# Characterizing the Brown Dwarf candidate KOI-1152.01:

## A short period transiting companion with high obliquity and eccentric orbit.


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### Introduction

In this study we aim to reconstruct the 3D orbital parameters of the Brown Dwarf candidate companion of the Kepler star KOI-1152 using the spot activity of the host star to constrain the companions (sky-projected) orbital obliquity**.** Such orbital reconstruction has been succesfully done in previous studies. The observational determination of the relative obliquities of planets or other sub-stellar companions is a very important input for planetary system formation theories

### Tools for determining obliquity

- **Rossitter-McLaughin effect:** During transit a charactheristic modulation is observable in the Radial Velocity curve of the star (due to the partial eclipsing of the rotating stellar surface). (Ohta et al. 2004)

- **Barnes-Szabó effect:** A characteristic deviation is observable in the transit light curve if the companion transits a gravitationally darkened stellar disc. (Barnes et al. 2011, Szabó et al. 2011)

- **Sanchis-Nutzman effect:** The active regions of a star cause rotational modulations in the overall light curve. If the companion eclipses some of these active regions during transit, an increase of relative flux within the transit light curve will be observable. (Sanchis et al.,Nutzman et al.)

**In Our study we utilized the Sanchis-Nutzman effect to give a constraint on orbital obliquity.**

### Parameters of the KOI-1152 system

| | |
|---|---|
| Star: | KOI-11521 |
| KIC ID: | 10287248 |
| RA (J2000) | 19.77971 |
| DEC (2000) | 47.3273 |
| Spectral type: | M1 |
| Magnitude (Kepler) | 13.987 |
| $M_*$ [$M_{Sun}$] | 0.58 |
| $R_*$ [$R_{Sun}$] | 0.65 |
| $T_{eff}$ [K] | 4069 |
| $\log g$ [cm/$s^2$] | 4.73 |
| Parameters of the companion: | KOI-1152.01 |
| Period [JD] | $4.7222521 \pm 0.0000012$ |
| $T_0$ [Kepler day] | $111.24278 \pm 0.00001$ |
| $k = R_b/R_*$ | $0.26720 \pm 0.00073$ |
| D [hour] | 3.4063 |
| b | $0.4441 \pm 0.102$ |
| a [AU] | 0.046 |
| $e_{min}$ | 0.26 |
| $R_b$ [$R_{\mathrm{Earth}}$] | 15.97 |
| $T_b$ [K] | 620 |

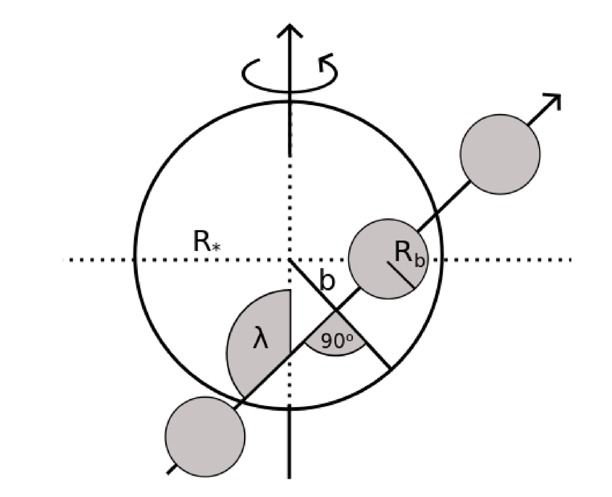
**Fig.1.** Parameters retreived from MAST (2012)

### Brown Dwarfs

- Brown Dwarfs are objects more massive than a planet, while not massive enough to sustain Hidrogen fusion in their cores. This criteria places them between 13 and 80 Jupiter masses. However due to the fact that the „stellar" mass-radius relationship becomes non-liner for very low masses and planets, the correct classification of objects detected via transit is not a trivial task.

