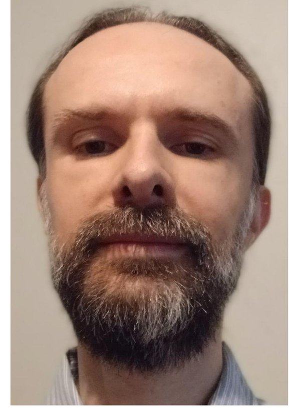


The Transit Mapping Method for Modelling Stellar Activity Contamination in Transits of CoRoT-2 b using ECLIPSE

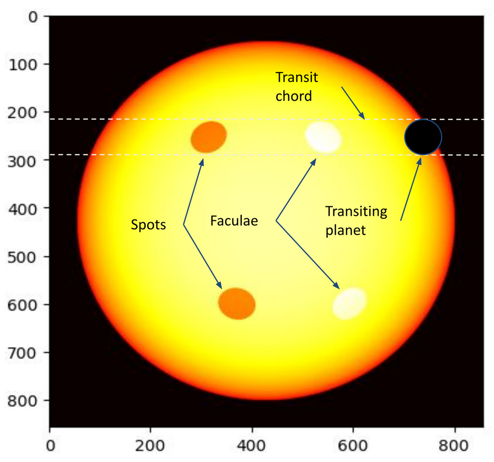
2025 Sagan Summer Workshop

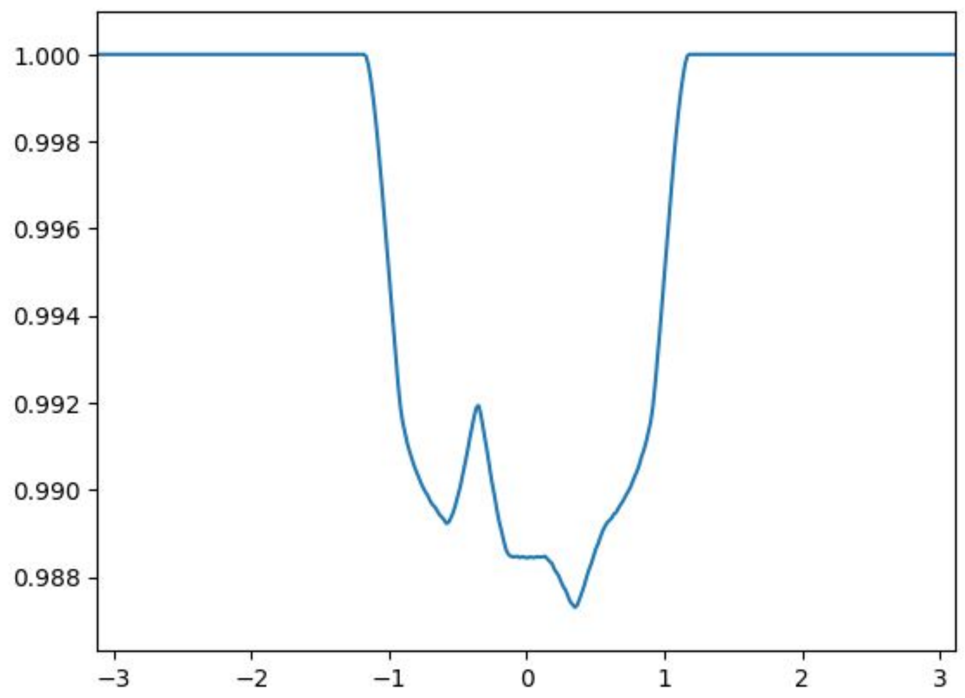
Andre O. Kovacs, Adriana Valio

Center for Radio Astronomy and Astrophysics Mackenzie (CRAAM), Mackenzie Presbyterian University

1. CONTEXT:

The Spot Transit Mapping method (Silva, 2003) uses the exoplanet as a probe to detect and measure the contamination from stellar activity, as small as the planet itself, like starspots and faculae, across the transit chord:





2. TARGET:

CoRoT-2 b:

- Our target, CoRoT-2 b, is a hot-Jupiter transiting exoplanet, around 1.5x larger than Jupiter, orbiting a young and active G-type star, very similar in size and temperature to our Sun (Alonso et al., 2008; Chavero et al., 2010). The system became a reference for studies of the contamination from stellar activity:

		CoRoT − 2	*Sun*
$R_*(R_{Sun})$	*Radius*	0.902	1.00
$T_{eff}(K)$	*Temperature*	5696.0	5772.0
$log\ g(cm/s^2)$	*Surf. grav.*	4.42	2.44
Metal. (dex)	−−	0.03	0.00
Spec. Type	−−	*G7 V*	*G2 V*
Age (Gyr)	−−	0.12	4.6

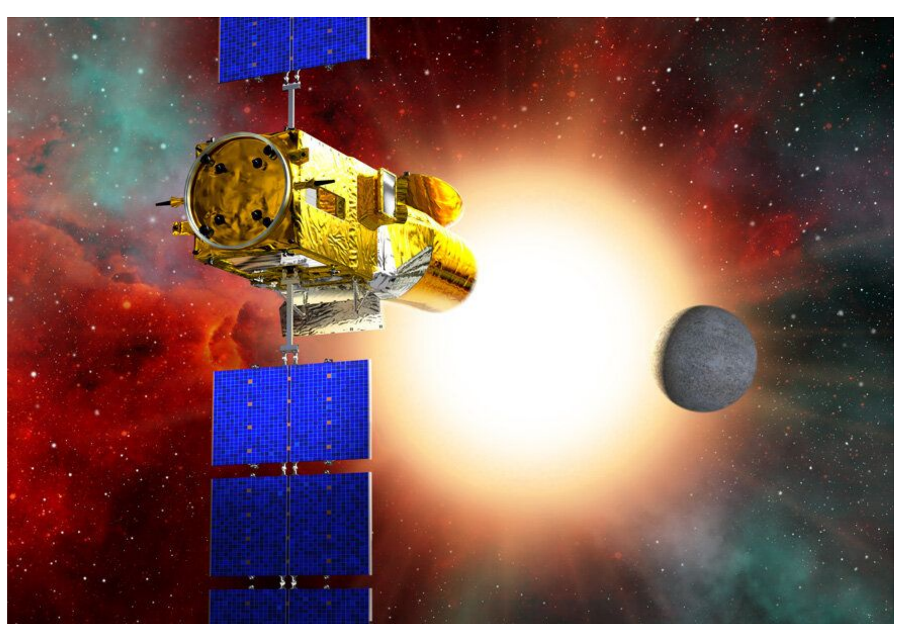
		CoRoT − 2b	*Jupiter*
P (days)	*Orb. period*	1.7429935	398.880000
i (deg)	*Orb. inclination*	87.84	1.303
ecc.	*Orb. eccentricity*	0.0000	0.0489
ω *(deg)*	−−	20.02	
$R_p\ (R_{Jup})$	*Radius*	1.465	1.00000
a (AU)	*Semi − major axis*	0.02809	5.20300

* The Sun and Jupiter are included for comparison.

3. DATA:

CoRoT space telescope:

- The CoRoT (COnvection, internal ROtation and Transiting planets) space mission was a space telescope by the CNES French space agency, with contribution from Austria, Belgium, Brazil, Germany, Spain, and the ESA Science Program, and was launched in December, 2006. It was the first space mission to search for transiting exoplanets, and the observations of the first field began in January, 2007, lasting until 2013 (Deleuil & Fridlund, 2018).
- The exoplanet CoRoT-2b was observed in the field LRc01, from May to October, 2007, receiving the initial designation CorotID 0101206560, until the confirmation of the transiting exoplanet, when the star received the denomination CoRoT-2 and the exoplanet CoRoT-2 b (originally CoRoT-Exo-2b) (Alonso et al., 2008).
- The initial cadence for the observations was done lasting 512 seconds, changing to a higher cadence of observations every 32 seconds right after the first transit detection.



