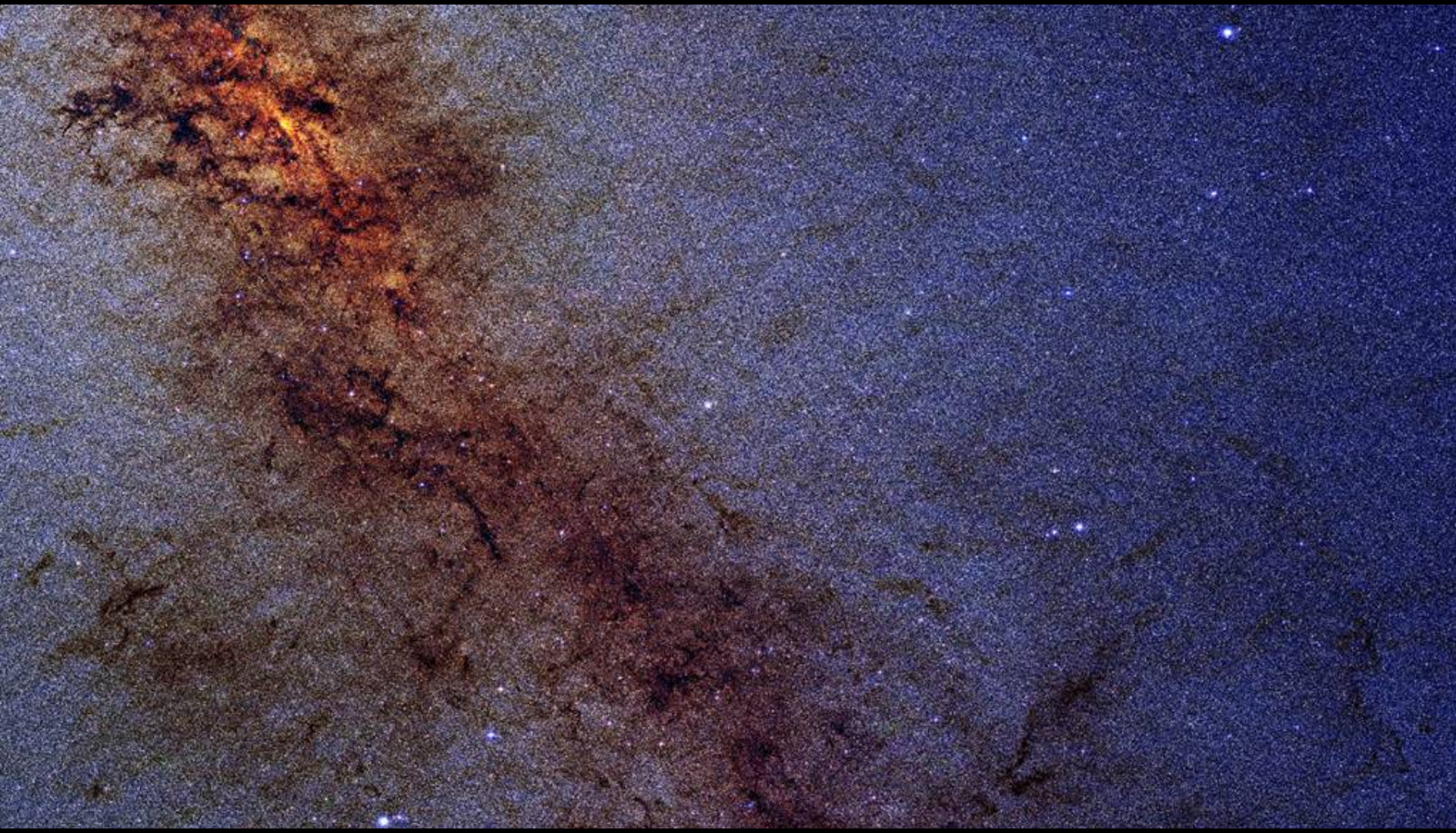
The Kepler Mission, Extrasolar Planets and the Search for a New Earth

Dr. Thomas. N. Gautier
Kepler Deputy Project Scientist
Jet Propulsion Laboratory,
California Institute of Technology.

picture: NASA/Tim Pyle

There are 200 billion stars in our galaxy…



There ought to be some other Earths.

Ways to See Exoplanets

Star wobble (Radial Velocity) Mass, orbital period and shape: distance from star

Star dimming (Transit photometry) Size, orbital period: distance from star

Star wobble (Astrometry)
Direct imaging
Microlensing
Pulsar timing
Reflection photometry

Ways to See Exoplanets

Star wobble (Radial Velocity) Mass, orbital period and shape: distance from star

Star dimming (Transit photometry) Size, orbital period: distance from star

With both mass and size get planet density. Then can tell if the planet is:
Gas : Low density
Ice : Medium density
Rock : High density

How do we know it when we find another Earth?

Look for Habitable Planets

Look for Habitable Planets

- Right temperature
- Liquid water
- Atmosphere

Look for Habitable Planets

- Right temperature
- Liquid water
- Atmosphere

Planets come is several sizes

Too big (about >10 M_{earth})

Holds onto light gases (Hydrogen and Helium) too well and turns into a gas giant. (Jupiter, Saturn, Uranus, Neptune)

Just right (0.5 - 10 M_{earth})

Holds on to heavier gasses (Nitrogen, Oxygen) long enough to have a potentially habitable atmosphere (Earth, Venus)

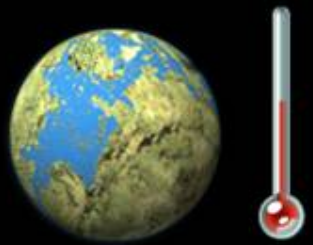
Too small (about <0.5 M_{earth})

Can't hold onto a life sustaining atmosphere.
(Moon, Mercury)

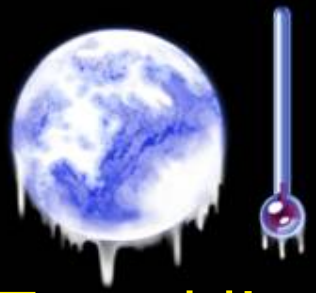
And a range of temperatures

Too hot!

(too close)



Just right



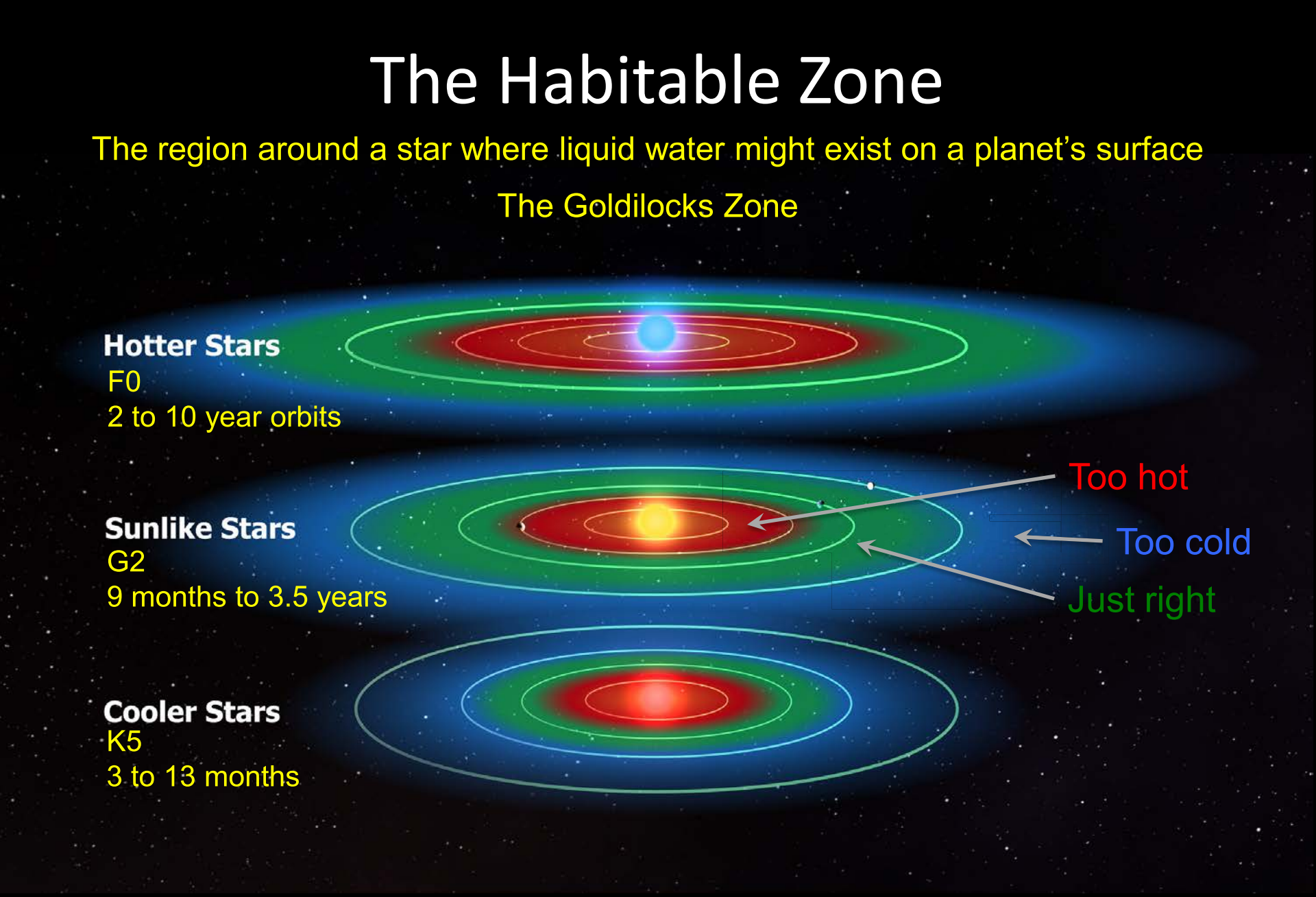
Too cold!

(too far)

The Habitable Zone

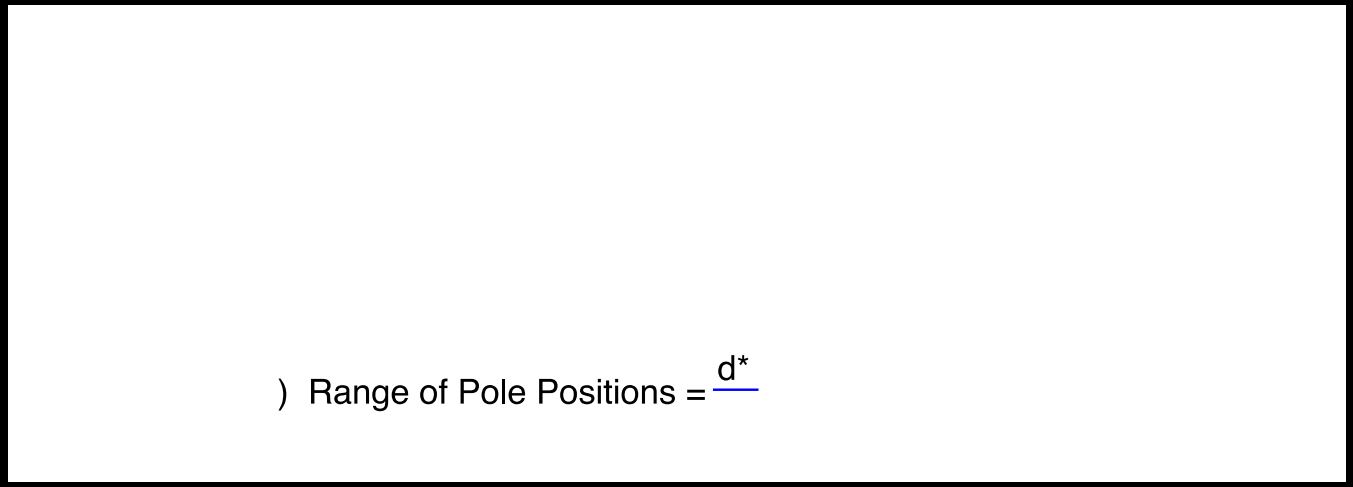
The region around a star where liquid water might exist on a planet's surface

The Goldilocks Zone



Transits Won't Find ALL Planets

Not all planetary orbits are aligned to produce a transit



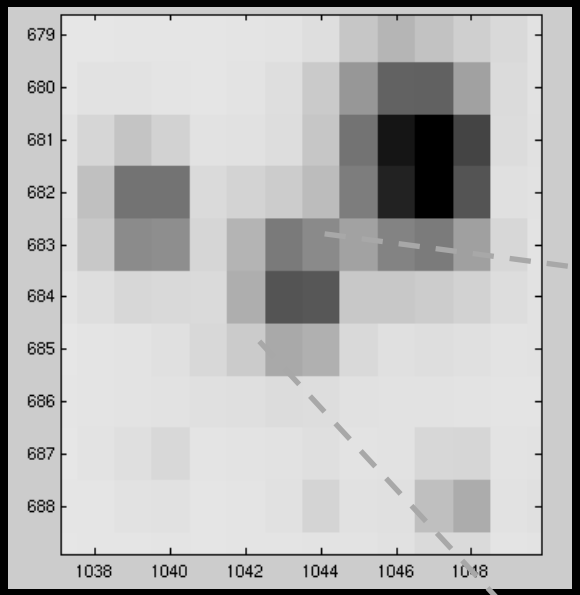
Only a few percent chance for a given planet to transit

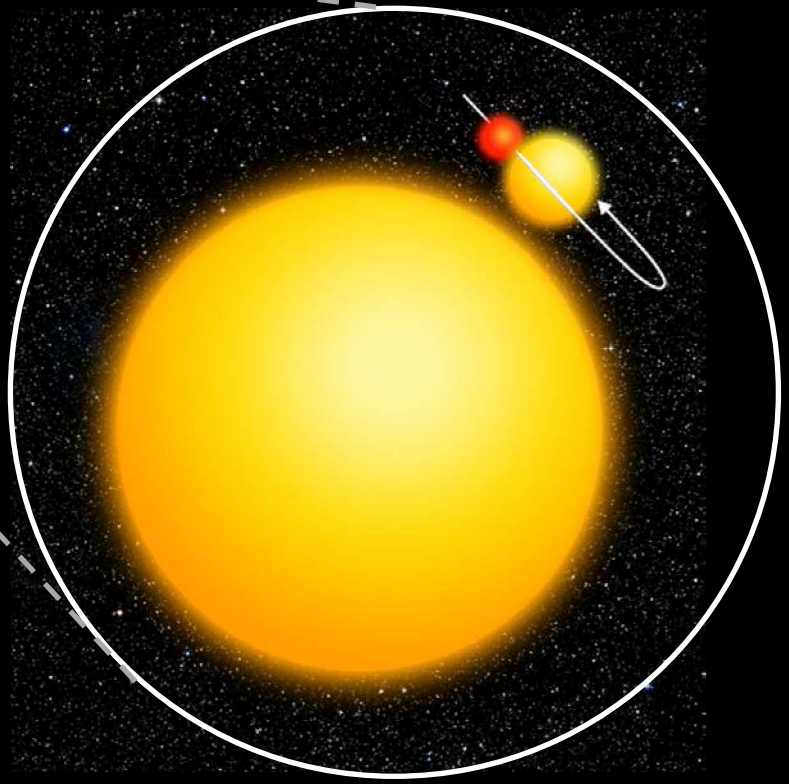
- Earth and Sun have only 0.5% chance

Transits last only a few hours each orbit

Must stare constantly at many thousands of stars to find many planets.

