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STRESS – STEREO TRansiting Exoplanet and Stellar Survey

Vinothini Sangaralingam[1a], Ian R. Stevens[1], Steve Spreckley[1] and Jonas Debosscher[2]

[1]School of Physics and Astronomy, University of Birmingham,
Birmingham, B15 2TT, UK. [1a]email: vs@star.sr.bham.ac.uk
[2]Instituut voor Sterrenkunde, Catholic University of Leuven, Belgium.

Abstract. The **H**eliospheric **I**mager (**HI**) instruments on board the two **STEREO** (**S**olar **TE**rrestrial **RE**lations **O**bservatory) spacecraft provides an excellent opportunity for space based stellar photometry. The HI instruments provide a wide area coverage ($20^\circ \times 20^\circ$ for the two HI-1 instruments and $70^\circ \times 70^\circ$ for the two HI-2 instruments) and long continuous periods of observations (20 days and 70 days respectively). Using HI-1A which has a pass band of 6500Å to 7500Å and a cadence of 40 minutes, we have gathered photometric information for more than a million stars brighter than 12th magnitude for a period of two years. Here we present some early results from this study on a range of variable stars and the future prospects for the data.

Keywords. methods: data analysis, techniques: image processing, stars: variables, survey, etc.

1. Introduction

At magnitude 12, it is estimated that at least 90% of the variables are unknown (Eyer & Blake, 2005). Even though we know the basic mechanism of pulsation in most of these objects, the models are still not adequate enough to explain the evolution of these objects across the HR diagram (Eyer & Mowlavi, 2008). In recent years, there has been an increased interest to study these variables due to the technical advancements which provides a high precision and long time-series data to the community. The **S**olar **TE**rrestrial **RE**lations **O**bservatory - STEREO, is a system of two identical spacecrafts in Heliocentric Earth orbit, one travelling ahead and another behind Earth. Each spacecraft houses a suite of identical instruments to study the origin and evolution of Coronal Mass Ejections (CME) from the Sun in 3D. There are two Heliospheric Imagers (HI), which are wide angle imaging systems designed to study the evolution of CMEs in the interplanetary medium and to enable a stereo-graphic reconstruction of CMEs propagating through the inner heliosphere up till 200 solar radii ($R_\odot$). Hence these instruments are also capable of continuously observing the background stars to a high precision, thus aiding us to do stellar photometry as well. The large cadence, high precision, wide magnitude range and broad sky coverage of this instrument makes it feasible to search for transiting extra solar planets. The 4 instruments together cover nearly 60% of the sky over a year, thus placing STEREO data as a compromise between other currently active surveys for transiting exoplanets and stellar variability studies. We have developed the basic data reduction and analysis pipeline to do aperture photometry on images from the HI-1A instrument so far. In this conference, we present the preliminary results obtained as well as the future prospects for the data.

2. Instrument overview

The HI-1 instrument is a multi-baffled imaging system sensitive to wavelengths ranging from 6500Å - 7500Å with a field of view of 20° centered at 50 $R_\odot$ and a resolution of 35.15″/pixel whereas the HI-2 instrument has a large passband varying from 4000Å to 10000Å , with a field of view of 70° centered at 200 $R_\odot$ and a resolution of 2.05′/pixel. A quick review of the main characteristics of the two HI instruments are given in Table 1.

Table 1. HI Instrument Characteristics

	HI-1 Characteristics	**HI-2 Characteristics**
Field of View	20° × 20°	70° × 70°
Plate scale	35.15″/pixel	2.05′/pixel
Passband	6500Å - 7500Å	4000Å - 10000Å
Nominal exposure time	40 sec	50 sec
Integrated cadence	40 min	2 hrs

The HI-1 and HI-2 cameras have individual exposure times (single shutter open/close cycle) of 40 and 50 seconds respectively separated only by the CCD read-out times of approximately 4.8 seconds. Thirty such exposures are summed up together, after correcting for cosmic ray effects (on-board), thus providing a cadence of 40 minutes for each HI-1 image. Similarly 99 exposures of HI-2 are summed to provide a digitally integrated image cadence of 120 minutes (Eyles *et al.*, 2009).

3. Data Analysis

The summed up images are publicly available for download from the UK Solar System Data Centre (UKSSDC) website of Rutherford Appleton Laboratory (RAL) in an interactive way (www.ukssdc.rl.ac.uk). All initial analysis of the data is done using IDL solar-soft packages and software basically developed by STEREO support team at RAL.

All the raw images have to be preprocessed with the pipeline developed by RAL to remove the various basic instrumental and spacecraft effects such as shutterless readout, saturated columns due to bright stars and planets, pre-flight flat fielding, bad files and also to update the spacecraft pointing and optical parameters in the header files (Brown *et al.*, 2009).

