How stellar activity affects exoplanet's parameters estimation

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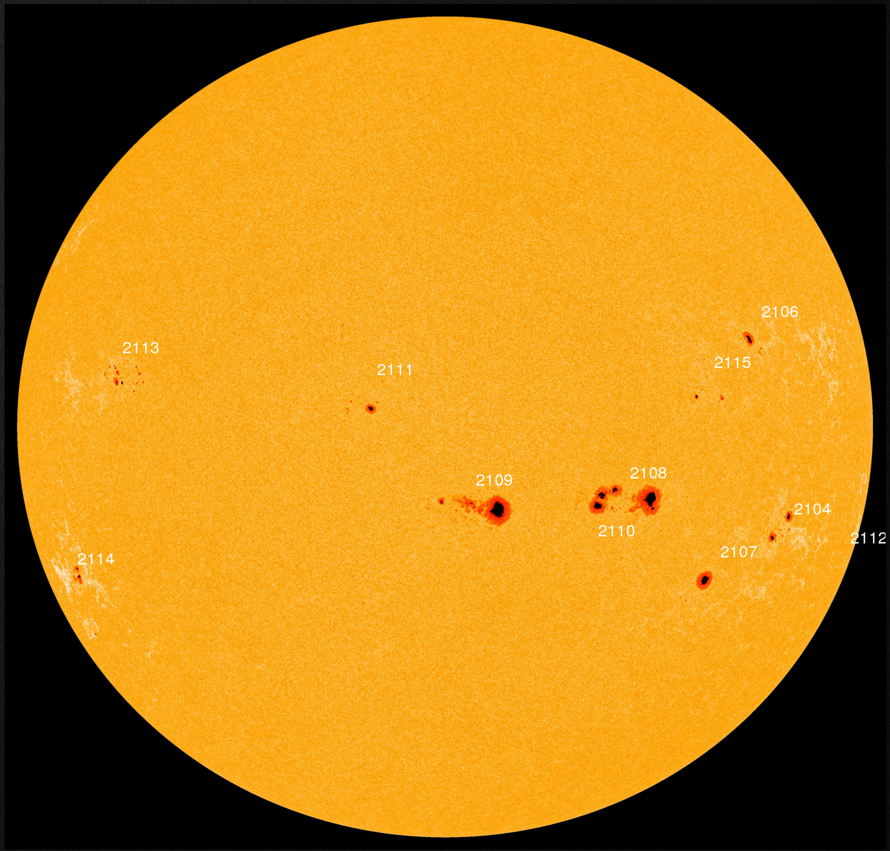
Outline

- Introduction
- Stellar activity induced signal in RV observation
- Stellar activity impact on high-precision transit observation
- Quantifying the impact of stellar activity on planet's parameters
- Impact of stellar activity on the planet atmosphere
- Conclusion

Introduction

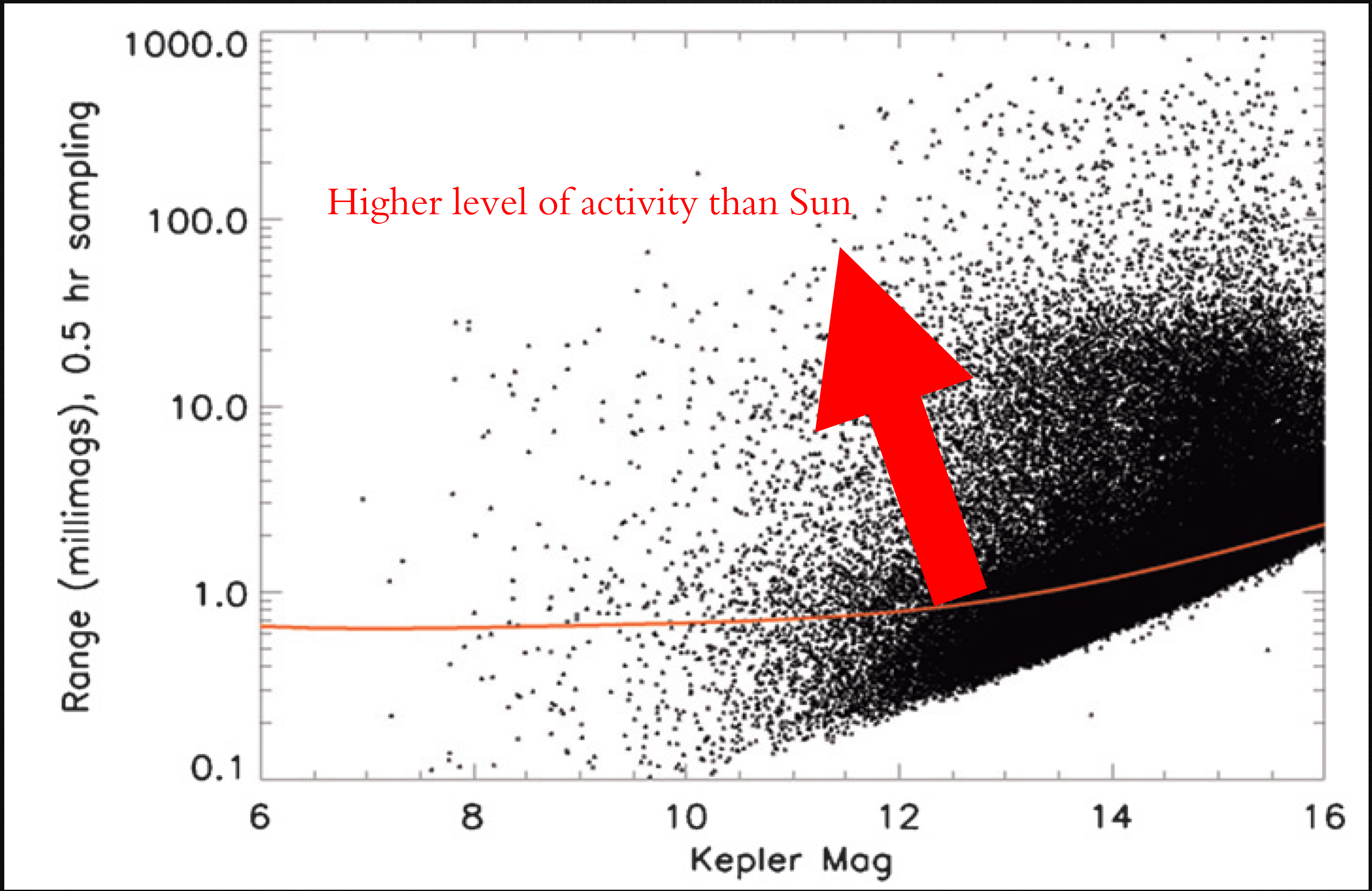
“Stellar Activity” is a collective name used to describe a group phenomena which generate the variability observed in the outer atmospheres of late type-stars mainly due to the presence of highly structured magnetic fields emerging from the convective envelope, namely spots, plage, facula, flares.

Spots and plages exist on all stars, even low-activity stars



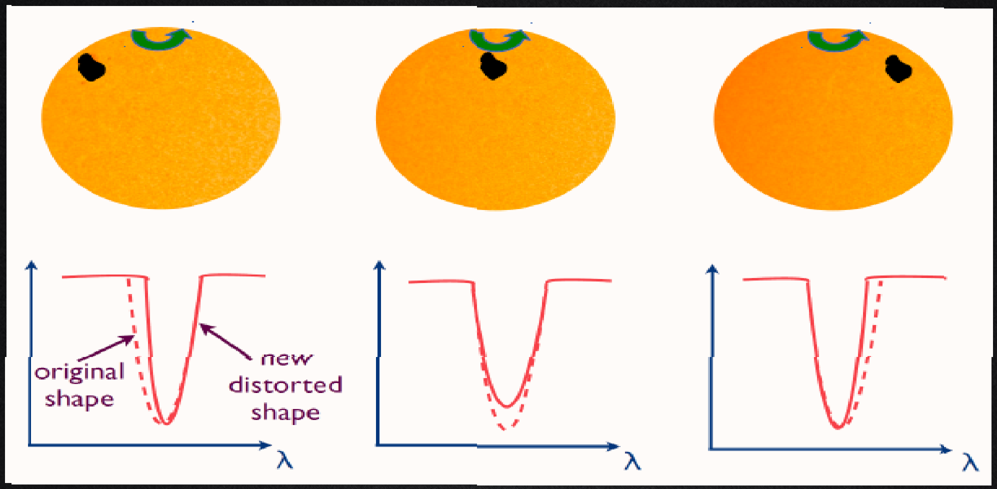
Introduction

About 33% of stars in Kepler FOV are more active than the Sun at its maximum activity cycle.

