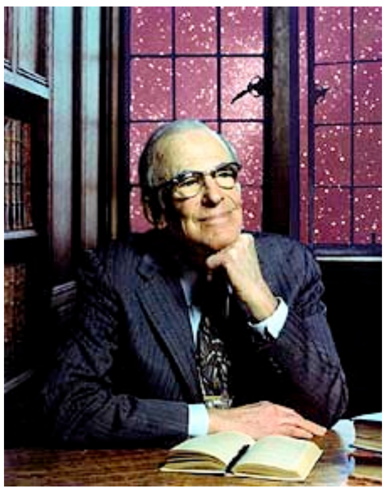
The Royal Astronomical Society
George Darwin Lecture

Advancing Astronomy and Geophysics

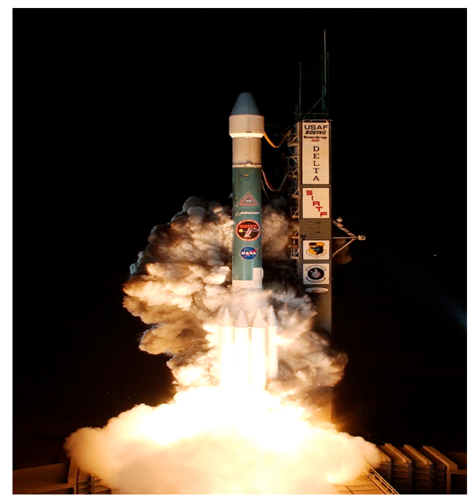
Friday 12th May 2006
Lecture Theatre of the Geological Society of London

The Spitzer Space Telescope: Probing the Universe with Infrared Eyes

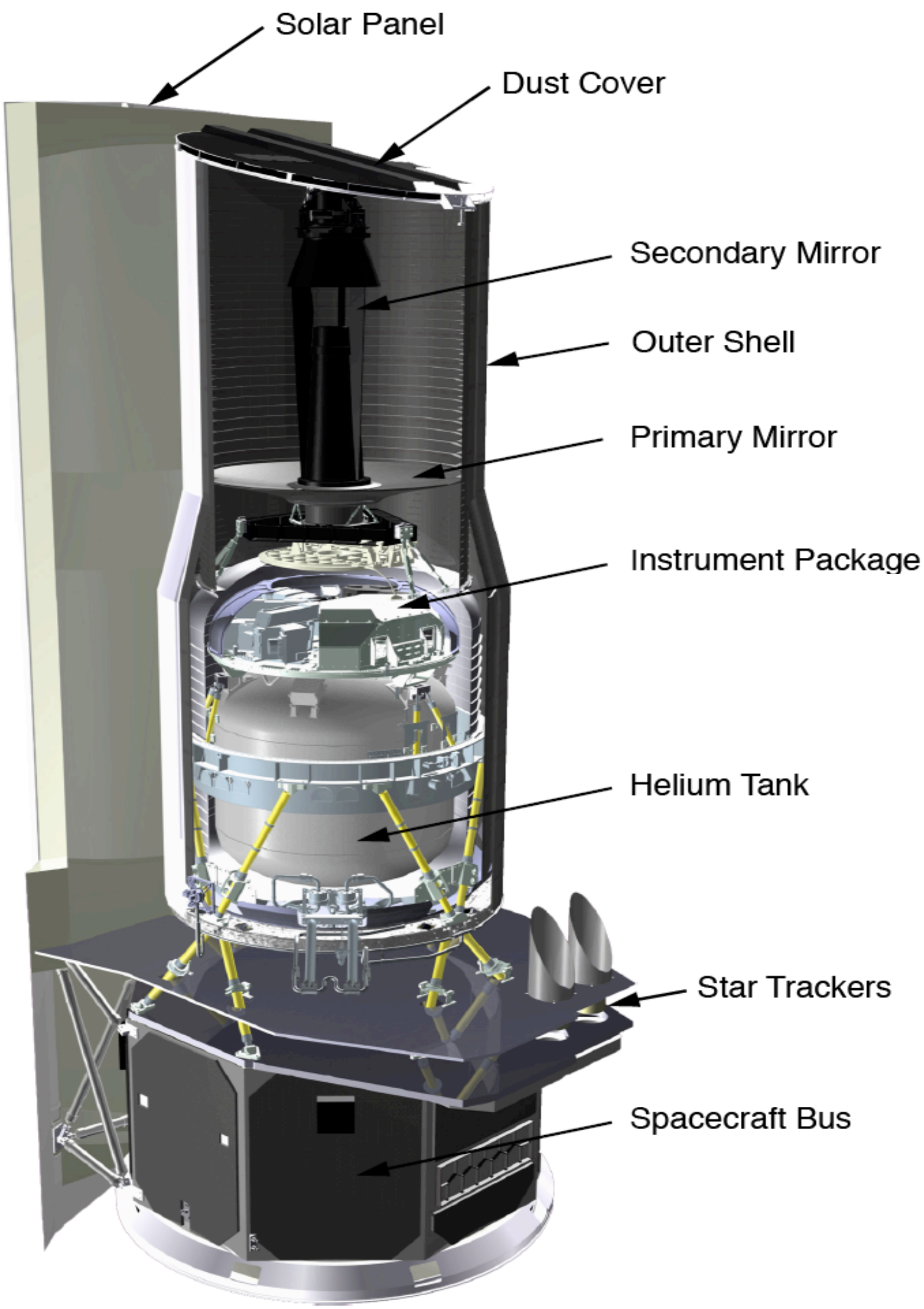
Michael Werner (JPL/Caltech)

