The Validation of habitable/rocky planets

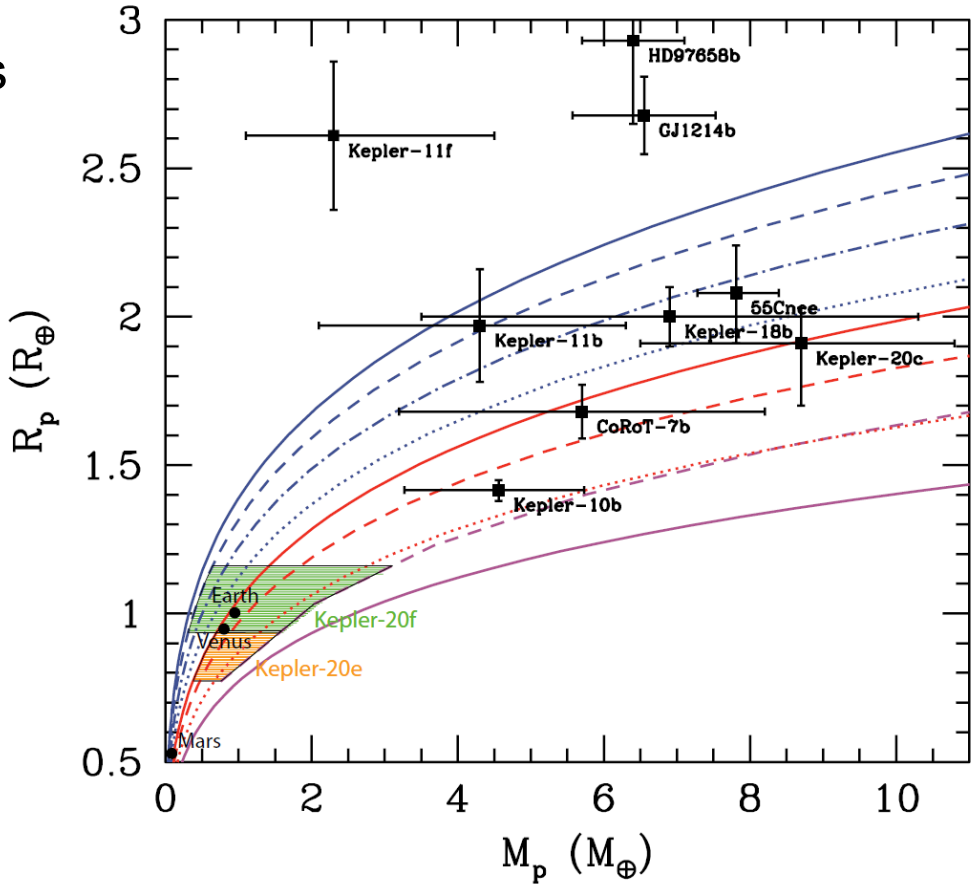
Francois Fressin

Validation does not provide a mass

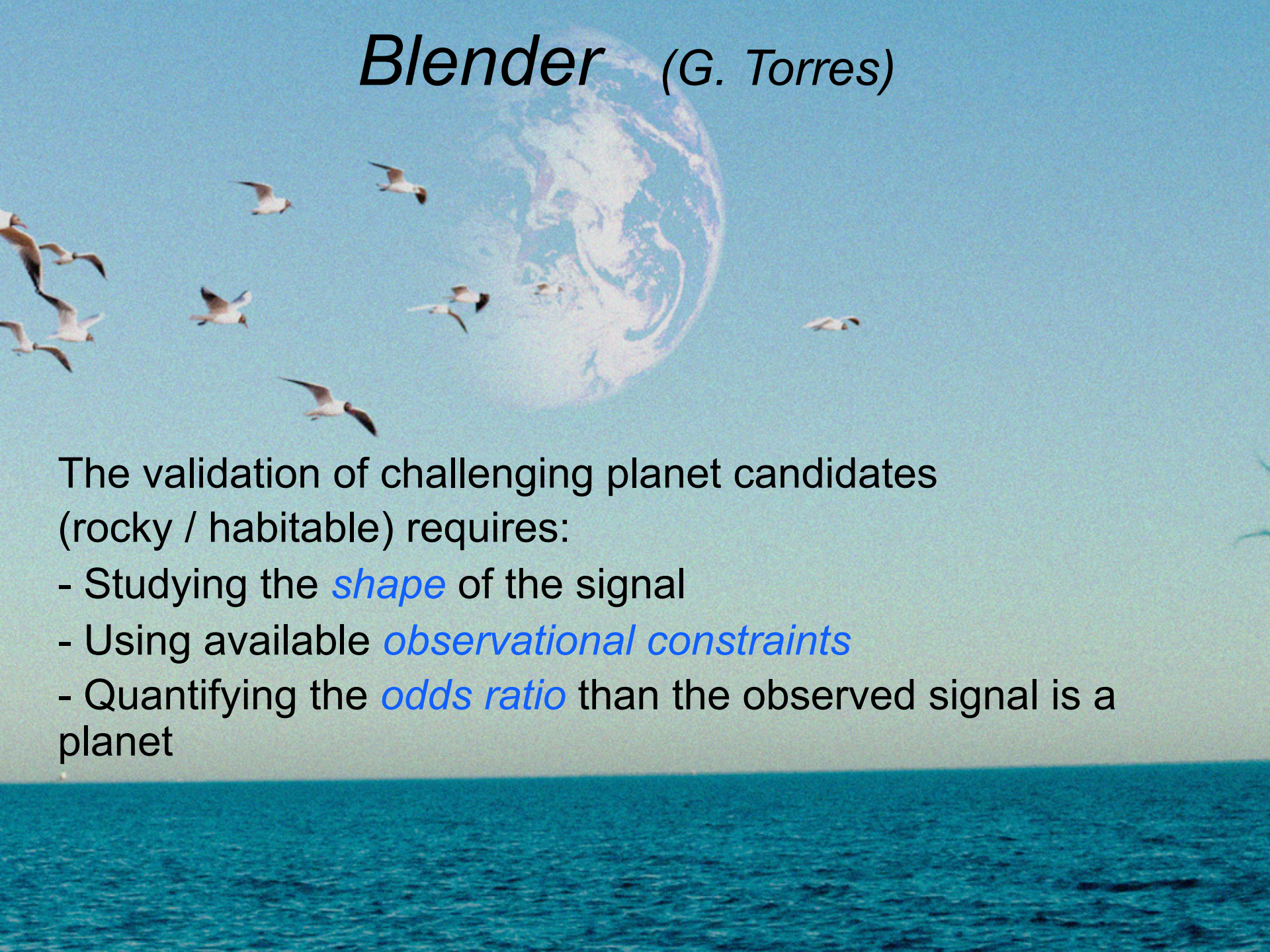
Obtaining the mass of small planets is of primary importance. (TTV, RV)

