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Disproving the validated planets K2-78b, K2-82b, and K2-92b

The importance of independently confirming planetary candidates

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ABSTRACT

Context. Transiting super-Earths orbiting bright stars in short orbital periods are interesting targets for the study of planetary atmospheres.

Aims. While selecting super-Earths suitable for further characterisation from the ground from a list of confirmed and validated exoplanets detected by K2, we found some suspicious cases that led to us reassess the nature of the detected transiting signal.

Methods. We performed a photometric analysis of the K2 light curves and centroid motions of the photometric barycenters.

Results. Our study shows that the validated planets K2-78b, K2-82b, and K2-92b are not planets, but background eclipsing binaries. The eclipsing binaries are inside the *Kepler* photometric aperture, but outside the ground-based high-resolution images that were used for validation.

Conclusions. We advise extreme care in the validation of candidate planets that are discovered by space missions. It is important that all the assumptions in the validation process are carefully checked. An independent confirmation is mandatory in order to avoid wasting valuable resources on further characterisation of non-existent targets.

Key words. methods: data analysis – techniques: photometric – eclipses – planets and satellites: detection

1. Introduction

Most of the 3 580 transiting planets known to date (i.e. Schneider et al. 2011[1]) have been found by space missions such as CoRoT (Baglin et al. 2006) and especially by *Kepler* (Borucki et al. 2010) and K2 (Howell et al. 2014). However, only a small fraction of these planets have been independently confirmed with radial velocity (RV) measurements. Fortunately, the extraordinary photometric precision of space-borne observatories has allowed a validation process of planetary candidates based on statistical studies of the distribution of planetary populations and the most common false-positive scenarios (Torres et al. 2011; Morton 2012; Díaz et al. 2014; Santerne et al. 2015), instead of a validation based on an independent characterisation of the planetary properties with spectroscopic measurements.

The photometric analysis of the light curve made to confirm the planetary nature of a transiting candidate is a standard step of the ranking process of planetary candidates (Armstrong et al. 2017). The simplest steps include the search for secondary eclipses or ellipsoidal variations (also referred to as out-of-transit variation), revealing the stellar nature of the transiting body. The analysis of the chromatic light curves in CoRoT (Almenara et al. 2009) or the centroid motion analysis in *Kepler* (Batalha et al. 2010) are also powerful tools to reject contaminating eclipsing binary scenarios. However, these steps are primarily used as a tool to disprove candidates before any time-consuming photometric or spectroscopic follow-up observations are carried out.

With *Kepler*, the validation of candidates that are too faint to be observed with ground-based observatories, or whose expected

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[1] `http://exoplanet.eu/`

mass was estimated to be too low to be detectable with current instruments, went a step forward. More sophisticated analysis tools like BLENDER (Torres et al. 2011) or PASTIS (Díaz et al. 2014; Santerne et al. 2015) succeeded in rejecting all possible non-planetary scenarios that were compatible with the properties of the planetary candidate found in the light curve. These tools were able to make efficient use of all available information (stellar properties, galaxy models, complementary observations in different wavelengths, etc.) to secure the posterior of the hypothesis that the candidate was indeed a planetary companion. Needless to say, the performance of these tools is as good as the reliability of the information used in the analysis of the hypothesis.

Recently, Crossfield et al. (2016) used the validation tool VESPA (Morton 2015; Morton et al. 2016) to confirm the planetary nature of 104 planets observed by K2. In particular, they validated the planetary nature of K2-78b (EPIC 210400751), K2-82b (EPIC 210483889), and K2-92b (EPIC 211152484), all with a false-positive probability lower than 1%. We were interested in the study of these targets from an observational point of view. They are super-Earths that receive strong stellar irradiation, have high equilibrium temperatures and consequently relatively large scale heights, and they orbit relatively bright stars, which is favourable for further characterisation. We show here that unfortunately, these validated super-Earth-sized planets are blended eclipsing binaries. This is not the result of a statistical fluctuation, but the consequence of not including all the available information about these targets, which resulted in an incorrect evaluation of the false-positive probability.