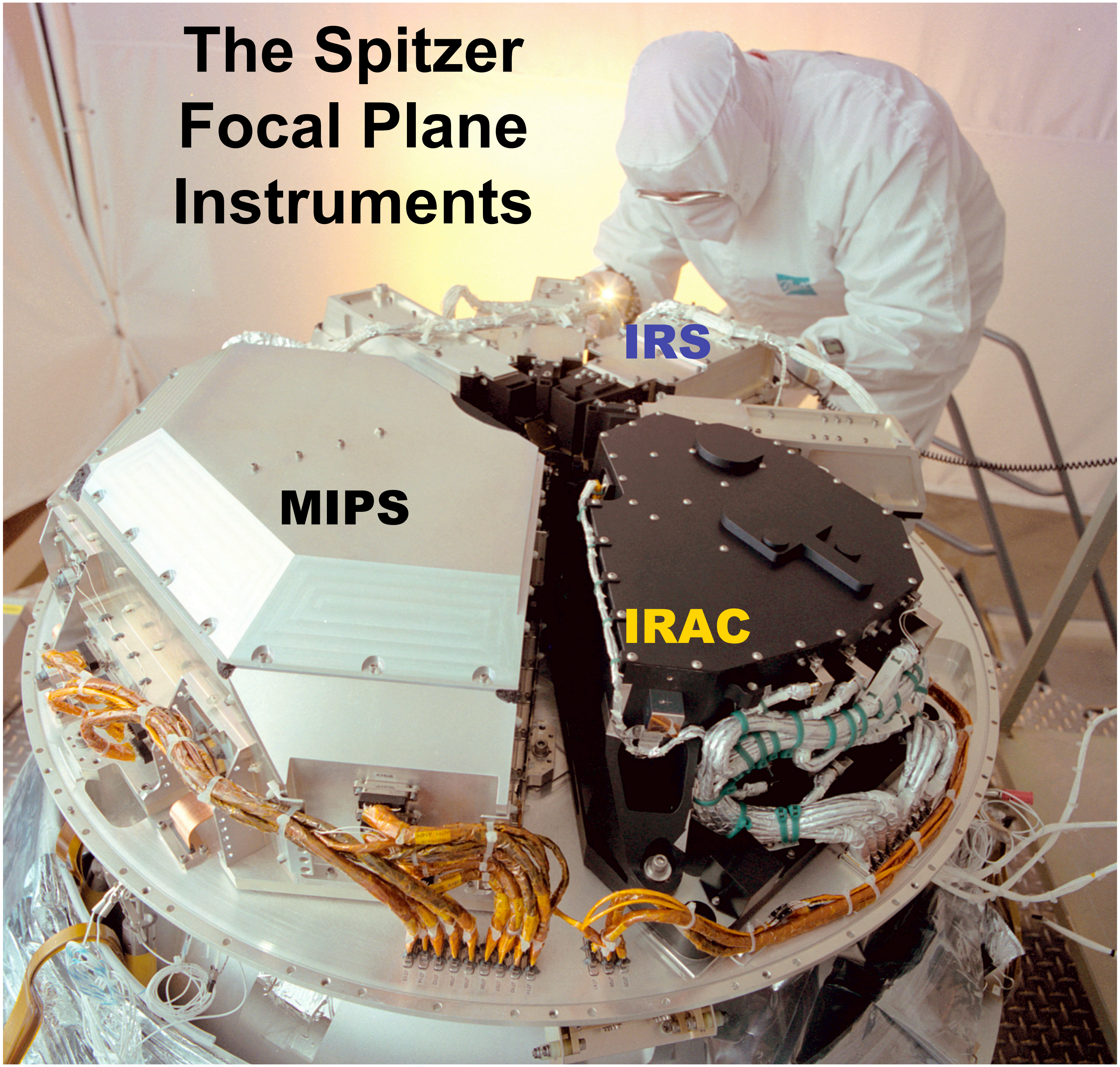


Spitzer image of the central ~1.4x1.9 degrees of our Milky Way Galaxy



Spitzer – Inside and Out

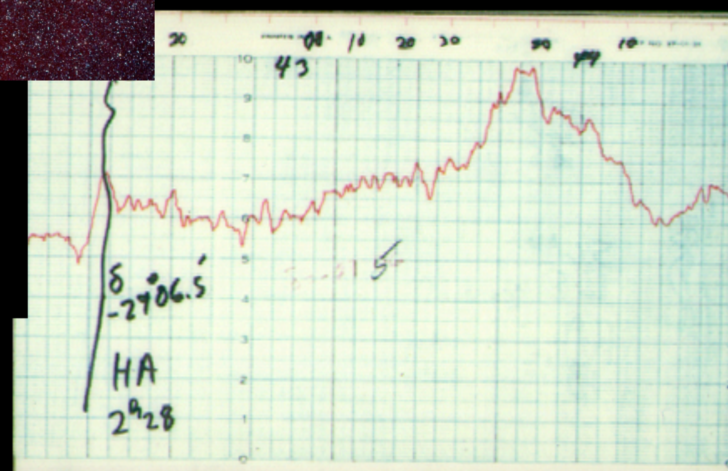


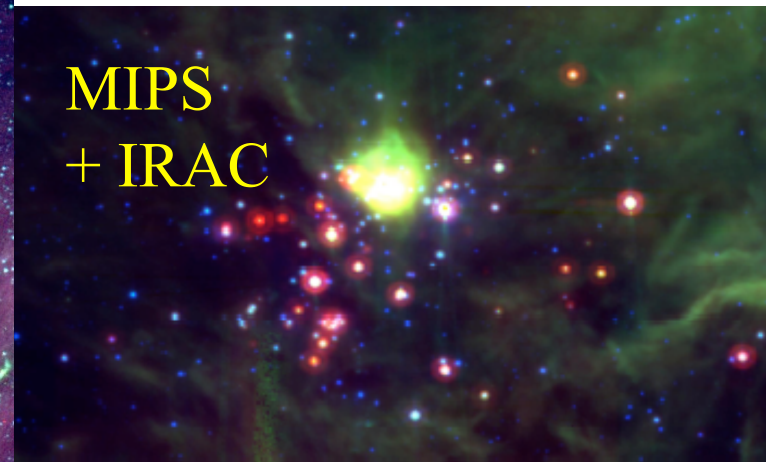

The Spitzer Focal Plane Instruments
IRS
MIPS
IRAC

Infrared Images: Then and Now

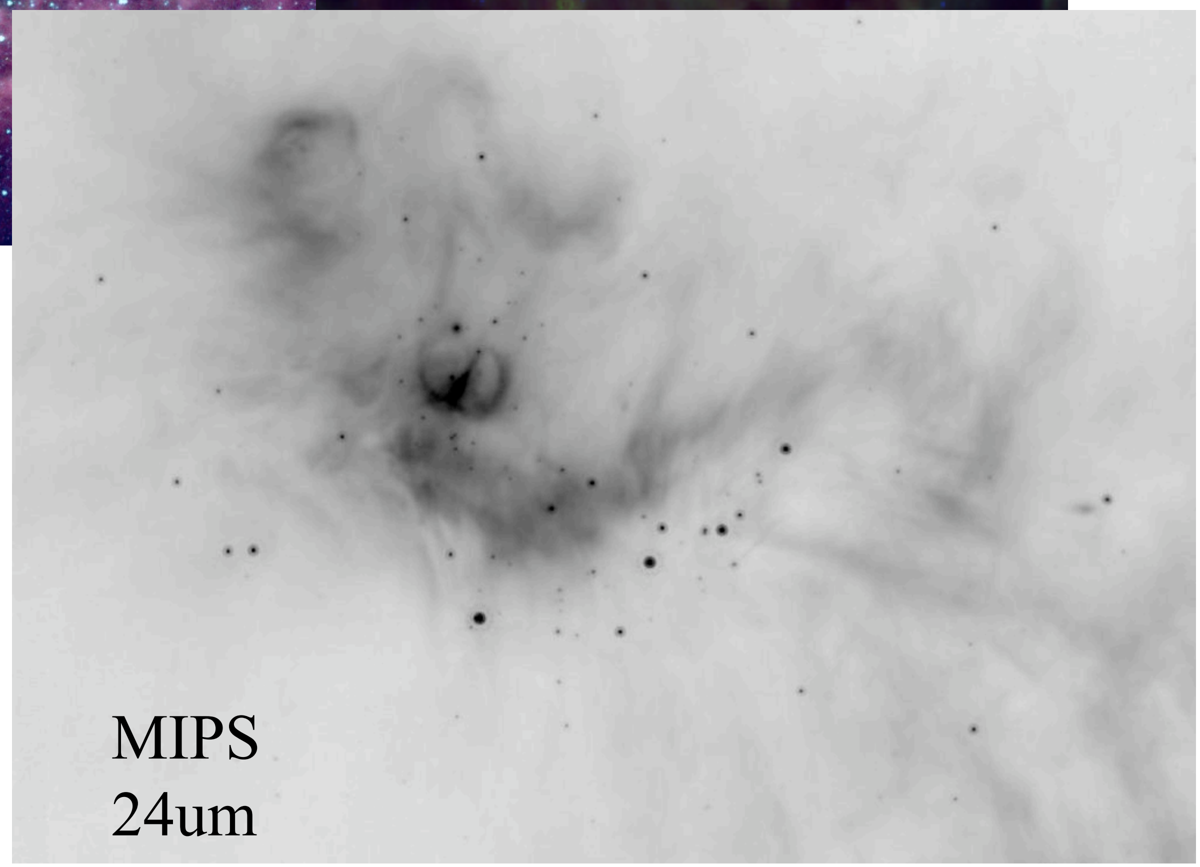
2006

1967





Spitzer Images of Star Forming Clouds



Spectra From Spitzer Trace Protostellar Evolution Sequence

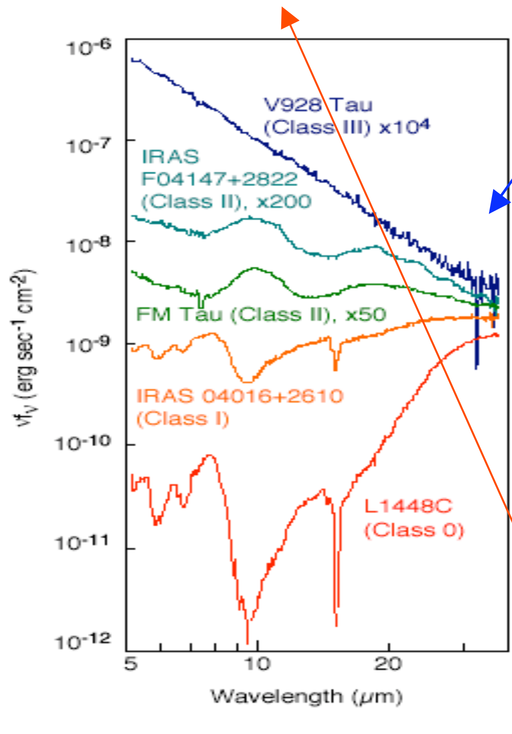
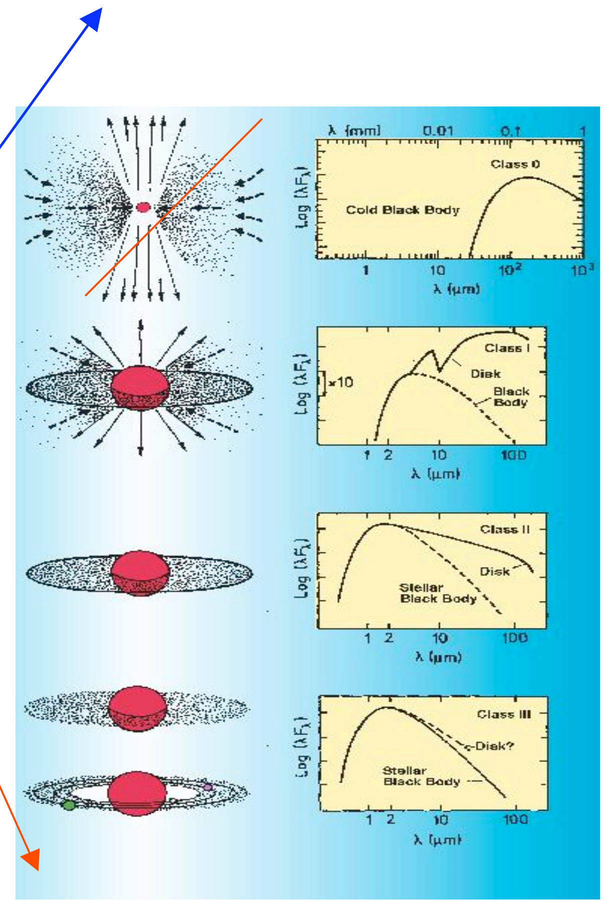


Figure 2



Class 0

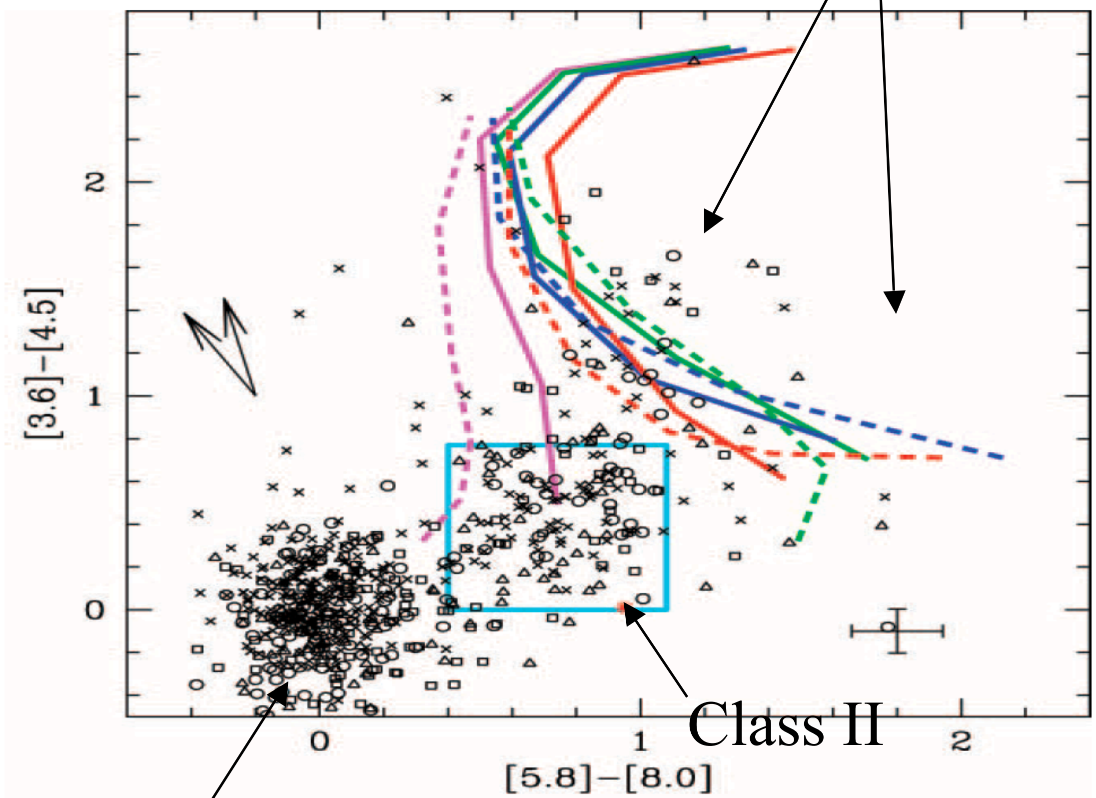
Class I

Class II

Class III

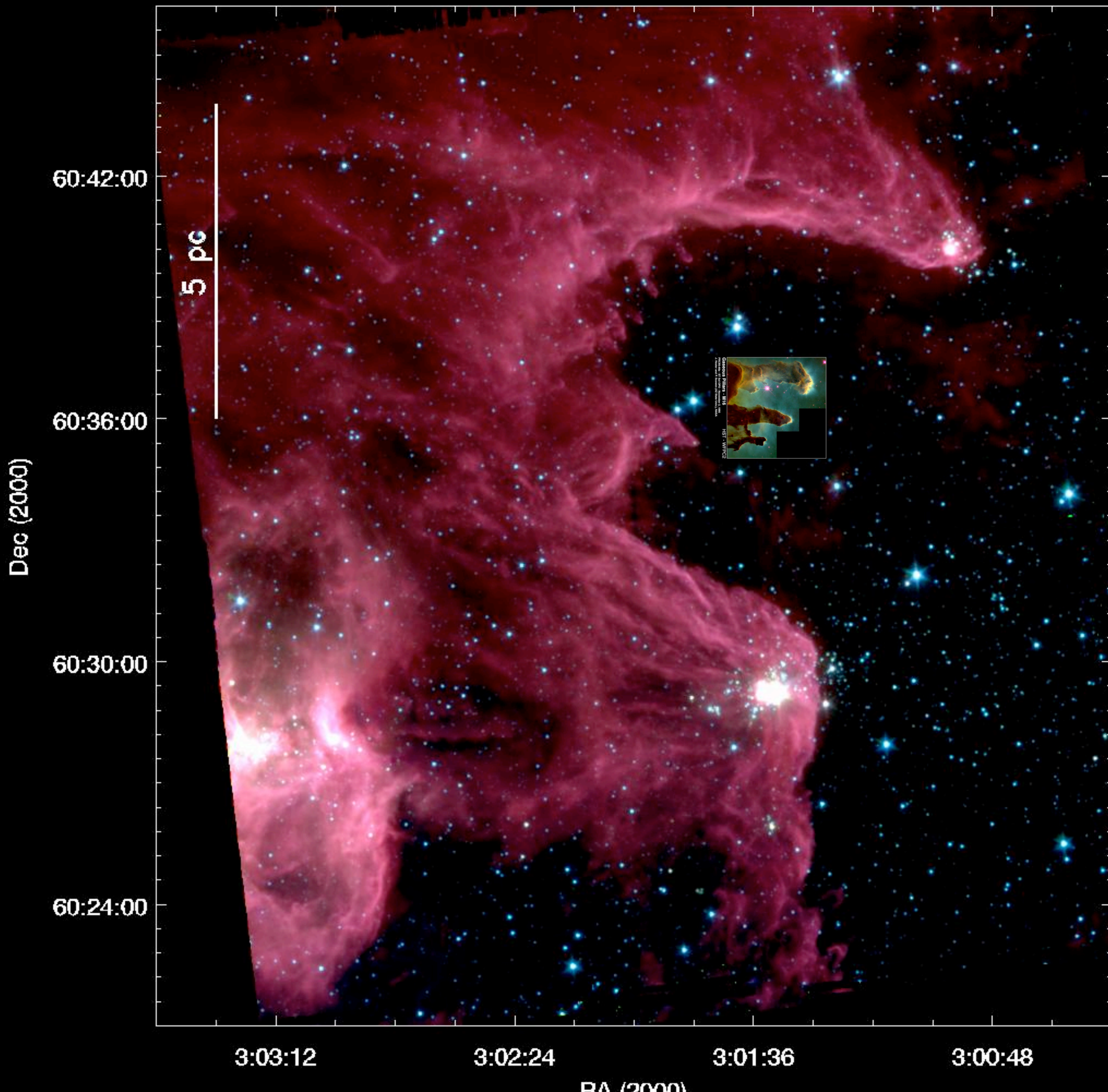
IRAC Color-Color Plot for Young Stellar Objects

