MULTI-INSTRUMENT ANALYSIS OF GAIA, KEPLER K2, ASAS-SN, AND ASAS OBSERVATIONS OF LONG-PERIOD VARIABLES

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Abstract. Several sky-monitoring projects provide the possibility to search for variations of long-period variables (LPVs) on a large combined photometric data-set. We used the newly published results from *Gaia* Data Release 2 together with the *Kepler* K2 survey and the earth-based observations of the All-Sky Automated Survey for Supernovae (ASAS-SN). In addition, we added information from ASAS observations starting from 1997, the database of the American Association of Variable Stars Observers (AAVSO), the International Variable Star Index (VSX) and the HIgh Precision PARallax COllecting Satellite (Hipparcos) to explore long-term trends. Using this combination of observation data we could finally calculate secondary periods, which are typical for long-period variables.

Keywords: stars: variables: general, stars: oscillations, telescopes, space vehicles: instruments

1 Introduction

The *Gaia* Data Release 2 (Gaia DR 2) provided details of 151,761 LPVs: Gaia Collaboration et.al. (2018). The All-Sky Automated Survey for Supernovae (ASAS-SN) V-band survey delivered light curves of 421 000 variable stars in the VSX Catalog. The *Kepler* K2 SFF data provided high quality light-curve details restricted to roughly 80 days' length: Huber et al. (2016). These three data sets have been obtained with some overlap in time, and thus allow a direct comparison of the obtained light curves. We selected a set of LPVs from our own *Kepler* K2 program for this study. We ran tests on several automated data-analysis tools for the Kepler data: Hartig et al. (2014), decided to use the *Kepler* High Level Science Products (K2HLSP) and selected the Self-flat-fielding tool (K2SFF) as the best suited for the LPV process: Vanderburg & Johnson (2014). The other data sets were taken as published in the corresponding catalogues. The prerequisite for the combination of several data sets are high precision photometric data. In this paper we discuss a selection of adjustment methods for the zero points of the various data sets and the problems encountered when looking for the most appropriate solution. We explore the effect of zero-point settings on the calculated periods of the combined data sets, in particular for cases with multiple periods. First results for a few showcases are presented.

2 Multi-instrumental Survey

To search the combined datasets for LPV candidates, an automated process for the combination of the various parts of the light curves is essential. This provides a particular challenge for stars crossing the sensitivity limit during their light change (ASAS) and data sets where only short fragments of time-series (*Kepler* K2 data) are available.

We first analyzed all data points of all data-sets using their catalogue zero-points; two examples are presented in the top left (**BW Sco**) and bottom left diagram (**UZ Sco**) of Fig. 1. Very long periods would become visible as an asymmetric distribution of the data points. In those cases we interactively varied their zero-points and found the best fit indicated by least-square fitting, which is also confirmed by the disappearance of extremely long, fake periods, often significantly longer than 1000 days, in our data analysis (see Fig. 1 left and middle diagram). The phase diagram, bottom right, confirms the quality and necessity of our adjustment. Fig. 1, right panel, shows the overall details of our first five targets. Our first search delivered 28 targets for which observations from multiple data sets exist. For ten of them we got both *Gaia* and *Kepler* K2 data in addition to the ground-based observations. Their properties and the three main periods resulting from our Fourier analysis are shown in table 1. For ten (four) more objects no *Gaia* (*Kepler*) data are available.

