A COMPREHENSIVE STUDY OF KEPLER PHASE CURVES AND SECONDARY ECLIPSES – TEMPERATURES AND ALBEDOS OF CONFIRMED KEPLER GIANT PLANETS

Daniel Angerhausen
Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180 USA

Emily DeLarme
Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180 USA

and

Jon A. Morse
Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180 USA

BoldlyGo Institute, 18 Hilander Drive, Loudonville, NY 12211 USA

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ABSTRACT

We present a comprehensive study of phase curves and secondary eclipses in the Kepler data set using all available data from 15 quarters. Our original sample consists of 489 Kepler Objects of Interest (KOI) with \( R_p > 1.5 R_E \), \( P < 10 \text{d} \), \( V_{mag} < 15 \) from the latest data release. Here we focus on 20 confirmed planets from that sample and derive their temperatures and albedos. Our results confirm and in most cases improve parameters derived by previous studies. We present new results for Kepler 1b-8b, 12b-15b, 17b, 40b, 41b, 43b, 44b, 76b, 77b, and 412b derived in a consistent manner. Furthermore we present a lightcurve analysis of Kepler 91b and Kepler 74b. Both show extra dimmings at times other than of the expected primary and secondary eclipses. Corrected for thermal emission we find the 20 planets we analyzed separate into two groups of high (> 0.1) and low (< 0.1) albedos, with no significant correlation to any stellar or planetary parameters. However the most massive planets from our sample are all low in albedo.

Subject headings: planets and satellites: gaseous planets; planets and satellites: general; planets and satellites: individual (Kepler 1b, Kepler 2b, Kepler 3b, Kepler 4b, Kepler 5b, Kepler 6b, Kepler 7b, Kepler 8b, Kepler 12b, Kepler 13b, Kepler 14b, Kepler 15b, Kepler 17b, Kepler 40b, Kepler 41b, Kepler 43b, Kepler 44b, Kepler 76b, Kepler 77b, Kepler 412b)

1. INTRODUCTION

1.1. The Kepler mission

Studying extrasolar planets is one of the major frontiers of astronomy today. The field has transformed from simple identification to comprehensive categorization and characterization of exoplanets and exoplanetary systems. Analyses of data provided by the NASA’s Kepl[1] mission has revolutionized this field by compiling a statistically significant number of transiting planets and planetary candidates (e.g., [Borucki et al. 2010b, Borucki et al. 2011] and [Batalha et al. 2013]).

For example, Kepler data allowed researchers to discover Kepler 9b ([Holman et al. 2010]), the first multiplanetary system outside our solar system, Kepler 10b ([Batalha et al. 2011]), one of the first confirmed rocky planets outside the solar system, and Kepler 16b ([Doyle et al. 2011]), the first circumbinary planet. Just recently the Kepler team announced the discovery of potentially habitable worlds in the Kepler 62 ([Borucki et al. 2013] and Kepler 69 ([Barclay et al. 2013]) systems.

Deeper analyses are possible using the exquisite Kepler data beyond merely detecting exoplanetary systems: researchers are now able to analyze large samples of planetary candidates to pin down occurrence rates such as \( \eta_{earth} \) (e.g., [Howard et al. 2012, Dressing & Charbonneau 2013 and Pressin et al. 2013]), find non-transiting planets via transit timing variations ([Ballard et al. 2011]), perform phase-curve analyses ([Faigler et al. 2013]), and may eventually even be able to detect exomoons ([Kipping et al. 2013]).

For the close-in, and therefore hot, planets around bright, high signal host stars, in the Kepler data set, we are able to analyze secondary eclipses, i.e., the modulated flux from the star-planet system when the (reflected) light of the planet disappears during its passage behind the parent star. Differential measurements then help us to characterize physical parameters of the planet such as albedo and temperature.

1.2. Transits and eclipses

Systems with transiting extrasolar planets mostly offer two important opportunities for observations. In pri-
mary transit the planet occults the star. From a broad-band transit-lightcurve, in this case, one can measure the planetary radius \( R_p \) in units of the stellar radius \( R_* \). The depth of the occultation is \( \sim (R_p/R_*)^2 \), which for a Jupiter radius planet transiting a sun-like star, is of the order of \( \sim 1\% \) (e.g., Henry et al. 2000).

If the geometry (inclination, eccentricity) is right the planet also disappears behind its host star in a so-called secondary eclipse. For a 2000 K hot Jupiter-size planet, the typical flux deficit during secondary eclipse is \( \sim 200 \) ppm at \( \sim 2\mu \text{m} \) in the near-infrared and even larger at longer wavelengths, but considerably smaller at optical wavelengths at which Kepler observes. However, for host stars that are bright enough, Kepler's outstanding sensitivity provides a direct measure of the planet's disk-averaged day side flux for some of its targets, particularly close-in gas giants – so called 'Hot Jupiters' and 'Hot Neptunes'.

Observing secondary eclipses combined with planetary phase curves can help us to characterize the planet and its atmosphere. For example, the depth of the secondary eclipse can constrain the albedo of the planet, while the timing and width of the secondary eclipse can help determine its orbital parameters. Comparing the amplitude of the reflected light in the phase curve with the depth of the secondary eclipse can constrain the day and night side temperatures, and therefore confirm the planetary nature of a candidate that is not self-luminous, and help to understand day to night side heat exchange.

Several previous studies have focused on eclipses and phase curves in the Kepler database, either on small samples of objects (e.g., Kimming & Bakos 2011, Coughlin & López-Morales 2012, Esteves et al. 2013) or for individual planets or candidates (e.g., Mazeh et al. 2012, Morris et al. 2013). Here we present initial results of a comprehensive and consistent study of secondary eclipses and phase curves using all available and useful data from quarters 0 through 15 of Kepler lightcurves (see Table 2) for a large sample consisting of 489 Kepler Objects of Interest (KOI) with \( R_p > 4R_* \), \( P < 10^d \), and \( V_{\text{mag}} < 15 \). In this paper we focus on the confirmed planets in this sample.

2. DATA REDUCTION

2.1. PyKE data preparation

For each of our targets, we used up to 16 quarters of the Pre-search Data Conditioning Simple Aperture Photometry (PDCSAP) lightcurves from the Kepler database available in the Mikulski Archive for Space Telescopes (MAST; see Table 2). The PDCSAP lightcurves are simple aperture photometry timeseries that have been cotrended in the Kepler pipeline to remove systematics common to multiple targets, using a best-fit of so-called ‘Cotrending Basis Vectors’ (CBVs). The CBVs are essentially the principal components of systematic artifacts for each science target and each operational quarter characterized by quantifying the features most common to hundreds of strategically-selected quiet targets sampled across the detector array (see Smith et al. 2012 and Stumpe et al. 2012).

We used PyKE (Still & Barclay 2012), a series of python-based PyRAF recipes, for the individual and target-specific analysis and reduction of Kepler time-series data. Our first step was to remove long-term variability using the kepflatten task to fit a quadratic polynomial to parts of the lightcurve for each quarter over time intervals at least five times the length of the published orbital period of each planet. We thus minimize any contamination or over-correction of the actual planetary phasecurves by the polynomial flattening. We then concatenated these flattened curves using the kepfill task, which created one long timeseries, containing – where available – up to all 16 quarters of data. Finally, using the kepfold task, we folded the entire lightcurve by the published orbital periods of each planet to get the phase curve, that was used in the next steps of our data analysis.

