

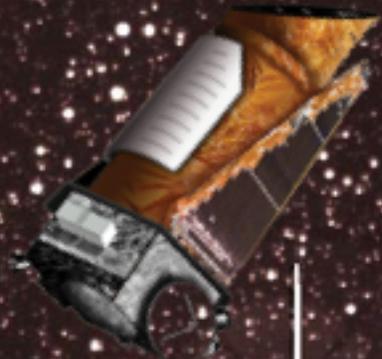


Chasing Shadow Worlds

**Jon M. Jenkins
NASA Ames Research Center**

Wednesday May 9, 2018

Orchard School, San Jose CA





Solar Eclipse 2017

Kepler
A Search for Earth-size
Planets



Solar Eclipse
August 21, 2017

EXPERIENCE
THE 2017 ECLIPSE ACROSS AMERICA

AUGUST 21, 2017

<http://eclipse2017.nasa.gov>

Image Credit: Phil Hart



We find planets by looking
for micro-eclipses





Solar Eclipse 2017



Credits: M. Druckmüller



NASA/Rami Daud, Alcyon Technical Services

We find planets by looking for micro-eclipses



All the Known Planets In 1994

Kepler
A Search for Earth-size
Planets



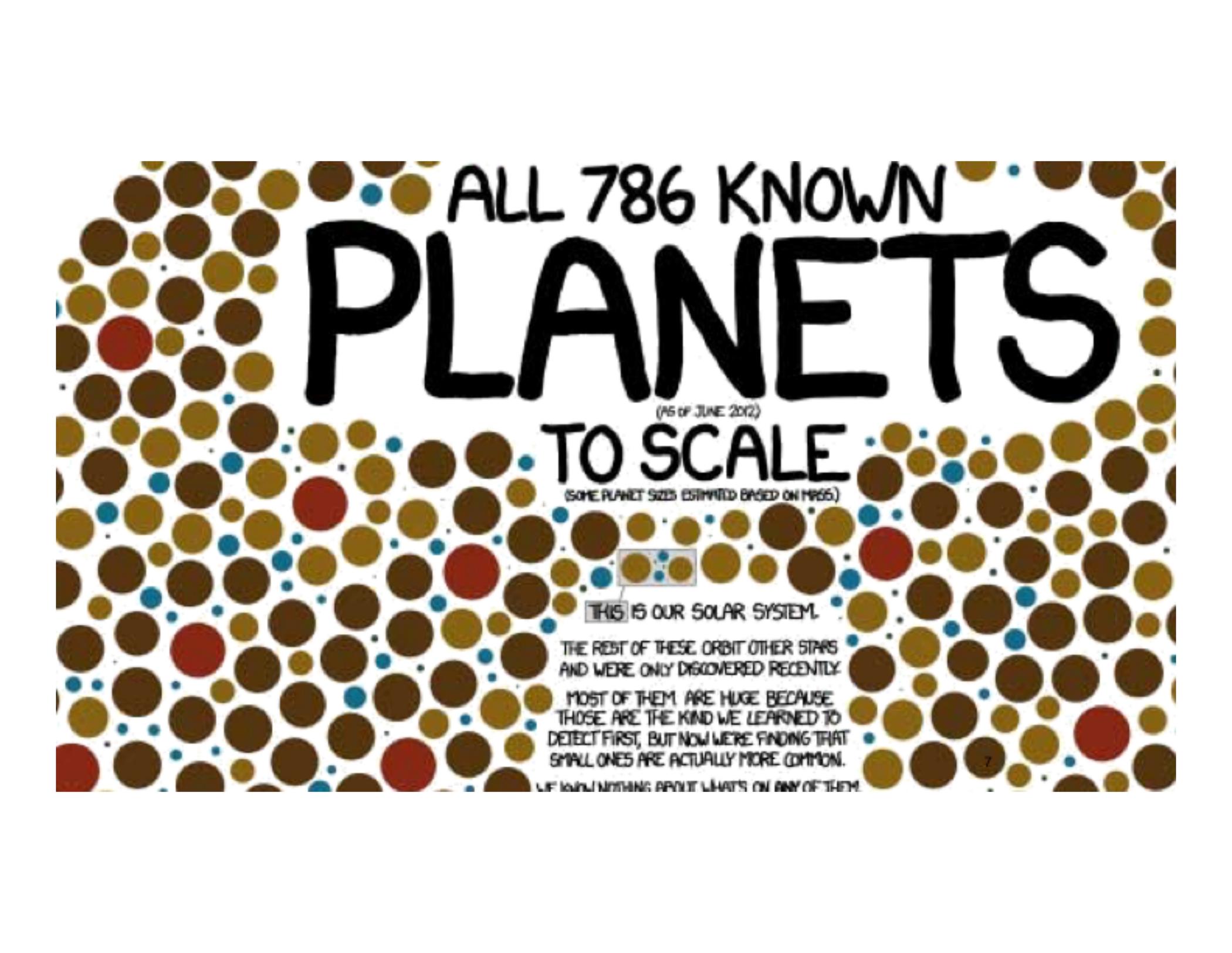


A More Recent Pictures of Planets

Kepler
A Search for Earth-size
Planets



<https://xkcd.com/1071/>



ALL 786 KNOWN PLANETS

(AS OF JUNE 2012)

TO SCALE

(SOME PLANET SIZES ESTIMATED BASED ON PROS)

THIS IS OUR SOLAR SYSTEM.

THE REST OF THESE ORBIT OTHER STARS
AND WERE ONLY DISCOVERED RECENTLY.

MOST OF THEM ARE HUGE BECAUSE
THOSE ARE THE KIND WE LEARNED TO
DETECT FIRST, BUT NOW WE'RE FINDING THAT
SMALL ONES ARE ACTUALLY MORE COMMON.

WE KNOW NOTHING ABOUT WHAT'S ON ANY OF THEM.



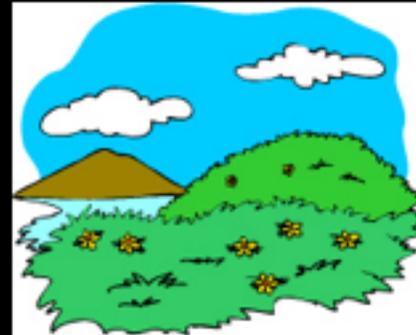
What Does Habitable Mean To You?





What Does Habitable Mean To You?

- Right temperature
- Air
- Liquid water
- Light
- Radiation shield
- Asteroid protection



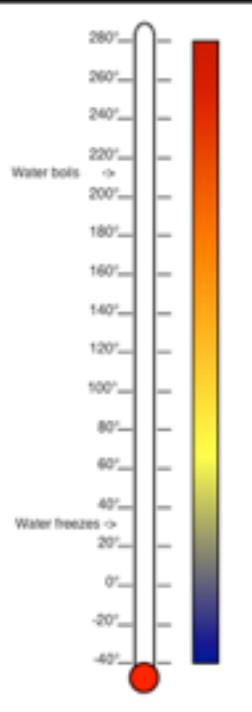


The Goldilocks Zone

Kepler
A Search for Earth-size
Planets



Venus: Way too hot!



Mars: Way too cold, and small!



Earth: Just right!



