



# Spitzer Beyond: The incredible continuing adventures of the Spitzer Space Telescope

Sean Carey  
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IPAC/Caltech

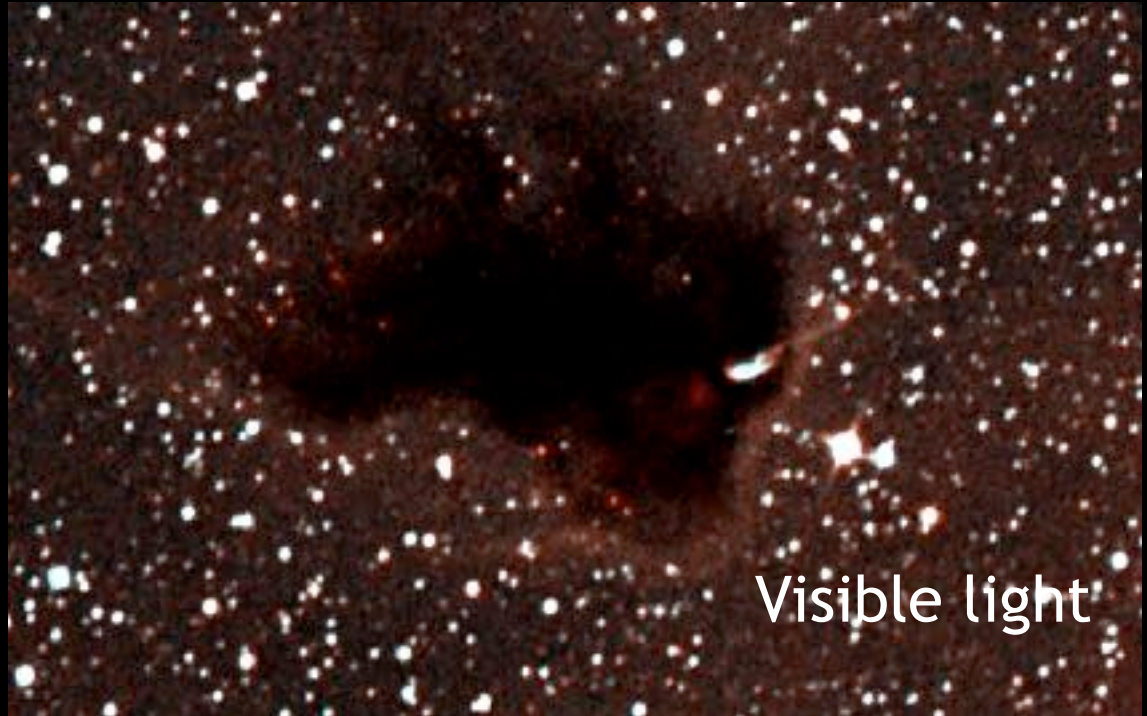


# Why Infrared?



# Why Infrared?

Objects colder than stars give off infrared light



# Why Infrared?

Objects colder than stars give off infrared light

Protostars

Planets

Asteroids and  
Comets



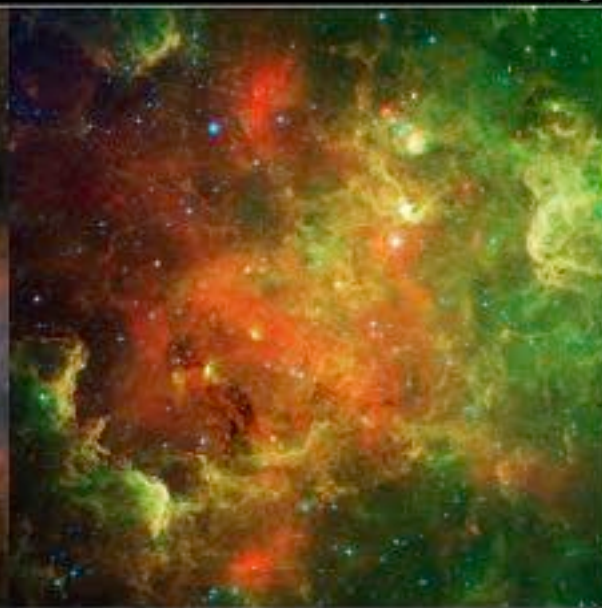
# Why Infrared?

Easier to see  
through dust in  
the infrared

Visible Light (DSS/D. De Martin)



Infrared Light

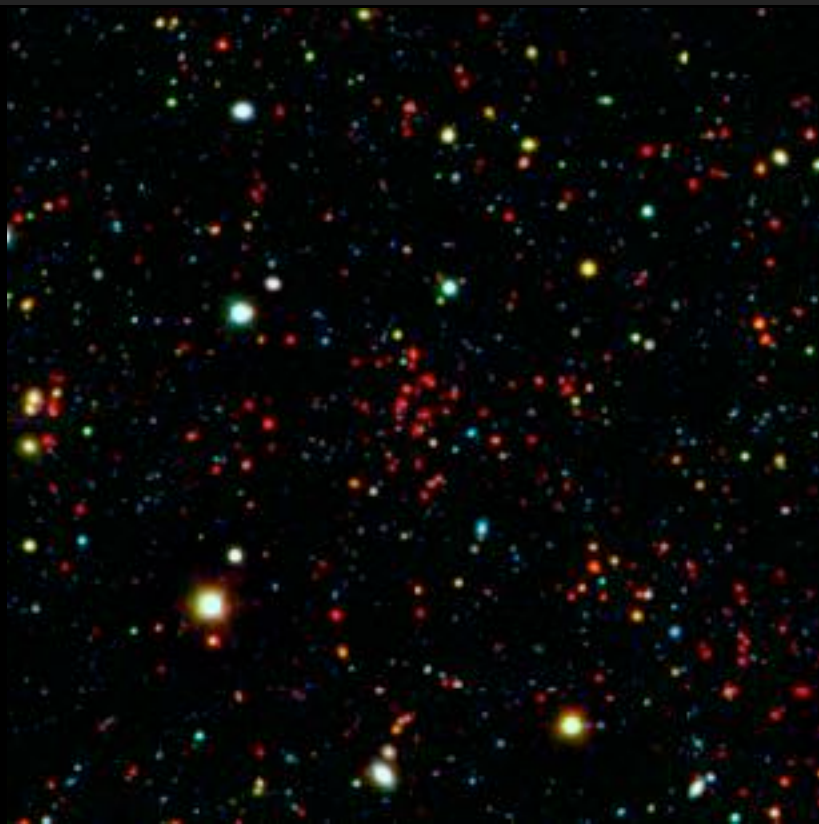


North America Nebula Comparison  
NASA / JPL-Caltech / L. Rebull (SSC/Caltech)

Spitzer Space Telescope • IRAC • MIPS  
ssc2011-03b

# Why Infrared?

Easier to see  
objects in the  
early Universe



Reddish  
blobs are  
distant  
galaxies

# Why Infrared?

Easier to see  
objects in the  
early Universe

Light from  
objects gets  
progressively  
redder with  
distance due to  
expansion of  
Universe



Reddish  
blobs are  
distant  
galaxies



# The Spitzer Space Telescope

Spitzer launched 25 August 2003

Last of NASA's Great Observatories Program

Expected lifetime 5 years

Cryogenic mission ended 15 May 2009

Warm mission science started 27 July 2009 and is still going!



# The Spitzer Space Telescope was named after Lyman Spitzer

Expert in the interstellar  
medium



# The Spitzer Space Telescope was named after Lyman Spitzer

Expert in the interstellar medium

First to think of a telescope in space

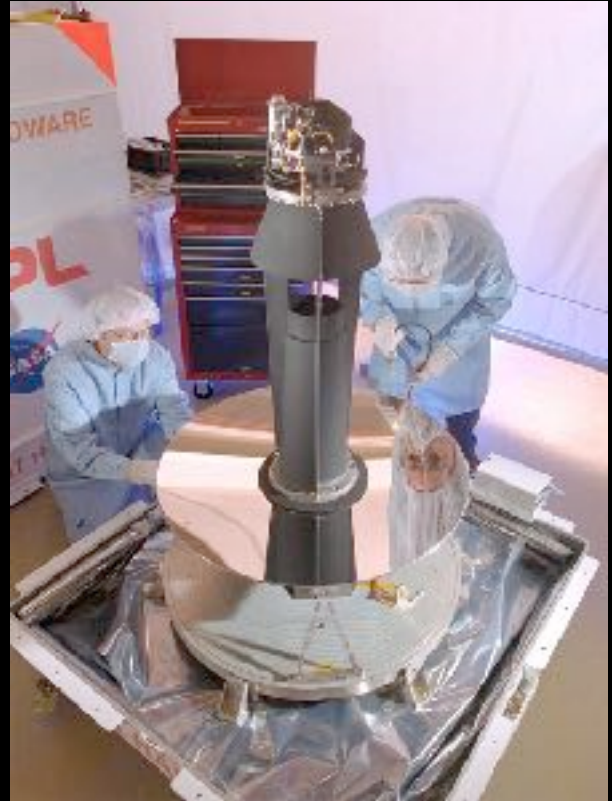


1990 reprinting of his 1946 article



# The Spitzer Space Telescope

85 cm infrared telescope

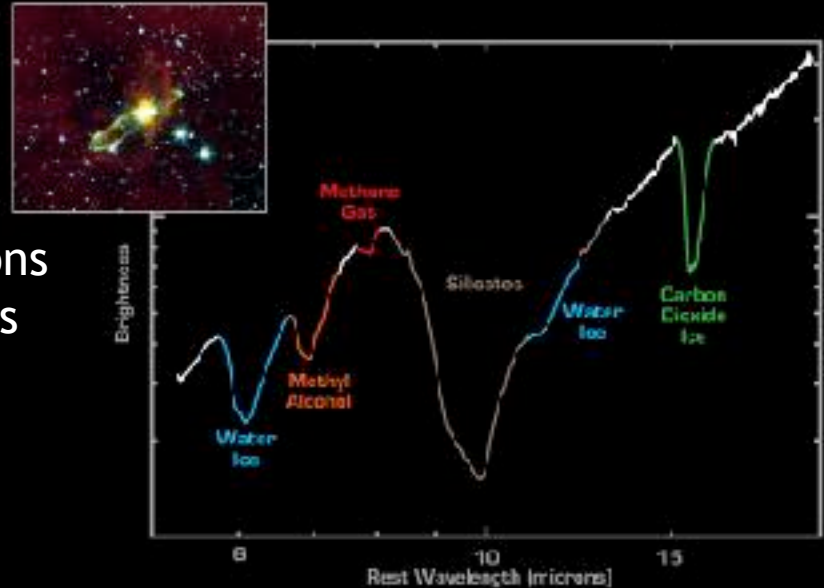


# The Spitzer Space Telescope

85 cm infrared telescope

3 instruments

set of 4 cameras from 3-9 microns  
spectrographs from 5-38 microns  
cameras at 24, 70, 160 microns



