



Spitzer Space Telescope

The Spitzer Space Telescope:
From the Youngest Galaxies to Exoplanets

Tom Soifer
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Caltech



The Spitzer Space Telescope



Lyman Spitzer (1914-1997)



One of the great Astrophysicists of the 20th Century

Invented the study of the interstellar medium

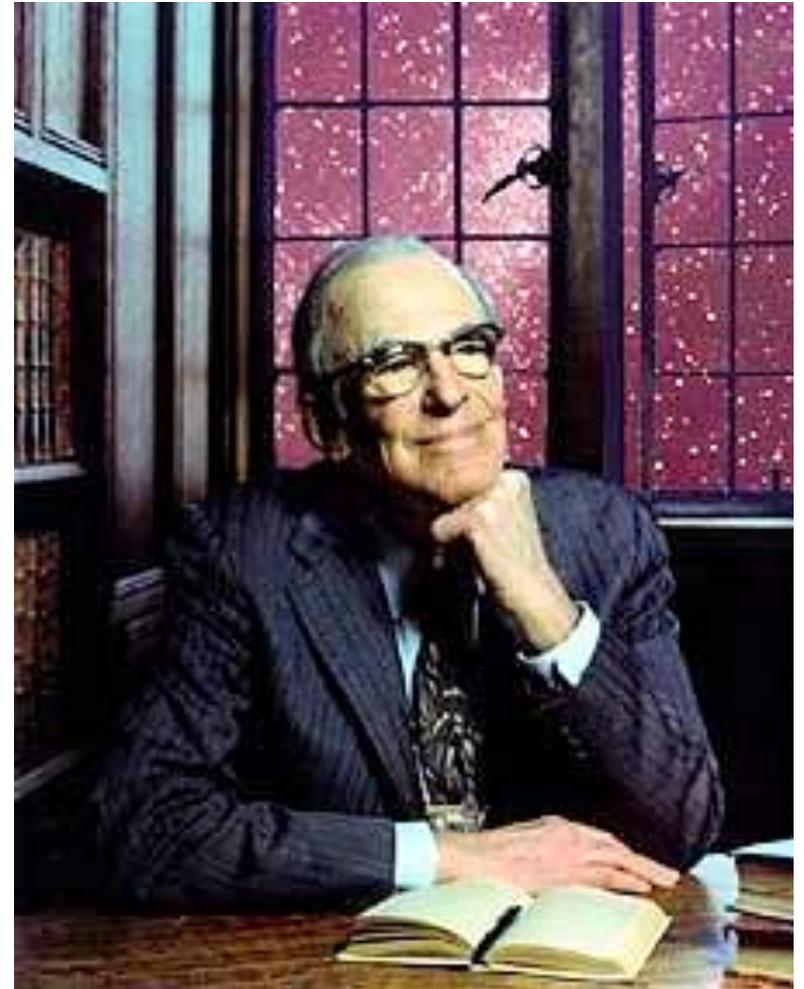
Major contributor to plasma physics & stellar dynamics

1946 report for Rand Corp. outlined motivation for a large space telescope

“to uncover new phenomena not yet imagined”

“to modify ..our basic concepts of space and time”

The “father” of space astronomy





WHY INFRARED ASTRONOMY?

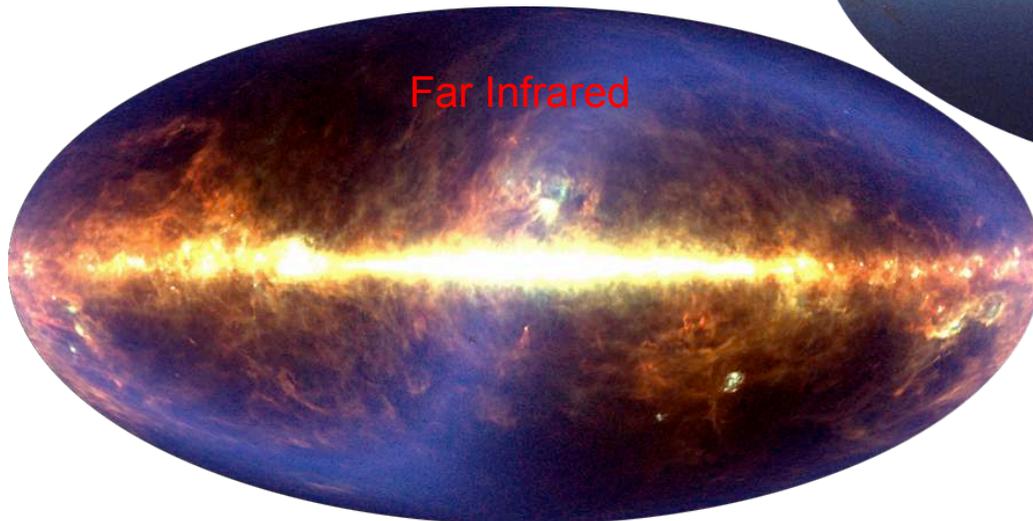
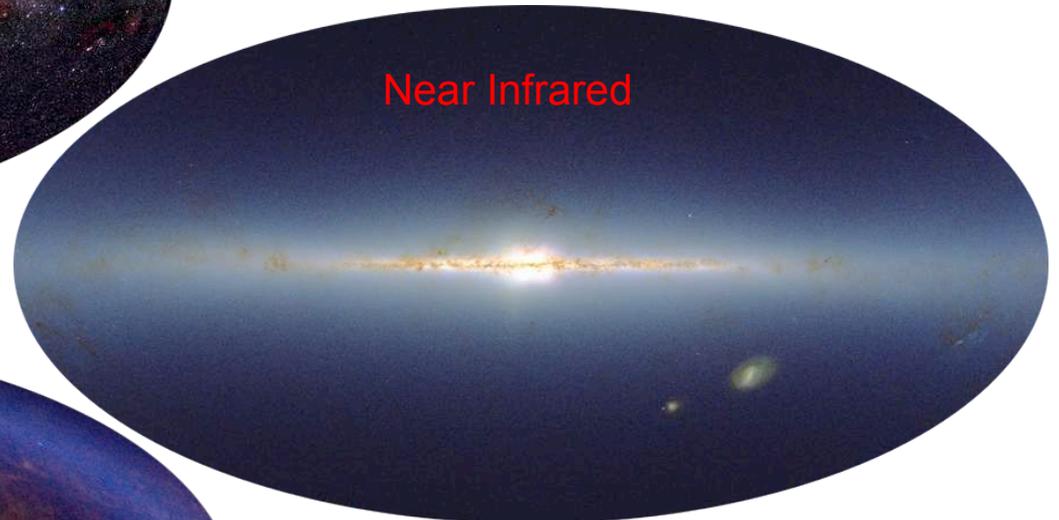
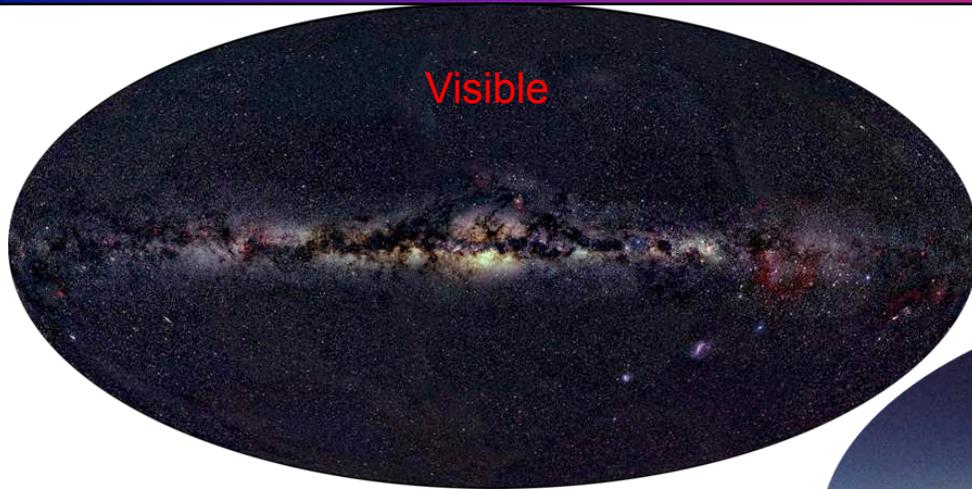


IR ASTRONOMY = 1-300 μm (micrometers) – a working definition
(your eye is sensitive to light in the wavelength range 0.4 – 0.7 μm)

- ◆ ATOMIC, MOLECULAR TRANSITIONS THAT PROBE DIFFERENT PHYSICAL CONDITIONS
- ◆ INTERSTELLAR DUST EXTINCTION
- ◆ BOLOMETRIC LUMINOSITY IN DUSTY ENVIRONMENTS
- ◆ DIAGNOSTICS OF SOLID STATE MATERIAL
- ◆ REDSHIFT PUSHES FAMILIAR FEATURES INTO IR



The Multispectral Sky





The Advantages of Space

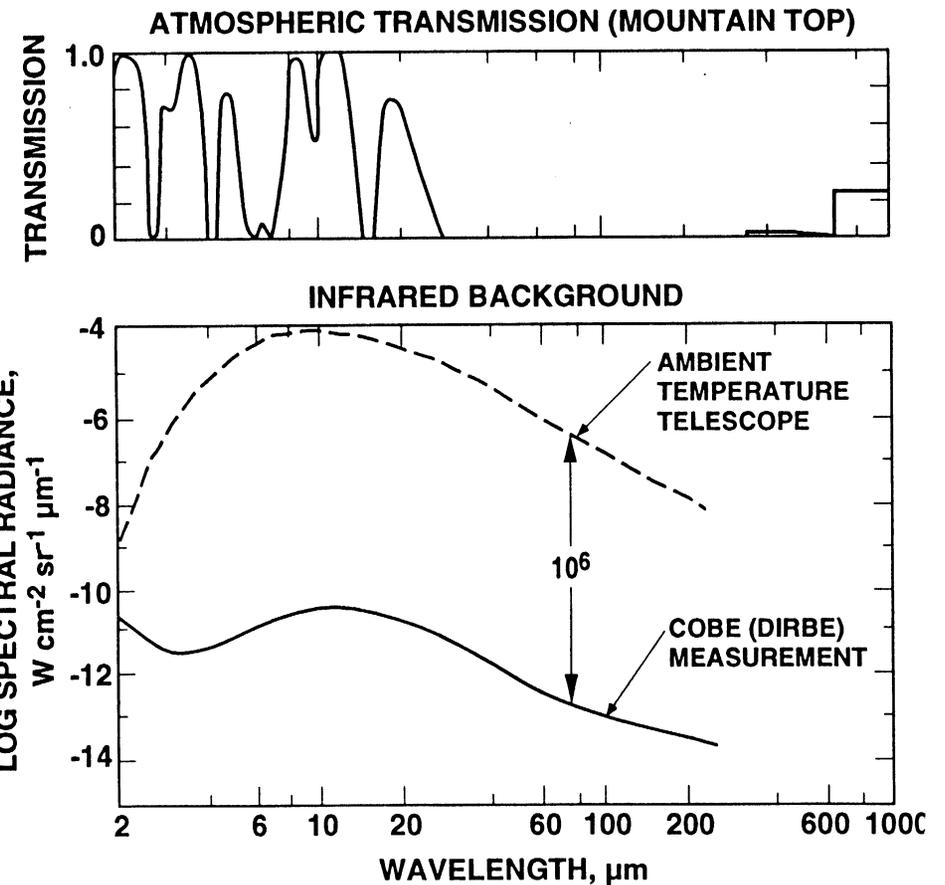


The Advantages of Space:

100% Transmission

**10^6 Decrease
in Sky Brightness
Gain in sensitivity is 10^3
over ground-based platforms**

**A stable environment –
Measurements to parts in 10^{-5}
or better**





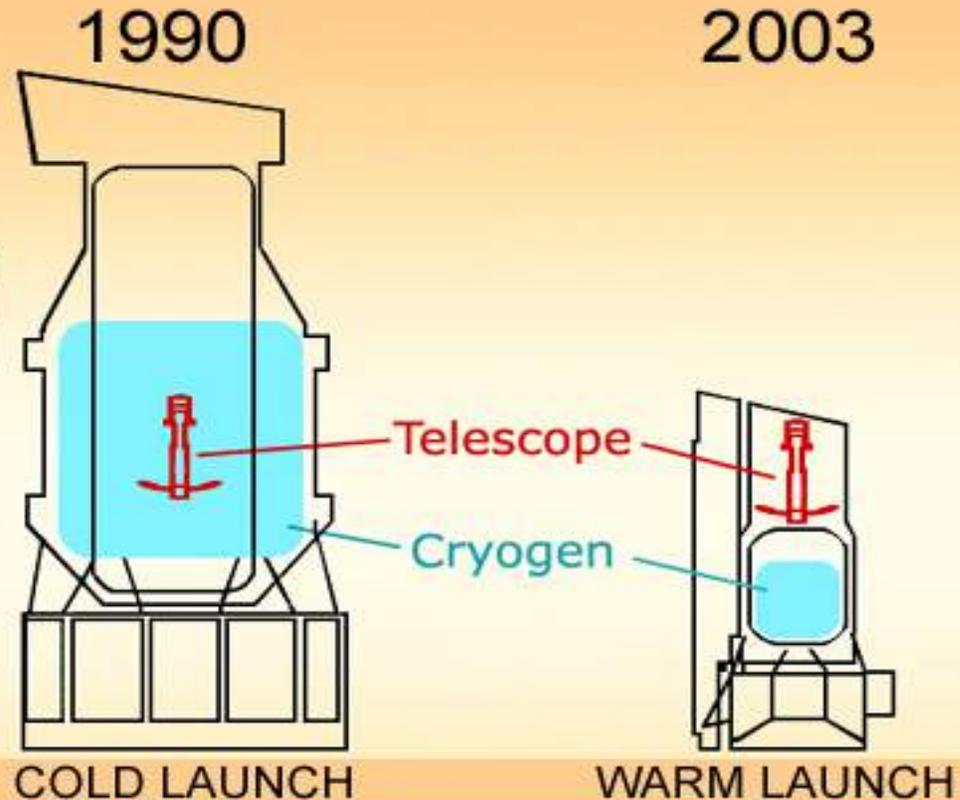
SPITZER (SIRTF) CHRONOLOGY



- ◆ 1972 – FIRST STUDIES OF A SHUTTLE BASED SIRTF
- ◆ 1984 – TEAMS SELECTED TO BUILD INSTRUMENTS FOR SIRTF – STILL SHUTTLE BASED
- ◆ 1985 – SIRTF MOVED TO FREE FLYER
- ◆ 1990 – SIRTF “HIGHEST PRIORITY SPACE ASTRONOMY MISSION OF 1990s ” DECADAL REVIEW
- ◆ 1990 – HST SPHERICAL ABBERATION
- ◆ 1992 – DAN GOLDEN – FASTER/BETTER/CHEAPER
- ◆ 1995 – SIRTF SLIMS DOWN FROM 2.2B\$ TO 0.5B\$
- ◆ **1996** – SIRTF STARTS
- ◆ **2003** – SIRTF LAUNCHES, NAME CHANGED TO SPITZER SPACE TELESCOPE
- ◆ **2009** - CRYOGEN DEPLETED, WARM MISSION BEGINS
- ◆ **2016** - SPITZER BEYOND BEGINS



DESIGN CHANGES



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



The Spitzer Space Telescope



- ◆ Multi-purpose observatory cooled passively and with liquid-helium for astronomical observations in the infrared /radiatively cooled after cryo depletion
- ◆ **Launch in August 2003 for a 2.5-5 year mission in solar orbit, continuing to operate in 2017**
- ◆ Three instruments use state-of-the-art infrared detector arrays / **½ instrument still functional**
- ◆ Provides a >100 fold increase in infrared capabilities over all previous space missions
- ◆ Completes NASA's Great Observatories
- ◆ An observatory for the community - **80%(100%)** of observing time is allocated via annual Call for Proposals



Assembled Spitzer Observatory at Lockheed-Martin, Sunnyvale.

Key Characteristics:

