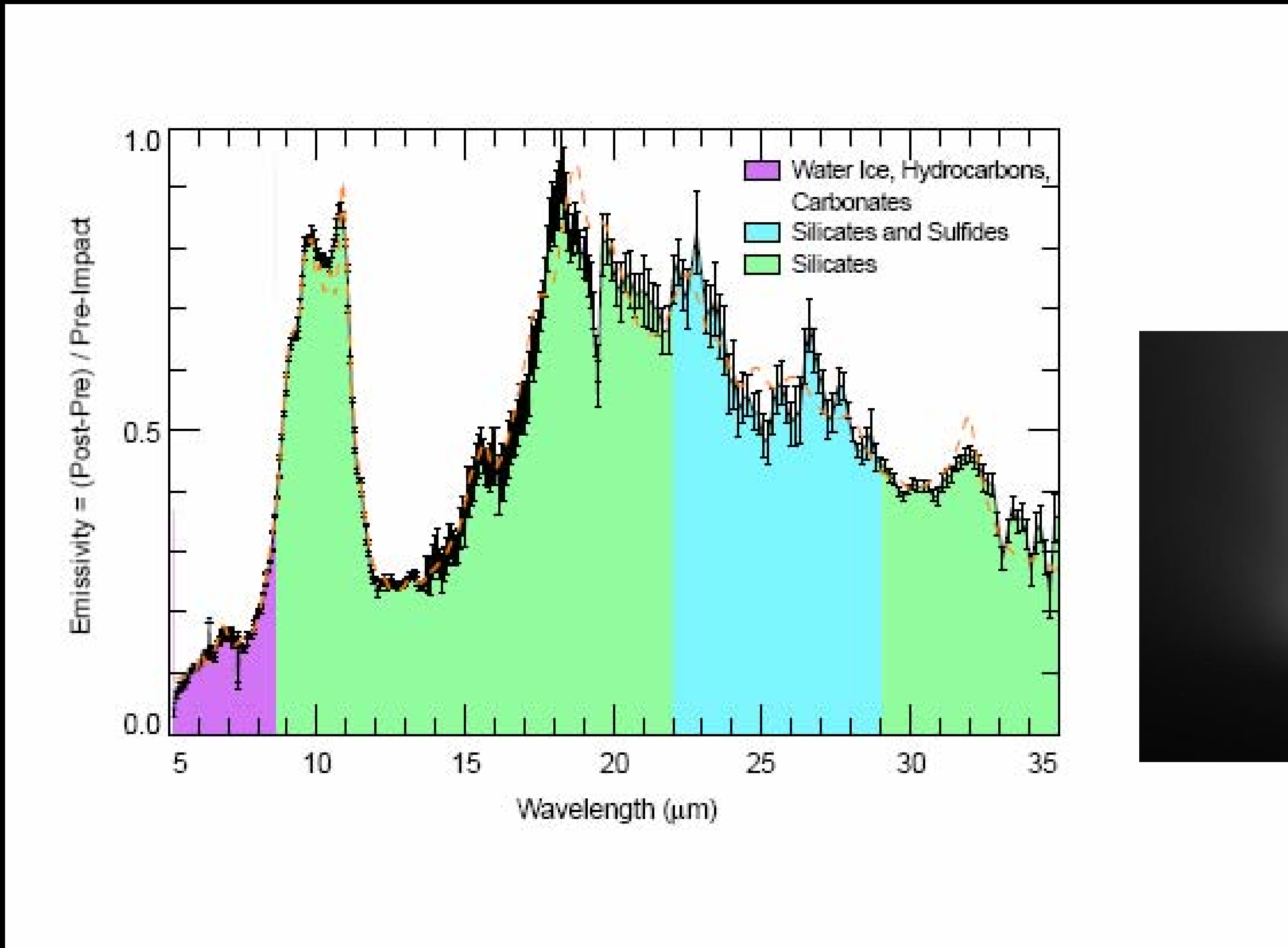
Spectral energy distribution of the central star of the Helix, showing infrared excess attributed to a debris disk created by comets and asteroids which survived the formation of the nebula

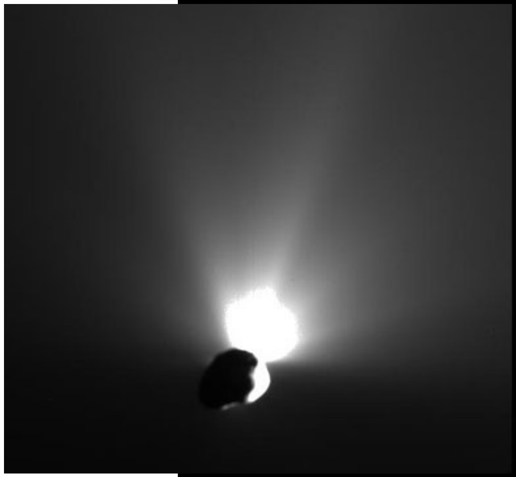


Crystalline silicates - from the green sand beaches of Hawaii to the outer solar system to nearby stars and beyond…..

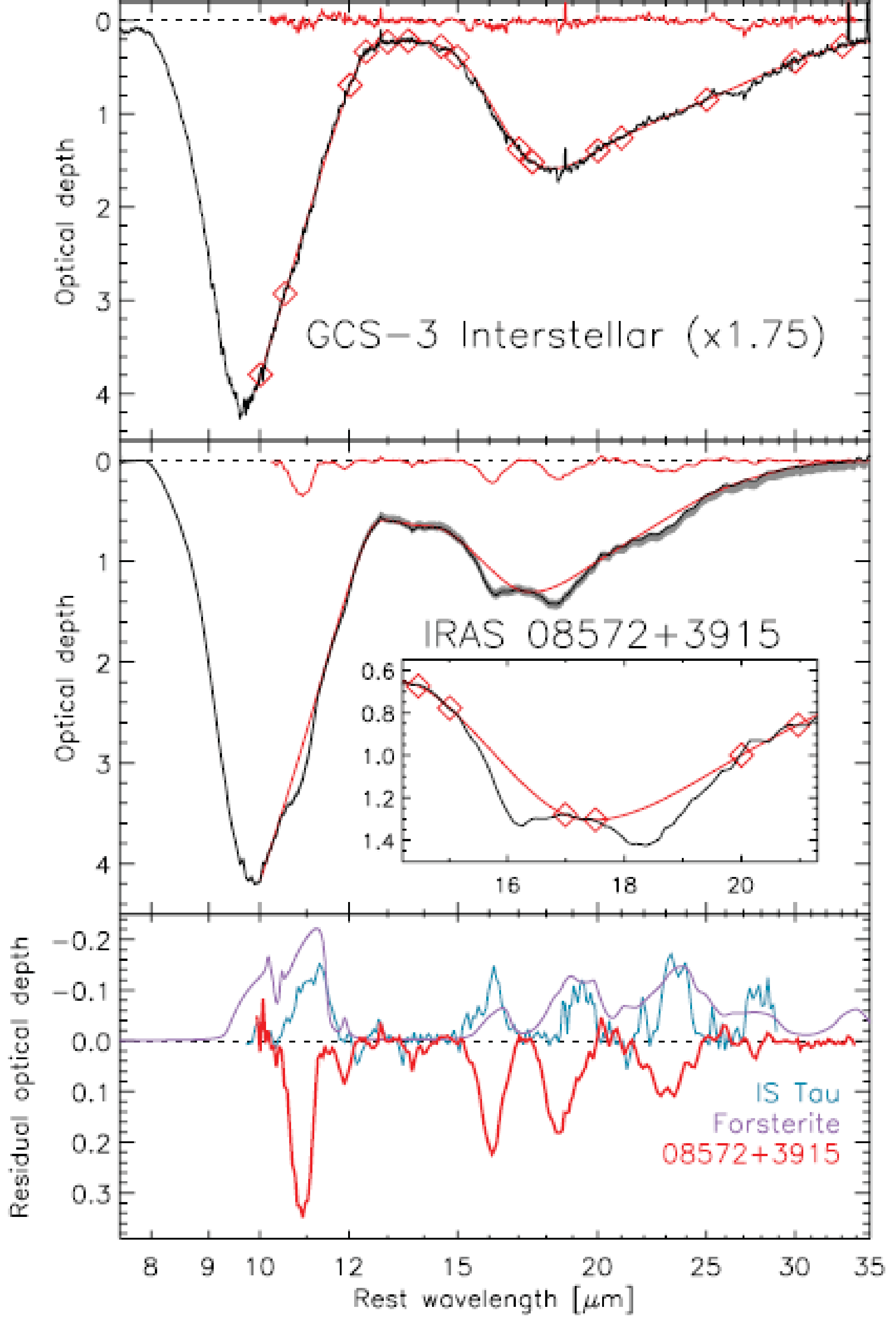






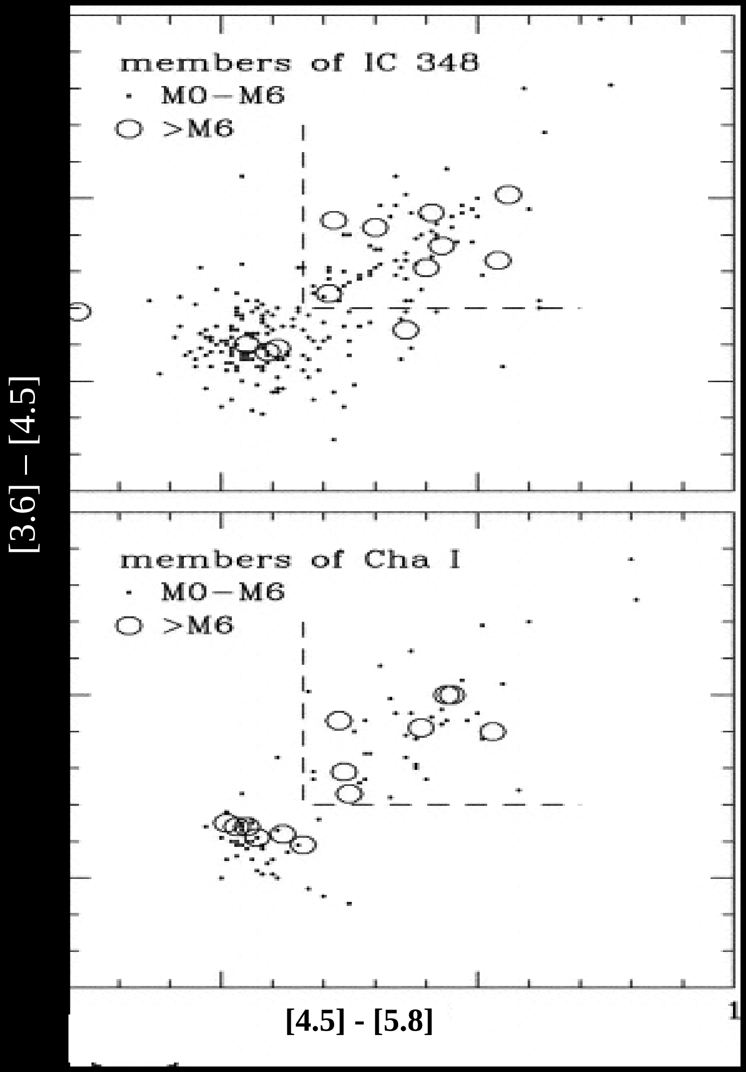


Spitzer spectrum of ejecta from Deep Impact event show surprising compositional variety, suggesting that the early solar system was complex and diverse [cf. Stardust]



Crystalline silicates, not present in the ISM of our galaxy, appear in absorption in at least one dozen Ultraluminous Infrared Galaxies

