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Research Note

Detecting low amplitude periodicities with HIPPARCOS*

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Abstract. The HIPPARCOS and TYCHO catalogues have proven to be a very powerful source for detection of variability in stars. The photometric errors for individual measurements are typically of the order of a few millimagnitudes. Amplitudes for periodic variability of stars and based on HIPPARCOS data are published which are of the same order. An example could be the still controversial case of ET And (Scholz et al. 1998; Weiss et al. 1998) with contradicting evidence for HIPPARCOS and ground-based observations. Another case could be the AGB star RV Cam (Kerschbaum et al. 2001) with a similar contradiction. In this paper we investigate the properties of HIPPARCOS photometry for a set of 4863 presumably constant stars and we determine the frequency ranges of HIPPARCOS which seem to be affected by the instrument.

Key words. stars: variable: general – techniques: photometric

1. Introduction

The remarkable scientific potentials of the Hubble Space Telescope Fine Guidance Sensor (HST–FGS) archival data for determining microvariability in a large sample of stars have been discussed by Kuschnig et al. (1997). The authors indicate some instrumental problems which are typical for photometry in space and their study was extended by Zwintz et al. (2000). Future photometric satellite projects, like the CNES–lead asteroseismology experiment COROT, the Canadian micro–satellite project MOST or the Danish project MONS can also benefit from the investigation of instrumental and environmental problems encountered when performing photometry from a space-borne platform. Another powerful data base for investigating various effects which impede the determination of intrinsic photometric characteristics of stars is provided by the HIPPARCOS mission. Despite all efforts to calibrate an instrument before launch and to develop reliable instrumental models already in the design stage, it always will be necessary to determine and/or check such model parameters independently, based on real data.

Triggered by publications claiming detection of low-level photometric variability of stars we tried to determine the relevant instrumental characteristics of this satellite from archival data only. In particular we were interested in frequencies induced in the analysis of light curves by the instrumental properties of HIPPARCOS.

2. Choosing constant stars

The diagram on p. 465 in the HIPPARCOS Catalogue vol. 1 (ESA SP-1200, 1997) illustrates that the fraction of variable stars is quite variable over the HR-diagram. In the giant branch the fraction is up to 100% and reduces to 10% on the main sequence. As a first step we binned a part of the HR-diagram according to spectral types (B, A, F, and G), luminosity classes (II and III, IV, and V), and the brightness at 4, 6, 8 and 10 mag(V) with an interval of ±0.5 magnitudes. For each bin we interrogated the SIMBAD database for stars observed by HIPPARCOS and which appear to be unsuspicious, i.e. to have no GCVS name, no suffixes to the spectral type, no peculiarities which might indicate photometric variability, etc. The result of this interrogation was a list of 12 500 stars. Furthermore we excluded those stars found to be variable by HIPPARCOS and stars with less than 60 data points. From the remainder we randomly selected half and hence reduced our list of candidate constant stars to 4863. As a next step we extracted the photometric data from the HIPPARCOS EPOCH PHOTOMETRY archive[1] or from ESA 1997 CD-ROM 2, where the file *hip_ep.dat* contains the HIPPARCOS EPOCH PHOTOMETRY ANNEX. A software tool extracted automatically the photometric data of the stars under consideration and removed bad data points as

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* Based on HIPPARCOS photometry and SIMBAD database interrogations.

