Effect of stellar activity on the high-precision transit light curve

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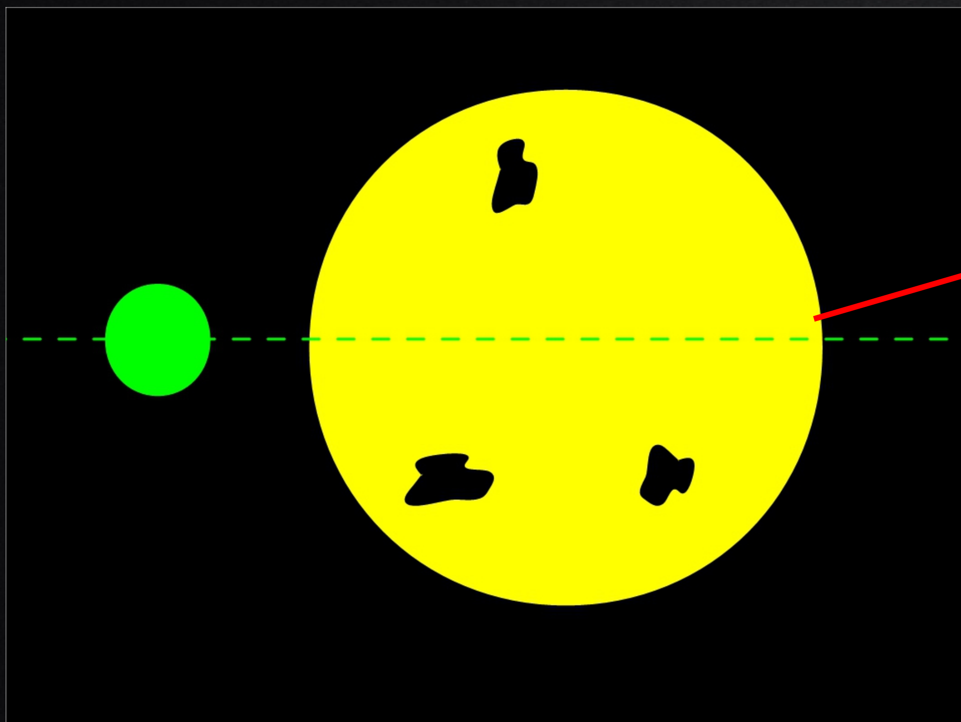
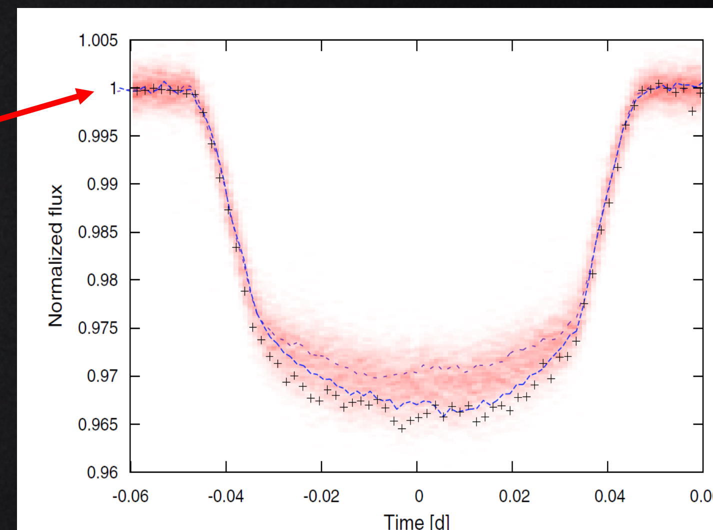
Outline

- Stellar spot impact on the planetary transit
- Quantifying the spot occultation impact
- Impact of stellar activity on transmission spectra
- Can stellar activity mimic the signature of blue sky in HD 189733b and GJ 3470b?
- Conclusions

Non-occulted stellar spots



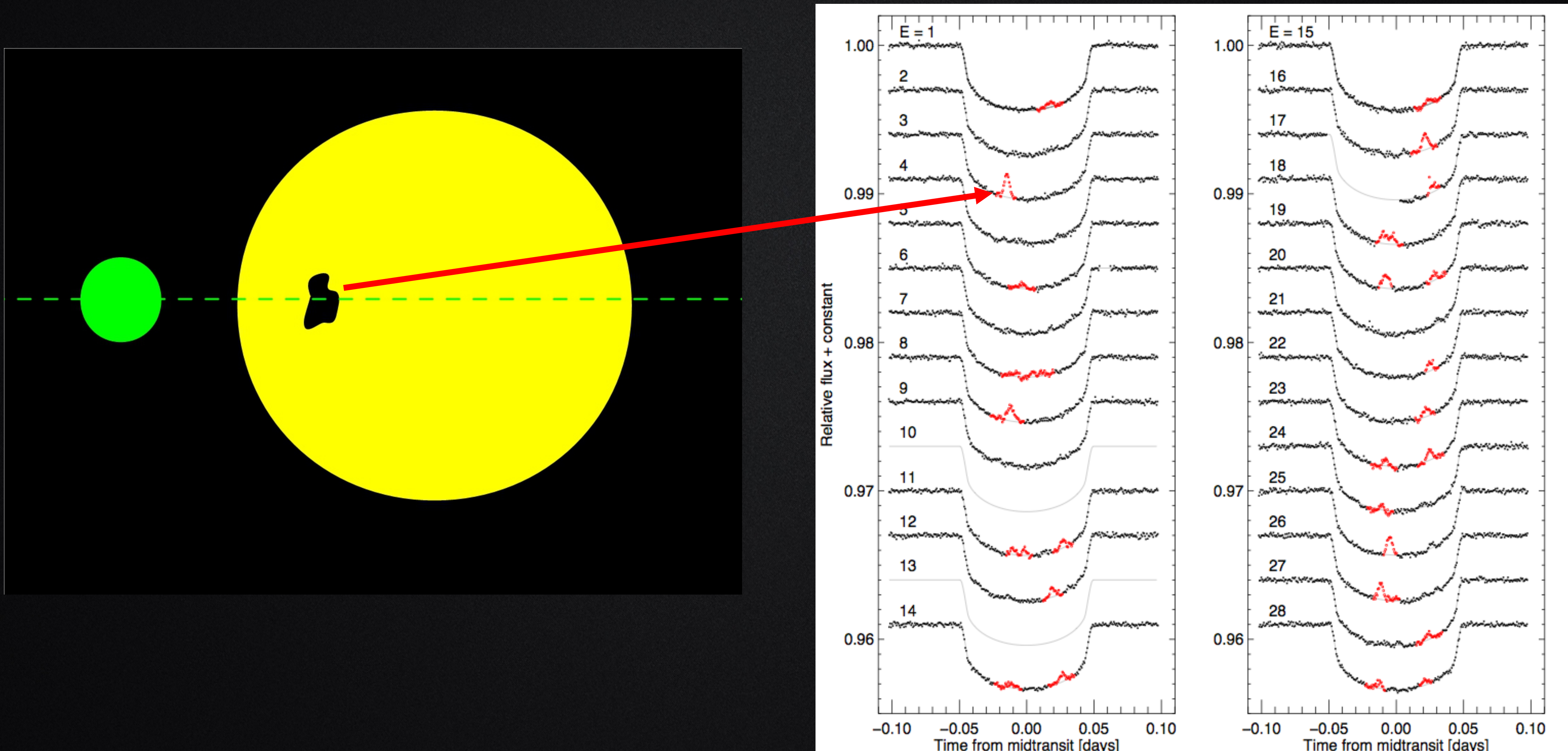
$$\frac{\Delta f}{f} = \left(\frac{R_p}{R_*}\right)^2$$



Czesla et al 2009, CoRoT-2b

Overestimation on the planet radius by 3–4% (Czesla et al 2009)

Occulted stellar spots



HAT-P-11b observed by Kepler

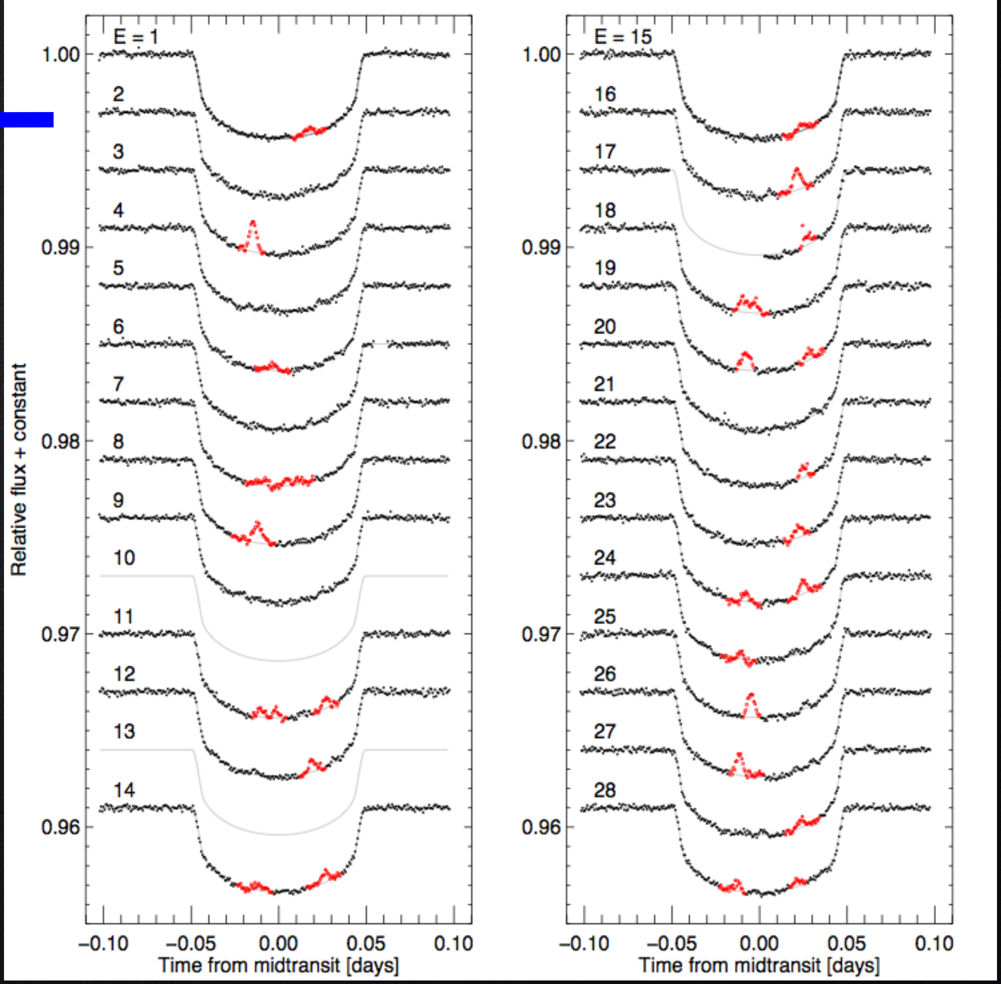
Occulted stellar spots

In the case that the spot anomaly is clearly identifiable

Some authors assigned a zero weight to the anomalous points of the light curve.

