

# Exoplanets

Fall/Winter 2025/2026

Lecture 5


31 October 2025

# Outline

- Space mission detecting exoplanets
- Planetary candidates turning into planets

# Exoplanet detection process

- Detection by a space mission (or by RVs)
- Spectroscopic characterization of the system
- High resolution imaging
- Precise Radial Velocities (RVs)
- Confirmed planet



# Need for ground based follow-up

## Case of the CoRoT space mission

- Ground based support of CoRoT
- Contribution to the follow-up observations
- Observations of the CoRoT target fields about 1 year ahead of CoRoT
- Contribution to additional science programme

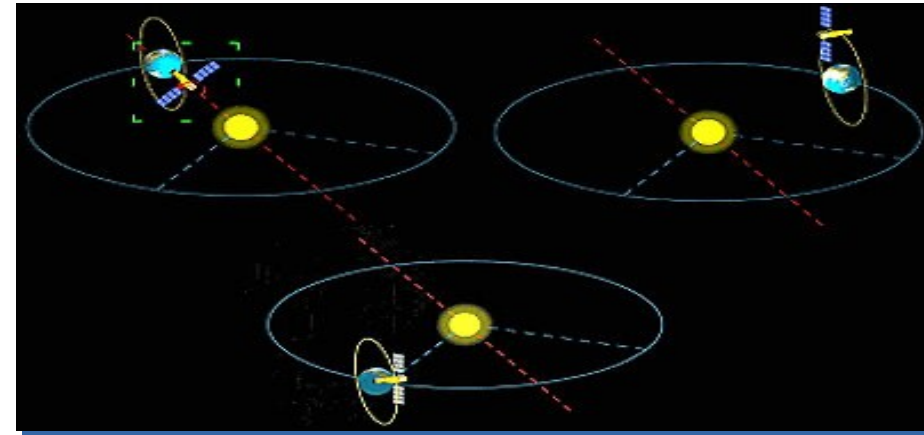
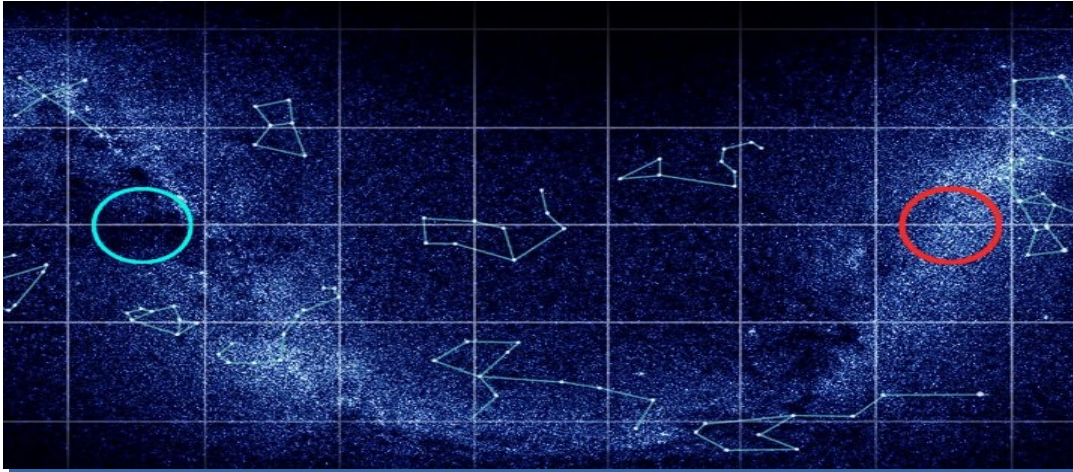
# CoRoT space mission

- Small aperture -27cm
- Exoplanets, Asteroseismology
- Launched 2006
- Mission end 2014
- More than 30 confirmed and fully characterized exoplanets
- Several hundreds of candidates



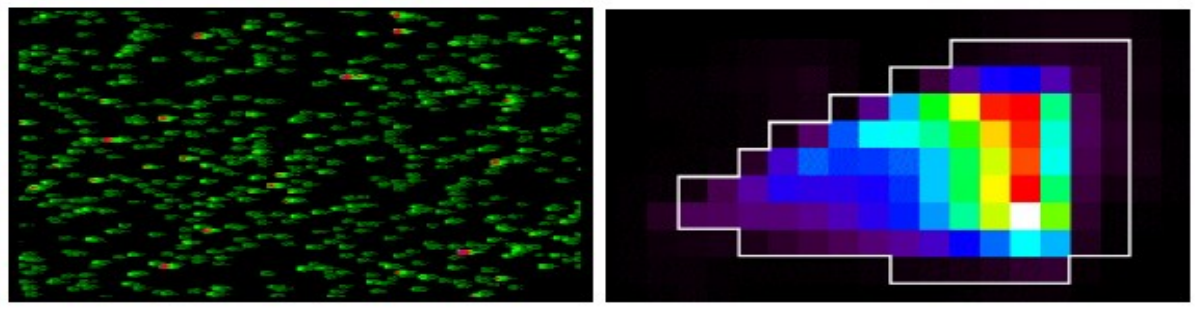
# Corot Observing Strategy

- Long run fields up-to 150 days
- Several shorter fields



# Need for ground based follow-up

Up to 12000 masks for objects



Angular resolution of CoRoT: 2.3 "/pixel



Broadening of stellar PSF due to prisms



FLASE POSITIVE ALARMS

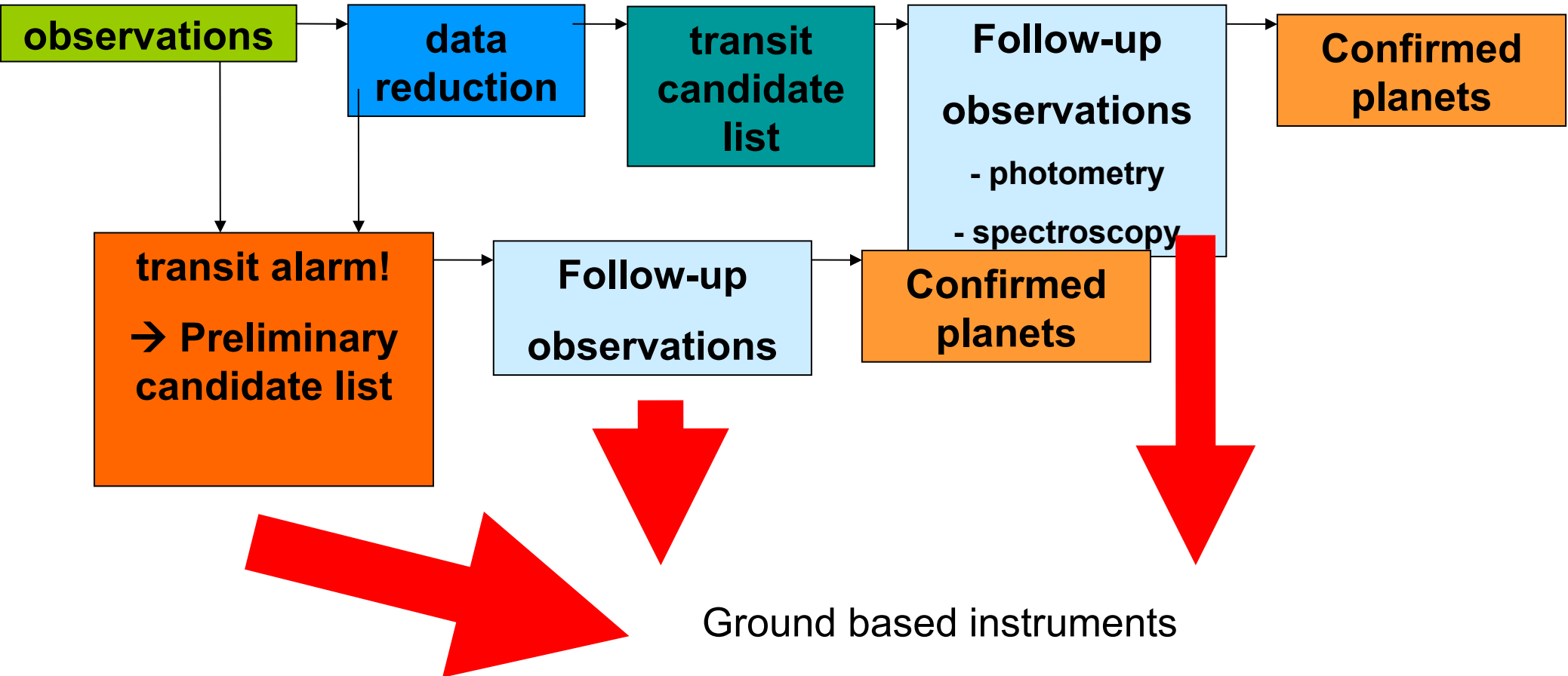


GROUND BASED FOLOW-UP

# Follow-up for CoRoT - BEST II

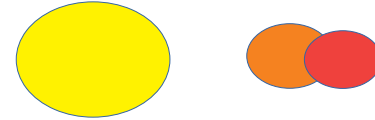


# Confirmation of candidates (Case of CoRoT)

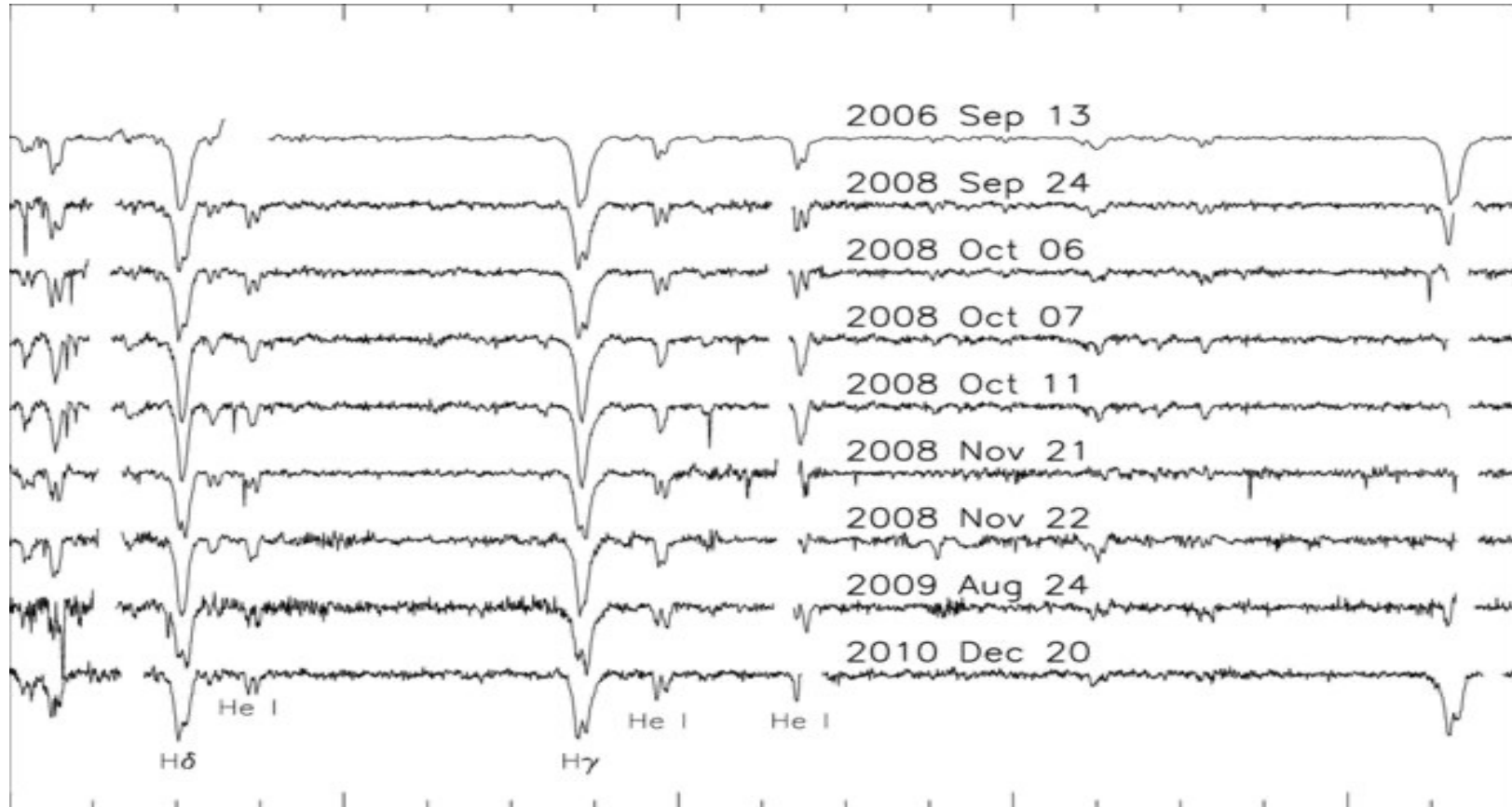


# False positives

- Eclipsing binaries
- Triple systems
- Background eclipsing binaries
- Background eclipsing BD/WD
- Star is not at main sequence
- False positives estimates Santerne et al. 2012 – around 40% for close-in giant planets Kepler candidates (from observing)
- Santerne et al. 2013 evaluates global false positive probability to about 11% for Kepler candidates



# Example of a binary from spectra



# Characterization of exoplanets

## combination of methods

- Transits

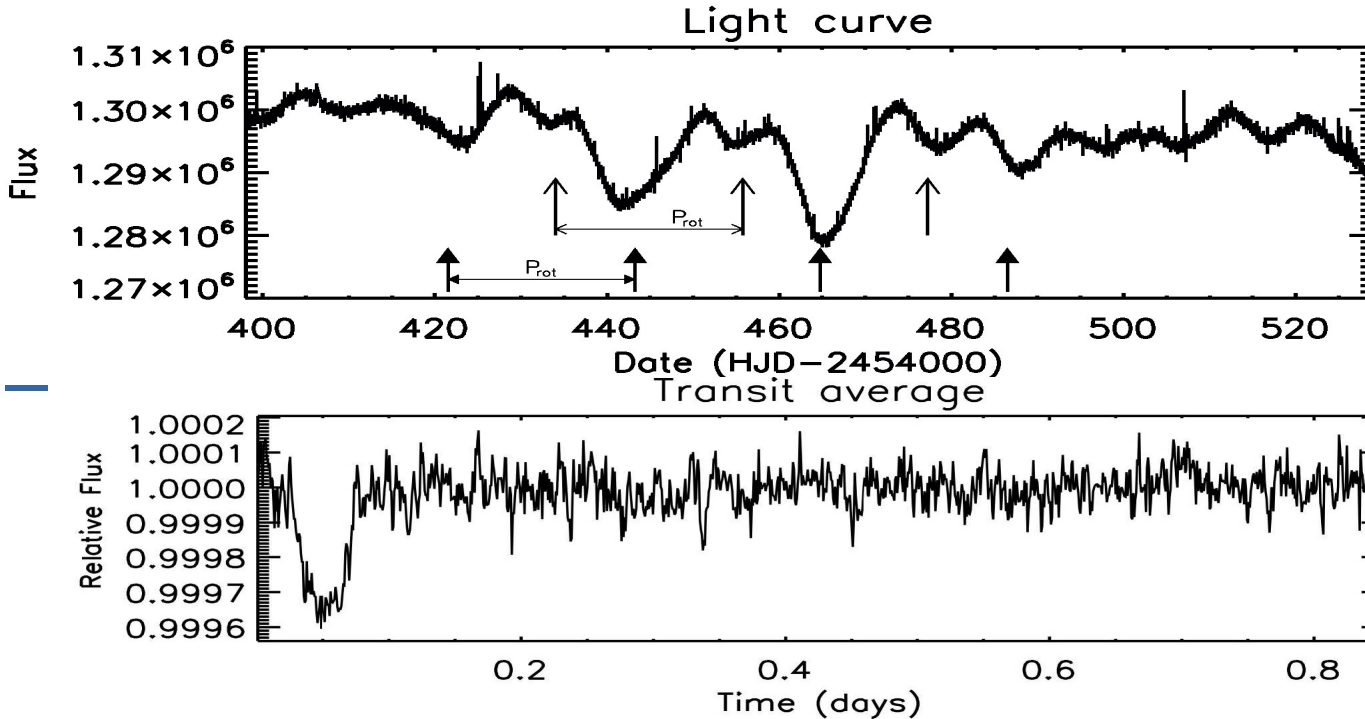
Radius of the planet (if stellar params known), inclination

- Spectroscopy

Mass limit, stellar parameters

- STELLAR PARAMETERS NEEDED (spectroscopy)

