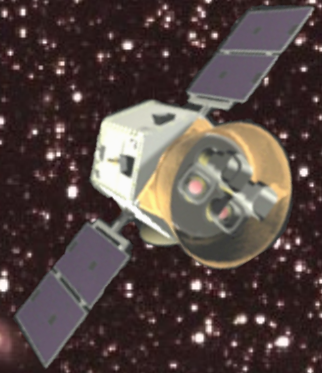
Prospecting for Habitable Worlds



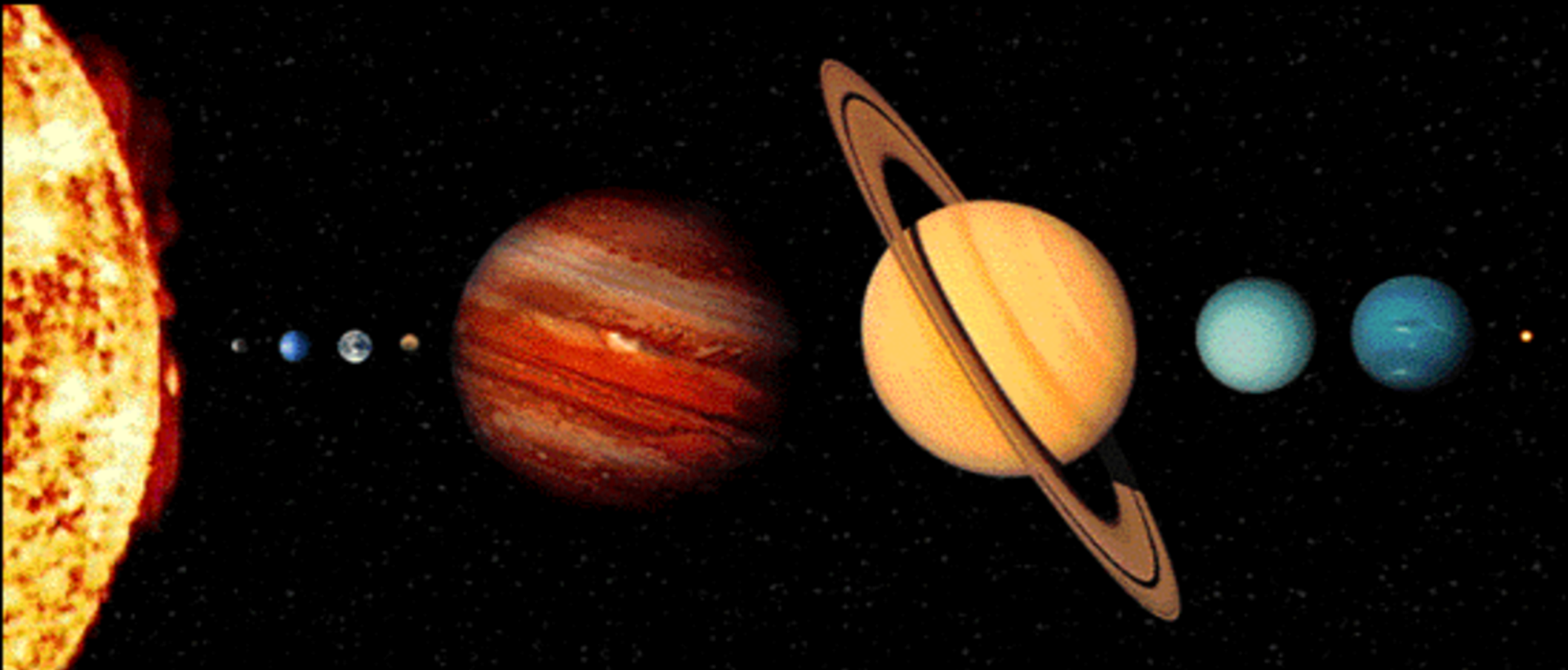
Jon M. Jenkins
NASA Ames Research Center

