Comm. in Asteroseismology
Vol. 156, 2008

A new photometric study of the high galactic latitude β Cep star HN Aqr

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Abstract

We have carried out 32 h of new time-resolved CCD UBV photometry of the high galactic latitude β Cephei star HN Aqr. We detected its known single pulsation frequency and noticed additional variability at lower frequencies. It is not clear whether or not this longer-term variation originates from HN Aqr itself. The UBV colour amplitudes of the star's β Cephei pulsation point towards an $\ell = 4$ or $\ell = 2$ mode, inconsistent with previous mode identifications.

Individual Objects: HN Aqr

Introduction

The β Cephei stars are a group of early B-type stars with masses between 9 and 17 $M_\odot$ that exhibit light, radial velocity and line-profile variability on time scales from two to eight hours (Stankov & Handler 2005). Their variability is caused by pulsations in pressure and gravity modes of low radial order that are driven in the ionization zone of the iron-group elements (Moskalik & Dziembowski 1992). As a direct consequence, the strength of the pulsational driving of these variables should be directly related to the abundance of the iron-group elements in the driving zone, and the pulsations should vanish if the metallicity (for a given element mixture) falls below a certain limit (e.g. Pamyatnykh 1999).

Nevertheless, numerous β Cephei stars were reported in the generally metal-poor Large Magellanic Cloud (Kołaczkowski et al. 2004). Still, this finding may be explicable by the presence of regions with higher metallicity within the LMC. Additional relief from the theoretical side may be supplied by the recent revision of the solar element mixture (Asplund et al. 2005) causing a *relative* increase of the abundances of the iron-group elements with respect to CNO that dominates determinations of the overall metallicity of early-type stars (Pamyatnykh 2007).

There is a single case of a galactic β Cephei star in a low-metallicity environment: HN Aquarii (=PHL 346). Discovered to pulsate by Waelkens & Rufener (1988) and confirmed by Kilkenny & Van Wyk (1990), this object has long been taken as evidence for star formation in the galactic halo (e.g. Keenan et al. 1986). However, proper motion measurements made an explanation in terms of a runaway star from the galactic plane possible (Ramspeck et al. 2001).

Asteroseismology may shed additional light on this problem. Pamyatnykh et al. (2004) showed that some pulsation modes are sensitive to the effects of metallicity on interior stellar structure and can therefore be used as a seismic probe of the overall interior metal abundance.

So far, only a single mode of pulsation has been detected for HN Aqr, but the published data sets are rather small by today's standards. The noise level in the prewhitened data of Kilkenny & van Wyk (1990), the most extensive photometric study of HN Aqr published to date, is 3.5 mmag. Heynderickx et al. (1994) reported a mode identification for the strongest pulsational signal of HN Aqr: by combining ultraviolet, Walraven and Geneva photometry, they suggested a spherical degree of $\ell = 1$ as the most likely. To improve the observational data base on HN Aqr, we decided to carry out new measurements in order to detect previously unknown pulsation modes and to provide mode identifications.

Observations and reductions

We used the 1.0-m telescope at the Siding Spring Observatory and the Wide-Field Imager (WFI) to acquire time-resolved UBV CCD photometry of HN Aqr. We measured the star in July and September 2006 during six nights each, totalling 32.2 hours of observation.

The data were reduced with standard IRAF[1] routines, and were corrected for overscan, flat field and nonlinear response of the CCD chip (only WFI chip #3, which had the best quality, was used); bias and dark count corrections were not found necessary. Photometry was carried out with the program package MOMF (Multi–Object Multi–Frame, Kjeldsen & Frandsen 1992) that applies combined Point–Spread Function/Aperture photometry relative to an optimal sample of comparison stars, ensuring highest-quality differential target light curves.

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[1] IRAF, the Image Reduction and Analysis Facility, is written and supported by the IRAF programming group at the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona.

Light curve and frequency analysis

We searched the data for periodicities using the program `Period04` (Lenz & Breger 2005). This package applies single-frequency power spectrum analysis and simultaneous multi-frequency sine-wave fitting. The amplitude spectrum of our V filter data is shown in Fig. 1.

This amplitude spectrum is dominated by two features: the known pulsational signal near 6.5 c/d plus some low-frequency variability. The latter dominates the residual amplitude spectrum after prewhitening the known pulsation frequency, leading to the disappointing result that no further β Cephei-type oscillations can be revealed in our data. Adopting the period derived by Kilkenny & van Wyk (1990) to resolve aliasing ambiguities, but optimizing it to accommodate possible frequency variability that may have occurred in the 18 years between the two data sets, results in a pulsation frequency of $6.5666 \pm 0.0004\,\mathrm{c/d}$ in our data[2]. The high formal accuracy quoted is a consequence of the two-month time baseline of our data. The UBV amplitudes of this pulsation mode are 21.6 ± 2.0, 21.2 ± 1.1, and 20.8 ± 1.0 mmag, respectively; the phase of the pulsational signal is the same at all wavelengths within the errors.