Embedded Outflow in HH 45/47

MAGE / JPL-Caltech / A. Neriello-Crespo (SSC, Caltech)

Spitzer Space Telescope • IRS • IRAC

iss2008-86j

# The Spitzer Space Telescope

85 cm infrared telescope

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Earth-trailing orbit around the sun



# The Spitzer Space Telescope

85 cm infrared telescope

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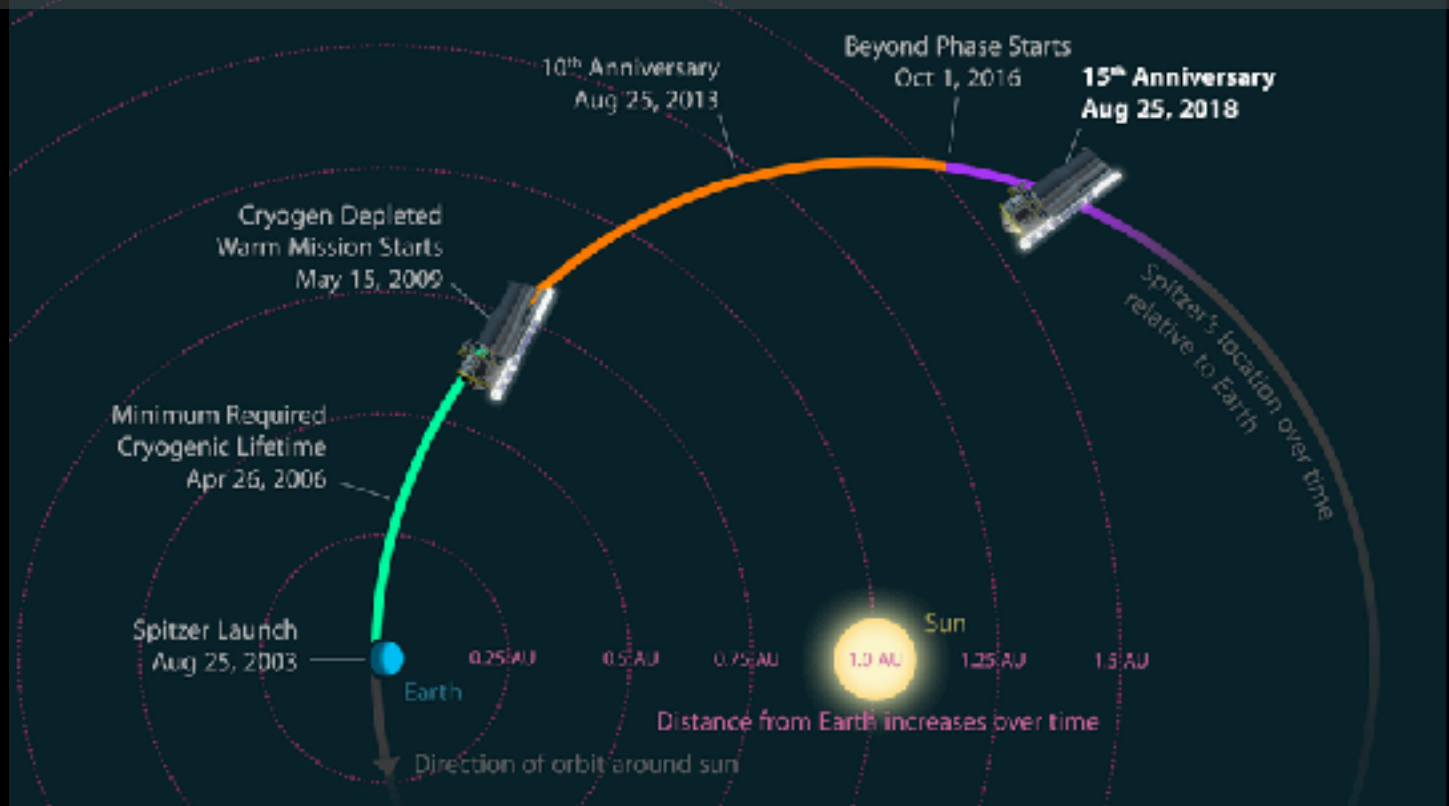
set of 4 cameras from 3-9 microns  
spectrographs from 5-38 microns  
cameras at 24, 70, 160 microns

Earth-trailing orbit around the sun

Passive cooling



# Spitzer gets farther away from the Earth







# Structure of our Galaxy



A Roadmap to the Milky Way

(artist's concept)

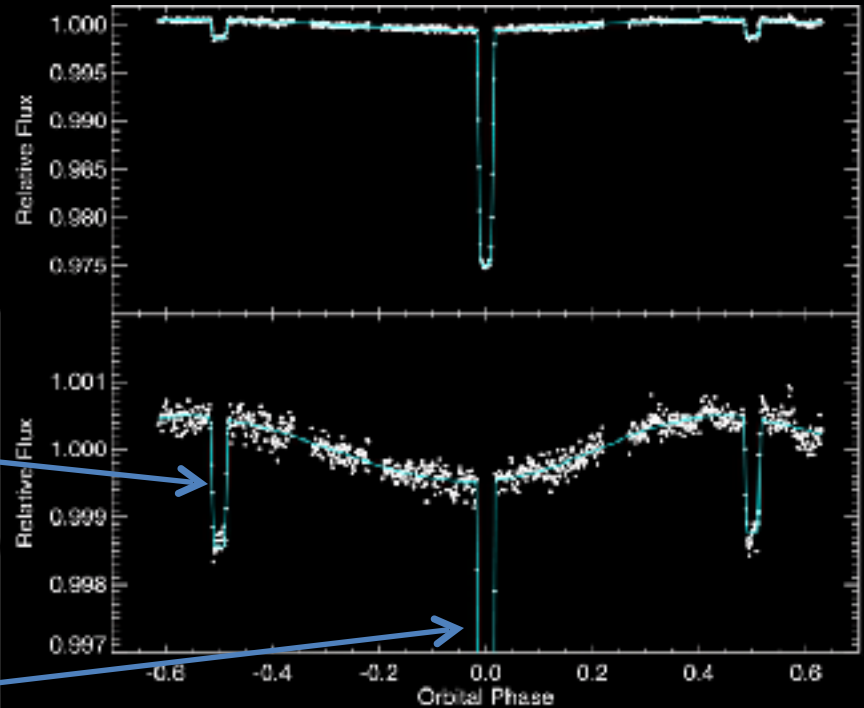
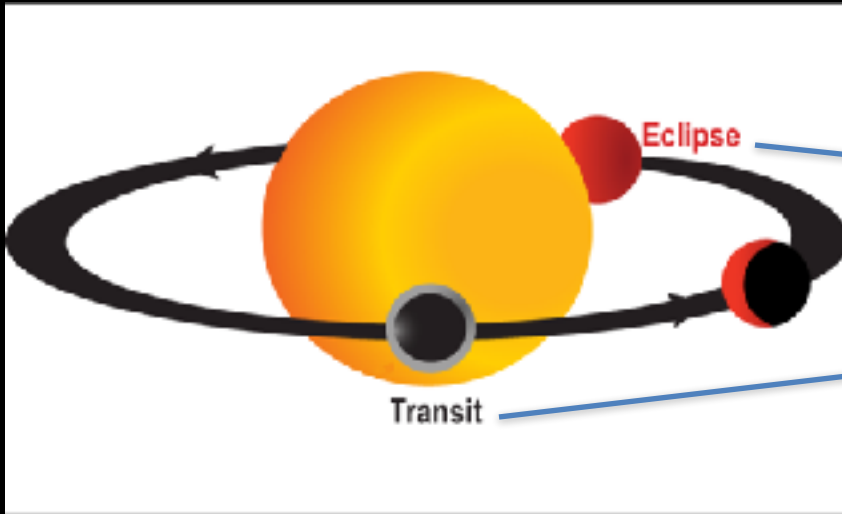
NASA / JPL-Caltech / R. Hurt (SSC-Caltech)

