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ASTRONOMY AND ASTROPHYSICS

Variations of the Ap star HDE 318107[⋆,⋆⋆]

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Abstract. The rotation period of the Ap star HDE 318107 has been determined from magnetic and photometric observations obtained between August 1992 and September 1998.

Key words: stars: chemically peculiar – stars: individual: HDE 318107 – stars: rotation

1. Introduction

The peculiarity of HDE 318107 (= NGC 6405-77 = CoD $-32°13074$) was first noticed by North & Cramer (1981) during a photometric study of the open cluster NGC 6405 in the Geneva 7-color system. There was statistical evidence of variability, and a period of 52.4 d was proposed later by North (1987) on the basis of a larger set of photometric measurements in the same system. More recently, the star was included in an extensive study of the mean magnetic field modulus of Ap stars with spectral lines displaying resolved Zeeman components (Mathys et al. 1997, and references therein). Here too, the dispersion of the field modulus was larger than the estimated measurement error. Although no satisfactory period could be found, the period deduced by North could be discarded.

Thanks to additional photometric and magnetic measurements, we are now able to derive a consistent value for the rotation period of HDE 318107.

2. Observations and analysis

Photometric material has been collected in 1996 during a 23-night observing run at La Silla with the 70 cm telescope of the Geneva Observatory equipped with the standard Geneva photometer (Burnet & Rufener 1979). The star was observed about once per night in the seven-colour Geneva photometric system (U, B, V, $B1$, $B2$, $V1$, G).

Although the absolute photometry is of high quality, we observed nearby HD 162515 as a comparison or check star.

Our differential data were supplemented with older Geneva observations obtained between 1976 and 1993 and kindly made available to us by P. North. No comparison star was observed. The photometric data are presented in Table 1, which is only available in electronic form at the CDS, via `http://cdsweb.u-strasbg.fr/Abstract.html`.

The spectroscopic data consist of high-resolution spectra ($7\,10^4 \lesssim R \lesssim 11\,10^4$) obtained between 1992 and 1998 with the ESO Coudé Echelle Spectrograph (CES; for a description see Lindgren & Gilliotte 1989 and Mathys 1994). The mean magnetic field modulus was derived from the wavelength shift between the components of the line Fe II $\lambda\,6149.2$ (see, e.g., Mathys et al. 1997).

As a by-product, values of the radial velocity were also derived. It would be beyond the scope of this work to present the individual measurements obtained from the various spectra. The accuracy of the radial velocity determinations is actually somewhat limited by the distortion of the measured lines under the combined effects of rotation and magnetic field (see below), but there is no evidence for significant variability, so that the average of all the measurements obtained should be representative of the actual radial velocity of the star. The derived value of this velocity is 9.4 ± 2.0 km s^{-1}. Since almost nothing is known about the radial velocities of the member stars of NGC 6405, this cannot at present be used as a criterion to assess membership of HD 318107 in this cluster.

Period searches were performed over the various data sets using two methods: (1) by looking for the minimum of the chi-square merit function over a set of trial periods (see, e.g., Manfroid & Renson 1994; Manfroid & Mathys 1997), and (2) by using the period-searching algorithm proposed by Renson (1978, 1980). The resulting values were checked by visual inspection of the phase diagrams.

Each data set presents difficulties of its own, so a comparison of all periodograms is necessary to select the correct period. The photometric variations are small and the data are subject to strong aliasing. The older observations spanning 17 years were essentially concentrated in two short time intervals separated by ten years. Hence, the features in the periodograms are split