2. Incorrectly identified planets

Crossfield et al. (2016) presented 197 candidates found in the K2 data, together with an ambitious ground-based follow-up programme, including photometric analysis, high angular resolution imaging, and stellar spectroscopy, which lead them to validate 104 planets, that is, they statistically confirmed their planetary nature. Sixty-four of the planets were validated for the first time.

Our study shows that 3 of these new 64 validated planets, all with false-positive probabilities lower than 1% as estimated by Crossfield et al. (2016), are blended eclipsing binaries.

2.1. K2-92b – EPIC 211152484

Many of the new candidates validated by Crossfield et al. (2016) are small planets (smaller than 2 Earth radii) in close orbits around relatively bright stars, which makes them interesting targets for atmospheric characterisation. One of the most interesting targets for our team was K2-92b (EPIC 211152484), which made us examine its properties more closely before further theoretical modelling and characterisation with ground-based facilities.

K2-92b was validated by Crossfield et al. (2016) as a planet with an orbital period of 0.7018180 days, a radius of 2.56 Earth radii, and a false-positive probability lower than 0.12%, orbiting a star of magnitude 12.136 in the *Kepler* pass-band. During our study, we compared the transit depth as a function of the size of the photometric aperture using data reduced with the pipeline by Vanderburg & Johnson (2014). We found out that the transit depth depended strongly on the size of the aperture used to extract the photometry.

When a neighbouring star is located close to the target, the transit depth is expected to decrease when the aperture is enlarged because background light or contaminating light from the neighbouring star is included. However, in the case of K2-92b, we observed the opposite effect. The largest transit depth corresponded to the largest aperture, which is a clear sign that the true transit signal comes from the background source. We compare in the top part of Fig. 1 the photometry of K2-92b extracted with Everest (Luger et al. 2016, 2017) and with the code by Vanderburg & Johnson (2014) folded at twice the orbital period quoted by Crossfield et al. (2016). The Everest data do not show any transit feature, neither does the Vanderburg code with the smallest aperture. However, the largest aperture from Vanderburg does show the expected signal at the correct period, only with a larger depth (about 0.4% compared to the tabulated 0.03%).

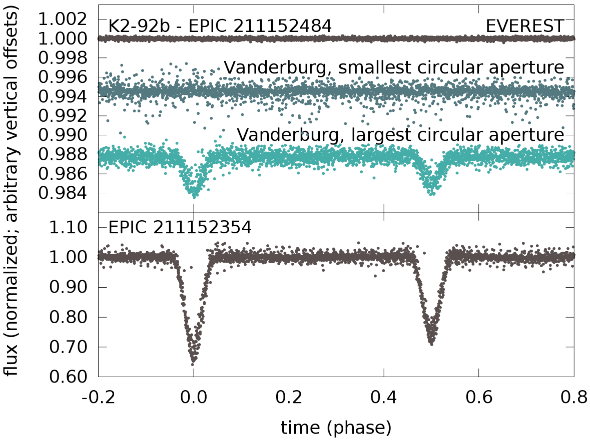

Fig. 1. Folded light curve of K2-92b with different apertures (*top*) and of EPIC 211152354 (*bottom*) folded at an orbital period of 1.4 days. See text for details.

We folded the data at twice the orbital period quoted in the validation paper because we considered that the transit depth differences between odd and even transit events at a 0.7 days period are significant. The analysis shows that the star responsible for the signal is an eclipsing binary with different depths for the primary and secondary eclipses, at an orbital period of about 1.4 days. In this particular case, the star responsible for the variability observed in the K2 light curve is a faint star (G band 17.045, Gaia Collaboration 2016) (with identification EPIC 211152354) about 15 arcsec south-east of the main K2 target (see bottom part of Fig. 1), showing eclipses of 35% depth.