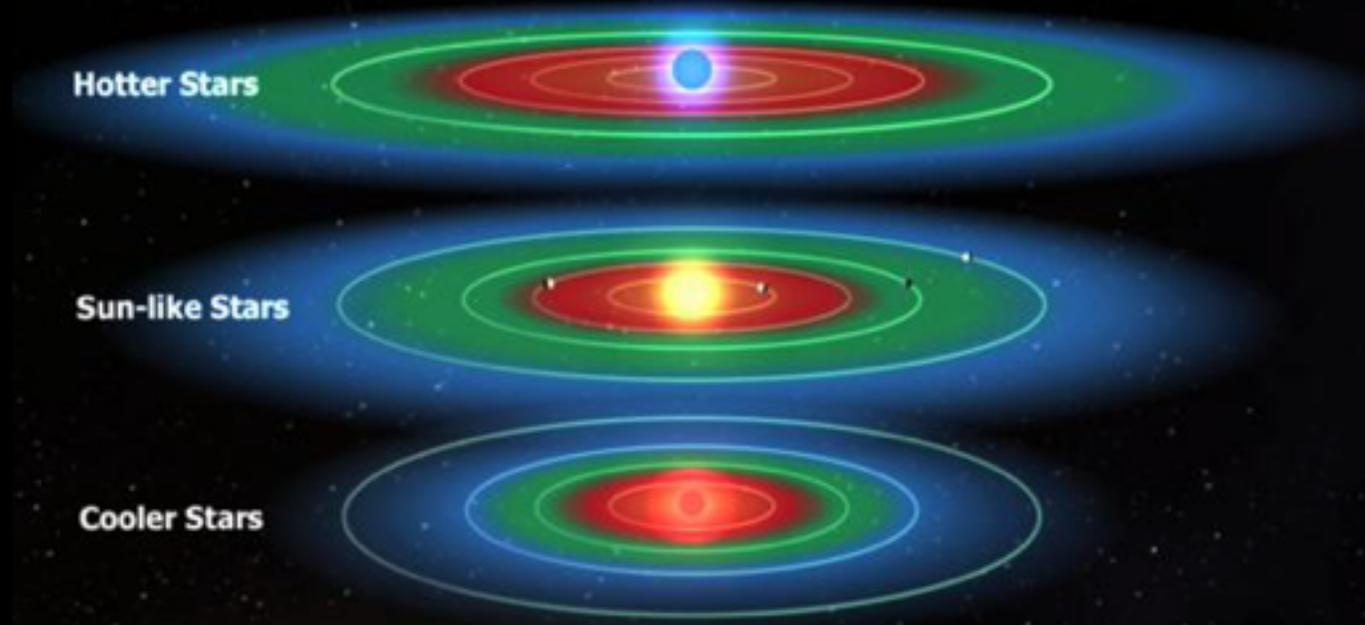
Habitable Zones

Kepler
A Search for Earth-size
Planets

Hotter Stars

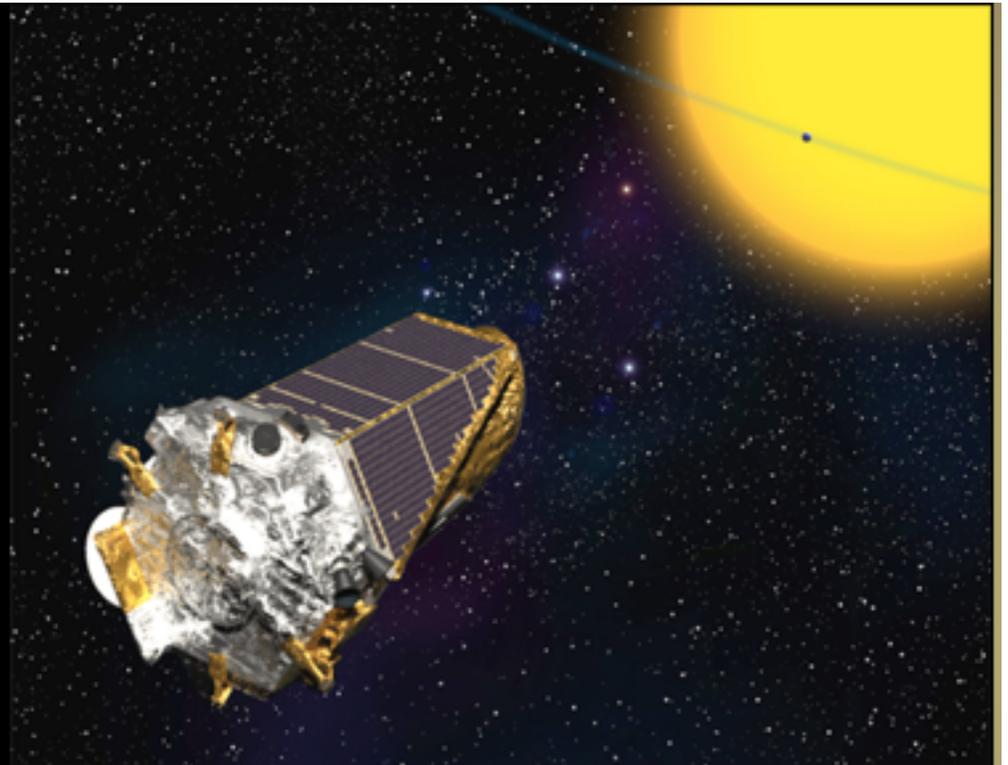
Sun-like Stars

Cooler Stars



The *Kepler* Mission

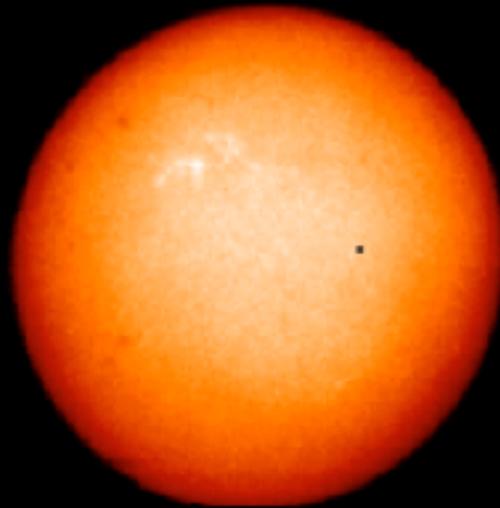
What fraction of sun-like stars in our galaxy host potentially habitable Earth-size planets?





Stars are far away ...

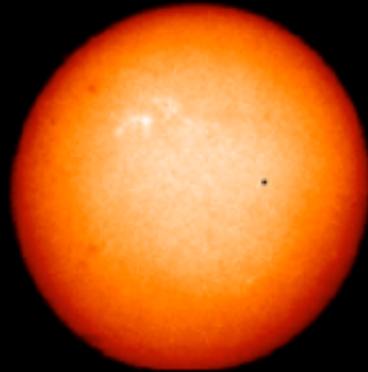
Kepler
A Search for Earth-size
Planets



Let's move this star away . . .

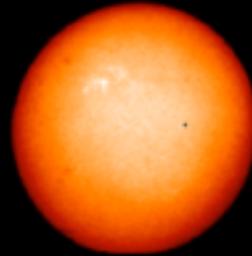


Kepler
A Search for Earth-size
Planets





Kepler
A Search for Earth-size
Planets



. . . and farther . . .



Kepler
A Search for Earth-size
Planets





Kepler
A Search for Earth-size
Planets





Kepler
A Search for Earth-size
Planets



...and farther



Kepler
A Search for Earth-size
Planets

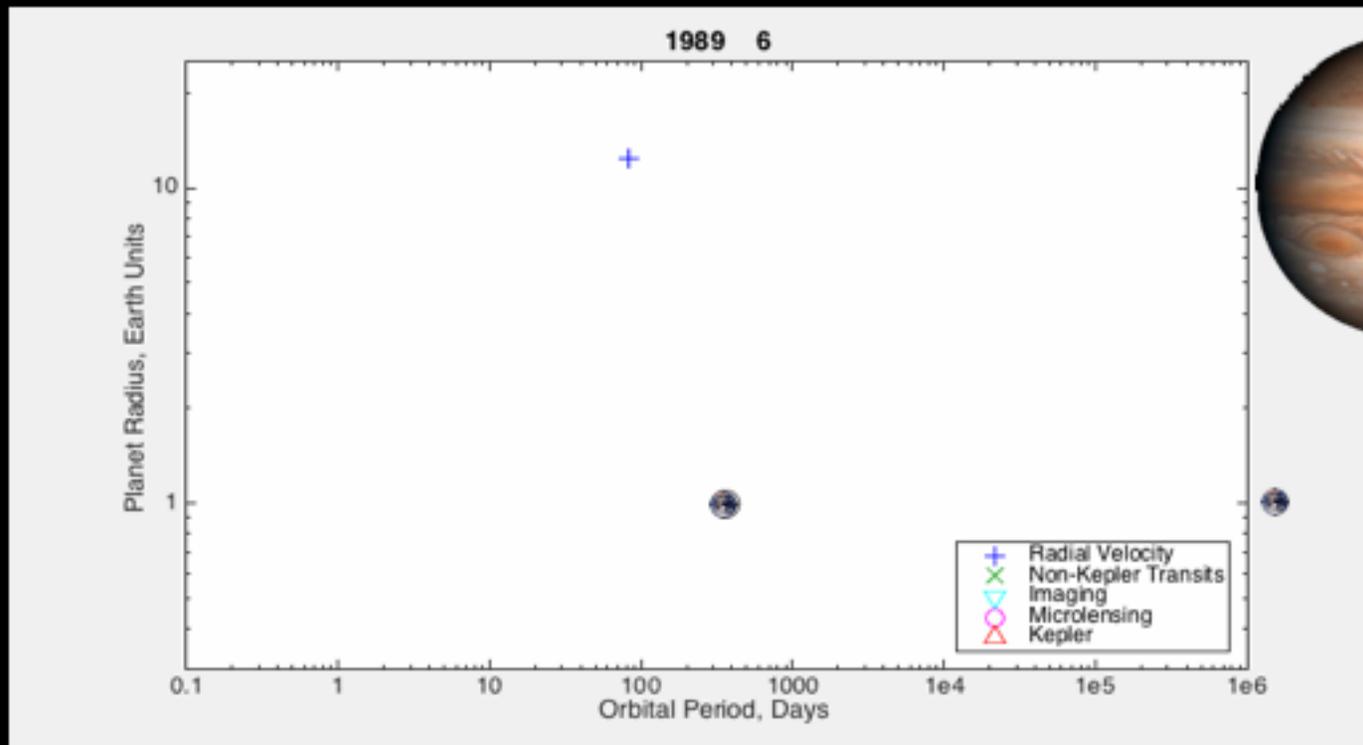




Stars are very far away.
We cannot see the planet cross in front of the star.



Exoplanet Discoveries Over Time*



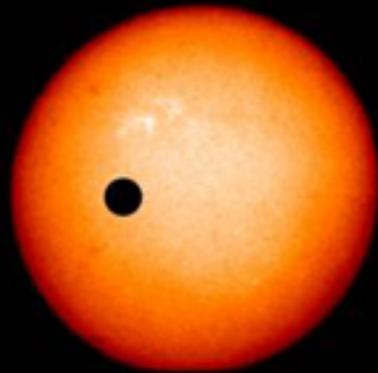
Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

*According to <https://exoplanetarchive.ipac.caltech.edu> as of 8/29/17

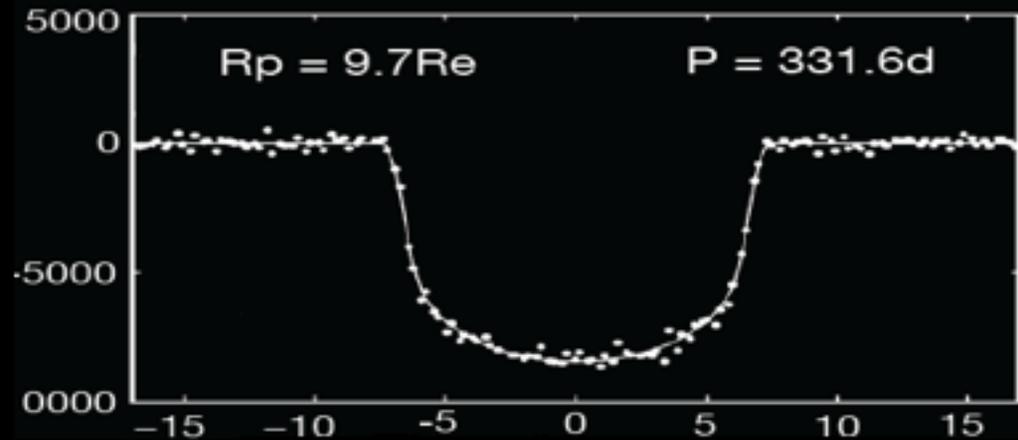


How Hard is it to Find Good Planets?