Thursday October 19, 2017

Symposium on Space Innovations 2017
Atlanta, GA

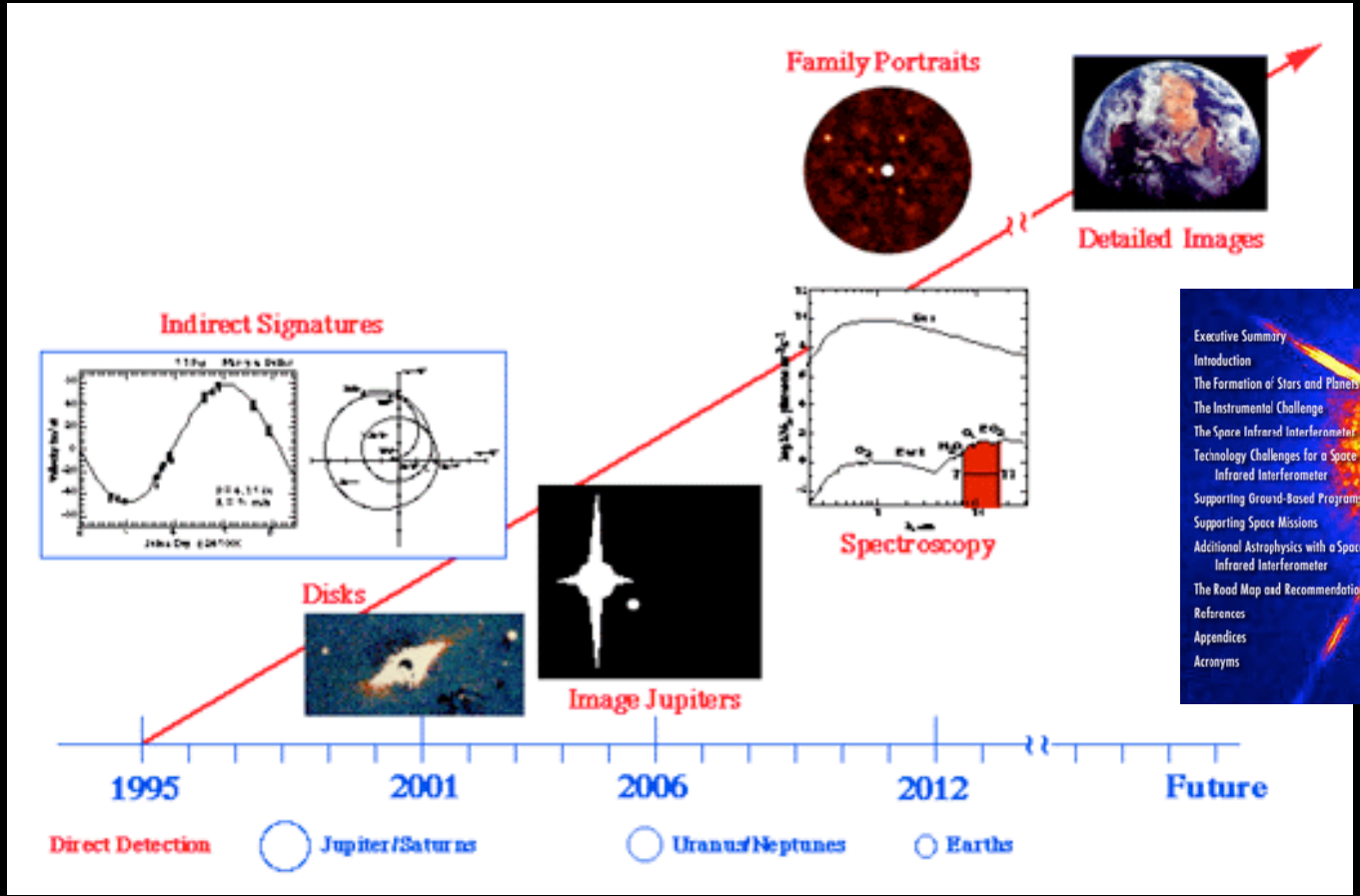
All the Known Planets In 1994

Kepler
A Search for Earth-size Planets

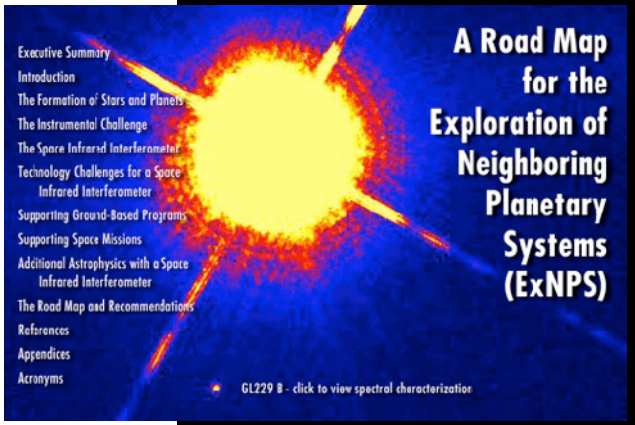


NASA's 1995 ExNPS Report

Kepler
A Search for Earth-size Planets

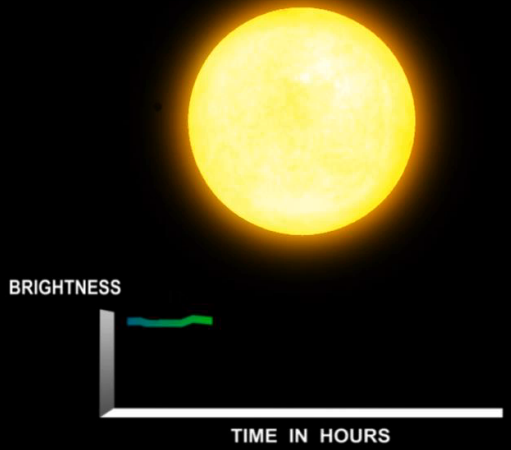


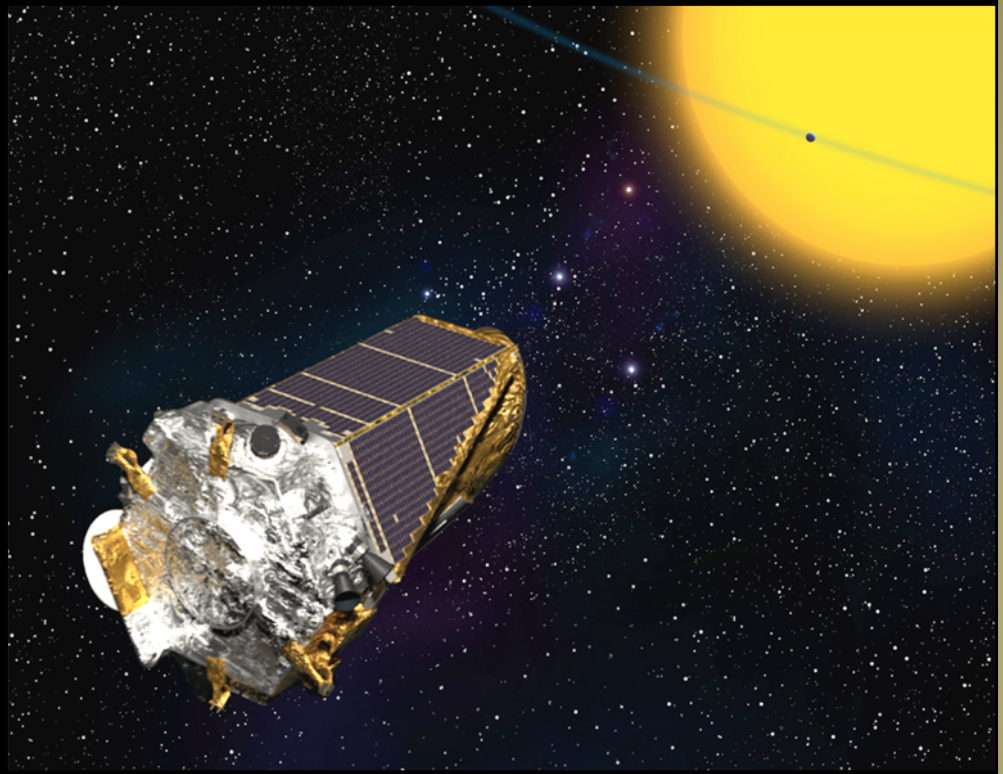
Transit Photometry not Recommended!



The *Kepler* Mission

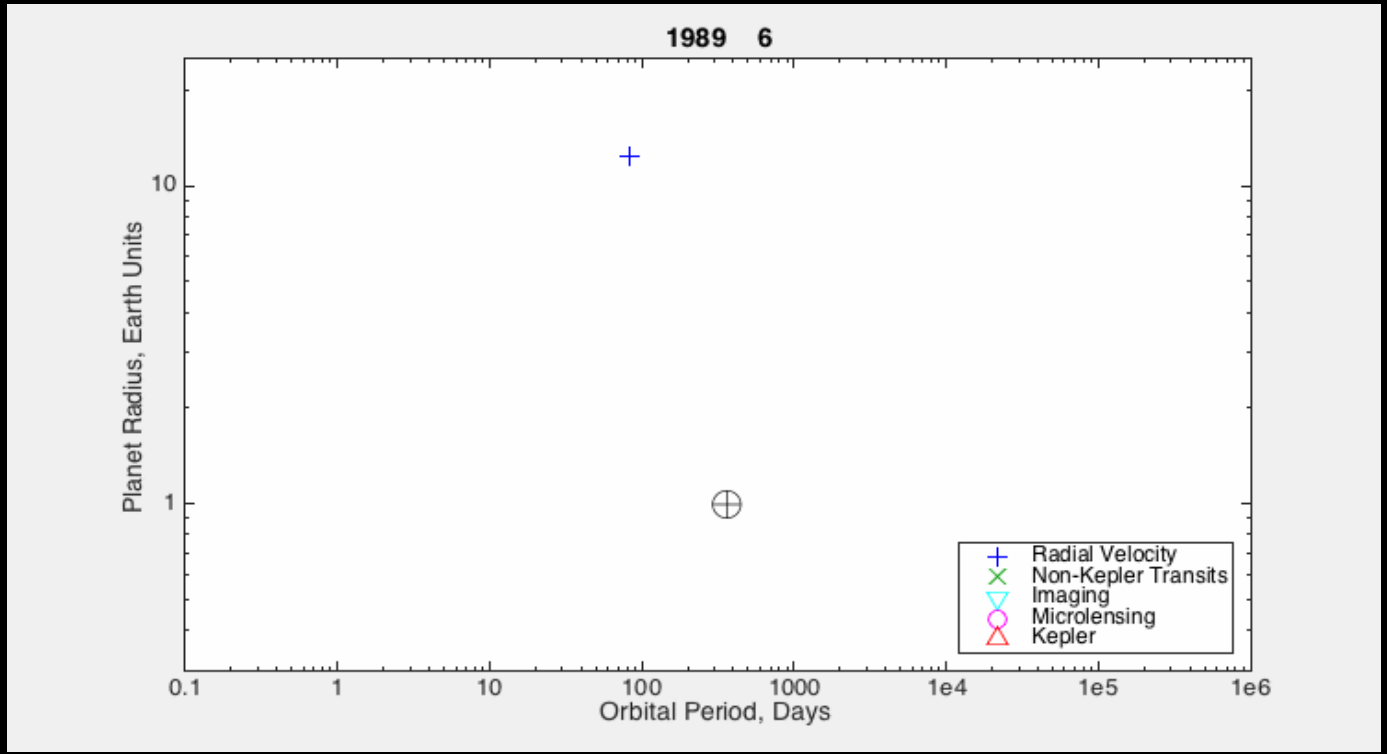
What fraction of sun-like stars in our galaxy host potentially habitable Earth-size planets?