With these amplitudes, the spherical degree ℓ of the pulsation mode can be constrained. A comparison between the observed and theoretically predicted UBV amplitudes for HN Aqr is shown in Fig. 2. We note that the measured amplitudes are most consistent with the prediction for an $\ell = 4$ mode, although $\ell = 2$ cannot be ruled out keeping in mind the possibility of systematic errors. Other ℓ values are difficult to be reconciled with our data.

Turning to the low-frequency variability, we cannot clearly say whether or not it is intrinsic to HN Aqr. Analysing the differential photometry of other stars of similar brightness in the field in the same way did not result in such low-frequency variability, suggesting that HN Aqr is responsible for it. On the other hand, the differential magnitudes of HN Aqr are correlated with its x-position on the chip (and are not correlated with y-position or seeing). A corresponding decorrelation did not fully remove the low-frequency signal.

Discussion

Our new CCD observations of the high-galactic latitude β Cephei pulsator HN Aqr did not suffice to deepen our understanding of the star. However, two questions turned up that may make a more in-depth study worthwhile.

First, it is unclear where the low-frequency variations in our light curves originate from. Interestingly, Kilkenny & van Wyk (1990) discussed a similar

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[2] Kilkenny (private communication) reports a period of 0.1523135 d from the published data supplemented by new observations from the following season.

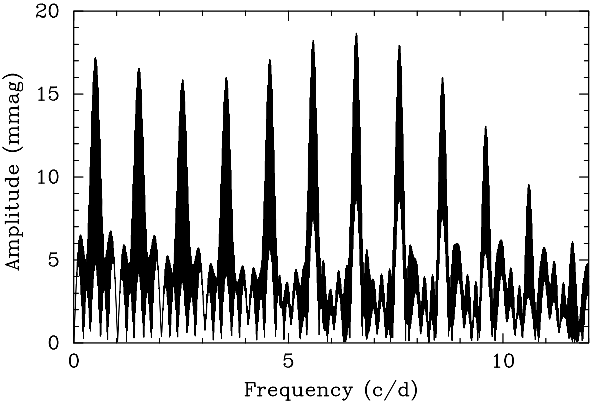

Figure 1: Amplitude spectrum of our V filter photometry of HN Aqr.

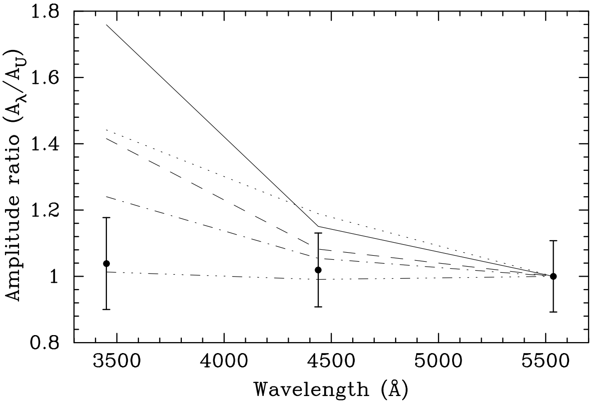

Figure 2: Mode identifications for HN Aqr from a comparison of observed and theoretical UBV amplitude ratios, normalized to unity at V (where the relative error of amplitude determination is smallest). The filled circles with error bars are the observed amplitude ratios. The full lines are theoretical predictions for radial modes, the dashed lines for dipole modes, the dashed-dotted lines for quadrupole modes, the dotted lines for octupole modes, and the dashed-dot-dot-dotted lines are for $\ell = 4$.

problem in their observations of HN Aqr, but they suspected that their single comparison star could be responsible for the slow variability. On the other hand, Waelkens & Rufener (1988) as well as Heynderickx (1992) did not mention low-frequency variations, although we have to mention that their data sets were less extensive than ours and Kilkenny & van Wyk's (1990).

Second, our mode identification does not agree with that by Heynderickx et al. (1994). Again, it is hard to pinpoint the cause of this disagreement. The previously mentioned authors did not give error estimates for the photometric amplitudes used. Perhaps the low-frequency variability went unnoticed in the small data sets available to them, but did affect the amplitude determinations systematically. The same comment may be applicable to our data.

One might also suspect that our U passband does not conform to the standard system. Therefore, we compared the UBV amplitudes of some β Cephei stars with those obtained from other sites and found them to be consistent within the errors. Nevertheless, we point out the necessity for well-defined U filter passbands when attempting to identify modes of hot stars from CCD photometry; the ultraviolet amplitudes are crucial for correct identifications.

We leave the reader with the standard trivial conclusion that follows many observational studies: more data are needed.

Acknowledgments. This research was supported by the Austrian Fonds zur Förderung der wissenschaftlichen Forschung under grant P18339-N08.
GH thanks Vichi Antoci, Dave Kilkenny and the referee for helpful discussions.

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