May not be the best approach, since the missing points in the transit light curve can cause offsets in the estimations

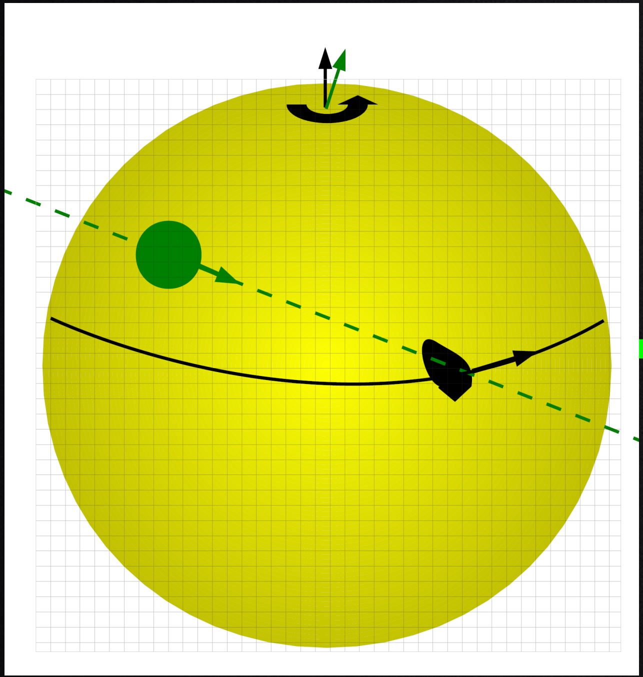
It is better to model them and then remove anomaly features from light curve

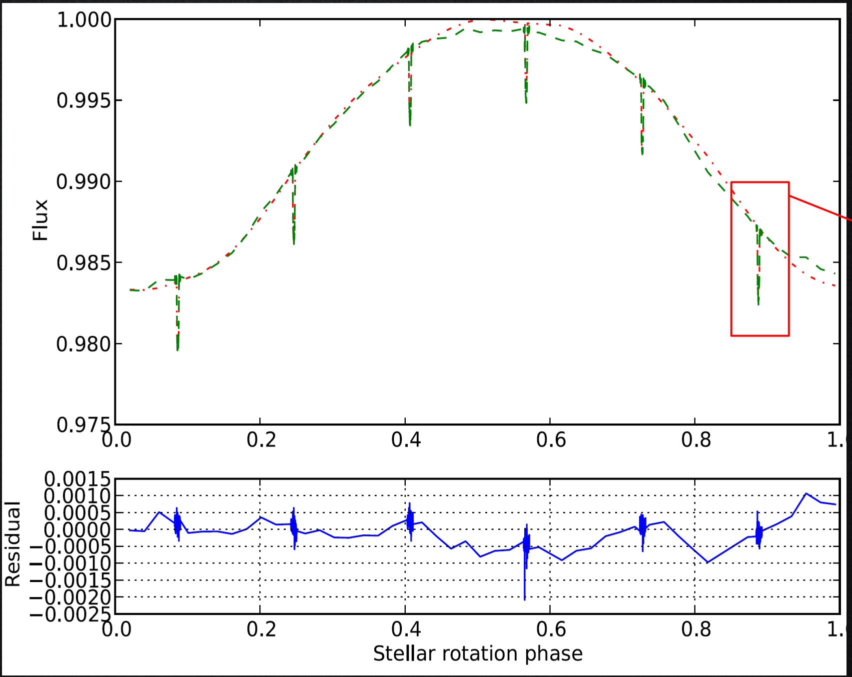


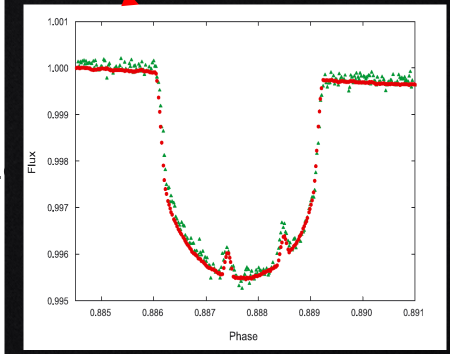
HAT-P-11b observed by Kepler

SOAP-T

SOAP-T produces the expected light curve and the radial velocity signal of a system consisting of a rotating spotted star with a transiting planet. SOAP-T is able to reproduce the "*positive bump*" anomaly in the transit light curve due to a planet-spot overlap.







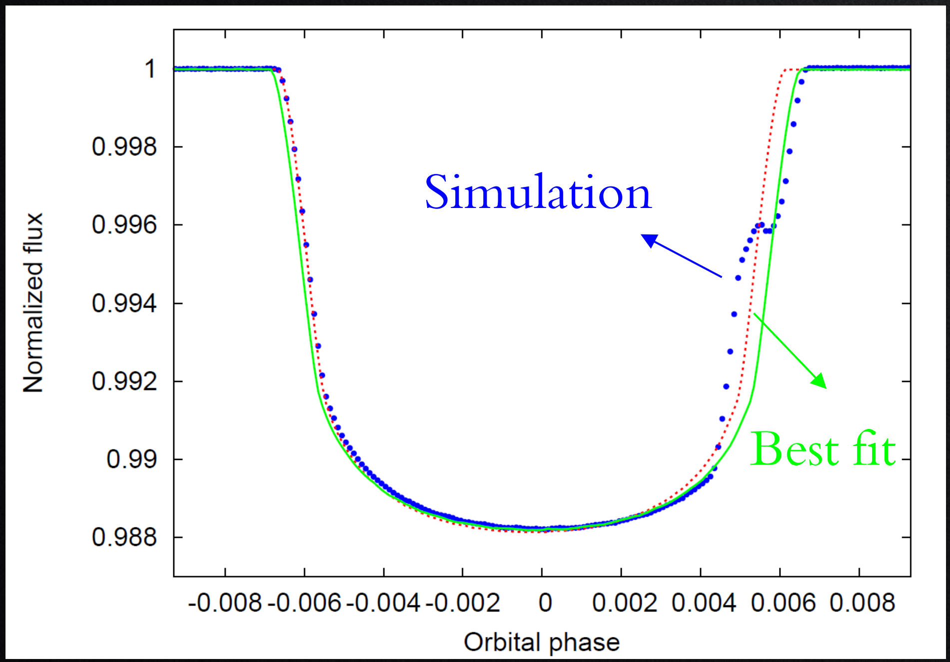
HAT-P-11, Oshagh et al 2013a

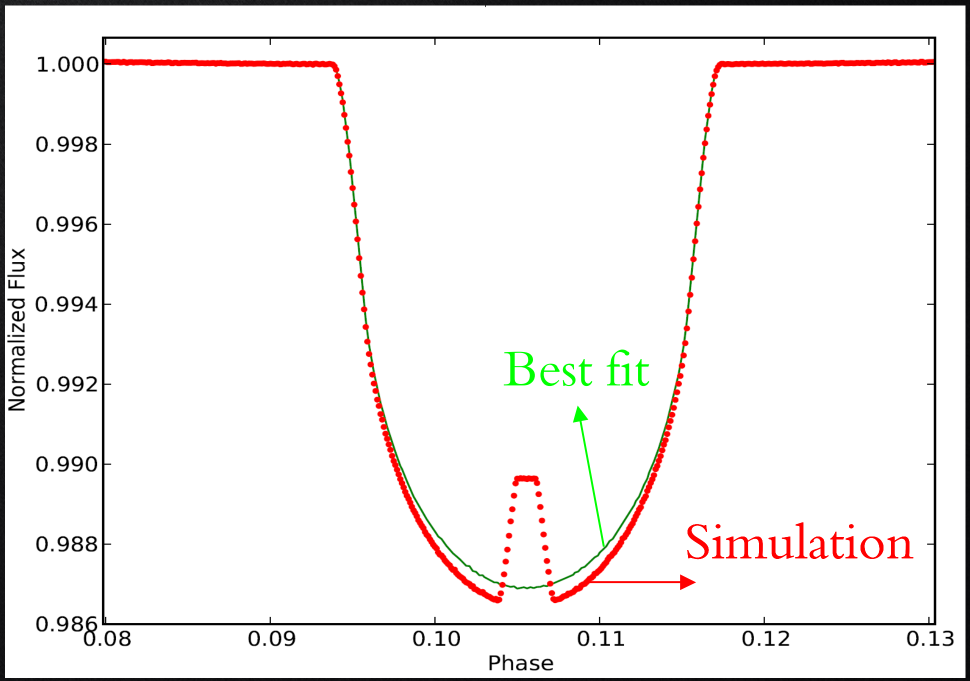
Quantifying the impact

In case that the spot anomalies are not identifiable, we want to quantify their effect on our measurements.

We generated a large number of mock transit light curves with spot anomaly inside for different combination of planet radius and spot size and try to fit them with transit light curve without anomaly.

Transit depth, duration and timing are free parameters, and compute the difference between fitted value and their actual value