2.2. Phase curve model

We removed the primary transit signature as a first step in modeling the phase-folded lightcurves. The remaining normalized, out-of-transit phase curve \( F_{\text{tot}} \) was then modeled as

\[
F_{\text{tot}} = f_0 + F_e + F_d + F_p + F_{\text{ecl}}
\]

- the sum of the stellar baseline \( f_0 \) and the following four contributions to the lightcurve as a function of phase \( \phi \), with \( \phi \in [0, 1] \), the primary transit at \( \phi = 0 \) and the secondary eclipse around \( \phi = 0.5 \):

(i) \( F_e \), the ellipsoidal variations resulting from tides on the star raised by the planet described by:

\[
F_e = -A_e \left( \cos(2\pi \phi) + f_1 \cos(2\pi \phi) + f_2 \cos(2\pi 3\phi) \right)
\]

where \( f_1 \) and \( f_2 \) are:

\[
f_1 = 3\alpha(a/R_*)^{-1} \frac{5 \sin^2(i) - 4}{\sin(i)}
\]

\[
f_2 = 5\alpha(M_p/M_*) (a/R_*)^{-3} \sin(i)
\]

The parameter \( \alpha \) is defined as

\[
\alpha = \frac{25u}{24(15 + u)} y + 1
\]

where \( u \) is the linear limb-darkening parameter and \( y \) is the gravity darkening parameter;

(ii) \( F_d \), the Doppler boosting caused by the host star’s changing radial velocity described by:

\[
F_d = A_d \sin(2\pi \phi)
\]

(for details see, e.g., Barclay et al. 2012, Slipor et al. 2010 or Groot 2012);

(iii) \( F_p \), the planet’s phase function modeled as the variation in reflected light from a Lambertian sphere (Russel 1916) described by:

\[
F_p = A_p \frac{\sin(z) + (\pi - z) \cos(z)}{\pi}
\]

Here \( A_p \) is the amplitude of the planetary phase function, and \( z \) is related to phase \( \phi \) and inclination \( i \) via:

\[
\cos(z) = -\sin(i) \cos(2\pi \phi)
\]
(iv) $F_{\text{ecl}}$, the secondary eclipse – i.e., the light that is blocked during the planet’s passage behind its host star – modeled using the description in Rogers et al. (2013):

$$r(\phi) = \frac{a}{R_s}[1 - \sin^2(i) \cos^2(\phi - \phi_m)]^{1/2}$$

where $\phi_m$ is the phase of the mid-point of the secondary eclipse.

$P_{\text{ecl}}$ is the eclipsed portion of the planet:

$$P_{\text{ecl}}(r) = \begin{cases} 0 & : r \geq 1 + p \\ f(\theta_1, \theta_2) & : 1 - p < r < 1 + p \\ 1 & : r \leq 1 - p \end{cases}$$

where $p = \frac{R_e}{R_s}$ and with

$$f(\theta_1, \theta_2) = \frac{1}{\pi^2}(\theta_1 - \sin \theta_1 \cos \theta_1)$$

$$+ \frac{1}{\pi}(\theta_2 - \sin \theta_2 \cos \theta_2)$$

Here $\theta_1$ and $\theta_2$ are defined as:

$$\cos \theta_1 = \frac{1 + r^2 - p^2}{2r}$$

$$\cos \theta_2 = \frac{r^2 + p^2 - 1}{2rp}$$

Hence the contribution $F_{\text{ecl}}$ of the secondary eclipse with depth $D_{\text{ecl}}$ is:

$$F_{\text{ecl}}(\phi) = D_{\text{ecl}}[1 - P_{\text{ecl}}(\phi, \phi_m)]$$

### Table 1

| KOI | Stellar parameters used in phasecurve fits |
|-----|-------------------------------------------|
| 1   | Kepler Mission Team (2009)                |
| 2   | Borucki et al. (2011)                     |
| 3   | Balona et al. (2010)                      |
| 7   | Boricki et al. (2010a)                    |
| 10  | Jenkins et al. (2010)                     |
| 13  | Kepler Mission Team (2009)                |
| 17  | Dunham et al. (2010)                      |
| 18  | Boricki et al. (2013)                     |
| 20  | Fortney et al. (2011)                     |
| 97  | Latham et al. (2010)                      |
| 98  | Buchhave et al. (2011)                    |
| 127 | Gandolfi et al. (2013)                    |
| 128 | Kepler Mission Team (2009)                |
| 135 | Bonomo et al. (2012)                      |
| 196 | Santerne et al. (2011a)                   |
| 202 | Delfini et al. (2014)                     |
| 303 | Bonomo et al. (2012)                      |
| 204 | Bonomo et al. (2012)                      |
| 428 | Santerne et al. (2011b)                   |
| 1658| Faigler et al. (2013)                     |

5 Limb- and gravity-darkening parameters derived from Claret & Bloemen (2011)

### Table 2

| KOI | LC Quarters | SC Quarters |
|-----|-------------|-------------|
| 1   | 0,1,2,3,4,5,6,7,9,10,11,13,14,15 | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 |
| 2   | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 |
| 3   | 0,1,2,3,4,5,6,8,9,10,12,13,14 | 0,1,2,3,4,5,6,8,9,10,11,12,13,14 |
| 7   | 0,1,2,3,4,5,6,8,10,11,13,15 | 0,1,2,3,4,5,6,8,9,10,11,12,13,14 |
| 10  | 0,1,2,3,4,5,6,7,9,10,11,13,15 | 1,2,3,4,5,6,7,8,9,10,11,12,13 |
| 13  | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 1,2,3,4,5,6,7,8,9,10,11,12,13 |
| 17  | 0,1,2,3,4,5,6,8,9,10,12,13,14 | 1,2,3,4,5,6,8,9,10,11,12 |
| 18  | 0,1,2,3,4,5,6,8,9,10,11,13,14,15 | 1,2,3,4,5,6,7,8,9,10,11 |
| 20  | 0,1,2,3,4,5,6,8,9,10,11,12,13,14,15 | 1,2,3,4,5,6,8,9,10,11 |
| 97  | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 2,3,4,5,6,7,8 |
| 98  | 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 2,3,4,5,6,7,8,9,10,11,12 |
| 127 | 1,2,3,4,5,6,8,9,10,11,12,13,14,15 | 2,3,4,5,6,7 |
| 128 | 1,2,3,4,5,6,8,9,10,11,12,13,14,15 | 2,3,4,5,6,7 |
| 135 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 2,3,4,5,6,7,8,9,10,11,12,13,14 |
| 196 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 3,4,5,6,7 |
| 200 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 3,4,5,6,7 |
| 202 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 3,4,5,6,7 |
| 203 | 1,2,3,4,5,6,8,9,10,12,13,14 | 3,4,5,6,7,8,9,10,11,12,13,14 |
| 428 | 1,2,3,4,5,6,8,9,10,12,13,14 | – |
| 1658| 1,2,3,4,5,7,8,9,11,12,13,15,16,17 | – |
| 2133| 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | – |

Kepler temperatures and albedos
We fit the cleaned and phase-folded light-curves using MPFIT, an IDL package that implements Levenberg-Marquardt non-linear least squares curve fitting. The period was held constant because we were fitting phase-folded data. The limb and gravity darkening parameters were trilinearly interpolated from the tables of Claret & Bloemen (2011) and held constant during the fitting. The starting values for size ratio and the distance between the planet and the star were obtained from the NASA Exoplanet Archive. The depth of the secondary eclipse was constrained to be positive. Other parameters in the fit were the amplitude of the phase curve, the amplitude of the Doppler boosting, the amplitude of the ellipsoidal variations, the inclination, and the phase of the secondary eclipse. In order to work on a uniform dataset and due to the computational intensity of fitting unbinned data, we cut out the transit part and binned all folded light-curves down to 400 points for phase $\phi = [0.1, 0.9]$. We sought to include the best available parameters for the host stars in our modeling. Values from the Kepler Input Catalog (KIC) were often inaccurate, so we relied on the stellar parameters derived in the (mostly spectroscopic) planet confirmation observations (see Table 1).