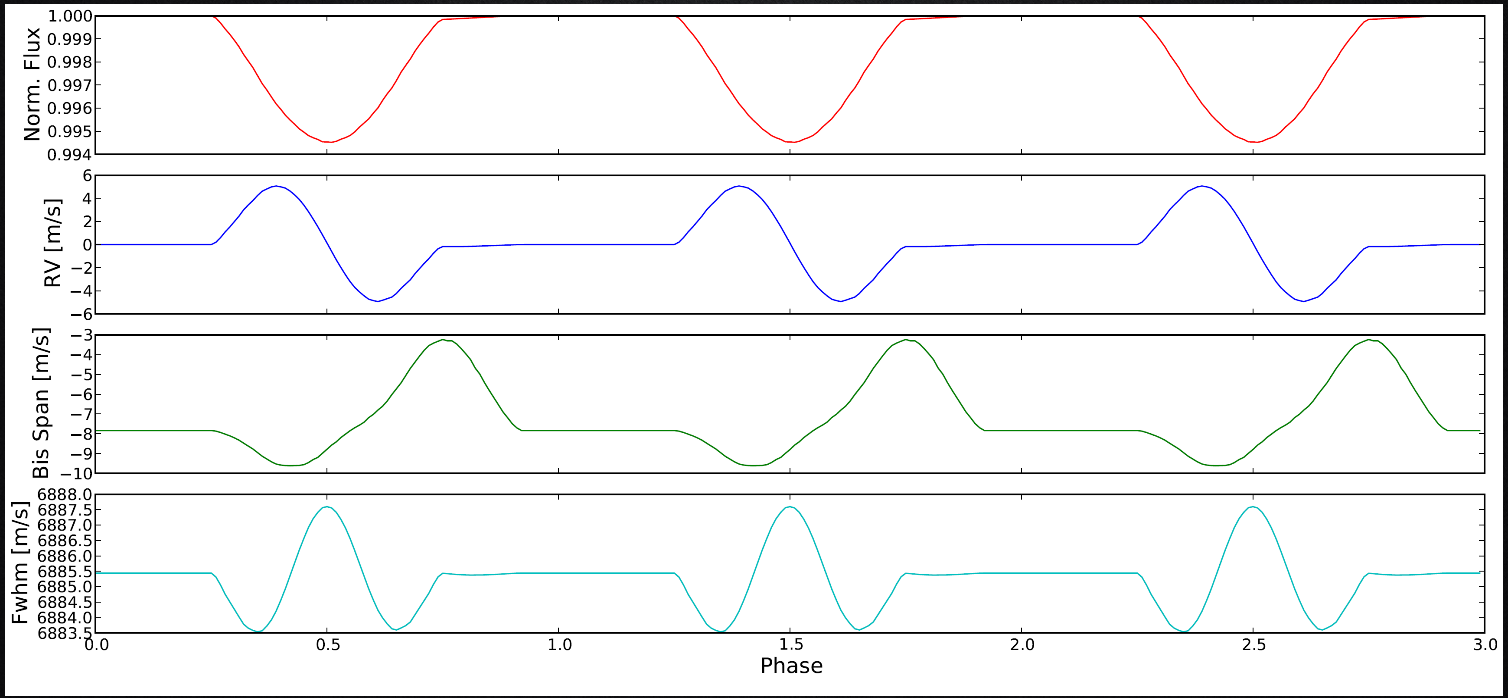


Basri+10

Activity induced RV signal



Haywood+2014



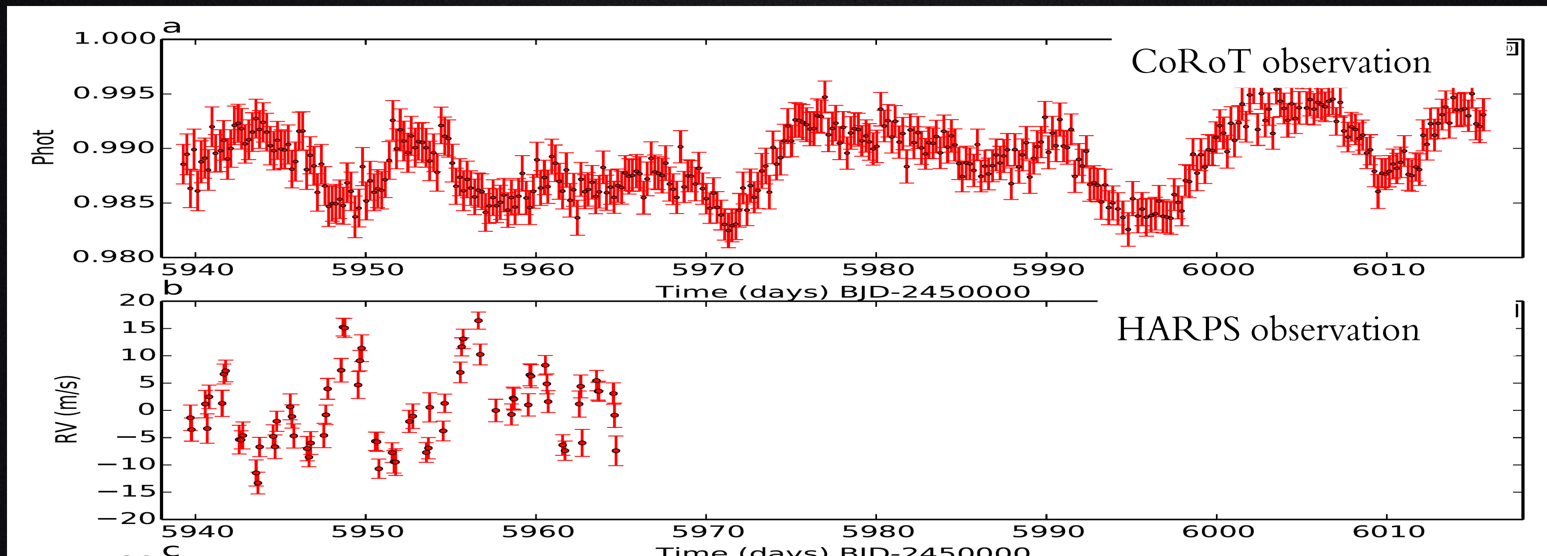
Dumusque+2014

Removing activity induced RV

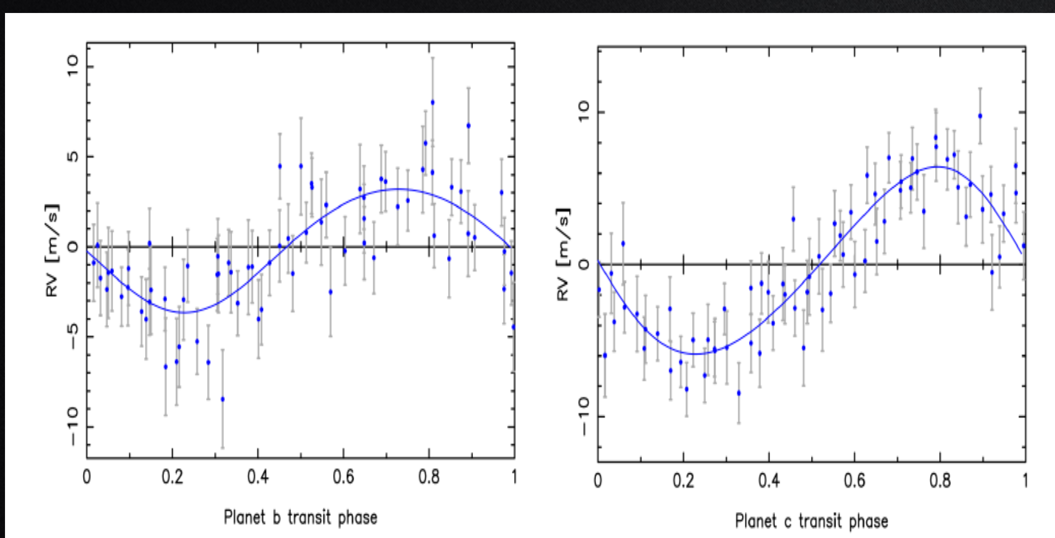
Several strategies have been used to remove activity induced signal in RV in order to be able to detect low mass planet's signal and also determine the accurate mass of planet, e.g.,

HD219828 (remove anti-correlation BIS-RV) Melo+2007
GJ674 (assume it as Keplerians) Bonfils+2007
HD189733 (remove anti-correlation BIS- RV) Boisse+2009
CoRoT-7 (harmonic decomposition of Prot) Queloz+2009
CoRoT-7 (fourier analysis) Hatzes+2010
CoRoT-7 (FWHM and BIS and spot modeling) Pont+2010
CoRoT-7 (spot modeling with SOAP tool) Boisse+2012
CoRoT-7 (FF' method and Gaussian process) Haywood+2014
CoRoT-7 (more realistic spot modeling with MACULA and SOAP2.0) Oshagh+2015(submitted)

CoRoT-7b and c



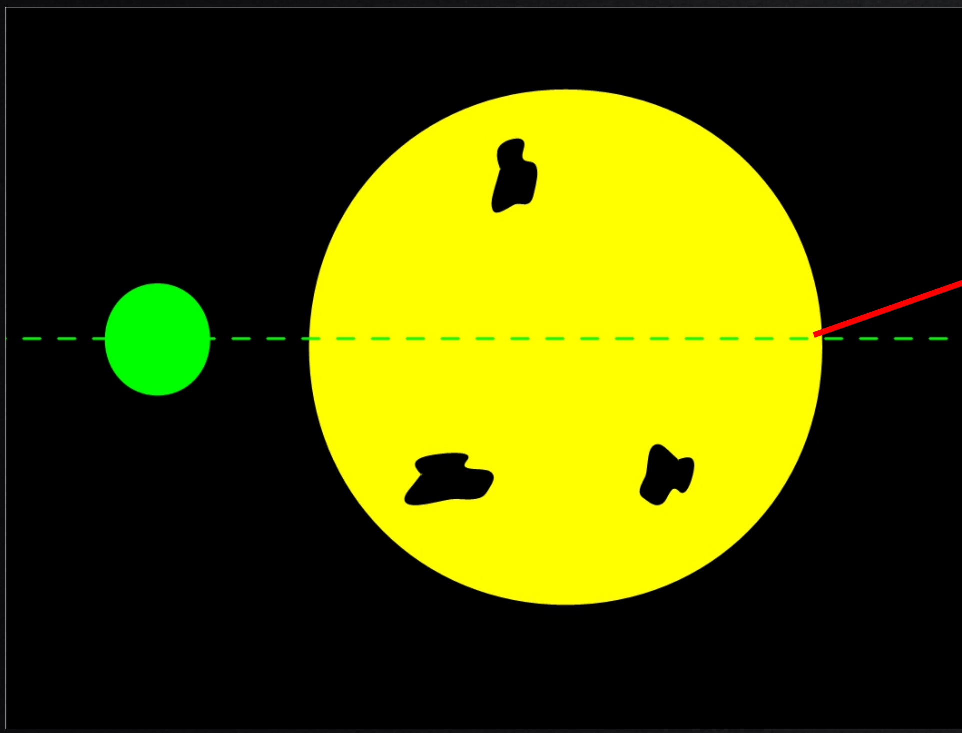
Haywood+2014

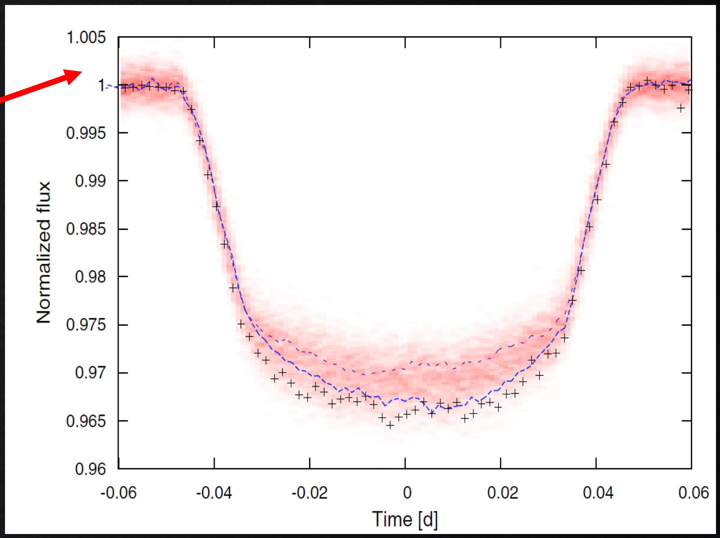


CoRoT-7b	CoRoT-7c	Reference
$4.8 \pm 0.8 M_{\oplus}$	$8.4 \pm 0.9 M_{\oplus}$	Queloz et al. (2009)
$6.9 \pm 1.4 M_{\oplus}$	$12.4 \pm 0.42 M_{\oplus}$	Hatzes et al. (2010)
$7.42 \pm 1.21 M_{\oplus}$	-	Hatzes et al. (2011)
$2.3 \pm 1.8 M_{\oplus}$	-	Pont et al. (2011)
$5.7 \pm 2.5 M_{\oplus}$	$13.2 \pm 4.1 M_{\oplus}$	Boisse et al. (2011)
$8.0 \pm 1.2 M_{\oplus}$	$13.6 \pm 1.4 M_{\oplus}$	Ferraz-Mello et al. (2011)
$4.8 \pm 2.4 M_{\oplus}$	$11.8 \pm 3.4 M_{\oplus}$	Tuomi et al. (2014)
$4.73 \pm 0.95 M_{\oplus}$	$13.56 \pm 1.08 M_{\oplus}$	Haywood et al. (2014)
$5.52 \pm 0.78 M_{\oplus}$	-	Barros et al. (2014)

Non-occulted stellar spots

$$\frac{\max(n_i - f_{le,i})}{p_m} = \left(\frac{R_p}{R_*}\right)^2 \frac{L_d}{c}$$