Class I



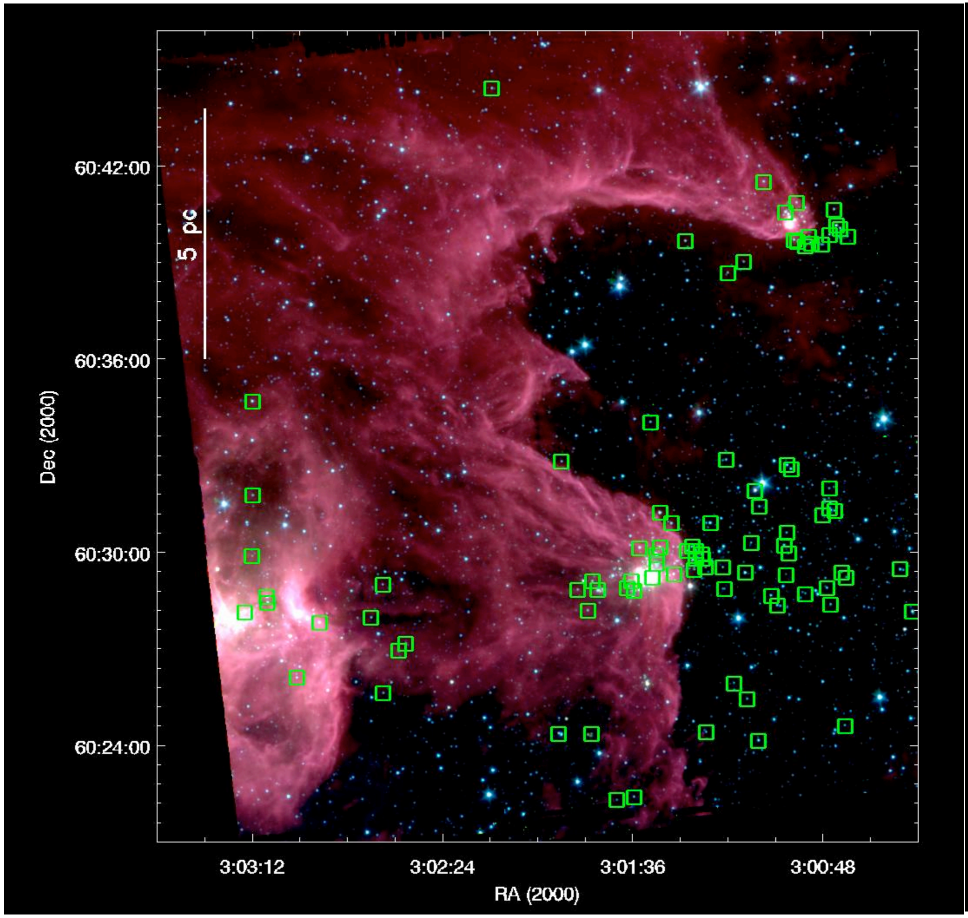
Class II

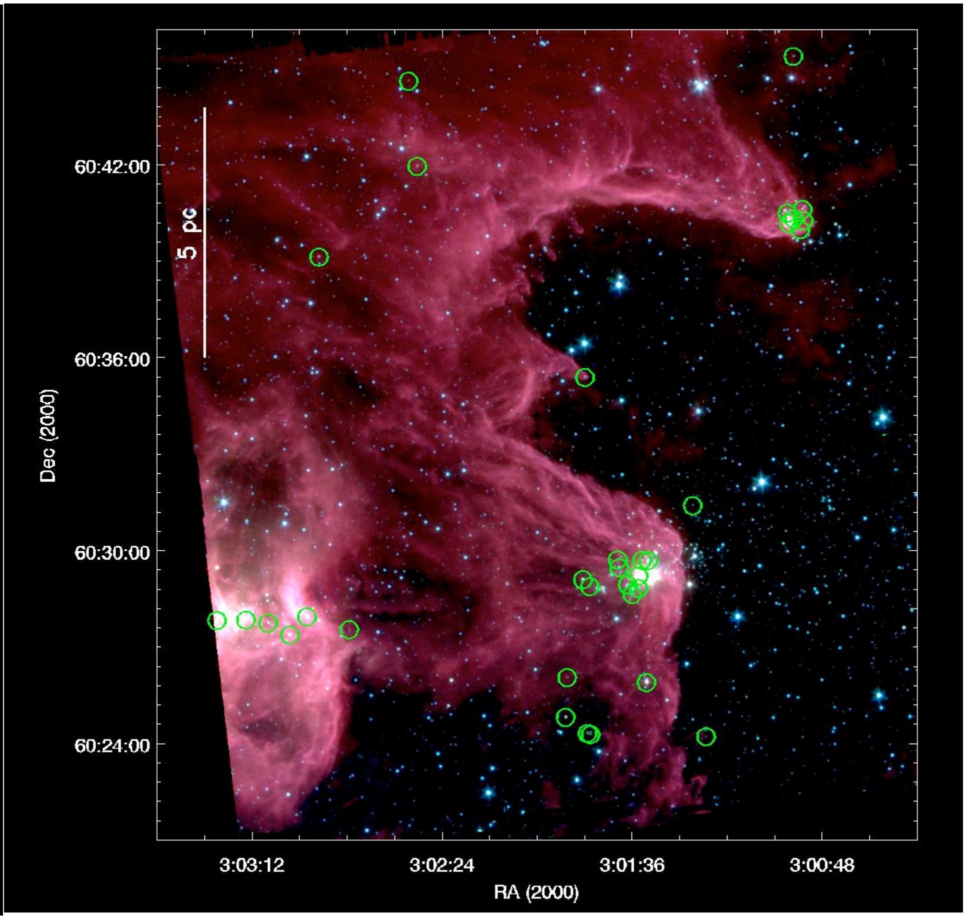
Class III



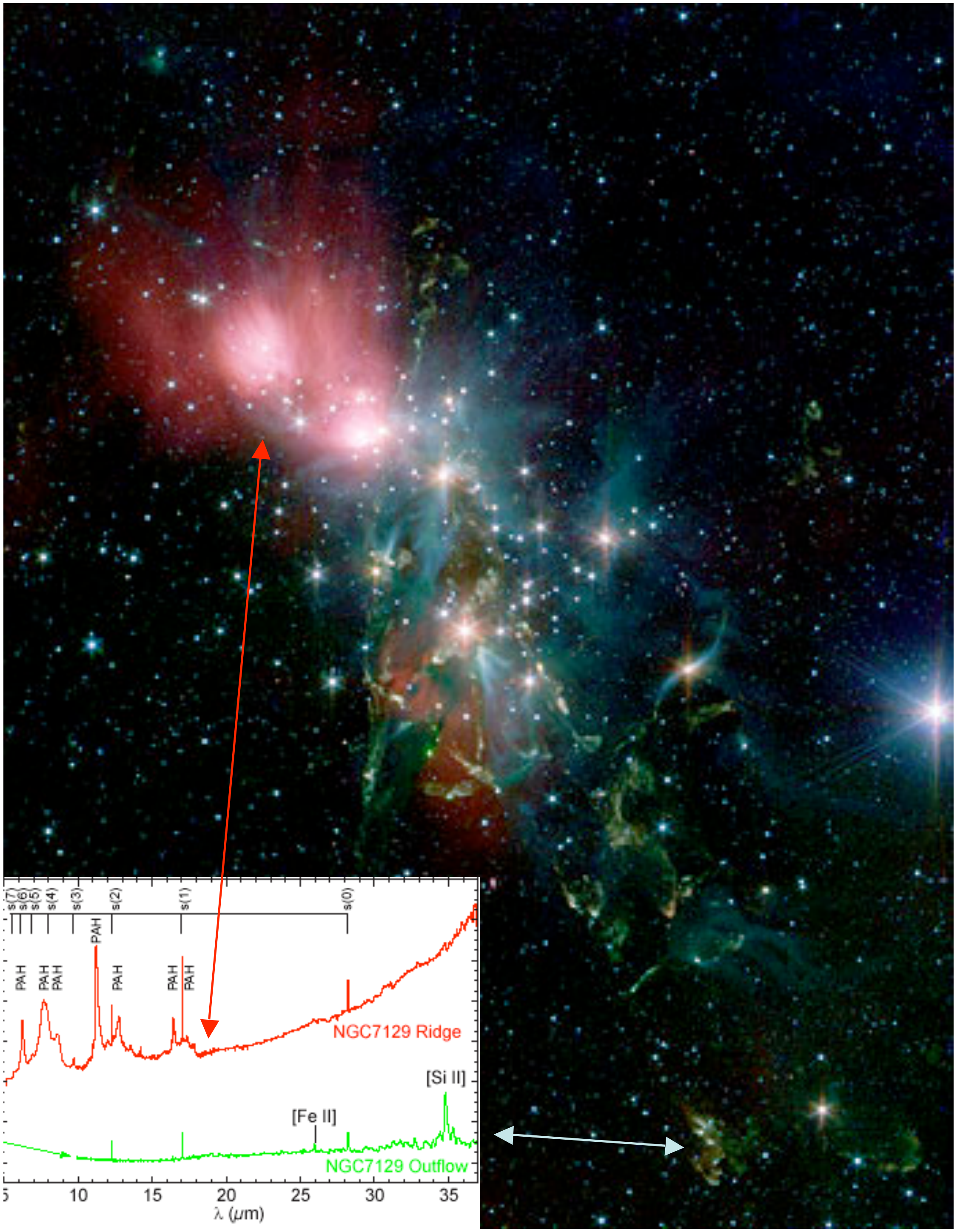
Spitzer has Found "The Mountains Of Creation"

L. Allen, CfA [GTO]





The Mountains Tell Their Tale – Interstellar erosion and star formation propagate through the cloud

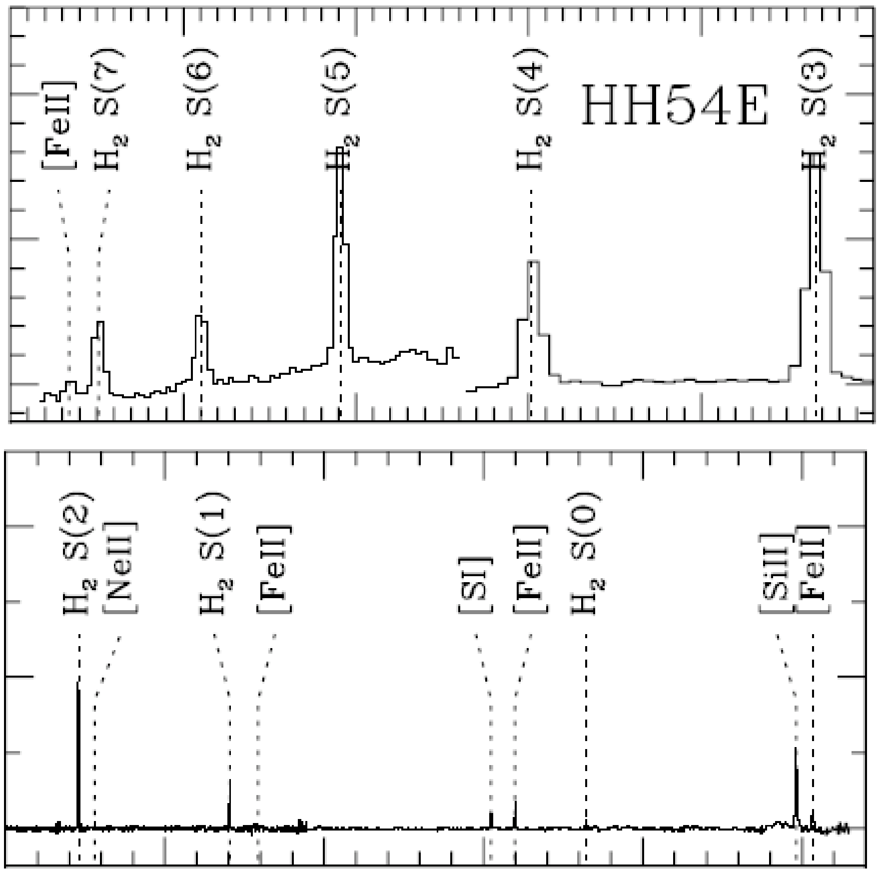


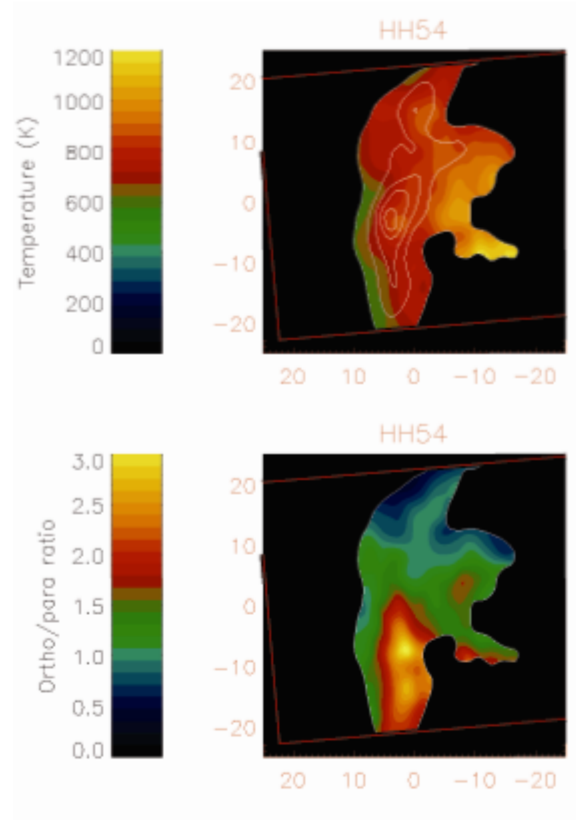
Star formation propagates from upper left to lower right in the NGC 1333 cluster in Perseus.

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

Green delineates embedded outflows and earlier stage of star formation

Colors show H2 rotational temperature





Colors show H2 Ortho-Para Ratio

Spitzer observations of H2 rotational lines will be used to compare dynamical and chemical ages in NGC 1333 outflows.

Hydrogen Molecules in Interstellar Space

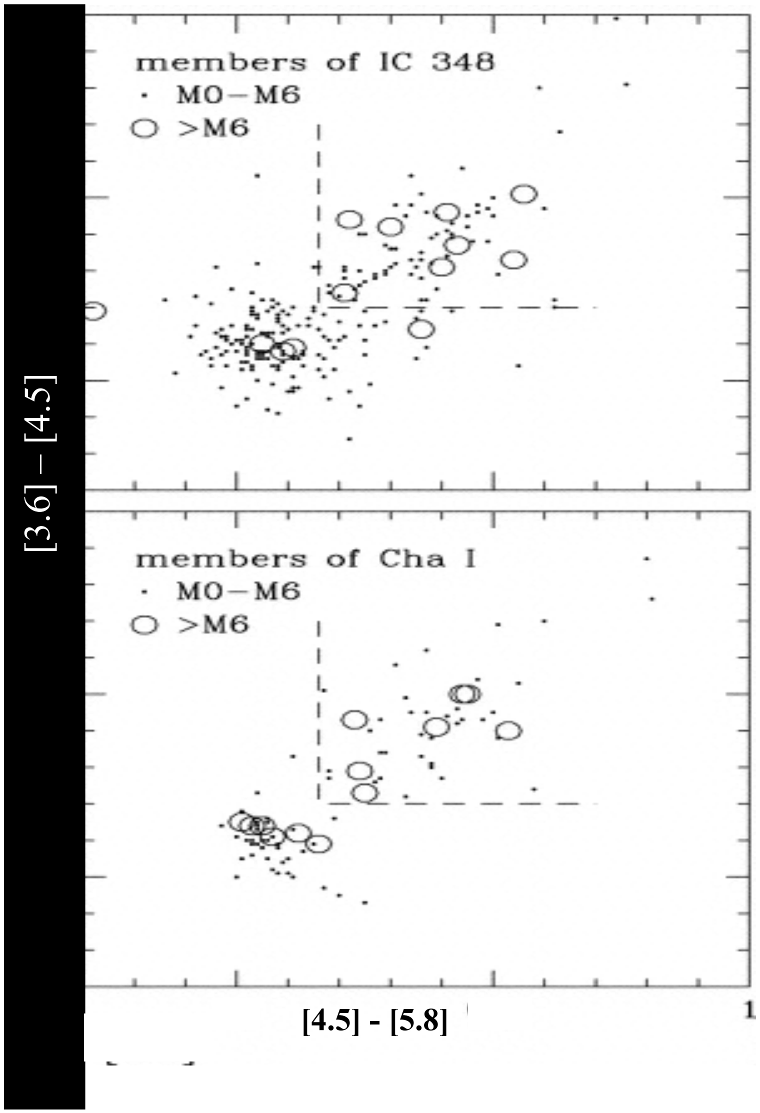
Lyman Spitzer

(George Darwin Lecture delivered on 1975 December 12)

The possibility that much of hydrogen in interstellar space might be molecular in form has been recognized for many years. It is perhaps appropriate to quote here a few sentences on interstellar clouds written in 1937 by Sir Arthur Eddington (1), under whose guidance I had the privilege of starting research in astronomy 40 years ago.

Our observatory's namesake discussed molecular hydrogen rotational temperature in his George Darwin Lecture 30 years ago!