2.4. Temperatures and albedos

We calculated the brightness temperatures using:

$$F_{ecl} = (R_p/R_*)^2 \int \frac{B_\lambda(T_\text{b})T_K d\lambda}{B_\lambda(T_*) T_K d\lambda}$$

(15)

where $F_{ecl}$ is the depth of the secondary eclipse, $R_p/R_*$ is the size ratio, $B_\lambda$ is the Planck function, $T_\text{b}$ is the brightness temperature, $T_K$ is the Kepler response function, and $T_*$ is the stellar temperature. To solve for $T_\text{b}$, we integrated the right hand side of

$$\int B_\lambda(T_\text{b}) T_K d\lambda = F_{ecl} (R_*/R_p)^2 \int B_\lambda(T_*) T_K d\lambda$$

(16)

and then numerically integrated the left hand side iteratively using successively larger temperature values, until we found the brightness temperature that best matched the data. The nightside temperatures are calculated in the same way, but using $F_{\text{nightside}} = F_{ecl} - A_p$ instead.

Furthermore we calculated the geometric albedo using:

$$F_{ecl} = A_{g,\text{obs}} (R_p/a)^2$$

(17)

which assumes no contribution from thermal emission. Correcting for thermal emission we used:

$$A_{g,\text{corr}} = A_{g,\text{obs}} - \frac{\pi \int B_\lambda(T_{eq}) d\lambda}{F_0} (a/R_*)^2$$

(18)

where

$$F_0 = \sigma T_0^4$$

(19)

with

$$T_0 = T_*(R_*/a)^{1/2}$$

(20)

Assuming a Lambertian criterion [$A_b = (3/2)A_g$] we calculated the equilibrium temperature using

$$T_{eq} = T_*(f_{\text{dist}} R_*/a)^{1/2}(1 - A_b)^{1/4}$$

(21)

The resulting albedos corrected for thermal emission for no redistribution, $f_{\text{dist}} = \frac{1}{2}$, and fully efficient redistribution, $f_{\text{dist}} = \frac{2}{3}$, of heat from planetary day to night side are shown in Table 6.

2.5. Phase shift due to clouds

For some of our targets we had to add a phase shift component to the model lightcurve, because the more general model produced an unphysically negative value for the doppler amplitude in these cases. This shift in the phase curve caused by planetary clouds (see e.g. Demory et al. 2013) was modeled in a similar fashion to the phase curve itself, where we added a parameter $\phi_{\text{shift}}$ to describe the phase shift:

$$\cos(z) = -\sin(i) \cos(2\pi (\phi + \phi_{\text{shift}}))$$

(22)

Using this model we found significant phase shifts $\phi_{\text{shift}}$ for KOI-20, KOI-97 and KOI-135 (see 3.1.7–3.1.8 and 3.1.10).

2.6. Upper limits

For some of the planets in our sample we did not detect a secondary eclipse and/or a phase curve. In these cases we were only able to give upper limits for the derived parameters (see section 2.3.2). In other cases our fits only constrained a limited number of parameters. For the planets in our sample for which the model does not fit a secondary eclipse, we took the standard deviation of the residual as a maximum detectable secondary eclipse depth.

3. RESULTS

An easily accessible summary of all our results can be found in Tables 3 to 6. Figures 1 to 5 illustrate our fitting efforts. In the following subsections we report individually on all our analyzed targets and – where possible – compare to previous observations and measurements.

3.1. Detected secondary eclipses

3.1.1. KOI 1.01 / TrES-2 / Kepler 1b

TrES-2b (or KOI 1.01, Kepler-1b) – a 1.28 $M_{\text{Jup}}$ and 1.24 $R_{\text{Jup}}$ planet on a 2.47 day orbit around a 50V star (O’Donovan et al. 2006) – was the first planet detected in the Kepler field. Kipping & Spiegel (2011) determine a day night contrast amplitude of $6.5 \pm 1.9$ ppm which corresponds to a geometric albedo of $A_g = 0.025 \pm 0.007$ and found a non-significant eclipse with depth of $16 \pm 13$ ppm, similar to Kipping & Bakos (2011), who derived a value of $21 \pm 22$.

Demory et al. (2011) found a geometric albedo of $0.06 \pm 0.05$ and an equilibrium temperature of 1464 K using only Q1 data. Barclay et al. (2012) derived a phase curve with ellipsoidal variations and Doppler beaming of amplitudes $2.79^{+0.44}_{-0.62}$ and $3.44^{+0.37}_{-0.32}$ ppm, respectively, and a difference between the day and night side planetary flux of $3.41^{+0.55}_{-0.50}$ ppm. They found a geometric albedo of $0.013^{+0.002}_{-0.003}$ and a secondary eclipse depth of $6.5^{+1.7}_{-1.4}$ ppm. Barclay et al. (2012) also showed that an atmosphere model that contains a temperature inversion is strongly preferred and suggested that the Kepler bandpass probes a significantly greater atmospheric
depth on the night side. The analysis of [Esteves et al. 2013] for TrES-2b shows an eclipse depth of 7.5 ± 1.7 ppm, a brightness temperature $T_b$ of 1910$^{+6}_{-5}$K a very low geometric albedo $A_g$ of 0.03 ± 0.001 and a night side temperature $T_{night}$ of 1700 K.

Our fit for KOI-1 shows an eclipse depth of 10.9 ± 2.3 ppm, a brightness temperature $T_b$ of 1901$^{+27}_{-1}$ a geometric albedo $A_g$ of 0.05 ± 0.01 a bond albedo $A_b$ of 0.08 ± 0.02, leading to an upper limit for the night side temperature $T_{night}$ of 1885$^{+51}_{-66}$ K. These results agree very well and therefore confirm the aforementioned measurements. Figure I (top, left) shows our fit results for KOI-1.

### 3.1.2. KOI 2.01 / HAT-P-7b / Kepler 2b

HAT-P-7b is a 1.78 $M_{Jup}$ and 1.36 $R_{Jup}$ planet on a 2.204 orbit around an evolved F6 star [Pál et al. 2008]. Due to its bright host star and its detection before the launch of the Kepler mission it is one of the best studied planets in our sample. A number of other groups already analyzed the secondary eclipse of this target using different methods with results spanning from 67 up to 130 ppm. From the first 10 days of Kepler calibration data [Borucki et al. 2009] derived an eclipse depth of 130 ± 11 ppm percent in the Kepler band. Using the whole first quartile Q1 data, Demory & Seager (2011) derived a geometric albedo of 0.20 ± 0.1 and an equilibrium temperature of 2085 K. [Esteves et al. 2013] measure an eclipse depth of 68.31 ± 0.69 ppm, a brightness temperature $T_b$ of 2846$^{+4}_{-1}$K a geometric albedo $A_g$ of 0.196 ± 0.002 and an upper limit for the night side temperature $T_{night}$ of 1950 K for HAT-P-7.

