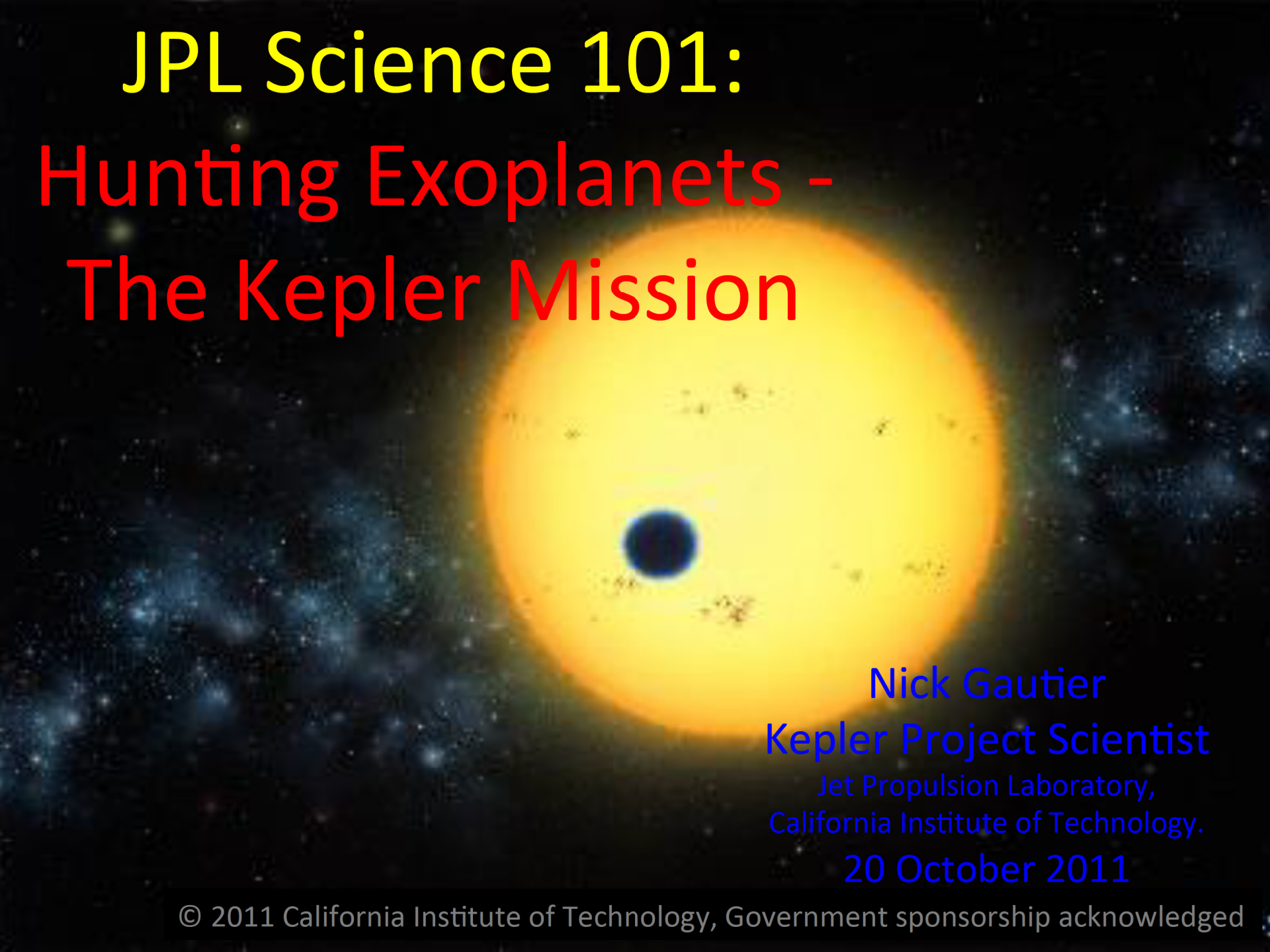
JPL Science 101:

Hunting Exoplanets - The Kepler Mission

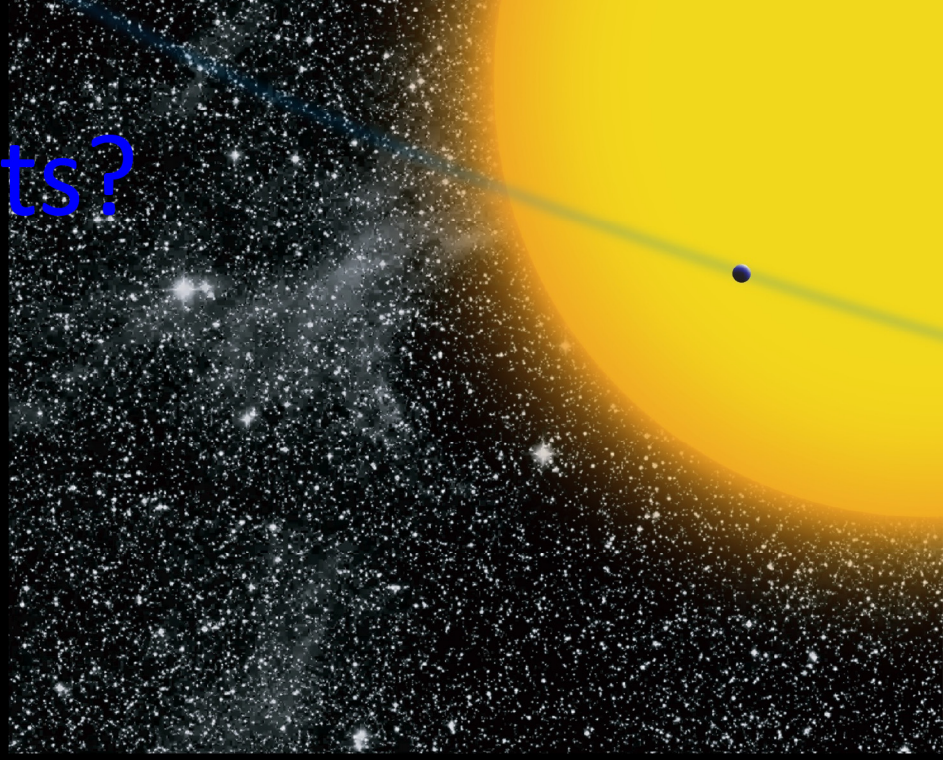


Nick Gautier
Kepler Project Scientist
Jet Propulsion Laboratory,
California Institute of Technology.

20 October 2011

© 2011 California Institute of Technology, Government sponsorship acknowledged

What are Exoplanets?



Exoplanets are planets orbiting stars other than our Sun.

689 known as of 2 October

This talk will cover which exoplanets might be habitable

How to find exoplanets

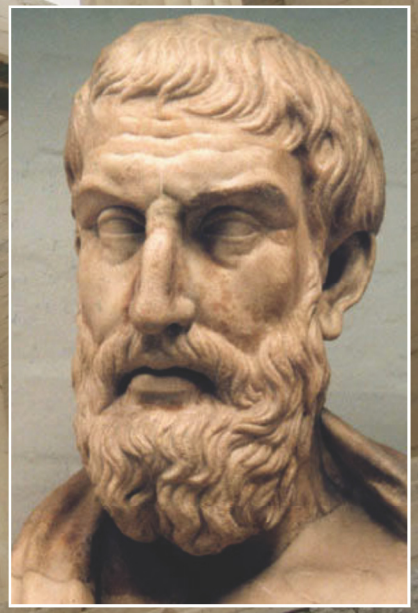
The Kepler Mission and its results

Conclude with some comments on what this all means

Speculation on the existence of other habitable worlds is age-old

There are infinite worlds both like and unlike this world of ours ... we must believe that in all worlds there are living creatures and plants and other things we see in this world....

Epicurus (341-270 BC)



Ideas of Other Worlds and Other Life Inspires Us Today

A Fundamental NASA Mission Goal:

To place our Solar System in context with other planetary systems

Are there Earth-like planets beyond our solar system?

Does life in any form however simple or complex, carbon-based or other, exist elsewhere than on Earth?

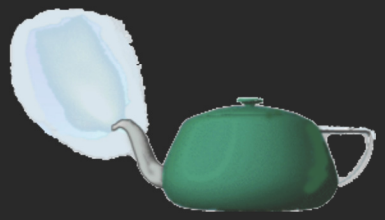
What is a Habitable Planet?

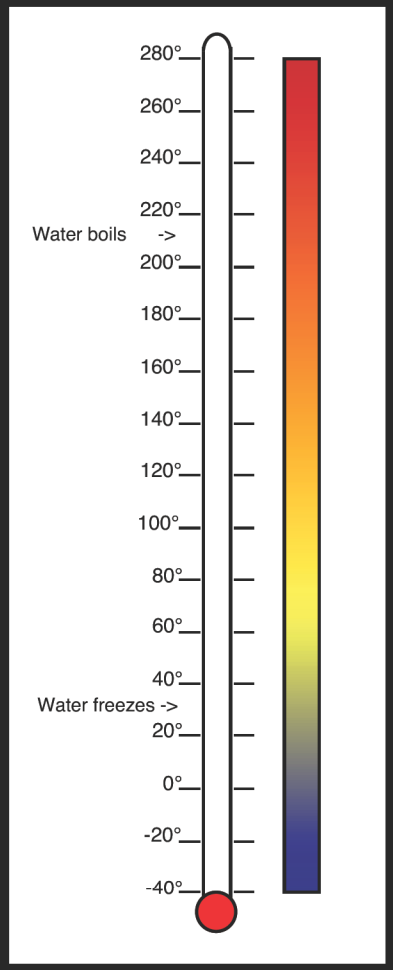
- Right temperature
- Liquid water
- Atmosphere

What Controls Temperature?

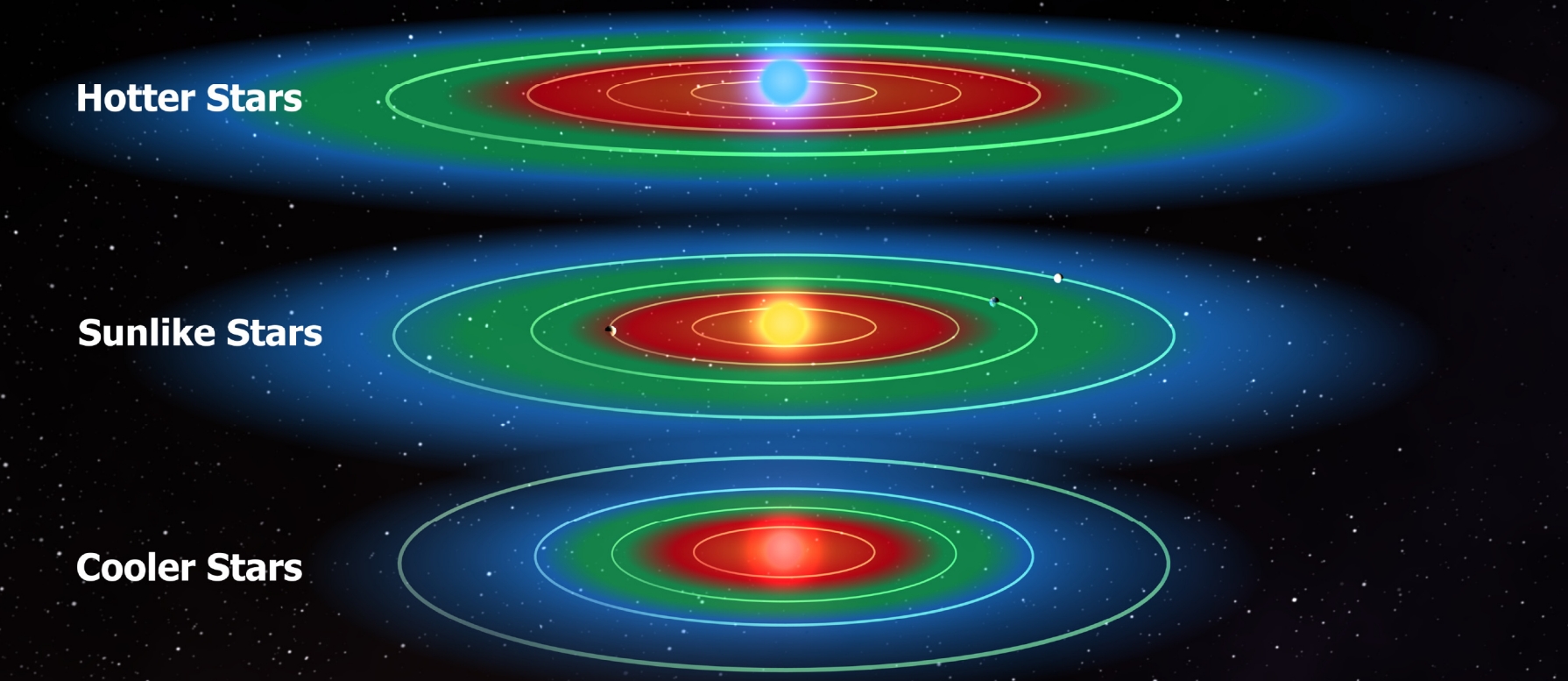
Distance from its star

Planet's atmosphere
greenhouse gases





The Habitable Zone



Planet Size Affects Habitability

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)

Exoplanet Search

So, we want to find:

Roughly Earth-size planets

In the habitable zones of their stars

How do you do that?

It's trickier to sort out planets with water or greenhouse gasses so we'll start with size and Habitable Zone distance.

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

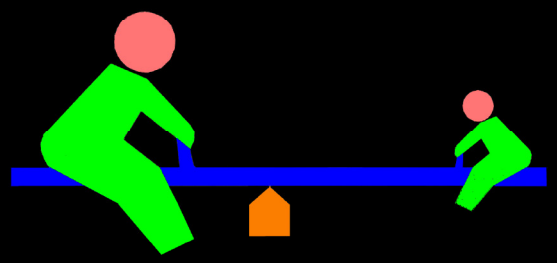
Star wobble (Astrometry)
Direct imaging
Microlensing
Pulsar timing
Reflection photometry

Planets Move Stars

Planets and stars orbit each other, both circling their common center of gravity.