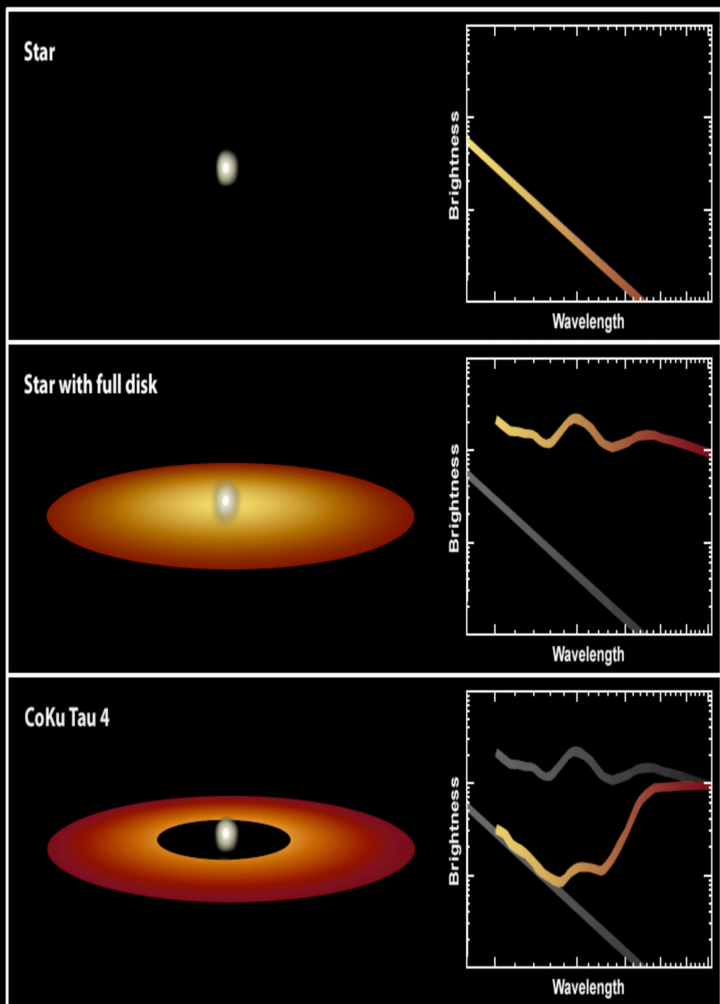
Stars and Substellar Objects have Equal Disk Fractions (~40%) in Young (4–5 MYr) Clusters IC348 and Cha I



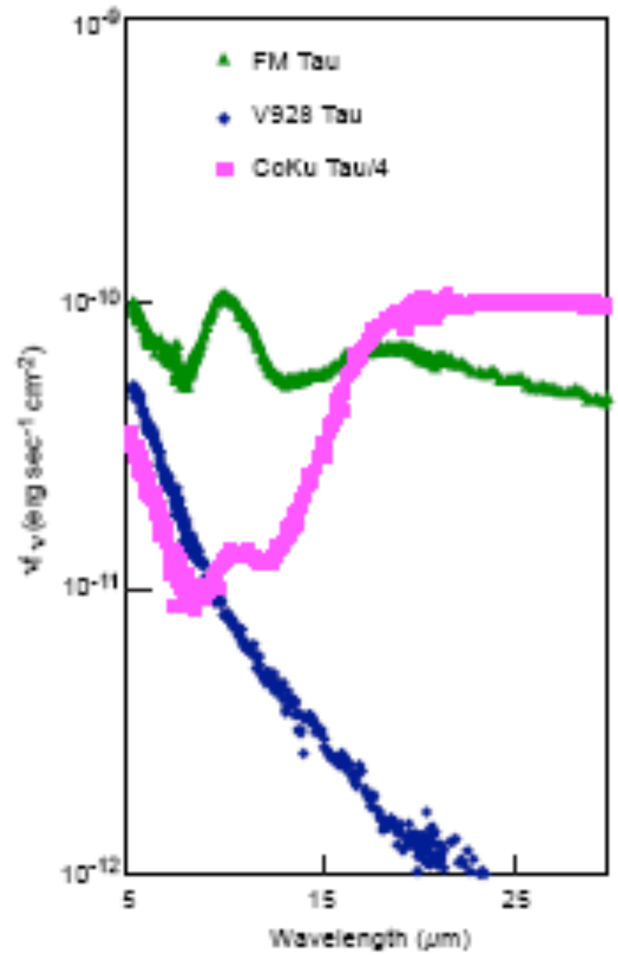
These and related studies show:

- *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 data suggest presence of central void due to planet formation at disk center



Disk Models (with and without clearing)



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

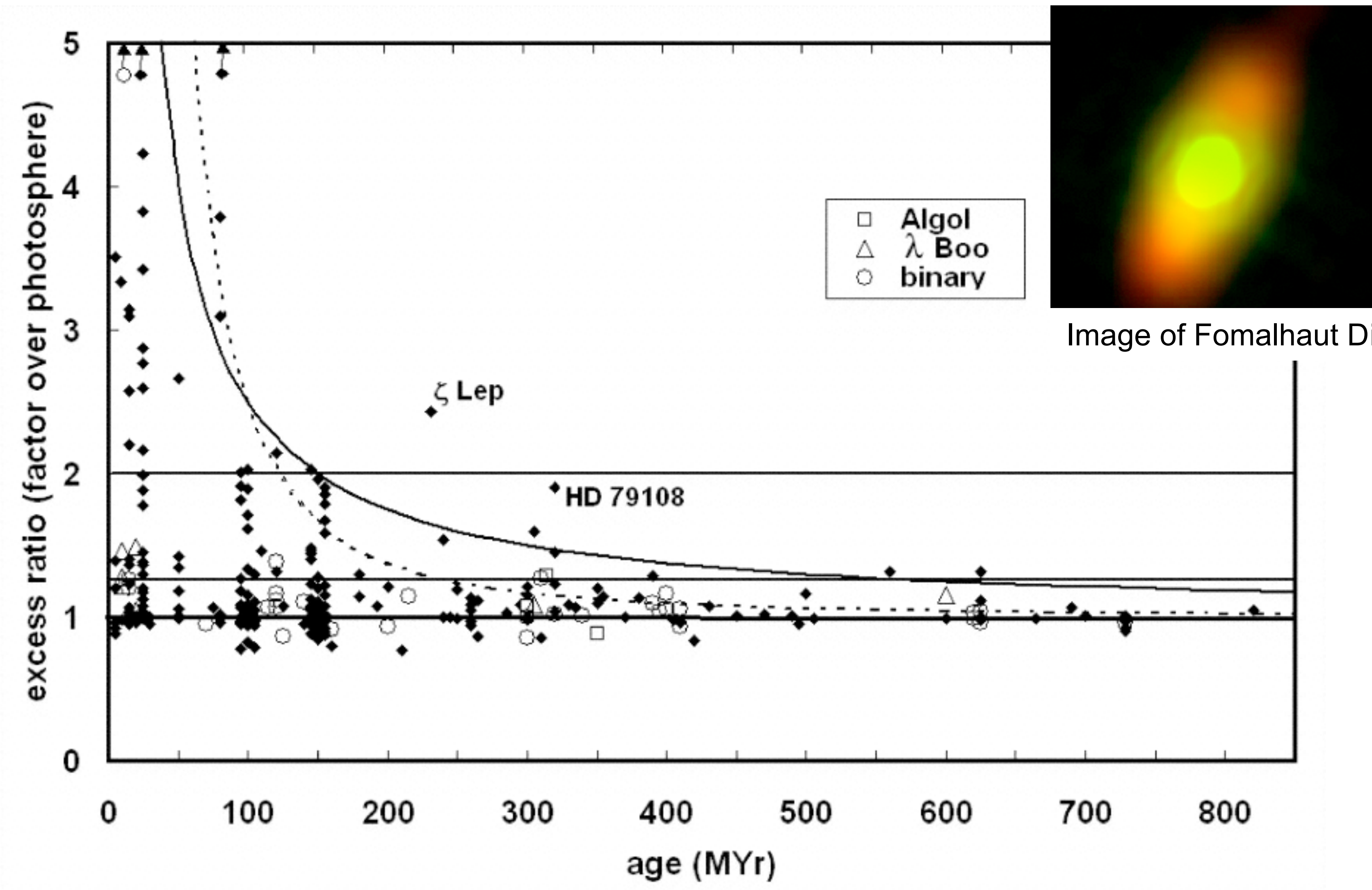
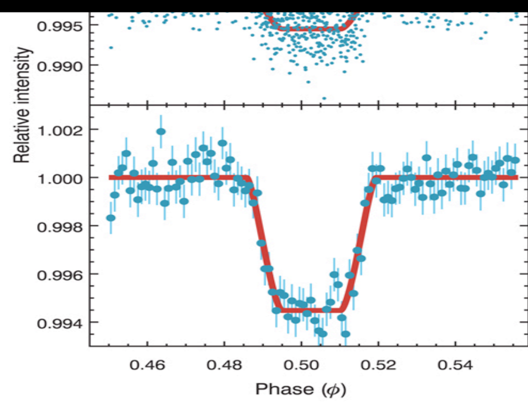
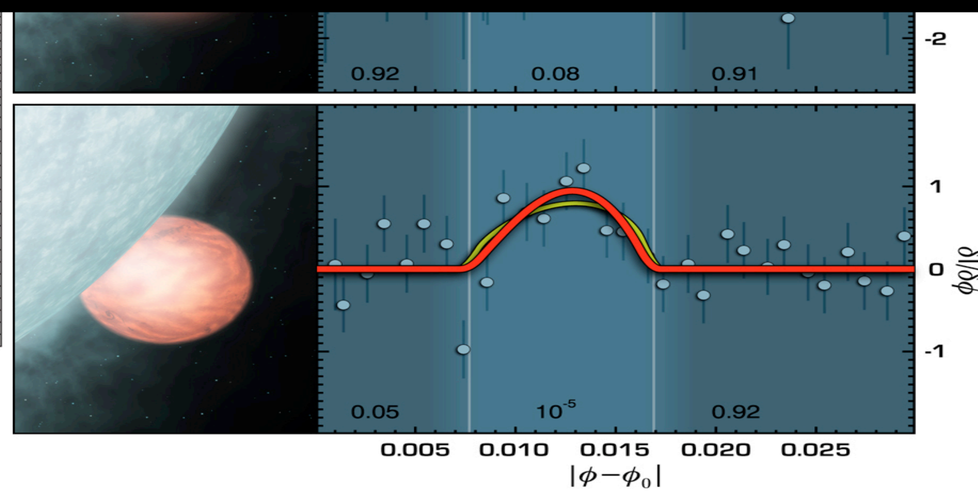


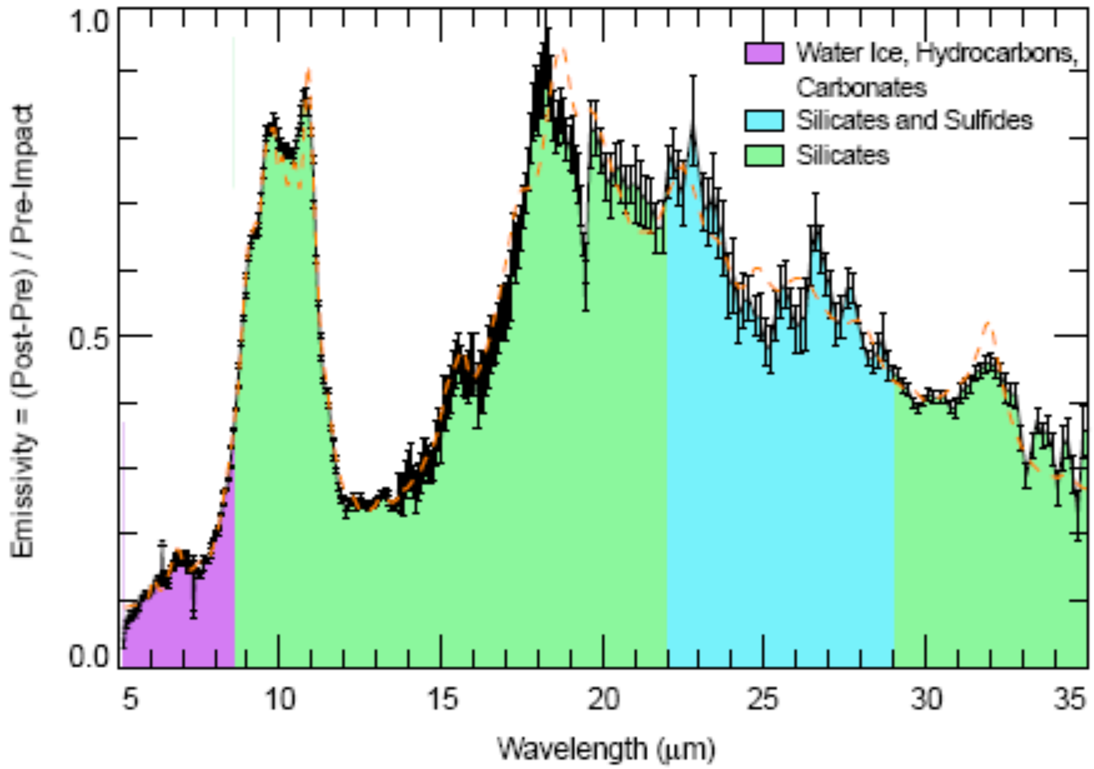
Image of Fomalhaut Disk

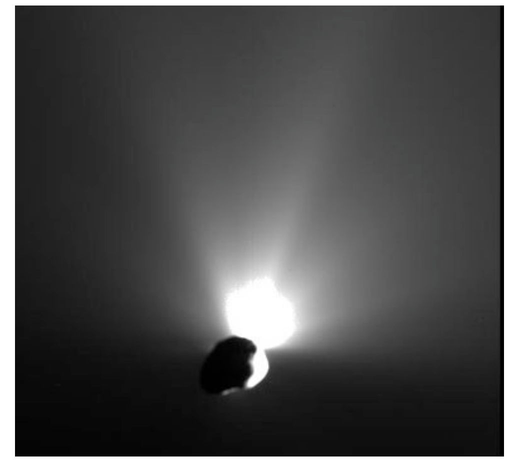
Light From Extrasolar Planets

- 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, and perhaps composition of planets can be determined. Detailed analyses of the eclipse curves may determine the temperature distribution across the planetary disk