For KOI-2, we find an eclipse depth of 69.3 ± 0.6 ppm, corresponding to a brightness temperature $T_b$ of 2897$^{+3}_{-4}$ K, a geometric albedo $A_g$ of 0.27 ± 0.01 and a bond albedo $A_b$ of 0.4 ± 0.01. The resulting upper limit for the night side temperature $T_{night}$ is 2235$^{+3}_{-24}$ K. Here - again - we are mostly in agreement with the other analyses. Figure I (top, right) shows our fit results for KOI-2.

### 3.1.3. KOI 10.01 / Kepler 8b

Kepler 8b, with a radius of 1.41 $R_{Jup}$ and a mass of 0.60 $M_{Jup}$, is among the lowest density planets ($0.26^{+0.06}_{-0.02}$ $g/cm^3$) known. It orbits a relatively faint (V = 13.89 mag) F8IV subgiant host star with a period of $P = 3.523$ d and a semimajor axis of 0.0483$^{+0.0012}_{-0.0012}$ AU [Jenkins et al. 2010]. Kipping & Bakos (2011) exclude secondary eclipses of depth 101.5 ppm or greater to 3-σ confidence, which excludes a geometric albedo $> 0.63$ to the same level. Demory & Seager (2011) report a geometric albedo of 0.21 ± 0.1 and an equilibrium temperature of 1567 K using only Q1 data. For Kepler 8b, Esteves et al. (2013) derive an eclipse depth of 26.2 ± 5.6 ppm, a brightness temperature $T_b$ of 2370$^{+50}_{-70}$ K a geometric albedo $A_g$ of 0.134 ± 0.03 and an upper limit for the night side temperature $T_{night}$ of 2100 K.

In our fits of KOI-10 we find an eclipse depth of 16.5 ± 4.45 ppm, a brightness temperature $T_b$ of 2241$^{+91}_{-77}$ K, a geometric albedo $A_g$ of 0.11 ± 0.03, a bond albedo $A_b$ of 0.16 ± 0.04 and an upper limit for the night side temperature $T_{night}$ of 1859$^{+227}_{-50}$ K. Our results are slightly lower, however consistent with [Esteves et al. 2013]. Figure I (bottom, left) shows our fit results for Kepler 8b.

### 3.1.4. KOI 13.01 / Kepler 13b

Kepler 13 (or KOI 13) is the second brightest host star in our sample with mag 9.958 in the Kepler band. The planet Kepler 13b was detected by [Shporer et al. 2011] due to its photometric orbit using the BEER algorithm [Faigler & Mazeh 2011]. It has [Mislis & Hodgkin 2012] conclude that KOI-13b is a super-Jovian planet with a mass of 8.3 $M_{Jup}$ and 1.4 $R_{Jup}$ radius on a 1.76 day orbit around a A7V host star. Santerne et al. (2012) found that the transiting planet is orbiting the main component of a hierarchical triple system of two fast rotating a stars and one more companion with mass between 0.4 and 1 $M_{Sun}$. Szabó et al. (2012) reported a spin-orbit resonance, transit duration variation and possible secular perturbations in the KOI-13 system. For KOI-13, Esteves et al. (2013) measure an eclipse depth of 143.0 ± 1.2 ppm, a brightness temperature $T_b$ of 3706$^{+6}_{-2}$ K a geometric albedo $A_g$ of 0.42 ± 0.0031 and an upper limit for the night side temperature $T_{night}$ of 2710.

For Kepler 13b, we find an eclipse depth of 84.8 ± 5.4, corresponding to a brightness temperature of 3421$^{+32}_{-31}$ K a geometric albedo of 0.27 ± 0.02, a bond albedo of 0.40 ± 0.03 and a night side temperature of 2394$^{+251}_{-216}$. Figure I (bottom, right) shows our fit results for Kepler 13b.

### 3.1.5. KOI 17.01 / Kepler 6b

Kepler 6b [Dunham et al. 2010] is a transiting Hot Jupiter orbiting a 3.8 Gyr old star with unusually high metallicity ([Fe/H] = +0.34 ± 0.04) in a P = 3.235 d orbit. It has a mass of $M_P = 0.67 M_{Jup}$ and a radius of $R_P = 1.32 R_{Jup}$, resulting in a density of 0.35 ($g/cm^3$). The host star Kepler 6 is more massive and larger than the sun (1.21 $M_{Sun}$, 1.39 $R_{Sun}$) but slightly cooler with $T_{eff} = 5724 K$. Kipping & Bakos (2011) exclude secondary eclipses of depth 51.5 ppm or greater to 3-σ confidence, which excludes a geometric albedo of more than 0.32 to the same level. [Désert et al. 2011] found a brightness temperatures of Kepler 6b from Spitzer observations of $T_B = 1660 ± 120$ K and an optical geometric albedo $A_g$ in the Kepler bandpass of $A_g = 0.11 ± 0.04$. Demory & Seager (2011) derive a geometric albedo of 0.18 ± 0.09 and an equilibrium temperature of 1411 K from Kepler’s Q1 data. For Kepler 6, Esteves et al. (2013) measure an eclipse depth of 8.9 ± 3.8 ppm, a brightness temperature $T_b$ of 2000$^{+80}_{-70}$ K, a geometric albedo $A_g$ of 0.058 ± 0.025 and an upper limit for the night side temperature $T_{night}$ of 1600 K.

For KOI-17, we derive an eclipse depth of 11.3 ± 4.2 ppm, a brightness temperature $T_b$ of 2060$^{+70}_{-59}$ K, a geometric albedo $A_g$ of 0.07 ± 0.03, a bond albedo $A_b$ of 0.11 ± 0.04 and an upper limit for the night side temperature $T_{night}$ of 1719$^{+230}_{-246}$ K - again confirming the results of Esteves et al. (2013). Figure I (top, left) shows our fit results for Kepler 6b.

### 3.1.6. KOI 18.01 / Kepler 5b

Kepler 5b (or KOI 18.01) is a 2.11 $M_{Jup}$ and 1.43 $R_{Jup}$ planet on a 3.55 day orbit around a 13th magnitude star [Koch et al. 2010]. Kipping & Bakos (2011) detect a weak secondary eclipse for Kepler 5b of depth 25 ± 17 ppm and a geometric albedo of $A_g = 0.15 ± 0.10$. [Désert et al. 2011] found a brightness temperatures of...
Kepler 5b from Spitzer observations of $T_B = 1930 \pm 100$ K and an optical geometric albedo in the Kepler band of $A_g = 0.12 \pm 0.04$. Demory & Seager (2011) report a geometric albedo of 0.21 and an equilibrium temperature of 1557 K using only Q1 data. For Kepler 5b, Esteves et al. (2013) find an eclipse depth of 18.8 ppm, a brightness temperature $T_b$ of 2400$^{+50}_{-60}$ K, a geometric albedo $A_g$ of 0.119 and an upper limit for the night side temperature $T_{night}$ of 2100.

Our lightcurve fits of KOI-18 show an eclipse depth of 19.8 ppm, a brightness temperature $T_b$ of 2305$^{+46}_{-52}$ K, a geometric albedo $A_g$ of 0.16 and a bond albedo $A_b$ of 0.25 and a night side temperature $T_{night}$ of 2169$^{+81}_{-113}$ K. These results are very close to the values of Esteves et al. (2013). Figure 2 (top, right) shows our fit results for KOI-18.