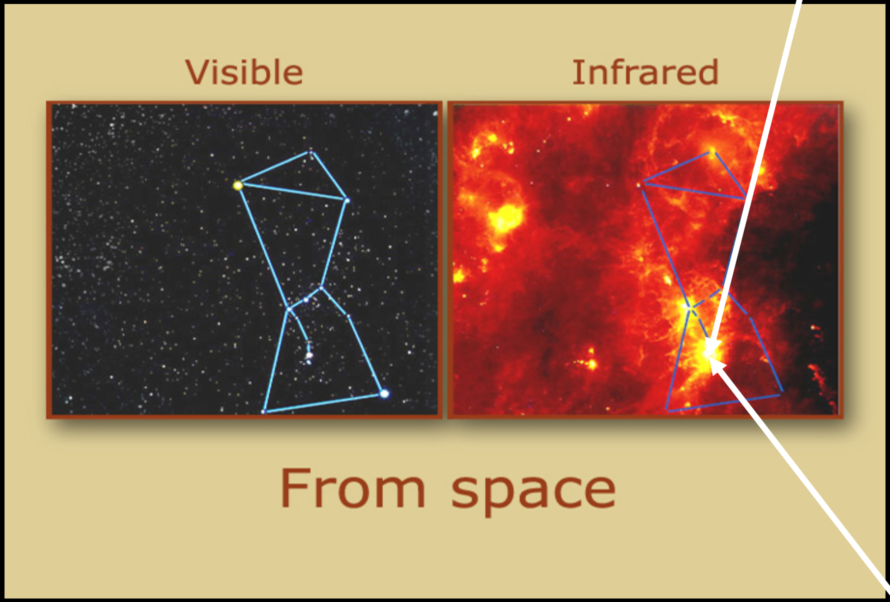
Stars and Substellar Objects have Equal Disk Fractions (~40%) in Young (4-5 MYr) Clusters IC348 and Cha I



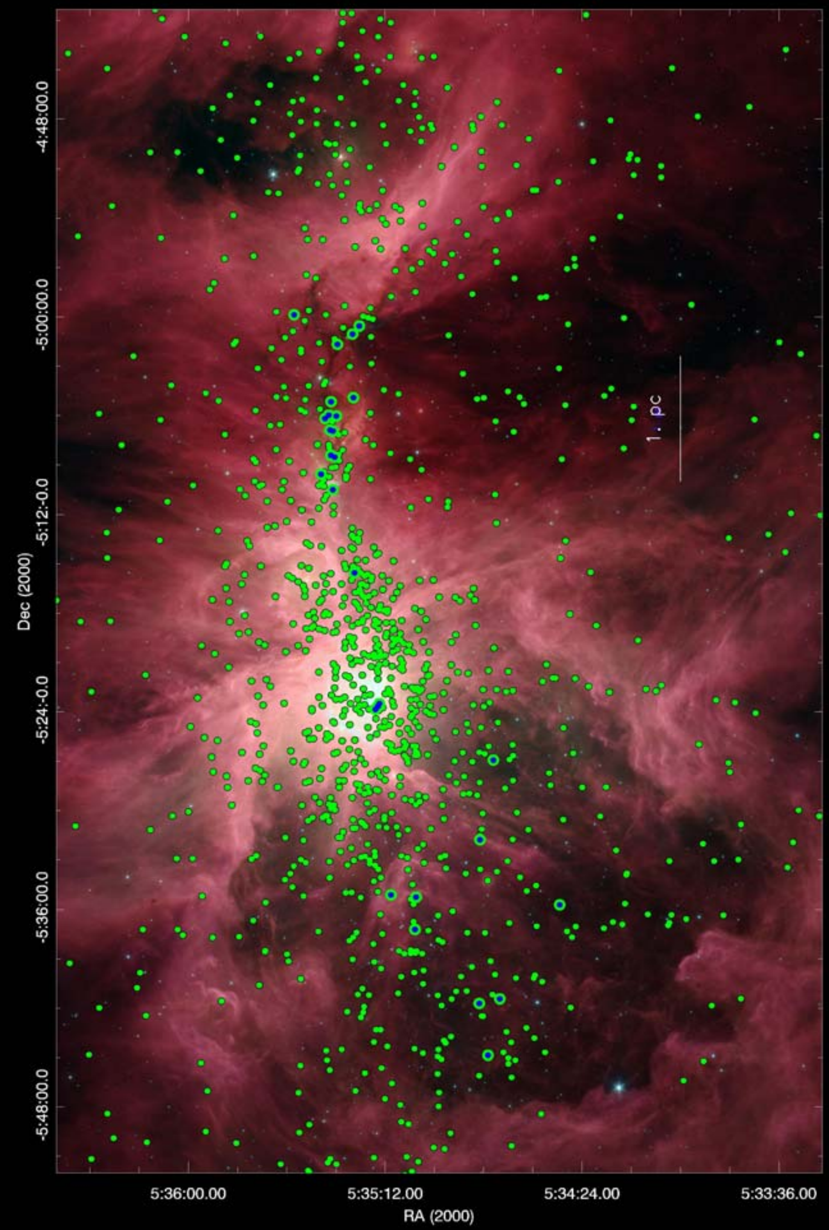
These and related studies show:

- Material in terrestrial planet zone dissipates in ~10 Myr or less
- Brown dwarfs as low in mass as ~10 Jupiters form by same process as stars
- Disk evolution around brown dwarfs shows start of planet forming process

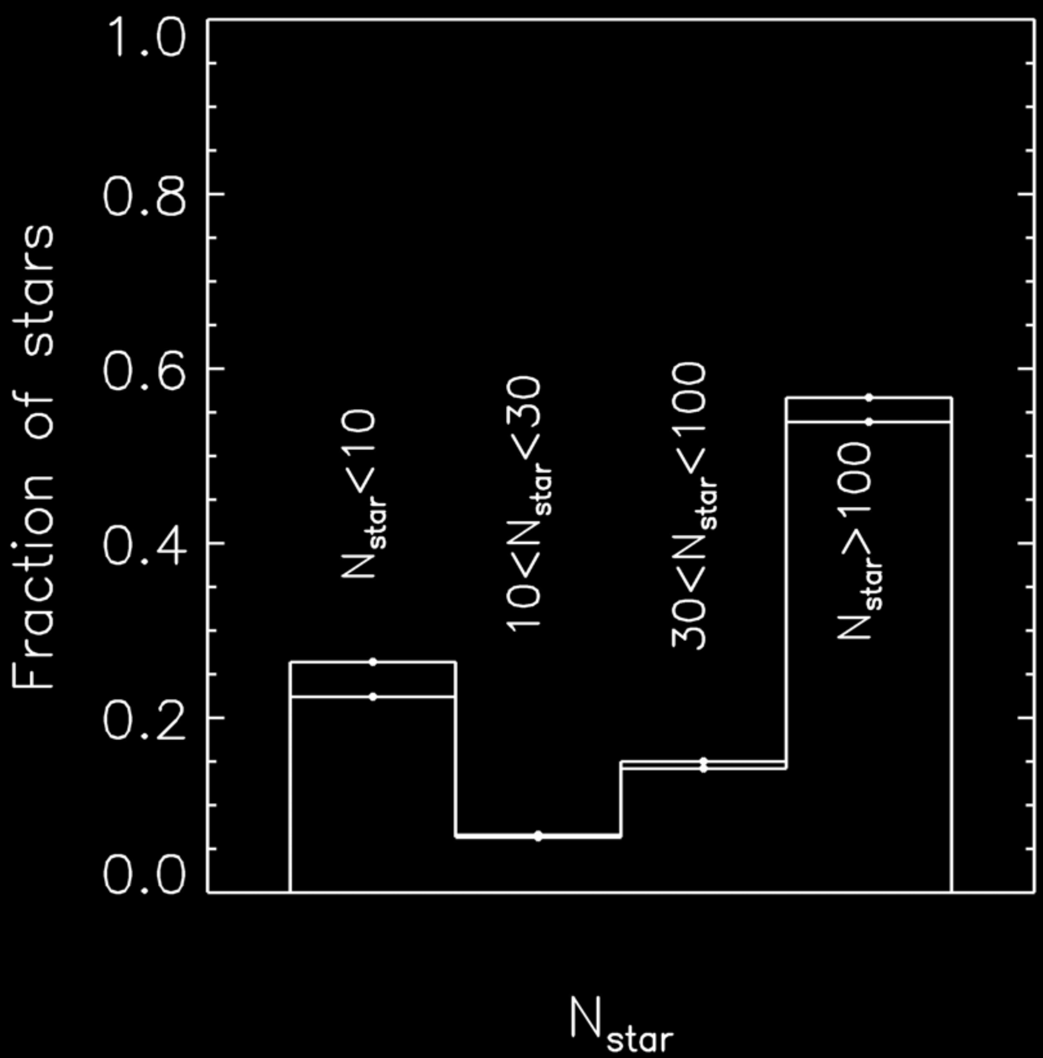
Spitzer Image of the Orion Molecular Cloud



Spitzer + 2MASS = Thousands of Young Stellar Objects

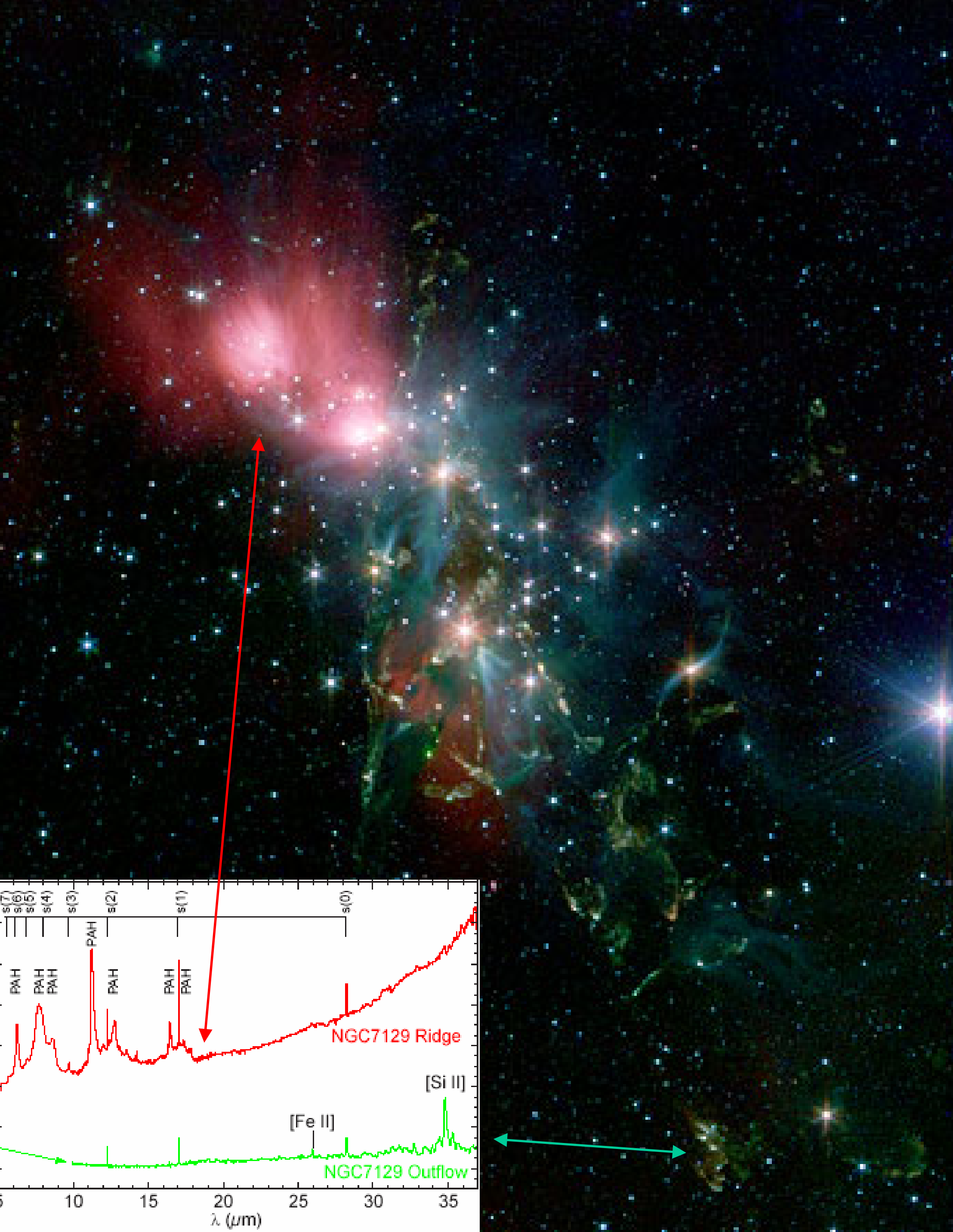


In what environment do stars typically form?