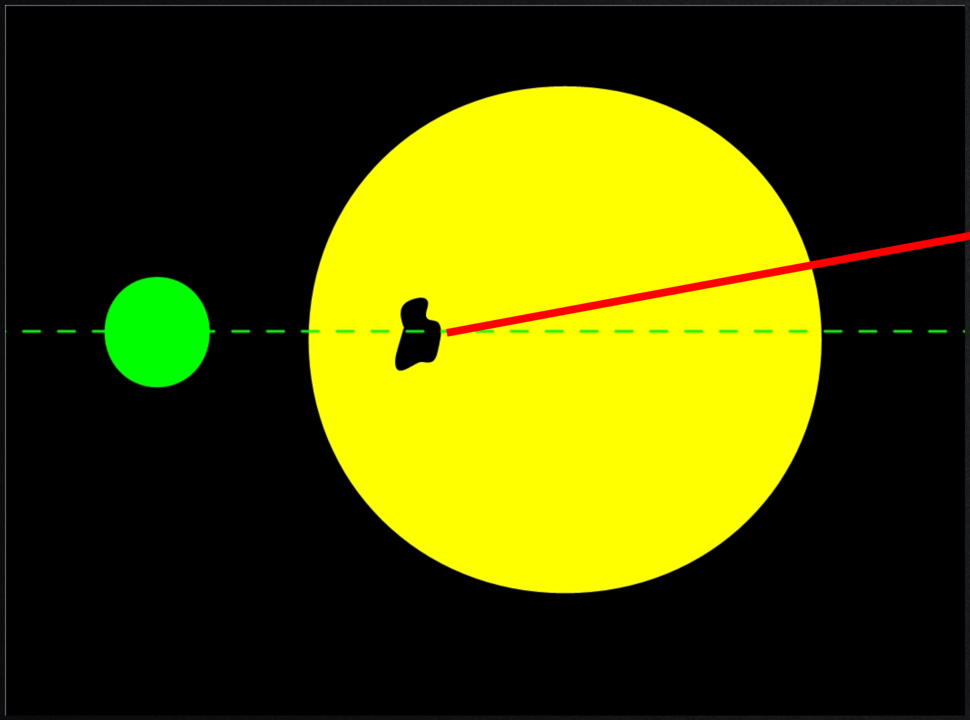


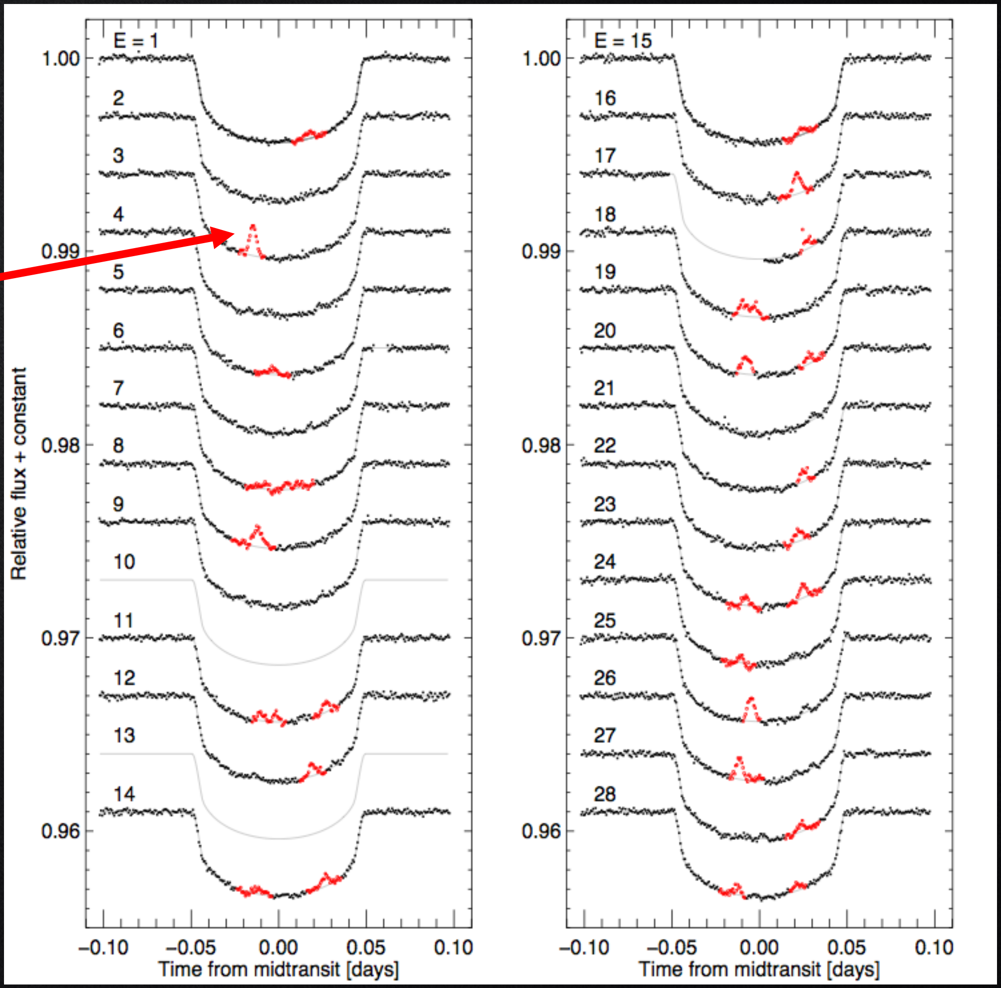


CoRoT-2b (Czesla et al 2009)

Overestimation on the planet radius 1/sqrt(c), which can reach up to 4% (Czesla+2009)

Occulted stellar spots

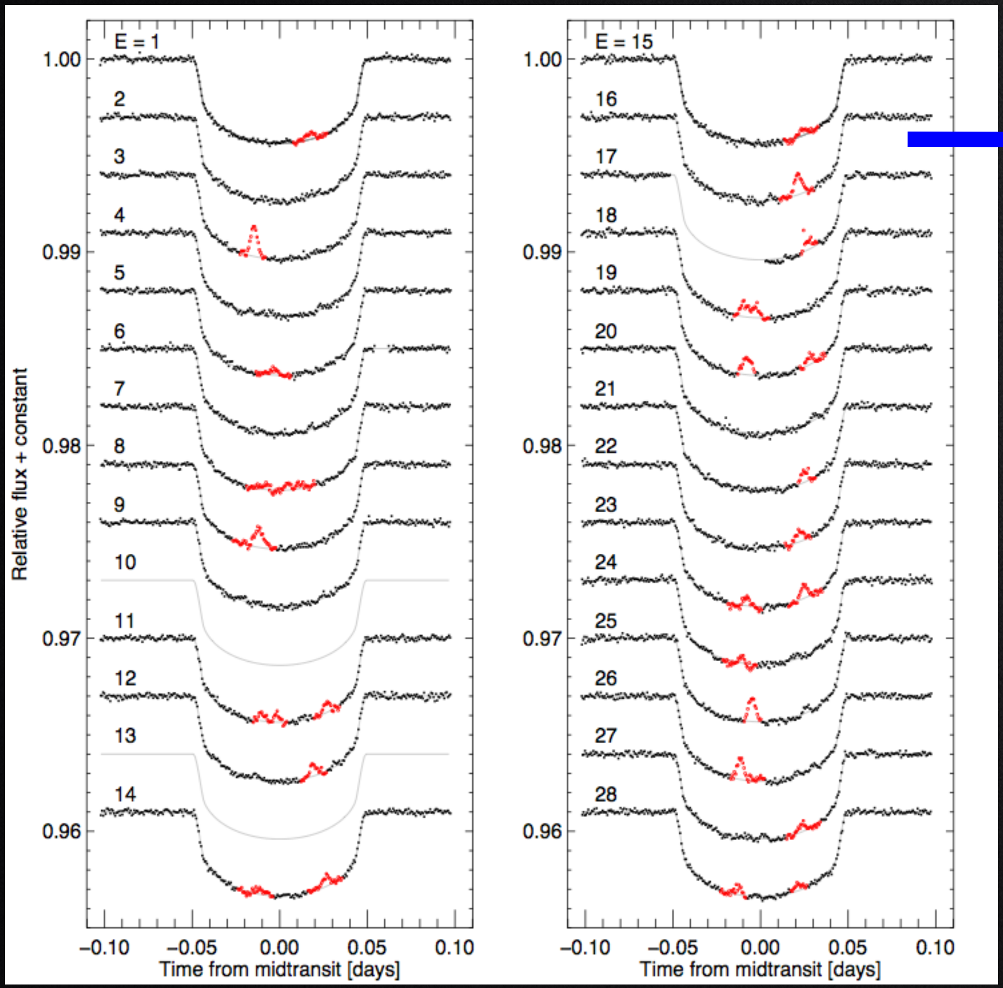




HAT-P-11b observed by Kepler

Spot-planet occultation

In the case that the spot occultation anomaly is clearly identifiable, it is well known that it affects our transit timing measurements.



HAT-P-11b observed by Kepler

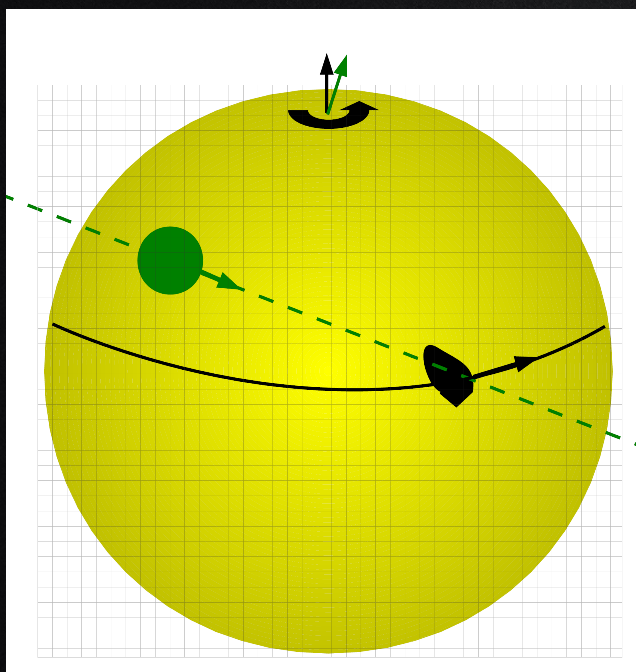
Some people consider assigning a zero weight to the anomalous points of the light curve (e.g Sanchis-Ojeda & Winn 2011)

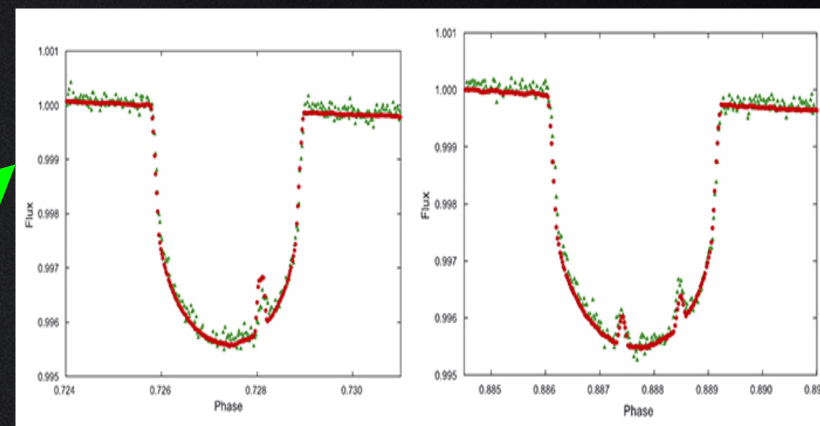
May not be the best approach (Oshagh et al 2012, Barros et al 2013)

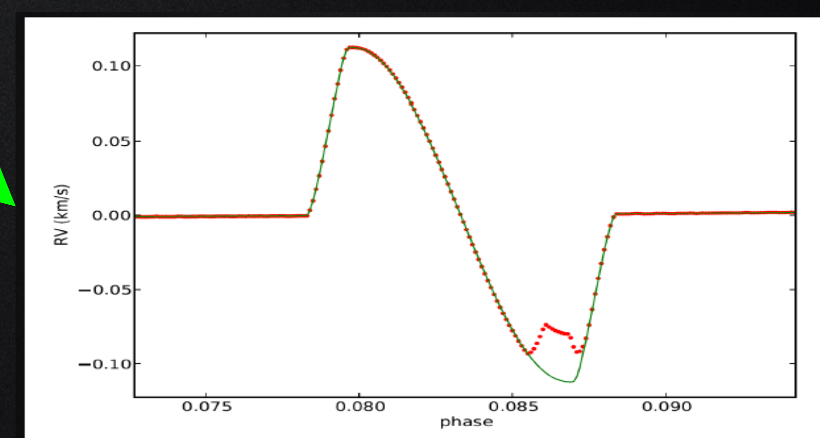
It is better to model them and then subtract them from light curve

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 and RV due to a planet-spot overlap (Oshagh et al, A&A, 2013a.).







Model spot anomalies in order to remove them.

Oshagh et al, A&A, 2013a.