- Some Brown Dwarfs orbit around normal stars, but single, binary and trinary Brown Dwarf systems have also been observed

- It is possible to directly detect the IR light of nearby Brown Dwarfs (2MASS, WISE). Also several of these objects have been found in the Kepler data, where apart from their large radius they produce the same signal as a planet.




| | |
|---|---|
| d [JD] | 0.1252171491 |
| $k = R_b/R_*$ | 0.27389516 |
| $P_b$ [JD] | 4.72225 |
| b | -0.5564338812 |
| $\lambda$ [°] | 136.3221482509 |

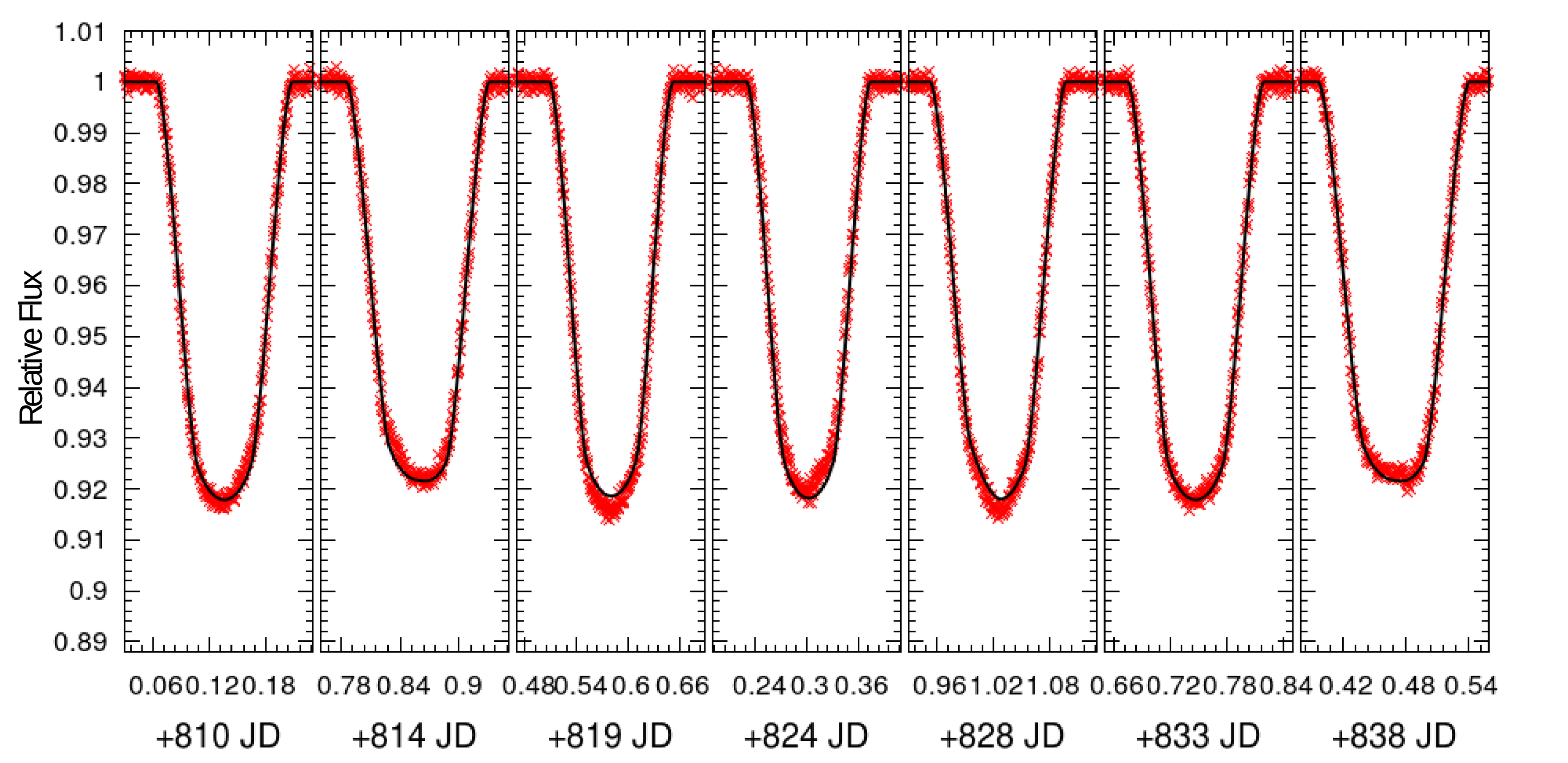
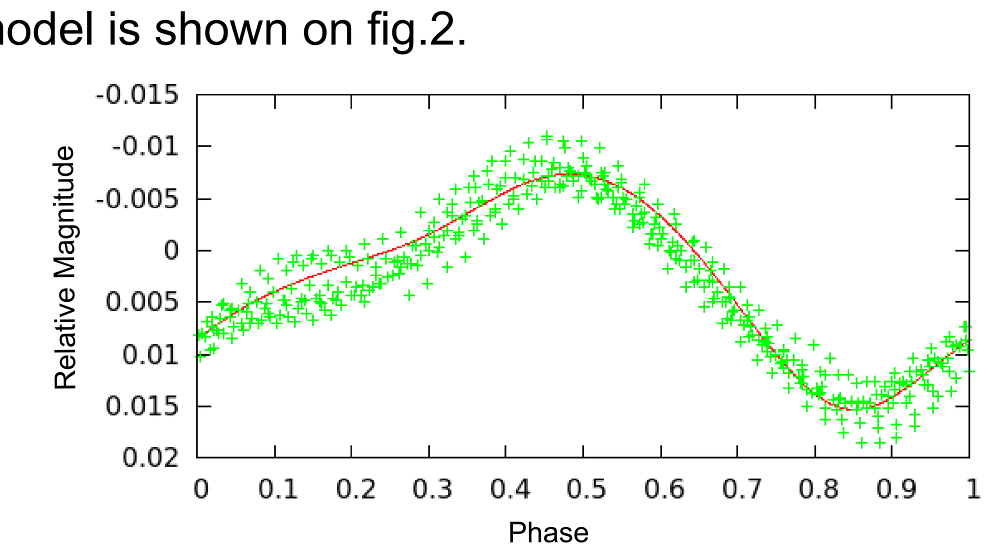