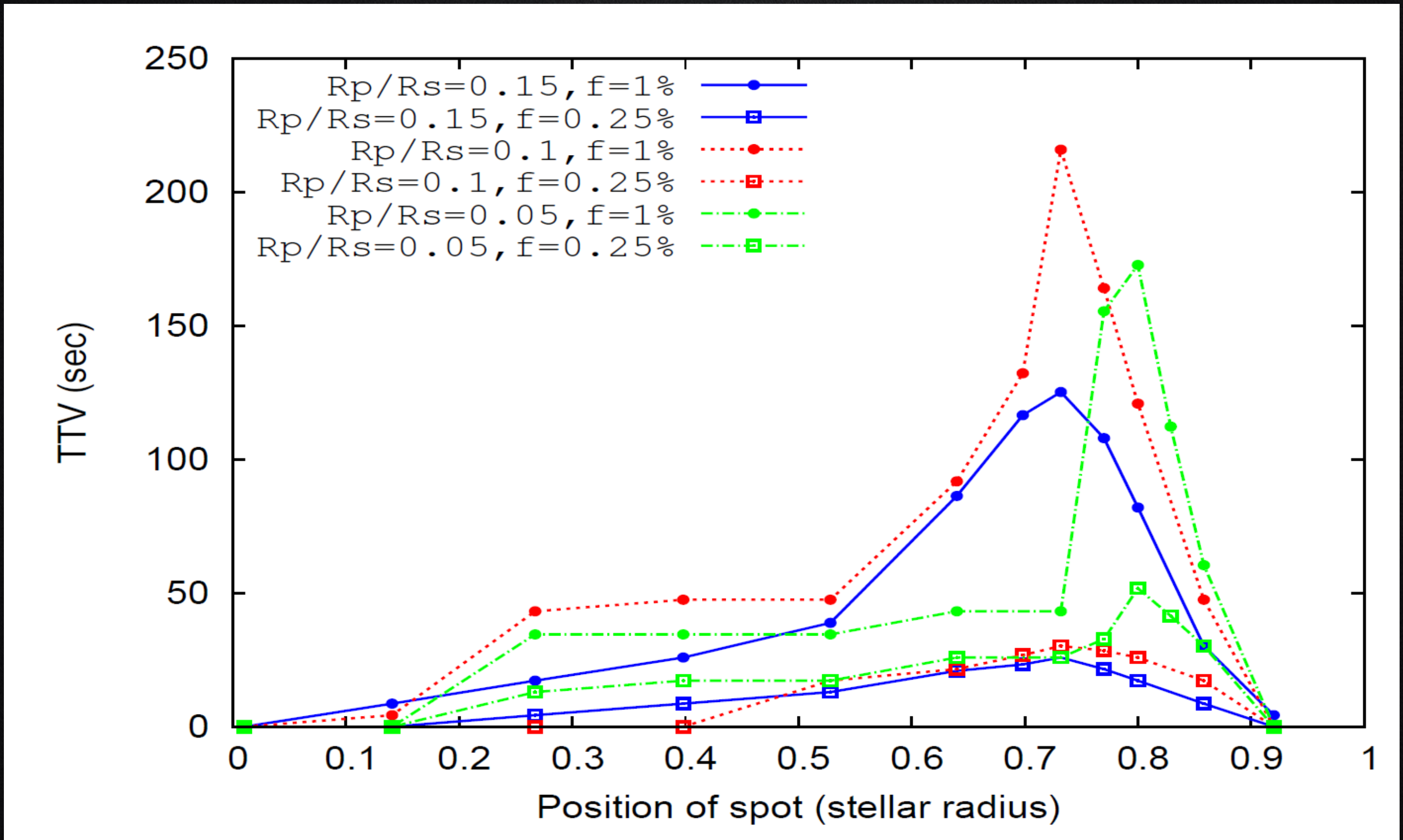




Transit timing measurements

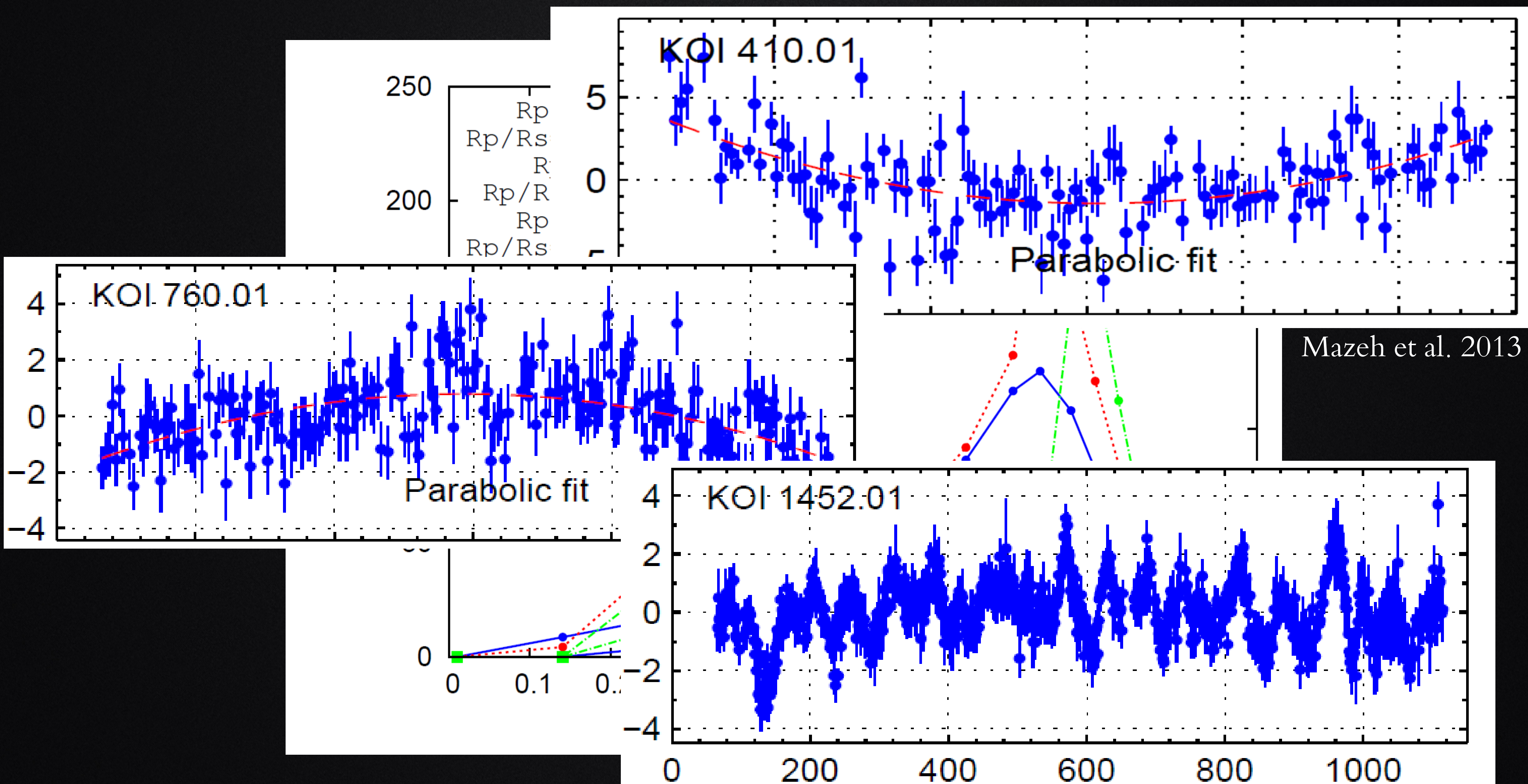
Rp/Rs=0.1 overlaps a spot with a filling factor of 1 %, produces the maximum value of TTV can exceed 200 seconds.

This amplitude of TTV can be induced by an Earth-mass planet in a mean-motion resonance with a Jovian-type body transiting a solar-mass star in a 3 day orbit



TTV signal caused by spot anomaly

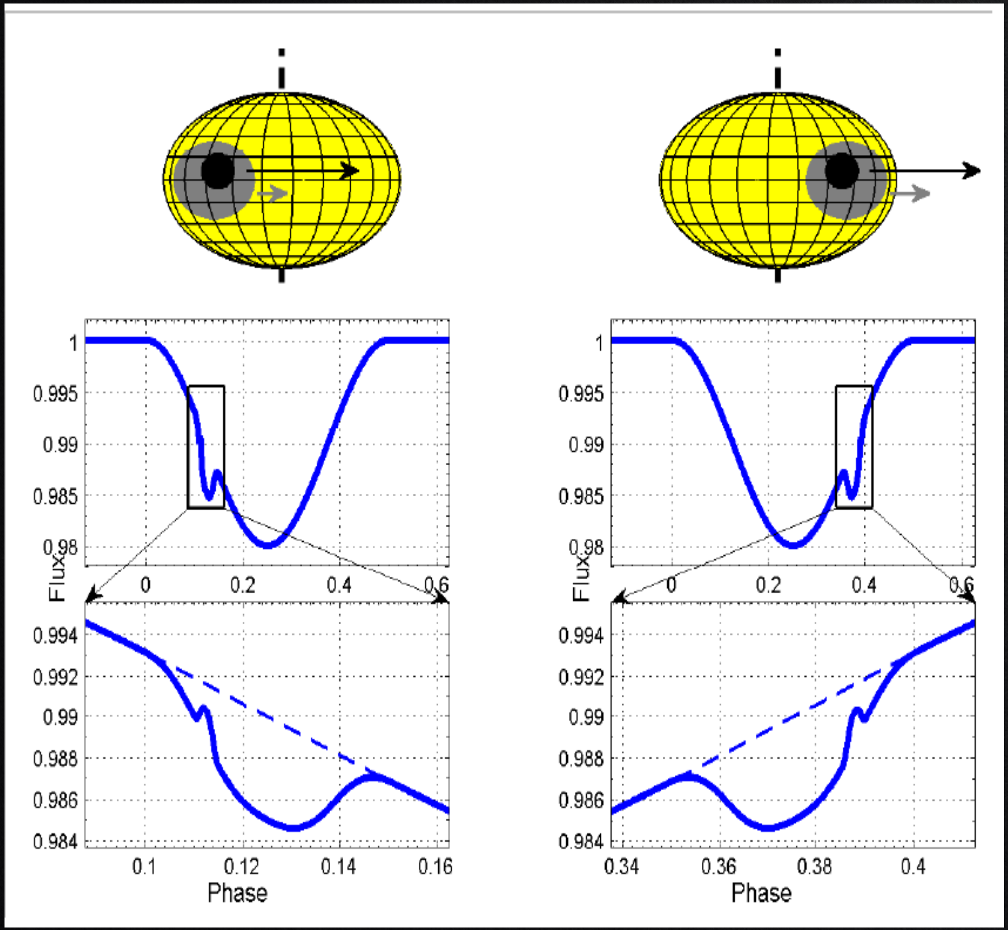
Rp/Rs=0.1 overlaps a spot with a filling factor of 1 %, produces the maximum value of TTV can exceed 200 seconds.

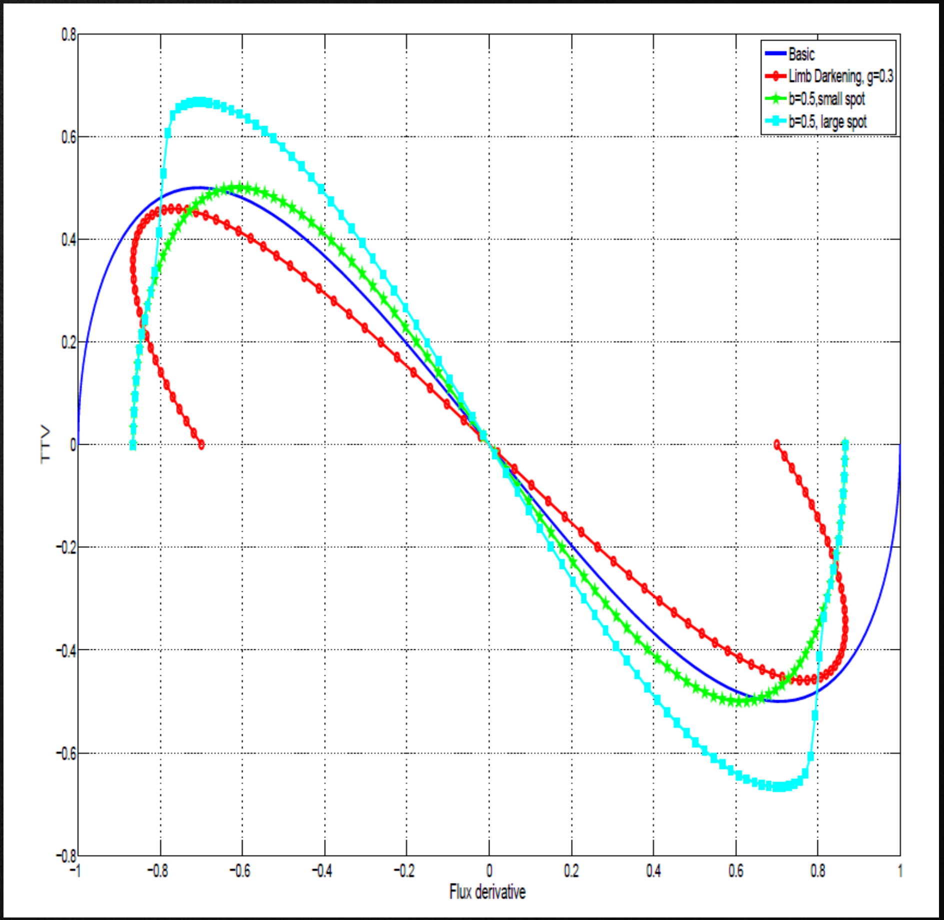


Mazeh et al. 2013

TTV signal caused by spot anomaly

Distinguish between prograde and retrograde transiting planets.

