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High-precision photometry with the WIRE satellite

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Abstract. Around 200 bright stars ($V < 6$) have been monitored with the two-inch star tracker on the WIRE satellite since observations started in 1999. Here we present new results for the solar-like star Procyon A, the two δ Scuti stars Altair and ϵ Cephei, and the triple system λ Scorpii which consist of two B-type stars – one of which we find to be an eclipsing binary.

Key words. Stars: variable, Stars: individual: Procyon A, Altair, ϵ Cephei, λ Scorpii

1. Introduction

The Wide-Field Infrared Explorer (WIRE) was launched in 1999 and designed to make a survey of star-burst galaxies (Hacking et al. 1999). Unfortunately, the coolant for the main camera leaked and the main mission failed. However, since then the star tracker has been used as the first asteroseismology instrument in space (Buzasi et al. (2000)). Oscillations have been detected in the solar-like star α Cen A (Schou & Buzasi (2001)) and the K giant Arcturus (Retter et al. (2003)), while Altair has been found to be a low-amplitude δ Scuti star (Buzasi et al. (2005); Suarez et al. (2005)).

About 200 targets have been observed by WIRE from 1999–2005 and their location in the Hertzsprung-Russell (HR) diagram are shown in Fig. 1. Temperatures were found using Strömgren indices with TEMPLOGG (Rogers 1995) and we used HIPPARCOS parallaxes and bolometric corrections from Bessell et al. (1998) to estimate luminosities. In the lower left corner typical error bars on the luminosity and temperature are shown. Also

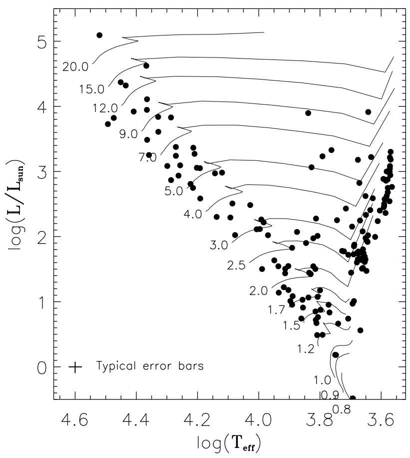

Fig. 1. HR diagram showing the WIRE targets.

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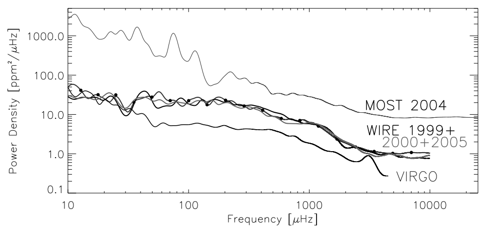

Fig. 2. Power density spectrum for VIRGO measurements of the Sun and data from the WIRE and MOST satellites for Procyon A.

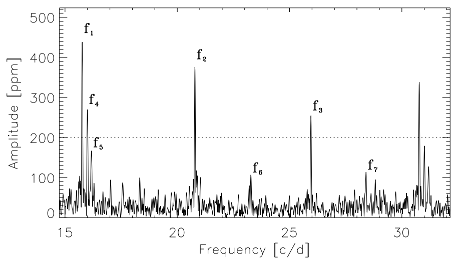

Fig. 3. Amplitude spectrum of Altair from WIRE.

plotted are evolution tracks for solar metallicity from Lejeune & Schaerer (2001); masses in solar units are indicated. Each star has been monitored continuously for typically 2–4 weeks.

In the following we will present some recent results obtained in 2005 for stars in different parts of the HR diagram. In order of increasing mass, we show results for the solar-like star Procyon A, the two δ Scuti stars Altair and ϵ Cep, and the β Cepheid type variable λ Sco, which is an eclipsing triple system.

2. A Solar-like star: Procyon A

Procyon A was monitored for 9.5 days in September/October 1999, 7.9 days in September 2000, and 19.7 days in March/April 2005. The first two datasets were analysed by Bruntt et al. (2005). The duty cycle is 18% in the datasets from 1999 and 2000 and 30% in the dataset from 2005. As a result of the low duty cycle there is significant power in the amplitude spectrum at the harmonics of the orbital frequency of around 174 μHz. This can be minimized by filtering out peaks in the low frequency part of the spectrum which leak power at the harmonics of the orbital frequency.

In Fig. 2 we show the power density spectrum (PDS) for Procyon A for three light curves from WIRE after some high-pass filtering (see Bruntt et al. (2005) for details) and we compare the PDS with results from the Sun and observations of Procyon A from MOST (Matthews et al. 2004). The much higher noise level seen in the MOST data could be due to scattered light (see Bedding et al. (2005)). The increase of the noise seen in the PDS from WIRE when going towards lower frequencies and the plateau below 300μHz is similar to that seen in the Sun. We have interpreted the signal seen in Procyon A as being due to the granulation. In the range 100–300μHz the granulation *amplitude* is about 1.8 times higher in Procyon A compared to the Sun, which is expected since granulation in Procyon A should be more violent since it is both hotter and more evolved.

3. δ Scuti stars: Altair and ϵ Cep

Altair was observed for about 22 days in October/November 1999 and Buzasi et al. (2005) reported that the star is a multi-periodic δ Scuti star with at least seven excited modes. Even though the star is the 12th brightest star in sky this was not known previously, since it is too bright ($V = 0.8$) to observe for even small ground-based telescopes.

The amplitude spectrum of Altair is shown in Fig. 3 where the seven modes are indicated. Note the peaks above 30 c/day which are aliases due to the combinations $[f_1 - f_3] + f_W$, where f_W is the orbital frequency of WIRE which is 15.0 c/day.

Suarez et al. (2005) tried to model Altair but found that the rapid rotation of the star makes this difficult. According to Royer et al. (2002) Altair has $v \sin i > 200\,\mathrm{kms}^{-1}$.