A pitfall: False Positives





Other things can look like transiting planets.

- Eclipsing binary stars behind target stars

Candidate transiting planets need to be carefully examined to look for false positives.

RV measurements good for finding large planets

- Also Earth-size around small, cool stars
- Not good enough to find Earths around Sun-like stars

Also too slow.

- Can only do 1 star at a time.
- Need many measurements totaling, maybe, hundreds, of hours

Transit searches from the ground good for finding lots of large planets.

- Not good enough to find Earths around Sun-like stars

Need another way to find Earths.

Kepler Telescope-Photometer

Wide field for lots of stars

15° diameter field

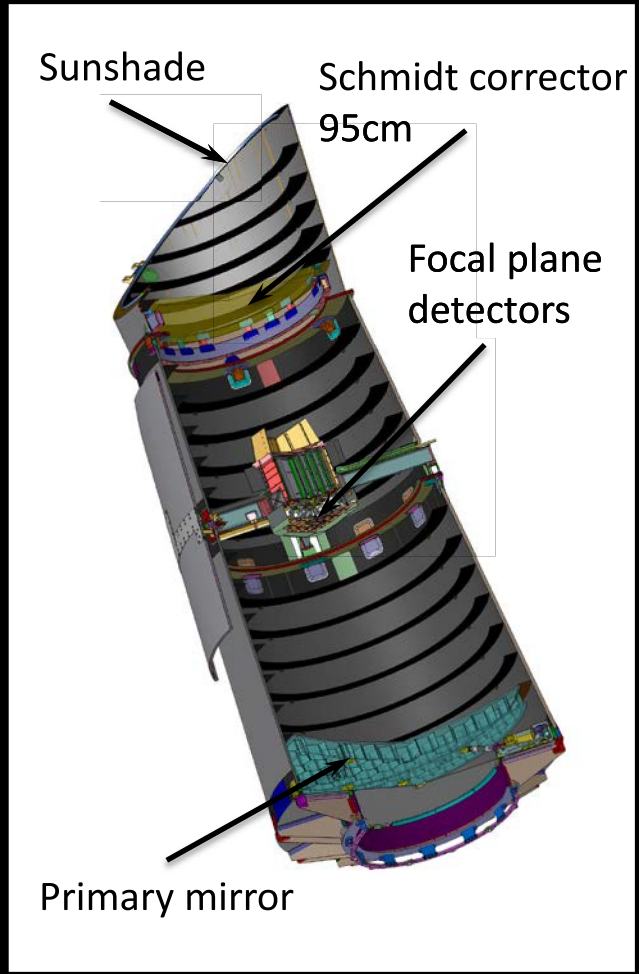
Monitor 150,000 stars at once

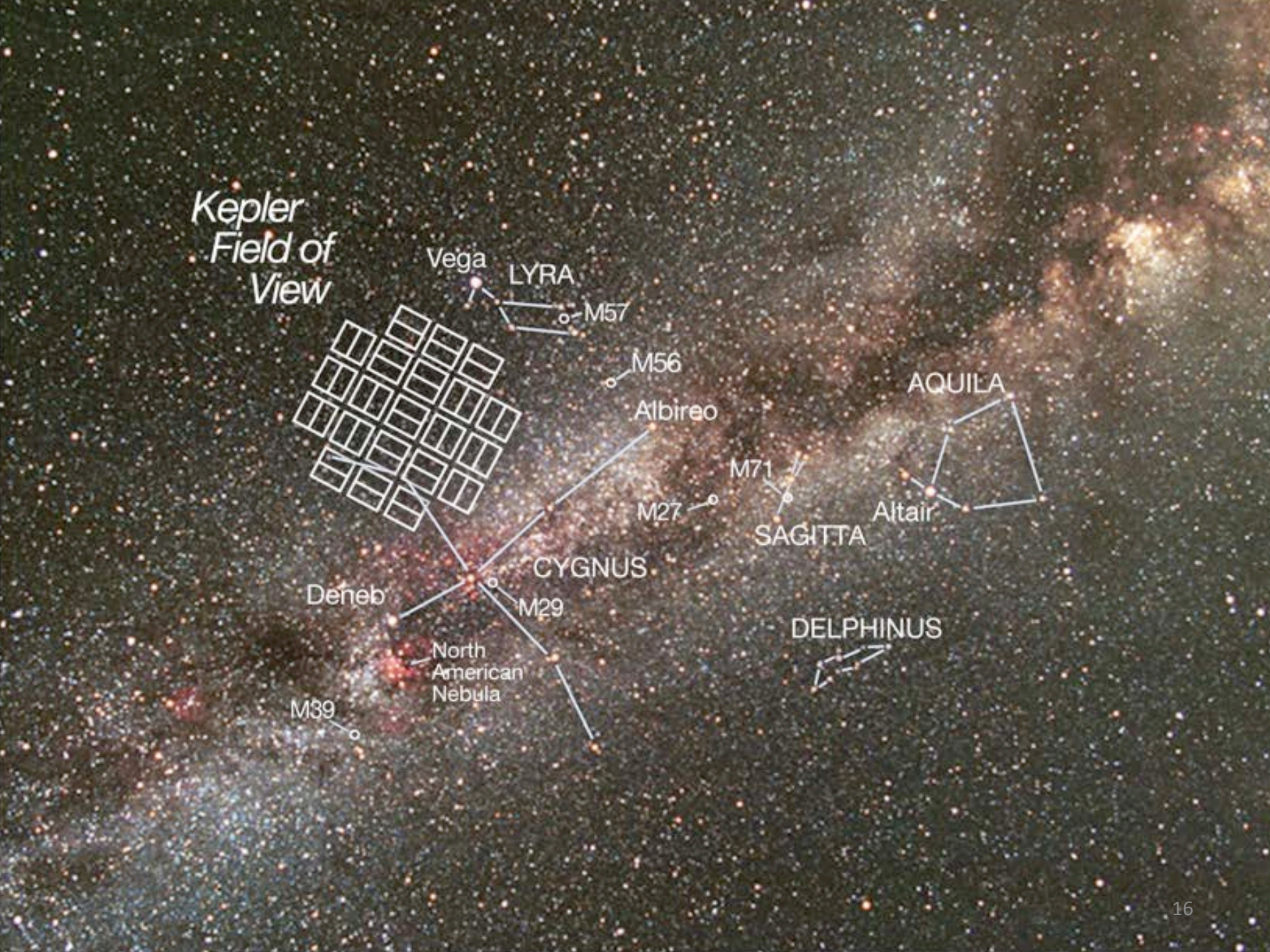
Big, to get enough light

95 cm aperture

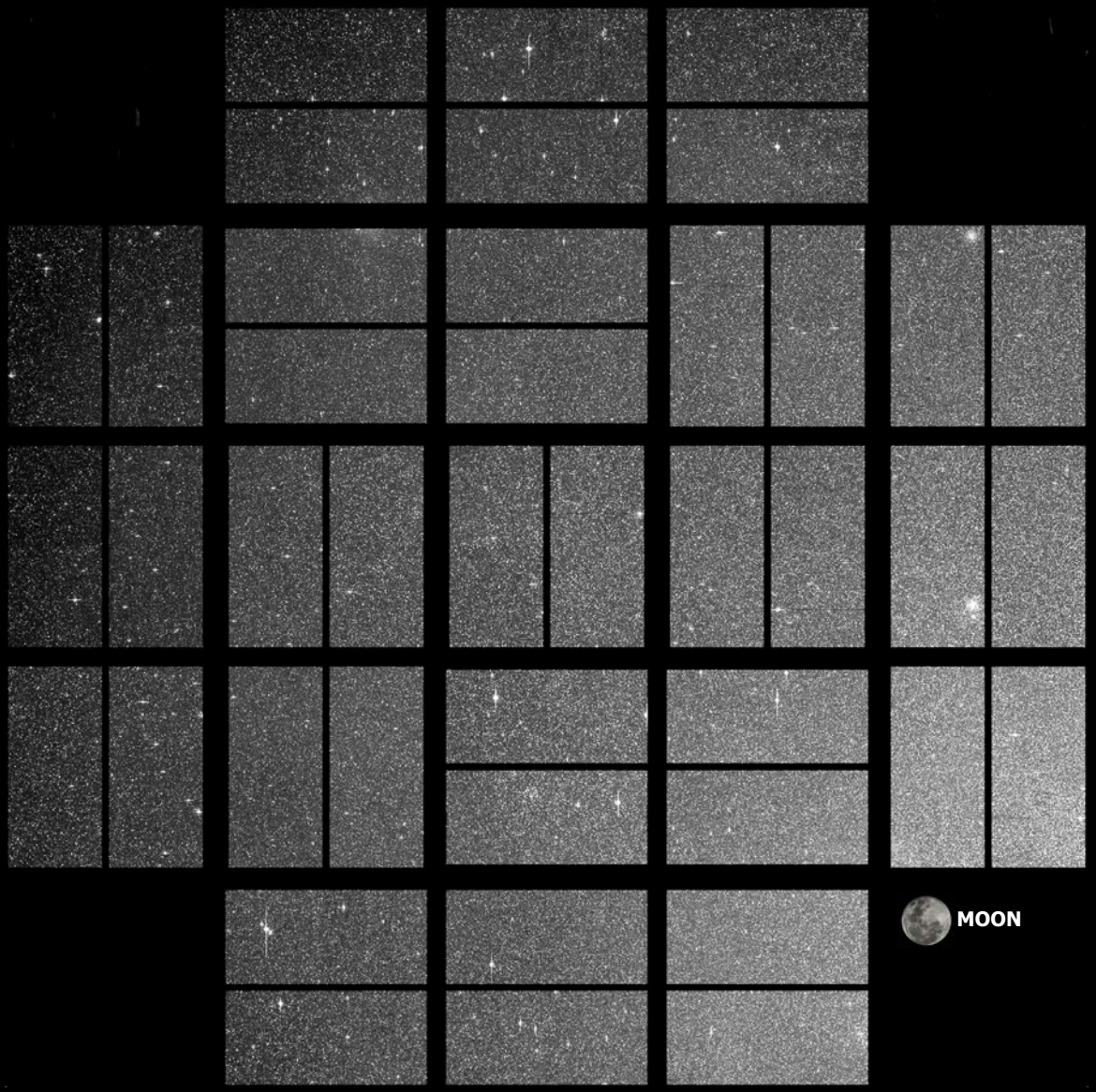
Build it for use in space

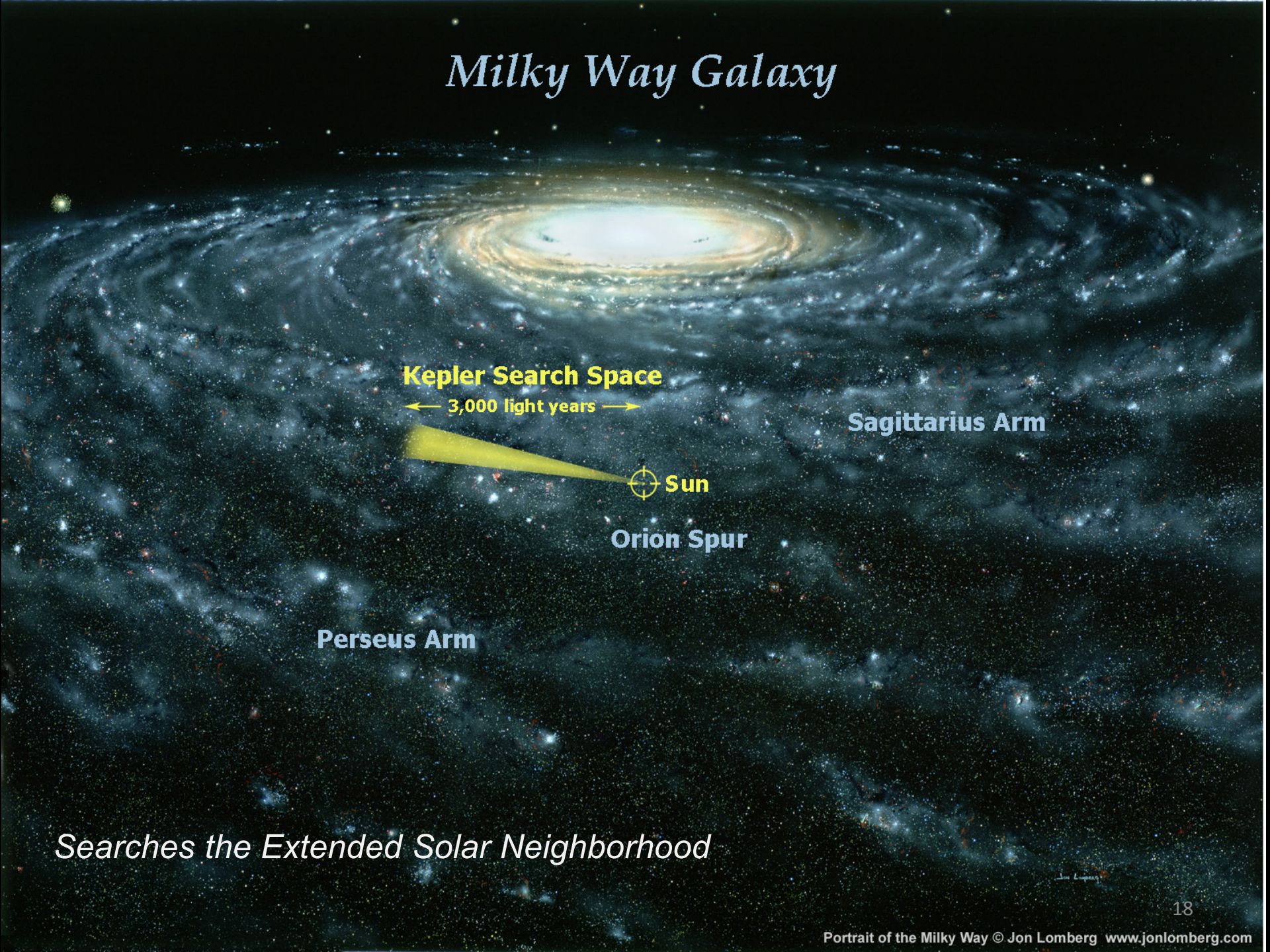
No variability from atmosphere to mask small transits