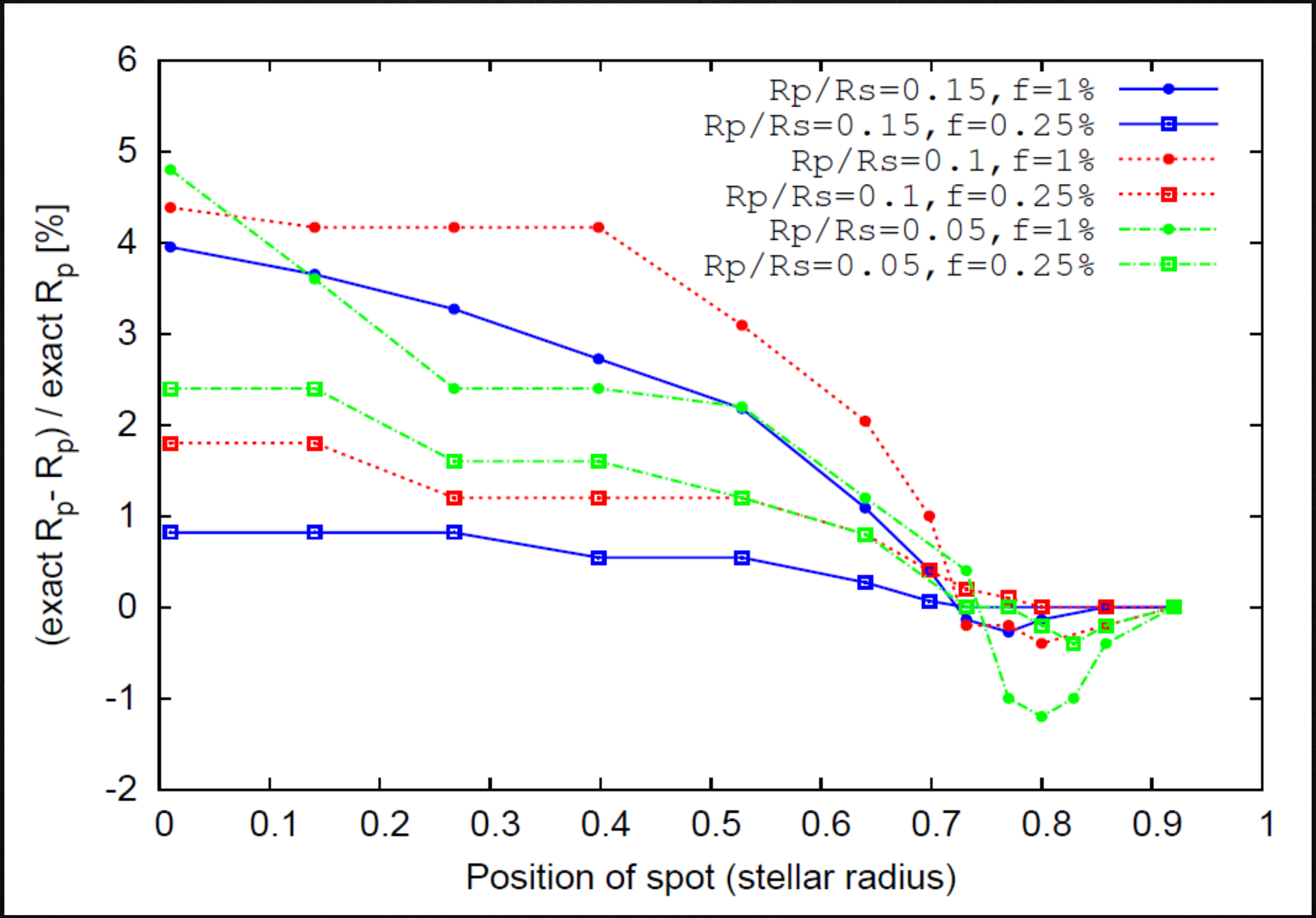




Mazeh et al. 2014

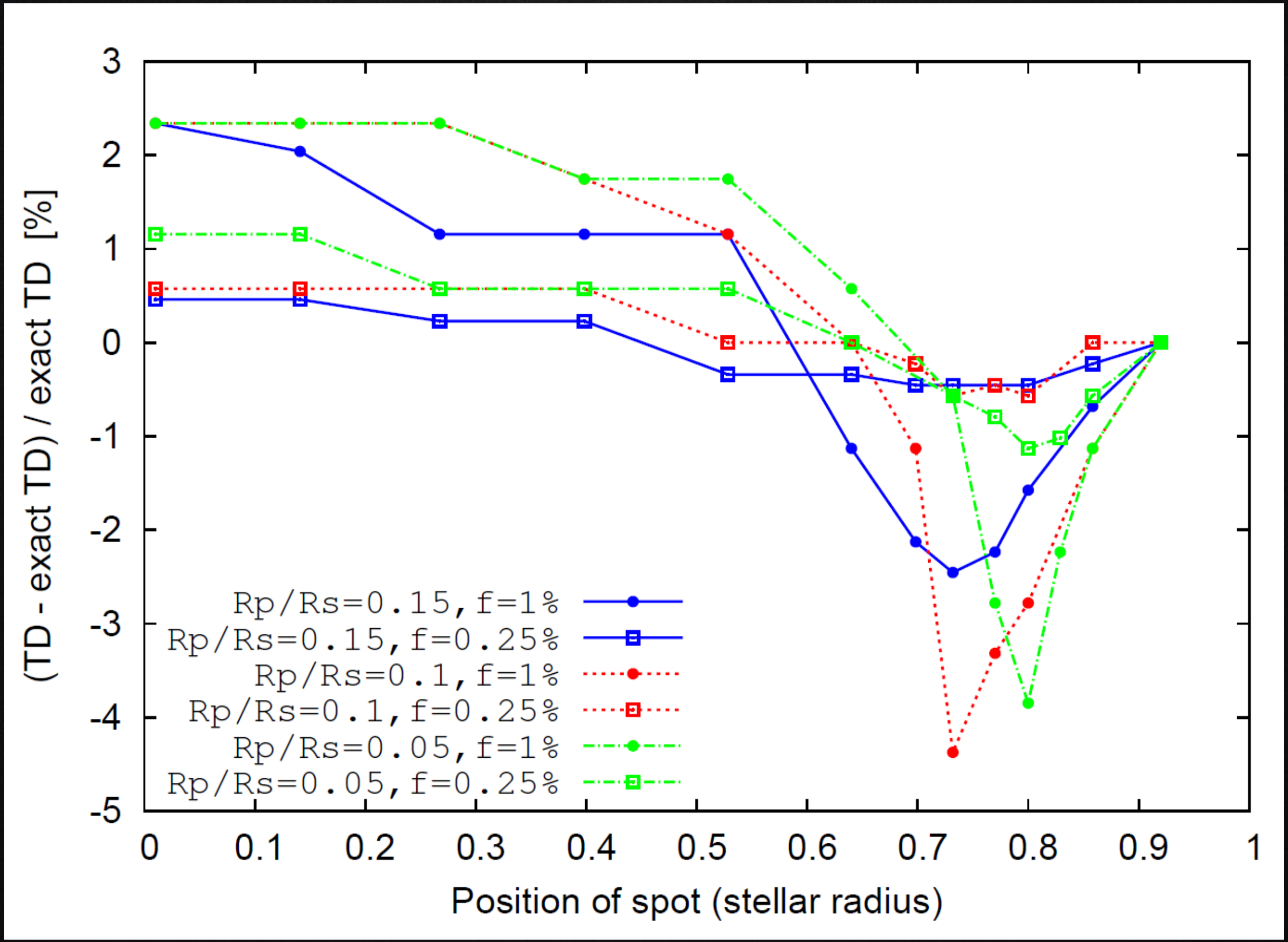
Deviation of planet radius caused by spot anomaly

Rp/Rs= 0.05 and the spot's filling factor is 1 %, can cause the underestimation of the radius of the planet to by 4%.

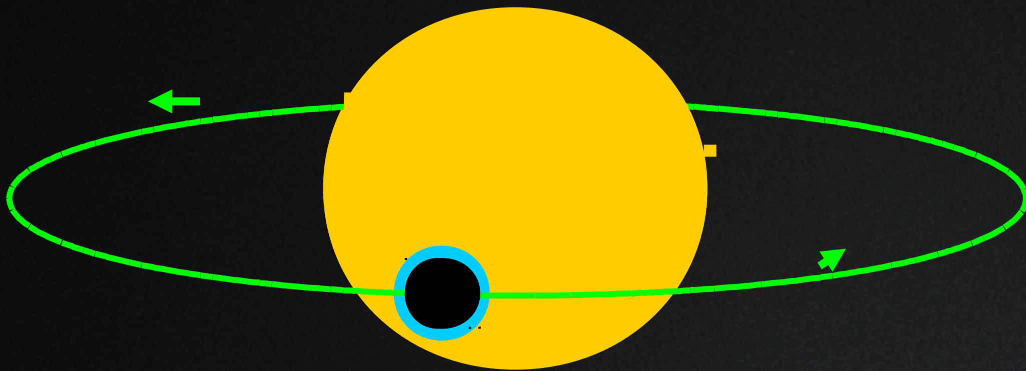


Deviation of transit duration caused by spot anomaly

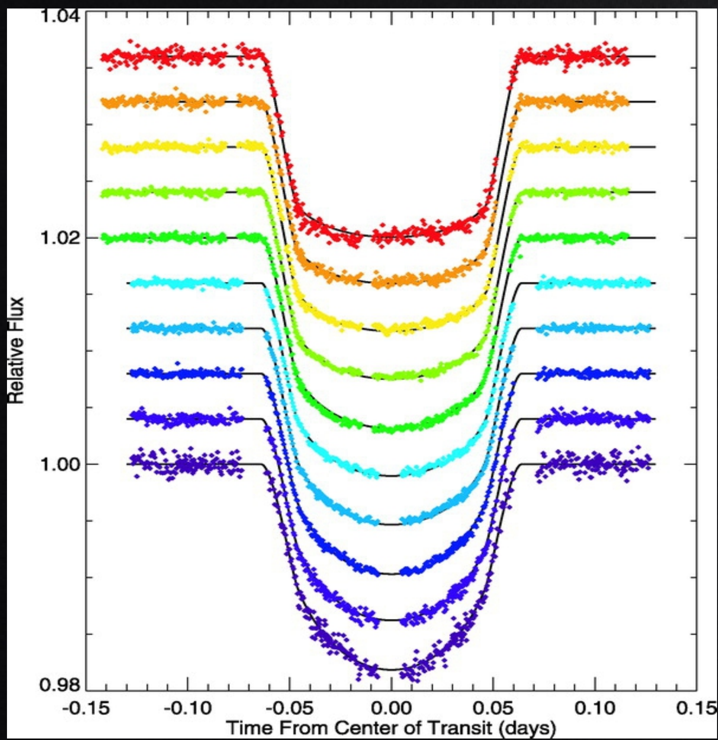
Rp/Rs=0.1 and spot filling factor of 1% causes transit duration to be 4%, longer or shorter, which affects the planetary inclination measurements.