Exoplanet Discoveries Over Time*

Kepler
A Search for Earth-size Planets



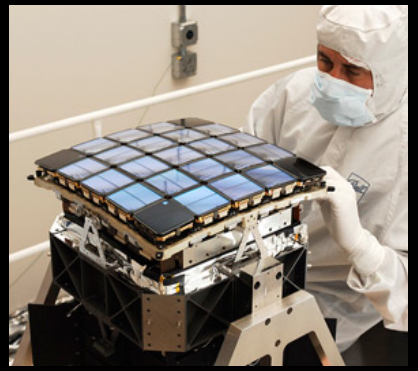
Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

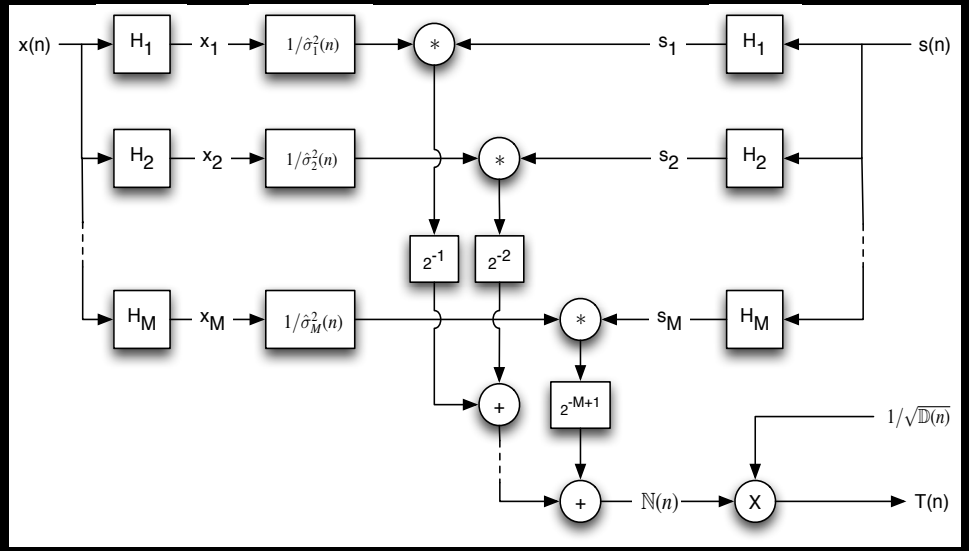
*According to https://exoplanetarchive.ipac.caltech.edu as of 8/29/17

Enabling *Kepler*

Kepler
A Search for Earth-size Planets

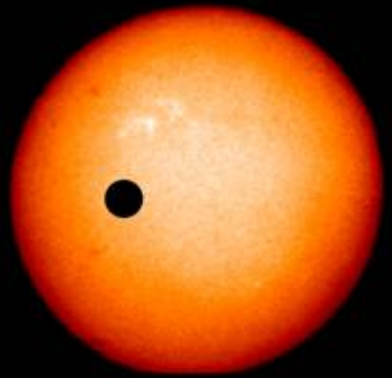
- Back illuminated CCDs (20 ppm photometric precision)
- Sophisticated algorithms
- Computational infrastructure



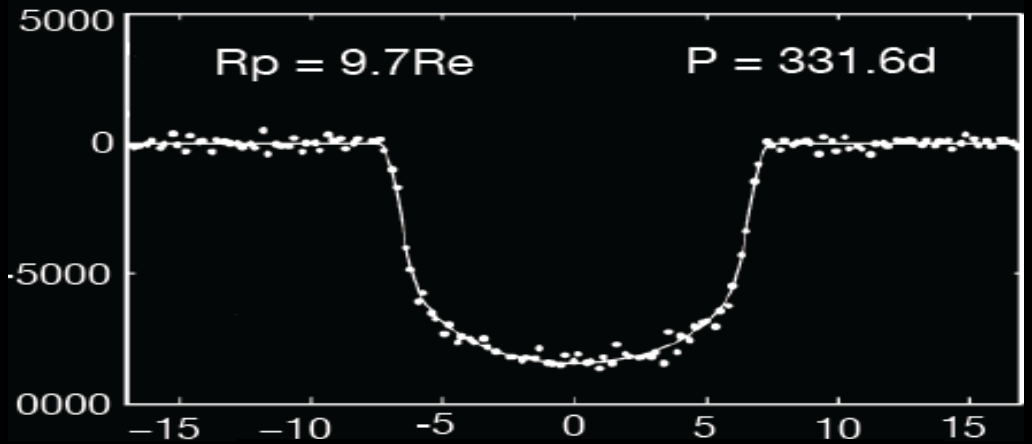


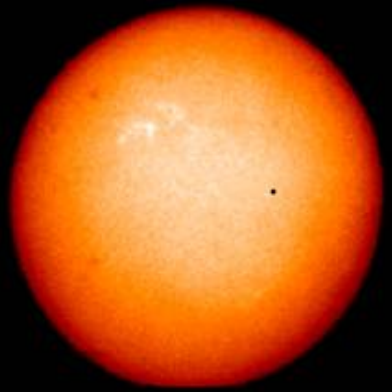
How Hard is it to Find Good Planets?

Kepler
A Search for Earth-size Planets

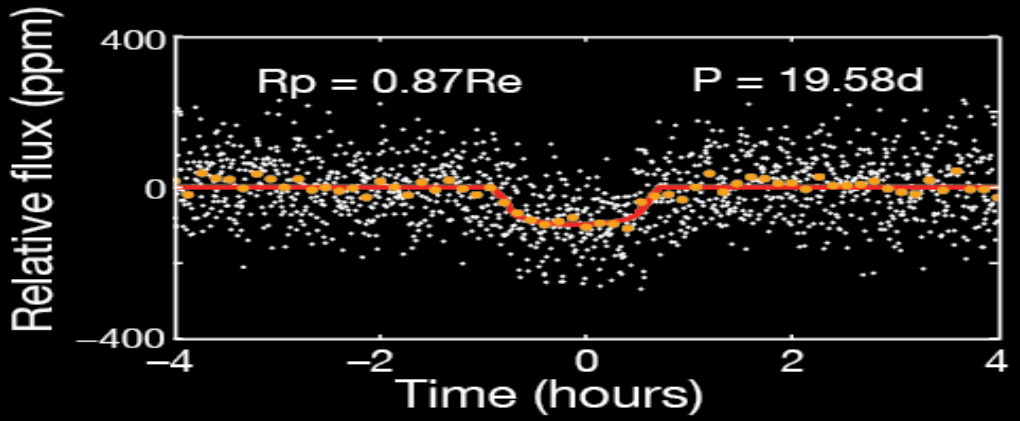


Jupiter (~1%)

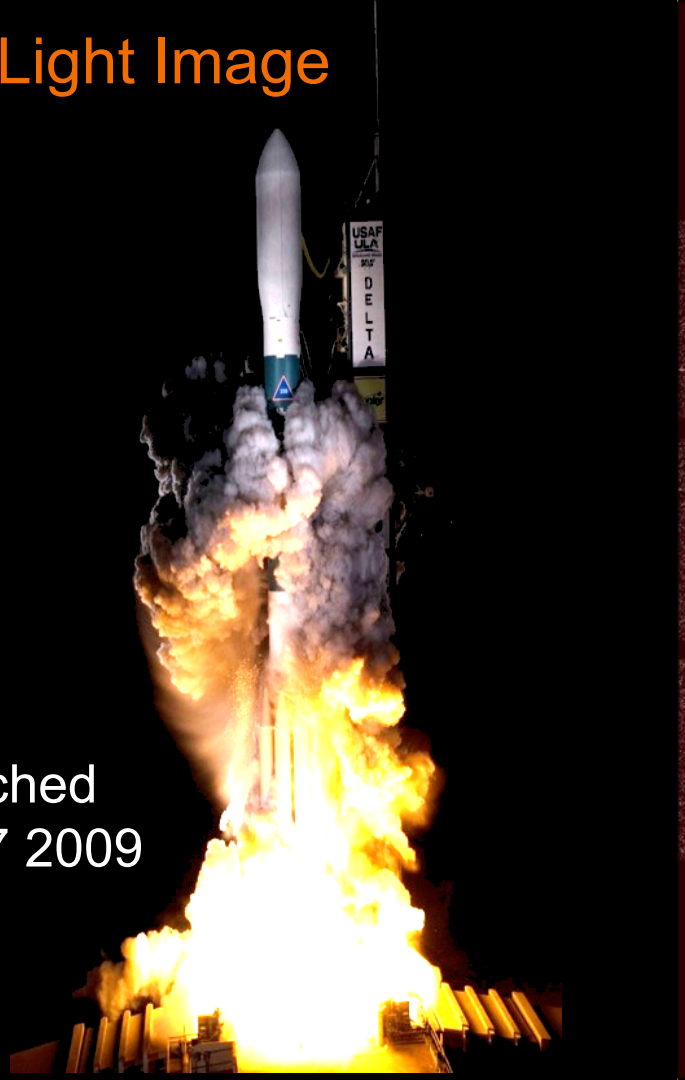




Earth (~0.01%)



