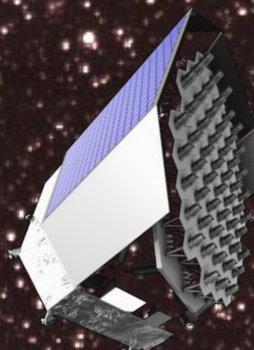
Synergies between the Kepler, K2 and TESS Missions with the PLATO Mission



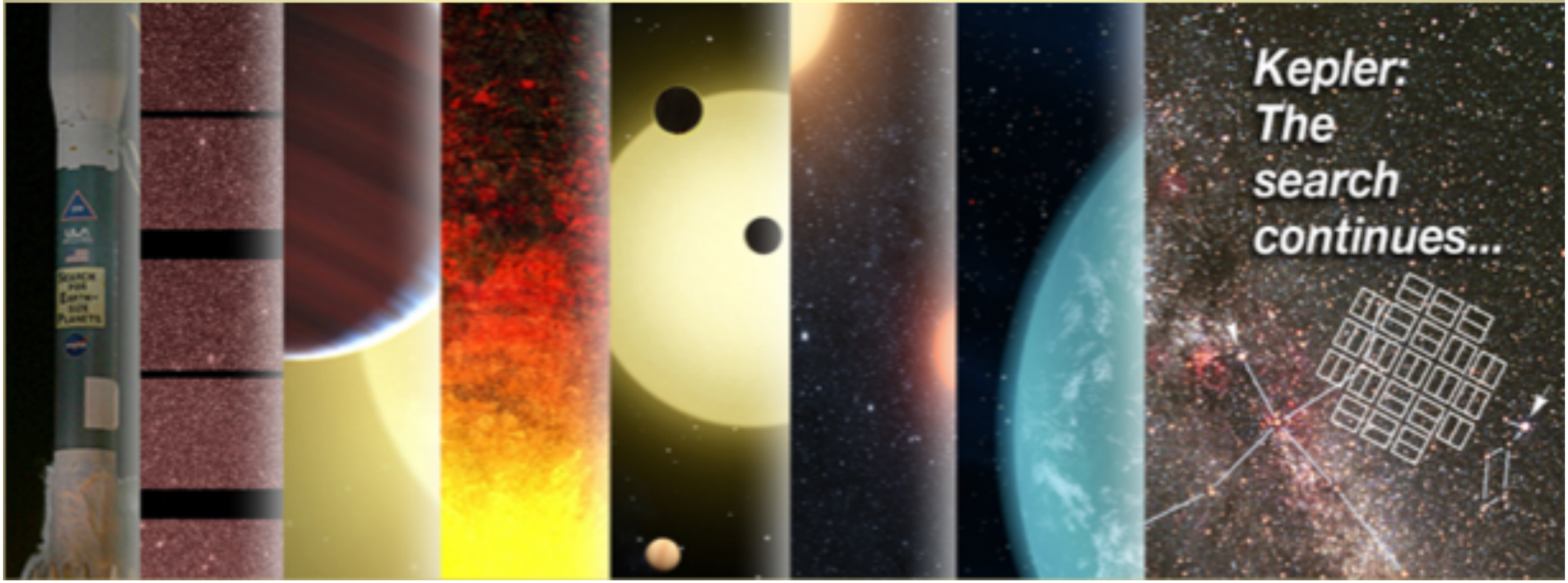
Jon M. Jenkins
NASA Ames Research Center

Tuesday September 5, 2017

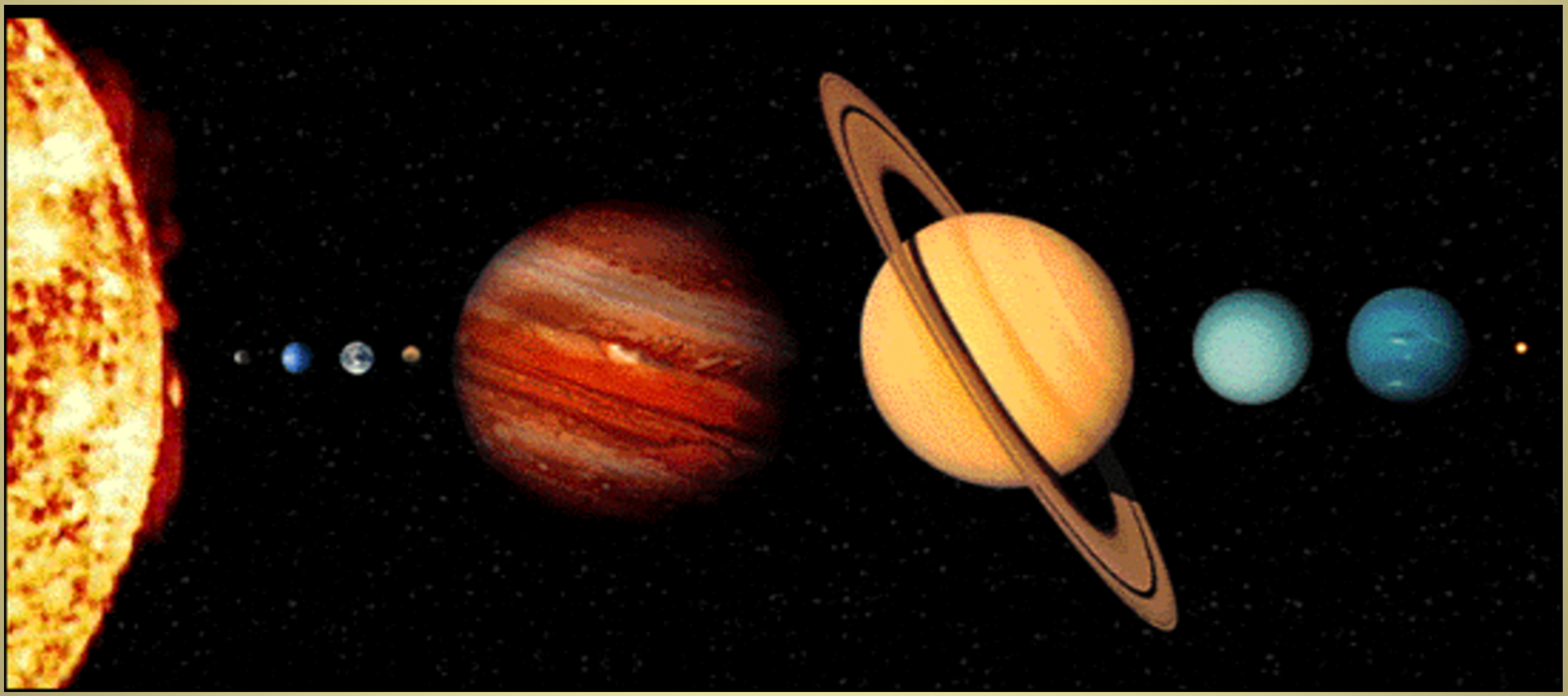
PLATO Mission Conference 2017
University of Warwick
Coventry UK

Overview

- Exoplanet Explosion
- Where PLATO fits in
- Challenges
- Asteroseismology
- Serendipitous Discoveries
- Summary