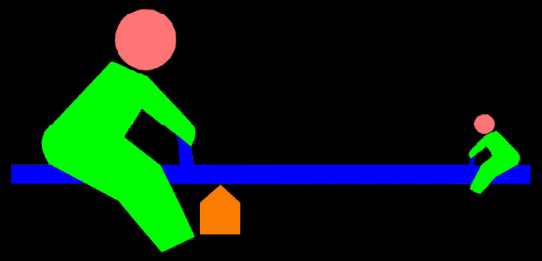
Larger planets pull the center of gravity farther from the star and make the star move in a larger orbit

Like kids on a see-saw:



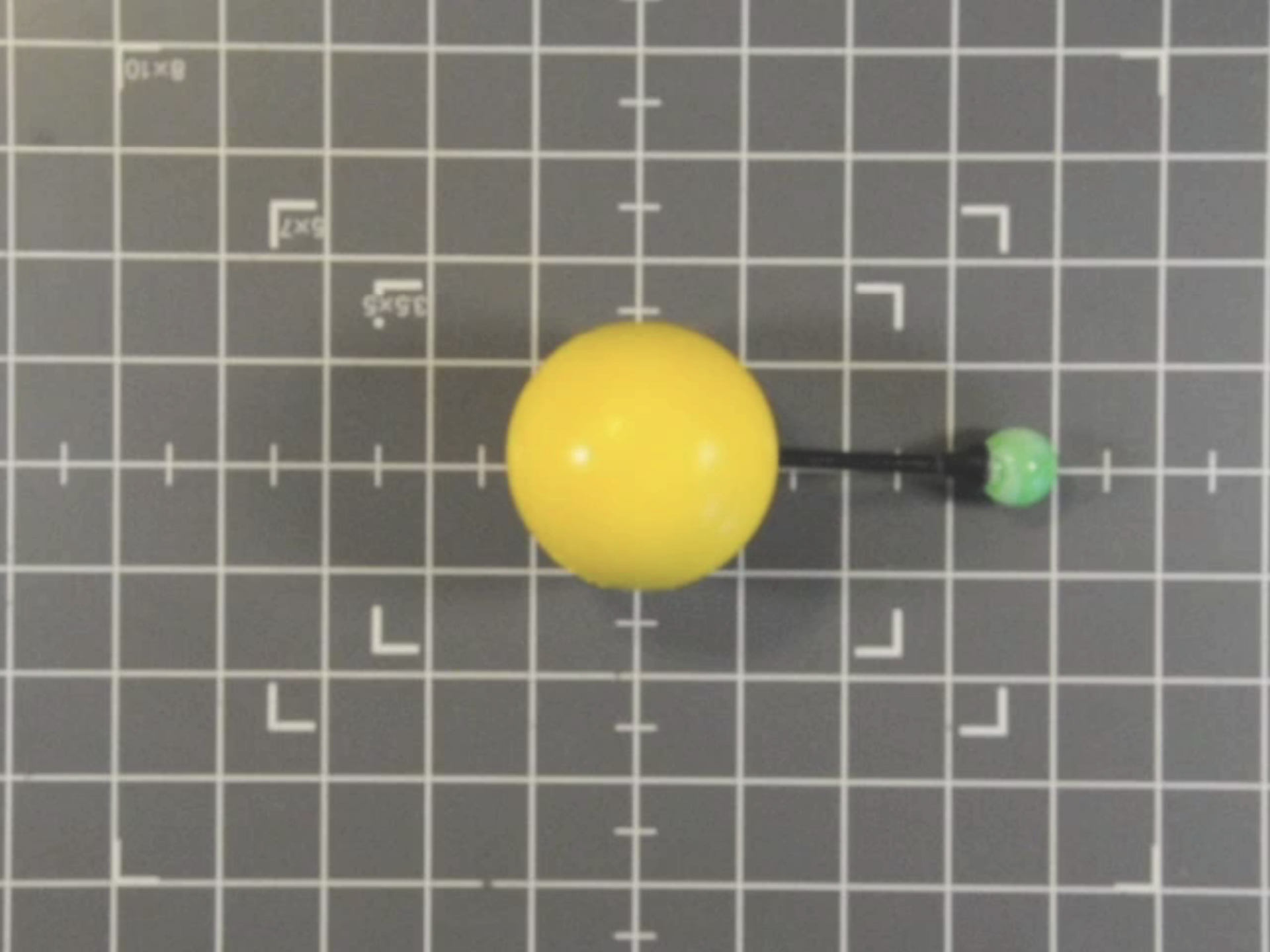
Big kid (star) sits farther from balance point with medium size partner (planet).

Moves more

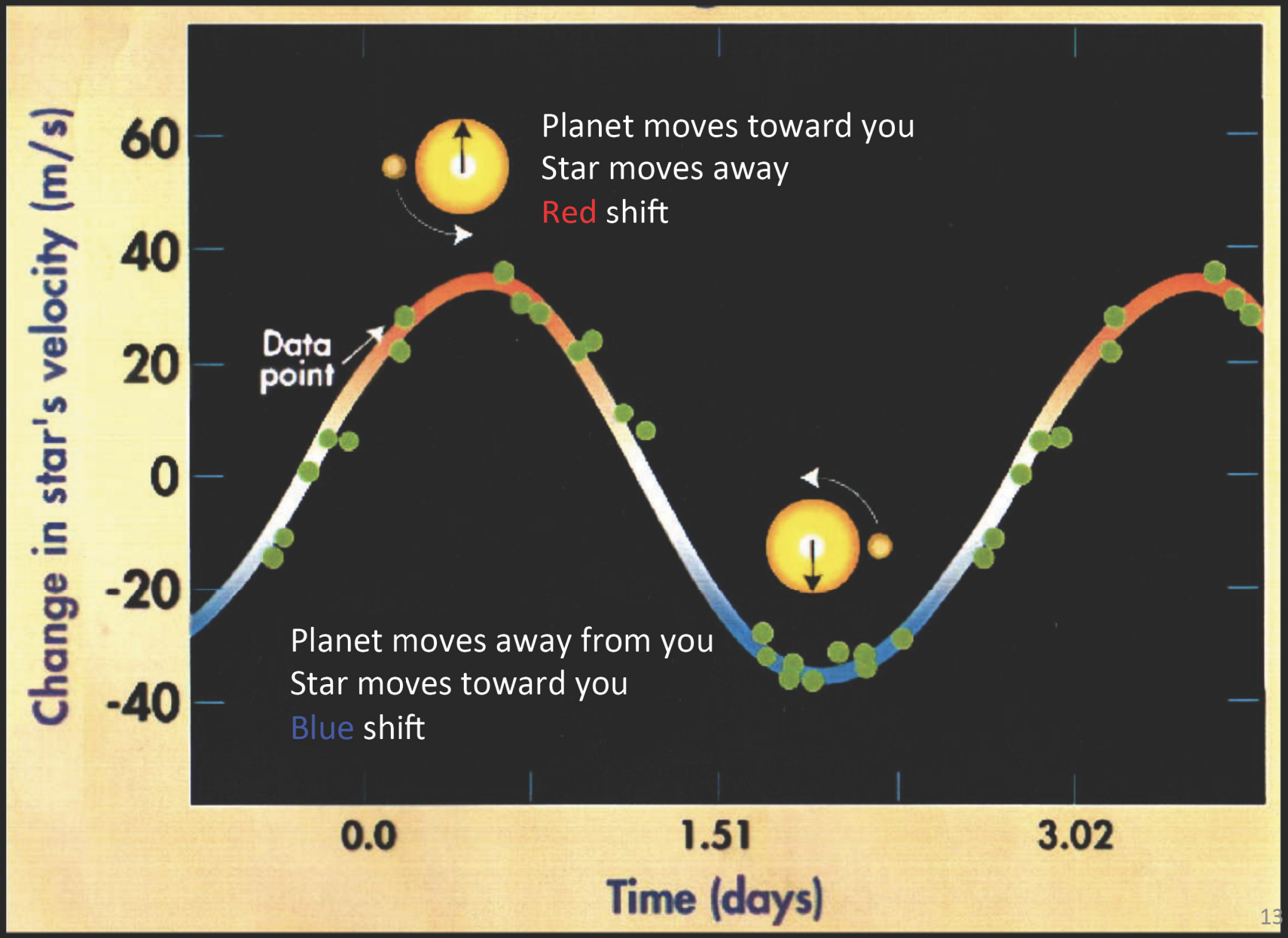


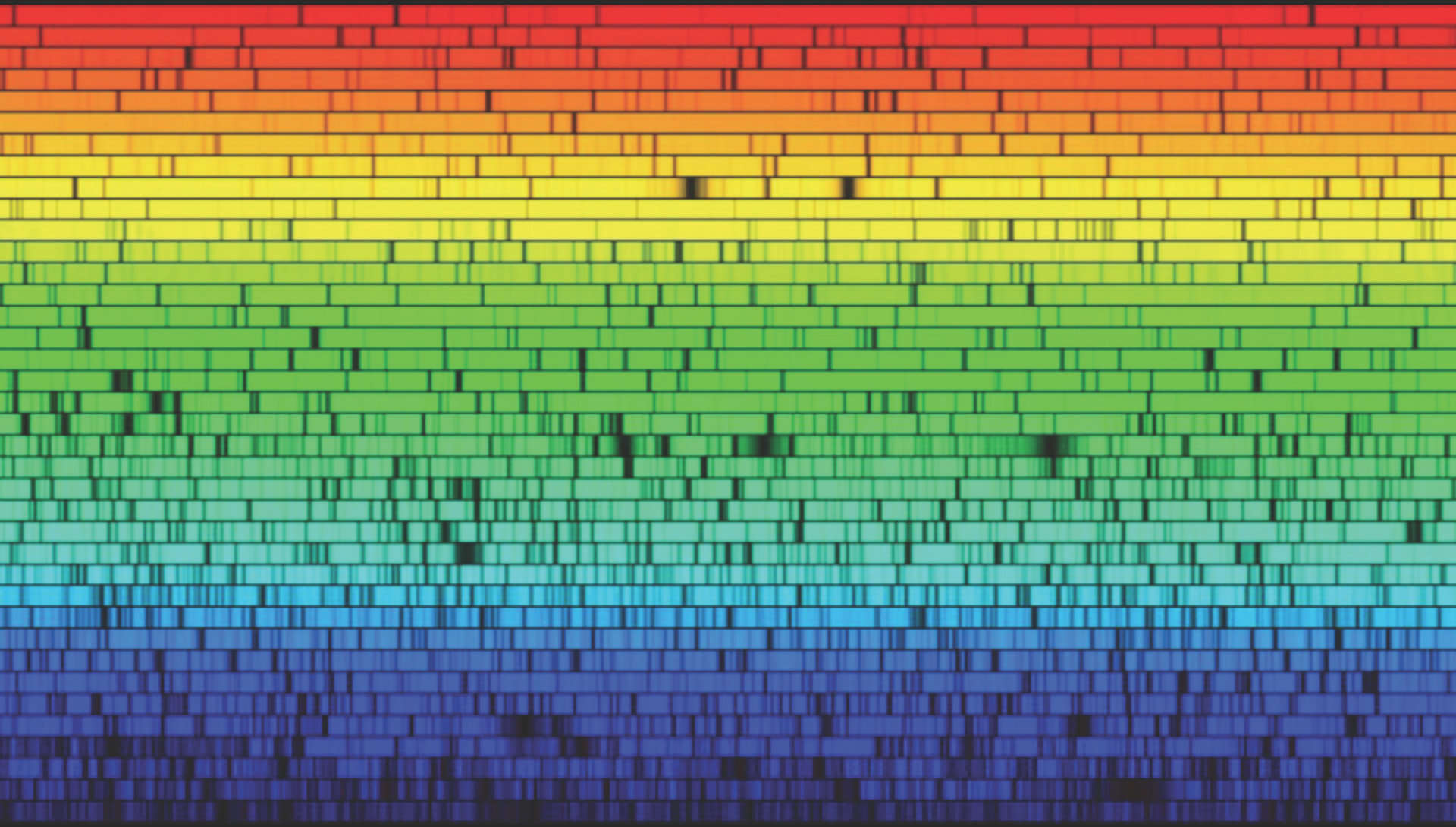
Big kid (star) sits closer to balance point with small size partner (planet).

Moves less


8x10
5x7
3.5x5

We See this Motion in the Star's Spectrum





Radial Velocity measurement can find planet's MASS

And distance from its star but not its size

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.

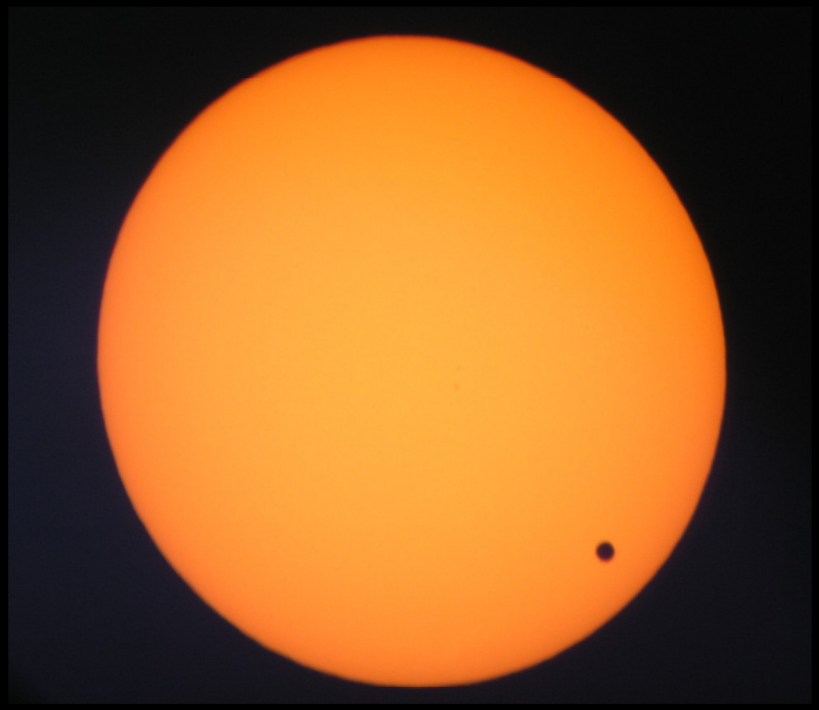
Can only do 1 star at a time.

Need many measurements totaling, maybe, hundreds, of hours

Need another way to find Earths.

But remember the RV method. It's important later.

Planetary Transits

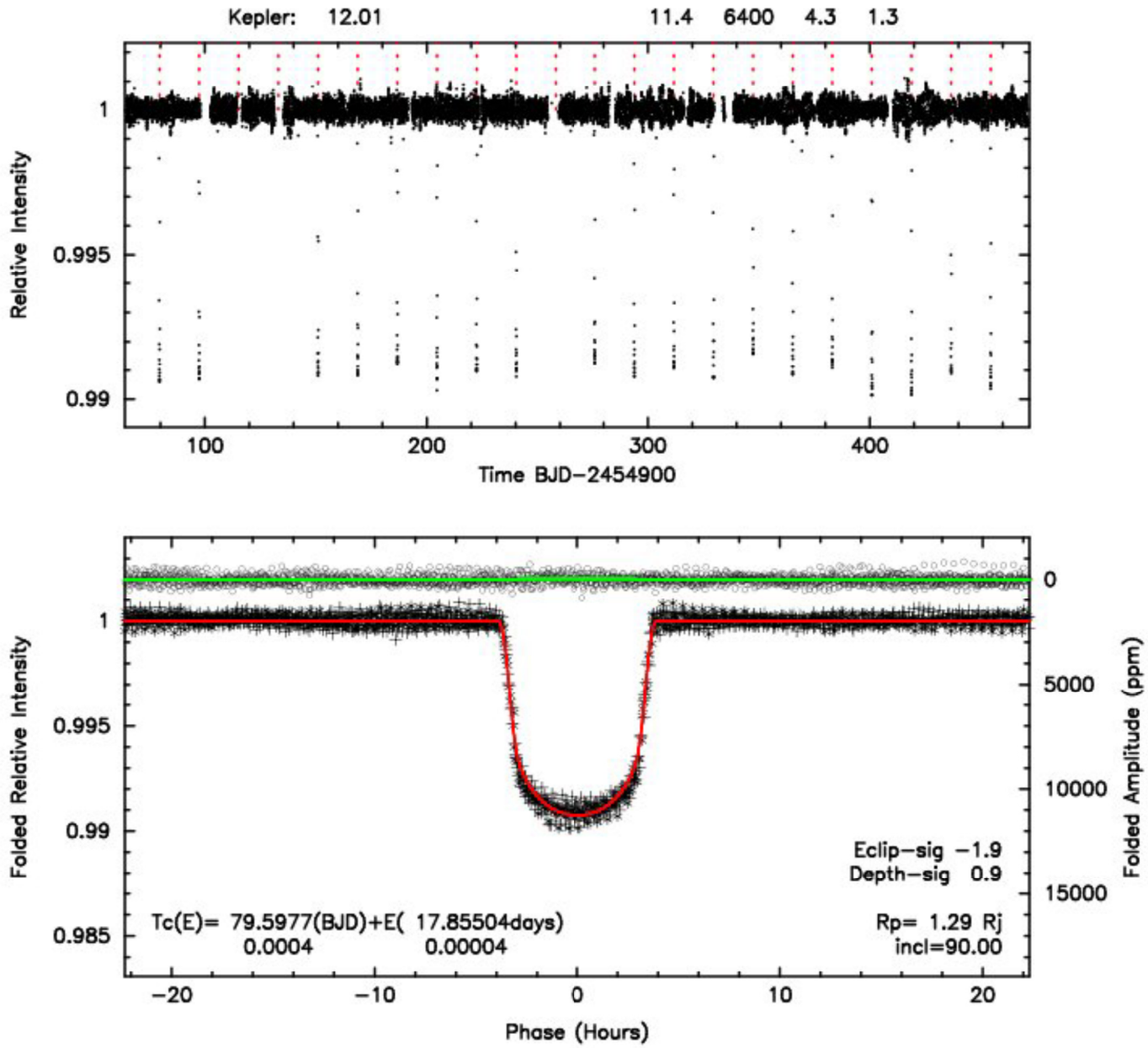


Sometimes a planet's orbit takes it in front of its star as seen from Earth.

