The *Spitzer* Space Telescope: Last of the Great Observatories

Rolf Jansen

Based mostly on:

- Werner, M.W., et al. 2004, ApJS 154, 1 — *Spitzer* mission
- Fazio, G.G., et al. 2004, ApJS 154, 10 — IRAC instrument
- Houck, J.R., et al. 2004, ApJS 154, 18 — IRS instrument
- Rieke, G.H., et al. 2004, ApJS 154, 25 — MIPS instrument

with additional information and graphics from:

— NASA Facts, *Spitzer* Space Telescope — factsheet
— Spitzer web-pages at: *http://ssc.spitzer.caltech.edu*

Outline

- What?
- Why?
- When?
- How?
- What?
- What?
- How?
- Wow!

Outline

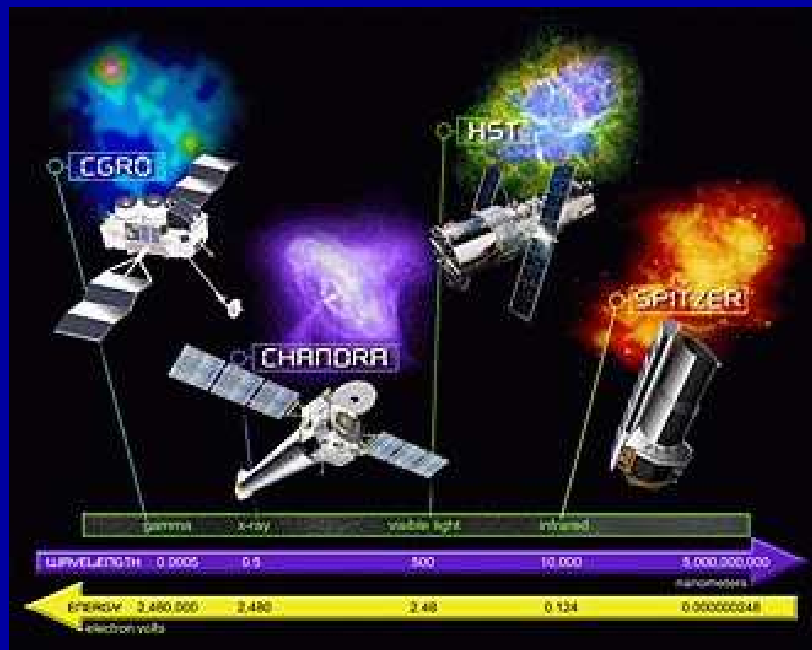
- **What — is NASA's orbiting Great Observatories program?**
- **Why — do we need coverage at multiple wavelengths, from space?**
- **When — or a bit of history of the field, particularly IRAS**
- **How — does *Spitzer* differ from IRAS?**
- **What — is *Spitzer* contributing?**
- **What — instruments does *Spitzer* contain?**
- **How — do these perform?**
- **Wow — pretty pics!**

NASA's orbiting Great Observatories program



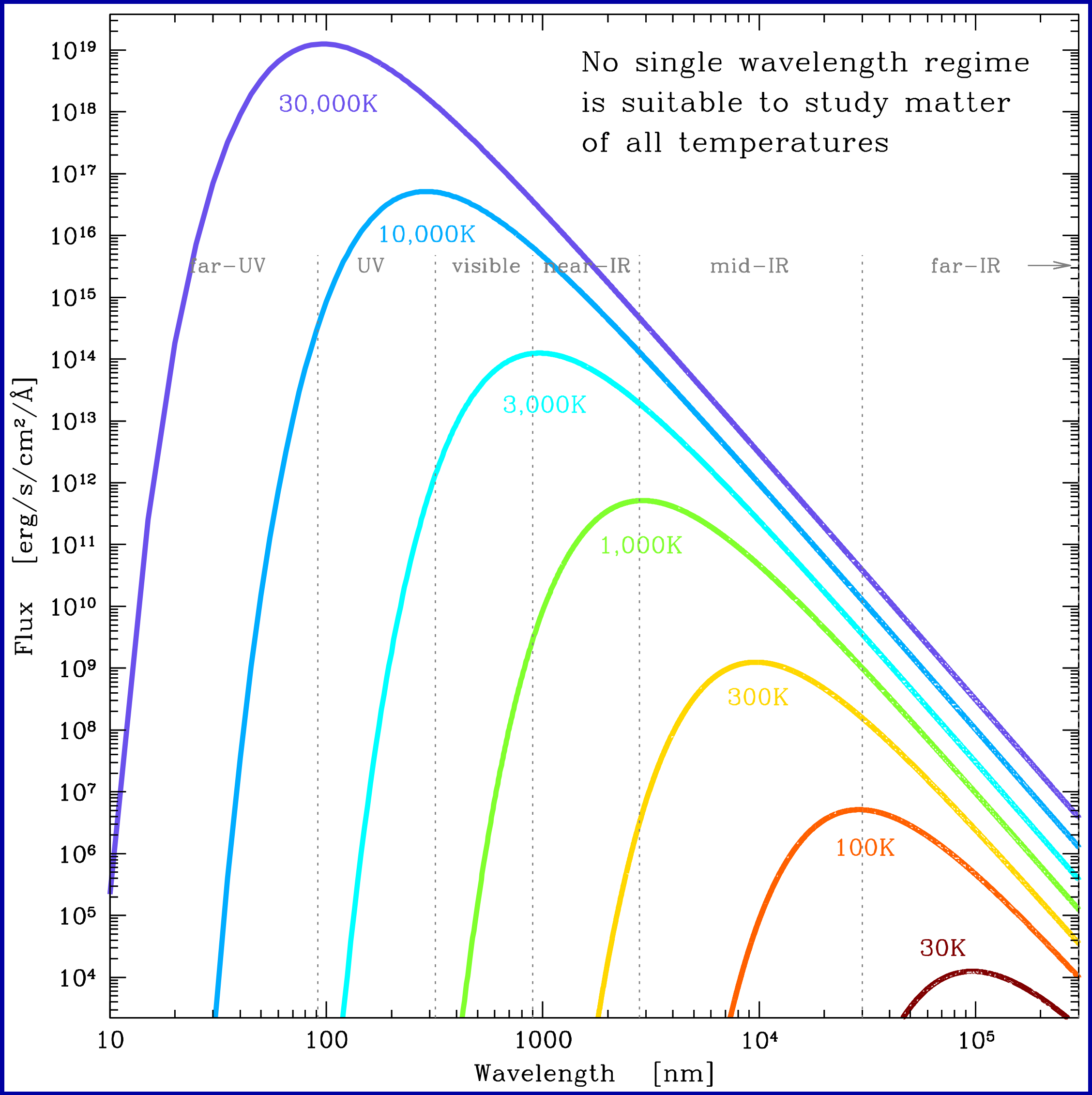

- Four observatories, each accessing different wavelength regime
  - *Hubble* Space Telescope (*HST*): UV–optical–near-IR
  - *Compton* Gamma-Ray Observatory (*CGRO*): γ-rays
  - *Chandra* X-ray Observatory (*Chandra*): X-rays
  - *Spitzer* Space Telescope (*Spitzer*): mid-IR–far-IR

NASA's orbiting Great Observatories program

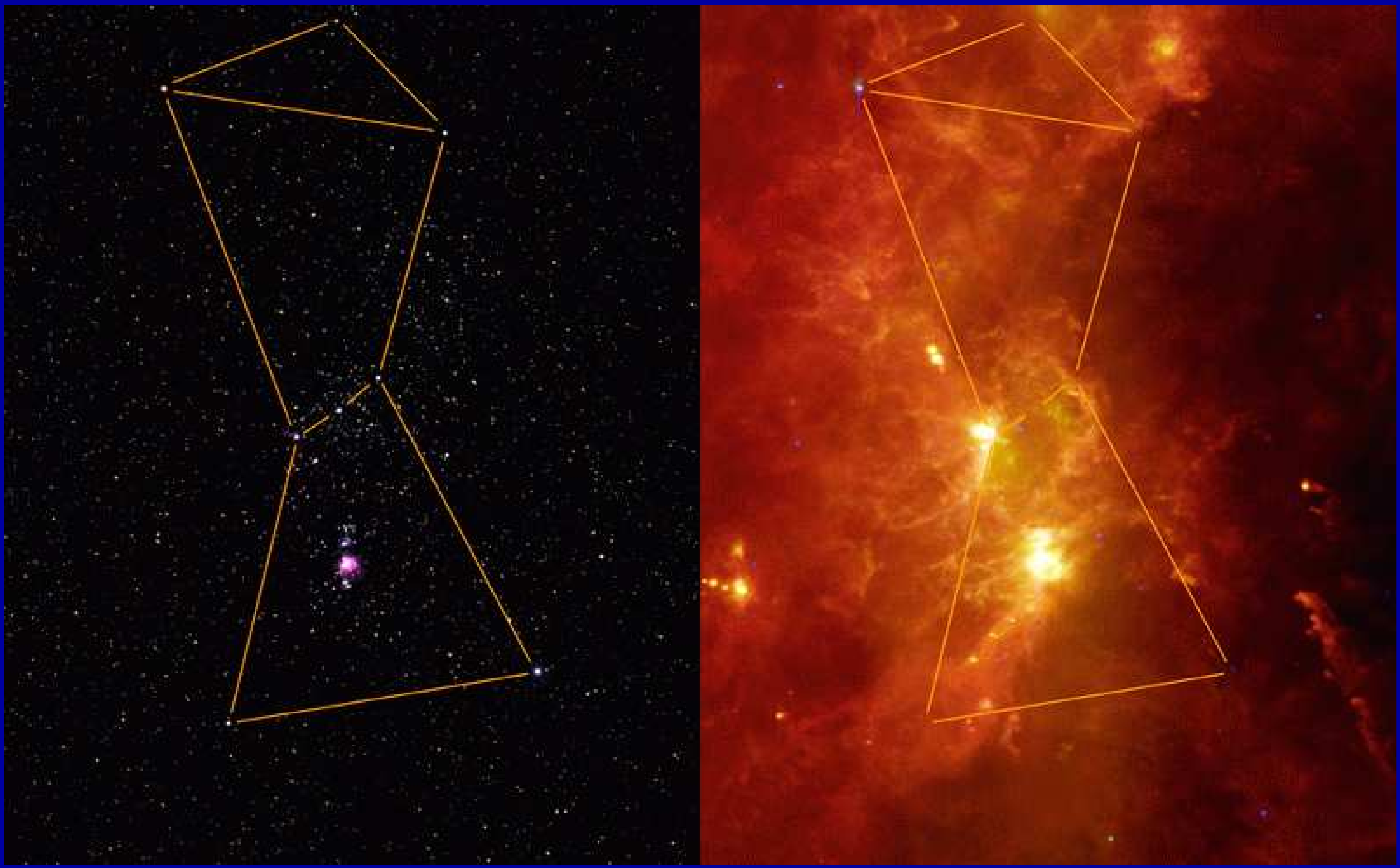


- Overlap between operational mission life: expected *synergy*
  - *HST*: 1990–present
  - *CGRO*: 1991–1999 (de-orbited)
  - *Chandra*: 1999–present
  - *Spitzer*: cold mission 2003–2009, warm mission 2009–??

Why multiple wavelengths?

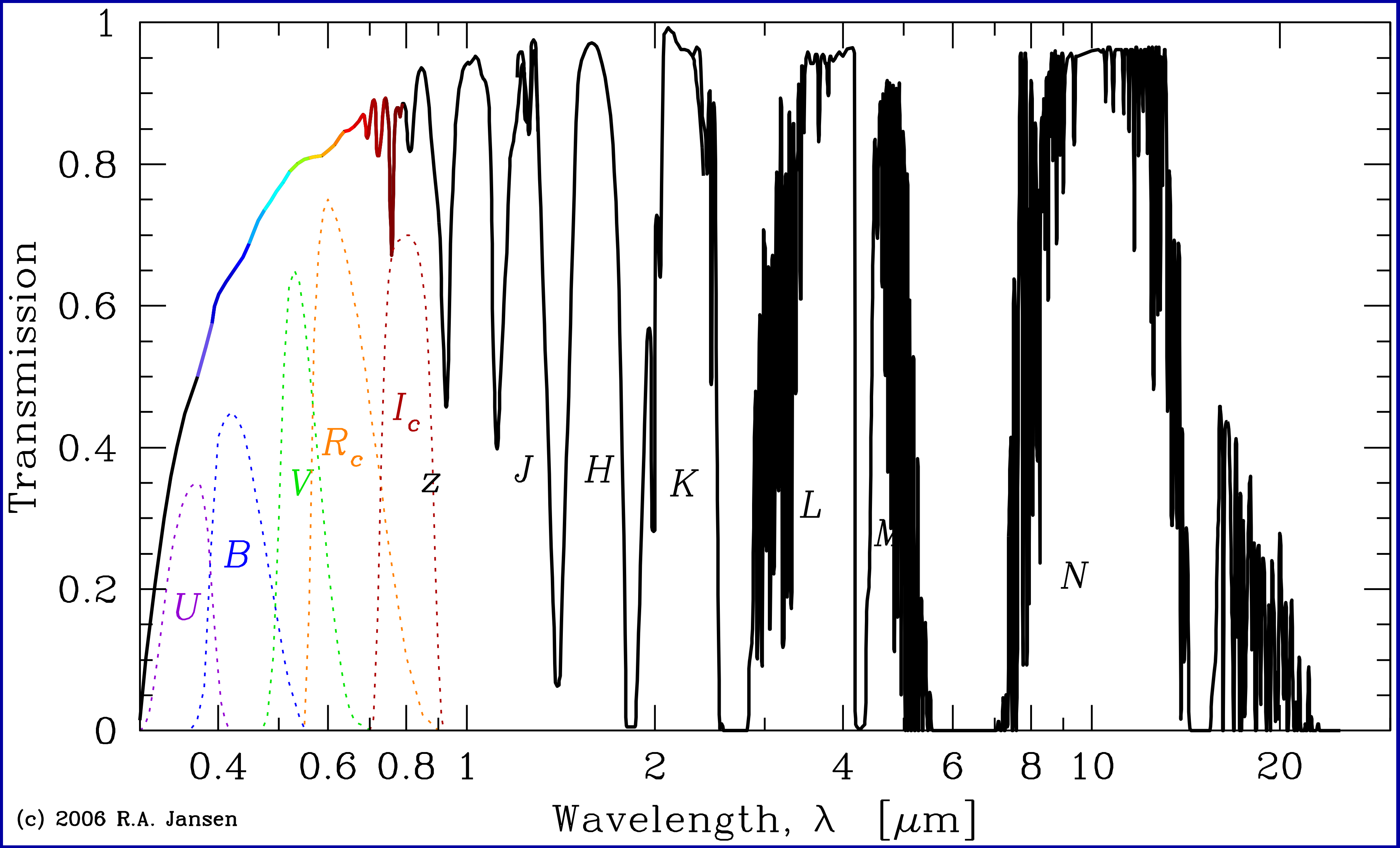


Why multiple wavelengths?