# The case of CoRoT-7b



**CoRoT-7b**

Orbital Period 0.85 days

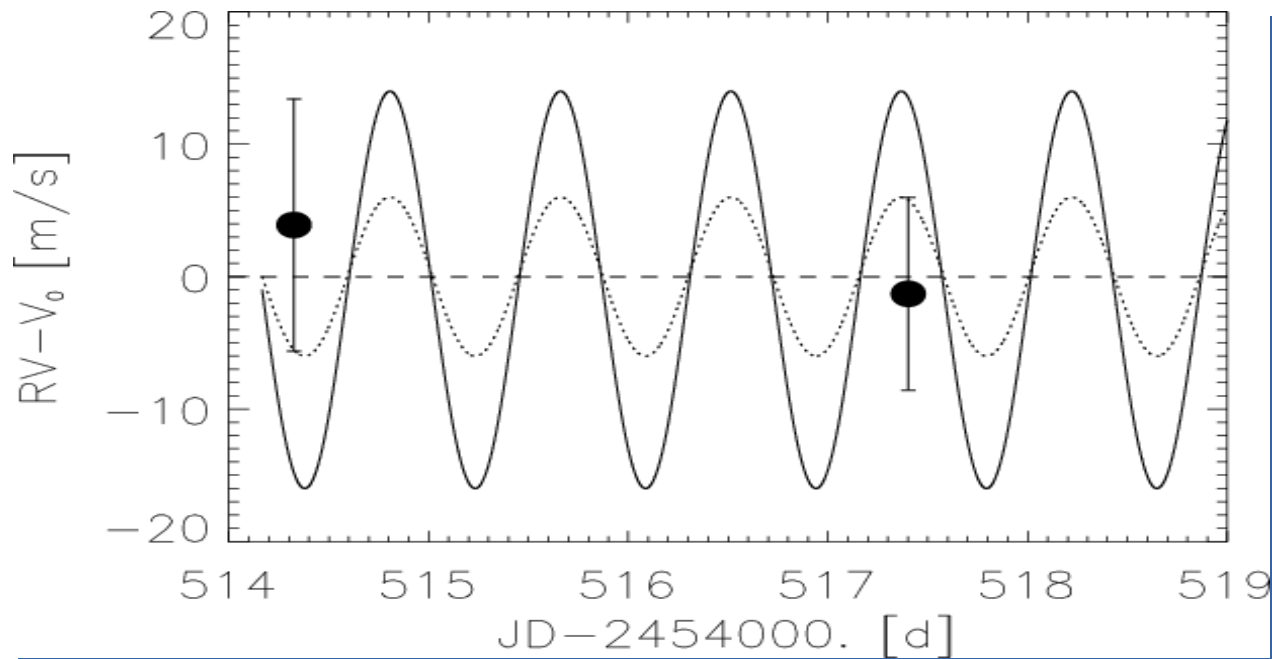
Mass  $< 9M_{\text{Earth}}$

Radius  $1.51R_{\text{earth}}$

From Leger et al. 2007, A&A

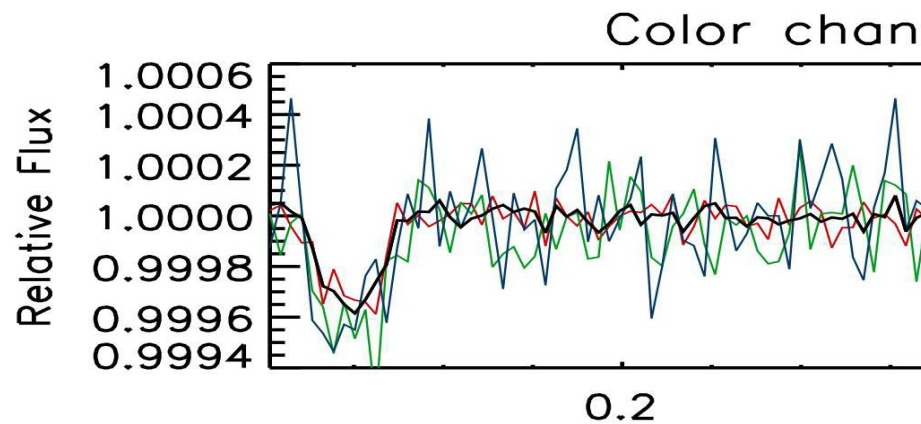
# CoRoT-7b

- SOPHIE at OHP
- Excluded large companion
- Case for small telescope



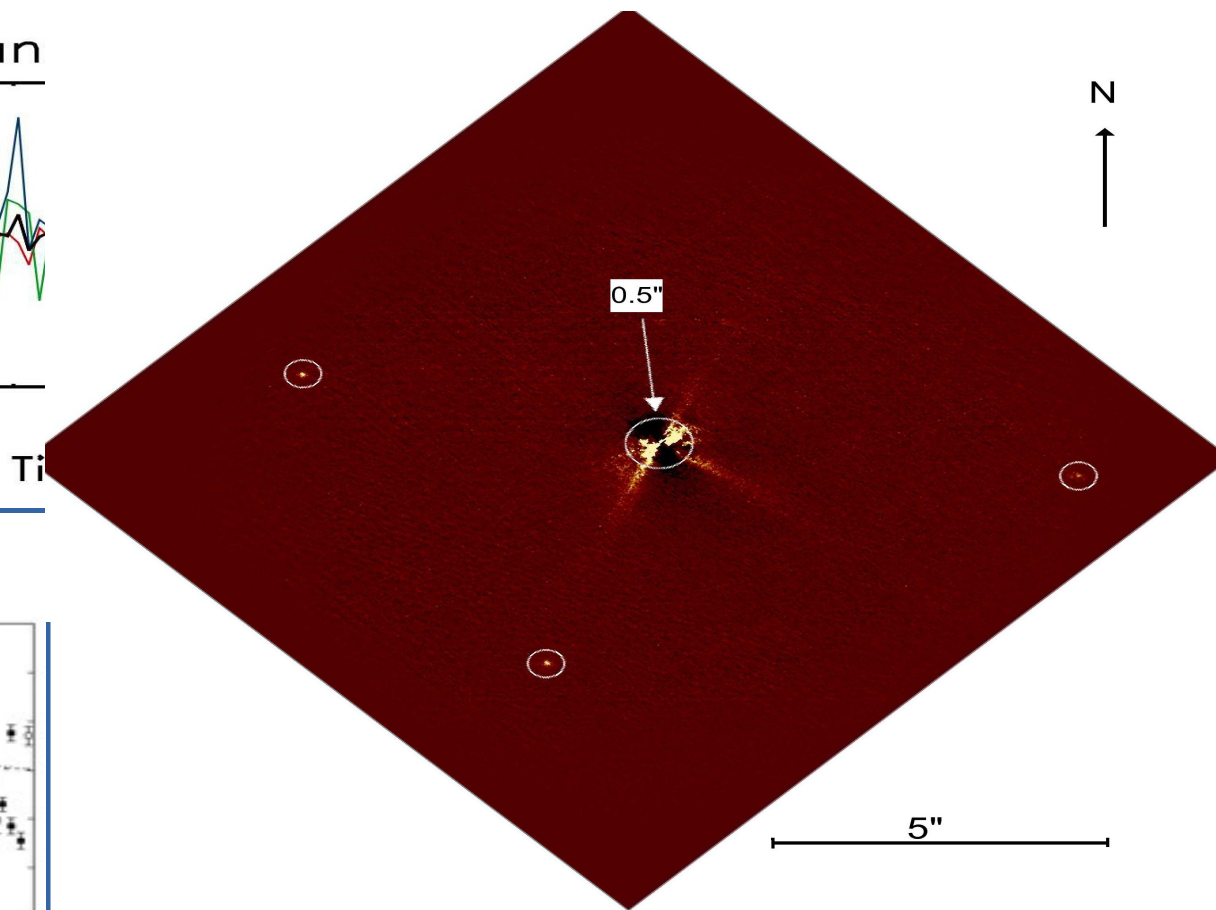
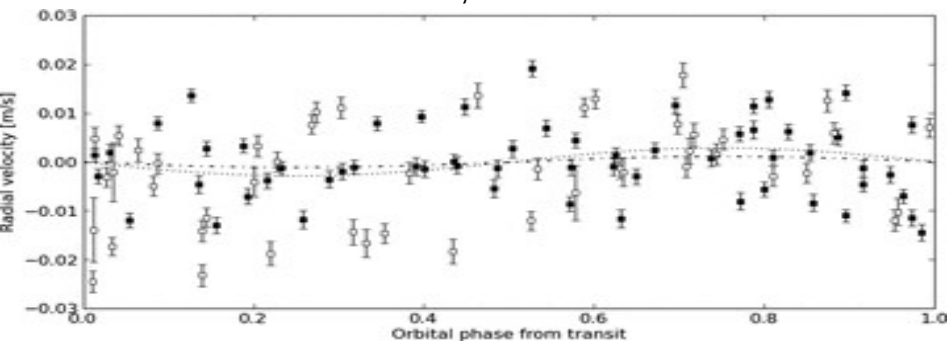
From Leger et al. 2007, A&A

# CoRoT-7b



From Leger et al. 2007, A&A

Bottom from F. Pont 2011, MNRAS

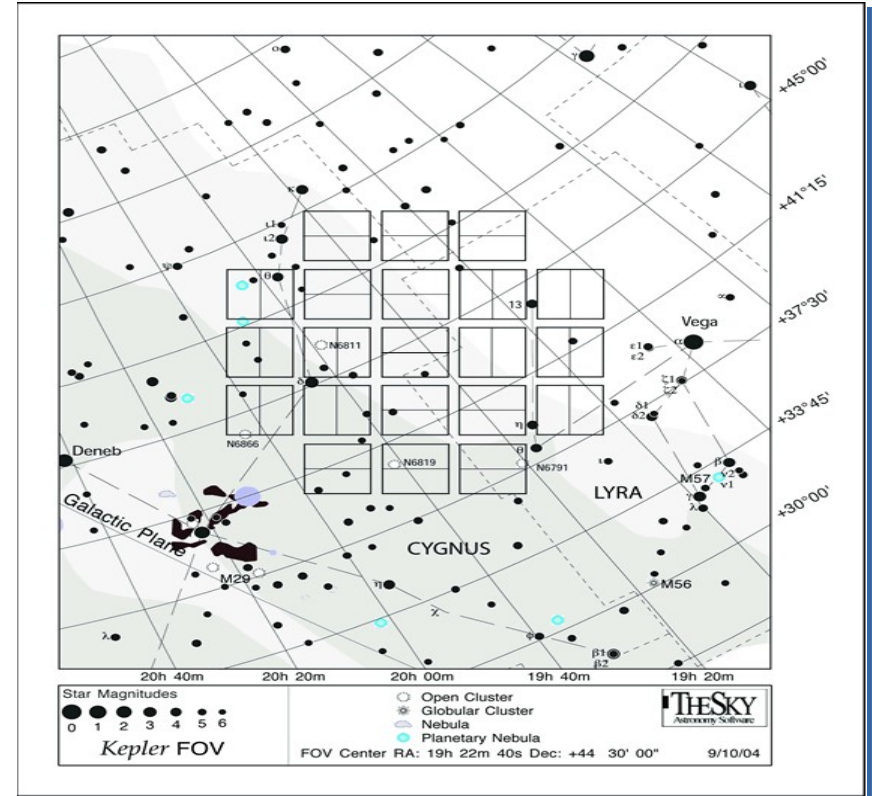
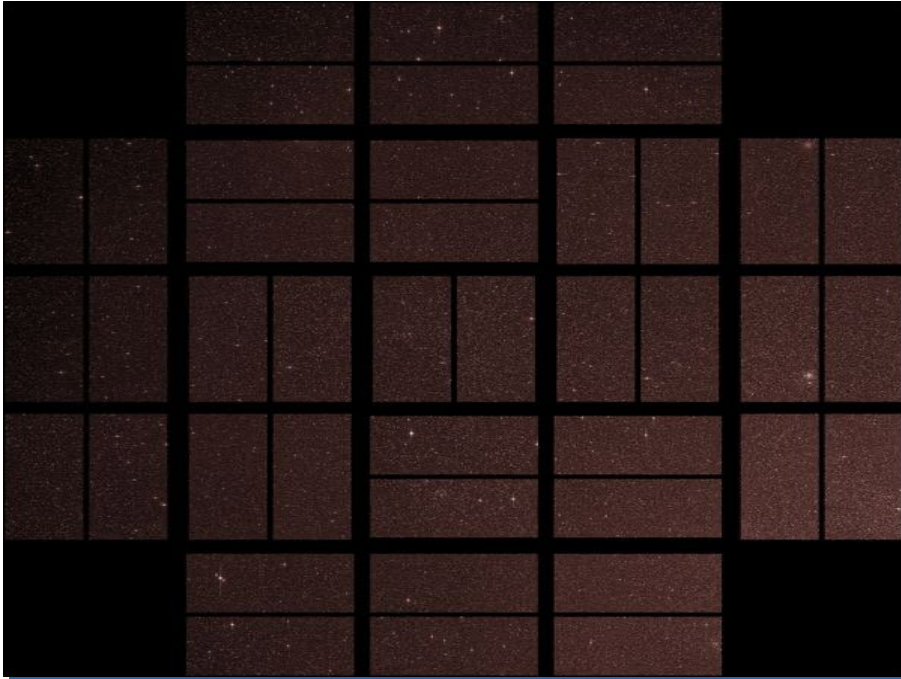


# The era of Kepler

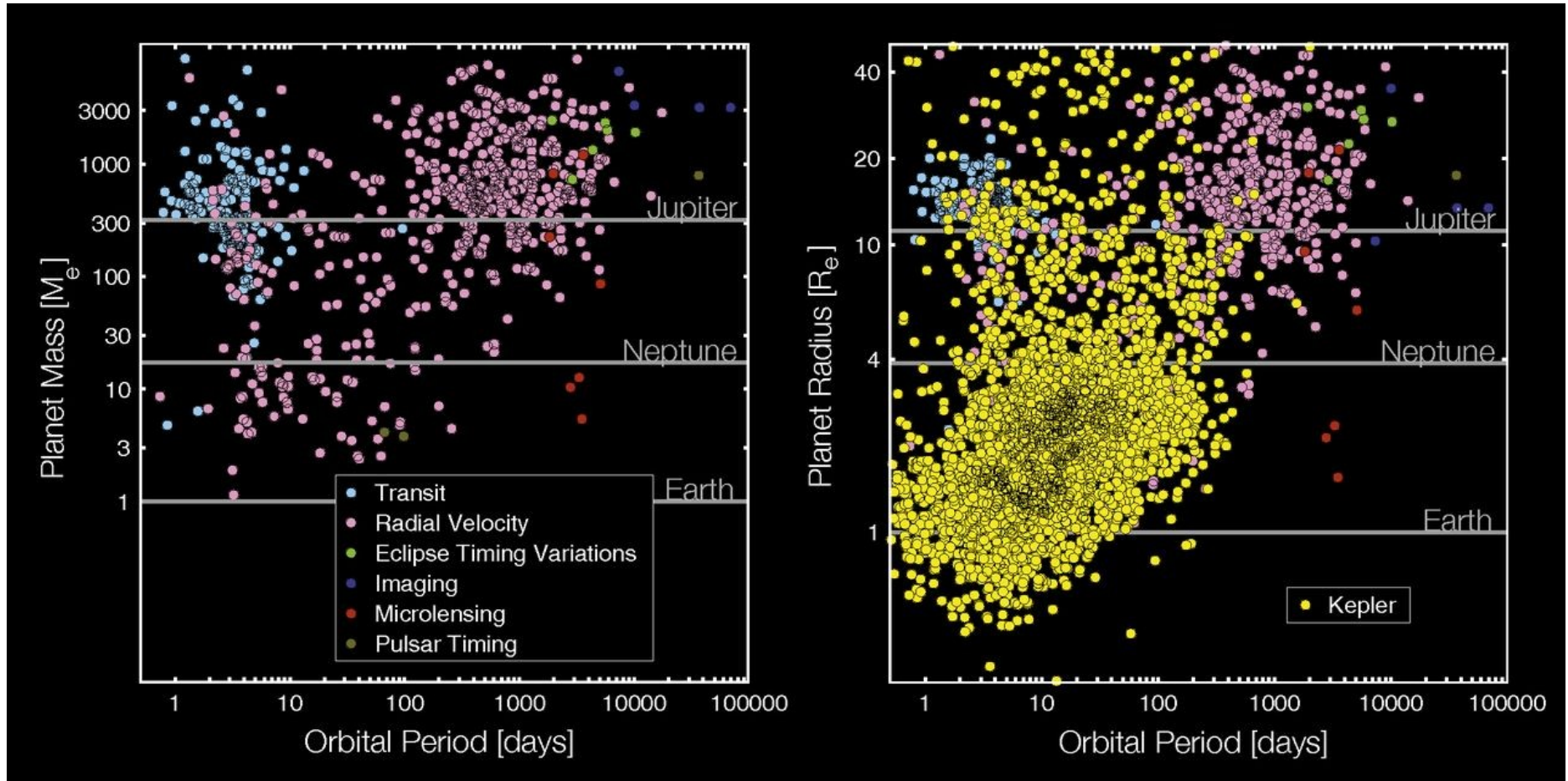
- Detections of exoplanets
- Launched 2009
- 1.4-m primary mirror
- Monitored 100k stars in Cygnus
- Around 2000 planets
- K2 continuation with different observing strategy
- Many stars were faint 13+ mag!