Blender can be used as a supporting tool
(e.g. Kepler-10b, CoRoT-7b)

… and to validate the most interesting planets (beyond the reach of other techniques)



Blender *(G. Torres)*



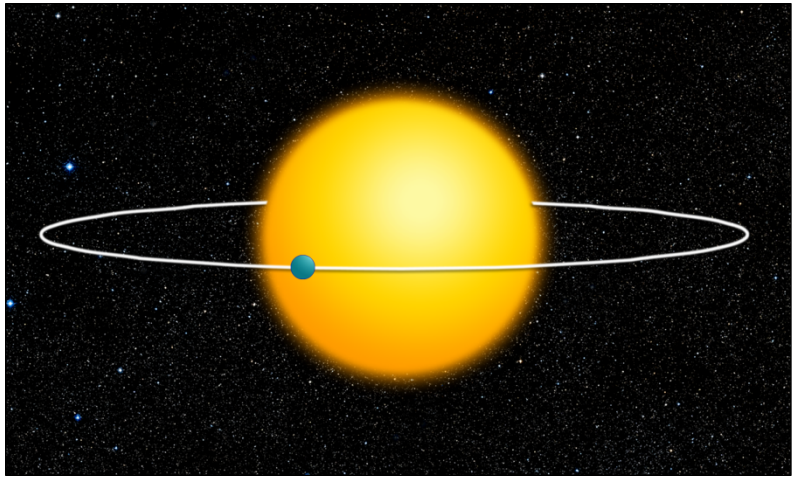
The validation of challenging planet candidates (rocky / habitable) requires:

- Studying the *shape* of the signal
- Using available *observational constraints*
- Quantifying the *odds ratio* than the observed signal is a planet

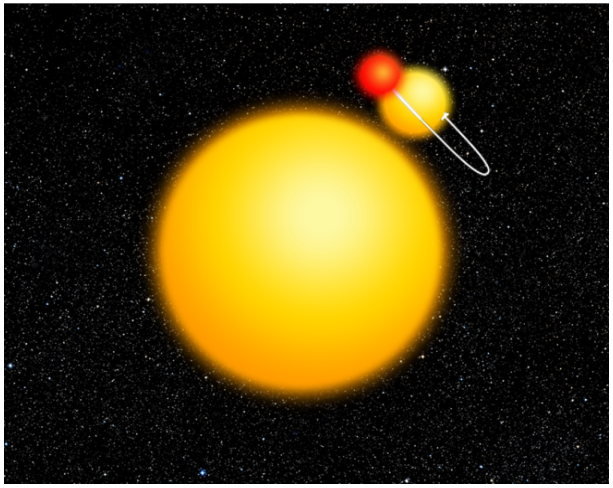
Planet or Blend?

An observed periodic transit signal could be due to:

Transiting Planet
(or planetary size object)



Eclipsing Binary *Physically bound or Chance alignment*



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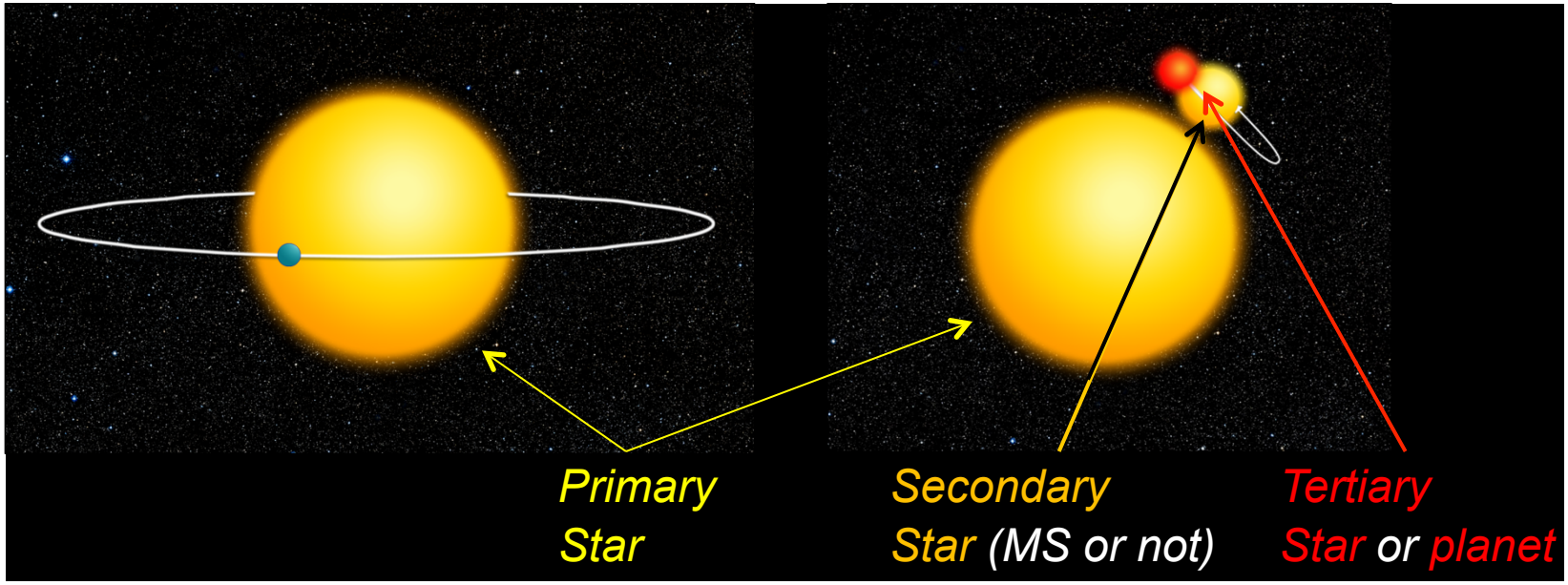


The information in transit light curves

We use ***Blender***, a light-curve fitting software

It attempts to explain Kepler candidates assuming they are the result of a pair of eclipsing objects in the photometric aperture.