Aperture – 85 cm

*Wavelength Range 3-to-180um/**3-5um***

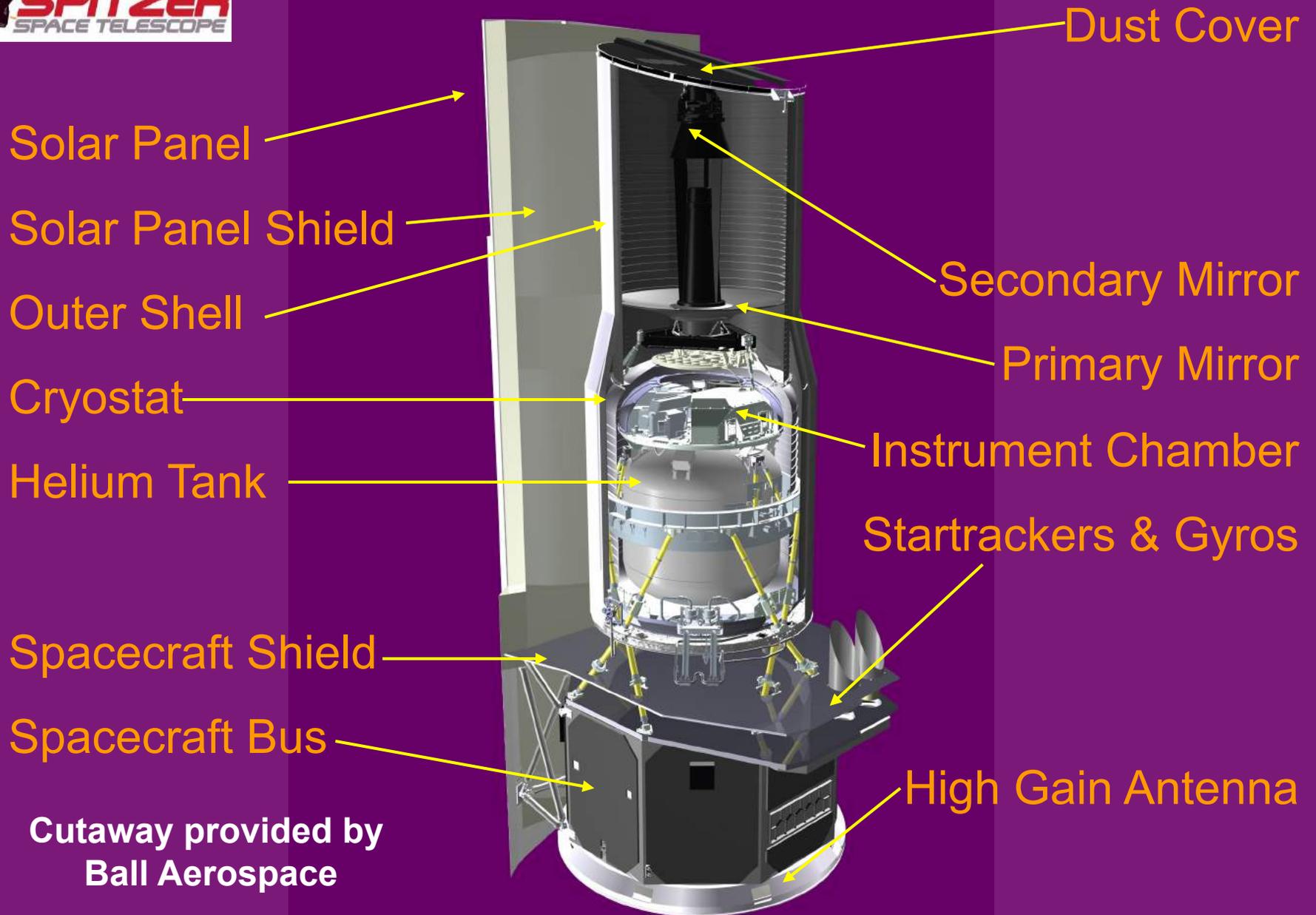
*Telescope Temperature – 5.5K/**25K***

Mass – 870kg

Height – 4m



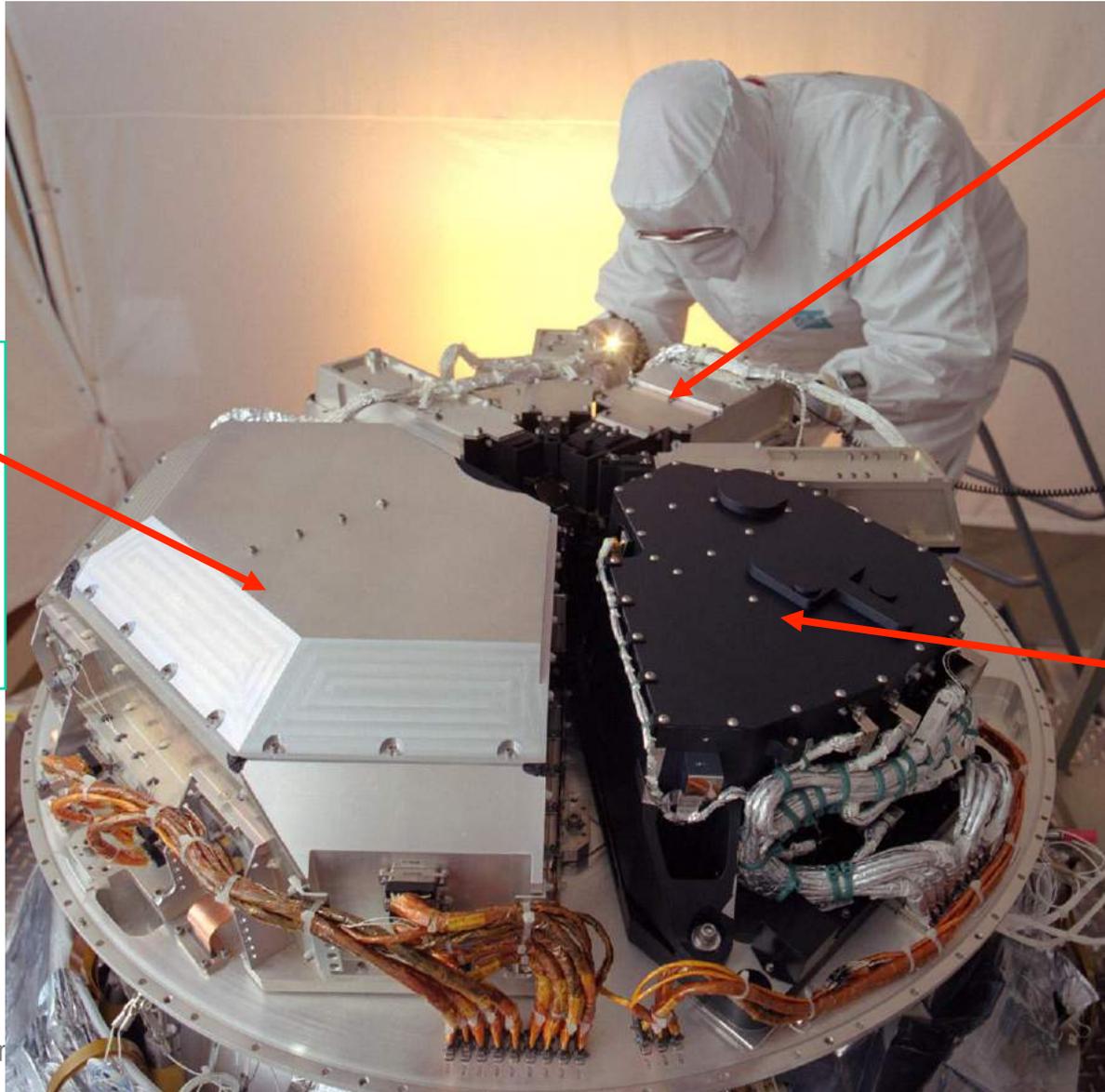
Cutaway View of the Spitzer Space Telescope



Cutaway provided by
Ball Aerospace



SPITZER Focal Plane Instruments



MIPS

Imaging 5'x5'
24 μ m, 70 μ m,
160 μ m

G.Rieke,
U Arizona/BATC

IRS

Spectroscopy
5 to 40 μ m R~100,
R~600

J.R. Houck
Cornell/BATC

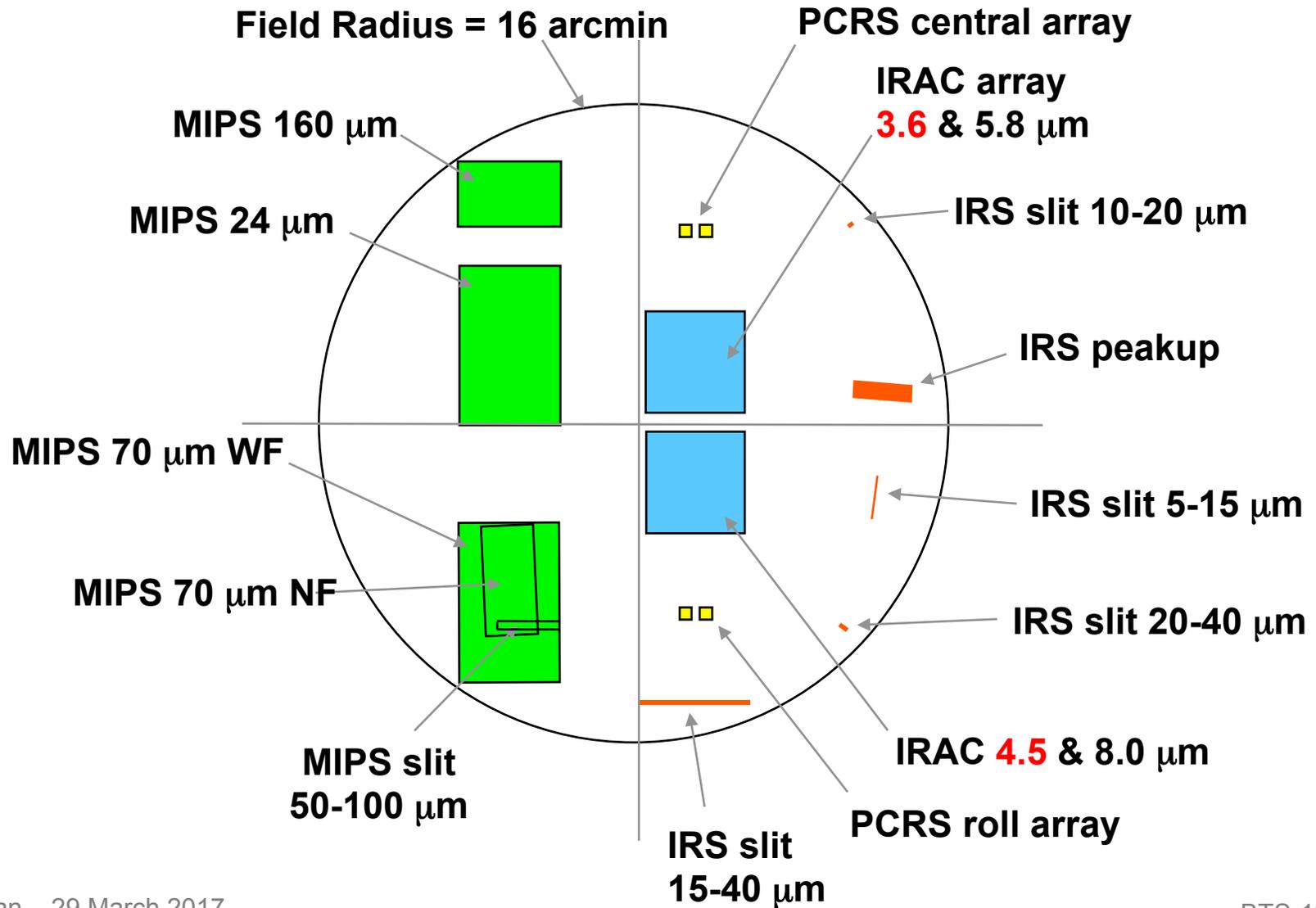
IRAC

Imaging 5'x5'
3.6 μ m, 4.5 μ m
5.8 μ m, 8 μ m

G. Fazio
SAO/GSFC



SPITZER Focal Plane Apertures





SIRTF Telescope Installation



Lyncean – 29 March 2017

BTS-13



SIRTF AT THE CAPE



Lyncean – 29 March 2017



Spitzer's Earth Trailing Orbit

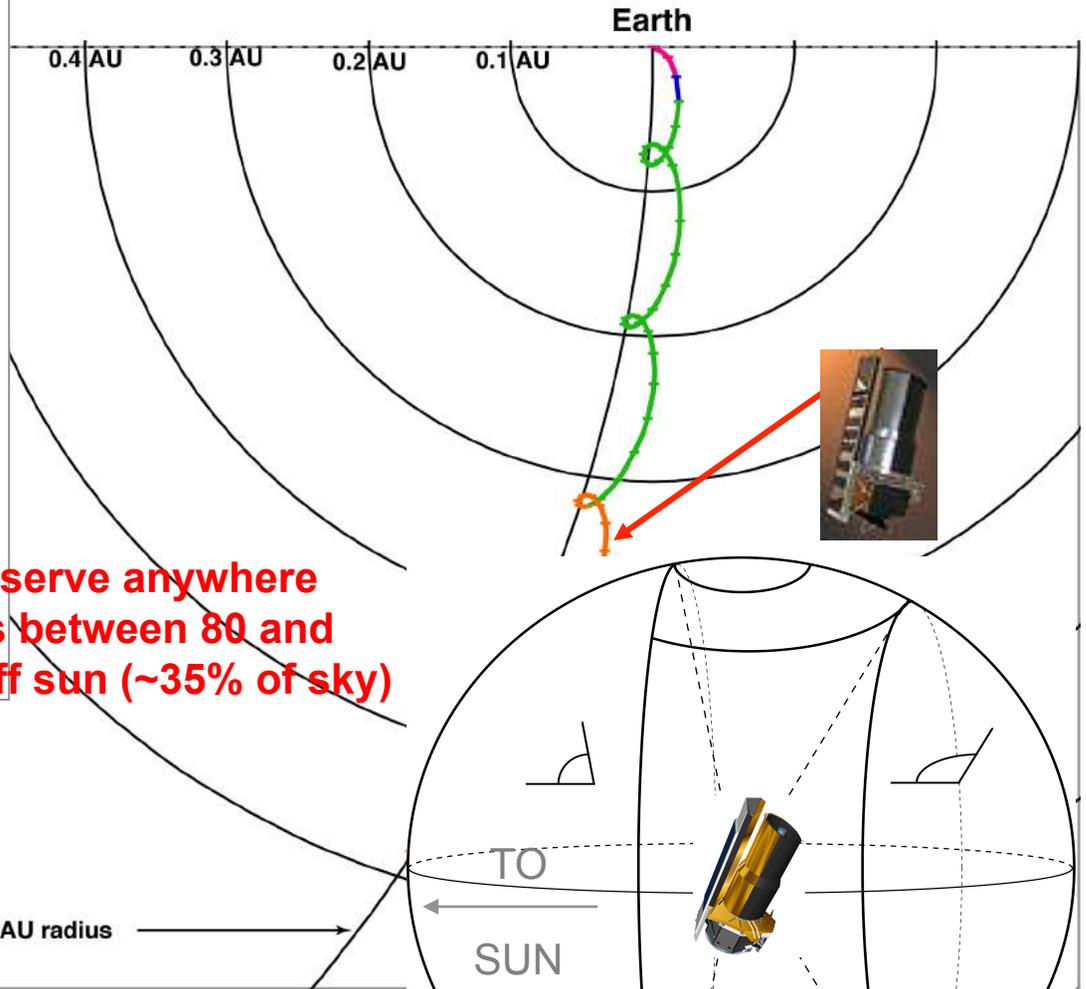


Advantages of Solar Orbit:



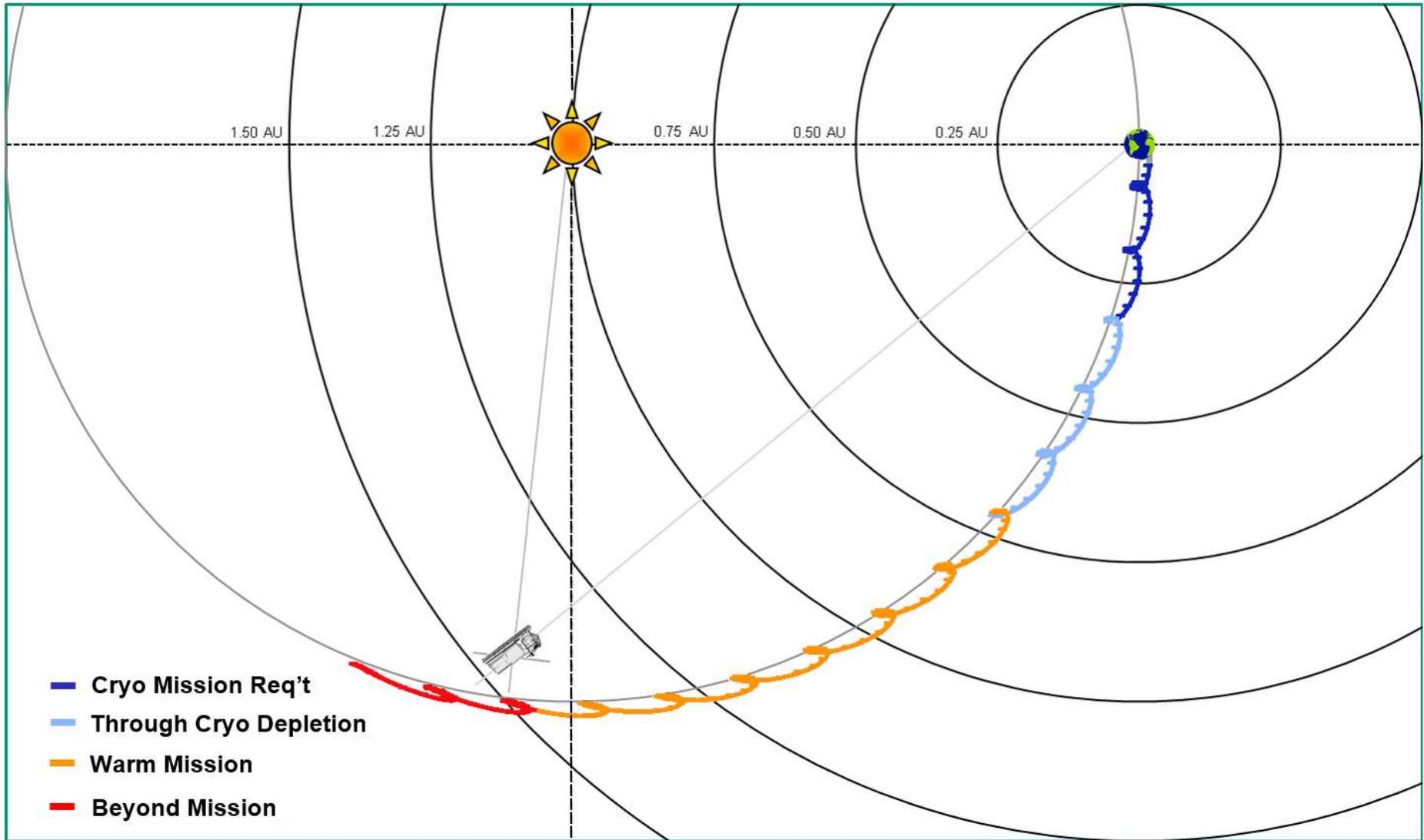
- 50% More Mass Than HEO
- Better Thermal Environment
- No Earth-Moon Avoidance
- No Need for Propulsion
- No Earth Radiation Belt
- Simpler Deep Space Tracking
- Less Complex Fault Protection
- Simpler Observation Planning

Spitzer can observe anywhere within annulus between 80 and 120 degrees off sun (~35% of sky)