# Kepler observing strategies

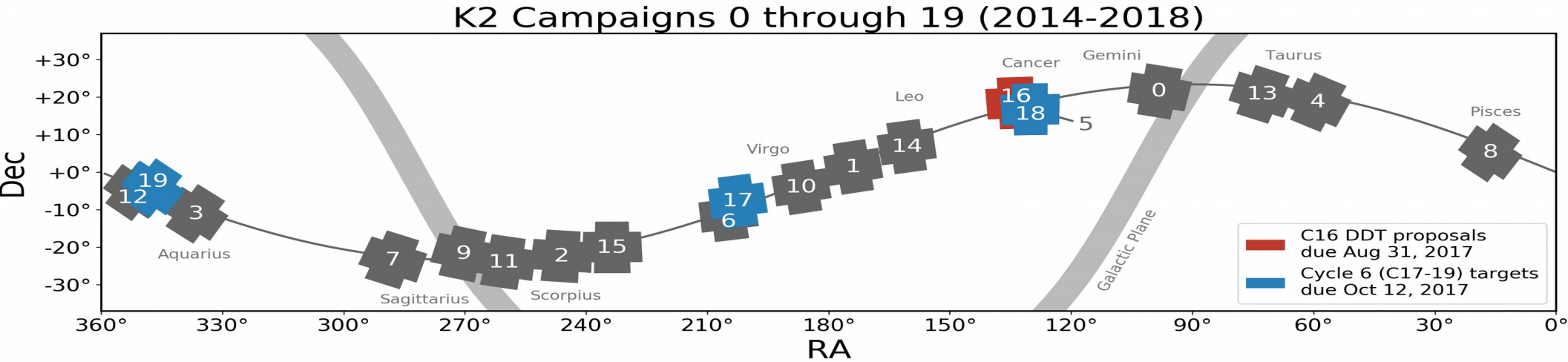


# KEPLER planets



Credit: NASA

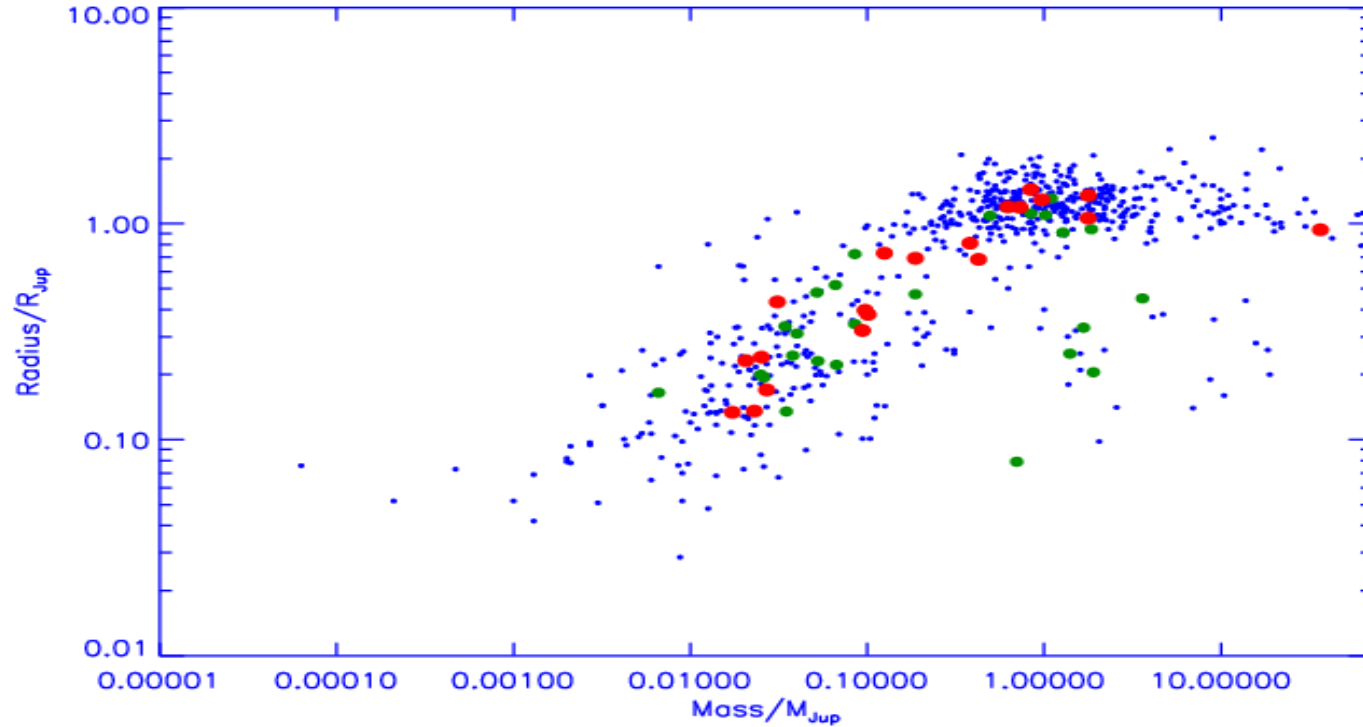
# K2 continuation of Kepler



Credit: Nasa

- Nowadays 325 planets from K2 (Sep 2018)
- About 400 candidate (Sep 2018)
- Need for ground-based RV

# Great but.....



In Sep. 2017 – approx. 120 K2 planets

Blue – all planets around 4000  
Green – K2 planets with masses (40)

Red – KESPRINT (21)

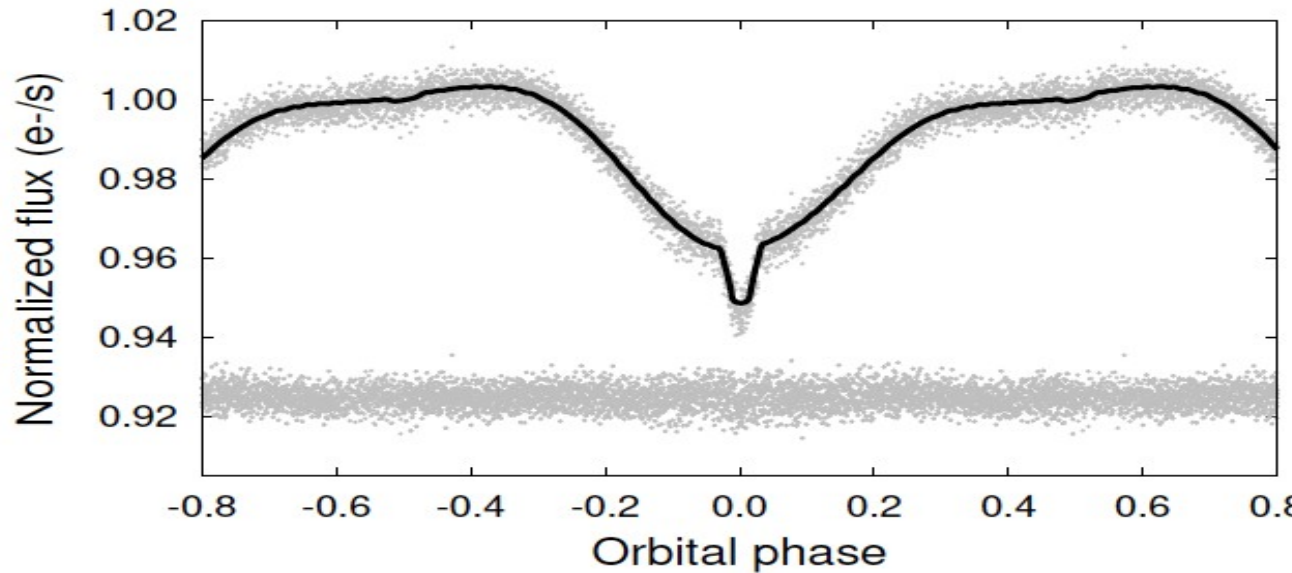
Numbers from Csizmadia et al. 2017

From Csizmadia et al. Plato mission conference 2017

# The case of HD99458

- Planetary candidate with
- Transit depth of a few %
- Suspected hot Jupiter
- Follow-up with OES at Ondrejov

# Intriguing system?

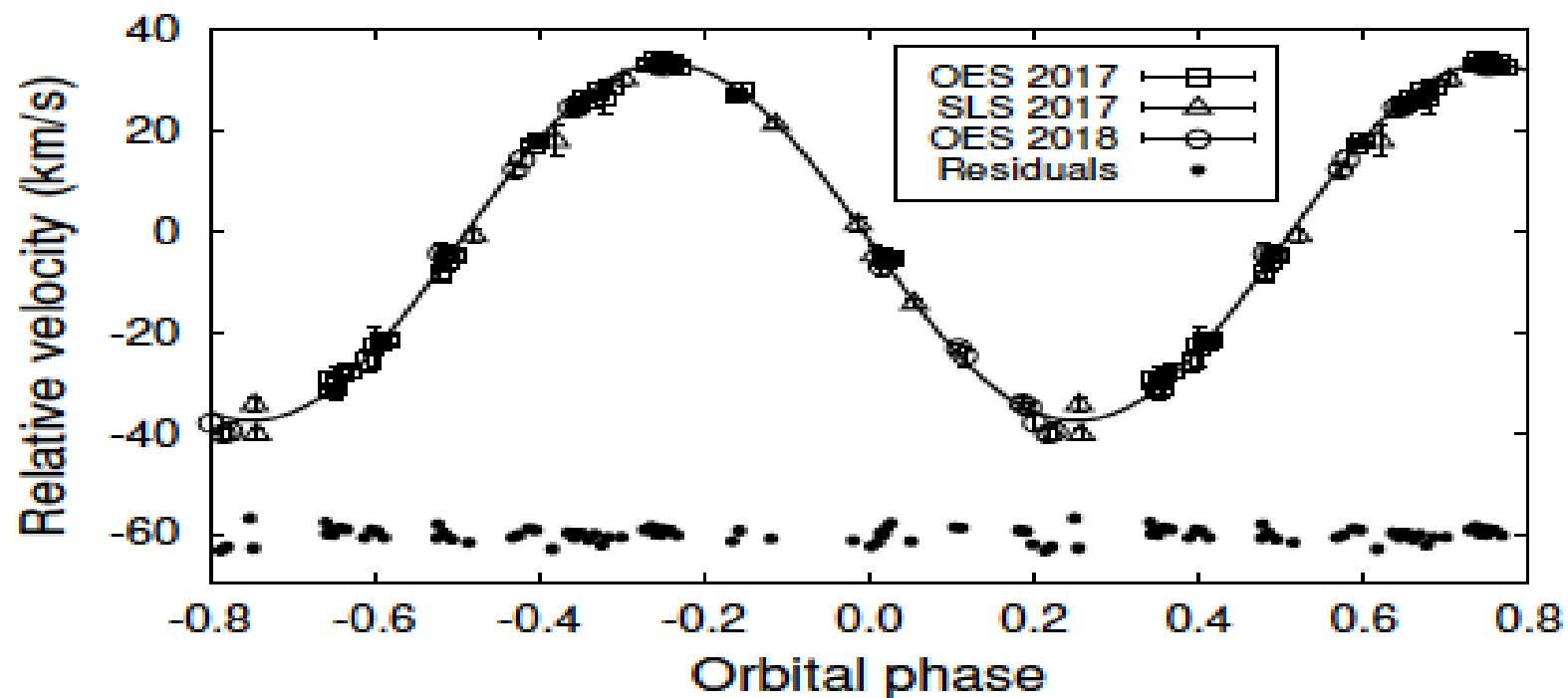


- Kepler candidate for Jupiter-sized planet
- Observing with OES and at Stará Lesná, SK
- Short period binary, magnetic star with DSCT pulsations and spots