**Fig.5.** *Left top:* Schematic model of the best fit scenario (white dot in fig.4.) *Left bottom:* best fit parameters (chisq=1.649) *Right:* All seven transit light curves with the predicted model light curve shown in black

### Modelling the stellar activity

We utilized the available Kepler short cadence dataset from Q9 (31 days). The observed light curve from the star shows very intense rotational modulations (fig.3.), and the effect of spots is also visible within the transits (fig.5.). We fitted the spot distribution of the star using the SpotModeL tool. A stellar inclination of 77° and T_spot=4030 K have been assumed. The mean stellar Rotational period was found to be P_rot=2.93277 days. The best fit model is shown on fig.2.




| Spot parameters : | Spot I | Spot II |
|---|---|---|
| $\lambda$ [°] (latitude) | $75.4209 \pm 22.74$ | $298.868 \pm 9.579$ |
| $\beta$ [°] (longitude) | $61.4351 \pm 14.42$ | $-48.7772 \pm 7.443$ |
| $\gamma$ [°] (radius) | $37.9204 \pm 11.56$ | $63.1745 \pm 11.08$ |

**Fig.2.** *top:* phase folded light curve and model. *bottom:* fitted parameters of the two spots

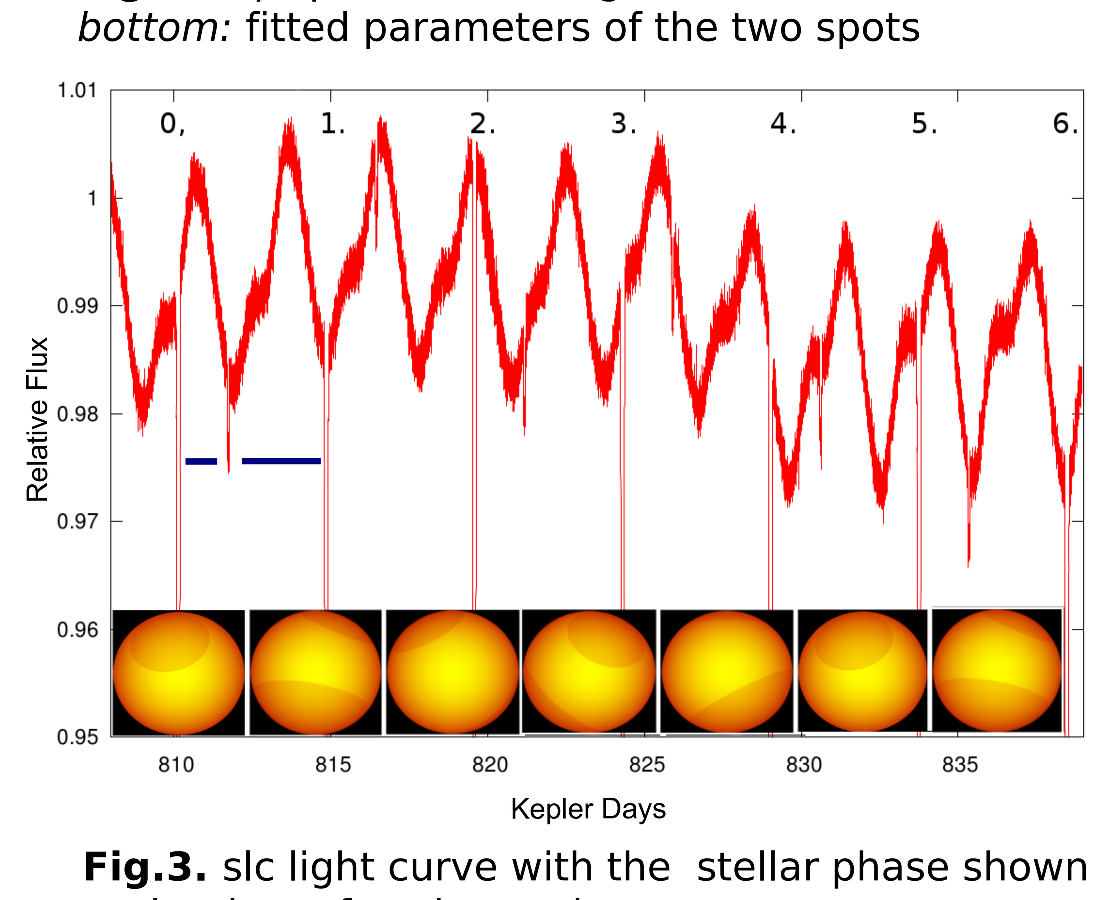



**Fig.3.** slc light curve with the stellar phase shown at the time of each transit.

### Constraining the orbital excentricity

A significant phase offset is present between the transit and the occultation of the companion (shown by the blue markers in fig.3). Previous studies have explored the phase curve of this particular star, and found that the phase offset corresponds to an excentricity of at least 0.26. (Szabó et al 2013)

### Exploring the transit parameter space

Using the obtained spot distribution we modelled transits numerically over the spotted stellar disc. The parameters of the transit configuration were sampled randomly over a given interval (fig.4.) with 2*10^6 points. The best fit scenario was identified using a Maximum-Likelihood method (fig.5.). For each set of parameters the different transit light curves were calculated and fitted to the observed Kepler transits. Since the spot modelling utilizes simplifying assumptions about the structure of the spots, the true confidence limits could not be calculated in a non-computing heavy way. This means that only the relative topography of the parameter space should be interpreted with a physical meaning.