In Spitzer surveys of the Orion A, Orion B and Ophiuchus molecular clouds, Spitzer finds the following demographics:

- 60% in large clusters
- 25% in relative isolation
- 15% in groups and small clusters

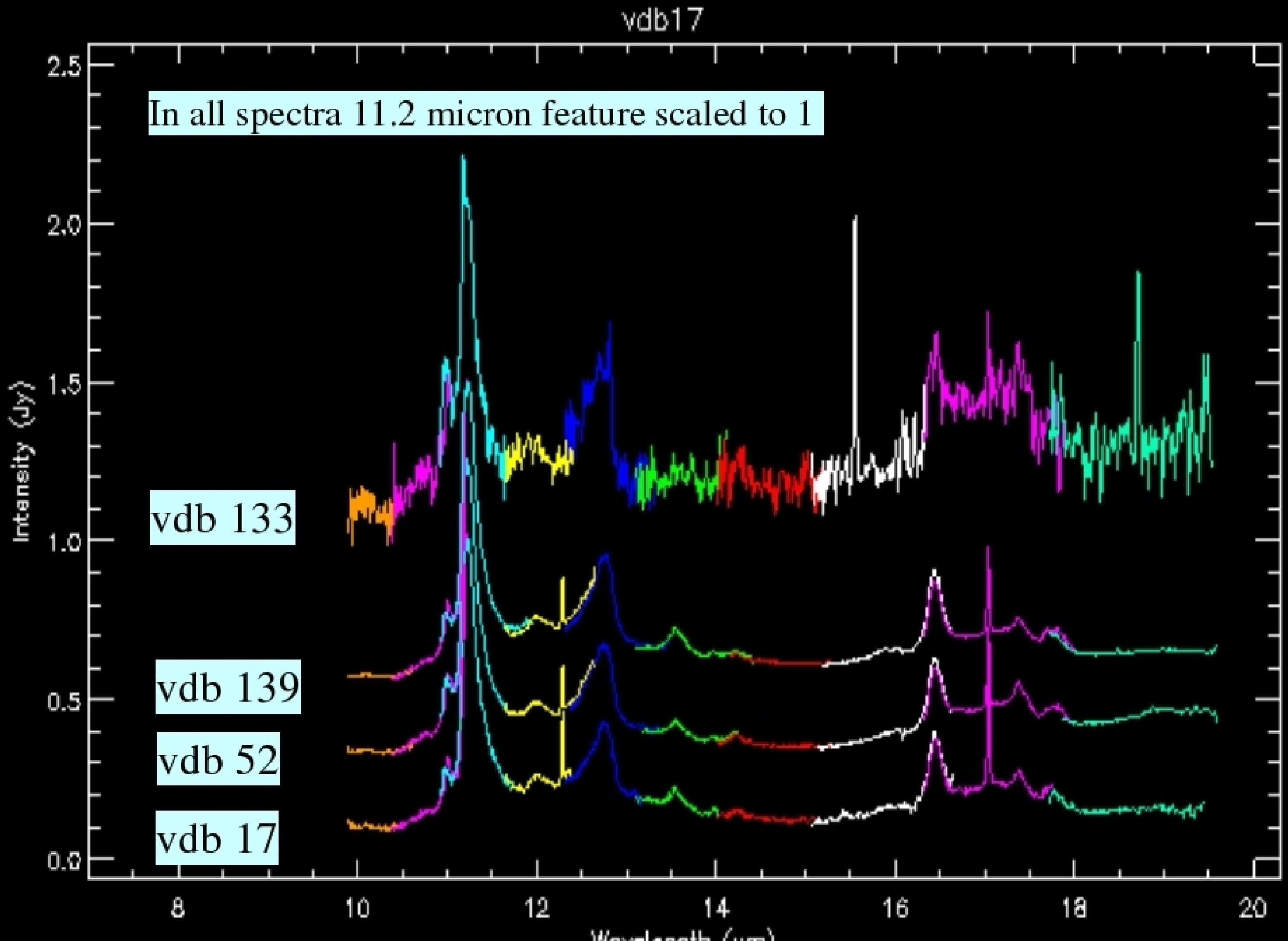


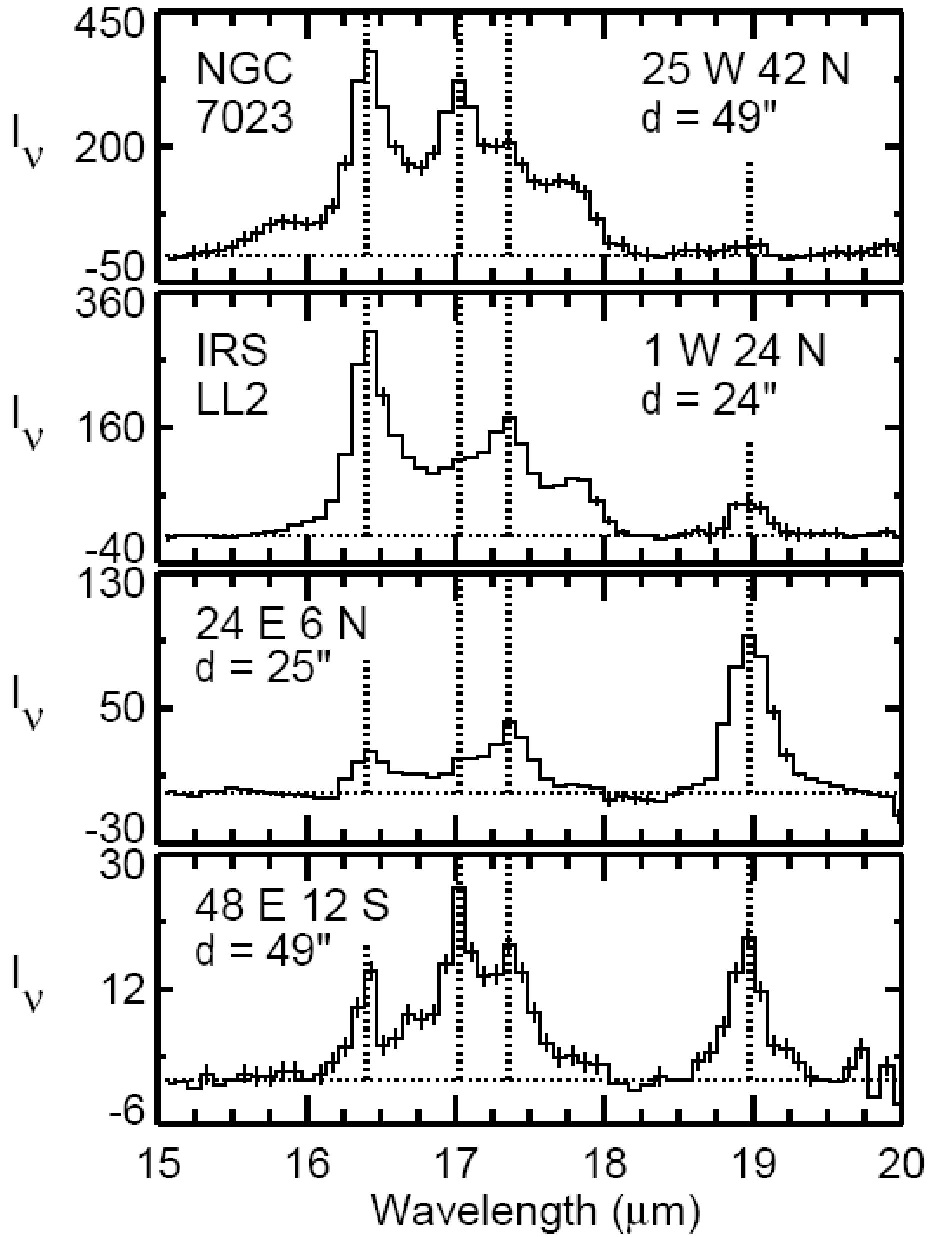
Star formation propagates from upper left to lower right in the NGC 1333 cluster in Perseus.

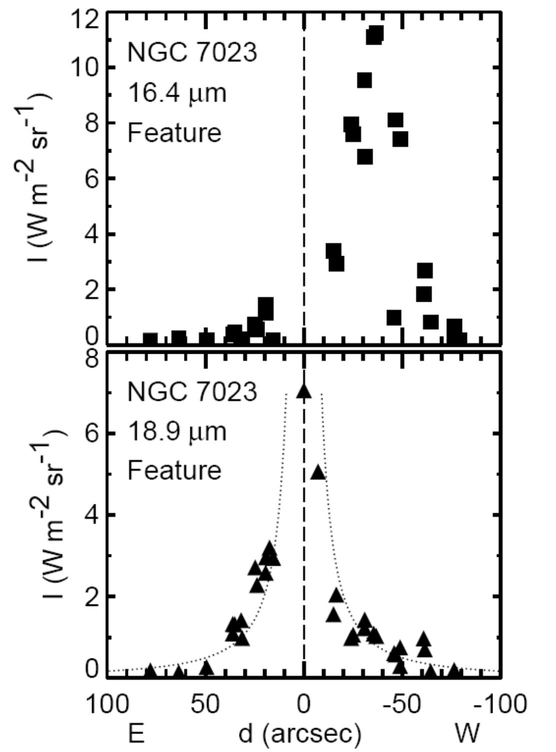
Red delineates hydrocabon-rich reflection nebulosity illuminated by main sequence stars

Green delineates embedded outflows and earlier stage of star formation

Spitzer 10-20um Spectra of Reflection Nebulae







New 18.9um Emission Feature in NGC7023 anti-correlates with 16.4um PAH feature….could it be C60?

