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Asteroseismology with SuperWASP

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Abstract. The highly successful SuperWASP planetary transit finding programme has surveyed a large fraction of both the northern and southern skies. There now exists in the its archive over 420 billion photometric measurements for more than 31 million stars. SuperWASP provides good quality photometry with a precision exceeding 1% per observation in the approximate magnitude range $9 < V < 12$. The archive enables long-baseline, high-cadence studies of stellar variability to be undertaken. An overview of the SuperWASP project is presented, along with results which demonstrate the survey's asteroseismic capabilities.

Keywords. asteroseismology, instrumentation: photometers, stars: chemically peculiar, stars: oscillations, stars: rotation, stars: variables: delta Scuti, stars: variables: roAp

1. Introduction

The Wide Angle Search for Planets (WASP) is one of the world's leading ground-based surveys for transiting exoplanets (Pollacco et al. 2006). The project has two robotic telescopes in roll-off roof enclosures, one at the Observatorio del Roque de los Muchachos on the island of La Palma in the Canary Islands, and the other at the Sutherland Station, South African Astronomical Observatory (SAAO). Both instruments consist of an array of eight 200-mm, f/1.8 Canon telephoto lenses and 2048×2048 Andor CCDs, provide a field of view of $7.8° \times 7.8°$ and pixel size of $13.7''$. A broad-band filter gives a 400–700 nm bandpass.

SuperWASP observes a set of pre-determined 'planet fields' each night, subject to their visibility and Moon avoidance. At each pointing, two sequential 30-second exposures are taken. The cameras return to same field with a typical cadence of around 10 minutes, but this is variable. Typically, in a given observing season, some 3000 points per star are taken over a period of 100 to 150 days.

The SuperWASP automated photometry extraction pipeline (Collier Cameron et al. 2006) uses the Tycho-2 and USNO-B1.0 catalogues to determine an astrometric solution for each field. Photometry is performed on all objects, using three different sized apertures, with a 3.5-pixel ($48''$) aperture being the default used in lightcurves. Given the size of the apertures, one has to be aware of object blending and dilution. The photometry is transformed to Tycho-2 V using around 100 stars per field, yielding WASP pseudo V magnitudes. Lightcurves are sent to the project archive in Leicester. Further trend removal is performed using the SysRem algorithm (Tamuz et al. 2005), which is effective at removing some of the correlated 'red noise' from the lightcurves (Smith et al. 2006). Overall photometric performance is better than 1% for V < 11.5 and 0.5% for V<9.4.

The SuperWASP archive currently holds over 420 billion data points covering 31 million stars, obtained from 12 million images taken during 2100 nights since 2004. The coverage of the survey is now virtually the entire sky, with the exception of the Galactic plane where the stellar density is too high to permit useful aperture-photometry of objects on account of the instrument's large pixel size. This multi-season and multi-site photometry is an excellent resource for studying stellar variability.

2. Variability studies with SuperWASP

There are many stars in the WASP archive that exhibit high amplitude pulsations over different timescale from hours to several days, including numerous RR Lyrae, Cepheid and δ Scuti variables (Fig. 1). This is, of course, in addition to many eclipsing and short-period binary systems (e.g. Norton et al. 2013). By cross-matching WASP photometry with high-precision lightcurves from *Kepler*, Holdsworth (PhD Thesis, in prep.) found a pulsation detection limit of 0.5 m mag. is possible for stars brighter than mag. 10.

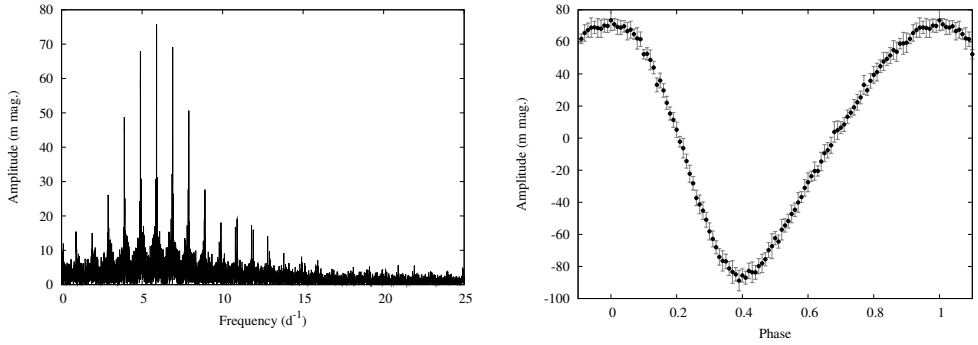

Figure 1. WASP periodogram (left) and lightcurve folded on the 0.17-day period (right) of the δ Sct variable UY Col (HD 40765).