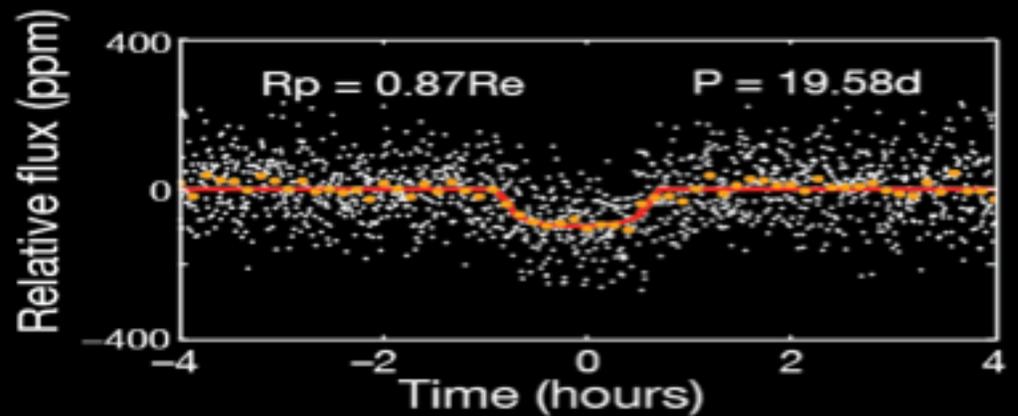
Kepler
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Planets



Jupiter (~1%)

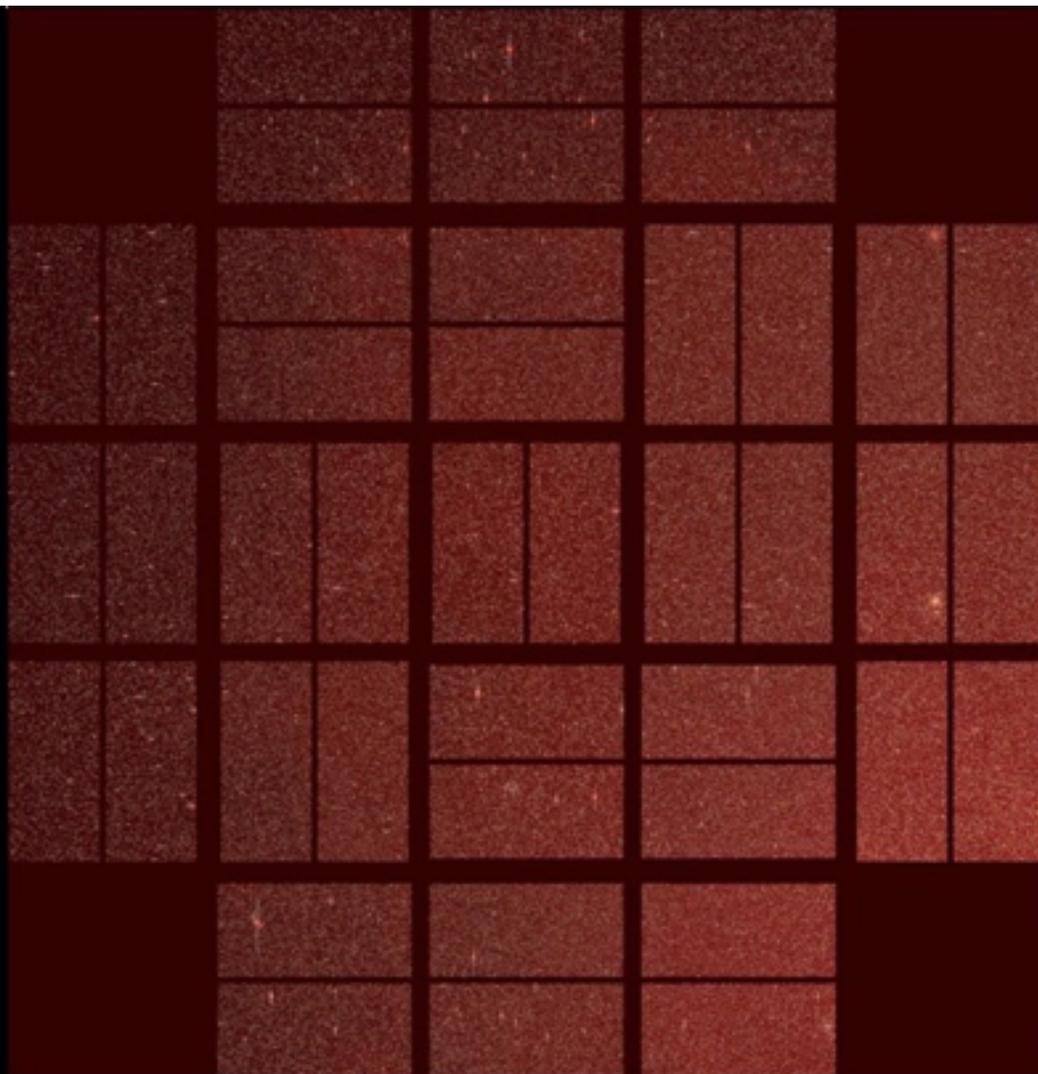


Earth (~0.01%)