ssc2000-10a

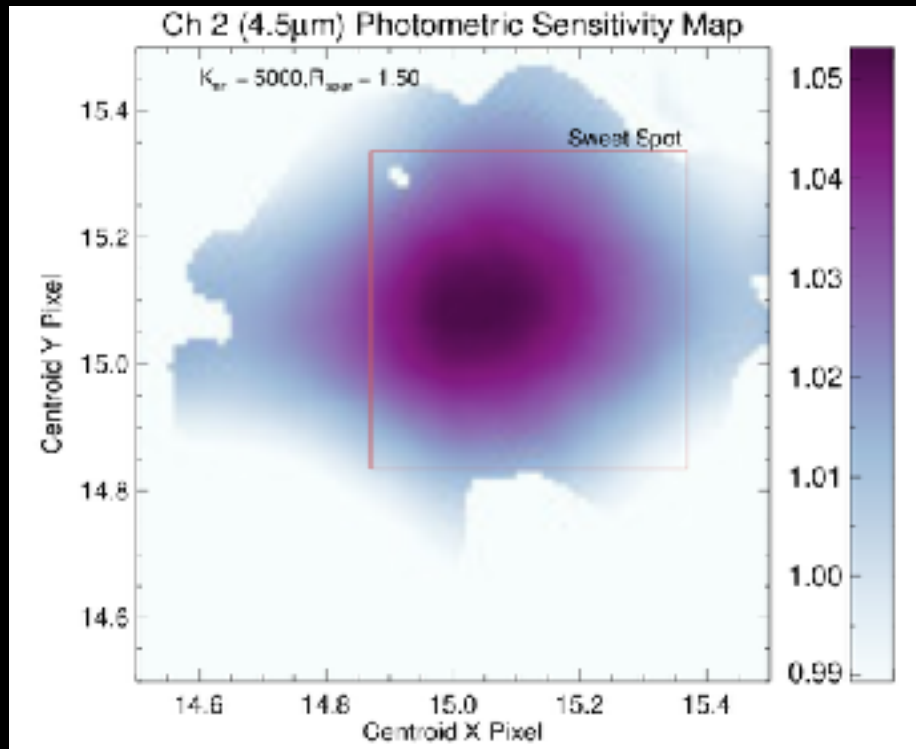
# Transiting Exoplanets

HD 189733b

Knutson et al. (2012)

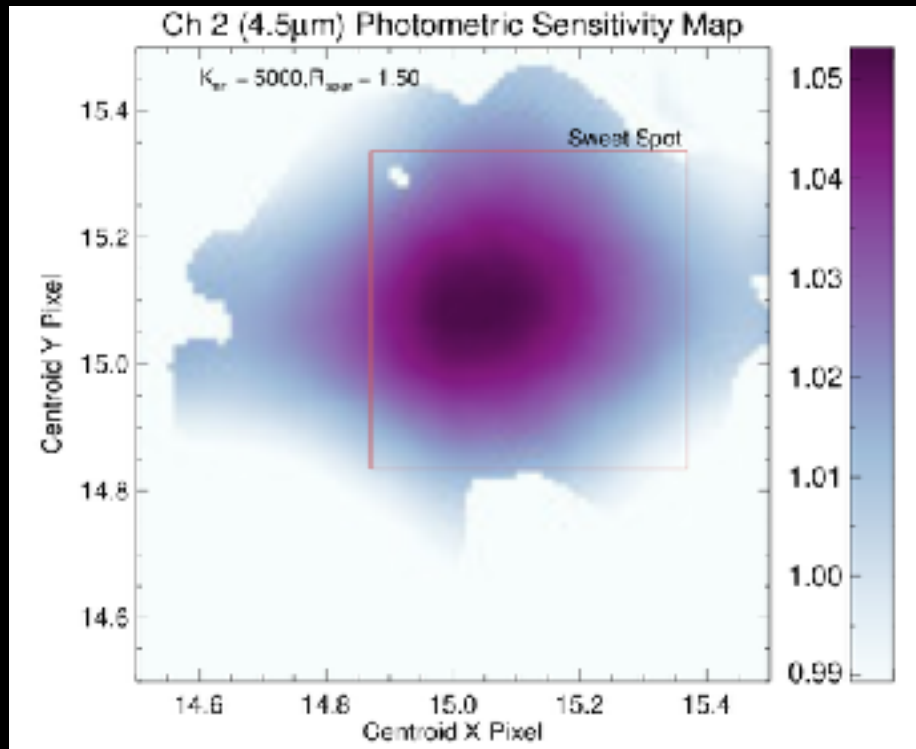


# Spitzer was not designed for exoplanets



Ingalls et al.  
(2018)

# Spitzer was not designed for exoplanets

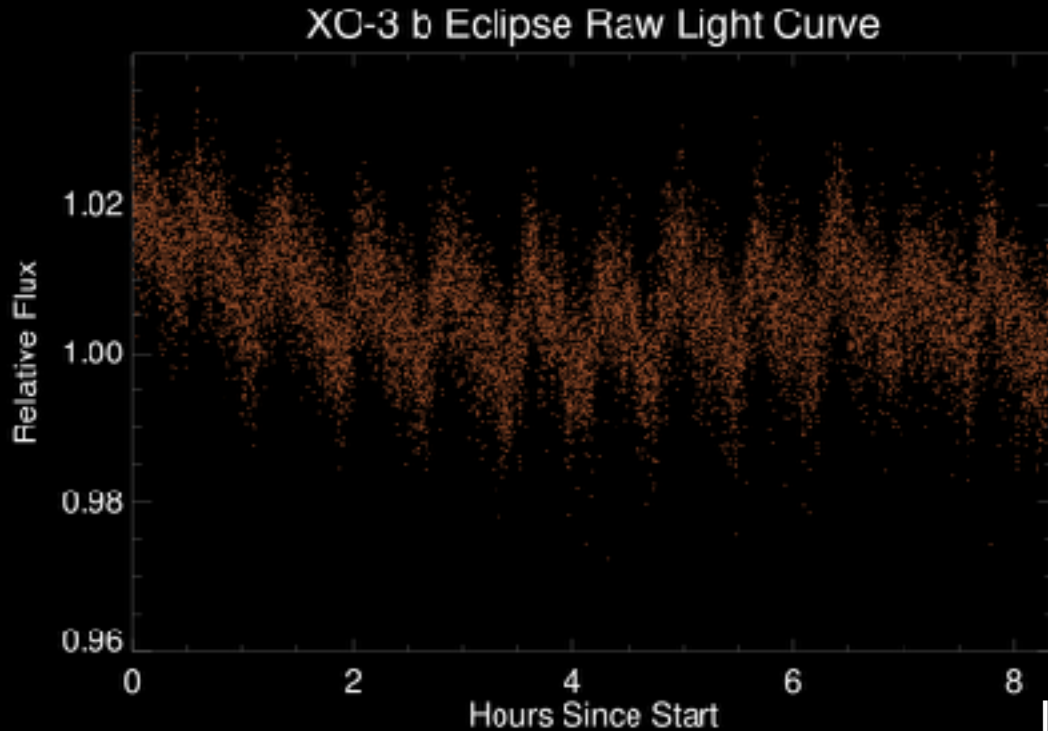


Brightness varies by a few percent with location on camera

Want to measure 0.005% variations to study exoplanets

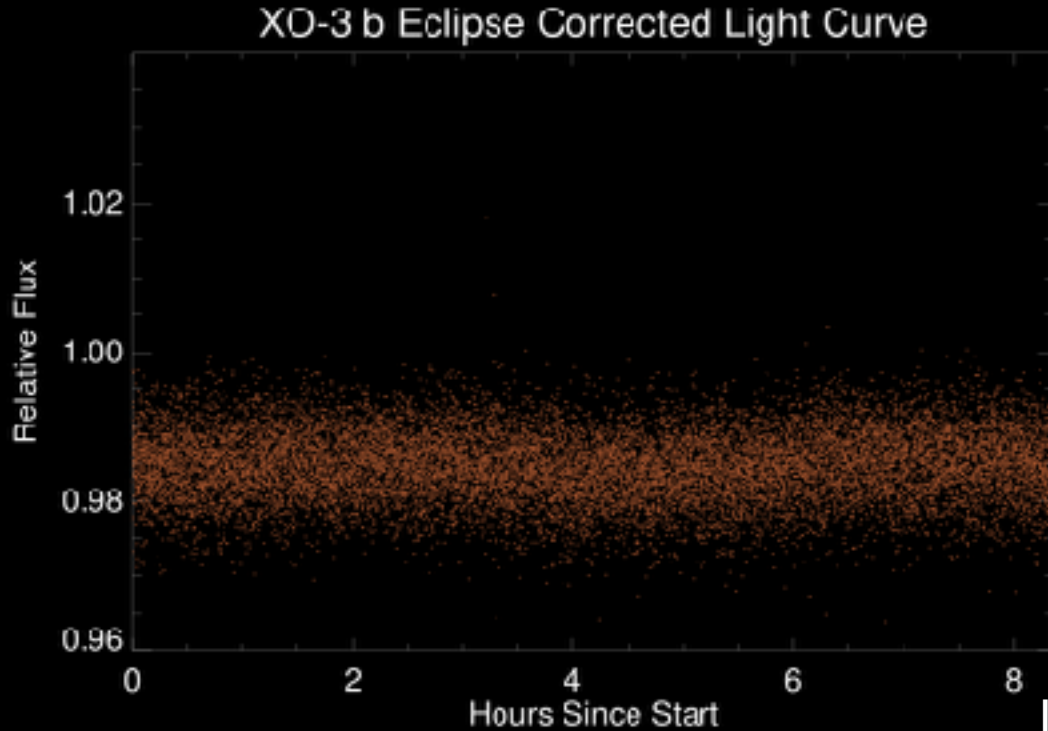
Ingalls et al.  
(2018)