3.1.7. KOI 20.01 / Kepler 12b

Kepler 12b (KOI-20, Fortney et al. [2011]), with a radius of 1.69 $R_{Jup}$ and a mass of 0.43 $M_{Jup}$, belongs to the group of planets with highly inflated radii. On a 4.44 day orbit around a slightly evolved G0 host, Kepler 12b is the least irradiated within the class of inflated and very low density planets (0.11 $g/cm^3$) and may have important implications for the question of the correlation between irradiation and inflation. Fortney et al. (2011) also detected a secondary eclipse depth of 31$^{+7}_{-5}$ ppm, corresponding to a geometric albedo of 0.14 $\pm$ 0.04.

Our fits of KOI-20's lightcurve confirm and improve this with a resulting eclipse depth of 18.7 ppm, a brightness temperature $T_b$ of 2121$^{+54}_{-57}$ K, a geometric albedo $A_g$ of 0.14 $\pm$ 0.04 and an upper limit for the night side temperature $T_{night}$ of 2100. Furthermore we found a phase shifts $\phi_{shift}$ of -0.19 for KOI-20b. Figure 2 (bottom, left) shows our fit results for Kepler 12b.

3.1.8. KOI 97.01 / Kepler 7b

Kepler 7b (Latham et al. [2010]) with a mass of 0.43 $M_{Jup}$ and radius 1.48 $R_{Jup}$ also has a very low densities of 0.17($g/cm^3$). Demory et al. (2011), using Q0-Q4 data, measure an occultation depth in the Kepler bandpass of 44$^{+5}_{-4}$ ppm, a geometric albedo $A_g$ of 0.09 $\pm$ 0.02, a bond albedo $A_b$ of 0.14 $\pm$ 0.04 and an upper limit for the night side temperature $T_{night}$ of 1711$^{+223}_{-116}$ K. Furthermore we found a phase shifts $\phi_{shift}$ of -0.19 for KOI-20b. Figure 2 (bottom, left) shows our fit results for Kepler 12b.

Kepler 12b (KOI-20, Fortney et al. [2011]), with a radius of 1.69 $R_{Jup}$ and a mass of 0.43 $M_{Jup}$, belongs to the group of planets with highly inflated radii. On a 4.44 day orbit around a slightly evolved G0 host, Kepler 12b is the least irradiated within the class of inflated and very low density planets (0.11 $g/cm^3$) and may have important implications for
also detected an additionally phase shifts $\phi_{shift}$ of $-0.08$ for KOI-97. Figure 2 (bottom, left) shows our fit results for Kepler 12b.

We also confirm the following results: Kipping & Bakos (2011) detect a secondary eclipse for Kepler 7b of depth $47 \pm 14$ ppm and a geometric albedo of $A_g = 0.38 \pm 0.12$. The day-night difference of $17 \pm 9$ ppm they calculate supports the hypothesis of thermal emission as a source for both the secondary eclipse and the phase curve. Demory & Seager (2011) find a geometric albedo of $0.35 \pm 0.11$ and an equilibrium temperature of $1370$ K using only data from the first quartile.

3.1.9. KOI 127.01 / Kepler 77b

Kepler 77b (Gandolfi et al. 2013) is a moderately bloated planet with a mass of $M_P = 0.430 \pm 0.032 \, M_{Jup}$, a radius of $R_P = 0.960 \pm 0.016 \, R_{Jup}$, orbiting G5 V star with a period of 3.58 days. Gandolfi et al. (2013) do not find a secondary eclipse with a depth larger than $10$ ppm which leads to limits of the geometric and Bond albedo of $A_g \leq 0.087 \pm 0.008$ and $A_b \leq 0.058 \pm 0.006$, respectively.

For KOI-127, we find an eclipse depth of $13.3 \pm 7.4$ ppm, which results in a brightness temperature of $2062^{+100}_{-165}$ K, geometric albedo of $0.15 \pm 0.09$, bond albedo of $0.23 \pm 0.13$ and night side temperature of $1854^{+216}_{-165}$ K. Figure 3 (top, left) shows our fit results for Kepler 77b.

3.1.10. KOI 135.01 / Kepler 43b

KOI-135b (Bonomo et al. 2012) with radius $R_P = 1.20 \pm 0.06 \, R_{Jup}$ and mass $M_P = 3.23 \pm 0.19 \, M_{Jup}$ orbits its parent star in 3.02 days. We are the first to report a secondary eclipse of KOI-135 with a depth of $17.0 \pm 5.3$ ppm. This corresponds to a brightness temperature $T_b$ of $2296^{+73}_{-95}$ K, a very low geometric albedo $A_g$ of $0.06 \pm 0.02$ and a bond albedo $A_b$ of $0.09 \pm 0.03$ respectively. Using our model we also found a phase shift $\phi_{shift}$ of $-0.10$ for KOI-135b. Figure 3 (top, right) shows our fit results for KOI-135.

3.1.11. KOI 196.01 / Kepler 41b

The planet KOI-196b, with a radius of $0.84 \pm 0.03 \, R_{Jup}$ and a mass of $0.49 \pm 0.09 \, M_{Jup}$ orbits a G2V star of $0.99 \pm 0.03 \, R_{sun}$ (Santerne et al. 2011a): KOI-196b is one the rare close-in Hot Jupiters with a radius smaller than Jupiter suggesting a non-inflated planet. Santerne et al (2011a) detect a secondary eclipse depth of $64 \pm 10$ ppm as well as the optical phase variation, leading to a relatively high geometric albedo of $A_g = 0.3 \pm 0.08$ and a temperature of $T_B = 193 \pm 80$ K.

Figure 2. Fitted lightcurves for KOI-17 (top, left) KOI-18 (top, right), KOI-20 (bottom, left) and KOI-97 (bottom, right). In each quarter: Phase curve, residuals (top). Center: phasecurve contributions: Doppler (blue), ellipsoidal (green), planetary phase (red). Bottom: zoom into phase curve subtracted secondary eclipse, residuals.
Figure 3. Fitted lightcurves for KOI-127 (top, left), KOI-135 (top, right), KOI-196 (bottom, left) and KOI-202 (bottom, right). In each quarter: Phase curve, residuals (top). Center: phasecurve contributions: Doppler (blue), ellipsoidal (green), planetary phase (red). Bottom: zoom into phase curve subtracted secondary eclipse, residuals.

Quintana et al. (2013) confirmed the Hot Jupiter Kepler 41b via phase curve analysis and find a secondary eclipse depth of 60 $\pm$ 9 ppm and a geometric albedo of $A_g = 0.23 \pm 0.05$.

For KOI-196, we find an eclipse depth of 46.2 $\pm$ 8.7 ppm, slightly lower than, but however consistent with Quintana et al. (2013) and Santerne et al. (2011a). Our fits correspond to a brightness temperature $T_b$ of 2395 $\pm$ 50 K, a geometric albedo $A_g$ of 0.18 $\pm$ 0.03 and a bond albedo $A_b$ of 0.27 $\pm$ 0.05. Figure 3 (bottom, left) shows our fit results for KOI-196.

3.1.12. KOI 203.01 / Kepler 17b

Kepler 17b is a $M_p$=2.45 $\pm$ 0.11 $M_{Jup}$ and $R_p$=1.31 $\pm$ 0.02 $R_{Jup}$ planet orbiting a 1.02 $\pm$ 0.03 $R_{Sun}$ star with a period of 1.49 days (Endl et al. 2011). Endl et al. (2011) find measure an eclipse depth of 58 $\pm$ 10 ppm and a geometric albedo $A_g$ of 0.1 $\pm$ 0.02. Bonomo et al. (2012) find a slightly different $M_p = 2.47 \pm 0.10 M_{Jup}$ and $R_p = 1.33 \pm 0.04 R_{Jup}$ and an upper limit for the geometric albedo of $A_g < 0.12$.