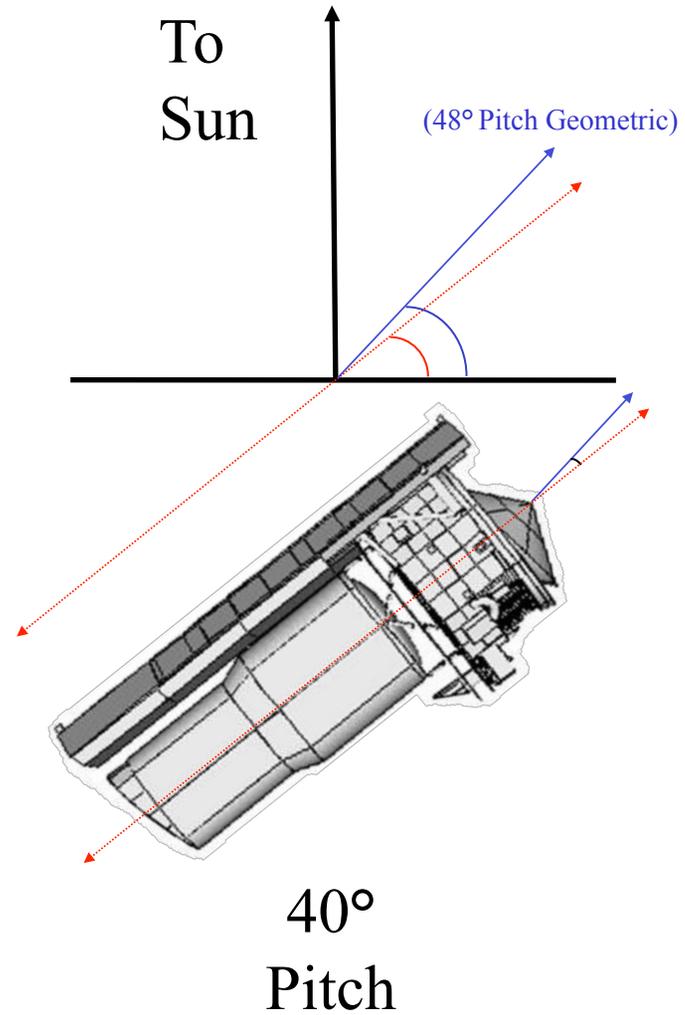
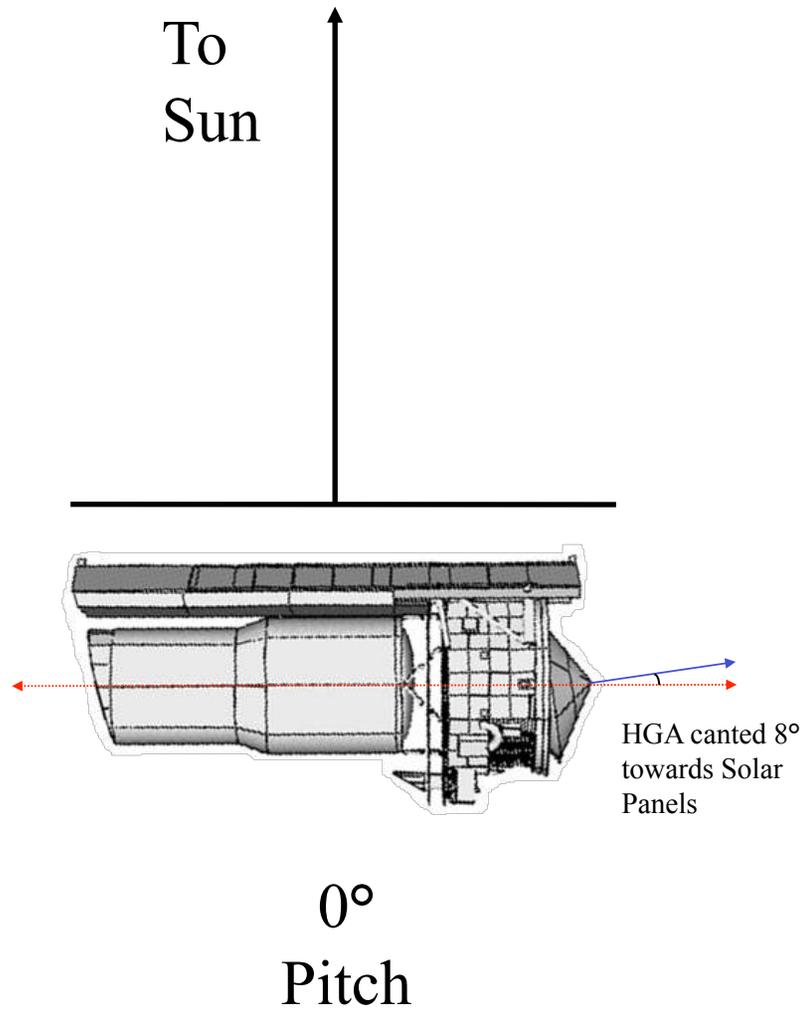


Where Spitzer is Now





Pitch Angle for Downlinks

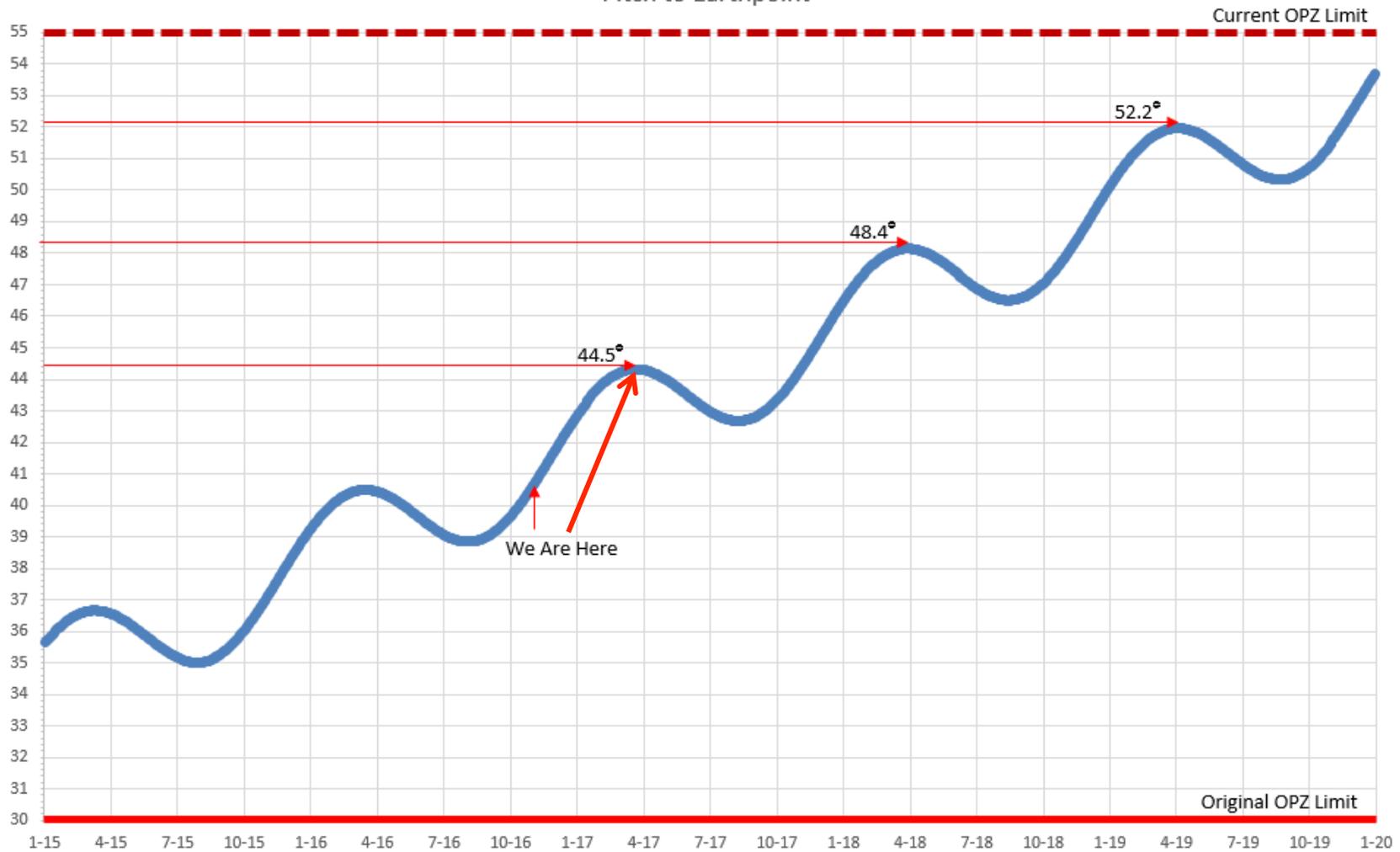




What Limits Spitzer's Operations



Pitch to Earthpoint





Science Topics

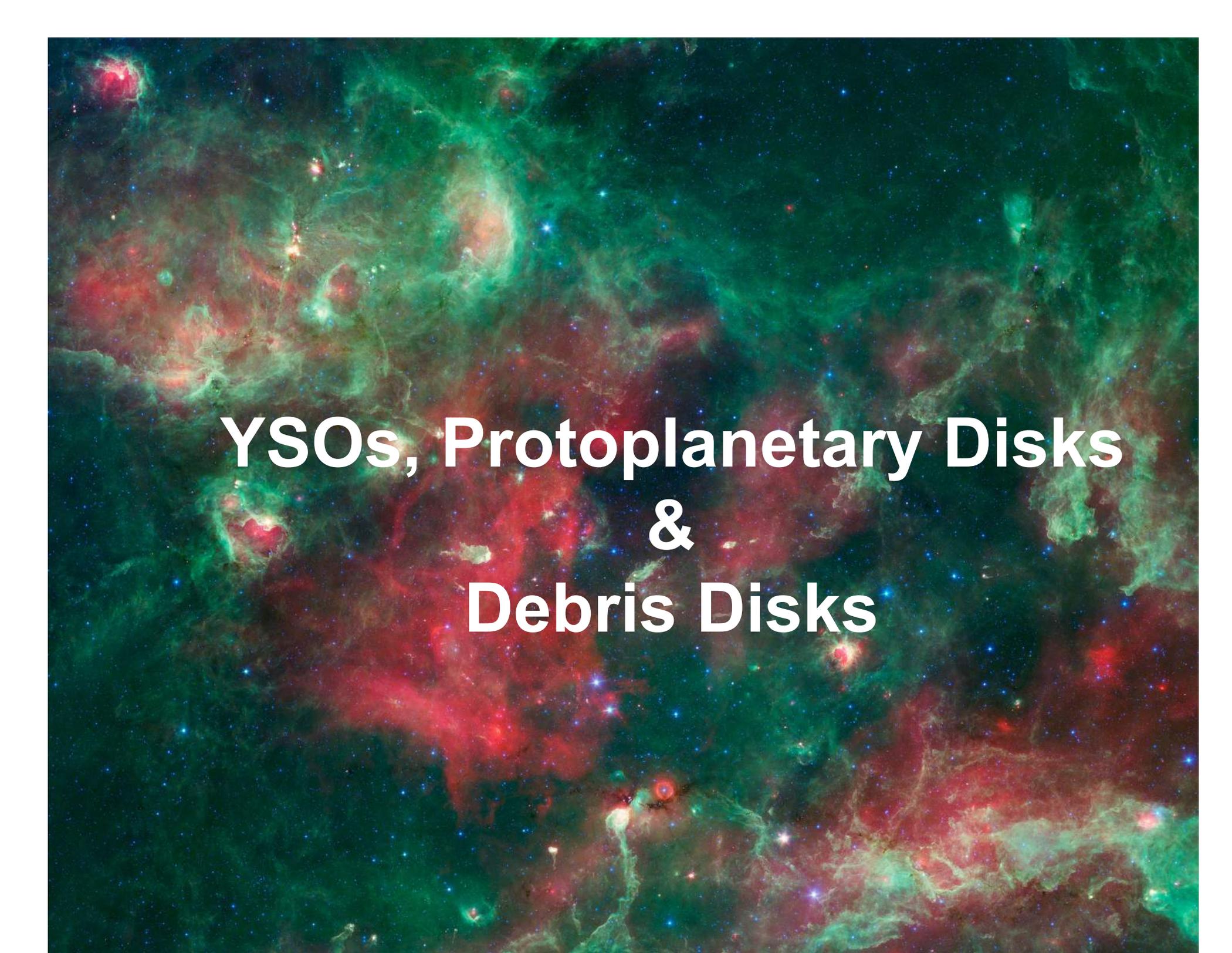


The Cryomission Science

- ◆ Young Stellar Objects (YSOs), Protoplanetary & Debris Disks
- ◆ Distant Dusty Galaxies

Continuing into the Warm mission

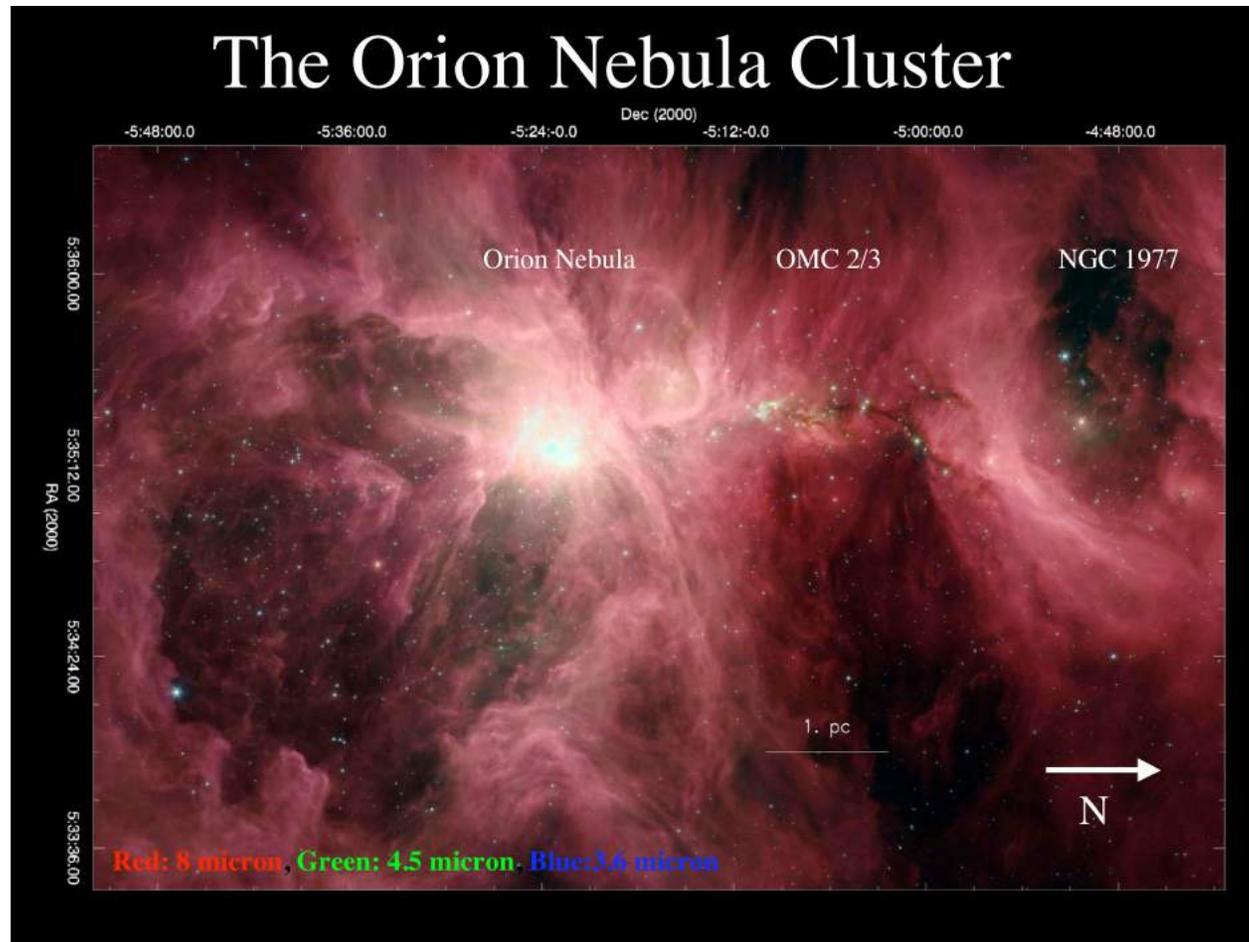
- ◆ Less than 1 Billion years after the Big Bang
- ◆ Probing exo-planets