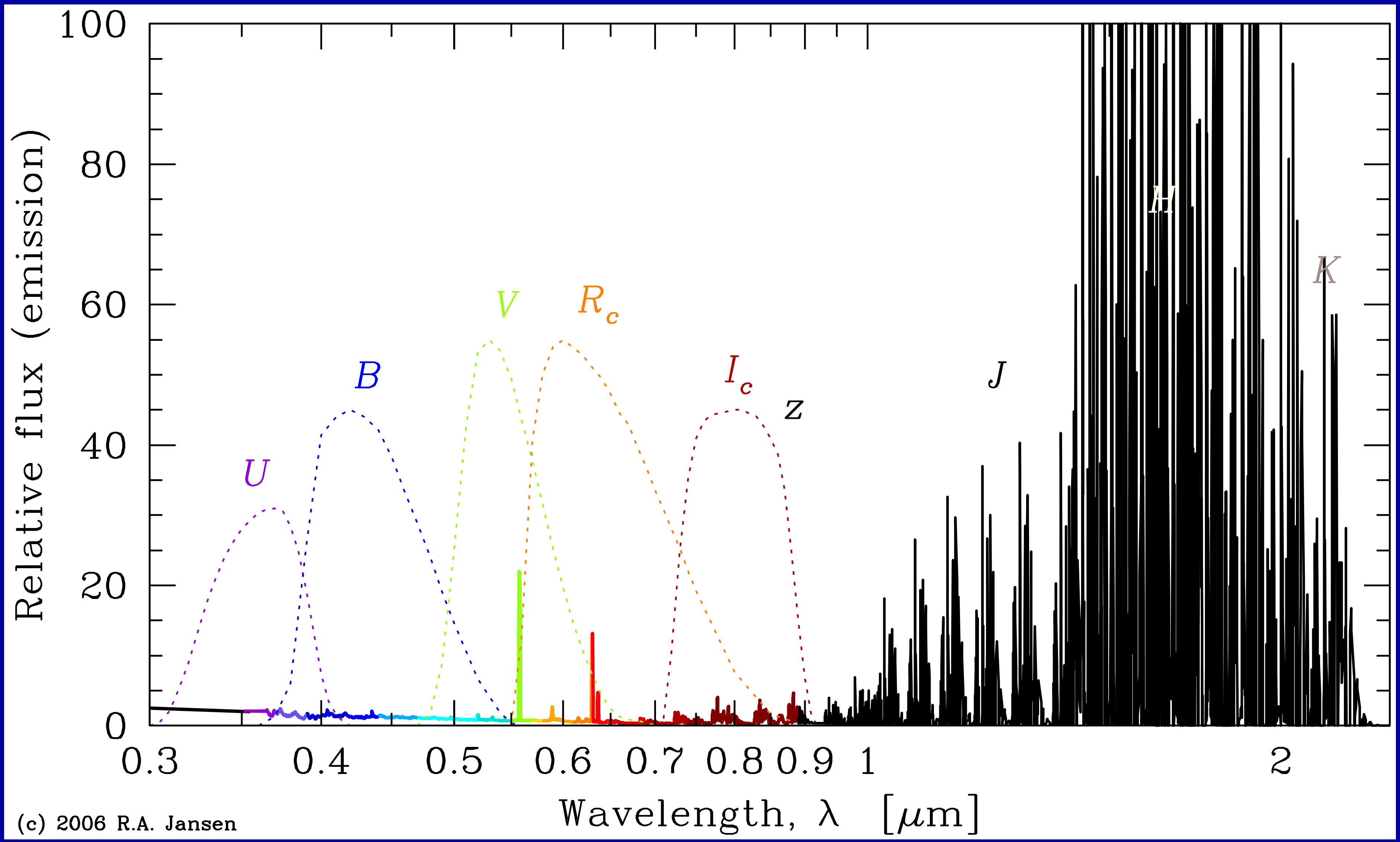


Ground-based visual and IRAS infrared images of Orion

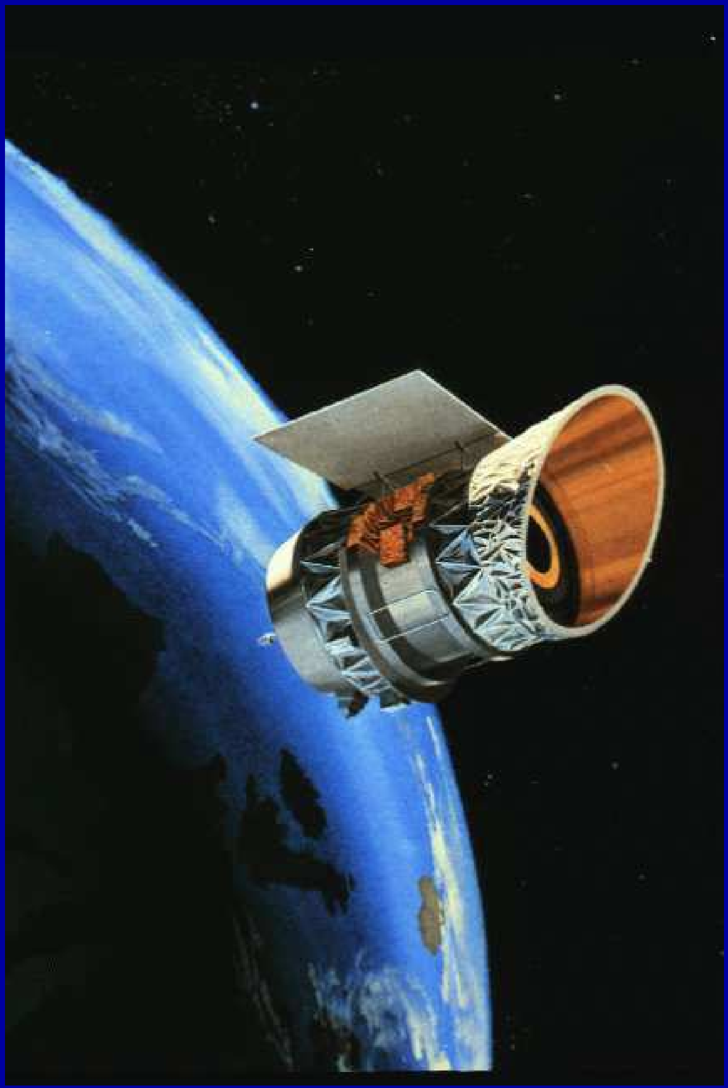
Why not from the ground?

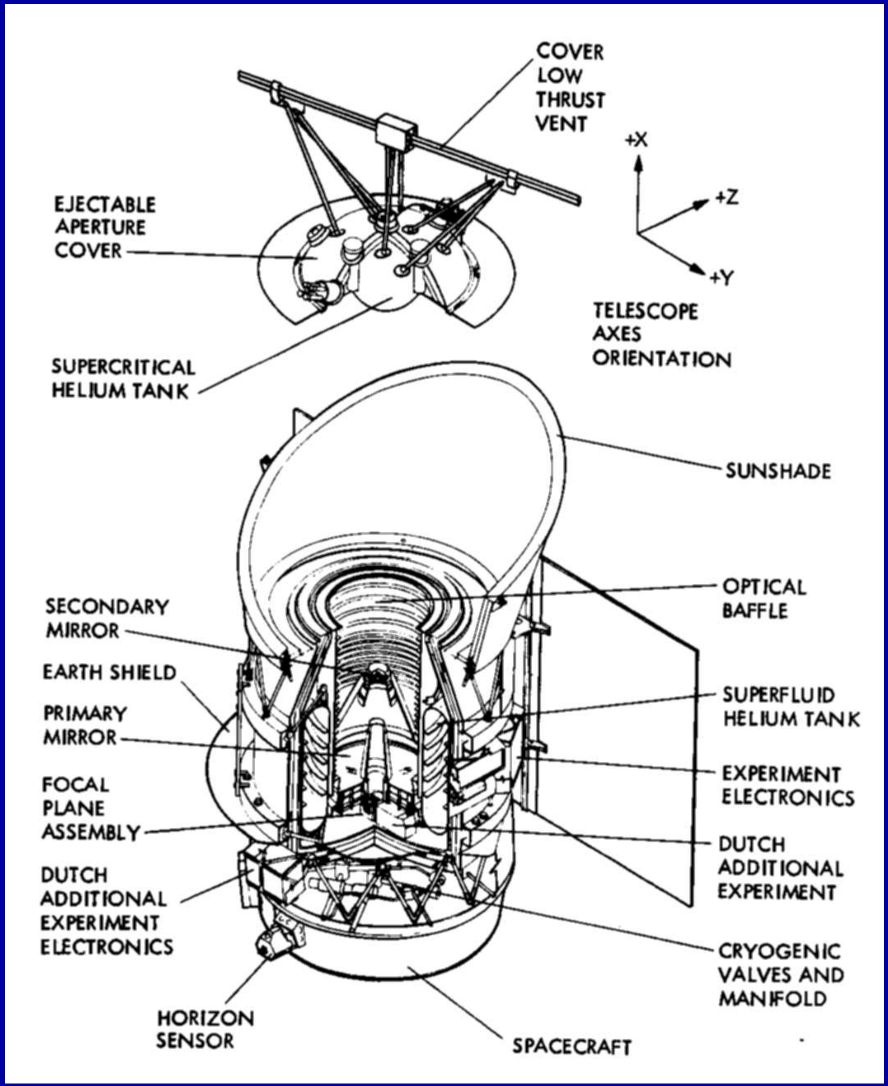


Why not from the ground?



A bit of history: the InfraRed Astronomical Satellite





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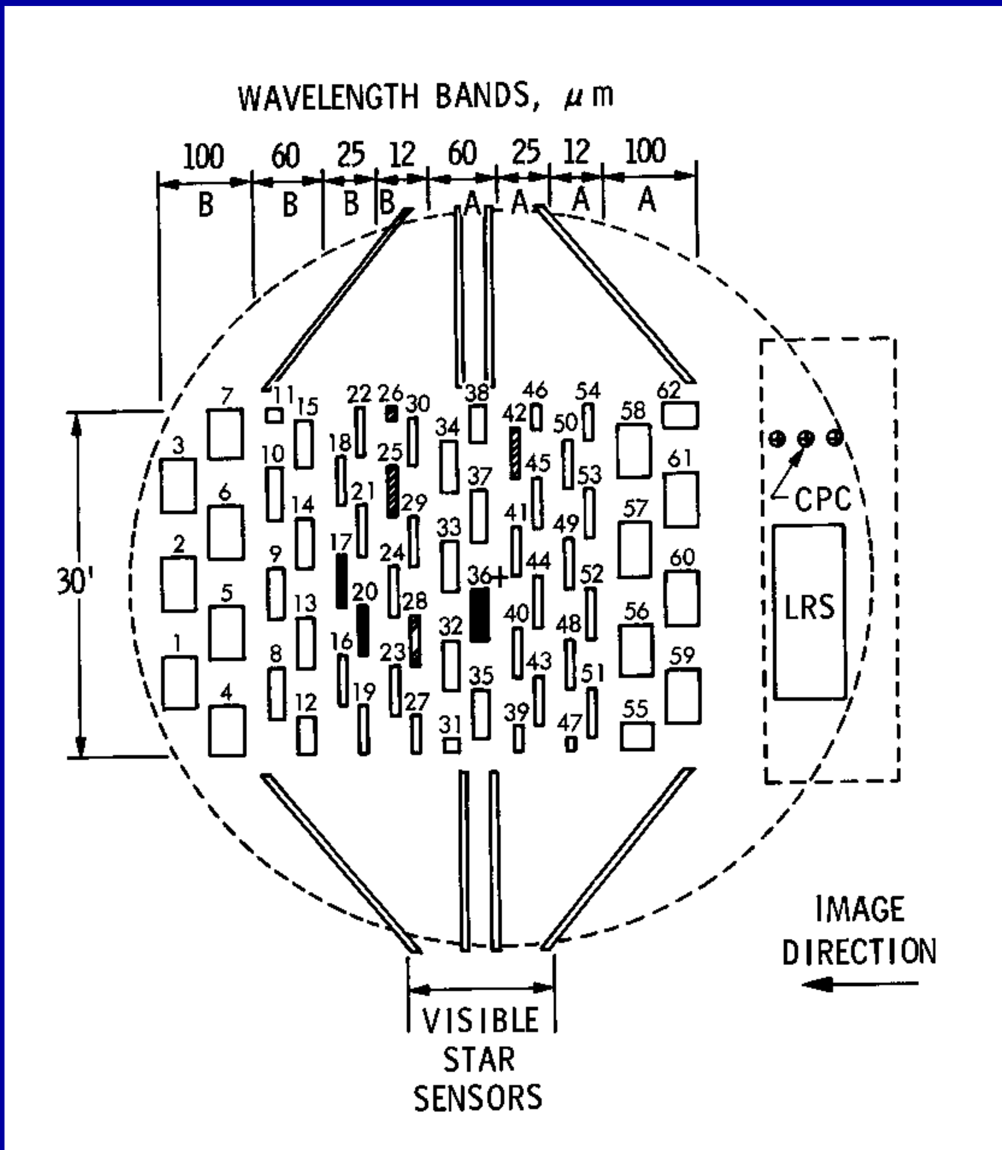
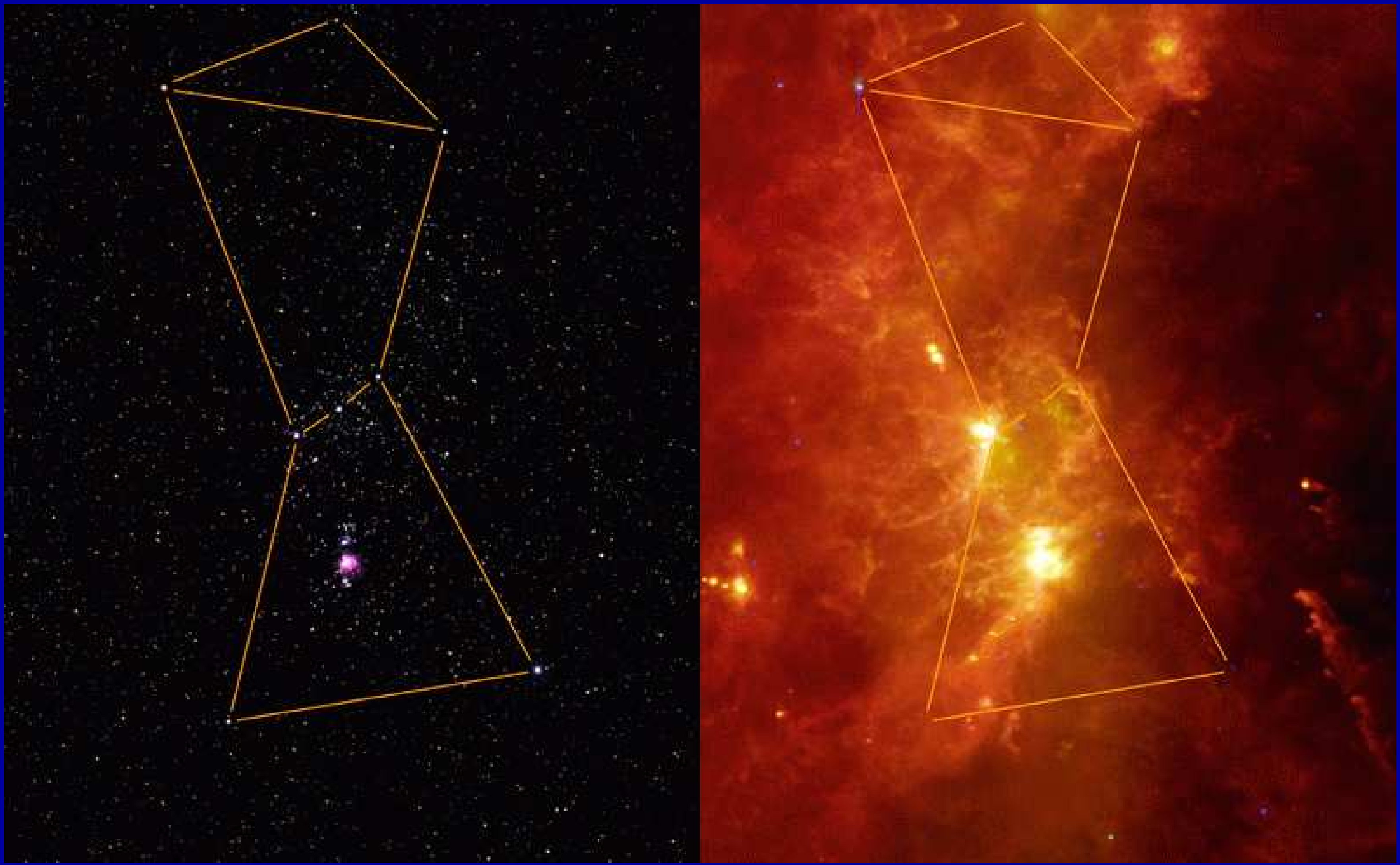