For KOI-203, we find an eclipse depth of 43.7 $\pm$ 6.4 ppm, a brightness temperature $T_b$ of 2247 $\pm$ 40 K, a geometric albedo $A_g$ of 0.08 $\pm$ 0.01 a bond albedo $A_b$ of 0.13 $\pm$ 0.02 and an upper limit for the night side temperature $T_{night}$ of 2229 $\pm$ 58 K. These results are slightly different from, but still consistent with Bonomo et al. (2012) and Endl et al. (2011). Figure 4 (top, left) shows our fit results for KOI 203.

3.1.13. KOI 203.01 / Kepler 17b

Kepler 17b is a $M_p$=2.45 $\pm$ 0.11 $M_{Jup}$ and $R_p$=1.31 $\pm$ 0.02 $R_{Jup}$ planet orbiting a 1.02 $\pm$ 0.03 $R_{Sun}$ star with a period of 1.49 days (Endl et al. 2011). Endl et al. (2011) find measure an eclipse depth of 58 $\pm$ 10 ppm and a geometric albedo $A_g$ of 0.1 $\pm$ 0.02. Bonomo et al. (2012) find a slightly different $M_p = 2.47 \pm 0.10 M_{Jup}$ and $R_p = 1.33 \pm 0.04 R_{Jup}$ and an upper limit for the geometric albedo of $A_g < 0.12$.

For KOI-203, we find an eclipse depth of 43.7 $\pm$ 6.4 ppm, a brightness temperature $T_b$ of 2247 $\pm$ 40 K, a geometric albedo $A_g$ of 0.08 $\pm$ 0.01 a bond albedo $A_b$ of 0.13 $\pm$ 0.02 and an upper limit for the night side temperature $T_{night}$ of 2229 $\pm$ 58 K. These results are slightly different from, but still consistent with Bonomo et al. (2012) and Endl et al. (2011). Figure 4 (top, left) shows our fit results for KOI 203.

3.1.14. KOI 204.01 / Kepler 44b

KOI-204b (Bonomo et al. 2012) is a 1.24 $\pm$ 0.07 $R_{Jup}$, 1.02 $\pm$ 0.07 $M_{Jup}$ planet orbiting its parent G2IV star in
Kepler temperatures and albedos

3.25 days.

For KOI-204, we marginally detect a secondary eclipse with a depth of $21.9 \pm 14.9$ ppm. This corresponds to a brightness temperature $T_b$ of $2348^{+149}_{-279}$ K, a geometric albedo $A_g$ of $0.28^{+0.19}_{-0.19}$, a bond albedo $A_b$ of $0.42^{+0.29}_{-0.29}$ and an upper limit for the night side temperature $T_{\text{night}}$ of $2347^{+149}_{-280}$ K. Figure 4 (top, right) shows our fit results for KOI 204.

3.1.15. KOI 428.01 / Kepler 40b

The planet KOI-428b (1.17 ± 0.04 $R_{\text{Jup}}$, 2.2 ± 0.4 $M_{\text{Jup}}$), orbits an F5IV star of $2.13 \pm 0.06 R_{\text{Sun}}$, $1.48 \pm 0.06 M_{\text{Sun}}$, one of the largest and the most evolved stars discovered so far with a transiting planet (Santerne et al. 2011b).

For KOI-428, we detect an eclipse depth of $7.91 \pm 7.55$ ppm, consistent with a non detection within one sigma. This corresponds to limits for the brightness temperature $T_b$ of $2348^{+149}_{-279}$, the geometric albedo $A_g$ of $0.09 \pm 0.08$, the bond albedo $A_b$ of $0.13 \pm 0.13$ and an upper limit for the night side temperature $T_{\text{night}}$ of $2347^{+149}_{-469}$ K. Figure 4 (bottom, left) shows our fit results for KOI 428.

3.1.16. KOI 1658.01 / Kepler 76b

Kepler 76b (Faigler et al. 2013) (2.0 ± 0.26 $M_{\text{Jup}}$, 1.25 ± 0.08 $R_{\text{Jup}}$) orbits a 1.2 $M_{\text{Sun}}$ star in 1.55 days. It is slightly denser than Jupiter indicating that it is not inflated like other planets in this sample. Faigler et al. (2013) find a secondary eclipse depth of $98.9 \pm 7.1$ ppm as well as significant contribution to doppler, ellipsoidal and phase modulations of 13.5, 21.1 and 50.4 ppm.

For Kepler 76b, our model fits an eclipse of $75.6 \pm 5.6$ ppm, about 25% less than in Faigler et al. (2013). Using our values we find a brightness temperature of $2776^{+26}_{-28}$ K, a geometric albedo of $0.22^{+0.02}_{-0.02}$ and bond albedo of $0.33^{+0.03}_{-0.02}$. Figure 4 (bottom, right) shows our fit results for KOI 1658.

3.2. Non detections

3.2.1. KOI 3.01 / HAT-P-11b / Kepler 3b

HAT-P-11b (KOI 3.01 or Kepler 3b, Bakos et al. 2010) is a Hot Neptune type planet (17 $M_{\text{e}}$, 3.8 $R_{\text{e}}$) orbiting a bright (V = 9.59) and metal rich K4 dwarf star with a period of 4.89 days. This planet, that was already detected before the start of the Kepler mission is he brightest in our sample and the whole Kepler catalog with a magnitude of 9.174 in the Kepler band. Several other groups already analyzed the phasecurves with no detection of a secondary eclipse (e.g Southworth 2011, Deming et al.)
Table 3

Fit results for the amplitudes of phasecurve \( (A_p) \), Doppler boosting \( (A_d) \) and ellipsoidal variation \( (A_e) \), and eclipse depth \( D_{ecl} \) - all in ppm

| KOI | \( A_p \) | \( A_d \) | \( A_e \) | \( D_{ecl} \) |
|-----|---------|---------|---------|---------|
| 1   | 3.0 ± 0.8 | 2.0 ± 0.2 | 2.9 ± 0.5 | 10.9 ± 2.2 |
| 2   | 60.8 ± 0.5 | 5.3 ± 0.1 | 16.8 ± 0.3 | 69.3 ± 0.5 |
| 10  | 13.8 ± 3.7 | 0 a  | 3.7 ± 2.0 | 16.5 ± 4.4 |
| 13  | 78.7 ± 5.4 | 0 a  | 37.1 ± 5.4 | 84.8 ± 5.4 |
| 17  | 9.5 ± 2.7 | 1.0 ± 0.9 | 0 a  | 11.3 ± 4.2 |
| 18  | 8.3 ± 2.6 | 0 a  | 3.1 ± 1.4 | 19.8 ± 3.6 |
| 20  | 16.7 ± 2.6 | 0 a  | 0 a  | 18.7 ± 4.9 |
| 97  | 47.8 ± 5.2 | 3.9 ± 4.0 | 0 a  | 46.6 ± 3.9 |
| 127 | 8.6 ± 5.4 | 0 a  | 0 a  | 13.3 ± 7.4 |
| 135 | 51.7 ± 3.3 | 0 a  | 16.9 ± 2.2 | 17.0 ± 5.3 |
| 196 | 46.3 ± 7.9 | 0 a  | 2.8 ± 4.3 | 46.2 ± 8.7 |
| 202 | 17.3 ± 7.4 | 2.7 ± 2.2 | 6.3 ± 3.9 | 40.2 ± 9.0 |
| 203 | 2.9 ± 5.9 | 24.7 ± 1.8 | 17.9 ± 3.2 | 43.7 ± 6.4 |
| 204 | 0 a  | 0 a  | 5.4 ± 4.8 | 21.9 ± 14.9 |
| 428 | 0 a  | 5.6 ± 2.1 | 8.5 ± 2.9 | 7.9 ± 7.5 |
| 1648 | 101.3 ± 3.6 | 11.4 ± 1.0 | 22.6 ± 1.9 | 75.6 ± 5.6 |