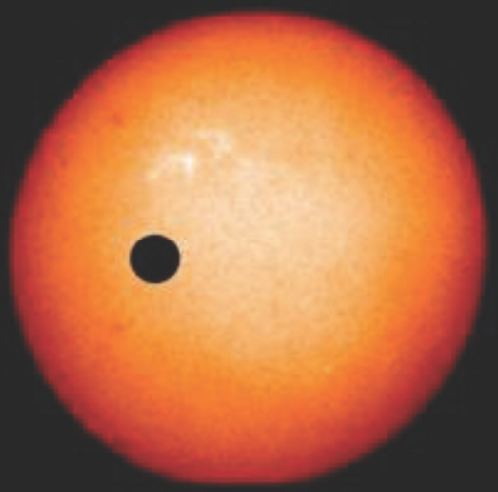
For a few hours each orbit, it blocks a small amount of the star and making the star appear dimmer.

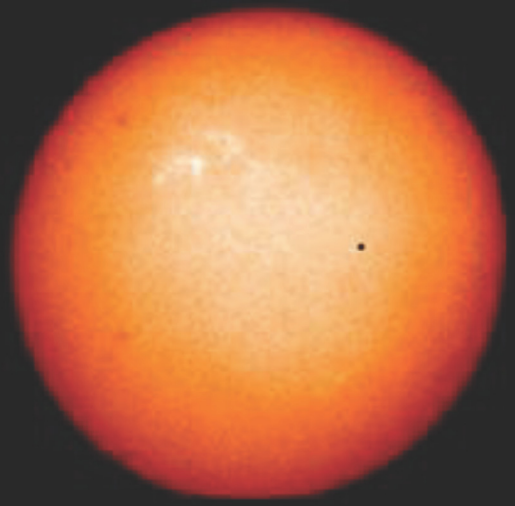
Transit measurements can find the <u>size</u> of the planet and distance from its star but not its <u>mass</u>.

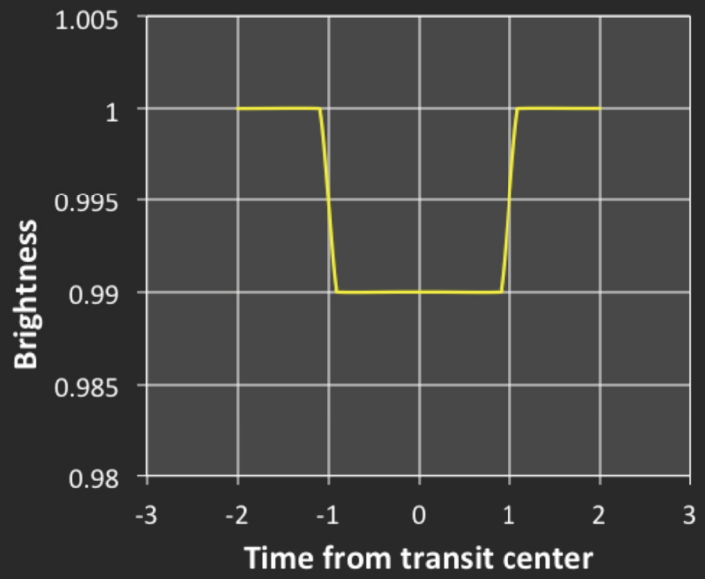
Transit Photometry

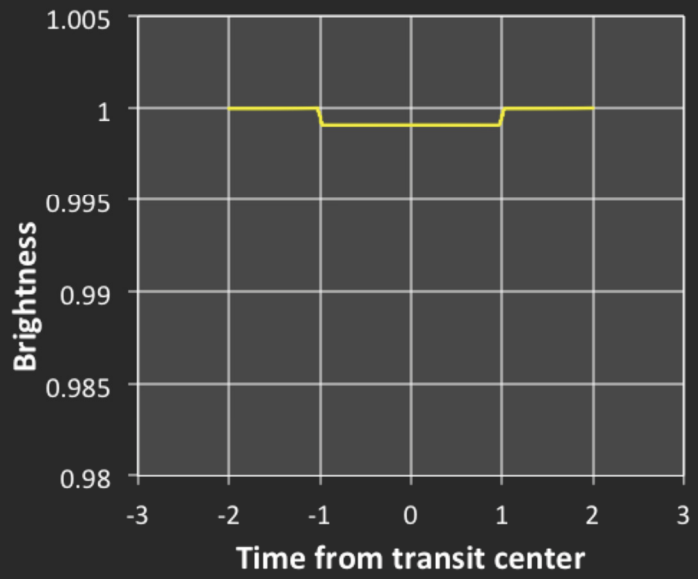

Kepler: 12.01
11.4 6400 4.3 1.3
Relative Intensity
1
0.995
0.99
100
200
300
400
Time BJD−2454900
Folded Relative Intensity
1
0.995
0.99
0.985
0
5000
10000
15000
Folded Amplitude (ppm)
Eclip−sig −1.9
Depth−sig 0.9
Tc(E)= 79.5977(BJD)+E(17.85504days)
0.0004 0.00004
Rp= 1.29 Rj
incl=90.00
−20
−10
0
10
20
Phase (Hours)

Transits Have Different Depths





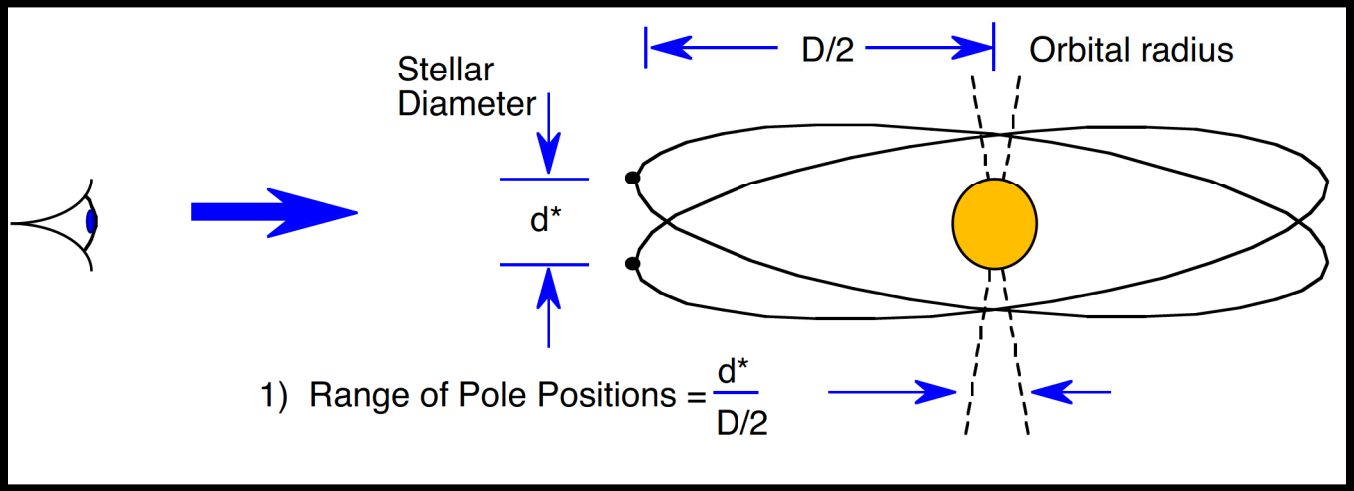




Simulated light curves

Transits Won't Find ALL Planets

Not all planetary orbits are aligned to produce a transit



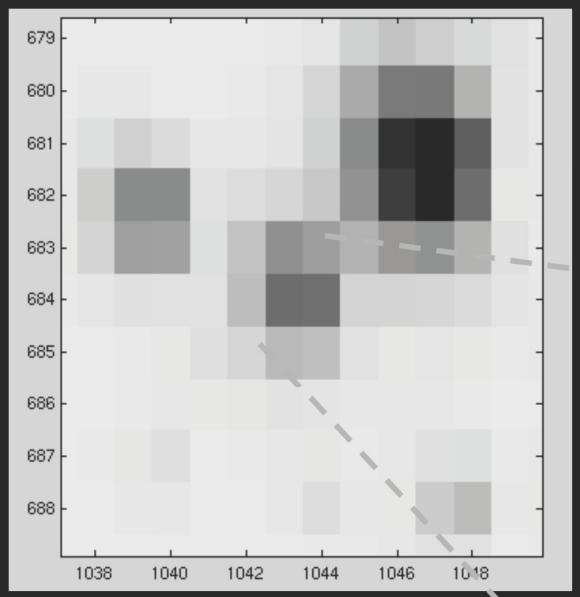
Only a few percent chance for a given planet to transit

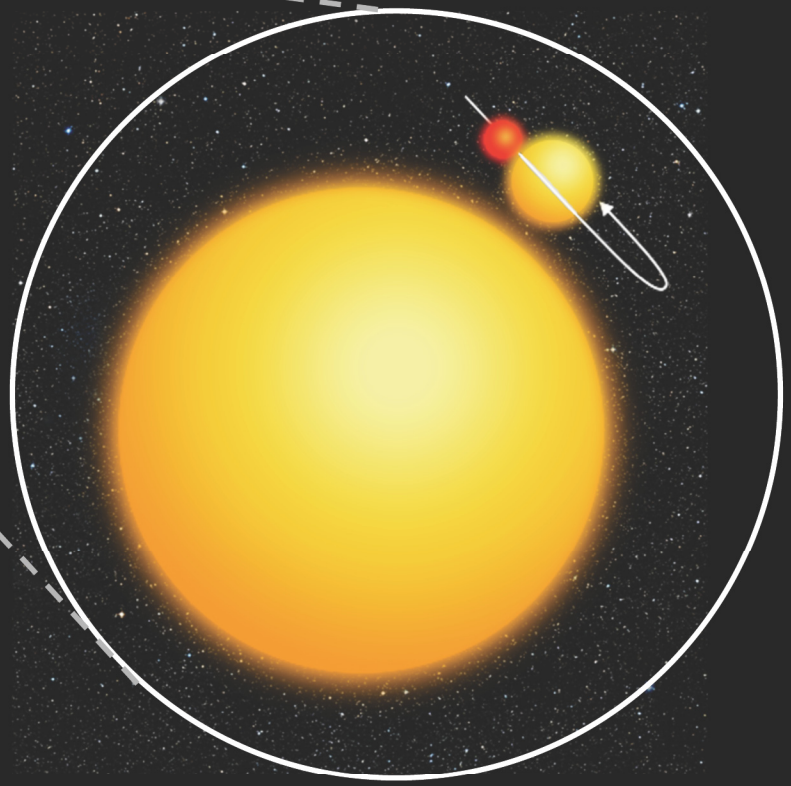
Earth and Sun have only 0.5% chance

Transits last only a few hours each orbit

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

A pitfall: False Positives

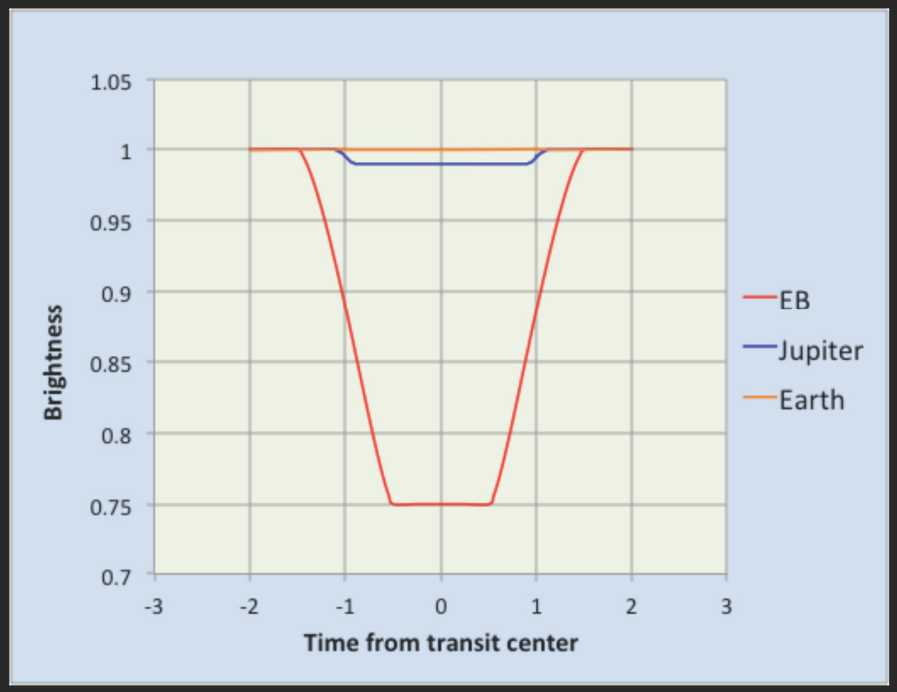


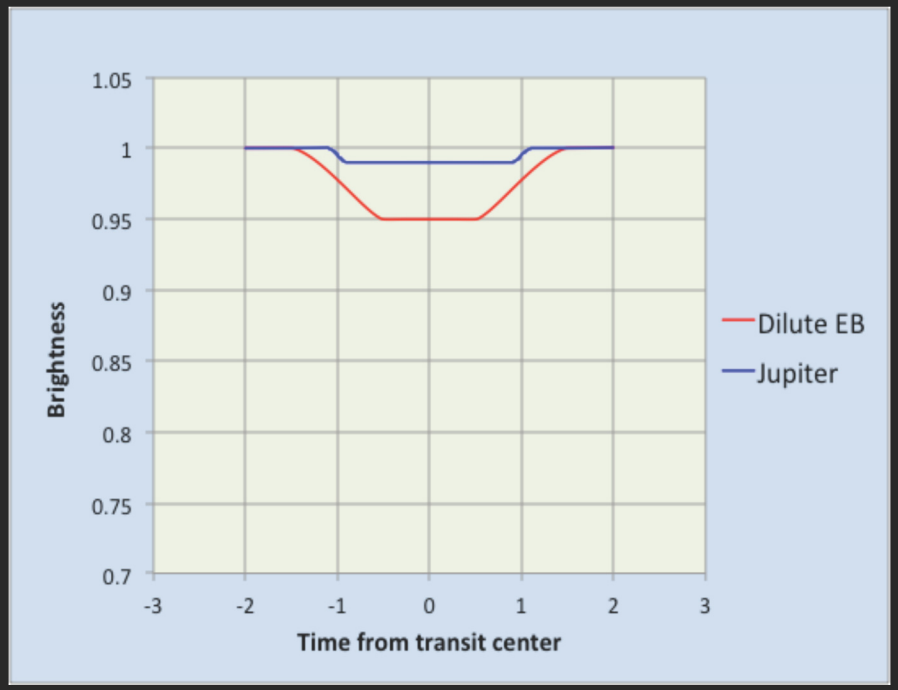


Most False Positives are Dilute Eclipsing Binaries

EB Jupiter Earth

Dilute EB





Simulated light curves

Follow-up observations confirm planets

Use ground based telescopes to:

- Take high resolution pictures to look for extra stars.
- Measure the mass of the transiting object with RV.
  - Stellar mass object means false positive.
  - Planetary mass means a good planet.