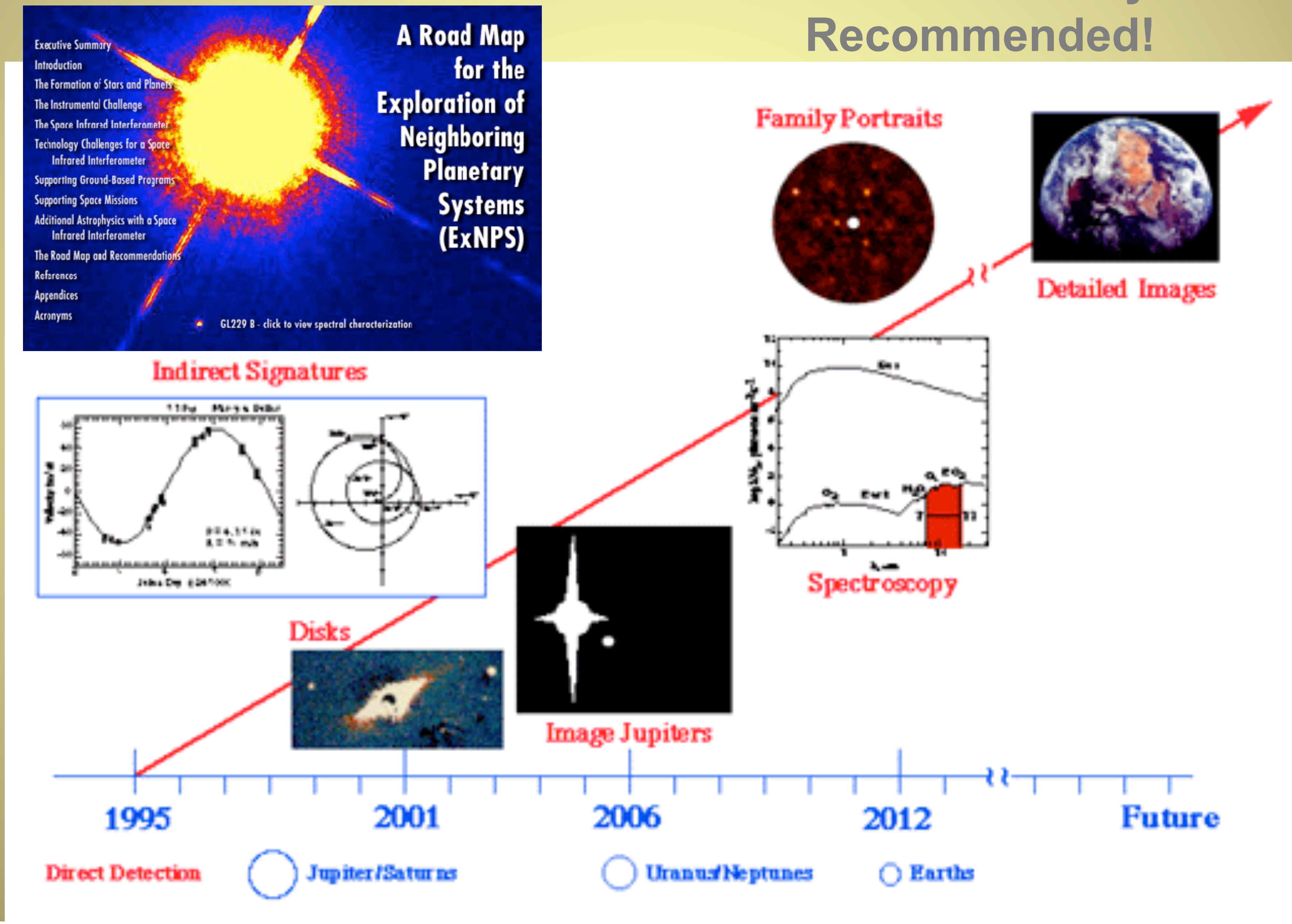
All the Known Planets In 1994



NASA's 1995 ExNPS Report

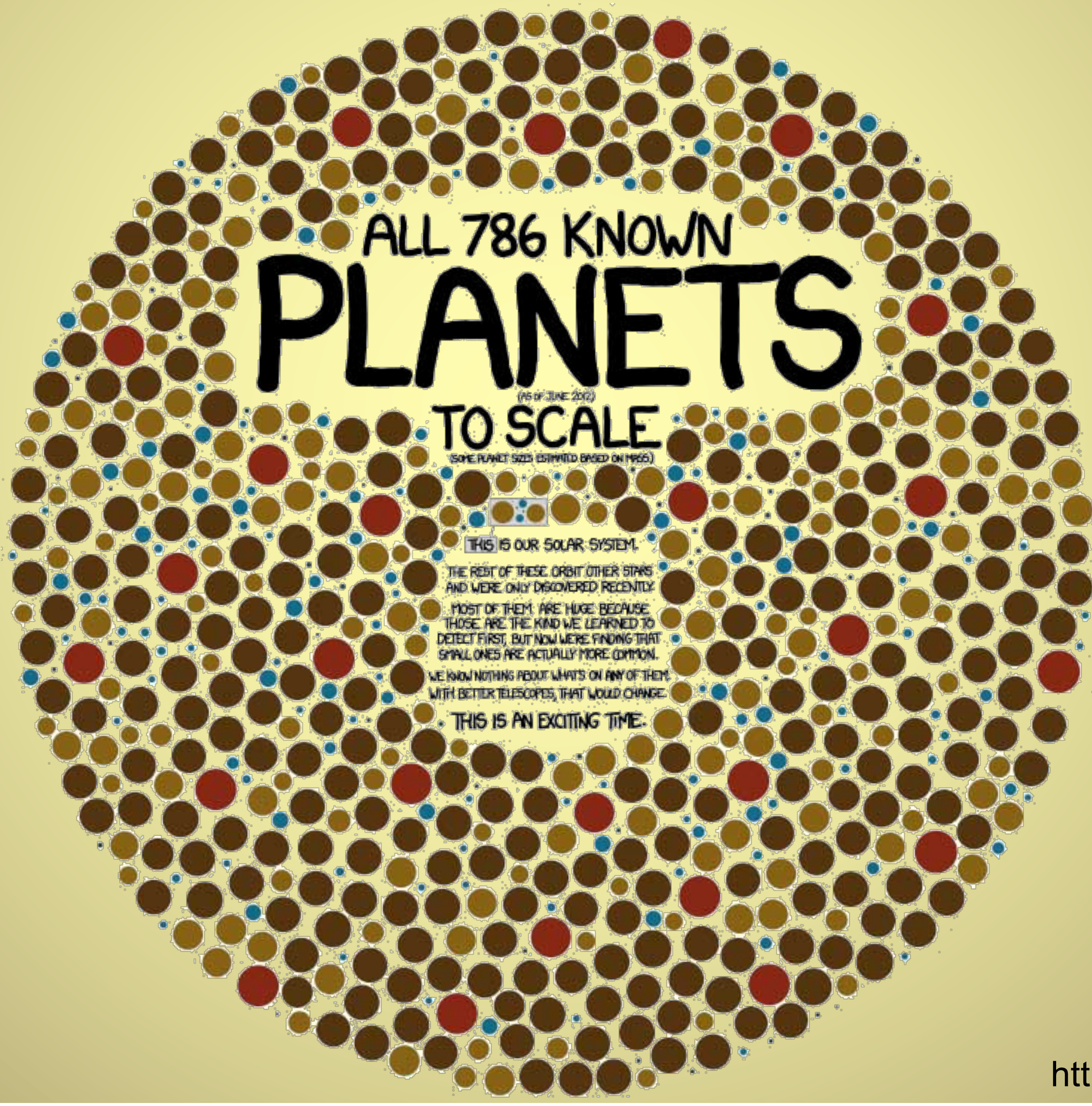
A Search for Earth-size Planets

Transit Photometry not Recommended!



A More Recent Pictures of Planets

Kepler
A Search for Earth-size Planets

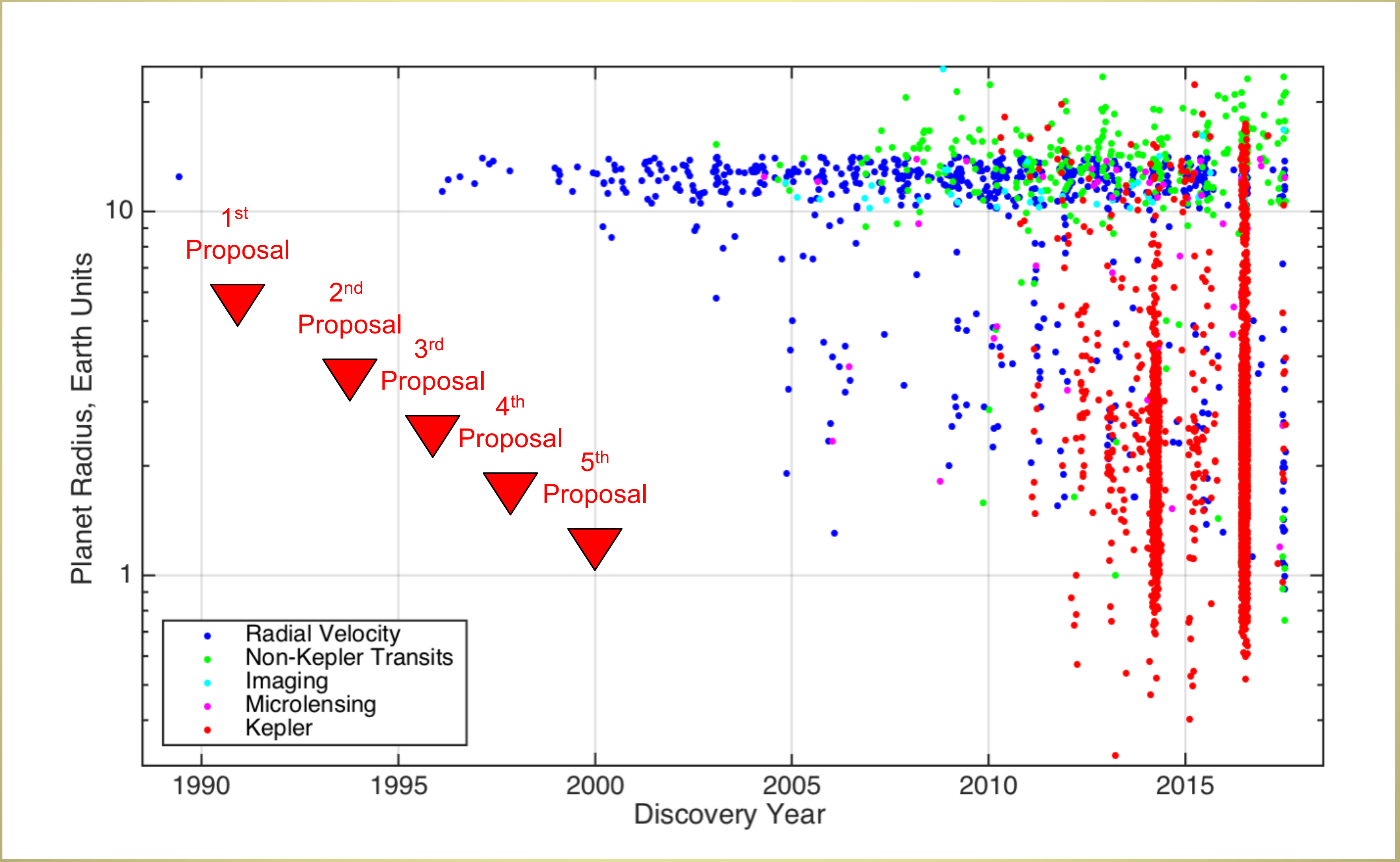


https://xkcd.com/1071/


ALL 786 KNOWN
PLANET
(AS OF JUNE 2012)
TO SCALE
(SOME PLANET SIZES ESTIMATED BASED ON MASS)
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.
Kepler
A Search for Earth-size