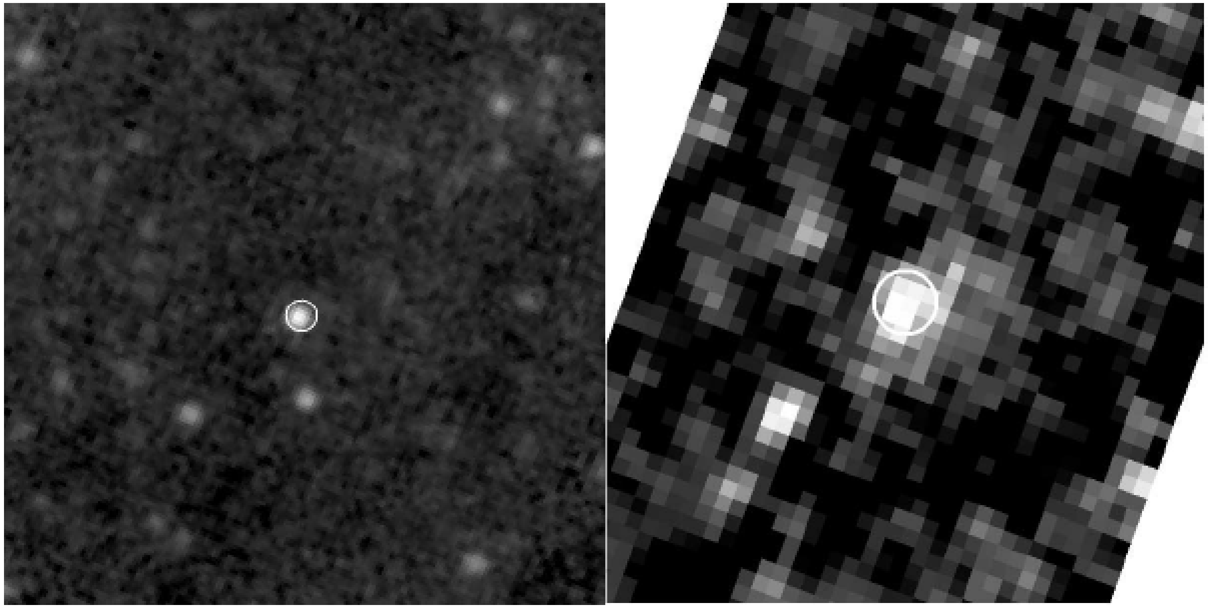
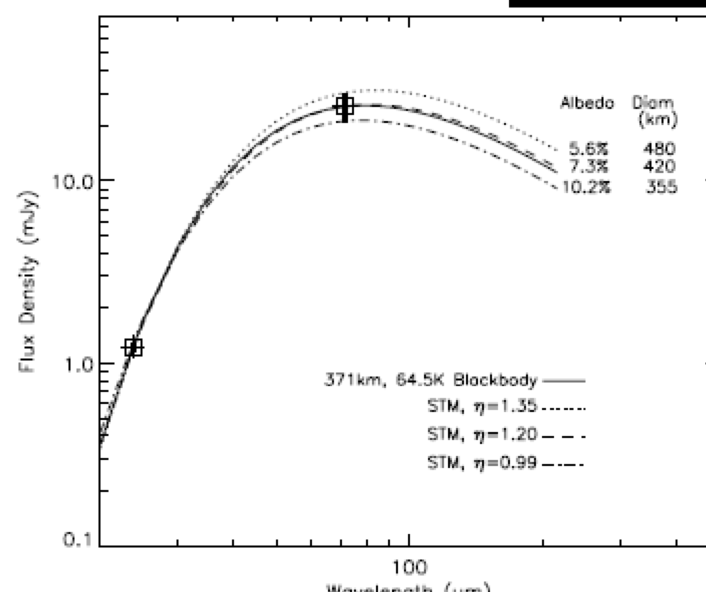


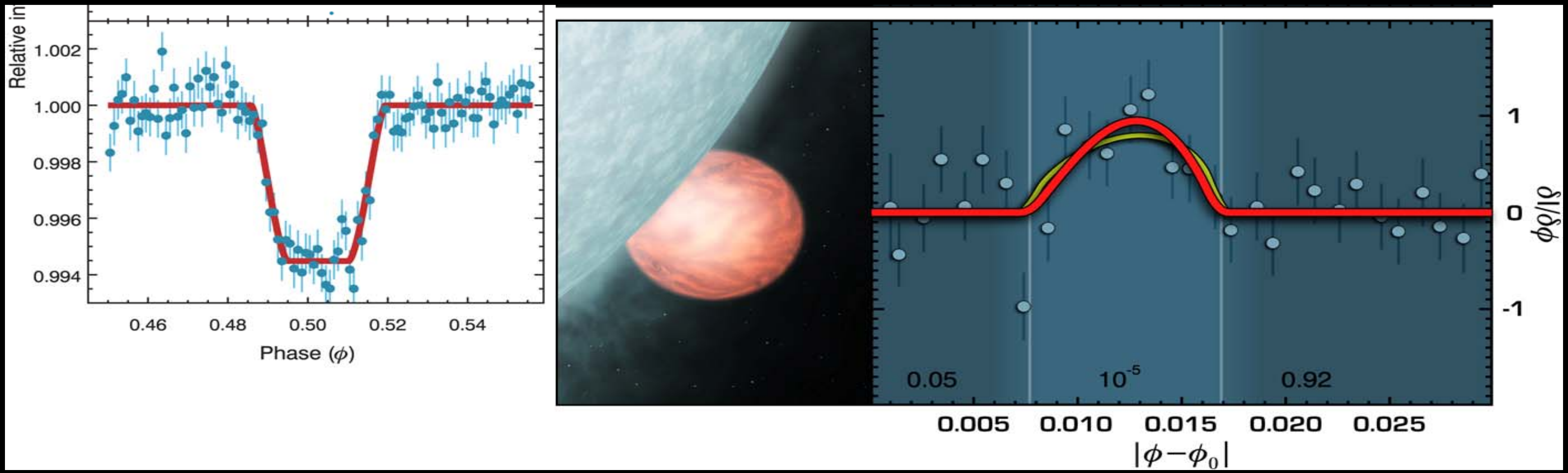
FIG. 1.—Images of (47171) 1999 TC_{36} at 24 μm (*left*) and 70 μm (*right*). Each image is 190″ square, and the orientation is north to the top, and east to the left. The circles are centered at the ephemeris position of the target. It is just possible to make out the first Airy maximum in the 24 μm image. There is no significant background structure due to cirrus at either wavelength.

Binary Kuiper Belt Object 1999TC36 has density between 0.3 and 0.8 gm/cm+3, but it is 250 miles in diameter!



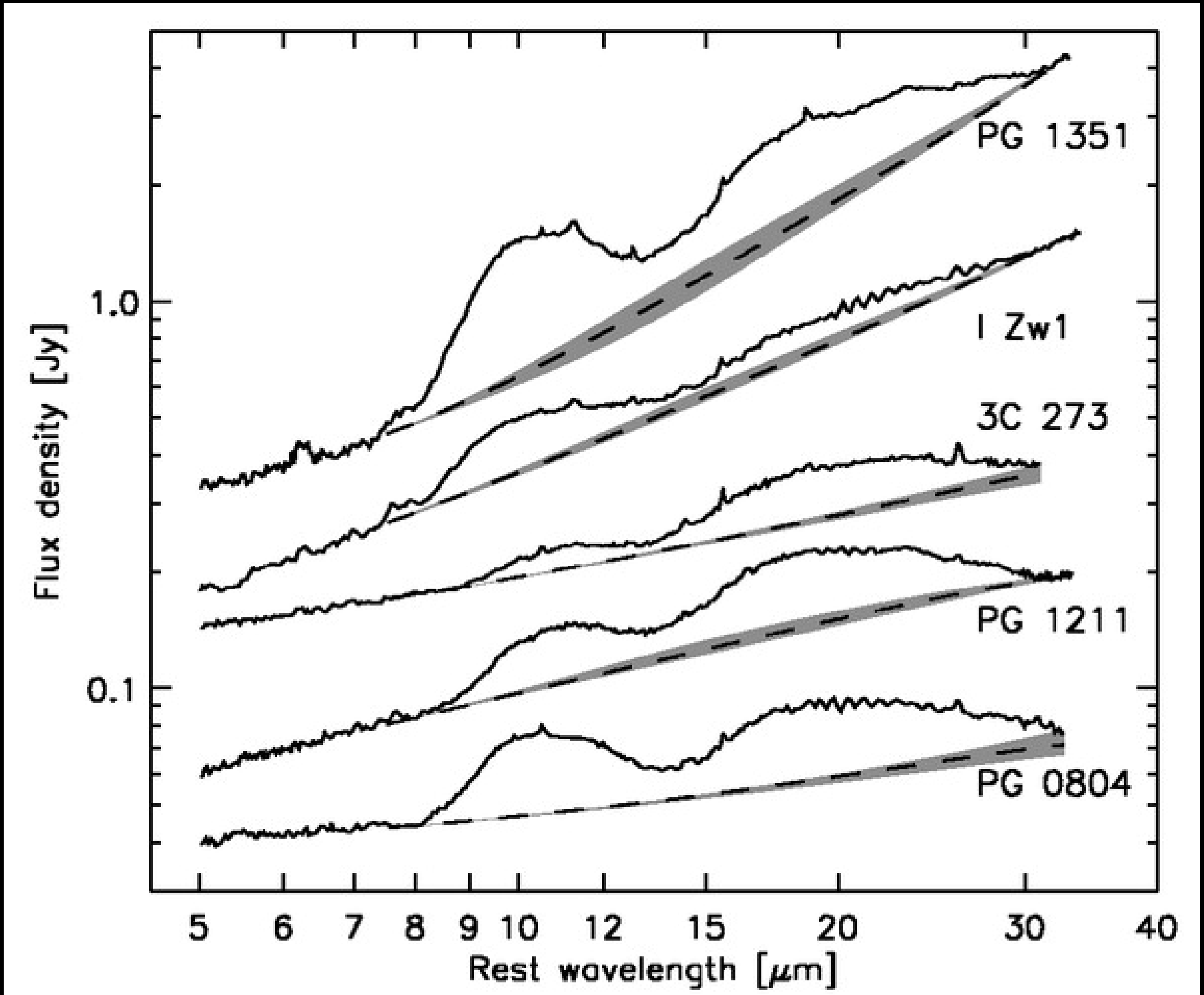
Light From Extrasolar Planets

- Spitzer has made first detections of light from extra solar planets by watching drop in infrared radiation as “hot Jupiters” pass behind the stars they orbit
- Temperature, albedo, day-night contrast, and perhaps composition of planets can be determined.