Analyze the light curves carefully to look for signs of the "V" shape of eclipsing binaries.

This process gets the mass of many planets.

- Important for deciding on habitability.

Kepler Telescope-Photometer

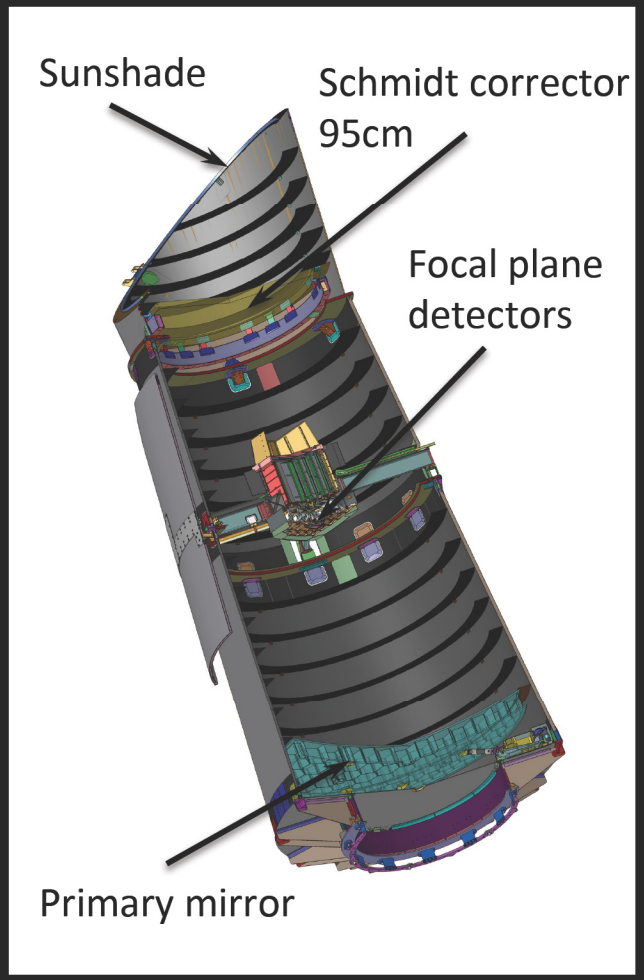
Wide field for lots of stars

Schmidt Camera – 15° diameter field

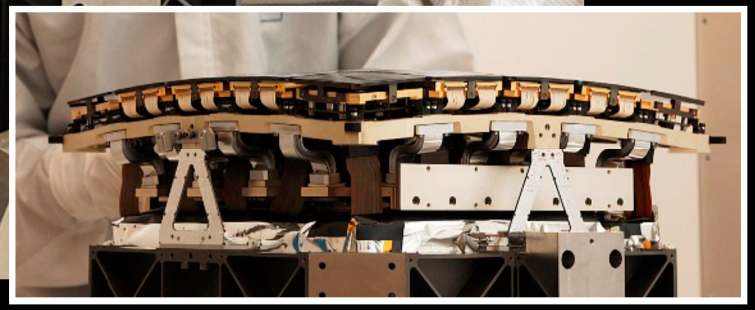
Big, to get enough light

95 cm aperture

Build it for use in space



Kepler's 95 Megapixel Camera

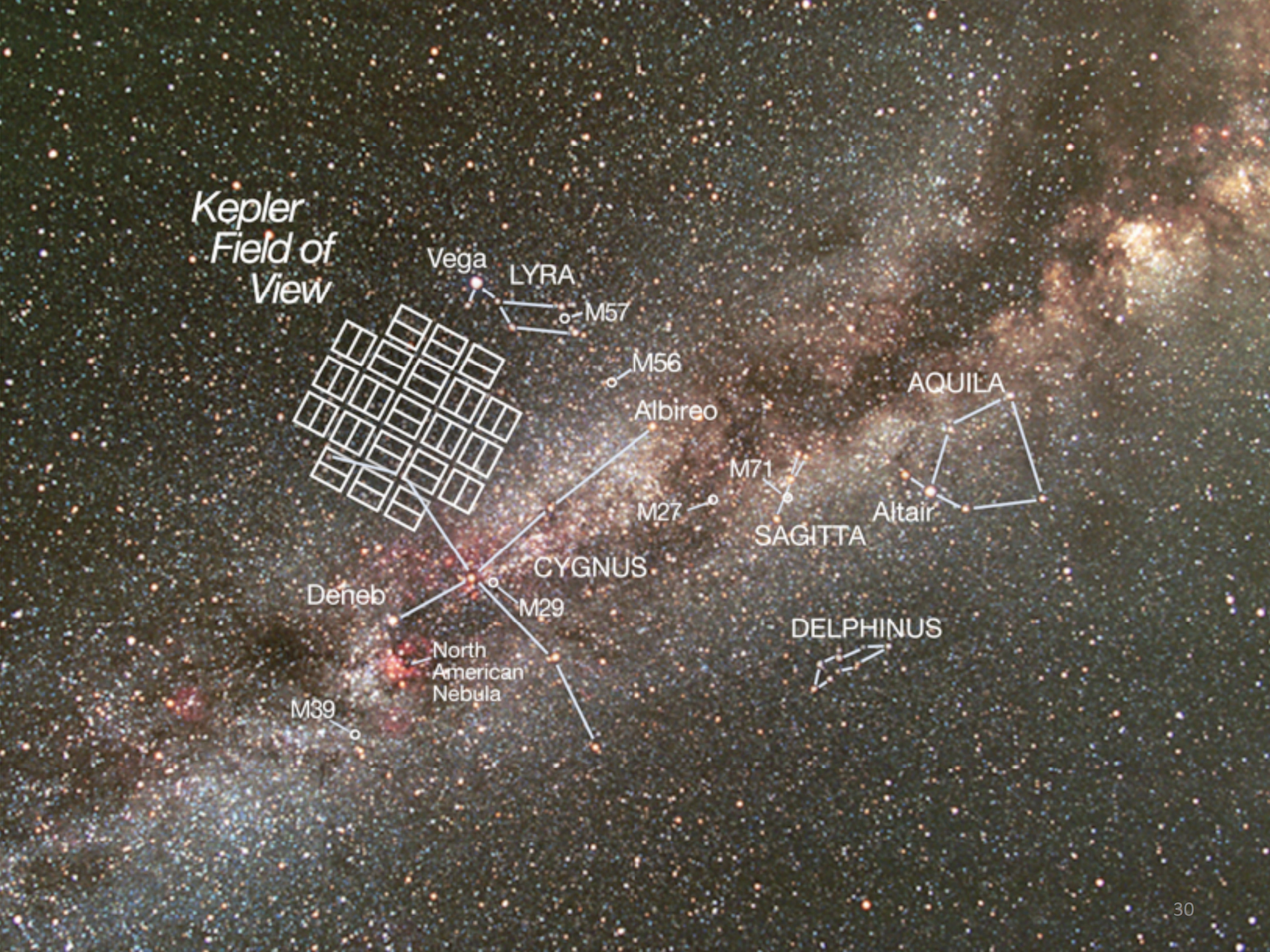