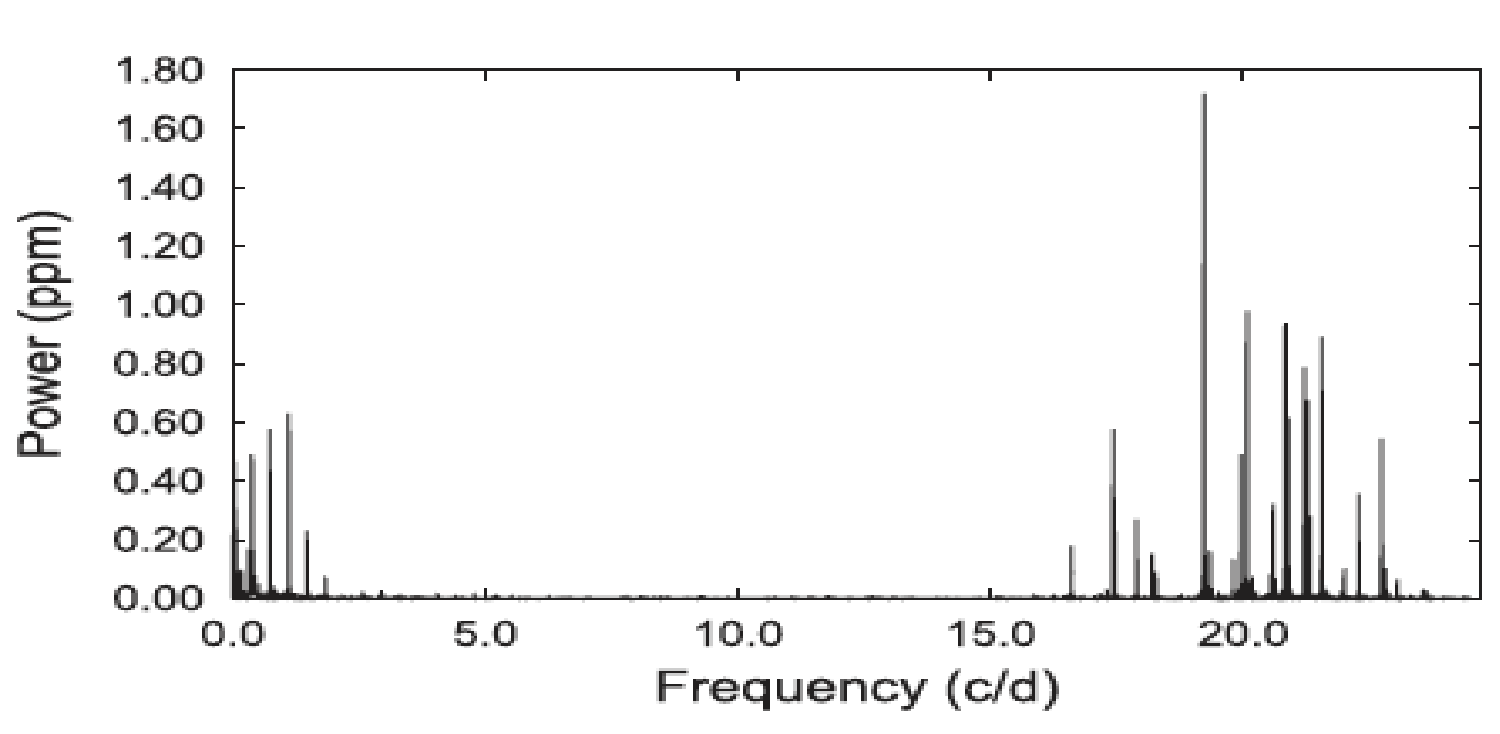
Skarka, Kabath, et al. 2019, MNRAS

• NO EXOPLANET

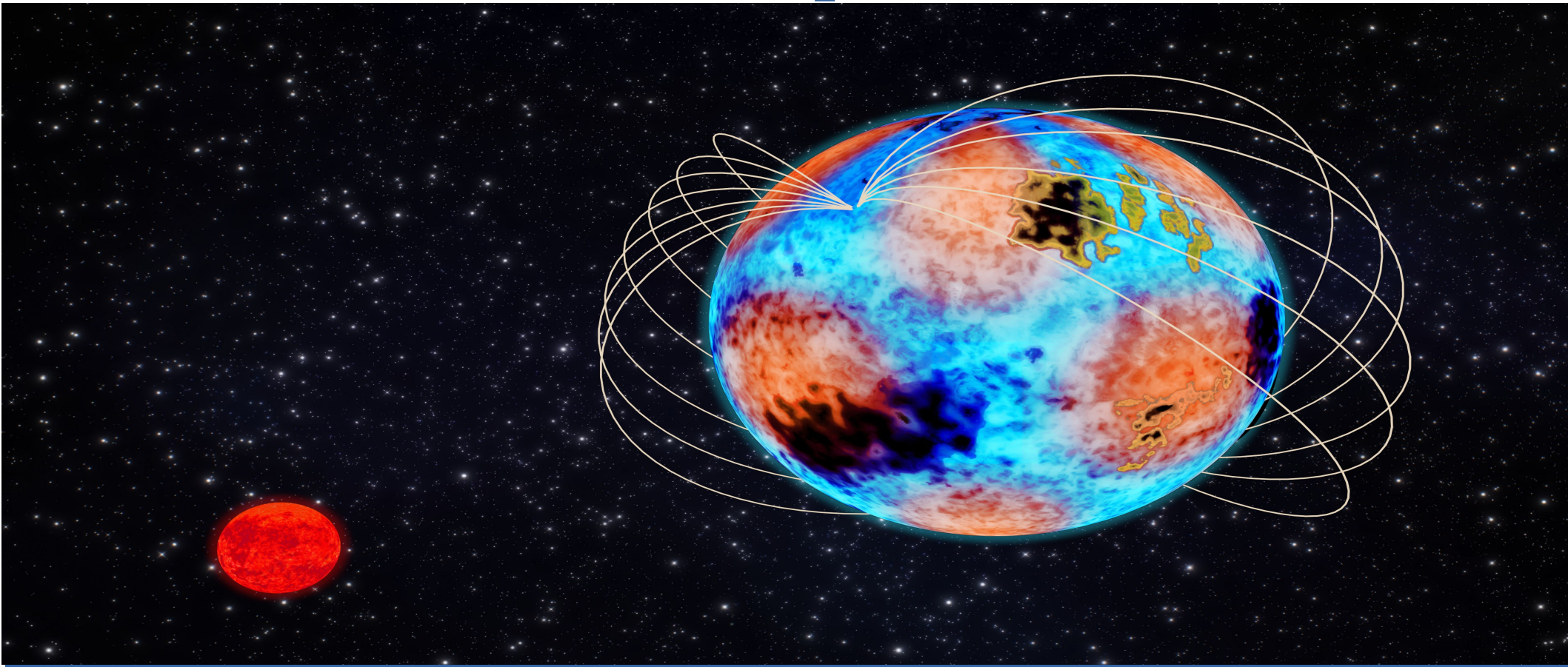
## A false positive



# Pulsations



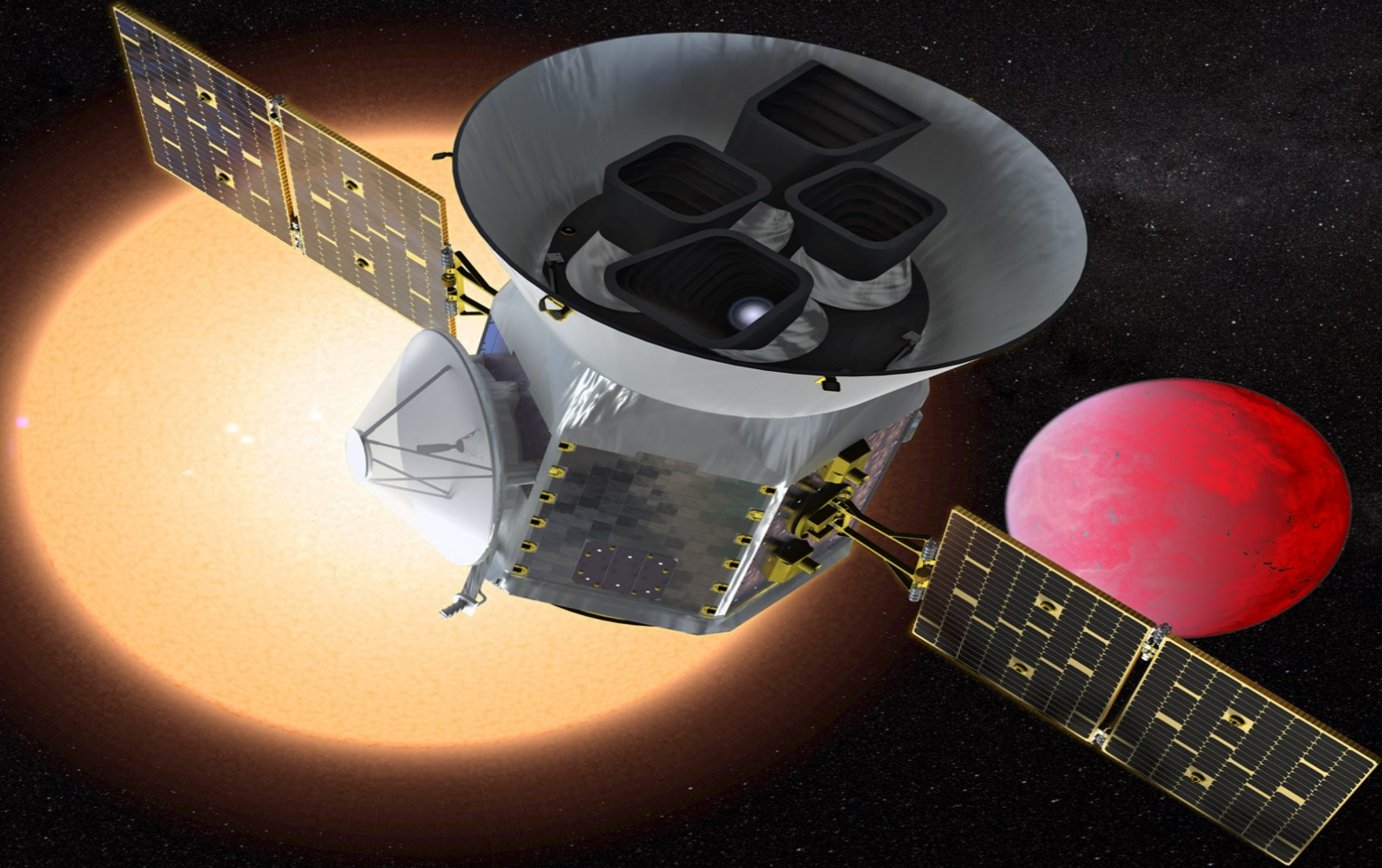
# Artists impression



# Need for coordination

- spectroscopic follow-up
  - spectral typing, stellar parameters (1-2-m class)
  - RV follow-up (1-8+ m class)
  - exo-atmospheres (2-8+ m class)
- Photometric follow-up
  - high spatial resolution imaging (small telescopes)
  - on-off photometry (small telescopes)
  - high-res. (AO) imaging (typicall 8-m)

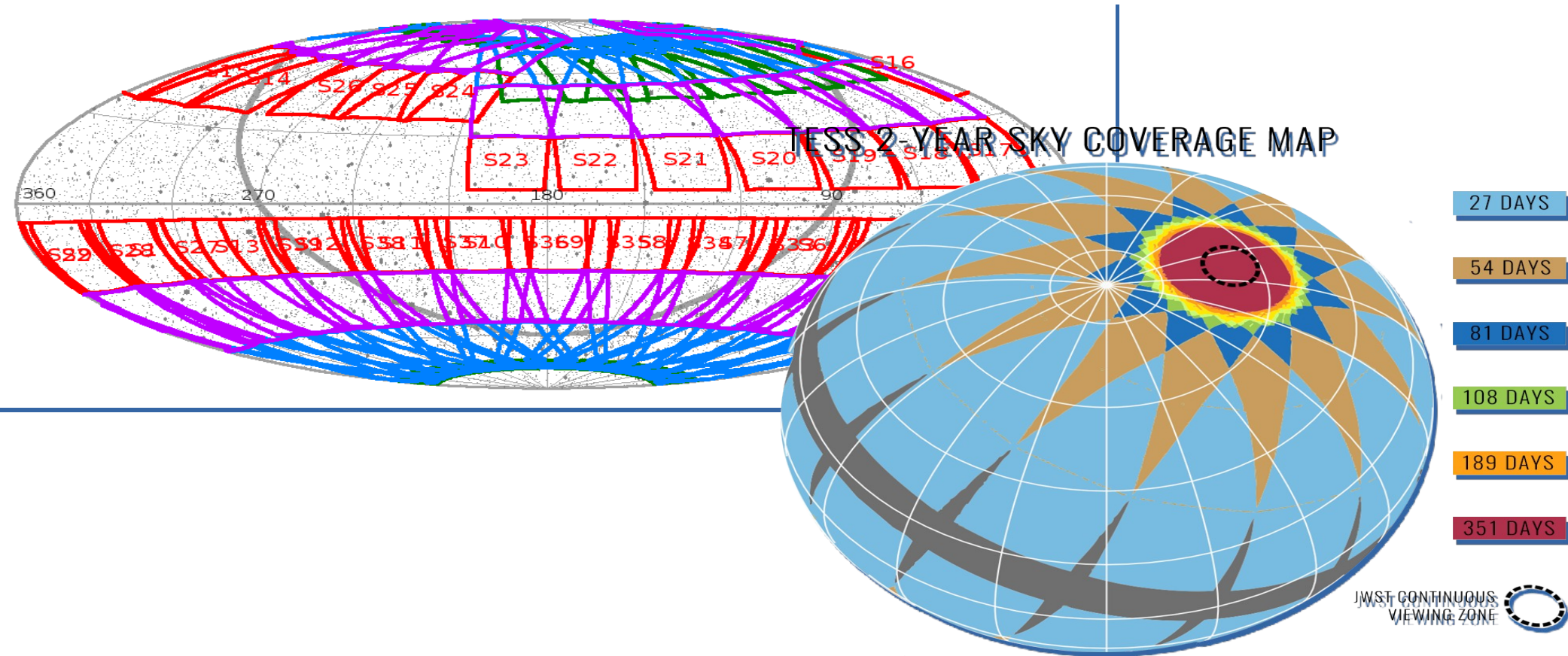
TESS



# TESS

- Almost all sky coverage
- 4 x 100mm lenses
- Monitoring of more than 200k bright stars
- Targets will be suitable for ground-based follow-up
- Perfect for small telescopes!!!
- First 73 candidates list delivered
  - Brightest TESS candidate is 5.1 mag
  - Most of targets brighter than 12 mag

# TESS observing fields



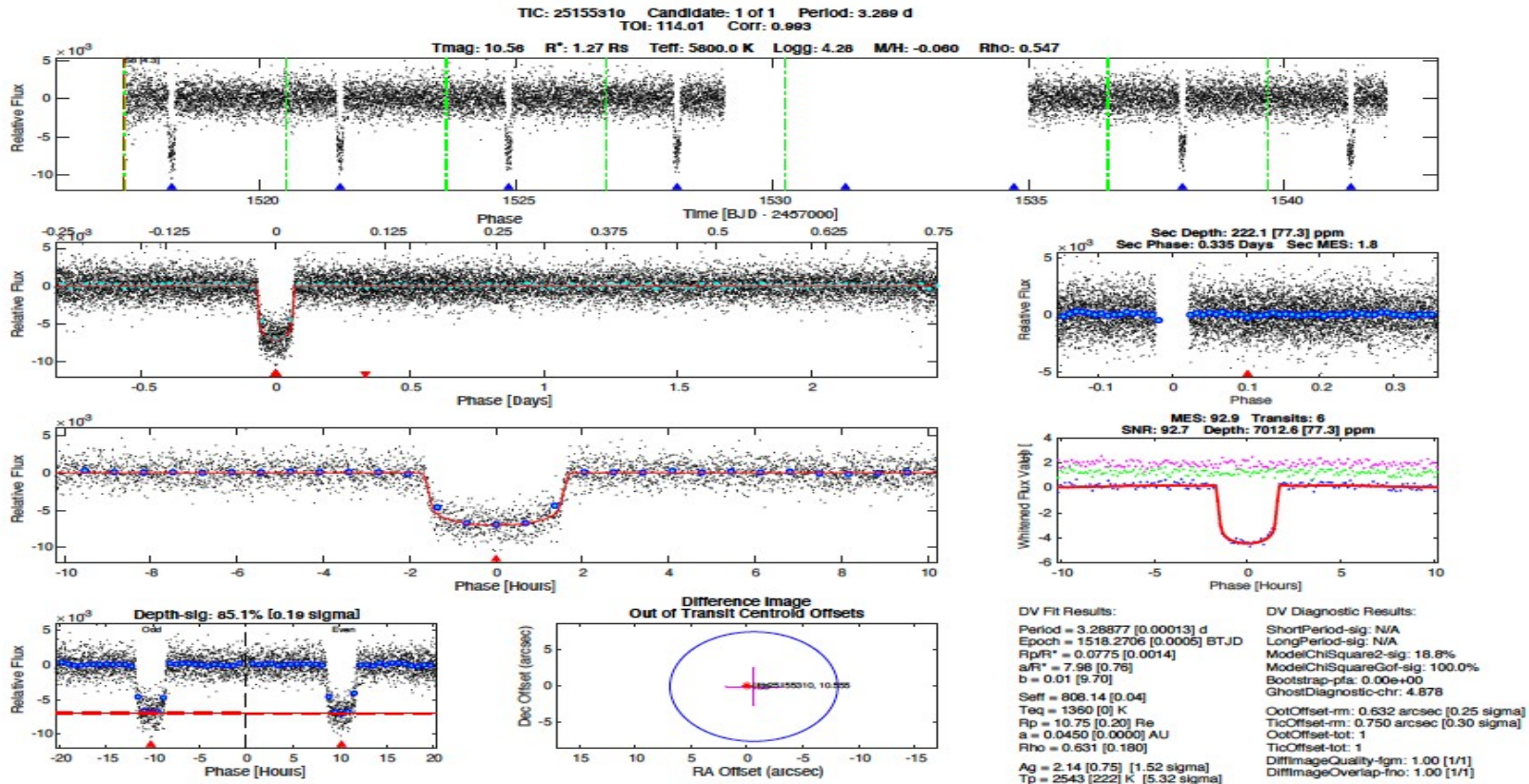
[://archive.stsci.edu/missions-and-data/transiting-exoplanet-survey-satellite-tess](https://archive.stsci.edu/missions-and-data/transiting-exoplanet-survey-satellite-tess)

# Example of a validation report

Summary Reports

Sectors 8 - 8

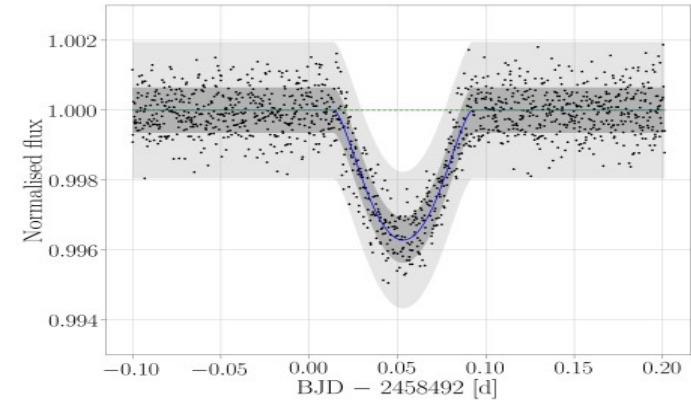
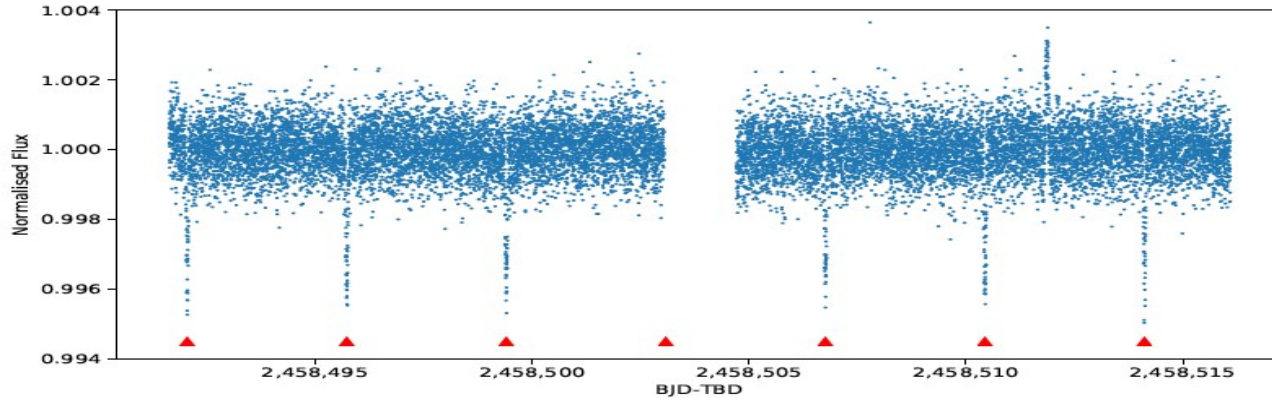
Target 25155310 / Planet Candidate 1



