Pulsating stars in SuperWASP

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Abstract. SuperWASP is one of the largest ground-based surveys for transiting exoplanets. To date, it has observed over 31 million stars. Such an extensive database of time resolved photometry holds the potential for extensive searches of stellar variability, and provide solid candidates for the upcoming TESS mission. Previous work by e.g. [15], [5], [12] has shown that the WASP archive provides a wealth of pulsationally variable stars. In this talk I will provide an overview of the SuperWASP project, present some of the published results from the survey, and some of the on-going work to identify key targets for the TESS mission.

1 Introduction

The WASP project is a wide-field survey for transiting exoplanets. The project is a two-site campaign: the first instrument is located at the Observatorio del Roque de los Muchachos on La Palma and achieved first light in 2003 November; the second is located at the Sutherland Station of the SAAO and achieved first light in 2005 December. Each instrument consists of eight 200-mm, f/1.8 Canon telephoto lenses backed by Andor CCDs of 2048×2048 pixels observing $\sim$61 deg^2 each through broad-band filters covering a wavelength range of $4000-7000$ Å (Figure 1; [13]). This set-up enables simultaneous observations of up to eight fields with a pixel size of 13.7 arcsec. The instruments capture two consecutive 30-s integrations at a given pointing, and then move to the next observable field. Typically, fields are revisited every 10 min.

The images collected are passed through the reduction pipeline, where the data are corrected for primary and secondary extinctions, the instrumental colour response and the system zero-point. The atmospheric extinction correction uses a network of stars with a known $(B-V)$ colour to determine the extinction terms, which are then applied to all extracted stars using an assumed colour of G-type stars. This process results in a "WASP V" magnitude which is comparable to the Tycho-2 V_t passband. The data are also corrected for systematic errors using the SysRem algorithm of [18].

Aperture photometry is performed at stellar positions provided by the USNO-B1.0 input catalogue ([10]). Stars brighter than $\sim 15^{\rm th}$ magnitude are extracted. Data are stored in FITS format with labels of the observed field, camera and date of observation. Such a configuration and extended time-base allow the extraction of multiple light curves for each object based on either date, field or camera. The extracted photometry achieves a precision of better than 1% for stars brighter than $11^{\rm th}$ magnitude, and 0.5% for stars brighter than magnitude 9.4.

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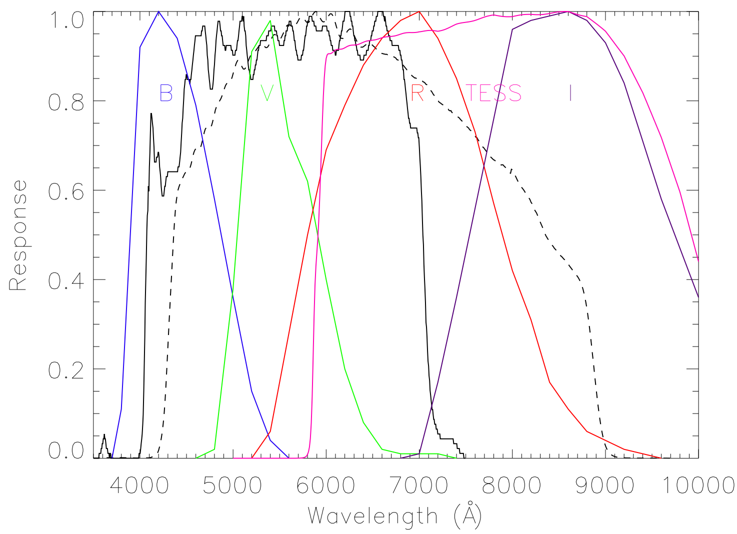

Figure 1. Comparison of the WASP filter (solid black line) with that used by *Kepler* (dashed line), *TESS* (pink line) and Johnson filters (coloured lines as labelled).

To date, there are over 428 billion data points in the archive covering over 31 million unique objects. With such a large data base of objects it is possible to search for a wide variety of stellar variability.

2 WASP capabilities

Before any analysis can be conducted, a thorough investigation into the capabilities of the data is required. An initial characterisation was conducted by [15] when investigating pulsations in Am stars, but a more detailed investigation was conducted by [7] as part of a global search for pulsations in hot stars.

By using the results of the *Kepler* mission as a benchmark, the latter study showed that for stars of magnitude 11 and brighter, it is possible to detect variability to an amplitude of 0.5 mmag (Fig. 2). This is, however, also dependant on the length of time-series available, blending of sources in the photometric aperture, and inherent noise in the data (seeing conditions, moon phase, etc.).

