

The Scientific Legacy of IRAS

A Personal Perspective



Tom Soifer

Caltech & Spitzer
Science Center



Before and After



◆ Before –

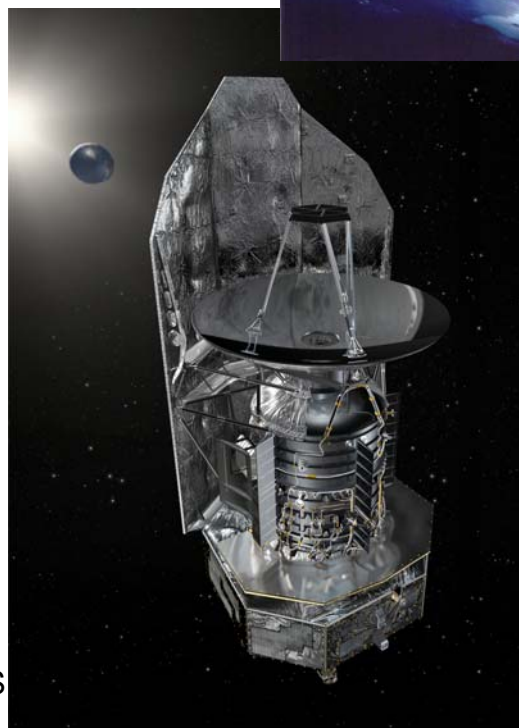
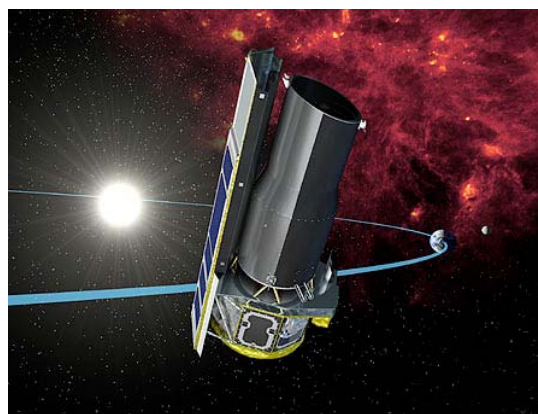
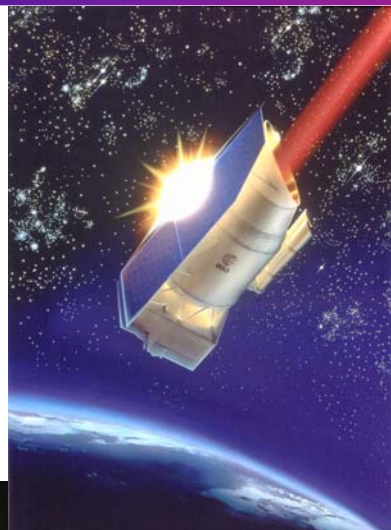
- ▶ *Ground – Surveys, IR Optimized Telescopes, Simple Instruments*
- ▶ *Airborne – Lear Jet, KAO*
- ▶ *Balloons – Surveys, Backgrounds*
- ▶ *Sounding Rockets – Backgrounds, Surveys*

◆ After

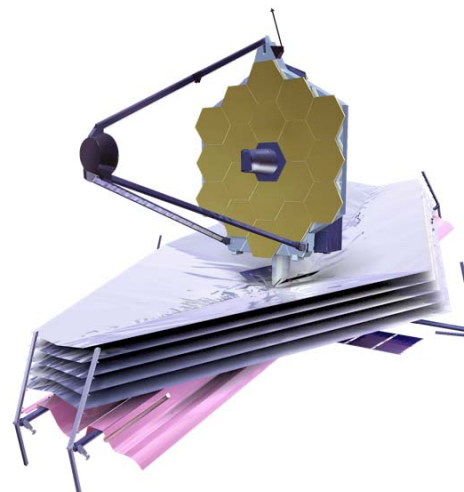
- ▶ *COBE, MSX, IRTS, ISO, SPITZER, AKARI, HERSCHEL, PLANCK, WISE, JWST*
 - Total cost - probably approaching \$10B

AFTER WOULD NOT HAVE HAPPENED WITHOUT THE RESOUNDING SUCCESS OF IRAS, BOTH TECHNICALLY & SCIENTIFICALLY

The Legacy of IRAS



IRAS



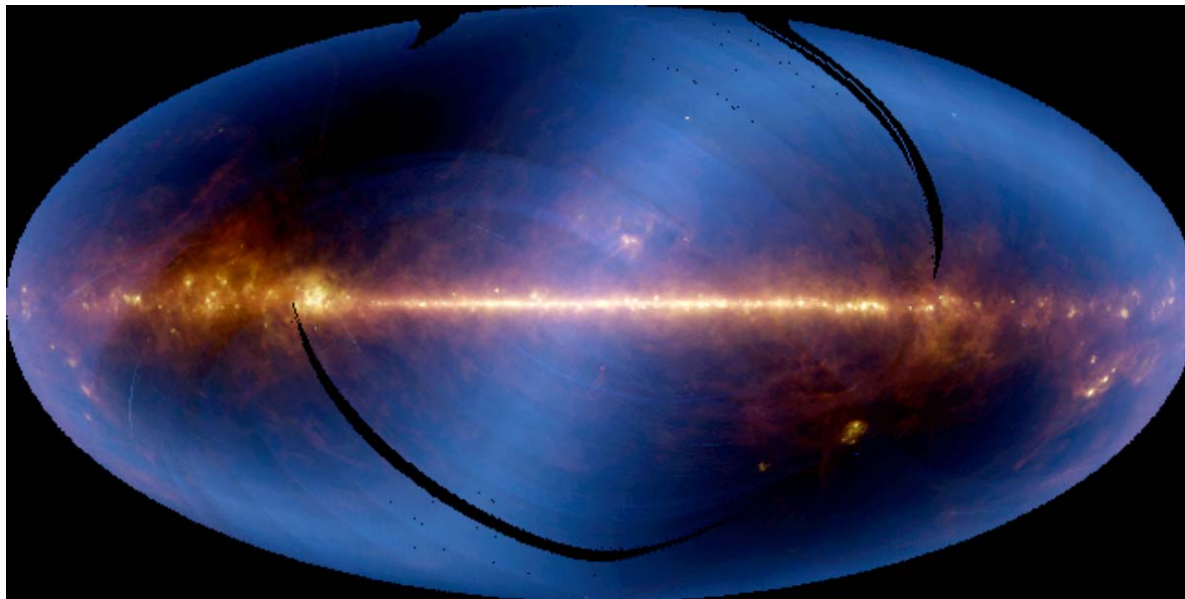
BTS-3

What was special about IRAS?

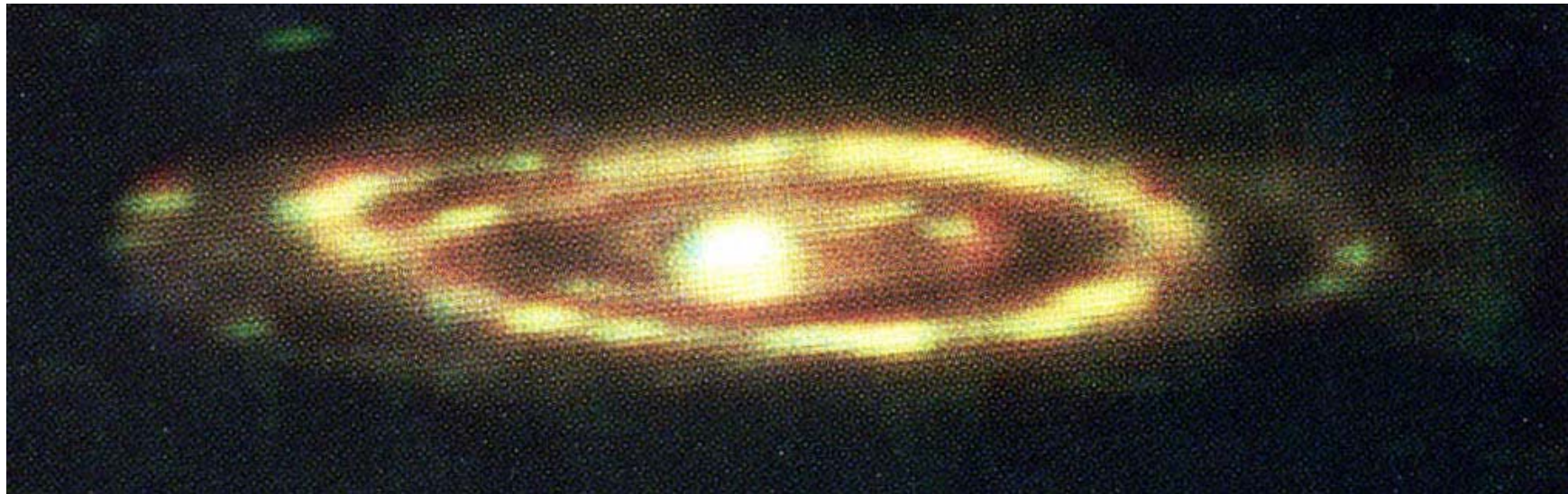


Wavelengths
Sensitivity
All Sky
Unbiased

Size, Quality of Catalogs, images
Rapid public release
Improved quality with reprocessing
Strong support for community usage