Software Revision: spoc-3.3.61-20190323 -- Date Generated: 27-Mar-2019 01:37:22 Z

This Data Validation Report Summary was produced in the TESS Science Processing Operations Center Pipeline at NASA Ames Research Center

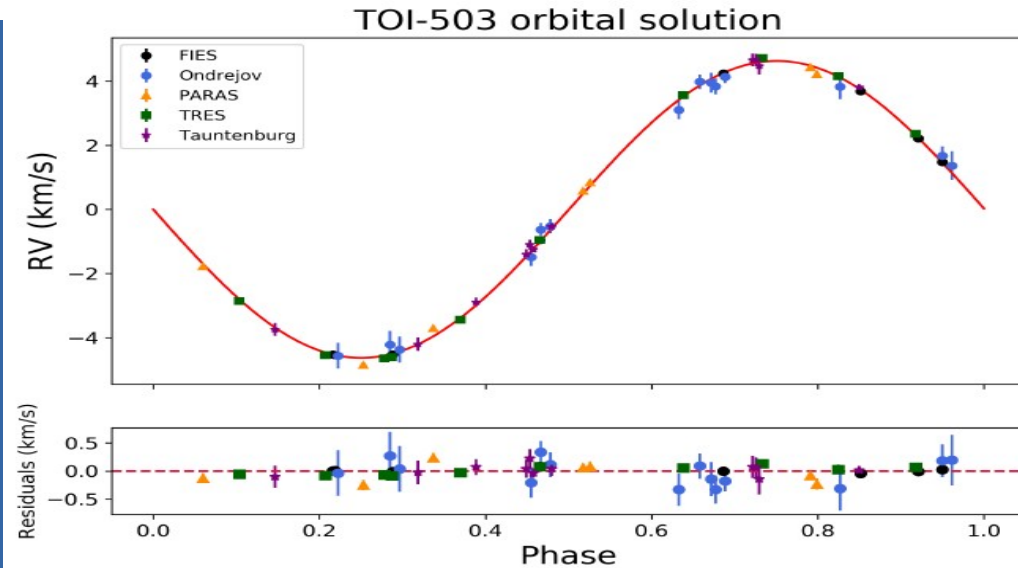
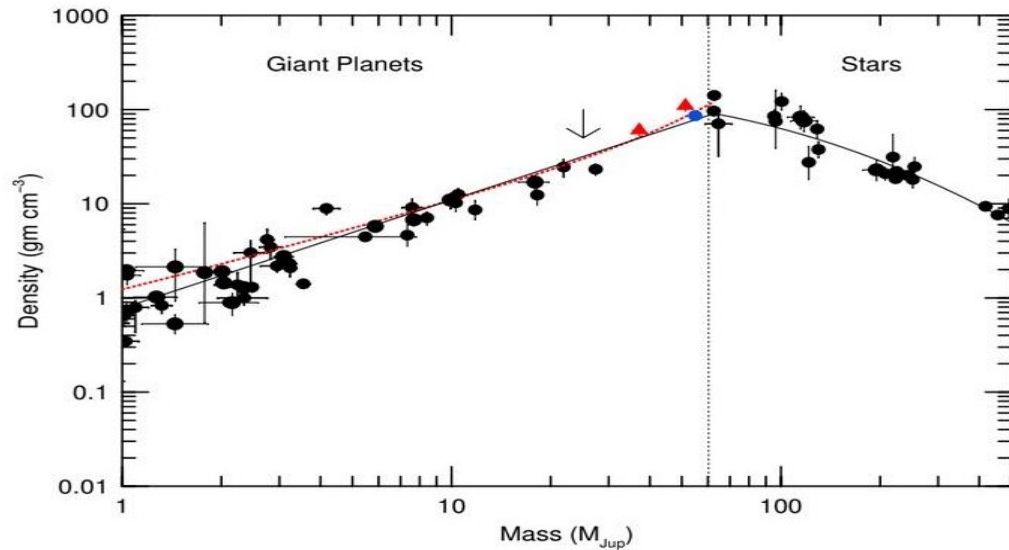
# Candidate from TESS TOI-503?



- TESS detected a Period around 3 days for TOI-503 A type star
- 3% depth – border line planet

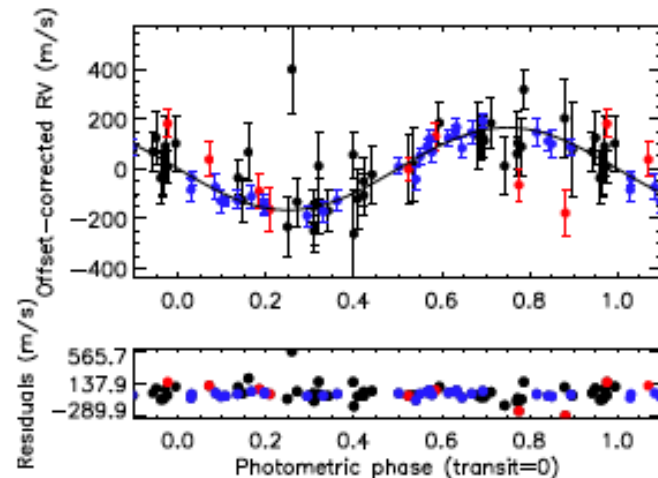
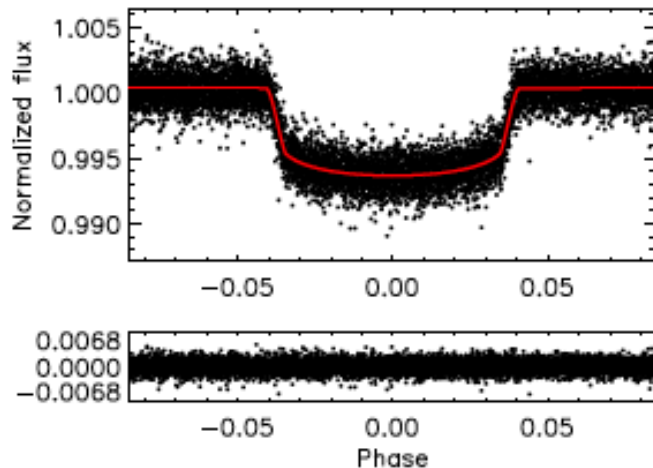
# First Brown Dwarf from Ondřejov

- Mass – 53 Jupiter masses
- Radial velocities between -5 a +5 km/s



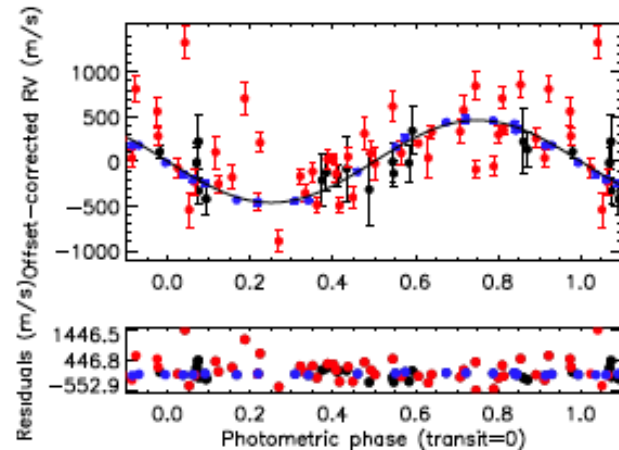
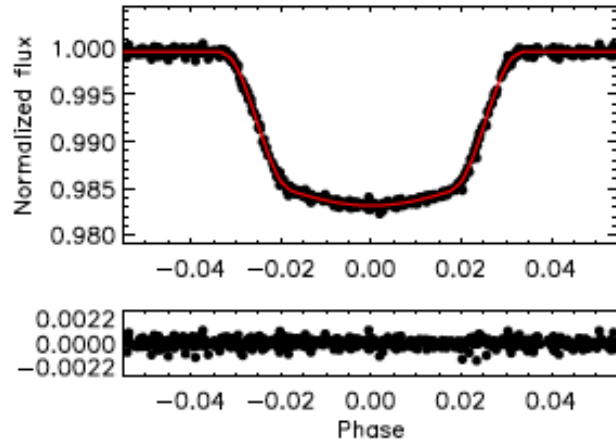
# TOI-1181b

- A hot Jupiter around a G subgiant star
- Period 2.1 days
- Radius  $1.3 R_{\text{Jupiter}}$  and Mass  $1.18 M_{\text{Jupiter}}$



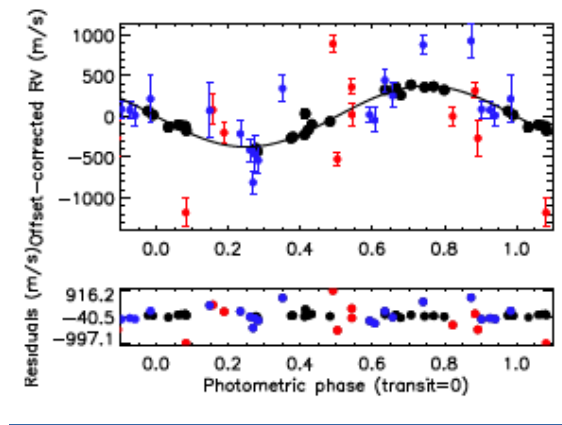
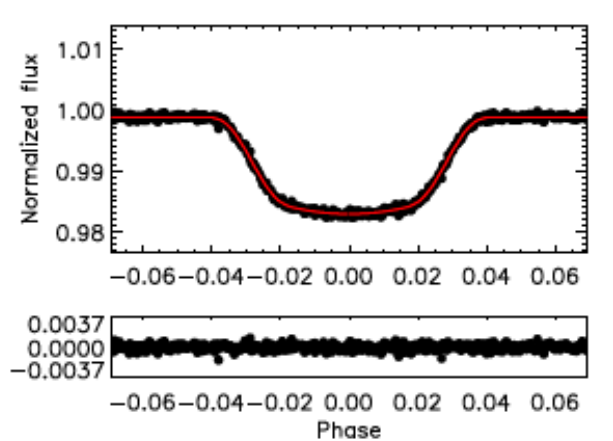
# TOI-1516b

- A regular hot Jupiter
- Period 2.06 days
- Radius  $1.36 R_{\text{Jupiter}}$  and Mass  $3.16 M_{\text{Jupiter}}$

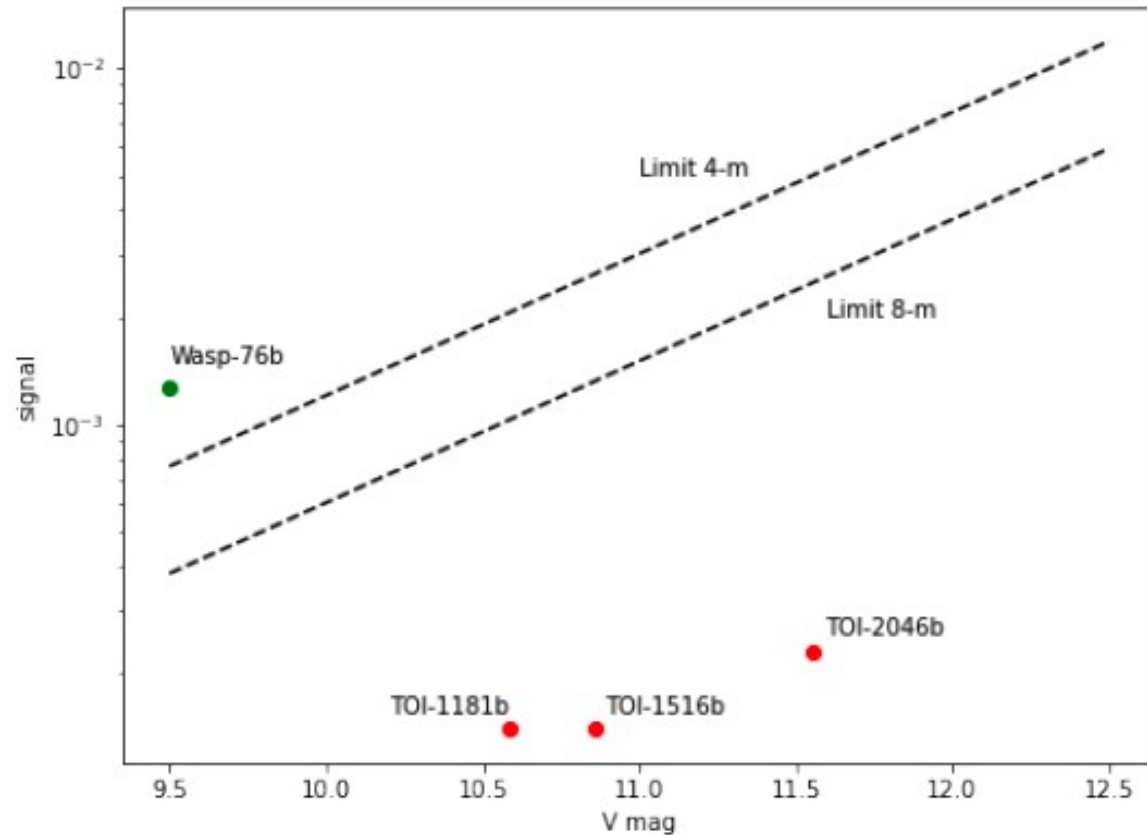


# Hot Jupiter around young star, TOI-2046b

- Young system perhaps 100-400 Myr (Li line)
- Period 1.5 days
- Radius  $2.44 R_{\text{jupiter}}$  and Mass  $2.3 M_{\text{Jupiter}}$