* Minimum in our fit, equivalent to a non-detection. Excluded multiple systems (e.g., Rowe et al. 2013). Multiplicity causes shifts and variations in the expected times of secondary eclipses. All planets contribute to the shape of the phasecurve. Figure 3 (left). These effects were not in the range of our applied model. Excluded multiple systems containing planets. For KOI 46 / Kepler 10, KOI 137 / Kepler 18, KOI 338 / Kepler 141, KOI 1779 / Kepler 318 and KOI 1805 / Kepler 319.

3.2.2. KOI 70.01 / Kepler 4b

Kepler 4b (or KOI 70.01, Borucki et al. 2010b) is a 24.5 ± 3.8 M\(_{\text{Jup}}\) and 3.99 ± 0.21 R\(_{\text{J}}\) planet with period of 3.21 days around a 4.5 Gyr old near-turnoff G0 star. With a density of about 1.9 g/cm\(^3\), Kepler 4b is slightly denser and more massive than Neptune, but about the same size. Kipping & Bakos (2011) exclude a secondary eclipse with an upper limit of 104 ppm for its depth, which corresponds to an upper limit for the brightness temperature of 3988 K.

Our analysis confirms this and is also consistent with a non-detection to a level of < 9 ppm, which enables us to constrain the brightness temperature T\(_b\) to < 2797 K. Figure 3 (top, right) and Table 3 show our fit results for KOI 7.

3.2.3. KOI 98.01 / Kepler 14b

Kepler 14b (or KOI 98.01) is a 8.40 M\(_{\text{Jup}}\) and 1.136 R\(_{\text{Jup}}\) planet on a 6.79 day orbit around an F star in a binary system (Buchhave et al. 2011).

Our analysis, which used an additional polynomial fit to correct for systematics caused by a close visual binary, is the first of this kind for KOI-98. The results show an eclipse depth consistent with a non-detection of < 0.1 ppm. This leads to a brightness temperature limit T\(_b\) < 2415 K, a geometric albedo A\(_g\) < 0.17. Figure 3 (bottom, left) and Table 3 show our fit results for KOI 98.

3.2.4. KOI 128.01 / Kepler 15b

Kepler 15b (Endl et al. 2011) is a 0.66 ± 0.1 M\(_{\text{Jup}}\), 0.96 ± 0.06 R\(_{\text{Jup}}\) planet in 4.94 day orbit around a metal-rich (Fe/H) = 0.36 ± 0.07 G star; its mean density of 0.9 ± 0.2 g/cm\(^3\) suggests a significant enrichment in heavy elements. Endl et al. (2011) find no sign of a secondary eclipse.

For KOI-128, we find an eclipse depth consistent with a non-detection of < 11 ppm. This corresponds to a brightness temperature T\(_b\) limit of < 2039 K and a geometric albedo limit A\(_g\) of < 0.11. Figure 3 (bottom, right) and Table 3 show our fit results for KOI 128.

3.3. Excluded planets

We excluded KOI 63.01 / Kepler 63b (Sanchis-Ojeda et al. 2013) from our sample because we were not able to apply our methods. In this case the lightcurve was dominated by contributions from an additional signal with a different periodicity most probably induced by stellar activity (see 6, left).

We also excluded planets from our sample that are part of multiple systems (e.g., Rowe et al. 2013). Multiplicity causes shifts and variations in the expected times of secondary eclipses. All planets contribute to the shape of the phasecurve (see Figure 3, right). These effects were not in the range of our applied model. Excluded multiple systems containing planets. For KOI 46 / Kepler 10, KOI 137 / Kepler 18, KOI 338 / Kepler 141, KOI 1779 / Kepler 318 and KOI 1805 / Kepler 319.

3.4. The case of KOI 200 / Kepler 74b and KOI 1335 / Kepler 91b

The planet Kepler 74b (Hebrard et al. 2013) has mass and radius of 0.68 ± 0.09 M\(_{\text{Jup}}\) and 1.32 ± 0.14 R\(_{\text{Jup}}\) and orbits its F8V host star in 7.34 days. Kepler 91b (Lillo-Box et al. 2014) (M\(_p\) = 0.883±0.017 M\(_{\text{Jup}}\), R\(_p\) = 1.384±0.054 R\(_{\text{Jup}}\) orbits its host star (R\(_*\) = 63.0 ± 0.16 R\(_{\odot}\), M\(_*\) = 1.31 ± 0.10 M\(_{\odot}\)) only 1.32+0.07−0.22 R\(_{\ast}\) away from the stellar atmosphere at the pericenter. Lillo-Box et al. (2014) argue that Kepler 91b could therefore be at a stage of the planet engulfment and estimate that Kepler 91b will be swallowed by its host star in less than 55 Myr. They derive phasecurve parameters A\(_g\) = 121 ± 33 ppm, A\(_p\) = 25 ± 15 ppm and A\(_d\) = 3 ± 1 ppm ppm and no clear secondary eclipse, but 3 other dips in the lightcurve.

In our analysis both planets do not show a typical secondary eclipse signature but instead also a series of extra dimmings at times other than of the expected eclipse (see Figure 7). The timing of some of these extra dips in the lightcurve at 0.166 of the period after transit and/or eclipse may be evidence for the presence of Trojan satellites - however, as also stated in Lillo-Box et al. (2014), this claim needs detailed stability studies to be confirmed.

4. SUMMARY AND DISCUSSION

With our consistent analysis we were able to confirm and in most cases improve parameters derived by previous studies. We present new results for Kepler 1b-8b, 12b-15b, 17b, 40b, 41b, 43b, 44b, 76b, 77b, and 412b. This sample of 20 planets is the largest so far, modeled and analyzed in such a comparative way.

4.1. Comparison to other fitting routines

For the cases of previously analyzed targets we were able to confirm results derived from various publications using different modeling approaches, from relatively simple boxcar fits of only the secondary eclipse to very sophisticated MCMC codes fitting all system parameters in an integrated way. The fact that we reproduce these results demonstrates the value of our compromise approach to use a relatively simple least squares fit to trade off between number of systems and computing time. Also our goal was to focus on eclipses and phasecurves while...
Table 4