[1] http://astro.estec.esa.nl/Hipparcos/apps/PlotCurve.html

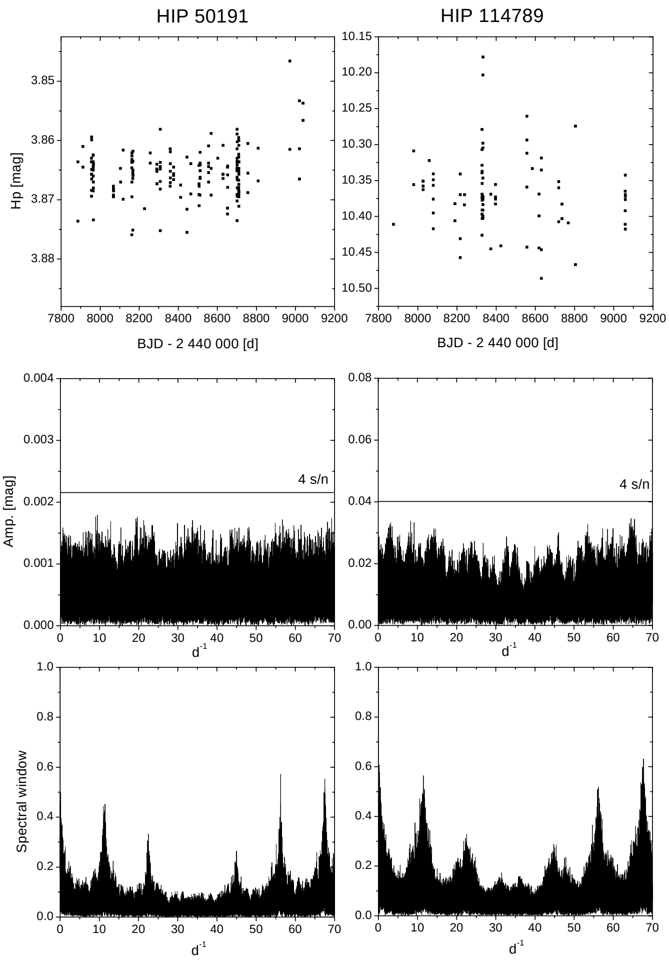

Fig. 1. The photometry (upper left panel) of the A2 V star HIP 50191 (HD 88955, 3.85 mag(V)) with 173 data points has a noise level of 0.54 mmag in the amplitude spectrum (middle left panel), which is the lowest in our sample of stars. The photometry (upper right panel) of the F5 V star HIP 114789 (HD 219269, 10.29 mag(V)) with 83 data points has a noise level of 10.3 mmag in the amplitude spectrum (middle right panel), which is the highest in our sample of stars. The spectral windows of the data are given in lower two panels.

indicated by a different to zero quality flag (Field HT4 in the file).

3. Light curves and Fourier analysis

During the HIPPARCOS mission an individual star was observed up to 350 times over the whole mission lifetime, depending on the position on the sky. The temporal distribution and density of photometric data can be very different from star to star (Figs. 1). It is an overlap of a 20 min to 108 min and a 3 to 5 week cycle (Eyer & Grenon 2000; van Leeuwen 1997). For our sample of stars we found light curves with up to 339 data points.

To analyse the large amount of data sets in a reasonable time we wrote a Fortran 90 program based on the DFT (Discrete Fourier analysis; Deeming 1975). The software tool computes the mean (noise) level in the amplitude spectrum from 0 to 34.9 d^{-1} with a frequency resolution of $(10\,T)^{-1}$, where T is the total time span of a dataset. The noise level and the up to 4 highest peaks in the amplitude spectrum, with a signal to noise ratio (S/N ratio) exceeding 3.25 and an arbitrarily selected minimum distance of 1 d^{-1}, were stored in an individual file.

Table 1. HIPPARCOS satellite frequencies.

Frequency	$f[\mathrm{d}^{-1}]$	P [h]
f_{rot}	11.25	2.13
$2f_{\mathrm{rot}}$	22.5	1.06
$1/2\ f_{\mathrm{rot}}$	5.6	4.26
f_{302°	13.4	1.79
$1/2\ f_{58^\circ} = f_{\mathrm{NYQ}}$	34.9	0.69
f_{orb}	2.25	10.66

In Figs. 1 we show amplitude spectra of the two extreme cases with the lowest (HIP 50191, 3.85 mag(V)) and highest (HIP 114789, 10.27 mag(V)) noise level encountered in our investigation. Both stars have no significant peak in the amplitude spectra. A PDM algorithm basically gives similar results but is more computer time consuming. Hence DFT was given preference.

Due to the instrumental design of HIPPARCOS, one would expect to find a priori some characteristic frequencies which are listed in Table 1 when analysing real data. The frequency which corresponds to the rotation of HIPPARCOS (f_{rot}), and the harmonics are prime candidates. Indeed they are found in all spectral windows (see also Fig. 1, lower panels). The optical axes of the system which images the sky onto the focal plane include an angle of 58°. Hence, when a star is in the field of view of one system, it will appear in the other after 20.6 min due to the satellite rotation. This is the shortest possible time interval for consecutive observations and can be taken as the clocking interval for HIPPARCOS. The frequency of 34.9 d^{-1}, relative to which the spectral window appears to be symmetric, corresponds to the Nyquist frequency for evenly spaced data, and corresponds to twice the shortest possible sampling interval of 20.6 min. Although, at a first glance, the HIPPARCOS data do not appear to be evenly spaced, this concept obviously still is applicable, because of the nearly constant rotation rate of the spacecraft. Due to the operation of HIPPARCOS, data gaps can be very large, which increases significantly the amplitude of sidelobes and hence the noise level in the amplitude spectrum.