**YSOs, Protoplanetary Disks
&
Debris Disks**

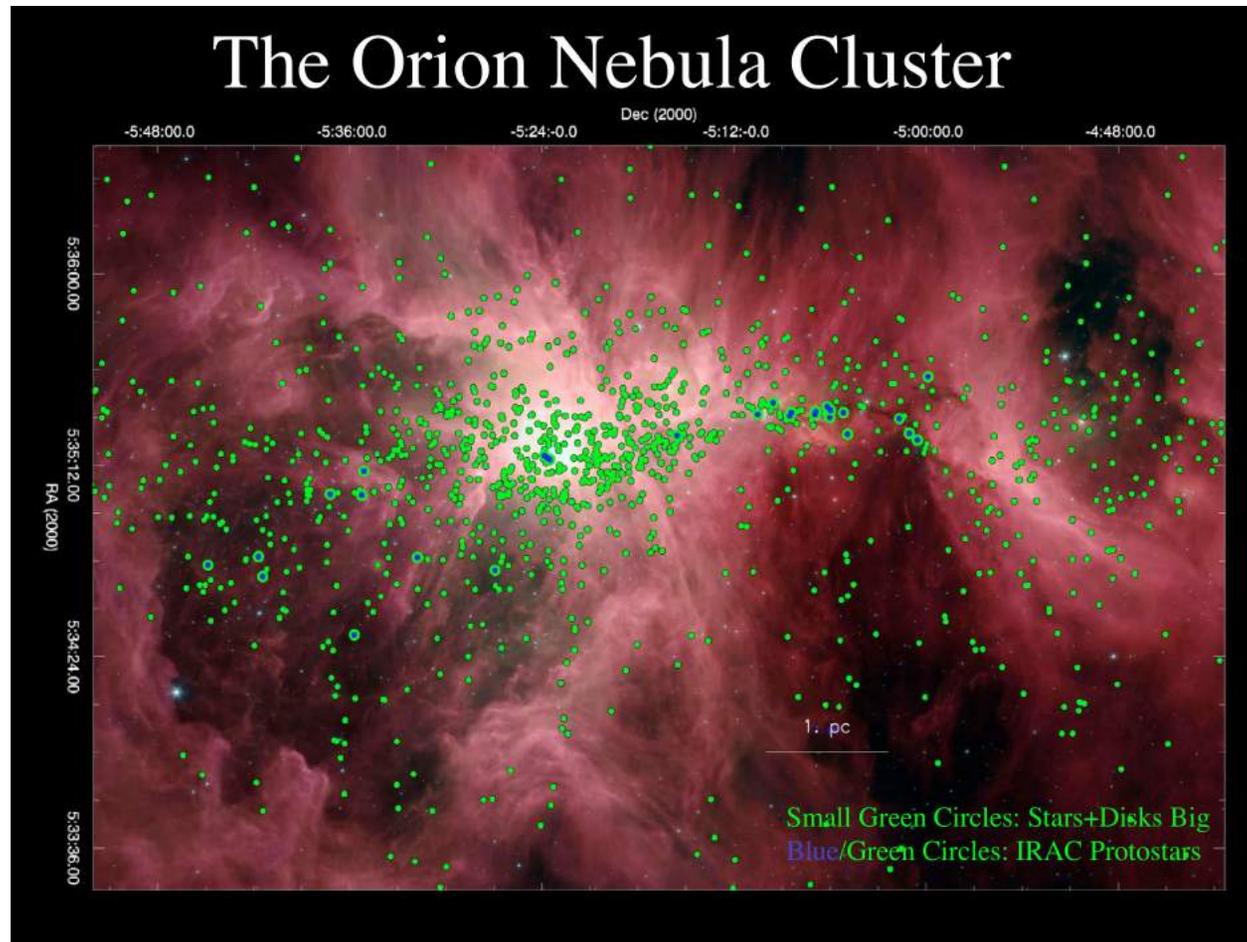


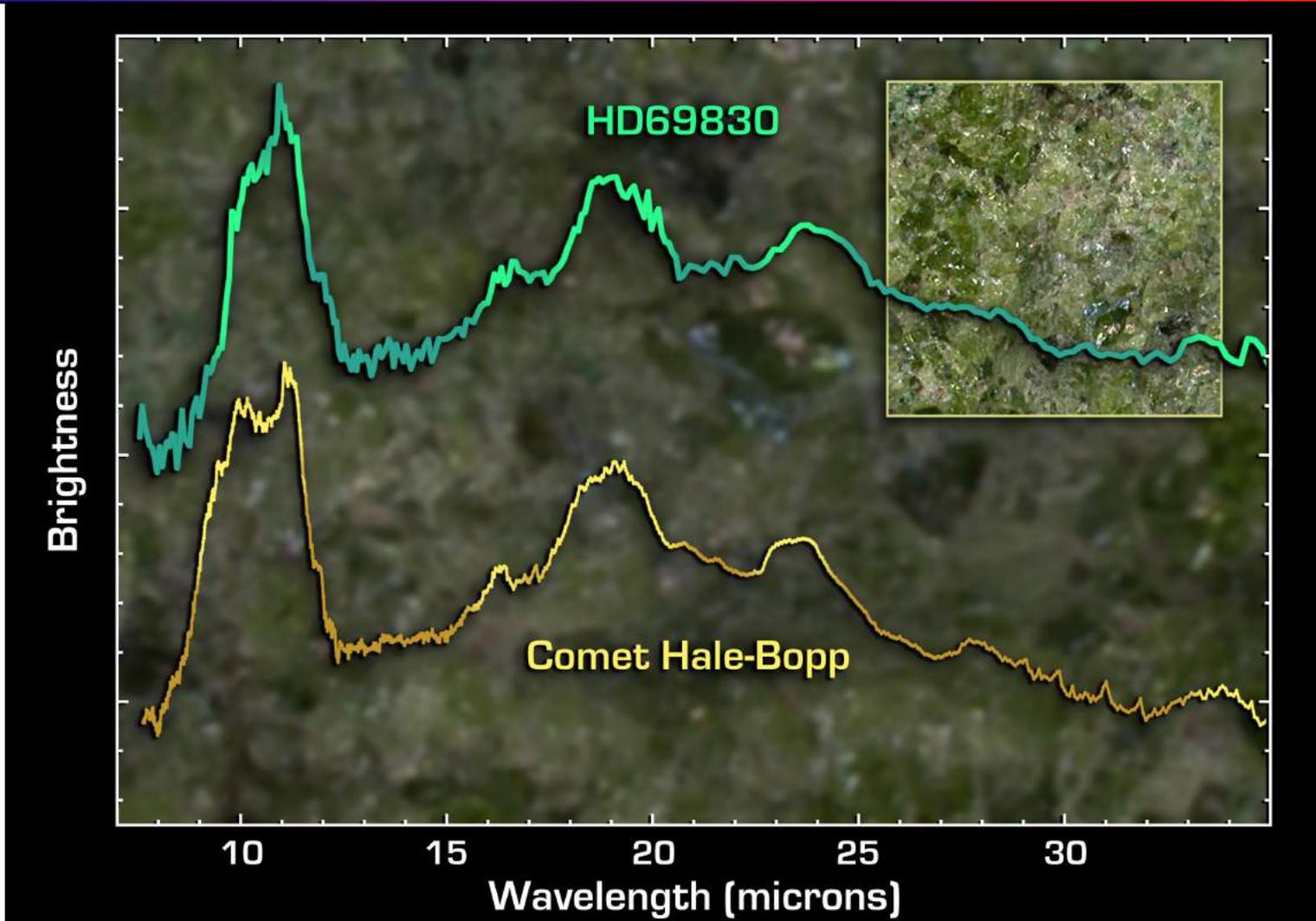
The Orion Nebula

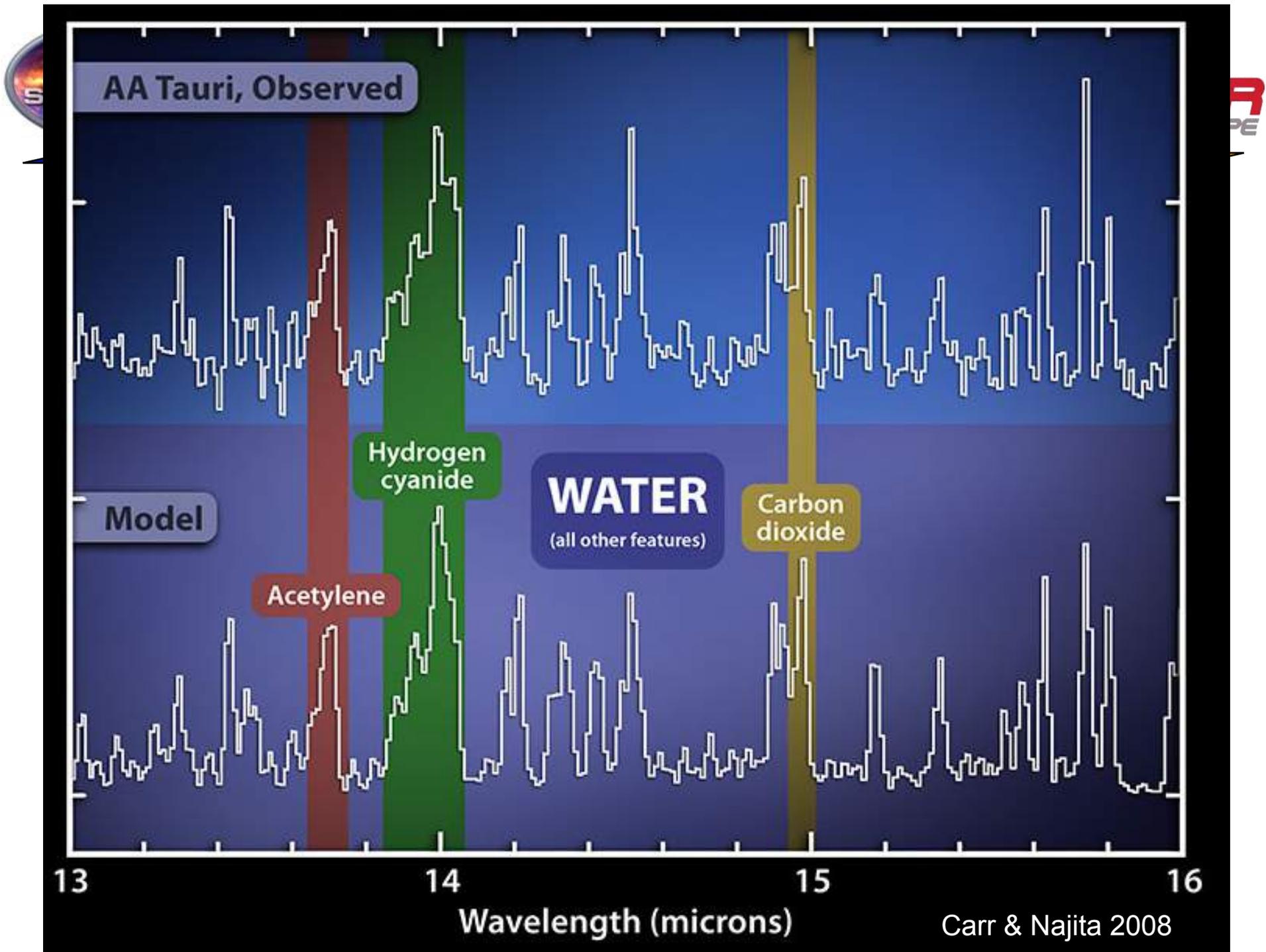




YSOs in Orion







AA Tauri, Observed

Model

Acetylene

Hydrogen cyanide

WATER
(all other features)

Carbon dioxide

13

14

15

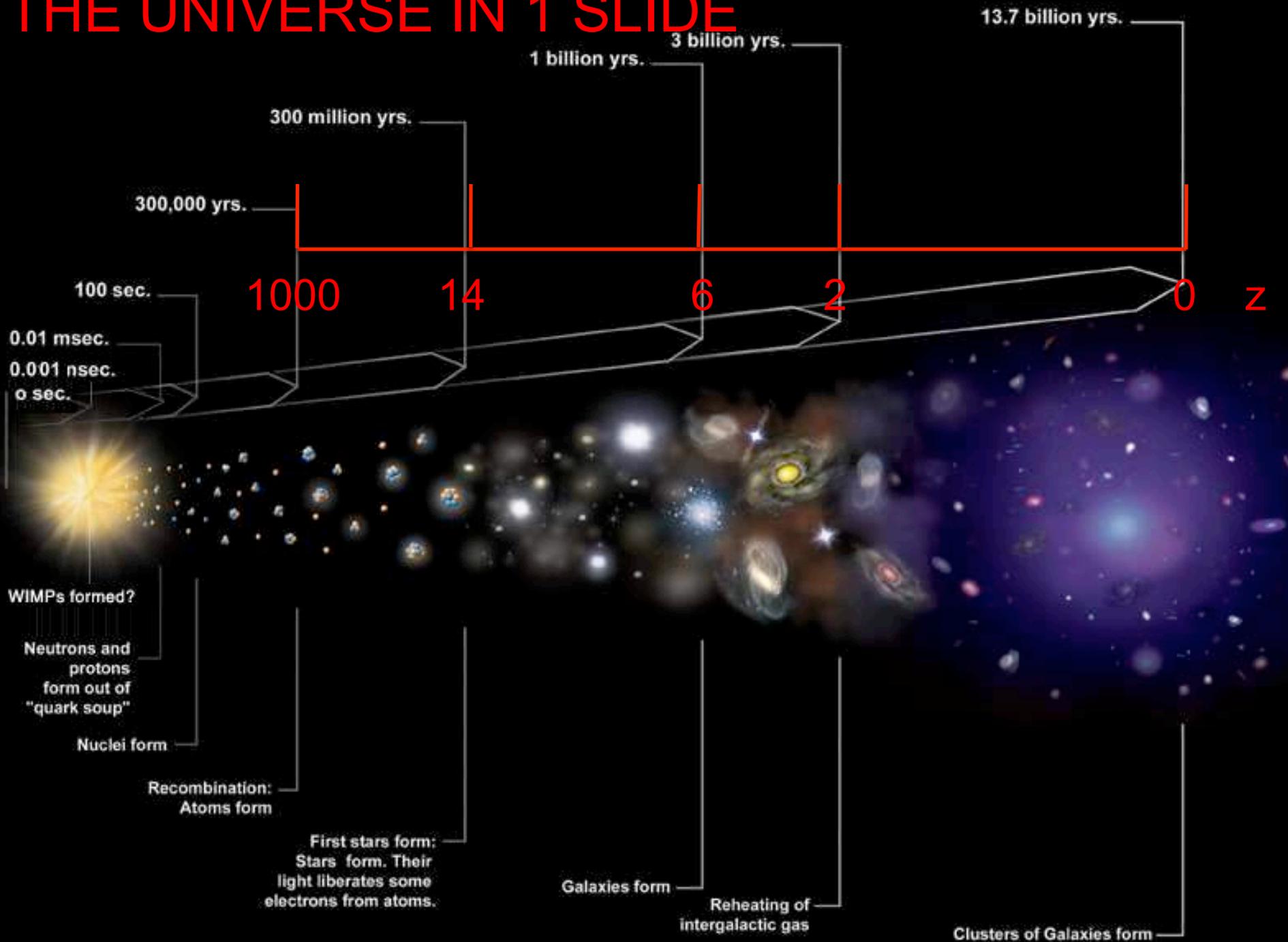
16

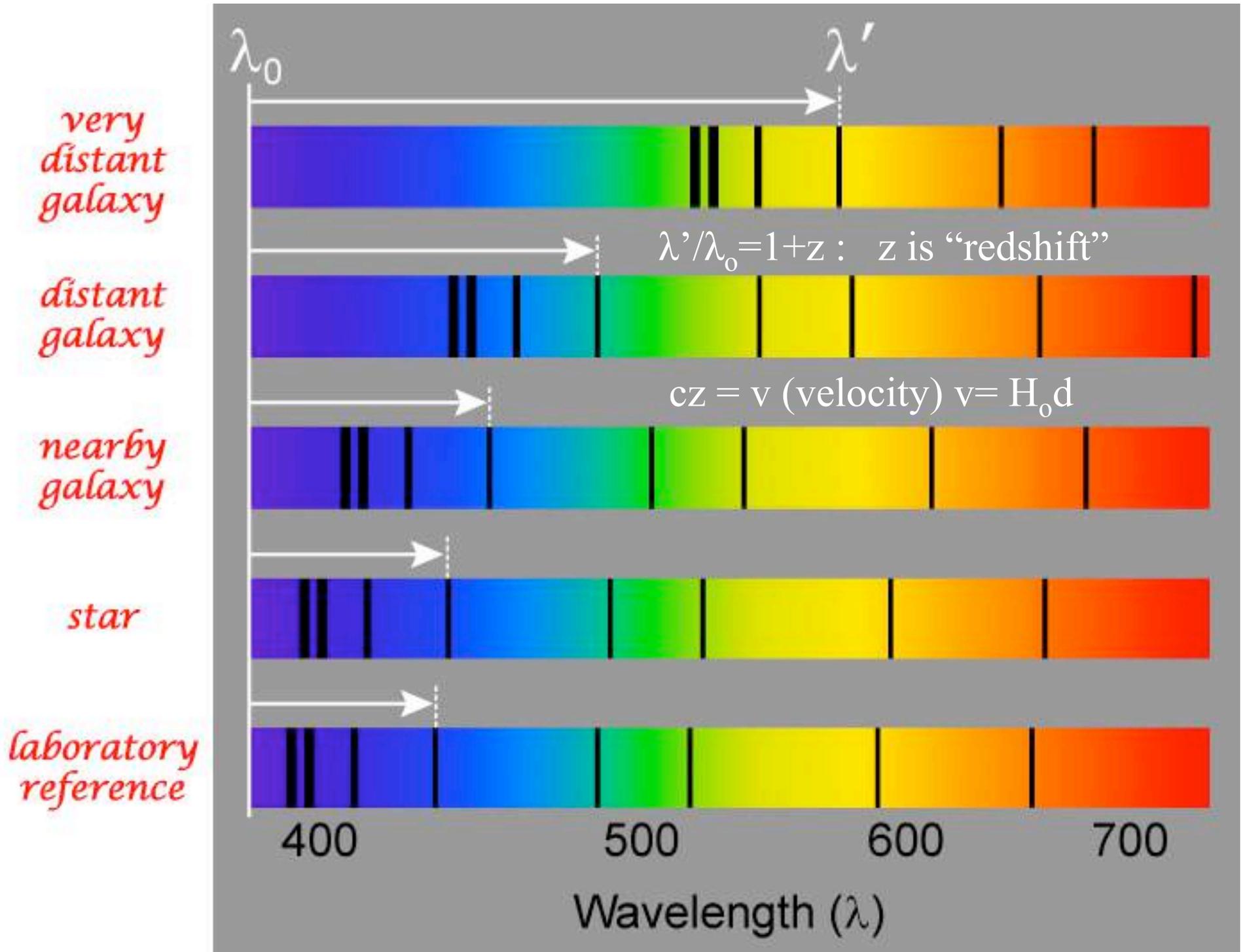
Wavelength (microns)