First Light Image

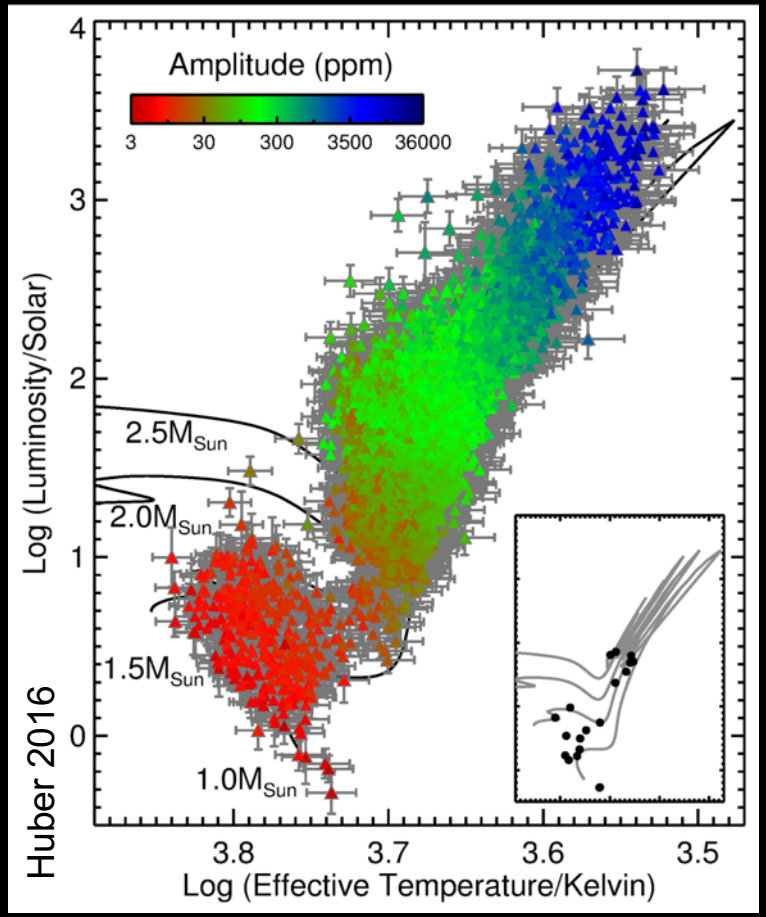


Launched
March 7 2009

First Light Image

Launched
March 7 2009

Asteroseismology with Kepler

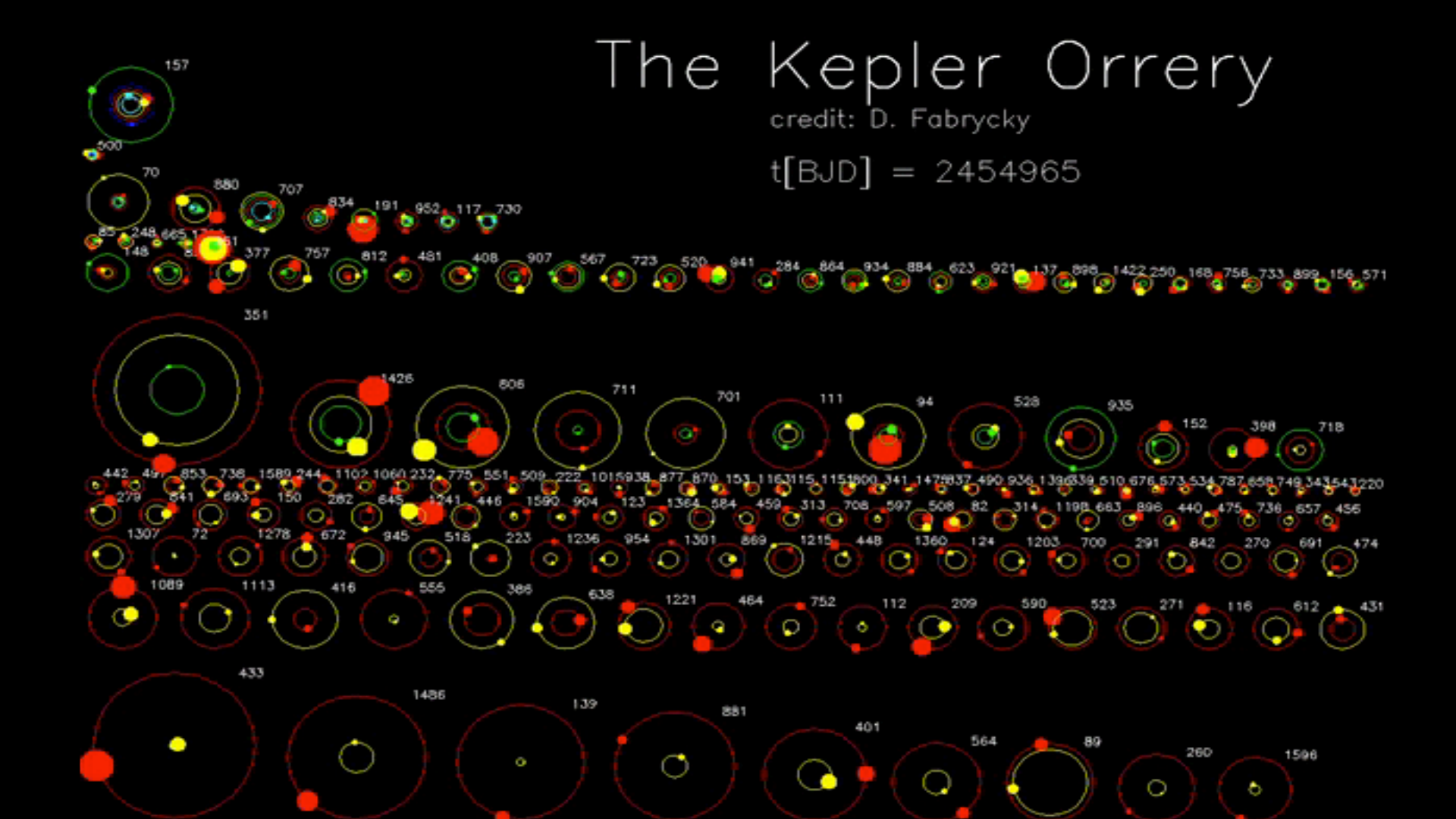


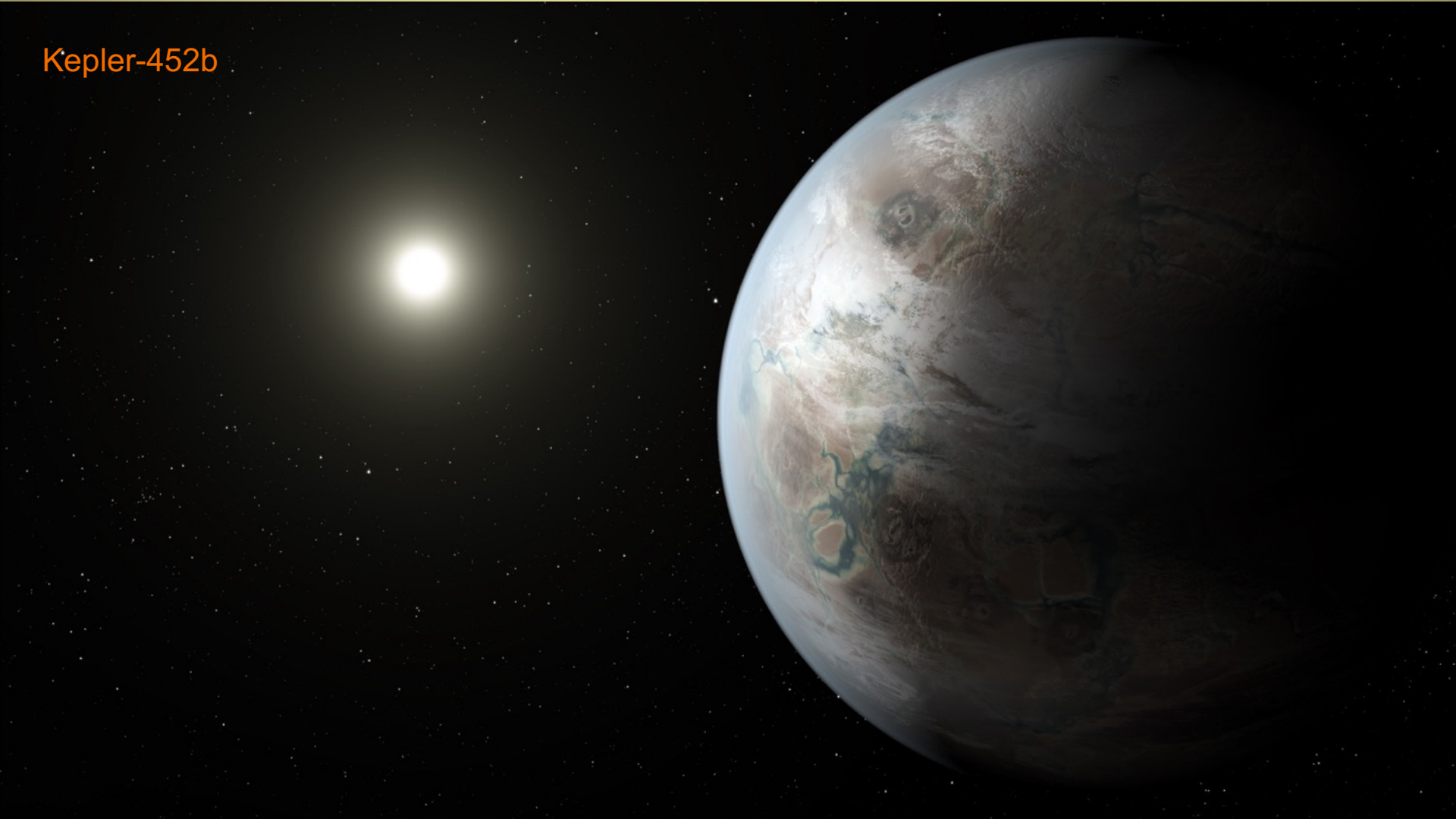
Inset – Stellar oscillation Detections before Kepler.