4. Characteristic frequencies

For the stars analysed by us, the four highest peaks above a S/N ratio higher than 3.25, 3.6, and 4.0 were used to produce a histogram. Kuschnig et al. (1997) demonstrated that a S/N ratio larger than 4 corresponds to a probability of more than 99.9% that a peak in the amplitude spectrum can be considered significant. A S/N ratio of more than 3.6 and 3.25 corresponds to a probability of more than 99% and 95%, respectively. The histogram (Fig. 2) illustrates how often at least one of the up to four highest peaks (above a chosen S/N ratio level) in the amplitude

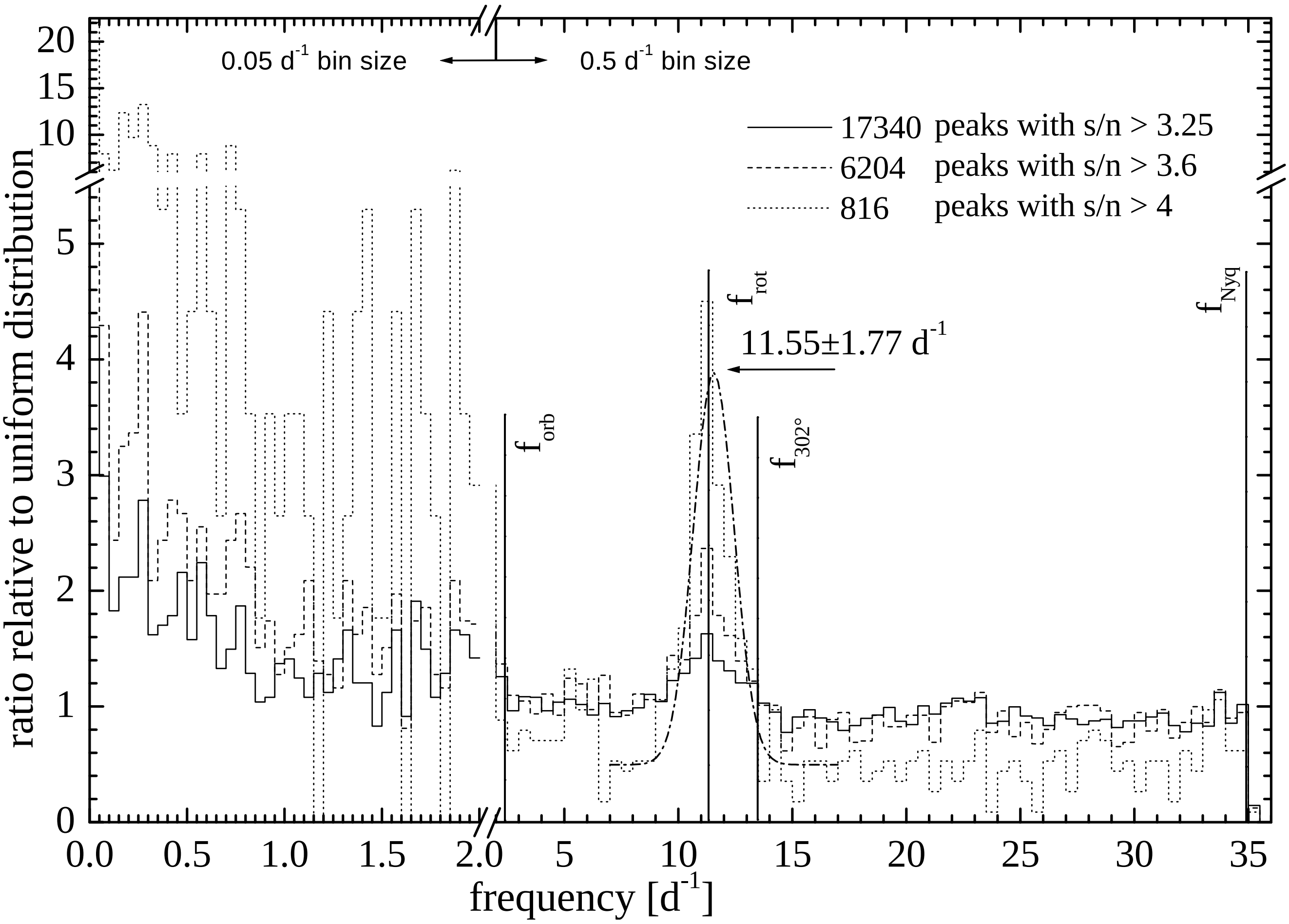

Fig. 2. The histrogram illustrates the incidence of frequencies determined in amplitude spectra of light curves of presumably constant stars with an amplitude exceeding a given S/N ratio. The numbers are normalised to a uniform distribution from 0 to 36 d^{-1}. It is split into a low- and high-frequency domain and uses different binnings.

spectra of our presumably constant stars falls into a given frequency bin of 0.5 d^{-1} width for the high-frequency domain and 0.05 d^{-1} width for the low-frequency domain. We compared this number with the number of cases we would expect if all the frequencies were uniformly distributed over all the bins in the histogram and plotted the corresponding ratio. Because of the minimum distance of the 4 peaks per star, a number we have chosen for our extraction routine (see Sect. 2) an individual star can appear only once in a given bin.

Figure 2 shows, e.g., that in the frequency bin ranging from 11 to 11.5 d^{-1} we found 4 times more frequencies with an amplitude exceeding the noise level than expected for an uniform distribution. These are 6.25% of 816 stars with a peak exceeding a S/N ratio of 4 and a 4.5 times higher incidence than expected from a uniform distribution. Some of the frequencies listed in Table 1 are also indicated in Fig. 2.