It includes stars (MS/giant/brown dwarfs, white dwarfs), planets

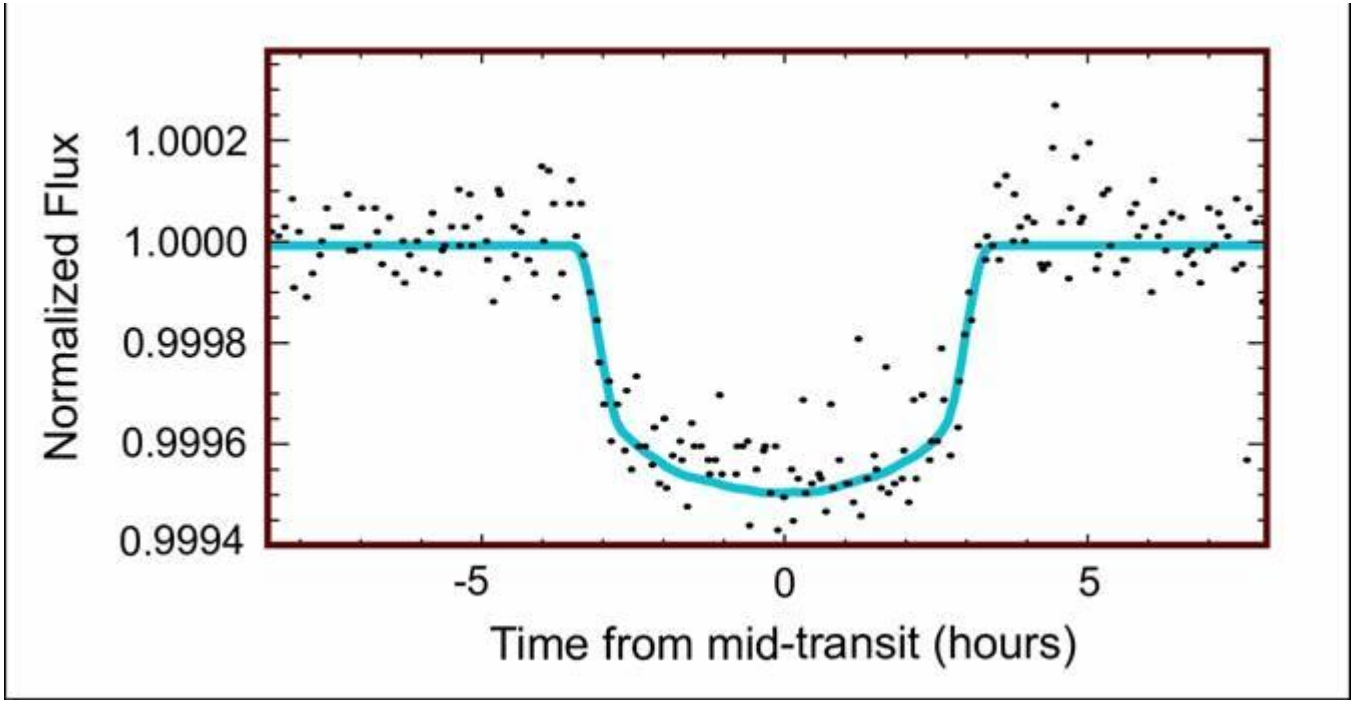
at different distances, orbital periods, eccentricities

and models their effects on photometric light curves: eclipses/transits, secondary transits, ellipsoidal variation, gravity darkening.

that all influence the ***shape*** *of the signal*

Nature can find a lot of ways to reproduce the shape you are looking for

Blender results : Example of Kepler-10c

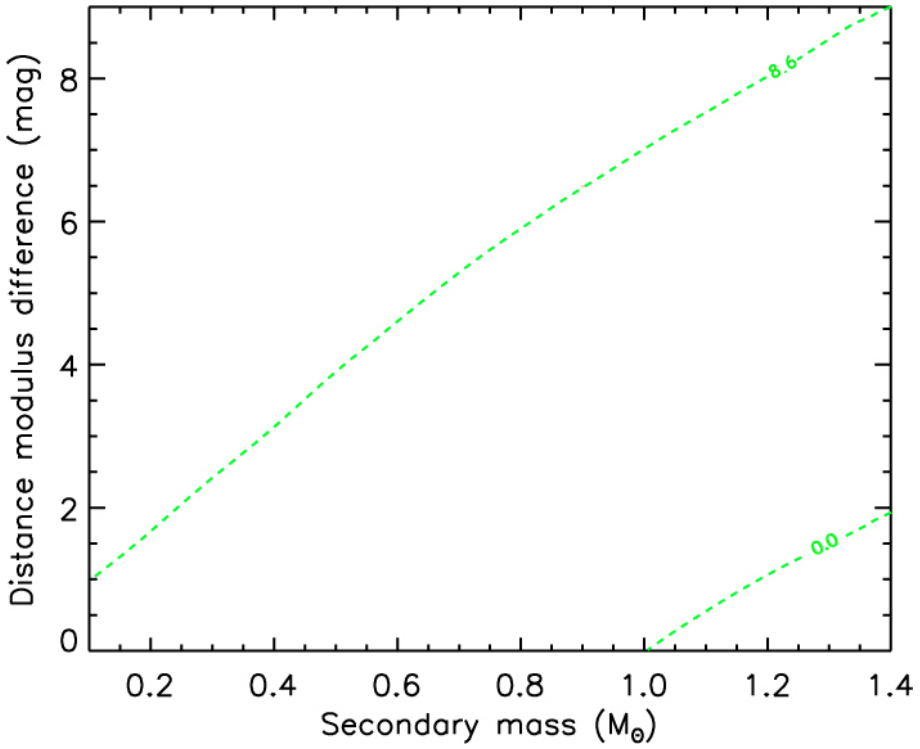


Planet ?
Period = 45.3 days
Radius = 2.23 R_{Earth}

Or another
astrophysical event ?