Kepler
Field of
View
Vega
LYRA
M57
M56
Albireo
AQUILA
M71
M27
Altair
SAGITTA
CYGNUS
Deneb
M29
DELPHINUS
North
American
Nebula
M39

Kepler Full Field Image

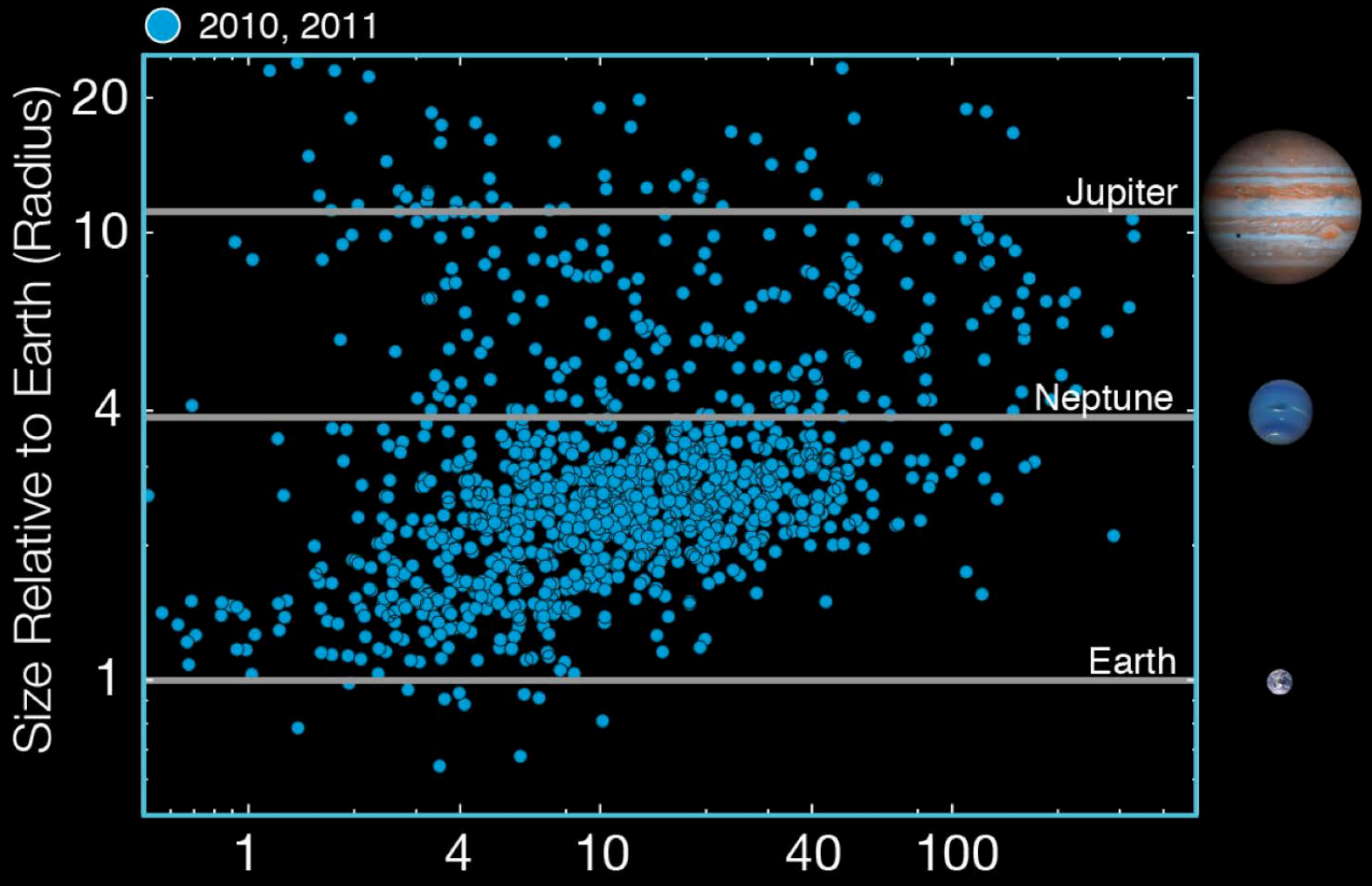




Searches the Extended Solar Neighborhood

Planet Candidates

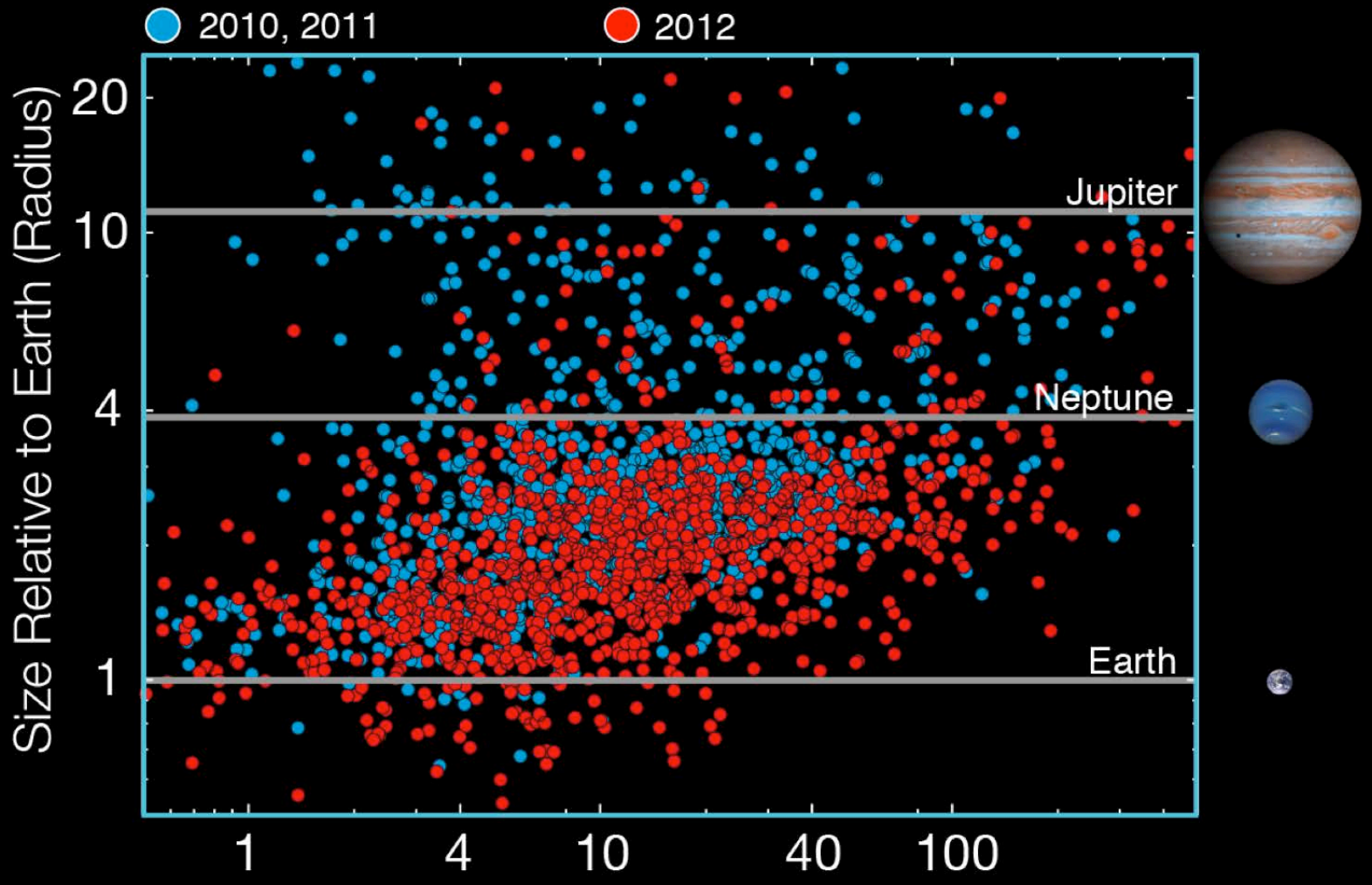
As of February 1, 2011



TOTAL = 1,235

Planet Candidates

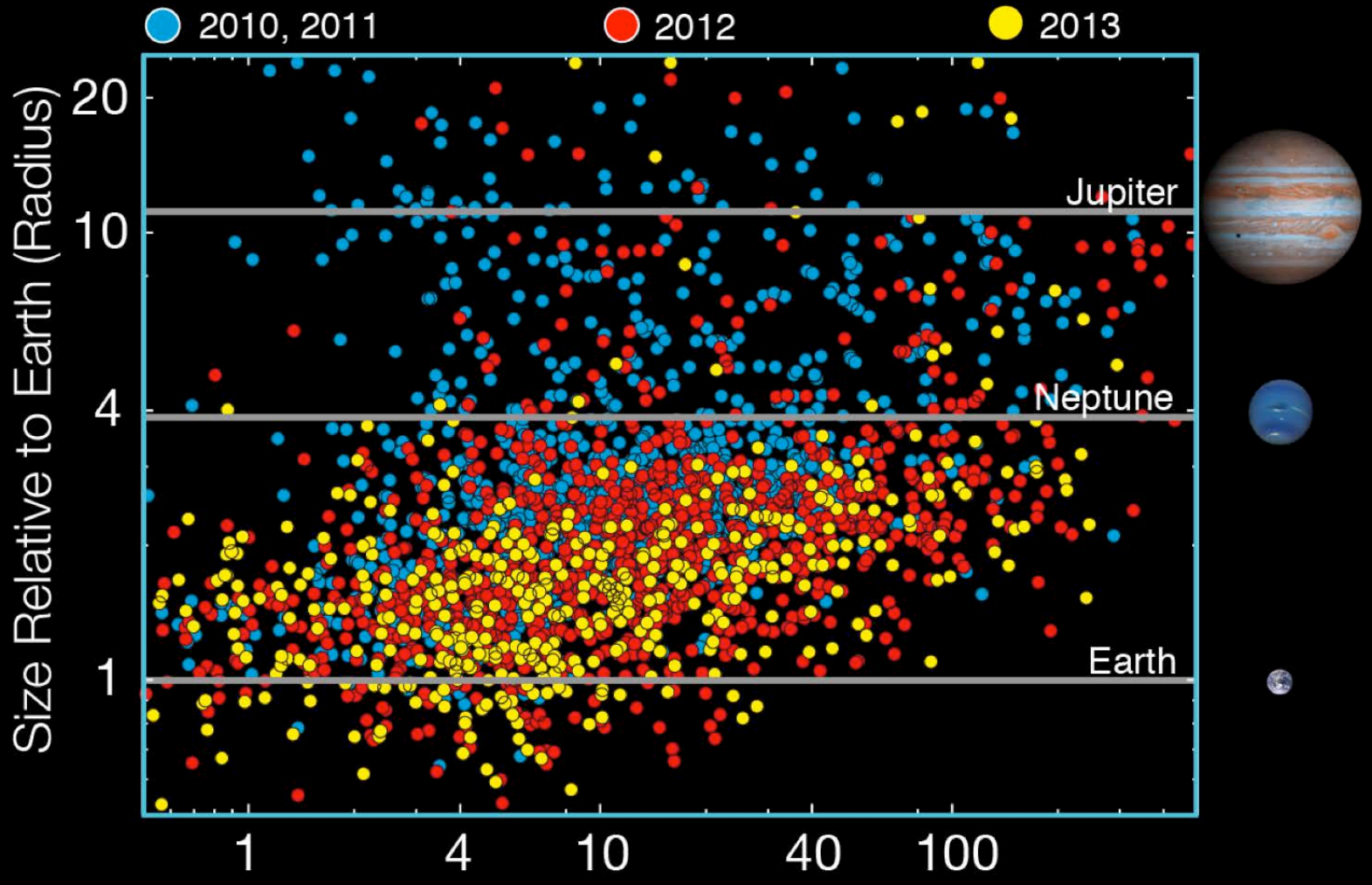
As of February 27, 2012



TOTAL = 2,321

Planet Candidates

