Validation of anomalous Cepheids with TESS

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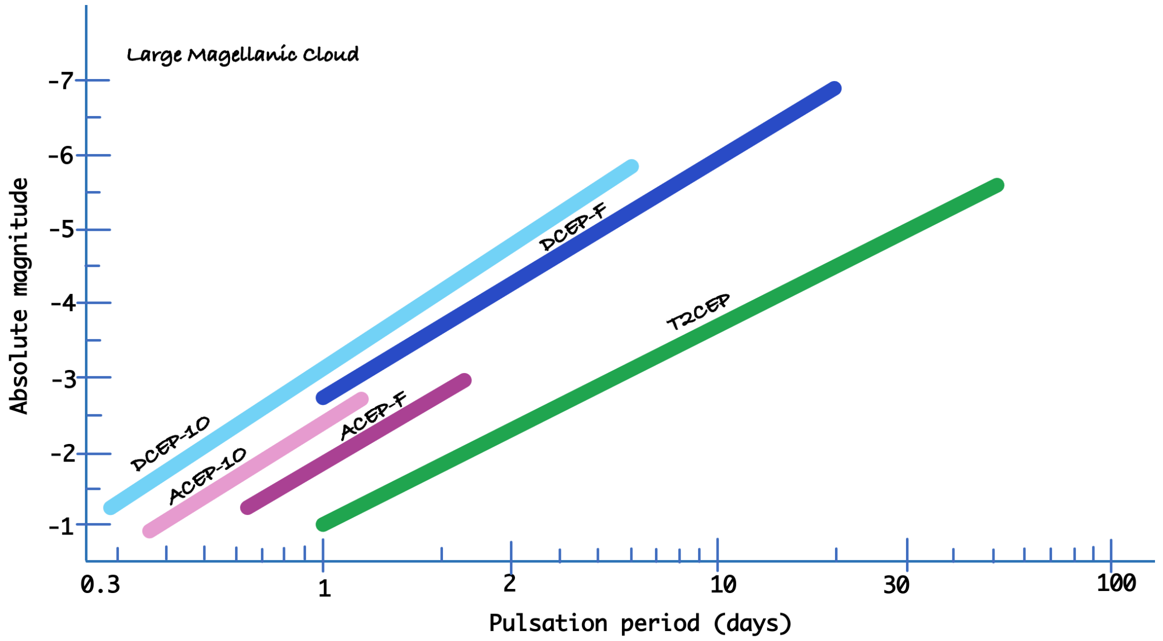
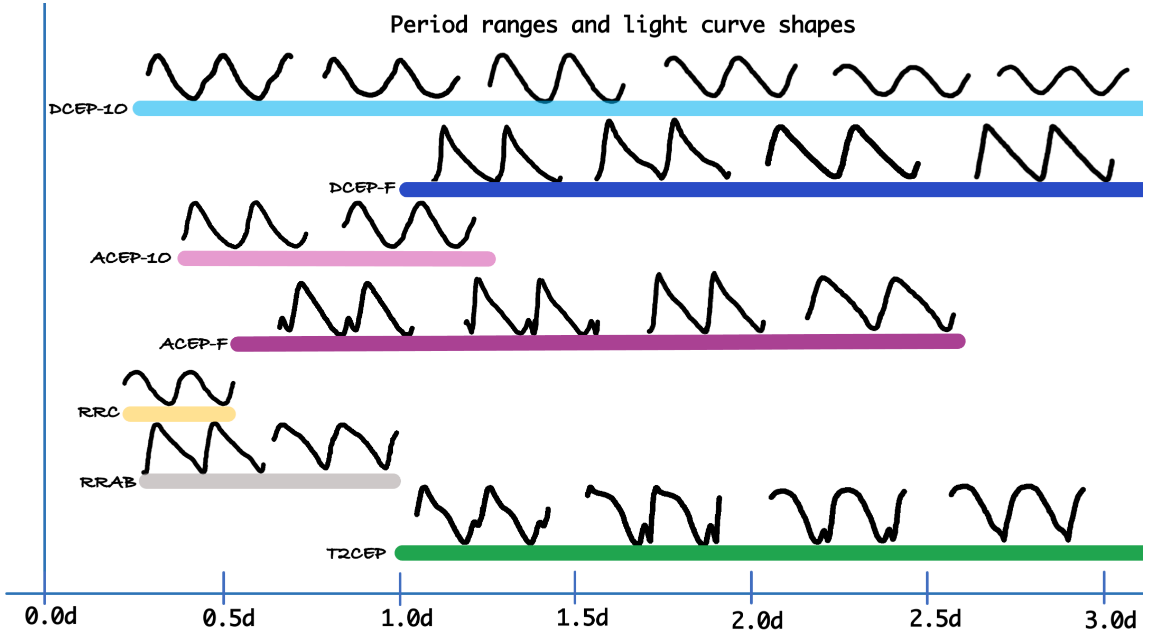
INTRODUCTION