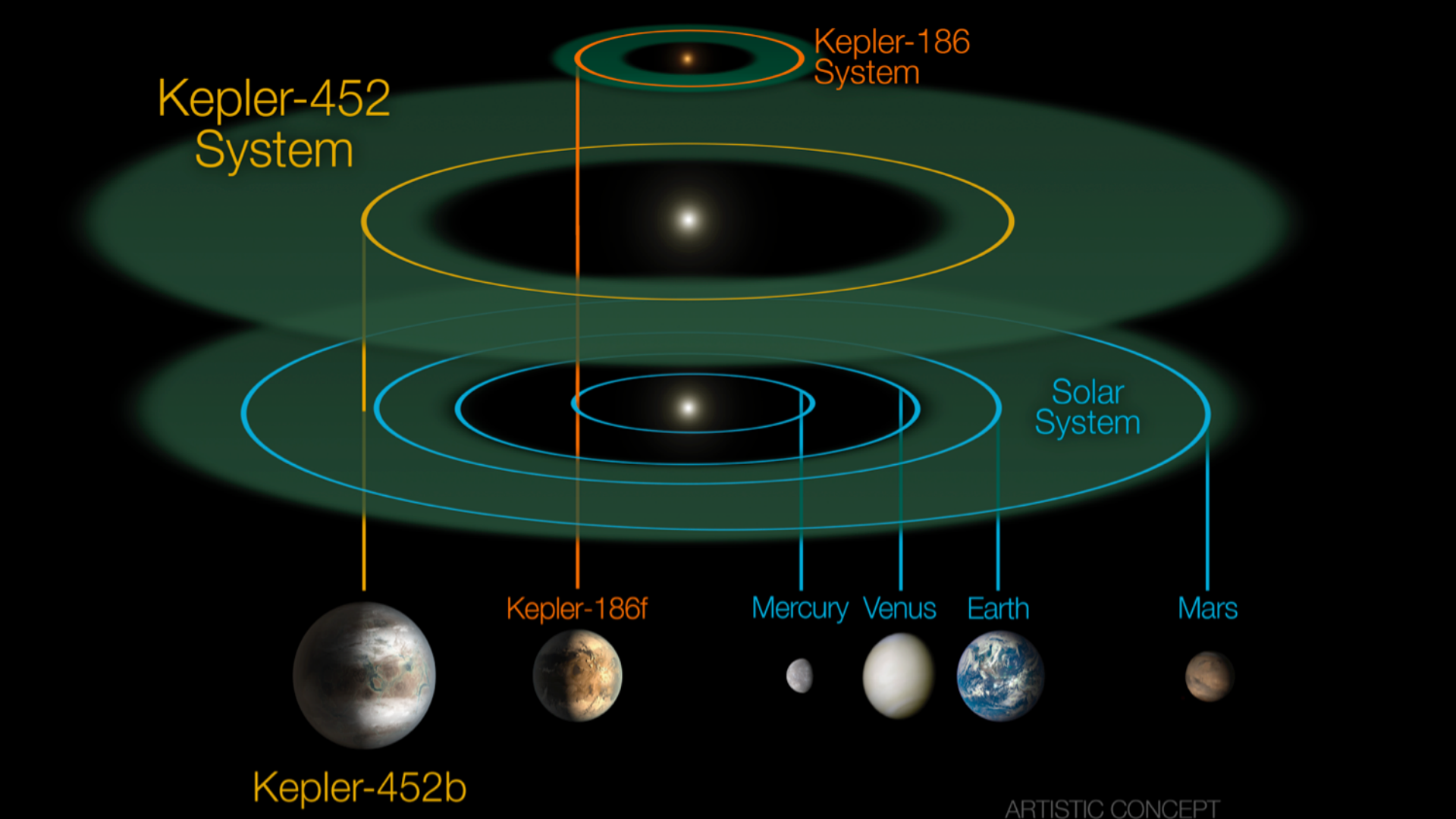
Main: Kepler's 4 years of study show the stars amplitudes (ppm) as color coded points. Extended study provides –

- Stellar ages and radii
- Internal differential rotation
- Convection zone depths ages
- Rotation axis orientation
- Heliophysics-like results