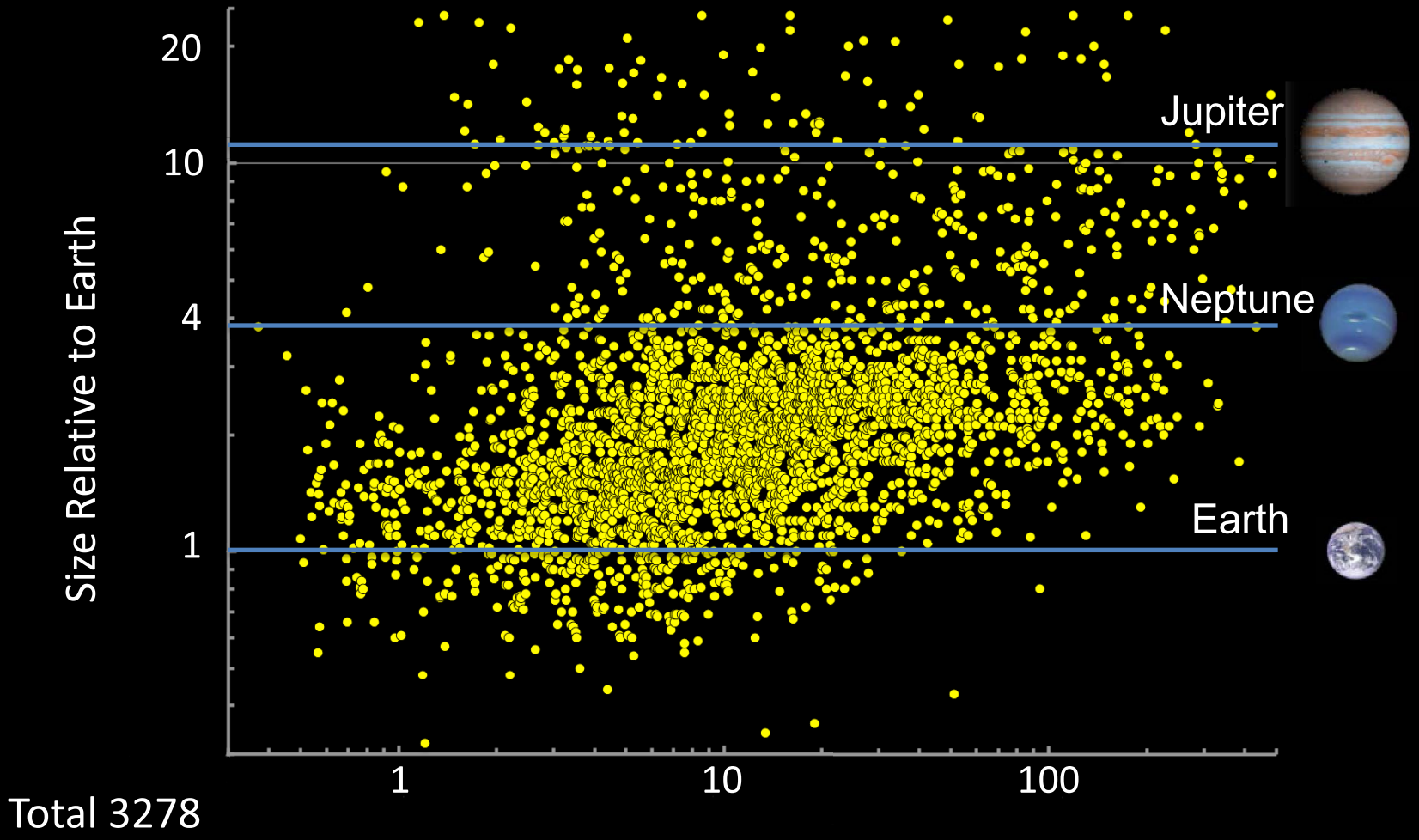
As of January 7, 2013



TOTAL = 2,740

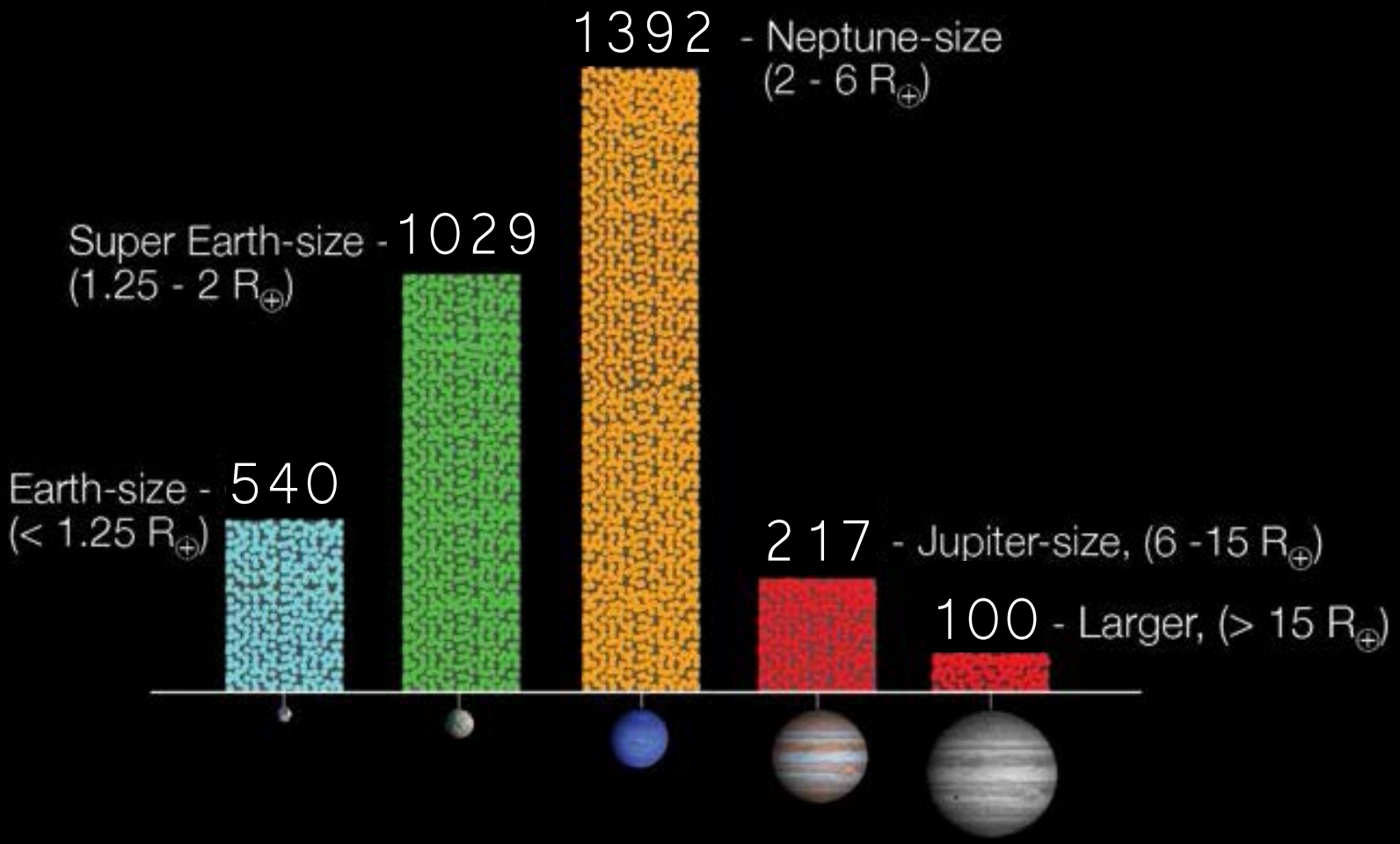
Candidates as of July 2013

36 Months of data



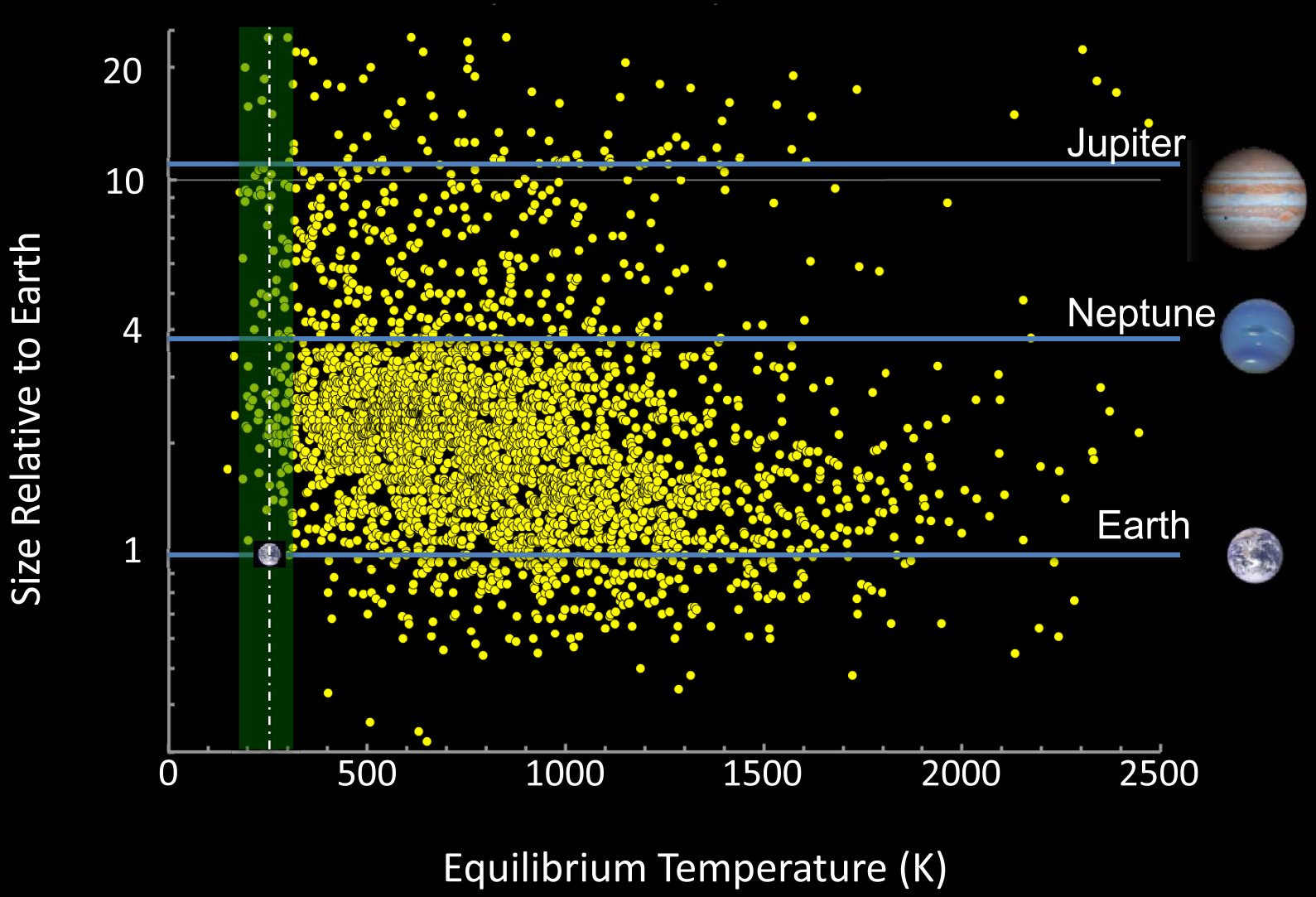
Total 3278

Taking the Planetary Census



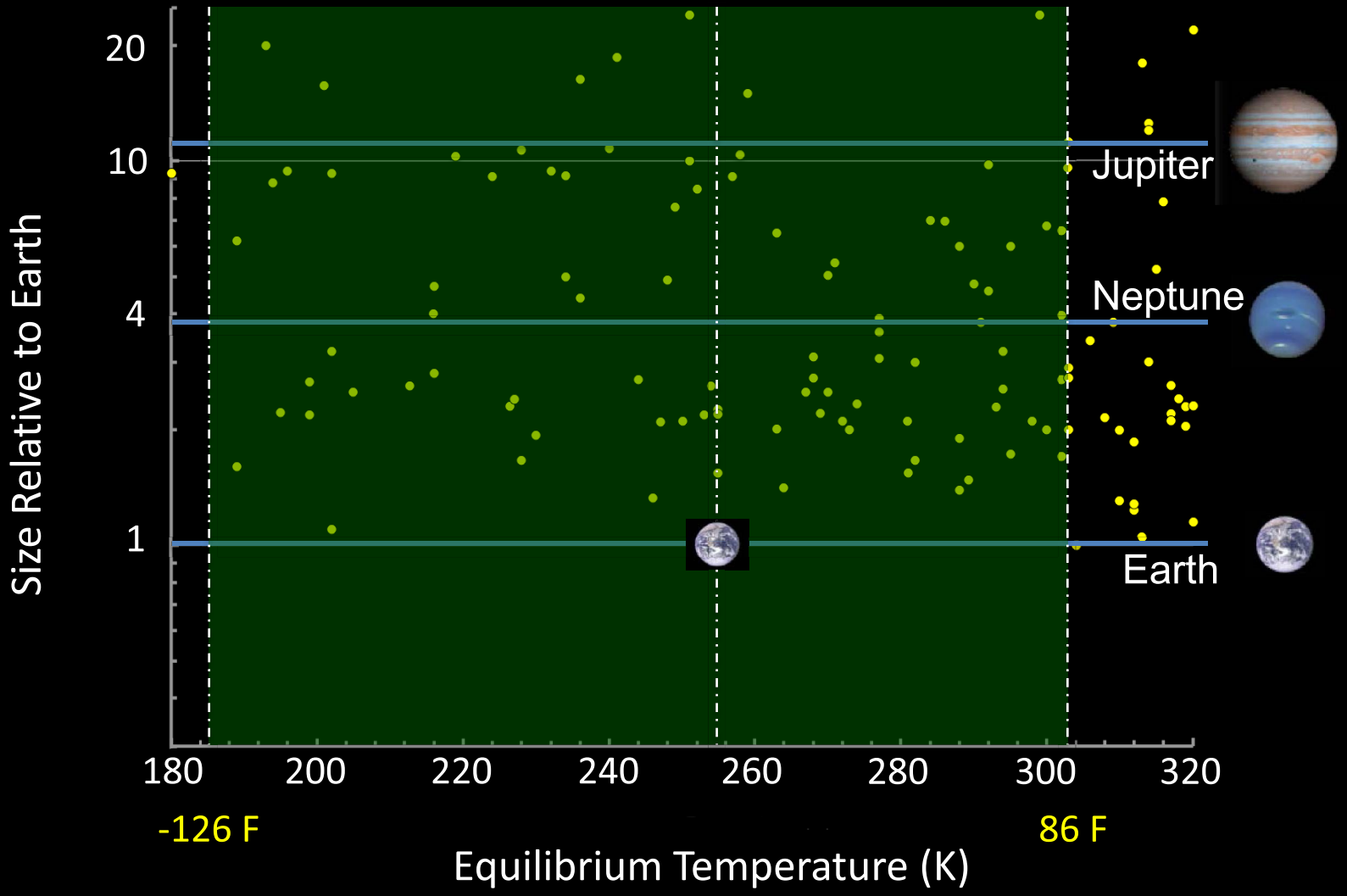
Candidates as of July 2013

36 Months of data

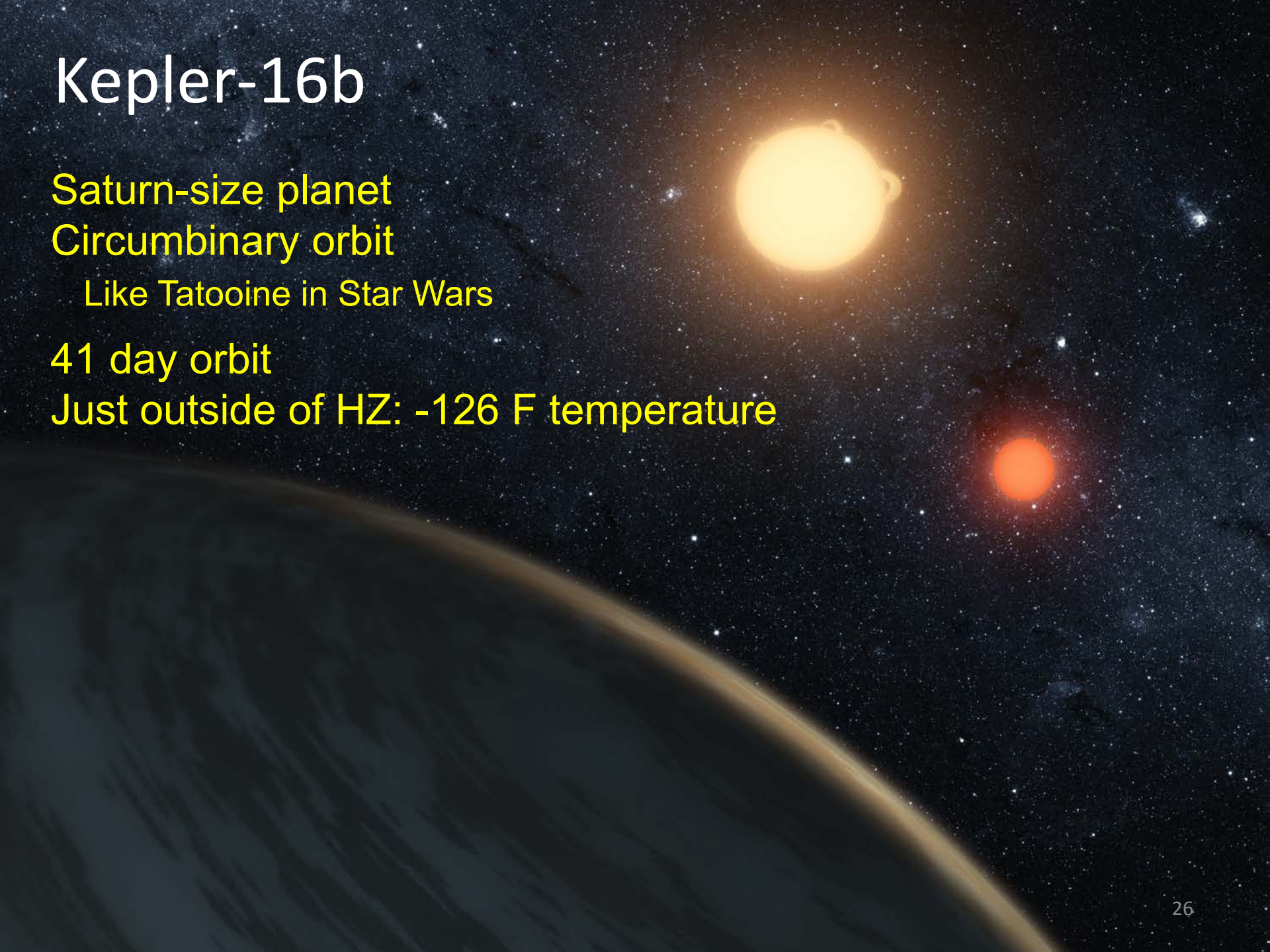


Candidates as of July 2013

36 Months of data

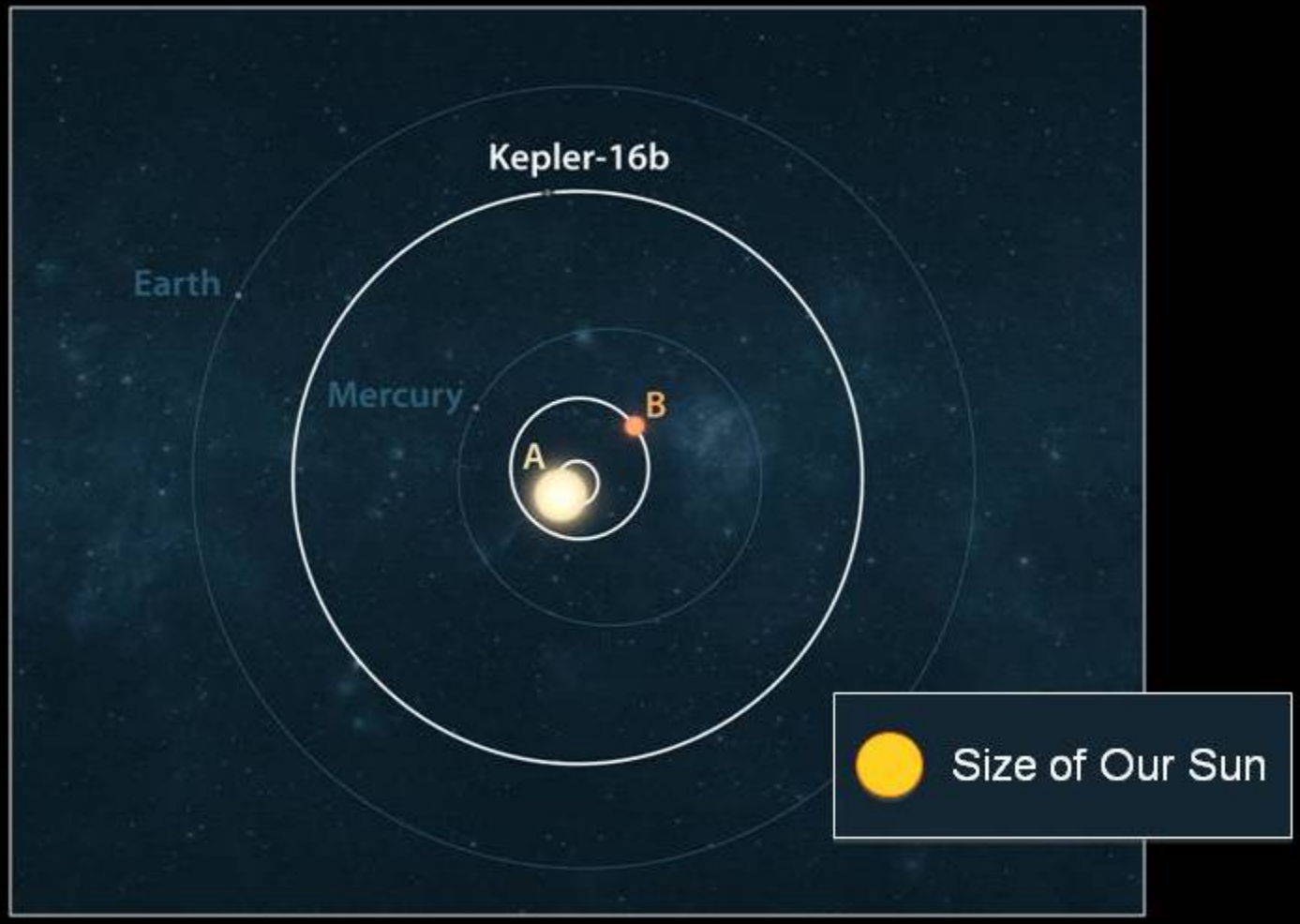


Kepler-16b