We are currently planing to observe a number of moderately rotating δ Scuti stars with WIRE and from ground-based observatories with multi-colour photometry. Our goal is to identify the modes and to test if our current

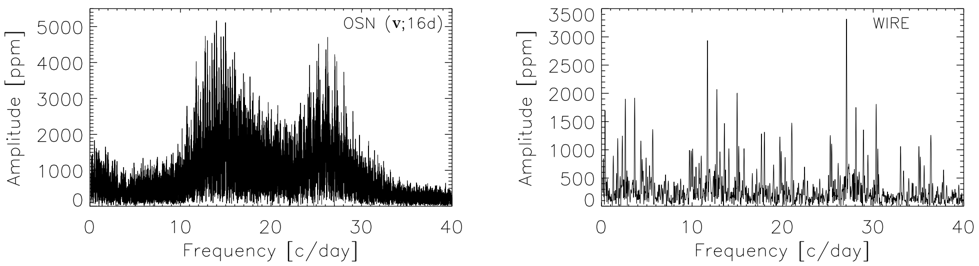

Fig. 4. Amplitude spectra of the δ Scuti star ϵ Cep from OSN and WIRE.

models of moderately fast rotating stars are able to describe the observed pulsation modes.

In Fig. 4 we show two amplitude spectra for the δ Scuti star ϵ Cephei. In the *left* panel we used 16 nights obtained from Observatorio de Sierra Nevada (OSN) over five months in Strömgren v (Costa et al. 2003) and the *right* panel is the result when using two weeks of observations with WIRE. Since there are no significant gaps in the WIRE time series the window function is much simpler than what is seen in the OSN dataset. This makes the cleaning of the amplitude spectrum a much easier task. On the other hand, the much longer time series from OSN makes the phase determination much more accurate. We are now using phase differences and amplitude ratios in the Strömgren filters to identify the modes (as was done by Moya et al. (2004)) seen in δ Scuti stars observed with WIRE and from OSN (Bruntt et al. 2005).

4. A β Cepheid star: λ Sco

The λ Sco system is a triple star system consisting of two B type stars in a wide orbit ($P \sim 1083$ d). One of the B stars has a cooler companion in a close orbit (Uytterhoeven et al. 2004) ($P \sim 5.95$ d). WIRE observed λ Sco twice in 2004 and the light curves are shown in Fig. 5. Apart from the main mode of oscillation at 4.680 c/day several low amplitude modes are observed. After subtracting the intrinsic variation both the primary and secondary eclipses are clearly seen. The primary eclipse is barely visible in the HIPPARCOS data (Uytterhoeven et al. 2004) but the new data allows for a study of the detailed shape and depth of both the primary and secondary eclipses.

We have modelled the light curve using the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1994). We find that the secondary star is an A-type star with a mass of $1.8(1)\,M_\odot$, radius $R/R_\odot = 1.7(1)$, and $T_{\rm eff} = 10\,500 \pm 500$ K. This agrees with the preferred scenario of Uytterhoeven et al. (2004) and definitely rules out a massive white dwarf as suggested by Berghöfer et al. (2000). A detailed study of λ Sco using the WIRE data is in preparation (Bruntt et al. 2005).

5. Future Prospects

Since the main mission of the WIRE satellite failed soon after launch in March 1999 the star tracker has been working as a very successful instrument for asteroseismic studies of a wide range of bright stars. The star tracker was in use from May 1999 until August 2000 and started again in December 2003. The main goal has been to study the variability of stars across the HR diagram. Today we have a database of reduced light curves for 200 stars that have been monitored for typically 2–4 weeks. In this paper we have presented results for a few selected stars observed with WIRE.

In the coming months we have coordinated simultaneous observations of a few δ Scuti stars with WIRE and from the ground with Strömgren photometry in order to be able to identify the modes. We plan to conduct two or more WIRE campaigns on some of the targets

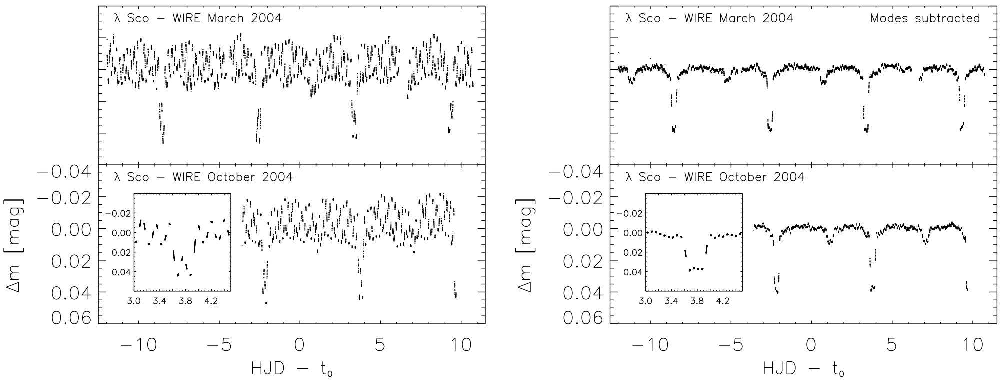

Fig. 5. Light curves of the β Cep star λ Sco before and after subtracting the intrinsic oscillation modes.

in order to achieve a higher frequency resolution to be able to resolve closely spaced modes. Breger (2006) notes that the amplitude variation often seen in δ Scuti stars may in fact be due to a combination of closely spaced modes and inadequate frequency resolution; thus an extended time baseline is needed. Obviously, this applies not only to asteroseismological studies of δ Scuti stars and we have already conducted observations of a few known β Cep stars with six months in between (e.g. λ Sco mentioned in this paper) to increase the frequency resolution.

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