- 0.60 m telescope
- 12, 25, 60, and 100 μm
- all-sky, driftscan survey
- discovered:
  - Ultra-Luminous InfraRed Galaxies (ULIRGs);
  - embedded starclusters;
  - IR-cirrus (WHIM)
- discrete detectors, not 2D arrays
- no pointed observations
- detector-limited resolution
- cold launch, low earth orbit:
  - only 10-mon mission life

A bit of history: the InfraRed Astronomical Satellite



Ground-based visual and IRAS infrared images of Orion

The *Spitzer* Space Telescope

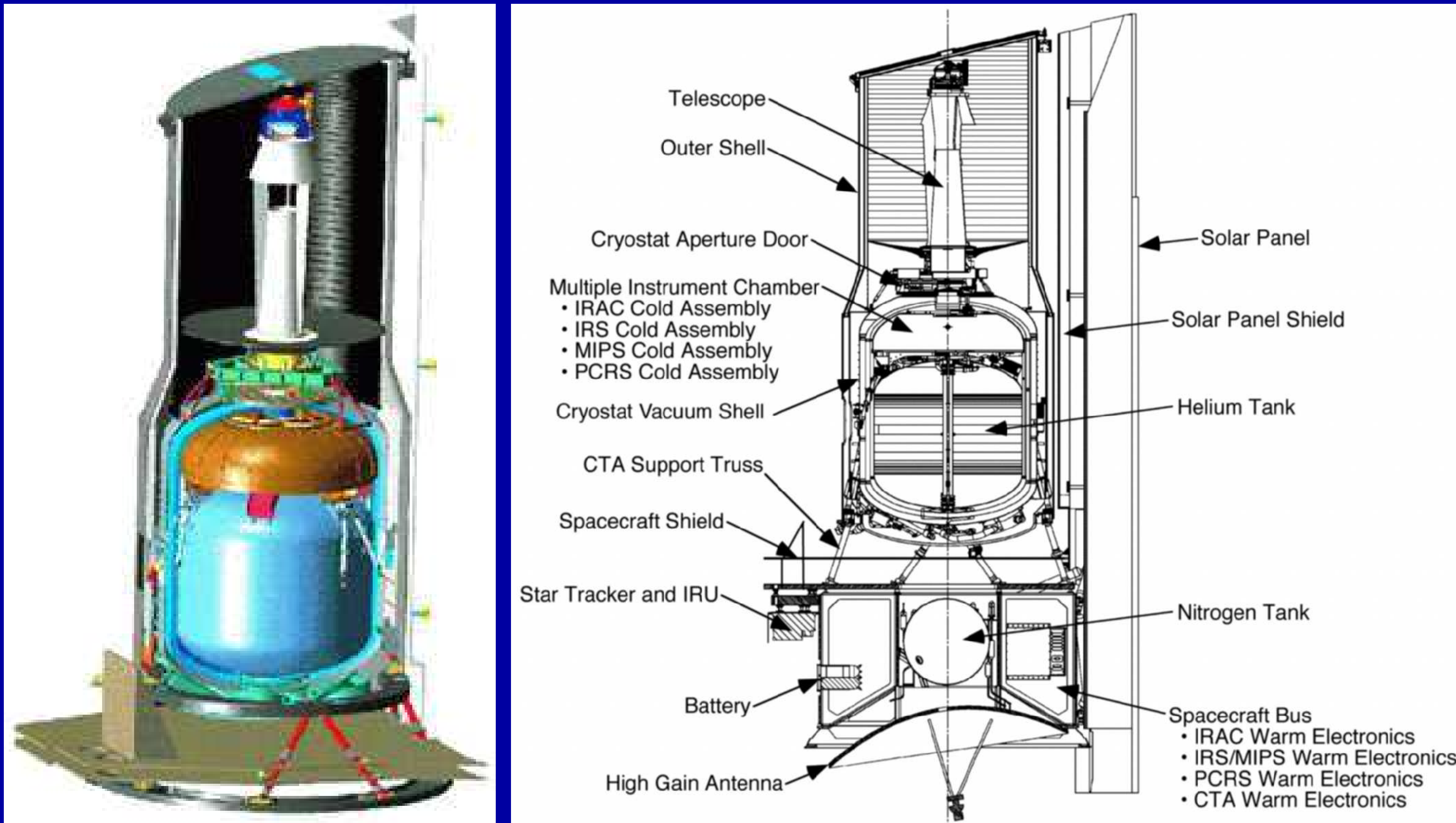


Fig. 1. — Cutaway view of the *Spitzer* flight hardware. The observatory is approximately 4.5 m high and 2.1 m in diameter. The dust cover is shown prior to its ejection approximately 5 days after launch.

The *Spitzer* Space Telescope

TABLE 1

Top-Level Observatory Parameters

Parameter	Value
Total Observatory mass at launch	861 kg
Dimensions (height × diameter)	4.5 m × 2.1 m
Average operating power	375 W
Solar array generating capacity at launch	500 W
Nitrogen reaction control gas at launch	15.59 kg
Estimated reaction control gas lifetime	17 yr
Mass memory capacity	2 Gbytes
Telescope primary diameter	0.85 m
Telescope central obscuration	14.2%
Superfluid helium at launch	337 l
Estimated nominal cryogenic lifetime	5.3 yr
Data transmission rate (high-gain antenna up to 0.58 AU from Earth)	2.2 Mb s^{-1}
Command communication rate	2 kbps

The *Spitzer* Space Telescope

Spitzer **satellite design:**

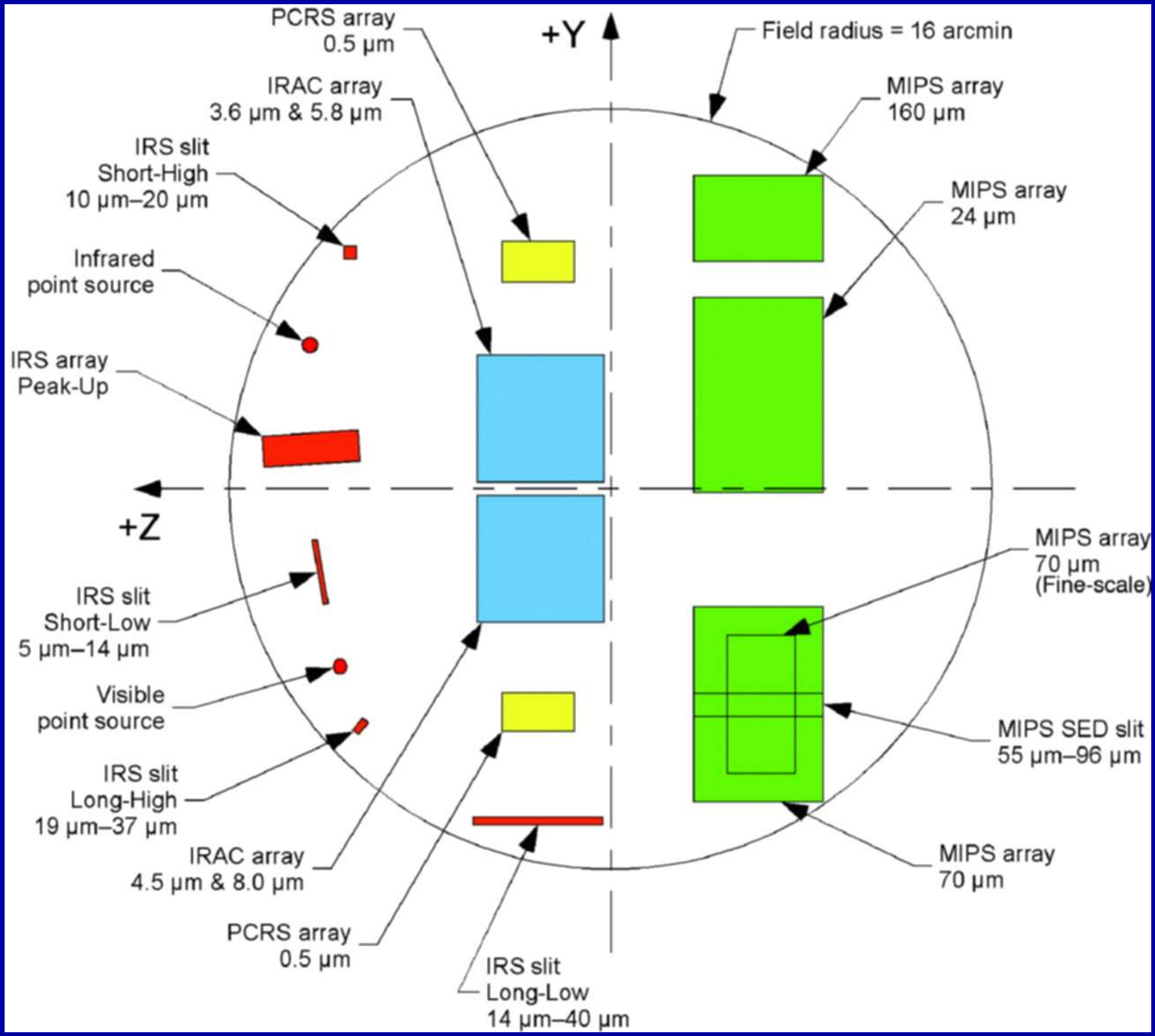
- **Spacecraft; operates at ambient temperature**
  - **observatory's power generation**
  - **Pointing and momentum Control System (PCS: reaction wheels, gyroscopes, star trackers, and Reaction Control System)**
  - **data processing and storage**
  - **telecommunications**
  - **warm electronics portions of instruments**
- **Cryogenic Telescope Assembly; cooled to 5.6 K for MIPS 160μm**
  - **telescope assembly**
  - **Multiple Instrument Chamber with cryogenic portions of science instruments and PCRS**
  - **superfluid helium dewar**
  - **thermal shields**

The *Spitzer* Space Telescope

Spitzer innovations:

- Warm launch: most of mass of CTA is external to cryostat and is warm at launch
  - far less helium needed for longer mission life
  - lower launch mass
- passively (radiatively) cool telescope in orbit to ∼30 K
- use helium boil-off vapor to further cool telescope assembly to 5.6 K
  - *cool* as needed via small adjustable *heater* in the helium bath
- Earth drift-away solar orbit:
  - benign thermal environment
  - avoid transits of Earth's radiation belts (SAA)
  - good observing efficiency (no obscuration by Earth or Moon)
  - distance increases by 0.12 AU/yr affecting data transmission rate and, eventually, observing efficiency