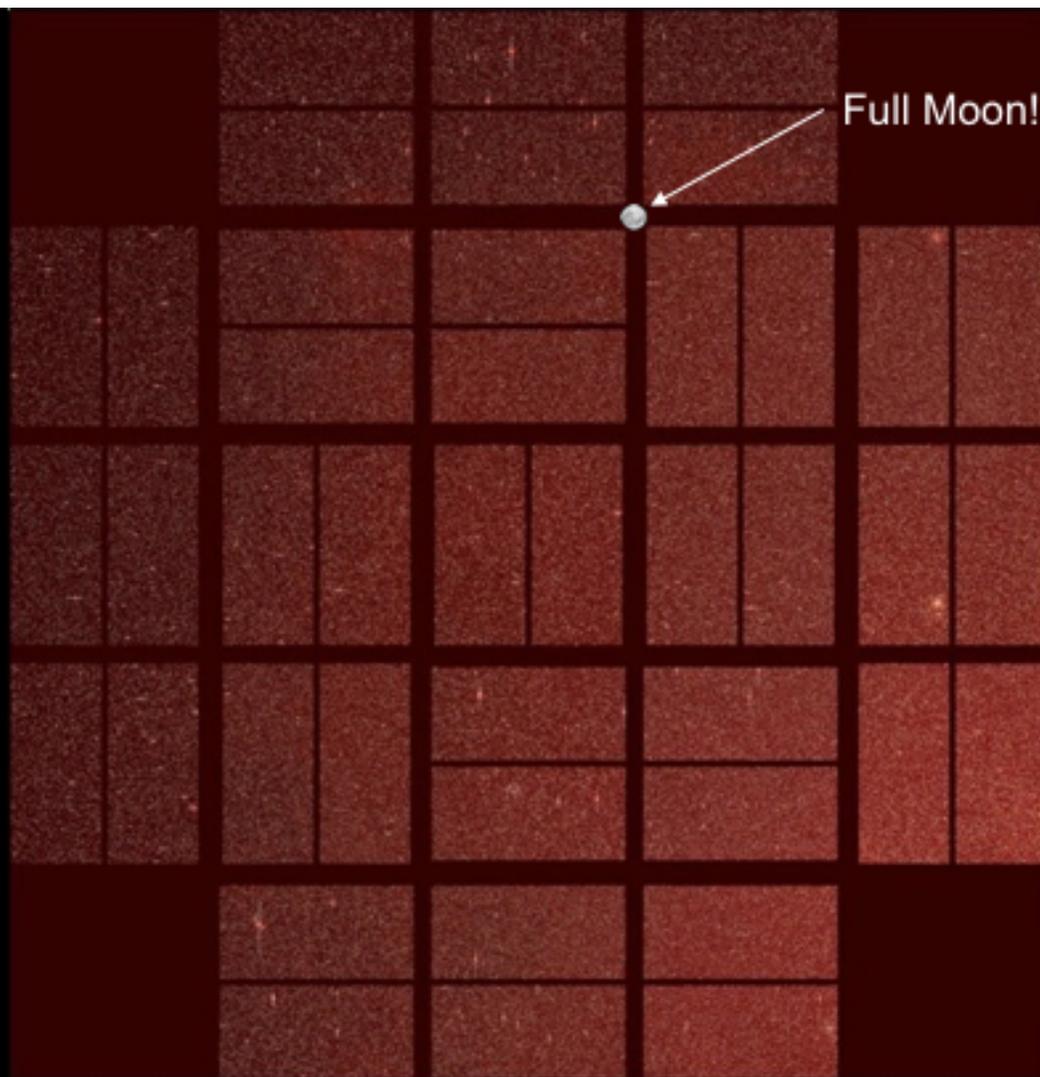
First Light Image

Launched
March 7 2009



First Light Image

Launched
March 7 2009





Small Rocky Planets

Kepler
A Search for Earth-size
Planets

Kepler-20e

Venus

Earth

Kepler-20f



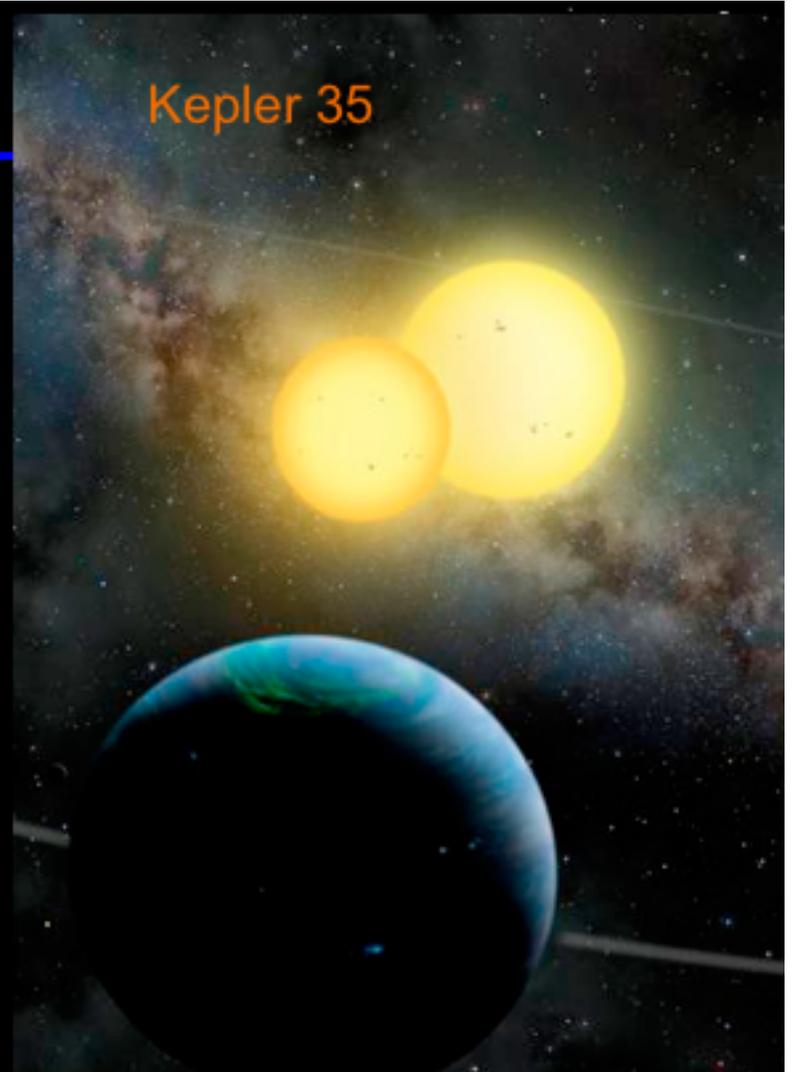
Kepler discovers two Earth-size planets, which are presumably rocky, Kepler-20e and Kepler-20f. These planets are members of multiple solar systems that contain additional larger gas giant planets in longer period orbits.



Circumbinary Planets:

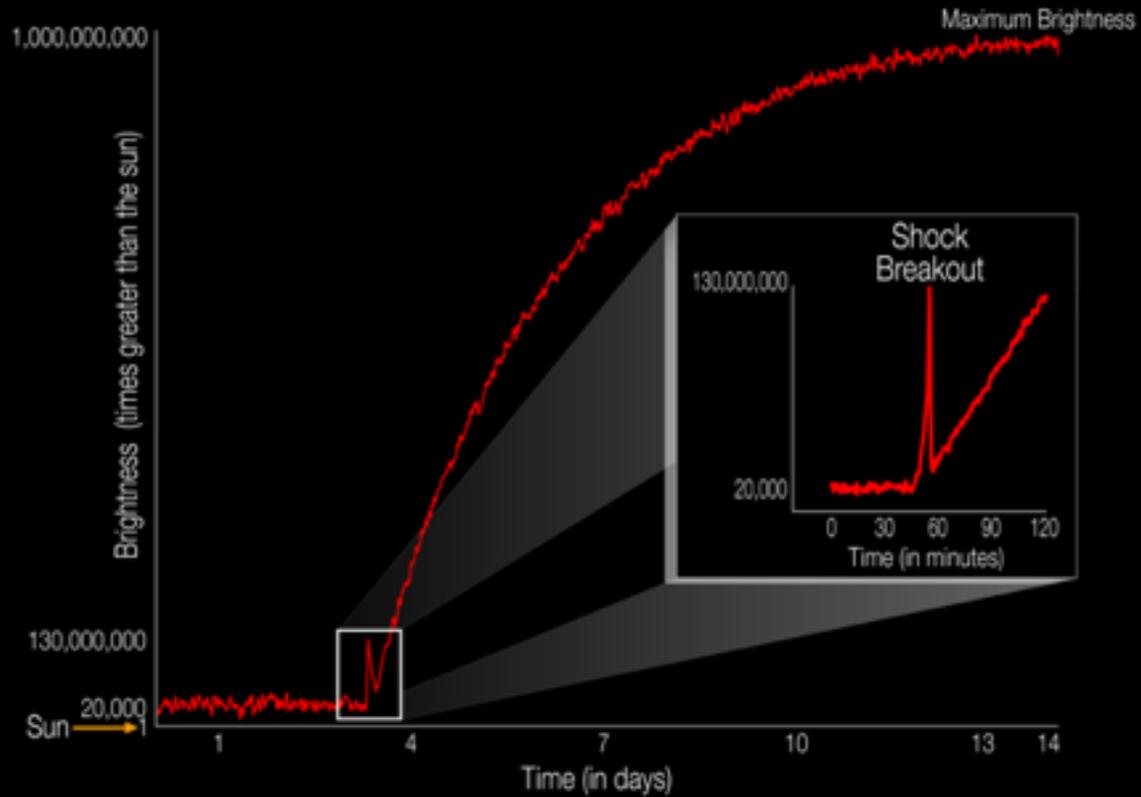


Kepler 35





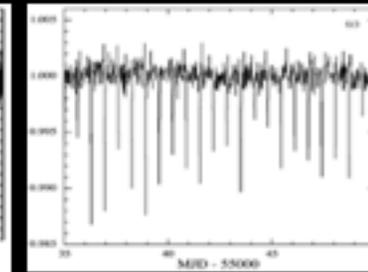
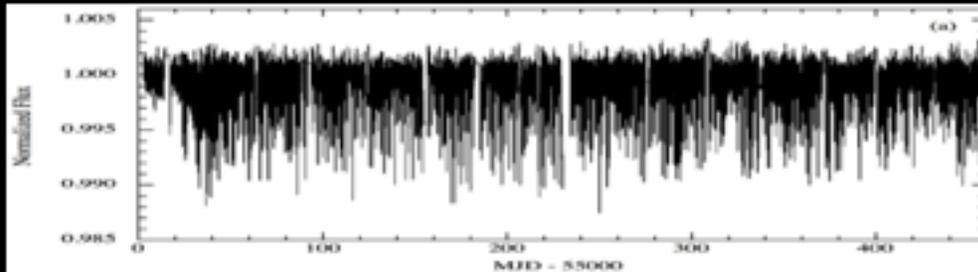
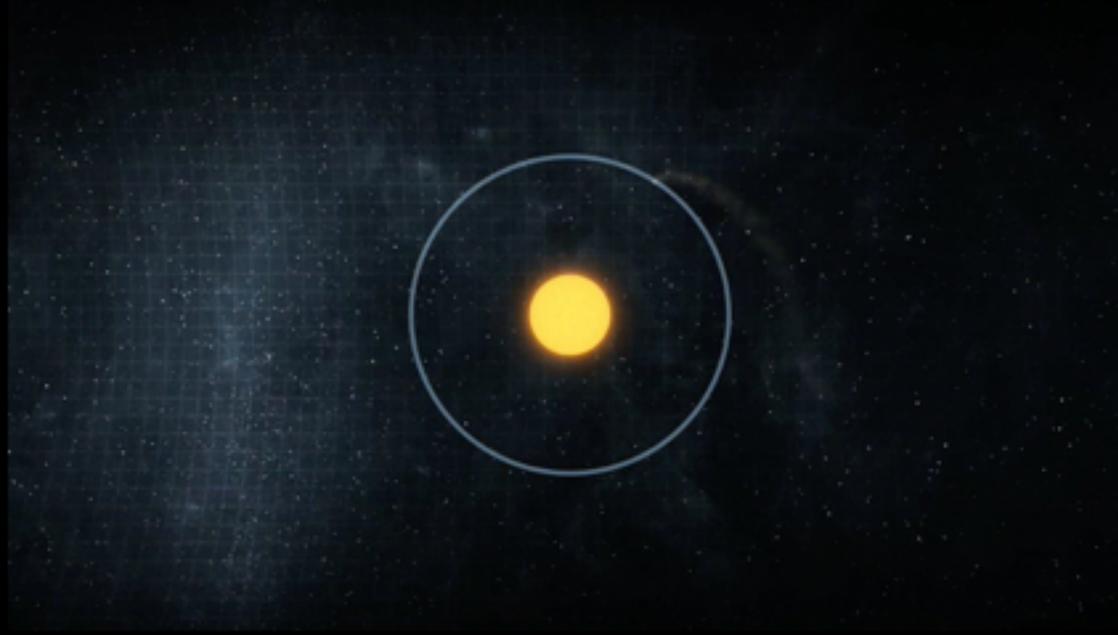
Shock Breakout of KSN 2011d