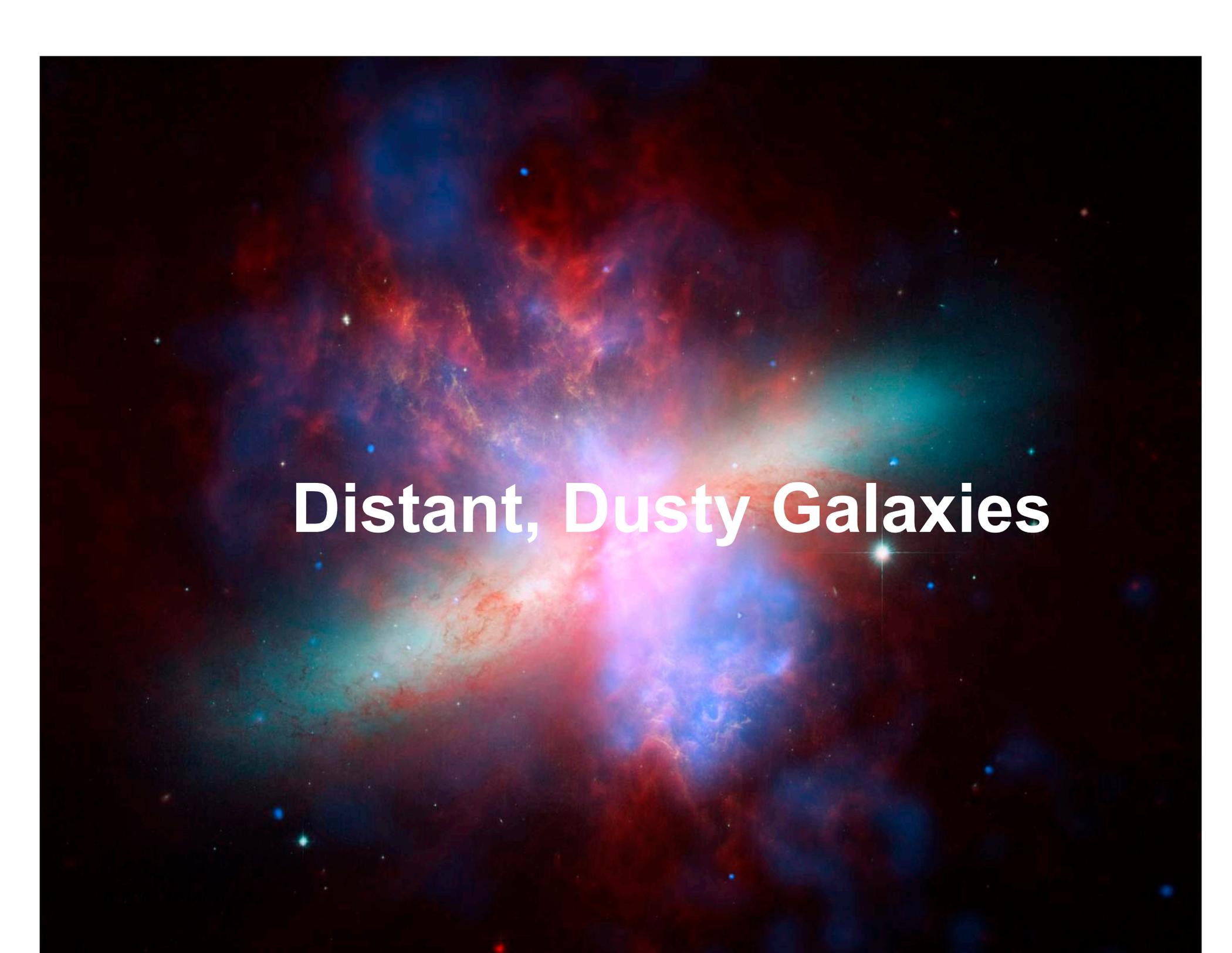
Carr & Najita 2008



THE UNIVERSE IN 1 SLIDE



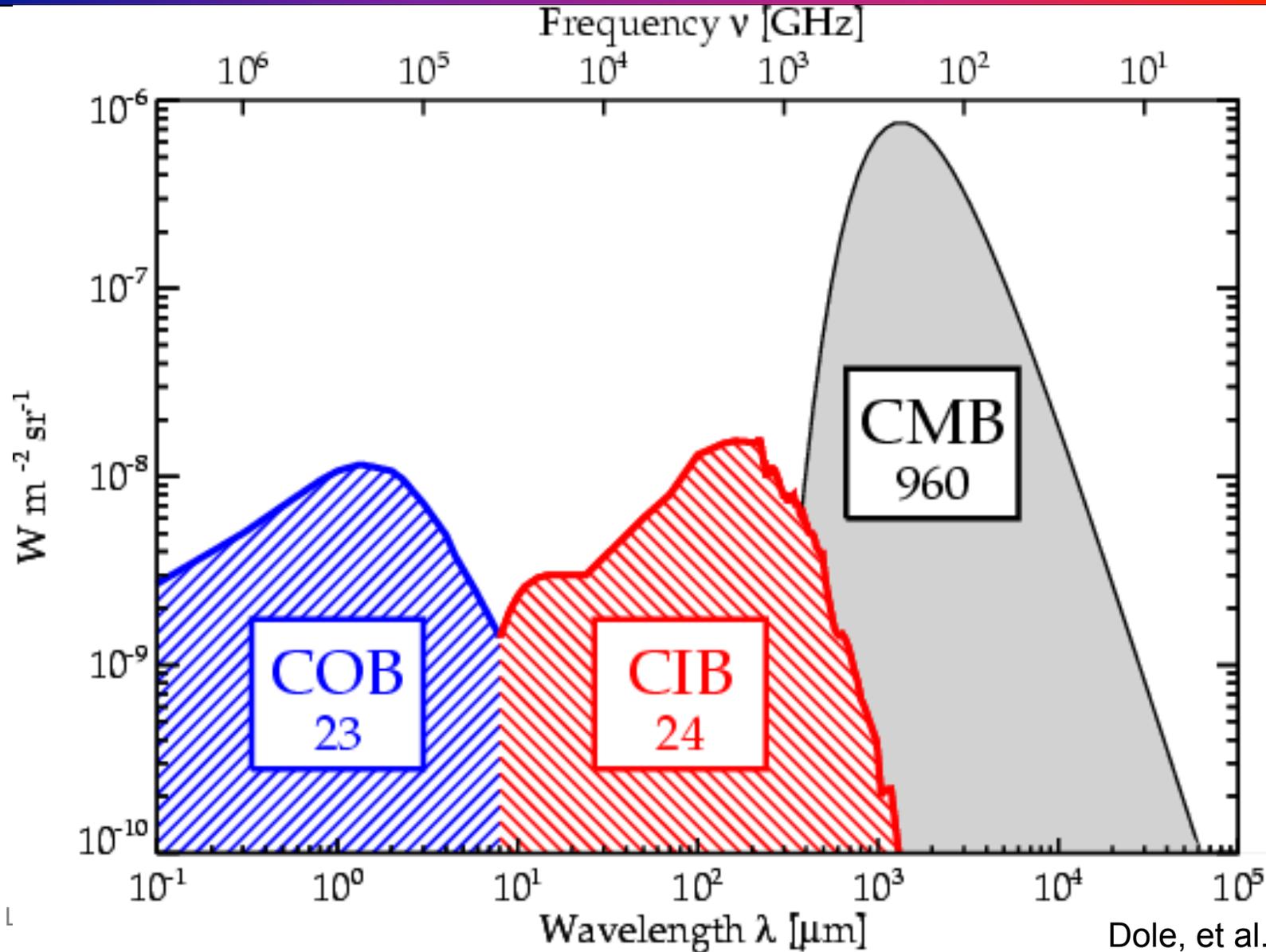




Distant, Dusty Galaxies



The Cosmic Infrared Background



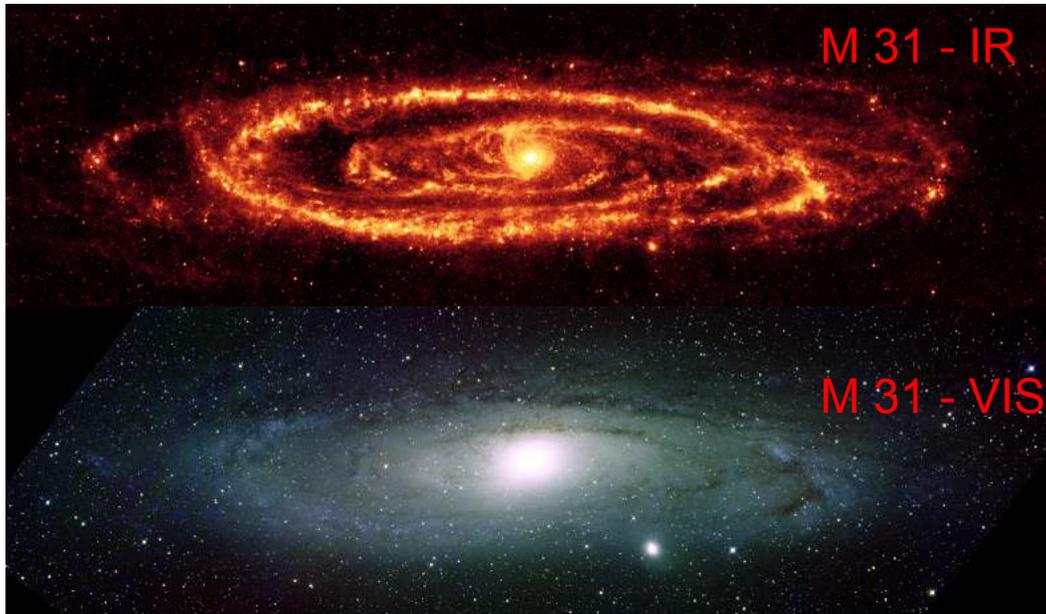
Dole, et al. 2006



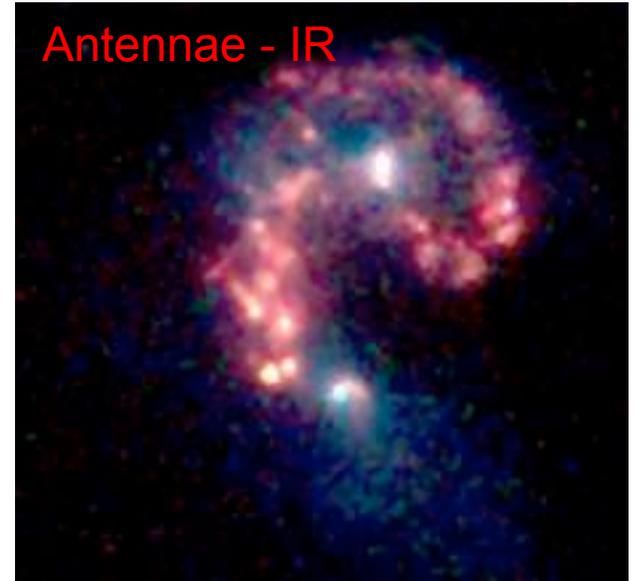
Nearby Galaxies: Boring (M31) Interesting (Arp 220, Antennae)



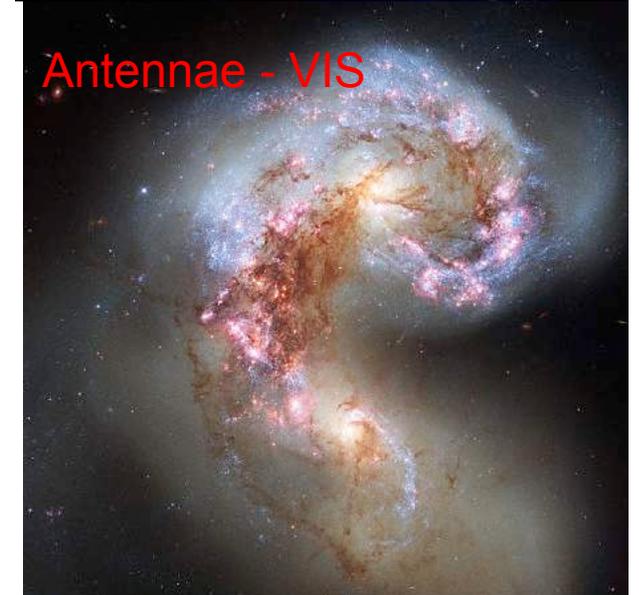
◆ [800 × 580 - en.wikipedia.org](http://800x580-en.wikipedia.org)



Antennae - IR

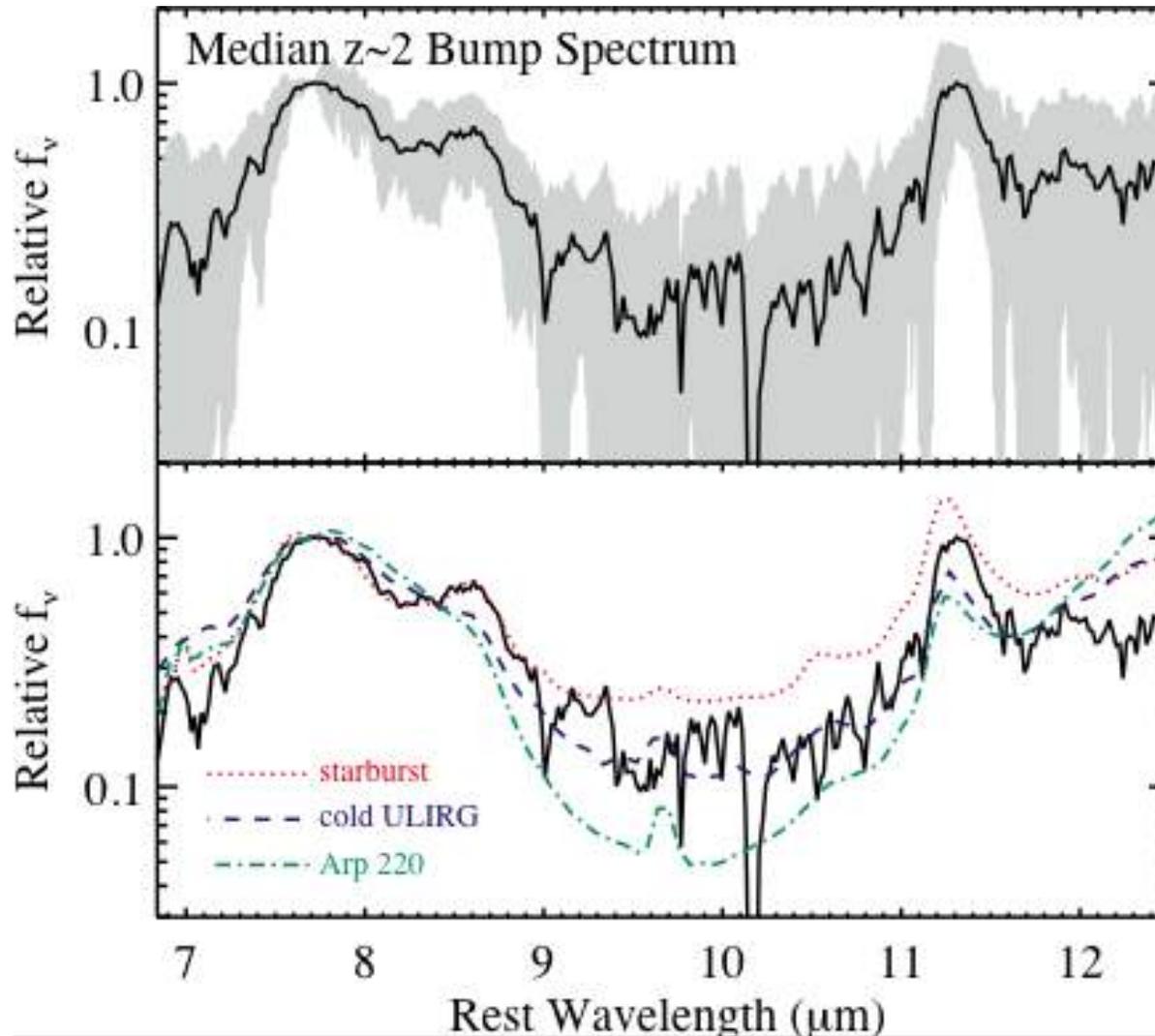


Antennae - VIS





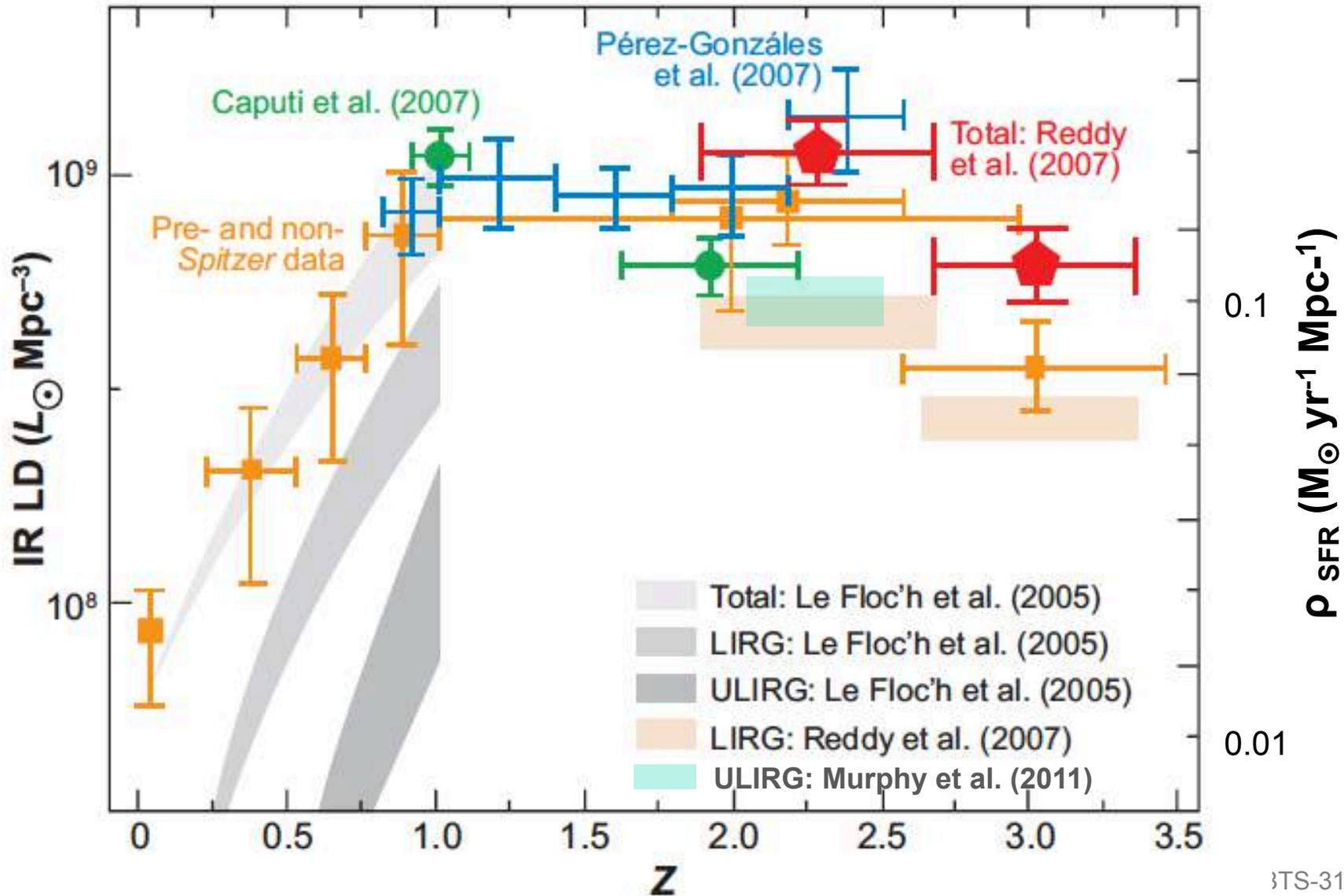
The Most Extreme Infrared Galaxies



Extreme Sources
selected at $24\mu\text{m}$
to have
 $L(24\mu\text{m})/L(R) > 50$,
>98% of Luminosity
emerges in infrared

Most show strong PAH
emission in the rest
frame

Appear at $z \sim 2$ due to
Selection effect





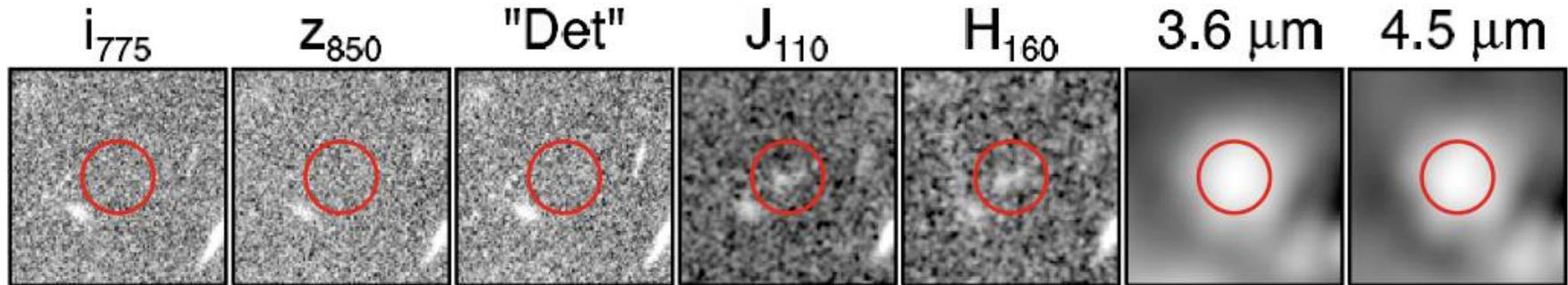
the first billion years of galaxies:
brought to you by some remarkable
observatories

Spitzer, HST, Keck



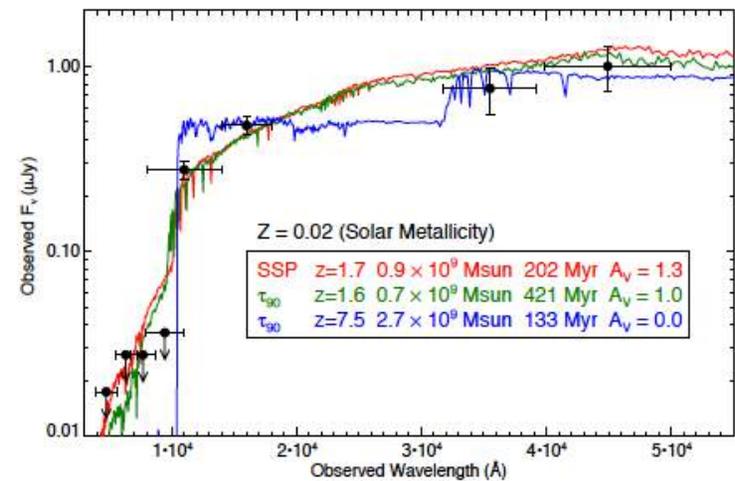
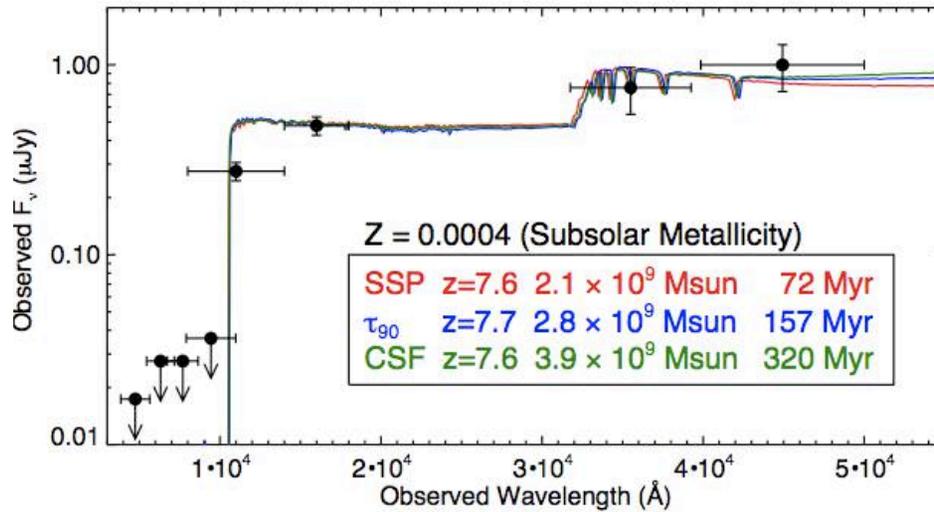