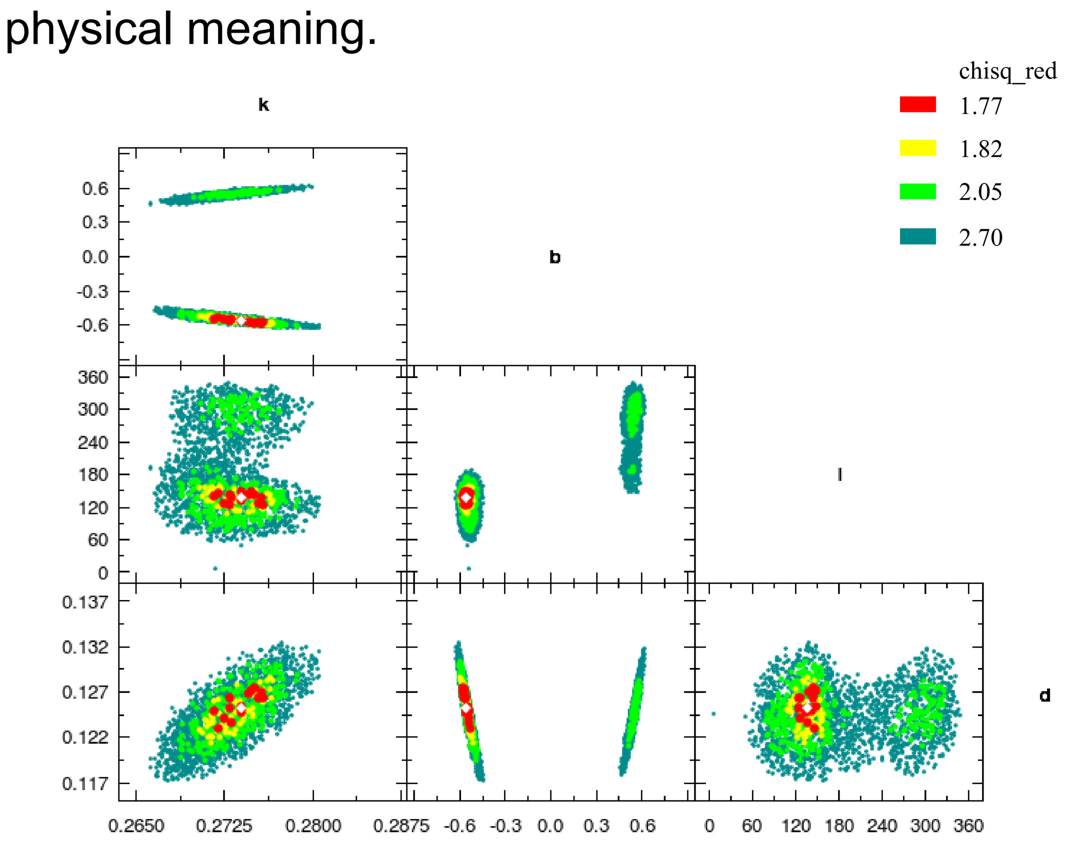



**Fig.4.** The distribution of goodness-of-fit values within the parameter space

### Conclusions

Our results show two possible scenarios, both corresponding to a nonzero obliquity. Numerical bootstrap calulations are currently under way to better charactherize the distribution of errors associated with the spot modelling. The inferred high obliquity and excentricity may result from an additional perturber present in the system, however a very young stellar age could also explain the observed short stellar period and excentricity.


**Acknowledgements:**

This work was made available by the "Lendület" Young Researchers Program, the OTKA K76816, K81421, K83790 and MB08C 81013 grants



**References:** Barnes et al. ApJS, 197:10, 2011; Nutzman et al. ApJl, 740:L10, 2011; Ohta et al. ApJ 622:11181135, 2005; Sanchis-Ojeda et al. ApJ, 733:127, 2011; Szabó et al. ApJl, 736:L4, 2011, Szabó et al. A&A 553:A17, 2013; SpotModeL webpage: konkoly.hu/staff/ribarik/SML