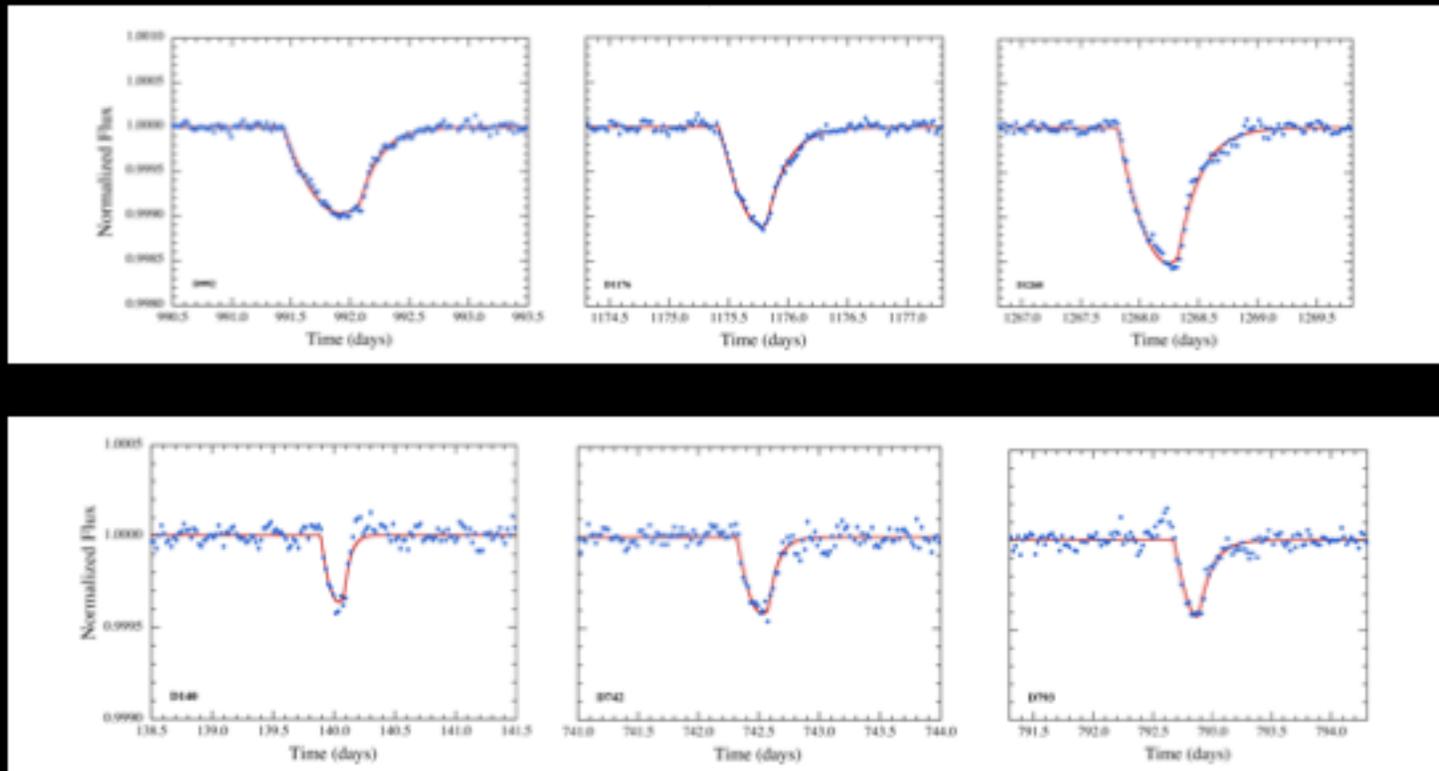
A Disintegrating Sub-Mercury-Size Planet

Kepler
A Search for Earth-size
Planets





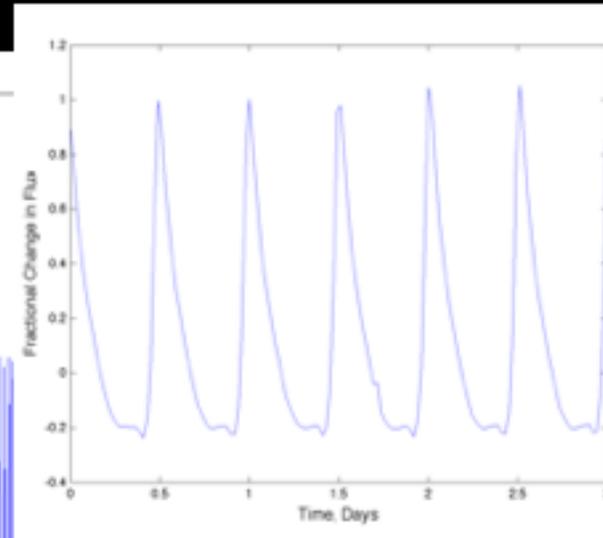
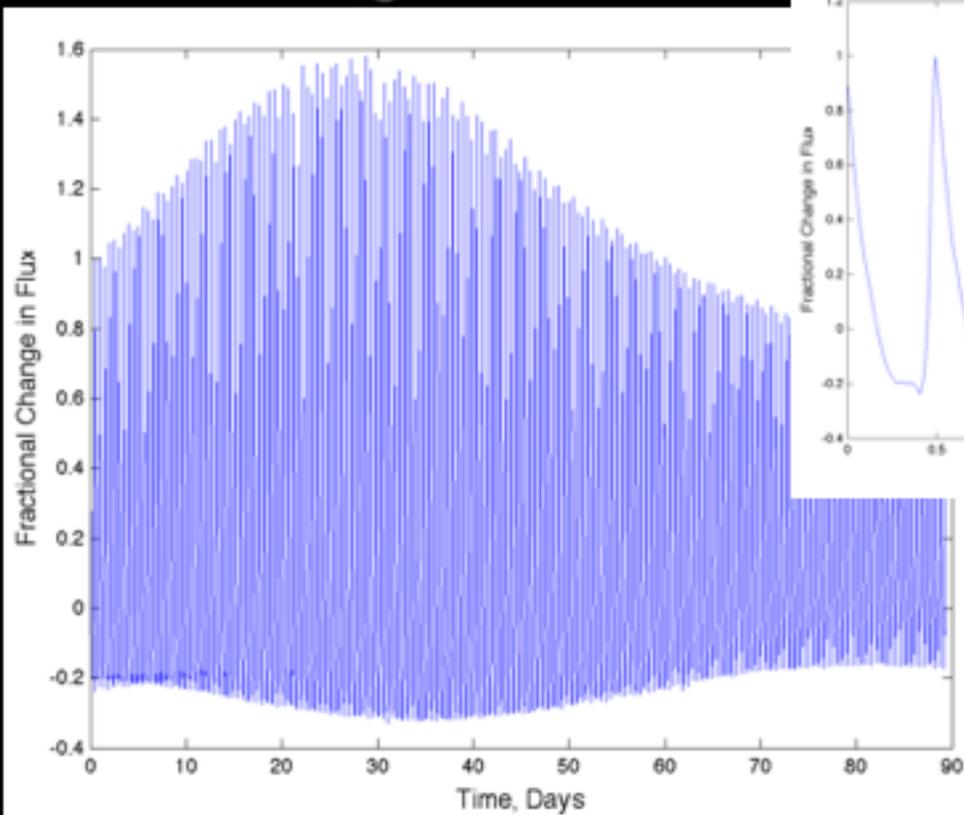
KIC 3542116: An Exocomet Candidate