…for 15000+ stars

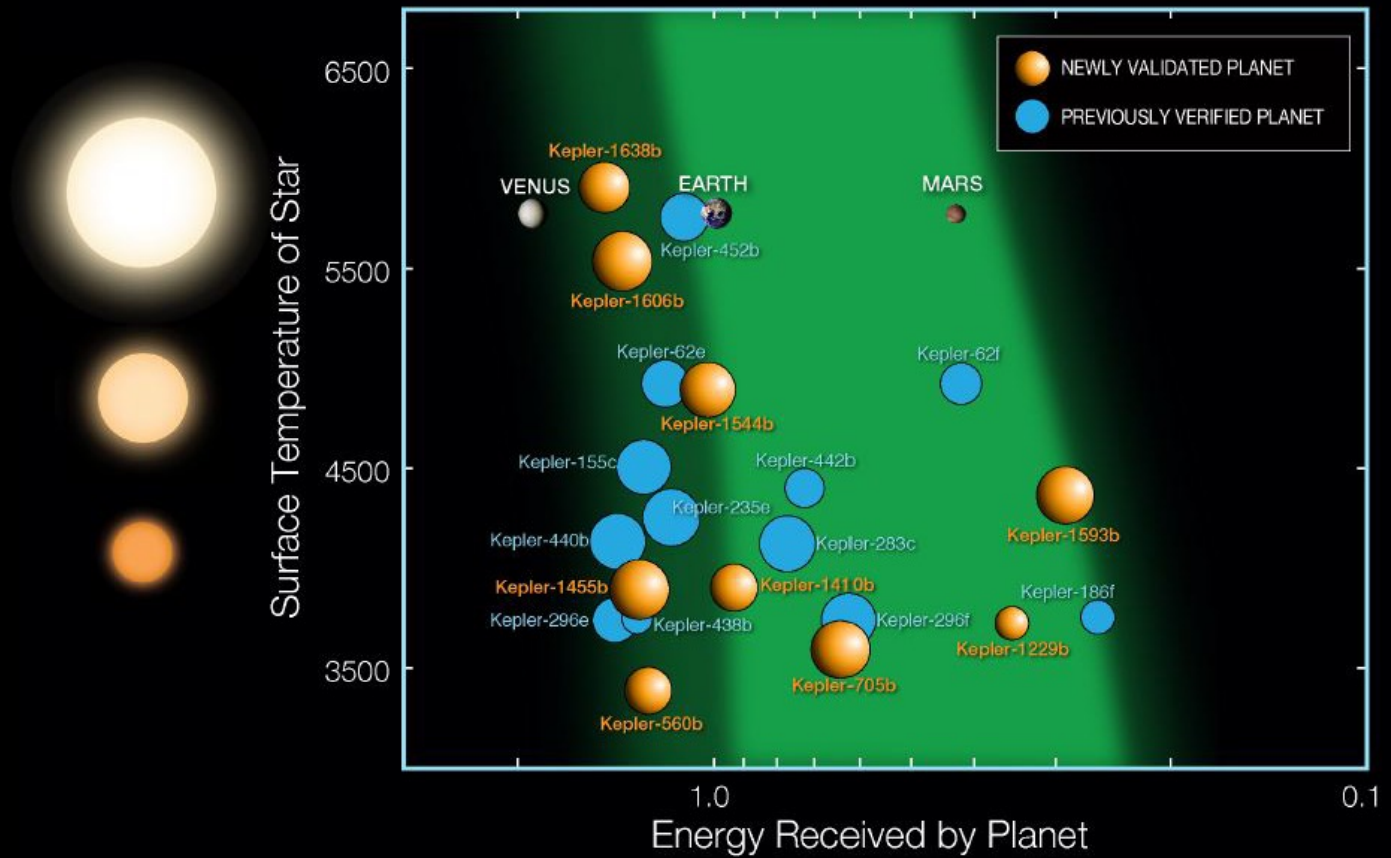

The Kepler Orrery
credit: D. Fabrycky
t[BJD] = 2454965


Kepler-452b

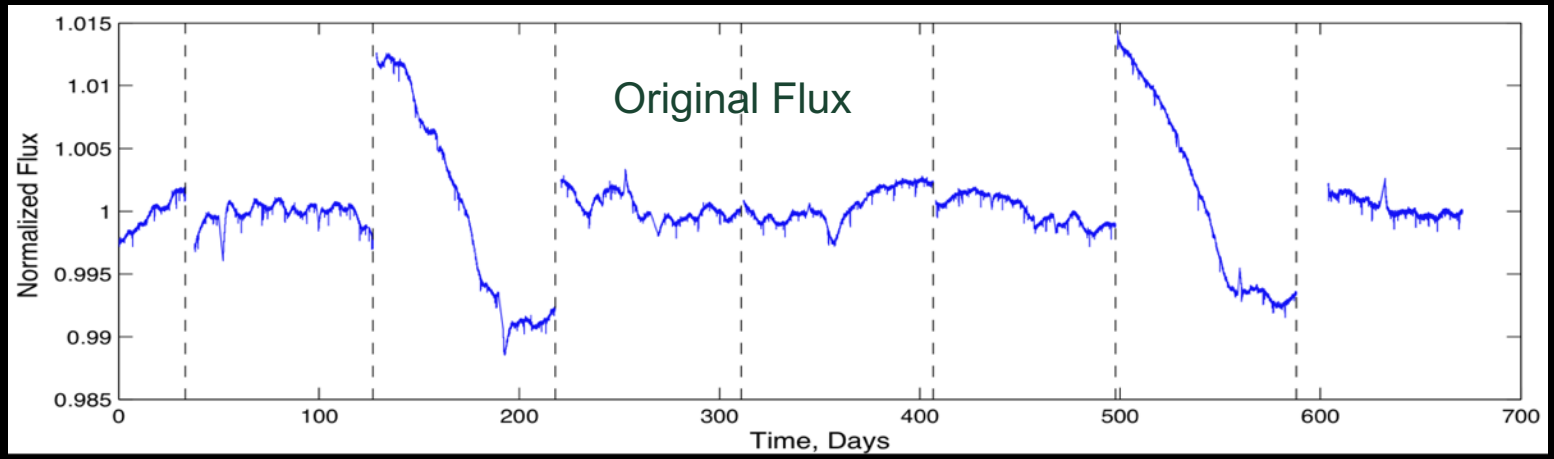

Kepler-186
System
Kepler-452
System
Solar
System
Kepler-186f
Mercury
Venus
Earth
Mars
Kepler-452b
ARTISTIC CONCEPT