Spitzer's Focal Plane



Spitzer's Science Instruments

- InfraRed Array Camera (IRAC) — 4-channel infrared imager
- InfraRed Spectrograph (IRS) — low-/moderate-res spectrometer
- Multiband Infrared Photometer for Spitzer (MIPS) — far-IR imager and spectral energy distribution photometer

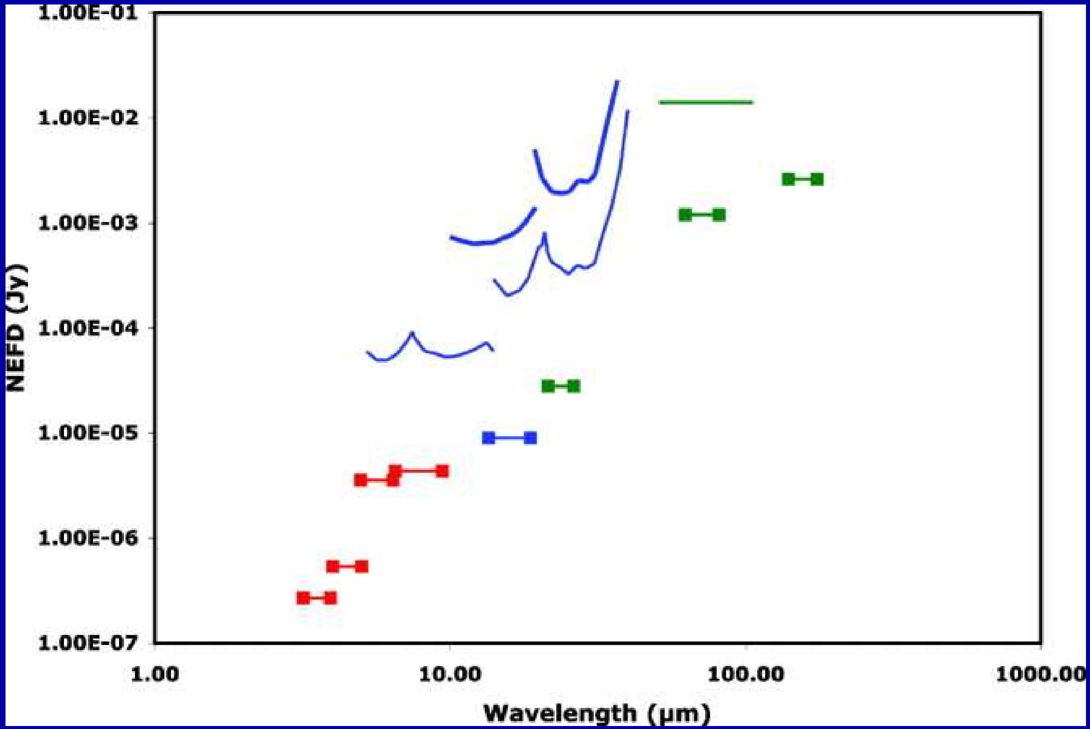


Fig. 3.— Point-source sensitivity and wavelength coverage of the *Spitzer* science instruments.

The InfraRed Array Camera (IRAC)

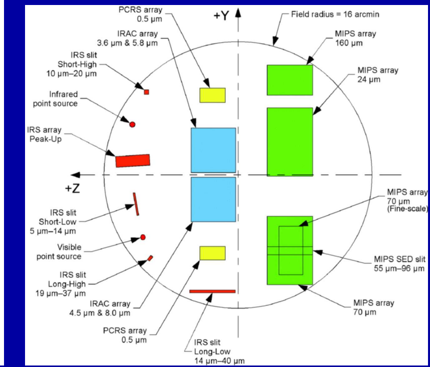
- 4-channel imager: 3.6, 4.5, 5.8, and 8.0 μm
- channels 1 and 3, and channels 2 and 4 have identical FoV
- true 2D detector arrays
- critical sampling of the effective PSF

TABLE 2

INFRARED ARRAY CAMERA (IRAC): FOUR-CHANNEL INFRARED IMAGER

Channel	Wavelength (μm)	Field of View (arcmin)	Detector
1......................	3.19–3.94	5.2 × 5.2	256 × 256 InSb
2......................	4.00–5.02	5.2 × 5.2	256 × 256 InSb
3......................	4.98–6.41	5.2 × 5.2	256 × 256 Si:As
4......................	6.45–9.34	5.2 × 5.2	256 × 256 Si:As

NOTE.—PI: G. G. Fazio, Smithsonian Astrophysical Observatory; instrument built at NASA Goddard Space Flight Center.



The InfraRed Array Camera (IRAC)

Design reference science program:

- the early universe (high-z galaxies)
- brown dwarfs and super-planets
- active galactic nuclei
- protoplanetary and planetary debris disks

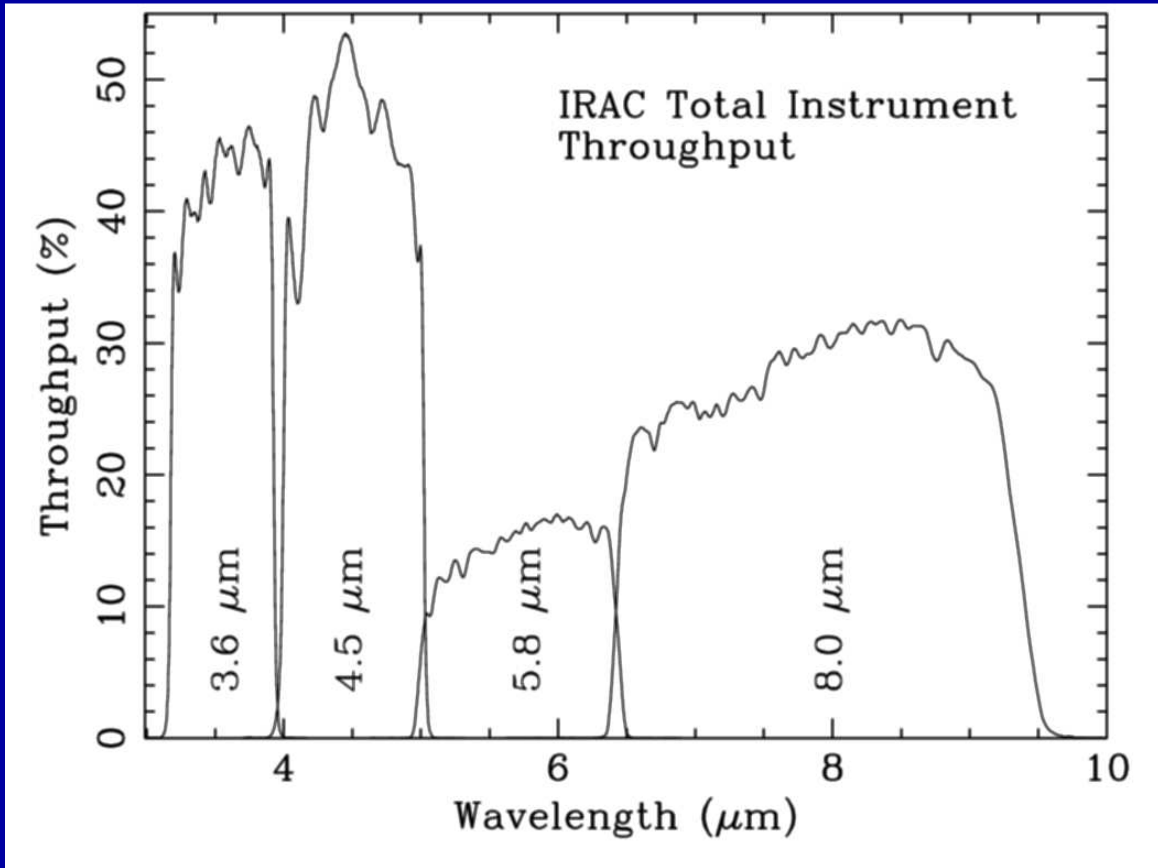


FIG. 3.—IRAC system total throughput, including transmission of the telescope, IRAC optics, and quantum efficiency of the detectors.

The InfraRed Array Camera (IRAC)

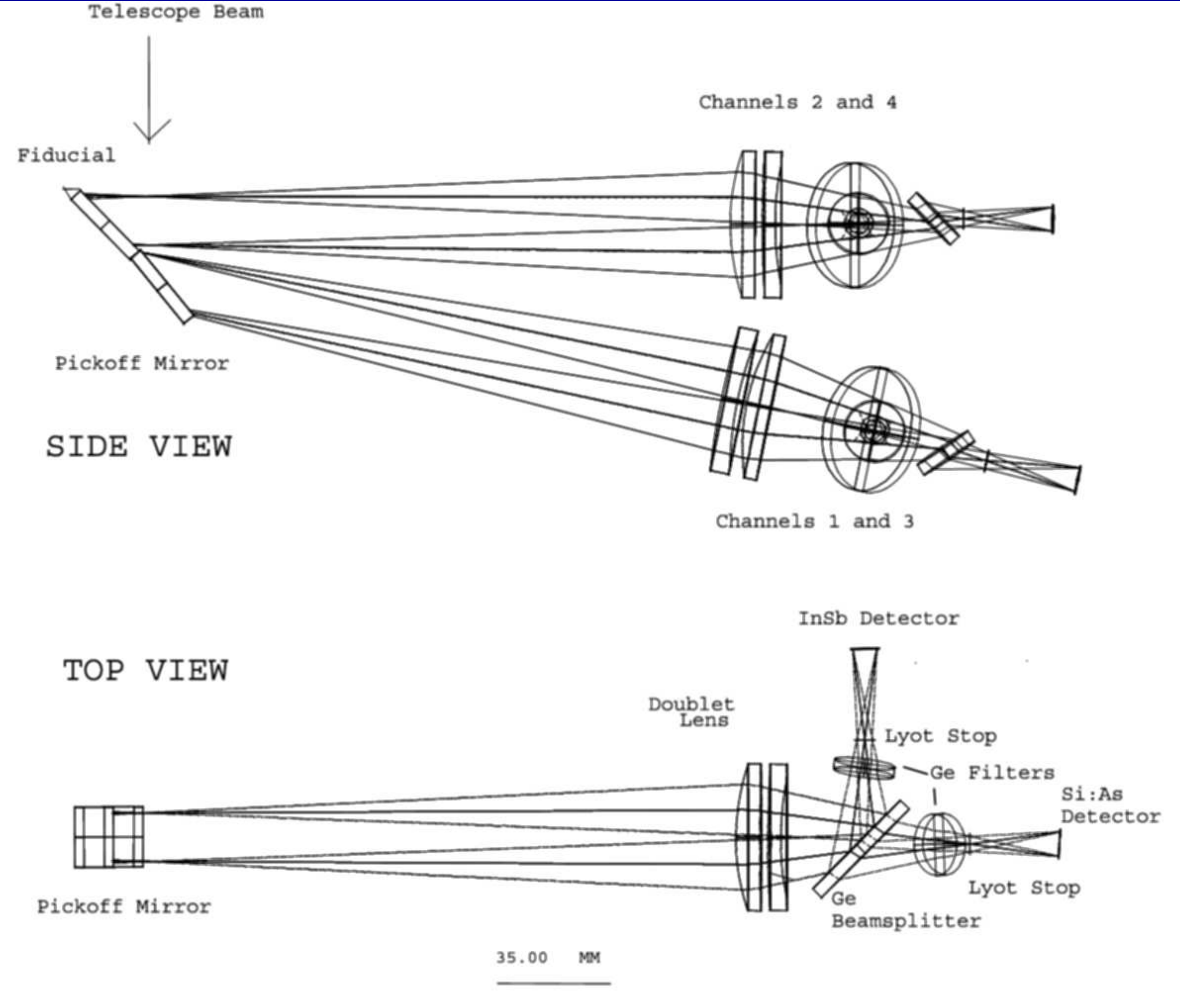


FIG. 2.—IRAC optical design, showing side view and top view.

The InfraRed Array Camera (IRAC)