Rappaport et al. 2017, arxiv1708.06069

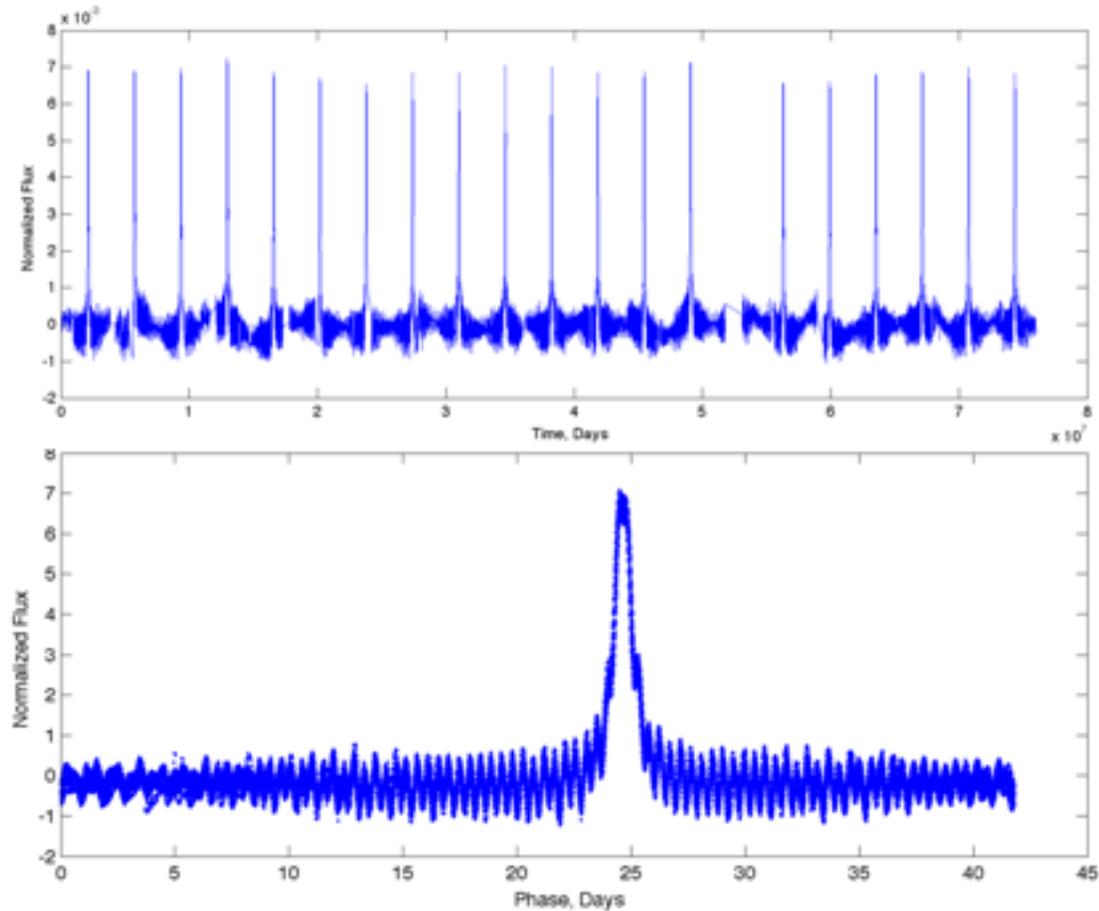


An RR Lyra Star





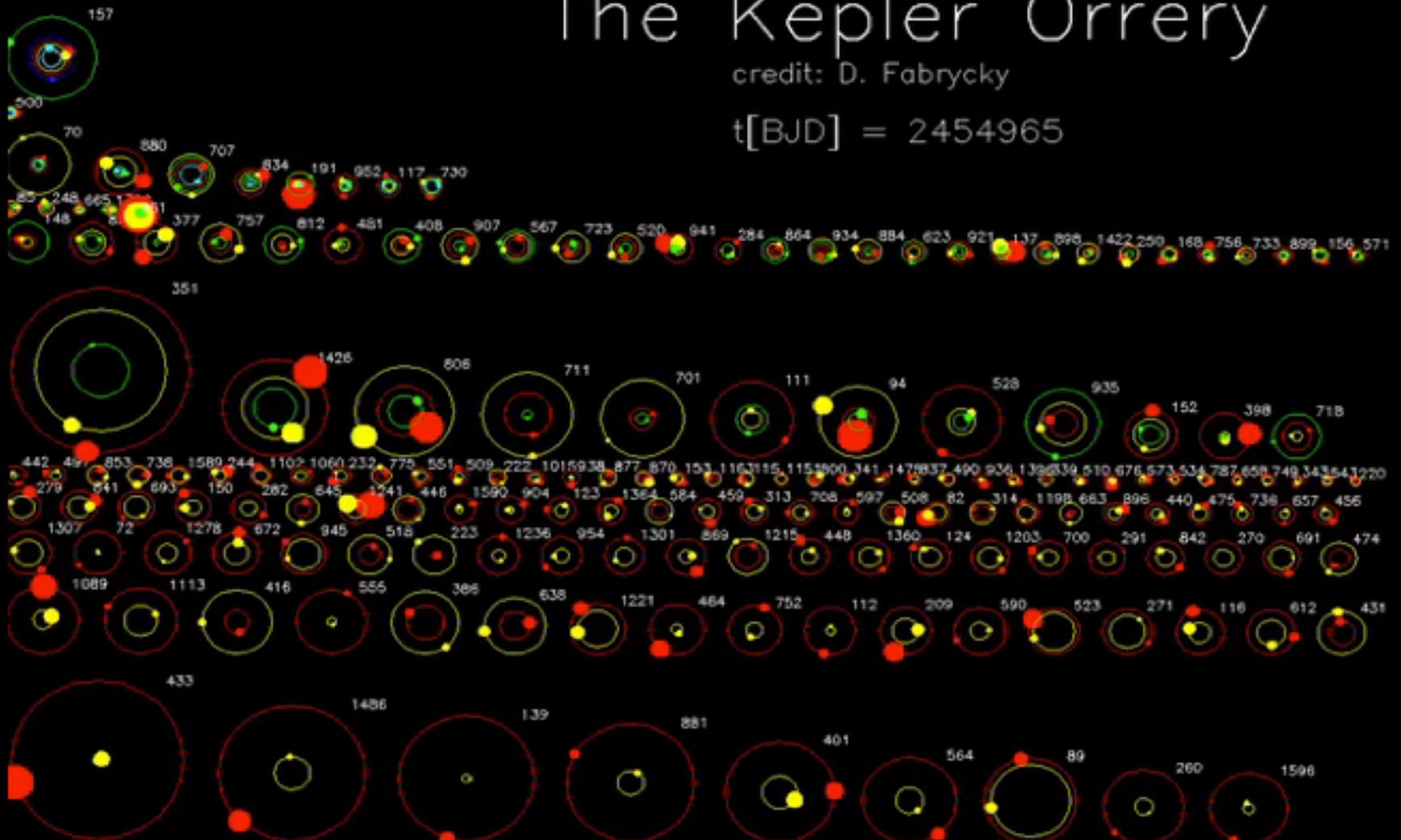
Heartbeat Stars: KOI-54



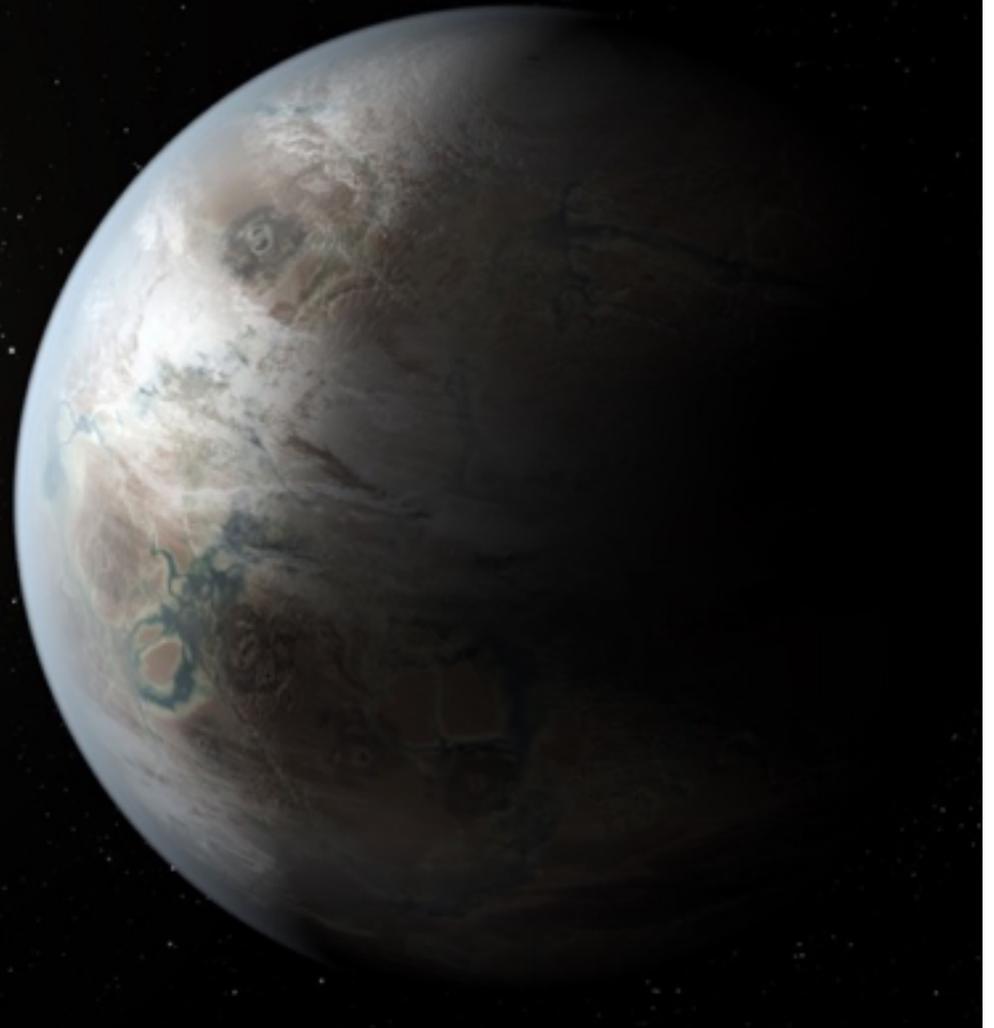
The Kepler Orrery