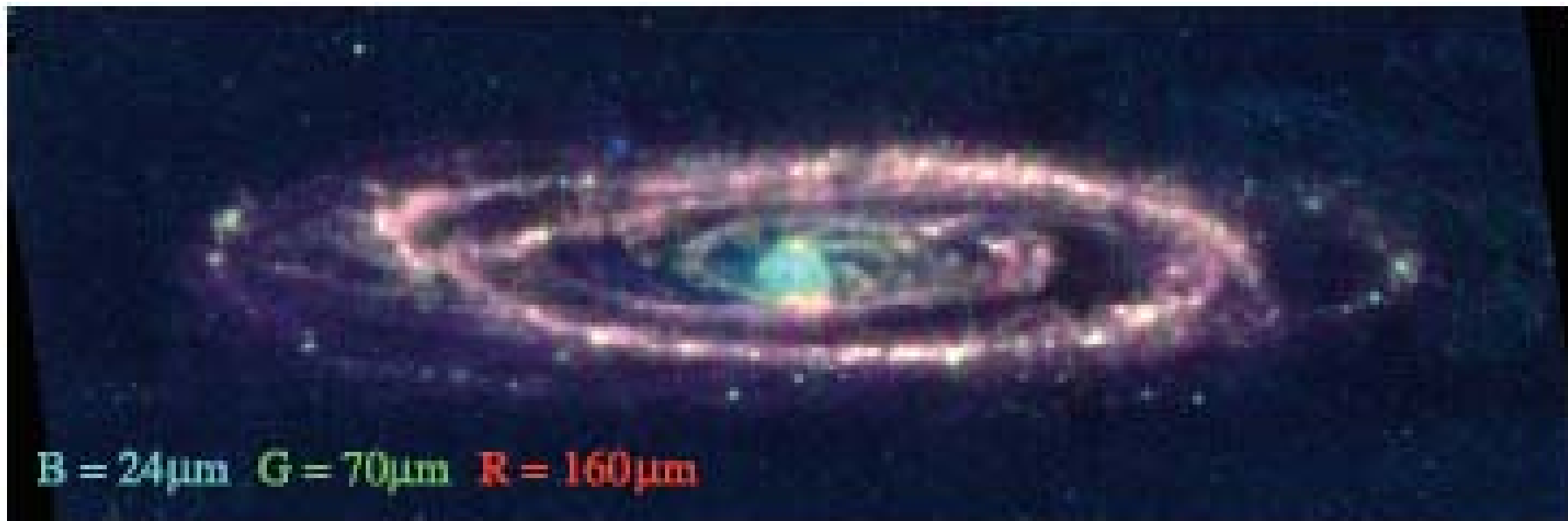


M31 in the FIR



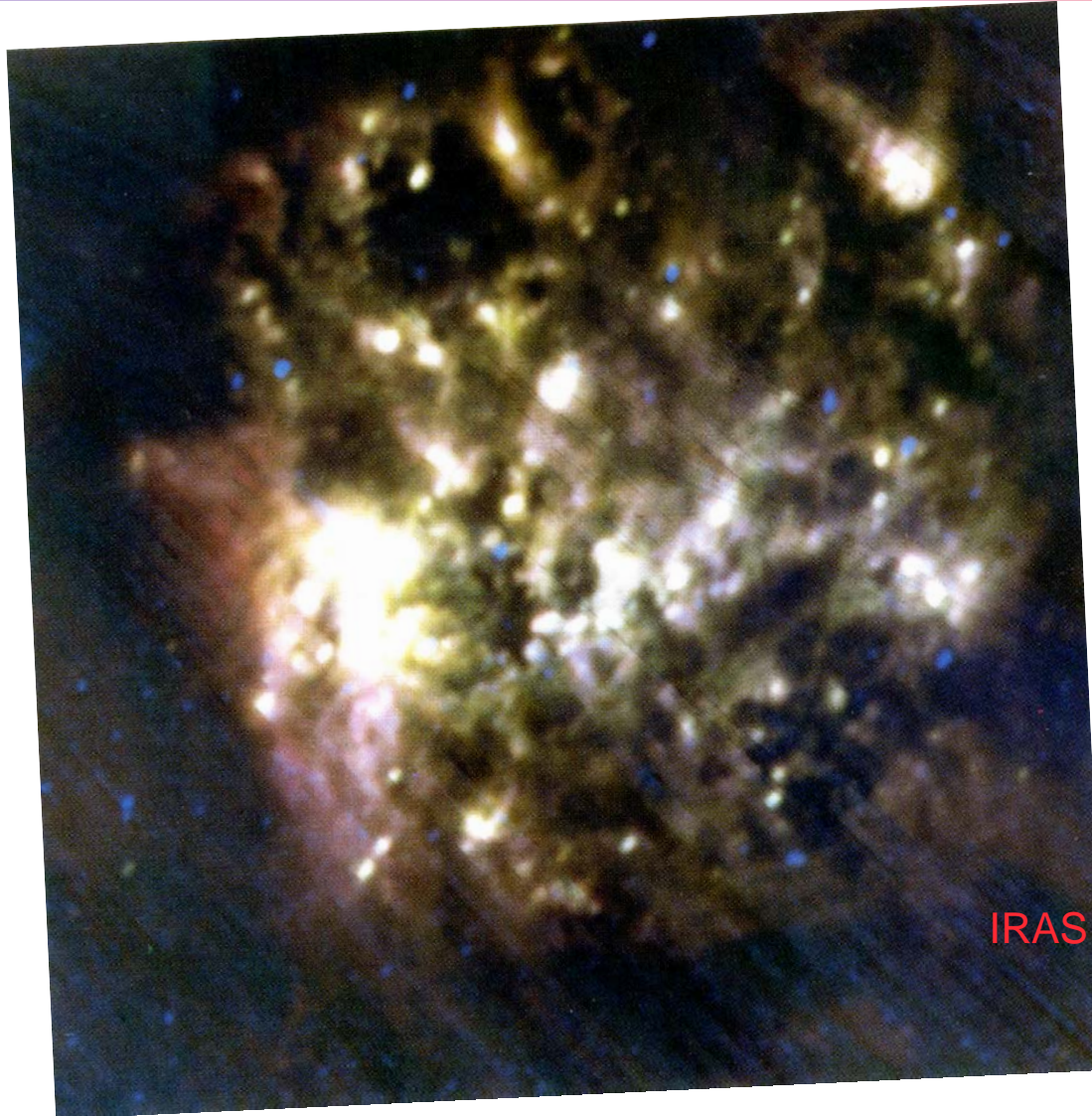
IRAS Image – Rice et al. 1988

M31 in the FIR



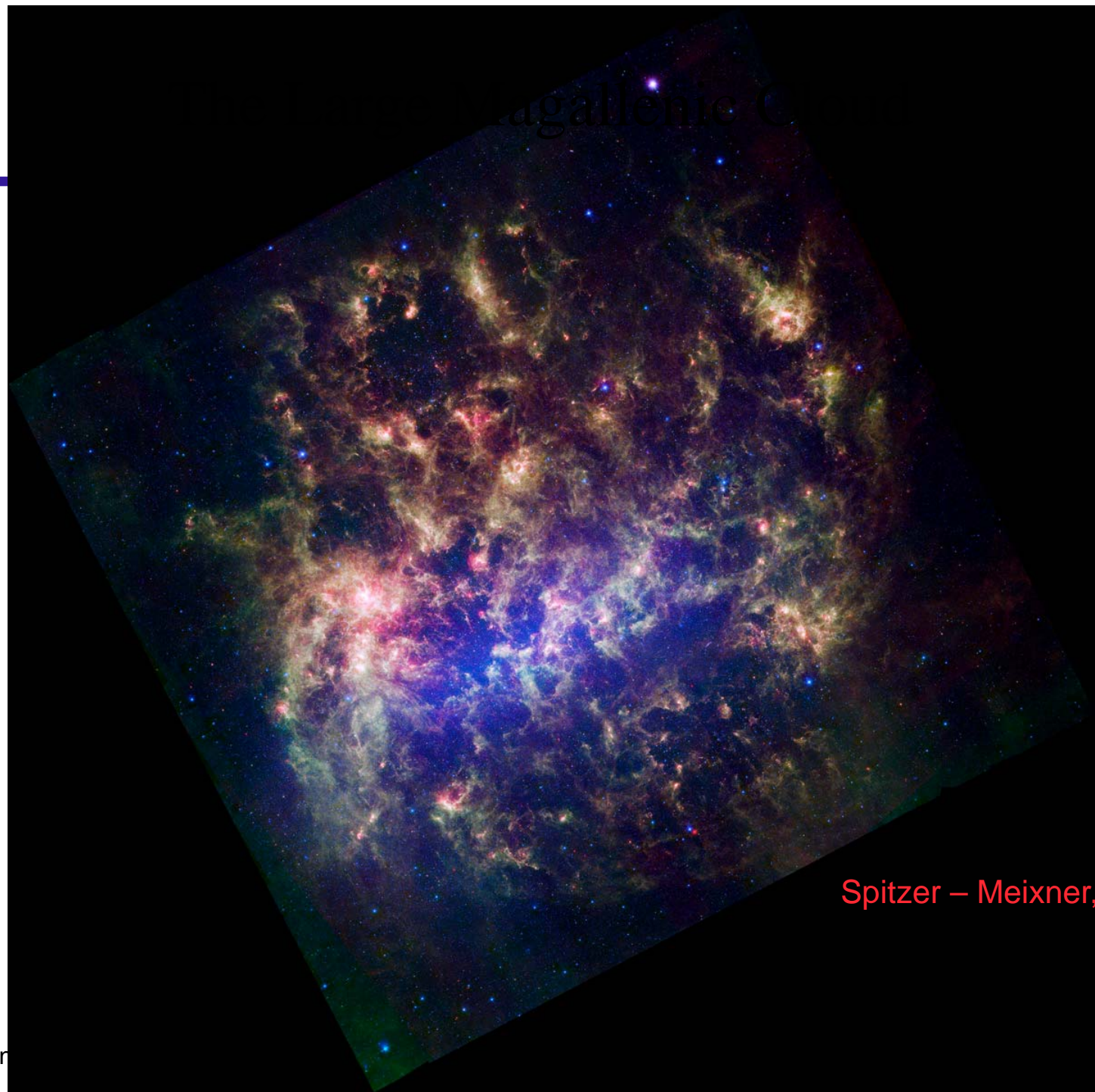
Spitzer Image – Gordon et al. 2006

The Large Magallenic Cloud



IRAS – Rice et al 1988

Magellanic Cloud



Spitzer – Meixner, et al. 2006

The Ubiquity of Cirrus (PAHs) in the ISM in our galaxy and normal Galaxies



Boulanger,
Baud &
van Albada, 1985

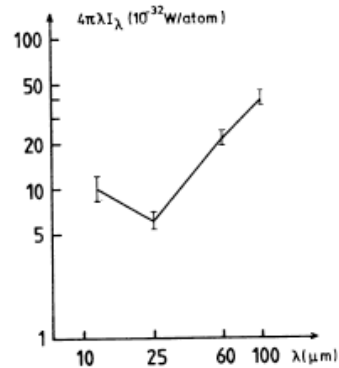
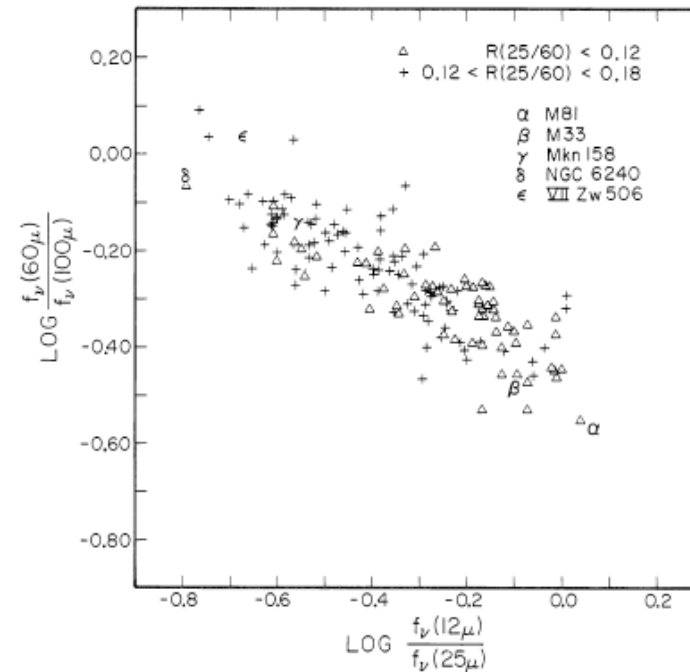
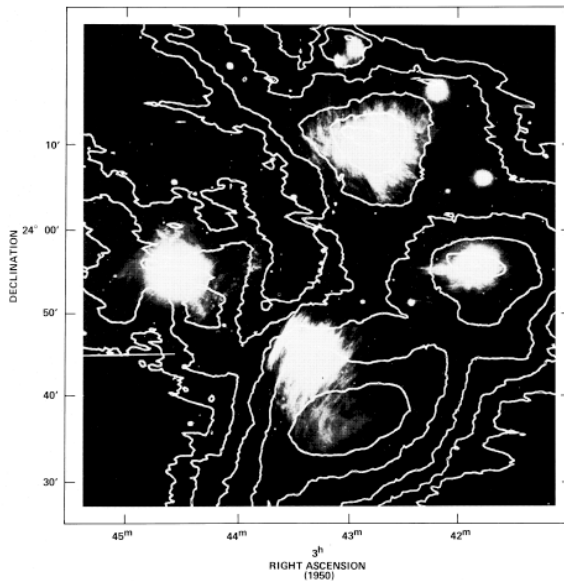


Figure 4: Infrared spectrum of the cirrus marked by a cross in figure 2. Its emission has been normalized by dividing its infrared brightness by its HI column density.



Helou 1986

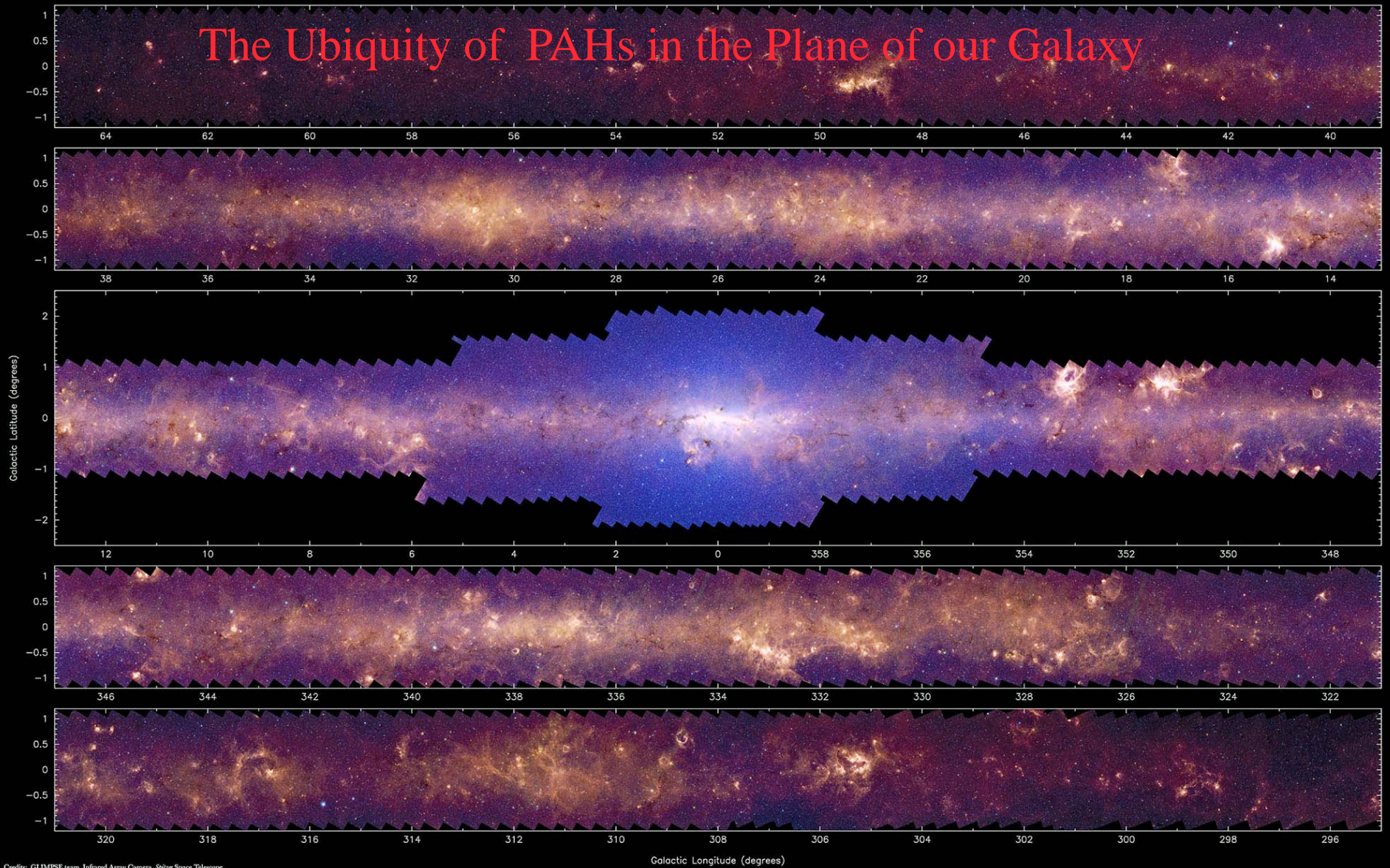


Castelaz,
Sellgren &
Werner 1987

GLIMPSE

The Galactic Legacy Infrared Mid-Plane Survey Extraordinaire

The Ubiquity of PAHs in the Plane of our Galaxy



Credits: GLIMPSE team, Infrared Array Camera, Spitzer Space Telescope.

GLIMPSE team: Ed Churchwell (PI), Marilyn Meade, Brian Babler, Rémy Indebetouw, Barbara Whitney, Christer Watson, Steve Bracker, Tom Robitaille, Bob Benjamin, Doug Watson, Mark Wolfire, Mike Wolf, Matt Povich, Tom Bania, Dan Clements, Martin Cohen, Claudia Cyganowski, Katie Devine, John Dickey, Fabian Heitsch, Jim Jackson, Katharine Johnston, Chip Kobalnicki, John Mathis, Emily Mercer, Jonghee Rho, Marta Sewilo, Susan Stolovy, Brian Uspen
Galactic center data: Susan Stolovy (PI)

