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Photometric exoplanet mass determination

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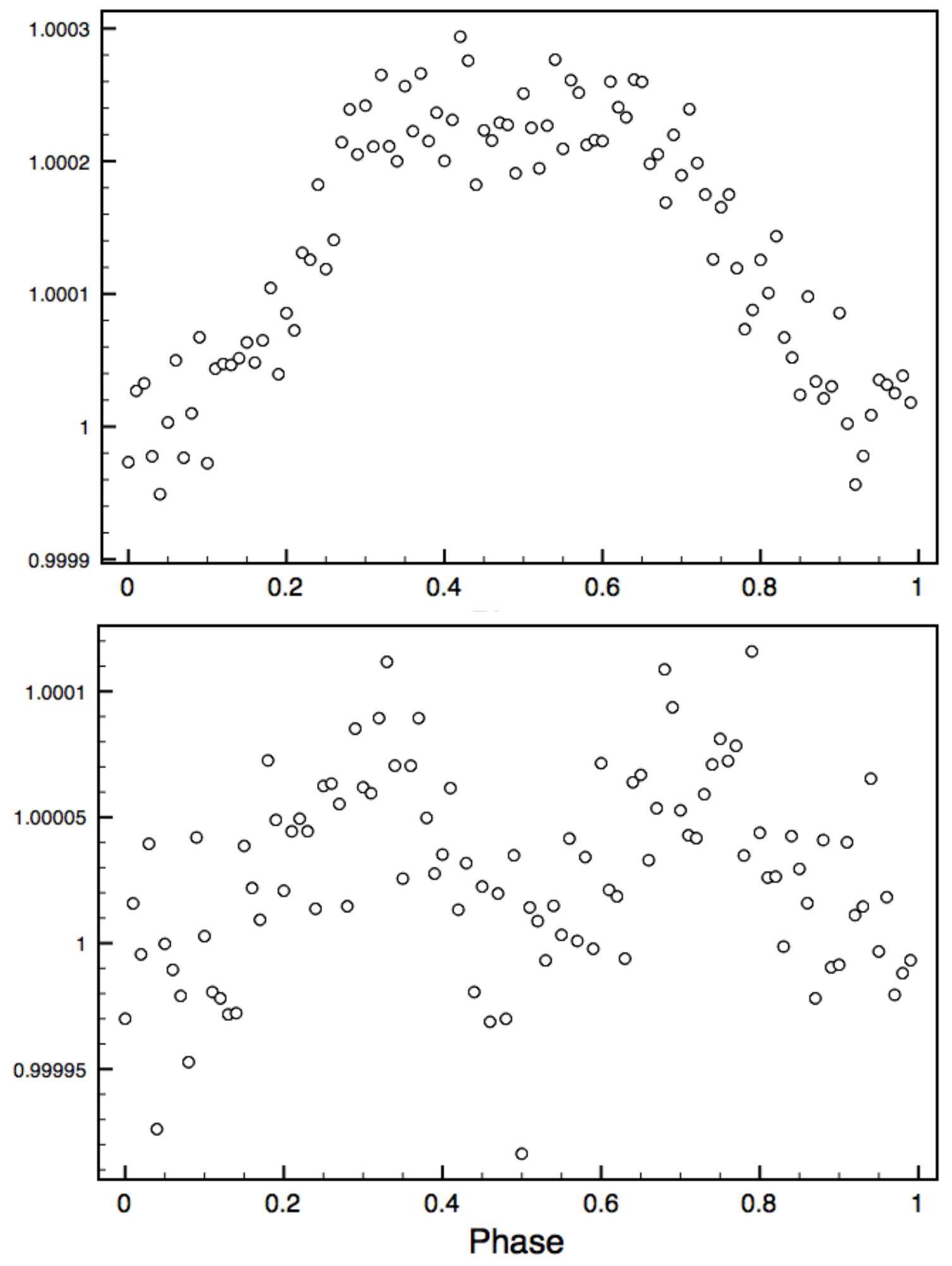
Abstract

We present a new approach to determine the parameters of transiting extrasolar planetary systems using photometric light curves (LCs). An analysis that combines a treatment of various phenomena in high-accuracy LCs allows a derivation of orbital and physical parameters. Our method considers the primary transit, the secondary eclipses, and the overall phase shape of a LC between the occultations. Phase variations are induced by reflected and thermally emitted light from the planet. Moreover, the ellipsoidal shape of the star due to the gravitational pull from the planet as well as the Doppler shift of the light on the CCD induce phase variations. As we find, the complete decipherment of LCs yields information about the planetary mass, orbital eccentricity, orientation of periastron, and the planet' s albedo. These parameters were impossible to extract from low-accuracy data of ground-based surveys.