The data at this stage still has the solar F corona which dominates the image. A minimum background map for each day is then subtracted from the image. The photometric information is now extracted from these images by the processing pipeline developed by us (Fig. 1) with the input catalogue from NOMAD - Naval Observatory Merged Astrometric Dataset for objects brighter than 12 in the R magnitude.

The light curves thus obtained exhibits two characteristic modes of variability. The minimum background subtraction actually leaves a residual one day signal in the data due to the variations in F corona in time scales of a few hours. One solution of the problem is to make a more robust background map which is being currently investigated by us with the help of the team at RAL. The other is to model the F corona which is beyond the scope of this project. Hence at present it is not possible to study periodicities in the region of one day. Another trend exhibited by the data is due to the path of the object across the CCD. Since the contribution from the F corona varies as we move from left

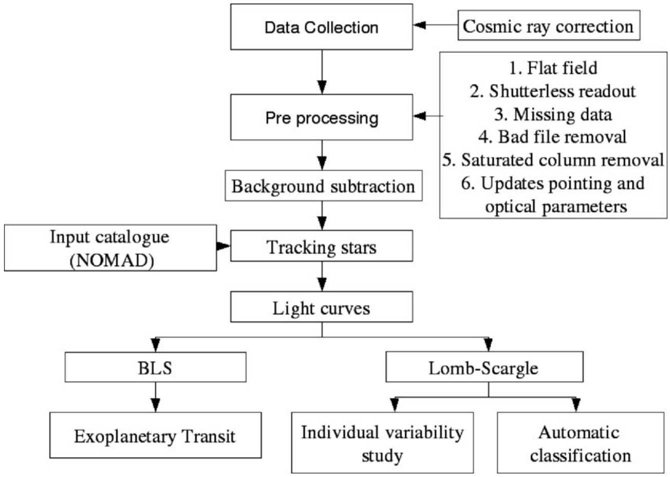

Figure 1. A schematic of the STEREO HI data analysis pipeline, showing the various stages of data preparation involved in producing light curves from raw images (see text for explanation).

to right of the CCD, a varying flux is subtracted during the minimum background step of the process. We are working on removing this trend using various filtering methods.

So far, we have processed data for nearly a million stars for two orbits of the spacecraft with 20 days of observation in each orbit for the HI-1A instrument. As a preliminary work, we analysed all the light curves using Lomb-Scargle periodogram (Scargle, 1982) for periods in the range of 0.1 days to 10 days (the Nyquist frequency is 18 cd^{-1}) excluding a region around one day. The lower cut-off of the point to point scatter of objects which are not flagged by Lomb-Scargle is less than a percent for stars of magnitude 6 to 8 and a few percentage for objects fainter than 8th magnitude. But these are just initial results, with the above mentioned systematic variabilities, hence more work needs to be done to get a very accurate estimate of these values. All these various parameters makes this data conducive to study variables like β Cepheids, δ Scutis, γ Doradus as well as exoplanetary transits. Another aspect of our work is to automatically classify these variables using neural networks (Debosscher *et al.*, 2007, Sarro *et al.*, 2009). A

stars

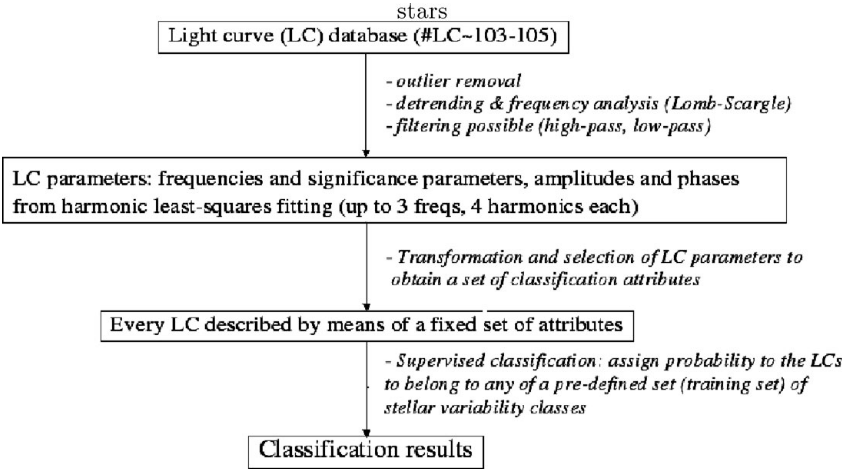

Figure 2. A Schematic of the steps involved in the automatic classification of these variable stars

brief schematic of the process involved is given in Fig. 2 (for more explanation please see the above references).