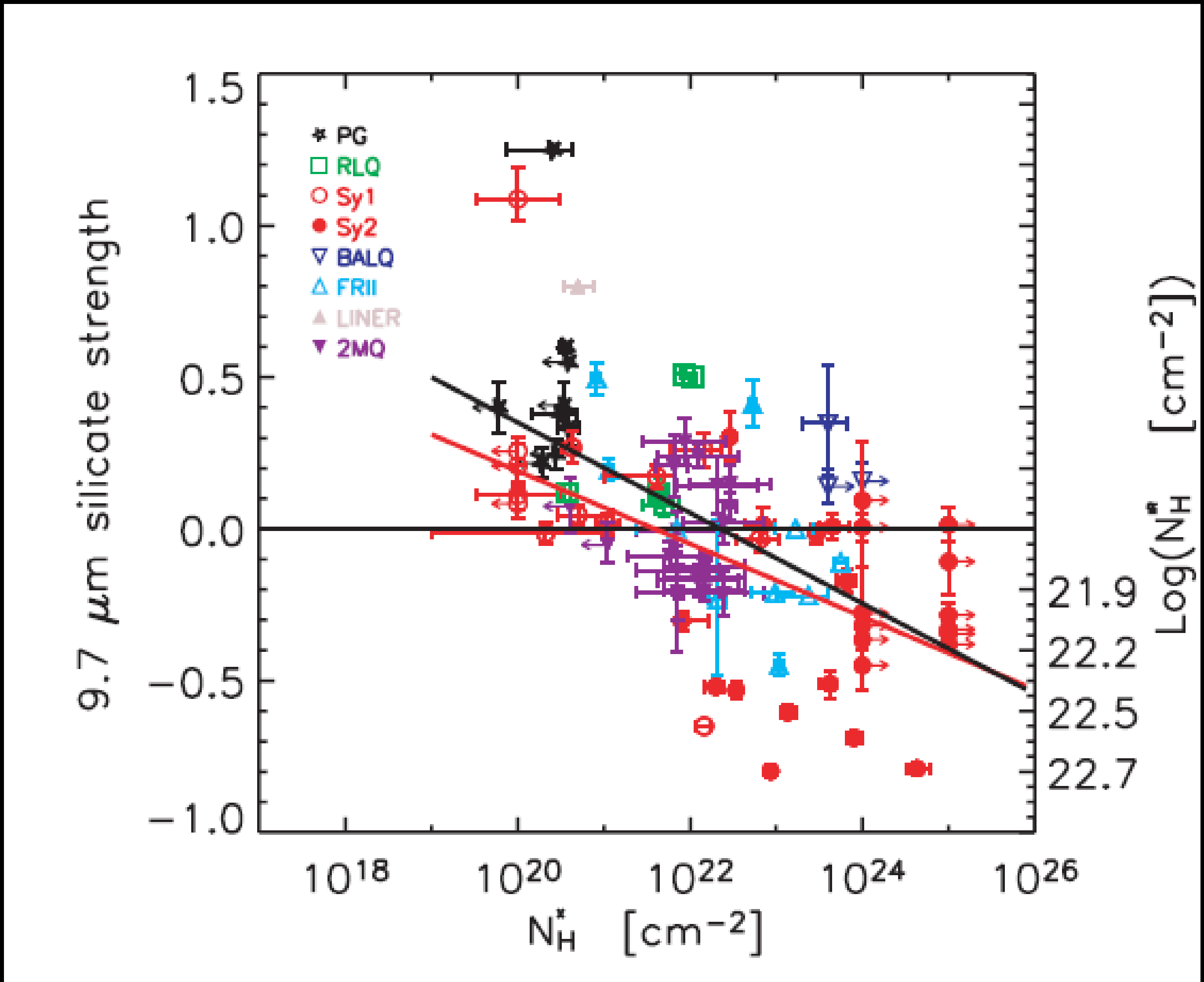


- The first true spectra of extrasolar planets are just around the corner

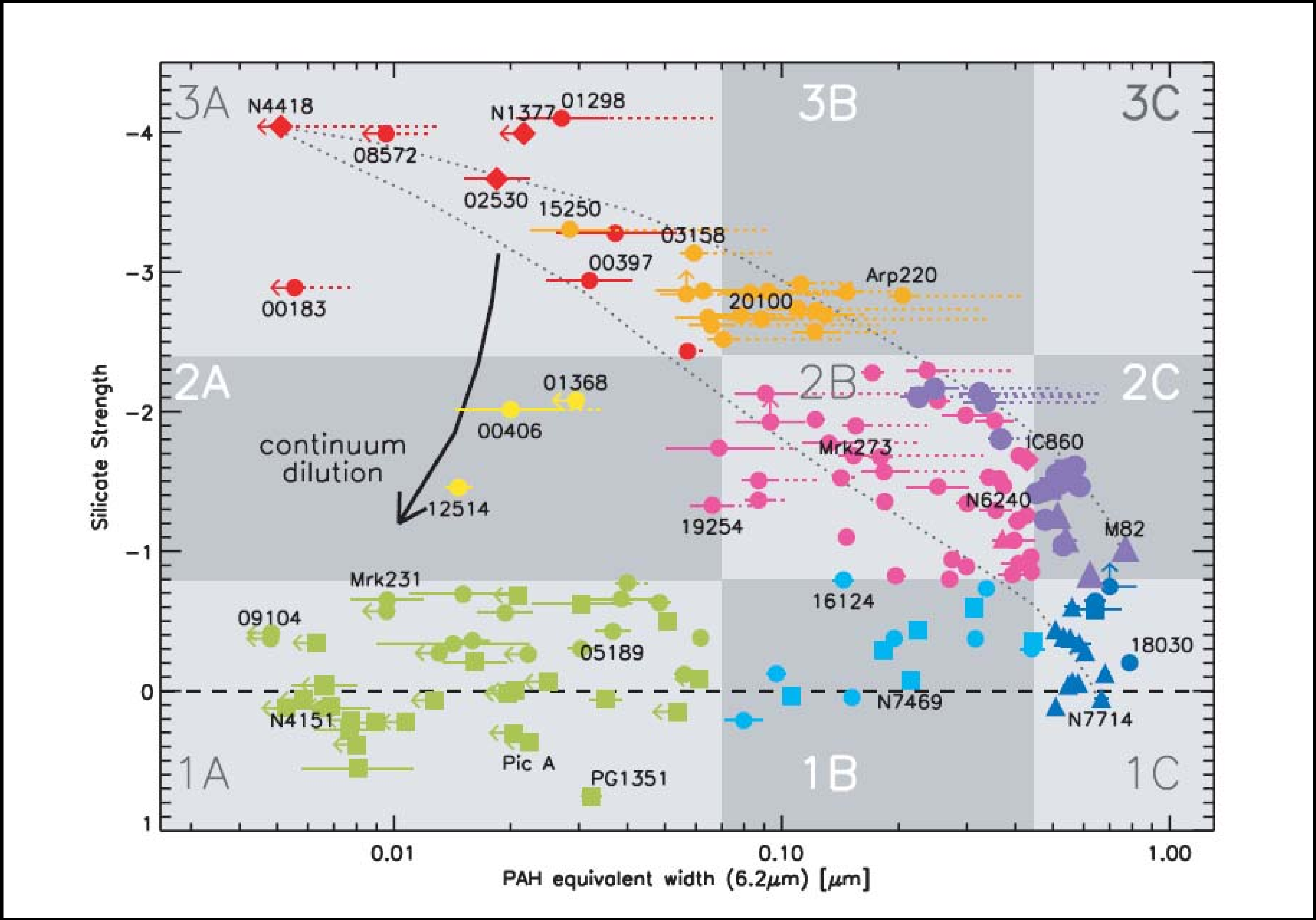
Silicate Emission in Type I AGN



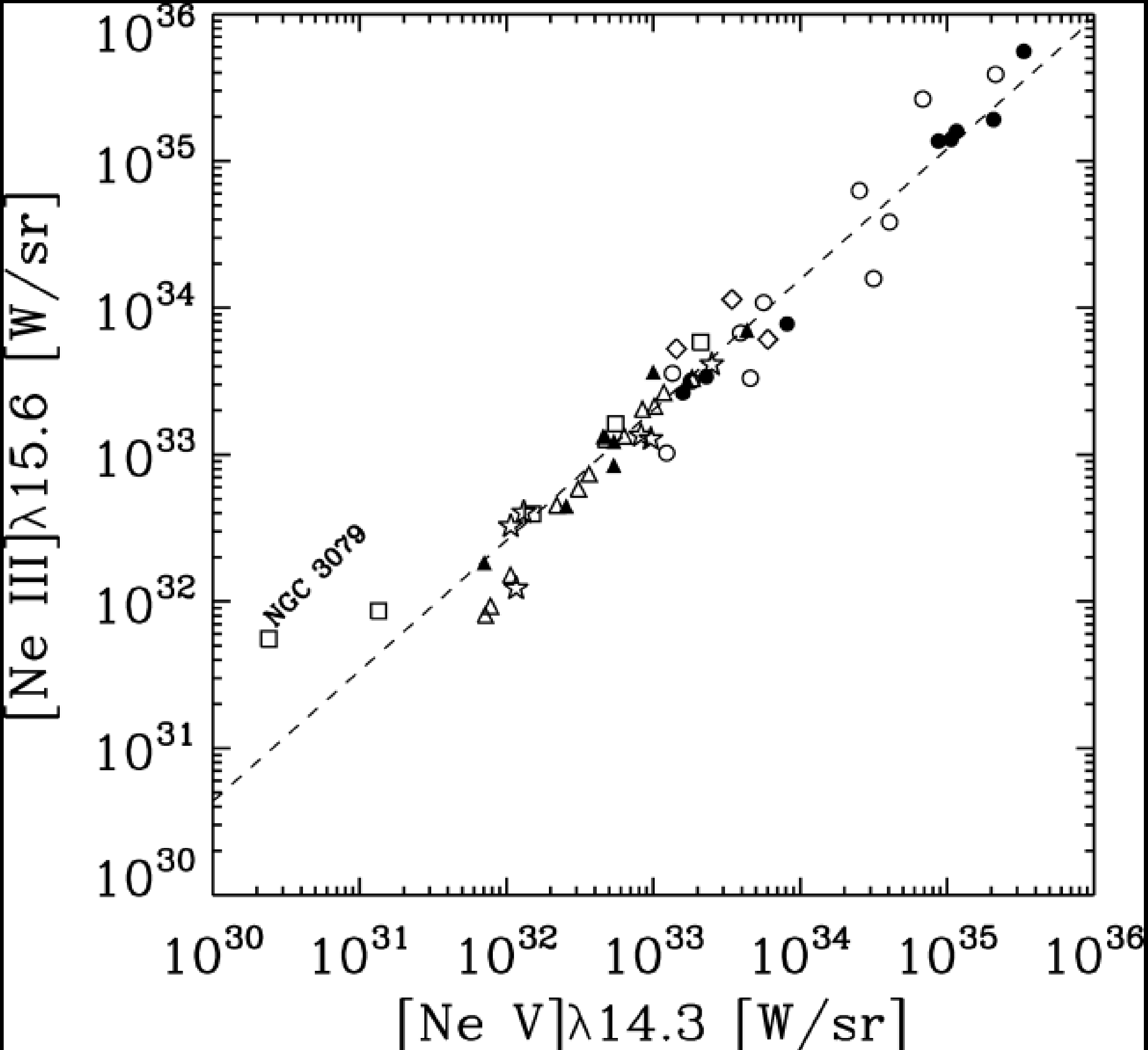
Correlation of Silicate Optical Depth and Xray Column Density Probes Circumnuclear Geometry in AGN



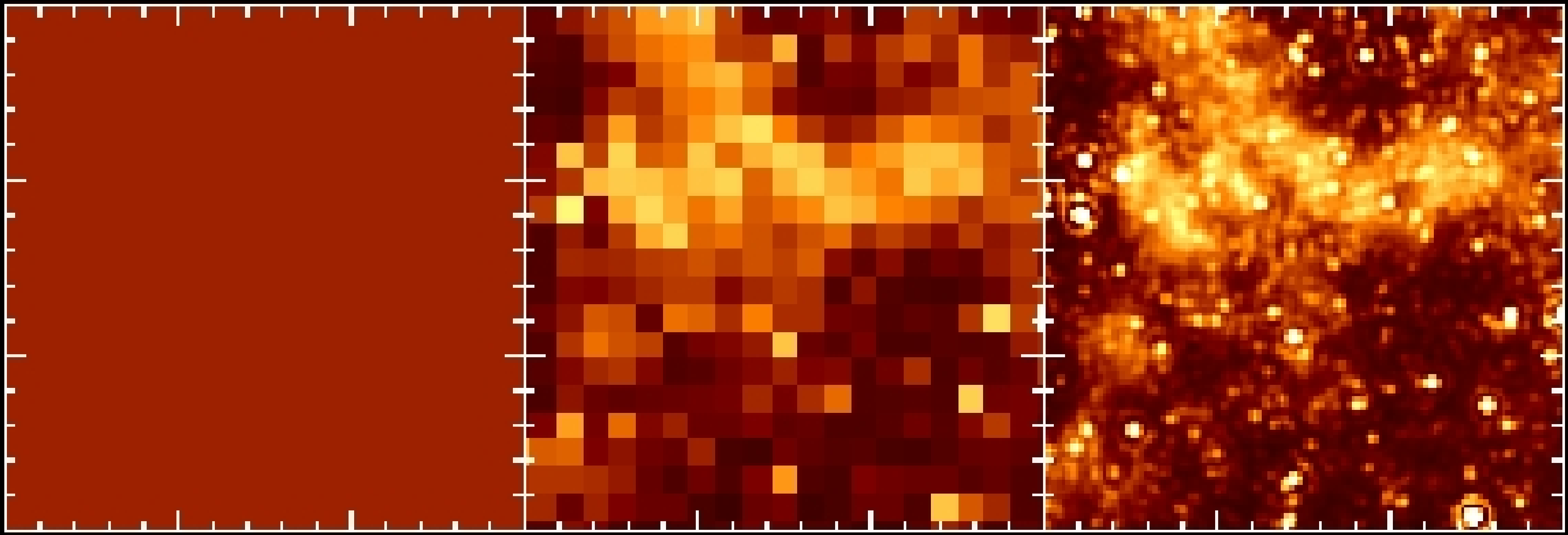
Newly Published Silicate-PAH IR-Luminous Galaxy Diagnostic