Saturn-size planet
Circumbinary orbit
- Like Tatooine in Star Wars

41 day orbit
Just outside of HZ: -126 F temperature


Kepler-16b
Earth
Mercury
B
A
Size of Our Sun

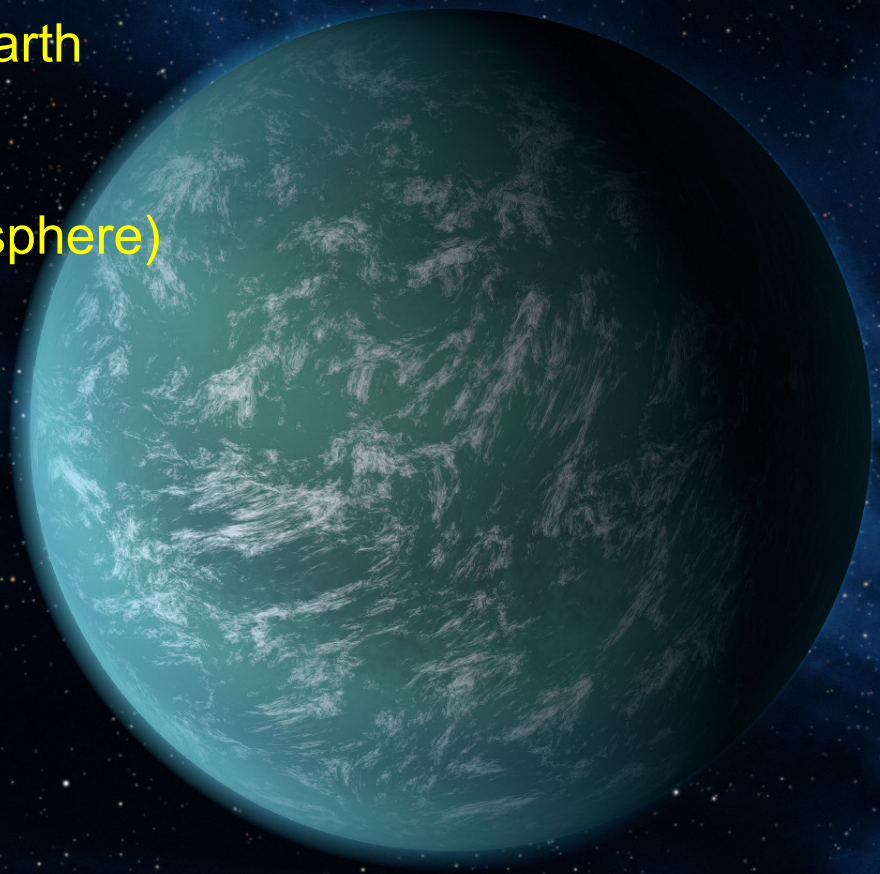
Sunset on a possible moon of Kepler 16b

We now know of 5 more planets in 3 other systems with two suns!
Circumbinary planets must be fairly common.

Kepler 22b

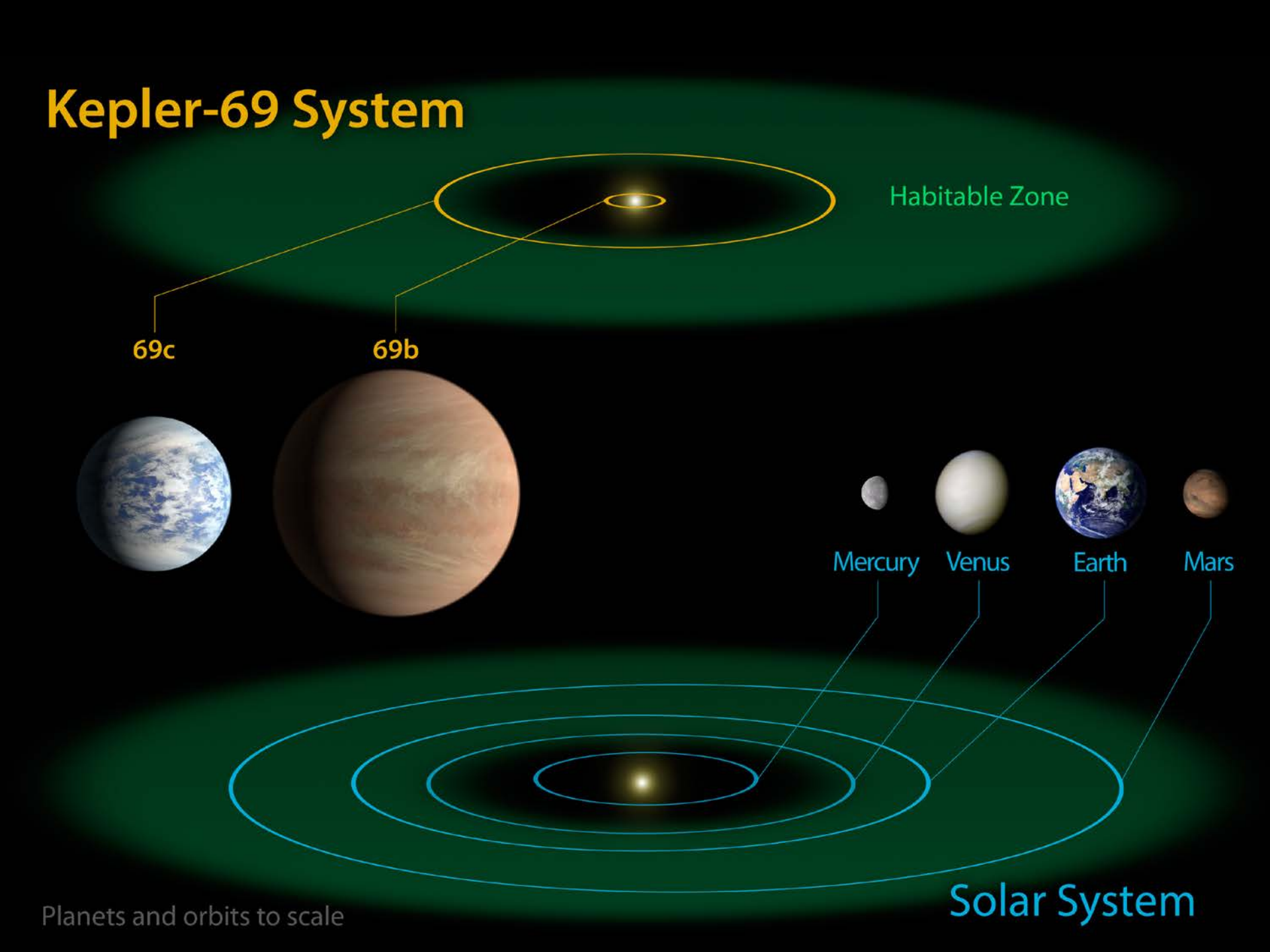
In the habitable zone of a Solar-like star
but 2.4 times the size of Earth