Exoplanet Discoveries Over Time*

Kepler
A Search for Earth-size Planets

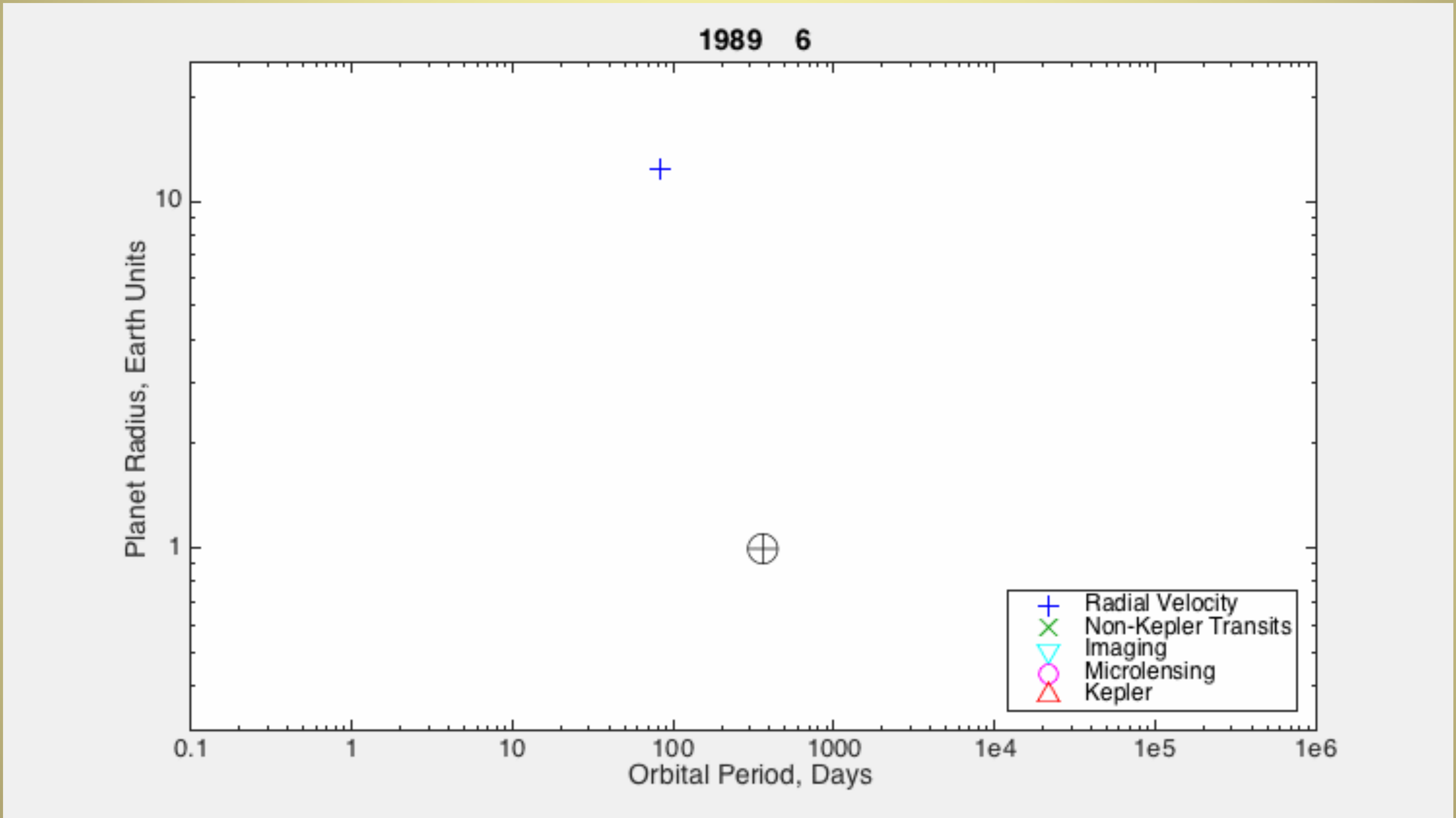


*According to https://exoplanetarchive.ipac.caltech.edu as of 8/29/17

Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

Exoplanet Discoveries

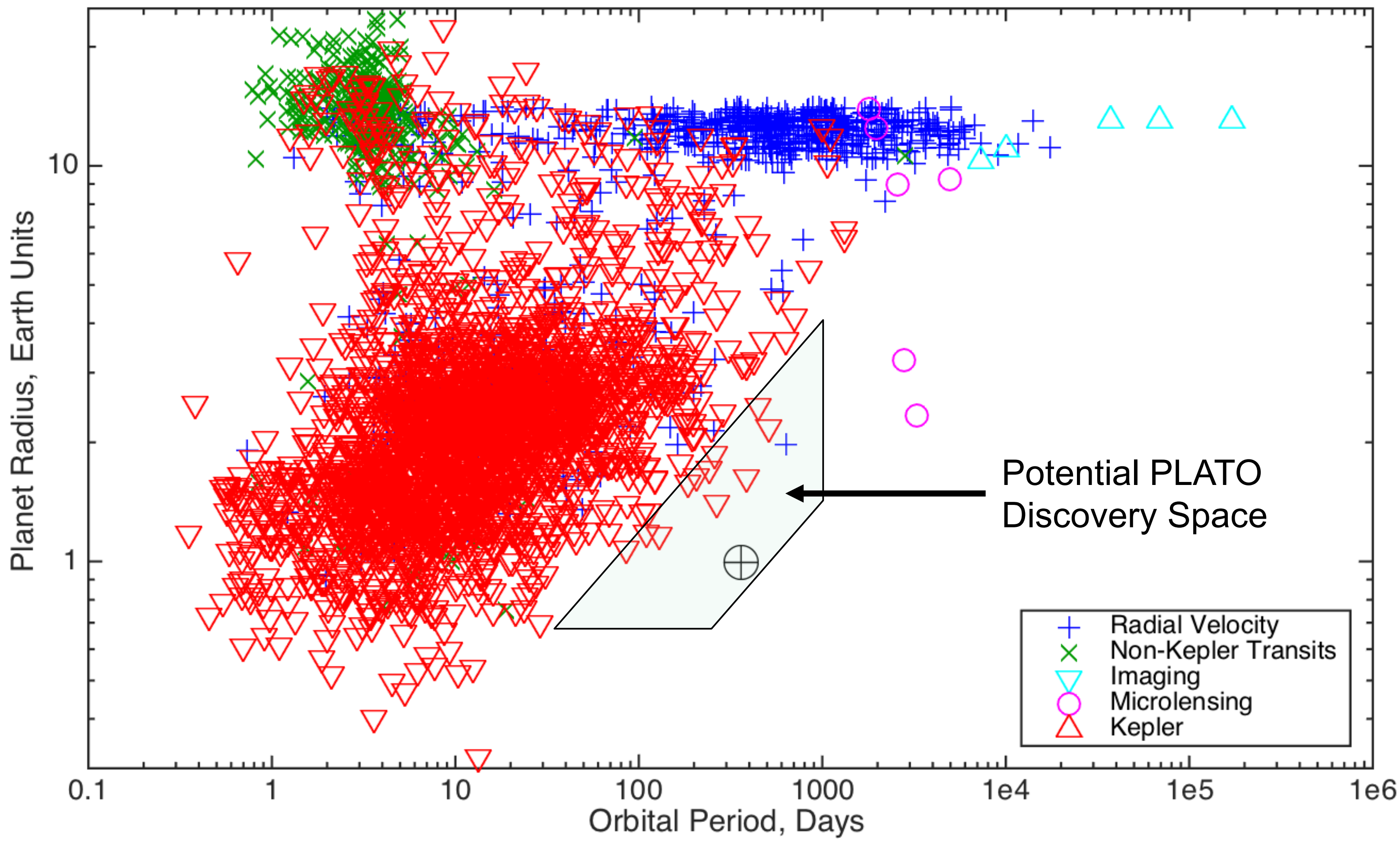
A Search for Earth-size Planets



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

Where Does PLATO Fit In Parametrically?