The model

We normalize the LC by the stellar flux, which can be deter- mined as the minimum flux observed at phase α = 0.0. Phase variations are dominated by the reflected light. But there are further contributions such as: (i) thermal emission from the day side of the planet; (ii.) thermal emission from the night side of the planet; (iii.) the ellipsoidal deformation of the star due to tidal forces and flux variations due to a Doppler shift (doppler boosting) of the stellar spectral energy distribution on the CCD (Mazeh & Faigler 2010).



Top: Reflected light variations (expected PLATO light curve). **Bottom:** Ellipsoidal variations (expected PLATO light curve)

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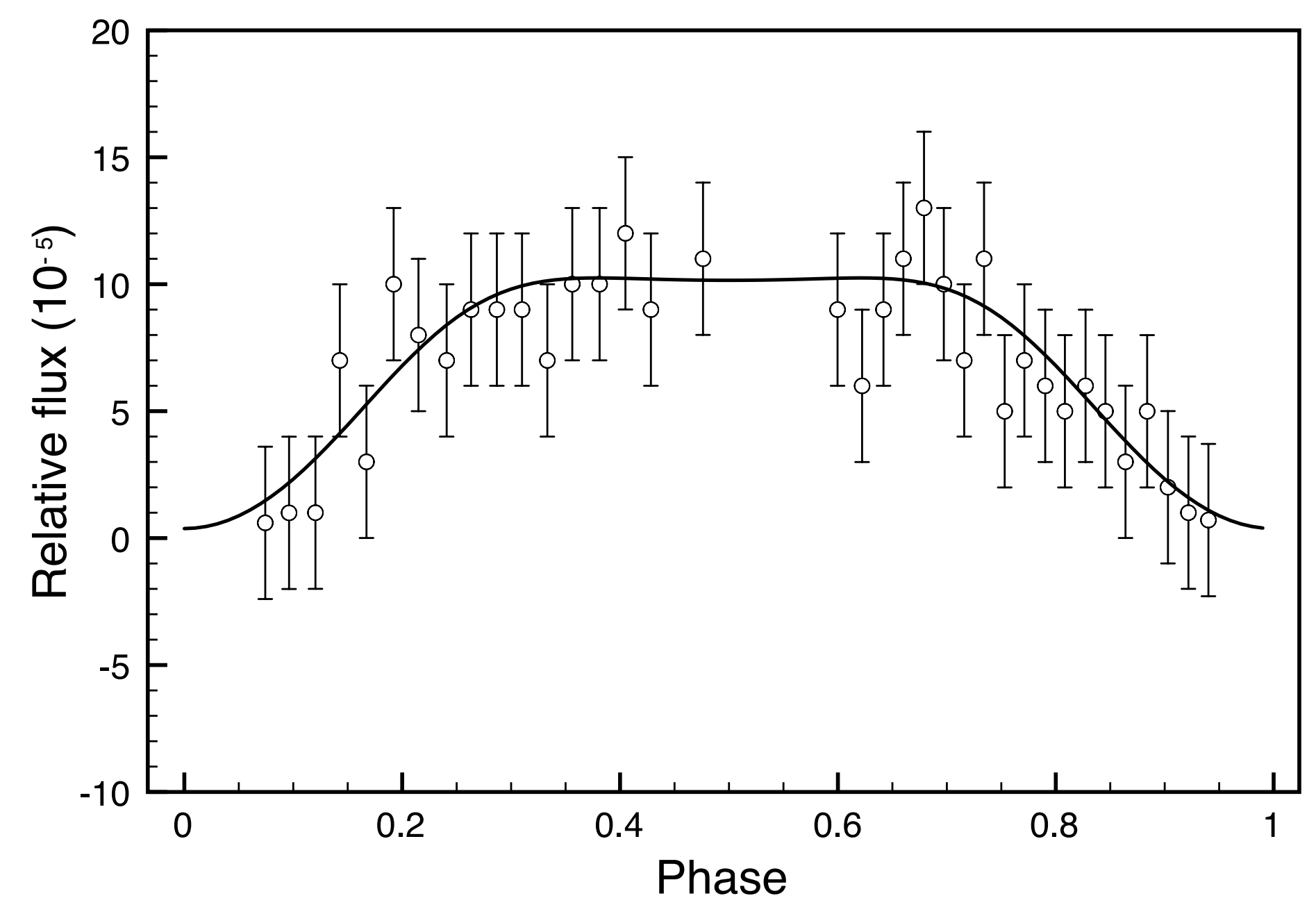
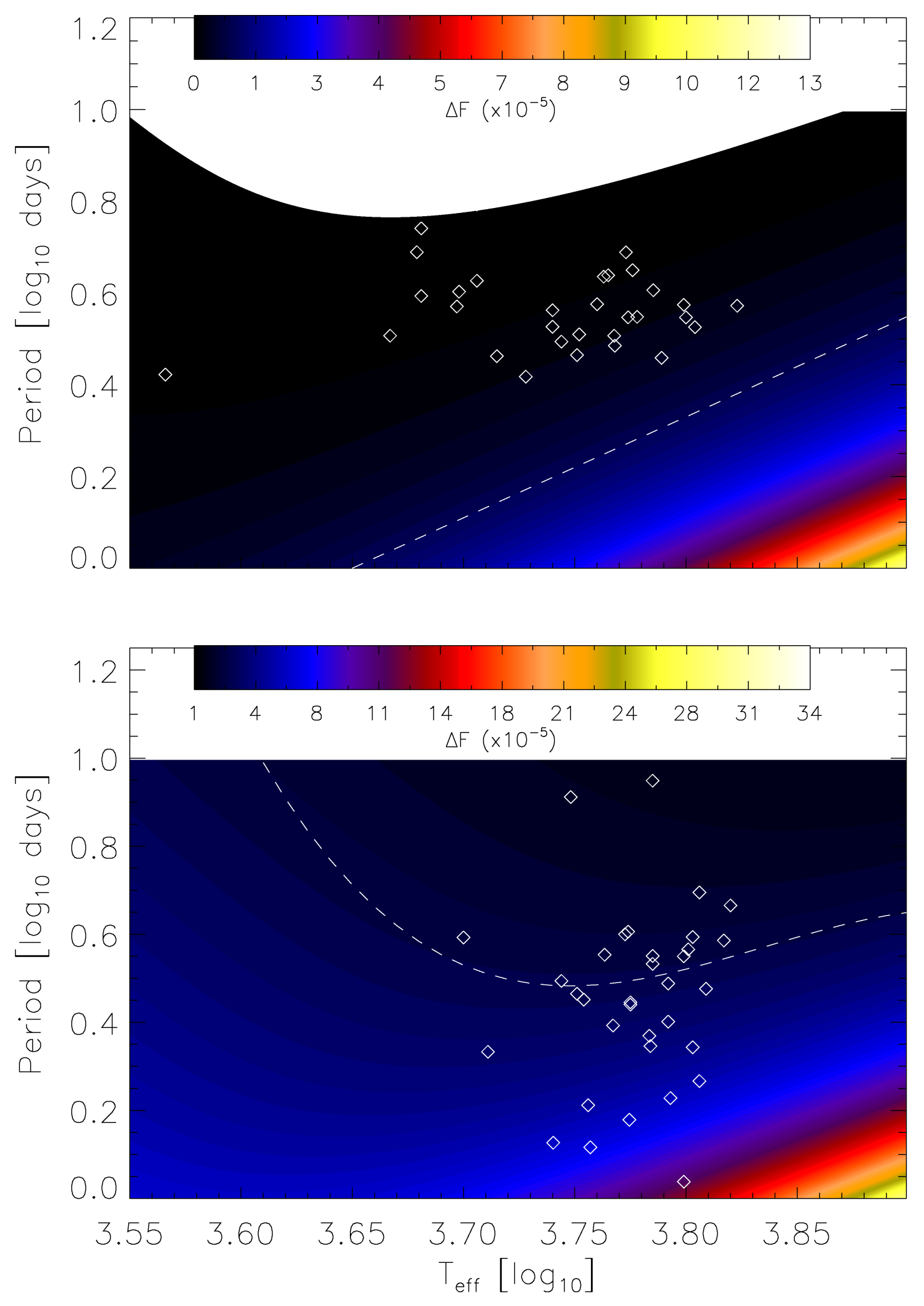