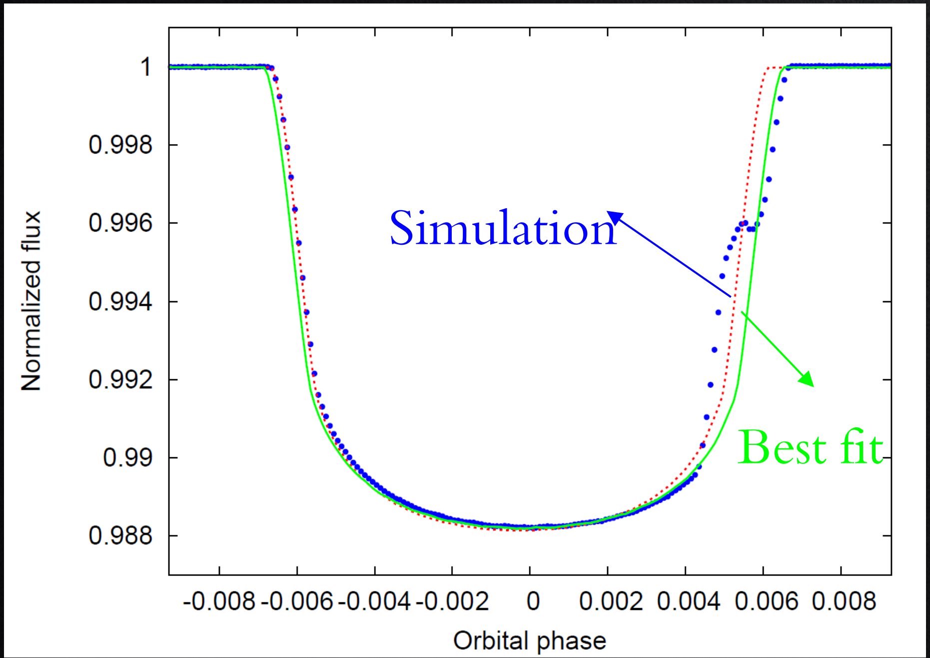
Quantifying the impact of stellar activity on the planetary parameters

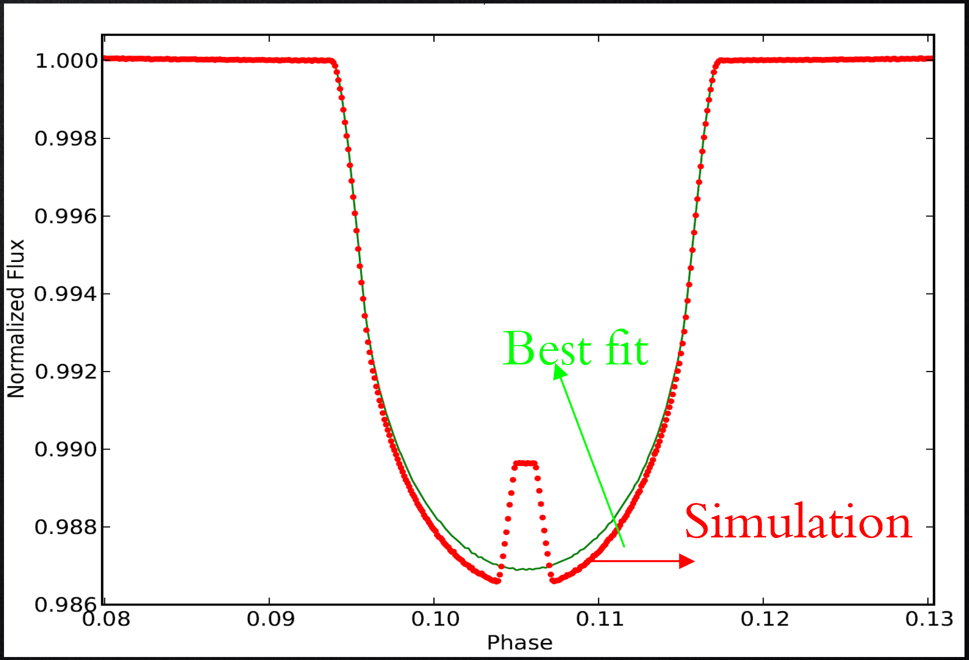
Quantifying the impact

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

Generated a large number of mock transit light curves with spot anomaly inside, for different combination of planet radius and spot size

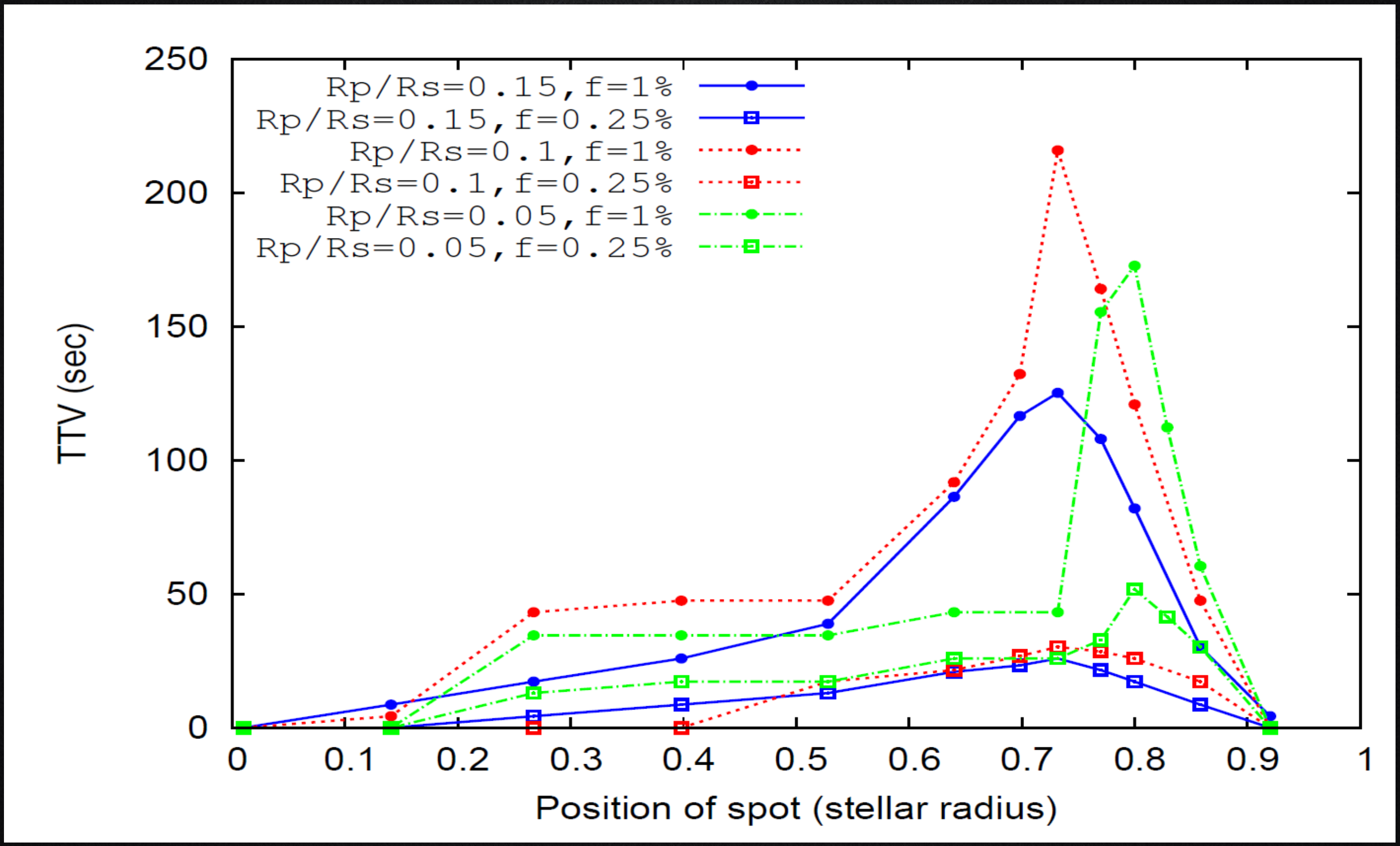
Fit them with transit light curve without anomaly. Transit depth, duration and timing are free parameters





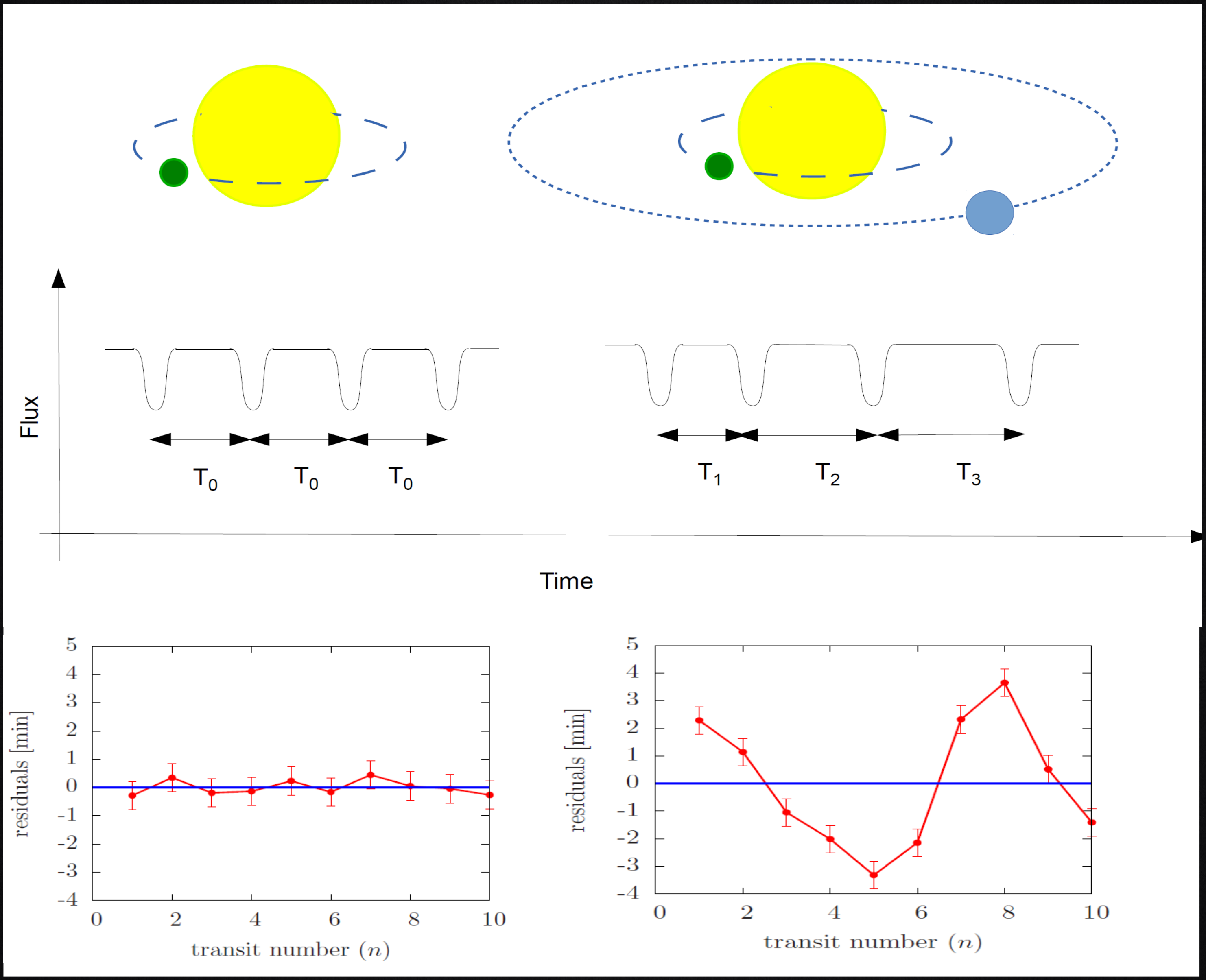
Transit timing measurements

Jupiter size planet transiting a solar-like star overlaps a spot with a filling factor of 1 %, produces the maximum value of TTV around 200 seconds.