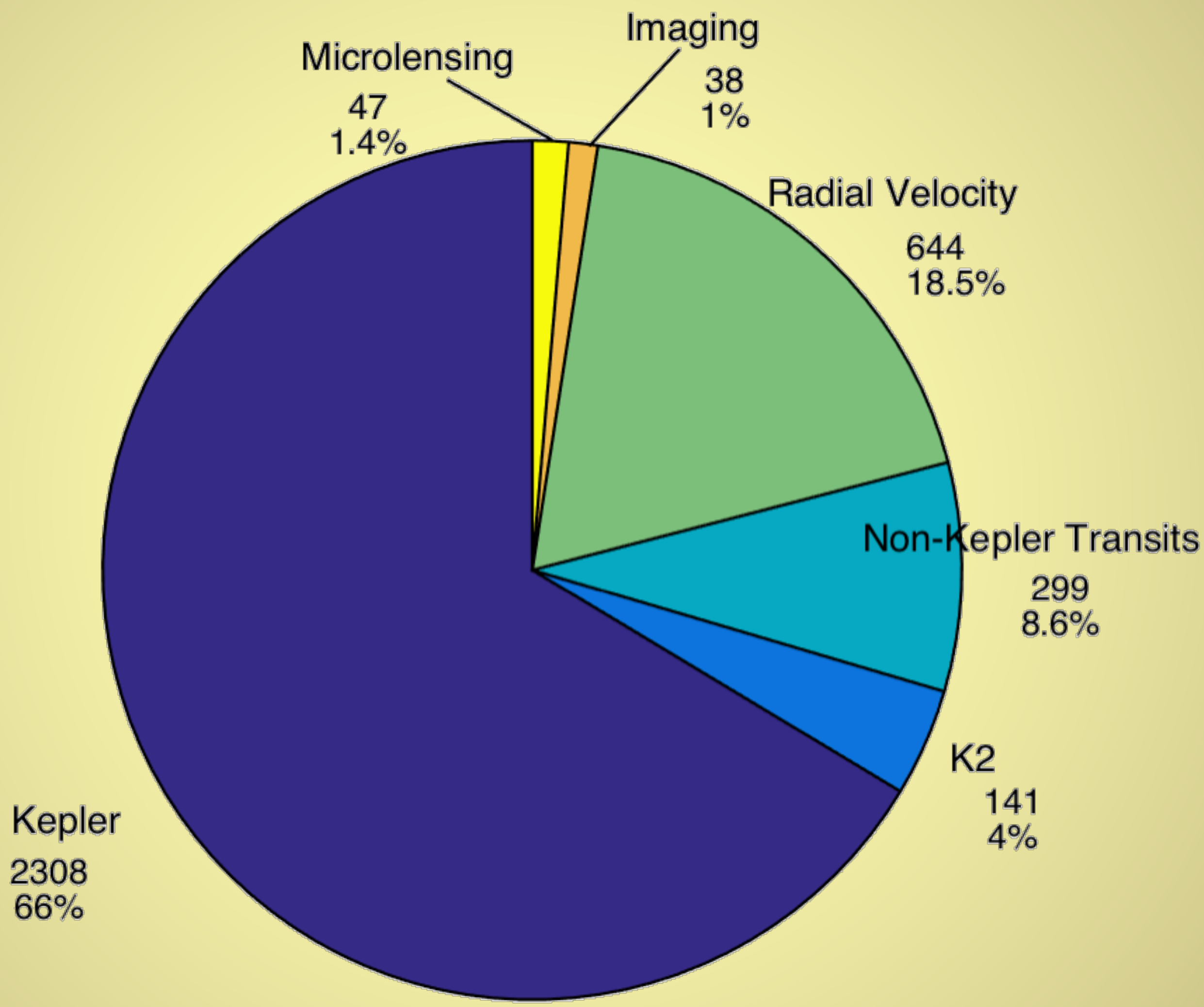
Kepler
A Search for Earth-size Planets



Challenge: Baseline duration of long stare campaigns is relatively short

Exoplanet Discoveries* by Method

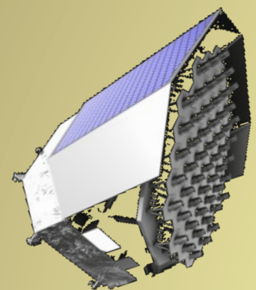
A Search for Earth-size Planets

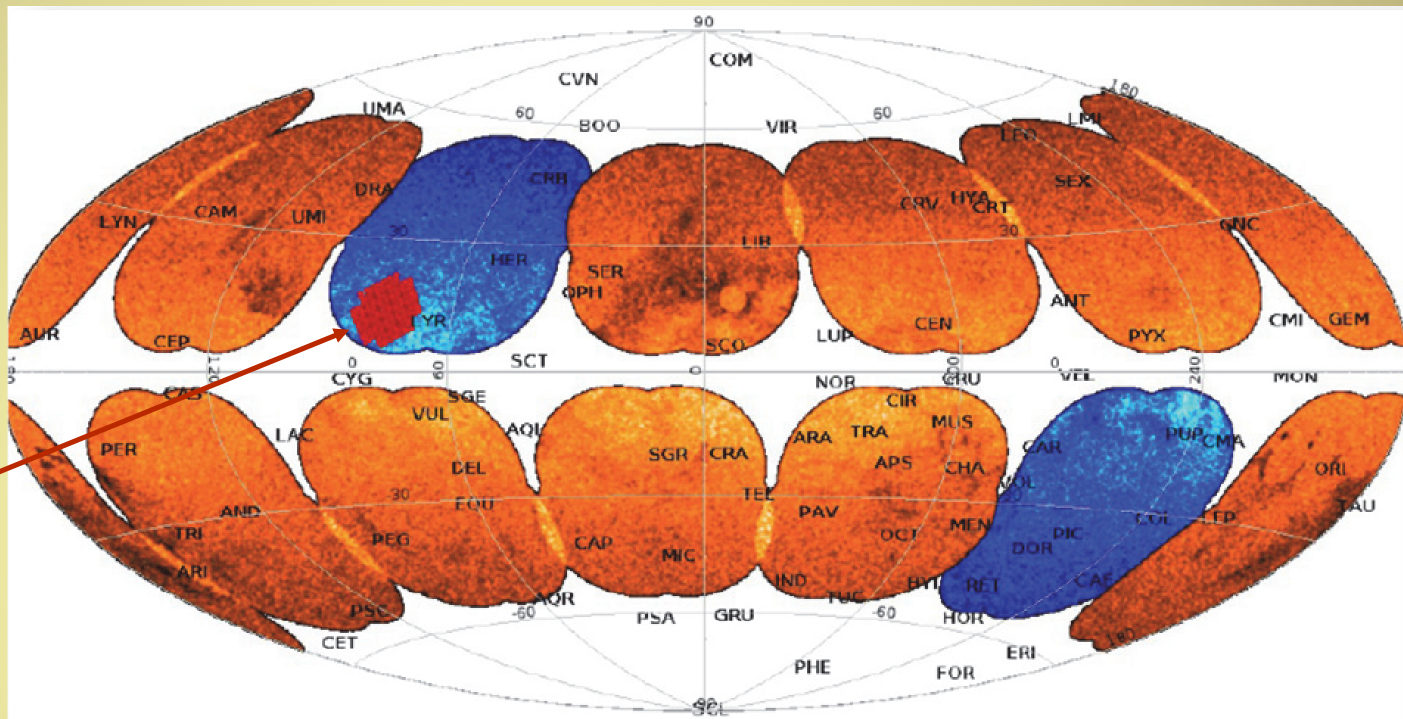


*According to https://exoplanetarchive.ipac.caltech.edu as of 8/29/17

Overlapping Fields of View

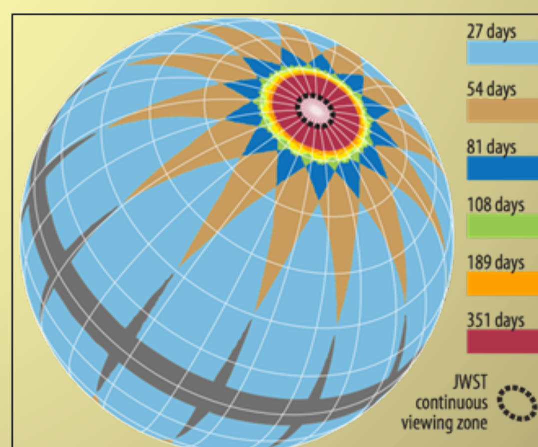
A Search for Earth-size Planets





Fields that overlap with Kepler/K2 and TESS offer opportunities to greatly extend knowledge for multiple transiting planet systems:

- Recover ephemerides
- Discover rocky, longer-period planets



Multiple Transiting Planet Systems*

A Search for Earth-size Planets

Kepler: 2308 Planets

- 1639 Host Stars; 444 Multis
- 111 systems; 220 planets with TTVs
- (195 TTVs with $T_p < 50$ days)

K2: 141 Planets

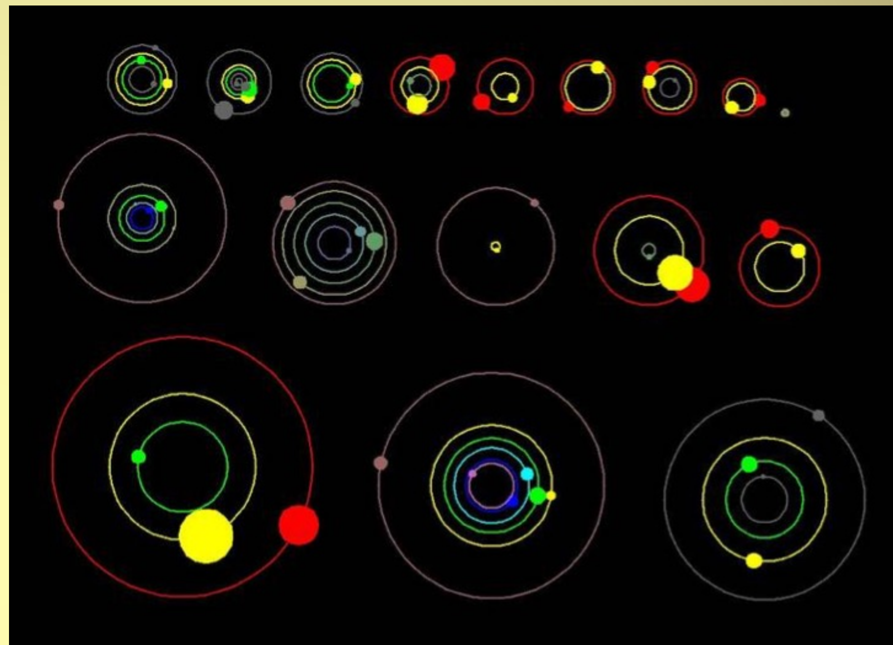
- 104 Host Stars; 25 Multis
- 1 system; 4 planets with TTVs

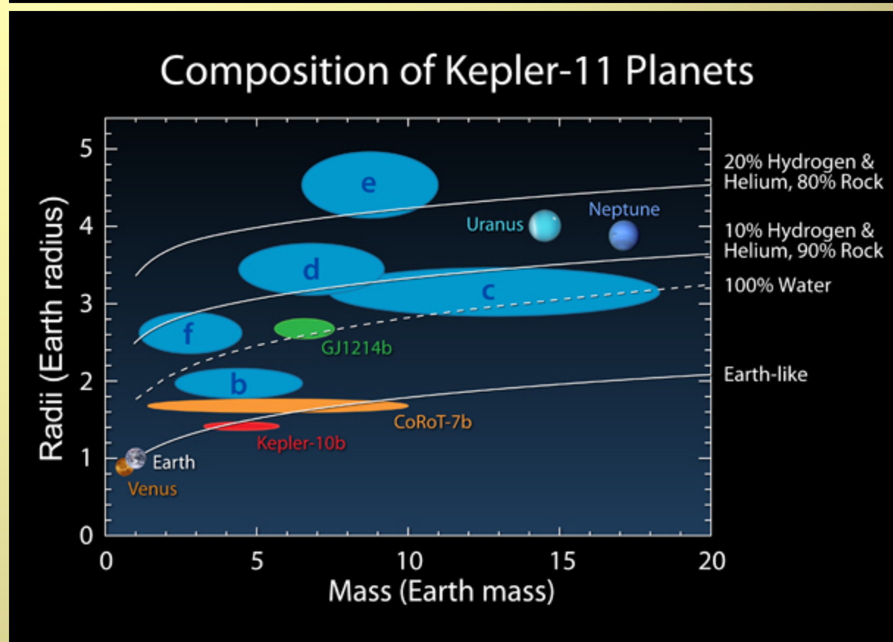
Non-Kepler/K2: 1060 Planets

- 871 Host Stars; 116 Multis
- 4 systems; 9 planets with TTVs

TTVs can deliver mass estimates

*Requires long stare campaign, but very rewarding!






TESS Elation!

TESS is a Treasure Trove for PLATO

A Search for Earth-size Planets

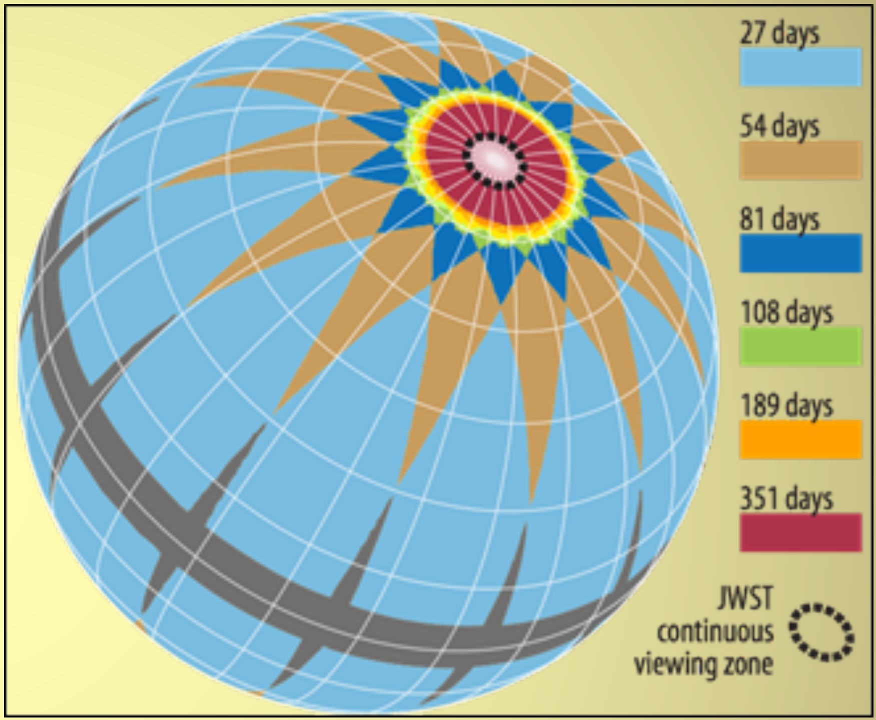
TESS launches in March 2018

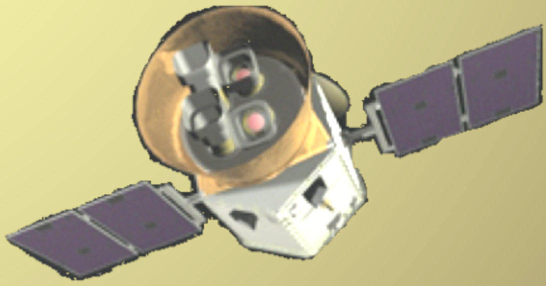
TESS will obtain 24° x 96° FFIs every half hour over each ~28 day sector

PLATO can construct light curves for almost every source it plans to observe over at least 28 days

(Likely will be able to download light curves from MAST created by somebody else)

Follow up activities for TESS are a good training exercise for PLATO follow up observers