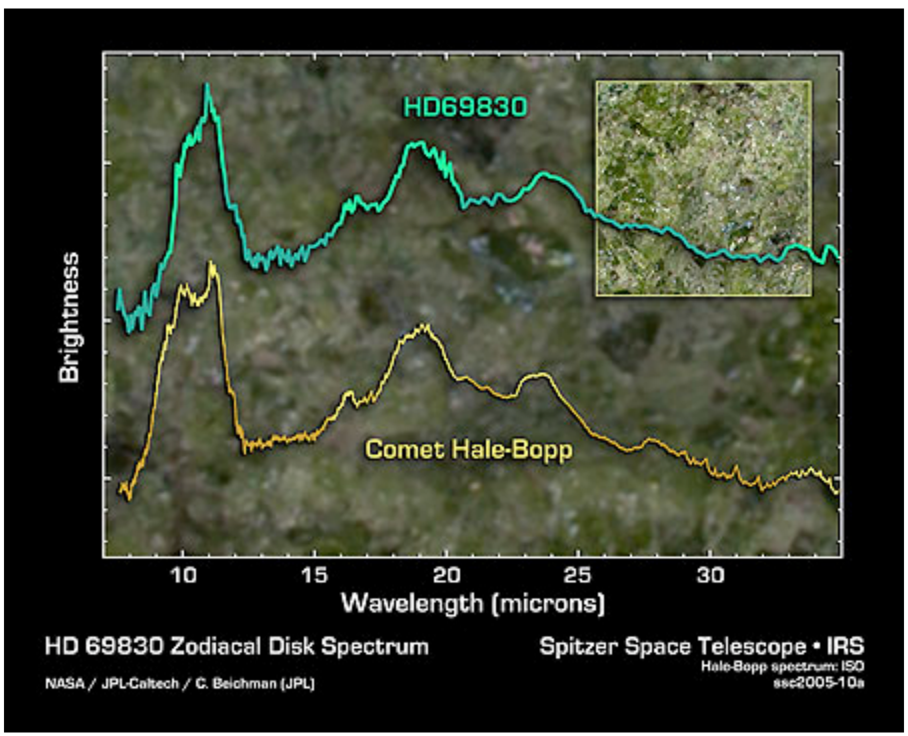


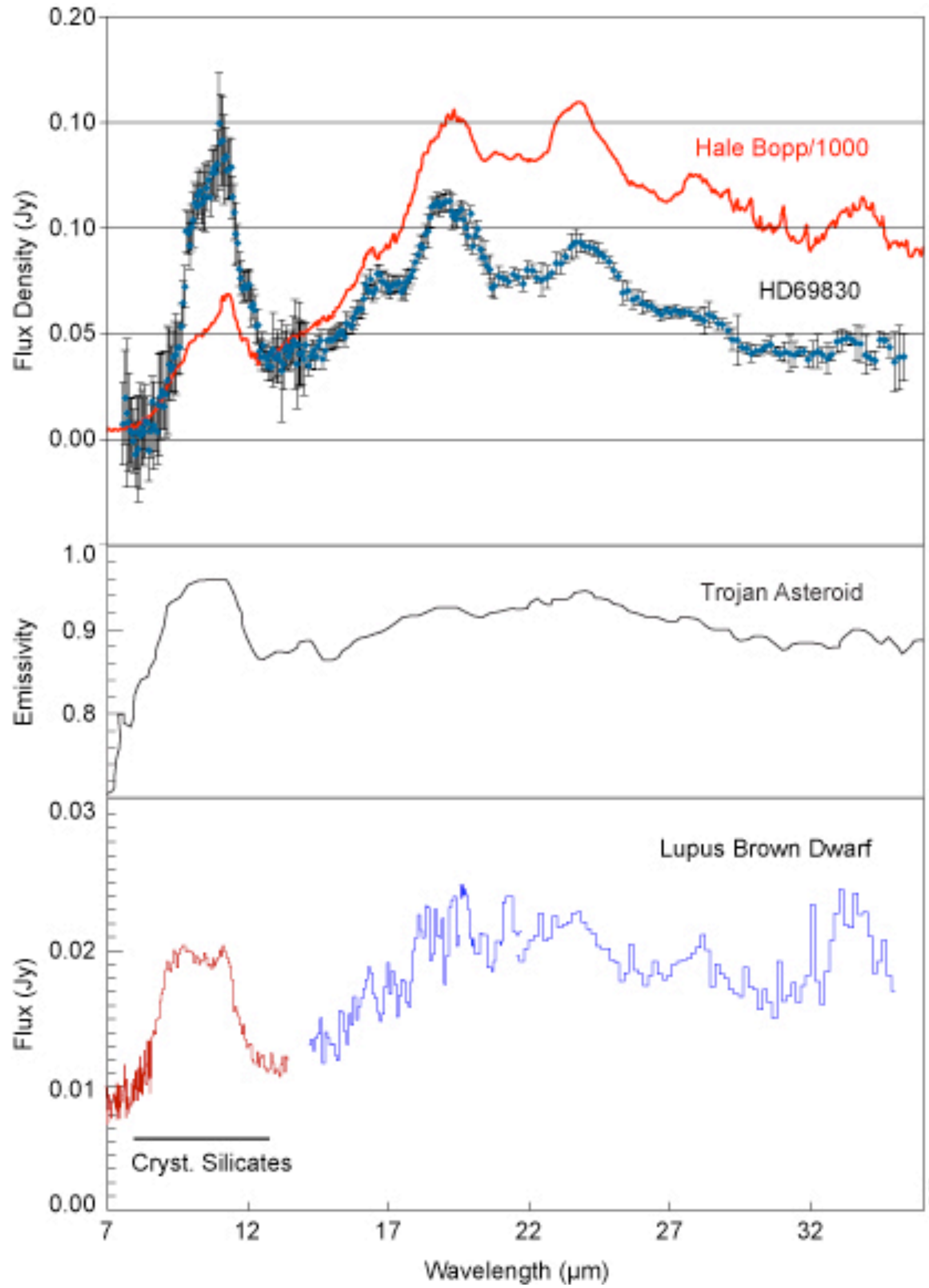


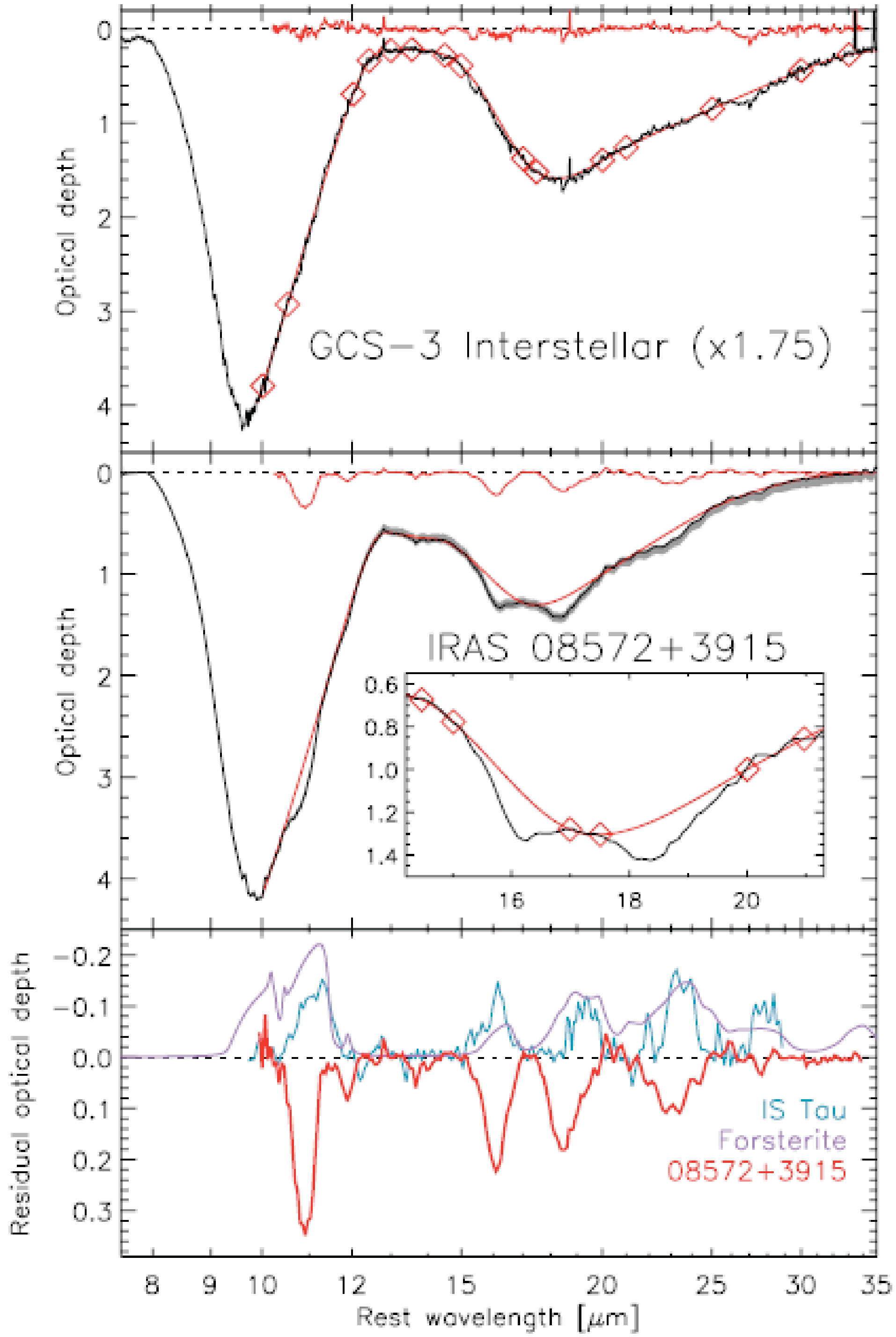


Spitzer spectrum of ejecta from Deep Impact event show surprising compositional variety, suggesting that the early solar system was complex and diverse [cf. Stardust]

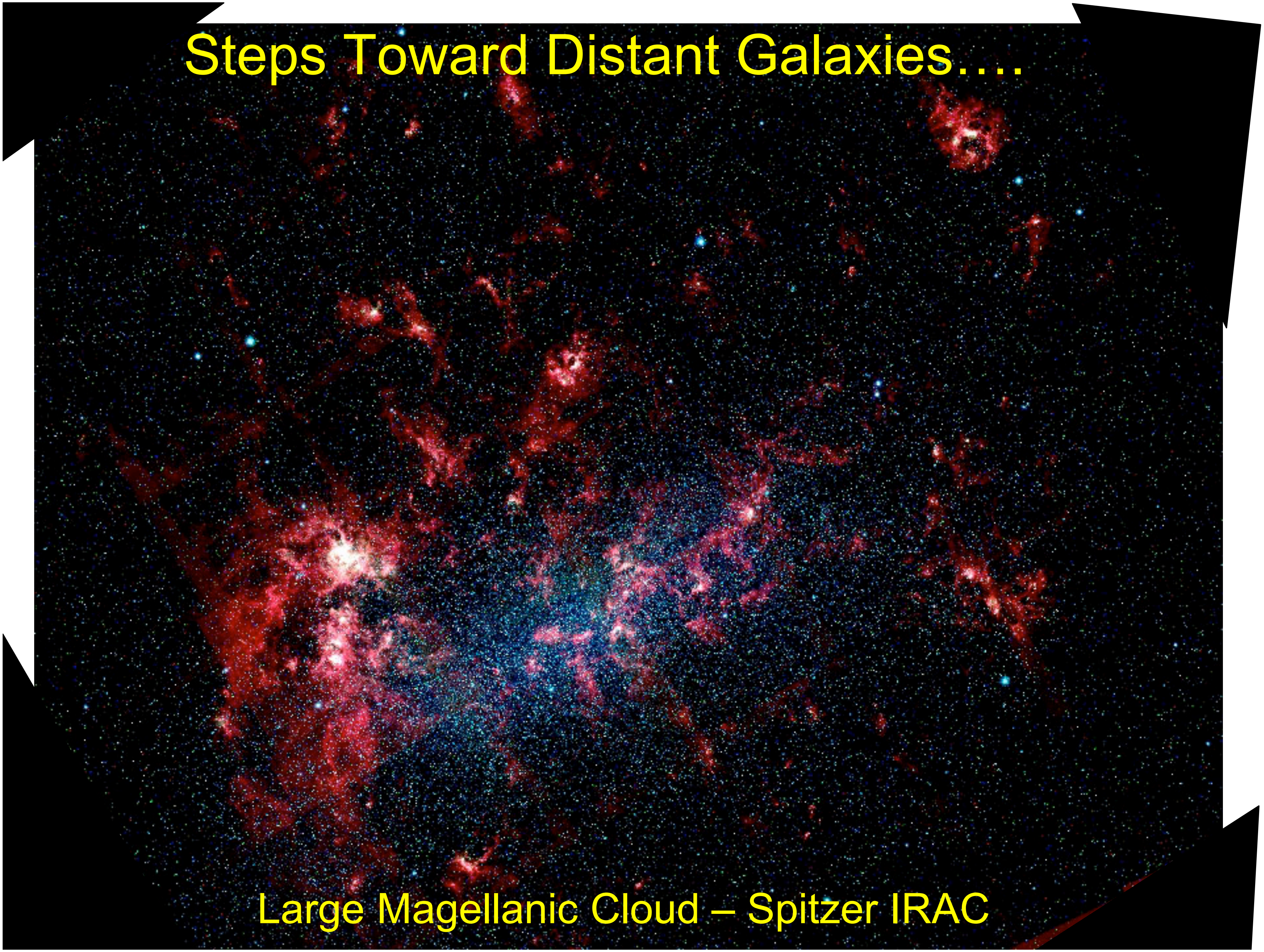
Crystalline silicates - from the green sand beaches of Hawaii to the outer solar system to nearby stars and beyond…..