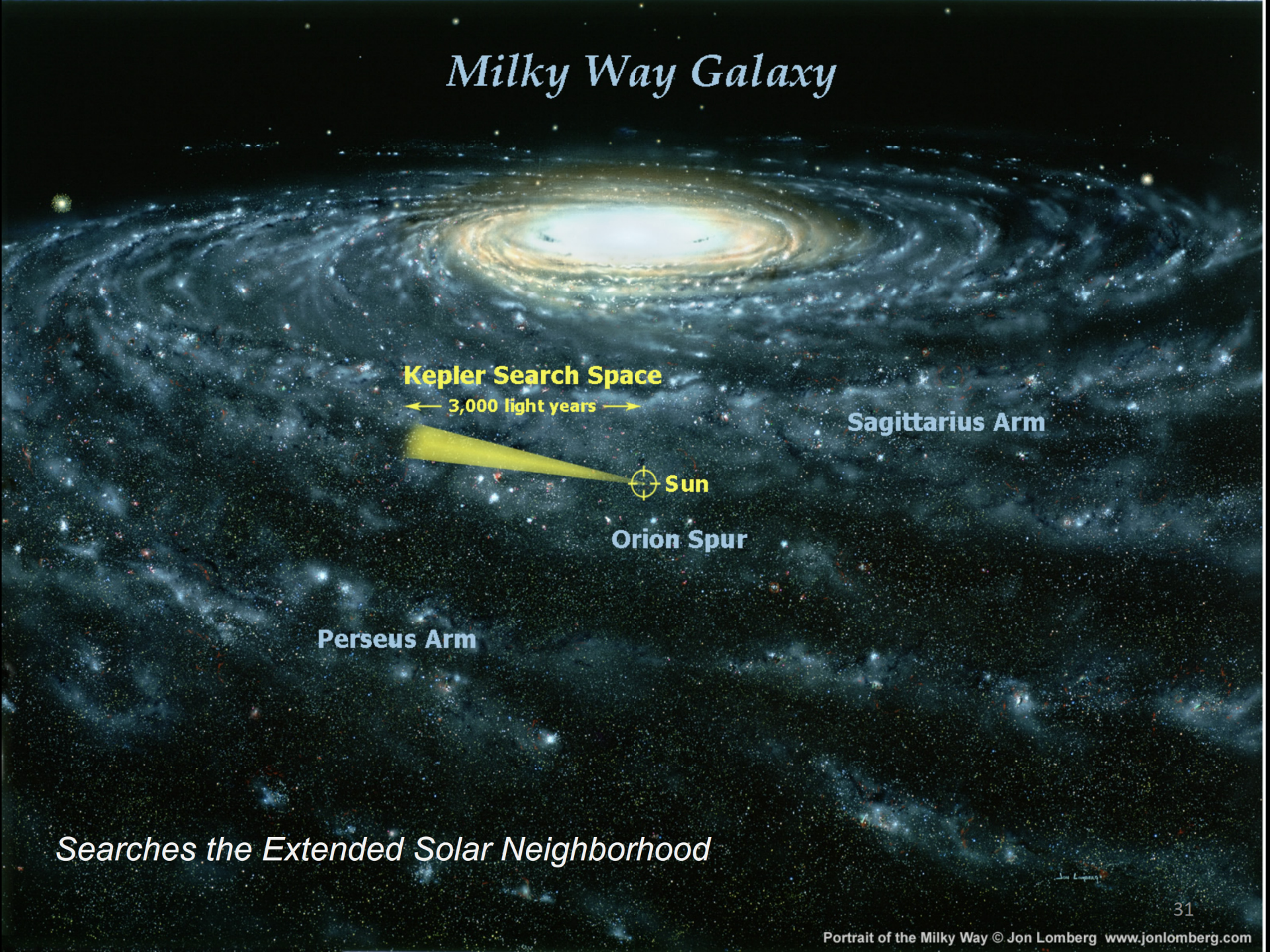
>100 square degree field of view

Kepler in final assembly

Kepler Used a Delta-II Rocket

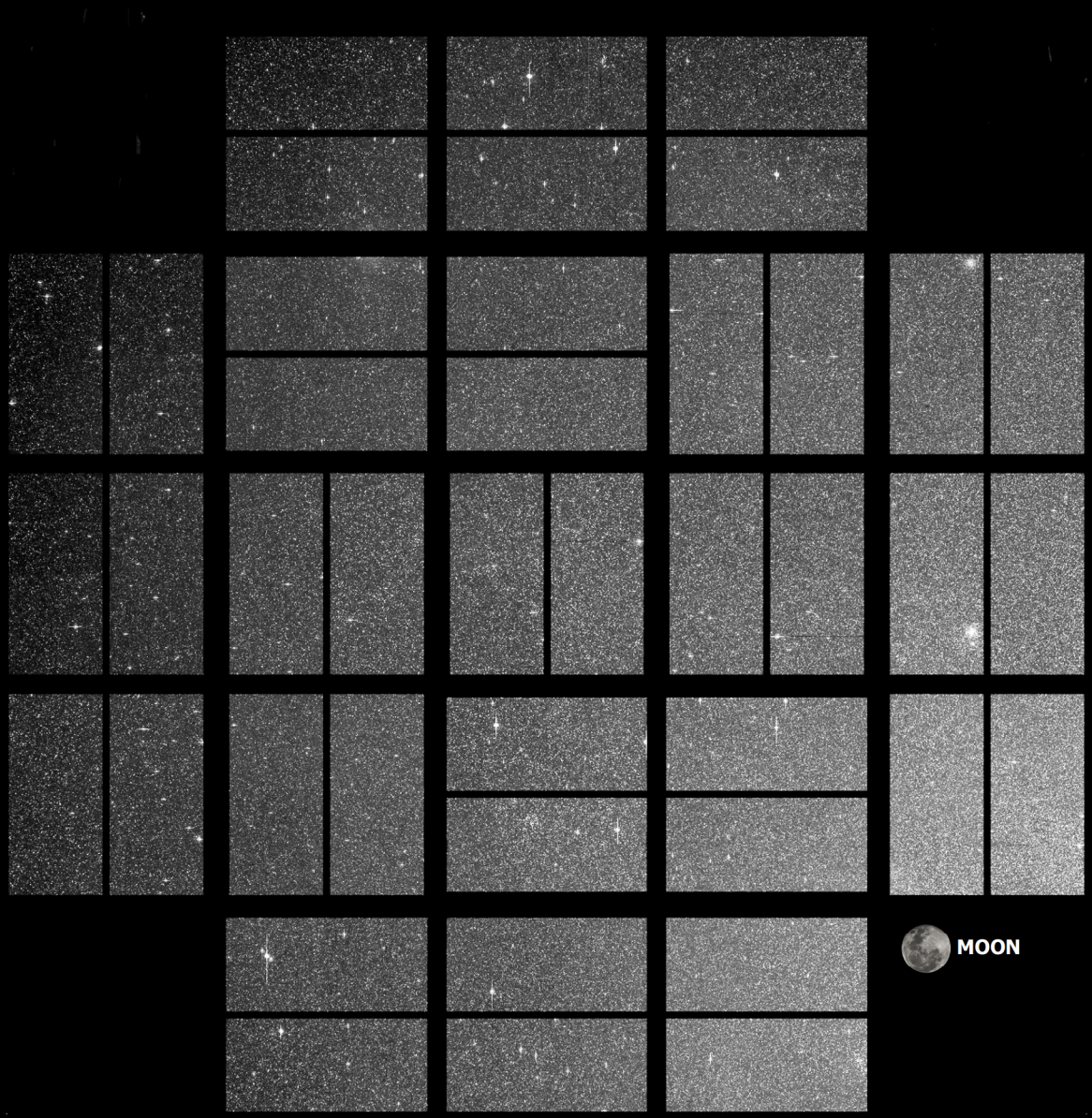
Kepler Launched March 6, 2009


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

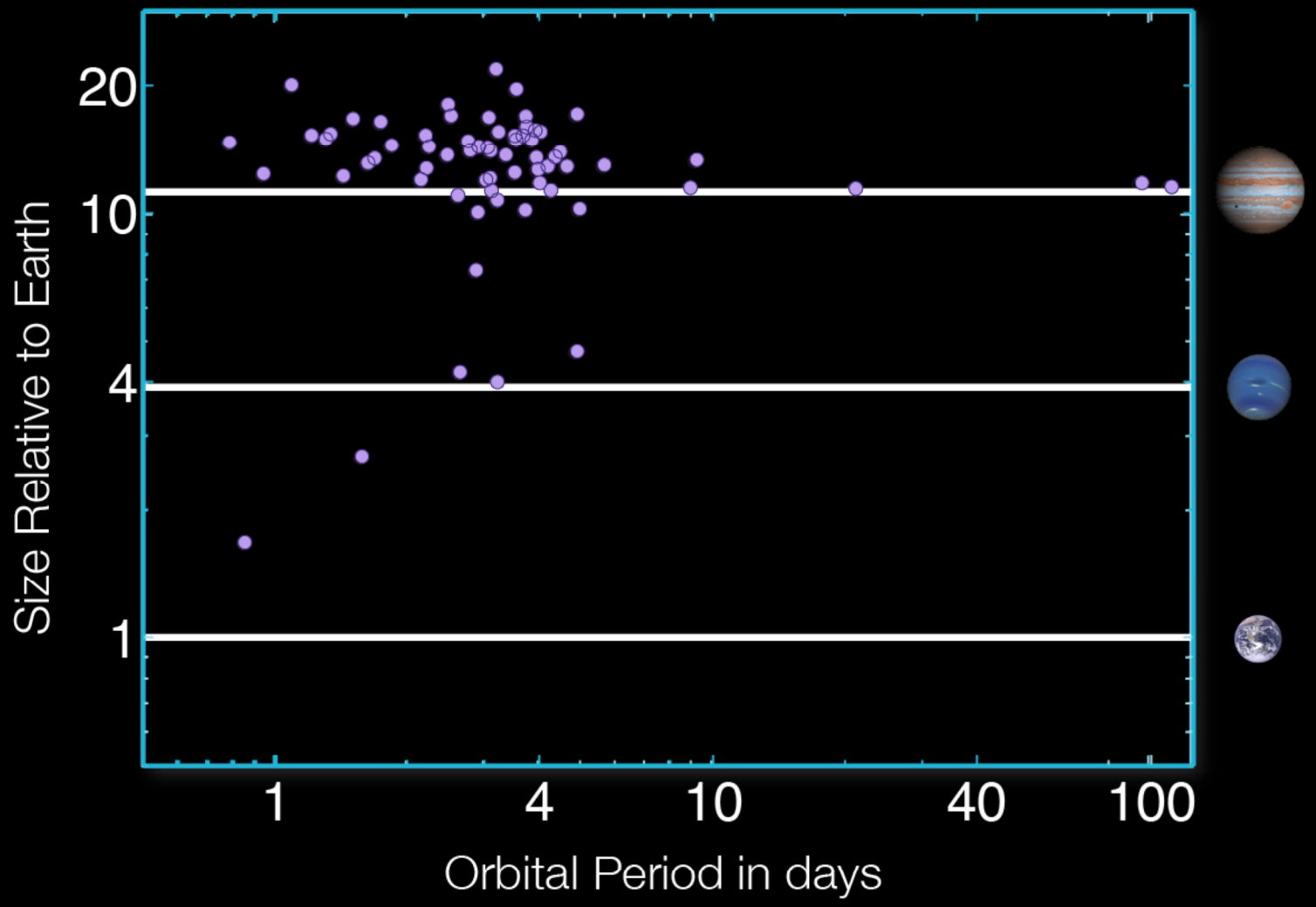


Searches the Extended Solar Neighborhood

Kepler Full Field Image

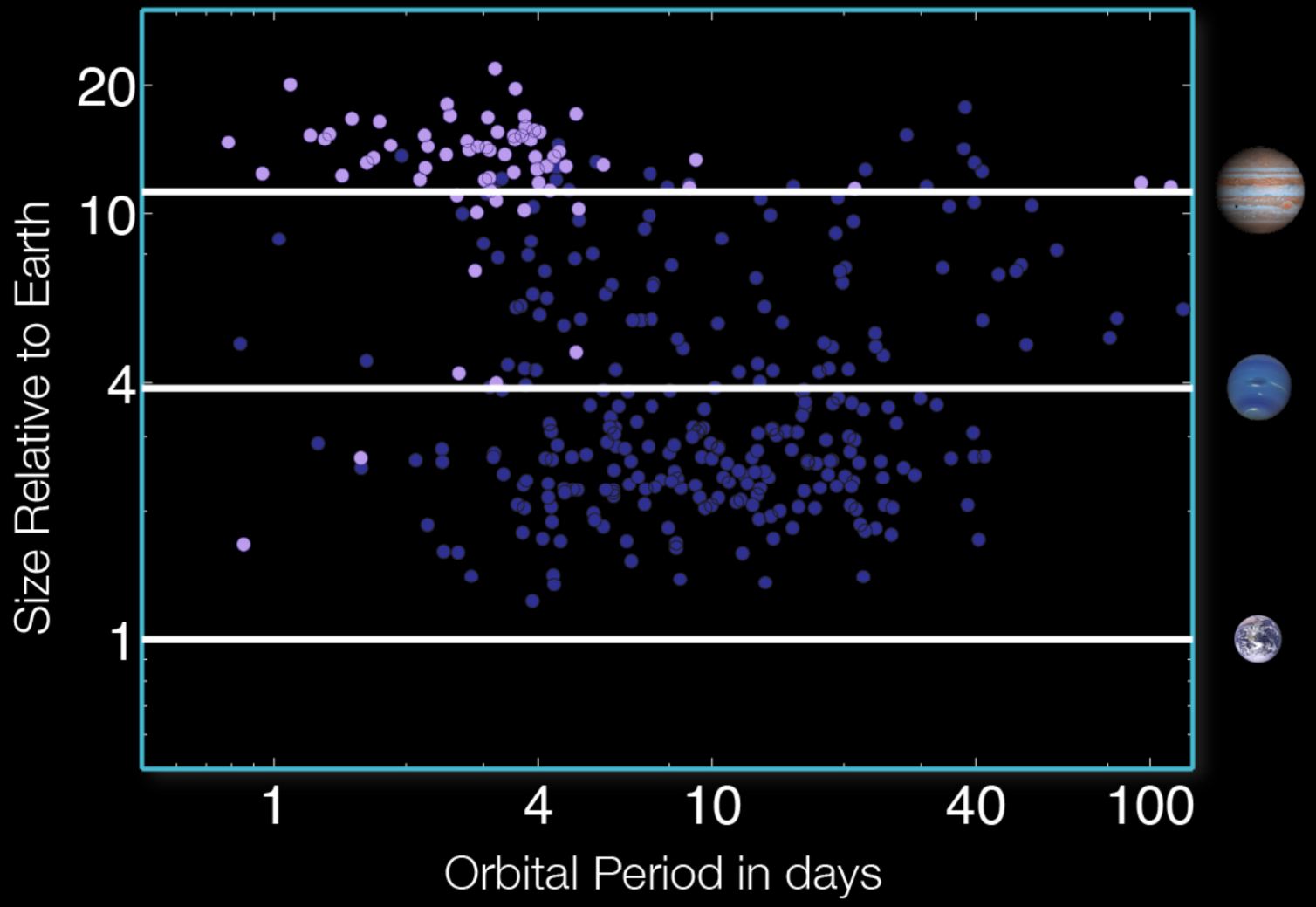


Pre-Kepler Transiting Planets – June 14, 2010

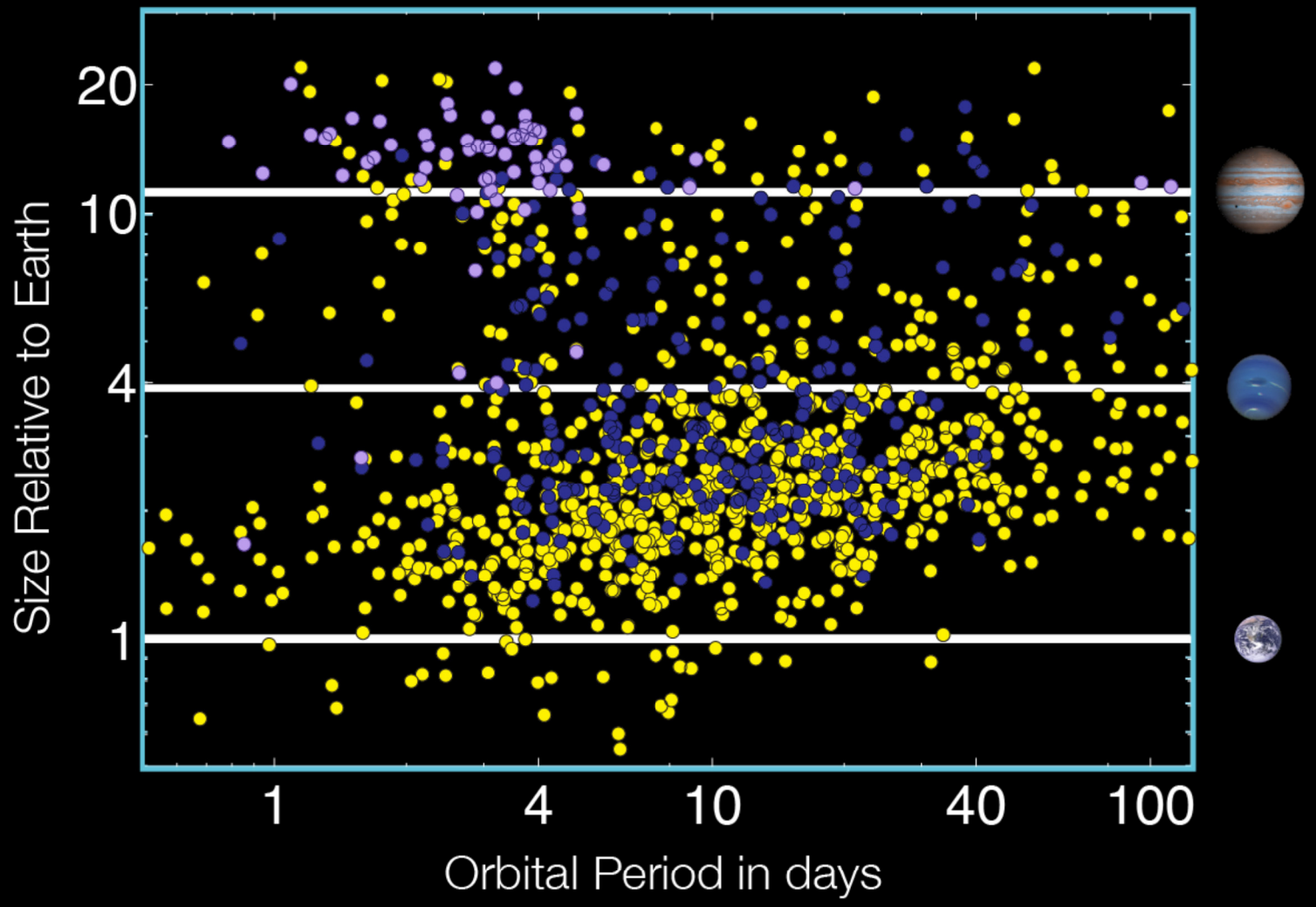


Transiting Planets –June 15, 2010