Additional Challenges

A Search for Earth-size Planets

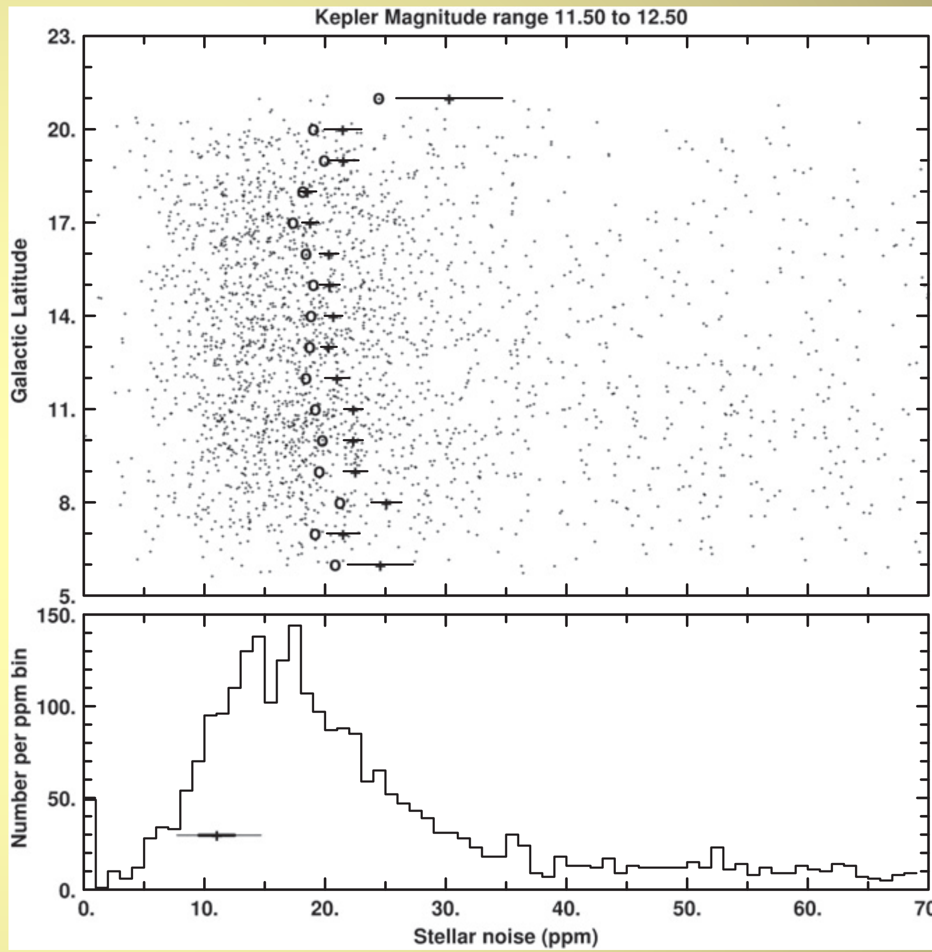
Stellar Variability is non-negligible

Residual Systematic Errors can drive up CDPP (NSR)

Detection Threshold of 7σ for *Kepler* was (overly) optimistic:

- Sufficient for detection
- Insufficient for vetting in many instances
- SNR>10σ typically yielded robust vetting results

Characterization and vetting require higher SNR than detection

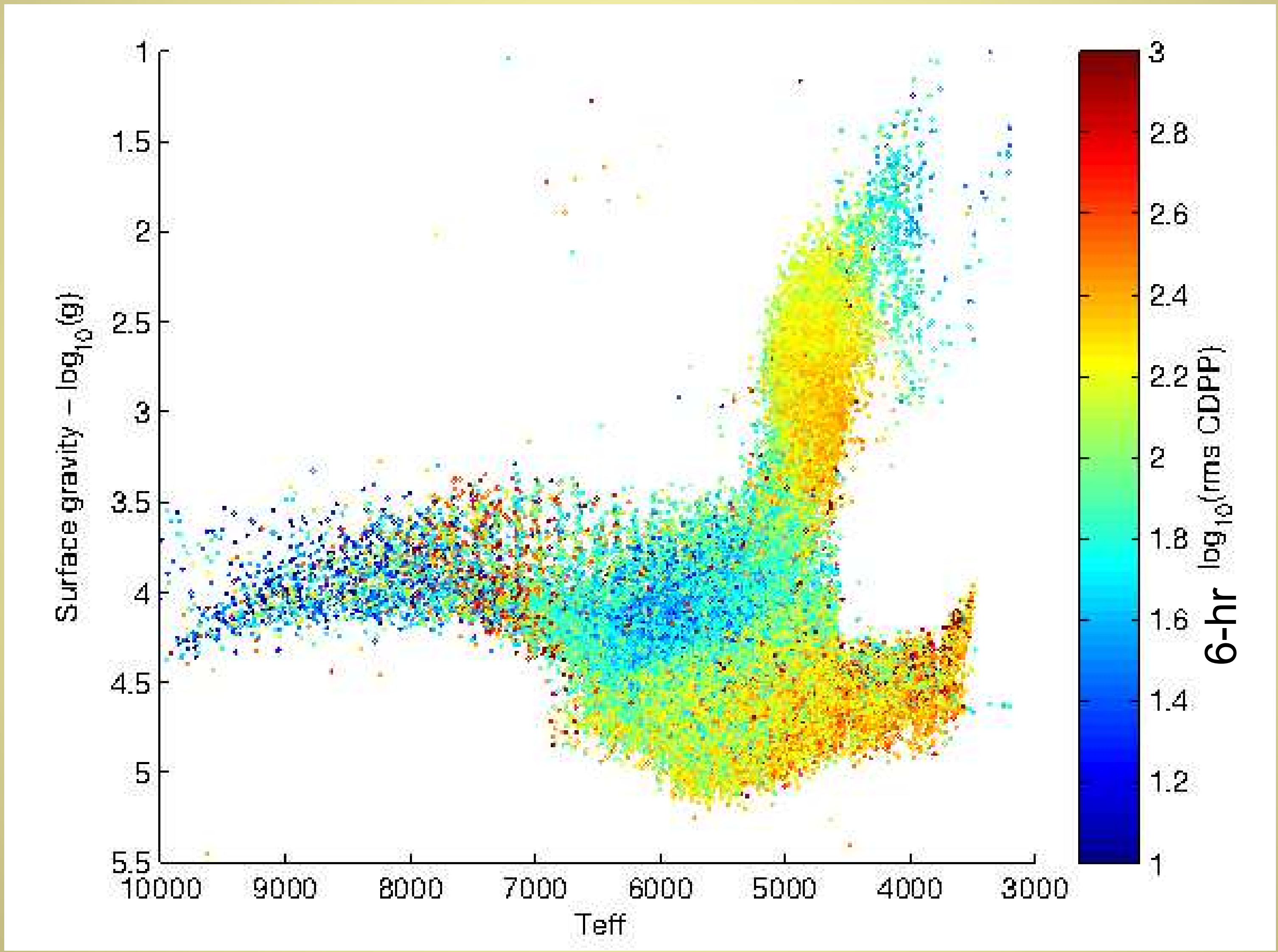


Gilliland et al. 2015 showed that stellar noise on 6.5-hr timescales contributes ~20 ppm

Other important stochastic noise sources: Sudden pixel sensitivity dropouts, thermal transients, etc.

Stellar Variability Across Spectral Type

Kepler
A Search for Earth-size Planets



Christiansen et al. 2012 PASP 124, 1279

η_{earth}: Mapping Completeness and Reliability

Kepler
A Search for Earth-size Planets

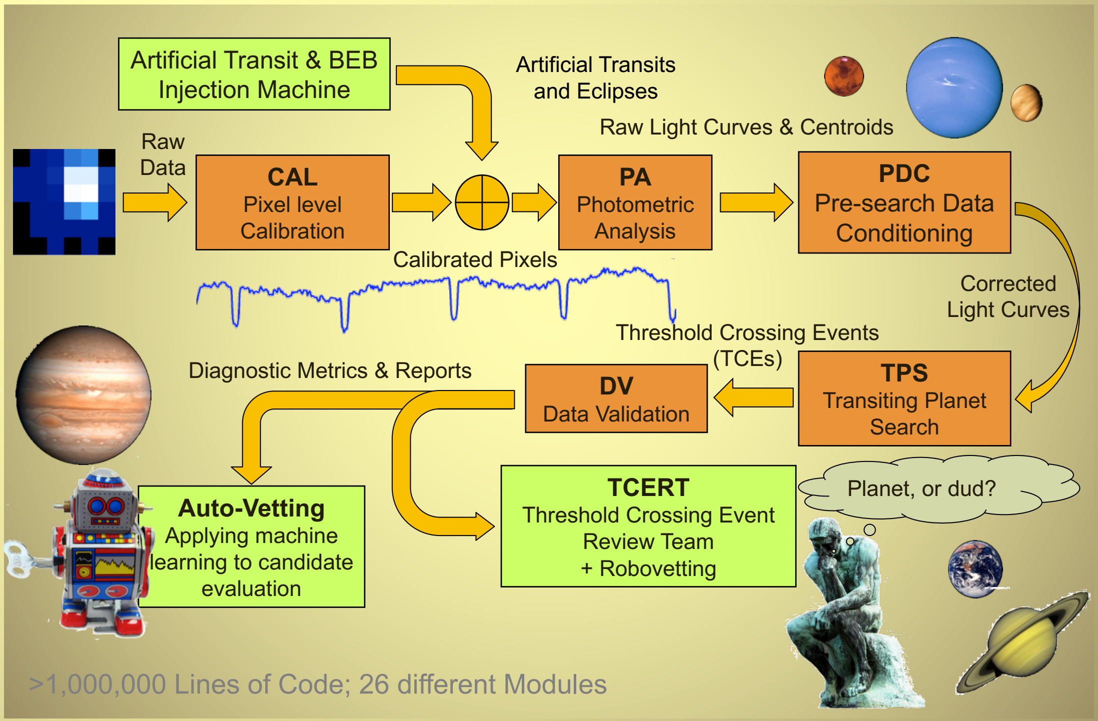
Characterizing completeness and reliability of software/people pipelines is extremely resource intensive