Oshagh et al , A&A,2013b

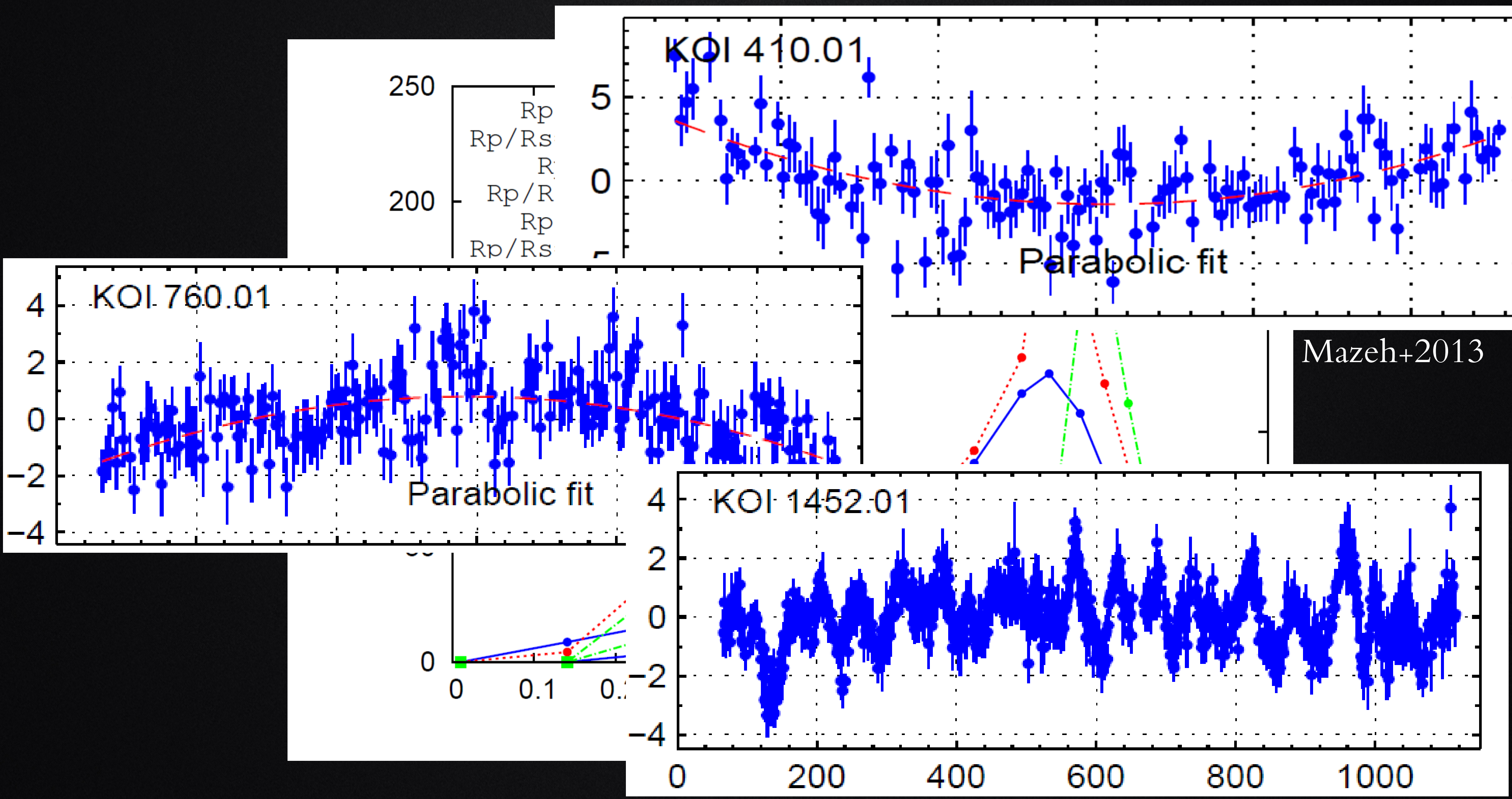
Transit timing variation (TTV)



Boue, Oshagh+2012

Transit timing measurements

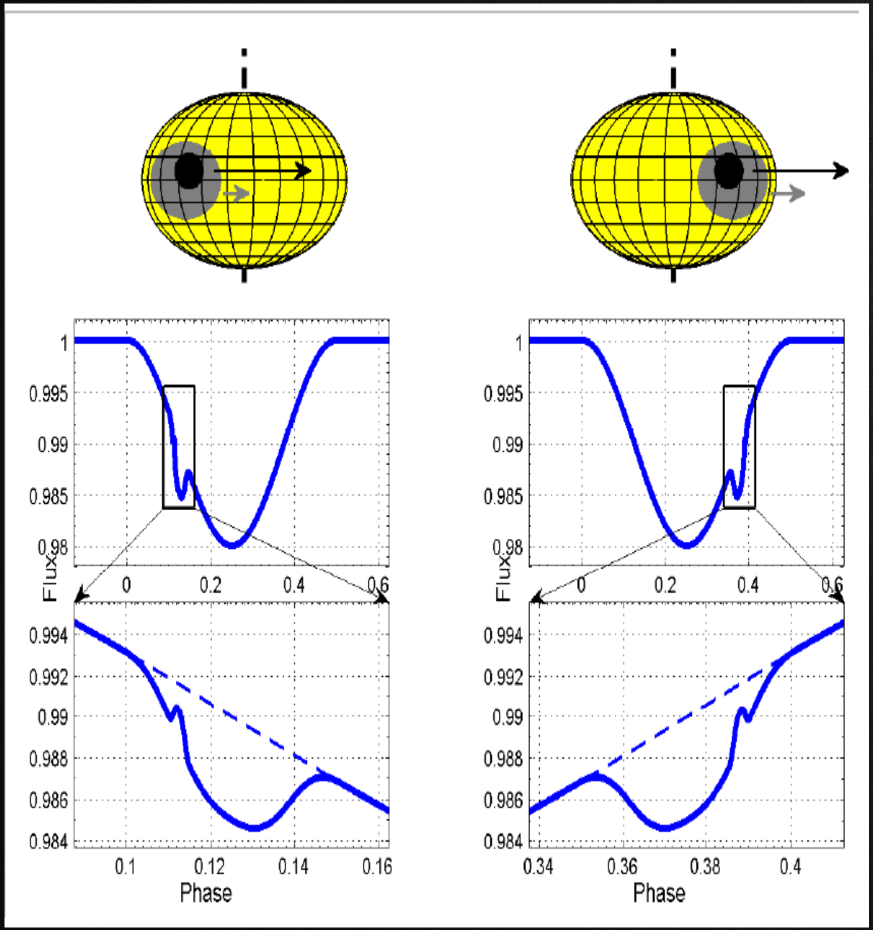
Jupiter size planet transiting a solar-like star overlaps a spot with a filling factor of 1 %, produces the maximum value of TTV around 200 seconds.

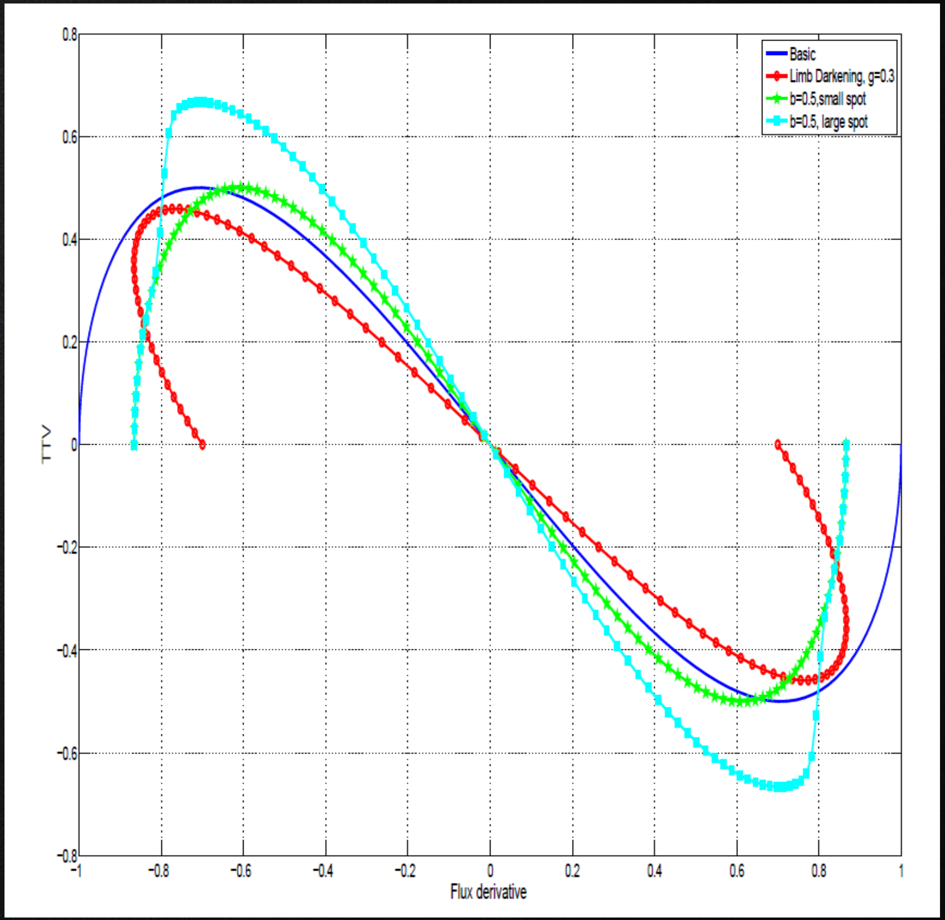


Mazeh+2013

Transit timing measurements

TTV induced by stellar spot occultation may be used to distinguish between prograde and retrograde transiting planets (Mazeh+2014).