# Spitzer was not designed for exoplanets



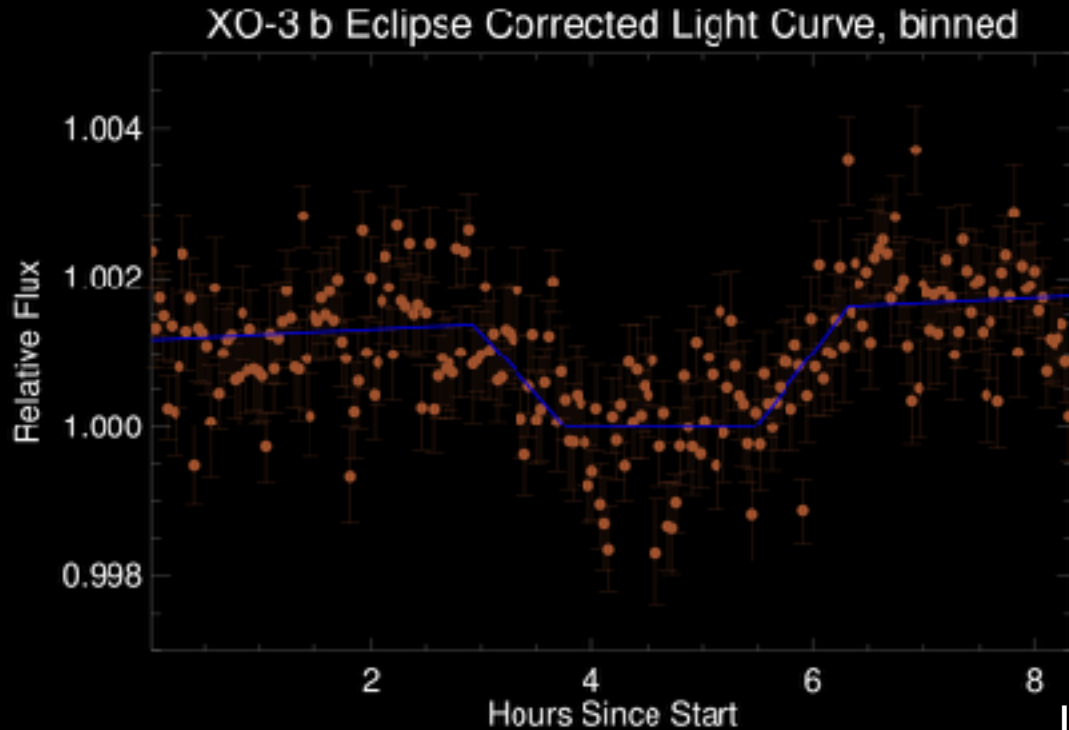
Ingalls et al.  
(2016)

# Clever processing is needed



Ingalls et al.  
(2016)

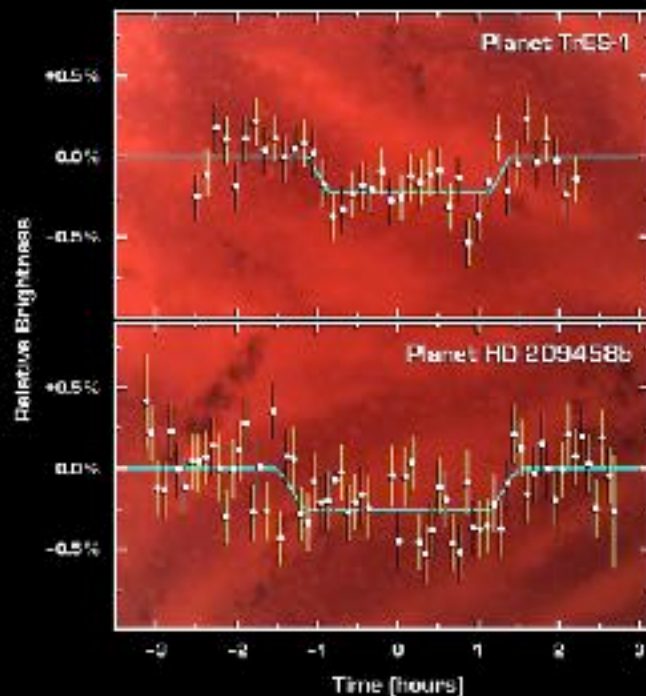
# Average data to reduce noise



Ingalls et al.  
(2016)



# First detections of thermal emission from exoplanets



Planetary Eclipses Spitzer Space Telescope • IRAC • MIPS

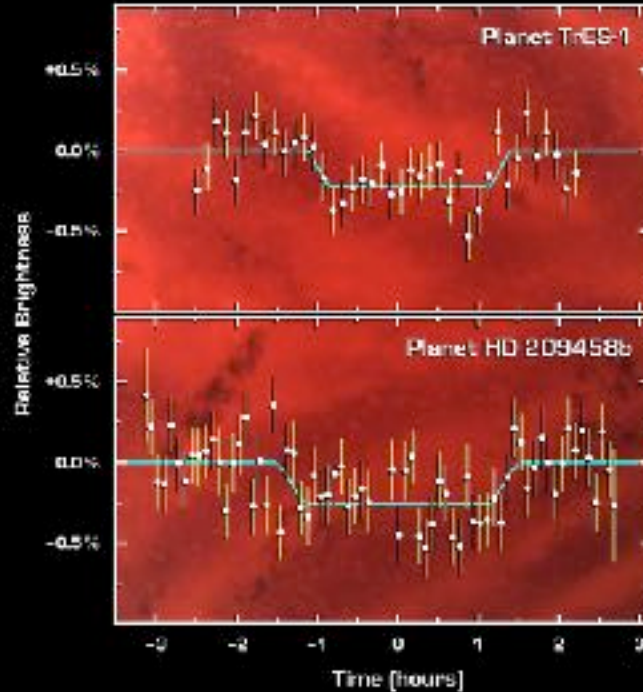
NASA / JPL-Caltech / D. Charbonneau (Harvard/Gemini/GA) /

ssc5036.06a

D. Darling (Goddard Space Flight Center)

# First detections of thermal emission from exoplanets

HD 209458b  
T = 1130 K  
Deming et al. (2006)



TrES-1  
T = 1060 K  
Charbonneau et al.  
(2006)

# What happened when Spitzer ran out of cryogen

Spitzer heated up from  $<12$  K  
to 28K

Only 2 cameras on one  
instrument still work

3.6 and 4.5 micron cameras  
Work same as they did before



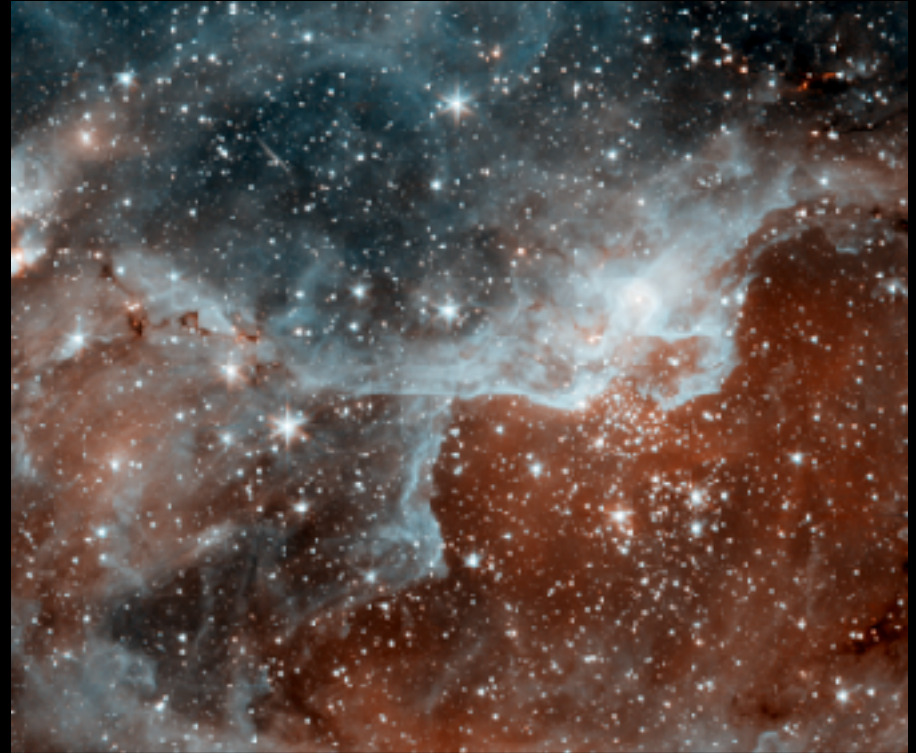
# What happened when Spitzer ran out of cryogen

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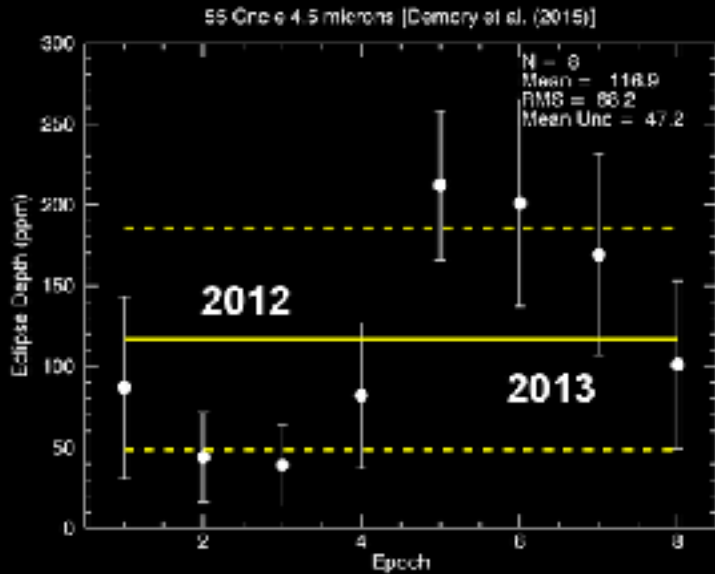
Only 2 cameras on one instrument still work

3.6 and 4.5 micron cameras  
Work same as they did before

More focus on exoplanets  
and distant galaxies!

