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"MOST" SATELLITE PHOTOMETRY OF REGULUS

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Regulus (α Leo) is a rapidly rotating, nearby B7V star which has been suspected of small-scale variability and binarity for a long time, this in addition to the known binary K2V + M4V companion $3'$ away. But only recently Gies et al. (2008) have discovered that it is indeed a moderately close binary with the orbital period $P = 40.11 \pm 0.02$ d. The discovery of radial velocity variations with the semi-amplitude of $K_1 = 7.7 \pm 0.3$ km s^{-1} was made in spite of the very strong broadening of the lines with $V \sin i \simeq 320$ km s^{-1}. The visible component moves radially by a distance only about twice its dimensions, $a_1 \sin i = 6.1 \pm 0.3\, R_\odot$. From the small value of the mass function and the assumed value for the mass of the primary $M_1 = 3.4 \pm 0.2\, M_\odot$, the authors derived $M_2 \geq 0.30 \pm 0.01\, M_\odot$. Using various theoretical arguments on the evolution of the Regulus binary system, Rappaport et al. (2009) argue that indeed $M_2 = 0.30 \pm 0.02\, M_\odot$, hence $q = M_2/M_1 \simeq 0.09$. The observed large value of $V \sin i$ suggests that the axis of rotation and the orbital momentum may be positioned not far from the plane of the sky implying a possibility of eclipses.

Chance and depth of eclipses depend on the size of the mutual orbit which – in turn – depends on the mass ratio $q = M_2/M_1$. Thus, for the case of Regulus' orbit, $(a_1 + a_2) \sin i = 6.1\,(1 + 1/q)\, R_\odot$. The secondary star cannot be large since it is spectrally undetectable; it can be an M-type dwarf, a low-mass white dwarf or a low-mass helium star. For $i = 90$ degrees and $q = 0.09 - 0.1$, the orbital dimensions would be $60 - 75\, R_\odot$. For such a large orbit eclipses would take place only within a small range of inclinations around $i = 90$ deg of about ± 3 degrees away from the edge-on orbital position. These limits are for an infinitesimally small secondary component and would increase for a physically larger secondary. The maximum duration of a central transit would be about 0.65 days.

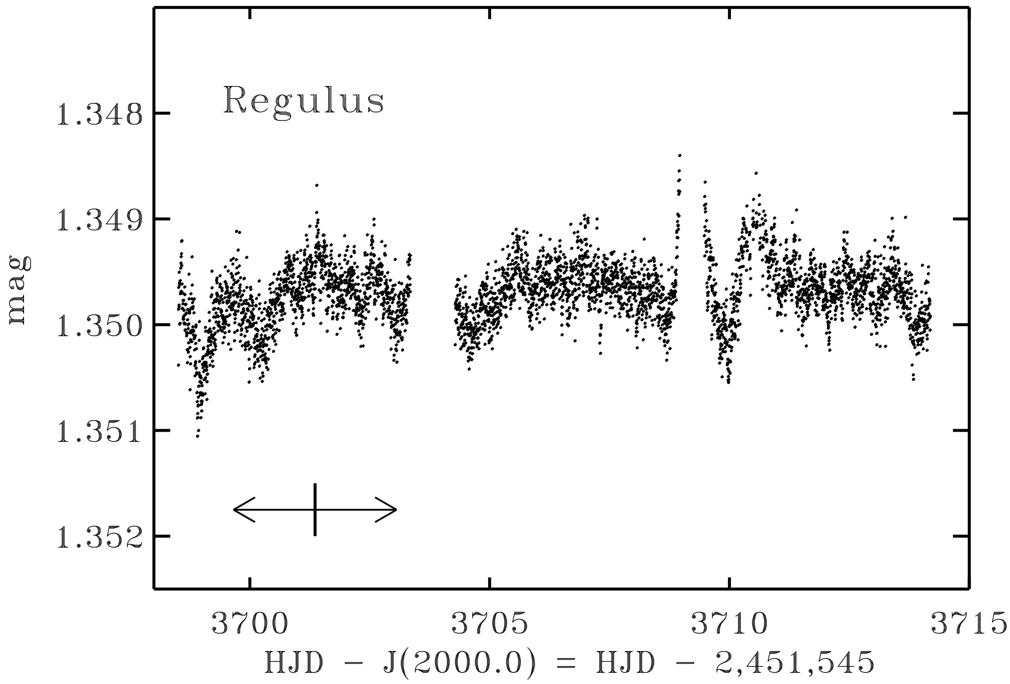

Figure 1. MOST observations of Regulus binned at 5 minute intervals. The vertical line and the arrows mark the expected time and its uncertainty of the transit of the invisible companion of Regulus.