Anomalous Cepheids (ACEP) differ from Classical (DCEP) and Type II Cepheids (T2CEP) in mass, metallicity, brightness and evolution. They have their own Period-Luminosity relations both for the fundamental mode (F) and first-overtone mode (1O). This is used for classification in the Magellanic Clouds that are sufficiently far away to be at the same distance, but is less useful in the Milky Way yet due to the uncertainties in individual distance measurements.



Anomalous Cepheids, can be potentially classified by their light curve shape. However, we have to consider that different types of Cepheids and RR Lyrae stars can be very similar to each other, and they also overlap in period. Moreover, light curve shapes vary by period and metallicity for a given type, too. Therefore, precise photometry and careful analysis of light curves are required for proper classification, which we tested on TESS data.



TARGETS

Many sky surveys do not have the precision to identify anomalous Cepheids and thus do not distinguish this type. In those catalogs these stars may hide among the other Cepheid or RR Lyrae groups. On the other hand, a few catalogs list anomalous Cepheid candidates, and here we focus on the validation of those.

- OGLE (Optical Gravitational Lens Survey) extensively observed the Magellanic Clouds, the Galactic bulge and a part of the disk, and provides a large number of reliable Cepheid and RR Lyrae classifications, including anomalous Cepheids (Soszynski+ 2017, 2018, 2019, Udalski+ 2019). We used the light curve properties from these databases as reference in our analysis.

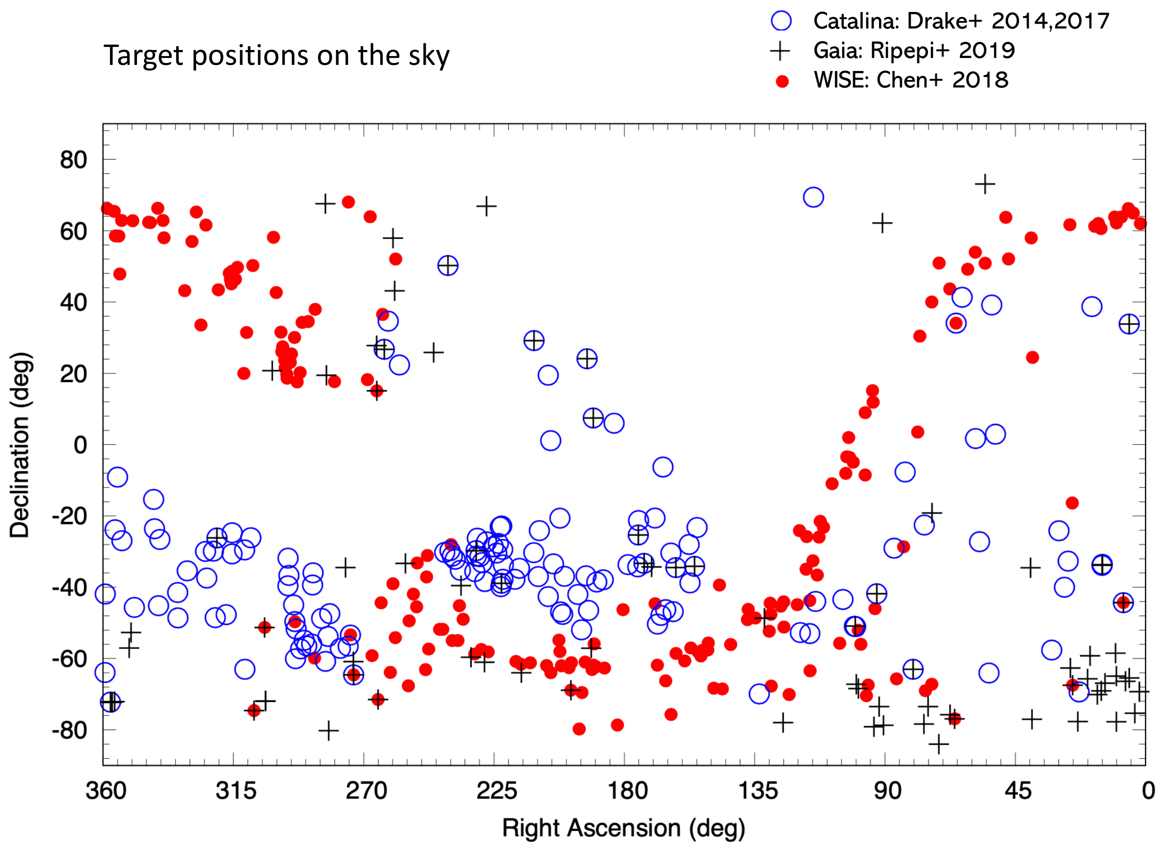
We selected targets for analysis from three other catalogs:

❖ Catalina Sky Survey (Drake+ 2014, 2017) provides 217 anomalous Cepheid candidates.

❖ Ripepi+ 2019 published a revised version of Cepheids classified in the Gaia SOS catalogue (Clementini+ 2019), which included 108 anomalous Cepheids.

❖ The WISE (Wide-field Infrared Survey Explorer) Periodic Variable Catalogue (Chen+ 2018) lists 231 objects marked as CepI/ACep/CepII. We hoped to find anomalous Cepheids in this group too.

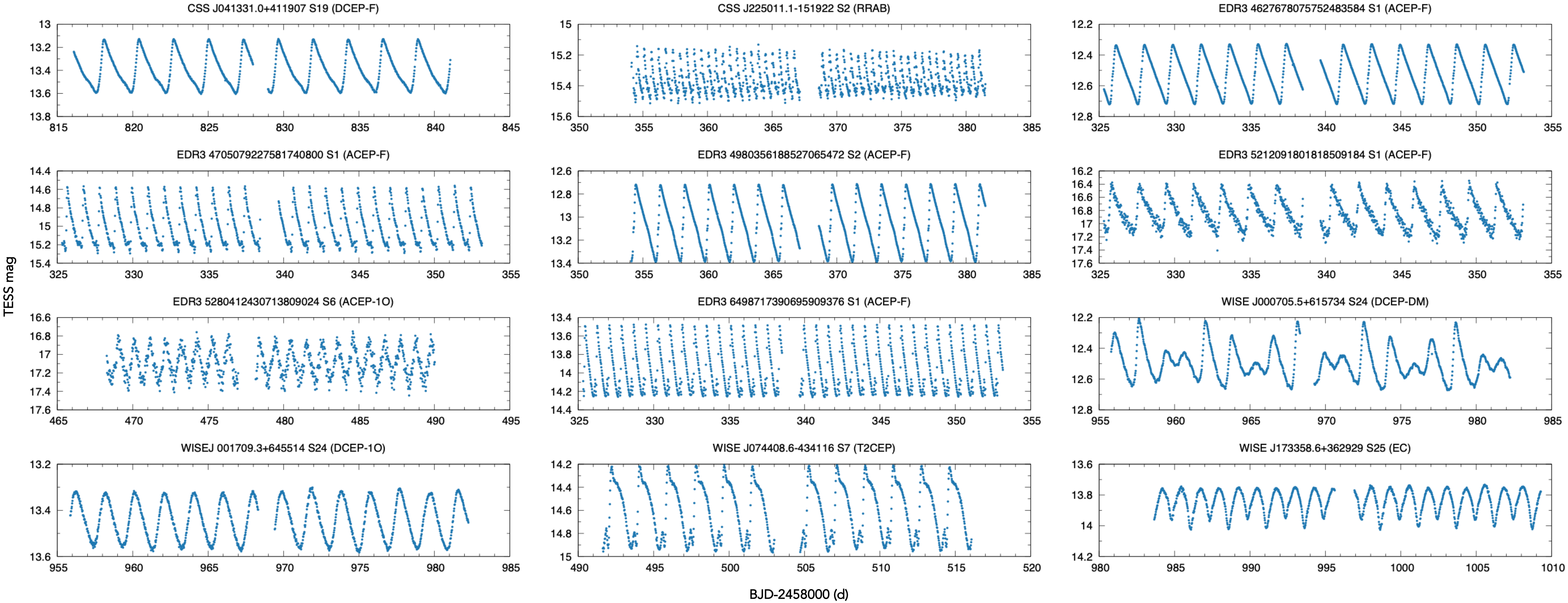
We checked the visibility of the anomalous Cepheid candidates of these catalogues in TESS Years 1 and 2, and found 386 targets. We note that the number of common candidates in the three catalogs is very small.