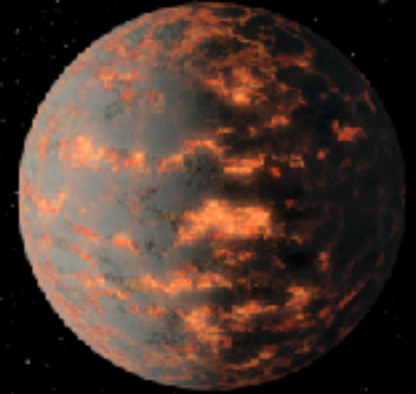


# Temperature variations for 55 Cnc e



2013

55 Cnc e



2012

High T ~ 2800 K  
Low T ~ 1300 K

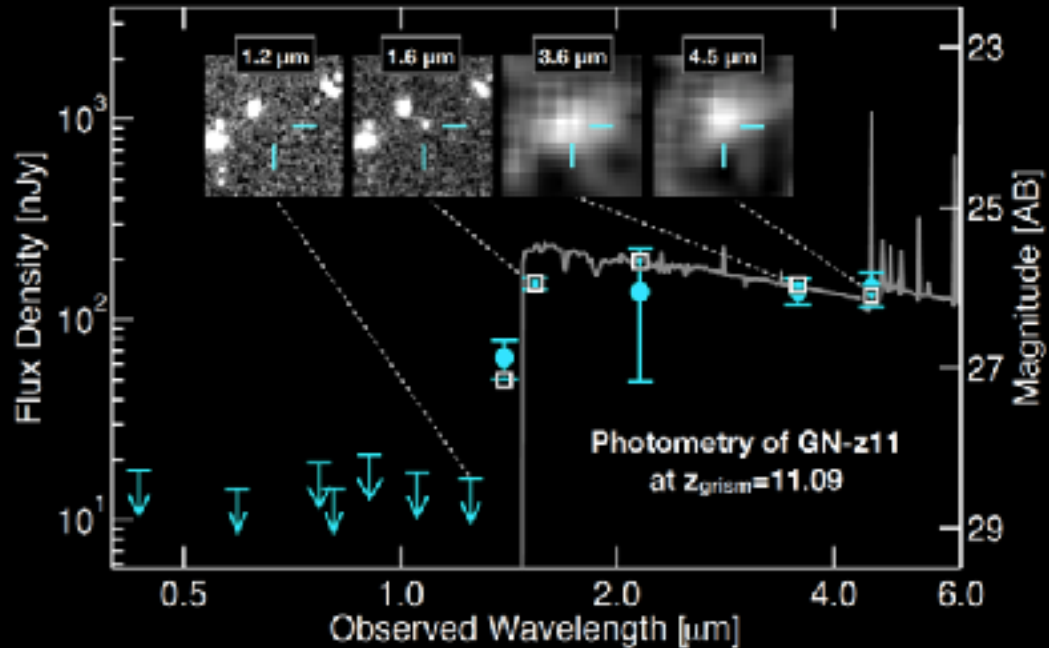
# Most distant galaxy

Oesch et al. (2014)

Observed at  $z=11$

13.4 billion years ago

1/100<sup>th</sup> the mass of the  
Milky Way



# Most distant galaxy

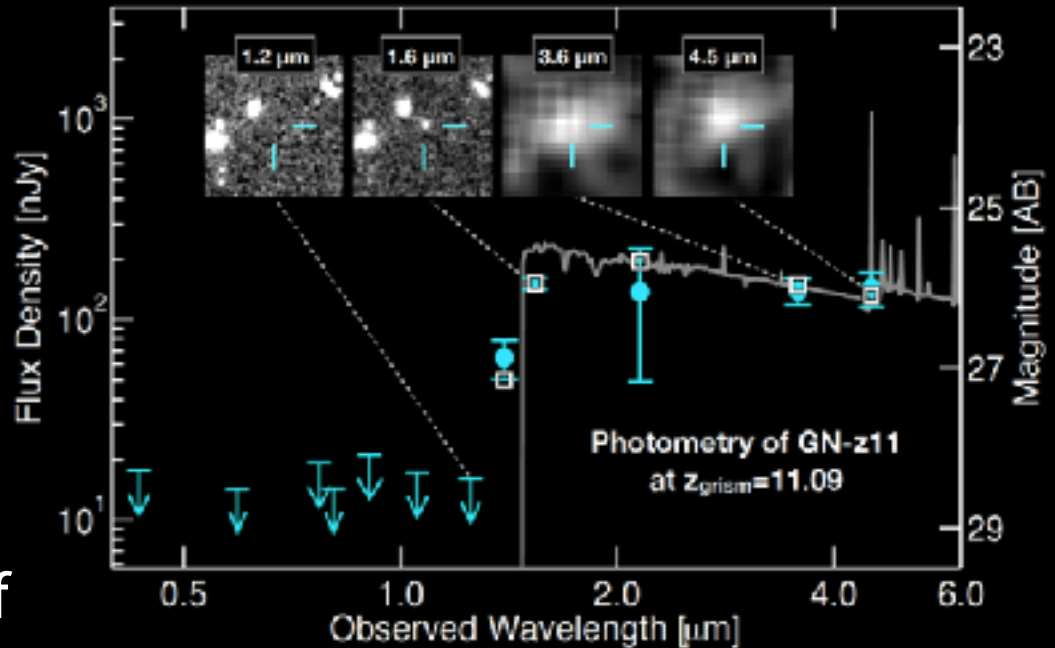
Oesch et al. (2014)