NeIII and NeV IR Lines Correlate Over Four Orders of Magnitude in Luminosity

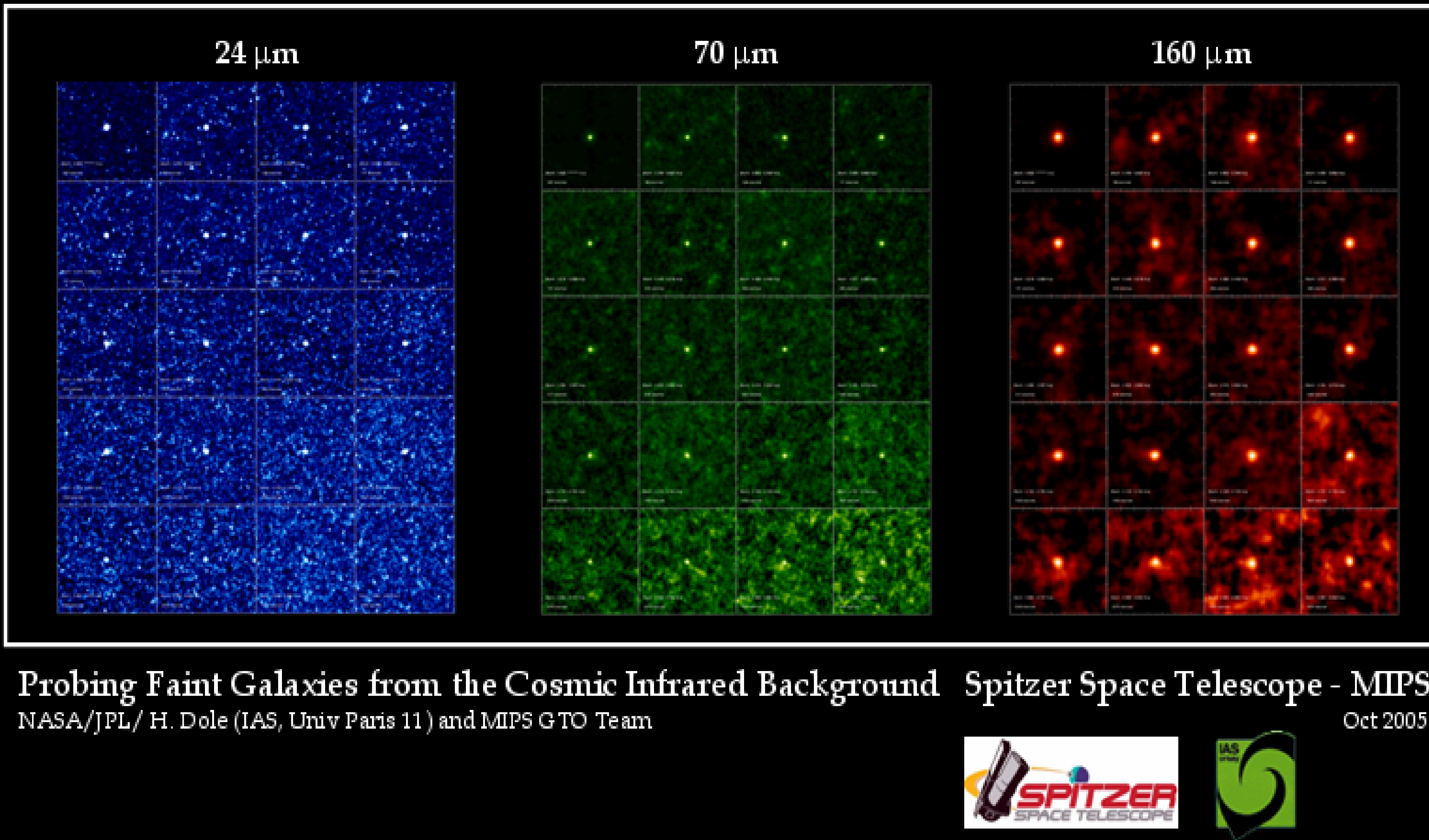


Can Spitzer Resolve the 160um Infrared Background?

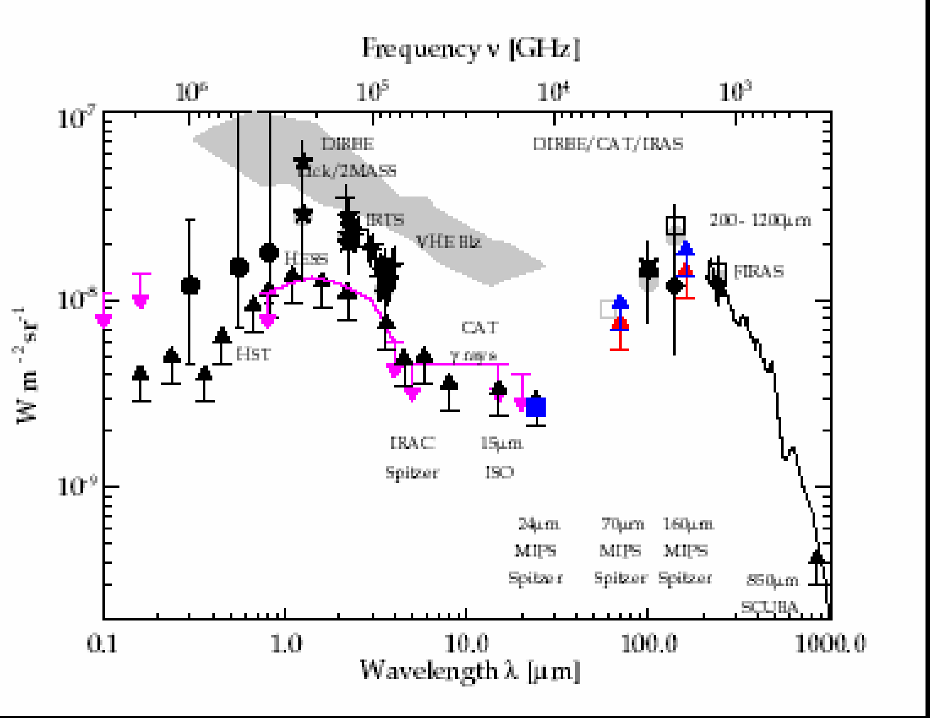


DIRBE 45’ ISO 90” MIPS 45”

This prelaunch simulation shows how the improved spatial resolution of Spitzer could identify the sources responsible for the 160um background seen by COBE. Dole et al have now done this!!

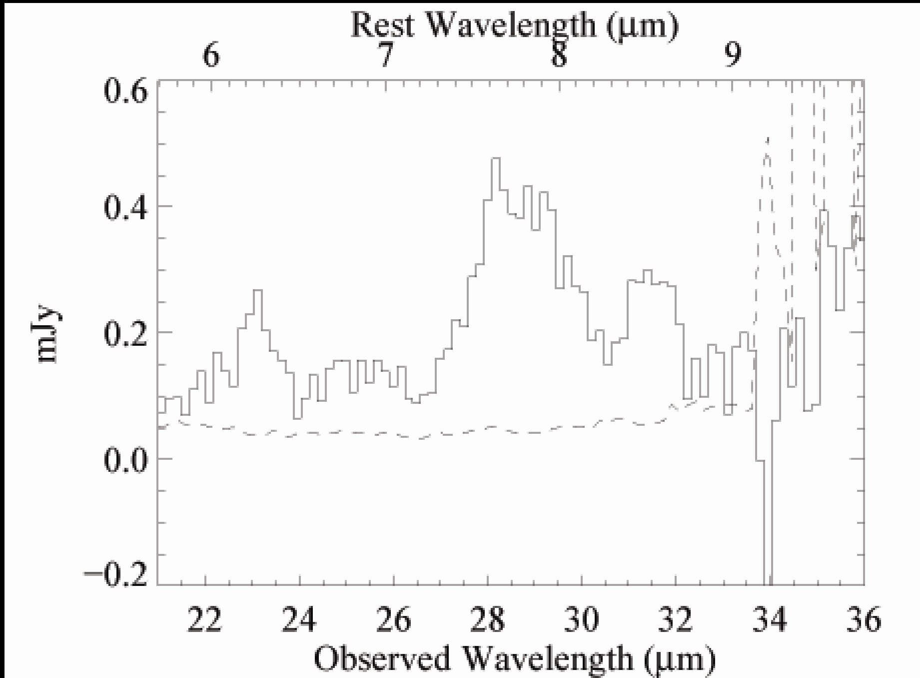


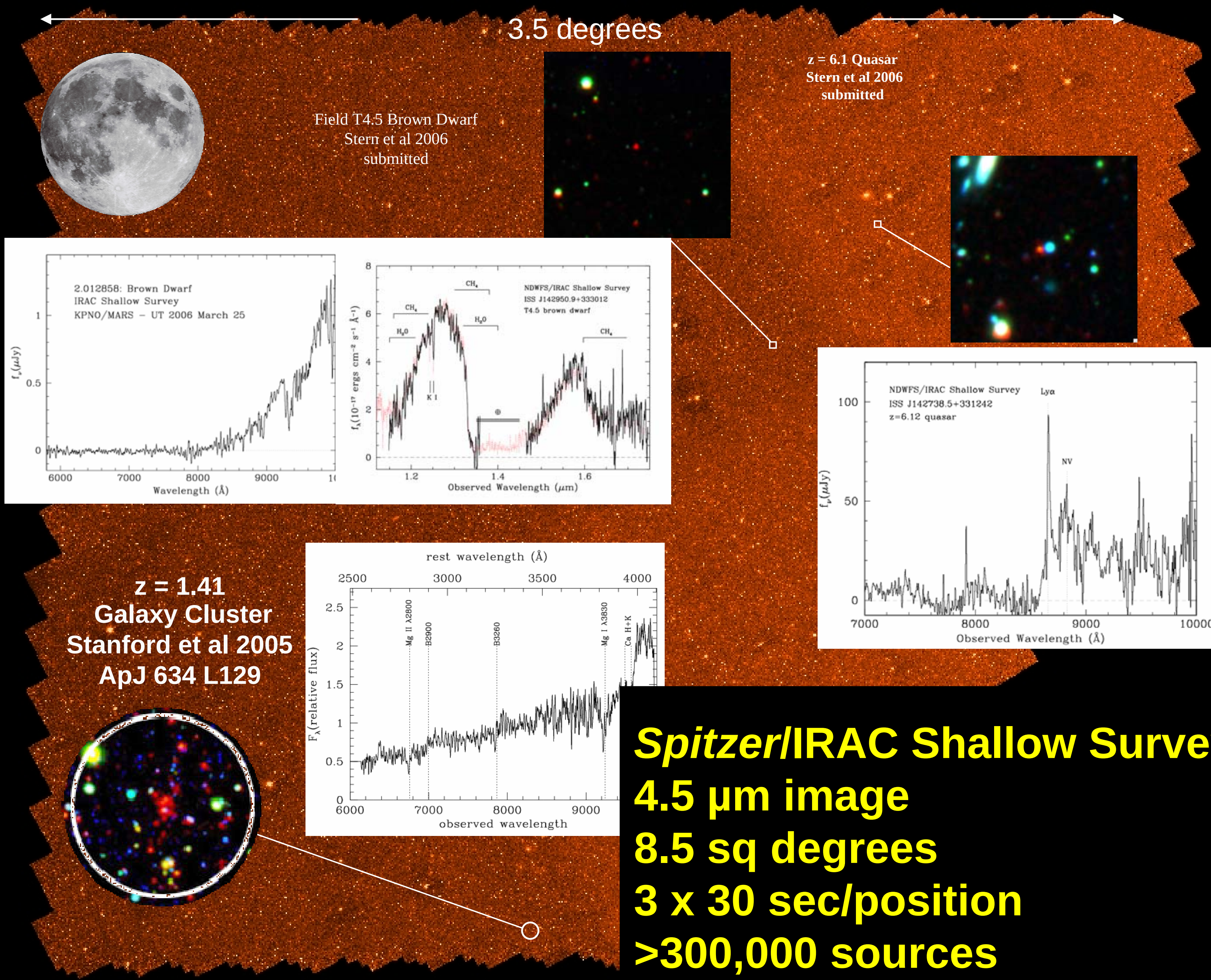
Dole et al have stacked 70/160um data at positions of 24um detections to find fainter sources than can be seen separately



The results strongly suggest that sources seen by Spitzer account for virtually all of the cosmic infrared background t0 ~200um.