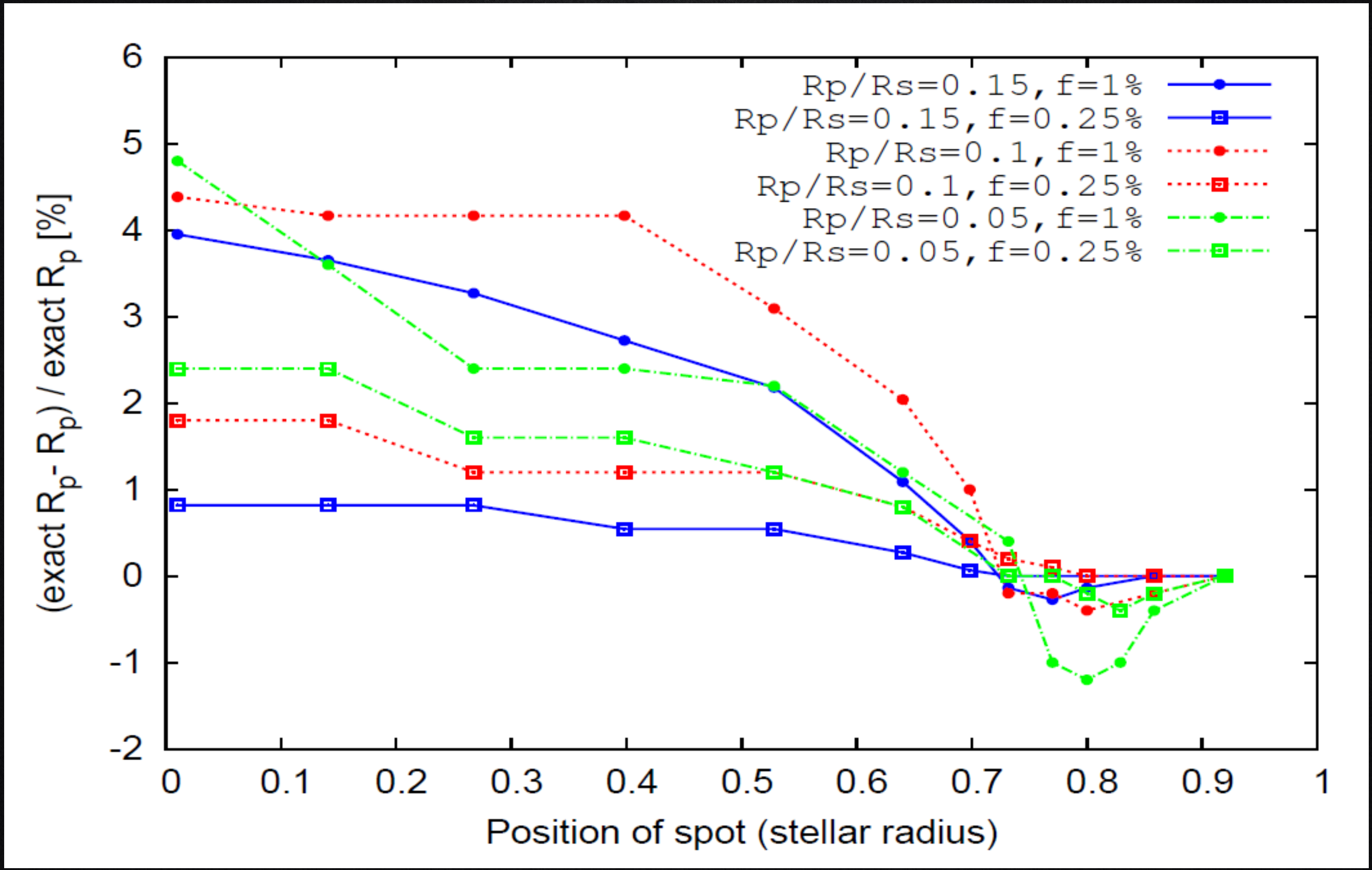




Mazeh+2014

Planet radius estimations

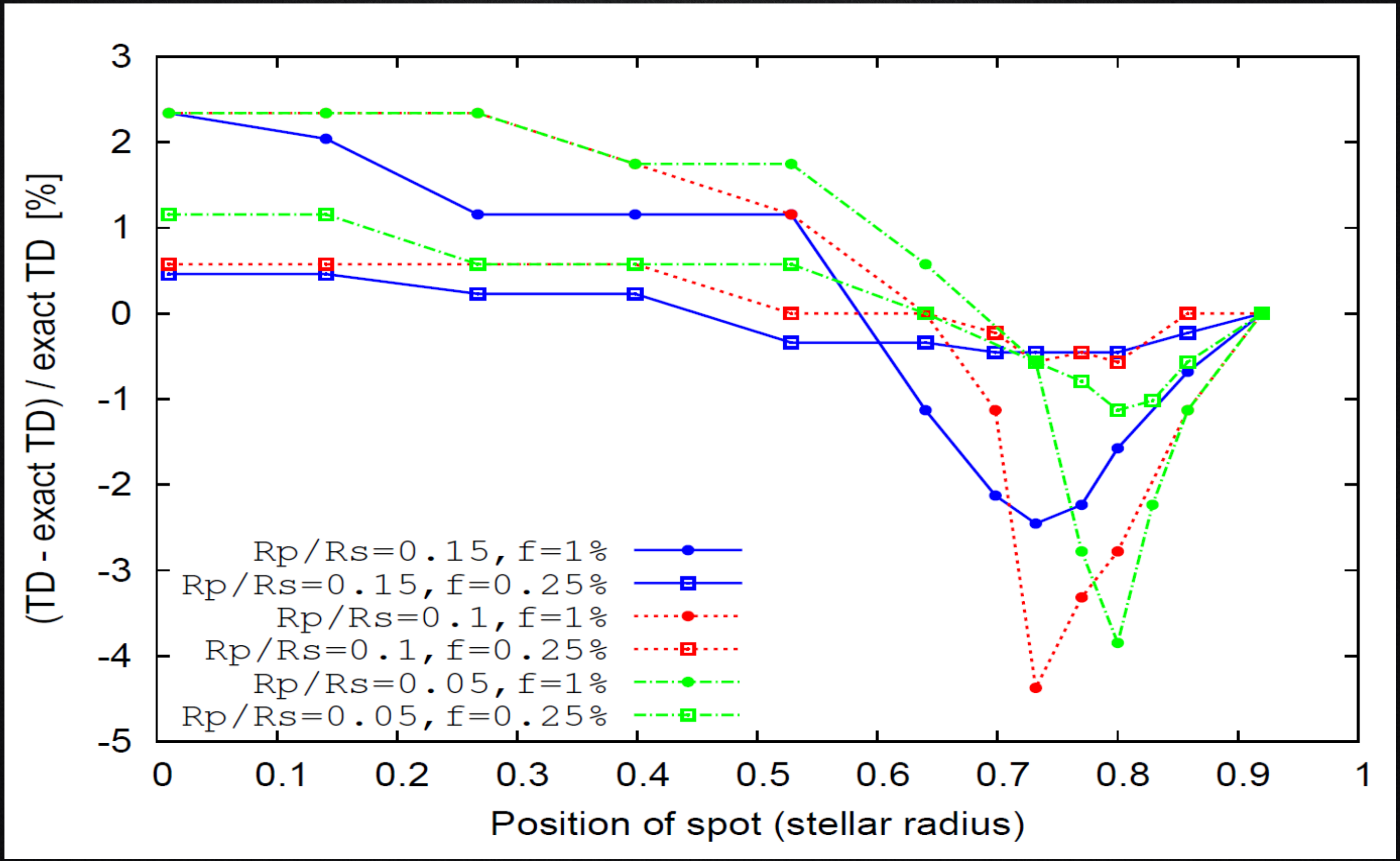
A radius of Neptune size planet transiting a solar-like star and overlapping a spot with filling factor of 1 %, can be underestimated by 4%.



Oshagh+2013b

Transit duration estimation

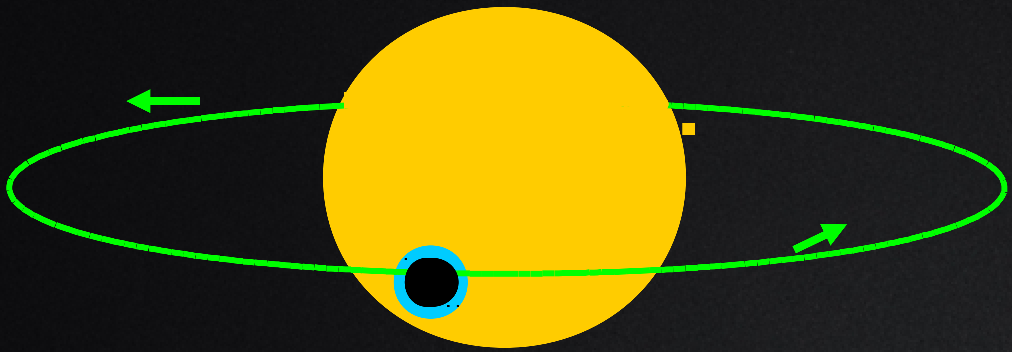
A Jupiter size planet transiting a solar-like star and overlaps a spot with filling factor of 1% causes transit duration to be 4%, longer or shorter, which affects the planetary inclination measurements.



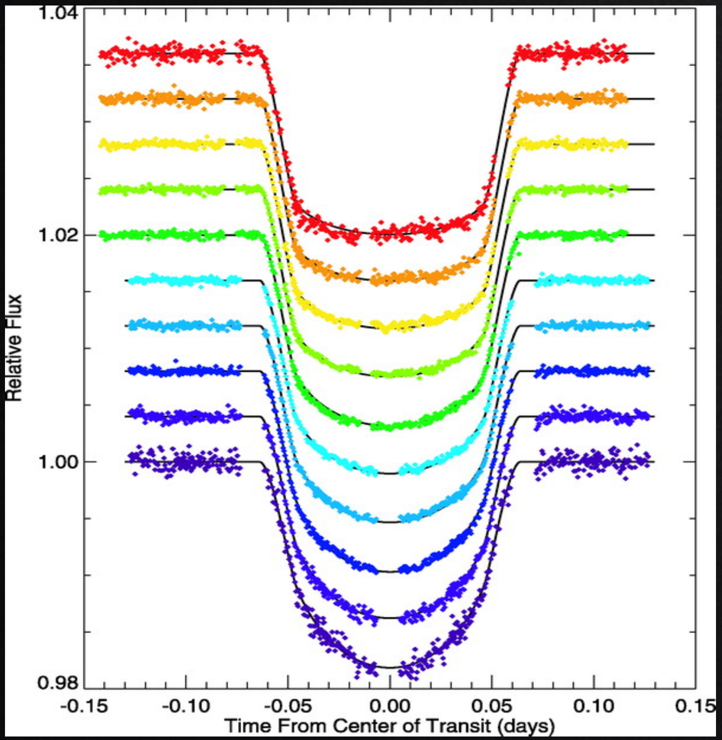
Oshagh+2013b

Impact of stellar activity on transmission spectroscopy

Transmission spectroscopy



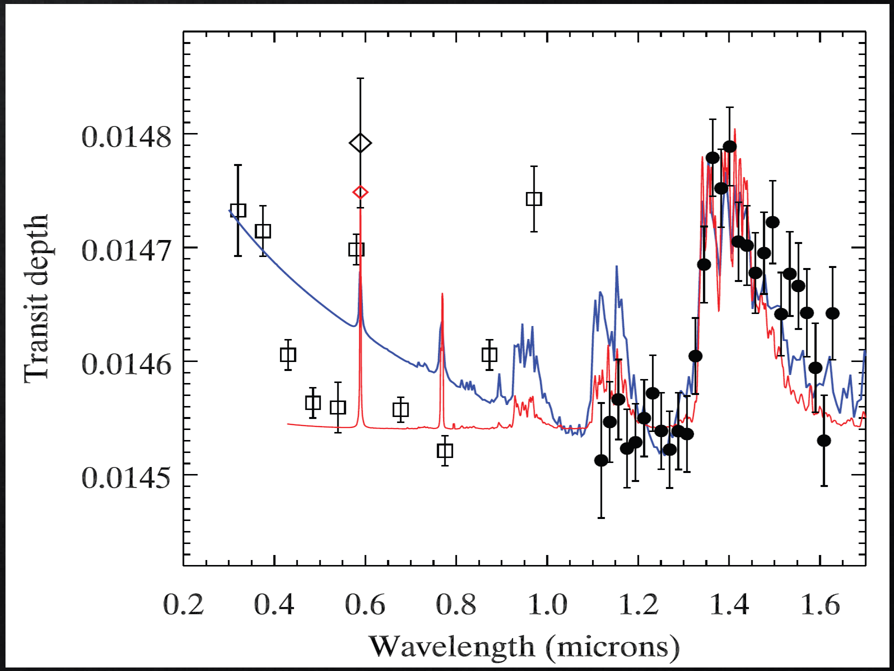
Multi-band photometry



HD 209458b from 290–1030 nm (Knutson +2007)