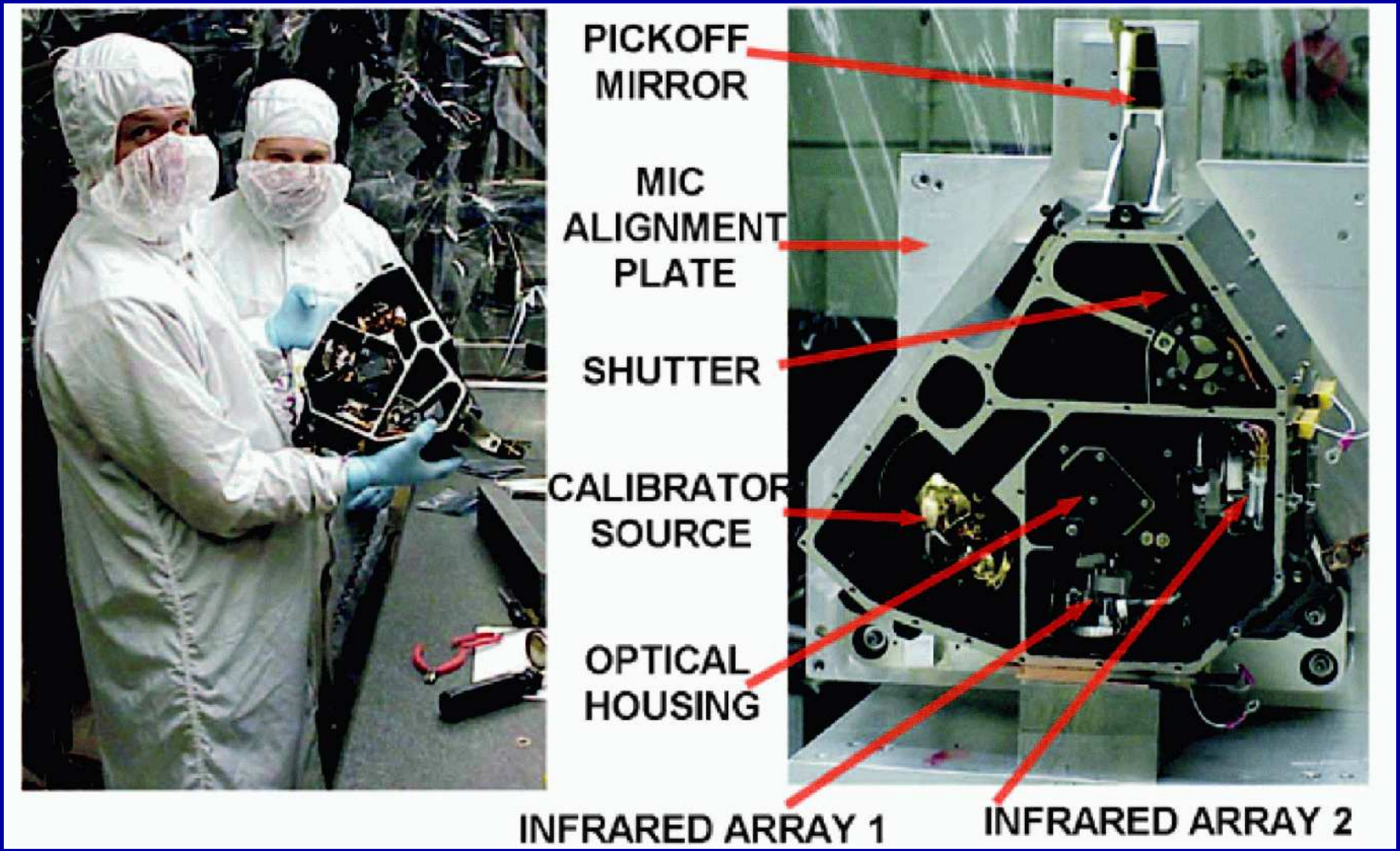
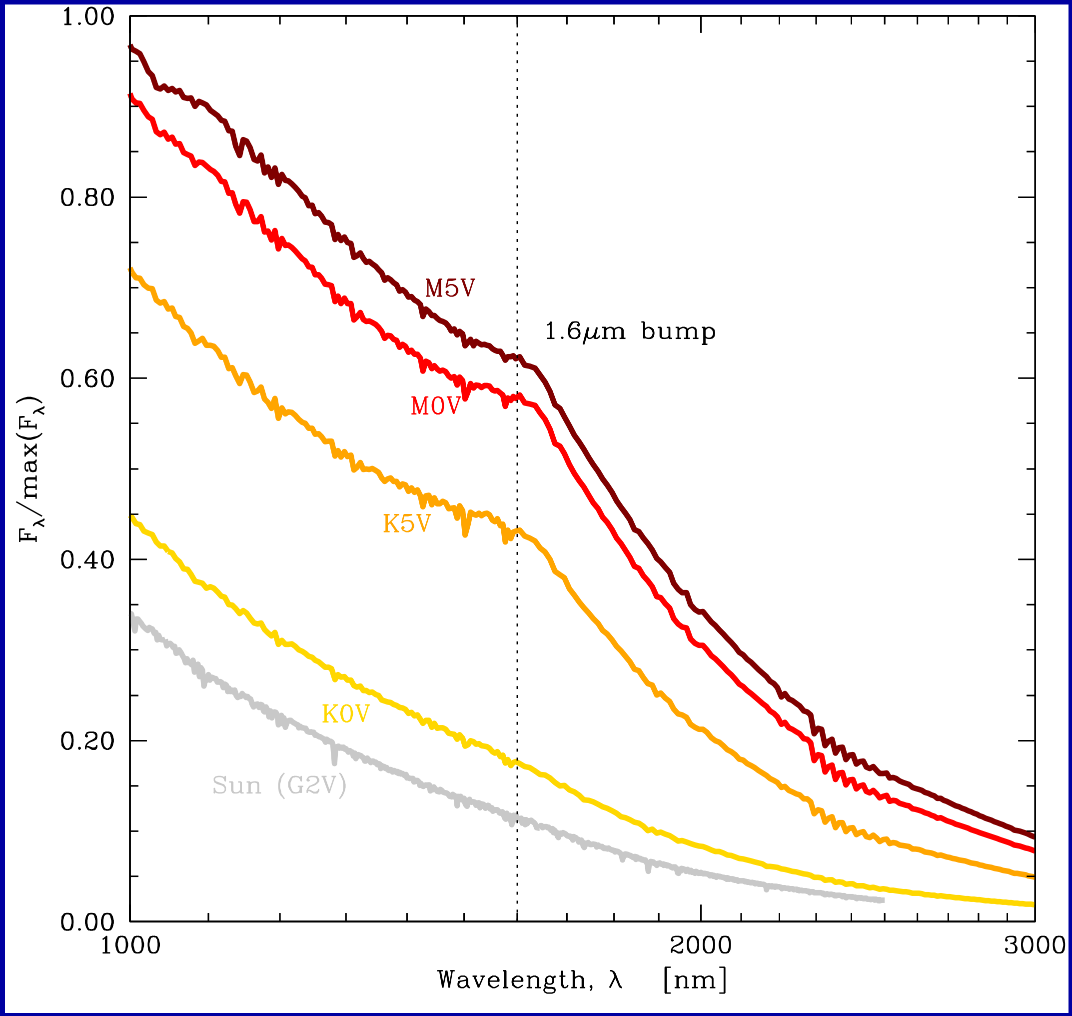


Fig. 1.— IRAC Cryogenic Assembly (CA) at NASA GSFC, with the top cover removed to show the inner components. The parts marked Infrared Array 1 and 2 are the IRAC channel 4 and 2 focal plane assemblies, respectively.

H^- opacity minimum at 1.6μm ???

Mentioned in Fazio et al. (2004) regarding motivation for IRAC wavelength range. Late-type stellar features are important contributors to the rest-frame near-IR light.



Critical sampling of PSF?

Theoretical highest angular resolution (PSF) delivered by the *Spitzer* telescope assembly:

$$\theta \sim 1.03 \cdot \frac{\lambda}{D} \quad \text{(PSF core)} \qquad \theta \sim 1.22 \cdot \frac{\lambda}{D} \quad \text{(FWHM)}$$

$$\left[\text{ radians} \longrightarrow \text{arcsec:} \quad \times \left(\frac{180}{\pi}\right) \cdot 3600 \;\sim\; 206,265 \right]$$

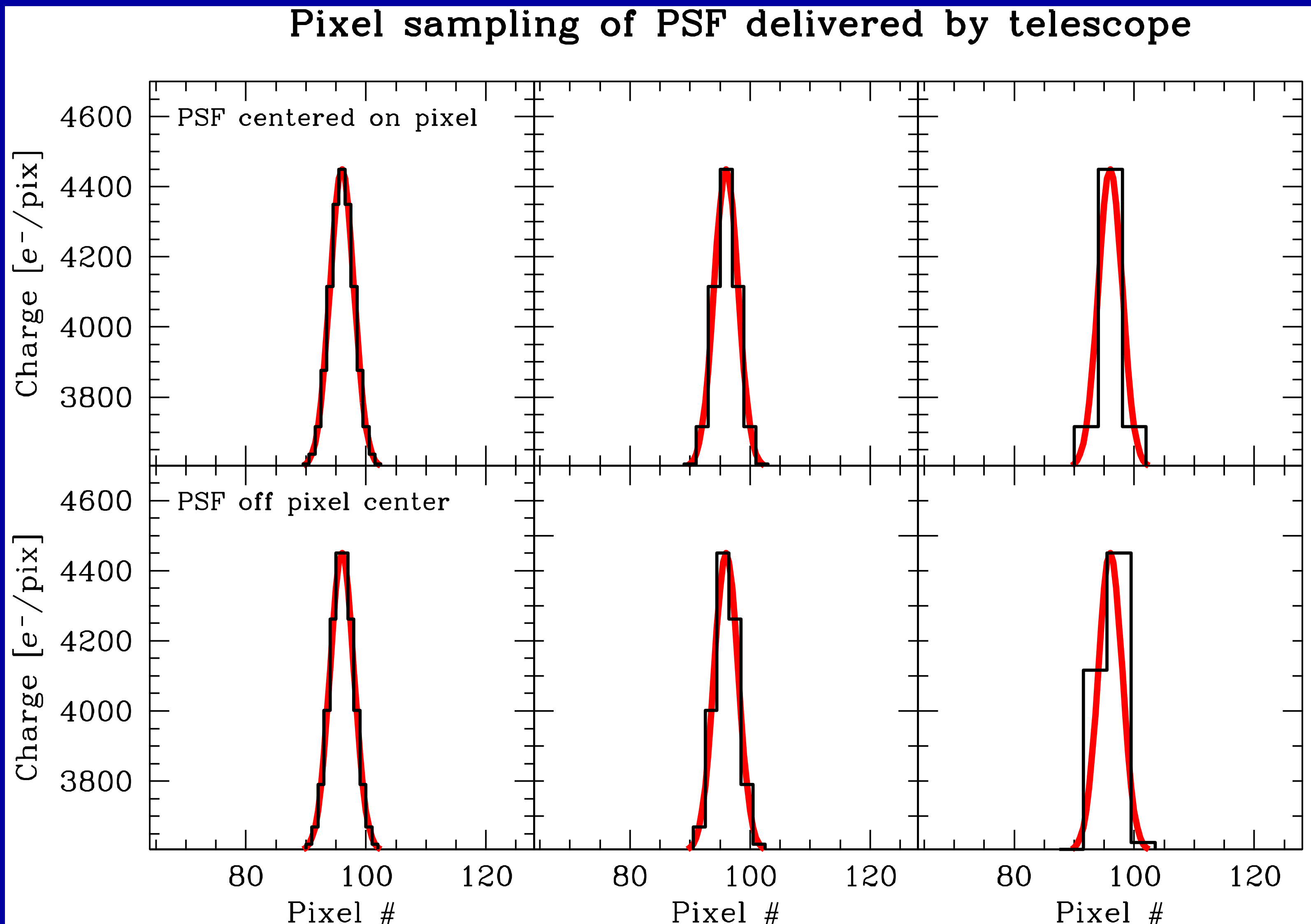
with $D = 0.85\,\mathrm{m}$ and $\lambda = 3.19$ (IRAC) – 174.5 (MIPS) μm:

$$\theta \sim 1.07'' \text{ at } 3.6\mu\text{m, and } \sim 48'' \text{ at } 160\mu\text{m}$$

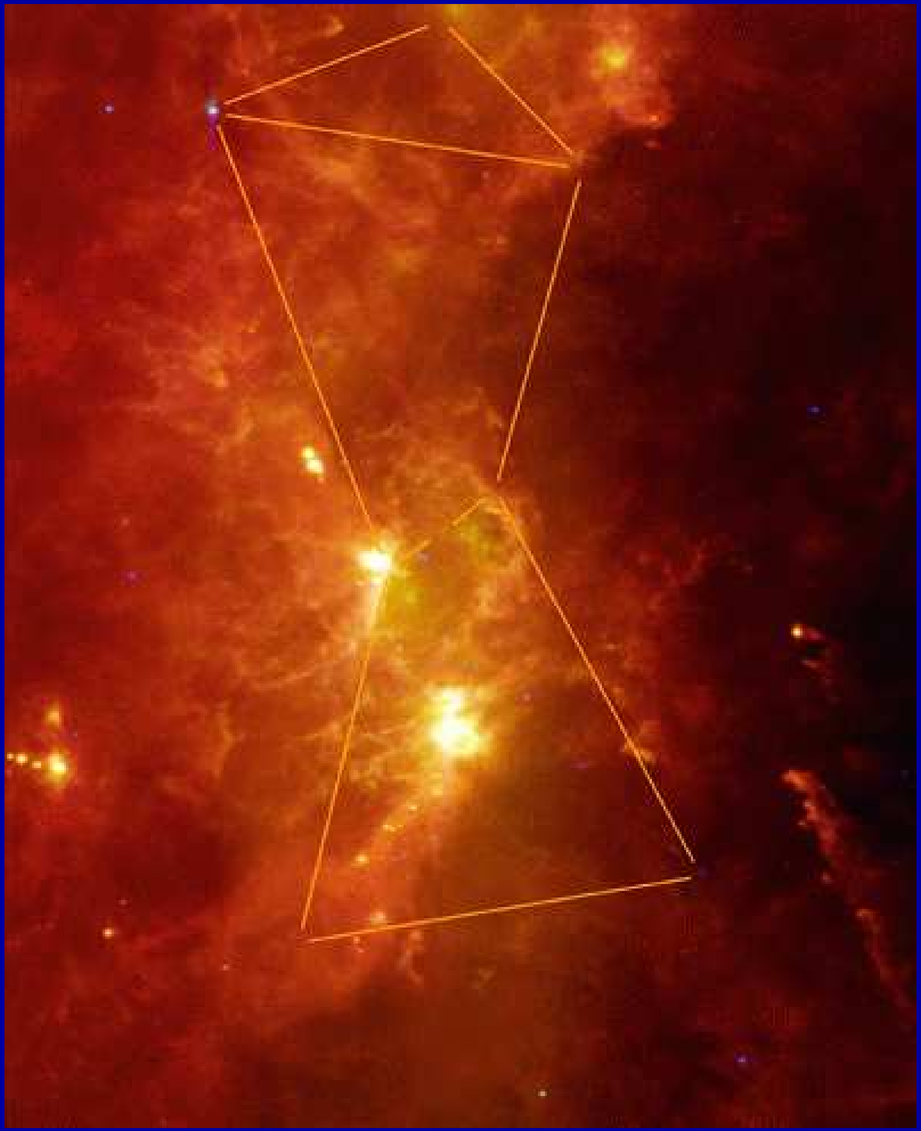
Telescope delivers diffraction limited performance only at $\lambda \geq 5.4\mu$m: $\theta \sim 1.6''$ at 3.6 μm