Blender results : Example of Kepler-10c

Eclipsing Binary Stars can mimic a transiting planet signal



Blender results : Example of Kepler-10c

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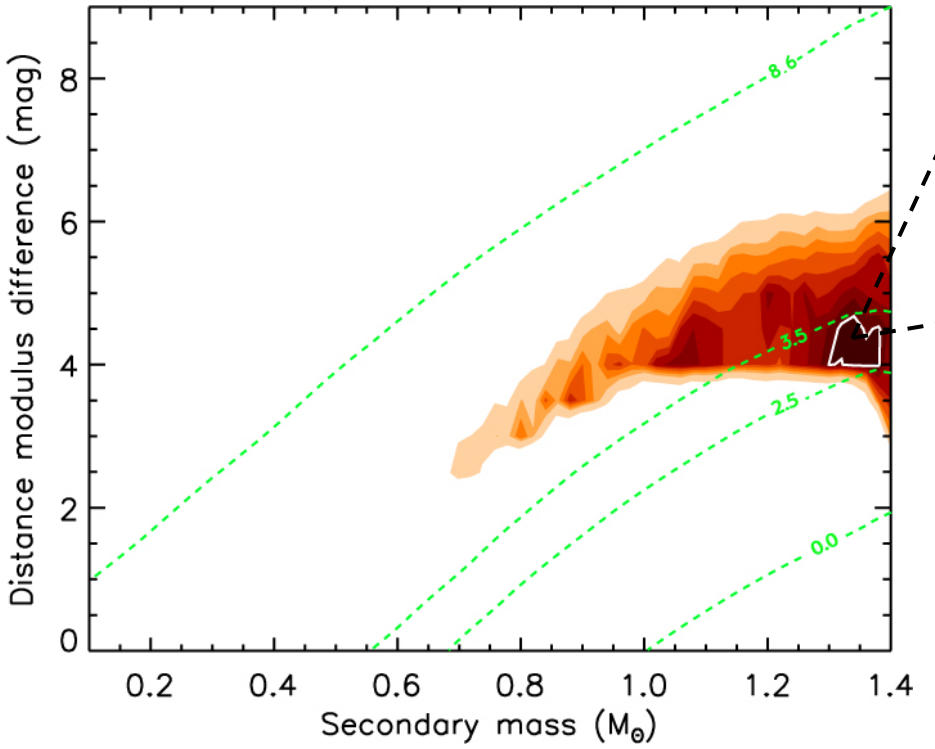

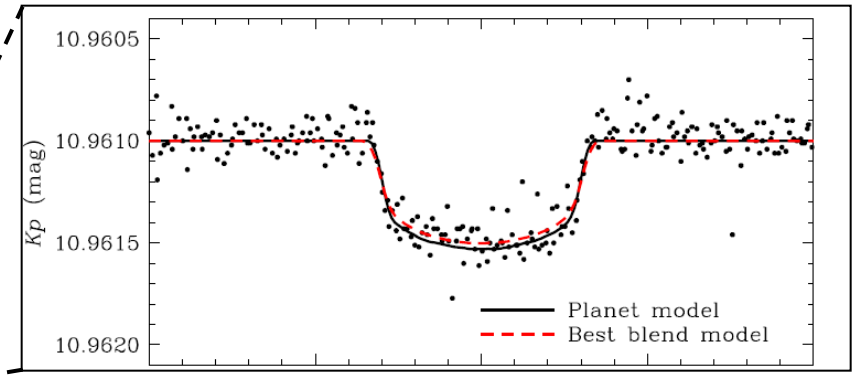

Blender results : Example of Kepler-10c

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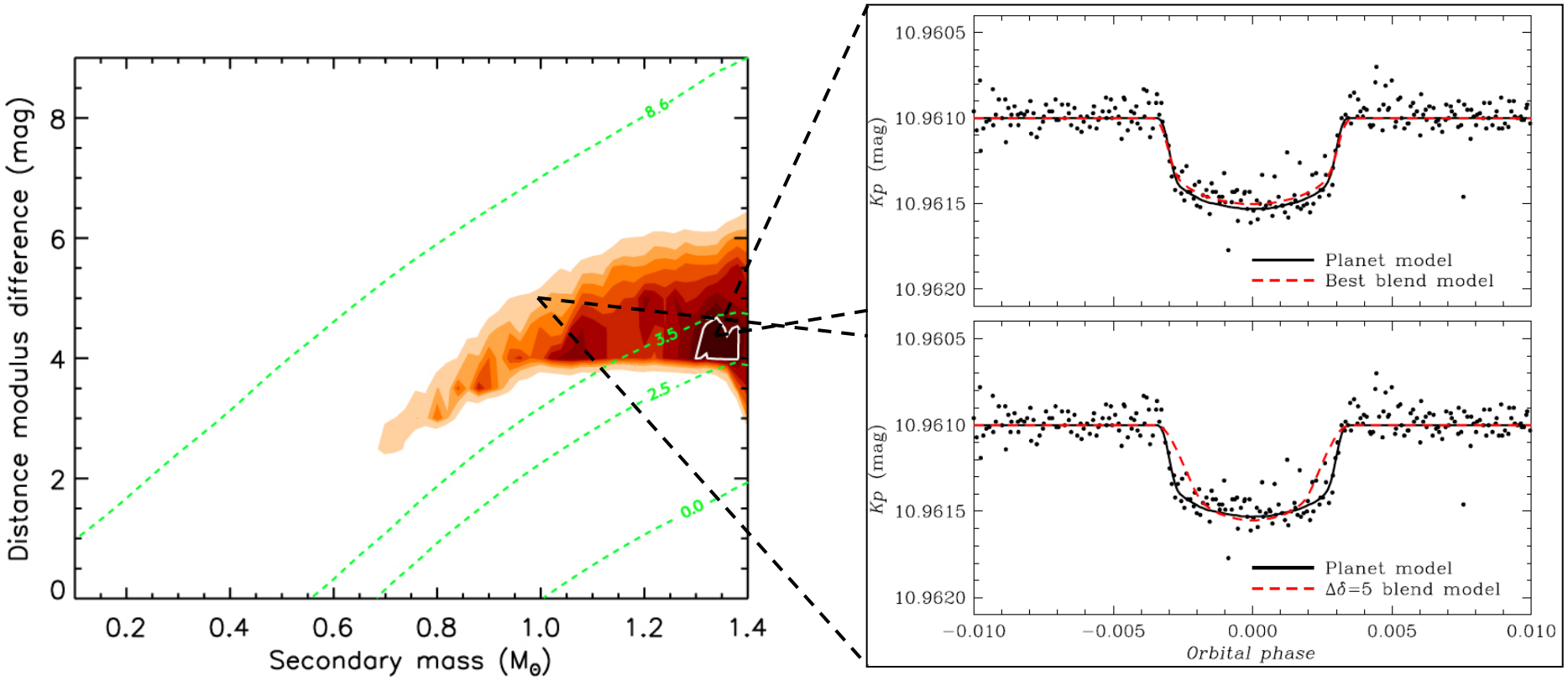
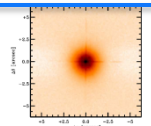
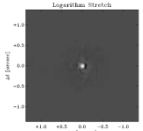