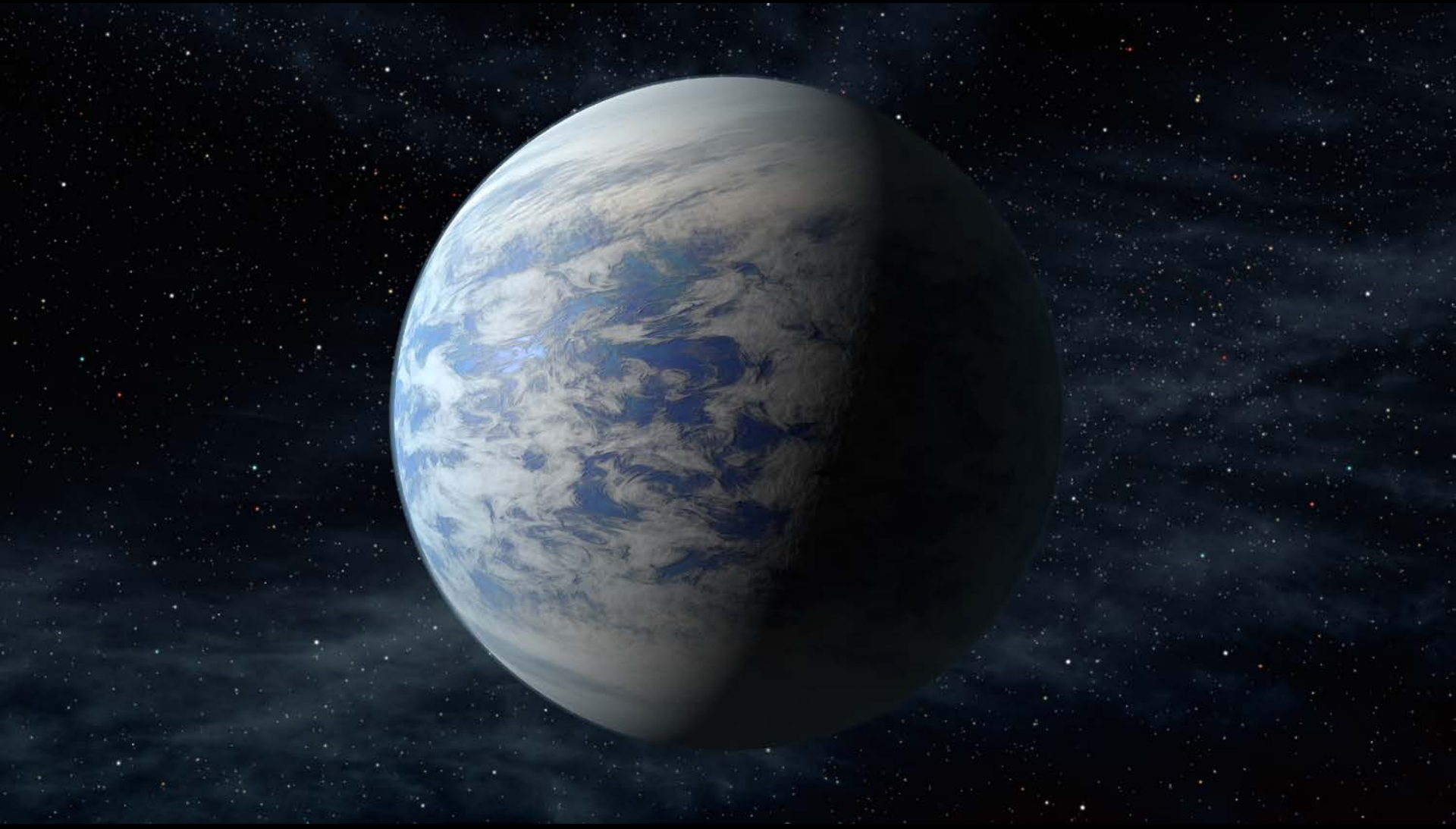
Temperature 14 F
(but warmer with an atmosphere)



Water planet?
Rocky surface?
Deep atmosphere?

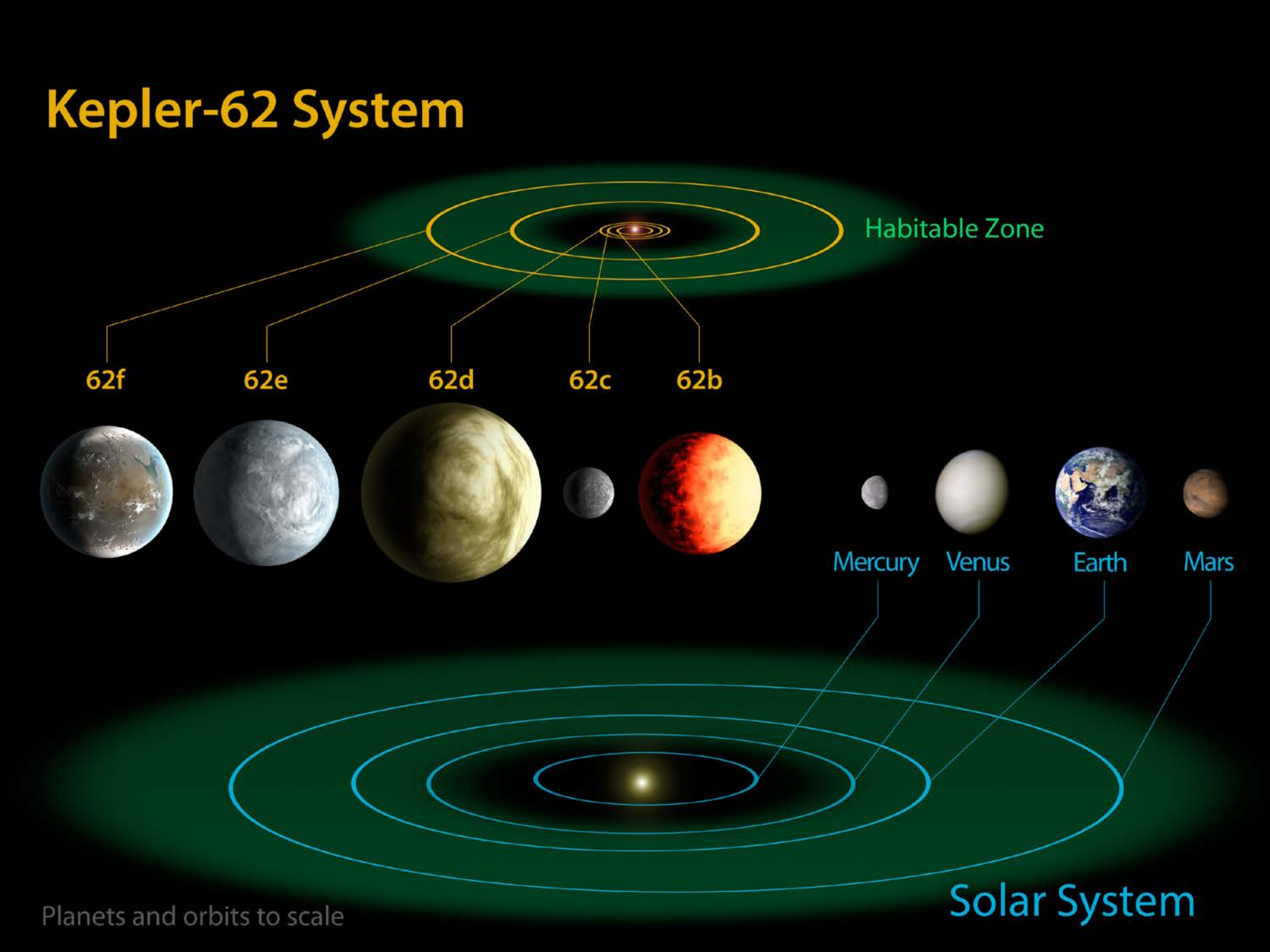
Kepler-22	G8 Dwarf
Mass:	.97 M_{Sun}
Radius:	.98 R_{Sun}
Luminosity:	.66 L_{Sun}

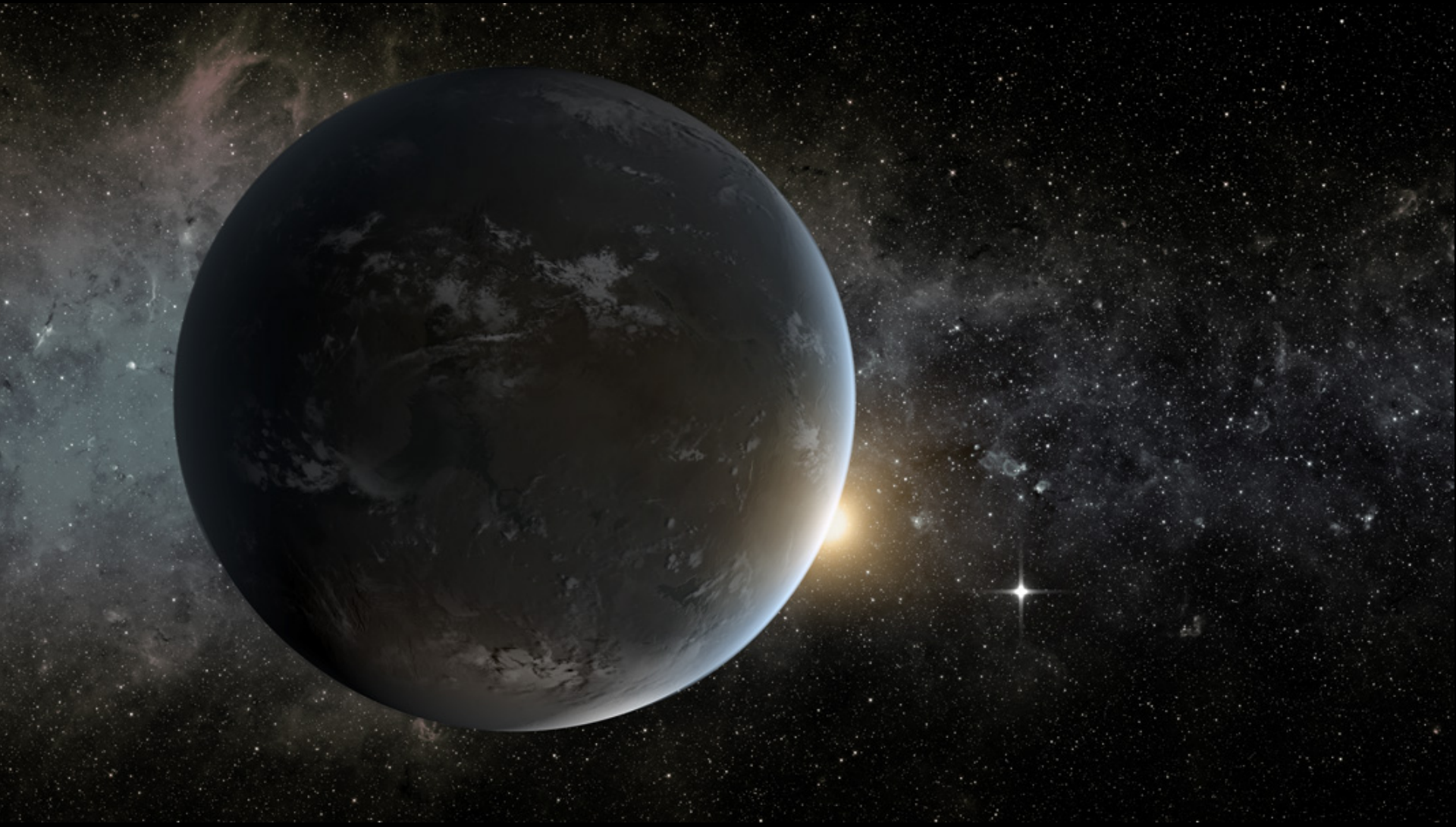

Kepler-69 System
Habitable Zone
69c
69b
Mercury
Venus
Earth
Mars
Solar System
Planets and orbits to scale



Kepler-69c Teq: 299K / 79F
Size: 1.7 R_{Earth}
Mass: unknown
Composition: probably rocky

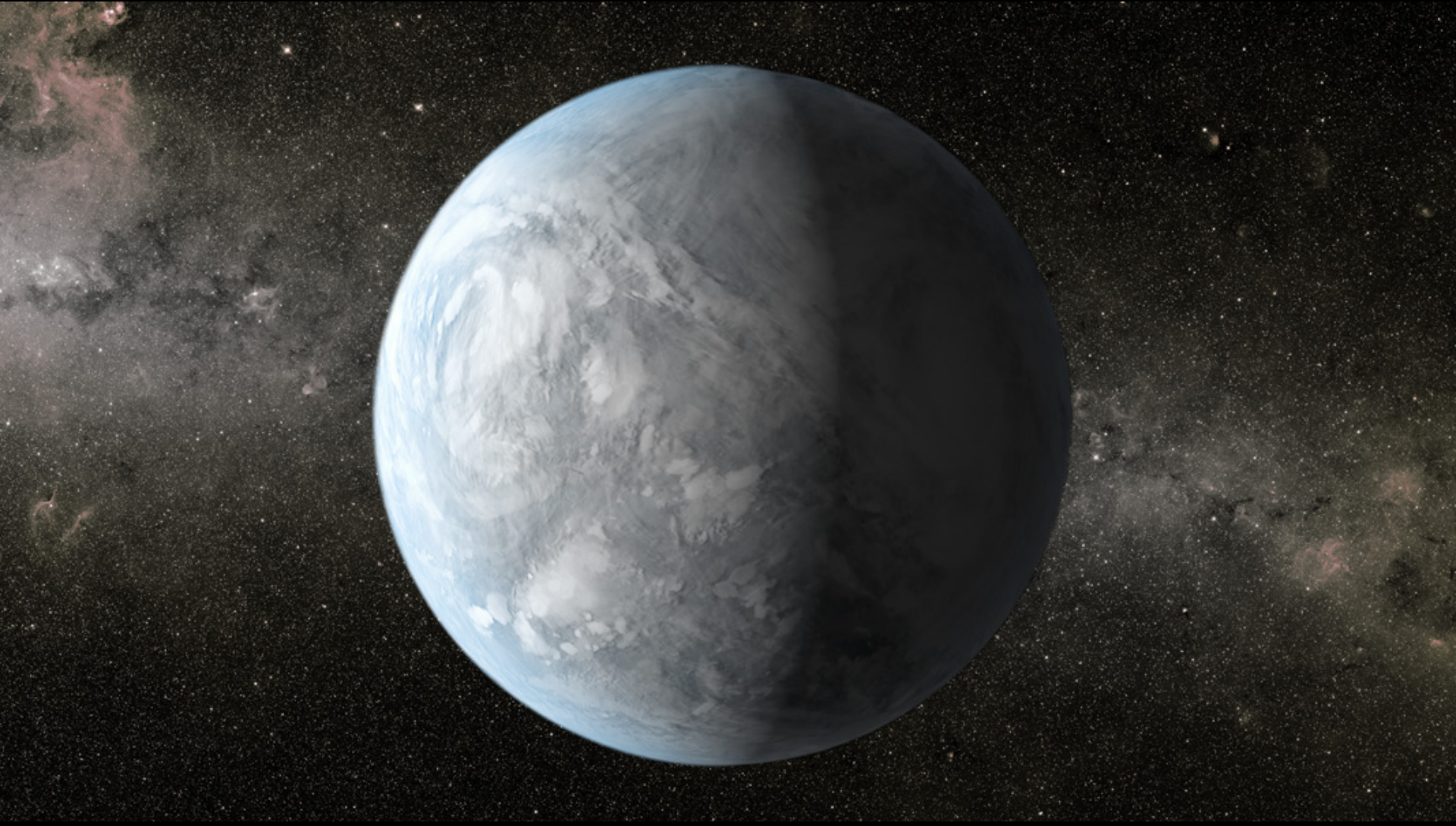
Kepler-69 G6 Dwarf
Mass: .81 M_{Sun}
Radius: .93 R_{Sun}
Luminosity: .75 L_{Sun}