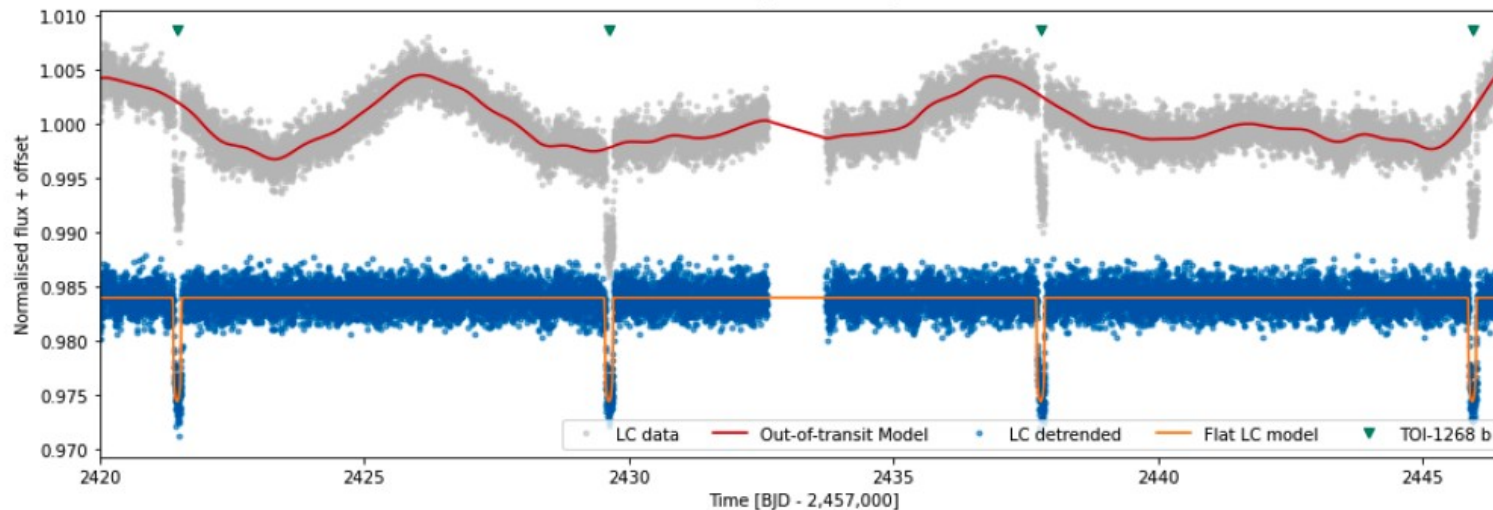


# Further characterization?



# TOI-1268 warm Saturn around a young K star

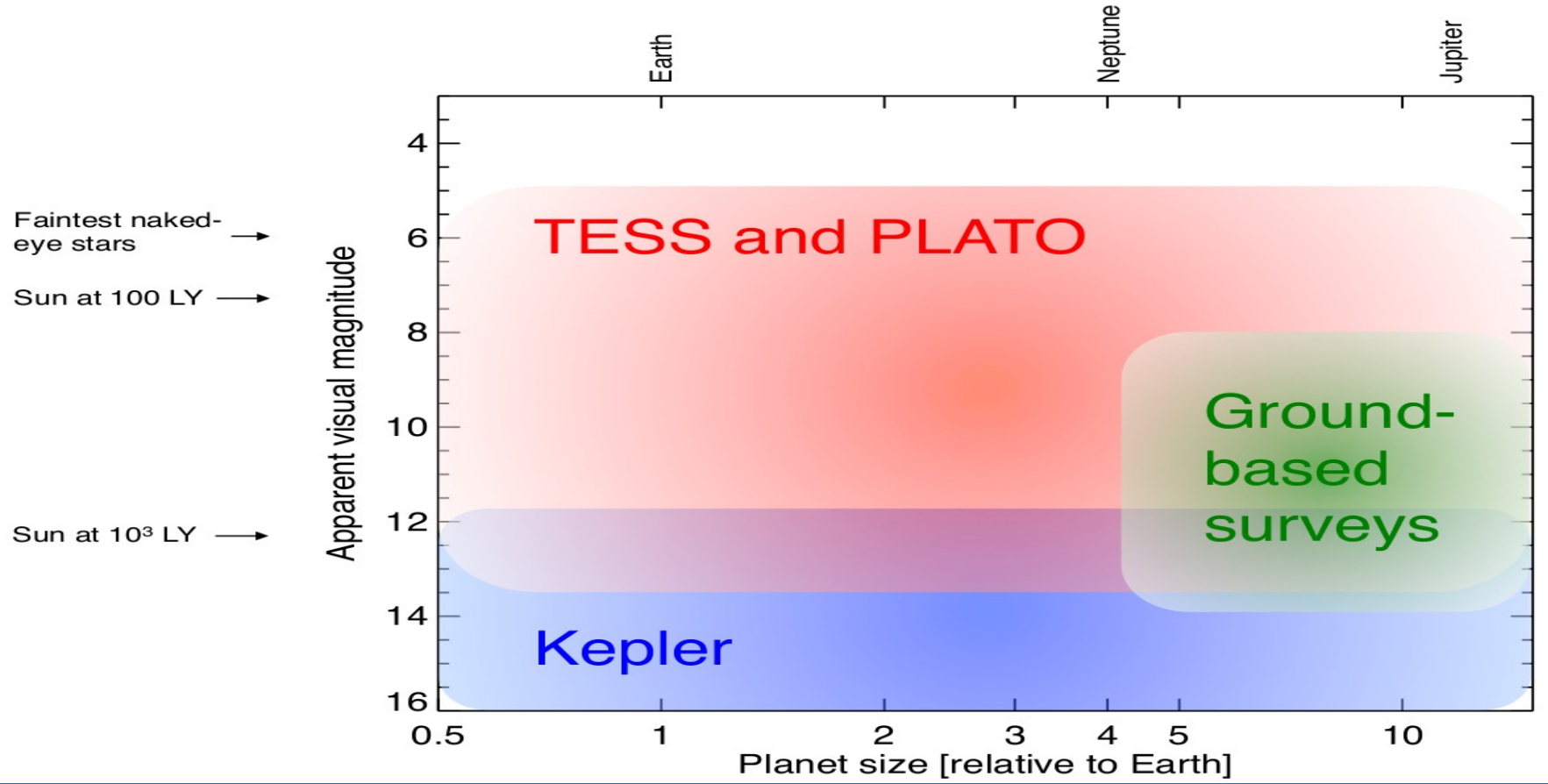
- A warm Saturn
- Period 8.1 days
- Paper J. Subjak et al. 2022, A&A



# Conclusions

- Detection of a candidate is the very first step
- Ground based follow-up is extremely important
- Confirmation process has several steps
  - stellar parameters, high. Res photometry, high precision RVs
- Only candidates passing all steps above are planets
- The mission strategy and follow-up strategy need to be synchronized
- The follow-up can take more than 6 months

# Space missions compared



# Exoplanet types

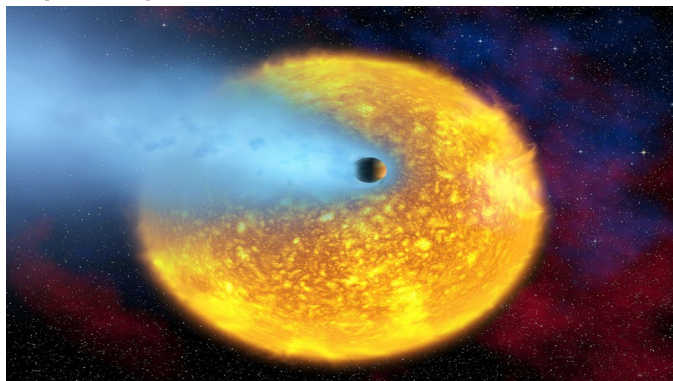
# State of the art in 2006

- Hot Jupiters – gas planets
- Super Earths – small terrestrial planets

# Types of planets (2006)

## Giant planets (hot Jupiters)

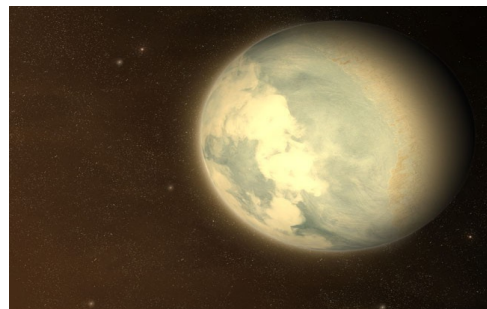
- close-in orbits
- short orbital periods (a few days)
- Jupiter-sized
- In transit with intensity decrease of a few %
- 1995 first detection 51 Peg (Mayor & Queloz 1995)



Vidal-Madjar et al. (2004)

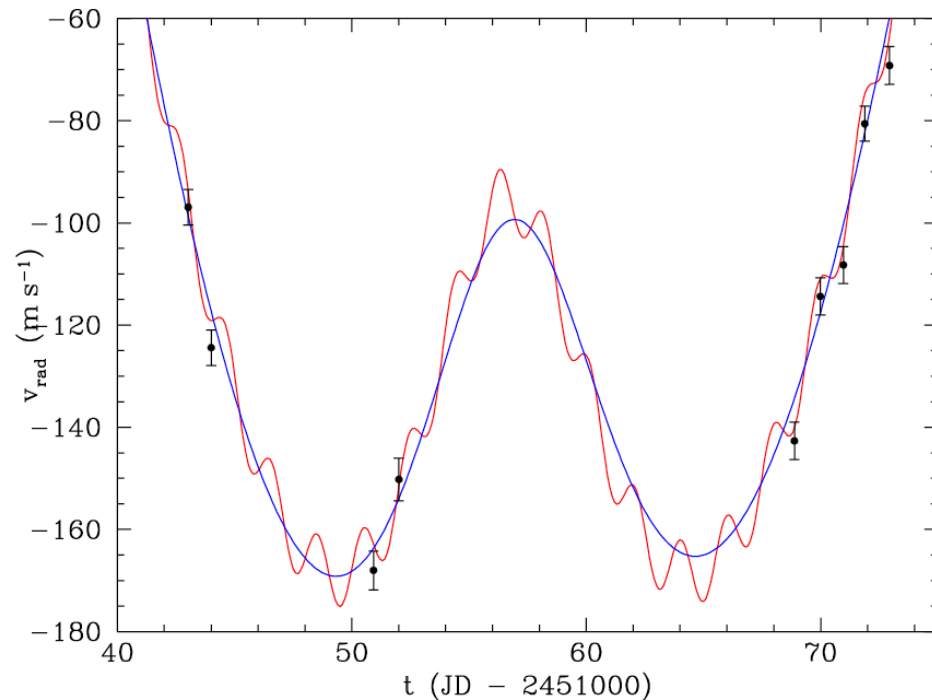
## Super Earths

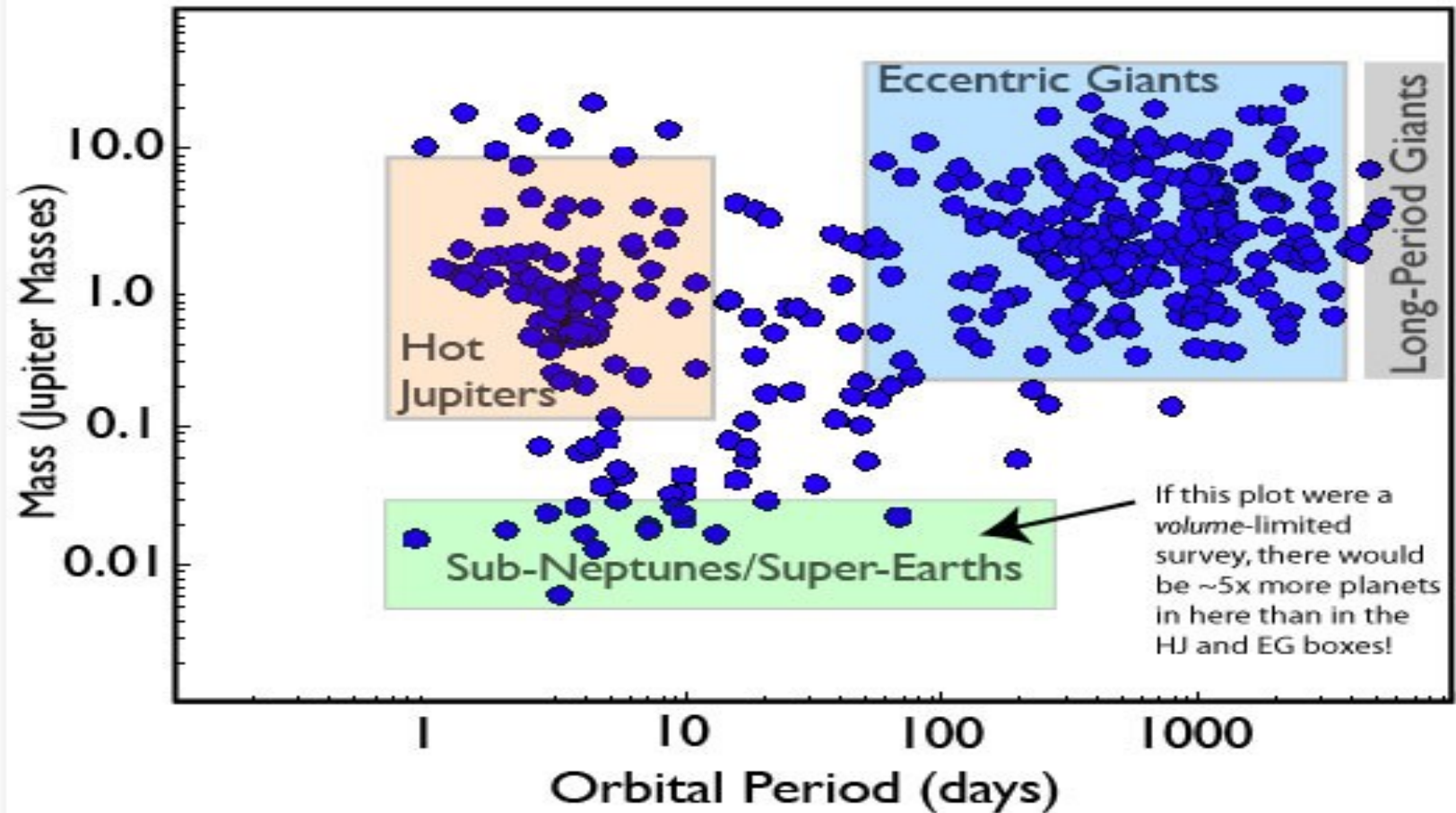
- masses up to  $10 M_{\text{Earth}}$  (Valencia 2007)
- constraint on radius:  $10 M_{\text{Earth}}$  – max  $1.9 R_{\text{Earth}}$  (Valencia 2007)
- consist of rocks and iron & planetary ice (Fortney 2007)
- Gliese 581 system (Mayor, Udry 2009)



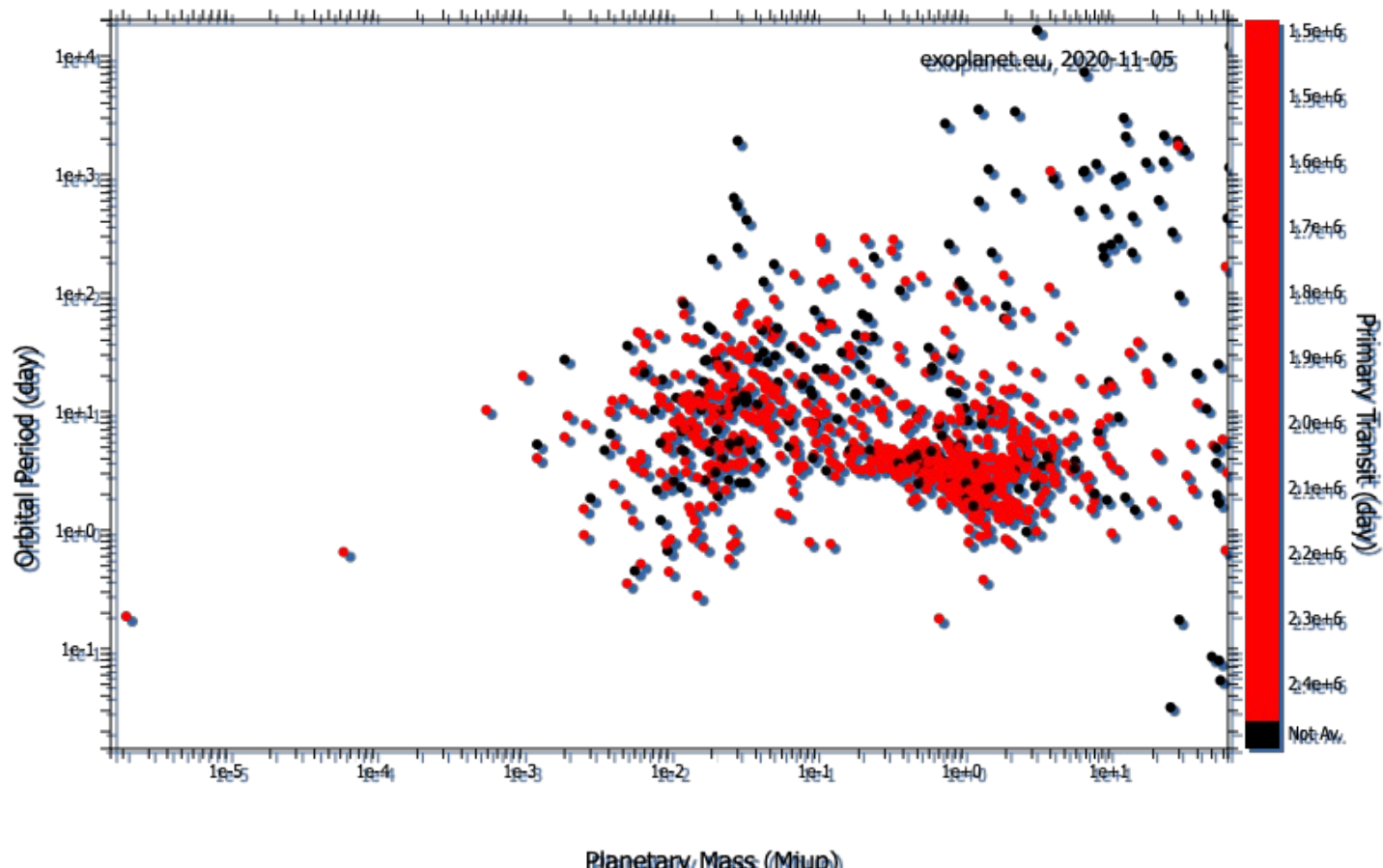
# The first Super Earth

- GJ 876d Rivera et al. 2005 (Figure with RVs)  
<https://arxiv.org/pdf/astro-ph/0510508.pdf>
- $M=7.5M_{\text{earth}}$
- The first model
- - Valencia et al. 2006  
[https://iopscience.iop.org/  
article/10.1086/509800/pdf](https://iopscience.iop.org/article/10.1086/509800/pdf)