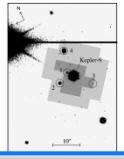
Blender results show that only a ***very small fraction*** can actually reproduce the exact transit shape

Combining Follow-Up Observations

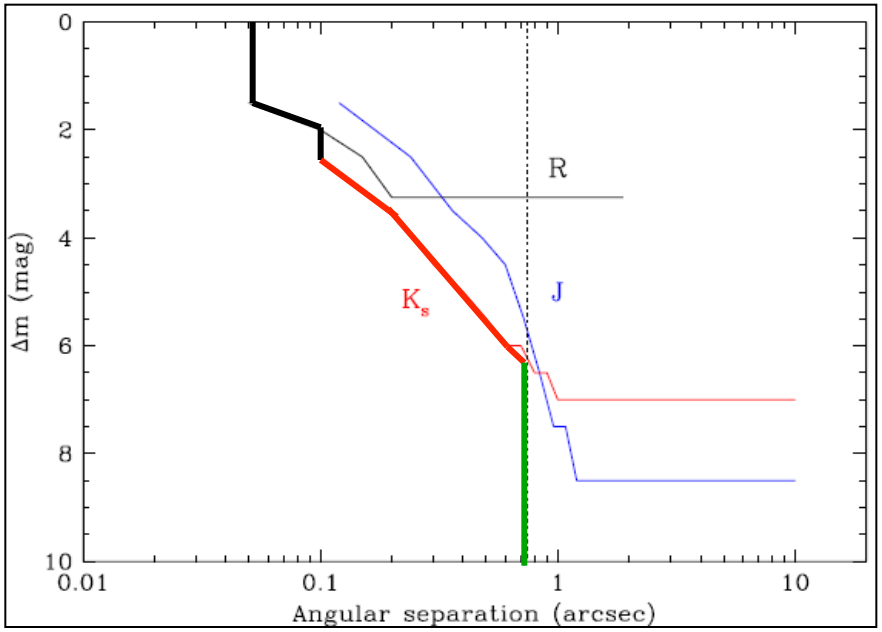
Separation
vs.
Magnitude





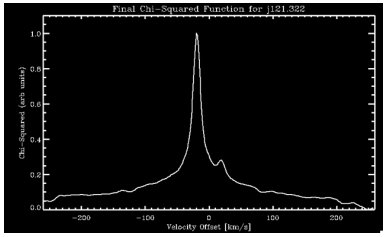
- **Speckle** interferometry
  (*WIYN at Kitt Peak*)
- Adaptive optics imaging
  (*PHARO at Palomar*)
- Centroid shift analysis
  (*Kepler* data)

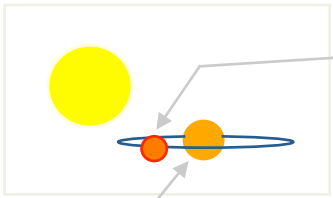


Combining Follow-Up Observations

Color
vs.
Magnitude

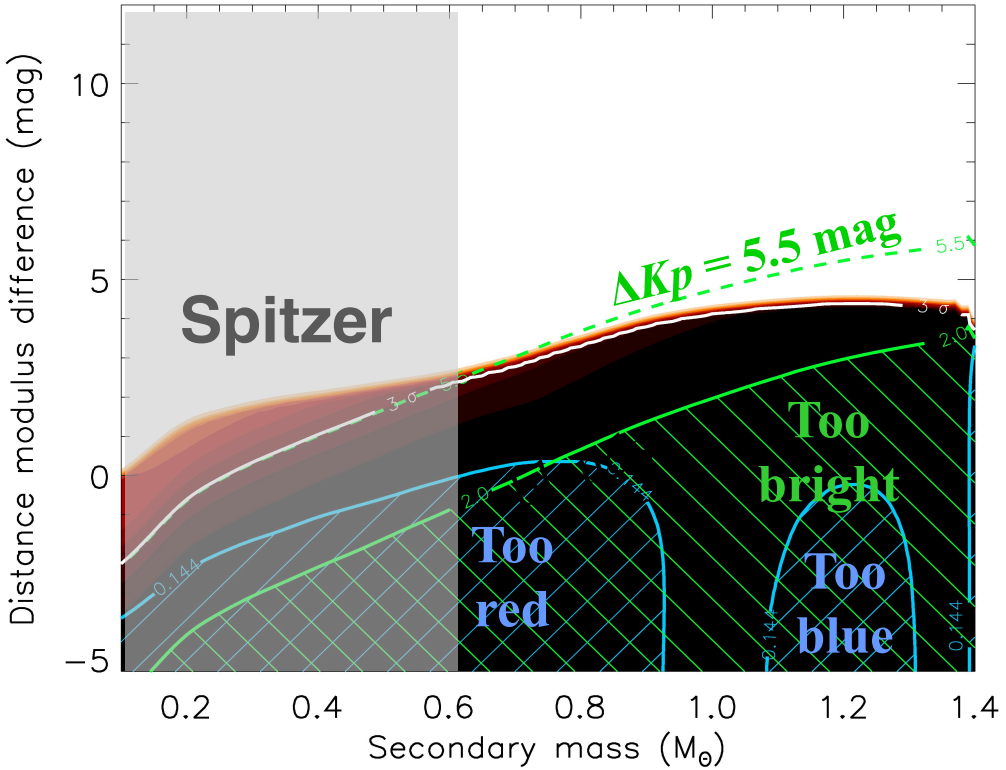
- Spectroscopy
(*Hires at Keck*)
- Multi-color photometry
(*KIC, 2MASS*)
- Infrared transit observation
(*WarmSpitzer)*