With knowledge of the detection limits of the WASP data, we are able to rule out variable stars which we know have amplitudes below that of our limit. We are, therefore, able to restrict variability studies to hot stars which show "high" amplitude pulsations, such as δ Scuti stars, subdwarf stars, RR Lyrae stars, and Cepheids.

3 Low-frequency variables

[7] identified over 80 000 stars with variability in the frequency range $5 - 50\,\mathrm{d}^{-1}$. However, studies of identified targets require detailed and time consuming analysis, on a star by star basis. This frequency range is plagued by the daily aliases suffered by single-site ground-based observations. Alongside this, harmonics of binary stars serve to add many false-positive detections of pulsational variability.

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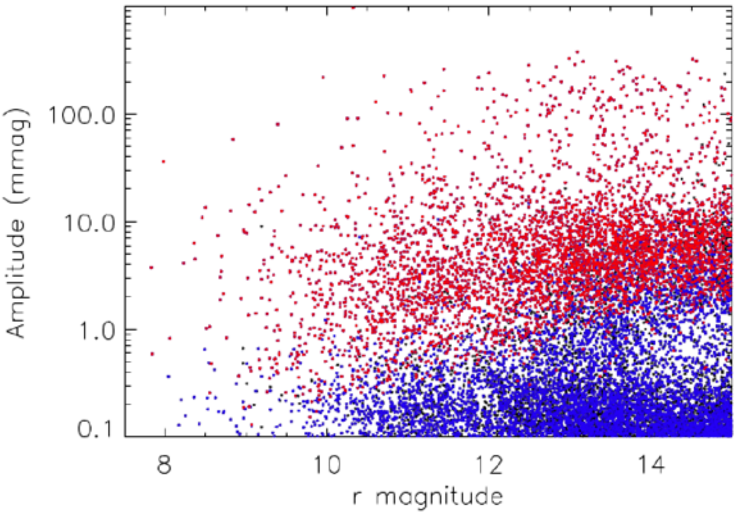

Figure 2. The detected peaks (red) and the undetected peaks (blue) of *Kepler* pulsations as analysed with WASP photometry. The detection rate is a function of stellar brightness, with WASP able to detect variability to 0.5 mmag for stars brighter than 11th magnitude.

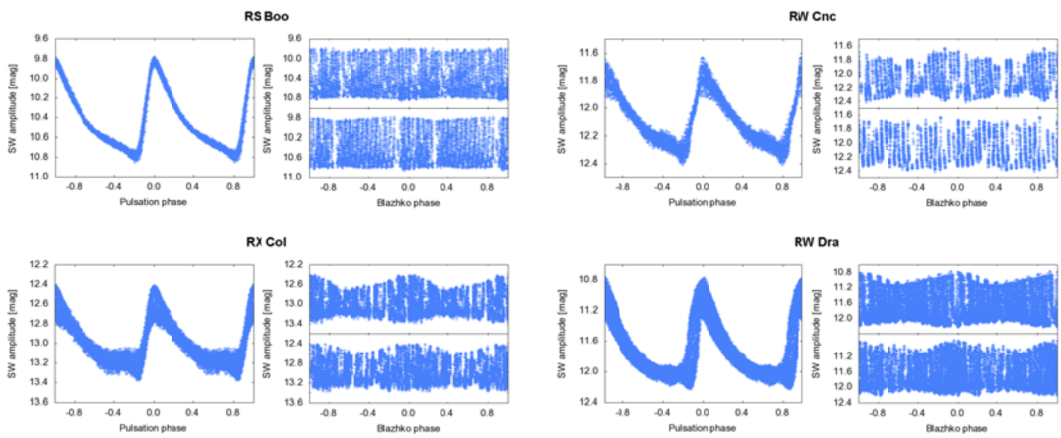

Figure 3. A selection of RR Lyrae stars identified in WASP photometry. The amplitude variability as a result of the Blazhko effect can be clearly seen. Figure from [14]. Reproduced with permission.

However, it is not all bad news in this frequency range. Studies by [15] and [17] detected γ Doradus and δ Scuti pulsations in Am stars, and [2] successfully identified rotational modulation signals in chemically peculiar stars.

