one can see that, without taking into account Kepler-296e, the agreement with the data is very good for ATLAS and PHOENIX model atmospheres for the $u_1$ coefficients, which shows a mean difference of $-0.046^{+0.133}_{-0.143}$ if one uses the ATLAS models and $-0.049^{+0.138}_{-0.140}$ if one uses the PHOENIX models, both of which are consistent with a zero mean difference. There is a barely significant offset of the $u_2$ coefficients ($2.8\sigma$ for the ATLAS models, $2.9\sigma$ for the PHOENIX models), with the model values apparently systematically overestimating those coefficients by a mean value of $\sim 0.3$. For the sample of high precision limb-darkening coefficients, which is also the hotter star sample (lower panels in those figures), the agreement of the $u_1$ coefficients is very good for the ATLAS models, with a mean difference of $-0.008^{+0.012}_{-0.012}$ which is consistent with zero, but poor for the PHOENIX models, whose mean difference is $0.083^{+0.008}_{-0.008}$, inconsistent with zero by more than $10\sigma$. Note that this bias is very evident and more prominent for stars hotter than 6000 K, where the model values overestimate the LDCs by $\sim 0.1$. For the $u_2$ coefficients, both model atmospheres show slightly significant biases, with the PHOENIX models doing a better job at predicting the observed LDCs with a mean difference of $-0.024^{+0.012}_{-0.011}$, which is $2\sigma$ away from zero, and with the ATLAS models showing a mean difference of $0.042^{+0.012}_{-0.011}$, which is $3.8\sigma$ away from zero.

As a final note, there is one particular object worth discussing in detail, Kepler-296e, which has LDCs which deviate more than $2\sigma$ from those of systems with host stars of similar stellar parameters, including Kepler-296f, which according to Torres et al. (2015) orbits the same host star in an orbit almost two times farther away from it. As we can see in Figures 8 and 9, the coefficient changes induced in Kepler-296e due to the geometry of the transit are not expected to be very different from those of Kepler-296f, so the geometry of the system cannot explain the differences on the observed LDCs. Activity could, in principle, produce significant biases on the LDCs through unnoculted spots (Csizmadia et al. 2013), but it seems unlikely that activity affected only one of the observed transits. Because Kepler-296 is known to be a tight binary (Lissauer et al. 2014), one might be tempted to think that Kepler-296e maybe did not orbit the same star as Kepler-296f as claimed by Torres et al. (2015), but its companion. However, both of the stars in the system have actually very similar spectral types and, thus, very similar LDCs, which implies that the observed LDCs are actually very different compared to *both* stars in the system. An analysis of other alternative hypotheses is out of the scope of this work, but we note that these are the kind of analyses that can be performed from measuring, comparing and interpreting LDCs from transit lightcurves using our MC-SPAM algorithm.

## 4 THE EFFECT OF USING FIXED LDCS IN TRANSIT FITTING

In the past section, we showed that, as first noted by Howarth (2011), LDCs extracted from fits to intensity profiles of stellar model atmospheres, $(u_1, u_2)$, are not directly comparable to the LDCs obtained from transit photometry, $(u_1^f, u_2^f)$. This is due to the fact that the two optimization procedures are significantly different from one another and, thus, a geometry dependent mapping using synthetic lightcurves has to be carried out in order to obtain the coefficients $(u_1^*, u_2^*)$ that can then be compared to the observed LDCs. This implies that even if one could measure with excellent precision the intensity profile of a given star, obtain its LDCs with that profile, and then measure those coefficients from transit photometry, also with excellent precision, there is an expected bias between the two sets of coefficients. This in turn means that if one fixes the LDCs obtained from the intensity profile in the transit fitting procedure, then one is using potentially biased coefficients that can then lead to biased transit parameters⋆. A strategy to avoid this bias could be to let the LDCs as free parameters in the fit. However, we also expect a bias on the transit parameters in this case if, as it is usually done, the intensity profile is modelled with a quadratic law which we we have seen is not able to accurately describe the full intensity profiles.

In addition to the above mentioned problems, there is the issue related to our imperfect knowledge of the underlying, "true", intensity profile. As we saw in §3, this is currently an issue as our models are not able to reproduce the observed LDCs with sufficient accuracy. On top of this, according to our results in §2, there are differences even between our own modelling of those profiles both between different model atmospheres and between the different methods used to derive the LDCs from them.

In order to explore these sources of bias, in this section we perform simulations to study the possible biases introduced by our limb-darkening assumptions on the retrieved transit parameters, using transit lightcurves generated with the formalism of Mandel & Agol (2002).

### 4.1 A simulation study

In order explore the effect on the retrieved transit parameters of fixing or having the the LDCs as free parameters, we simulate transit lightcurves with unit period, circular orbits and an assumed intensity distribution for the host star of the transiting planet. The choice of units such that $P = 1$ is just for convenience of sampling directly in phase and has no consequences for what follows. The geometric parameters of the transit we can retrieve from our simulated light curves are the planet-to-star radius ratio, $p = R_p/R_*$, the semi-major axis to stellar radius ratio, $a_R = a/R_*$, and the inclination of the orbit, $i$. The simulations were performed as follows. First, based on the data from all transiting planets discovered to date, we choose to generate synthetic transit lightcurves for planets with all the combinations of parameters $\{a_R, p\}$ with values $a_R = \{3.27, 3.92, 4.87, 6.45, 9.52, 18.18, 200\}$ and $p = \{0.01, 0.06, 0.11, 0.16, 0.21\}$. In order to explore the effect of different impact parameters, $b = \cos(i)a_R$, we also varied $b$ from 0 to 0.9 in steps of 0.1. This defines 350 different orbital configurations for our simulations. For each orbital configuration, we simulated 100 noiseless, uniformly sampled lightcurves with 1000 in-transit points and 400 out-of-transit points each, whose initial times were randomly perturbed. We first assume perfect knowledge of the underlying intensity profile by generating the transits using the non-linear law with the coefficients $\{c_1, c_2, c_3, c_4\}$ obtained in Section 2 for models with $\log g = 4.5$, solar metallicity, $v_{\text{turb}} = 2$

⋆ The level of bias will depend, among other factors, on the bandpass. In particular, issues noted in this paper should in general be less severe in the infra-red.