| KOI | $T_b$ | $A_g^a$ | $A_b$ | $T_{eq}^{1/2}$ | $T_{eq}^{2/3}$ | $T_{night}$ [K] |
|-----|-------|------|------|---------------|---------------|---------------|
| 1   | $1947_{-45}^{+37}$ | 0.05 ± 0.01 | 0.08 ± 0.02 | 1363 | 1574 | 1885_{-51}^{+46} |
| 2   | $2897_{-96}^{+3}$ | 0.27 ± 0.003 | 0.4 ± 0.003 | 1892 | 2185 | 2235_{-66}^{+3} |
| 10  | $2241_{-96}^{+61}$ | 0.11 ± 0.03 | 0.16 ± 0.04 | 1536 | 1774 | 1859_{-236}^{+227} |
| 13  | $3421_{-35}^{+32}$ | 0.27 ± 0.02 | 0.40 ± 0.03 | 2620 | 3025 | 2394_{-66}^{+251} |
| 17  | $2060_{-96}^{+76}$ | 0.07 ± 0.03 | 0.11 ± 0.04 | 1413 | 1632 | 1719_{-236}^{+238} |
| 18  | $2305_{-54}^{+45}$ | 0.16 ± 0.03 | 0.25 ± 0.05 | 1429 | 1650 | 2169_{-113}^{+81} |
| 20  | $2120_{-56}^{+47}$ | 0.09 ± 0.02 | 0.14 ± 0.04 | 1422 | 1642 | 1711_{-223}^{+231} |
| 97  | $2547_{-28}^{+26}$ | 0.32 ± 0.03 | 0.48 ± 0.04 | 1364 | 1575 | – |
| 127 | $2062_{-165}^{+100}$ | 0.15 ± 0.09 | 0.23 ± 0.13 | 1136 | 1312 | 1854_{-216}^{+105} |
| 135 | $2295_{-50}^{+74}$ | 0.06 ± 0.02 | 0.09 ± 0.03 | 1930 | 2229 | – |
| 196 | $2305_{-57}^{+50}$ | 0.18 ± 0.03 | 0.27 ± 0.05 | 1513 | 1933 | – |
| 202 | $2355_{-40}^{+45}$ | 0.11 ± 0.02 | 0.16 ± 0.04 | 1701 | 1965 | 2210_{-163}^{+105} |
| 203 | $2247_{-40}^{+35}$ | 0.08 ± 0.01 | 0.13 ± 0.02 | 1660 | 1917 | 2229_{-54}^{+150} |
| 204 | $2348_{-277}^{+149}$ | 0.28 ± 0.19 | 0.42 ± 0.29 | 1217 | 1405 | 2347_{-280}^{+149} |
| 428 | $2331_{-627}^{+154}$ | 0.09 ± 0.08 | 0.13 ± 0.13 | 1774 | 2048 | 2327_{-669}^{+195} |
| 1658| $2776_{-28}^{+26}$ | 0.22 ± 0.02 | 0.33 ± 0.02 | 1875 | 2165 | – |

*a* Albedos corrected for thermal emission can be found in Table 5.

![Figure 5](image-url)

**Figure 5.** Fitted lightcurves for KOI-3 (top, left) KOI-7 (top, right), KOI-98 (bottom, left) and KOI-128 (bottom, right). None of these systems showed a significant secondary eclipse larger than our noise threshold. However, we were able to calculate upper limits for some of the parameters of these systems (see Table 6).

fixing all other parameters to previously derived values. However, we plan to apply a fully integrated Bayesian MCMC fitting method in the future (see 4.3).

### 4.2. Correlations with system parameters

For further analysis we used the albedos corrected for thermal emission for no redistribution ($f_{dist} = 1/2$) that are shown in Table 5 (center). Our results confirm the general trend of relatively low albedos for most of the Hot Jupiters but we also show outliers with higher albedos. In fact our data seem to show hints of a division into two populations: planets with high (emission corrected) albedos above 0.12 and another group of low albedo planets below 0.08 (see Figure 8).

We see no significant correlations in our data with these two clusters. Neither the stellar parameters ([Fe/H] and log(g), see Figure 9) nor the planetary characteristics (mass, radius, density and surface gravity, see Figure 10) explain the partition. Massive planets, however, populate only the low albedo regime (Figure 10, left). Taking into account the planets with large error bars in the albedo (red error bars in Figure 8, red symbols in Fig-
Table 5
Albedos corrected for thermal emission for no $f_{dist} = \frac{1}{2}$ and full redistribution $f_{dist} = \frac{2}{3}$

| KOI | $A_g$ | $A_{g,c}(f_{dist} = \frac{1}{2})$ | $A_{g,c}(f_{dist} = \frac{2}{3})$ |
|-----|------|---------------------------------|---------------------------------|
| 1   | 0.05 | 0.03                            | -0.05$^a$                       |
| 2   | 0.27 | 0.23                            | 0.1                             |
| 10  | 0.11 | 0.07                            | -0.06$^a$                       |
| 13  | 0.27 | 0.09                            | -0.27$^a$                       |
| 17  | 0.07 | 0.06                            | -0.03$^a$                       |
| 18  | 0.16 | 0.15                            | 0.08                            |
| 20  | 0.09 | 0.07                            | -0.03$^a$                       |
| 97  | 0.32 | 0.31                            | 0.28                            |
| 127 | 0.15 | 0.15                            | 0.13                            |
| 135 | 0.06 | -0.01$^a$                       | -0.22$^a$                       |
| 196 | 0.18 | 0.16                            | 0.09                            |
| 202 | 0.11 | 0.08                            | -0.05$^a$                       |
| 203 | 0.08 | 0.05                            | -0.08$^a$                       |
| 204 | 0.28 | 0.28                            | 0.26                            |
| 428 | 0.09 | 0.02                            | -0.21$^a$                       |
| 1658| 0.22 | 0.18                            | 0.06                            |

$^a$ equivalent to a zero albedo

Table 6
Upper limits for planets without detected secondary eclipse.

| KOI | ecl. depth [ppm] | $T_b$ [K] | $A_g$ | $A_b$ |
|-----|-------------------|-----------|-------|-------|
| 3   | < 147             | --        | --    | --    |
| 7   | < 9               | < 2797    | < 0.62 | < 0.93 |
| 98  | < 10              | < 2415    | < 0.17 | < 0.26 |
| 128 | < 11              | < 2039    | < 0.11 | < 0.17 |

1 The noise in KOI-3 is much bigger than in all other planets of our sample, which misleads our models to an unrealistic albedo value. However, given the orbital parameters, the maximum secondary eclipse depth we should ever find (assuming it is not self luminous) is 12 ppm. Therefore we did not carry through the temperature calculations for KOI-3
2 For KOI-128, we used the sum of the (0.5 sigma) detected secondary eclipse value and the error in that value as maximum detectable eclipse value.

Even though we present the largest sample character-

Figure 6. Example for the excluded systems: KOI-63 (left) was dominated by stellar activity on comparable timescales as the planetary orbit; KOI-137 (right) is a multiple system.

Figure 7. Lightcurves of the systems KOI-200 (top) and KOI-2133 (bottom). The marked region of the lightcurve show dims that are not explainable with just a secondary eclipse.

Figure 8. Emission-corrected geometric albedo $A_{g,c}$ versus the incident stellar flux for our sample of Kepler giant planets. The data seem to point at a distribution in two clusters: planets with high albedos above 0.12 and another group of low albedo planets below 0.08.

4.3. Future prospects

In order to also increase the statistical relevance of our results we are currently working to extend the analysis to the whole sample of 489 Kepler Objects of Interest with $R_p > 4R_e$, $P < 10d$, $V_{mag} < 15$: we plan to apply EXONEST (Placek et al. 2013), a Bayesian model selection algorithm to the whole set of 489 candidates. With a sample of that size we hope to find statistically significant correlations of stellar and planetary parameters with the position of the planet, e.g., in albedo vs incoming flux phase space (see Figure 8) and test whether the clustering in two populations can be confirmed.

Parallel to the characterization of giant planets that we presented here, we are also working on a similar analysis on a smaller sample of rocky KOIs.
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