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Asteroseismic Results from WIRE

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Abstract. The failed NASA infrared mission WIRE was successfully converted into a high-precision photometry experiment which operated for 17 months. Below I summarize the mission characteristics and performance, as well as providing some examples of the data obtained.

1. Introduction

The NASA spacecraft called the *Wide-Field Infrared Explorer* (WIRE) was launched in March 1999 with the primary mission of observing galaxies at IR wavelengths. Unfortunately, due to a series of unlucky events, within days of launch coolant was lost and the mission was declared a failure. However, in addition to the primary science instrument, the WIRE spacecraft also carried a 52-mm aperture star camera, and it proved possible to convert this small telescope into a scientific instrument with the capability of performing high-precision, nearly photon-limited photometry from space.

Below I present a brief summary of the instrument characteristics and observing strategy for WIRE during its active life (May 1999 – September 2000). In addition, I summarize data analysis progress to date and present some examples; others can be found in Poretti et al. and Cuypers et al. (these proceedings).

2. Instrumental characteristics

The WIRE star camera is an unfiltered 52 mm f/1.75 refracting telescope feeding a 512^2 SiTe CCD, which can be read out at rates as high as 10 Hz (Smith & Deters, 1999, private communication). The pixels subtend 1 arc minute on the sky, the CCD gain is 15 e^-/ADU, and the read noise is $30e^-$; stellar images are defocused to a nominal FWHM of 2 pixels. The high observation cadence is made possible by software that locates the 5 brightest stars in the field and reads only an 8×8 pixel box around one selected image; a second operating mode, implemented in November 1999, makes count rate data available on all five stellar images at a read rate of 2 Hz.

The key performance parameter governing the potential of WIRE for asteroseismology is pointing, since the lack of a good flat field for the instrument implies that only by accurately maintaining the stellar position on the detector can we be assured that the signal is relatively uncontaminated by the translation of pointing jitter into flux variations. Fortunately, WIRE has performed superbly in this arena, typically achieving rms pointing of < 1 arc second.

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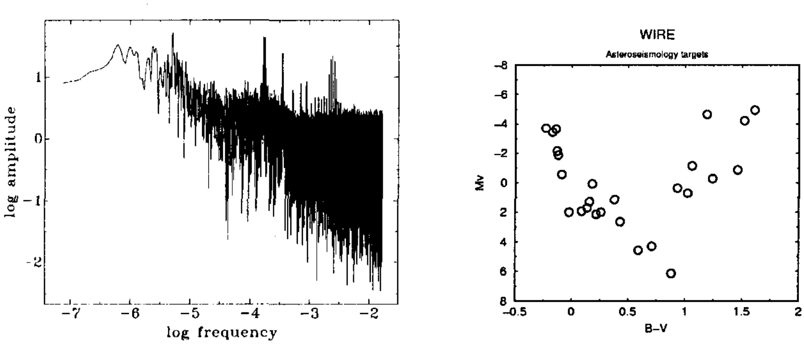

Figure 1. Left: log-log plot of the amplitude spectrum of the WIRE time series for the roAp star α Cir. The plot shows a basically flat (i.e., white) response from high frequencies down to $\log f \approx -4.6$, or periods of about 12 hours, with a red noise component becoming steadily more important for lower frequencies. Superimposed on the general trend are peaks corresponding to α Cir's rotation rate ($\log f = -5.4$), primary oscillation frequency ($\log f = -2.7$), and the satellite orbital frequency ($\log f = -3.8$). The total noise level at $\log f \geq -3.5$) is about 1.2 times photon noise, which is typical of WIRE's photometric performance. Right: color-magnitude diagram for all targets observed by WIRE from 5/1999 – 9/2000. Target selection was guided by the desire to observe stars that spanned the HR diagram to the greatest extent possible.

Given good pointing precision and stability, the greatest difficulty in working with WIRE data has been accurately accounting for scattered light, primarily due to the bright Earth. We first make a rough removal of the scattered light signal by approximating it as equivalent to the mean signal from the four corners of the 8×8 pixel field around each target. For faint targets ($m_V > 4$ or so), this works reasonably well, but brighter targets have PSFs that extend well beyond the borders of the field of view and thus contaminate the nominal scattered light signal. In these cases, modeling of the scattered light has proceeded on something of a case-by-case basis; typically the first-order scattered light signal is decorrelated from the nominal stellar flux, the stellar position, and the spacecraft orbital position and orientation. Fig. 1a gives an example of the noise performance routinely achieved by WIRE.