Tertiary is a transiting planet

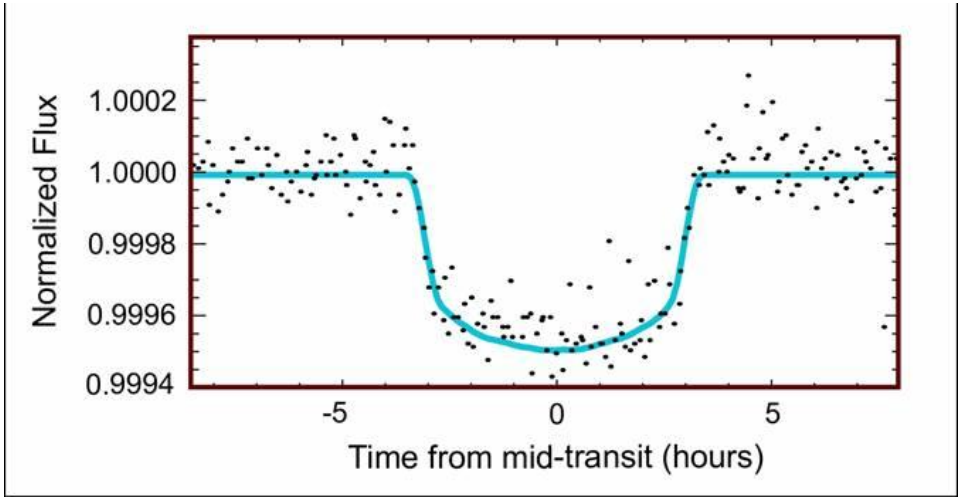
Secondary

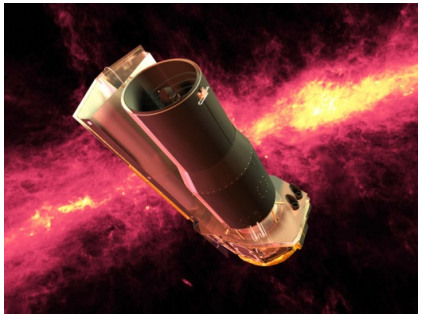


Using Spitzer to constrain blend scenarios

Kepler

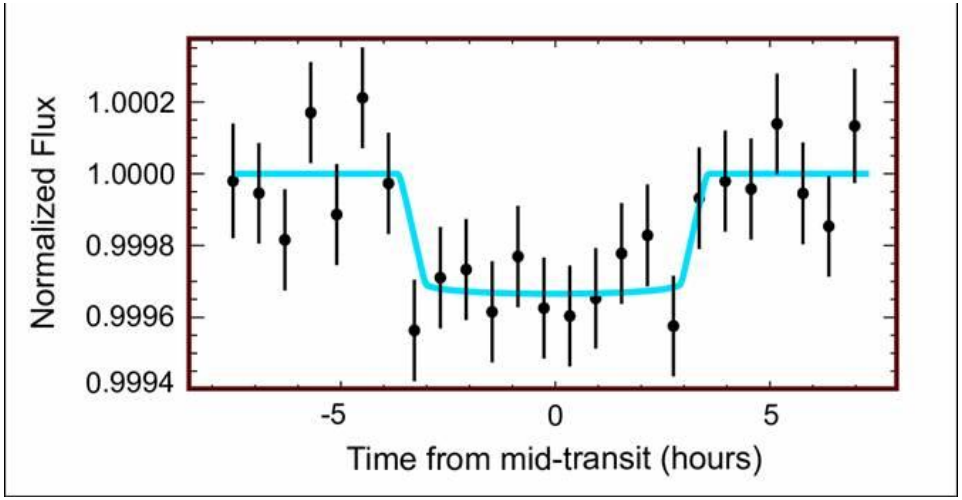
In visible light





SPITZER SPACE TELESCOPE

In Infrared



Determining the ‘odds’ ratio

Combining ***Blender results*** with ***observational follow-up*** tools provides knowledge of what Blend scenarios can mimic the transit signal.

We then ***quantify*** the likelihood of the occurrence of such scenarios,

- based on galactic structure models (for background stars),
- & multiple stars surveys (for bound stars)

taking into account dynamical constraints

Once we estimated the likelihood of a **neighbor star** allowed by **Blender results** and **observational follow-up** constraints, we quantify its **chance** to have an eclipsing transiting object of **the adequate size**, based on the Kepler survey itself.