Dole suggests that these sources are Luminous Infrared Galaxies at Z~1. Spitzer's IRS can get good spectra of galaxies as distant as Z~3!





Spitzer/IRAC Shallow Survey

4.5 μm image

8.5 sq degrees

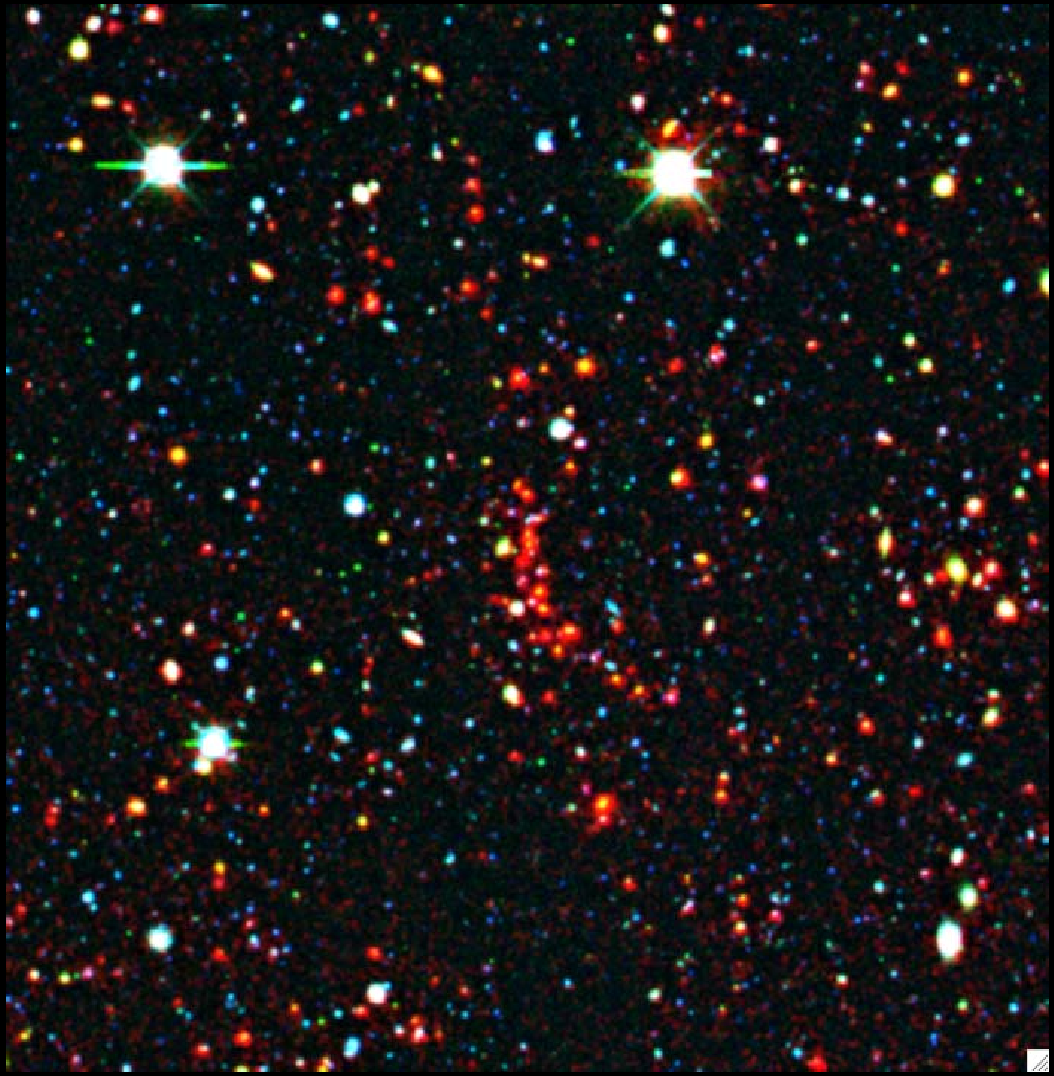
3 x 30 sec/position

>300,000 sources

FINDING A DISTANT CLUSTER IN A ~5' SECTION OF THE IRAC SHALLOW SURVEY FIELD:

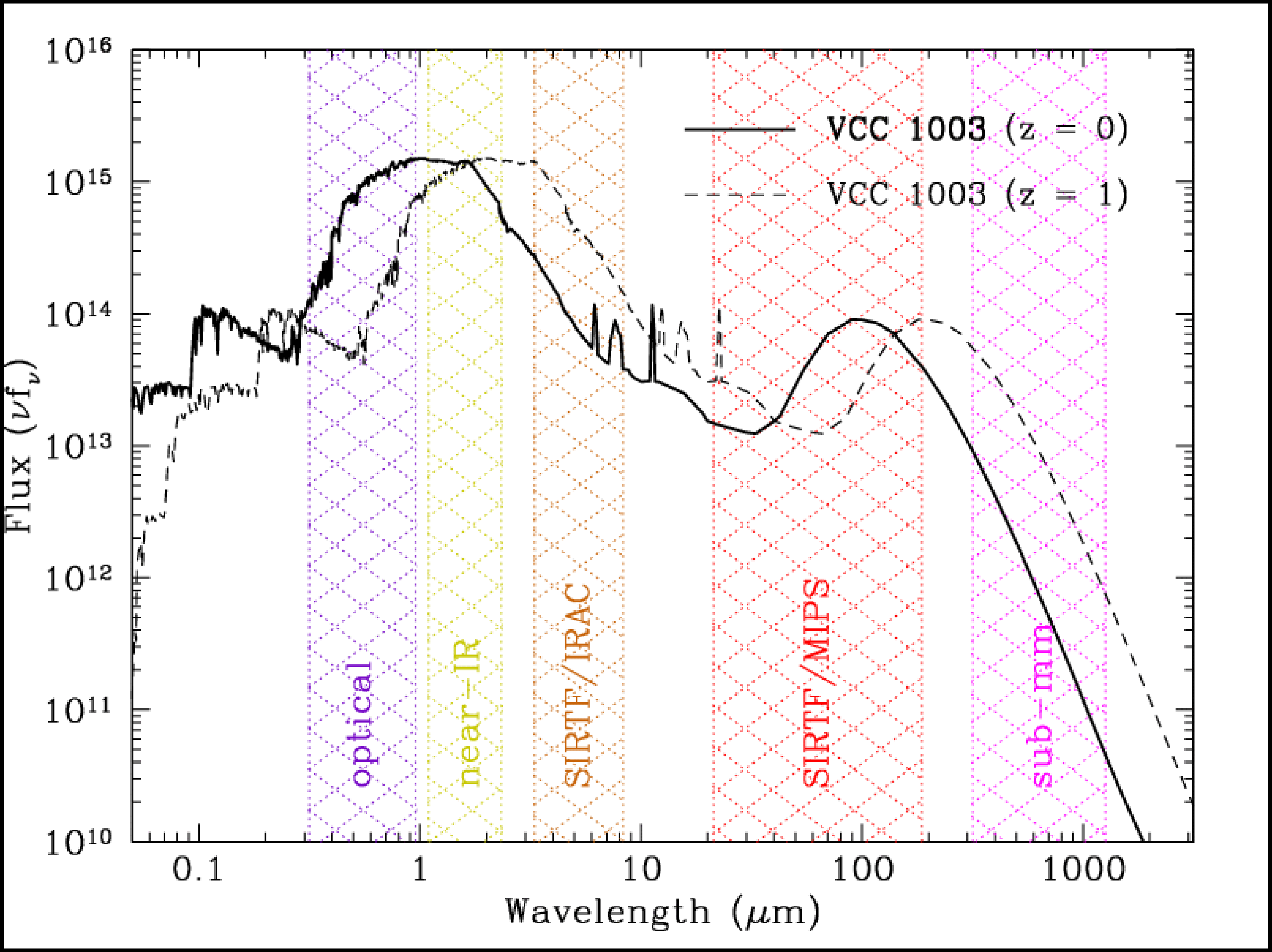
START WITH IMAGE IN VISIBLE LIGHT BANDS – V,R, I

ADD IRAC 4.5UM BAND AND, VOILA!