4. TRANSIT MAPPING METHOD:

Advantages over other activity/surface mapping methods:

- Doppler Imaging: The Transit Mapping method can probe much smaller stellar contaminations, as small as the size of he transiting planet; and can be applied to stars of slow rotation;
- Photometric Modulation: The Transit Method requires much shorter observing baselines, and can probe as many features as required;

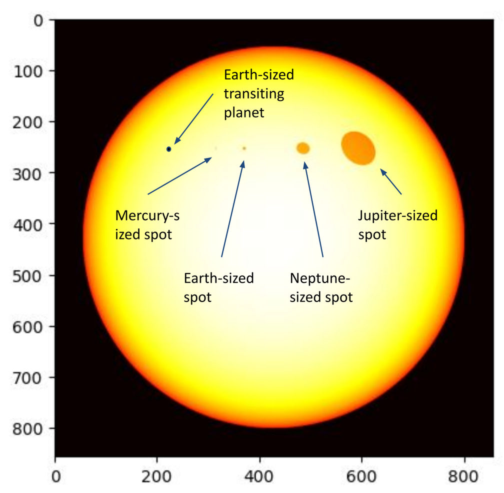
Disadvantages over both alternative methods:

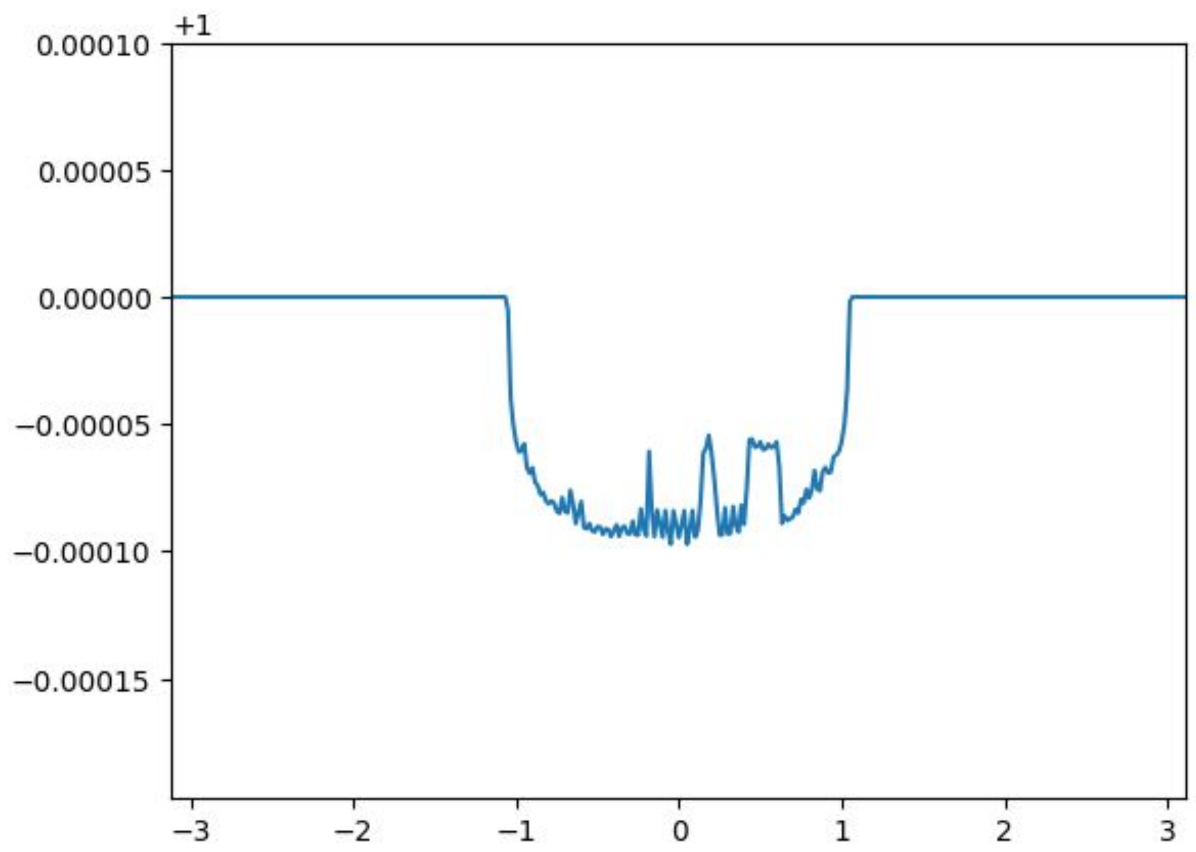
- Can only probe the transit chord;