In the low-frequency domain (0 to 2 d^{-1}) we found a total of 228 peaks exceeding a S/N ratio of 4. The highest bin from 0 to 0.05 d^{-1} corresponds to the typically 3 to 5 week data gaps in the lightcurves. A comparison with spectral windows does not show correlations with other bins in the histogram. Aliasing therefore should not contribute significantly to the low frequency peaks. Our result seems to confirm what Kerschbaum et al. (2001) have found for the AGB star RV Cam. Whereas Koen & Laney (2000) reported on the discovery of a period of 7.67 days (0.13 d^{-1}), based on HIPPARCOS photometry, Kerschbaum et al. do not find such a periodicity in ground based photometric data with a 10 times lower noise level. Our Fig. 2 illustrates the verbal description of aliases and spurious periods by Eyer & Grenon (2000), who report on a poor detection capability of HIPPARCOS photometry in the frequency range from 0.05 to 0.2 d^{-1} and at 0.0017 d^{-1}.

In a further step we investigated possible effects due to luminosity and spectral types. No such dependency was found on either of these astrophysical parameters (Fig. 3). Figure 4 illustrates the uniform distribution of our program stars in the HR-diagram and shows that stars with "significant" periods are found everywhere.

5. Conclusions

A Gaussian fit to the main peak in the histogram (Fig. 2) results in a formal maximum occurrence of 8% in our analysed (constant) stars with an amplitude exceeding 3.25 times the noise level at a frequency of 11.55 d^{-1}.