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

–Molecular composition
–Thermal structure of the atmosphere

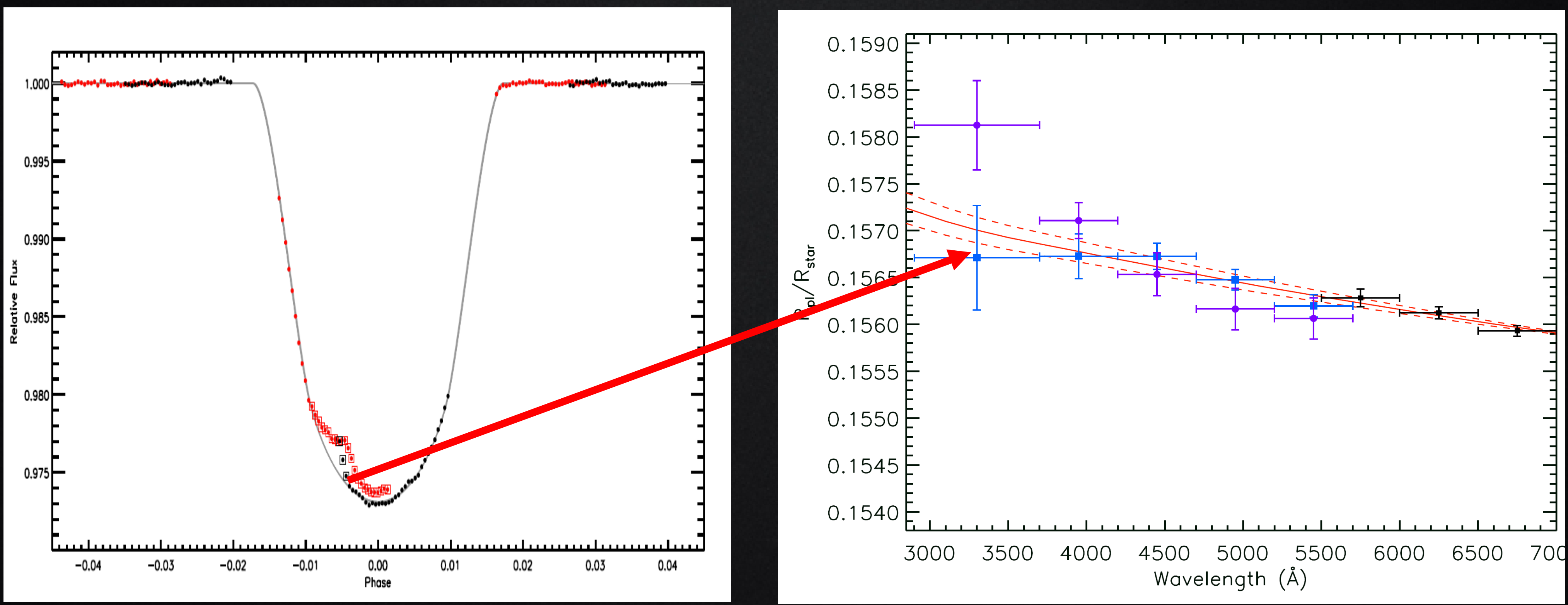


HD 209458b (Deming +2013)

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 +2011

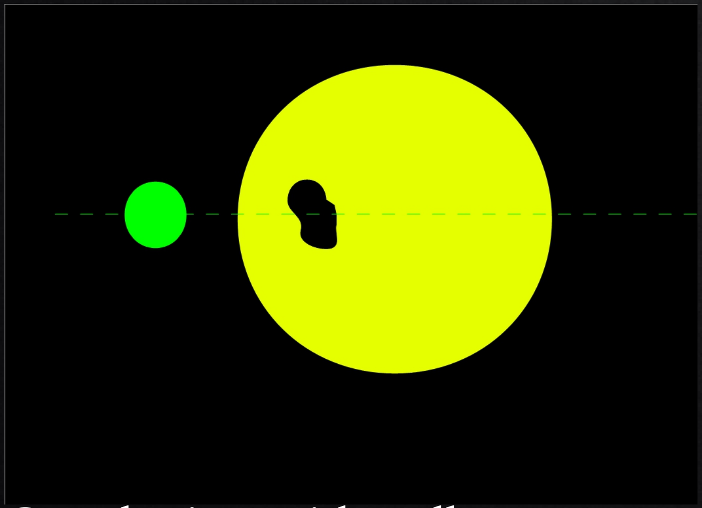
Quantifying the impact

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

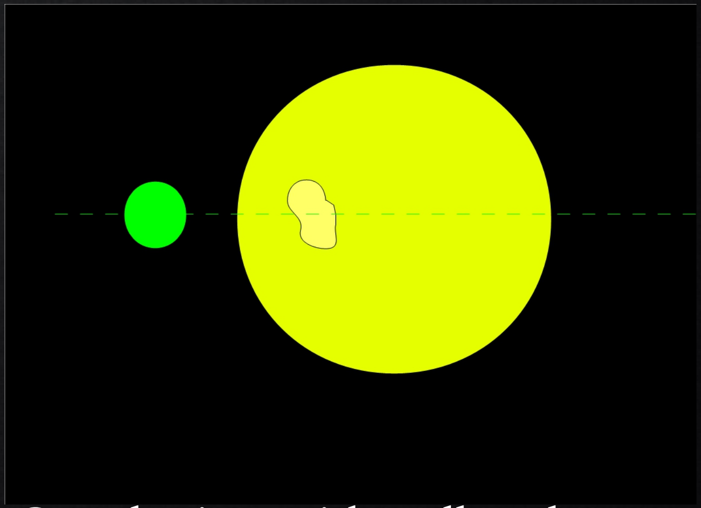
Modify SOAP-T to generate transit light curves at different wavelengths.

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



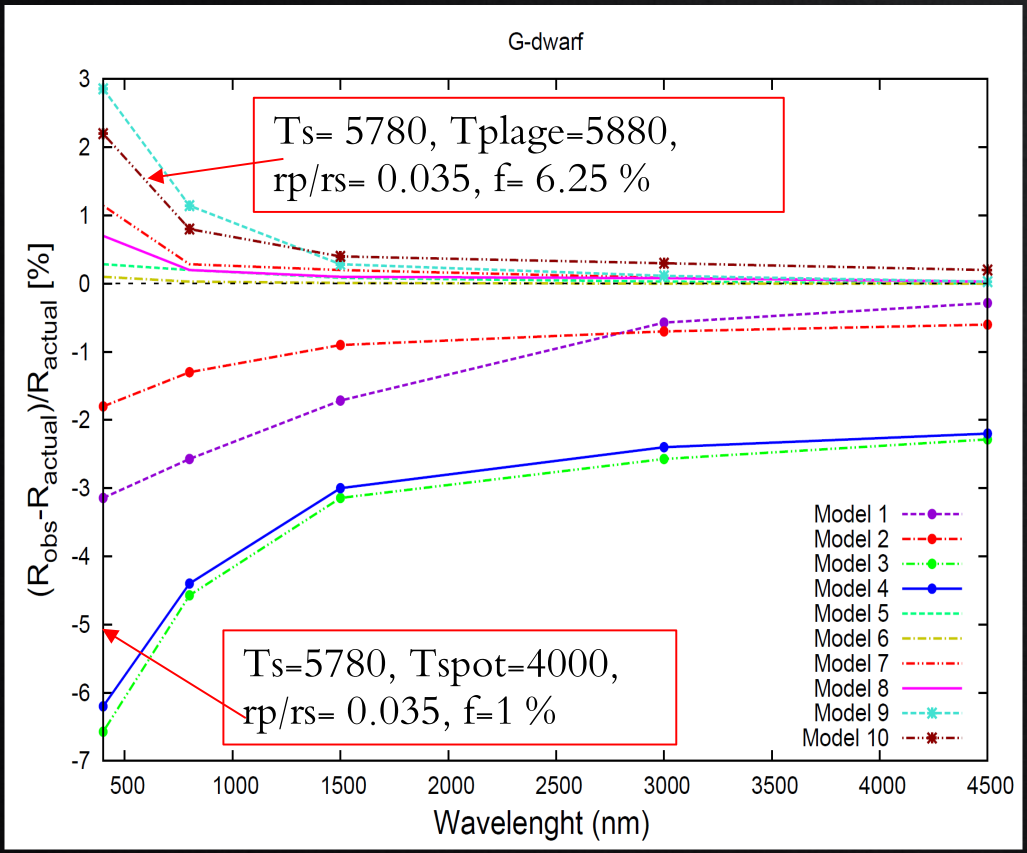
Occultation with stellar spot

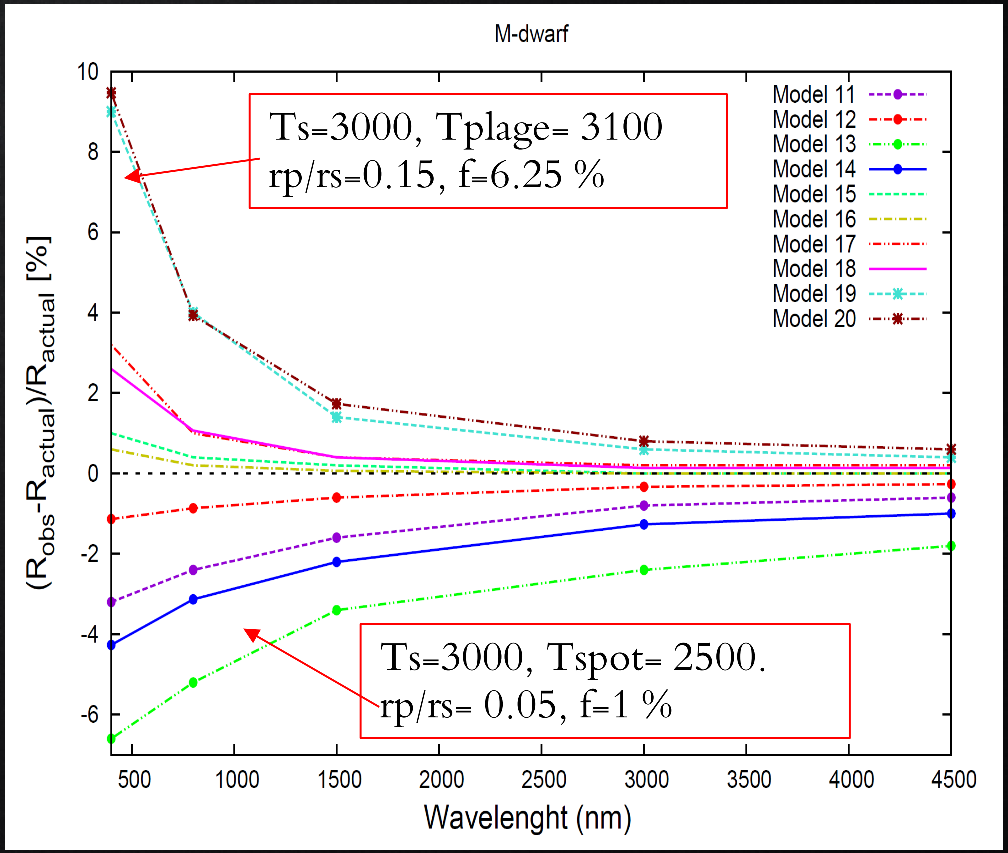


Occultation with stellar plage

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.