Kepler shipped the final light curve products in April 2015

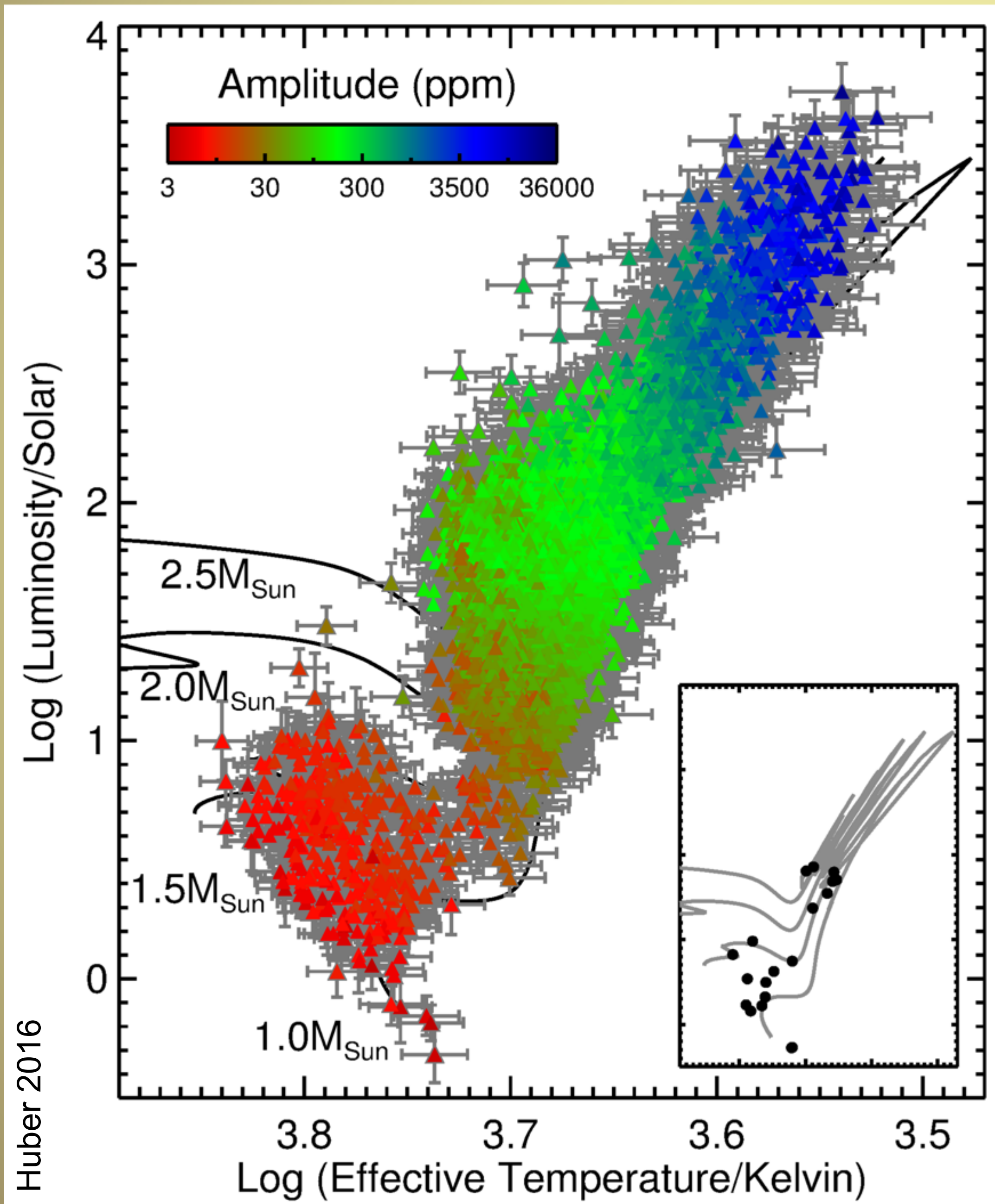
We've spent the remainder of the time until present adding artificial transits, BEBs, scrambling the data temporally, inverting the light curves etc., etc.

Mapping completeness and reliability and characterizing the candidate vetting process is difficult

Recommendation: Pursue machine learning for conducting or modeling the candidate vetting process



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 –

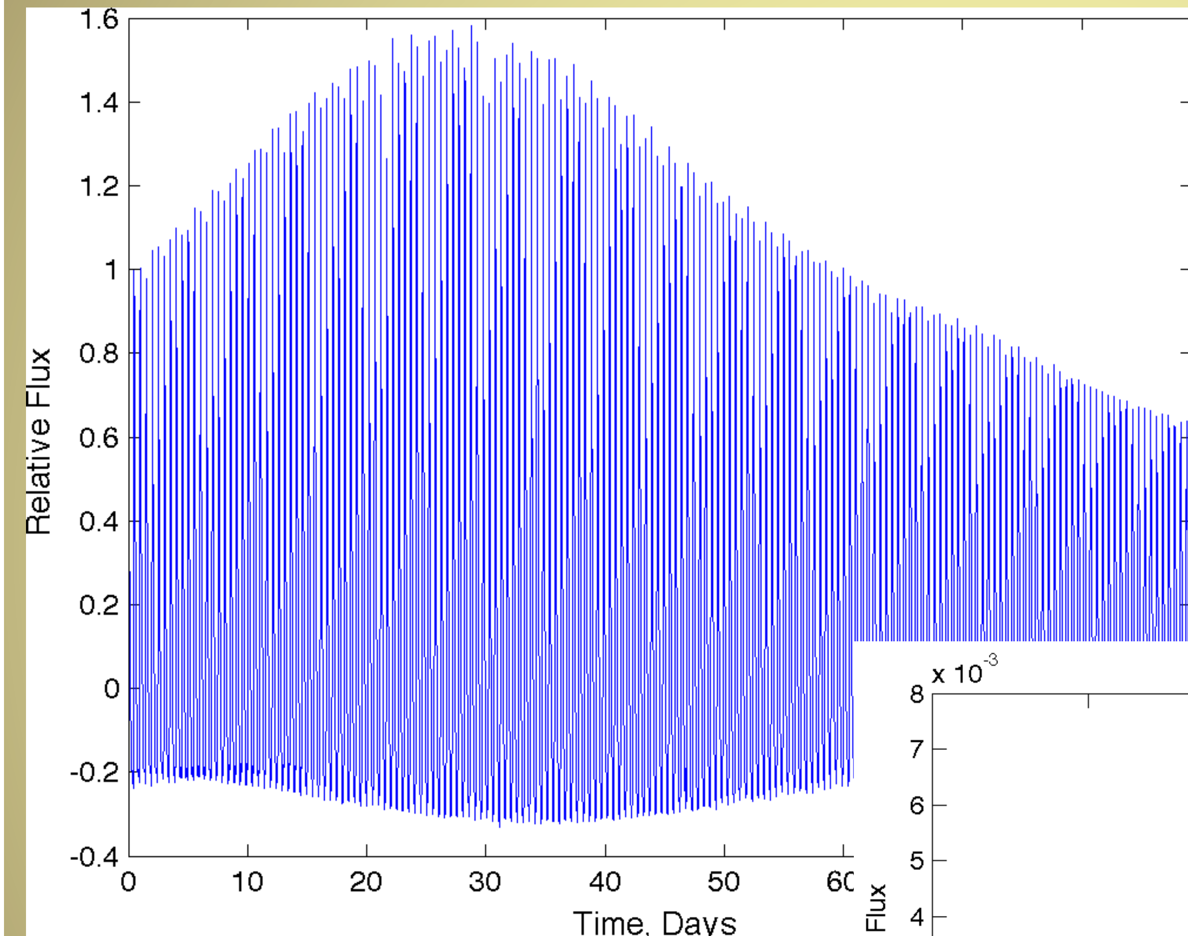
- Stellar ages and radii
- Internal differential rotation
- Convection zone depths ages
- Rotation axis orientation
- Heliophysics-like results

…for many thousands of stars

Asteroseismology with PLATO should prove to be as revolutionary as it was for *Kepler*