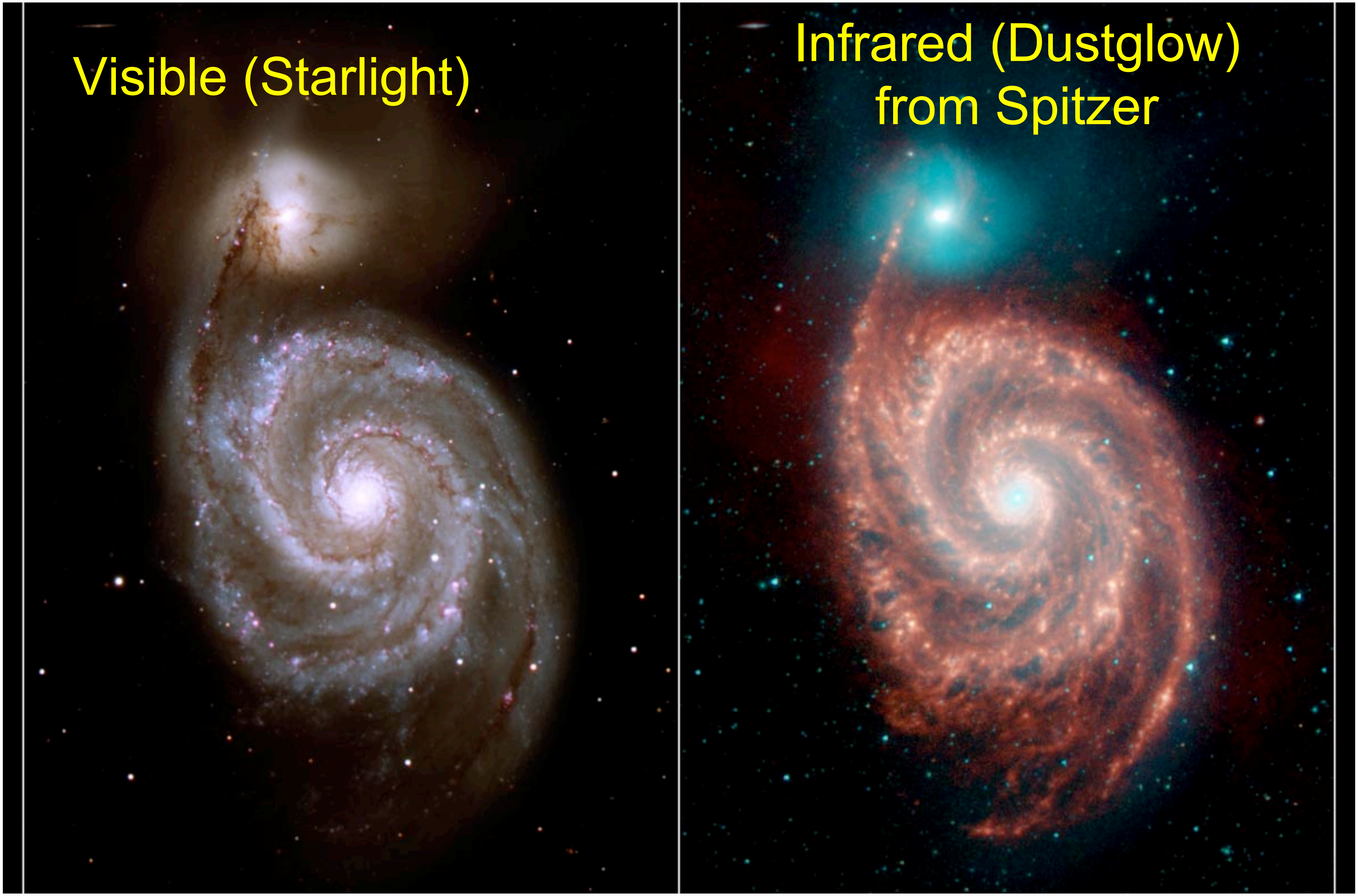






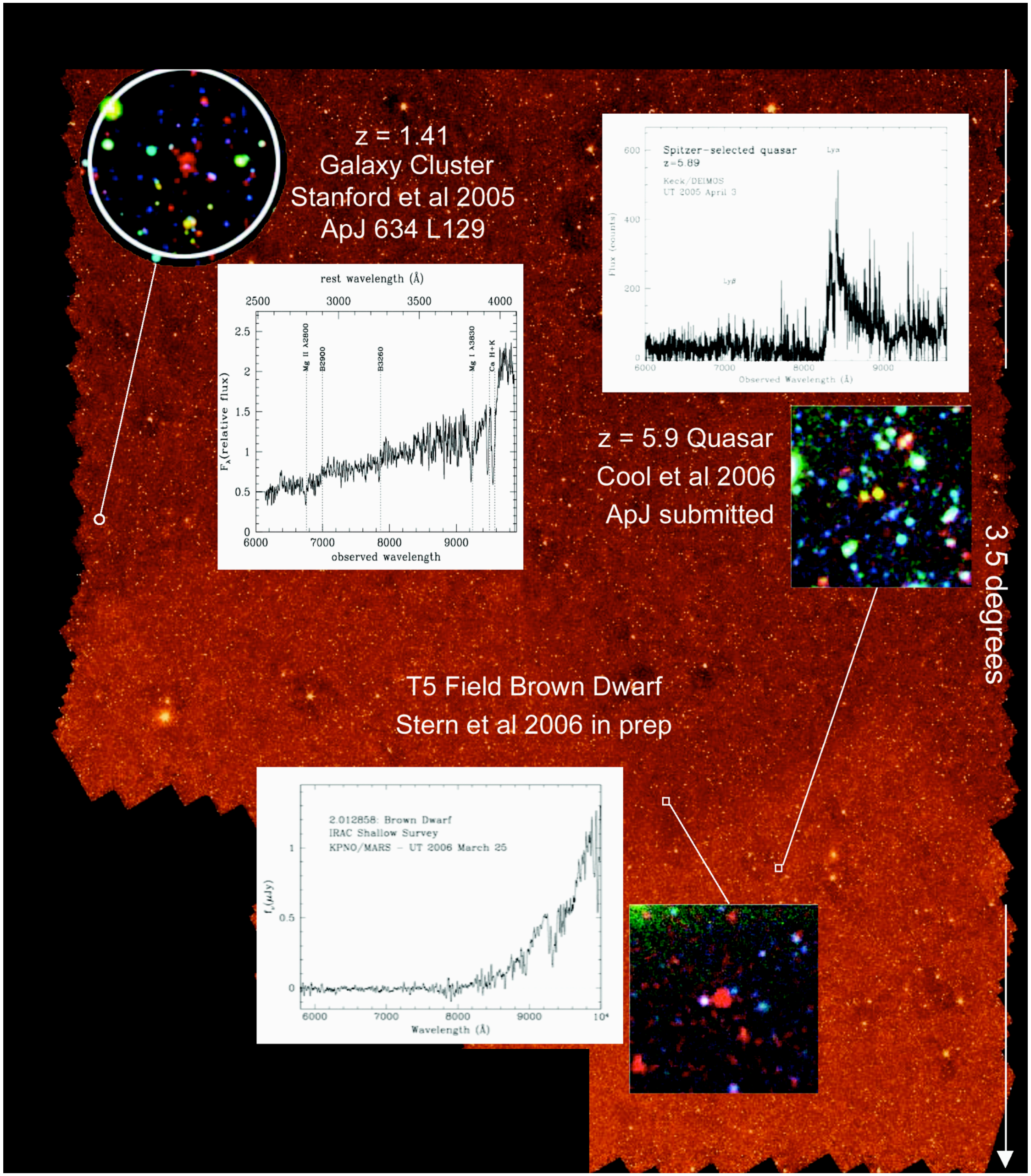
Crystalline silicates, not present in the ISM of our galaxy, appear in absorption in at least one dozen Ultraluminous Infrared Galaxies


Steps Toward Distant Galaxies….
Large Magellanic Cloud – Spitzer IRAC



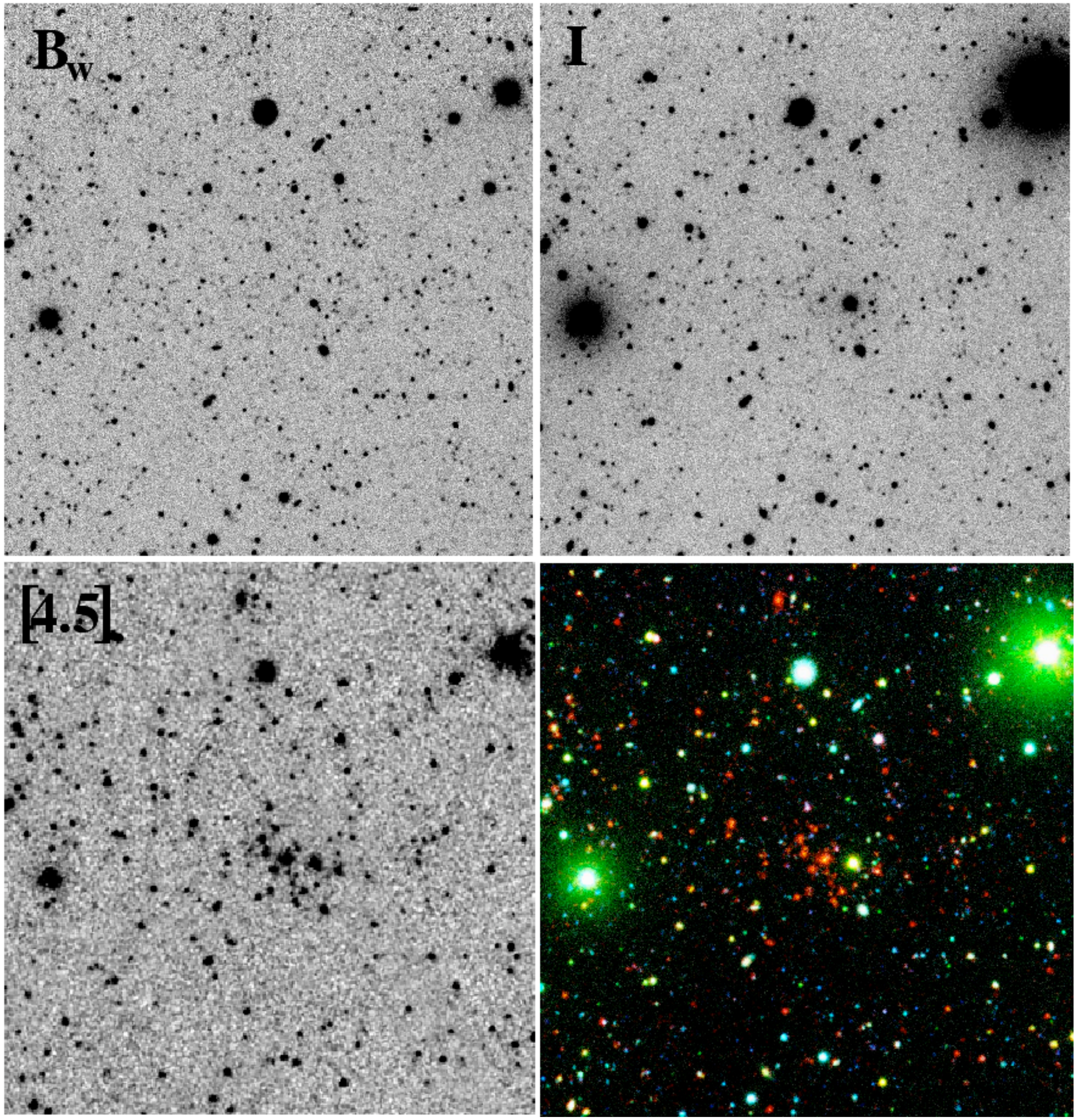
Steps Toward Distant Galaxies….Images of the Whirlpool Galaxy


Steps Toward Distant Galaxies…..
M81 Galaxy
Spitzer Space Telescope
IRAC + MIPS 24 um

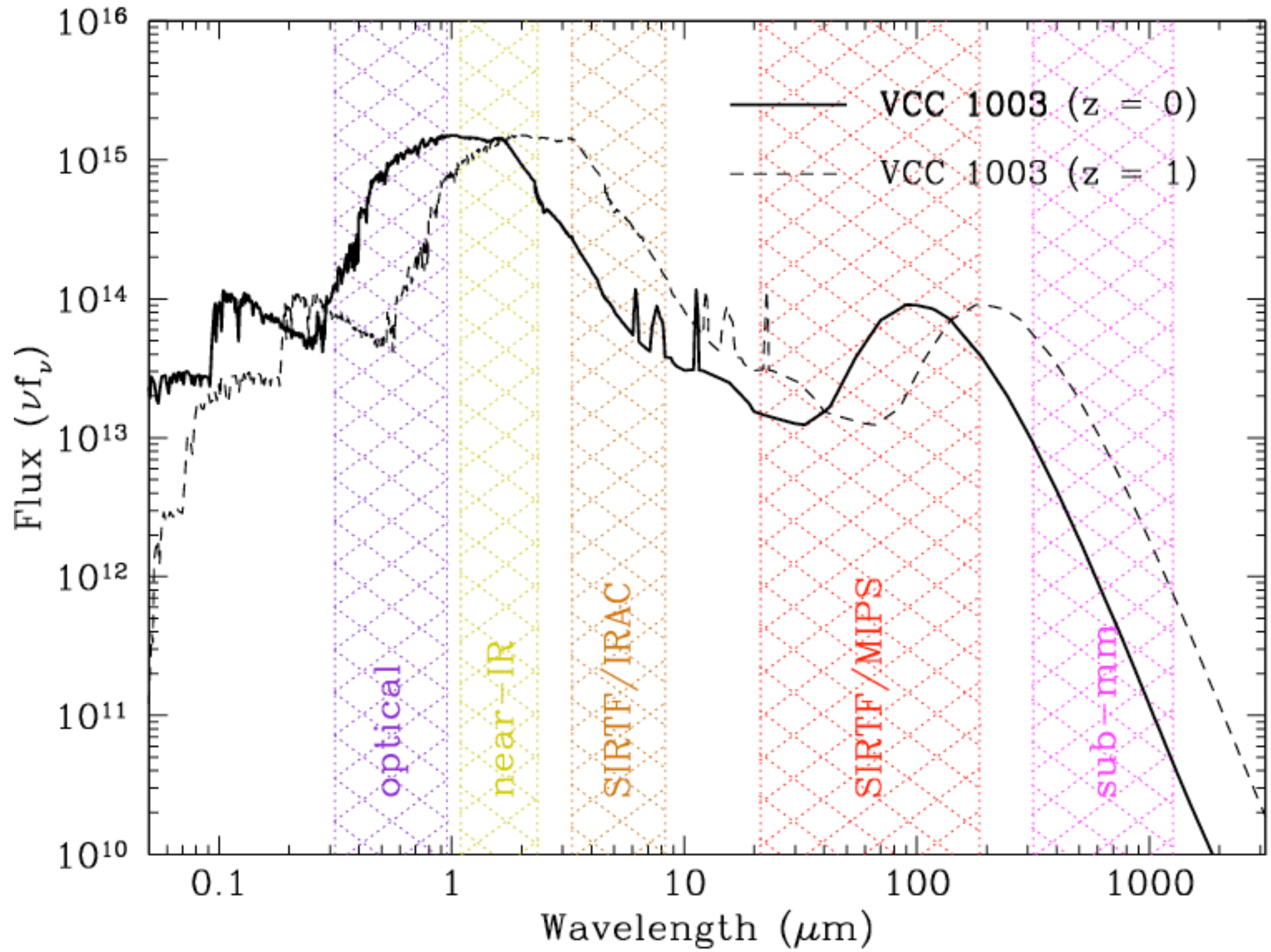


IRAC "shallow" survey covers 8.5 sq degree in well-studied NOAO Bootes field. integration time ~90s per point. Total IRAC time ~ 62 hrs. Limiting 5-sigma sensitivity ~19th mag at 3.6um. Total number of sources detected ~ 370,000

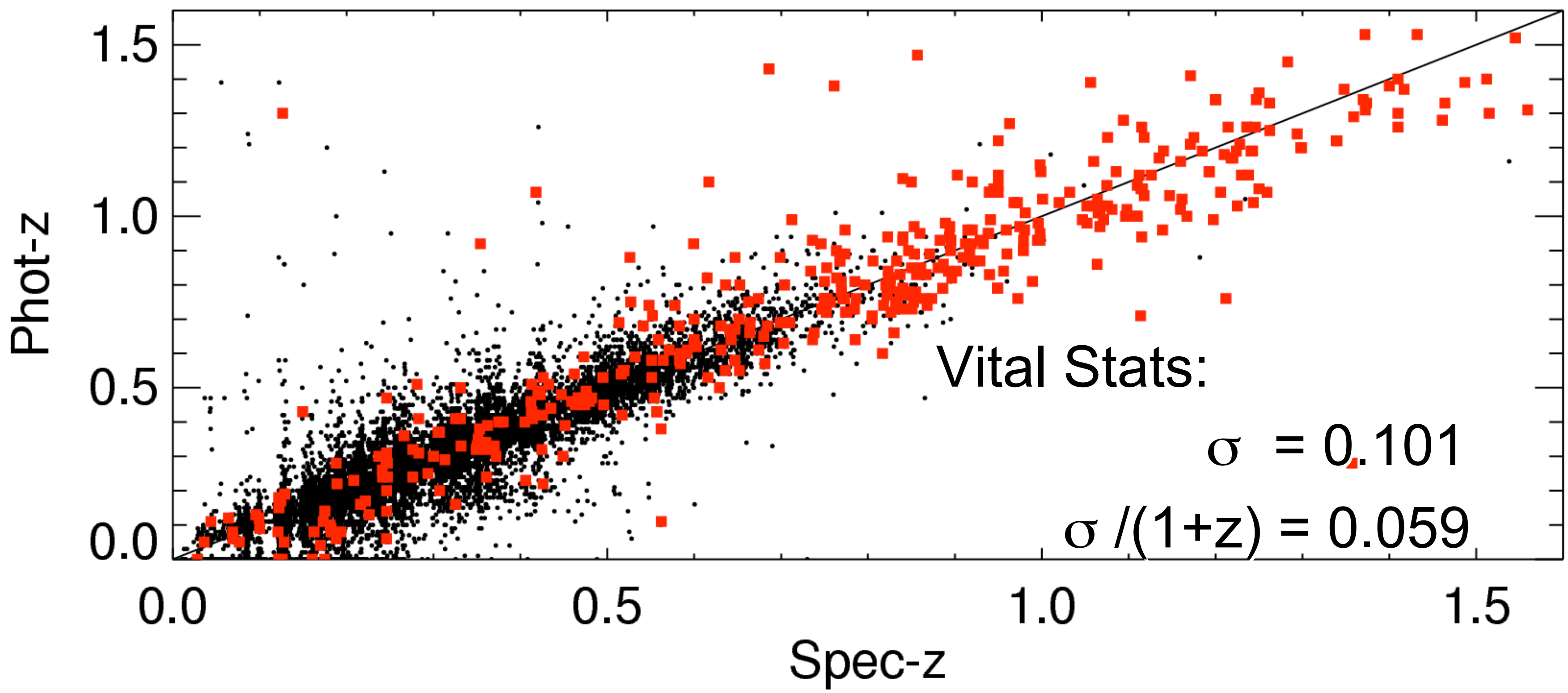
A z=1.26 Cluster Discovered in the IRAC "Shallow" Survey