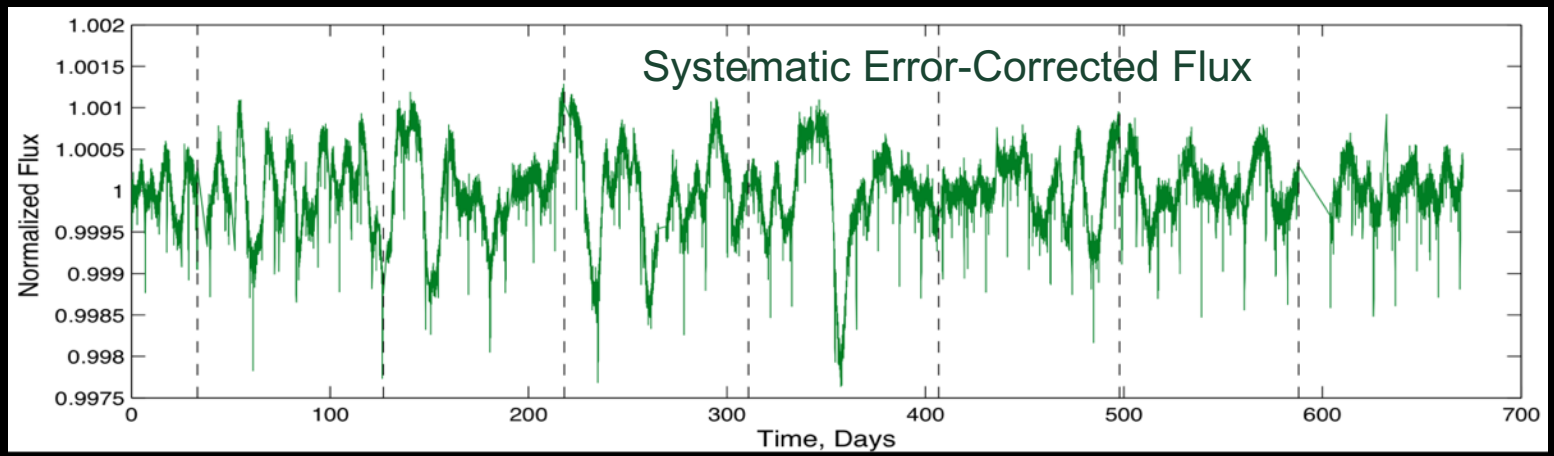
Kepler's Small Habitable Zone Planets

As of May 10, 2016



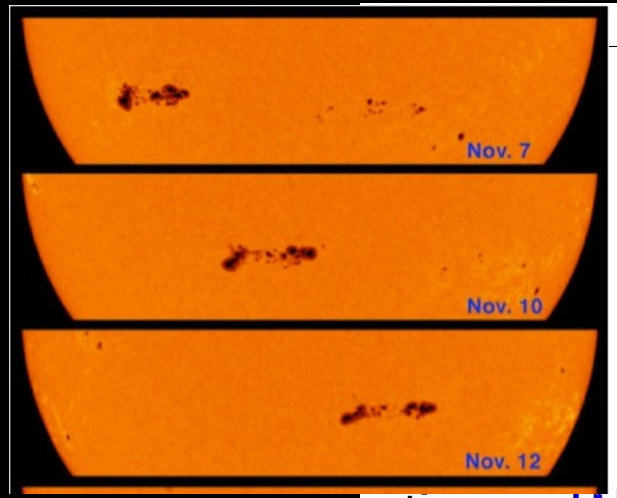
Correcting Systematic Errors

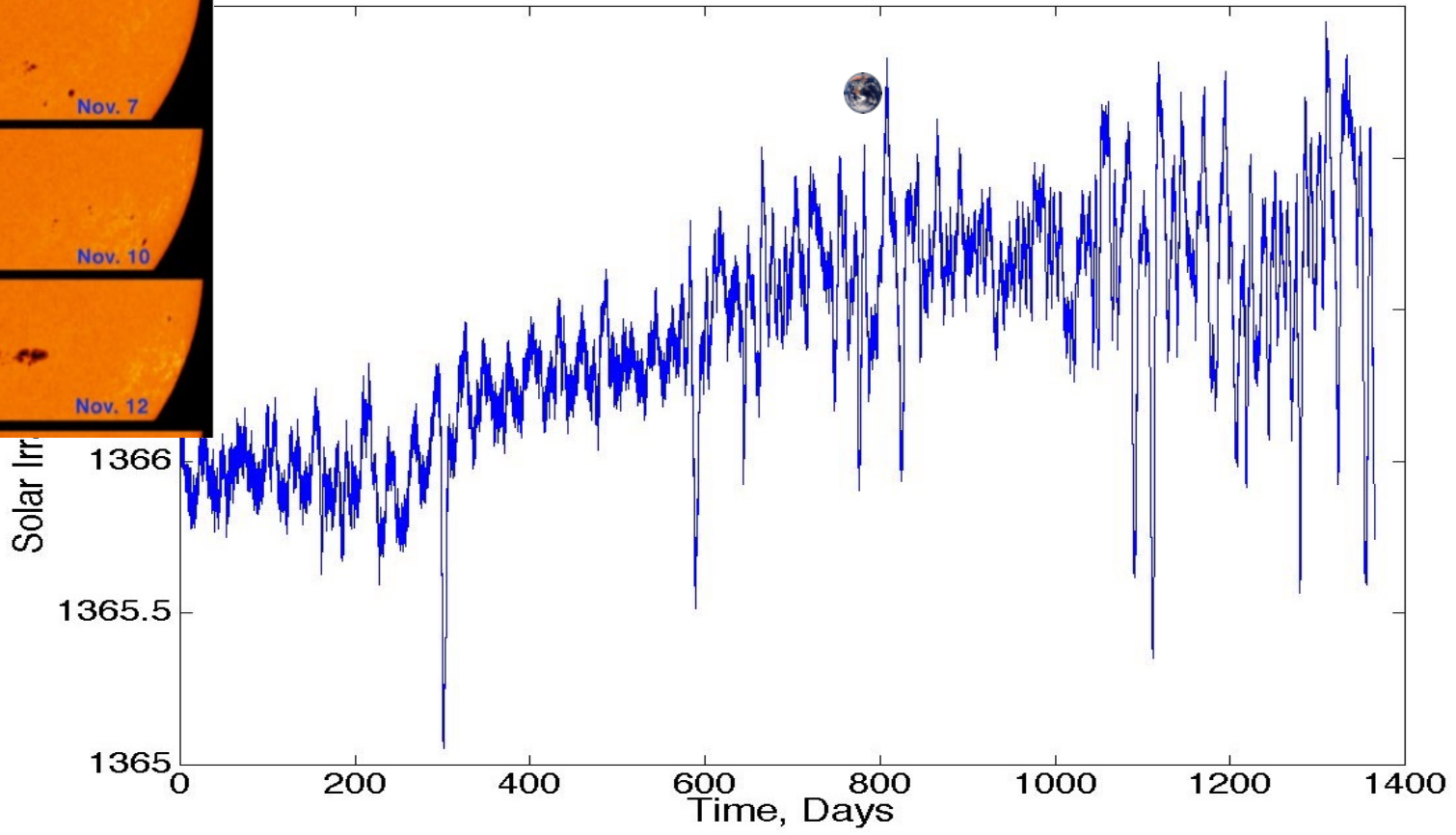




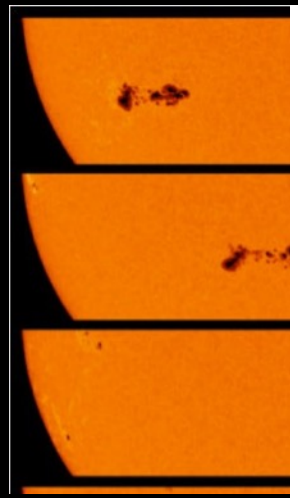
The Search Problem

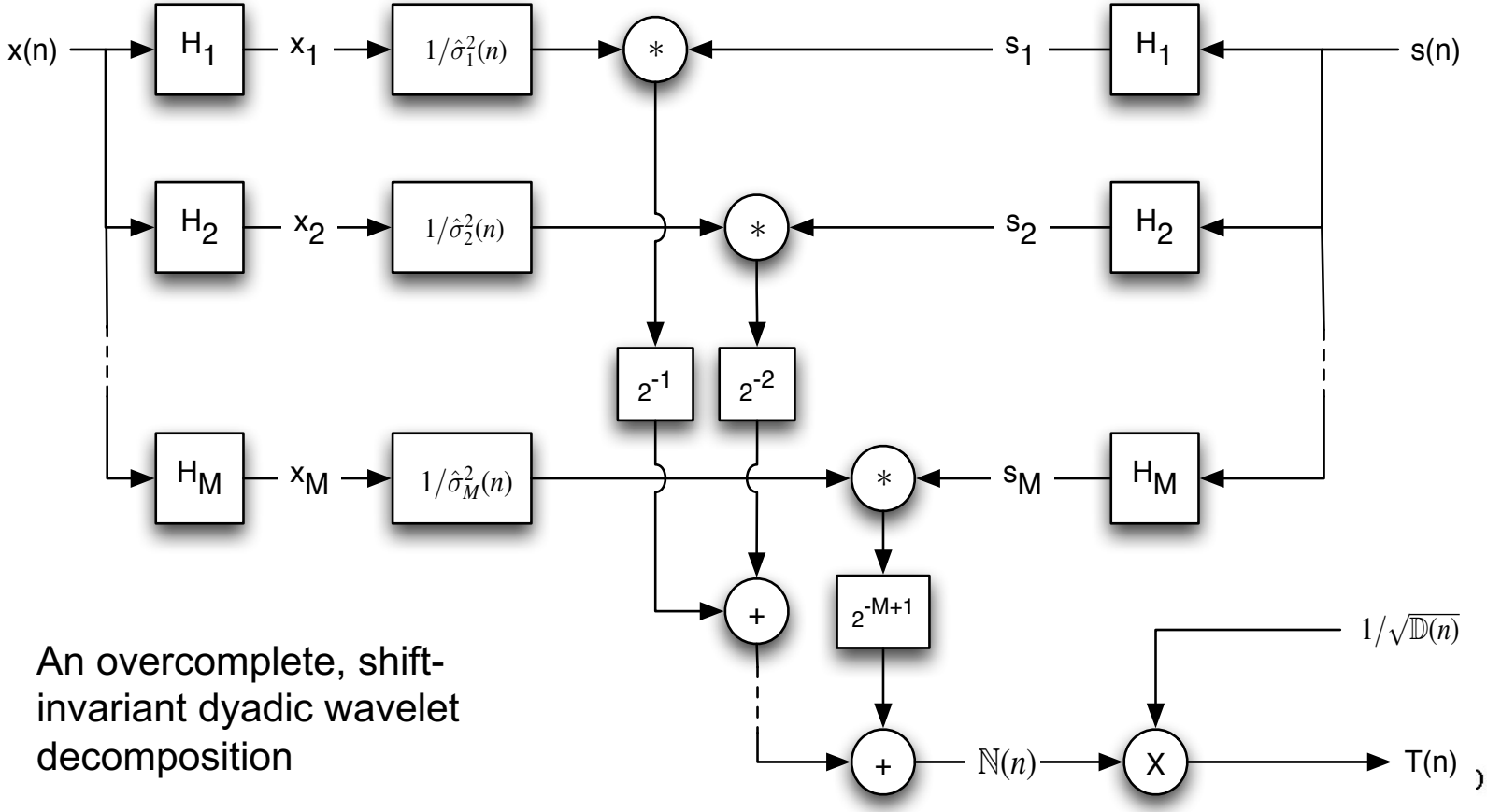
Solar Variability





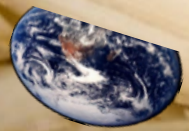
Sophisticated Signal Processing Algorithms