with Kepler candidates

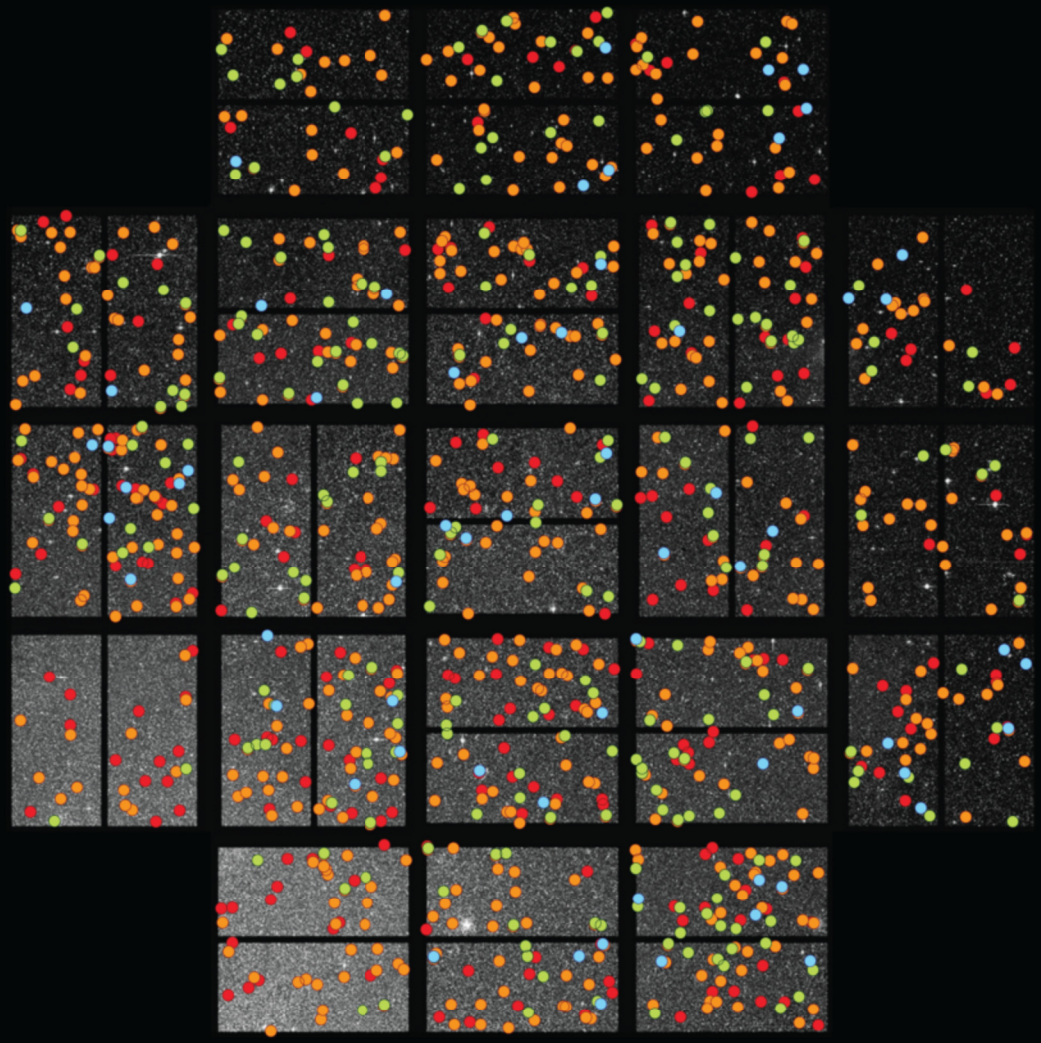


Kepler Candidates – February 1, 2011



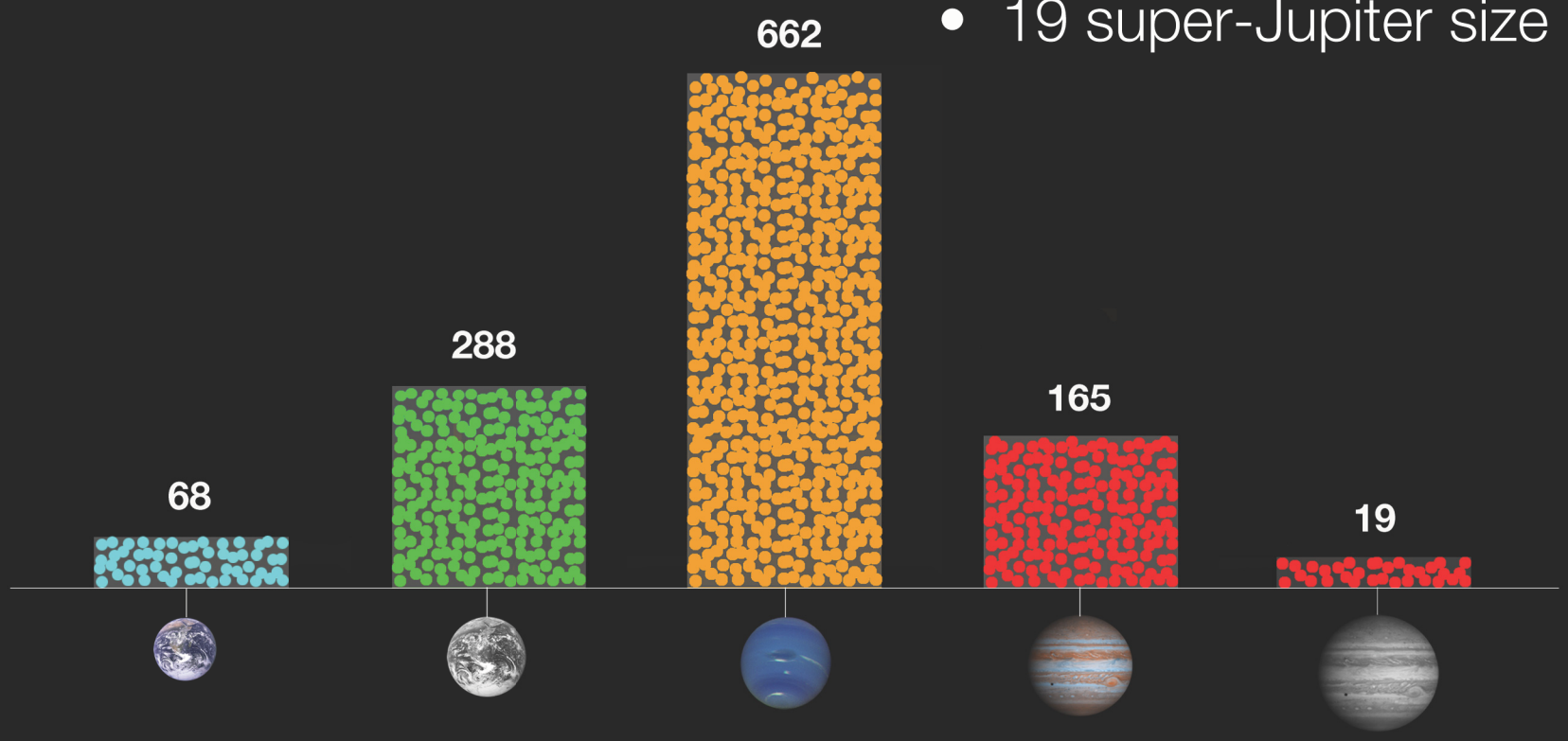
Locations of Kepler Planet Candidates

- Earth-size
- Super-Earth size
  1.25 - 2.0 Earth-size
- Neptune-size
  2.0 - 6.0 Earth-size
- Giant-planet size
  6.0 - 22 Earth-size



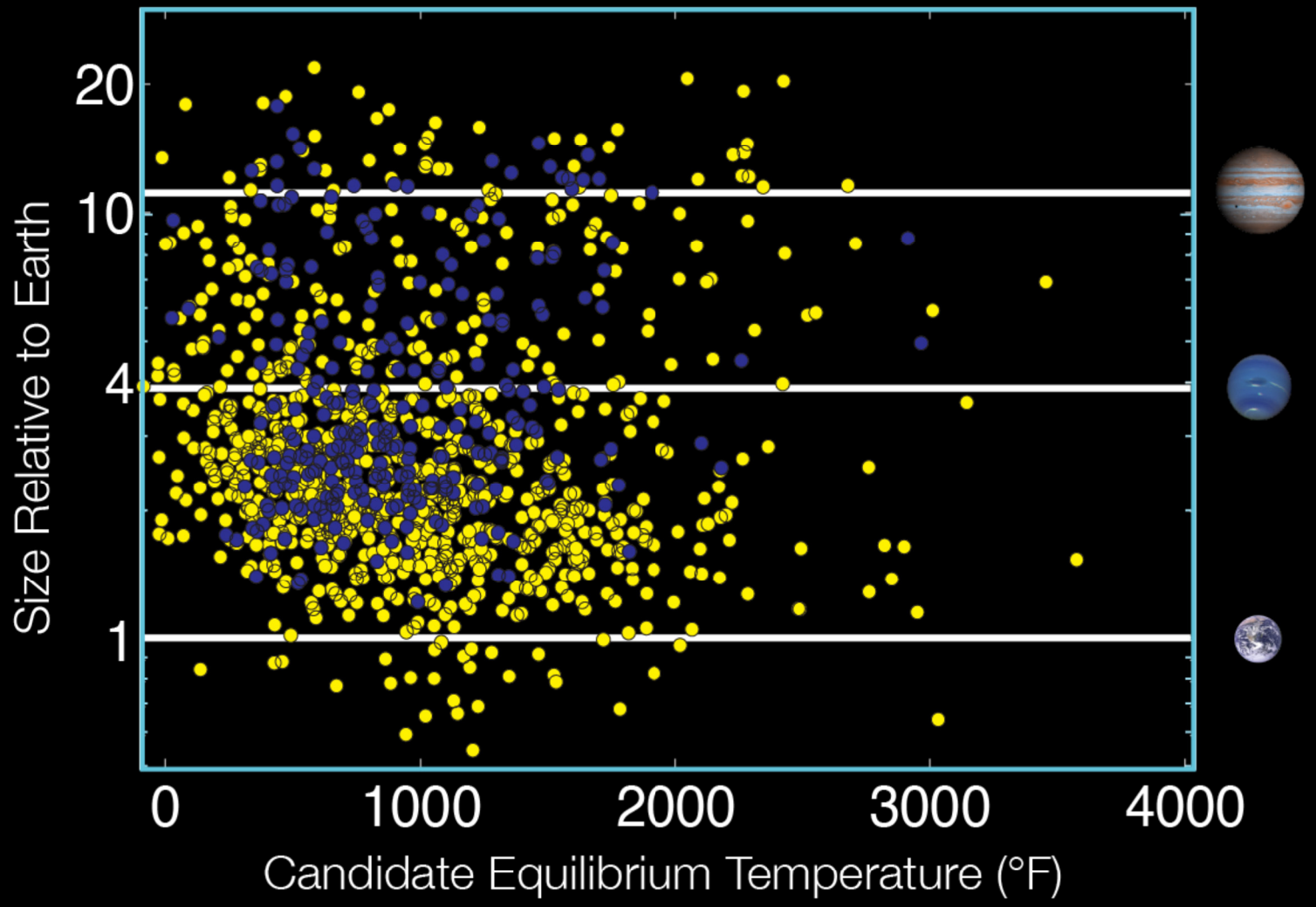
Numbers of Planet Candidates

- 68 Earth-size
- 288 super-Earth size
- 662 Neptune size
- 165 Jupiter size
- 19 super-Jupiter size