2.1. *Pulsations in Am stars*

The large sky coverage of the SuperWASP data allows for statistical studies of the pulsational properties of selected groups of stars. In an extensive study, Smalley et al. (2011) took the Renson & Manfroid (2009) catalogue of Am stars and selected stars with greater than 1000 WASP data points. Excluding eclipsing binaries, 1620 Am stars were studied using Lomb periodograms to select candidate pulsating stars. These were subsequently examined in more detail using PERIOD04 (Lenz & Breger 2005). A total of 227 pulsating Am stars were identified, representing 14% of the sample. Pulsations in Am stars are more common than previously thought, but not where expected (Turcotte et al. 2000).

While the amplitudes are generally low, the presence of pulsation in Am stars places a strong constraint on atmospheric convection, and may require the pulsation to be laminar. While some pulsating Am stars had been previously found to be δ Sct stars, the vast majority of Am stars known to pulsate have been found by SuperWASP, thus forming the basis of future statistical studies of pulsation in the presence of atomic diffusion.

2.2. *Rotational modulation in Ap stars*

WASP photometry can be used to investigate the rotational modulation of stars, as is routinely performed as part of the planet detection programme (Maxted et al. 2011). Rotational modulation is also be seen in the magnetic Ap stars. For example, WASP photometry was used, in conjunction with that from ASAS and Hipparcos, to improve the rotational ephemeris for HD 96237 (Elkin et al. 2011).

2.3. *Rapidly Oscillating Ap stars*

The rapidly oscillating Ap (roAp) stars are a relatively rare subset of the magnetic Ap stars which exhibit short period oscillations. There exists lightcurves of several known roAp stars in the WASP archive, including HD 12932 (BN Cet). This star exhibits 124.1 d^{-1} (11.6 min) oscillations (Schneider & Weiss 1990) and are clearly detected in

the WASP periodogram (Fig. 2). The amplitude in the WASP filter is approximately half that in B, consistent with the expected variation of amplitude with filter wavelength (Medupe & Kurtz 1998).

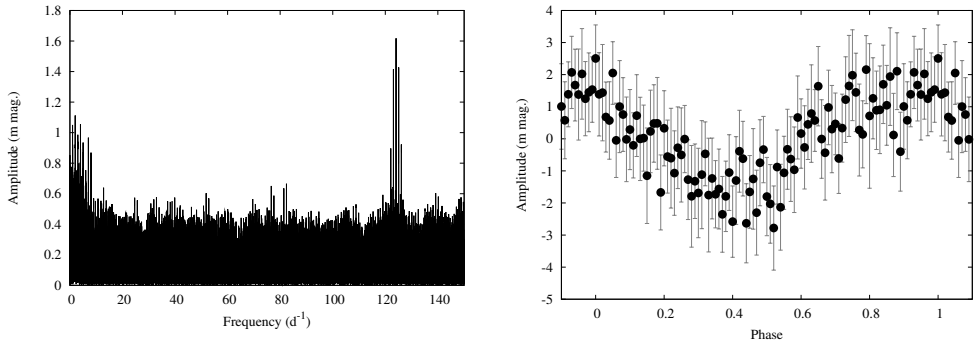

Figure 2. WASP periodogram (left) and lightcurve folded on the 11.6-minute period (right) of the roAp star BN Cet (HD 12932).

For stars with sufficient WASP photometry, no new roAp stars have been found among the Ap stars in the Renson & Manfroid (2009) catalogue. Nevertheless, a systematic search of over 1.5 million A and F type stars in the WASP archive has yielded over 200 stars with pulsation frequencies higher than $50\,\mathrm{d}^{-1}$. Subsequent spectroscopic follow-up has confirmed that at least ten of these stars are new roAp stars (Holdsworth & Smalley 2013).