5. SIMULATIONS:

Earth-sized planet orbiting a Sun-like star:

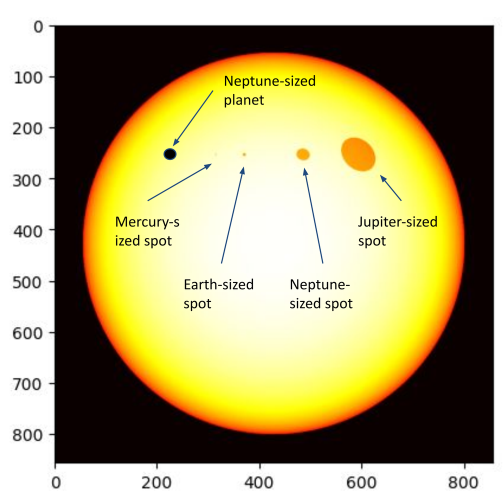
- Considering spots of increasing size centered on the transit chord (left to right): 1x $R_{Mercury}$, 1x R_{Earth}, 1x $R_{Neptune}$, and 1x $R_{Jupiter}$

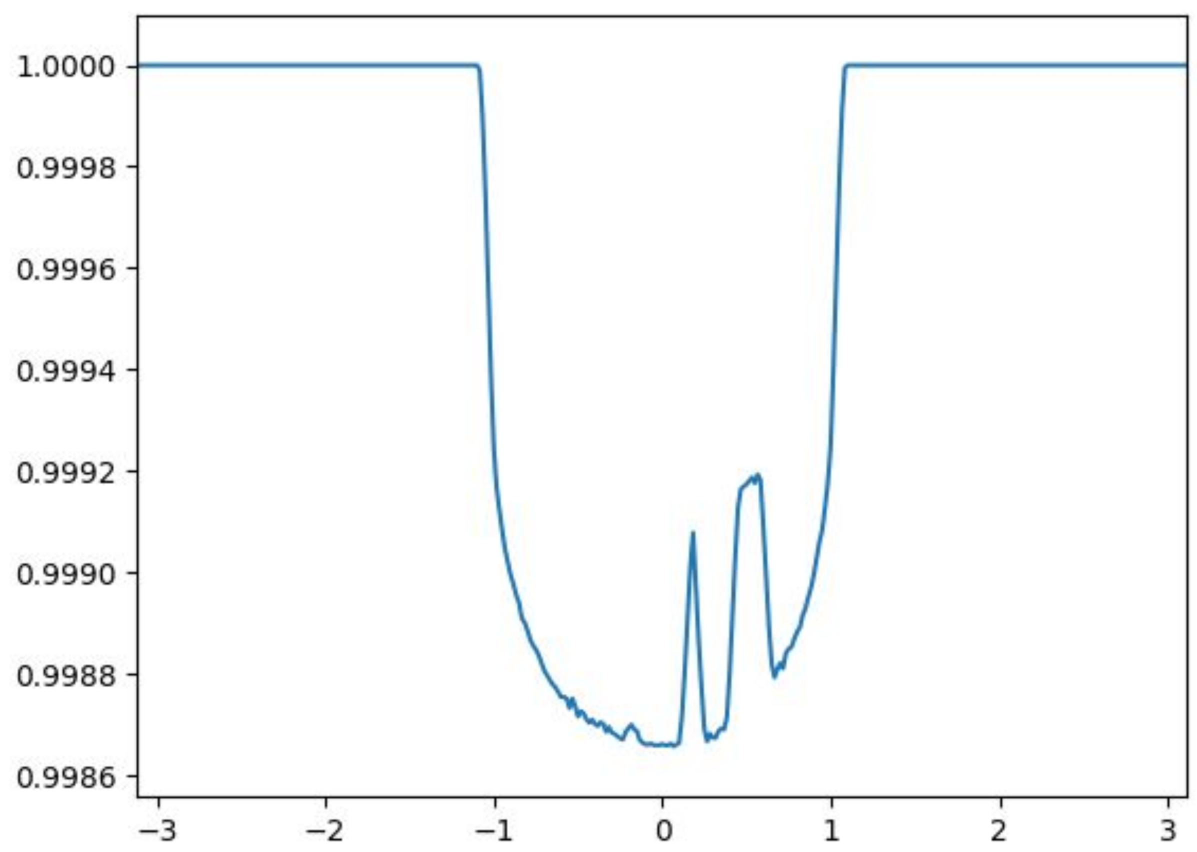




Neptune-sized planet orbiting a Sun-like star:

- Considering spots of increasing size centered on the transit chord (left to right): 1x $R_{Mercury}$, 1x R_{Earth}, 1x $R_{Neptune}$, and 1x $R_{Jupiter}$