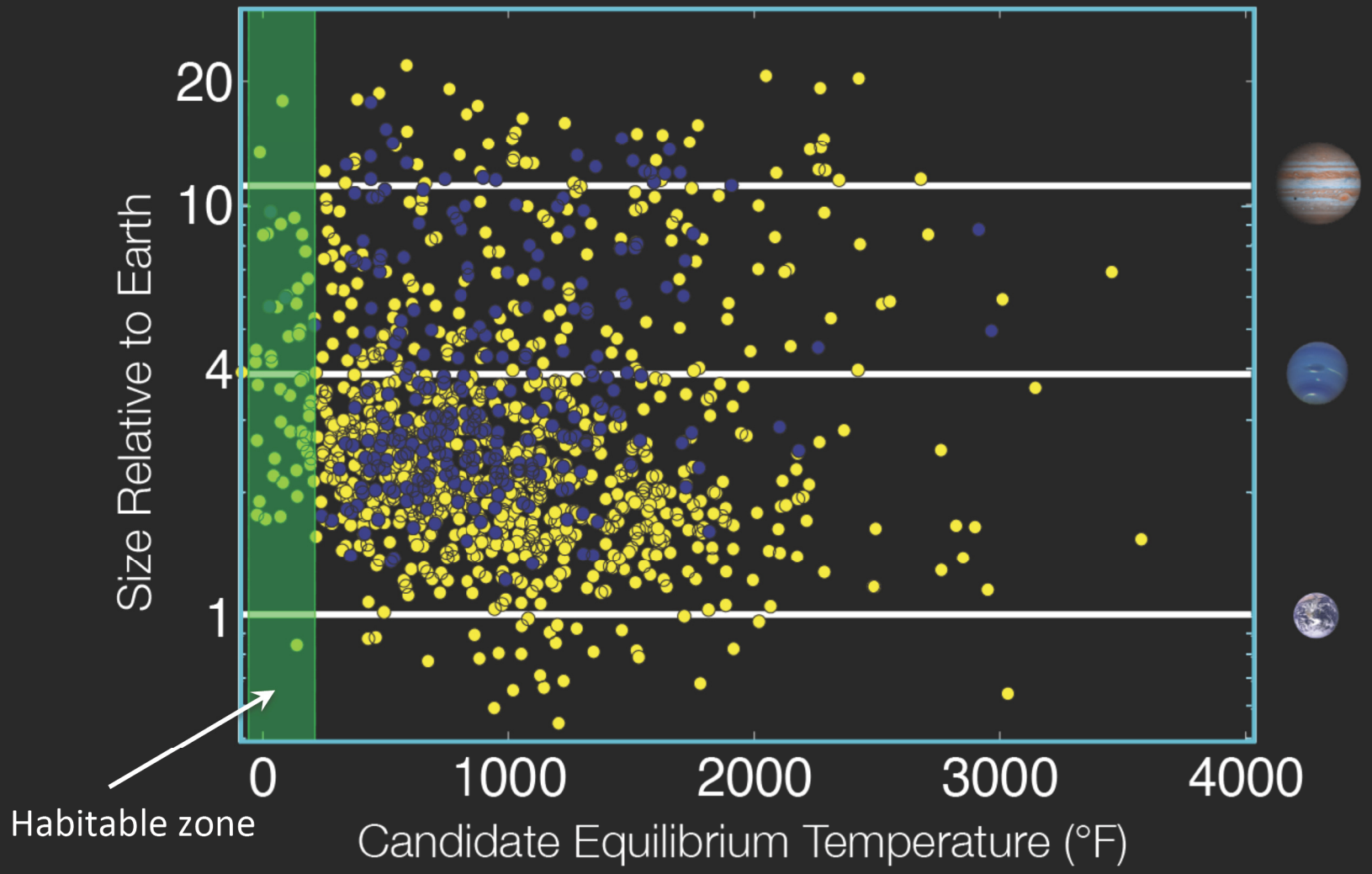
Kepler Candidates – February 1, 2011

showing temperature

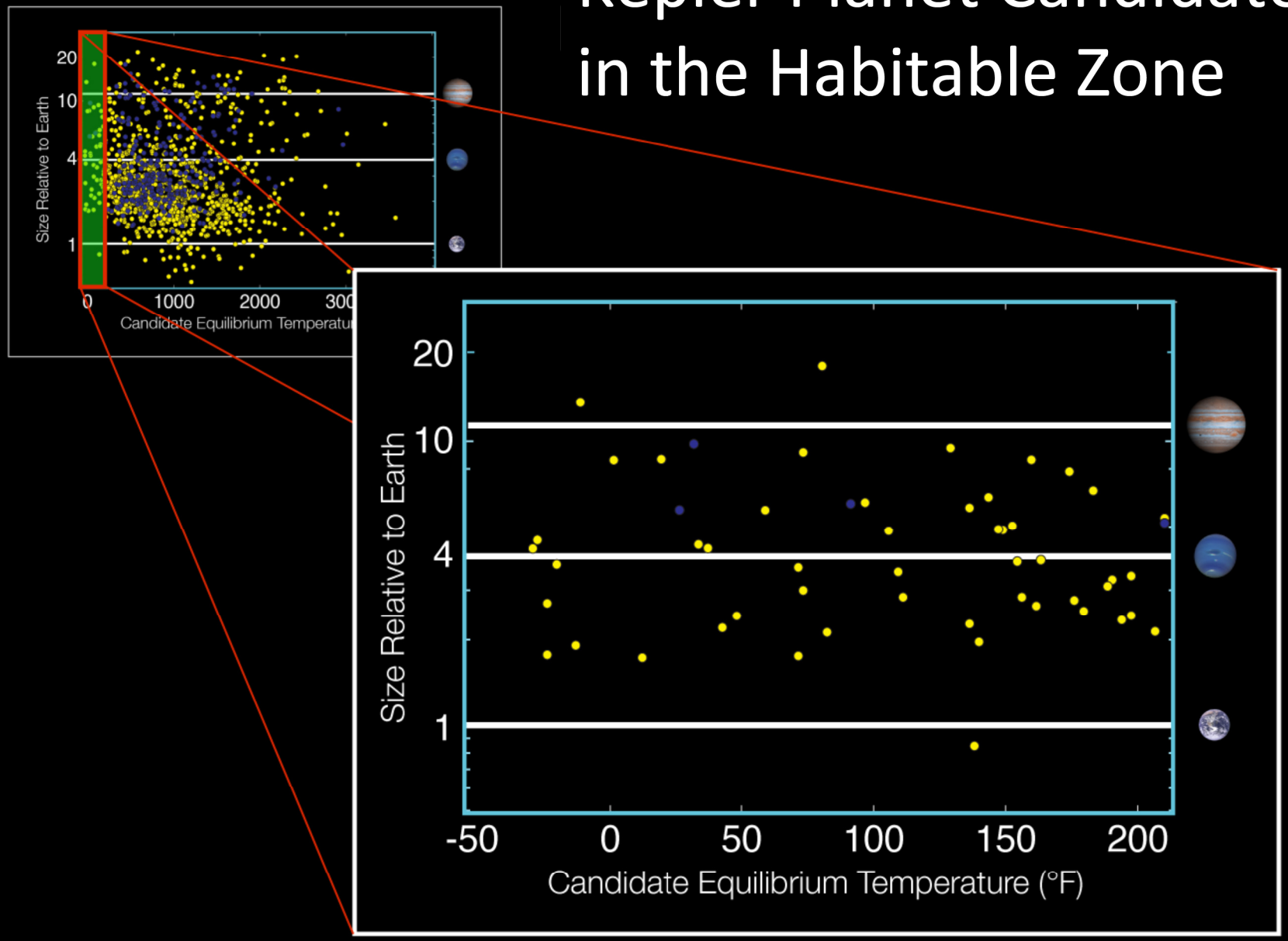


Kepler Candidates – February 1, 2011

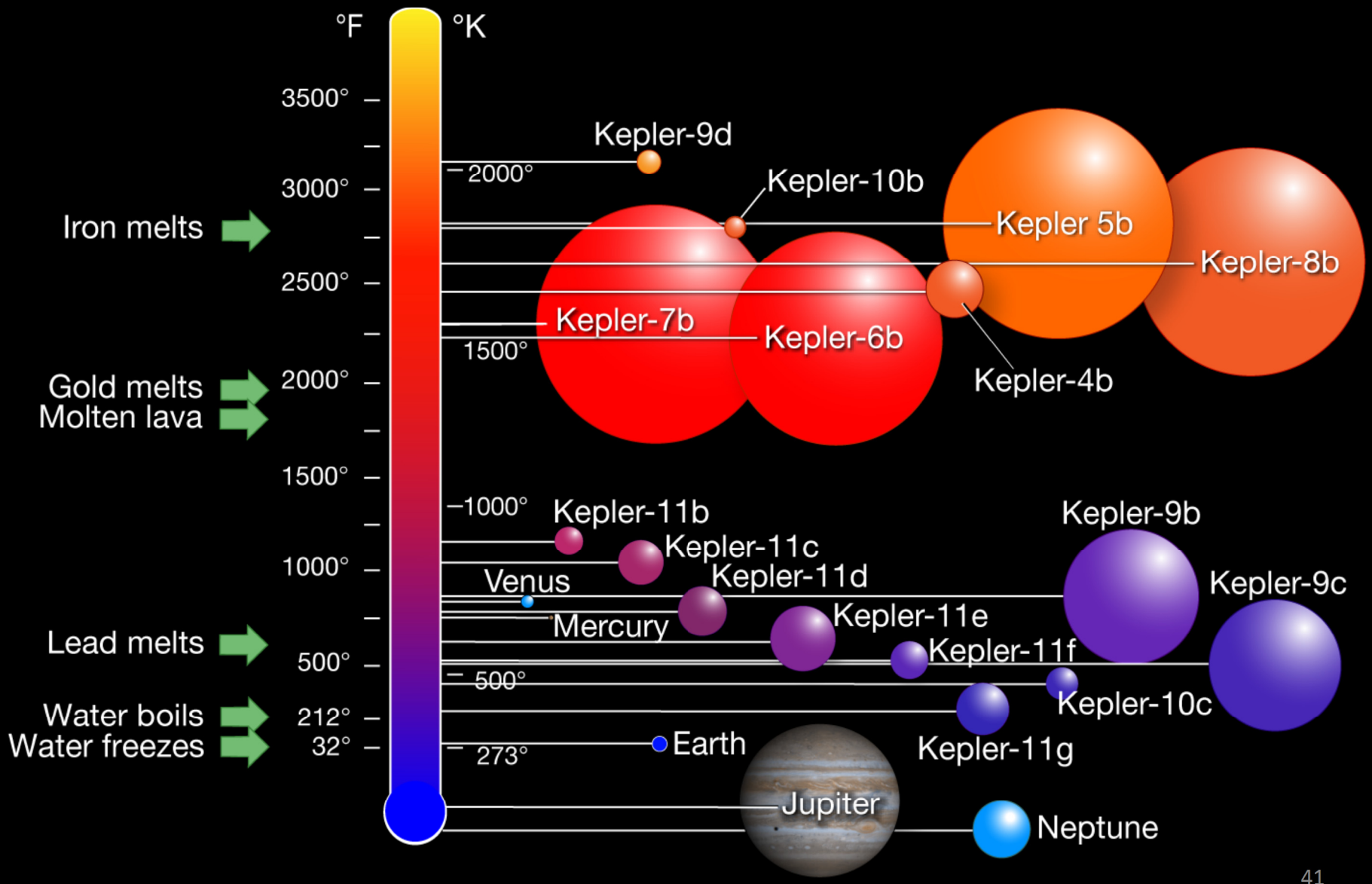
showing temperature



Kepler Planet Candidates in the Habitable Zone



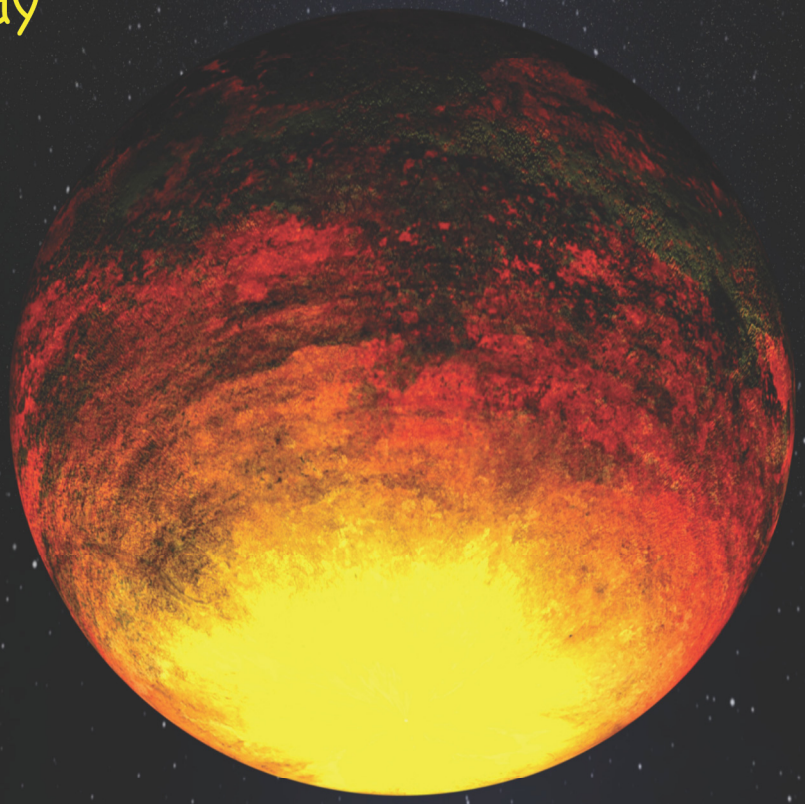
Planet Temperature & Size



Kepler-10b

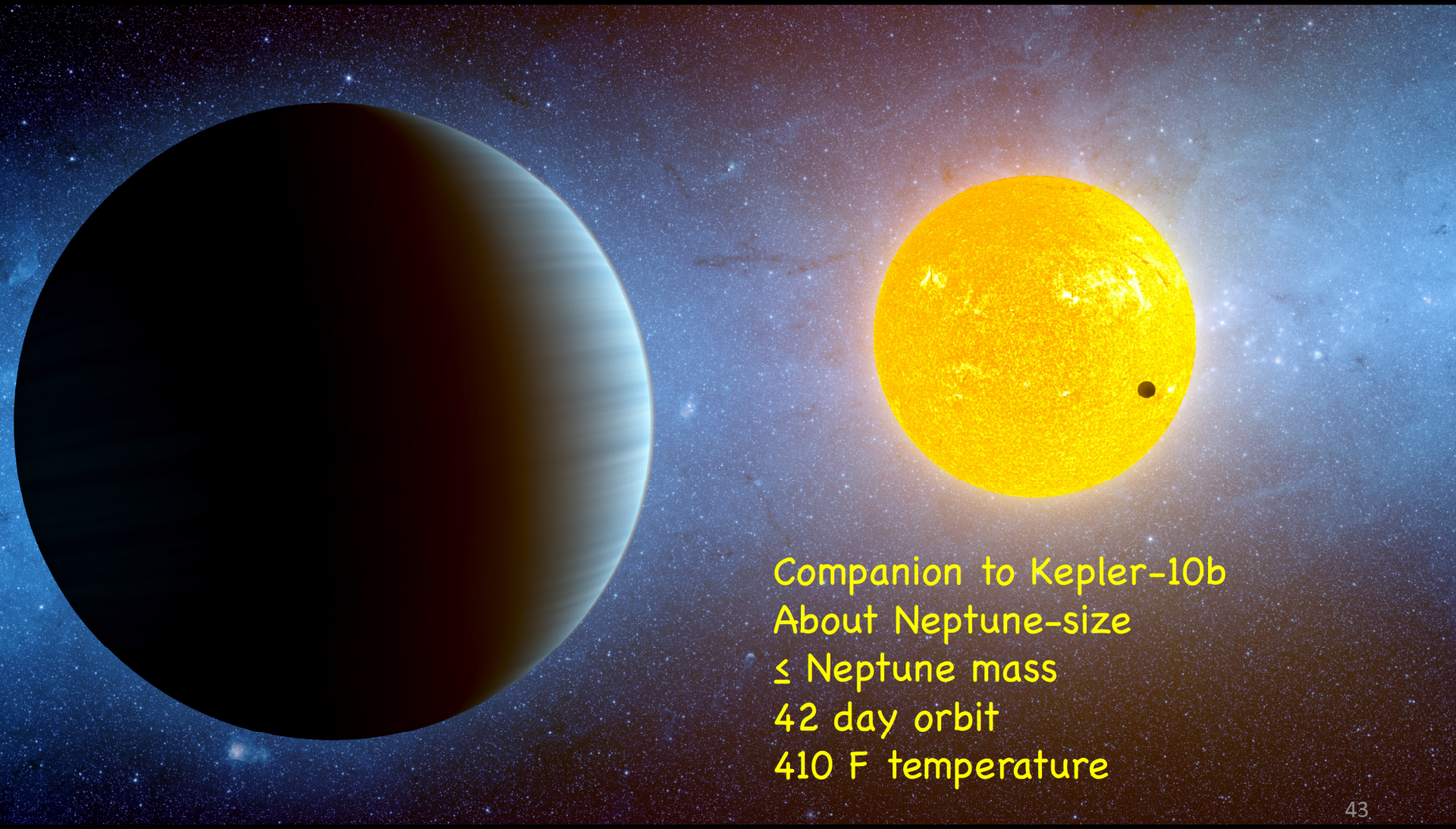
Rocky planet around a star a lot like the Sun
560 light-years away

1.4 x Earth size
4.6 x Earth mass



70 x closer to its star than Earth
19 hour orbit
2800 F surface temperature

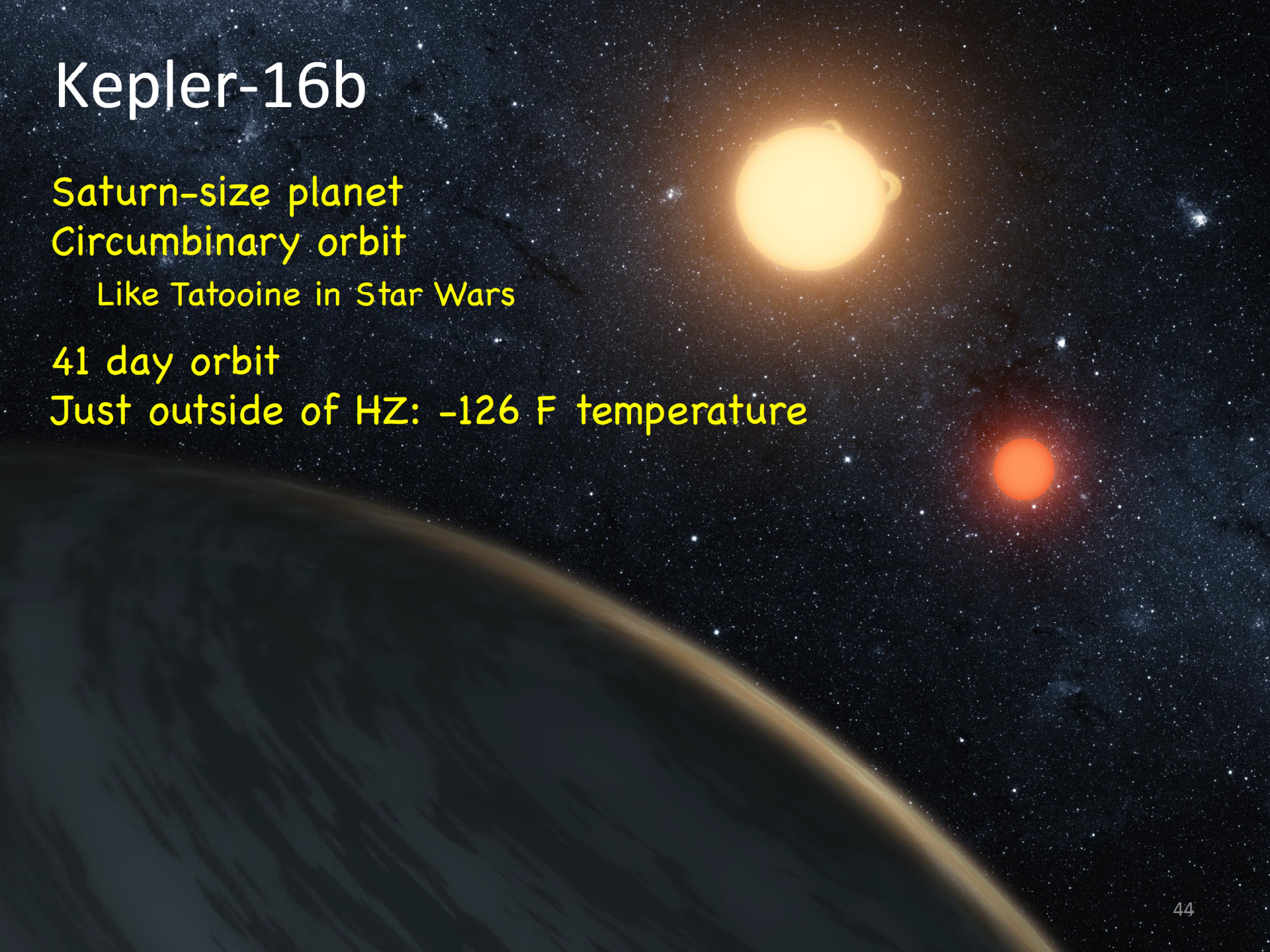
Kepler-10c


Companion to Kepler-10b
About Neptune-size
≤ Neptune mass
42 day orbit
410 F temperature