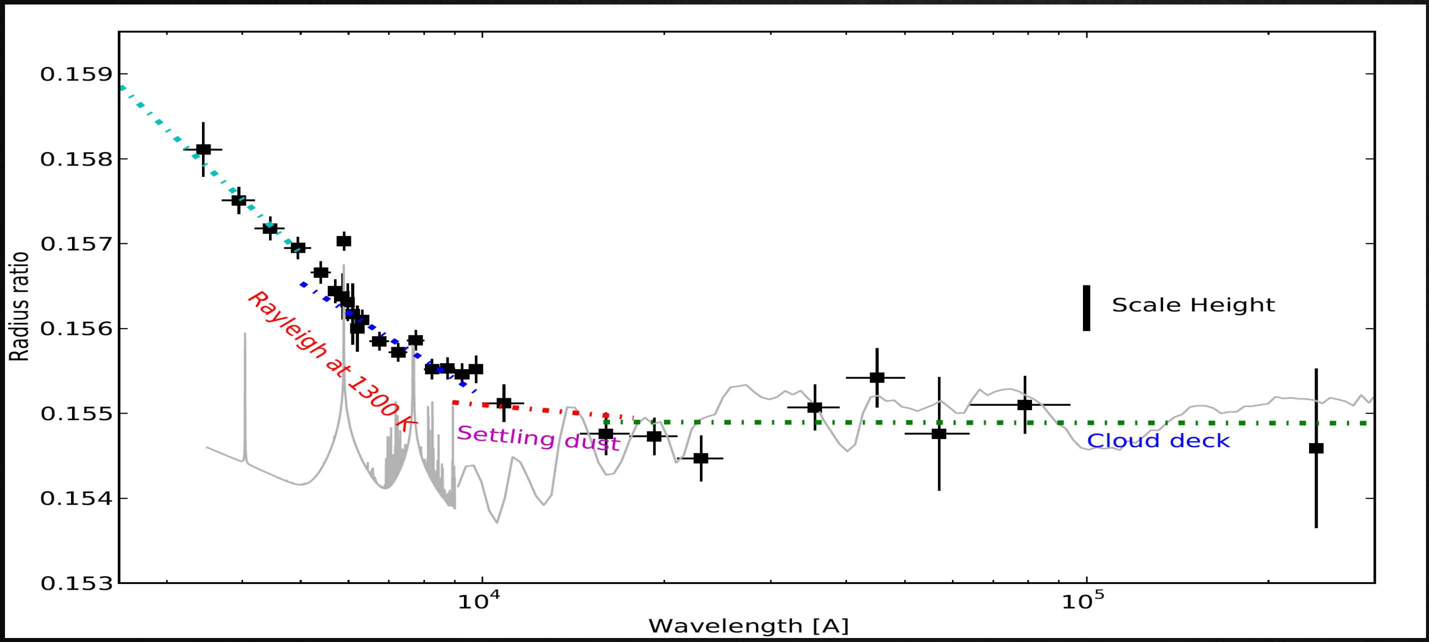


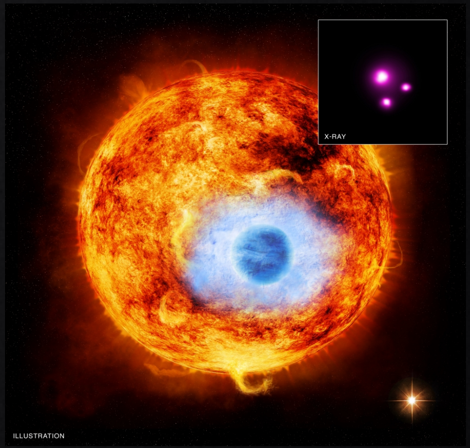


HD 189733 b

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).

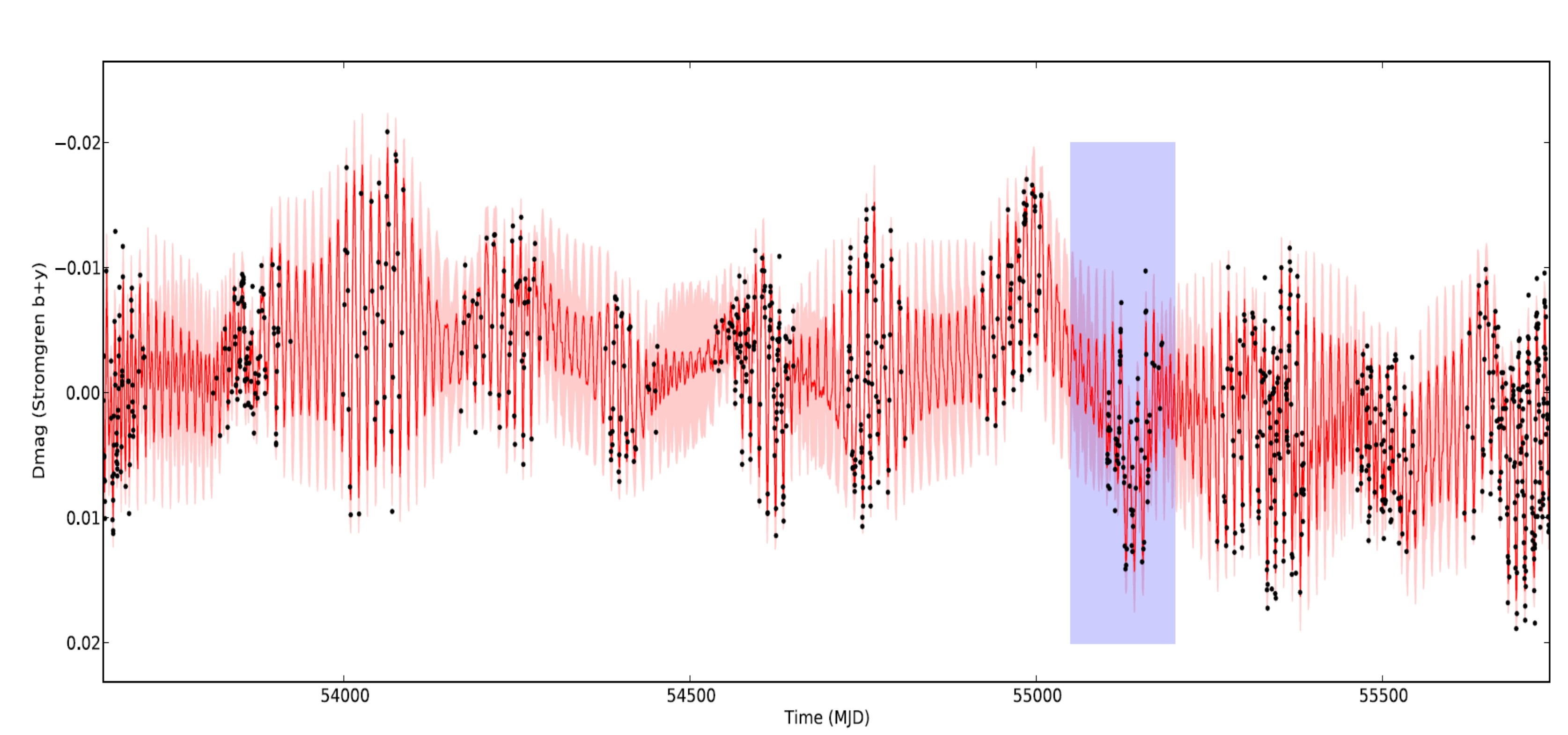




Pont +2013

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).

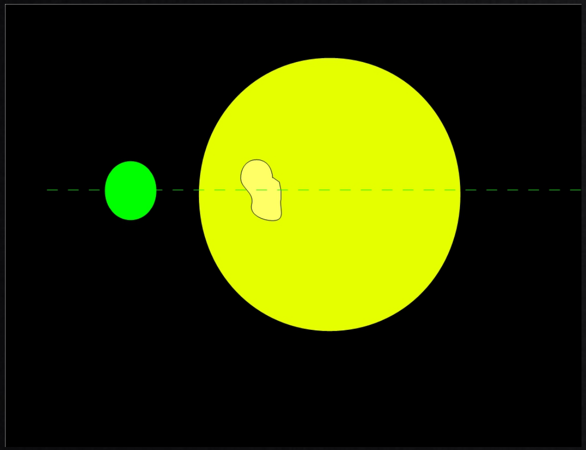


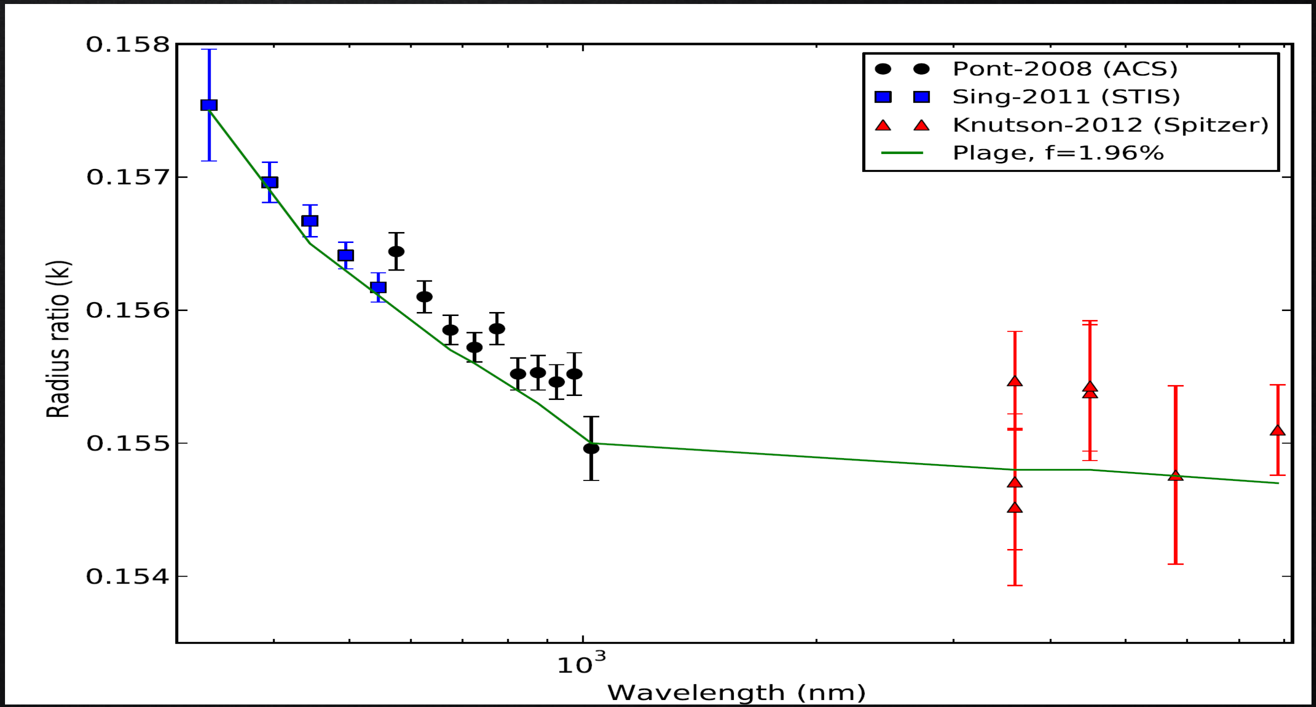
Pont et al. (2013)

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.



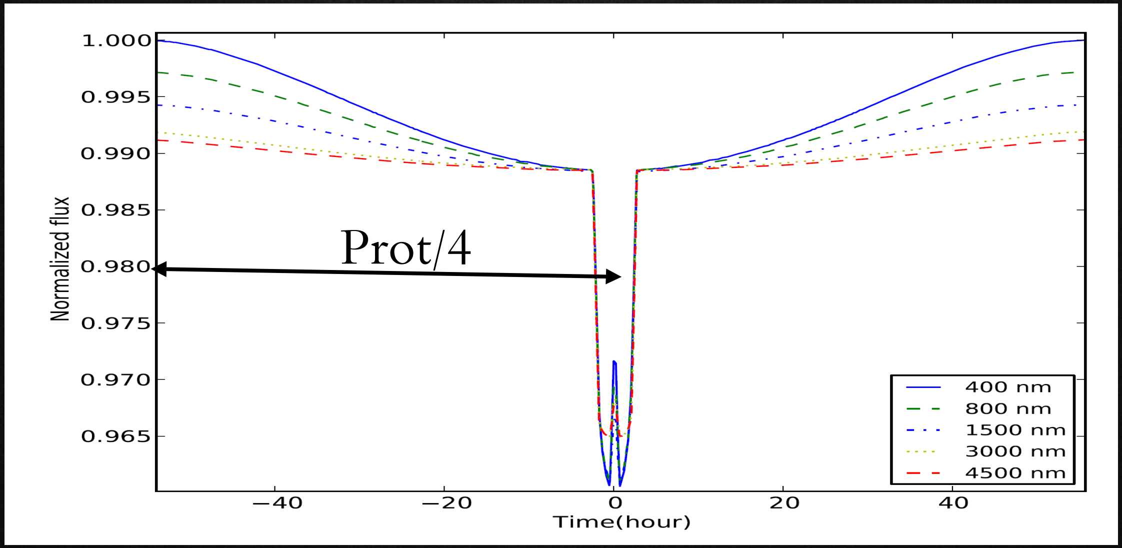


Oshagh+2014

conclusion

RV observation: Search for better activity indicators (e.g., see poster by A. Mortier), or to find a "super indicator" which combine all information in all indicators (BIS,FWHM,Vasy, log Rhk', and flux).

Transit observation: Rule out the influence of occulted and non-occulted stellar active regions, either by multi-band photometry out and inside transit or by modeling it with realistic models.



Thanks for your attention!