Furthermore, stars with high amplitude variability are much easier to detect above the low-frequency noise and artefacts. [14] studied RRab stars in the SuperWASP archive and found nine new Blazhko stars in their sample (see Figure 3). More recently, Greer (`http://www.star.uclan.ac.uk/stars2016/slides/Greer.pdf`) is working on almost 5 000 RR Lyrae stars (of the ab type) in the SuperWASP archive – the most extensive survey of these stars in the SuperWASP archive to date – and is identifying hundreds of new Blazhko candidates.

4 High-frequency variables

Moving into the high-frequency range, [5] published an extensive list of variable stars with frequencies above 50 d^{-1}. Within the results were δ Sct pulsators, rapidly oscillating Ap (roAp) stars, and subdwarf B (sdB) variables.

The most significant results are the discovery of 11 new roAp stars. These are rare stars, with only 61 known (see [16] for a catalogue), which pulsate in high-overtone, low-degree modes. Follow up observations of some of these discoveries are revealing that these stars are more peculiar than previously thought, and that current excitation mechanisms might not be able to explain all the observed frequencies (e.g., [6, 8]). The use of SuperWASP removed the sample biases which have been present in previous surveys of these stars, thus providing new and interesting stars to study in detail.

The sdB stars are also rather rare, with a little over 100 known in their class. [9] published three newly discovered stars of this type, after searching the SuperWASP archive. This demonstrates the power of ground-based surveys to probe to very high frequencies in the search for rapid variability.

Pre-main-sequence (PMS) stars are also present in the archive. HD 34282 was discovered to be a pulsating PMS star by [1] in a search for pulsations in Herbig Ae/Be stars to constrain the PMS instability strip. An investigation into the WASP archive for these objects also identified HD 34282 as a pulsating star (see Fig. 4). Although the light curve is very noisy at low frequency, the presence of the pulsations is clearly evident in the periodogram. There is undoubtably more of this type of star in the archive to be exploited.

5 Combining data

Large survey archives provide the possibility of extending data sets by, in some cases, decades or more. In the case of SuperWASP, this was well demonstrated by [11] and [4]. In the case of [4], the authors were able to combine WASP data with *Kepler* data on the star KIC 7106205. This star shows dramatic amplitude modulation of just one of its many modes ([3]).

By including the WASP data for this star, it was shown that the amplitude of the one mode was much greater before the start of *Kepler* observations, making the loss of pulsation energy much more dramatic. Figure 5 shows the amplitude of the variable mode over the period of both the WASP (red) and *Kepler* (blue) observations. This is just one example of such a study, with more being conducted.

6 Summary

We have shown that the SuperWASP archive is an excellent source of data for the study of a whole host of variable stars. With its short cadence and pseudorandom sampling, it is possible to probe to very high frequencies in the search for variable stars.

As well as for discovery purposes, SuperWASP is very useful for extending the data of other projects or missions before their first light. Although the WASP data do not have the precision of dedicated observations, or space-based observations, to be able to extend the time-base of any observations can often be invaluable in the long-term study of stellar variability.

With the launch of the TESS mission in 2018, and the ongoing K2 mission, the WASP archive is an excellent source of complimentary data.

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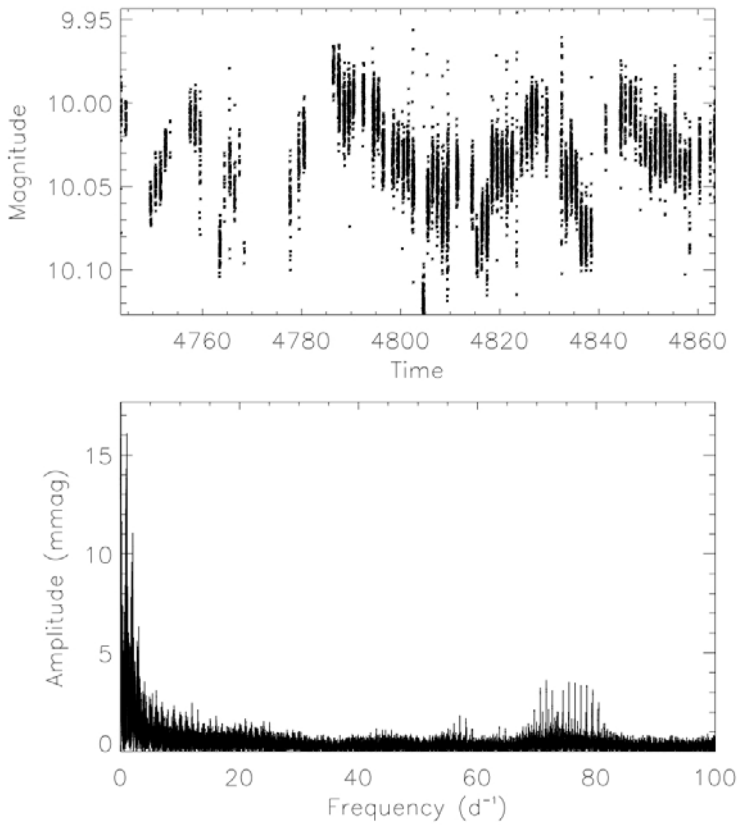