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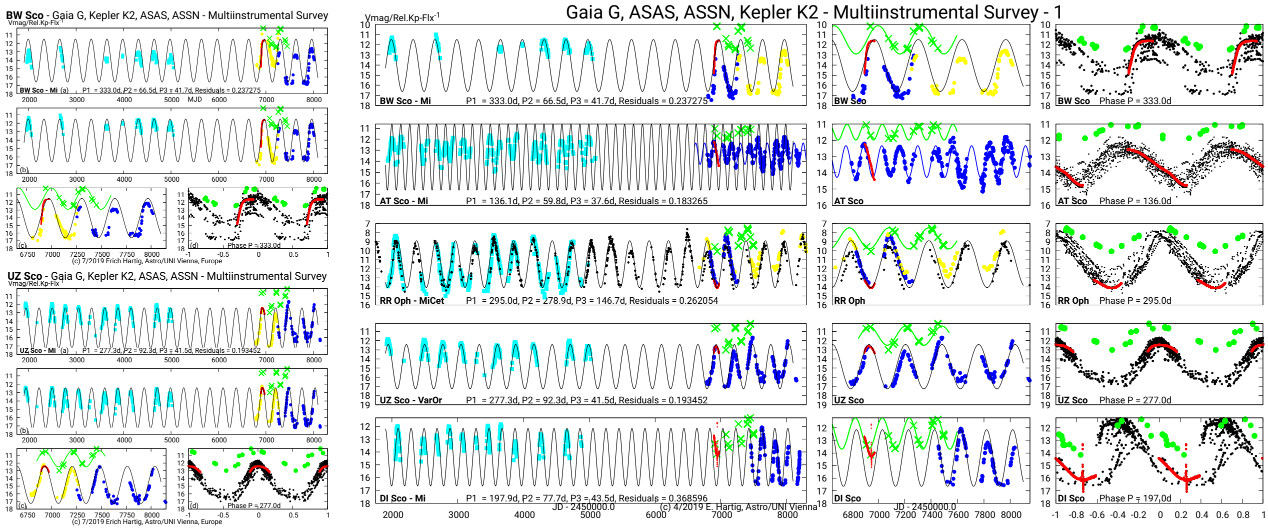

Fig. 1. Top Left: BW Sco, **Bottom left:** UZ Sco: Raw data (left top), 0-Point adjusted (left middle), zoom (bottom left), phase (bottom right). **Figure Right:** Five Observations: all adjusted data (left), zoom (middle), phase for P1 (right); Colors: *Gaia* G (green), *Kepler* K2 (red), ASAS (light blue), ASAS-SN (blue/yellow), P1 (black line); Phase Diagram: all ground based (black); RR Oph: AAVSO (black)

3 Preliminary conclusions

In all tested cases, the light curves were found in good agreement between the various surveys and confirm the reliability of each data set for the study of LPV light changes. This holds also when comparing data sets of very high photometric precision with data sets of medium photometric accuracy. Therefore, a combination of the data sets seems feasible allowing one to study long-term trends in these light-curves, both in terms of long secondary periods and in terms of period changes. We will soon extend our analysis to our full sample and explore the possibilities of combining data-sets from multiple missions for further light-curve studies.

Table 1. Summary of *GAIA* (G), ASAS (AS), AAVSO, ASAS-SN (SN), *Kepler* K2 (Kp) data, and the final results.

#	Name	*Kepler* EPIC	Gper	ASAS	AS-SN	G-P1	AS-P1	SN-P1	Kp-P1	ALL-P1	
	Typ	Gaia Id		AAVSO		G-P2	AS-P2	SN-P2	Kp-P2	ALL-P2	ALL-P3
1	BW-Sco	K2-C2 203748709	335.0	330.0	377.5	336.6	330.7	323.2	189.3	333.0	
	Mi	6048860248373535744				6.2	145.7	168.9	74.9	66.5	41.7
2	AT-Sco	K2-C2 202913758	133.9	136.3	133.7	136.1	135.8	136.3	117.0	136.1	
	Mi	6044303249415452800				158.6	1.0	158.0	67.6	59.8	37.6
3	RR-Oph	K2-C2 205087771	297.7	299.0	289.9	300.2	299.3	291.3	334.1	293.4	
	MiCet	4130587357014777088		294.3		2.4	148.9	387.8	209.4	321.8	47.4
4	UZ-Sco	K2-C2 203763661	252.7	271.2	276.1	255.5	277.0	274.1	76.3	277.3	
	VarOr	6049609015792443008				50.3	295.5	532.9	75.9	92.3	41.5
5	DI-Sco	K2-C2 203795904	206.9	197.5	197.5	397.9	198.0	200.8	318.4	197.9	
	Mi	6046766086744209280				1.5	1.0	683.8	46.7	77.7	43.5

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