The analysis of the centroid motion has been proposed as a useful tool to reject false-positive scenarios (Batalha et al. 2010). Although in this case the source of the contaminant is clearly identified, we decided to use the pipeline POLAR, which is based on the CoRoT imagette pipeline, to calculate the centroid motion of K2-92 in phase with the transit signal. A full description of the POLAR pipeline was presented in Barros et al. (2016). Briefly, the centre of light is calculated using the modified moment method by Stone (1989), then the line of sight of the *Kepler* satellite is subtracted to obtain the centroid motion of each star. This pipeline has been used to discover and characterise several K2 exoplanet discoveries, for instance, Barros et al. (2015). The reduced light curves up to campaign 6 are publicly available through the MAST[2].

In Fig. 2 we show the centroid motion of K2-92b for the x and y directions, phase folded on the 1.4 day orbital period

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[2] `https://archive.stsci.edu/prepds/polar/`

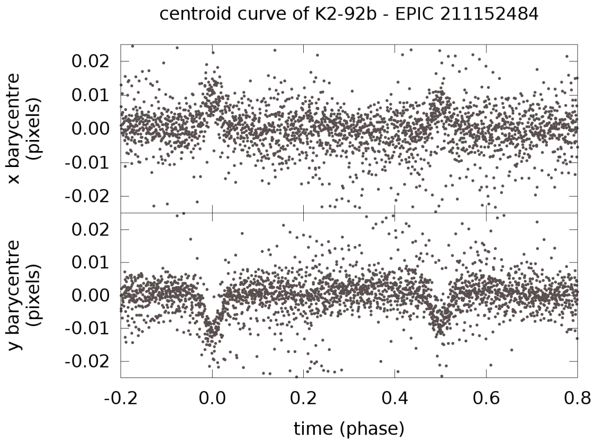

Fig. 2. Time series of the centroid motion of K2-92 folded at the period of the photometric transit. See text for details.

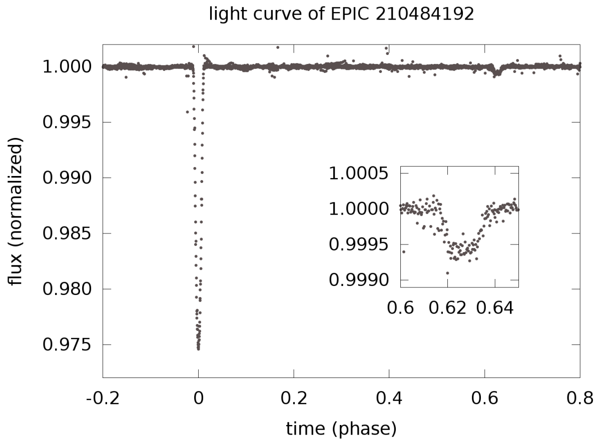

Fig. 4. Folded light curve of EPIC 210484192 at the ephemeris published by Crossfield et al. (2016) for K2-82b. The *close-up* shows the phase around the secondary eclipse. See text for details.

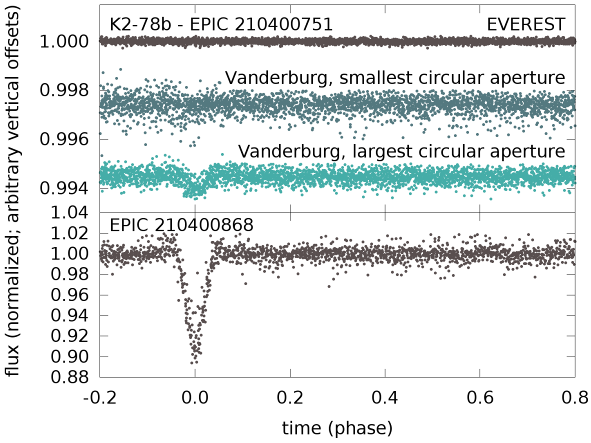

Fig. 3. Folded light curve of K2-78b with different apertures (*top*) and of EPIC 210400868 (*bottom*) folded at an orbital period of 2.3 days. See text for details.

of the binary. It is clear that a strong correlation exists between the centroid motion and the transit phase, which indicates that a neighbouring star is the source of the signal.