We attempted to discover eclipse transits of Regulus by the invisible companion using the MOST satellite†. The optical system of the satellite consists of a 15 cm reflecting telescope with a custom broad-band filter covering the spectral range of 380 – 700 nm with the effective wavelength close to the Johnson V band. The pre-launch characteristics of the mission are described by Walker et al. (2003) and the initial post-launch performance by Matthews et al. (2004). Since the failure of the attitude control CCD in 2006, photometric observations are formed by adding short, typically one second exposures which are needed for stabilization of the satellite. For Regulus, we used the Fabry-lens mode with the star image spread within 30×30 pixels. The temporal sampling after the on-board addition was 30 sec. Because of the addition of the read-out noise, the final mean standard error per single observation is a complex function of the star brightness; it is expected to be at the level of 0.25 mmag (milli-magnitude) for the brightness of Regulus (Kuschnig 2010, unpublished). It should be stressed that the satellite was designed to be used for detection of *periodic signals* with time scales of minutes to hours and that long-term trends may happen and are sometimes hard to characterize. Some of them can be removed by using stars simultaneously observed with the target or by following satellite thermal and ambient magnetic field variations.

The MOST observations of Regulus were done over 15 days, February 10 to March 4, 2010. The predicted time of the spectral inferior conjunction (transit) using the Gies et al. spectroscopic elements for $E = 267$ elapsed epochs is: $T_0 + P/4 + E * P =$ HJD 2,455,246.36 ± 1.7 or MOST time = 3701.36, counted from J2000.0. Dr. Gies (private communication)

†The MOST satellite is a Canadian Space Agency mission, jointly operated by Dynacon Inc., the University of Toronto Institute of Aerospace Studies, and the University of British Columbia, with the assistance of the University of Vienna.

estimated that this time is uncertain by ±1.7 days.

The observations of Regulus are shown in Figure 1 after binning in 5 minute intervals, with the mean level adjusted to $V = +1.35$ which is the normally observed magnitude of the star; note that – as common for brightest stars – the scatter in the literature values of V is large reaching ±0.02 mag. We show the whole data well beyond the predicted moment of the eclipse to illustrate that the small depressions observed at the predicted conjunction time may be spurious or intrinsic to the star and cannot be interpreted as an eclipse. Similar fluctuations which reach 0.5 mmag of the mean signal and are present throughout the duration of the whole run could not be eliminated using any known instrumental effects. This is best visible around occurrences of two breaks of the sequence for 0.9 and 0.4 days which were caused by the telescope solar-door problem and an interruption to monitor a super-Earth transit. Note also that a depression of about 0.5 mmag at the MOST time $\simeq 3700$ appeared to last too long to be a grazing eclipse.

The residual variability seen in Regulus cannot be unambiguously interpreted as coming from the star, since the background measurements and telemetry show variability on similar time scales. Frequency analysis of the data and the telemetry did not reveal significant, periodic, coherent variations that would be clearly unique to Regulus at the amplitude level larger than 0.07 mmag (7×10^{-5} mean signal). Although the frequency range 0.3 to 3 cycles per day may require further investigation, at this point we have no convincing evidence for variations related to the rotation of Regulus at a frequency of about 1.7 cycles per day.

Summarizing: MOST observations did not lead to detection of any obvious eclipse deeper than about 0.5 mmag at the predicted moment of the spectroscopic inferior conjunction. For an orbit inclined by $i > 87$ degrees this excludes a red dwarf with $M_2 \simeq 0.3\,M_\odot$ as a companion because such a star would produce an eclipse up to 8 mmag deep. However, a low-mass white dwarf or a helium star – which according to Rapport et al. are more likely candidates for a companion of Regulus – would be undetectable by MOST. With their expected radius $R \simeq 0.02 - 0.06\,R_\odot$, the eclipse would be only 0.04 to 0.3 mmag deep.

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