DATA

We produced light curves from the full-frame images with a differential aperture photometric pipeline (Pál, 2012) with an aperture size of 2.5 pixels. We present some examples below.

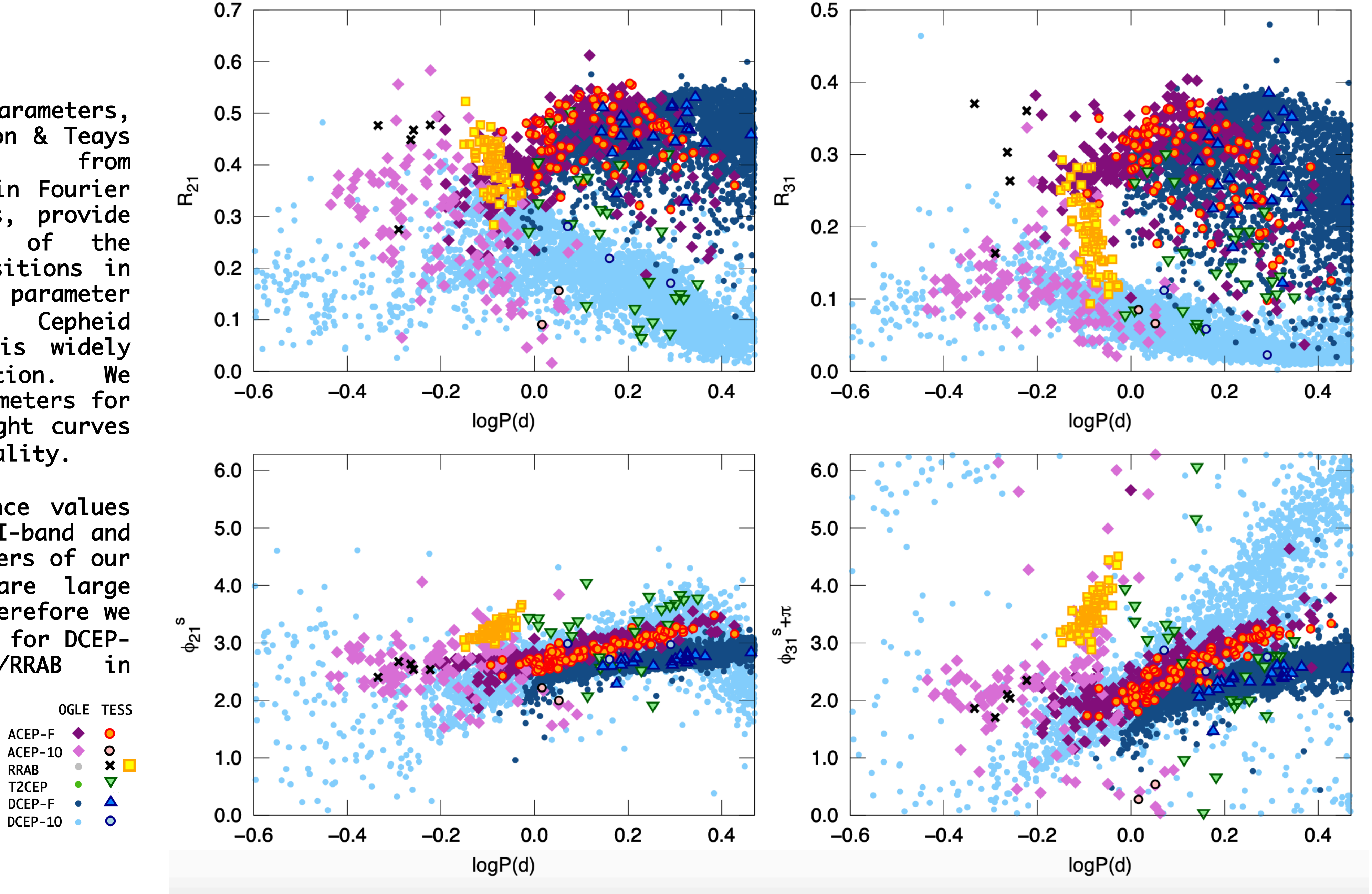
Many of the light curves needed postprocessing: we removed trends (by polynomial fitting), outliers (with phase dispersion minimization) and in some cases we also removed the bad-quality parts. We also filtered out the light-curves that were strongly contaminated or noisy. We found 85 non-pulsating stars in the sample, mostly eclipsing binaries and rotational variables (all from the Chen+ 2018 catalog).