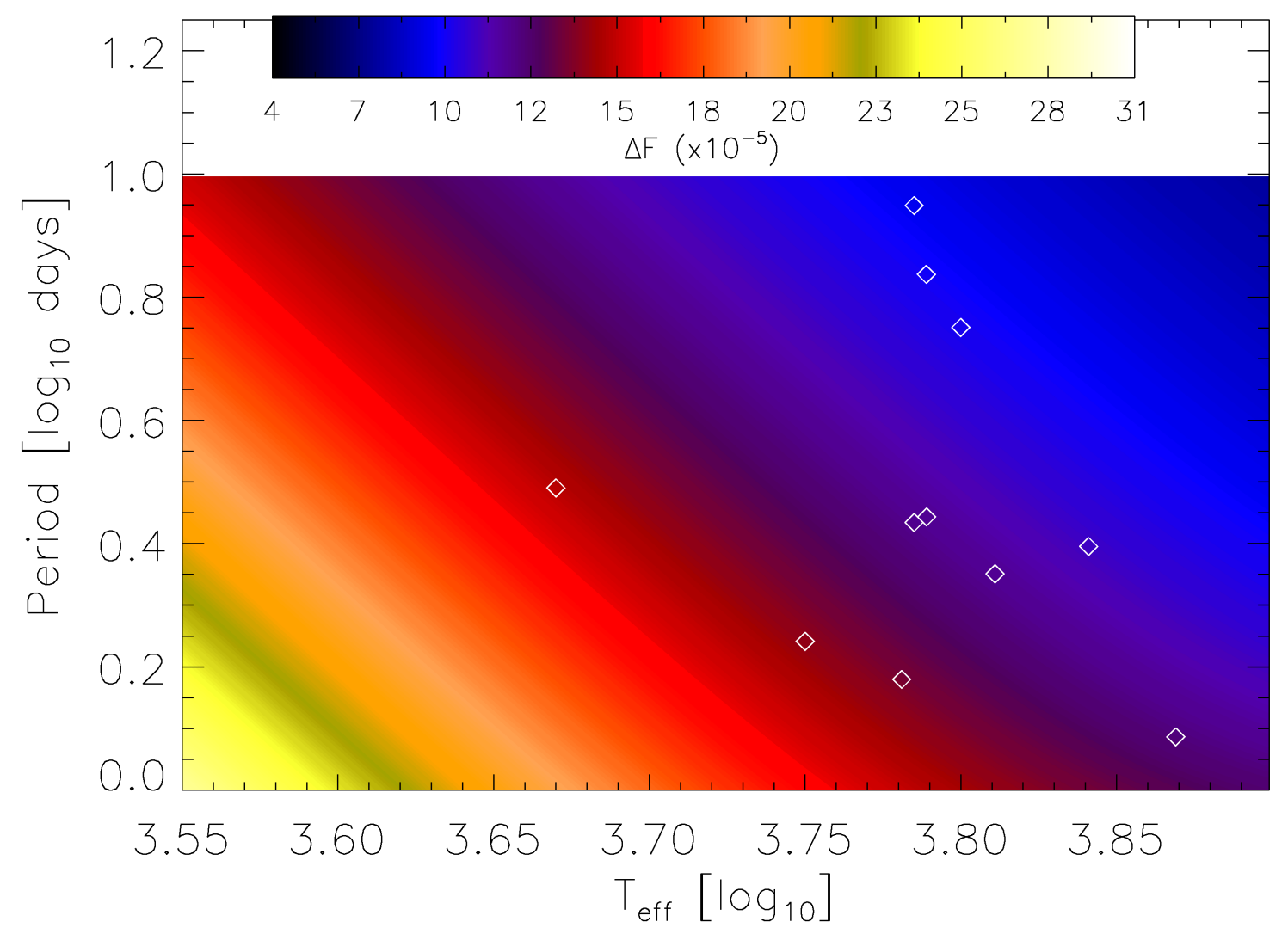
We apply our model to the phase LC of HAT-P-7b. Using a F-test, we found that full model explains the data better than the simple model of the reflected light. In Fig. at the left, we show the observed LC of HAT-P-7 with our best fit. We find the ratio of the planetary mass over the stellar mass to be Mp/Ms= 1.35 MJ/Mo, compared to Mp/Ms = 1.20 MJ/Mo deduced by Welsh et al. (2010).