Transmission spectroscopy

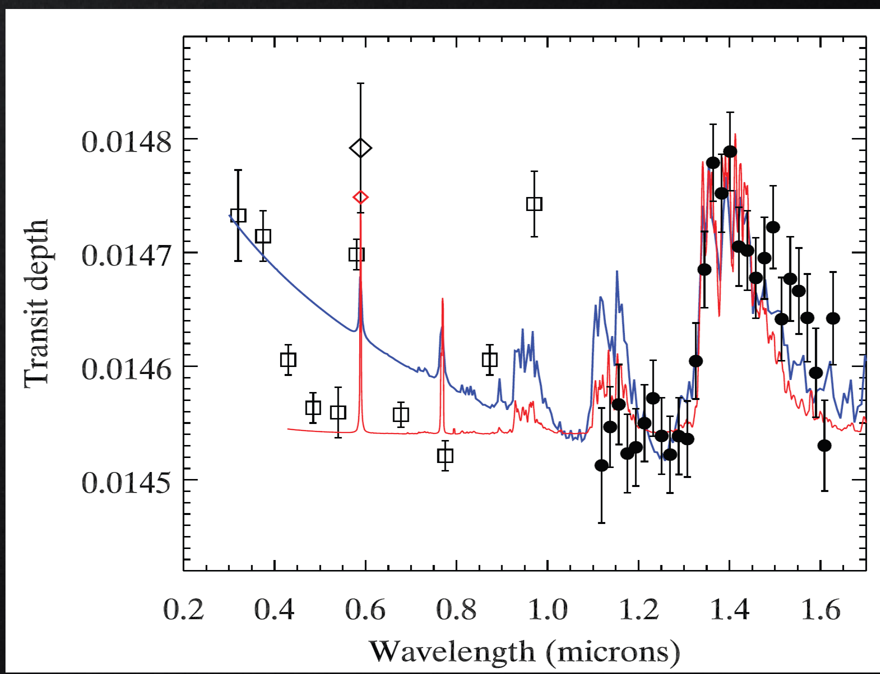


Multi-band photometry



$$\frac{R_p}{R_*}(\lambda)$$

–Molecular composition
–Thermal structure of the atmosphere



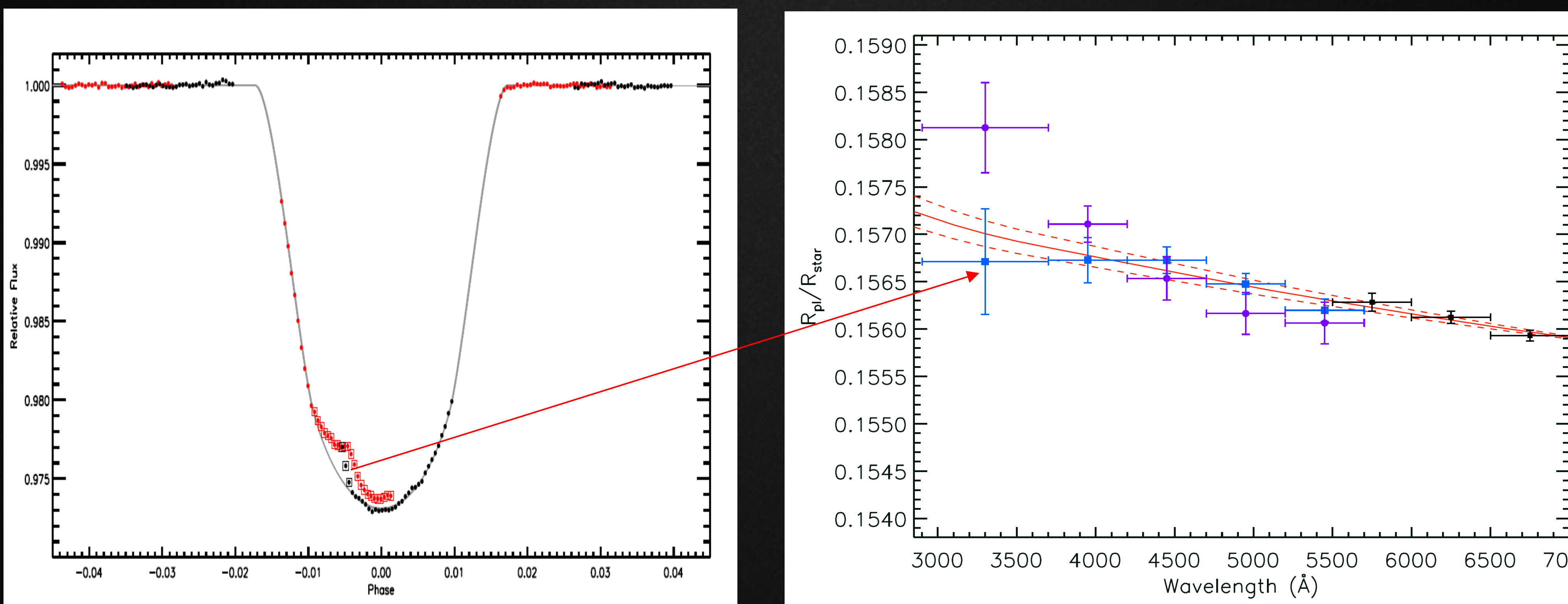
HD 209458b from 290–1030 nm (Knutson et al. 2007)

HD 209458b (Deming et al 2013)

Stellar activity impact on transmission spectra

Mostly the impact of non-occulted stellar spot are taking into account (e.g HD 189733b, GJ 3470b).

Occulted spots are corrected if their anomaly are clearly identified (e.g HD 189733b).



HD 189733b Sing et al. (2011)

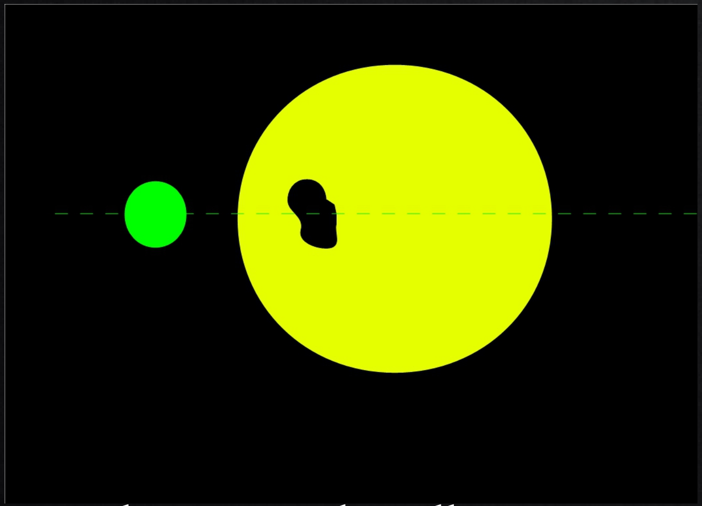
Quantifying the impact

Quantify the impact of occultation of stellar active regions, such as spot and plage, on the transmission spectroscopy measurements.

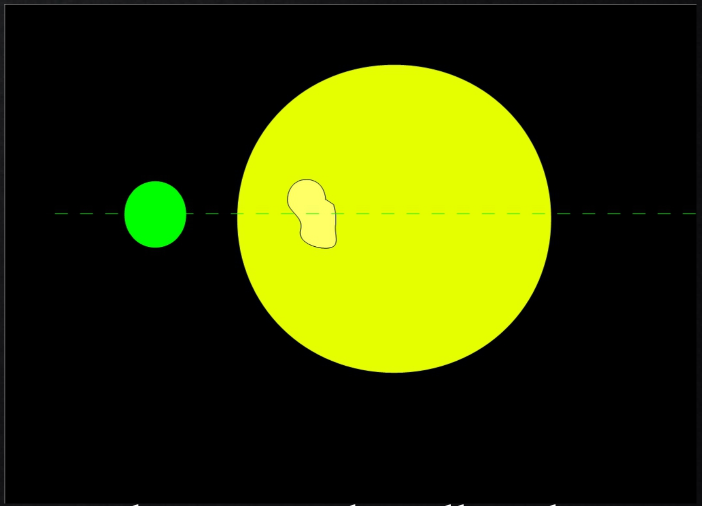
Modify SOAP-T to be able to generate transit light curves at different wavelengths.

We generated a large number of mock transit light curves with spot anomaly inside for different combination of planet radius and spot/plage size.

Transit depth is the only free parameters, and compute the difference between fitted value and their actual value



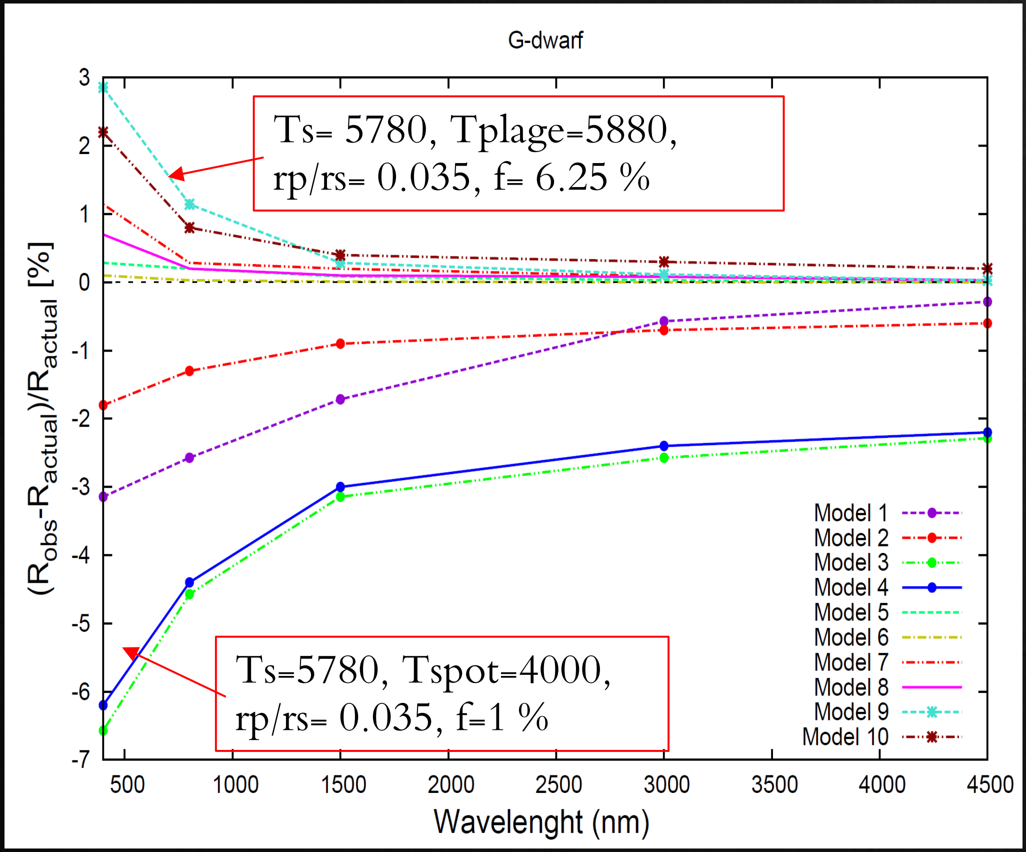
Occultation with stellar spot

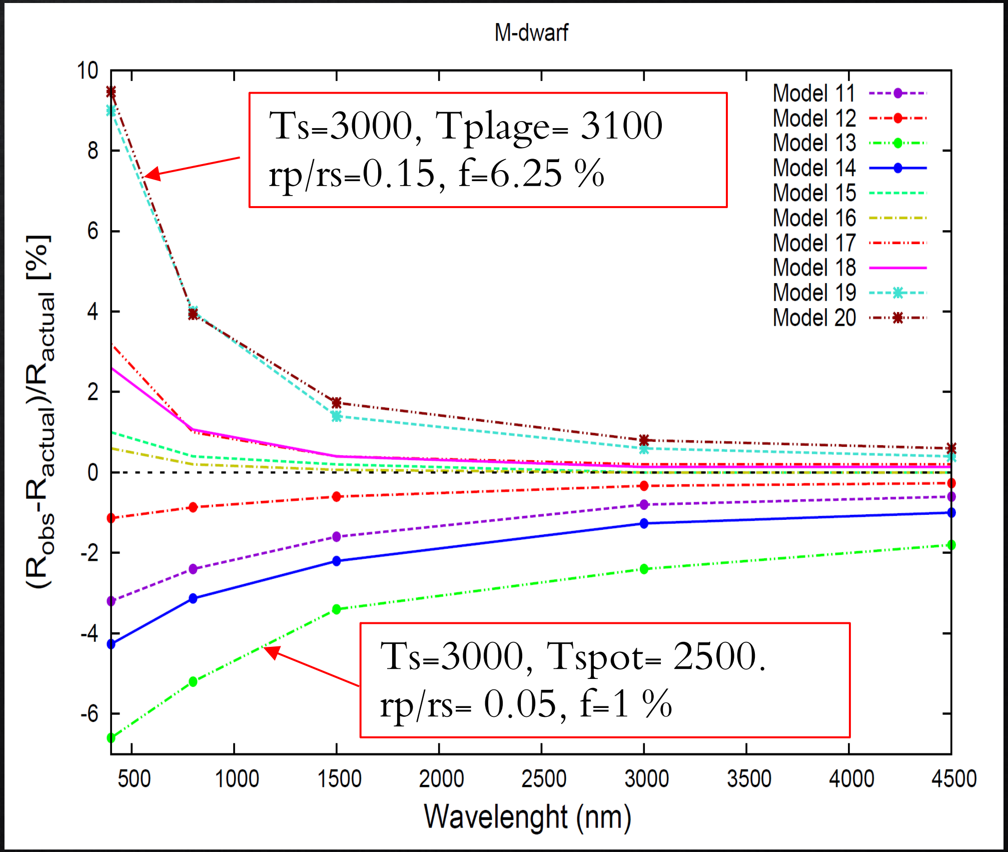


Occultation with stellar plage

Quantifying the impact

The anomalies inside the transit lead to a significant underestimation or overestimation of the planet-to-star radius ratio as a function of wavelength. At short wavelengths, the effect can reach up to a maximum difference of 10% in the planet-to-star radius ratio.