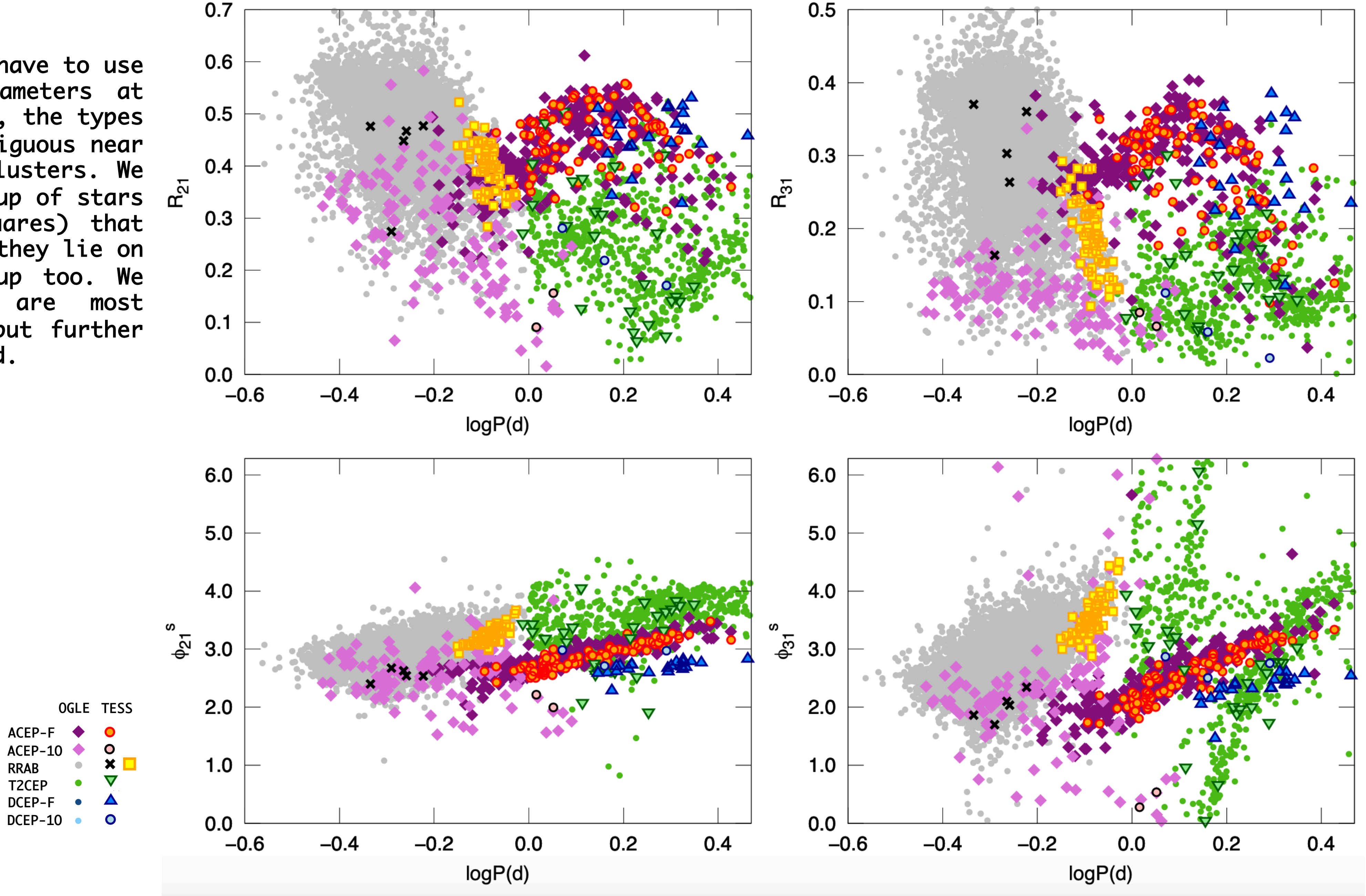
METHOD

The relative Fourier parameters, R_{21}, R_{31}, ϕ_{21}, ϕ_{31} (Simon & Teays 1982), calculated from coefficients of the main Fourier peak and its harmonics, provide quantitative measures of the light curve shape. Positions in the Period-Fourier parameter space determine the Cepheid types, and therefore is widely used in classification. We calculated Fourier parameters for 207 stars that have light curves of sufficiently good quality.

We plotted the reference values of the OGLE Survey in I-band and overplotted the parameters of our TESS targets. There are large overlapping regions, therefore we present the OGLE values for DCEP-F/DCEP-10 and T2CEP/RRAB in separate plots.



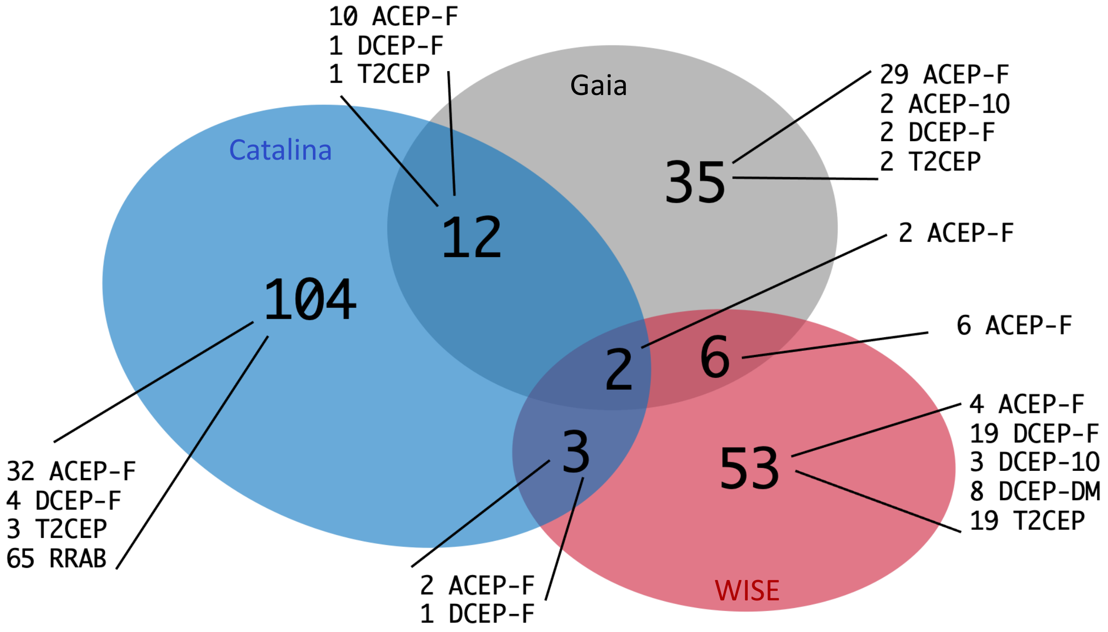
To classify a star we have to use all four Fourier parameters at the same time. However, the types are still somewhat ambiguous near the borders of some clusters. We identified a large group of stars (marked in yellow squares) that could be ACEP-10, but they lie on the edge of RRAB group too. We suspect that these are most probably RRAB stars, but further investigation is needed.



RESULTS

We classified 215 anomalous Cepheid candidates from the three catalogs based on their TESS light curves. We confirmed that 87 stars belong to this type. For 86 stars we could not determine the proper type due to light curve quality issues or vagueness of the light curve shape. The rest of the sample consists of other types of Cepheids (63), RR Lyrae (65) and non-pulsating stars (85). We visualize the distribution of pulsators in a Venn diagram broken down by catalog and type, where we can see that misclassifications occurs even between targets common among catalogs.

Our results show that validation of short period Cepheids is a necessary task, and TESS is a very powerful classifier. In this study we were able to classify nearly 80 percent of the sample, but this ratio may increase with improved photometry in the future.



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