Observed at  $z=11$

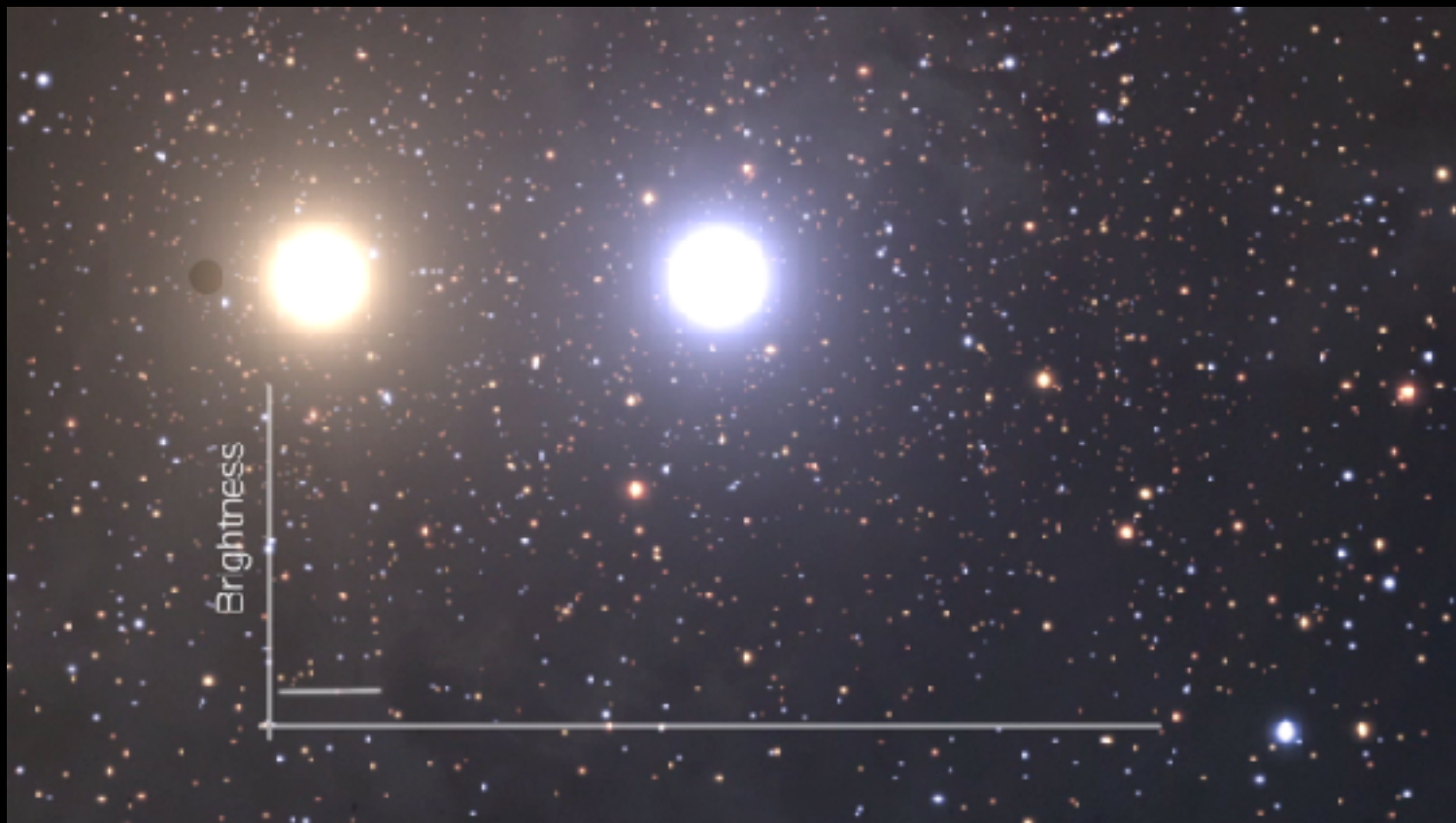
13.4 billion years ago

$1/100^{\text{th}}$  the mass of the Milky Way

HST gives redshift (time)  
Spitzer gives mass/age of stars



# Gravitational Microlensing

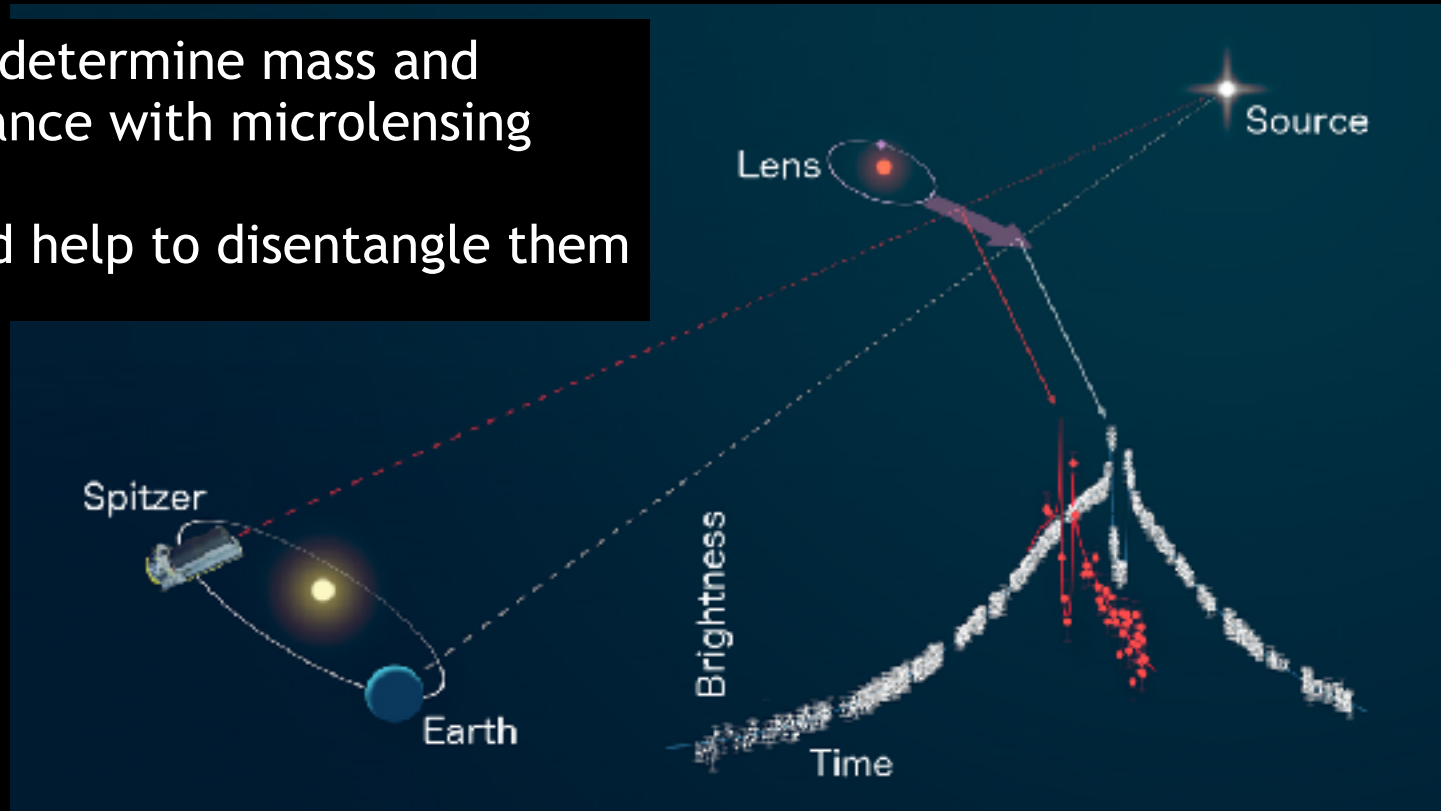




# Microlensing Parallax

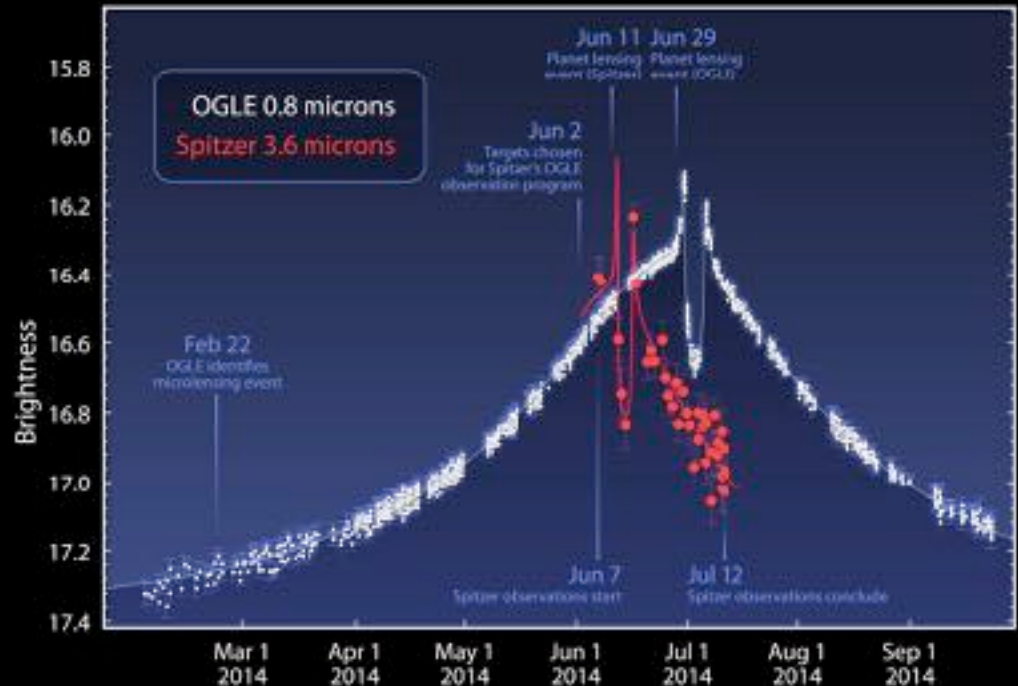
Can determine mass and distance with microlensing

Need help to disentangle them



# First microlensing planet with Spitzer

Star mass = 0.7 Solar



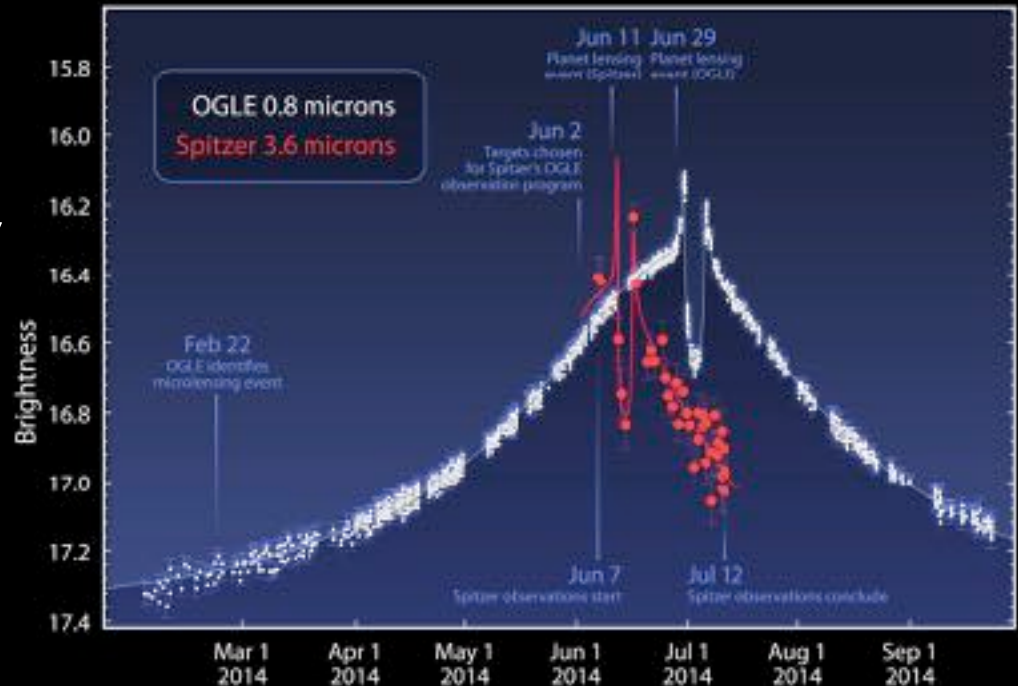
Microlens Parallax Vector of OGLE-2014-BLG-0124L  
NASA / JPL-Caltech / A. Udalski (Warsaw University Observatory)