Kepler-62 System
Habitable Zone
62f
62e
62d
62c
62b
Mercury
Venus
Earth
Mars
Solar System
Planets and orbits to scale



Kepler-62f Teq: 208K / -85F
Size: 1.4 R_{Earth}
Mass: uncertain (<43 M_{Earth})
Composition: probably rocky

Kepler-62 K2 Dwarf
Mass: .69 M_{Sun}
Radius: .64 R_{Sun}
Luminosity: .30 L_{Sun}



Kepler-62e Teq: 270K / 27F

Size: 1.6 R_{Earth}

Mass: uncertain (<36 M_{Earth})

Composition: probably rocky

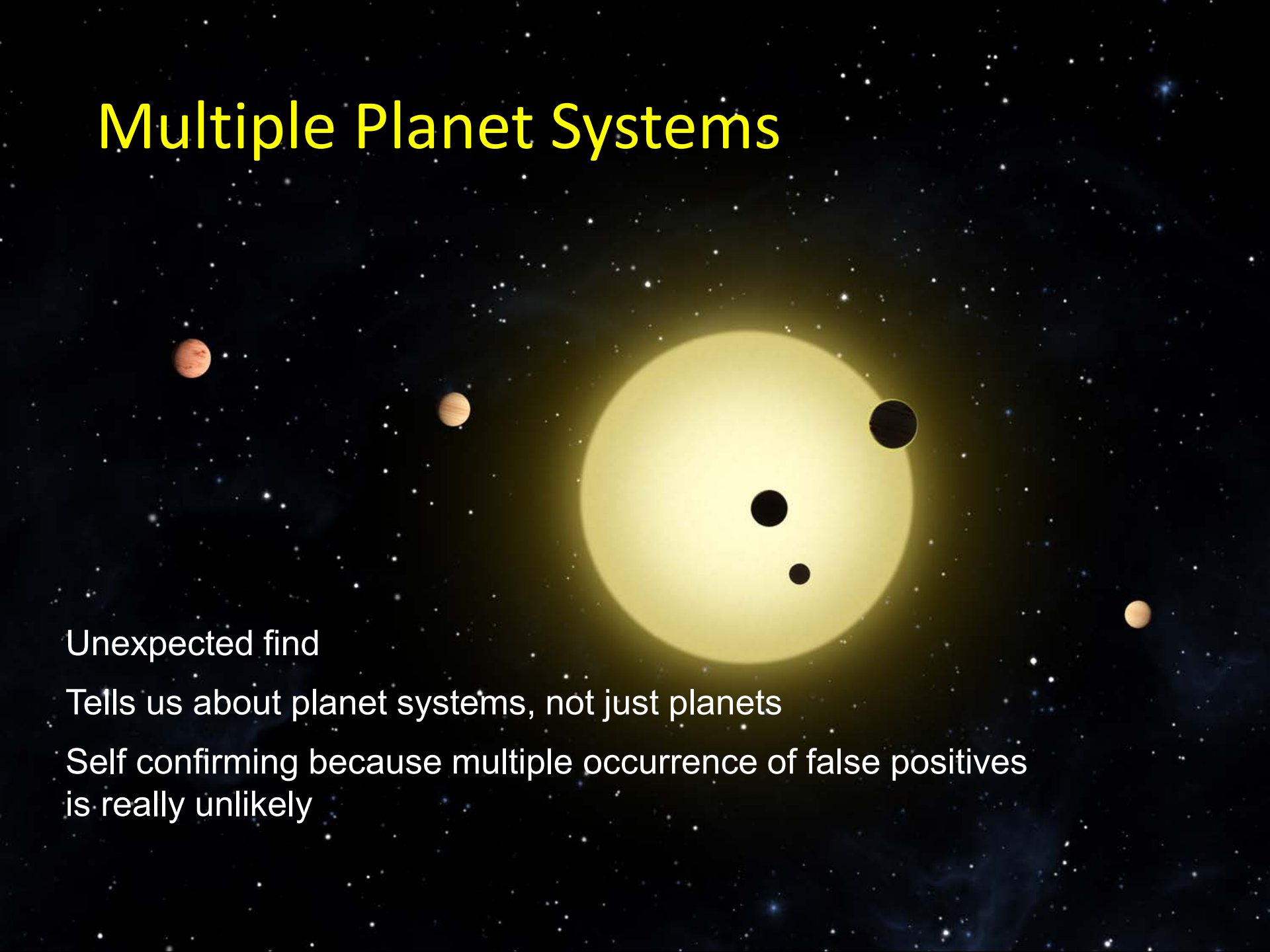
Kepler-62 K2 Dwarf

Mass: .69 M_{Sun}

Radius: .64 R_{Sun}

Luminosity: .30 L_{Sun}

Multiple Planet Systems

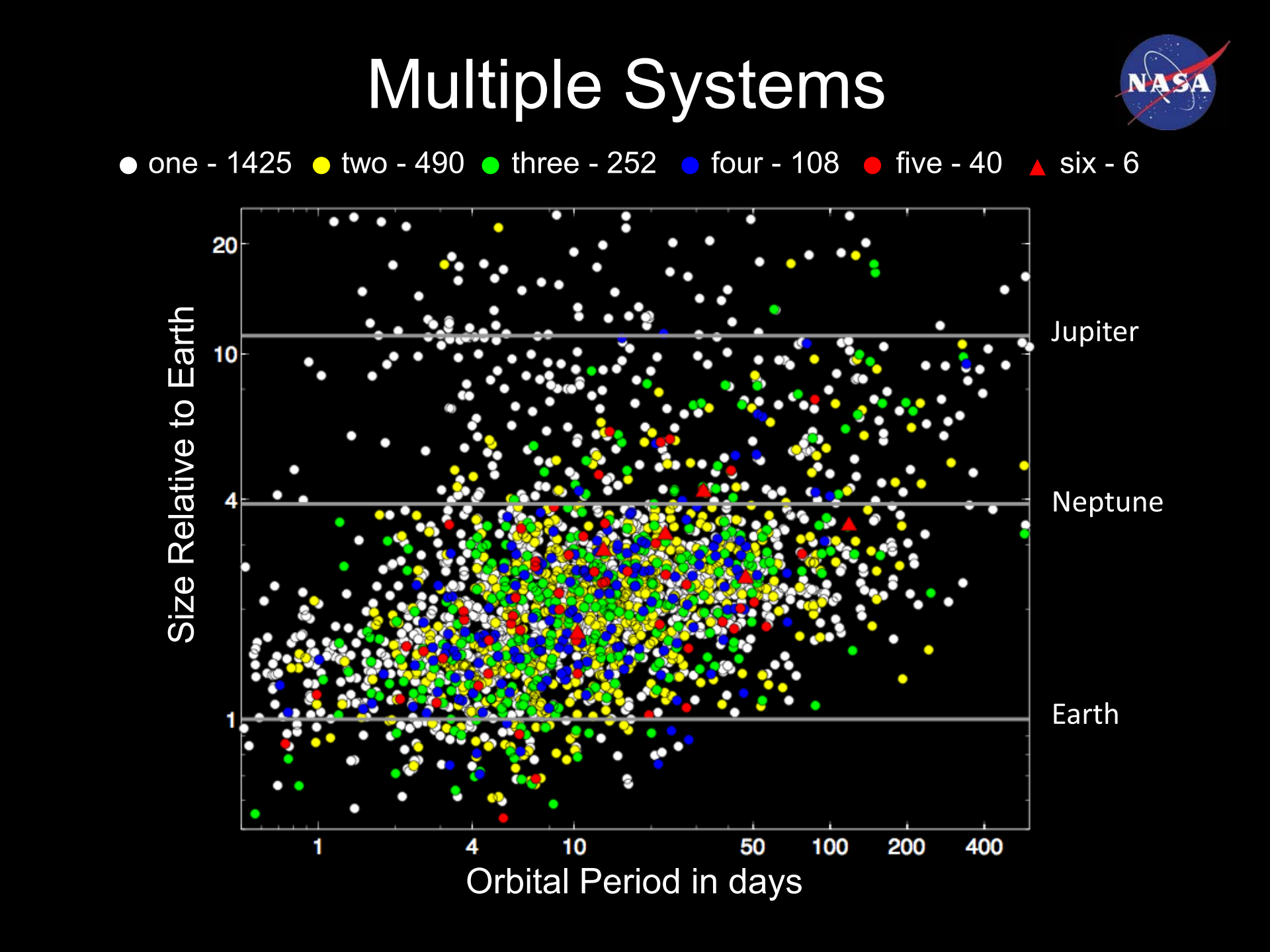


Unexpected find

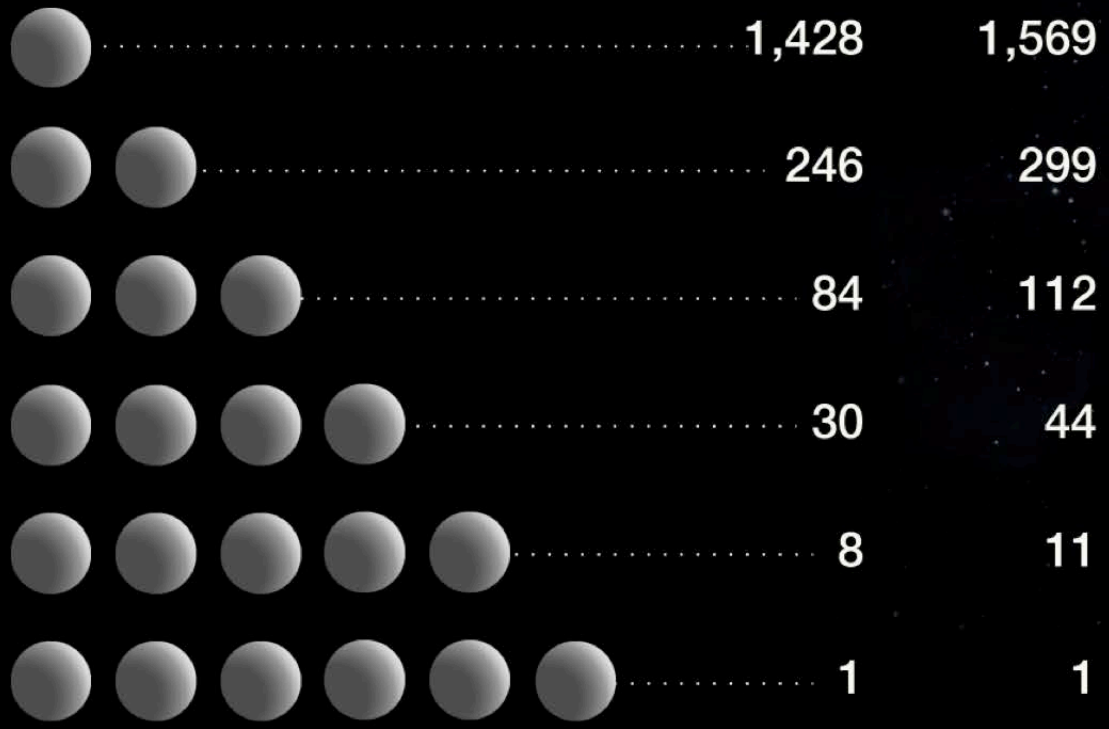
Tells us about planet systems, not just planets

Self confirming because multiple occurrence of false positives is really unlikely

Multiple Systems



Kepler Transiting Multi-Candidate Systems



467 stars with 1171 planets in multiple systems

Kepler's Confirmed Multiple Planet Systems

>150 more multiple planet systems with >800 planet candidates

41 New Transiting Planets in Kepler Field of View

Steffen et al. 2012, arXiv:1208.3499

Ji-Wei Xie 2012, arXiv:1208.3312

41 New Transiting Planets in Kepler Field of View

Steffen et al. 2012, arXiv:1208.3499

Ji-Wei Xie 2012, arXiv:1208.3312

Kepler Census – May 2013

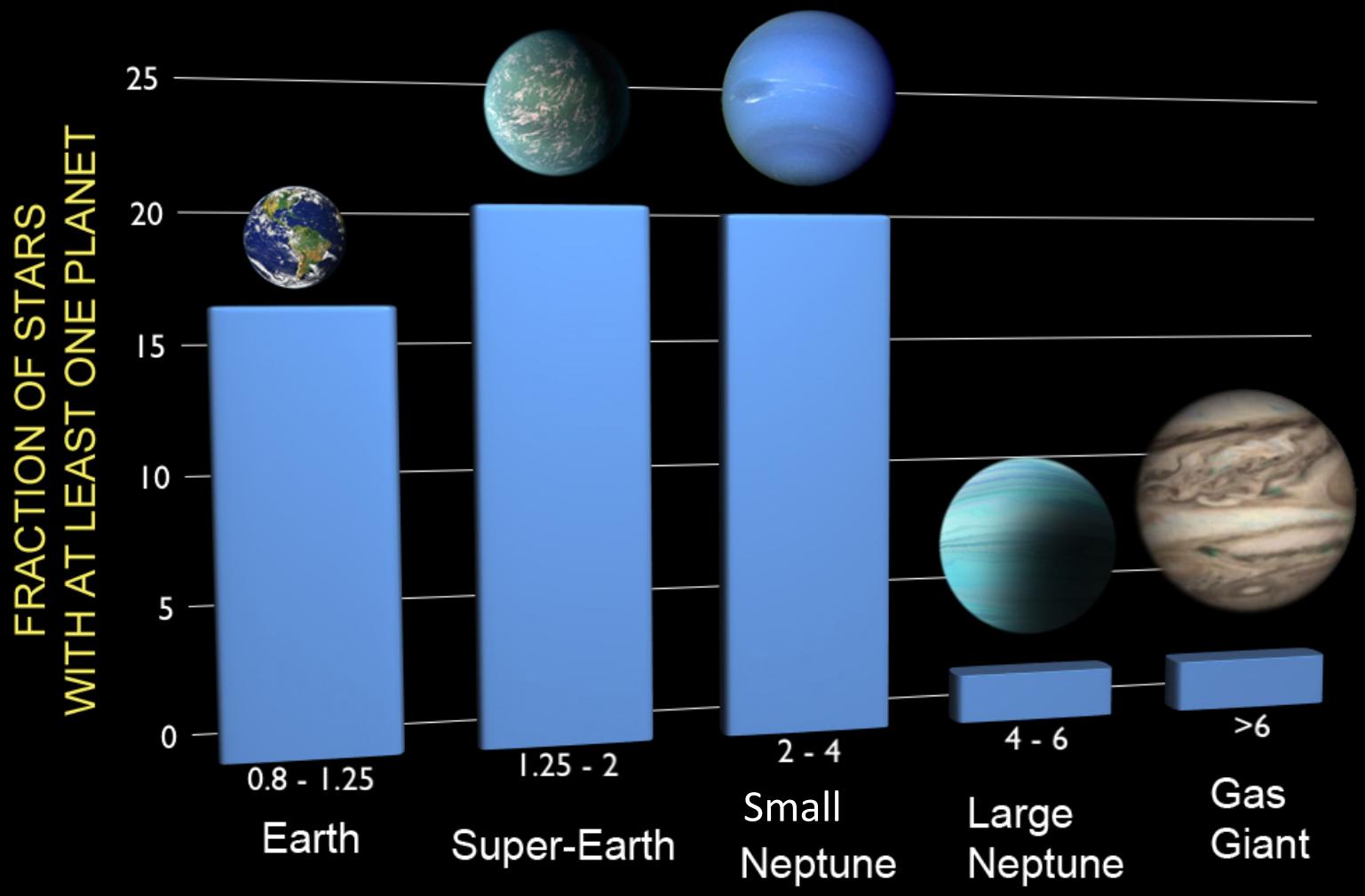
- 2,740 candidates around 2,036 stars from 22 months of data.
  - 351 are earth-size
  - 58 are in the HZ
  - 23% (467) of stars have more than one candidate
  - 10 candidates in habitable zone are less than twice the size of Earth.
    - One, now confirmed, orbits a sun-like star: Kepler-69c
  - New candidates added as they are found
    - 2810 now on observer's web site https://cfop.ipac.caltech.edu and http://exoplanetarchive.ipac.caltech.edu/
    - More to come soon
- 132 confirmed planets