Discovering the Most Distant Galaxies



Possible $z = 7.6$ galaxy along strong lensing caustic. Age of universe 0.7 Gyr, galaxy formed at $z > 8.5$

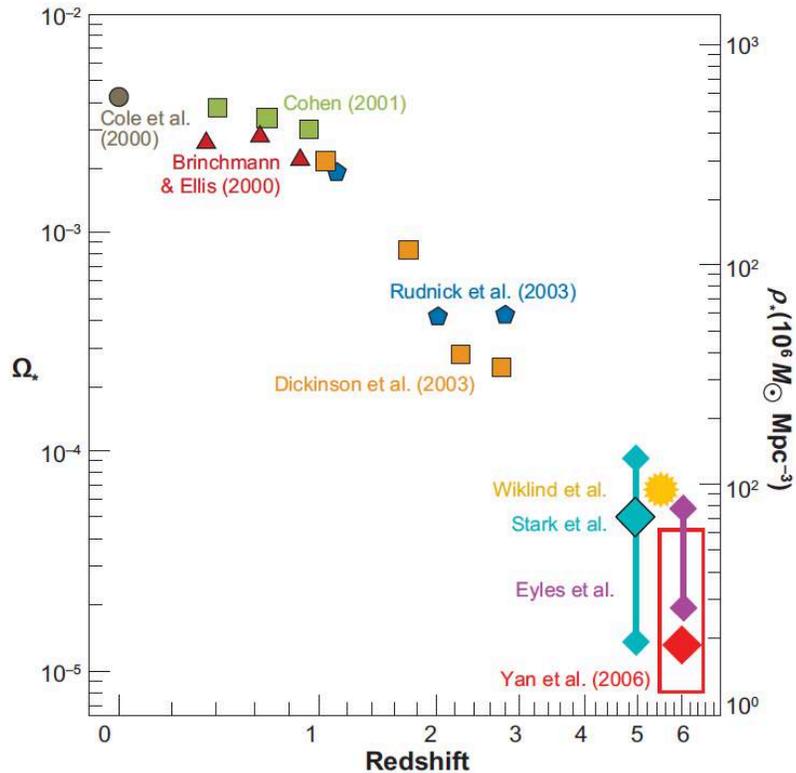
Best fit low redshift solution
Inconsistent with limits at shortest wavelengths



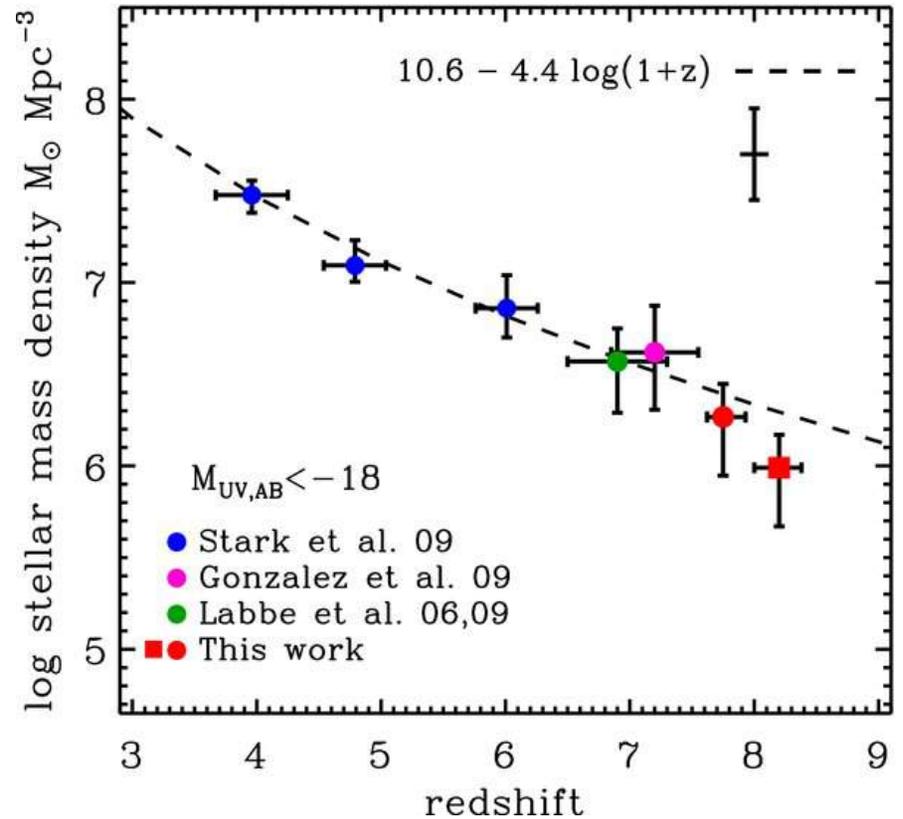
Bradley et al. 2008



The growth of Galaxies in the Universe



Status as of 2007, ARAA



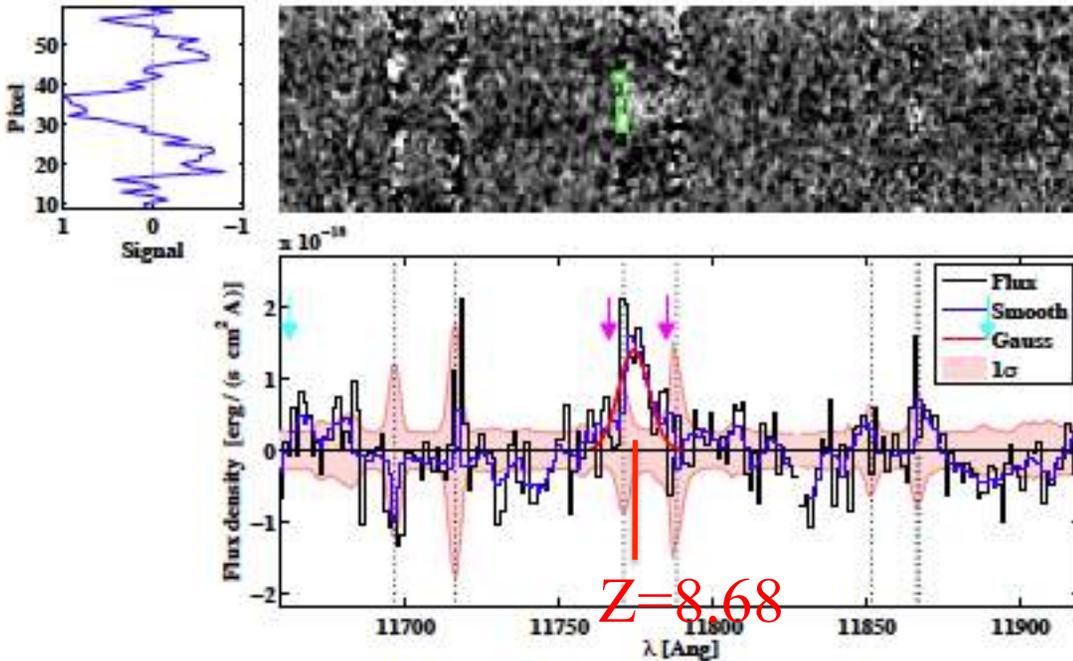
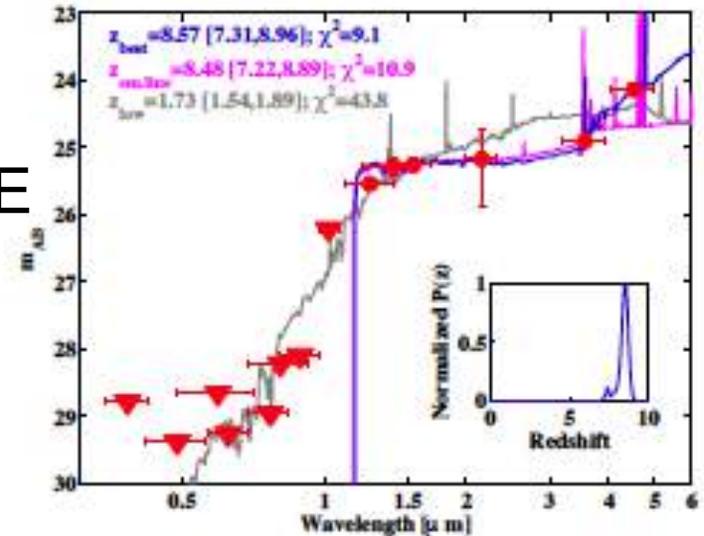
Labbe, et al. 2010



Keck Spectroscopy Confirms Redshifts



Distant Galaxies discovered by Hubble & Spitzer
Redshift confirmed by Keck/MOSFIRE

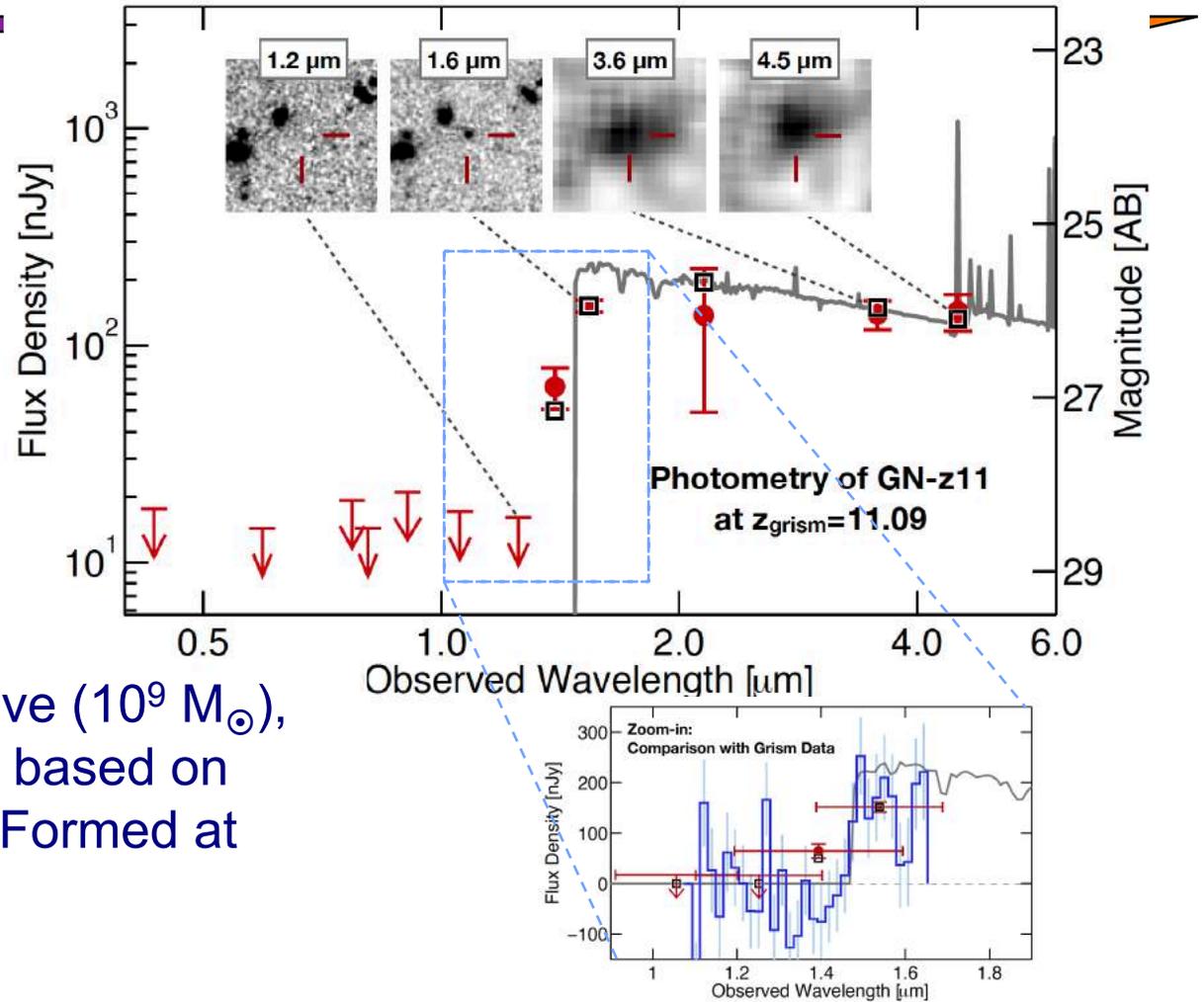


Seen 580 Million Years after the Big Bang

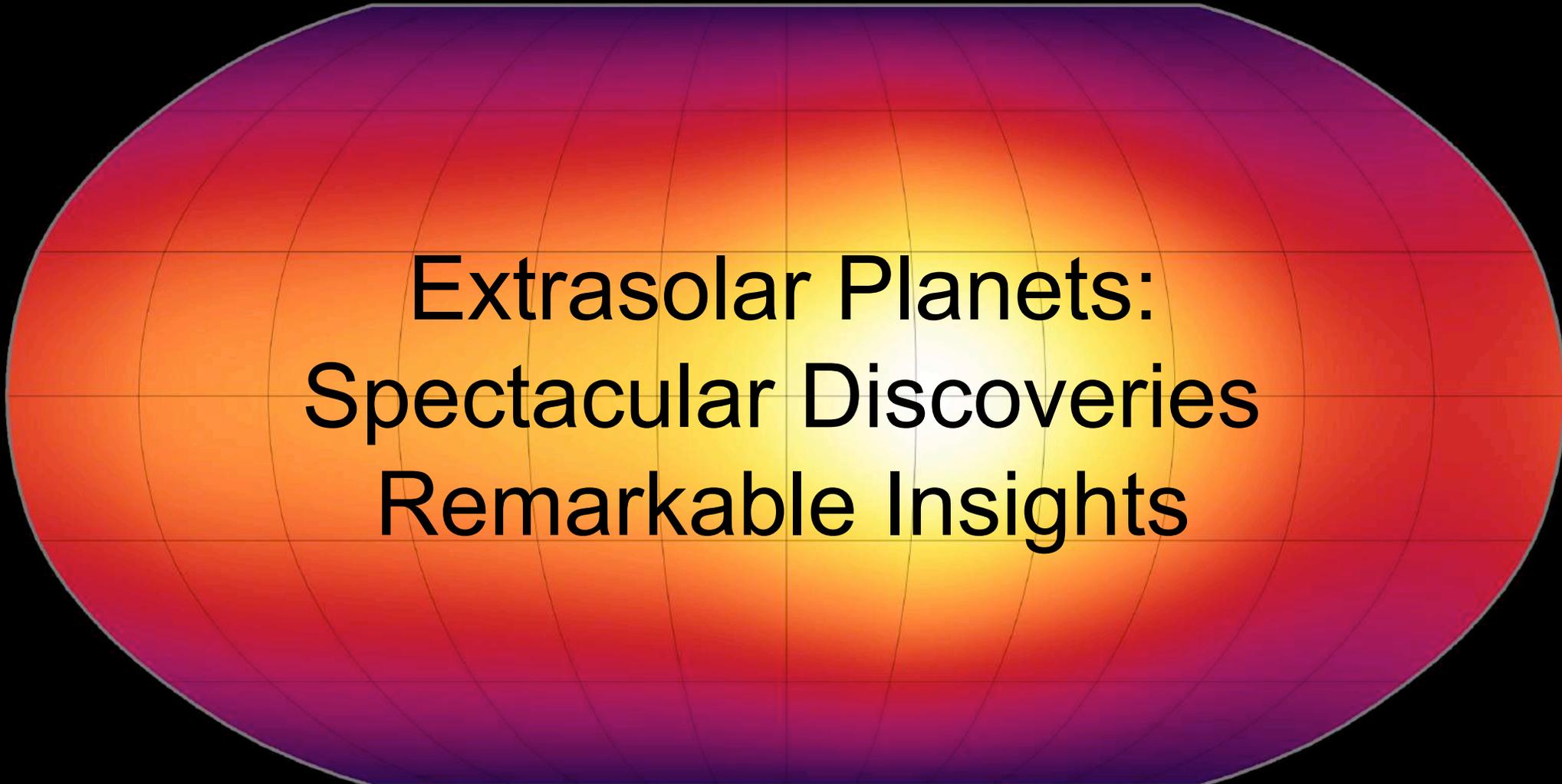
Pushing the Limits The Most Distant Galaxy



- ◆ Bright, $z > 10$ galaxy detected with Spitzer and HST
- ◆ WFC3/HST confirms Ly-break and sets $z=11.09$ (400 Myr after Big Bang)
- Luminous ($3L^*$), massive ($10^9 M_{\odot}$), young (40 Myr) galaxy based on Spitzer observations. Formed at $z \sim 12$
- Prime target for JWST.