Spitzer Space Telescope • IRAC  
sig15-005

# First microlensing planet with Spitzer

Star mass = 0.7 Solar

Planet mass = 0.5 Jupiter

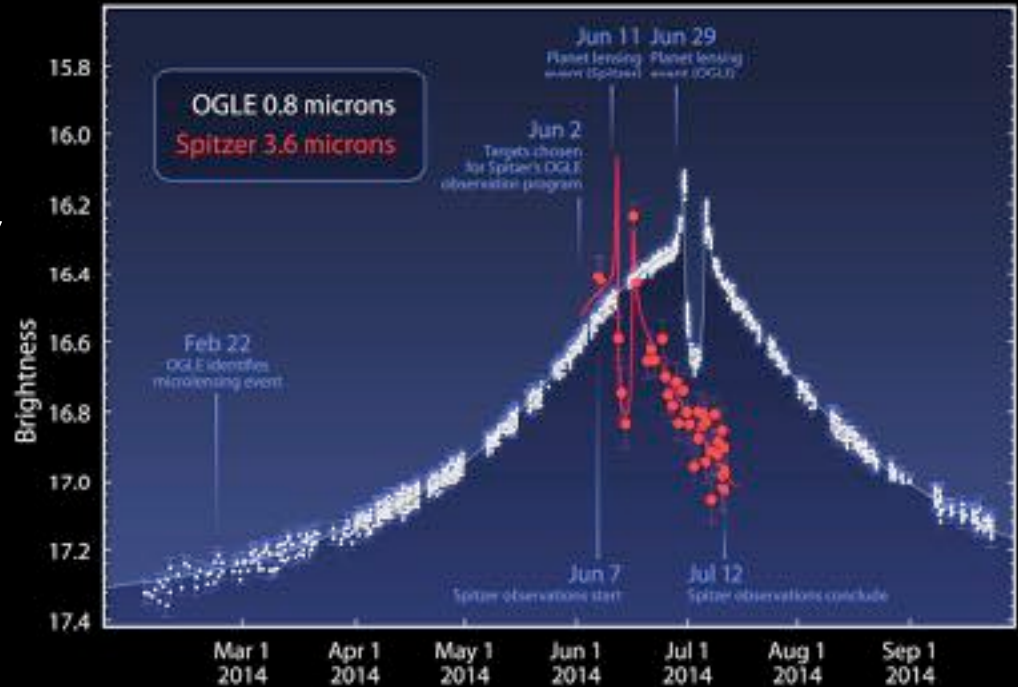


# First microlensing planet with Spitzer

Star mass = 0.7 Solar

Planet mass = 0.5 Jupiter

Planet distance from  
star = 3.1 au



# TRAPPIST-1 facts

Star discovered in 2000

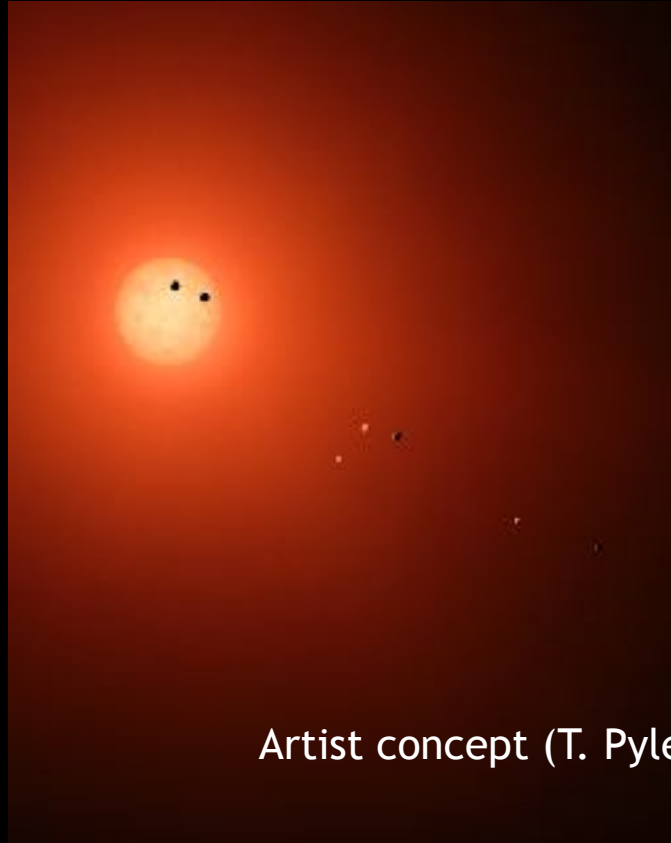
Distance = 39.6 light years

Star mass = 0.08 Solar

Star radius = 1.1 Jupiter radii

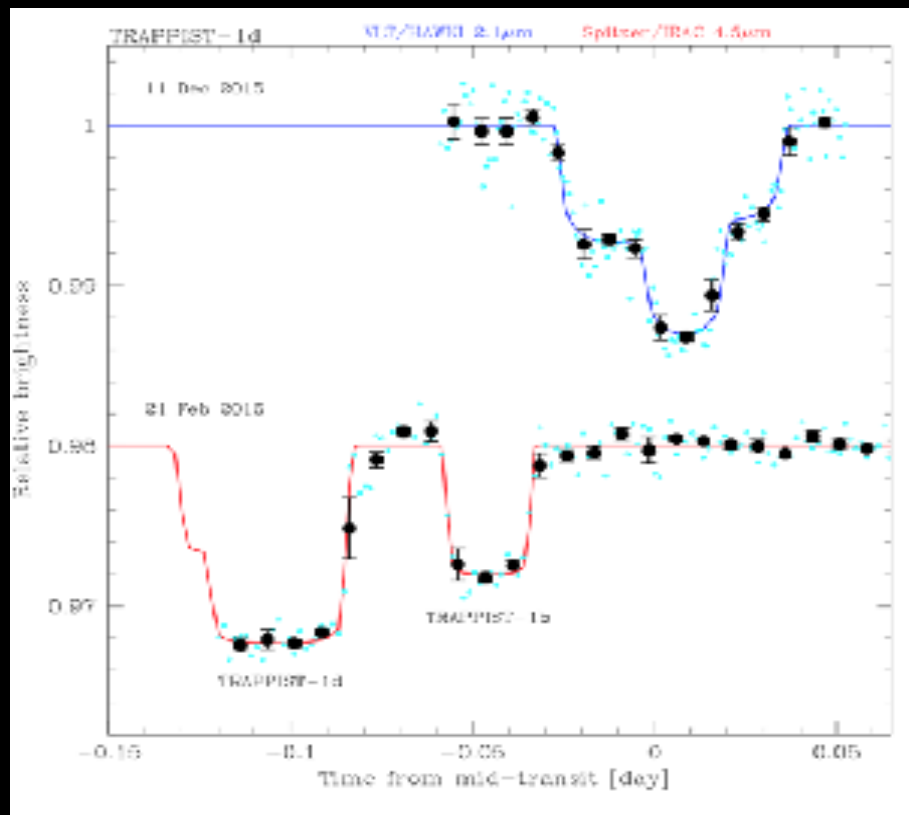
Star temperature = 2500 K

4000x brighter in IR



Artist concept (T. Pyle, JPL/Caltech)

# TRAPPIST-1 had weird transits



VLT follow-up photometry

Spitzer DDT 21 Feb 2016 (5hrs)

At first, did not understand the light curves!



# TRAPPIST-1 system is much smaller than ours

Jupiter & Major Moons



TRAPPIST-1 System



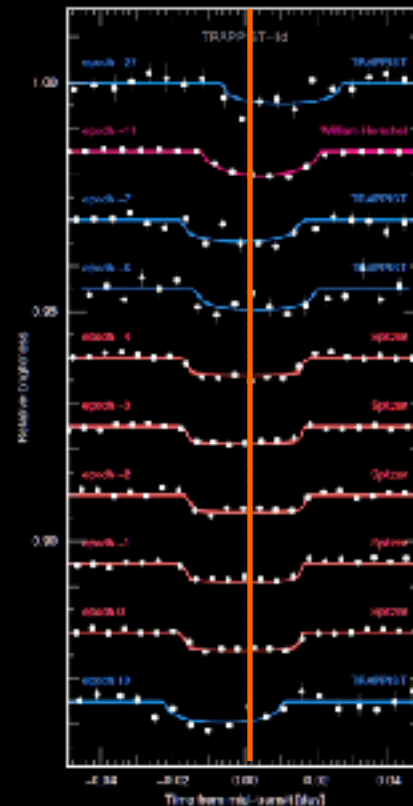
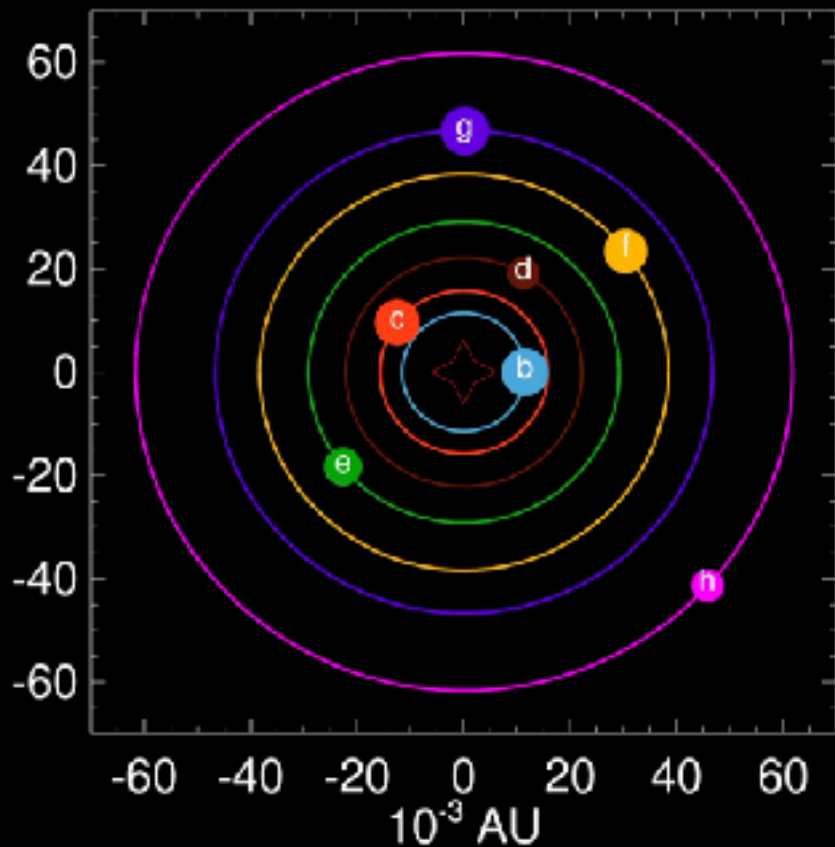
Inner Solar System