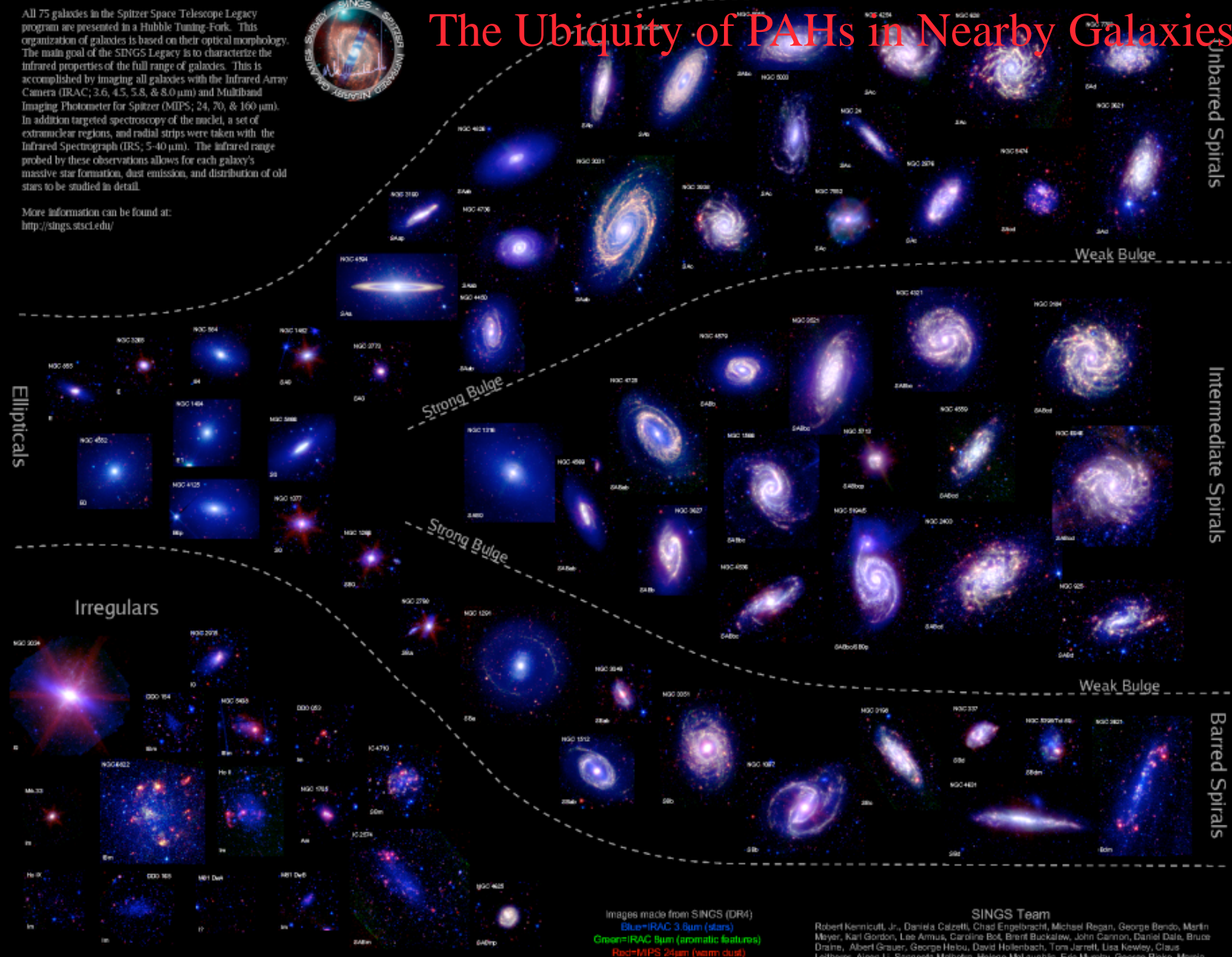
The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

All 75 galaxies in the Spitzer Space Telescope Legacy program are presented in a Hubble Tuning-Fork. This organization of galaxies is based on their optical morphology. The main goal of the SINGS Legacy is to characterize the infrared properties of the full range of galaxies. This is accomplished by imaging all galaxies with the Infrared Array Camera (IRAC; 3.6, 4.5, 5.8, & 8.0 μm) and Multiband Imaging Photometer for Spitzer (MIPS; 24, 70, & 160 μm). In addition targeted spectroscopy of the nuclei, a set of extranuclear regions, and radial strips were taken with the Infrared Spectrograph (IRS; 5–40 μm). The infrared range probed by these observations allows for each galaxy's massive star formation, dust emission, and distribution of old stars to be studied in detail.

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



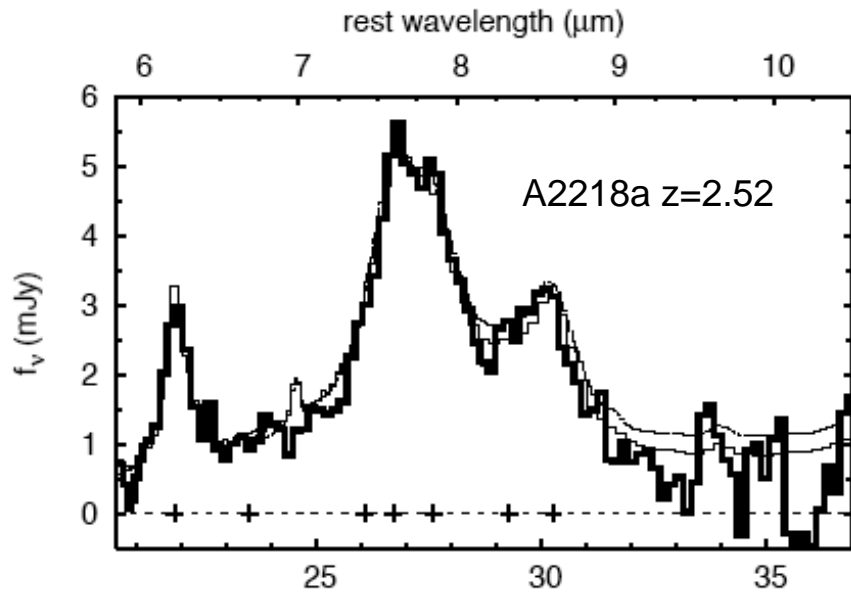
The Ubiquity of PAHs in Nearby Galaxies



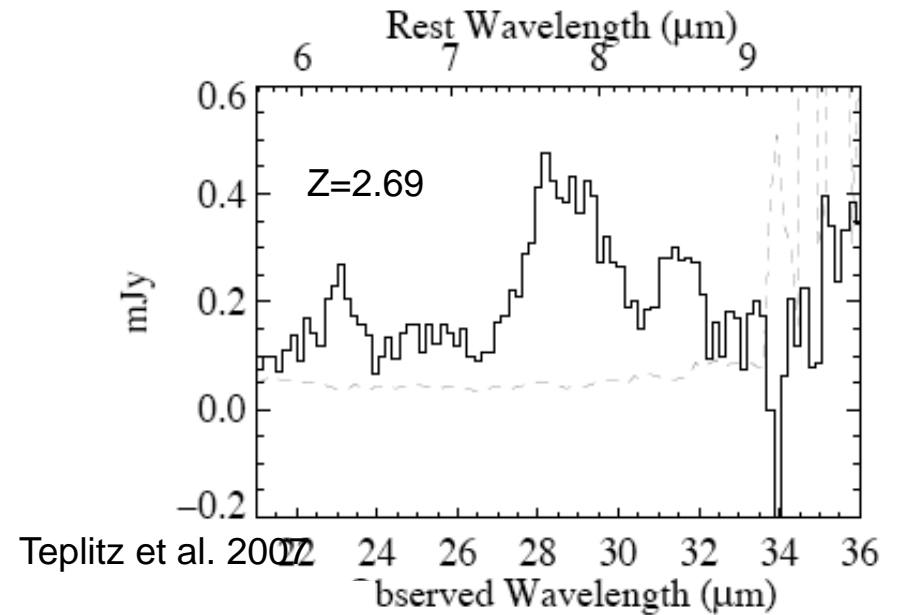
Images made from SINGS (DR4)
 Blue=IRAC 3.6 μm (stars)
 Green=IRAC 8 μm (aromatic features)
 Red=MIPS 24 μm (warm dust)

SINGS Team
 Robert Kennicutt, Jr., Daniela Calzetti, Chad Engelbracht, Michael Regan, George Bendo, Martin Meyer, Karl Gordon, Lee Armus, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Albert Grauer, George Helou, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Helene McLaughlin, Eric Murphy, George Rieke, Marcia Rieke, Helene Roussel, Karik Sheth, J.D. Smith, Michele Thumley, Fabian Walter

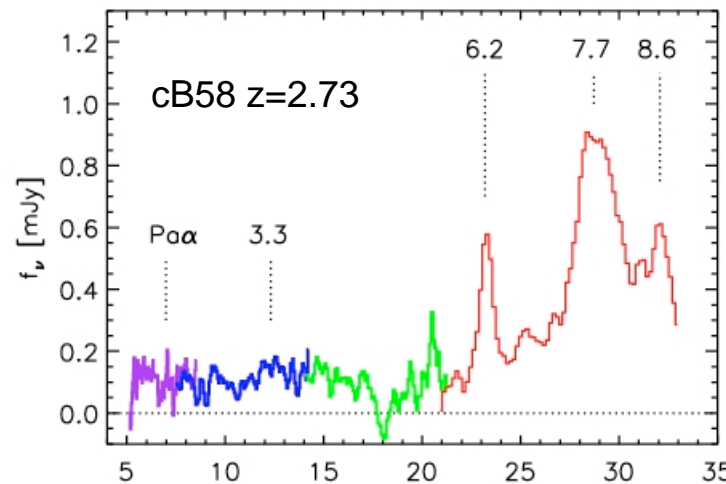
The Ubiquity of PAHs in the Universe Beyond $z \sim 2.5$



Rigby et al. 2008 observed wave

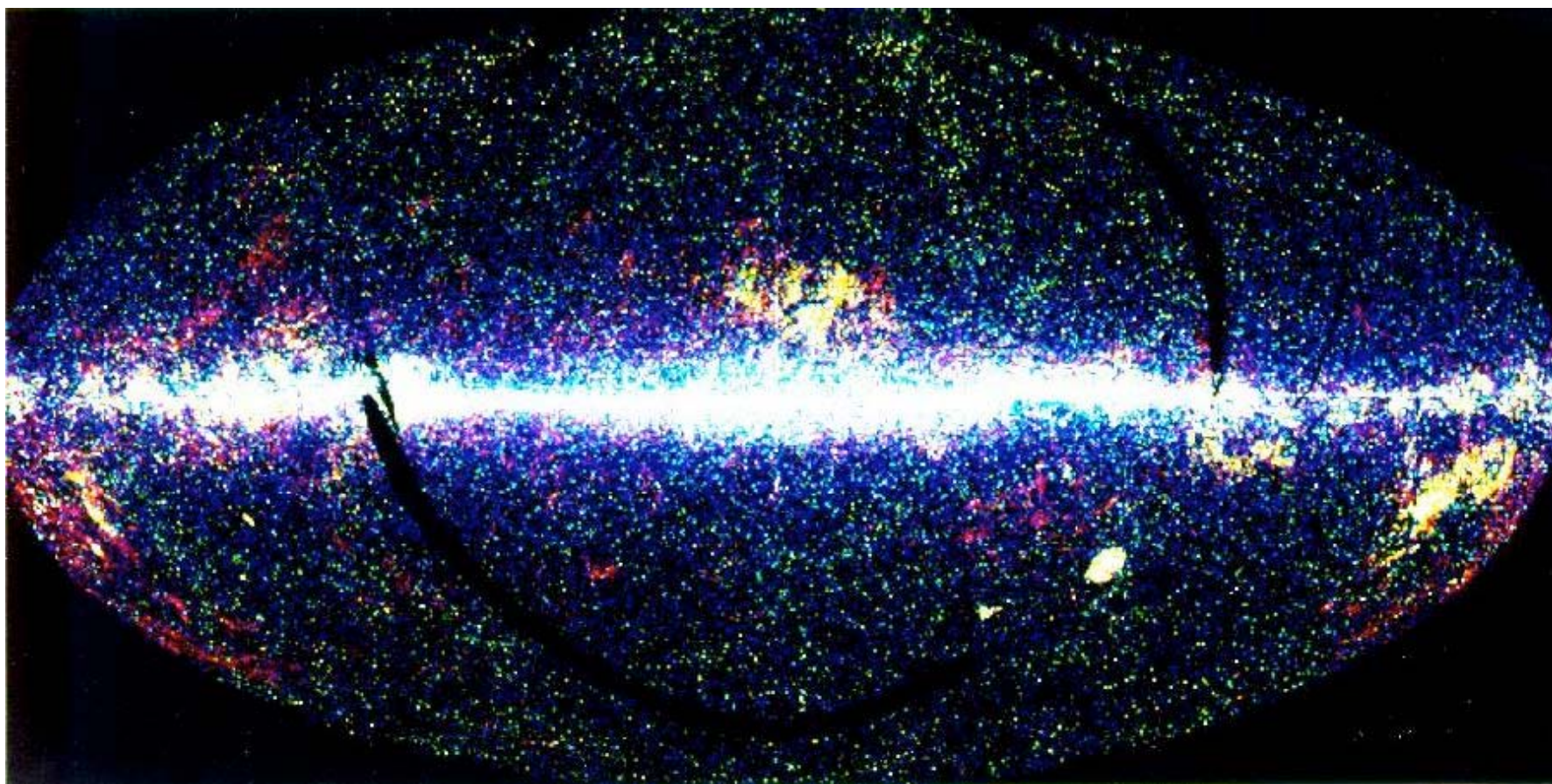


Teplitz et al. 2002

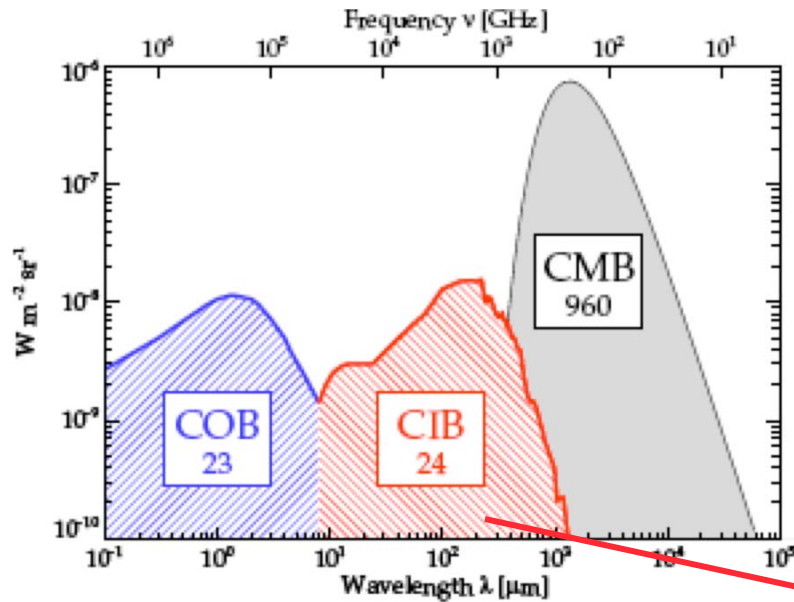


Siana et al. 2008 Observed Wavelength [μm]