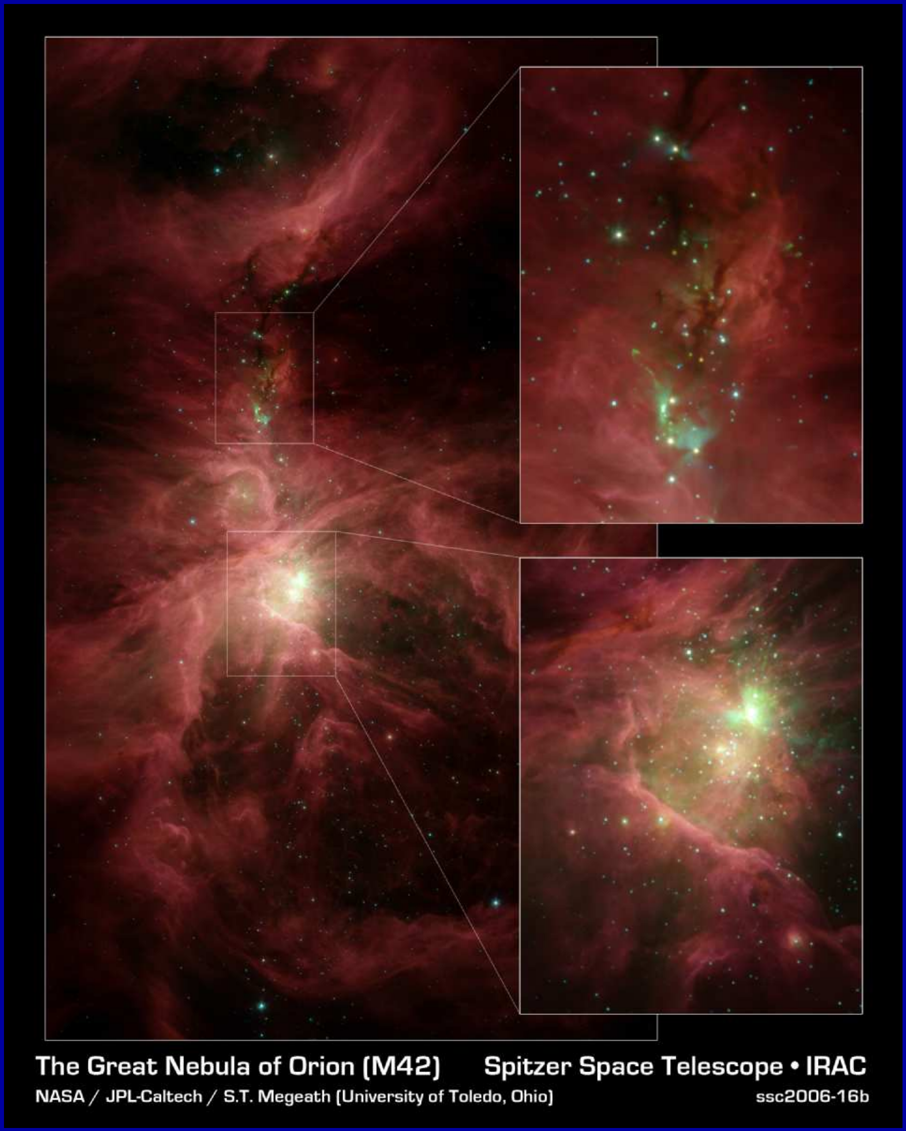
Signal theory (Nyquist): need $\gtrsim$2.3 pixels per FWHM to sample PSF without loss of information. Critical sampling: $\sim$2 pixels per FWHM.

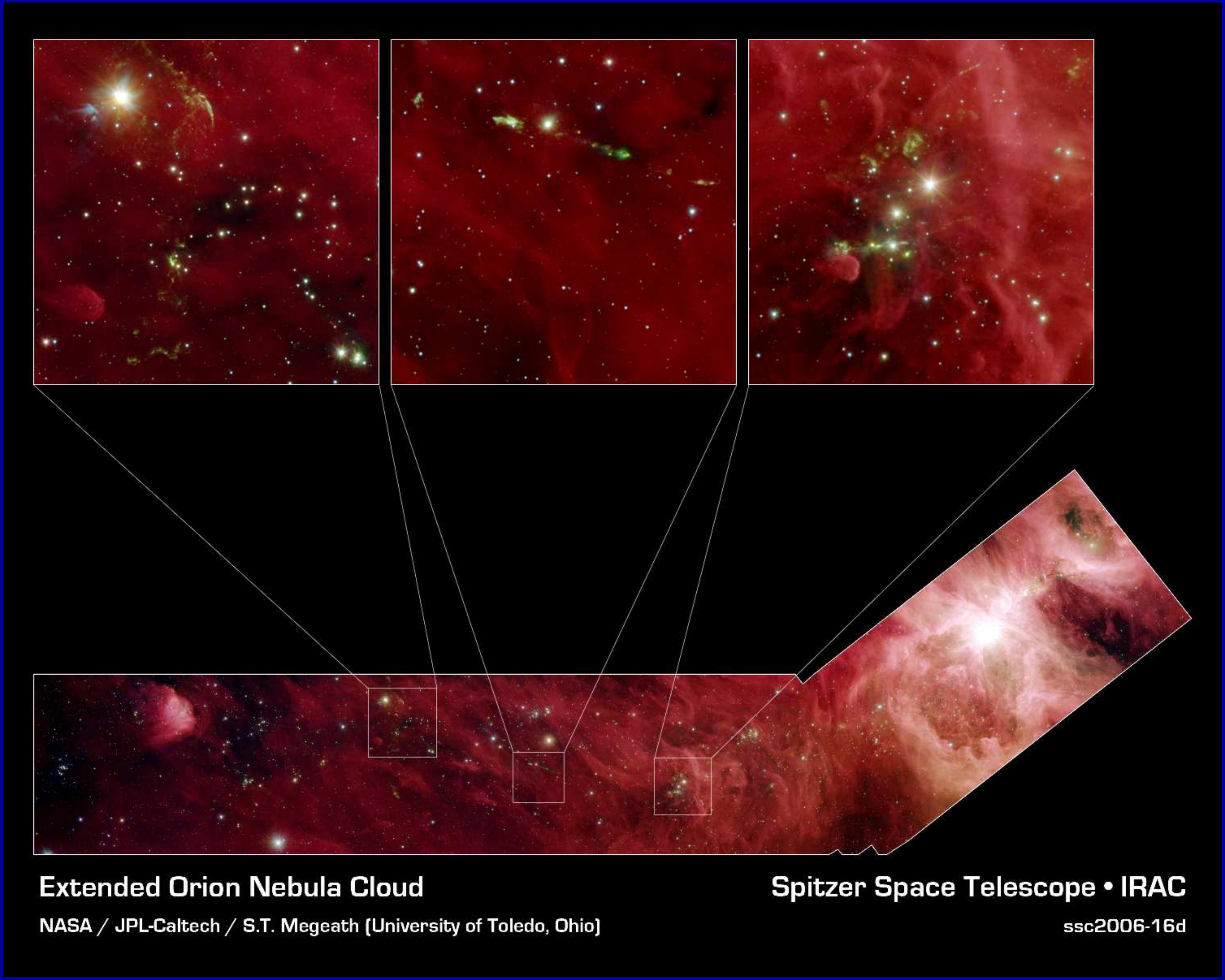
Critical sampling of PSF?



Spitzer versus IRAS






Extended Orion Nebula Cloud
NASA / JPL-Caltech / S.T. Megeath (University of Toledo, Ohio)
Spitzer Space Telescope • IRAC
ssc2006-16d

The InfraRed Spectrograph (IRS)

FIG. 1.—Infrared Spectrograph on *Spitzer*. The four IRS modules, SH, SL (which includes the peak-up cameras), LH, and LL are marked. A schematic of the location of the spectrograph slits on the *Spitzer* focal plane is presented in Fig. 2 of Werner et al. (2004).

The InfraRed Spectrograph (IRS)

TABLE 3

INFRARED SPECTROGRAPH (IRS): LOW- TO MODERATE-RESOLUTION SPECTROMETER

Module	Wavelength Range (μm)	Slit Dimensions (arcsec)	Spectral Resolution $\lambda/\Delta\lambda$
Short-Low	5.2–7.7, second-order	3.6 × 57	80–128
	7.4–14.5, first-order	3.7 × 57	64–128
Long-Low	14.0–21.3, second-order	10.5 × 168	80–128
	19.5–38.0, first-order	10.7 × 168	64–128
Short-High	9.9–19.6	4.7 × 11.3	~600
Long-High	18.7–37.2	11.1 × 22.3	~600
Peak-up array (blue)	13.3–18.7	56 × 80	3
Peak-up array (red)	18.5–26.0	54 × 82	3

NOTE.—PI: J. R. Houck, Cornell University; instrument built at Ball Aerospace.

The InfraRed Spectrograph (IRS)

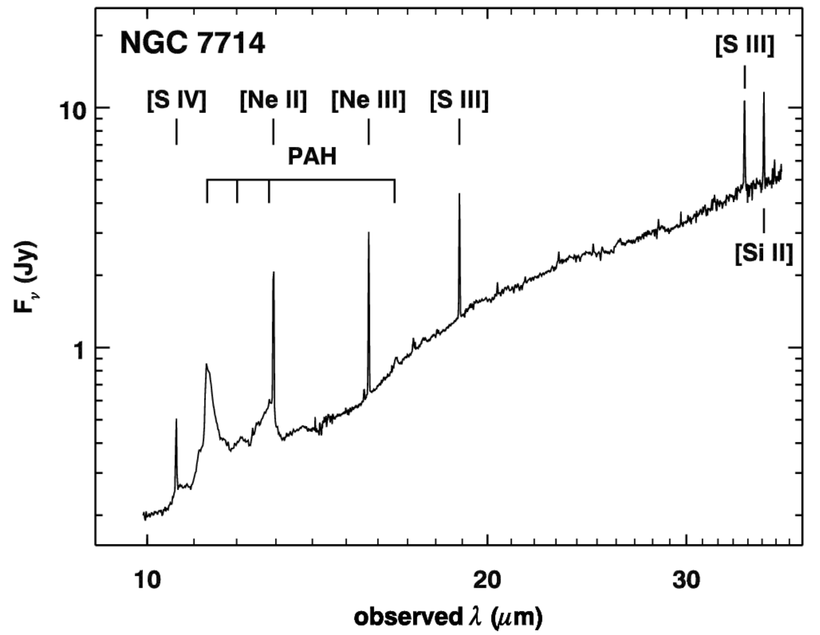


FIG. 3.—High-resolution spectrum of the starburst galaxy NGC 7714 (using both SH and LH) with the detected features marked (shifted for $z = 0.0093$). This spectrum was obtained with 240 s of integration in SH and LH (each). Brandl et al. (2004) describe these observations in more detail.

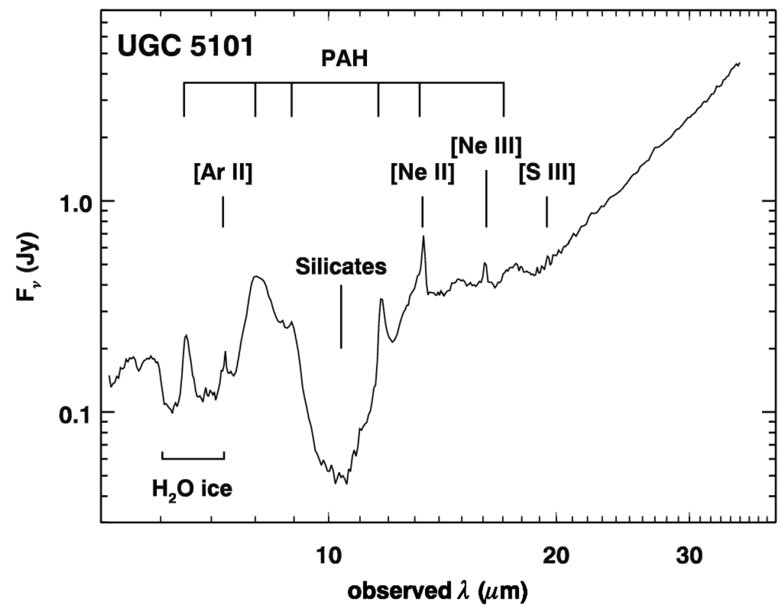
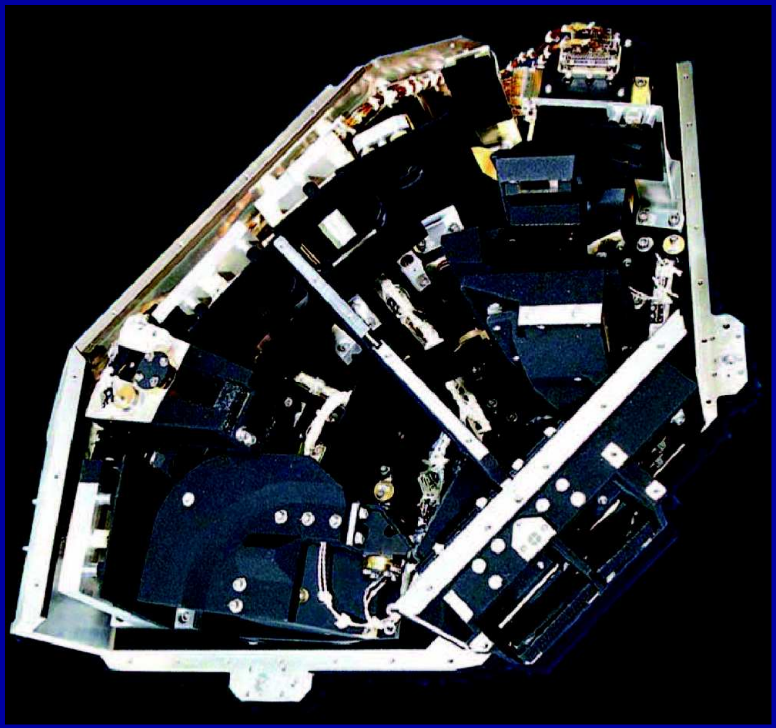
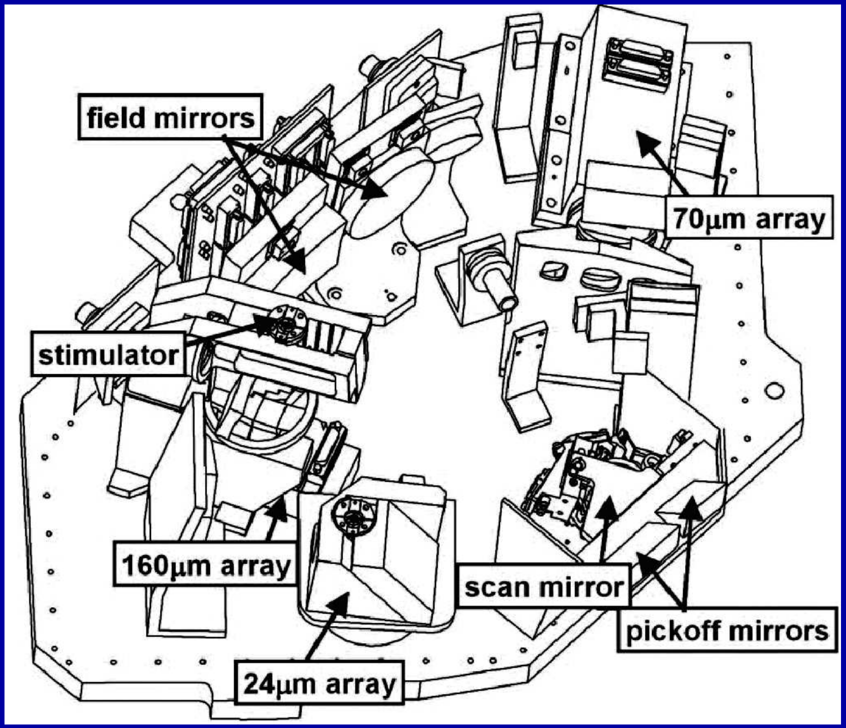


FIG. 4.—Low-resolution spectrum of UGC 5101 (using both SL and LL), showing several strong bands from PAHs, dust, and ice along with atomic emission lines (redshifted for $z = 0.039$). The integration time was 12 s in each SL subslit and 28 s in each LL subslit (total 80 s). Armus et al. (2004) discuss this spectrum more completely.