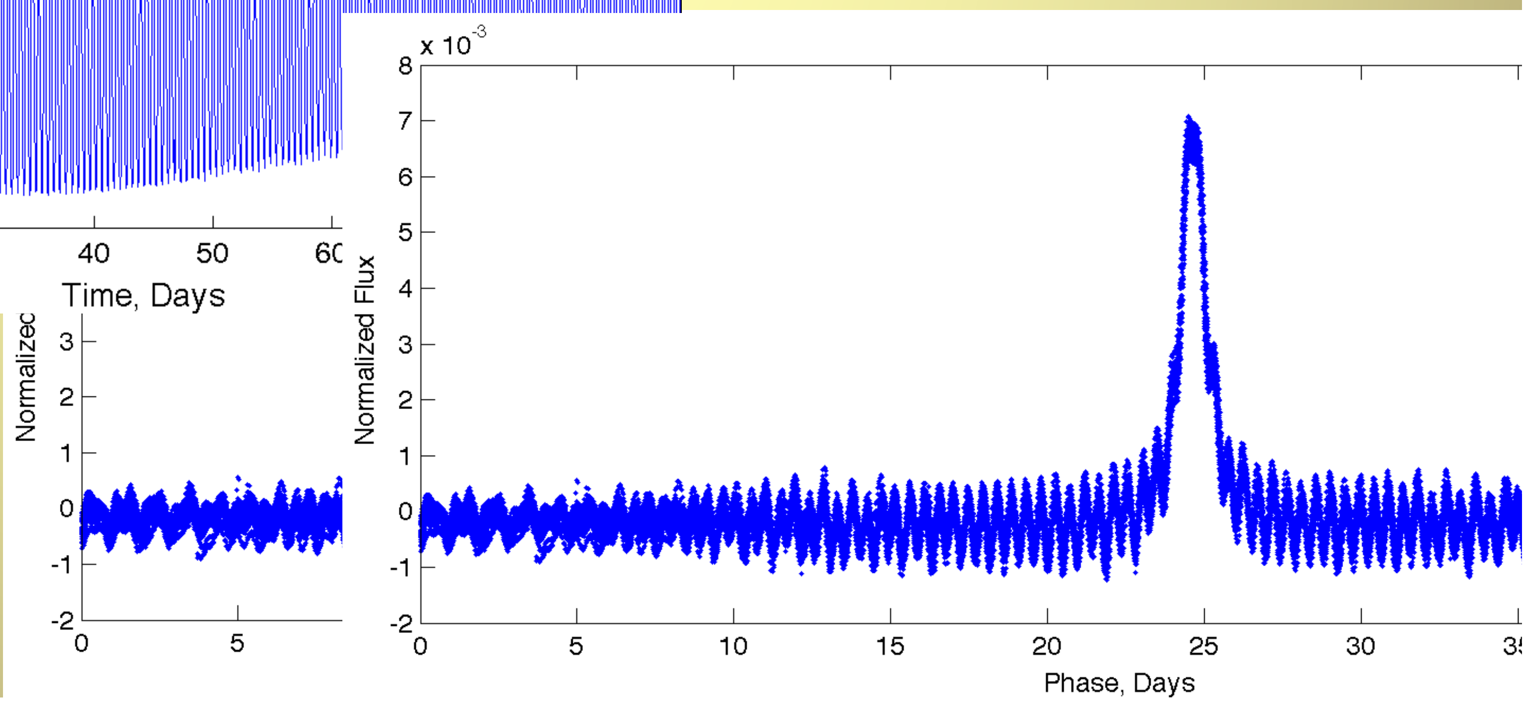
Pulsating Stars

A Search for Earth-size Planets



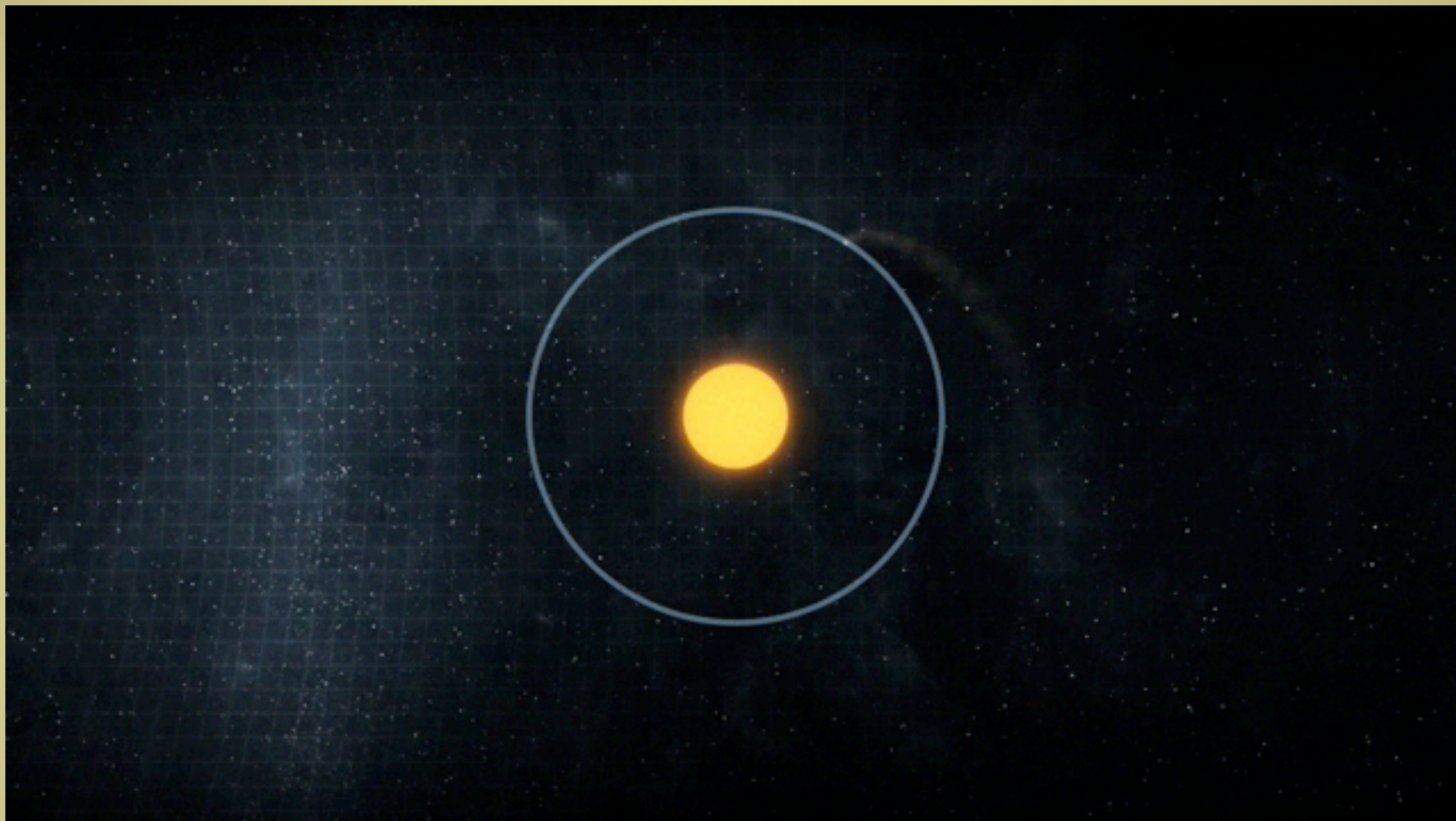
An RR Lyrae star

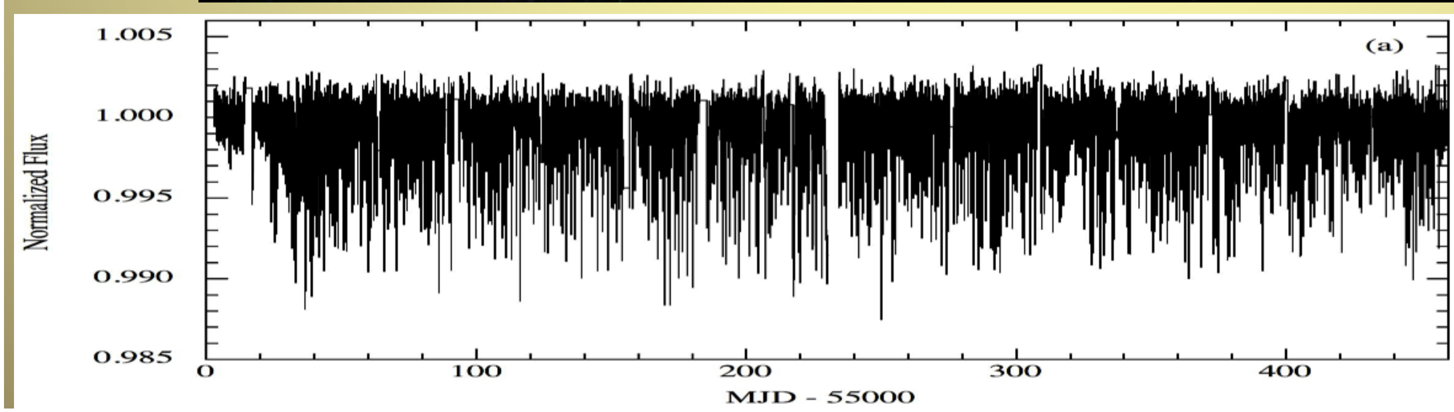
KOI-54:
A Heartbeat Star

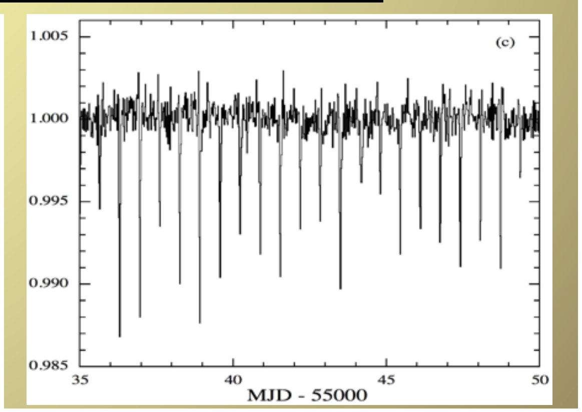


A Disintegrating Planet: KIC 12557548

A Search for Earth-size Planets



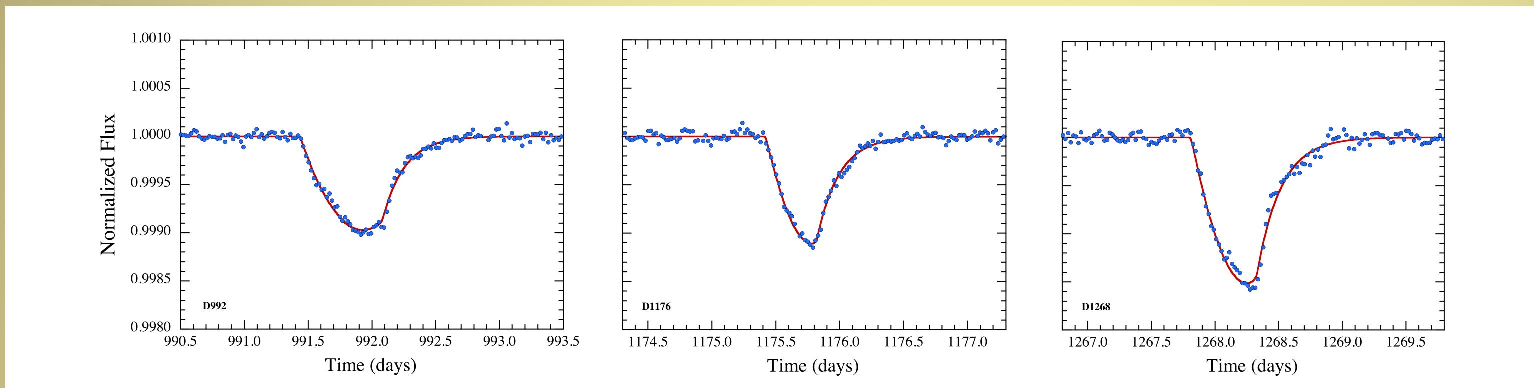


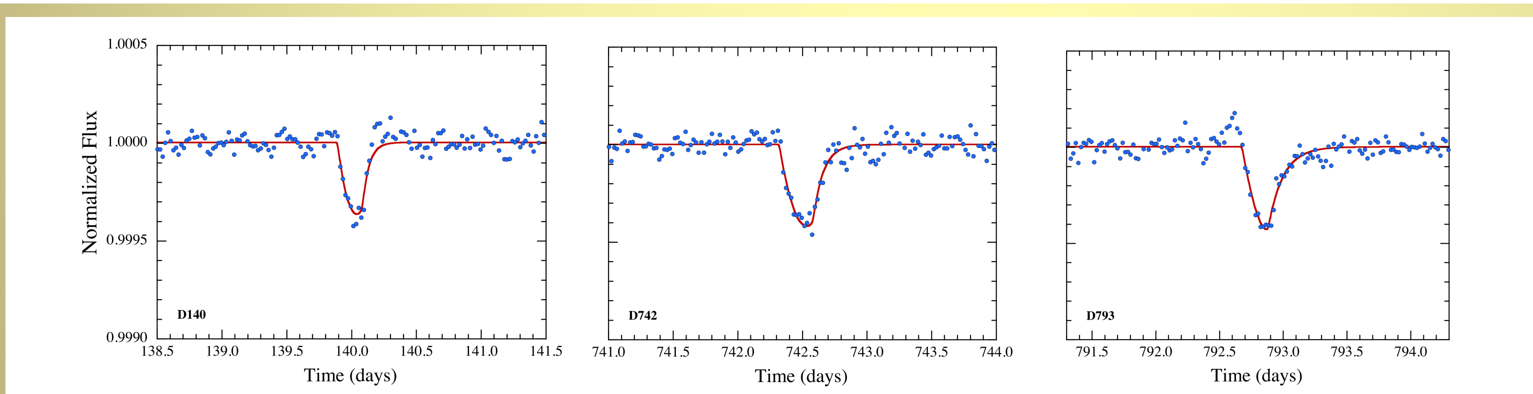


KIC 3542116: An Exocomet Candidate

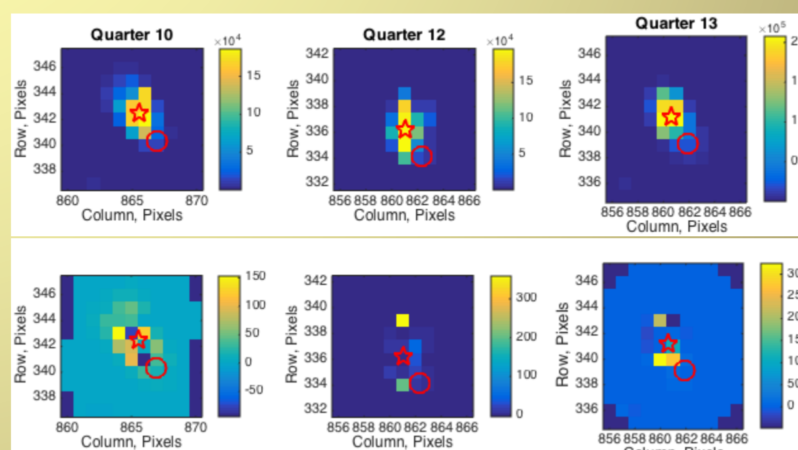
Kepler

A Search for Earth-size Planets



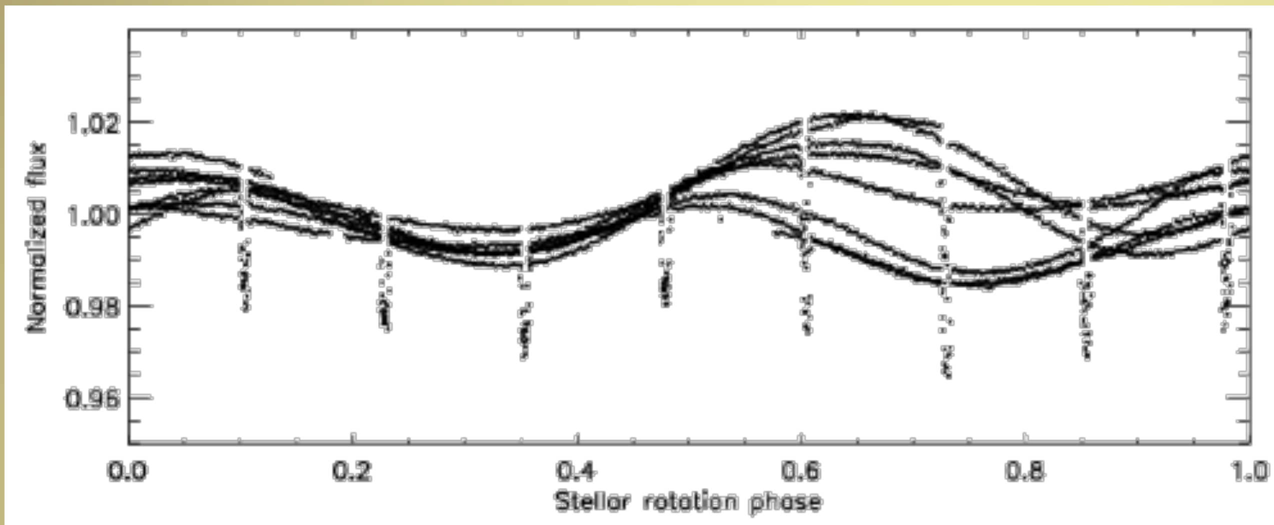


Rappaport et al. 2017, arxiv1708.06069

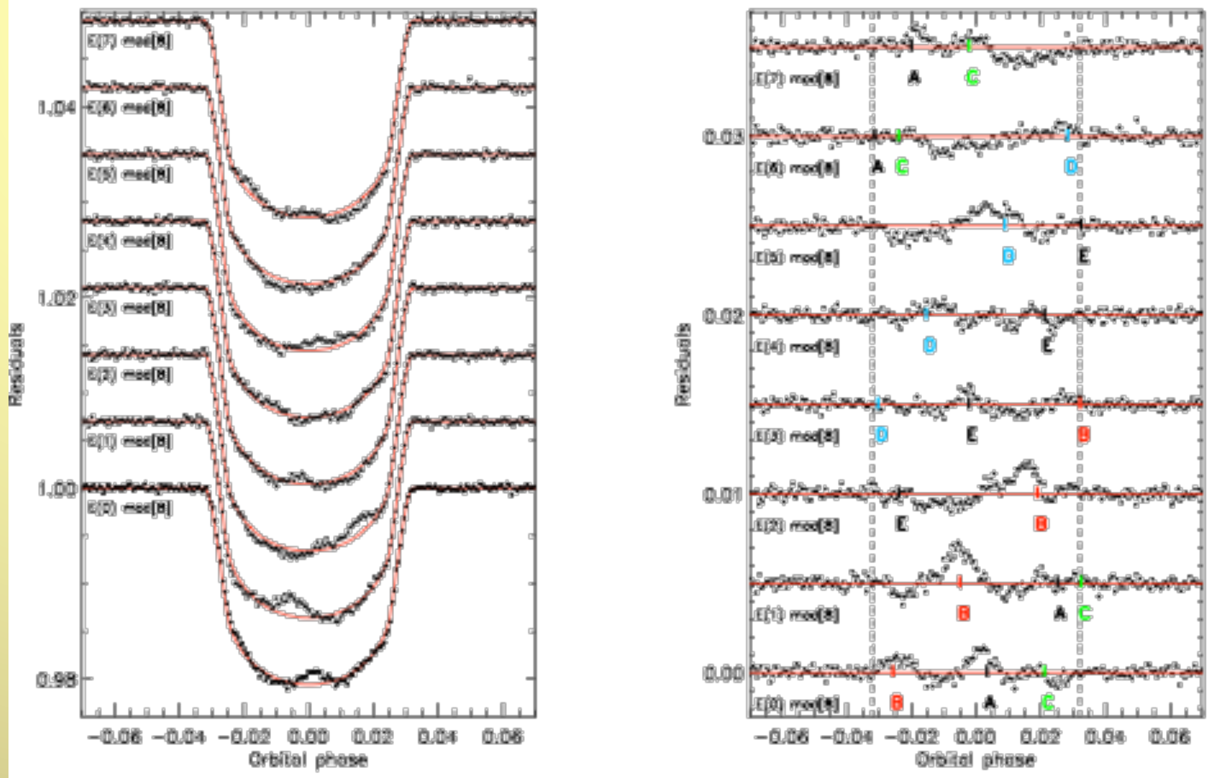


Kepler-17b: Stroboscopic Spots

Kepler
A Search for Earth-size Planets

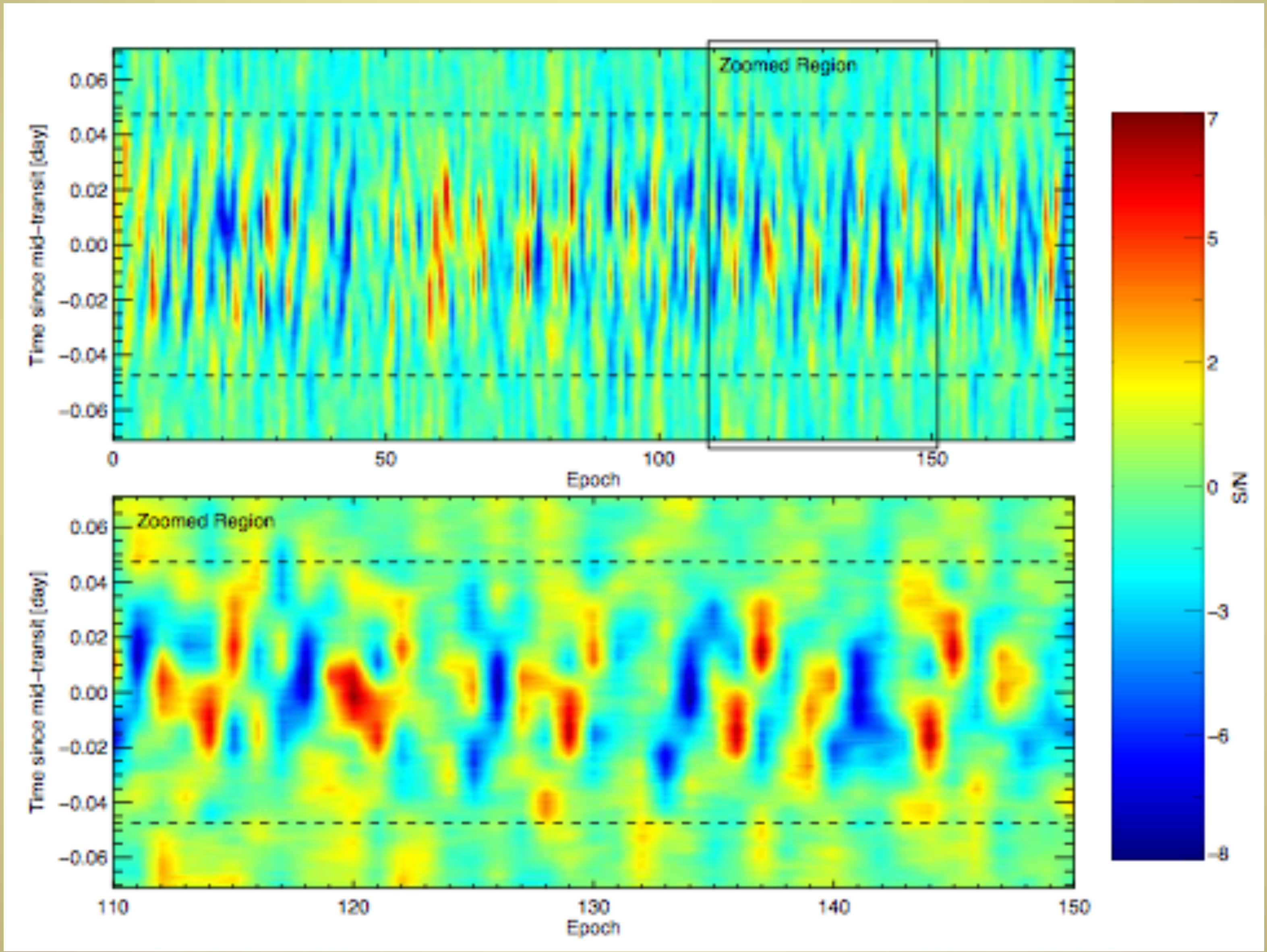


The stellar rotation period is 11.9 days, 8X the planet's orbital period of 1.49 days



Désert et al. 2011 AJS **197**, 14

Kepler-17b: Spot Lifetime



Désert et al. 2011 AJS **197**, 14

Summary

- Transit photometry has dominated the discovery of exoplanets in the past 8 years
- PLATO can extend and amplify the science results particularly of Kepler by re-observing the Kepler FOV to recover TTVs and permit identification of longer period planets by combining data sets and for TESS if either or both of the Webb Continuous Viewing Zones are observed
- PLATO can extend the discovery space for small, rocky planets to 1-year periods, but likely only with 3+years at a given FOV, due to stellar variability
- Stellar noise is an important limiting factor
- Robust determination of η_{earth} requires significant investment in probing completeness and reliability of data processing pipelines and vetting protocols
- Expect the unexpected! And have fun.