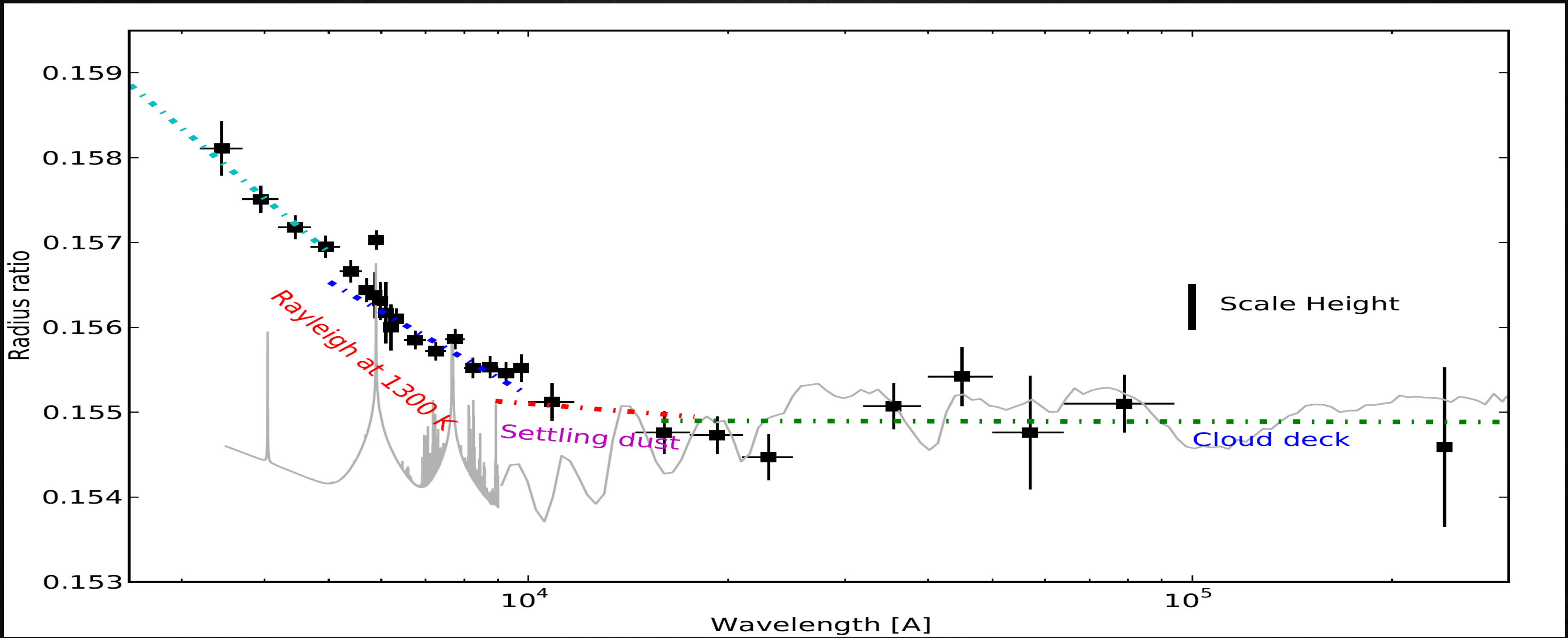




HD 189733 b

HD 189733b is a hot Jupiter orbiting a K-dwarf. The brightness of HD 189733 ($V \simeq 7.7$) and the HD 189733b large planet to star radius ratio and also its short-orbit, has made it one of the first and also the most well studied planet in the planetary atmosphere investigations.

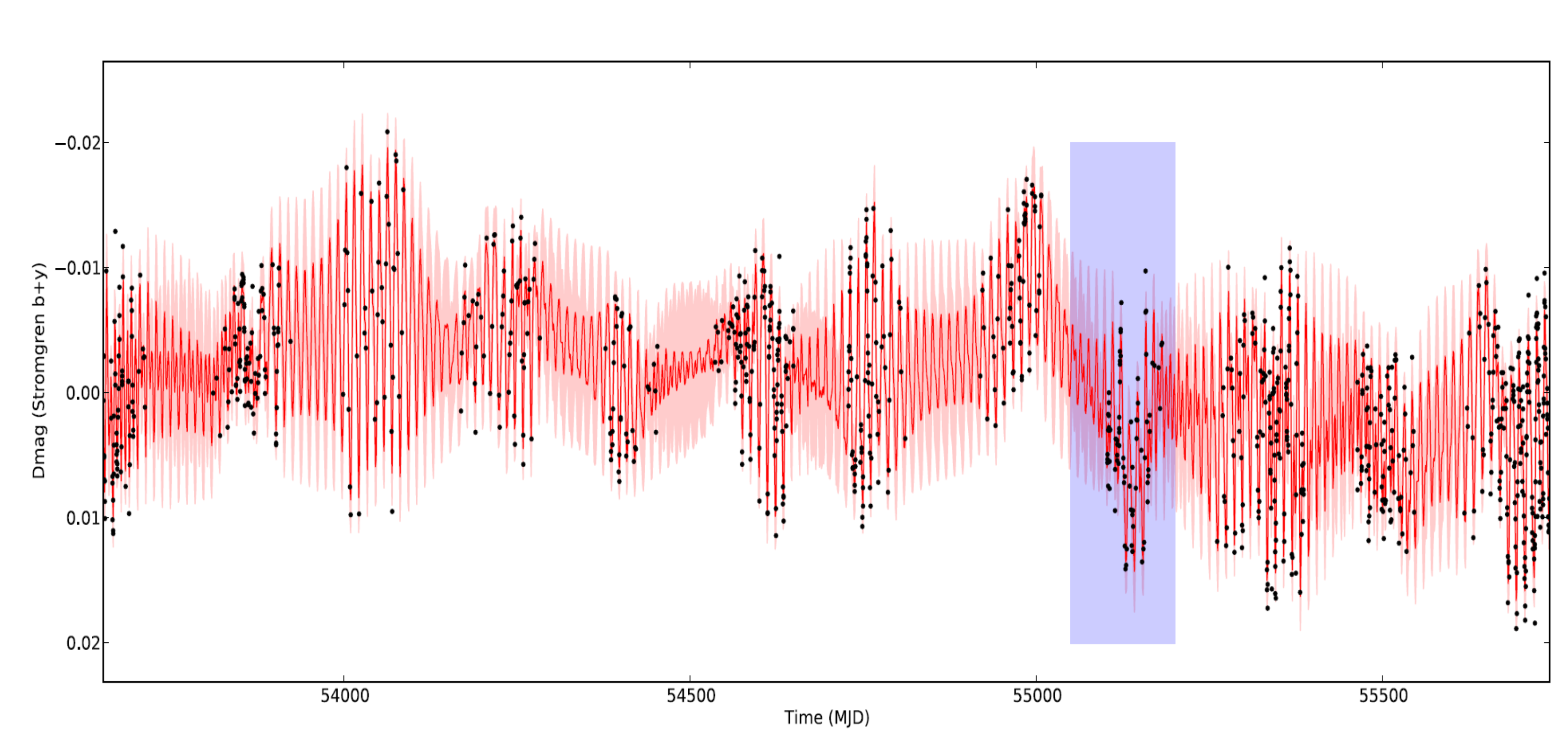
Sing et al. (2011) and Pont et al. (2013) both reported excess in the planet radius in the short wavelength (300−800nm) and the authors find a good agreement between this observation and the prediction of Rayleigh scattering in the planet atmosphere (blue sky).



Pont et al. (2013)

HD 189733 b

HD 189733 is an active star which shows photometric modulation up to ≃2% during its 12 days stellar rotation period Boisse et al. (2009); Sing et al. (2011).

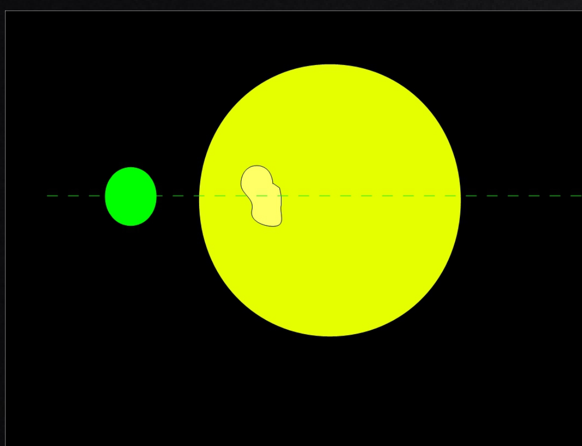


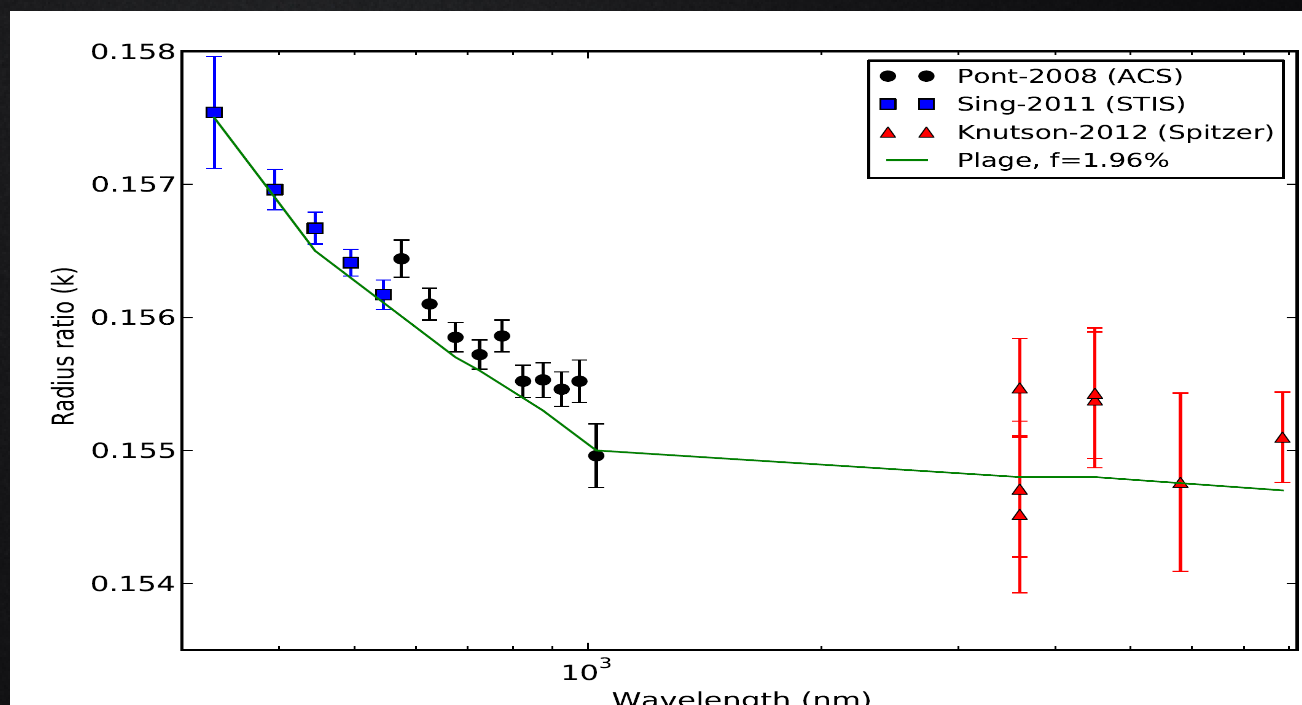
Pont et al. (2013)

HD 189733 b

We found out that the observed transmission spectrum of HD 189733b can be reproduced simply by considering the overlap of HD 189733b with a stellar plage with **filling factor of 1.96%** and a **temperature contrast of +100 K** with the stellar temperature.