Kepler Census - 10 July 2013

- 3,278 candidates around 2,468 stars from 36 months of data.
  - 540 are earth-size
  - 102 are in the HZ (185 to 303 K, -126 to 86 F)
  - 22% (540) of stars have more than one candidate
  - 17 candidates in habitable zone are less than twice the size of Earth.
    - One, now confirmed, orbits G type, sun-like star: Kepler-69c
  - New candidates added as they are found
    - 3278 now on observer's web site https://cfop.ipac.caltech.edu and http://exoplanetarchive.ipac.caltech.edu/

- 135 confirmed planets

Occurrence of Planets



Stars & Planetary Systems

17 %, 1 in 6, stars have an Earth-size planet with period less than 85 days

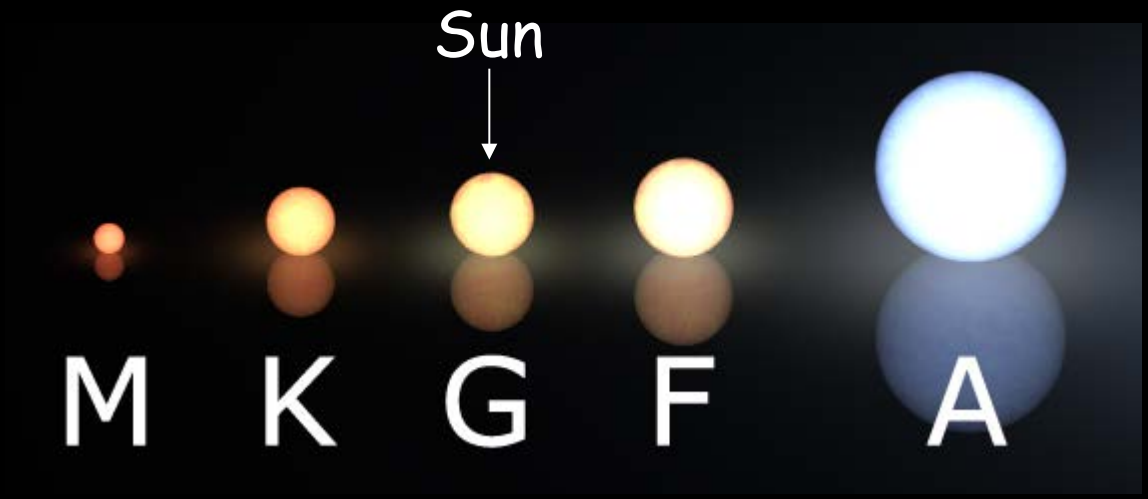
And 70 % have a planet of any size with period less than 400 days

Not including long-period Earths & Super Earths

Almost all Sun-like stars have a planetary system !

Planets and stellar type

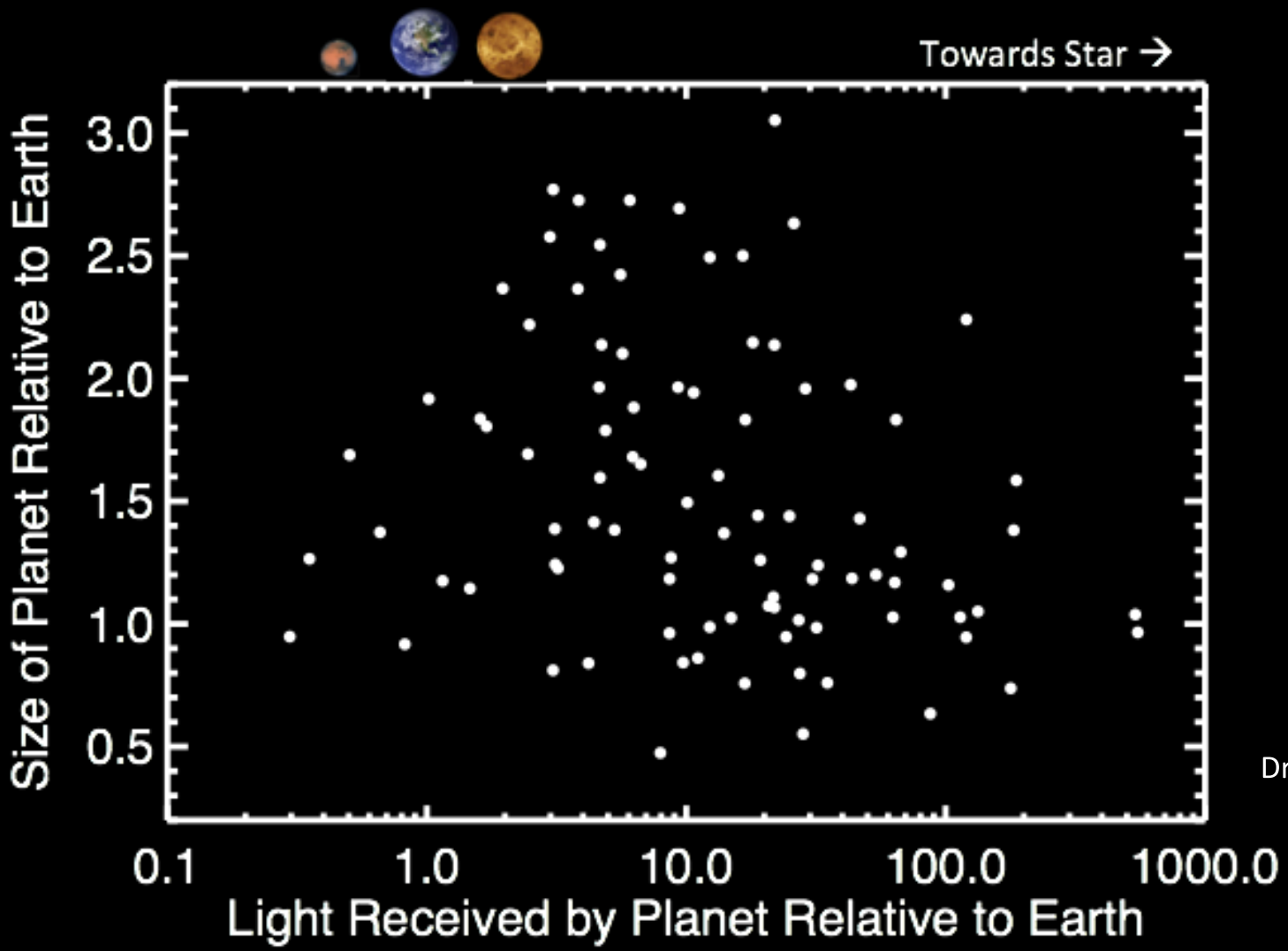
It was previously thought that small planets were more common orbiting small stars



The results of Kepler can be explained with planets equally common orbiting the different stellar types

Stars in the Solar Neighborhood

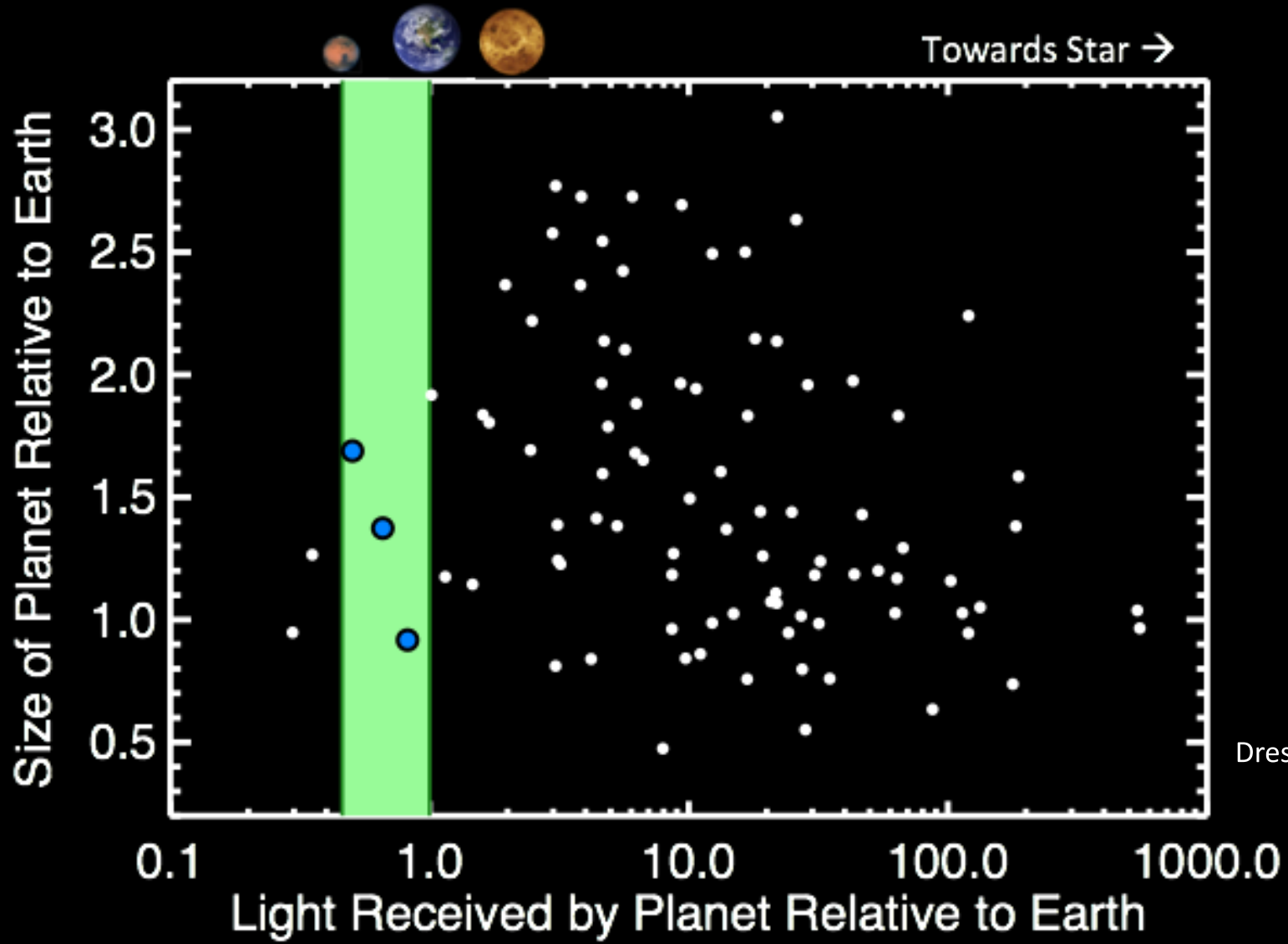
95 Planet Candidates Orbiting M-type Stars



Dressing et al

At least 60% host a planet smaller than Neptune

3 HZ Candidates Orbiting M-type Stars

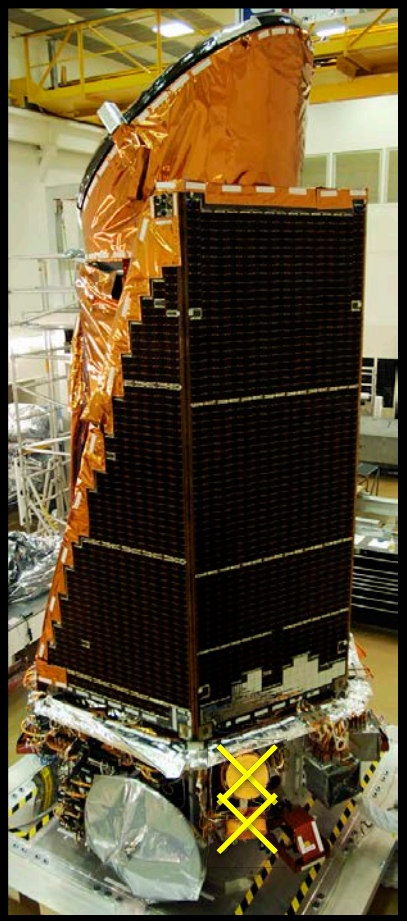


Dressing et al.)

6% host planets smaller than 2.5R_e in the HZ

..the nearest earth-size planet in the Habitable Zone could be just a “stroll across the park,” or 13 LY.

Kepler Status



Kepler is stable and safe in Point Rest State.

Two if its four reaction wheels have failed.

Kepler cannot point with precision with less than 3 wheels. Science data collection has stopped.

Kepler must use thrusters to maintain attitude

Point Rest State is very fuel efficient.

Expect 3-4 years of fuel. We have time to think.

But *Kepler* is not dead!

All science data on the spacecraft was retrieved.

The last 2 years of data have yet to be analyzed.

This analysis will continue and we expect many more planets and much more science to come from *Kepler*.

The elusive Earth-analog may still lurk in the data!

Kepler Status

Kepler has three known cards to play

Try to restart recently dead wheel

Wheel spins in reverse. Still have to check forward.

Try to restart previously dead wheel

Spins but don't know about performance

A wheel restart could add some lifetime to the exoplanet survey but we would not expect the revived wheel to last long.

Try to implement a 2-wheel/thruster hybrid pointing mode

If restarts fail the hybrid pointing mode could, if it works, revive Kepler with lower precision photometry.

We would then have to decide if the science return was worth the cost.