2.4. *Ultra-high frequencies*

Pushing to higher frequencies, WASP photometry can be used to search for frequencies up to $\sim$1000 d^{-1}. For example, the sdB star QQ Vir has $626\,\mathrm{d}^{-1}$ (2.3 min) pulsations (Silvotti et al. 2002). Figure 3 shows the WASP periodogram where the pulsations are present with an amplitude of 0.02 mag. A preliminary search of the WASP archive for very rapidly pulsating stars has resulted in the identification of a hot sdBV star with $636\,\mathrm{d}^{-1}$ pulsations and an amplitude of only 8 m mag.

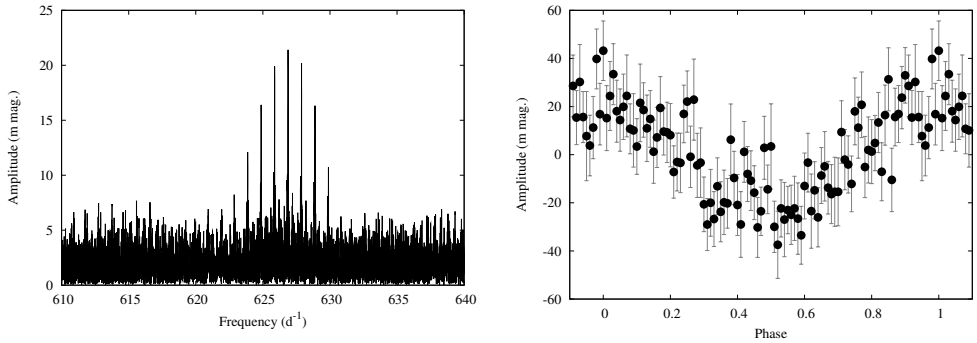

Figure 3. WASP periodogram (left) and lightcurve folded on the 2.3-minute period (right) of the sdB pulsator QQ Vir.

2.5. *Signal in noise*

During the WASP project's trawl for planetary transits, lightcurves are encountered which appear very poor and unsuitable for planet hunting. However, closer inspection

reveals that some are actually due to real stellar variability. For example, HD 34282 (V1366 Ori) has an apparently random noise lightcurve (Fig. 4) but the periodogram recovers the $79.5\,\mathrm{d}^{-1}$ and $71.3\,\mathrm{d}^{-1}$ δ Scuti-type pulsations known to be hiding in the dusty environment of this pre-main sequence star (Amado et al. 2004).

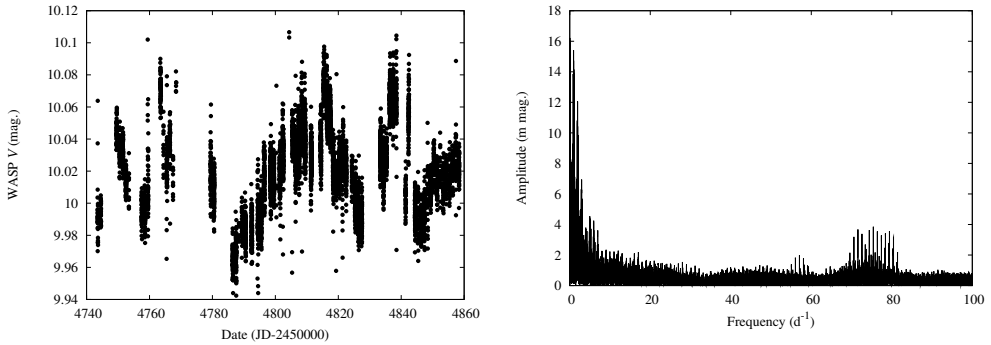

Figure 4. WASP lightcurve (left) and periodogram (right) of the pre-main sequence star V1366 Ori (HD 34282) showing random variations due to dust, but with periodic short period δ Scuti-type pulsations.

3. Summary

The WASP archive contains broadband photometry for over 31 million stars with a precision of <0.01 mag. The observing strategy yields two consecutive 30-second exposures every 10 minutes. The relatively large 14″ pixels and 48″ photometry aperture means that blending and dilution can be an issue for certain stars. Nevertheless, the photometry has proved invaluable in the investigation of the statistical occurrence of variability and allowed for the identification of new members of several classes of variable stars. There are certainly a lot of interesting stars in the WASP archive.

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