6. ECLIPSE TOOL:

Transit model for starspot crossing events:

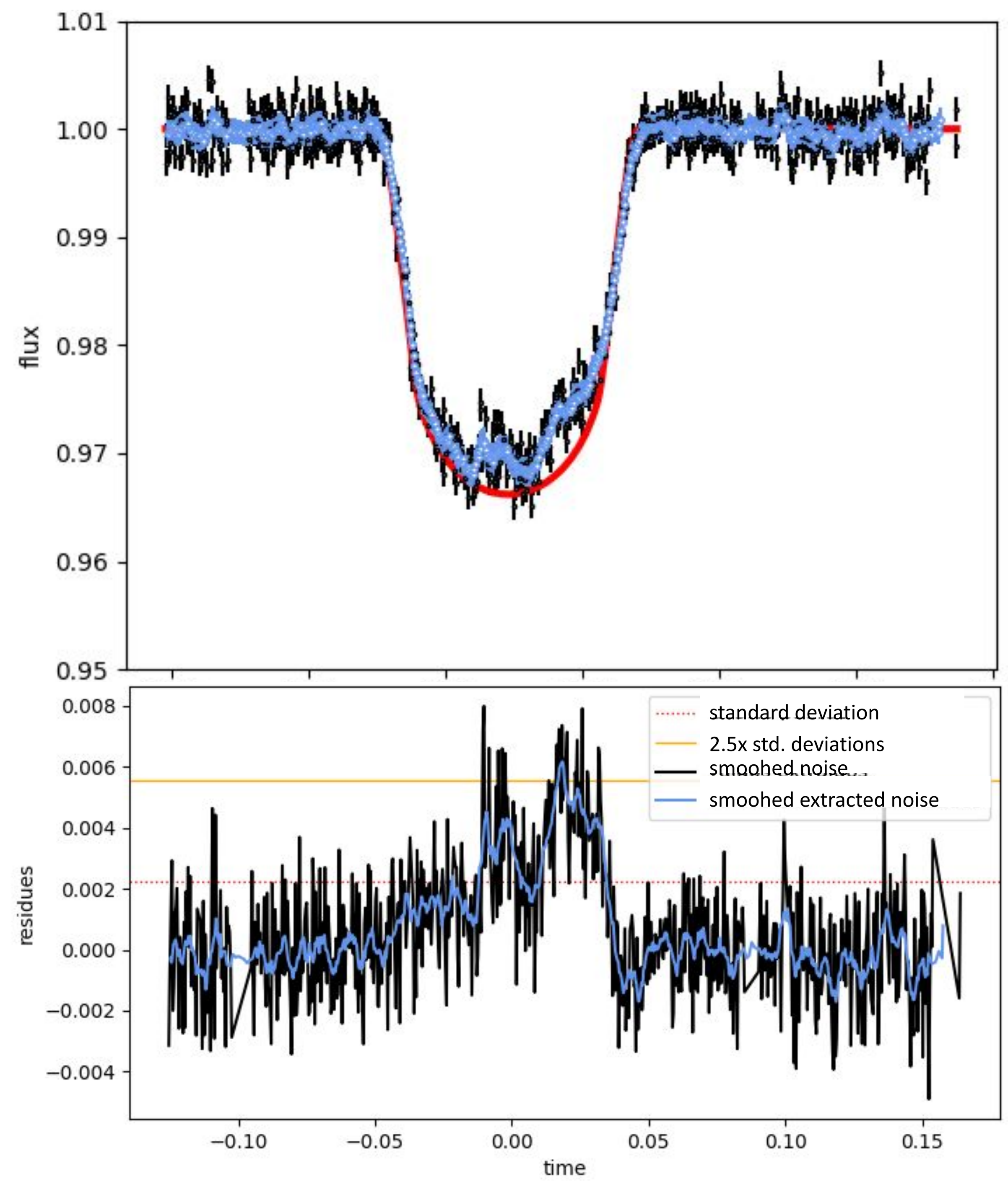
- The ECLIPSE tool simulates a star, assuming a limb darkening model, as a 2D pixelated image, where the planet is represented as a dark and opaque circular disk;
- Stellar contamination from starspots and faculae are represented as projected darker/brighter circles on the surface of the star;
- Support for time evolvolving contaminations, such as flares and CMEs (Coronal Mass Ejections), is being developed.