Figure 4. The variability of the known pulsating PMS star HD 34282 in the WASP data. The top panel shows the noisy light curve, with the periodogram shown in the bottom panel. The pulsations are clearly visible in the lower plot.

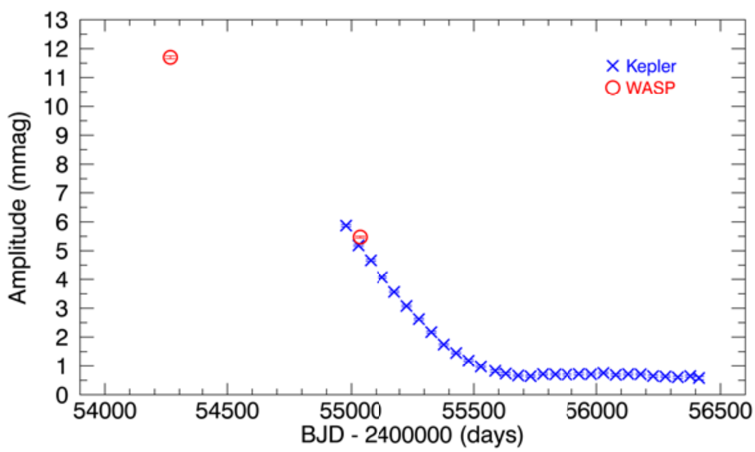

Figure 5. The amplitude variation of one mode in KIC 7106205. The original detection was made with *Kepler* data (blue), but has been extended with WASP data (red). Figure adapted from [4].

References

[1] Amado, P. J., Moya, A., Suárez, J. C., Martín-Ruiz, S., Garrido, R., Rodríguez, E., Catala, C., & Goupil, M. J., MNRAS, **352**, 11 (2004)

[2] Bernhard, K., Hümmerich, S., & Paunzen, E., AN, **336**, 981 (2015)

[3] Bowman, D. M., & Kurtz, D. W., MNRAS, **444**, 1909 (2014)

[4] Bowman, D. M., Holdsworth, D. L., & Kurtz, D. W., MNRAS, **449**, 1004 (2015)

[5] Holdsworth, D. L., Smalley, B., Gillon, M., et al., MNRAS, **439**, 2078 (2014)

[6] Holdsworth, D. L., Smalley, B., Kurtz, D. W., Southworth, J., Cunha, M. S., & Clubb, K. I., MNRAS, **443**, 2049 (2014)

[7] Holdsworth, D. L., Ph.D. Thesis (Keele University, 2015)

[8] Holdsworth, D. L., Kurtz, D. W., Smalley, B., Saio, H., Handler, G., Murphy, S. J., & Lehmann, H., MNRAS, **462**, 876 (2016)

[9] Holdsworth, D. L., Østensen, R. H., Smalley, B., & Telting, J. H., MNRAS, **466**, 5020 (2017)

[10] Monet, D. G., Levine, S. E., Canzian, B., et al., AJ, **125**, 984 (2003)

[11] Murphy, S. J., Pigulski, A., Kurtz, D. W., et al., MNRAS, **432**, 2284 (2013)

[12] Paunzen, E., Skarka, M., Walczak, P., Holdsworth, D. L., Smalley, B., West, R. G., & Janík, J., MNRAS, **453**, 1241 (2015)

[13] Pollacco, D. L., Skillen, I., Collier Cameron, A., et al., PASP, **118**, 1407 (2006)

[14] Skarka, M., A&A, **562**, A90 (2014)

[15] Smalley, B., Kurtz, D. W., Smith, A. M. S., et al., A&A, **535**, A3 (2011)

[16] Smalley, B., Niemczura, E., Murphy, S. J., et al., MNRAS, **452**, 3334 (2015)

[17] Smalley, B., Antoci, V., Holdsworth, D. L., et al., MNRAS, **465**, 2662 (2017)

[18] Tamuz, O., Mazeh, T., & Zucker, S., MNRAS, **356**, 1466 (2005)