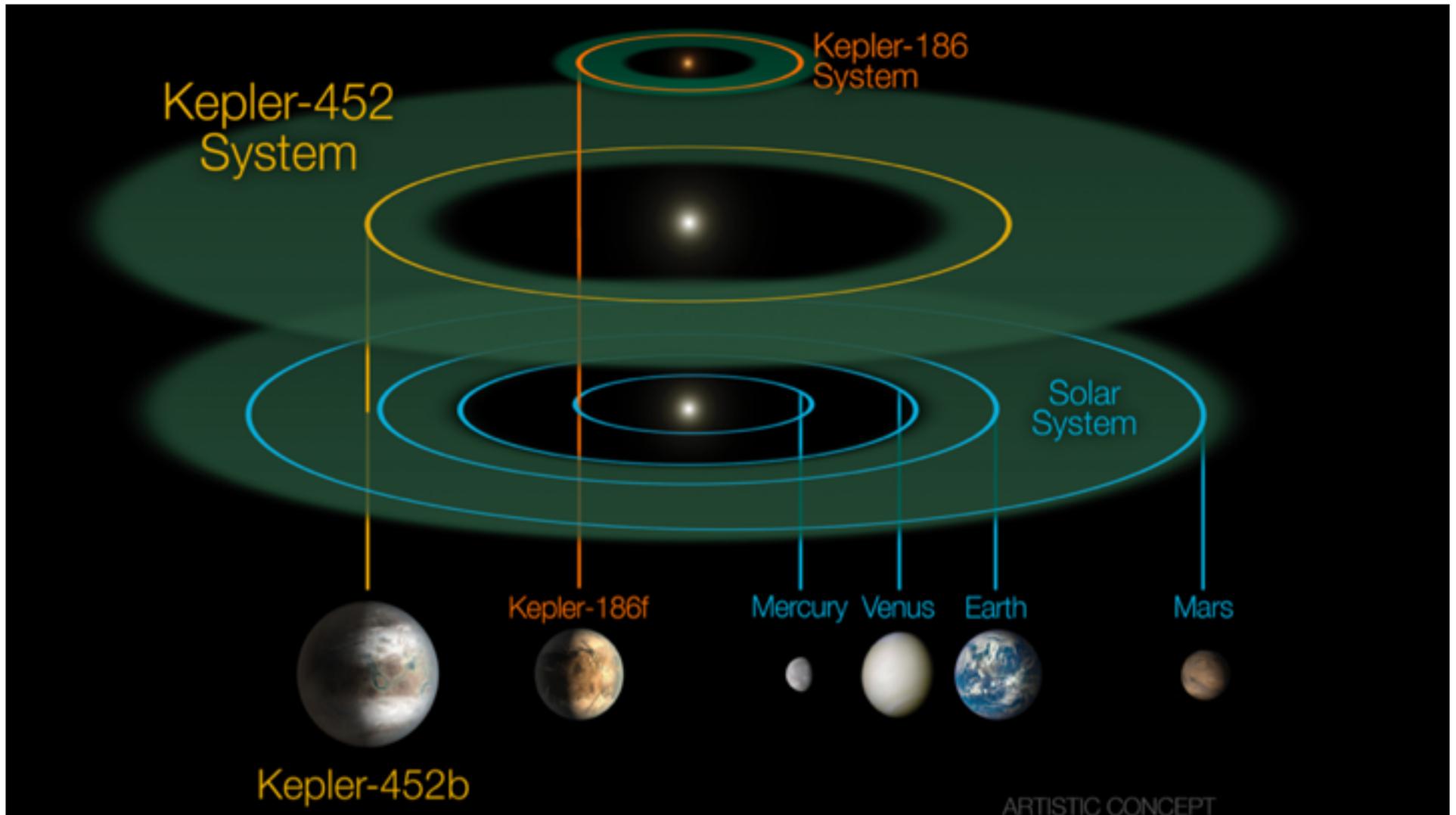
credit: D. Fabrycky

$t[\text{BJD}] = 2454965$



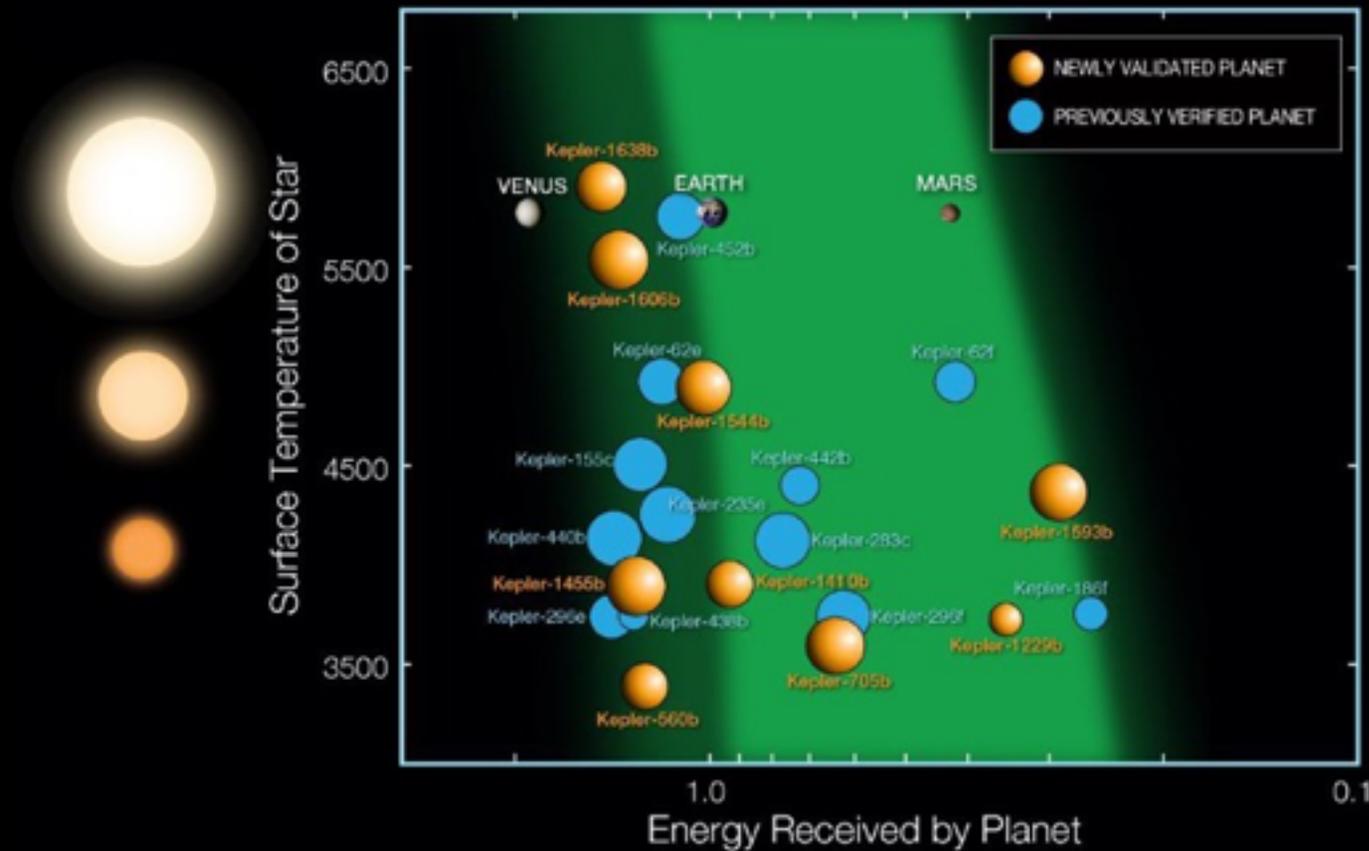
Kepler-452b





Kepler's Small Habitable Zone Planets

As of May 10, 2016



Kepler taught us that planets are everywhere!

What Next?