Note: Determining the plage's temperature and its filling factor are strongly degenerate.



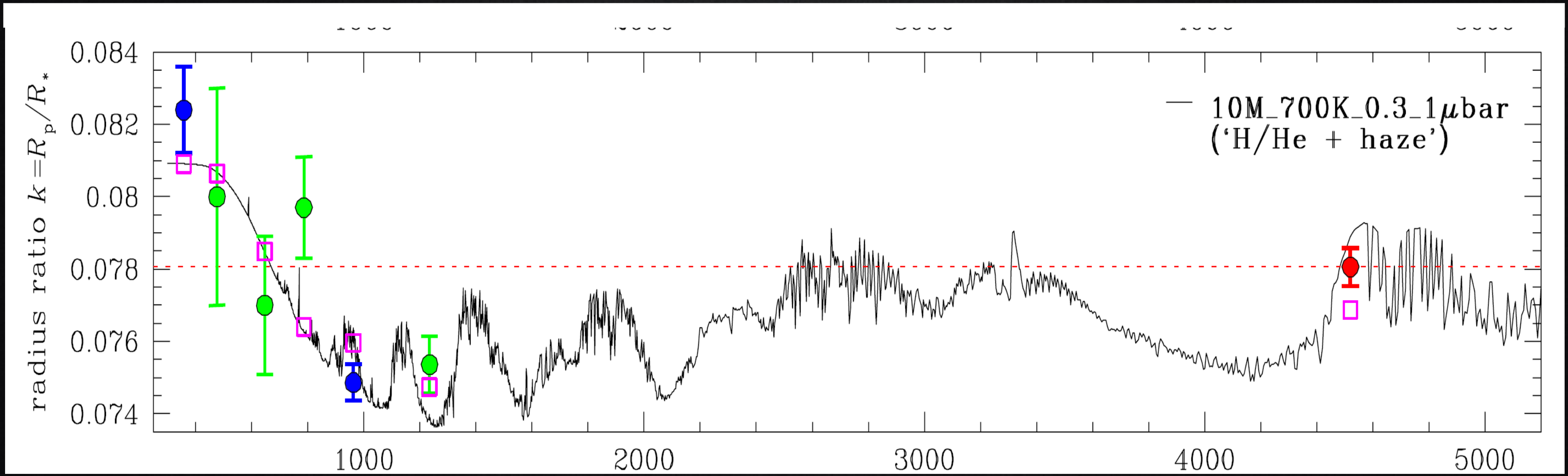


Oshagh et al. 2014

GJ 3470 b

GJ 3470b is a hot Uranus which orbits an active M-dwarf , GJ 3470,

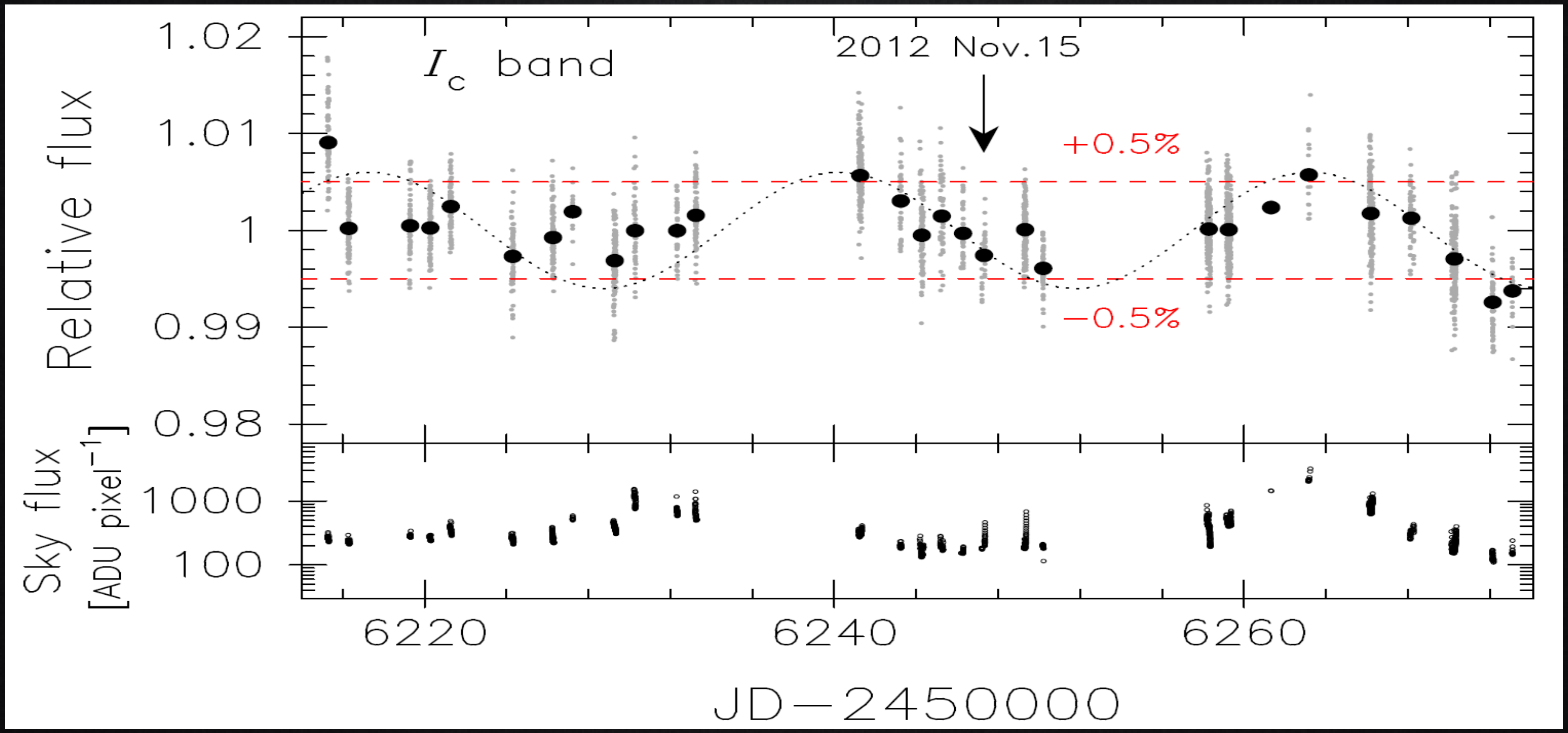
An increment slope towards the blue side of spectrum (~360nm), which was interpreted by Nascimbeni et al. (2013) as Rayleigh scattering processes in the planet's atmosphere (blue sky).



Nascimbeni et al. (2013)

GJ 3470 b

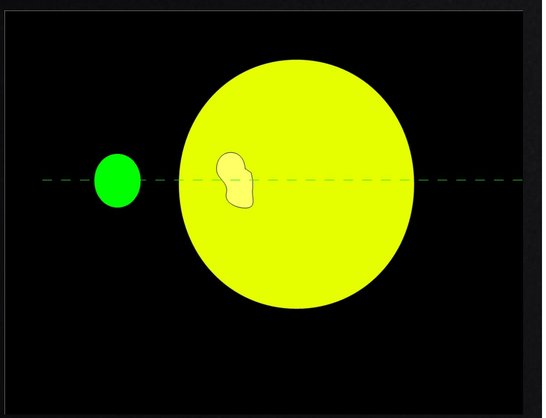
Fukui et al. (2013) reported photometric variability on GJ 3470 during 60 days observations around Photvar $\simeq$ 1%, which can be explained by GJ3470 being an active star which may harbor a spot with a filling factor of 1%.

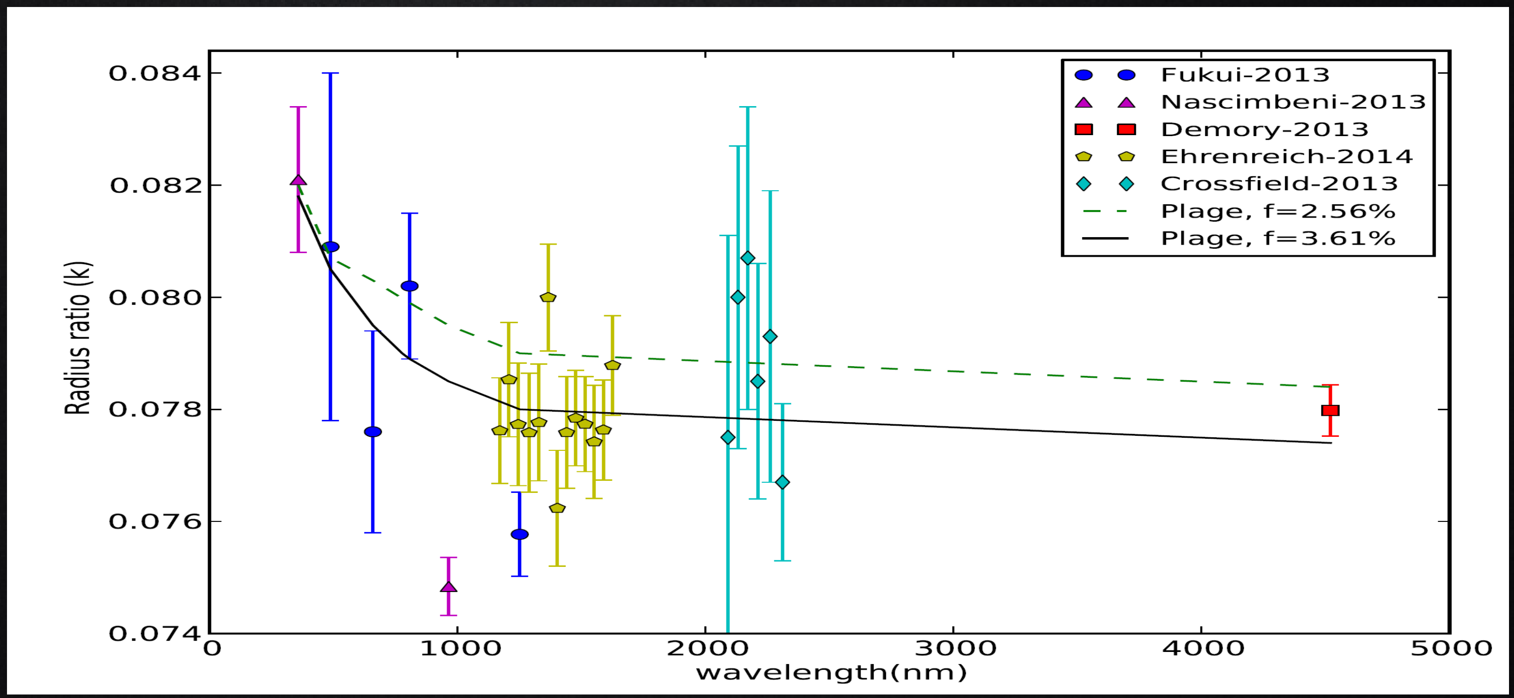


Fukui et al. (2013)

GJ 3470 b

The plage which was needed to justify the observed excess planet radius has filling factor around 2.56% with a temperature contrast of +100 K with the stellar temperature. The size and relative brightness of the plage required by our scenario also generates a photometric variation around (1.3%) which is compatible with the observed one (Photovar ≃1%) (Fukui et al. 2013).