4. Results and Discussions

In this section, we present sample light curves of some well known variable types, obtained from our analysis pipeline. Also, to illustrate the potential of the data, we present light curve of a new variable object as well as a suspected micro-variable star. We advise caution when viewing these results since they are very preliminary and definitely more investigation is needed to confirm or dismiss these results. We also present an example from our automatic classification work.

These objects are selected at random from our database just to represent the various types of stars which can be studied as well as to describe the quality of the data at this early stage. We would like to draw your notice to the fact that these data contain all the various noise discussed in the previous section as well as some unknown factors.

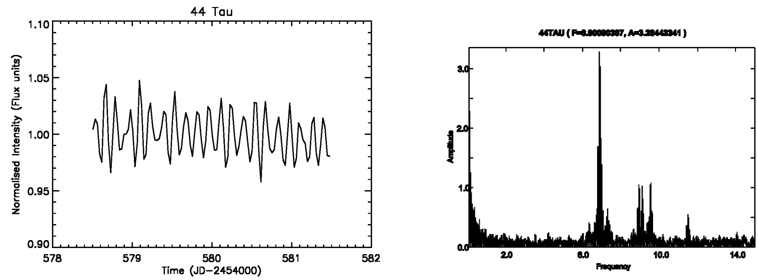

Figure 3. STEREO light curve of 44 Tau - a δ Scuti (Vmag = 5.39) and its frequency spectrum (produced by Period04).

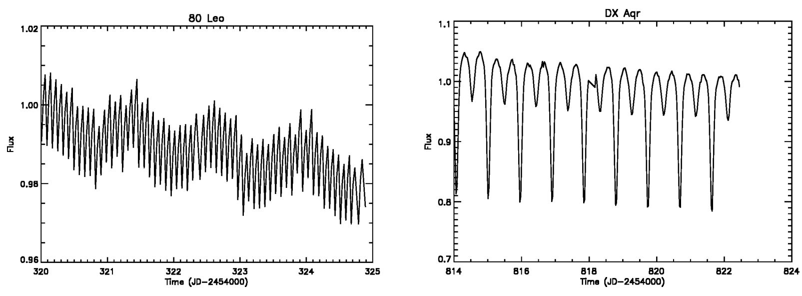

Figure 4. Left: STEREO light curve of 80 Leo - a γ Dor - Vmag = 6.35. Right: DX Aqr - Vmag = 6.37 - An Algol type eclipsing binary.

<u>44 Tau</u>: A δ Scuti variable with known 29 pulsational frequencies (Vmag = 5.39) in the region of 6 - 29 cycles per day (Antoci *et al.*, 2007). From STEREO data (Fig. 3), we can detect nine of those frequencies with an SNR of 26.9 at the prominent frequency of 6.9 cycles per day. Right panel of Fig. 3 is the power spectrum obtained using Period04 (Lenz & Breger, 2005), which clearly shows the different periods present. The amplitude of few of the frequencies detected were different from that in literature, indicating that more work needs to be done to understand this star.†

† The SNR of all objects are computed by the Period04 software.

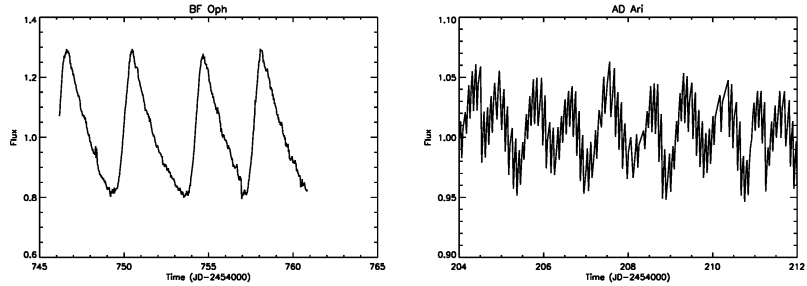

Figure 5. Left: BF Oph - Classical Cepheid - Vmag = 7.37. Right: AD Ari - δ Scuti - Vmag = 7.43

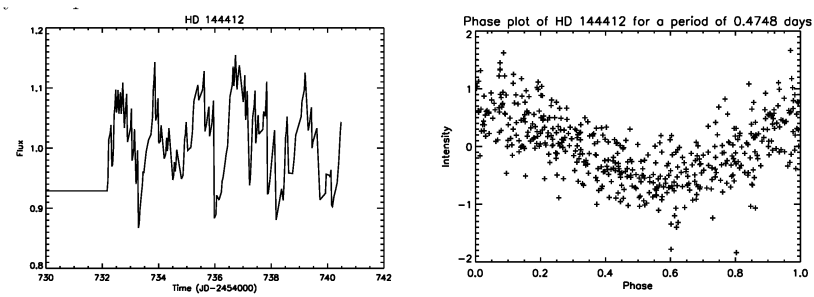

Figure 6. Left panel - STEREO light curve of HD 144412 which is found to execute a previously unreported variability. Right panel contains the phase plot at a period of 0.4748d.