We note that Adams et al. (2016) also reported an unusual behaviour of the transit depths of K2-92b. They mentioned stellar variability, debris clouds, or even a comet as possible explanations for the irregular behaviour of the candidate. However, they failed to identify the eclipsing binary as the source of the signal.

2.2. K2-78b – EPIC 210400751

The source K2-78b was validated by Crossfield et al. (2016) as a planet with an orbital period of 2.29016 days, a radius of 1.42 Earth radii, and a false-positive probability lower than 0.31%, orbiting a star of magnitude 11.892 in the *Kepler* pass-band. We proceeded in the same way as for K2-92b (see Fig. 3) and show that the star responsible for the variability (with eclipses of 10% depth) lies north of the main target and is about four magnitudes fainter (EPIC 210400868).

2.3. K2-82b – EPIC 210483889

The source K2-82b was validated by Crossfield et al. (2016) as a planet with an orbital period of 7.195834 days, a radius of 2.6 Earth radii, and a false-positive probability lower than 0.059% orbiting an M dwarf of magnitude 13.519 in the *Kepler* pass-band. The transit depth reported by Crossfield et al. (2016) is about 2.0%, but because the EPIC target is an M dwarf (0.17 $R_{\rm Sun}$), the planetary radius is very small (2.6 $R_{\rm Earth}$). In this case, our analysis of the Everest light curve shows a primary eclipse of 2.5% depth and a clear secondary eclipse at phase 0.62 (the eclipsing binary being eccentric) in the light curve, which is incompatible with the occultation of a planetary object (see Fig. 4). It is unclear why the signal of the secondary eclipse was ignored in the validation process. The source of the signal is not the M dwarf, but a bright star (V = 9.0) north of the main target (EPIC 210484192), which had its own aperture in the C4 campaing of K2 (Armstrong et al. 2016).

3. Discussion

Our result shows that although planet validation techniques are useful tools, great care needs to be taken to correctly validate candidate planets that are discovered by space missions. Crossfield et al. (2016) made a sound statistical study and a careful and detailed ground-based characterisation of the targets, including high angular resolution imaging, but they failed to search for possible contaminants a few arcseconds away from the targets. In the cases mentioned above, the contaminants were too far away to be included in the field of view of the high-resolution image, and they were not considered further in the analysis.

The reliability of a statistical study is only as good as the understanding of the contamination sources. Here we show i) that the validation methods applied to these targets by Crossfield et al. (2016) underestimate the effect of background contaminants, and that consequently; ii) the planet likelihood estimates are not representative of the true nature of the candidates in these cases. We insist that this is not the result of a failure of the design of the validation procedure, but the result of an incorrect assessment of the effect of neighbouring sources on the photometry. Our results can be used to improve the performance of planet validation techniques.

Checking the light curves using different aperture sizes is a common validation step made in ground-based transit surveys. In this paper we showed that it can also reveal false-positive scenarios in space-borne surveys, saving valuable follow-up resources. We suggest that these tests are introduced in the pipelines of TESS (Ricker et al. 2015) and PLATO (Rauer et al. 2014).

The use of validated planets might be justified for statistical studies of large populations, as long as the theoretical studies can cope with a certain contamination that might not be completely described by the false-positive values of individual systems. The reliable statistical validation of individual systems is complex and costly, and we might risk saying that the detailed study of individual planetary systems requires the use of independently confirmed planets with RV measurements, or as a minimum, significant independent evidence, such as additional planetary companions in the system or transit-timing variations consistent with the planetary scenario (Barros et al. 2013). The risk is wasting telescope time and modelling efforts on false-positive scenarios. Furthermore, if a significant number of particularly valuable "false-positive" planet candidates are not discarded by validation procedures, statistical analysis studies of planet populations in which they are included may be biased.

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