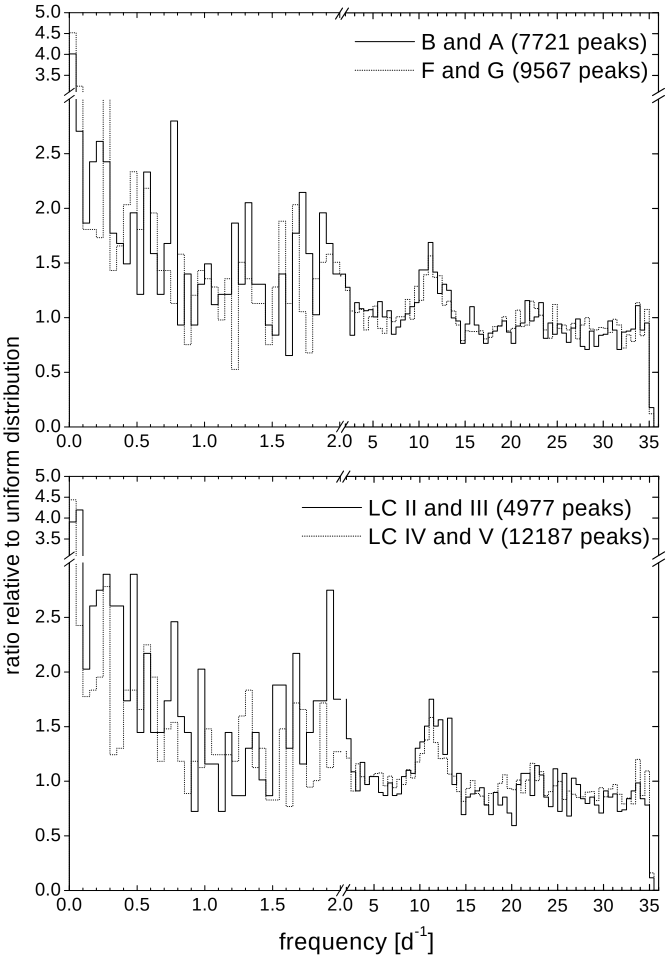

Fig. 3. Histogram similar to Fig. 2 (S/N ratio = 3.25), but with the data separated according to spectral type (upper panel) and luminosity class (lower panel).

This frequency clearly is related to the rotation of HIPPARCOS. Considering the width of that fit one can question any published detections of variability, based on HIPPARCOS photometric data *alone*, with frequencies ranging from 9.78 to 13.32 d^{-1} and amplitudes exceeding the noise level only a few times.

The low frequency peaks in the analysis of presumably constant stars may result from at least three effects: not yet identified intrinsic variations of stars in our sample, instrumental drifts and aliasing. In the present investigation we tried to simulate a "blind" analysis of HIPPARCOS photometry where it is impossible to disentangle such effects on the basis of a statistical treatment. Large periods obviously have to be checked independently from HIPPARCOS data.

The optimum frequency interval for detecting low frequency variability with HIPPARCOS, claimed by van Leeuwen (1997) to range from 0.5 to 11 d^{-1}, is questioned by our histogram (Fig. 2) at least for amplitudes comparable to the noise level. Such an interval seems to be restricted rather to 2 to 9 d^{-1}. However, it is comfort to see that the orbit frequency of 2.25 d^{-1} has only marginal effects on determining intrinsic stellar photometric periods.

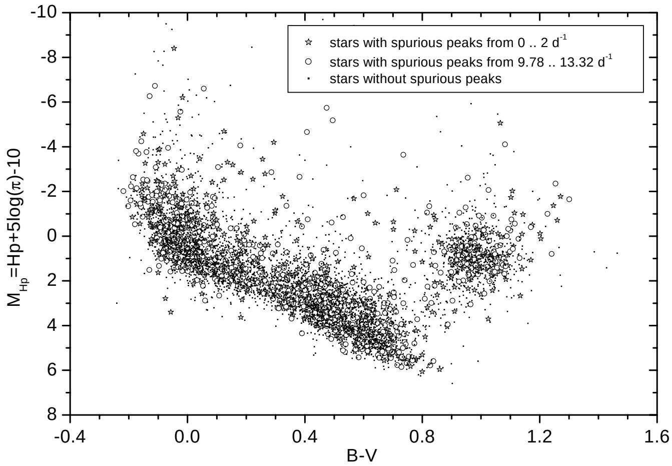

Fig. 4. HR-diagram of our candidate stars, using different symbols for stars with and without spurious periodicities (π in mas).

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Note added in proof: E. Paunzen brought our attention to a paper by Koen (2001) where the author lists in his Table 3 stars from the "unsolved" part of the HIPPARCOS catalogue which are multiperiodic according to his criterium. It is interesting to note that *all* stars in his Table, except of 5 (from 36), were selected on the grounds of frequencies coinciding with what we call "spurious" frequencies for our sample of presumably constant stars. We take this evidence as an independent indication for critical frequency ranges in the HIPPARCOS photometry, where HIPPARCOS data *alone* are insignificant and have to be supplemented by independent observations.

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