80 Leo: A γ Doradus star (Vmag = 6.35) with a known period of 0.45286d (Henry & Fekel, 2002). We observe a period of 0.4529d with a SNR of 15.7. This light curve (Fig. 4 - Left) also shows the long term systematic effect due to the path of the object across the CCD as well as the one day periodicity.

DX Aqr: Known as a binary both visually and spectroscopically with an A0 and A1 companion and a period of 0.945d from GCVS. We detect a period of 0.9453d with an SNR of 46.65 (Fig. 4 - Right).

BF Oph(HD 154365): A Classical delta cepheid of Vmag = 7.37 and a period of 4.0677d (Hertzsprung, 1930). The STEREO light curve (Fig. 5 - Left) also reveals the quality of data in terms of continuous coverage.

AD Ari: A known but not very well studied δ Scuti F0 star with a Vmag of 7.4. GCVS has a period of 0.5397d and we also find the same period (Fig. 5 - Right).

HD 144412: A relatively not known A2 star with a Vmag of 8.70. From the STEREO light curves (Fig. 6 - Left panel). We found a period of 0.4748d with an SNR of 15.32. Right panel of Fig. 6 shows the phase plot at found period. But definitely more work needs to be done to confirm this variability.

HD 202369: A 5.34 mag M3 giant, suspected to be a variable by Rufener *et al.*, 1982. We find a prominent period of 0.4447d from STEREO data (Fig. 7 - left). The power spectrum (Fig. 7 - right) has a broad peak indicating the presence of more than one period as well as many modes.

Fig. 8 is an example result from our automatic classification method using neural networks. This is a well known δ Scuti star - VW Ari of Vmag = 6.71 and spectral class F0 (Liu *et al.*, 1996). Fig. 8 also shows the phase plot at the prominent frequency f1 and the corresponding amplitude spectrum.

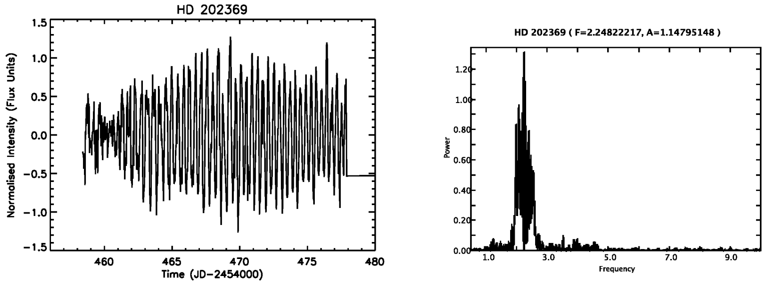

Figure 7. Left - STEREO light curve of HD 202369 which is previously suspected to be a variable. Right panel contains the power spectrum with the broad peak around the prominent period.

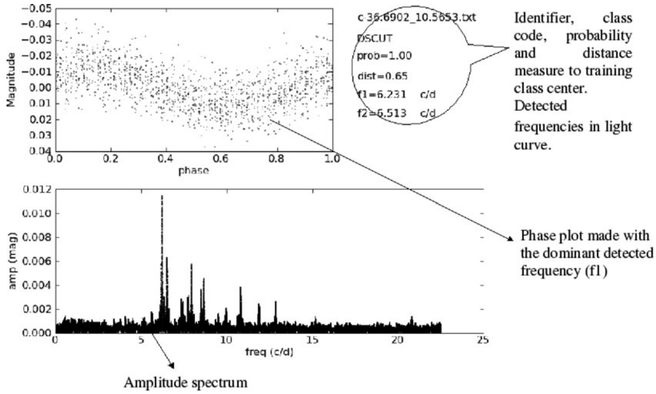

Figure 8. VW Ari - A F0 star of Vmag of 6.71 - δ Scuti

5. Summary

The HI instruments with their wide field, shallow magnitude coverage, continuous observation and a good PSF provides the compromise with other active transit search and stellar variability studies. Our current investigation involves studying in detail the new and suspected variables to confirm their periodicities apart from working on automated classification of these variable stars using neural networks. We are also working on correcting for the various instrumental and consistent variations which are present in the light curves. All these, we are sure will enable us to look for transiting exoplanets in our data in the near future.

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