Although our values are not as accurate as those from RV measurements, we can infer the planetary nature of the companion.

PLATO Mission

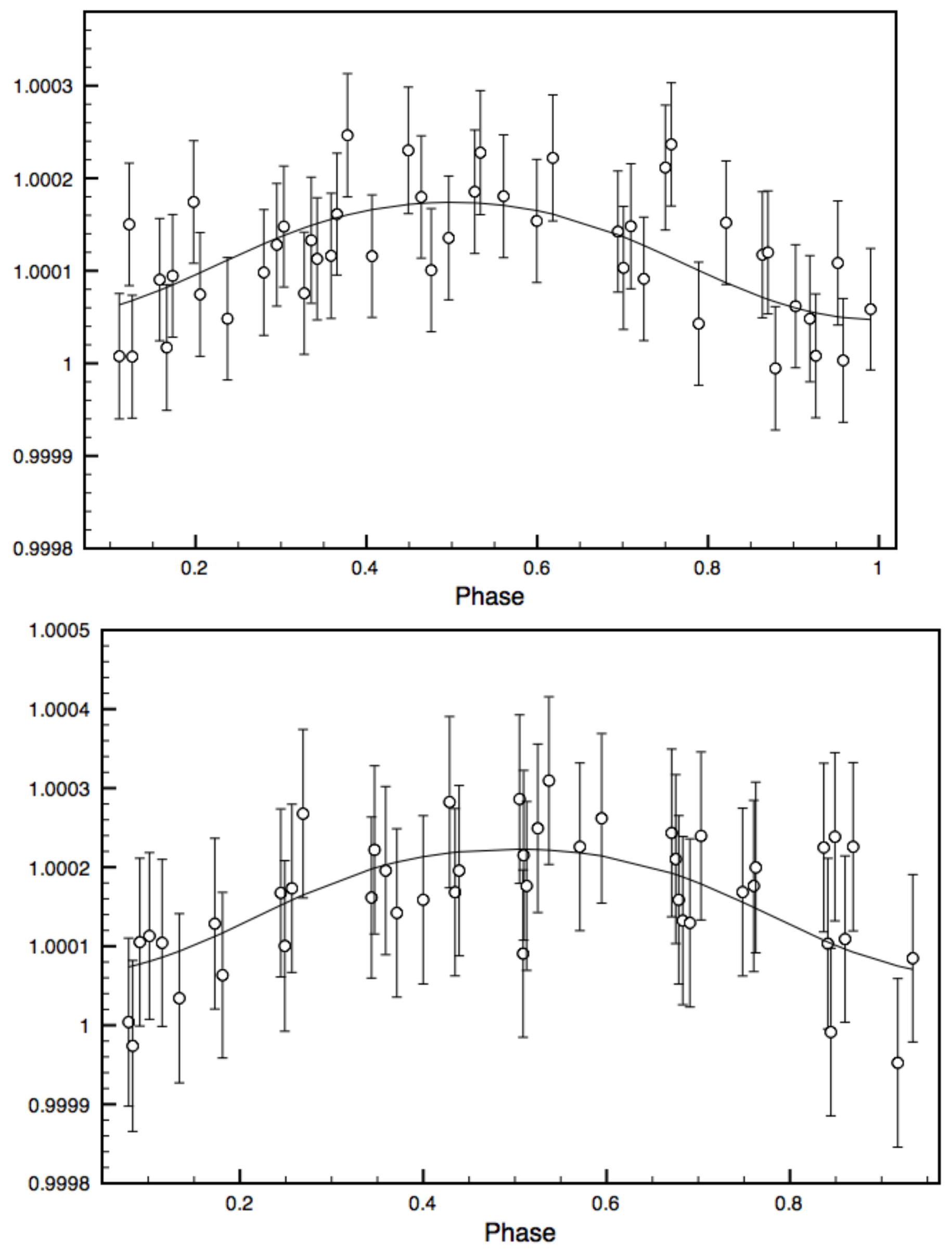


PLATO is a prospective ESA mission aiming at the characterization of transiting exoplanets. PLATO' s data quality will satisfy the needs of our procedure. We investigate the detectability of reflected light and ellipsoidal variations in a range of different systems. Assuming that our target stars belong to the main sequence, we fit temperature and period. For each combination we calculate the amplitude of the flux variations ΔF in the light curve. We present three plots, each belonging to a different planetary mass: Mp = 0.5 MJ (top), 1 MJ (middle), and 5 Mj (top next page). For comparison we indicate some known transiting systems with similar masses. In the upper panel ΔF is dominated by fell. Here, for the sample of known systems log(ΔF) > -5.0, which would be challenging to be detected. Nevertheless, with PLATO one will be able to detect reflected light for planets with P < 3 d around stars with spectral type K0 or later (blue zone in the top panel). In the middle diagram (Mp = 1MJ) both the reflected light and the ellipsoidal variations affect the light curve and log(ΔF) ∼ -4.3 for most of the known systems – detectable with PLATO. In the bottom panel, where the model planet is most massive, the LCs are mostly affected by the Doppler shift variations rather than by the ellipsoidal geometry of the star. The phenomenon is fairly detectable for the most cases of the known planets while log(ΔF) ∼ -3.9.



Non-transiting planets

The inclination of the planet plays a minor role in both components of the model (reflected light & ellipsoidal variations). Therefore we could detect many more planets than we expect from the transit technique. The probability of the non-transiting planets reaches the probability level of the RV method. Even if the planetary albedo is zero and no reflected light could be detected from the planet, ellipsoidal variation is string evidence for a secondary small body (planet). Figure at the right shows two candidate non-transiting exoplanet using Kepler' s data.



References

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