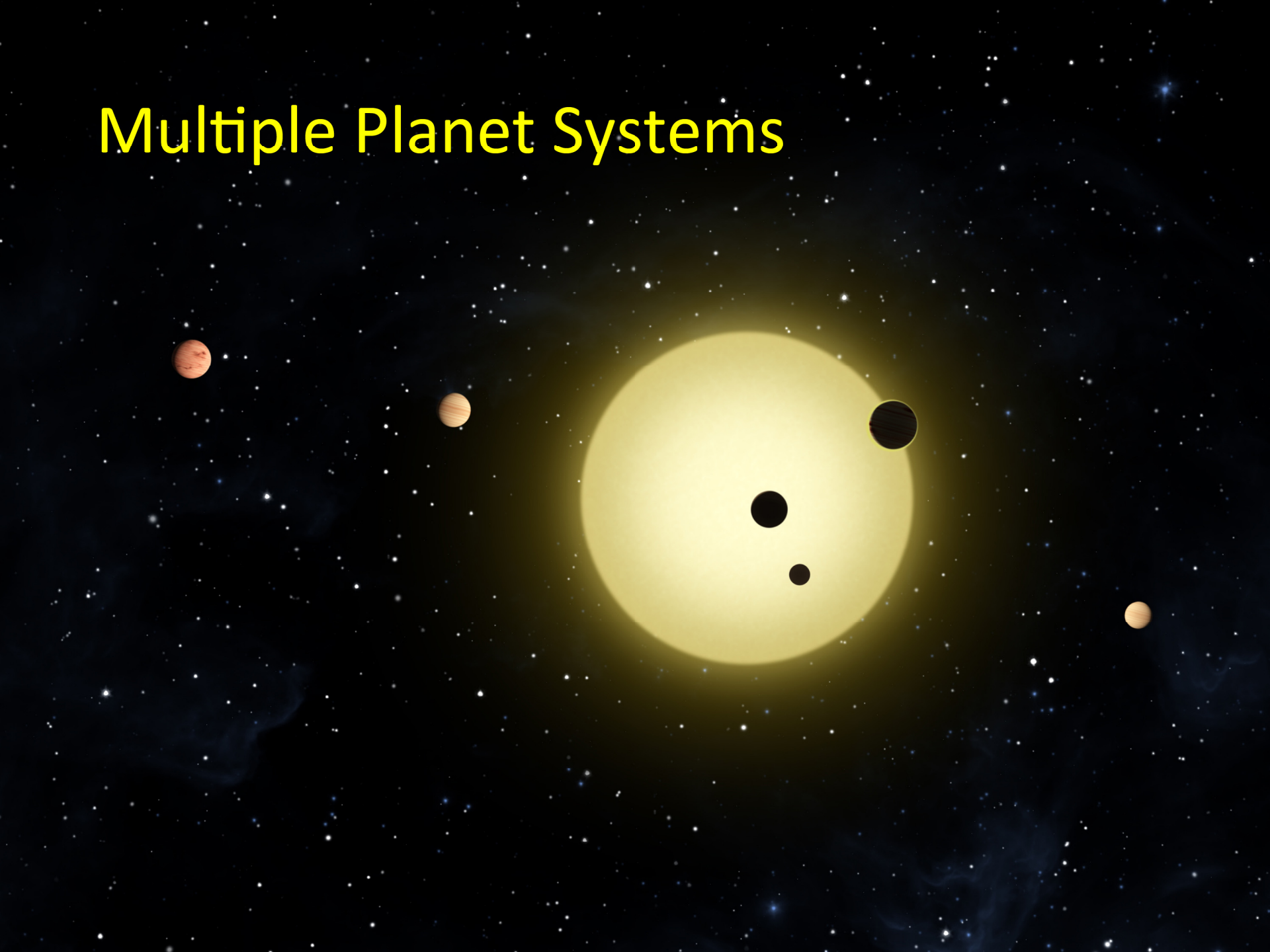
Kepler-16b

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

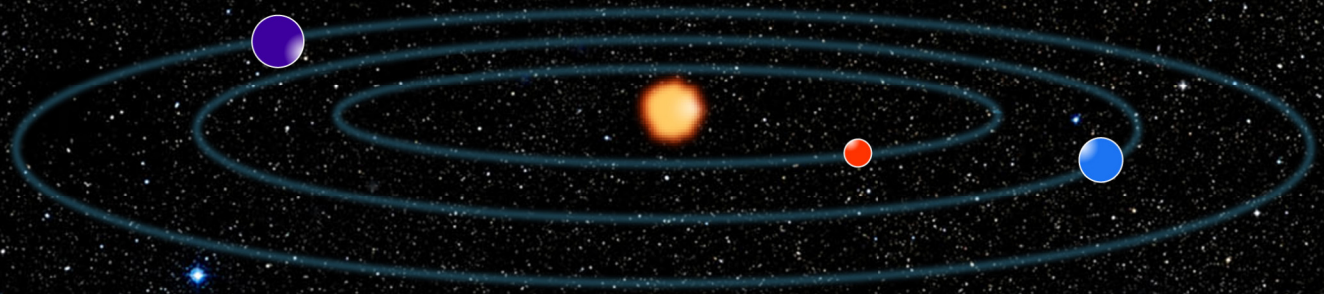
41 day orbit
Just outside of HZ: -126 F temperature



Multiple Planet Systems

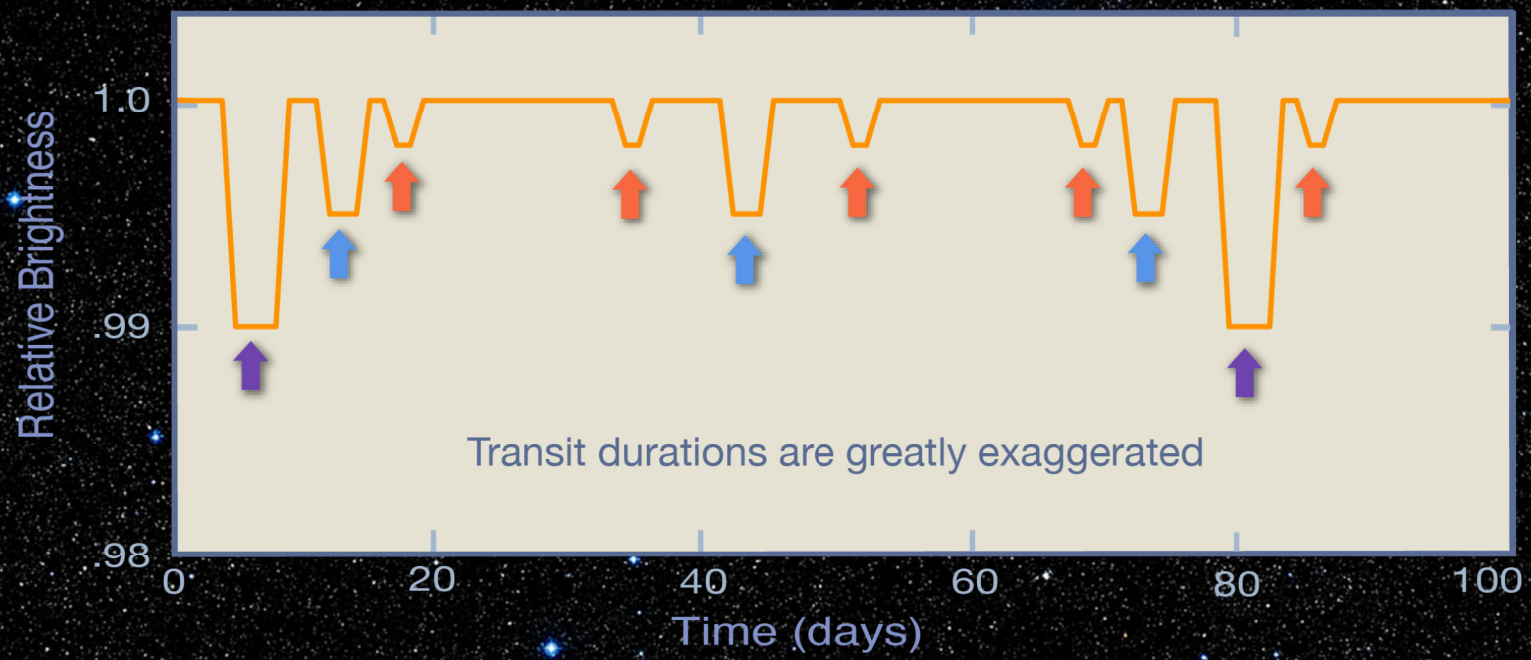


Transit Signature of a Multiple-Planet System

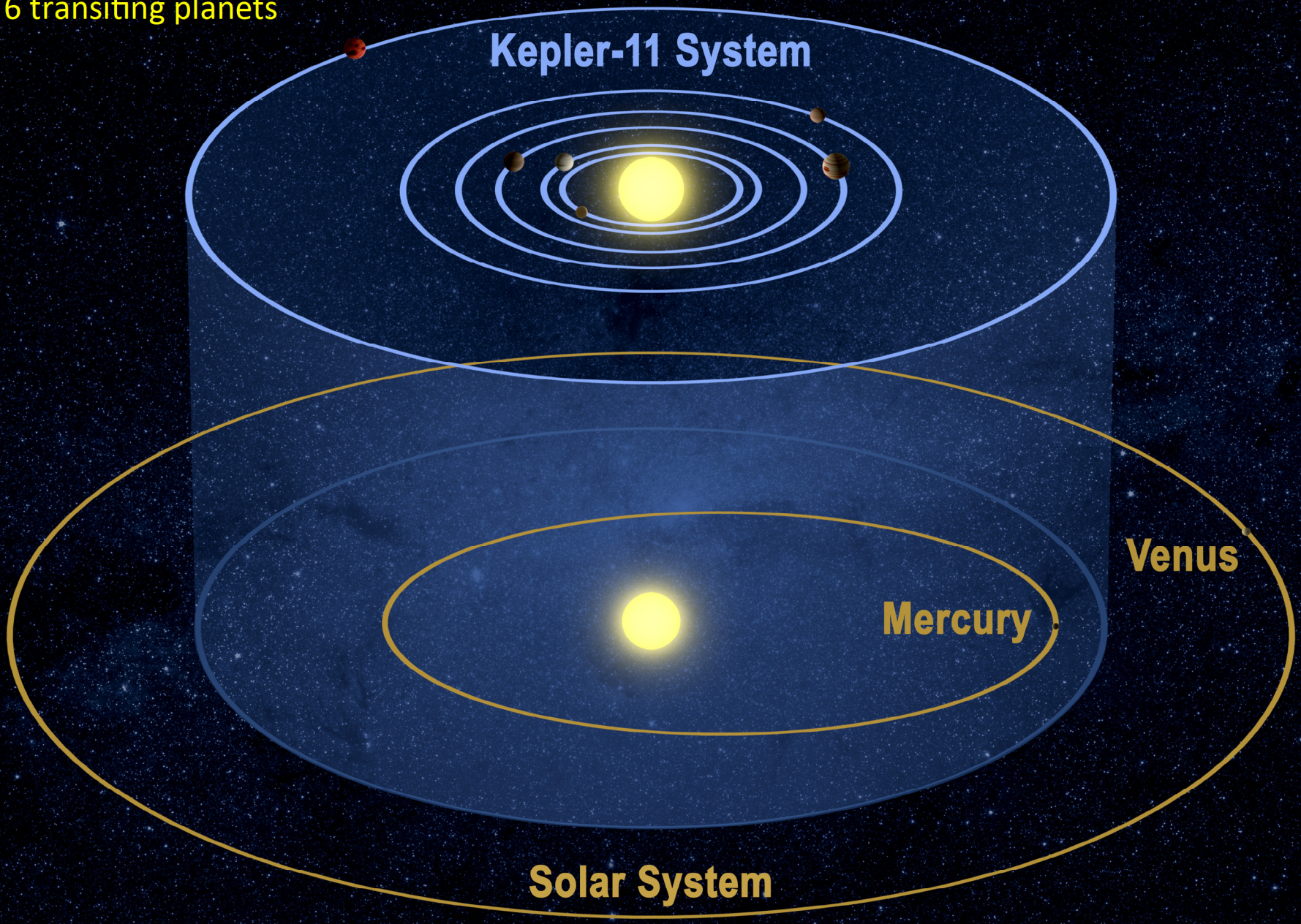


Planets can be distinguished by:

- Different periods
- Different depths
- Different durations



6 transiting planets

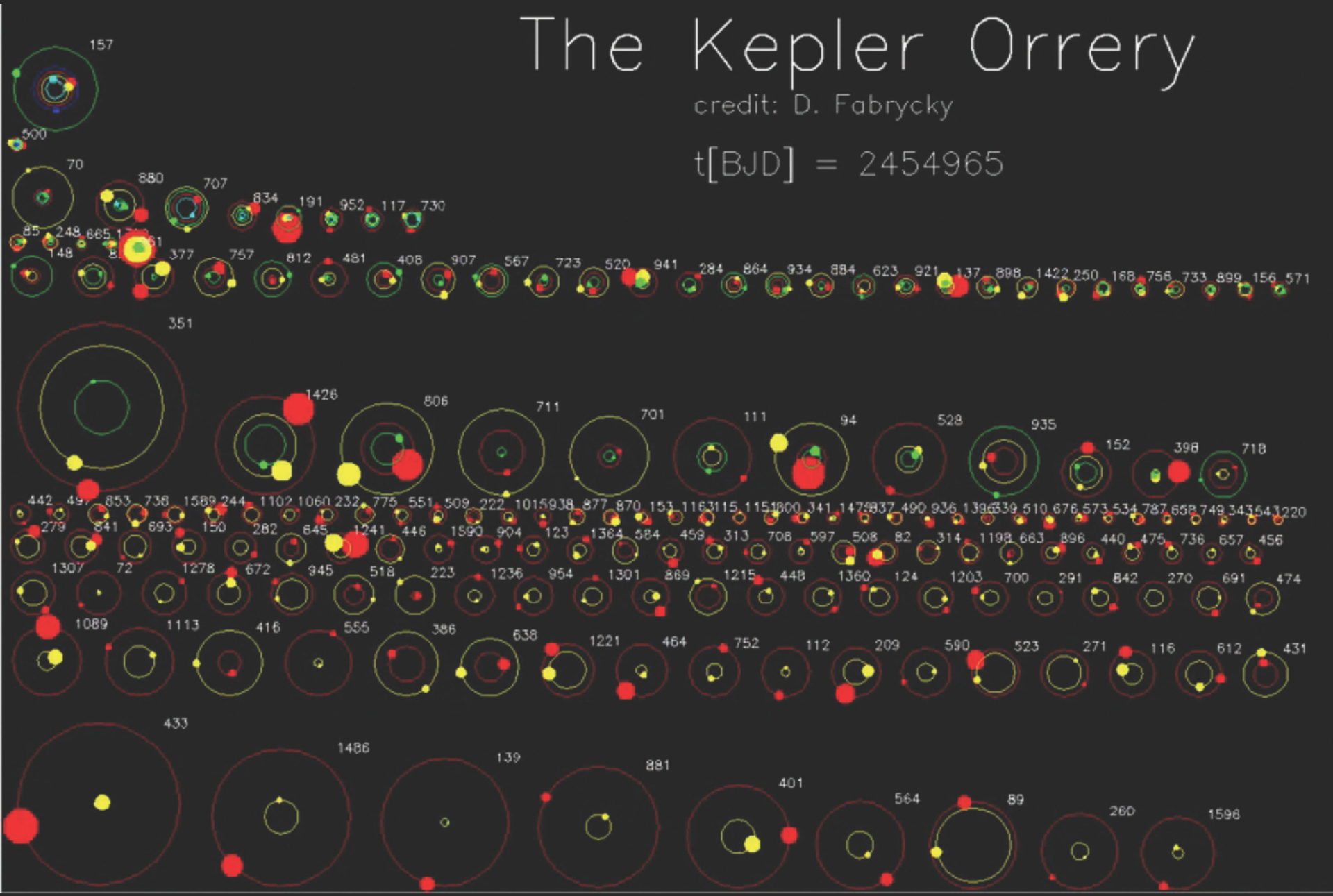


Lissauer, et al., Nature v470, pp 53–58 (03 February 2011)

The Kepler Orrery

credit: D. Fabrycky

t[BJD] = 2454965



"One day, from the shores of a new world, we'll gaze at the sea that took us there. And its waves will be stars."

http://kepler.nasa.gov/education/sagan

FIND THEM. BEFORE THEY FIND US.
ALIEN PLANETS
STARRING
KEPLER
SPACECRAFT
KEPLER TEAM:
NASA AMES RESEARCH CENTER (ARC), SPACE TELESCOPE SCIENCE INSTITUTE (STSCI), BALL AEROSPACE, DEEP SPACE NETWORK (DSN),
JET PROPULSION LABORATORY (JPL), LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS (LASP), SETI INSTITUTE,
SMITHSONIAN ASTROPHYSICAL OBSERVATORY, AND LAWRENCE HALL OF SCIENCE
A FILM BY EXPLORATION, INNOVATION, AND DISCOVERY IN ASSOCIATION WITH RESEARCH, SCIENCE, TECHNOLOGY, ENGINEERING, AND MATH
PRODUCER THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA). NASA EMBRACES BOLD DEVELOPMENT OF NEW TECHNOLOGIES
TO PROPEL EXPLORATION FROM OUR OWN HOME PLANET TO THE BOUNDARIES OF OUR SOLAR SYSTEM TO THE BEGINNINGS OF THE UNIVERSE.
INTERNATIONAL PARTNERSHIPS WILL FUEL OUR CAPABILITIES WITH GREATER RESOURCES AND INTELLECTUAL PROWESS.
JOIN US ON OUR JOURNEY TO THE FUTURE FOR THE BENEFIT OF ALL HUMANKIND.
NOW SHOWING