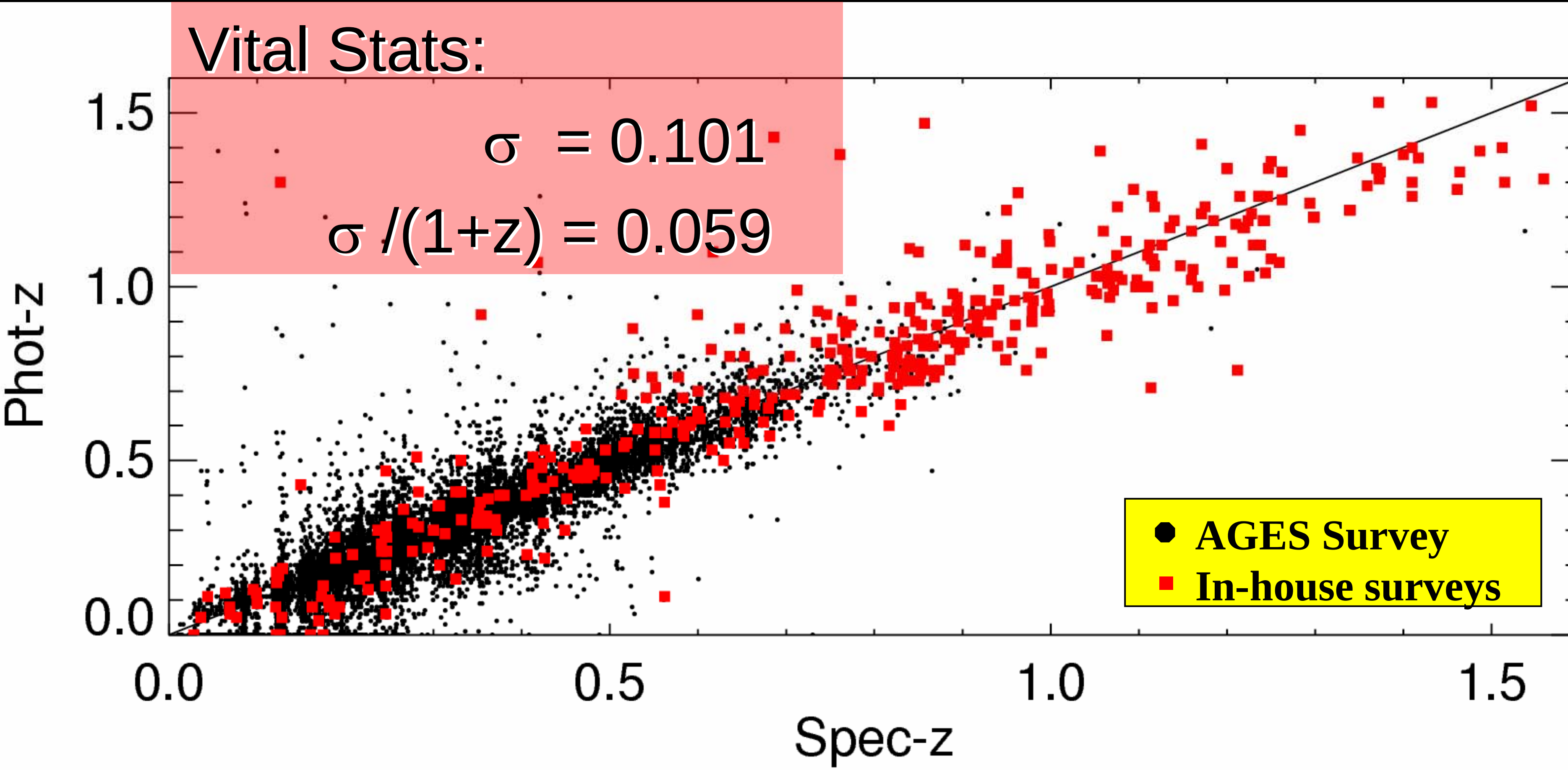


A CLUSTER WITH Z=1.24

For z>1, emission peak due to stars in galaxies shifts into the IRAC bands

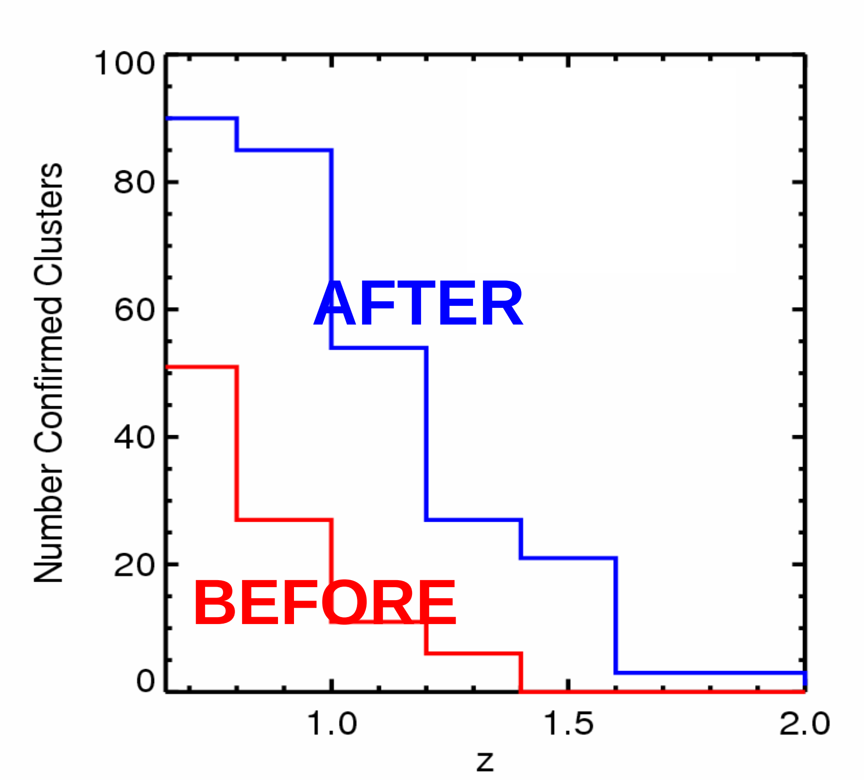


Photometric Redshifts, based on SED rather than true spectrum, suffice to define candidate clusters



Brodwin et al. (ApJ, 651, 791)

Clusters discovered in Bootes field may greatly increase the number of known high redshift clusters [from red to blue].

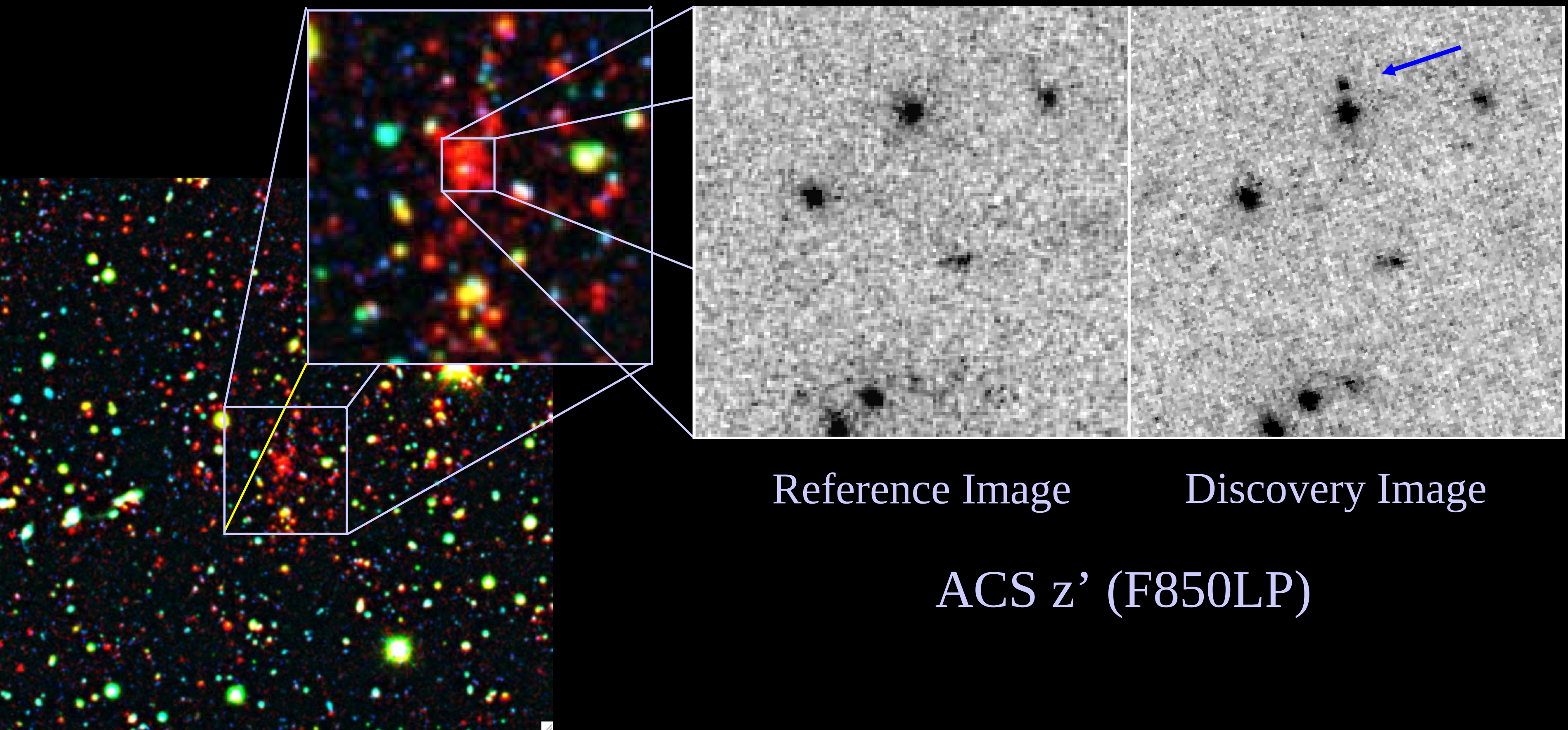


Potential Applications Include:

- Determination of Cosmological Parameters
- Studies of Evolution of Cluster Galaxies
- Identification of z>1 Supernovae in Dust-Poor Galaxies

Cluster SN Cosmology

- **Supernovae in cluster galaxies are ideal probes of dark energy. This supernova candidate at z=1.41 is one of the most distant known**



Spitzer, Hubble data on Galaxy with Spectroscopic Redshift = 5. 83

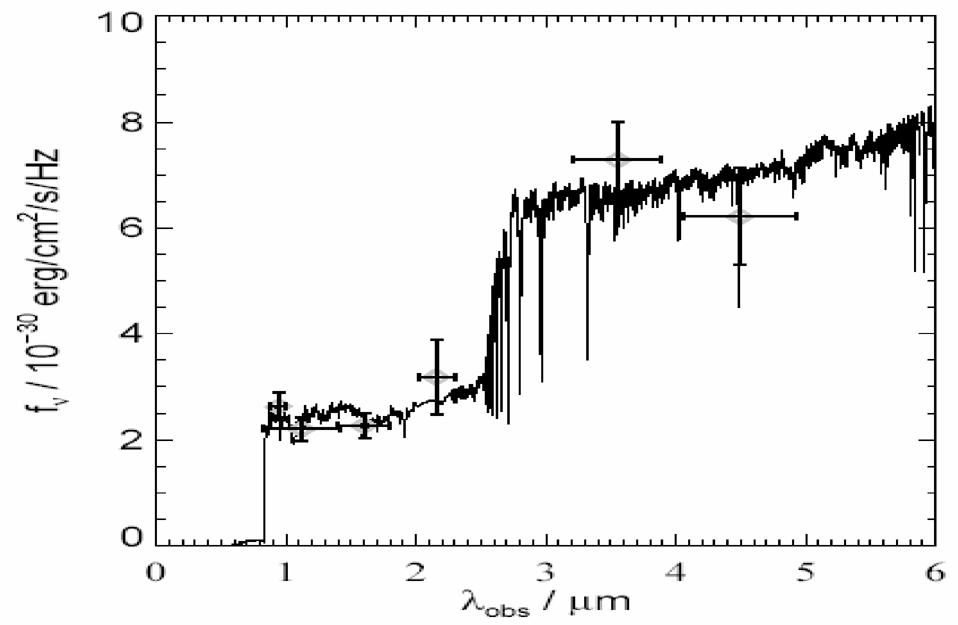
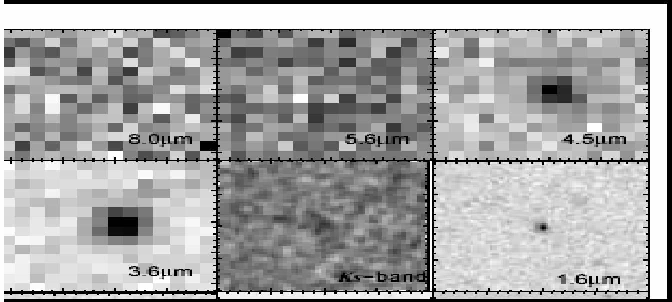


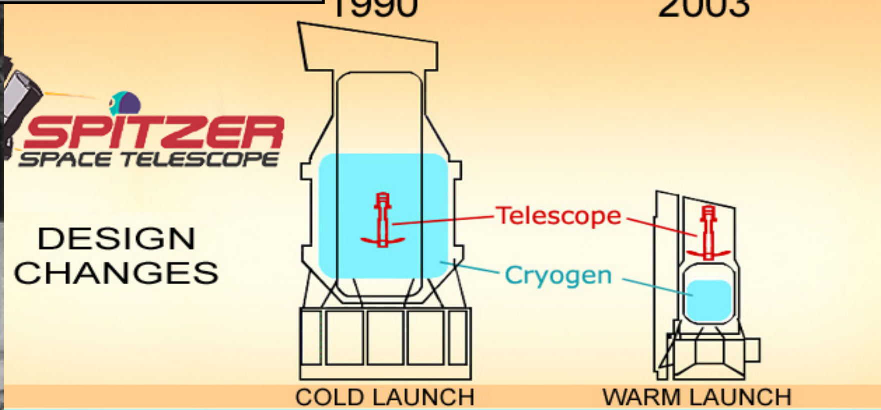
Figure 6. Best-fit Bruzual & Charlot model for SBM03#1: an exponentially decaying star formation rate with τ = 300 Myr, viewed 640 Myr after the onset of star formation. The stellar mass is 3.4×10^{10} $M_\odot$. Flux density is in f_ν units.



Stellar mass 3.4e+10 solar masses; Population age 450 Myr; Age of Universe 983 Myr

Spitzer posed a Cosmic Conundrum by finding very massive galaxies in the early Universe….This caught the fancy of Science News and challenges theories of structure formation

Spitzer – One Slide History



	COLD LAUNCH	WARM LAUNCH
Launch Mass	5700 kg	870 kg
Lifetime	5 years	5 years
Development Cost	~$2.2B	$0.67B
Launch Vehicle	Titan IV	Delta

Spitzer Science Team:
Mike Werner, Frank Low, George Rieke, Jim Houck, Giovanni Fazio, Mike Jura, Ned Wright, *Tom Roellig, Marcia Rieke, Tom Soifer, Bob Gehrz, Dale Cruikshank, Charles Lawrence*