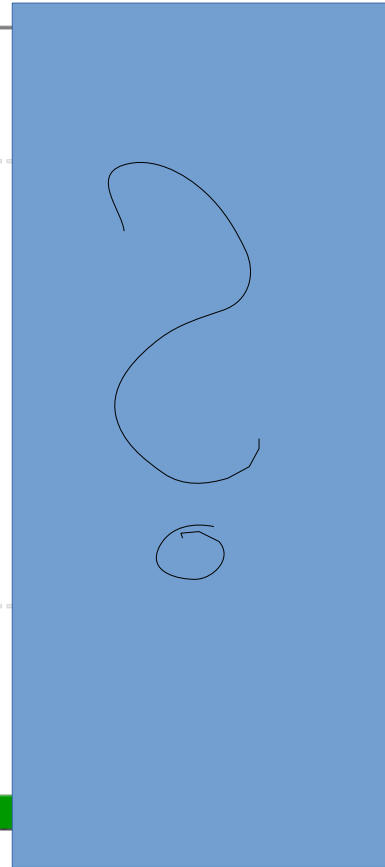
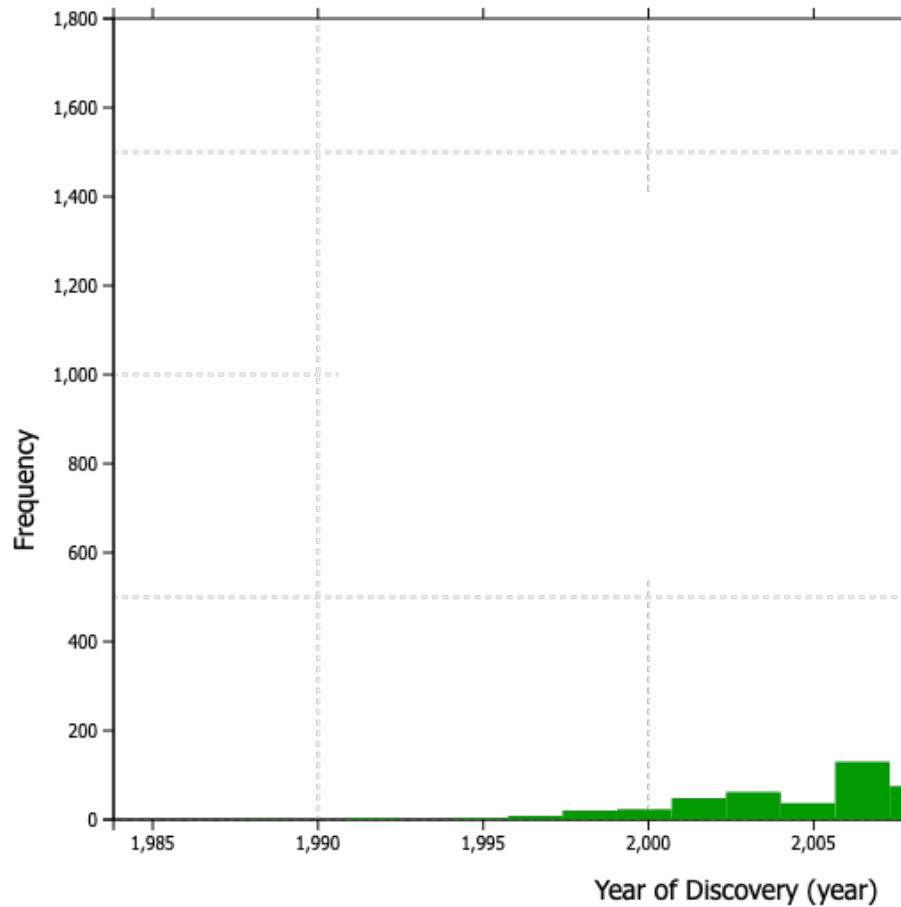




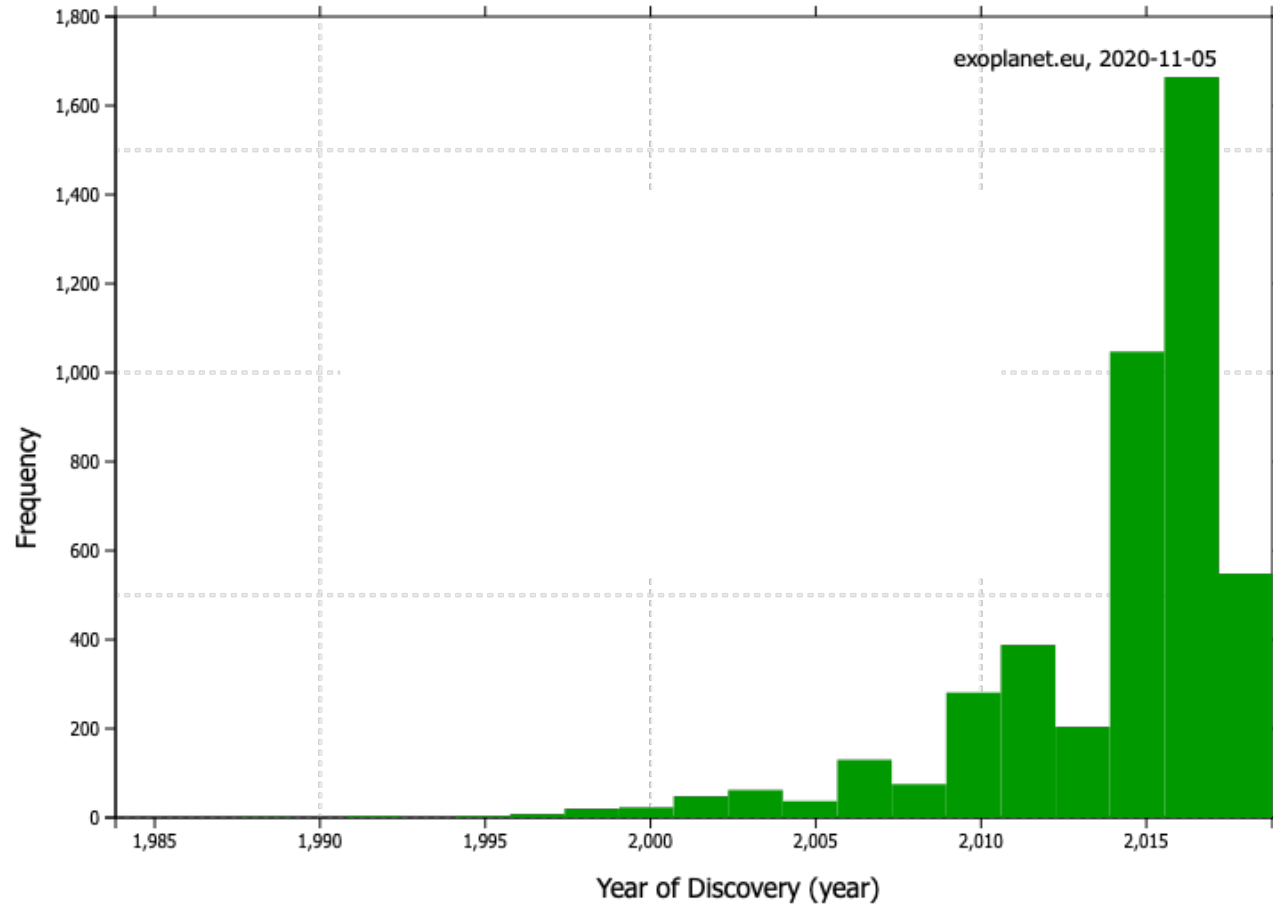
# Mass vs. Period



# Status 2006



# How is the status today?



Then came mini-Neptunes

# GJ1214b

- Super-Earth-sized planet detected in 2010  
*Charbonneau et al. 2010, Nature*

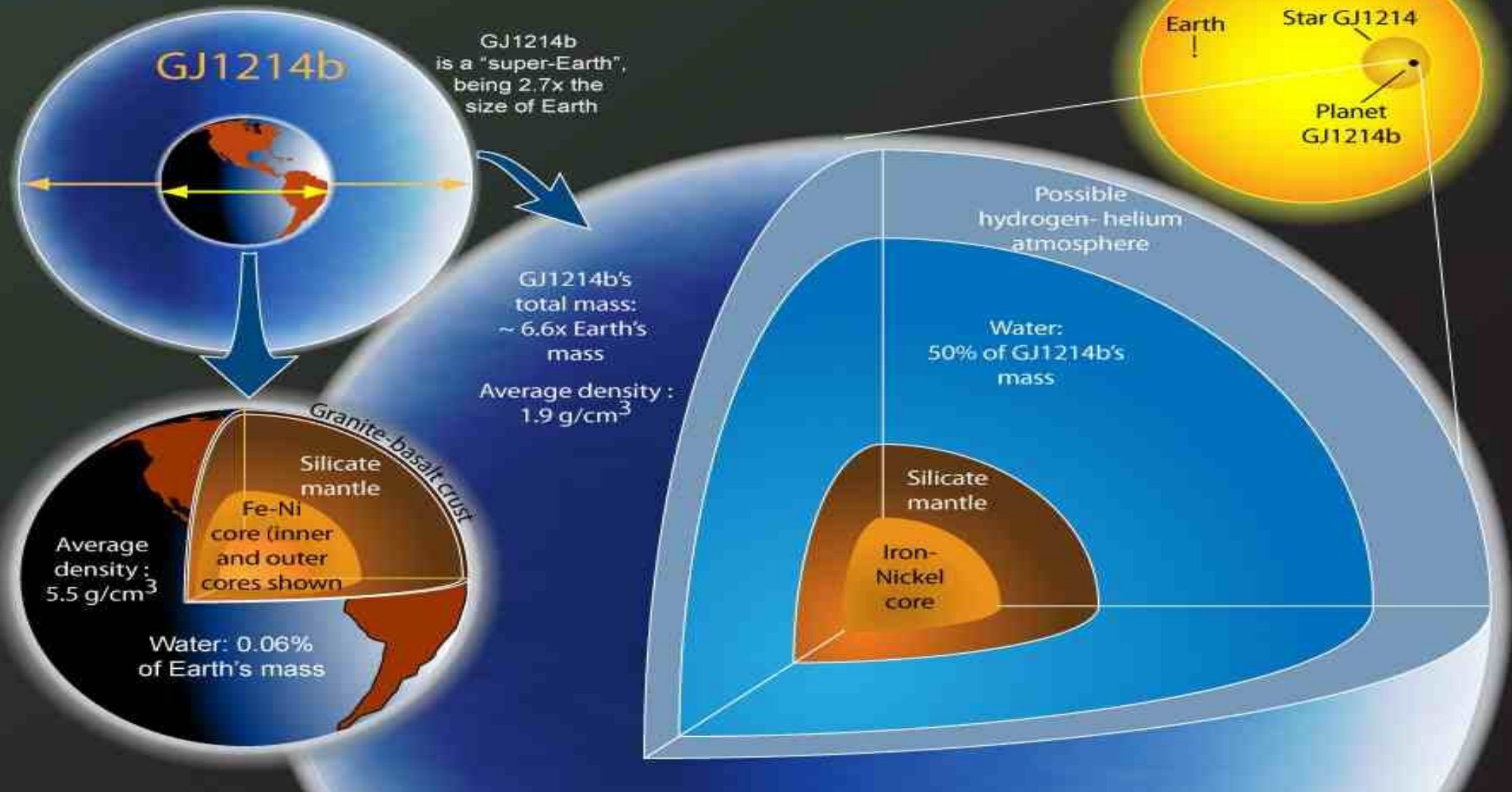
## PARAMETERS

- Orbiting M dwarf star ( $V=14.71$  mag) in 1.58 days
- Only 14pc distance
- $M=0.02M_j$
- $R=0.245R_j$
- Mysterious atmosphere?

# Water World: Exoplanet GJ 1214b

From Nature 17 Dec. 2009; Review by Marcy; Letter by Charbonneau et al.

Illustration © copyright John Garrett



# Super Earths and Rocky planets

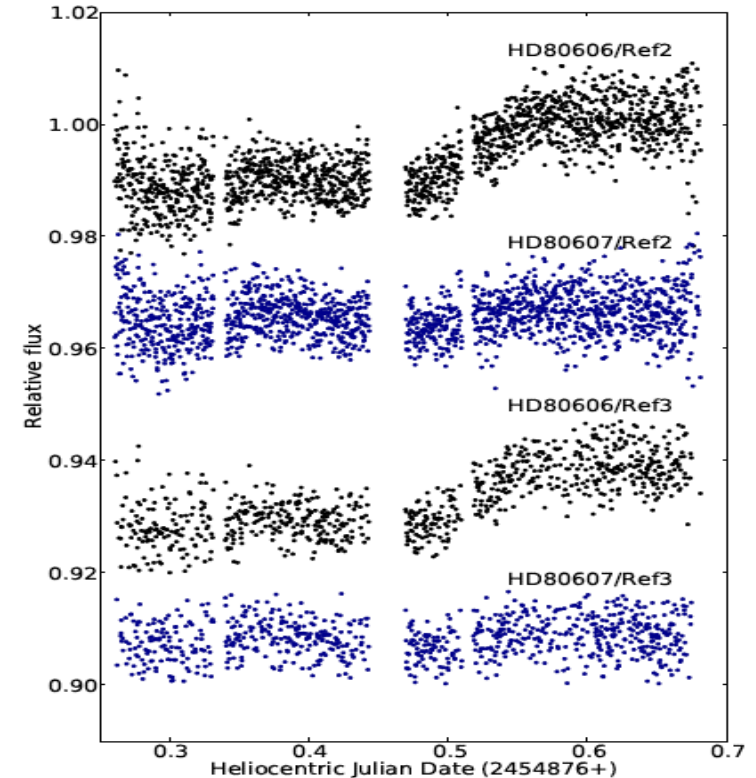
- Super Earths < 10 M Earth (Valencia et al. 2006)
- Planets with a solid surface
- Sub-group of SuperEarths
- They can have an atmosphere or not
- Kepler discovered the most of them

# Super Earths mass limits

- 1-10 Mearth
- Ida et al. 2004, ApJ,  
<https://iopscience.iop.org/article/10.1086/381724/fulltext/58801.txt.html>
  - 10MEarth is the limit where H. He gas can be retained
  - lower bound is for historical reasons
- In this group belong planets with oceans, rocky and massive Earths planets

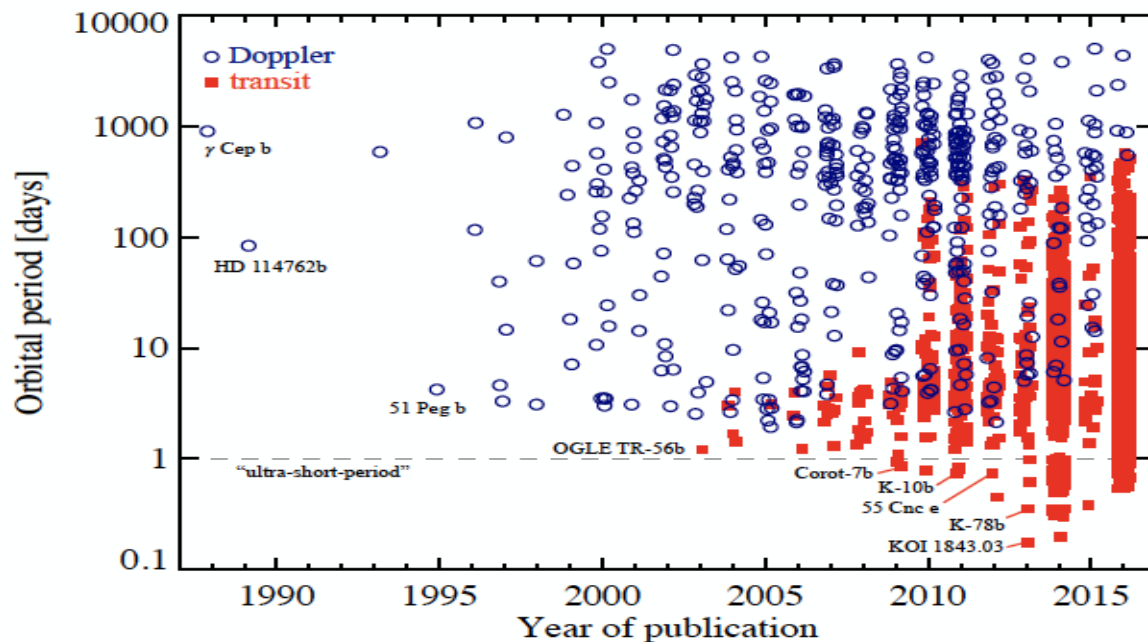
# Warm Jupiters

- Gas giants with orbital periods 10-200 days
- HD 80606 b – 111 days period
  - binary component HD 80607
  - 4 Jupiter masses
  - 12 hrs. Transit
  - 0.93 eccentricity (very high)
- Orbital parameters  
might be the key to formation?
- Discovery:  
Naef et al. 2001  
<https://www.aanda.org/articles/aa/pdf/2001/32/aade293.pdf>