The Multiband Imaging Photometer for Spitzer (MIPS)





The Multiband Imaging Photometer for Spitzer (MIPS)

TABLE 4

MULTIBAND INFRARED PHOTOMETER FOR *Spitzer* (MIPS): FAR-INFRARED IMAGER AND SPECTRAL ENERGY DISTRIBUTION (SED) PHOTOMETER

Band Identification	Wavelength Range (μm)	Field of View (arcmin)	Detector Array
24 μm	21.5–26.2	5.4 × 5.4	128 × 128 Si:As
70 μm	62.5–81.5	5.2 × 5.2[a]	32 × 32 Ge:Ga
160 μm	139.5–174.5[b]	5.3 × 0.5	2 × 20 Stressed Ge:Ga
SED ($\lambda/\Delta\lambda$ = 15–25)	51–106	2.7 × 0.34	32 × 24 Ge:Ga

NOTE.—PI: G. H. Rieke, University of Arizona; instrument built at Ball Aerospace.

[a] The MIPS 70 μm array consists of two 5.′2 × 2.′6 halves. Because of a problem in the cold cabling, one of the halves has significantly worse sensitivity than the other.

[b] The MIPS 160 μm channel has a short-wavelength filter leak that admits some 1.6 μm light that must be accounted for when observing blue objects. See the *Spitzer* Science Center Web site for more information.

The Multiband Imaging Photometer for Spitzer (MIPS)

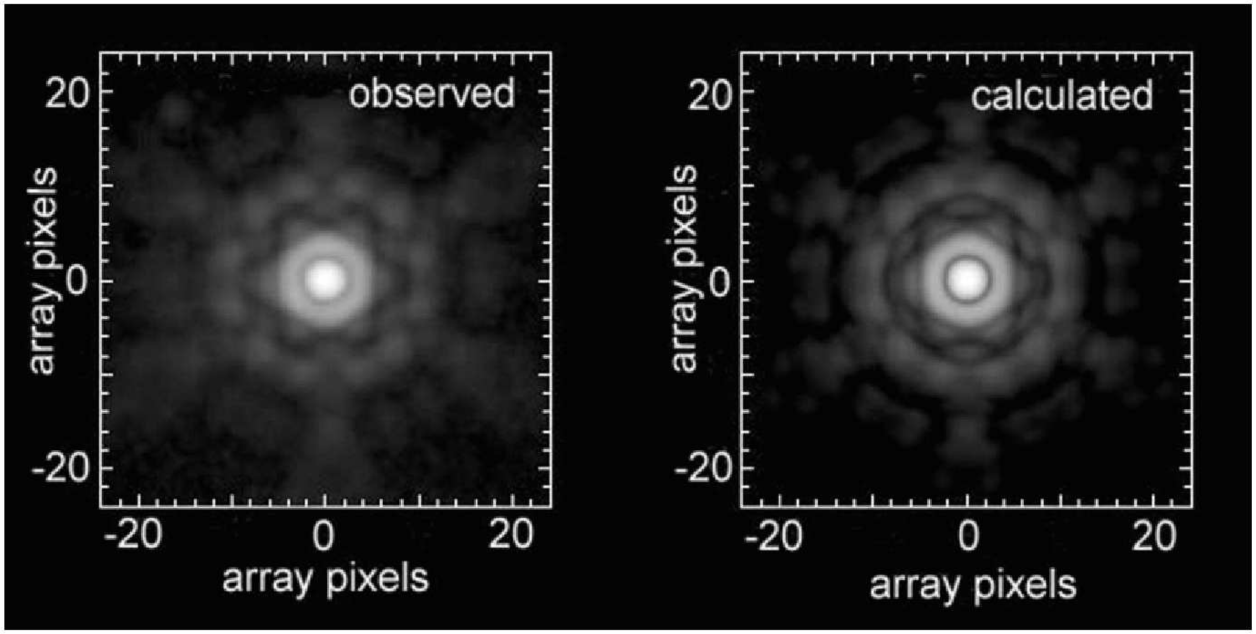
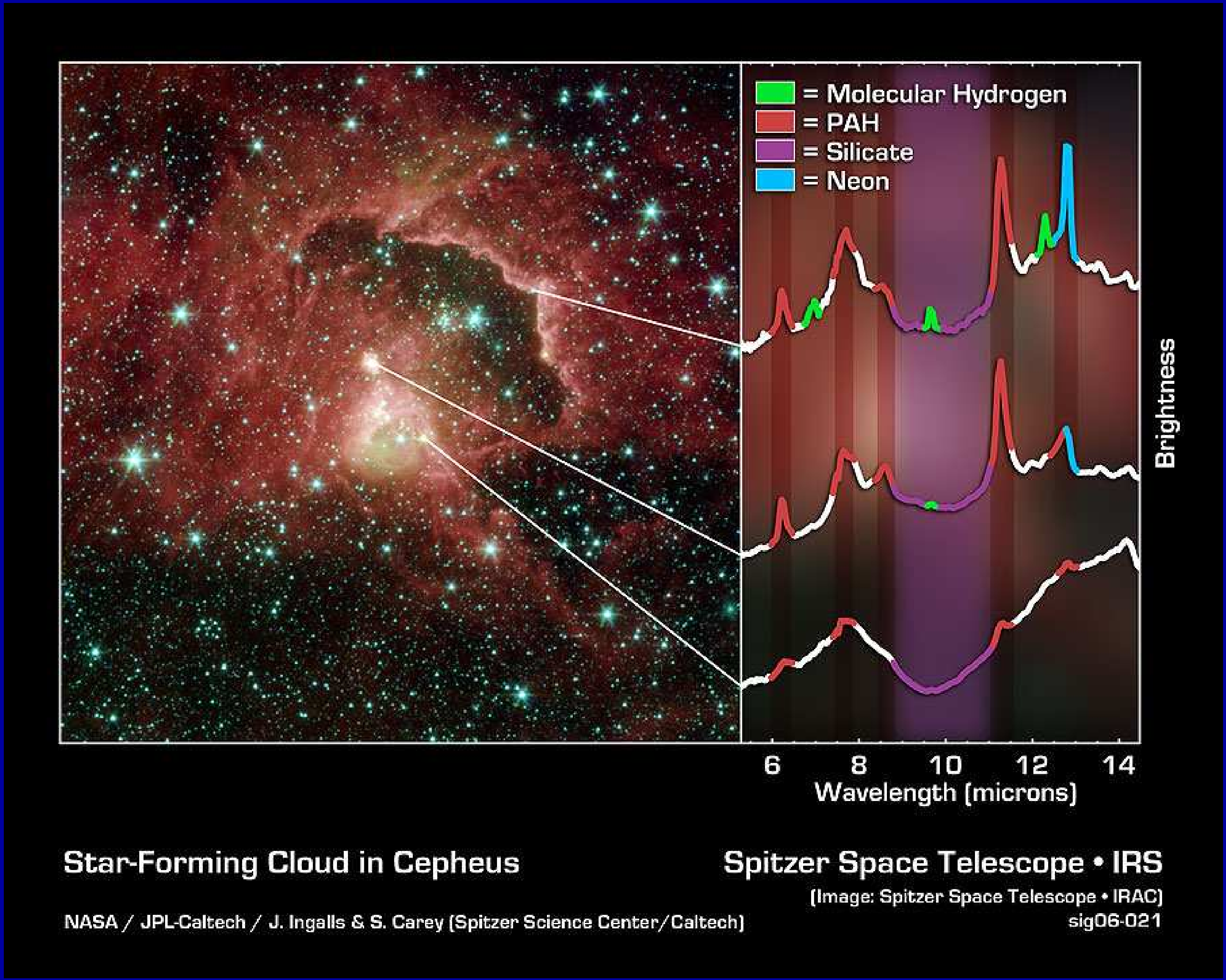


FIG. 2.—Point-spread function at 24 μm (*left*) and calculated PSF (*right*).

Spitzer Infrared Diagnostics



Spitzer Infrared Diagnostics

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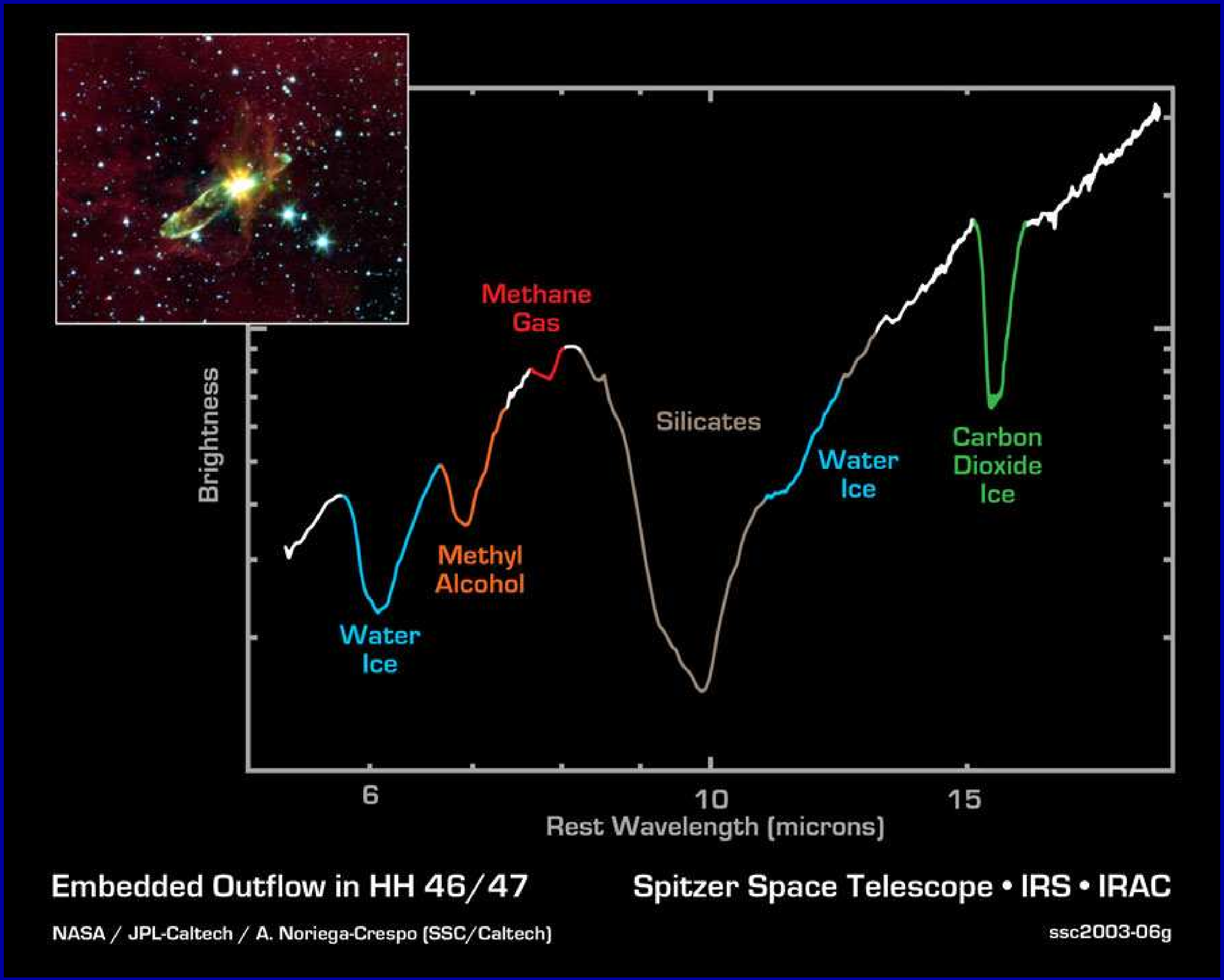