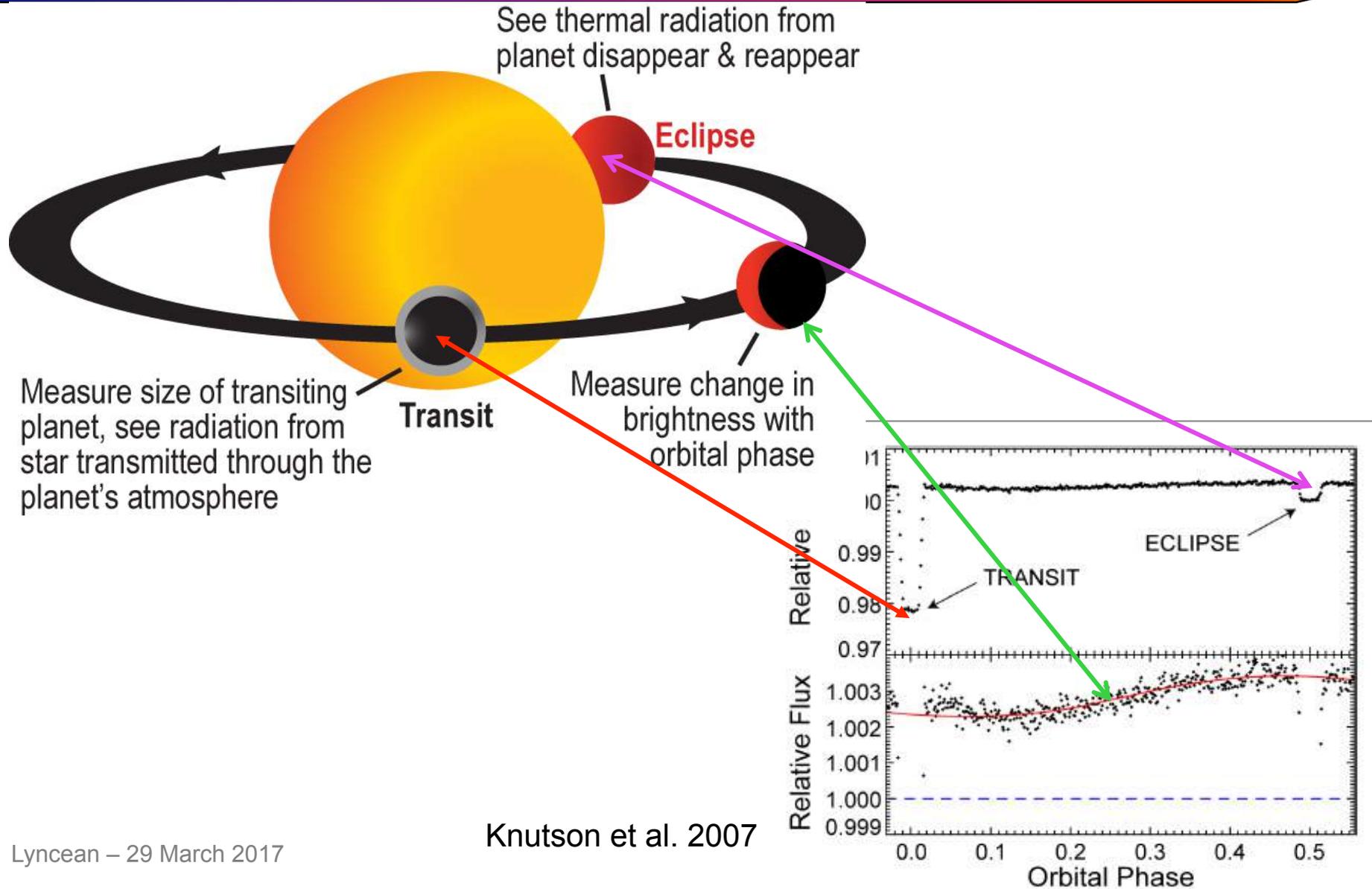
Oesch et al. 2016



**Extrasolar Planets:
Spectacular Discoveries
Remarkable Insights**

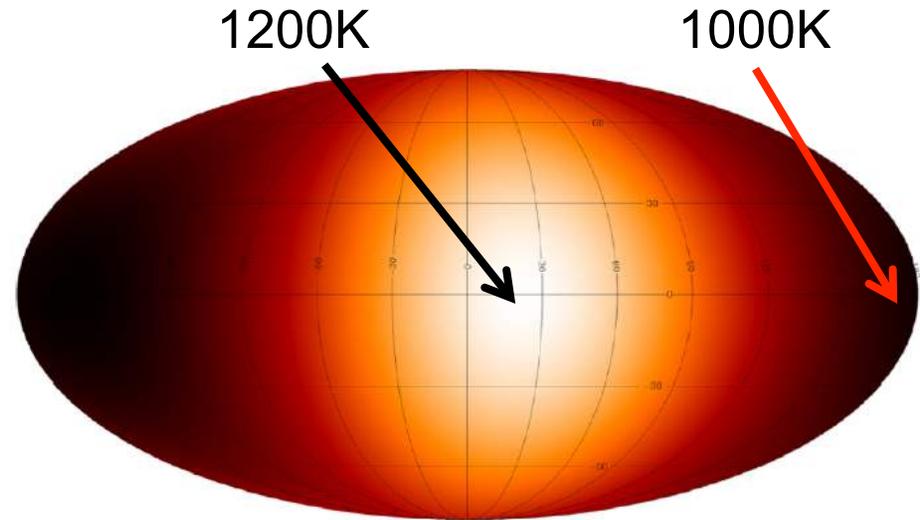
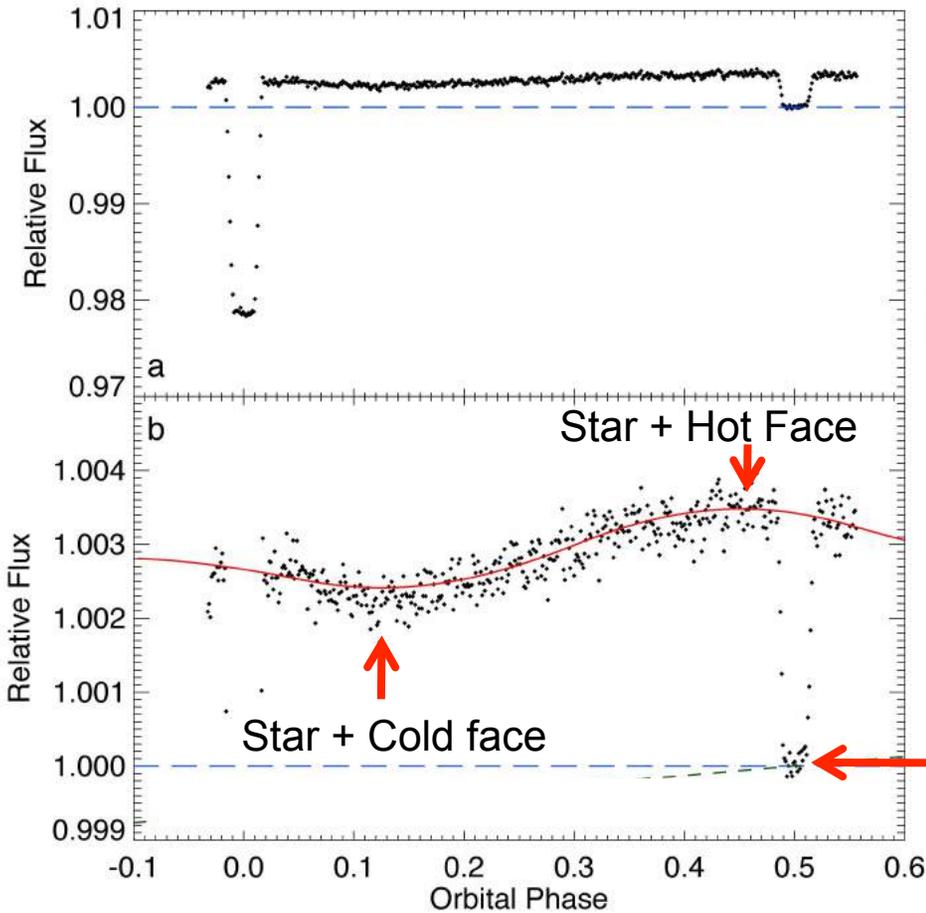


Transits, Eclipses And Phase Curves





Mapping the Brightness Distribution in 189733b



Reconstructed Image Majeau et al, 2012

Star Only

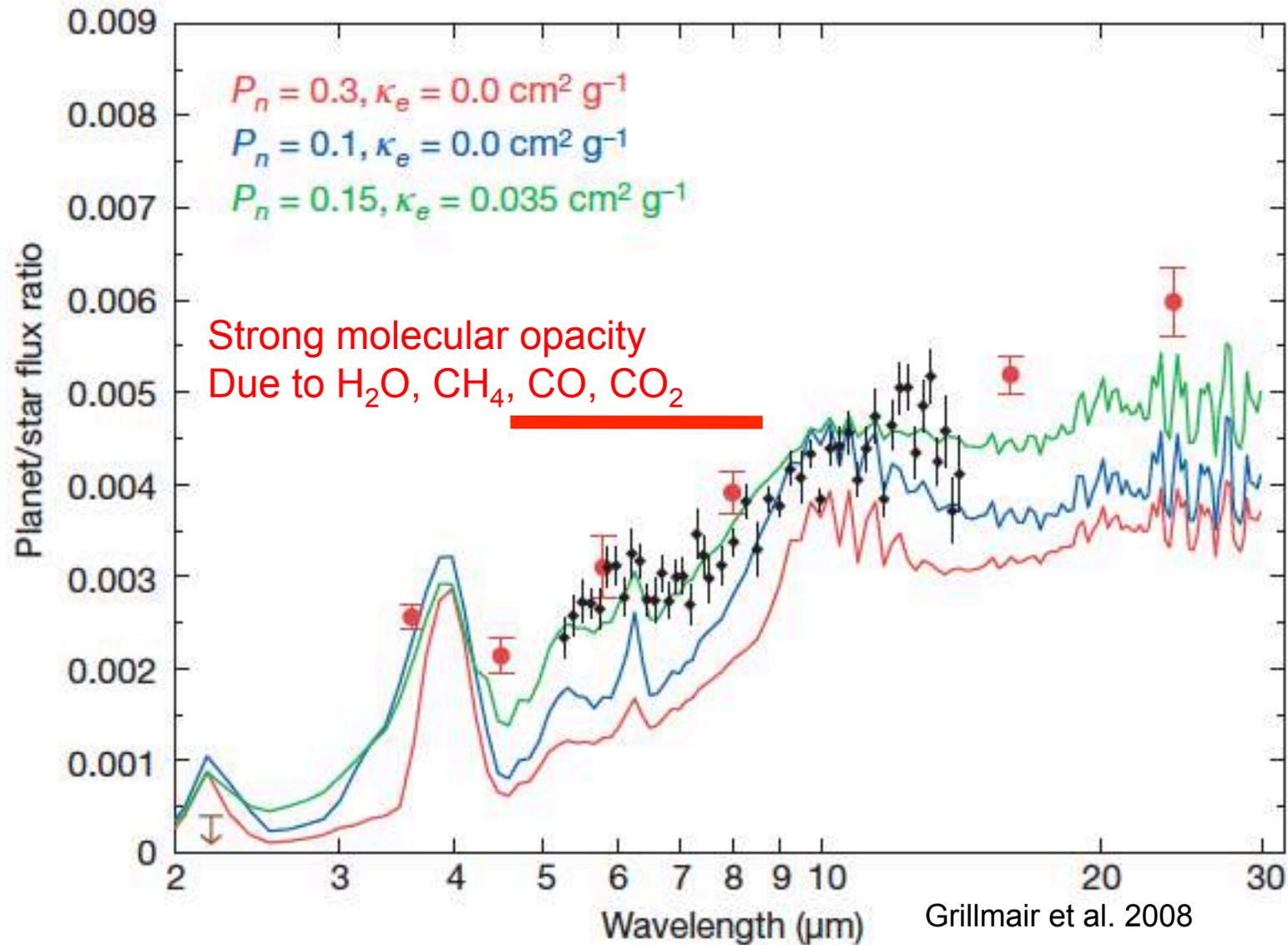
8 μ m observations of HD189733
33 hrs continuous observations

Knutson et al. 2007
Lyncean – 29 March 2017

“warm spot” 30 degrees E of high-noon point.
High “easterly” winds, 6000 mph, carries heat around planet



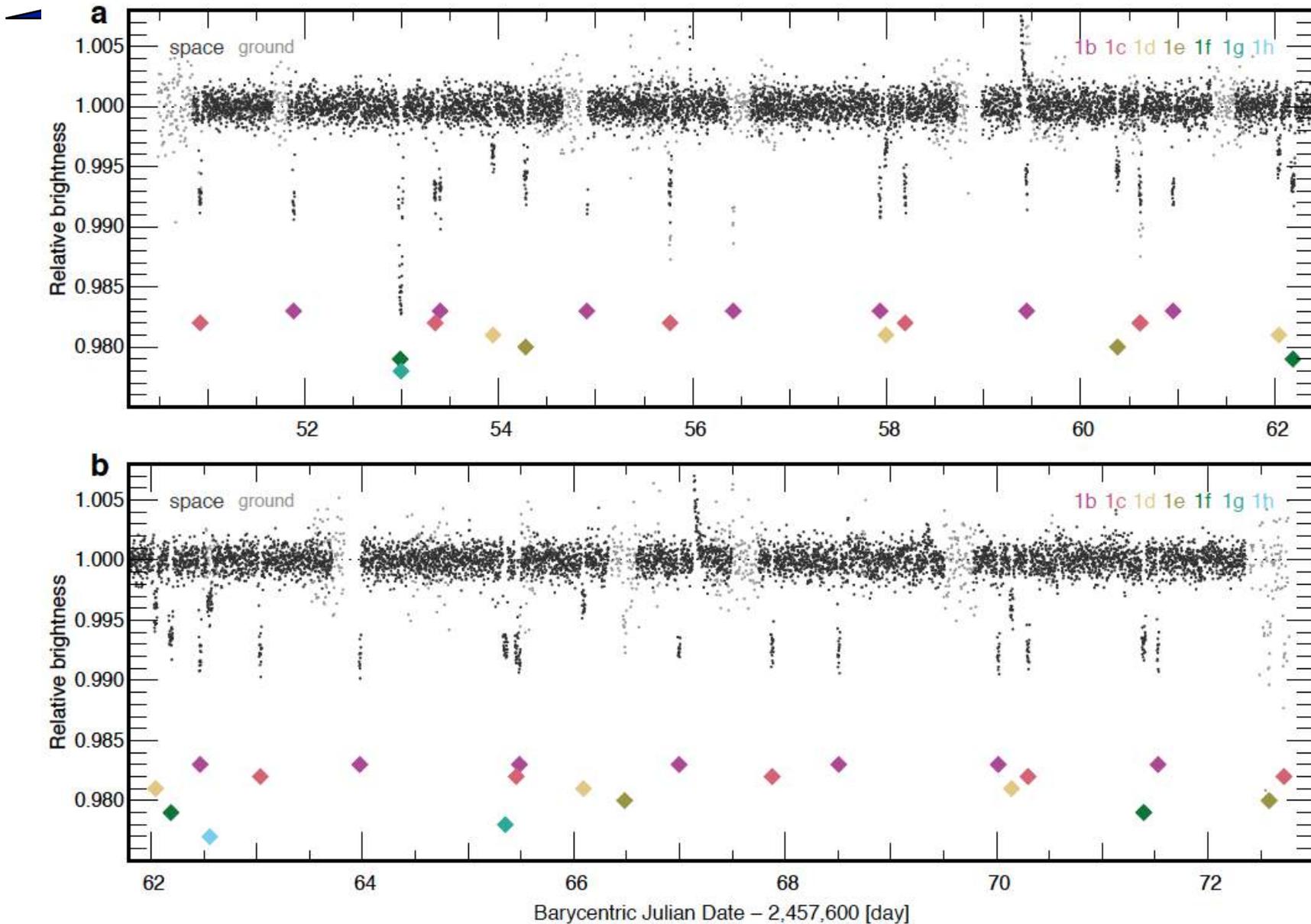
Daytime Spectrum of HD189733b





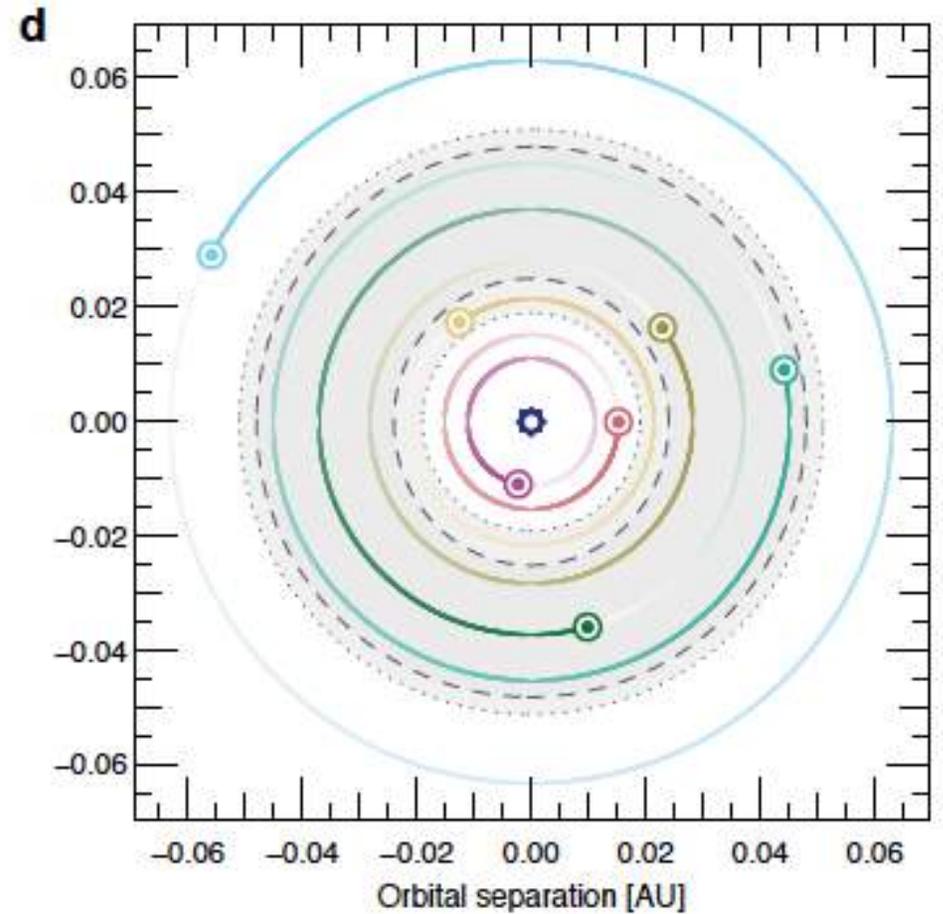
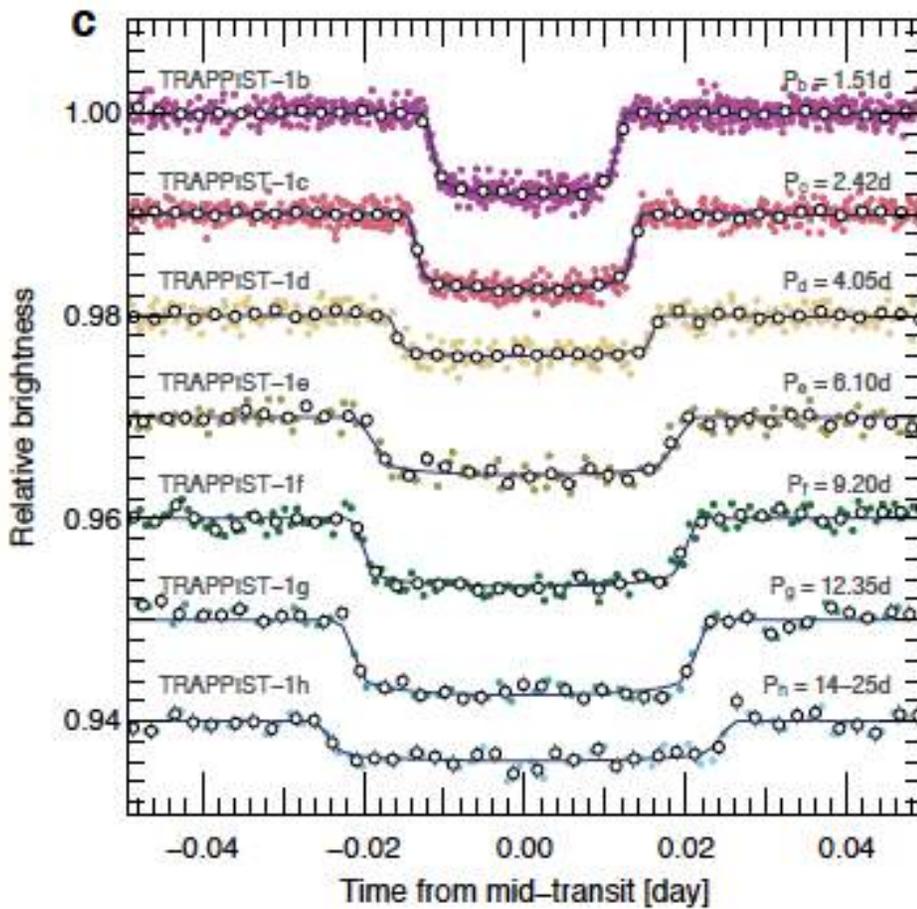