Github repo.

7. TRANSIT AND CONTAMINATION MODEL FIT:

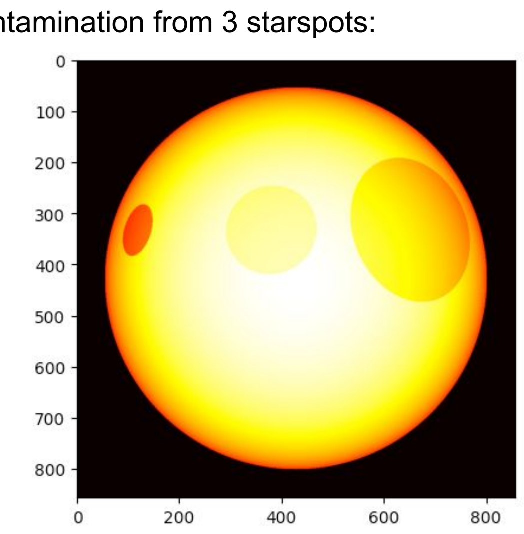
Transit model fit:

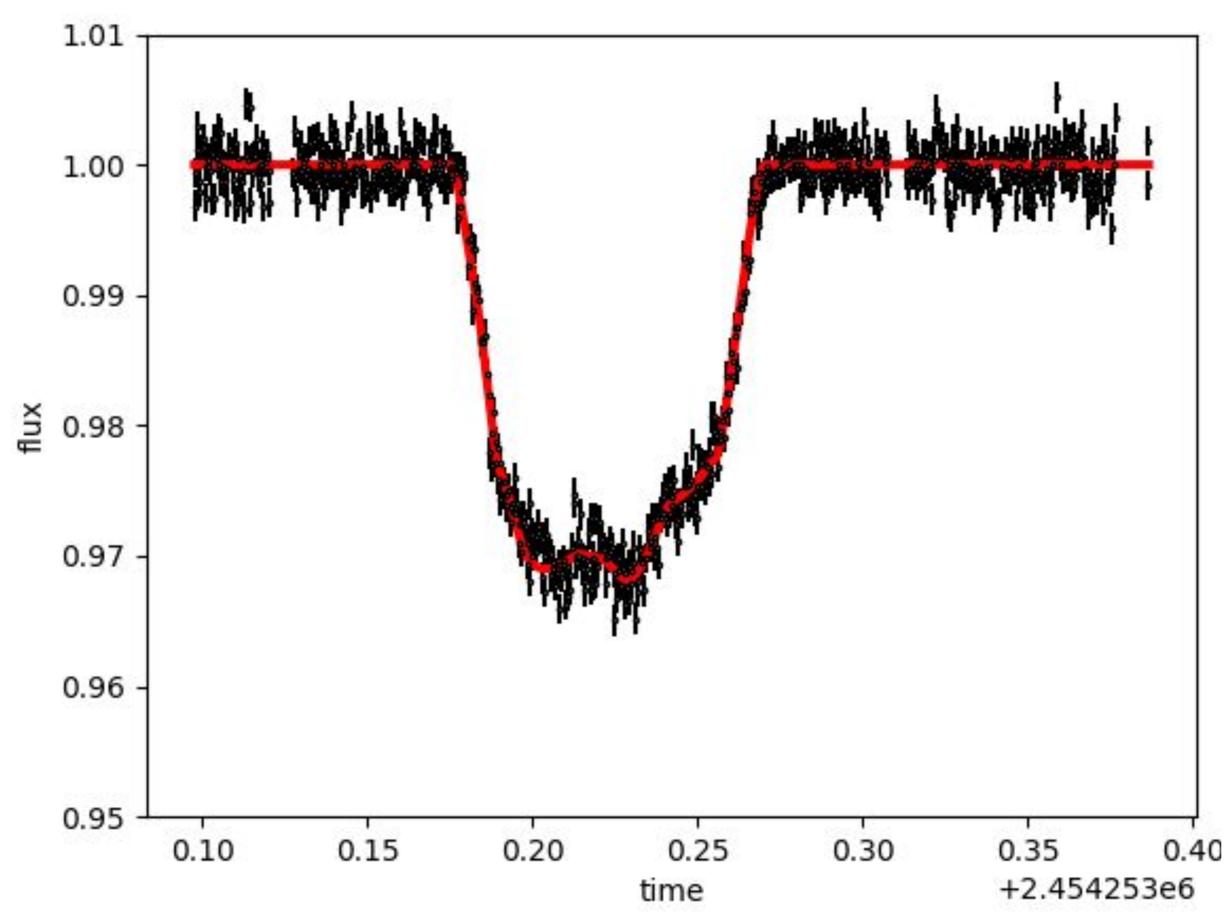
- Analysis for the transit number 9 (32s cadence data):
  - The transit displays clear signs of 2, or possibly 3, starspot crossing events:



Transit and stellar contamination model fit:

- Model fit considering contamination from 3 starspots:





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8. CONCLUSIONS:

Simulations:

- As expected, our simulations show that the Transit Mapping method is capable of probing stellar contaminations as small as the transiting exoplanet itself, providing better detections as the planet size decreases;

CoRoT-2 b:

- The Transit Method confirmed our expectations, and was capable to detect two clear spots, the first close in size to the planet (0.24 R_* or 1.44 R_p) and approximately at mid-transit (on the center), and the second much larger than the planet (0.39 R_* or 2.34 R_p) and located closer to the transit egress (on the right);
- However, as also expected, the third spot near the transit ingress (on the left) had a much lower detection level, since it is a smaller (0.14 R_* or 0.84 R_p) than CoRoT-2 b, and introducing a "bump" very close in amplitude to the scatter due to the noise level on the light curve data, and very close to the limb of the star.

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CONTACT: Andre O. Kovacs: andre.kovacs@gmail.com