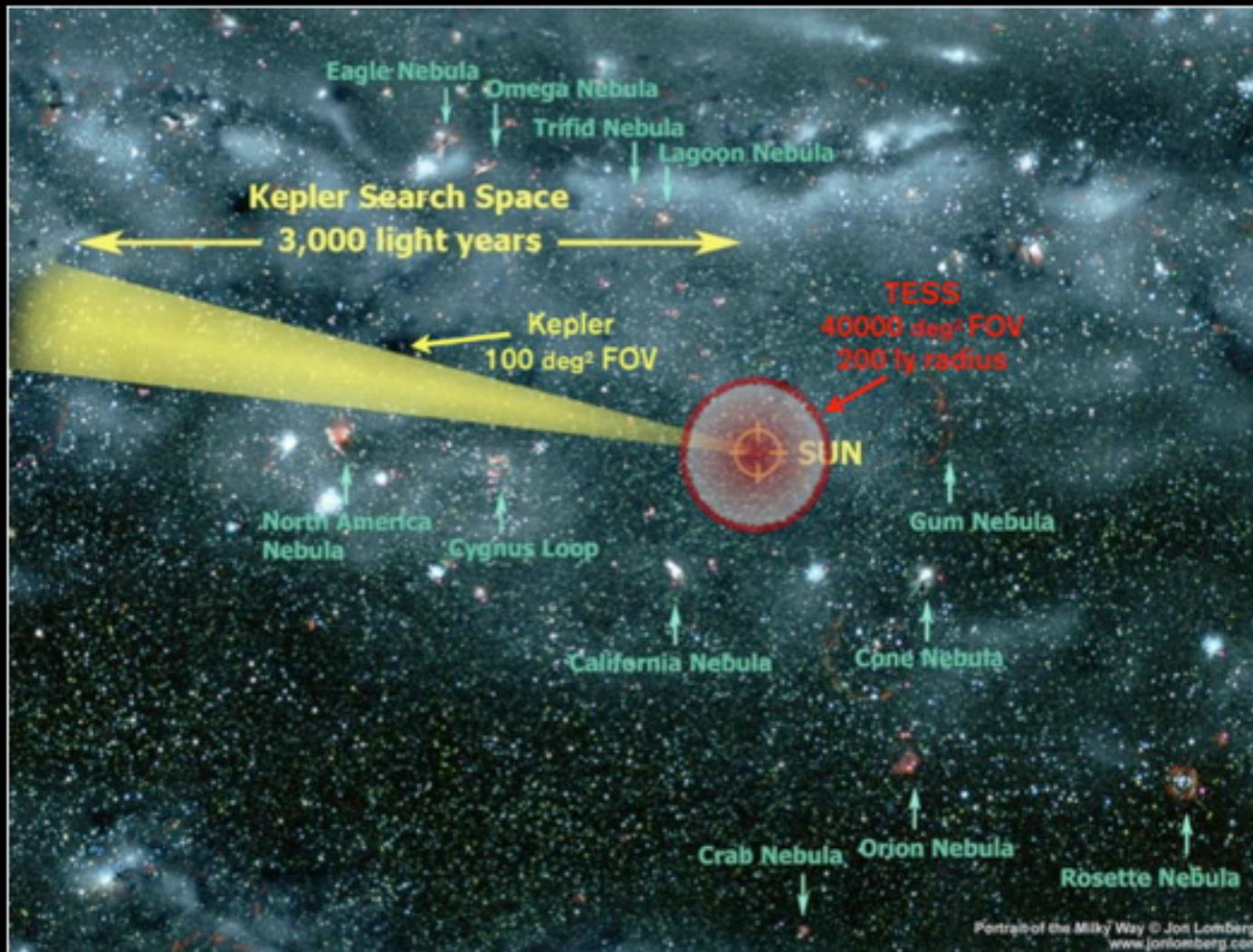




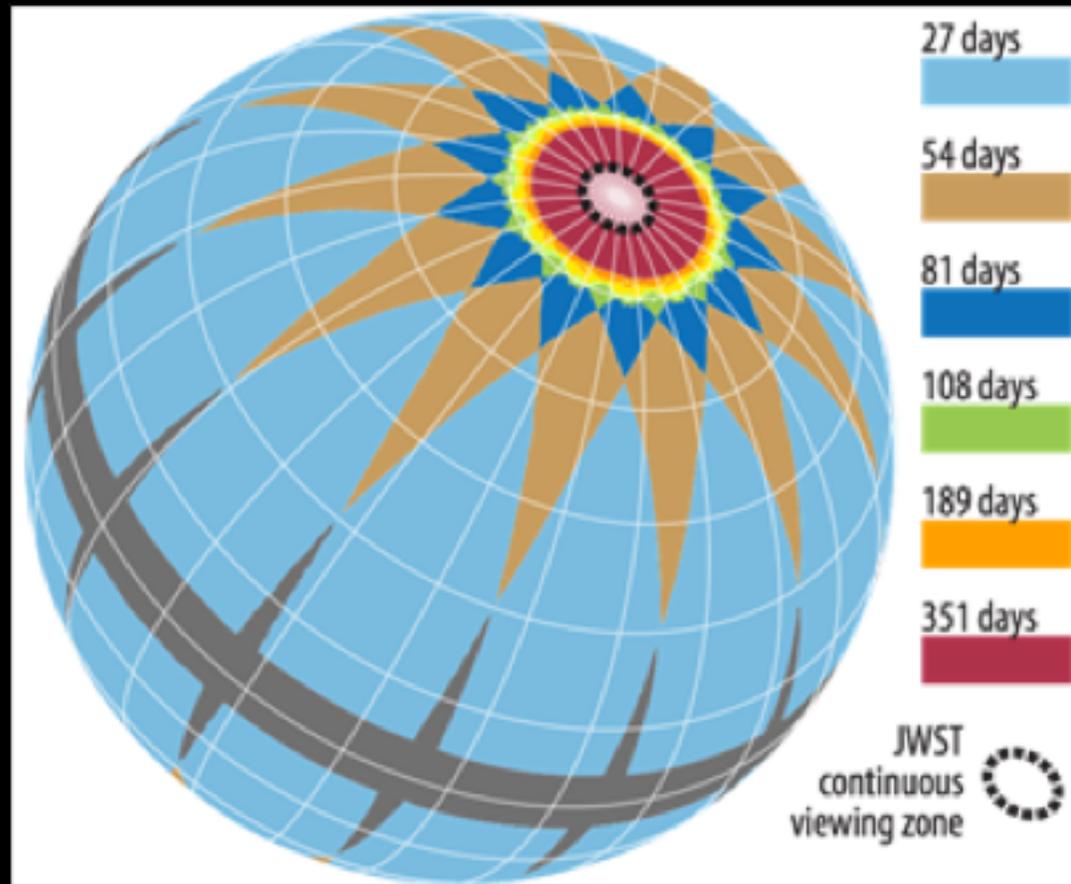
TRANSITING EXOPLANET SURVEY SATELLITE

*DISCOVERING NEW EARTHS AND SUPER-EARTHS
IN THE SOLAR NEIGHBORHOOD*

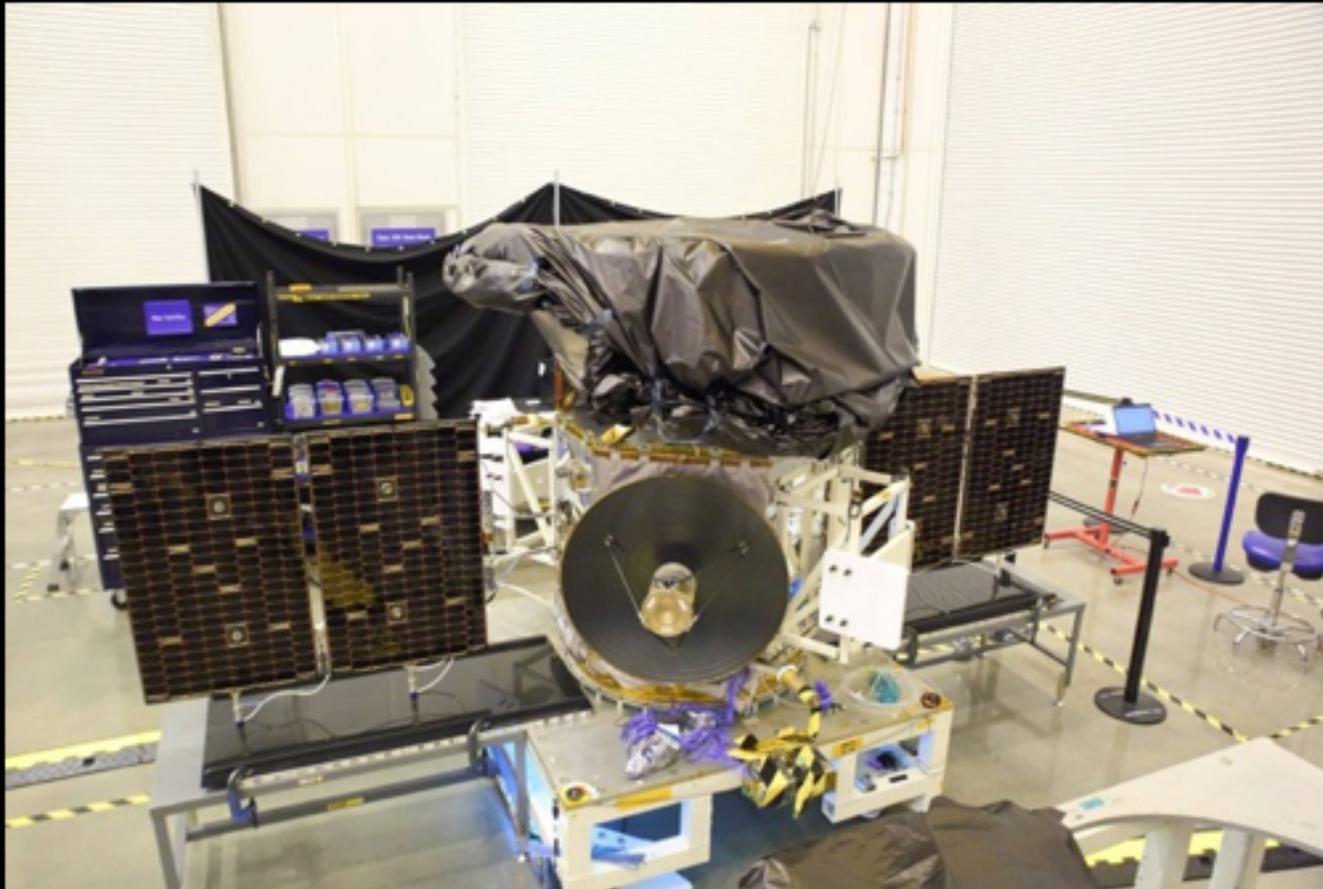




TESS Sky Coverage



TESS Spacecraft



Detecting Biomarkers through Transit Spectroscopy

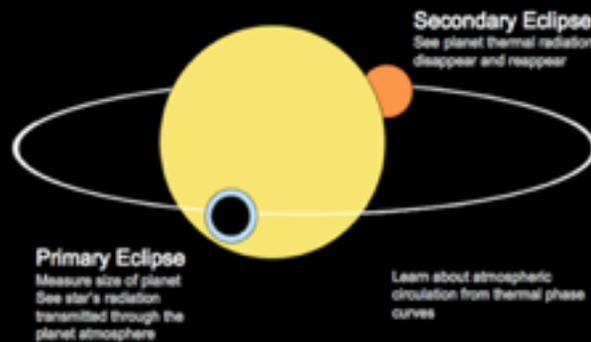
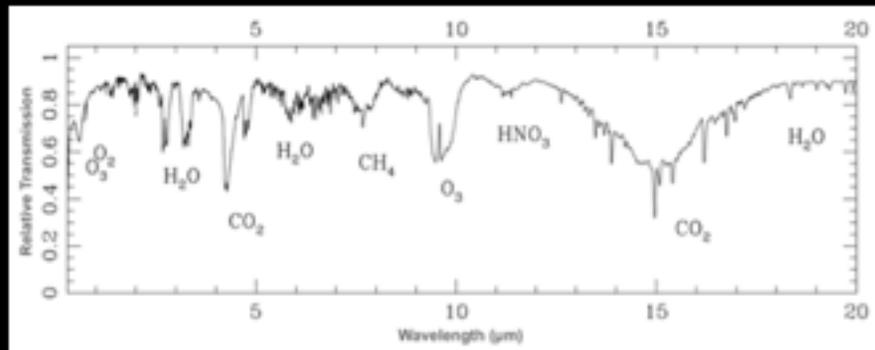


Figure by S. Seager



Kaltenegger, L. and Traub, W. (2009) Transits of Earth-Like Planets, ApJ

Exoplanet Missions



2001
Decadal
Survey



2010
Decadal
Survey

What can you do to help study exoplanets?

Do you like Science?

Do you like Math?

Do you like Art?

We need:

- Scientists
- Astronomers
- Engineers
- Data Scientists
- Mathematicians
- Software Engineers
- Artists



Do you have questions?