The IRAS Point Source Catalog

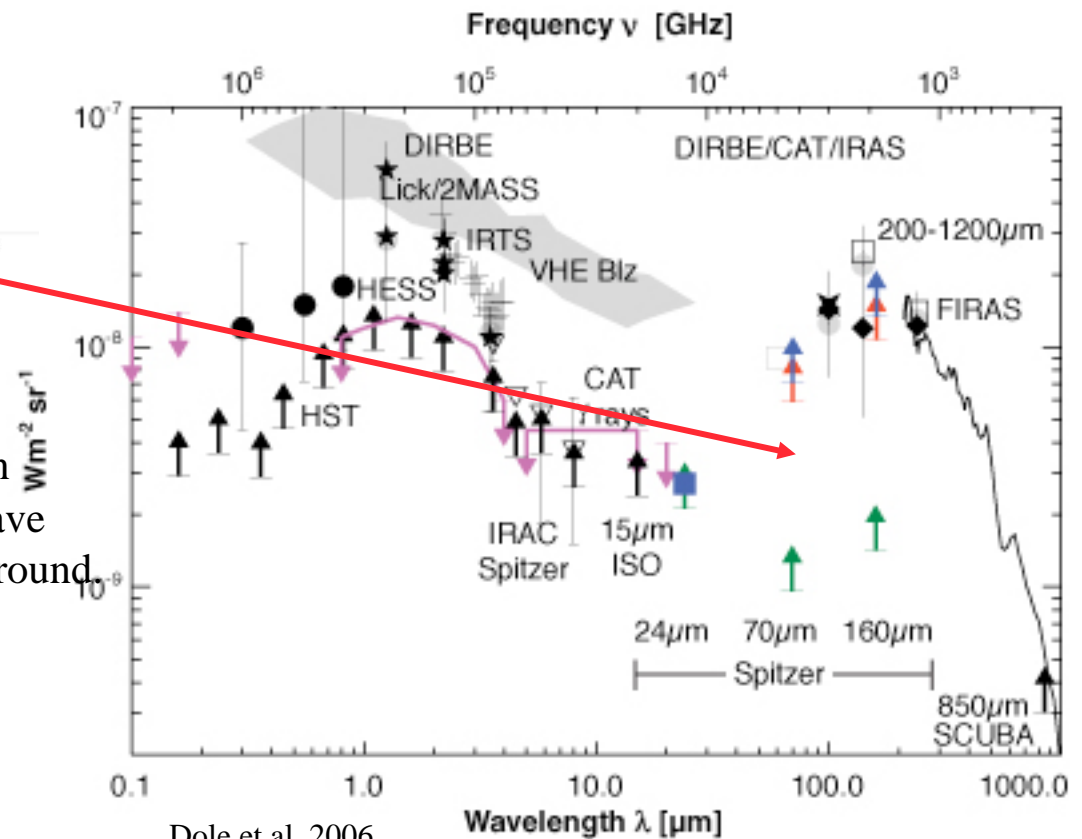


The Far Infrared Background is Resolved

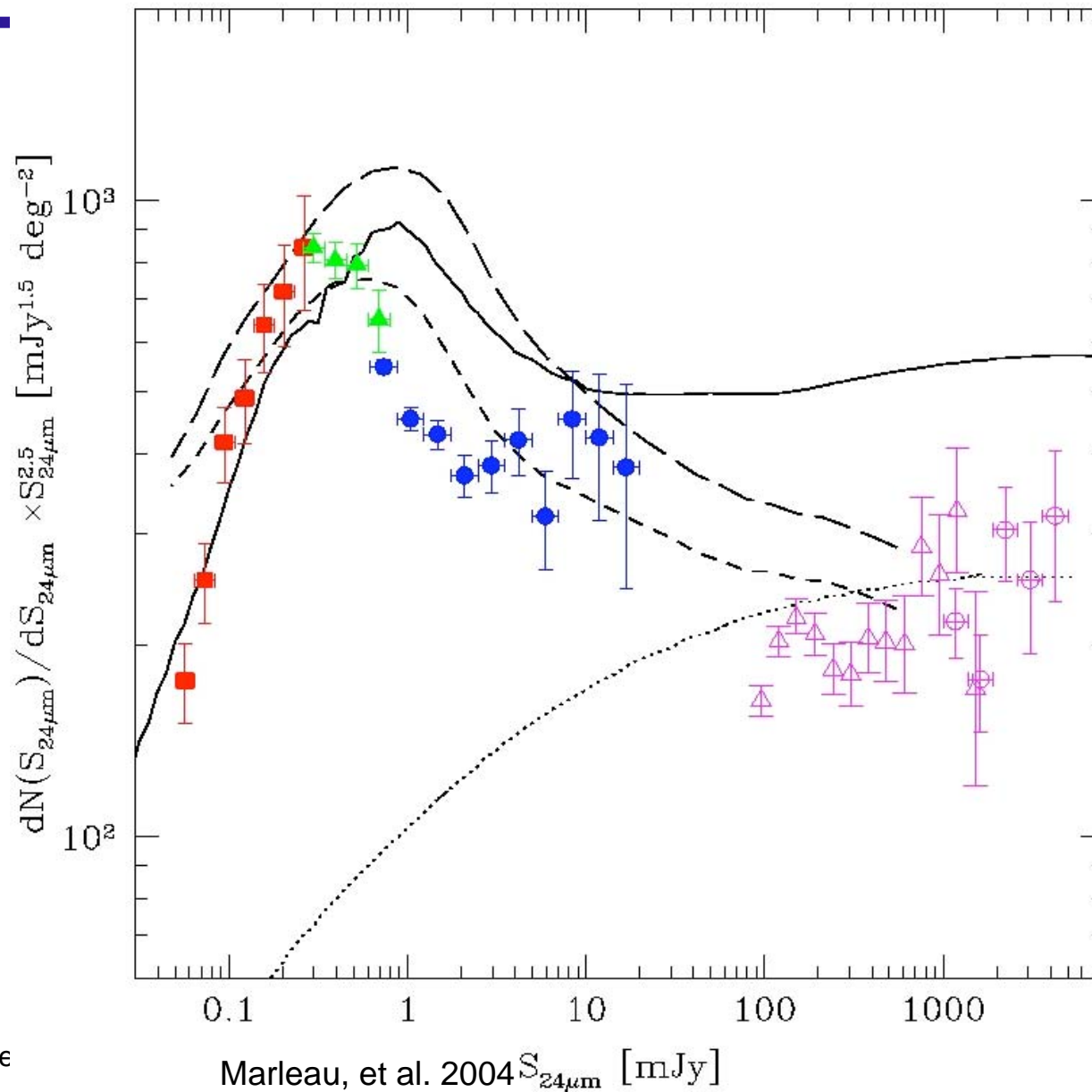


The Cosmic Infrared & Optical Backgrounds record the history of star formation and black hole growth in the Universe.

IRAS found that the FIR emission from nearby galaxies is ~25% of total luminosity. The CIB measured with COBE required strong evolution in the IR galaxy population. ISO and Spitzer have seen this evolution and resolved the FIR background.



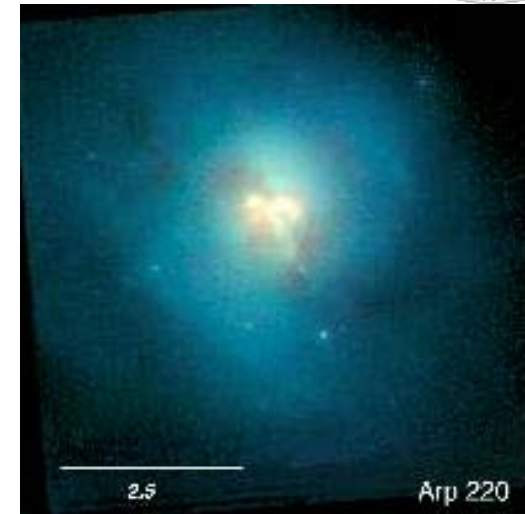
IRAS Discovered & ISO, Spitzer Confirmed That IR Luminous Galaxies Evolve Strongly



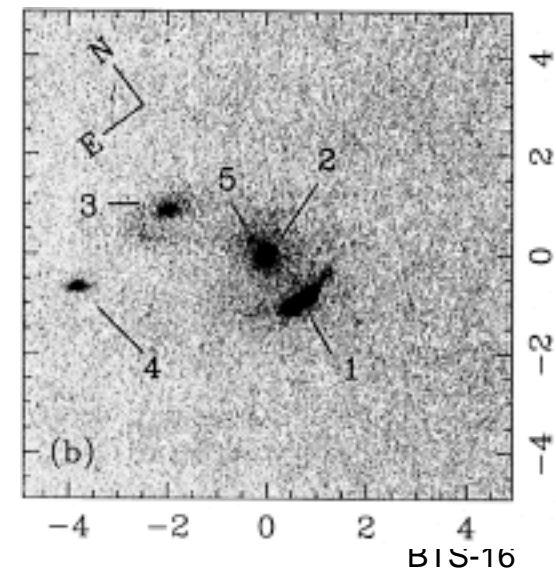
ULIRGs and HyperLIRGs



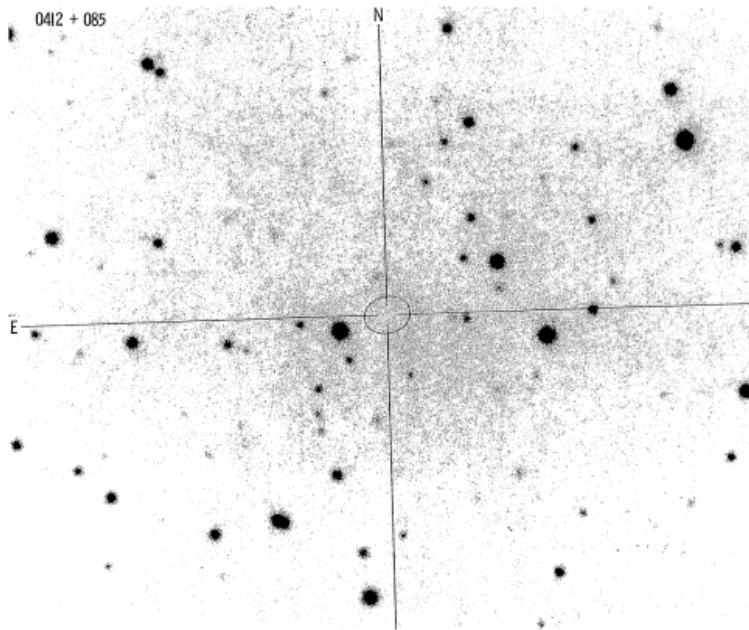
Arp 220 – The Prototype
Ultra-luminous Infrared
Galaxy (ULIRG)



FSC10214+4724 –
The most distant IR Luminous
Source seen in IRAS

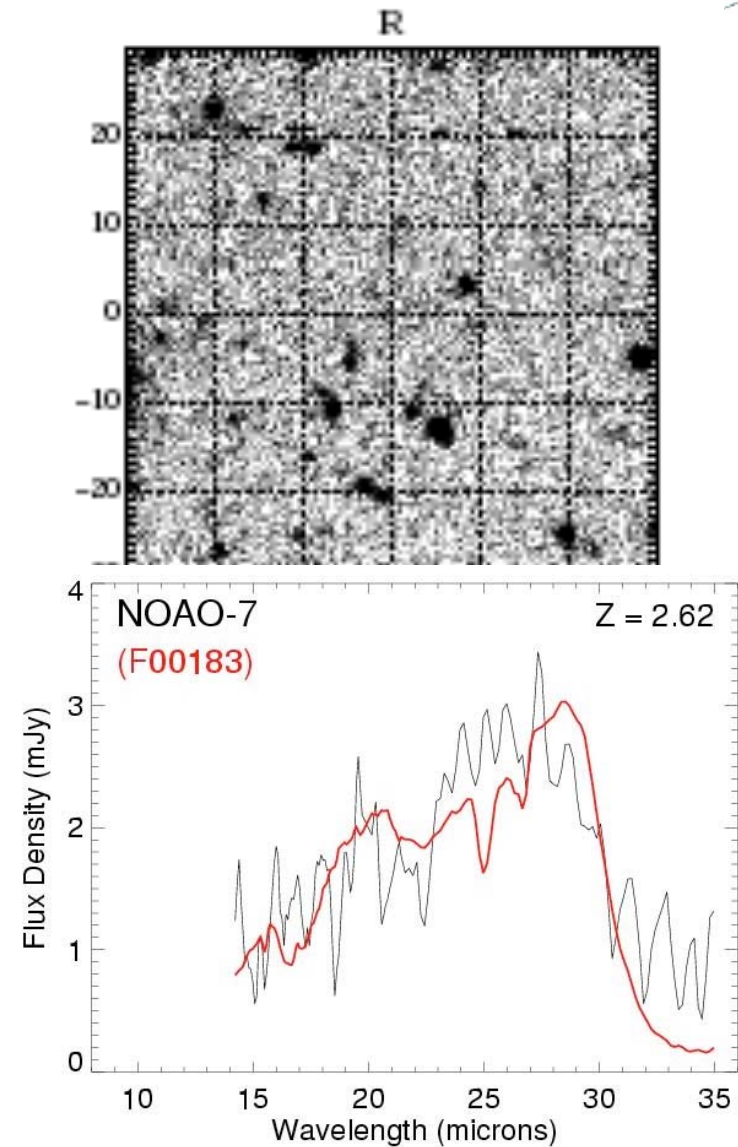


IR Loud, Optically Invisible Sources



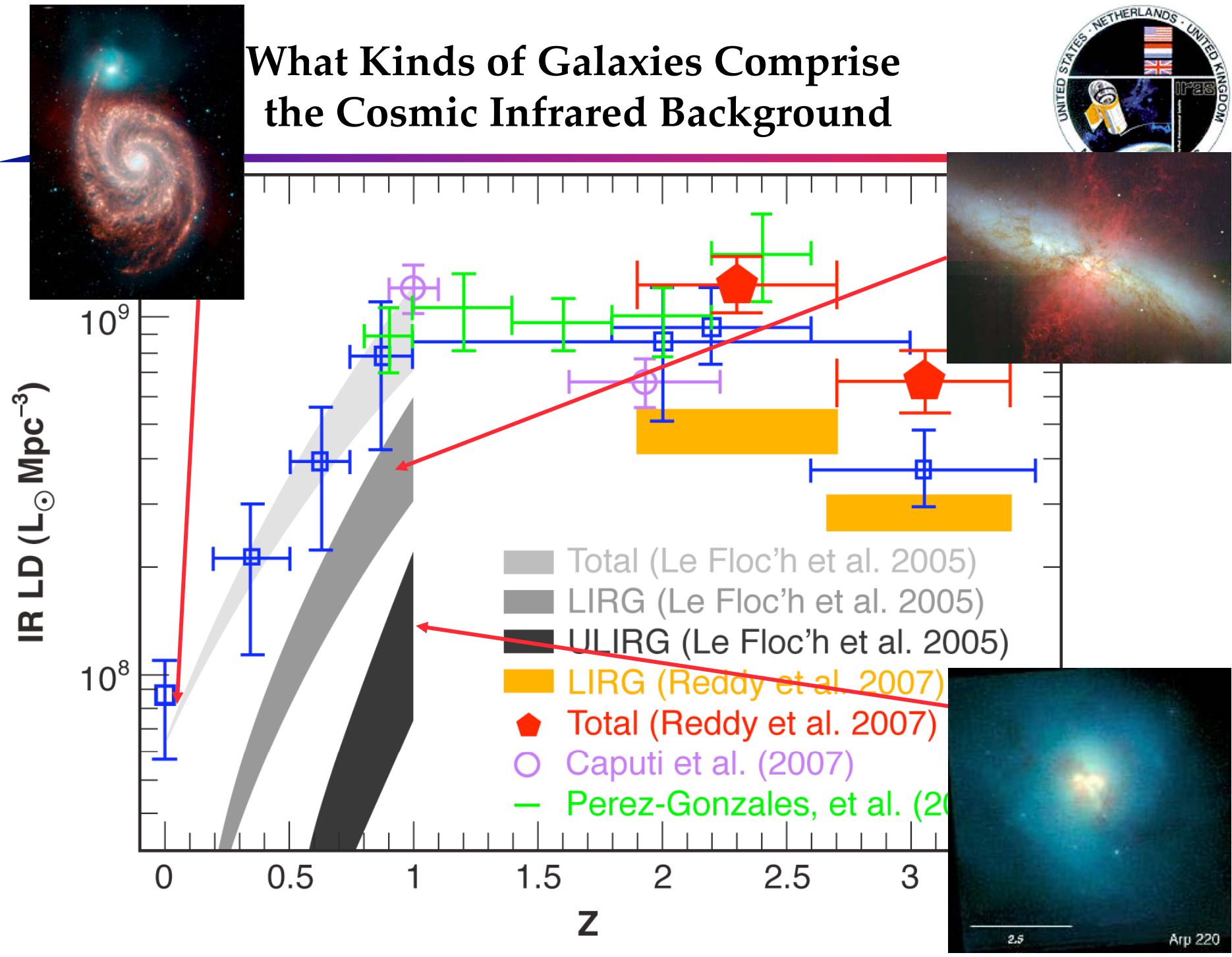
Houck et al 1984, ~ 0.5 Jy @ $60\mu\text{m}$,
>20mag@ R