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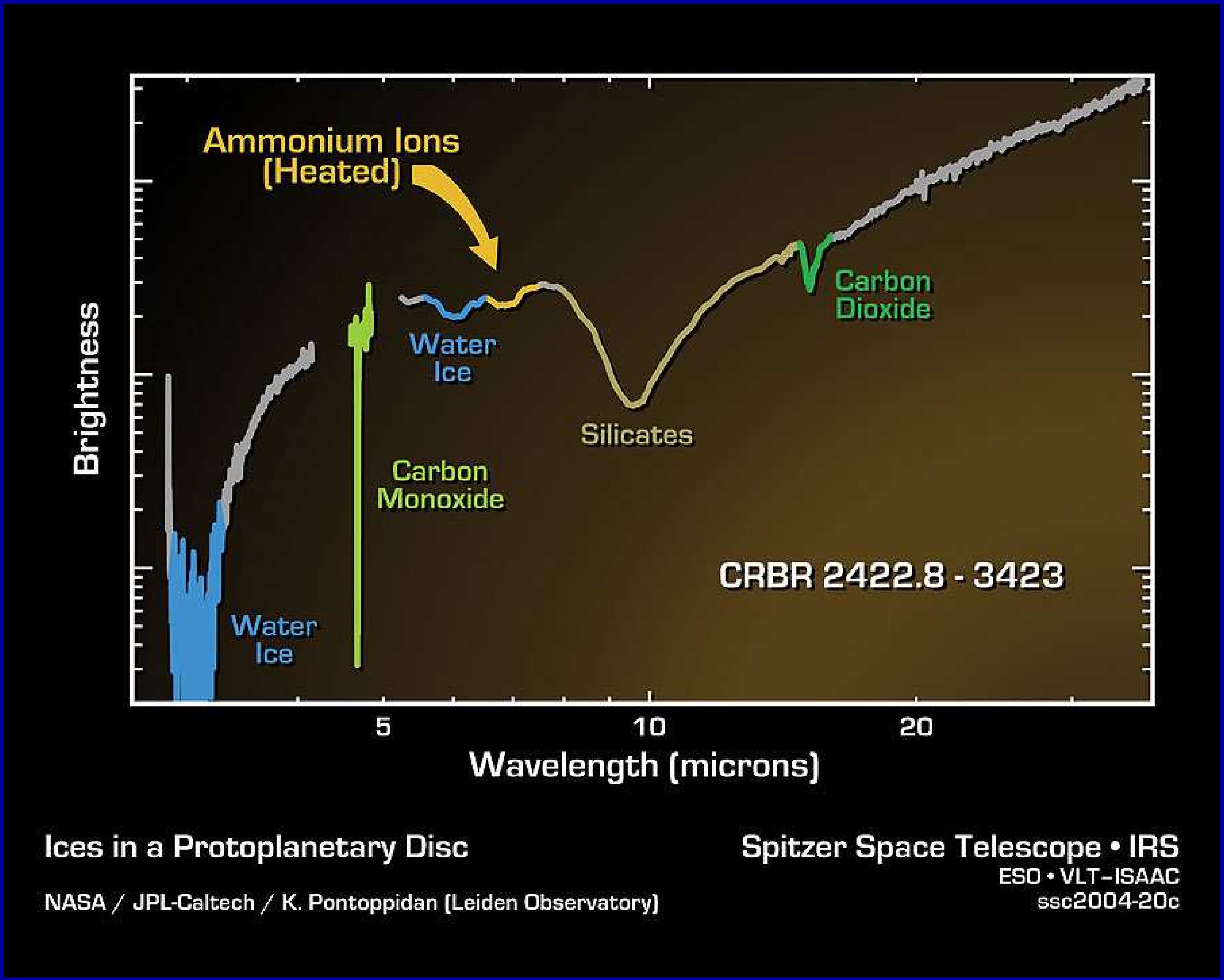

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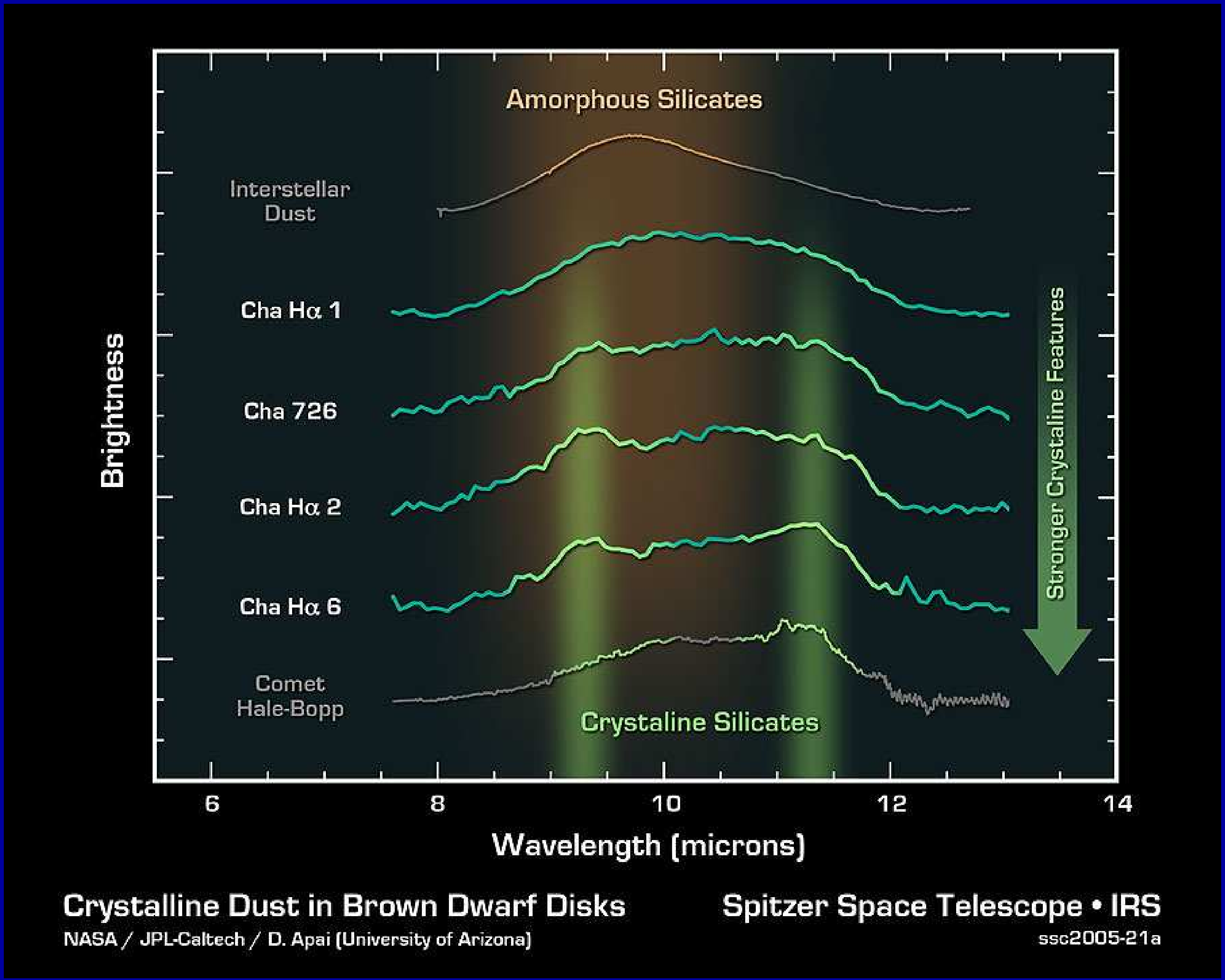

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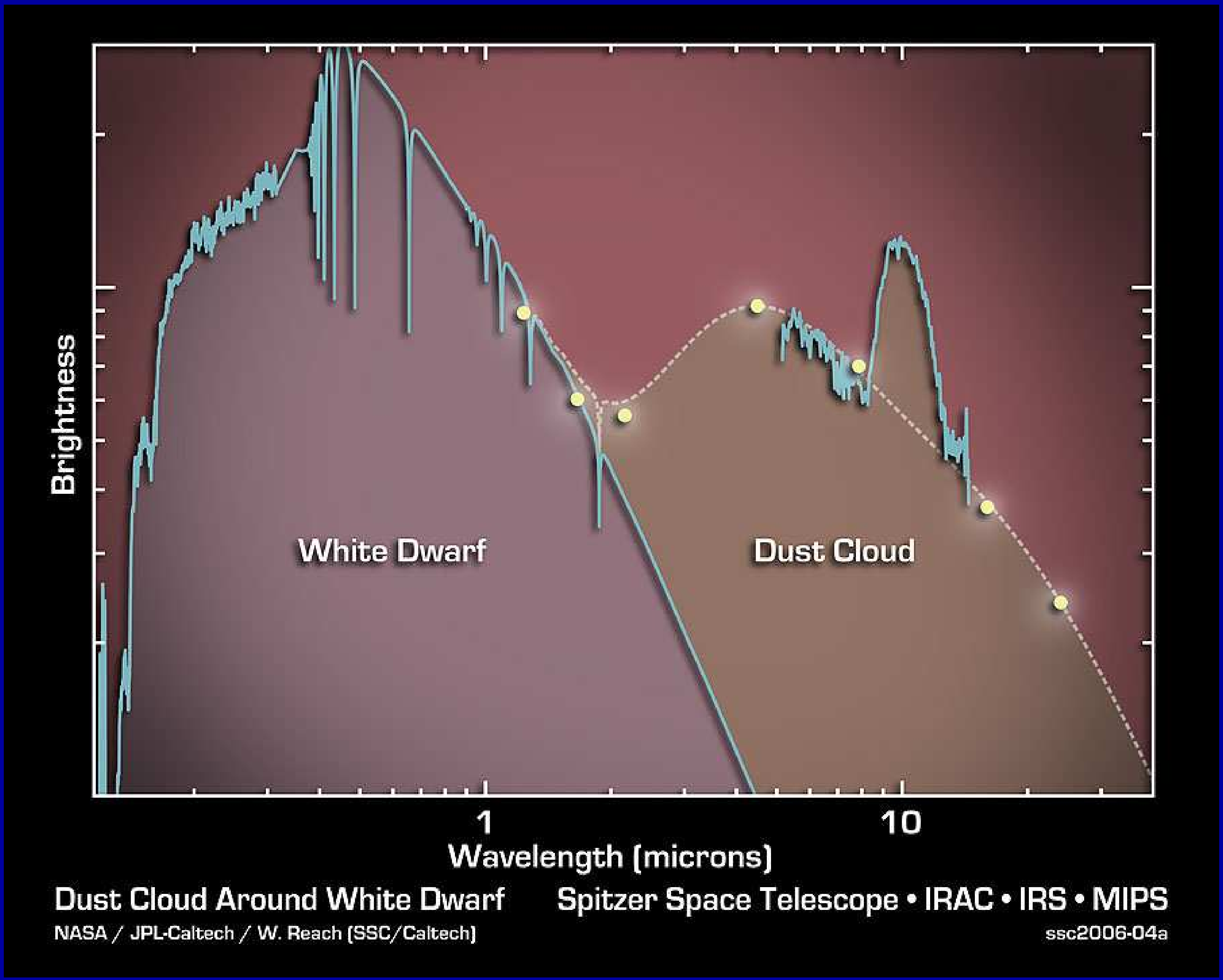

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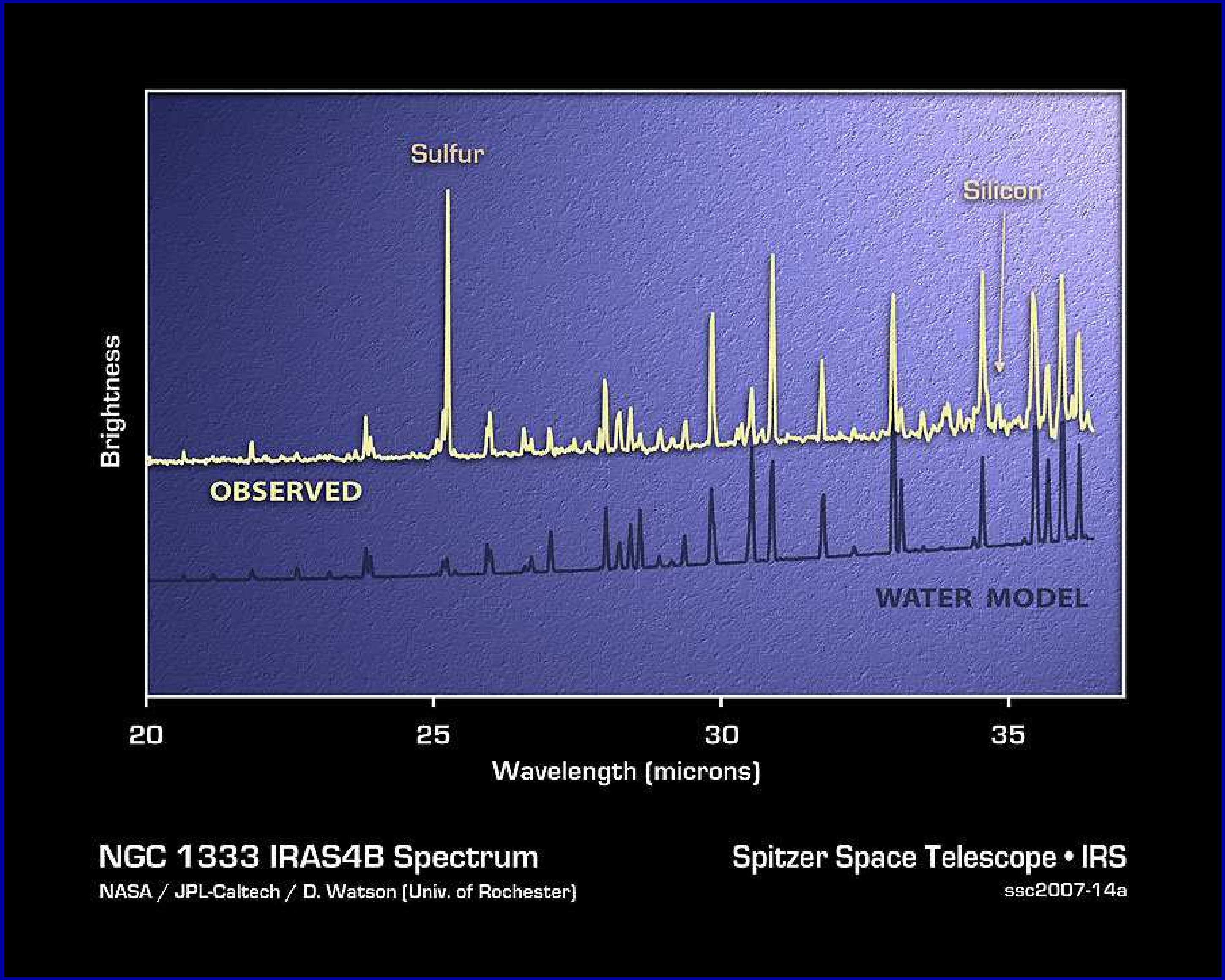

The *Spitzer* Space Telescope

$\longrightarrow$ Gallery of selected Pretty Pictures