We do the same for the true **transiting planet** scenario

We compare the odds between the **planet prior** and the **blend frequency**

Estimating specific transiting objects occurrence using Kepler catalogs

The Kepler catalogs (Batalha et al. 2012, Slawson et al. 2011) provide the best estimate of the occurrence of eclipsing binaries & transiting planets

But there are biases in these catalogs:

-They are incomplete

-They contain false positives

-Occurrence could be correlated with spectral type

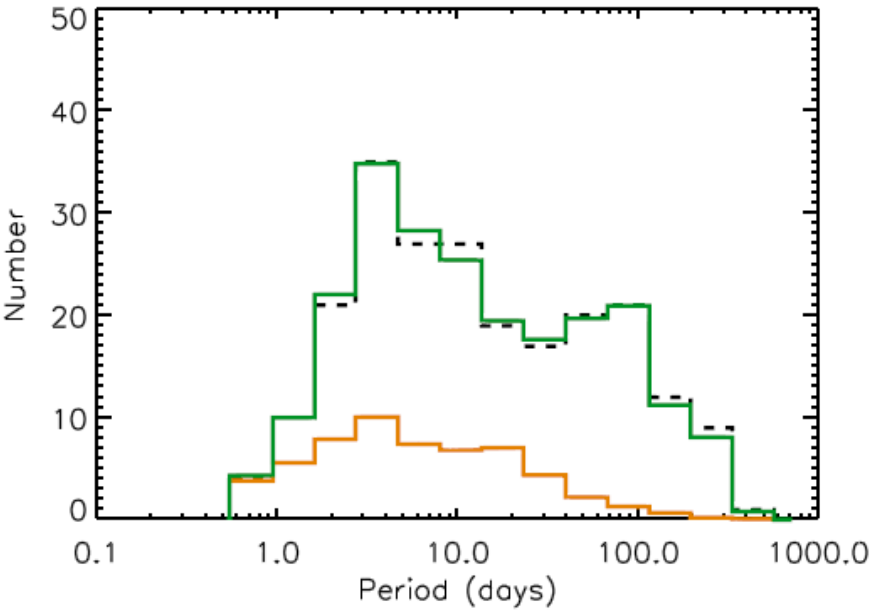
-We do a MC simulation of the Kepler survey to estimate these three effects considering all kinds of blends, and their detectability

Example:

Giant planet KOIs

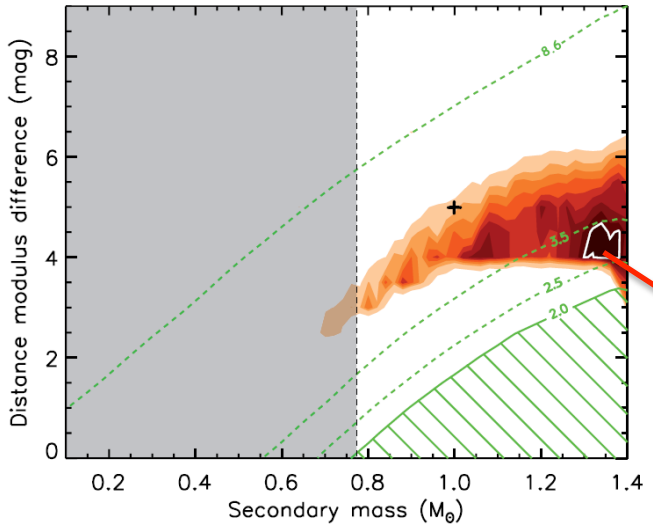
Blends of all kinds

Simulated planets + blends

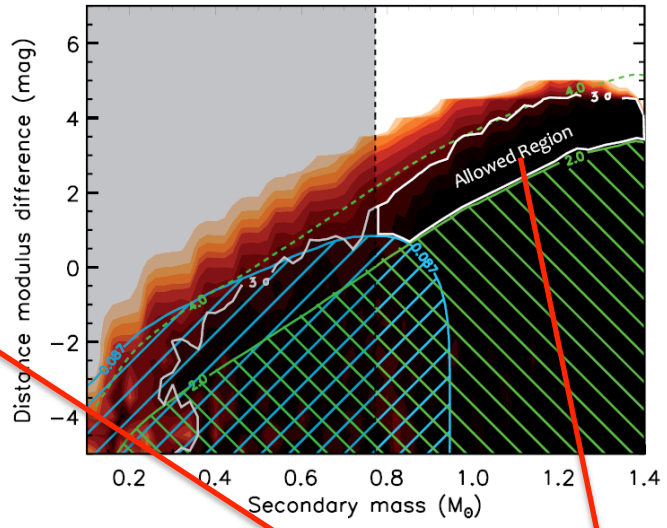


Quantifying the blend probability

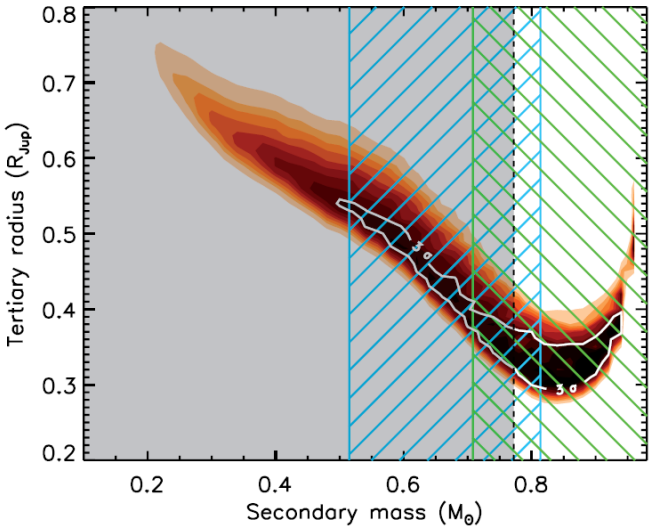
Background star + star



Background star + planet



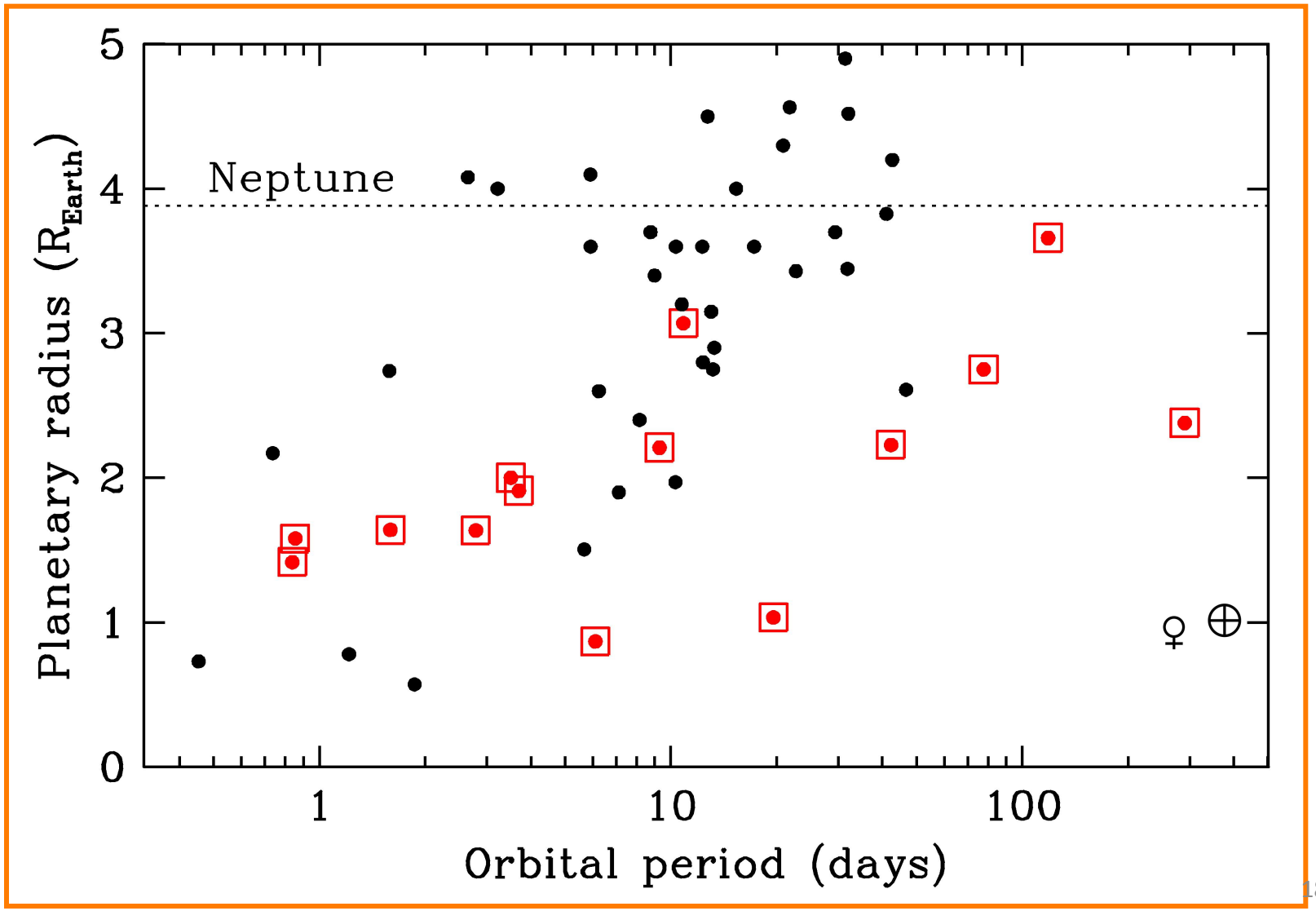
Physically bound star + planet



- Blend frequency = (0.41 + 1.21) x 10^{-8}
  = 1.62 x 10^{-8}
- Planet prior = 1.0 x 10^{-3}

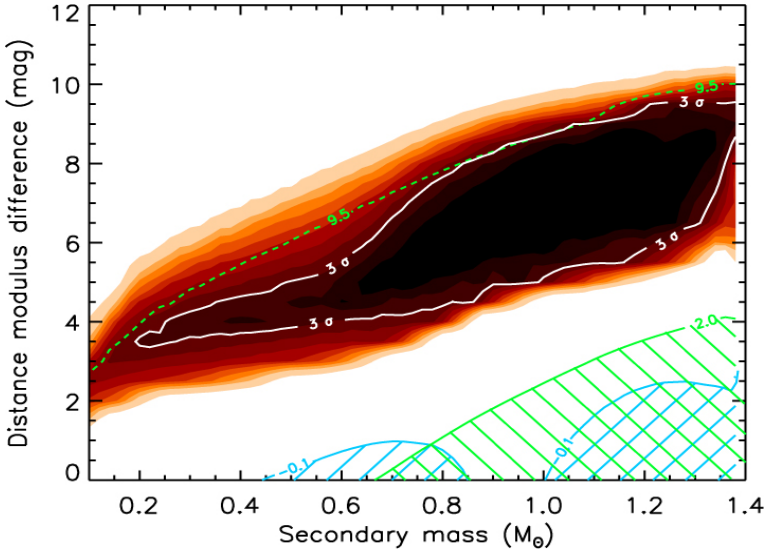
The planet hypothesis is 60,000 times more likely than a blend

A picture of transiting planet detections

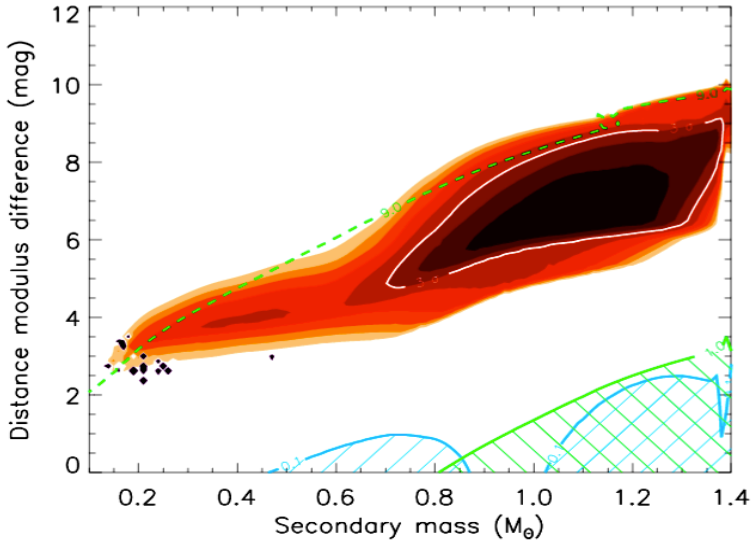


***Blender** results **strongly** scale with the amount of data.*

Sub-Earth-size Kepler candidate



*Allowed Eclipsing binaries using **Q1 – Q5***



*... are **divided** by **3** using **Q1 – Q8***

*Gathering more data won't only provide more critical KOIs, but also **strongly help validating** them (improved Centroid and Blender)*