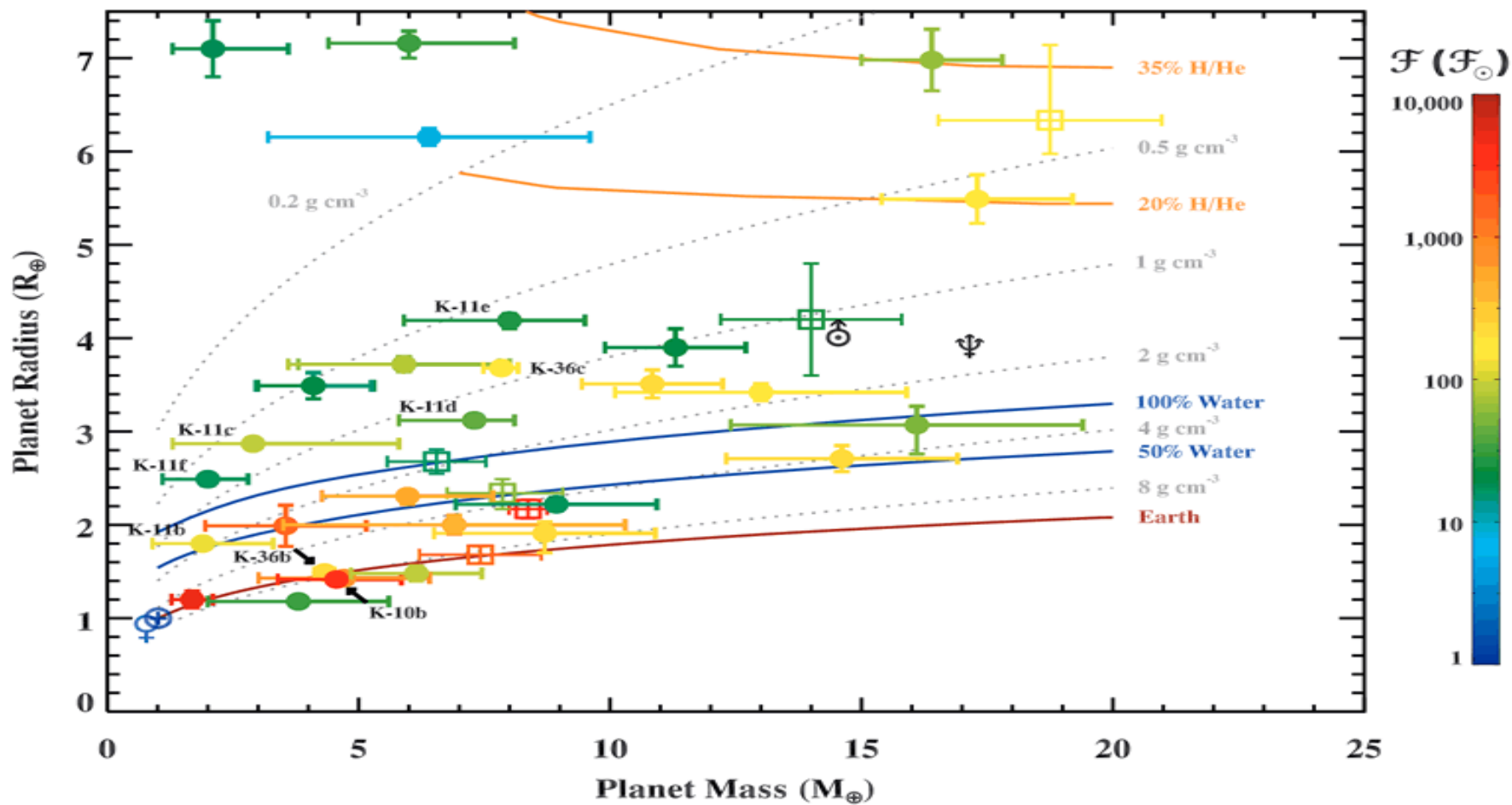


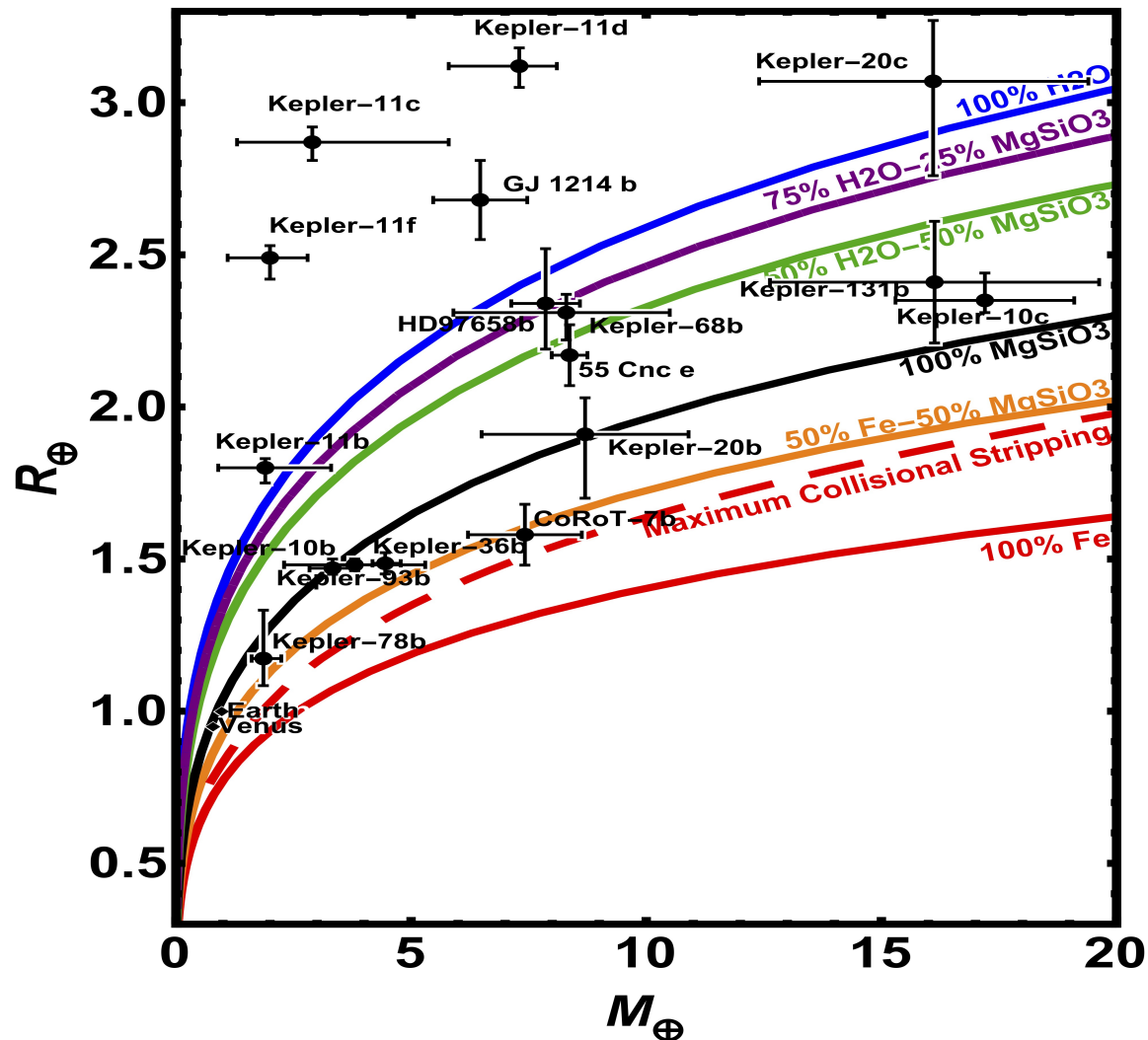
# Ultrashort period planets (USPs)

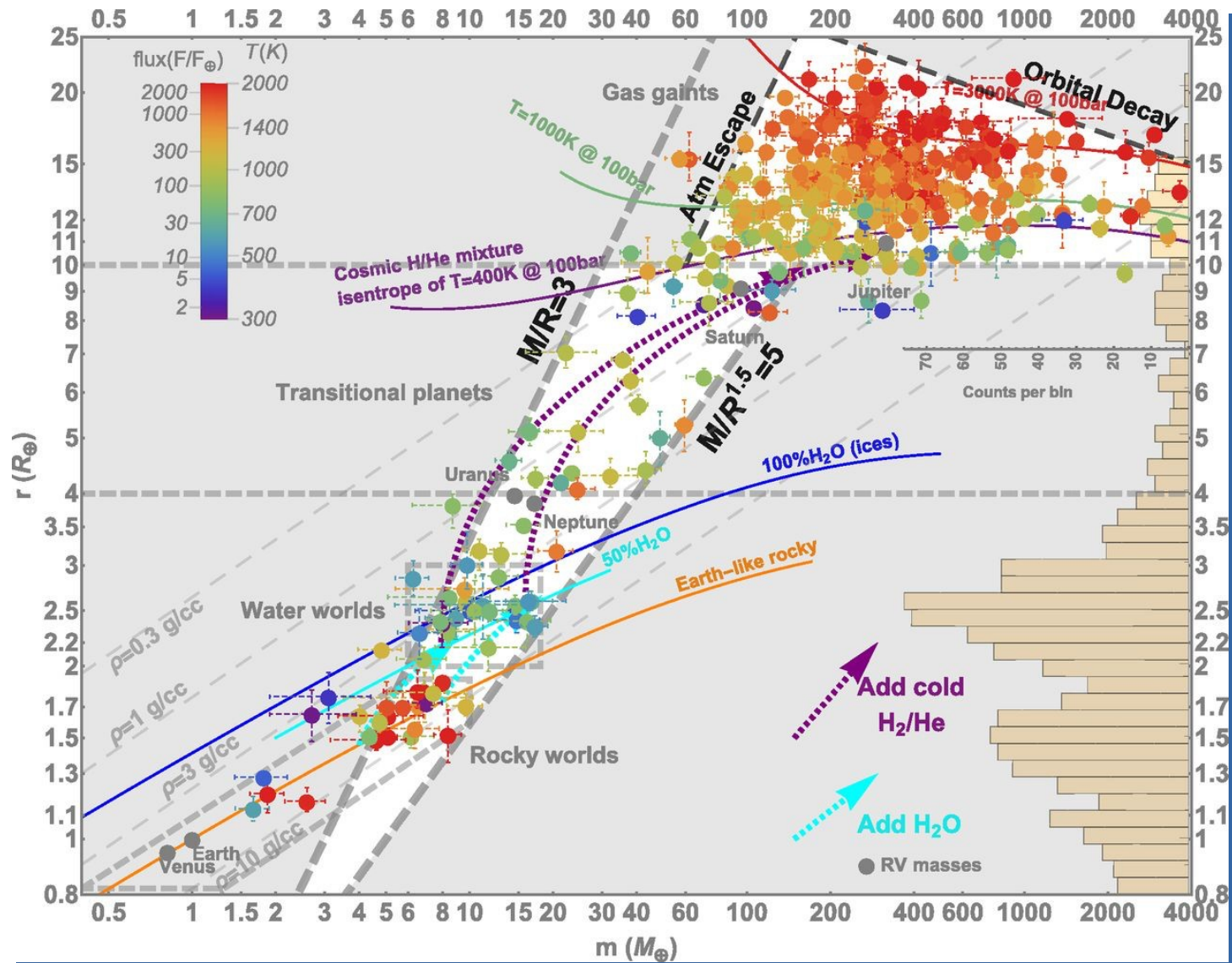
- Small planets often called Lava worlds
- Orbital periods  $< 1$  day
- Very close to host stars
- Very high surface temperature



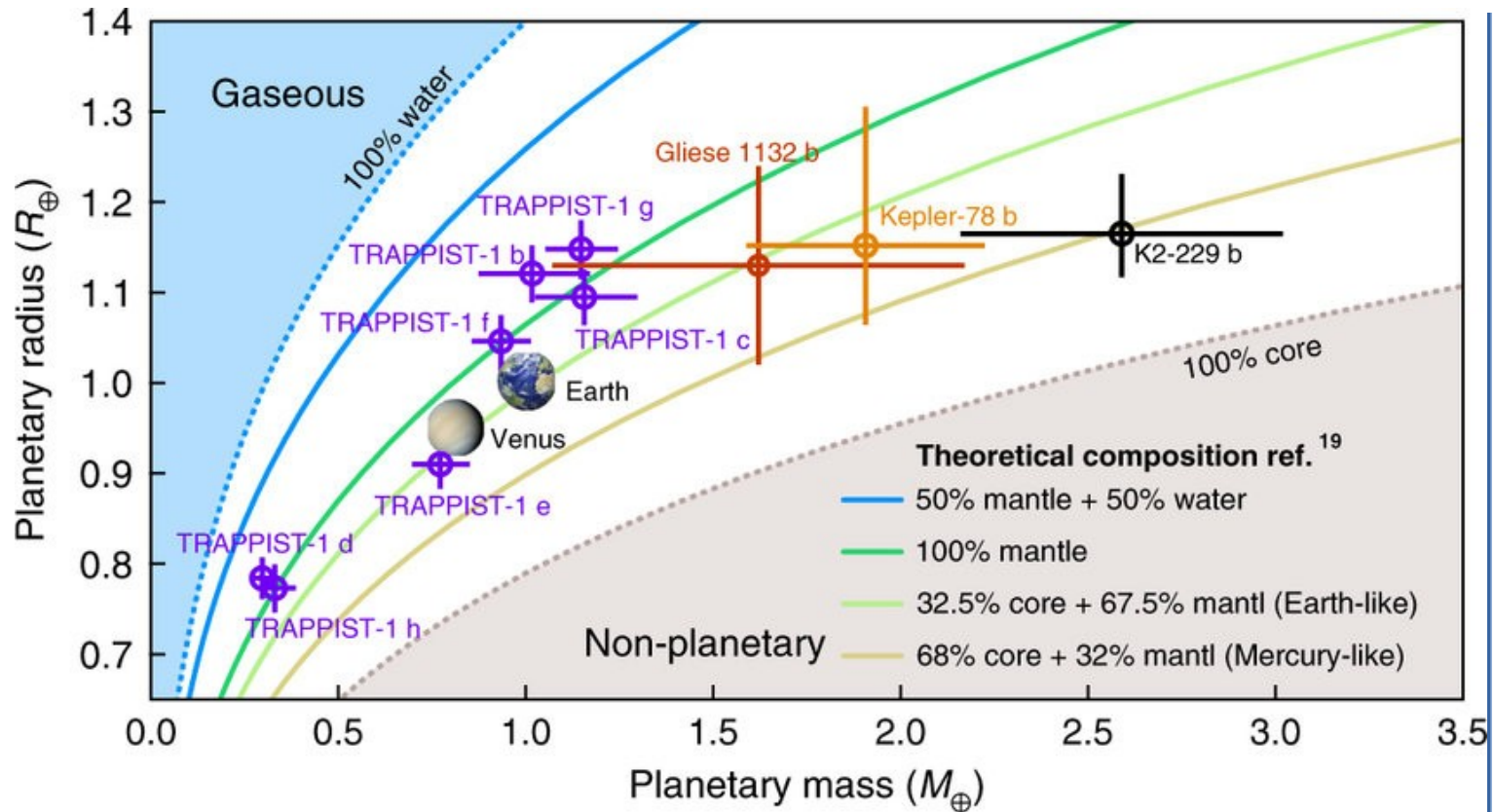
# Mass radius diagrams







# Getting closer to the Earth-like



# Next lecture

- Evolution of our Solar System
- Evolution of exoplanetary systems
- The place of our Solar system in the Universe