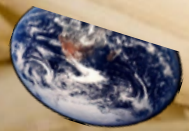


An overcomplete, shift-invariant dyadic wavelet decomposition

The Search Problem



The Search Problem




Keeping Up with the Data

Hardware Architecture:
Kepler Science Operations Center

Kepler
A Search for Earth-size Planets

64 hosts, 712 CPUs,

3.7 TB of RAM,

148 TB of raw disk storage

Hardware Architecture: NAS Pleiades Supercomputer

Kepler
A Search for Earth-size Planets

7.25 Pflop/s peak cluster

246,048 cores

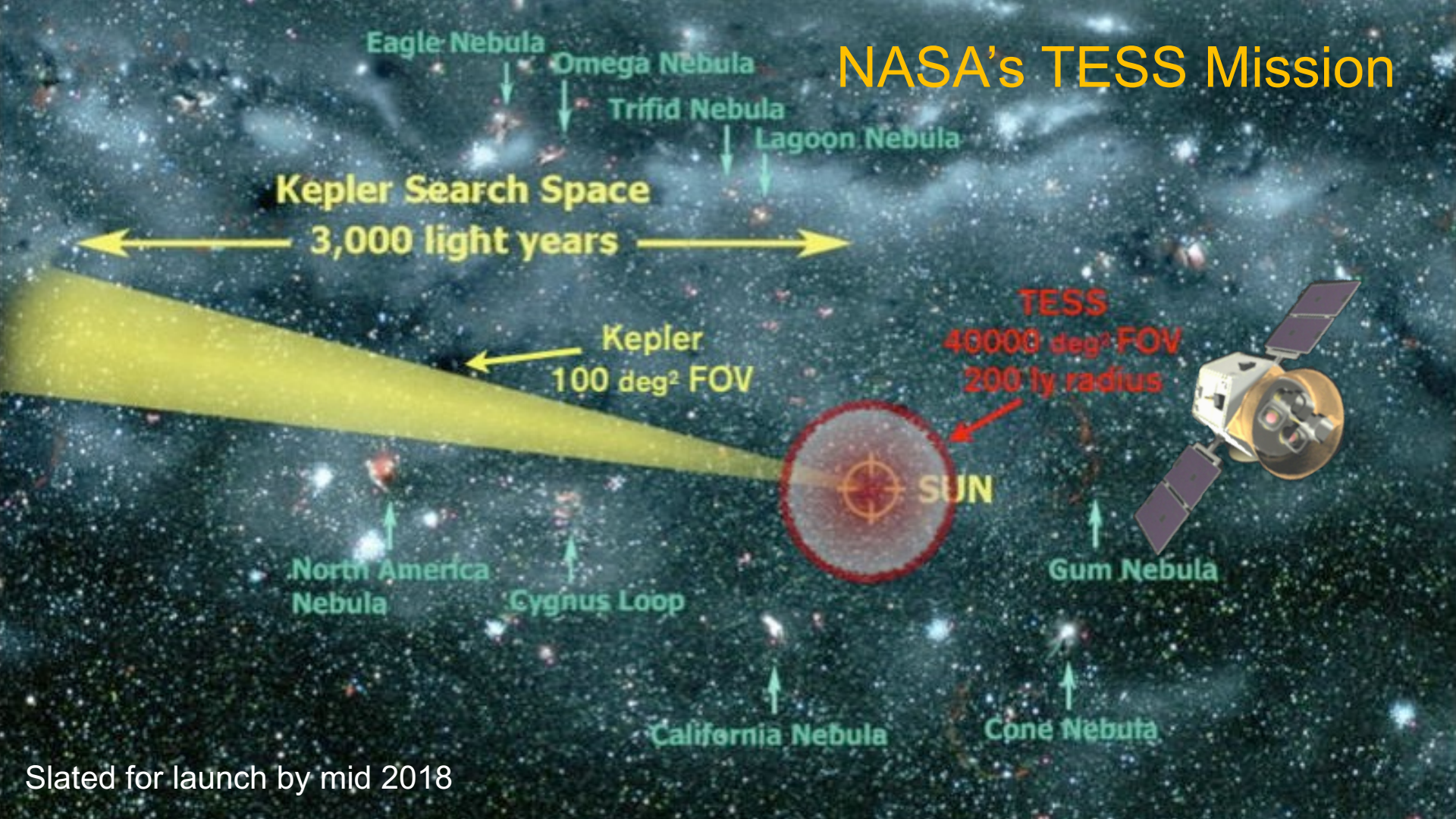
938 TB of memory

15 PB of storage

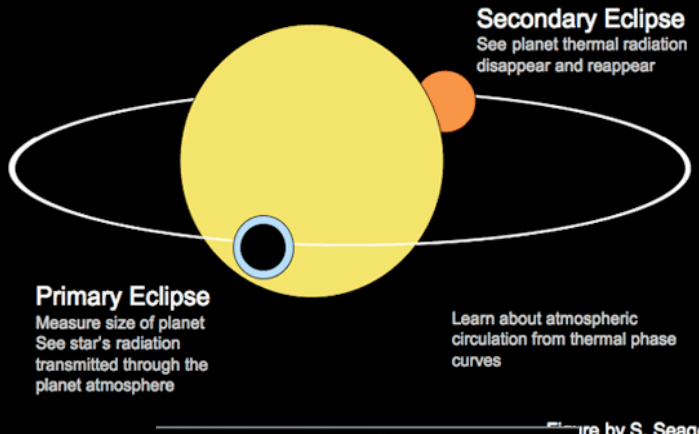
Kepler taught us that planets are ubiquitous:

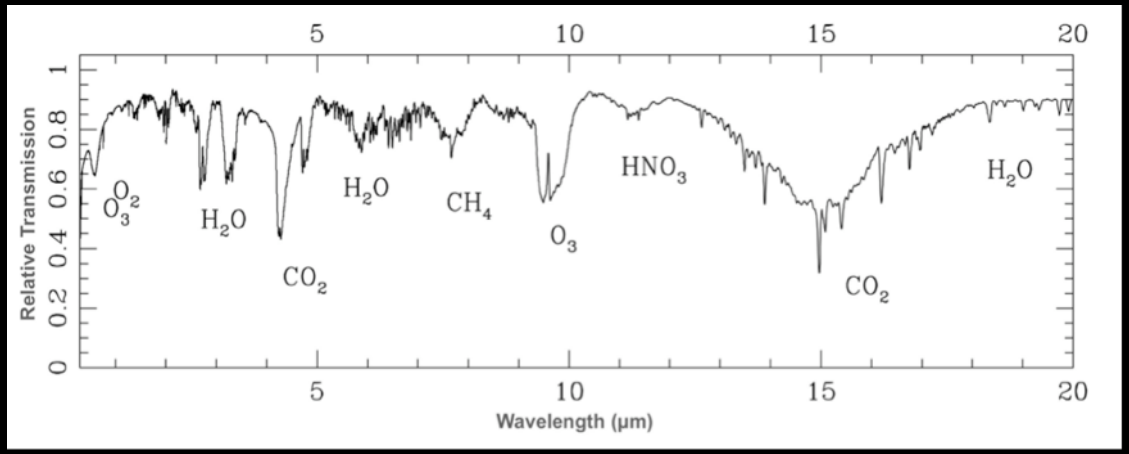
What Next?


The View from Proxima b
NASA/JPL

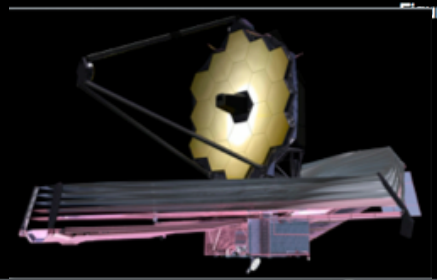

NASA's TESS Mission
Eagle Nebula
Omega Nebula
Trifid Nebula
Lagoon Nebula
Kepler Search Space
3,000 light years
Kepler
100 deg² FOV
TESS
40000 deg² FOV
200 ly radius
SUN
North America Nebula
Cygnus Loop
Gum Nebula
California Nebula
Cone Nebula
Slated for launch by mid 2018

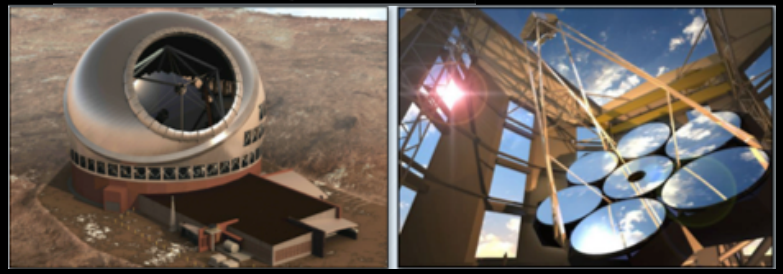
Detecting Biomarkers through Transit Spectroscopy





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





Transiting planets provide opportunities to determine the bulk planetary density and to characterize their atmospheres

Exoplanet Missions

NASA

JWST

WFIRST-AFTA

TESS

Kepler

New Worlds Telescope

Spitzer

Hubble

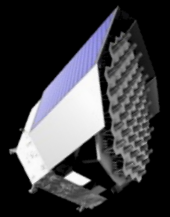
Ground-based Observatories

2001 Decadal Survey

2010 Decadal Survey

+ ESA's CHEOPS (2018)

ESA - C. Carreau



+ ESA's PLATO Mission (2026)