Houck et al 2005, ~ 1 mJy@ $24\mu\text{m}$,
>25mag@R





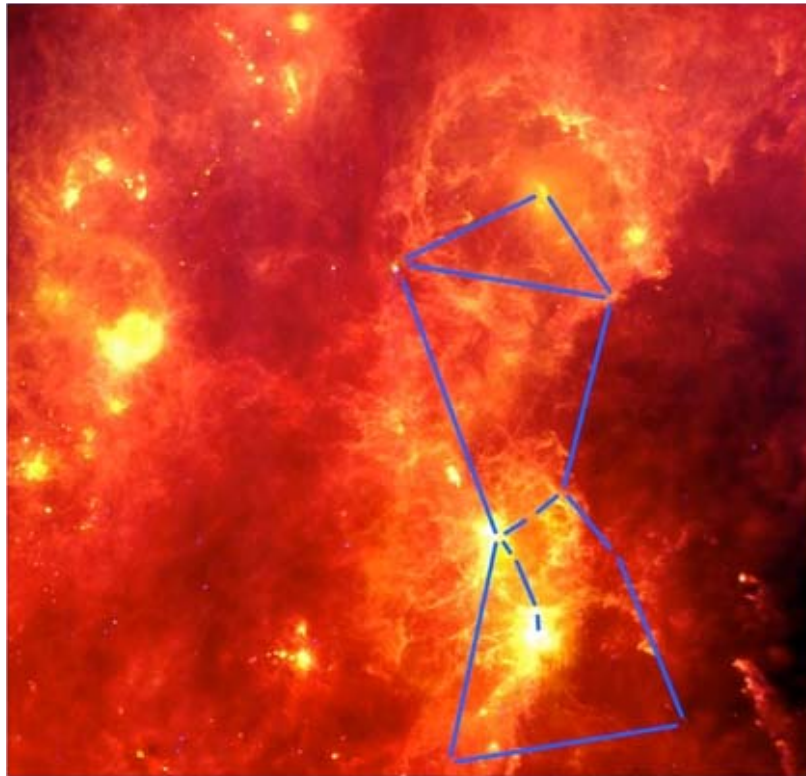
What Kinds of Galaxies Comprise the Cosmic Infrared Background



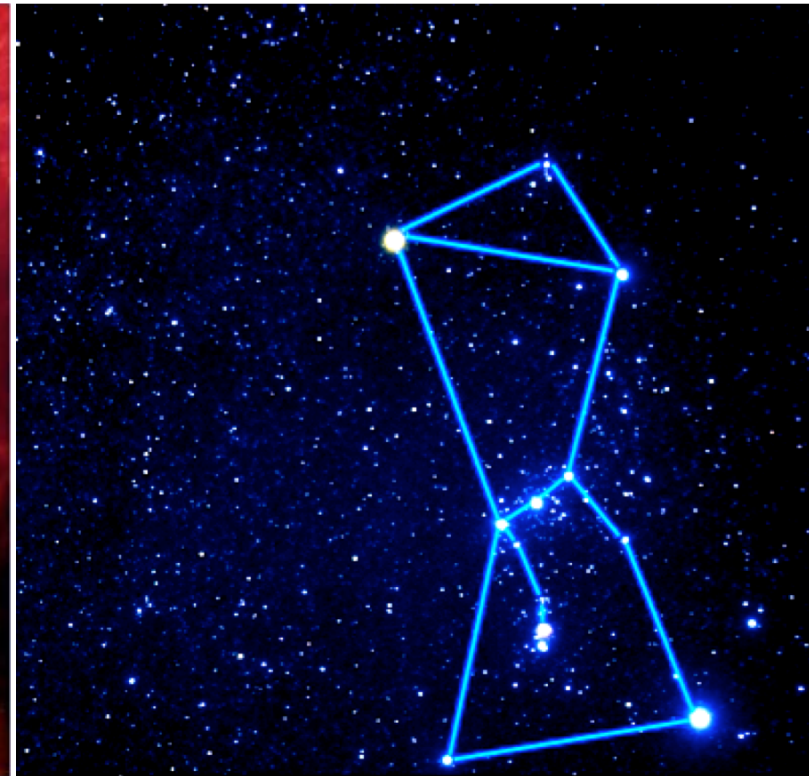
Views of Orion



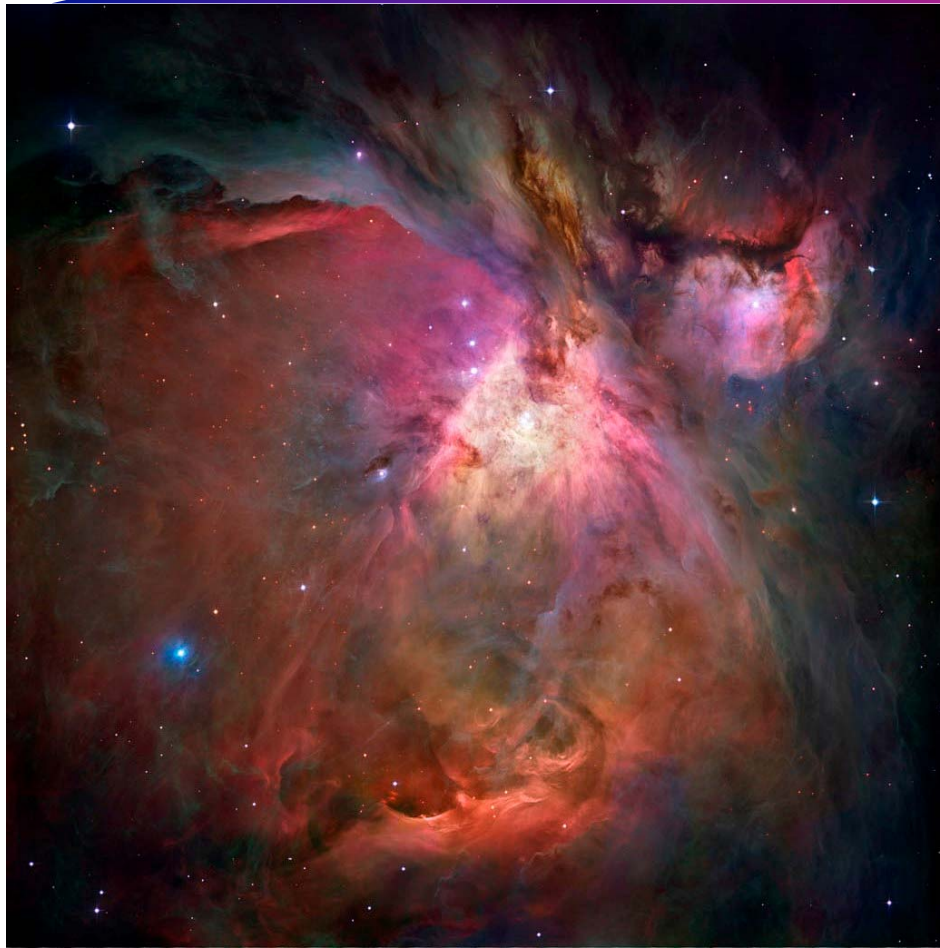
Infrared (IRAS)



Visible Light (Akira Fujii)



The Core of Orion – HST & Spitzer



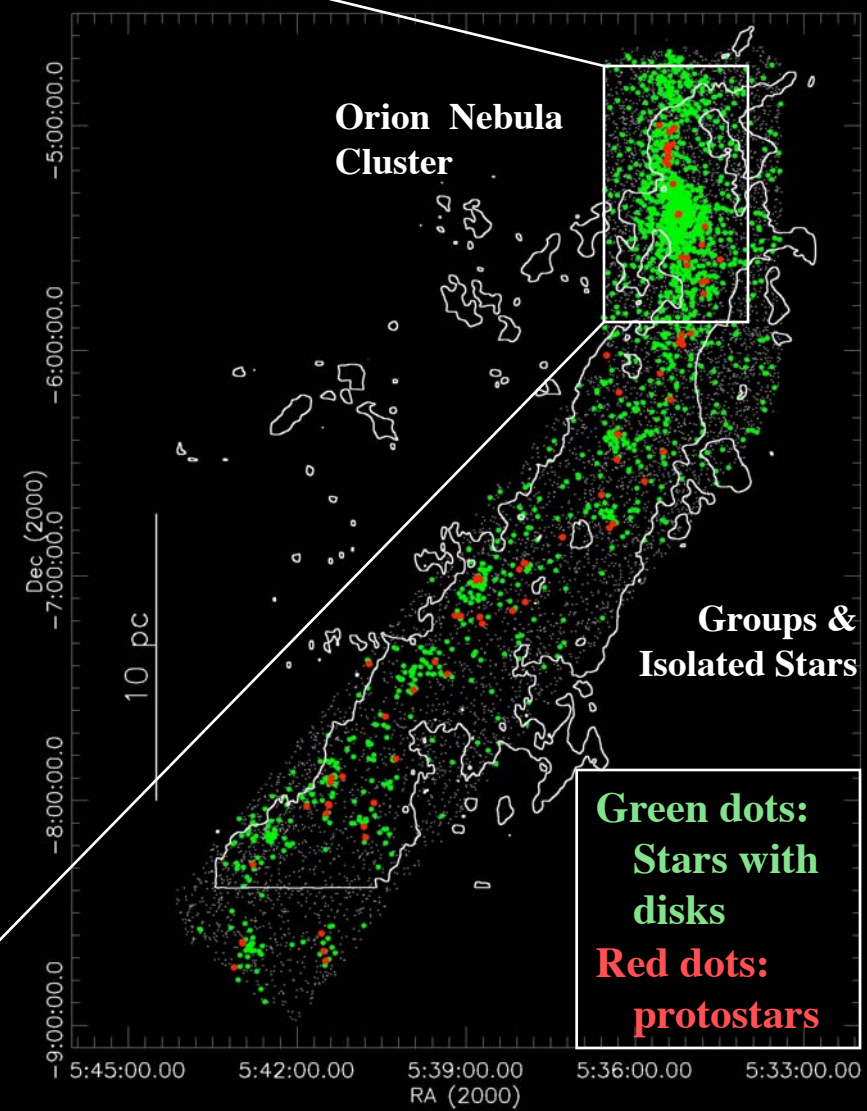
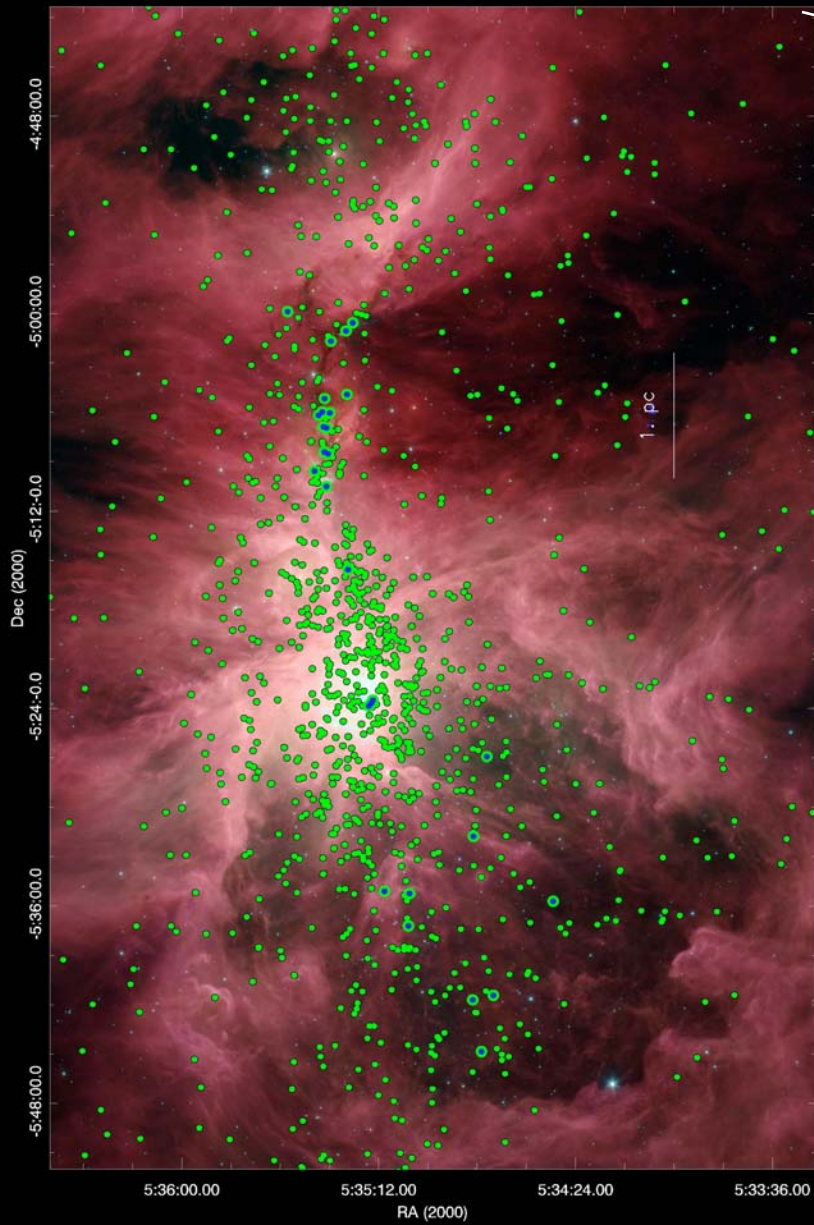
VISIBLE LIGHT IMAGE