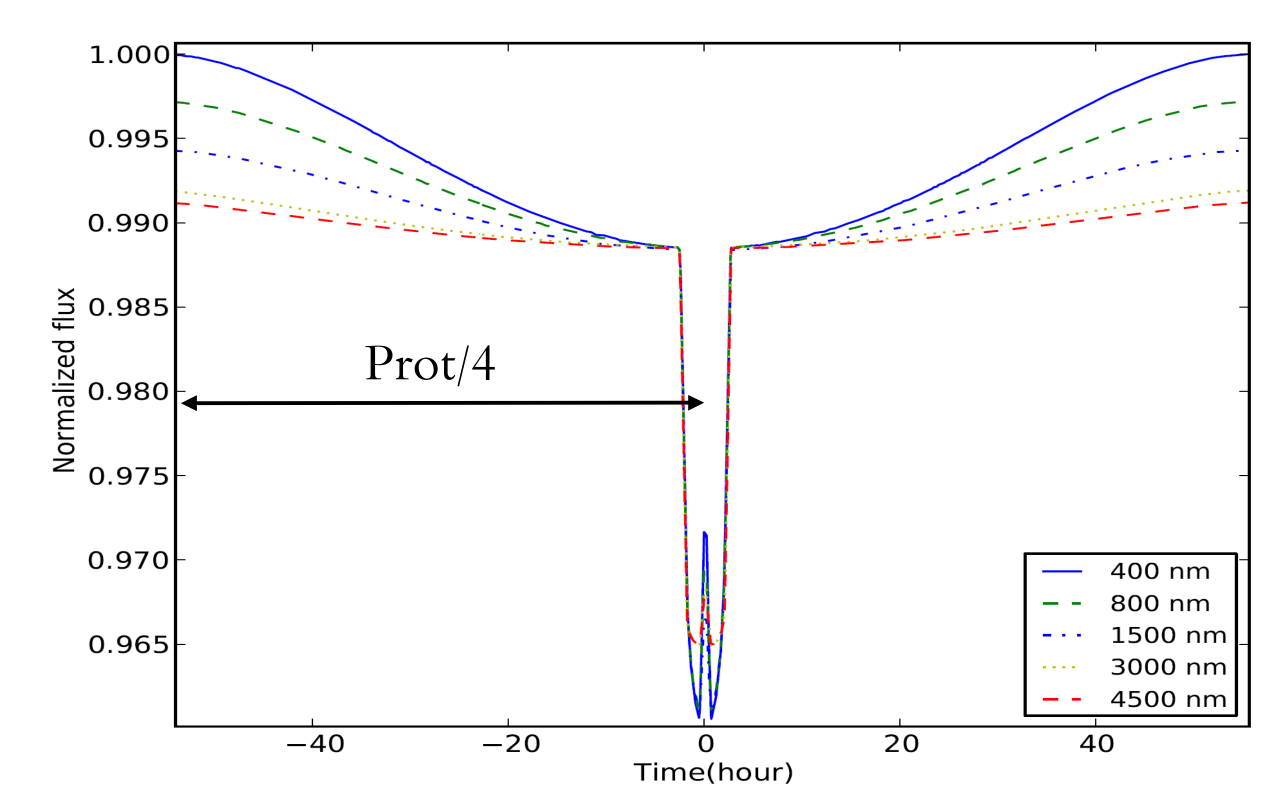


Oshagh et al. 2014

Observational Strategy

1) Several observations of a transit in a given wavelength and use the variations of transit depth as a function of time

2) Simultaneous multi-band photometric observations for a quarter of the stellar rotation period before and after the transit.



Conclusions

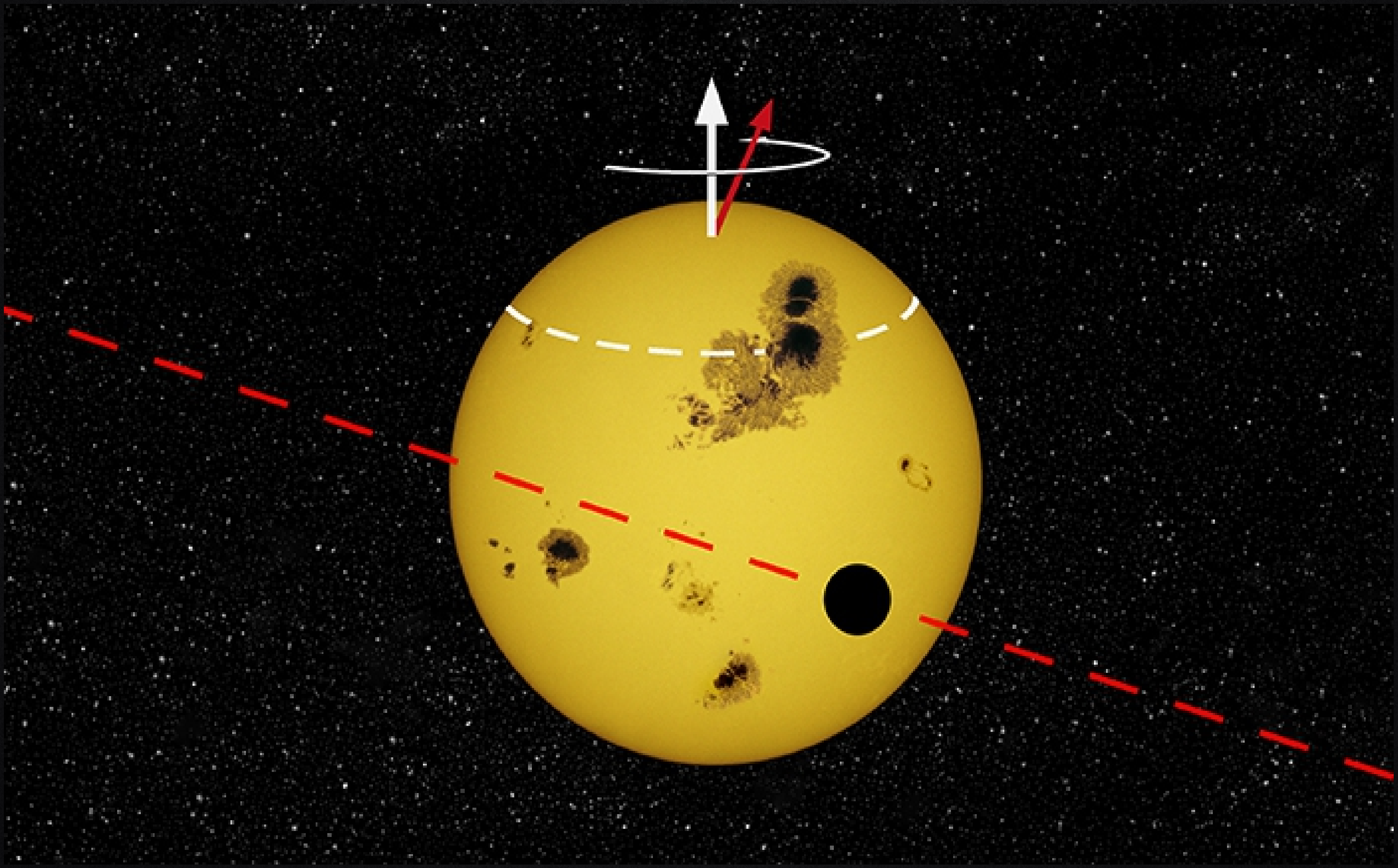
In case of an active star we have to pay attention to the inside the transit light curves anomalies.

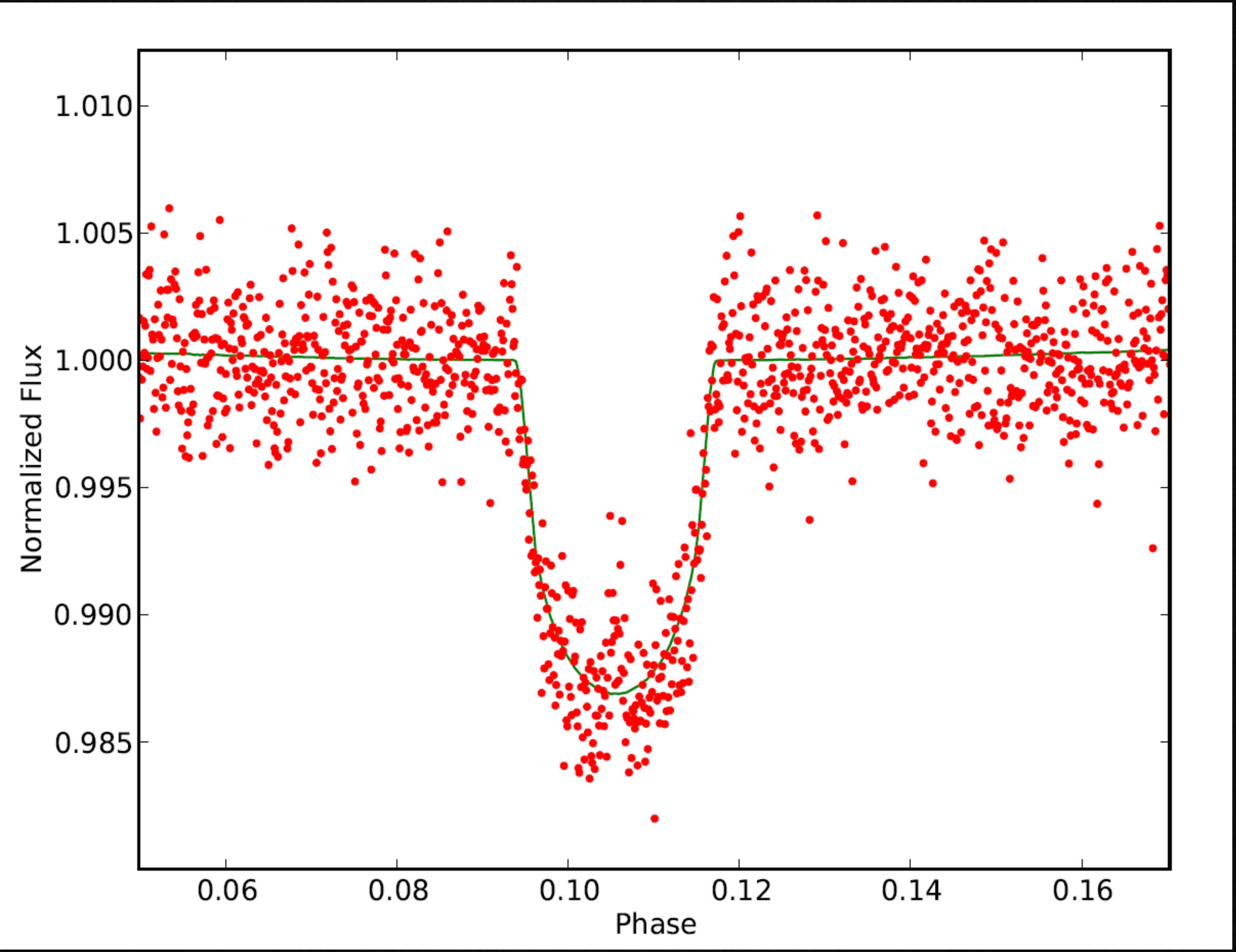
If we can identify spot occultation anomalies, we have to remove them by modeling them (e.g. using SOAP-T). If we could not identify them, we have to be careful about our planetary parameters estimation.

Prior to interpreting the transmission spectra and attempting to set constrains on the exoplanetary atmospheric models, it is critical to rule out the possible contamination due to stellar activity (both occulted and non-occulted stellar active region).

We showed that the transmission spectra of the active stars HD 189733b and GJ 3470b, and especially their excess of the planet radius in the bluer part of the spectra, can almost exactly be reproduced by assuming the occultation of the HD 189733b and GJ 3470b with the active region (plage) of their host star.

Thanks for your attention!





1.010
1.005
1.000
0.995
0.990
0.985
Normalized Flux
0.06
0.08
0.10
0.12
0.14
0.16
Phase