Orbits Enlarged 25x

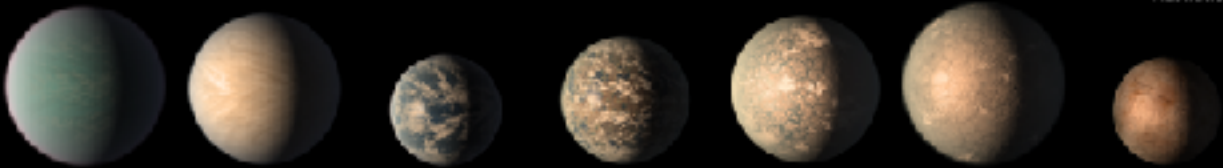


# TRAPPIST-1 resonance and transit timing



# What we know about the TRAPPIST-1 planets

TRAPPIST-1 System  
*Trappist-1/16*



Illustrations

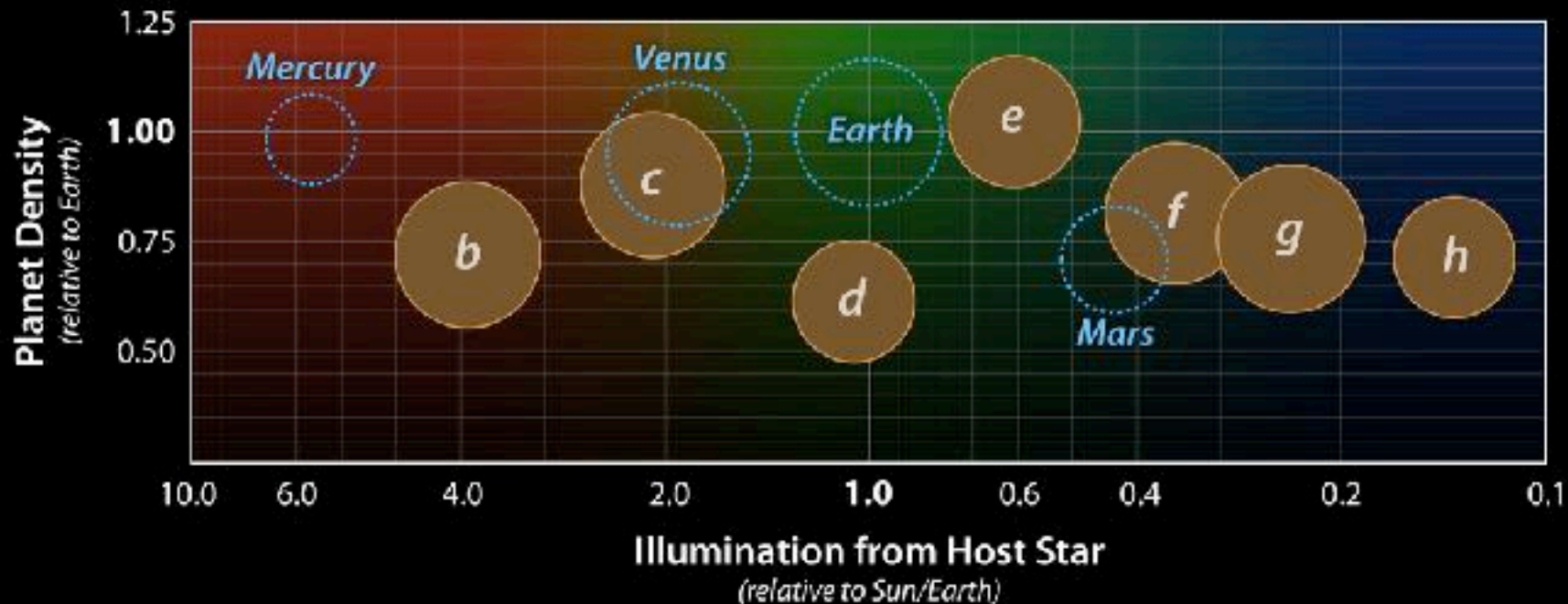
	b	c	d	e	f	g	h
<i>O</i> rbital Period	1.51 days	2.42 days	4.05 days	6.10 days	9.21 days	12.36 days	18.76 days
<i>D</i> istance to Star	0.0115 AU	0.0158 AU	0.0223 AU	0.0293 AU	0.0385 AU	0.0469 AU	0.0619 AU
<i>R</i> adius	1.12 $R_{\text{Earth}}$	1.10 $R_{\text{Earth}}$	0.78 $R_{\text{Earth}}$	0.91 $R_{\text{Earth}}$	1.05 $R_{\text{Earth}}$	1.15 $R_{\text{Earth}}$	0.77 $R_{\text{Earth}}$
<i>M</i> ass	1.02 $M_{\text{Earth}}$	1.16 $M_{\text{Earth}}$	0.30 $M_{\text{Earth}}$	0.77 $M_{\text{Earth}}$	0.93 $M_{\text{Earth}}$	1.15 $M_{\text{Earth}}$	0.33 $M_{\text{Earth}}$
<i>D</i> ensity	0.73 $\rho_{\text{Earth}}$	0.88 $\rho_{\text{Earth}}$	0.62 $\rho_{\text{Earth}}$	1.02 $\rho_{\text{Earth}}$	0.82 $\rho_{\text{Earth}}$	0.76 $\rho_{\text{Earth}}$	0.72 $\rho_{\text{Earth}}$
<i>S</i> urface Gravity	0.81 g	0.95 g	0.48 g	0.93 g	0.85 g	0.87 g	0.55 g

Solar System  
*Rocky Planets*



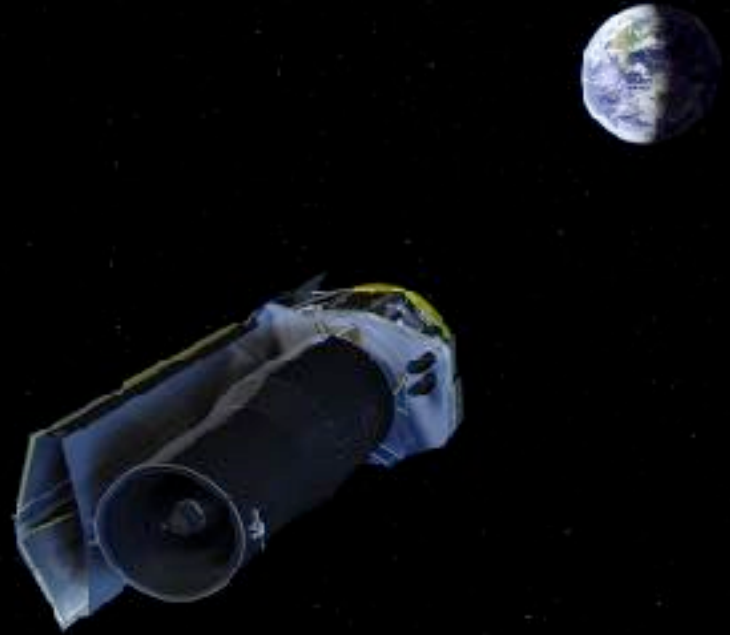
	Mercury	Venus	Earth	Mars
<i>O</i> rbital Period	87.97 days	224.70 days	365.26 days	686.98 days
<i>D</i> istance to Star	0.387 AU	0.723 AU	1.000 AU	1.524 AU
<i>R</i> adius	0.39 $R_{\text{Earth}}$	0.95 $R_{\text{Earth}}$	1.00 $R_{\text{Earth}}$	0.53 $R_{\text{Earth}}$
<i>M</i> ass	0.06 $M_{\text{Earth}}$	0.82 $M_{\text{Earth}}$	1.00 $M_{\text{Earth}}$	0.11 $M_{\text{Earth}}$
<i>D</i> ensity	0.98 $\rho_{\text{Earth}}$	0.95 $\rho_{\text{Earth}}$	1.00 $\rho_{\text{Earth}}$	0.71 $\rho_{\text{Earth}}$
<i>S</i> urface Gravity	0.38 g	0.90 g	1.00 g	0.38 g

# TRAPPIST-1/Solar System Comparison



# Looking to the future

Spitzer operations continue until  
November 2019



# Looking to the future

Spitzer operations continue until  
November 2019

Looking for planets around cooler  
stars (and brown dwarfs) than  
TRAPPIST-1



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Spitzer operations continue until  
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Looking for planets around cooler  
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May measure the mass of an  
isolated stellar mass black hole



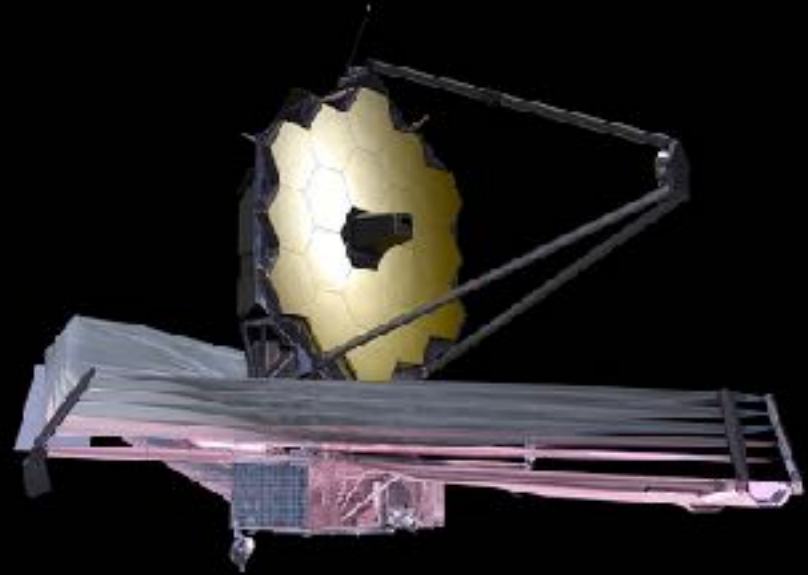
# Looking to the future

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May measure the mass of an  
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JWST to launch in 2021



The background of the slide is a rich, multi-colored field of galaxies, likely from the Hubble Ultra Deep Field. The galaxies are in various stages of evolution, with colors ranging from deep blue (young stars) to red and orange (older stars or dust). A semi-transparent dark grey rectangular box is centered on the image, containing white text.

**Thank you!**

**For more information**  
**[www.spitzer.caltech.edu](http://www.spitzer.caltech.edu)**  
**@NASAspitzer**  
**@NASAJPL**