IRAS Science Legacy

0.43-0.53 μ m
0.60-0.91 μ m
3.6 μ m 8.0 μ m



The Spitzer Survey of the Orion Nebula and Orion A Molecular Cloud



Megeath et al. (2005)

Contours: Bell Labs CO survey of Orion A

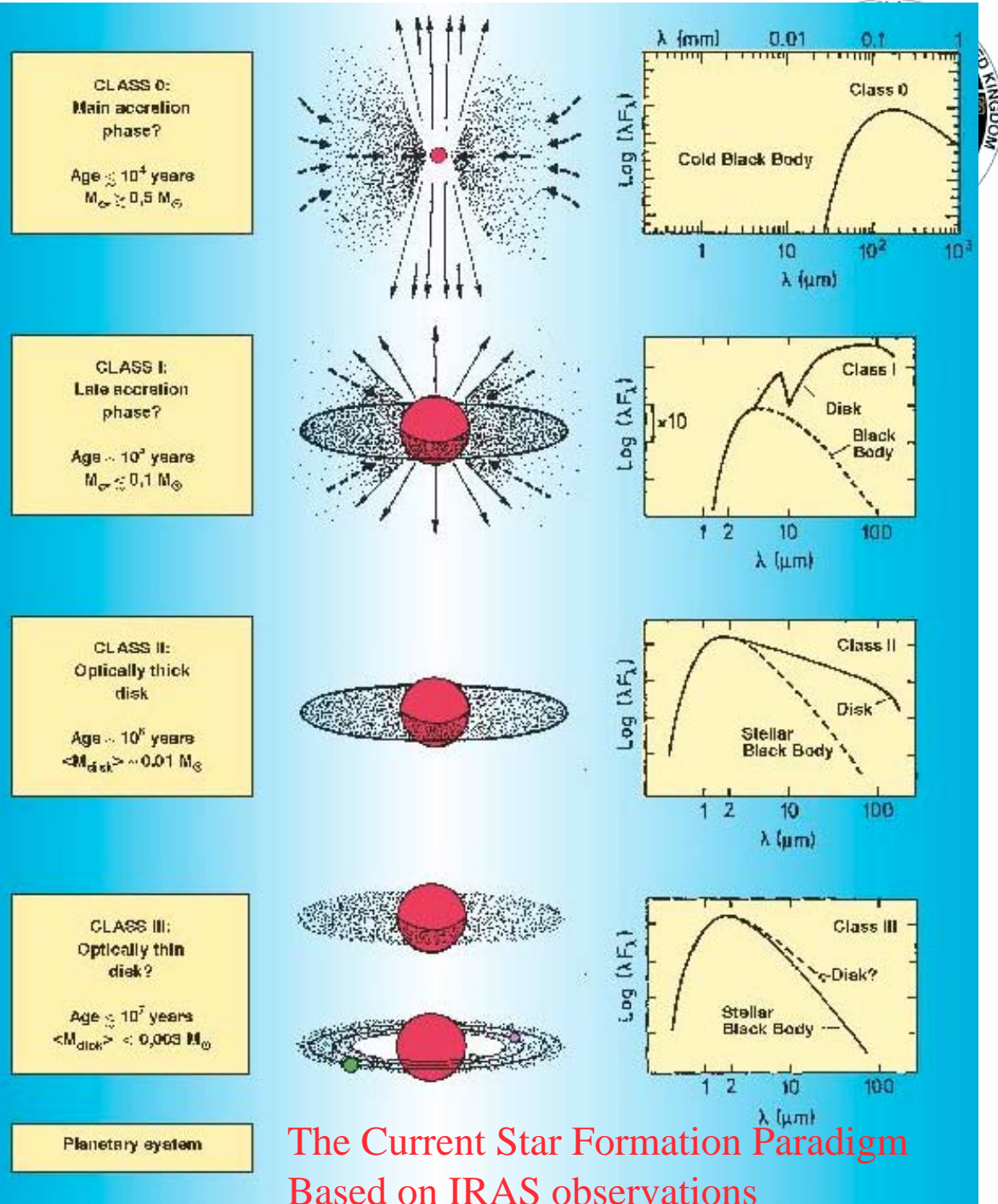
BAS-21

Class 0
Main accretion phase?
 $M_{env} > \sim 0.5 M_{sun}$
 $< \sim 10^4$ years

Class I
Late accretion phase?
 $M_{env} < \sim 0.1 M_{sun}$
 $\sim 10^5$ years

Class II
Optically thick disk
Avg $M_{disk} \sim 0.01 M_{sun}$
 $\sim 10^6$ years

Class III
Optically thin disk
Avg $M_{disk} < \sim 0.003 M_{sun}$
 $\sim 10^7$ years



The Vega Phenomenon



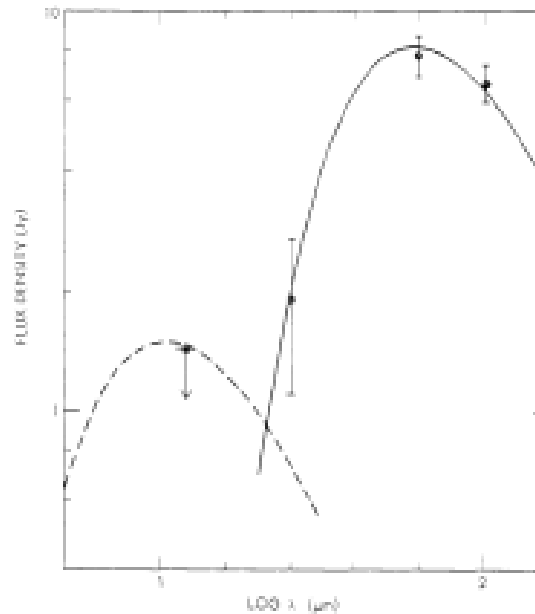
THE ASTROPHYSICAL JOURNAL, **278**:L23–L27, 1984 March 1

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DISCOVERY OF A SHELL AROUND ALPHA LYRAE¹

H. H. AUMANN, F. C. GILLETT, C. A. BEICHMAN, T. DE JONG, J. R. HOUCK, F. J. LOW,
G. NEUGEBAUER, R. G. WALKER, AND P. R. WESSELIUS

Received 1983 September 22; accepted 1983 November 18

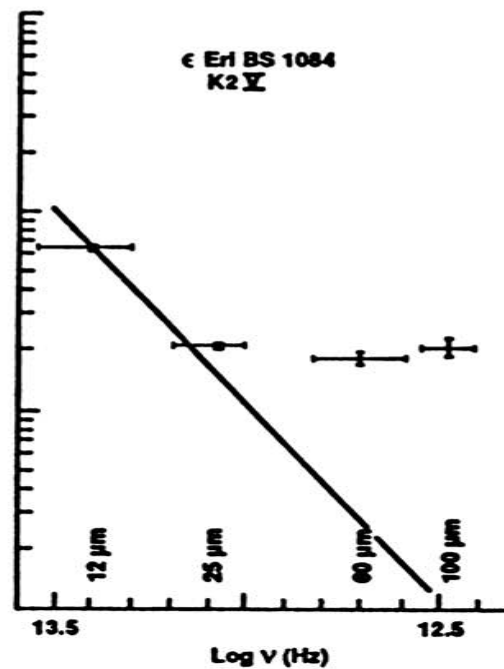
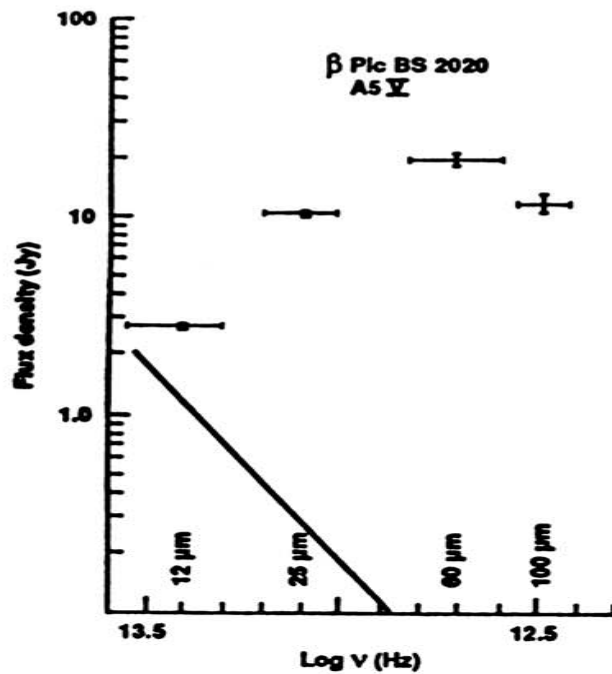
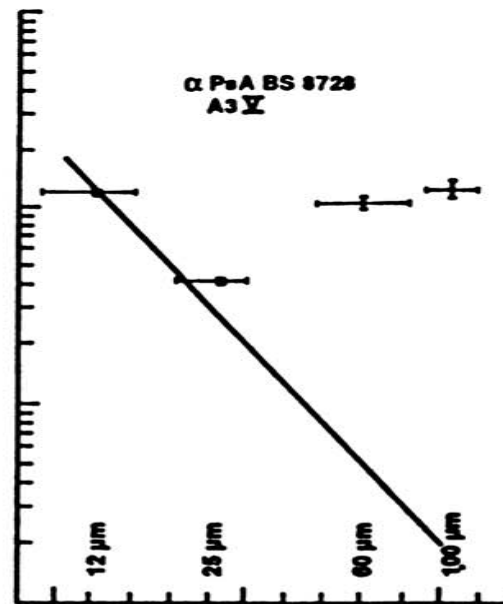
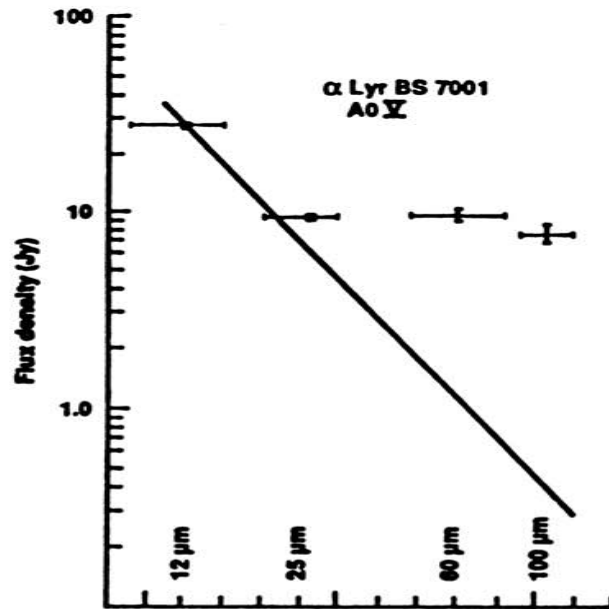