The Most Amazing System Yet TRAPPIST 1 – 20 days of Spitzer





7 Earthsize Planets 3 in Habitable Zone

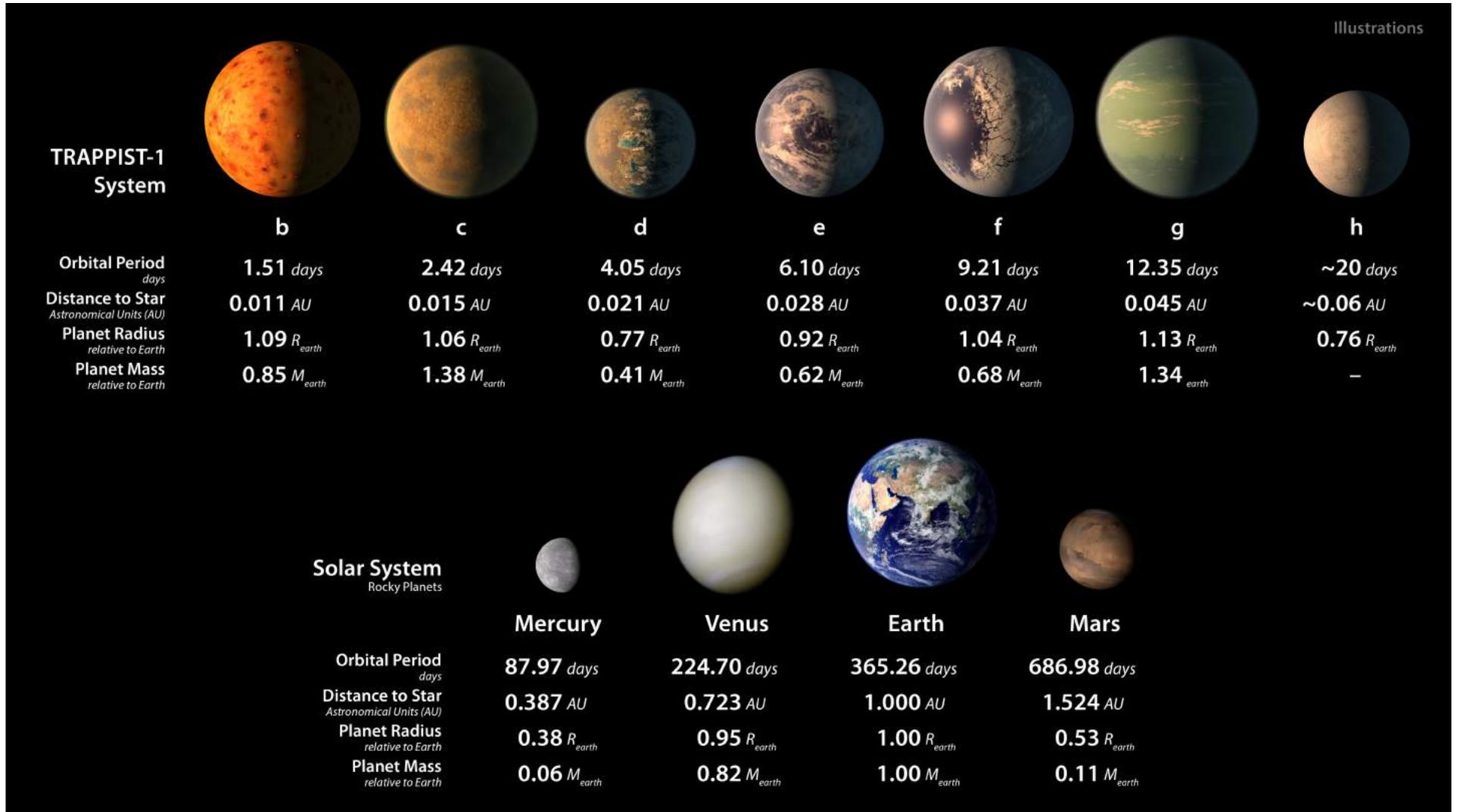




TRAPPIST-1 System

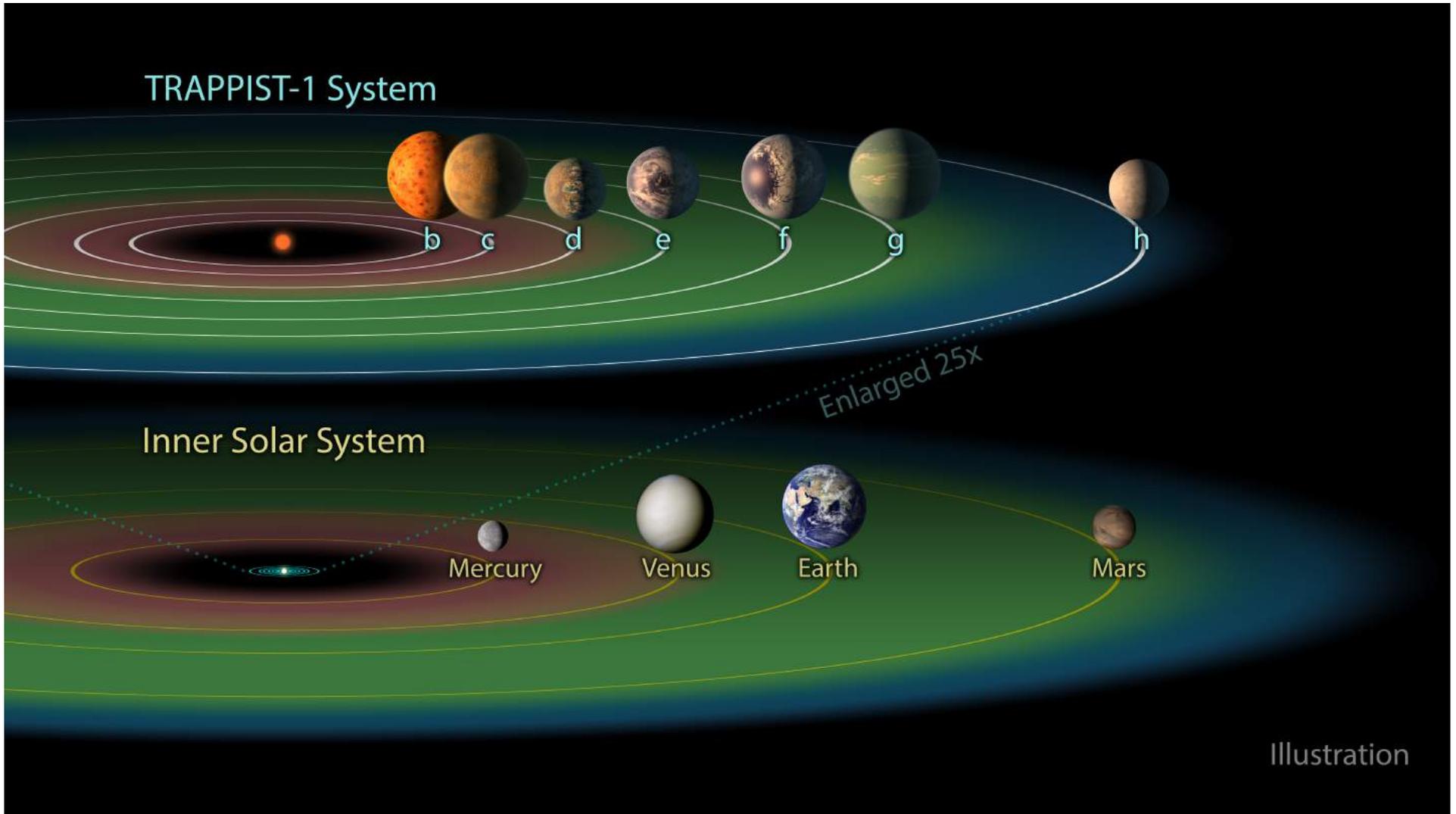


Illustration





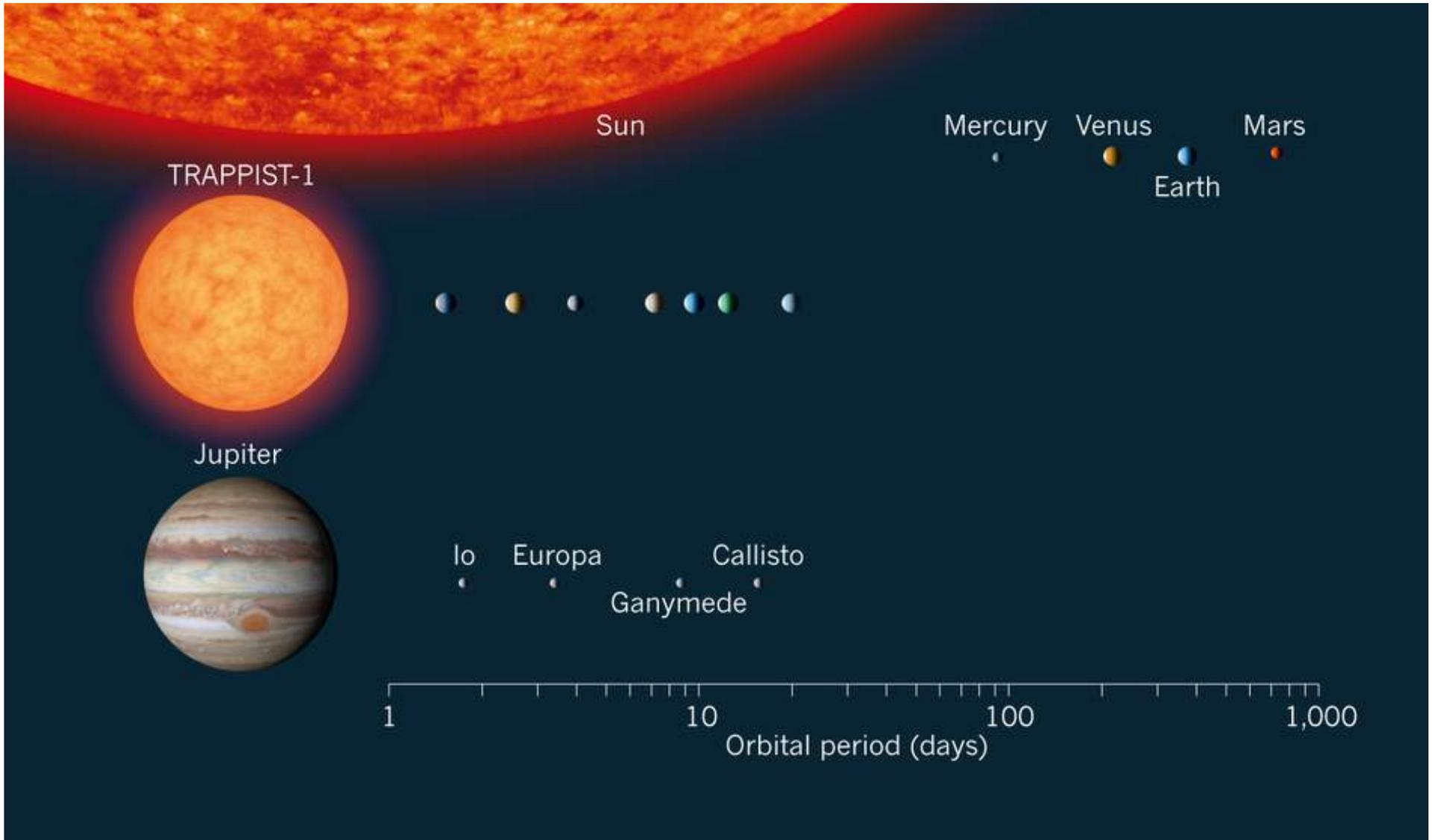
Habitable Zone in Trappist System



Illustration



The Trappist & Jovian Systems





Properties of Trappist 1 Planets

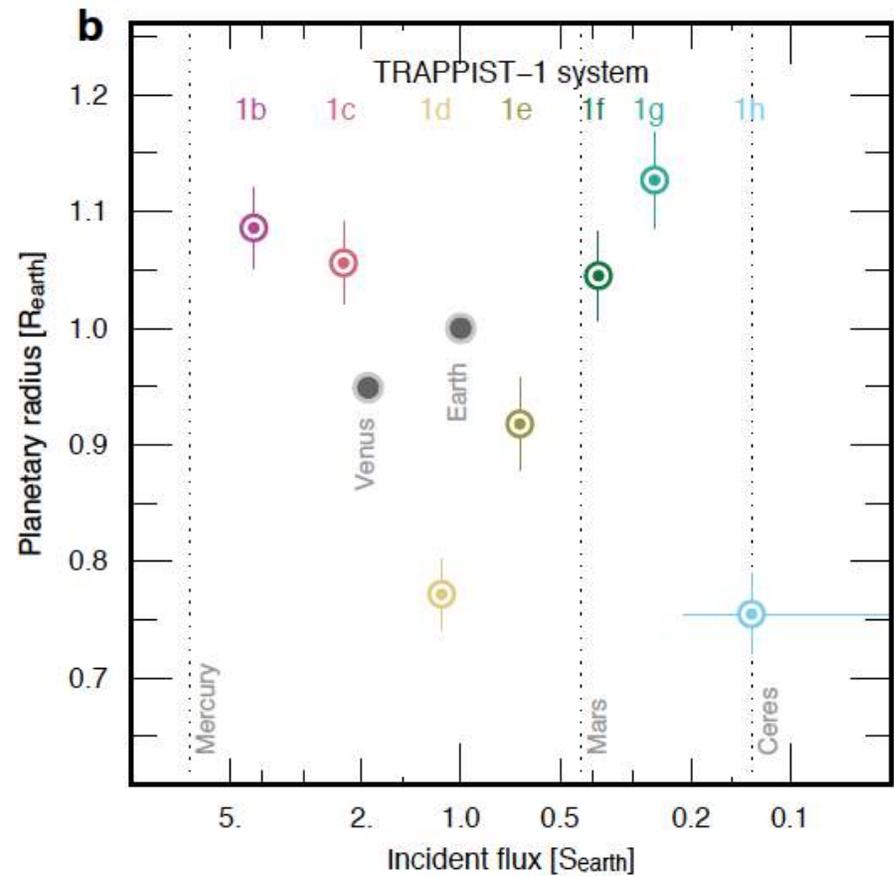
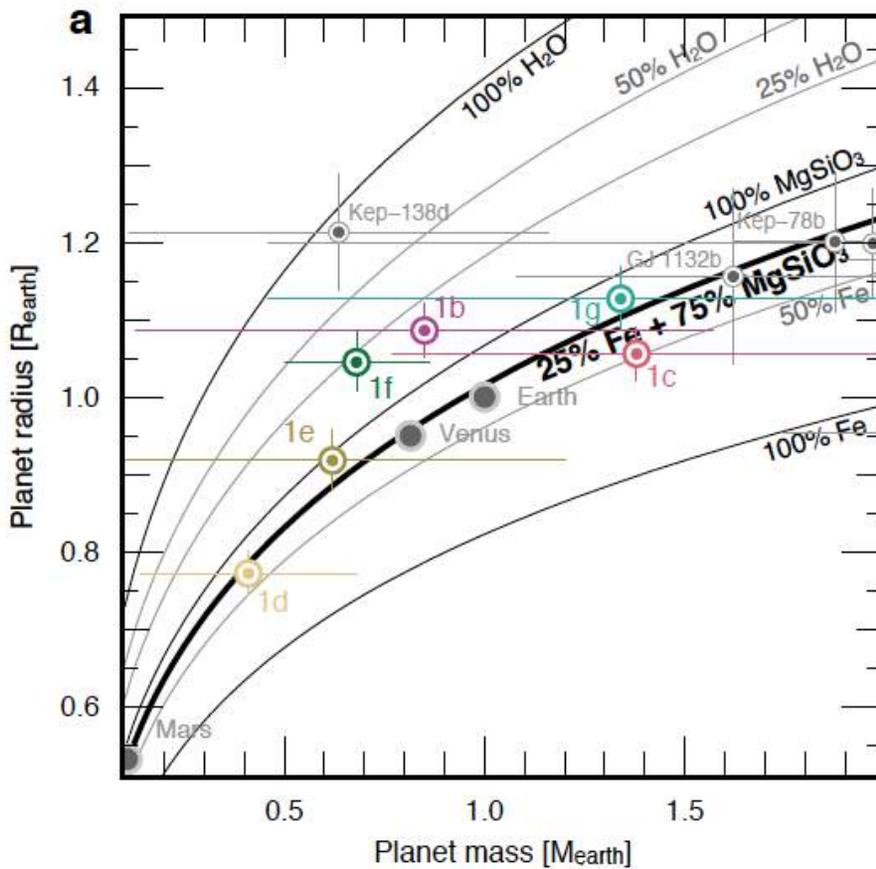


Planet	b	c	d	e	f	g	h
Period (d)	1.51	2.42	4.05	6.10	9.21	12.35	20+15/-6 (18.76 ⁺)
R (R_{earth})	1.1	1.06	0.77	0.92	1.05	1.13	0.72 ⁺
a (10^{-3} au)	11	15	21	28	37	45	60 ⁺
Irr (S_{earth})	4.3	2.3	1.1	0.7	0.4	0.26	0.15 ⁺
T_{eq} (K)*	400	342	288	251	219	199	169 ⁺

For Reference: Mercury = 6.7 S_{earth} , Venus= 1.9 S_{earth} , Mars=0.43 S_{earth} , Ceres=0.13 S_{earth}

* Assuming albedo = 0, i.e. black surface

+ New result from Kepler – 15 March 2017





Era of Rocky Planets Discovery Has Begun



Groundbased searches

- ◆ Trappist survey has found 1 low mass star with 7 planets in searching 60 low mass stars
- ◆ Speculoos – follow-on to Trappist – will search for planets around 1000 low mass stars
- ◆ SuperWASP, XO, HAT, among many other “transit” projects underway

Spacebased searches

- ◆ K2 searches fields
- ◆ TESS, CHEOP – Space missions to be launched in 2018

Spitzer will pursue follow-up of discoveries through March 2019, possibly through 2020