3. Observation strategy

Since the WIRE aperture is only 52 mm, target selection is immediately restricted to relatively bright targets. In practice, however, since the star camera achieves count rates of $\approx 1.8 \times 10^7$ counts s^{-1} for a 0 magnitude star, the limiting magnitude is in fact set by the ability of the spacecraft to point with the required stability. In the single-star mode, the limiting magnitude is approximately 3.5, while in the 5-star mode, due to the increased integration time for the pointing feedback loop, stars as faint as $m_V = 6$ are observable.

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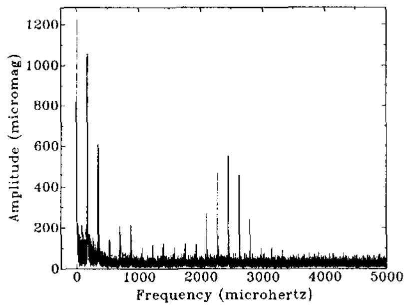

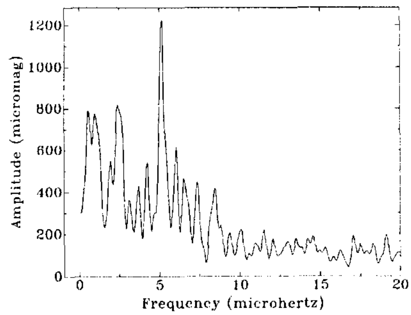

Figure 2. The amplitude spectrum for α Cir (left) shows the large peak at 2442 μHz and the associated alias peaks, as well as the larger modulation due to the stellar rotation. A closer look at the low-frequency portion of the amplitude spectrum (right) shows the large peak presumably due to stellar rotation. The peak lies at twice the rotational frequency 2.59 μHz reported in the literature (Kurtz et al. 1994). Note that the noise level at these low frequencies is of order 100 μmag, indicating that instrumental drift is minimal.

Early on, flight software limited pointings to only $\approx$ 8 minutes per orbit, but this figure was rapidly increased, until it stabilized in late summer 1999 at approximately 40 minutes per orbit. While the fixed orientation of the solar panels eliminated access to the zone of continuous visibility, and thus introduced unwelcome aliasing into the time series, we were able to compensate to some degree by observing two targets (separated by approximately 12 hours in RA) during each orbit; observing efficiency was then typically in excess of 80%.

Working under the limitations imposed by pointing and target brightness, we nevertheless attempted to achieve two goals. First, we observed the two solar-like targets accessible to WIRE (α Cen and Procyon), together with several other δ Scuti and roAp stars with well-known oscillation periods. Second, we blanketed the HR diagram as effectively as possible. Fig. 1b shows a color-magnitude diagram for all of the WIRE targets; a list of the targets can be found in Cuypers et al. (2001).

4. Progress and results

A total of 28 targets were observed primarily as asteroseismology targets, and an additional 10 were observed for other projects. Results for 5 stars (α Cen (Schou & Buzasi, 2000, 2001), α UMa (Buzasi et al., 2000), θ^2 Tauri (Poretti et al., 2001 and these proceedings), β Cas and β Cru (Cuypers et al., 2001 and these proceedings) have been published, while data analysis is actively proceeding for a number of additional stars. Data analysis is slowed by both the complexity of the scattered light modeling and data reduction, and by the sheer volume of the data sets (approximately 400 million observations were made).

In this brief paper there is little room to discuss new data, but I will show a few samples of data as yet unpublished. Fig. 2 shows the Scargle periodogram

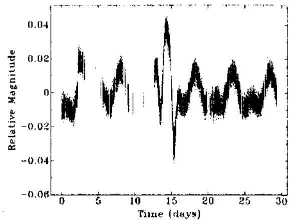

Figure 3. The raw WIRE time series of the Ap star ϵ UMa. The 5.09 day period reported in the literature is apparent, but there are clearly other frequencies present, none of which has been previously detected.

for the WIRE observation of the brightest roAp star, α Cir. The periodogram is based on approximately 6 million observations over a time period of about 6 weeks. As is obvious from the periodogram, we easily detect the known dominant mode at 2442 μHz. However, we do not detect the presence of the additional frequencies reported by Kurtz et al. (1994), though this is perhaps not surprising as these detections were marginal.

Fig. 3 shows a sample of "raw" WIRE data (after aperture photometry and scattered light removal) for the Ap star ϵ UMa; raw data for other targets can be seen in Poretti et al. and Cuypers et al. (these proceedings). The 5.088 day rotational period reported based on ground-based data (see, for example, Catalano et al., 1993) is easy to see. However, it is also easy to see beating between that period and at least one other, particularly between 15 and 30 days. In addition, there are relatively large (by WIRE standards) excursions in luminosity, which have not been detected from the ground, and which remain unexplained. This data set also exemplifies the stability of the WIRE instrument.

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