The importance of independent confirmation of 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 characterization from the ground among a list of confirmed and validated exoplanets detected by K2, we found some suspicious cases that led to us re-assessing the nature of the detected transiting signal.

Methods. We did 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 actually not planets but background eclipsing binaries. The eclipsing binaries are inside the Kepler photometric aperture, but outside the ground-based high resolution images used for validation.

Conclusions. We advise extreme care on the validation of candidate planets 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 characterization of non-existent targets.

Key words. methods: data analysis – techniques: photometric – eclipses – planets and satellites: detection – planets and satellites: individual: K2-78b, K2-82b, K2-92b

1. Introduction

The largest fraction of the 3 580 transiting planets known to date (i.e. [Schneider et al.2011] http://exoplanet.eu/) have been found by space missions like 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; Morton2012; Diaz et al.2014; Santerne et al.2015), rather than on an independent characterization of the planetary properties with spectroscopic measurements.

The photometric analysis of the light curve 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 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 veto candidates before any time consuming photometric or spectroscopic follow-up observations are carried out.
With Kepler, the validation of candidates which are too faint to be observed with ground-based observatories, or whose expected mass was estimated too low to be detectable with current instruments, gave 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 compatible with the properties of the planetary candidate found in the light curve. These tools could 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 210400071), K2-82b (EPIC 210483889), and K2-92b (EPIC 211152484), all with a false-positive probability of less than 1%. We were interested in the study of these targets from an observational point of view. They are super-Earths receiving large amount of stellar irradiation, having high equilibrium temperatures and consequently relatively large scale heights, orbiting relatively bright stars, favorable for further characterization. Unfortunately, in this paper, we show that these validated super-Earth-sized planets are actually 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, resulting in a wrong evaluation of the false-positive probability.

2. The falsified planets

Crossfield et al. (2016) published a study where they 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 i.e. statistically confirm their planetary nature, 64 of them validated for the first time.

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

2.1. K2-92b – EPIC 211152484

Many of the new candidates validated by Crossfield et al. (2016) are small planets (below 2 Earth radii) in close orbits around relatively bright stars, which makes them interesting targets for atmospheric characterization. One of the most interesting targets for our team was K2-92b (EPIC 211152484), which drove us to a closer examination of its properties prior to further theoretical modelling and characterization 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 of less 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.

If there is a neighbouring star close to the target, one would expect the transit depth to decrease when enlarging the aperture, due to the inclusion of background light or contaminating light from the neighbouring star. 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 real transit signal comes actually 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, same as the Vanderburg code with the smallest aperture. However, the largest aperture from Vanderburg does show the expected signal at the right period, only with a larger depth (about 0.4% compared to the tabulated 0.03%).

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 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 about 1.4 days orbital period. In this particular case, the star responsible for the variability observed in the K2 light curve is a faint (G band 17.045, Gaia Collaboration et al. 2016) star (with identification EPIC 211152354) about 15 arcseconds 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 an useful tool to reject false positive scenarios (Batalha et al. 2010). Although in this case the source of the contaminant has been clearly identified, we decided to use the pipeline POLAR that 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 characterize several K2 exoplanet discoveries e.g. Barros et al. (2015). The reduced light curves up to campaign 6 are publicly available through the MAST (https://archive.stsci.edu/prepds/polar/).

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 of the binary. It is clear that there exists a strong correlation between the centroid motion and the transit phase, which we 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

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 of less than 0.31% orbiting a star of magnitude 11.892 in the Kepler pass-band. During our study, we compared the centroid motion has been proposed as an useful tool to reject false positive scenarios (Batalha et al. 2010). Although in this case the source of the contaminant has been clearly identified, we decided to use the pipeline POLAR that 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 characterize several K2 exoplanet discoveries e.g. Barros et al. (2015). The reduced light curves up to campaign 6 are publicly available through the MAST (https://archive.stsci.edu/prepds/polar/).

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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.
2.3. K2-82b – EPIC 210483889

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 of less 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 the fact that the EPIC target is an M dwarf (0.17 \( R_{\text{Sun}} \)) results in a very small planetary radius (2.6 \( R_{\text{Earth}} \)). 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 (\( V = 9.0 \)) to the north of the main target (EPIC 210484192), which got its own aperture in the C4 campaign of K2 (Armstrong et al. 2016).

3. Discussion

Our result shows that, though planet validation techniques are useful tools, great care needs to be taken to correctly validate candidate planets discovered by space missions. Crossfield et al. (2016) made a sound statistical study and a careful and detailed ground-based characterization of the targets, including high angular resolution imaging, but they failed to look 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 validation methods applied to these targets by Crossfield et al. (2016) underestimate the impact of background contaminants and 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 impact on the photometry of neighbouring sources. 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 show that it can also reveal false positive scenarios in space-borne surveys, saving valuable follow-up resources. We
suggest to introduce these tests 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 deal with a certain contamination which 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 one could 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, like 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 in false positive scenarios. Furthermore, if a significant number of particularly valuable "false positive" planet candidates are not discarded by validation procedures, their inclusion in statistical analysis studies of planet populations may be biased.

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