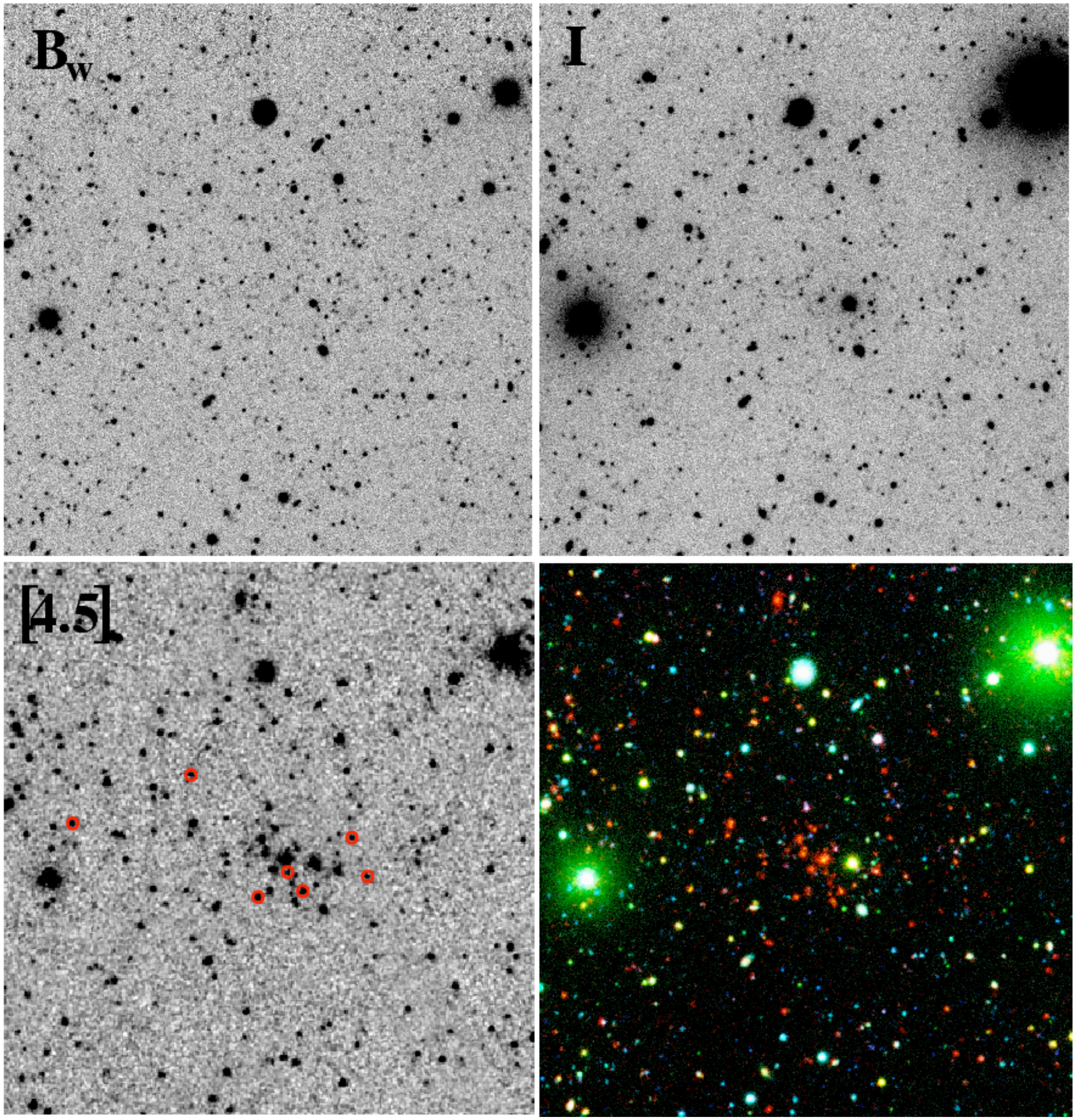


For z>1, emission peak due to red stars in galaxies shifts into the IRAC bands



Large number of spectroscopic redshifts in the Bootes field has allowed reliable determination of photometric redshifts used to identify candidate clusters

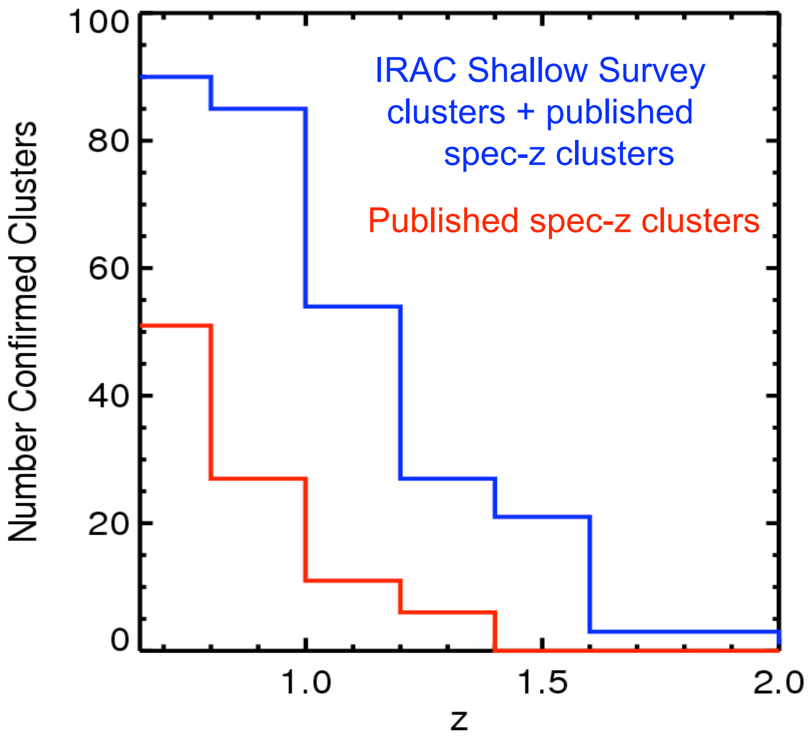




Red circles in 4.5um image show spectroscopically confirmed members of Z = 1.26 cluster

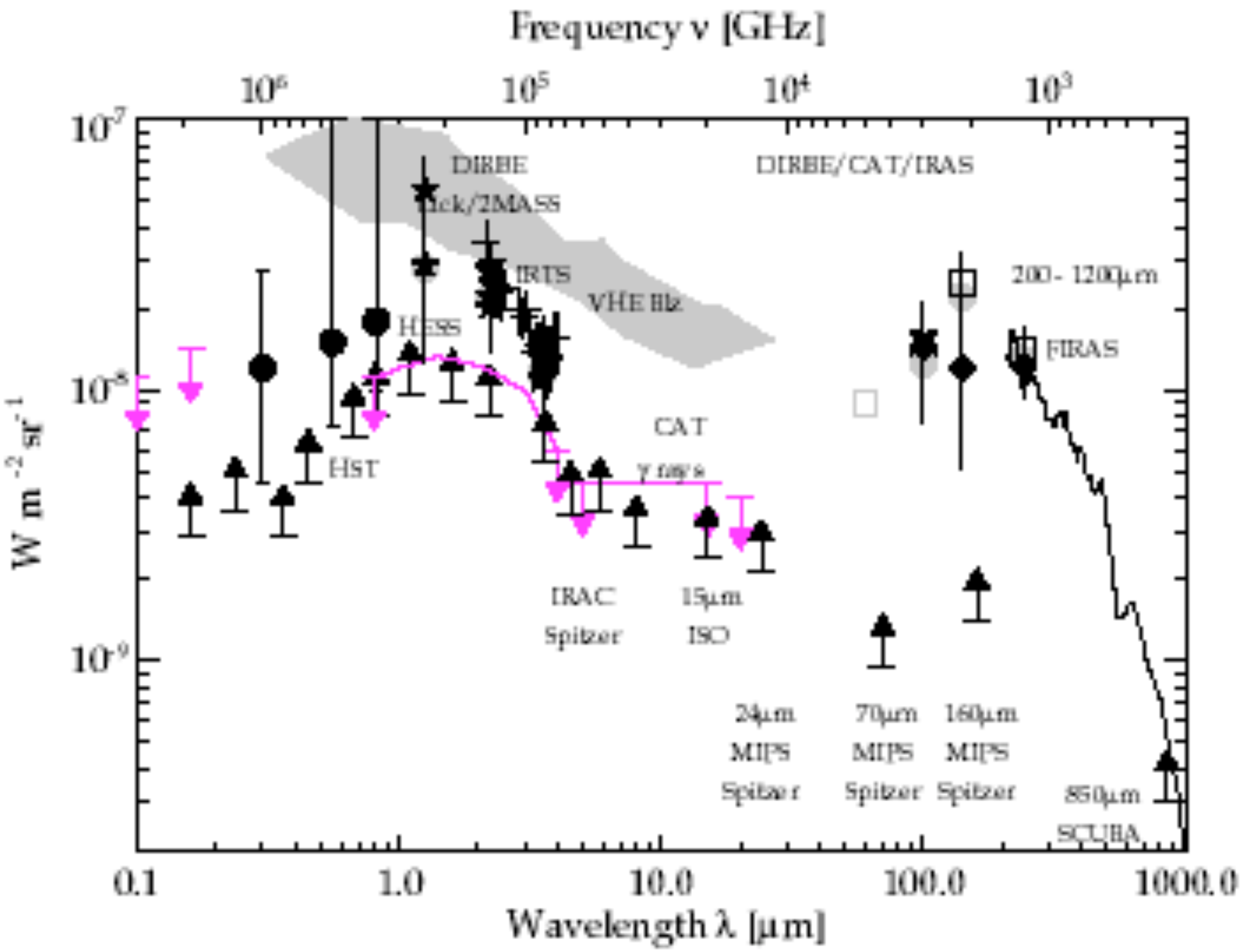
Using this technique, Stanford et al have found the most distant known cluster, at z=1.41

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

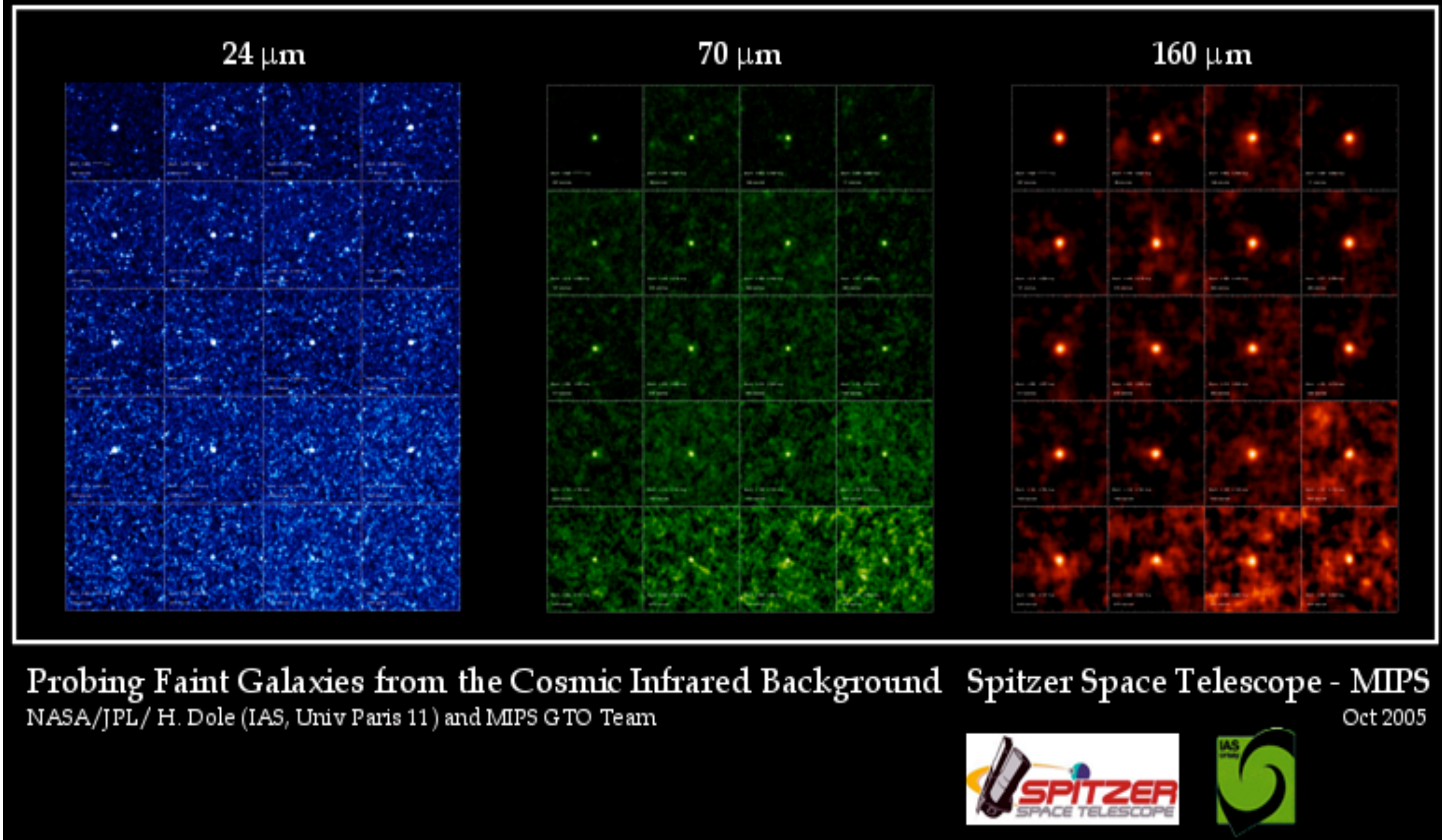


Potential Applications Include:

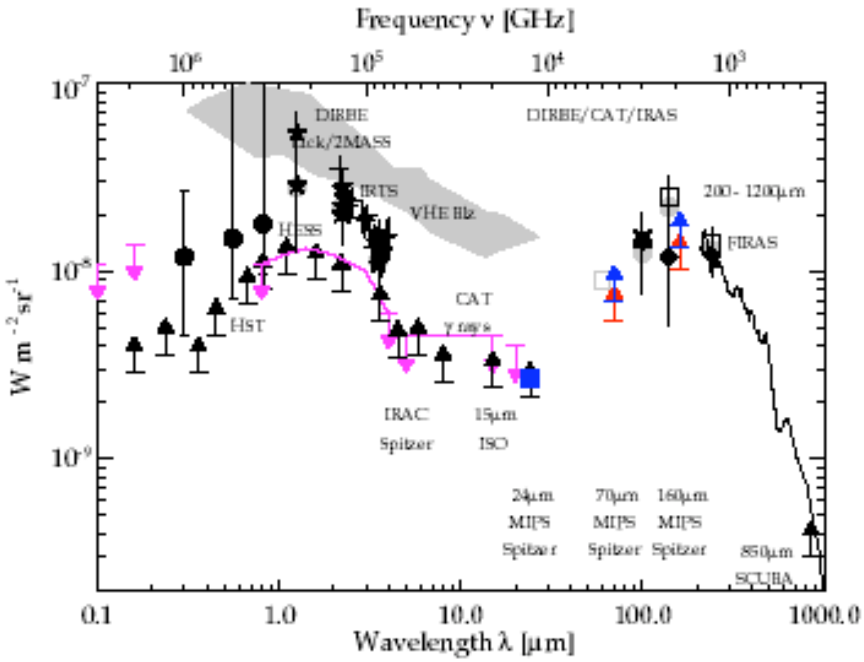
- *Determination of Cosmological Parameters*
- *Studies of Evolution of Cluster Galaxies*
- *Identification of z>1 Supernovae in Dust-Poor Galaxies*



Spitzer has searched for the sources of the diffuse far infrared background, which is comparable in energy density to the uv/visual background. At 70 and 160um, Spitzer does not see enough individual point sources to account for the background. Due to confusion, Spitzer will not be able to go deep enough to resolve the background directly.

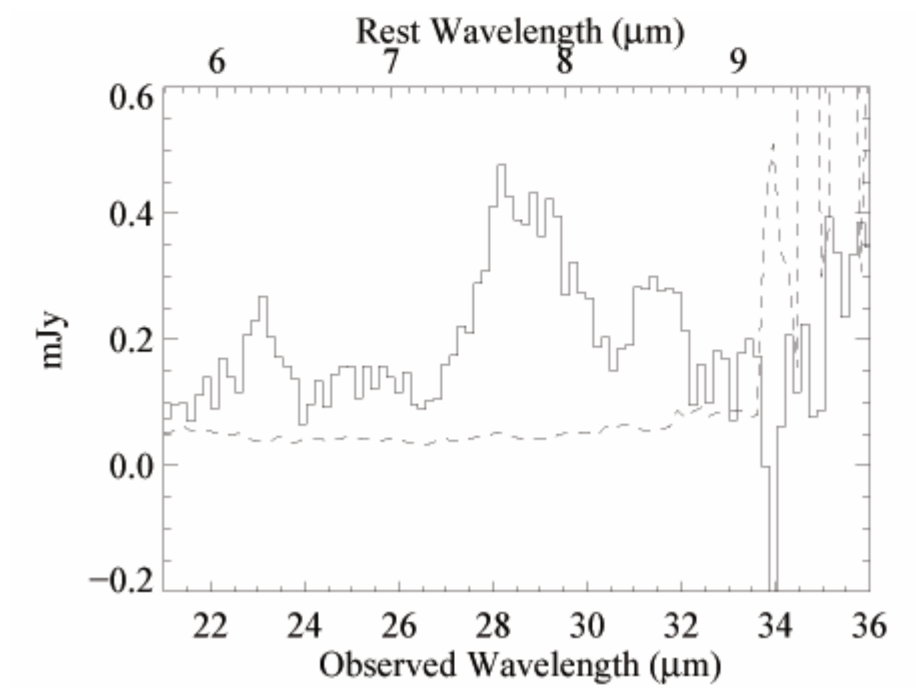


Dole et al have stacked 70/160um data at positions of 24um detections to find fainter sources than can be seen separately



The results strongly suggest that sources seen by Spitzer account for virtually all of the cosmic infrared background. Our next job is to understand the nature of these sources.

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!



data on Galaxy with Spectroscopic Redshift = 5. 83

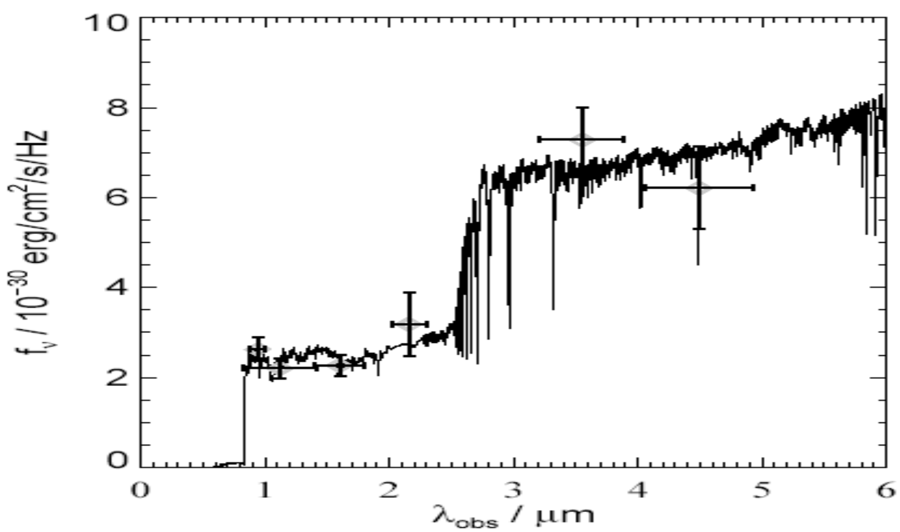
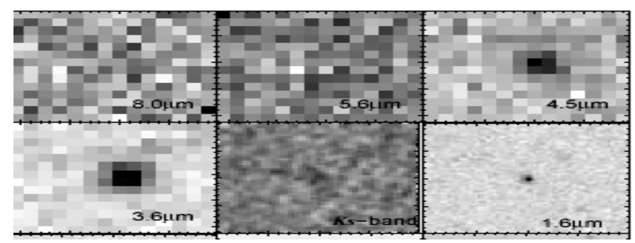
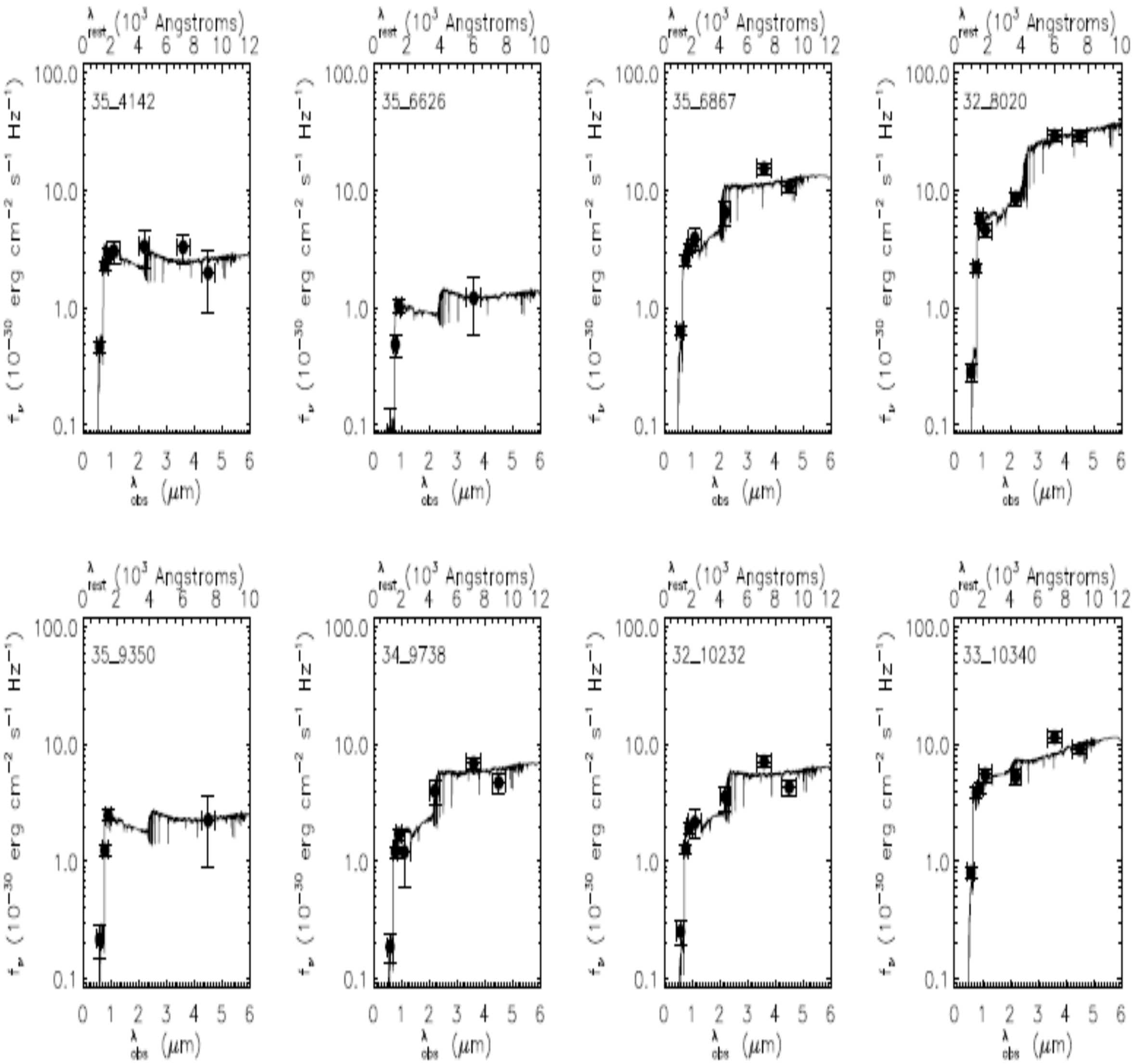


Figure 6. Best-fit Bruzual & Charlot model for SBM03#1: an exponentially decaying star formation rate with $\tau = 300$ Myr, viewed 640 Myr after the onset of star formation. The stellar mass is $3.4 \times 10^{10}\ M_\odot$. Flux density is in f_ν units.



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

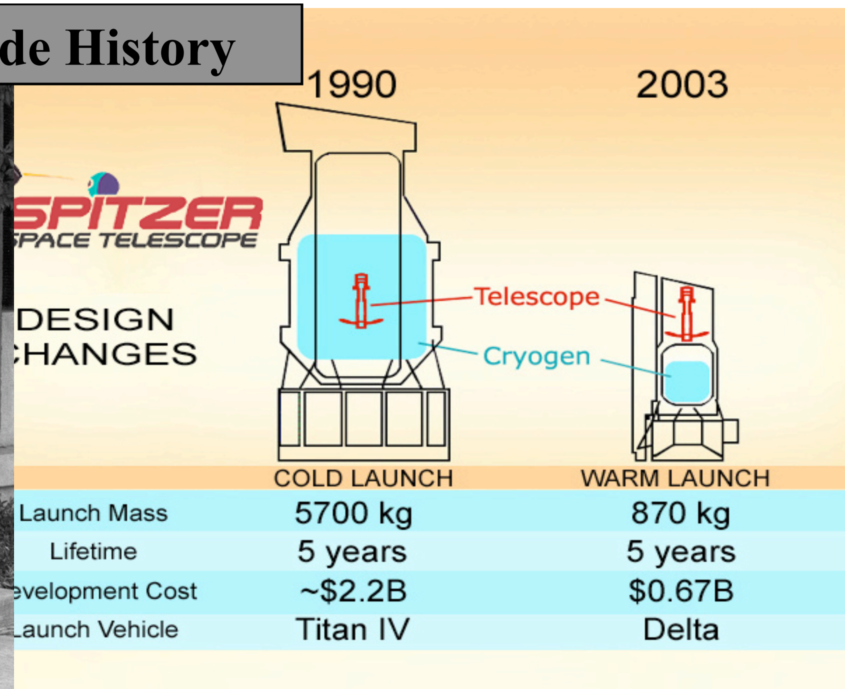
Spitzer posed a Cosmic Conundrum by finding very massive galaxies in the early Universe….This caught the fancy of Science News and challenges theories of structure formation



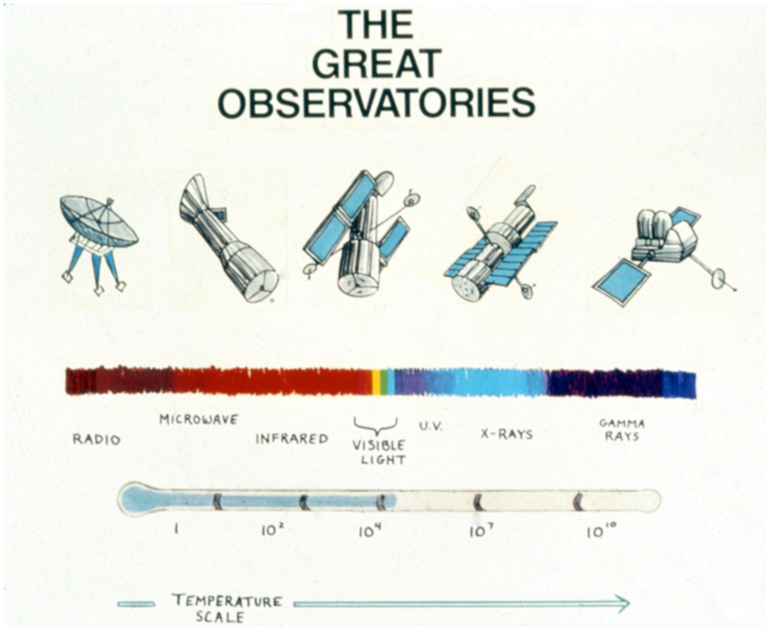
Herman and his siblings - a family of massive galaxies at redshift z = 5 allows estimate of stellar mass density at this early epoch

This in turn constrains star formation history at still earlier epochs

Spitzer – One Slide History



<u>Spitzer Science Team:</u>
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*



The Great Observatories:

A Dream Realized!