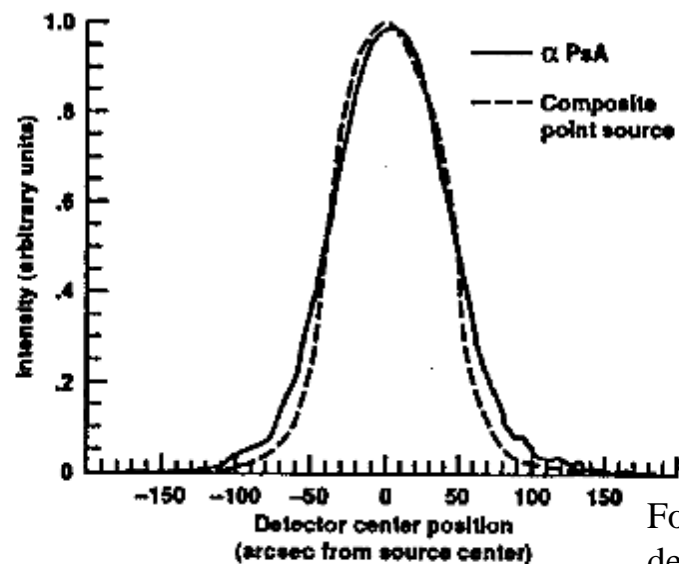


The Fabulous Four debris disk SEDs Gillett 1984

Vega A0V
Fomalhaut A3V

Beta Pictoris A5V
Epsilon Eridani K2V

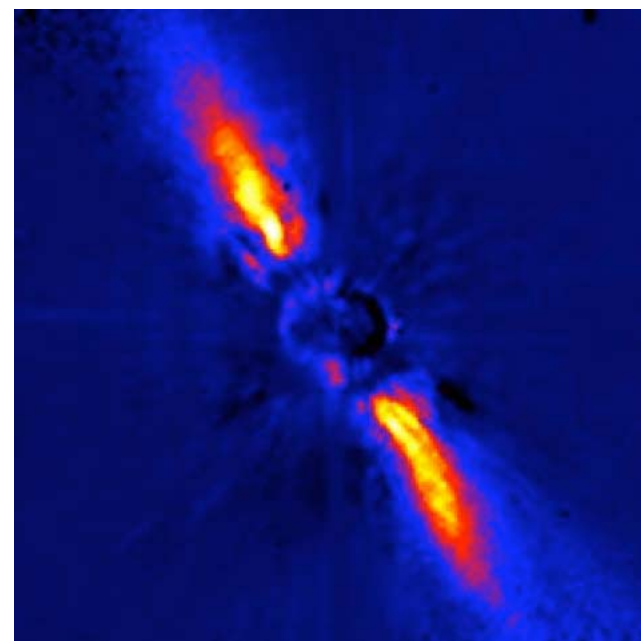




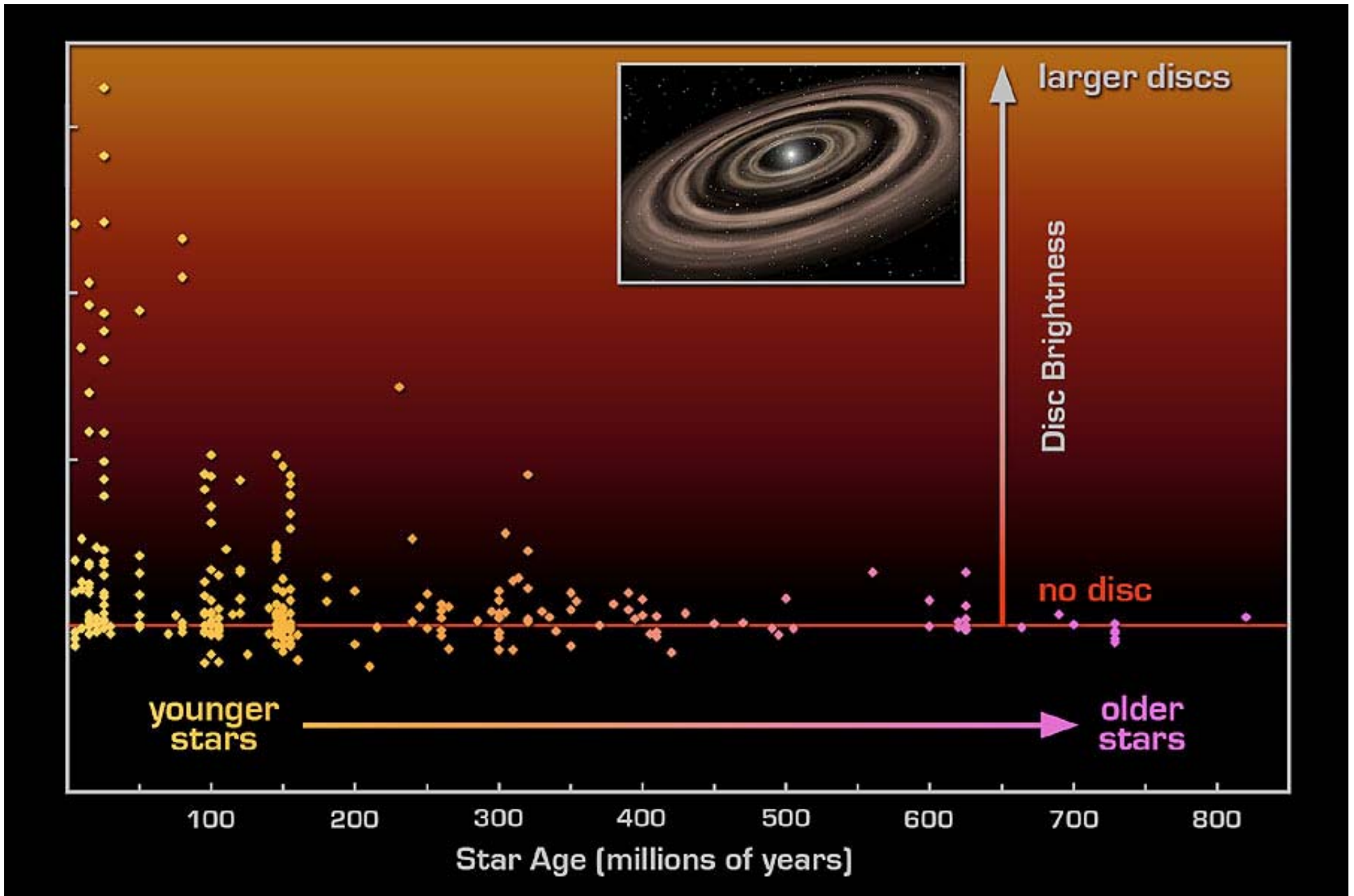
Fomalhaut
debris disk
scan profile,
60 microns

Backman &
Paresce 1993

Figure 3.—Comparison of IRAS 60 μm scan profiles of α PsA, the most extended of the “Big 3,” with a composite of several point sources. The scans were made at 1/2 the all-sky-survey scan rate with a sampling interval of 3.6 arcsec. Scan widths represent a combination of detector FOV, detector response time, telescope diffraction and intrinsic source width; the FWHM is equal to the 90 arcsec detector width parallel to the scan direction (“in-scan”). The profiles are normalized to 1 at their peaks, which makes the broader source appear narrower above the FWHM points. Irregularities in the α PsA profile wings indicate the noise level (data provided courtesy of F. Low, F. Gillett, G. Neugebauer, J. Good and H. Aumann).



B Pic in optical,
Smith & Terrile, 1984



Rieke et al. 2005

Understanding what disks are made of

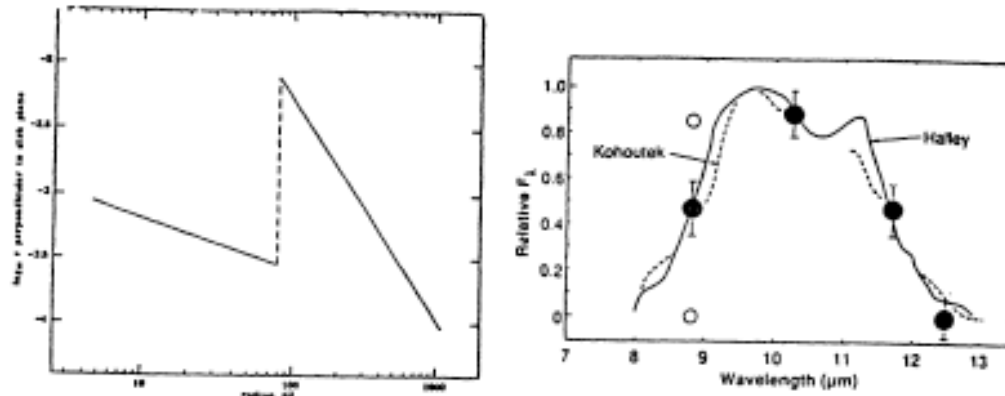
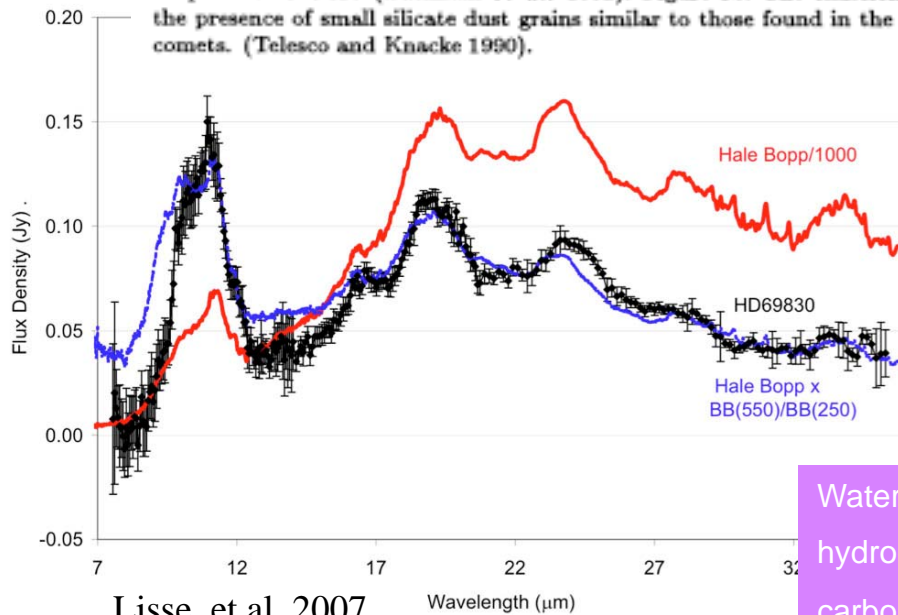


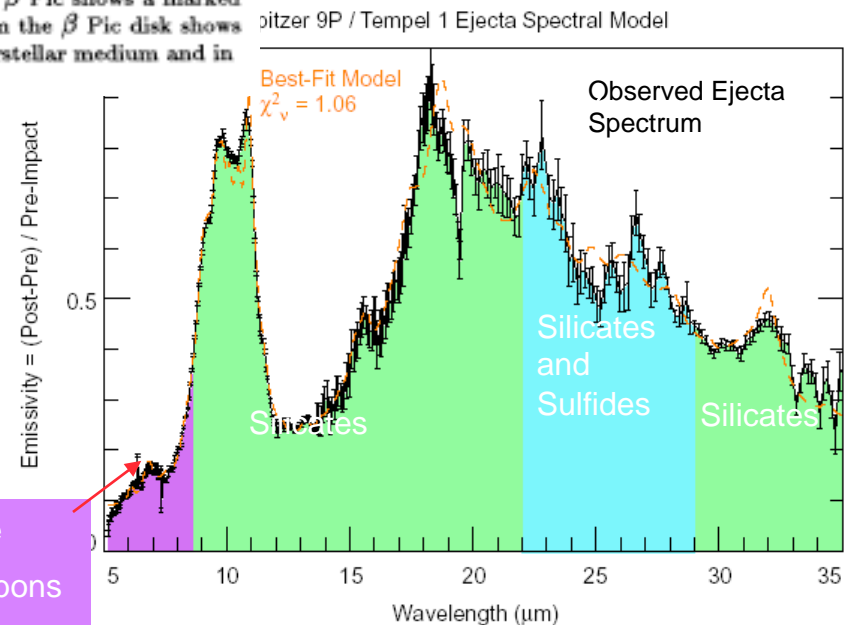
Figure 3a. The inferred density distribution of material in the disk around β Pic shows a marked drop within 100 AU (Backman *et al.*, 1992). Figure 3b. The emission from the β Pic disk shows the presence of small silicate dust grains similar to those found in the interstellar medium and in comets. (Telesco and Knacke 1990).



Lisse, et al. 2007

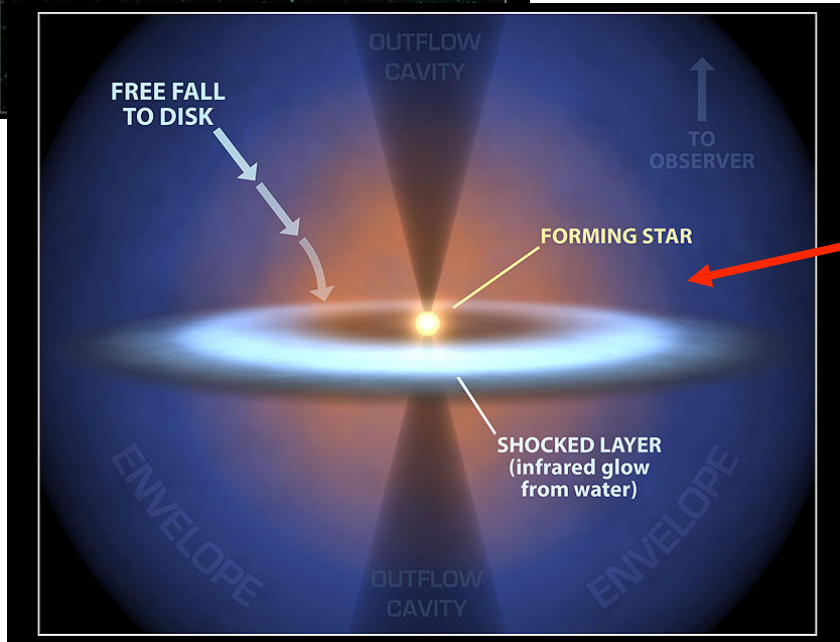
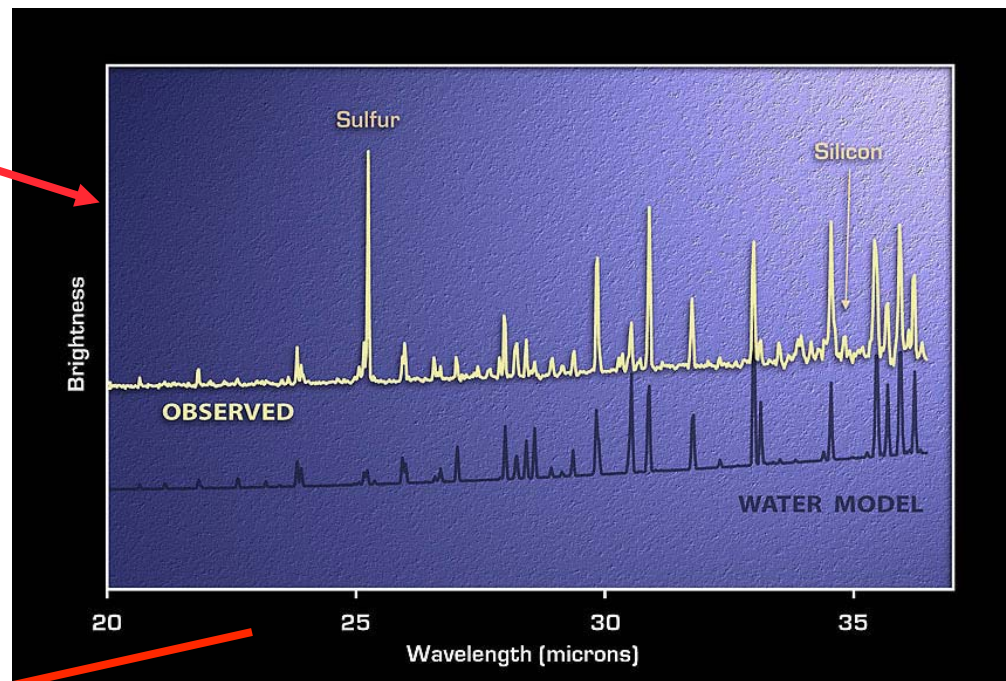
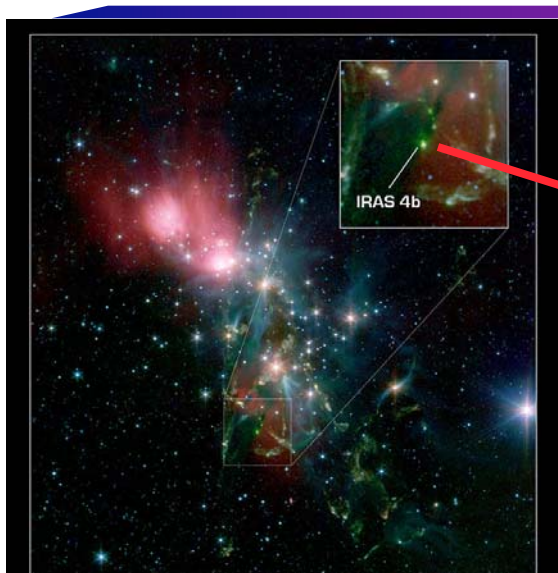
Wavelength (μm)

Water ice
hydrocarbons
carbonates



Lisse, et al. 2006

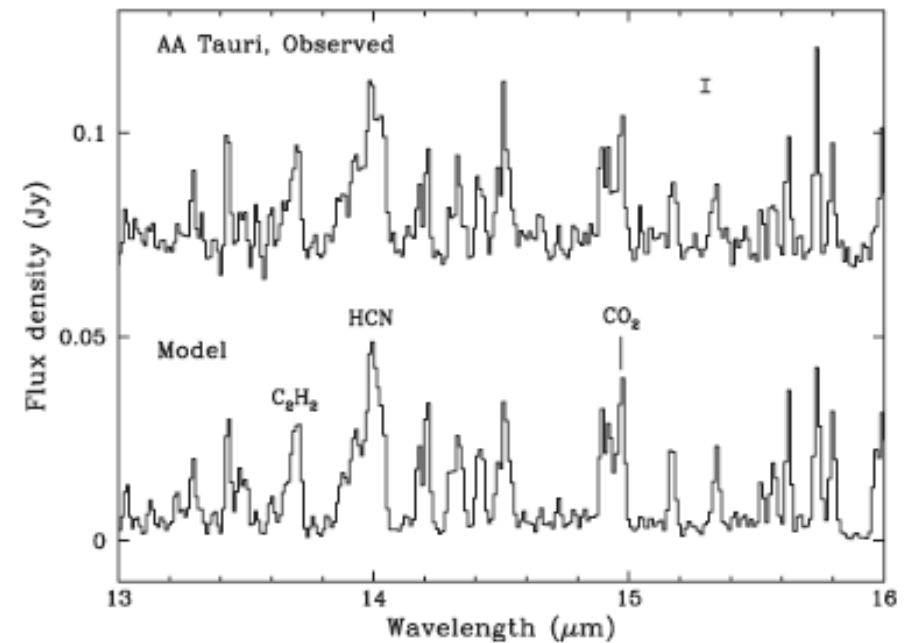
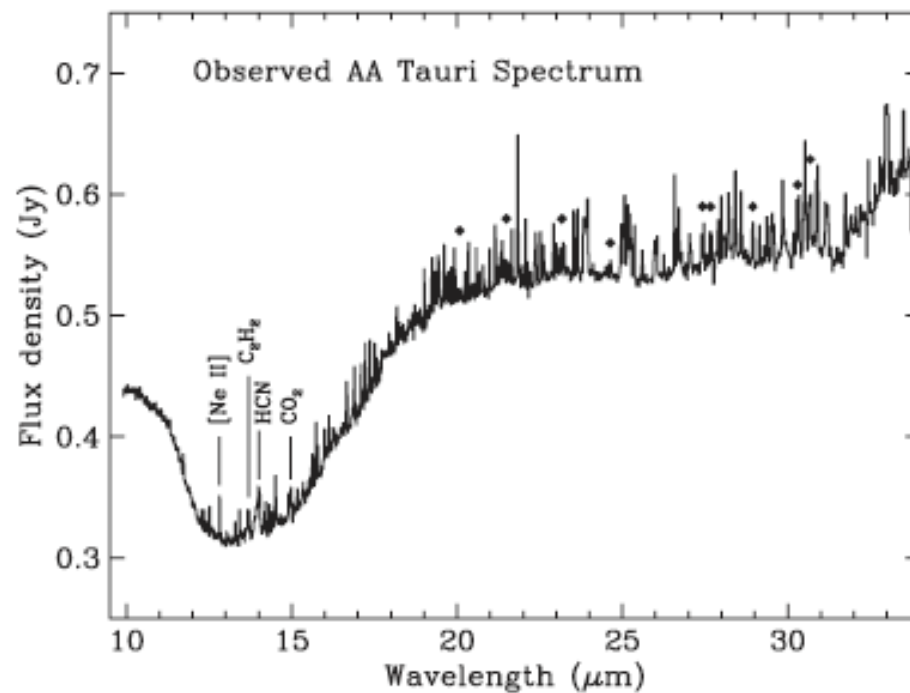
Oceans of Water in forming Planetary Systems



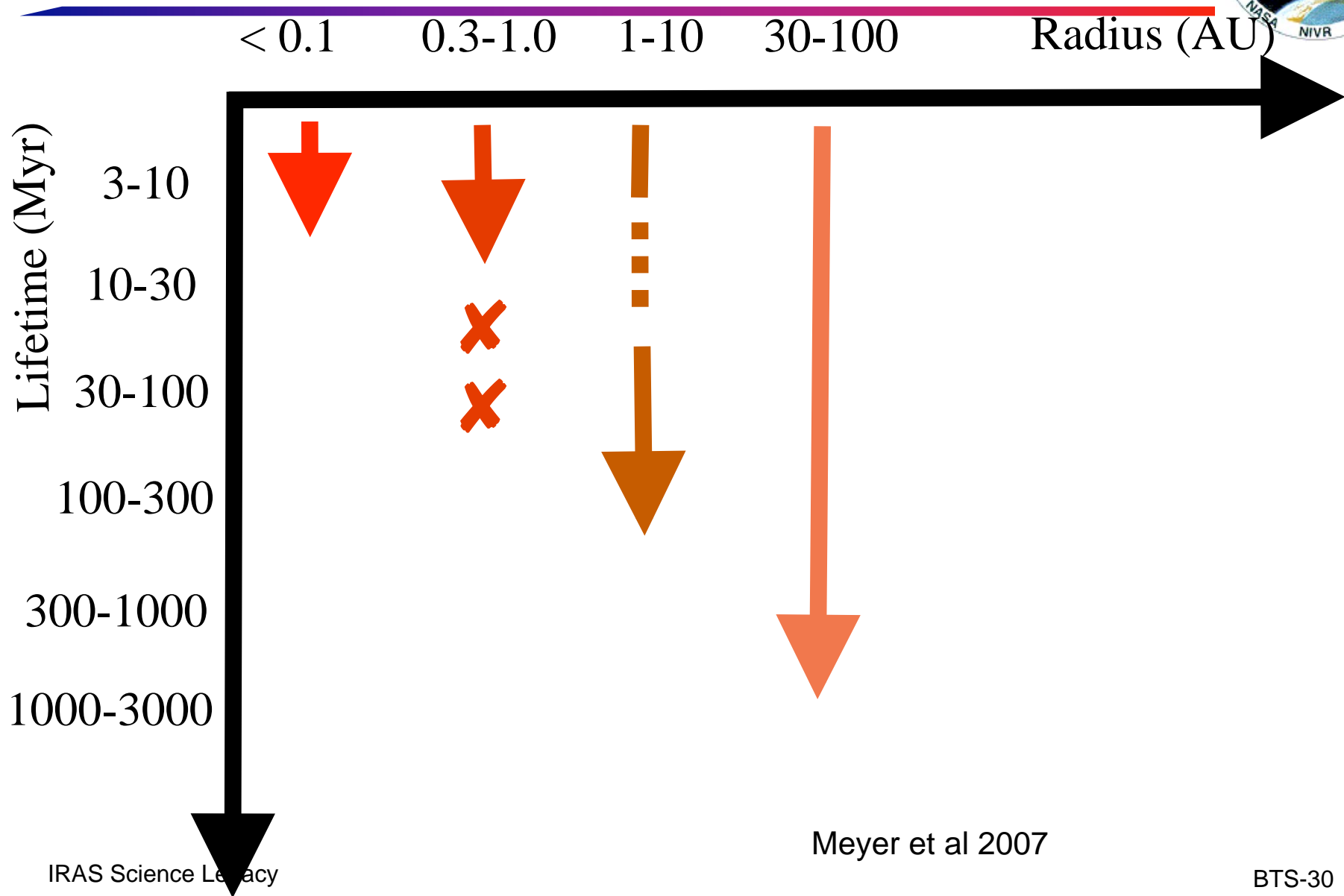


Organic Molecules and Water in the Planet Formation Region of Young Circumstellar Disks

John S. Carr¹ and Joan R. Najita²



FEPS *Preliminary* Results: Debris Disk Lifetimes



The Washington Post

in the mid
light, low in
cloudy with
50s. Yester-
temperature
Page C2

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No. 248

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WEDNESDAY, AUGUST 10, 1983

Figures in Areas Approximately 75 Miles
From Center of Chubasco See Box on A10



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Col. 1

VIOLENCE IN ULSTER



Belfast youths examine remains of a truck burned late Monday. British troops shot and killed a young Catholic man during disturbances yesterday. Story, Page A10.

New Evidence of Other Worlds

Satellite Discovers Possible Second Solar System

By Thomas H. Dineen
Washington Post Staff Writer

A satellite carrying an infrared telescope has discovered swarms of large particles around the star Vega, and scientists say they think the particles and the star make up a complete solar system like our sun and the nine planets and thousands of asteroids and meteorites that surround it.

If true, it is the first evidence that the universe contains a second solar system like this one.

Though scientists have speculated for years that the Earth and its eight sister planets are not alone in the cosmos, they have never had evidence that their speculations were correct.

"The discovery provides the first direct evidence that solid objects of substantial size exist around a star other than the sun," said a statement yesterday from the Jet Propulsion Laboratory in Pasadena, where the Infrared Astronomical Satellite (IRAS) pictures are analyzed.

"The material could be a solar system at a dif-

ferent stage of development than our own," the statement said. Vega is a young star only 1 billion years old. The Earth's sun is almost 5 billion years old.

Nevertheless, Vega is similar to the sun. Its surface temperature has been measured at 10,000 degrees, almost the same as the sun. This suggests that though it is younger, Vega and its surrounding system may be undergoing the same kind of evolution that this solar system went through 4 billion years ago. Among the bodies in evolution around Vega could be even the equivalent of a young Earth.

What the IRAS satellite has seen time after time since it left the Earth last January is that Vega has appeared "much brighter and larger in infrared light" than any other similar star the satellite has observed, strongly suggesting there were gaseous bodies in orbit around Vega just as the planets in this solar system circle the sun.

Further investigation showed that the bodies

around Vega had temperatures measured by the infrared telescope at about 300 degrees below zero Fahrenheit. This is far above the temperature of empty interstellar space and approximates the temperature of the inner rings of Saturn.

"The telescope on IRAS has no way of counting the number of bodies in orbit around Vega or even of estimating their size. But the statement released yesterday by JPL said the particles could range "from backshot to the size of asteroids and planets."

"The statement said the material the telescope sees around Vega "could be comparable in mass to all the nine planets and other matter in our solar system, excluding our sun."

While the telescope is sensitive to dust, it cannot resolve, or "see," the mass of particles around Vega precisely enough to distinguish between them. All it sees is a ring of particles, not individual bodies. The backshot-sized particles men-

See VEGA, A1, Col. 1

Detected material ("dust") would be destroyed on time scales much shorter than the age of Vega -- thus the material must be "2nd generation", not primordial !!

Backman

BTS-31

From the Vega Phenomena to ExoPlanets



The Washington Post
 WEDNESDAY, AUGUST 10, 1983

VIOLENCE IN ULSTER

New Evidence of Other Worlds
Satellite Discovers Possible Second Solar System

By Thomas H. O'Keefe

A satellite carrying an infrared telescope has discovered streams of larger particles around the star Vega, and so others say they think the picture is not so bleak as it once was. The discovery is a first step toward a possible second solar system, it is the first evidence that the universe contains a second solar system, says the scientist.

Through scientific, basic research for years that the Earth and its eight major planets are not alone in the cosmos, they have never had evidence that their conditions were unique.

The discovery provides the first direct evidence that solid objects of substantial size exist around a star other than the sun, said a statement yesterday from the Jet Propulsion Laboratory in Pasadena, where the infrared astronomical satellite IRAS's pictures are analyzed.

"The infrared could be a solar system in a different stage of development than our own," the statement said. Vega is a young star only 1 billion years old. The Earth's sun is almost 5 billion years old.

Nevertheless, Vega is similar to the sun. Its surface temperature has been measured at 10,000 degrees, about the same as the sun. This suggests that though it is younger, Vega may be undergoing the same kind of evolution that took our solar system through a billion-year era. Among the bodies in evolution around Vega could be even the equivalent of our Earth.

What the IRAS satellite has seen here after five years is that the Earth last January is that Vega has appeared "much brighter and larger in infrared light" than any other similar star the satellite has observed. "Despite" says the statement, "the fact that Vega is so bright, it is not a star, it is a star."

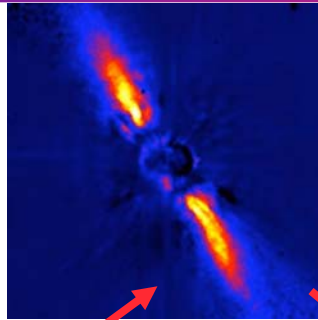
Further investigation showed that the bodies orbiting Vega had temperatures measured by the infrared telescope at about 200 degrees below zero Fahrenheit. This is far above the temperature of empty interstellar space, and approximates the temperature of the inner rings of Saturn.

The telescope on IRAS has no way of counting the number of bodies in orbit around Vega or even of estimating their size. For that, it depends on how bright they are. The particles could range from boulders to the size of asteroids and planets.

The statement said the material the telescope saw around Vega "could be responsible in mass for all the inner planets and other matter in our solar system, including our own."

While the telescope is unable to tell, it can not measure the "size" of the particles around Vega, precisely enough to distinguish between them. All it sees is a ring of particles, not individual bodies. The bunched-up particles mean-

See VEGA, A04C1



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ASYMMETRIES IN THE BETA PICTORIS DUST DISK

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ABSTRACT

Five types of asymmetry are identified and measured in the circumstellar dust disk of Beta Pictoris using new K -band coronagraphic data. Models of axisymmetric dust disks show that the observed tilt of the midplane may result from a small inclination of the disk to our line of sight combined with a nonisotropic scattering phase function. The remaining four asymmetries indicate a nonaxisymmetric distribution of orbiting dust particles between 150 and 800 AU projected radius. The disk may have been gravitationally perturbed in the past 10^3 – 10^4 yr, though a perturbing agent has not been detected. The statistical probability of a stellar close-approach is very small and no field stars have been uniquely identified as having passed near Beta Pictoris recently. Planets are unlikely candidates due to the large scale of the asymmetries, while a brown dwarf search has yielded negative results. © 1995 American Astronomical Society.

A Jupiter-mass companion to a solar-type star

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The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

A planetary system as the origin of structure in Fomalhaut's dust belt

Paul Kalas¹, James R. Graham¹ & Mark Clampin²

Some of the IRAS Scientists



A Few of the Unsung Heroes



The IRAS Scientific Legacy



- ◆ Infrared Bright Galaxies are an important population in the local Universe
 - ▶ *>3/4 of star formation in the universe is obscured by dust and its luminosity emerges in the infrared*
- ◆ IR Cirrus is important in our galaxy and in nearby galaxies, 12 μ m emission is much brighter than expected
 - ▶ *PAH emission is ubiquitous in environments from the Milky Way to galaxies at $z \sim 3$*
- ◆ IRAS identified newly formed/forming stars
 - ▶ *The current paradigm emerged from IRAS and we are now exploring in detail how stars form*
- ◆ Planetary Debris disks found in the Fabulous 4
 - ▶ *Debris disks are shaped by the presence of planets; their composition, structure and evolution is being traced*

The Infrared Universe Viewed by IRAS