[⋆] Based on observations collected at the European Southern Observatory, La Silla, Chile (ESO programmes Nos. 49.7-030, 50.7-067, 51.7-041, 52.7-063, 53.7-028, 55.E-0751, 58.E-0159, and 61.E-0711, and at the Geneva Observatory photometric telescope, La Silla)
[⋆⋆] Table 1 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbd.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html
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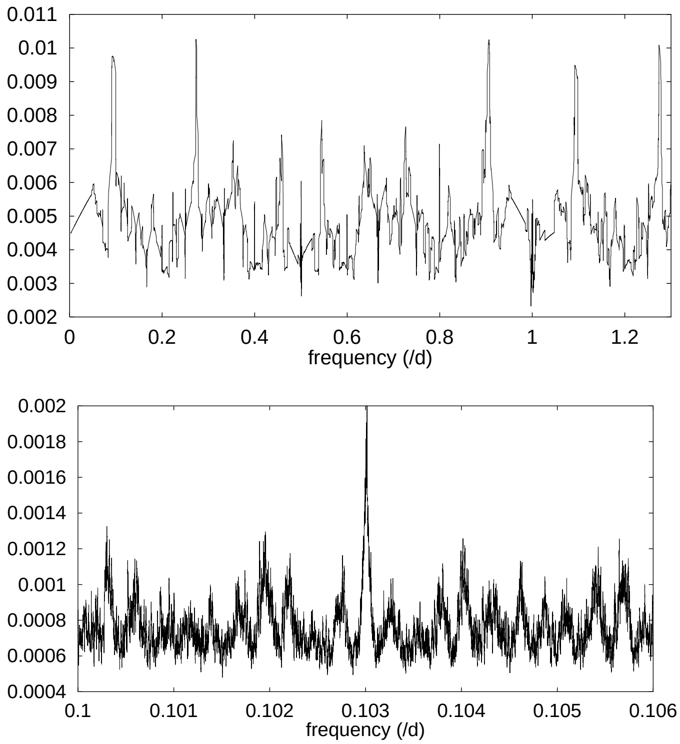

Fig. 1. Renson's periodograms for the photometric data of HDE 318107 in Geneva $U-B$. The parameter plotted is Renson's $1/\theta_1$. The horizontal axis is the frequency in d^{-1}. The upper plot shows the differential data obtained in 1996. The lower plot includes all available, mostly non-differential, data

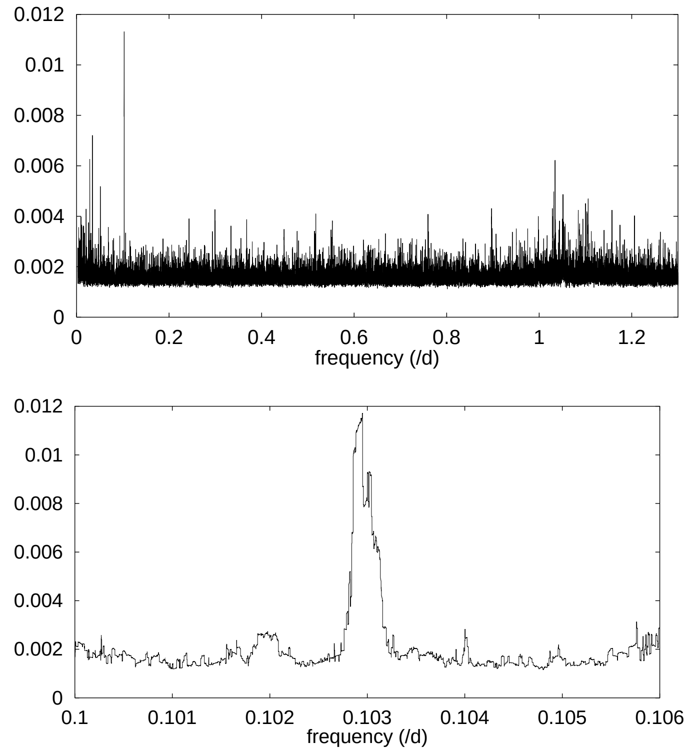

Fig. 2. Renson's periodograms for the measurements of the mean magnetic field modulus of HDE 318107 deduced from the wavelength shift between the components of the line Fe II $\lambda\,6149.2$. The parameter plotted is Renson's $1/\theta_1$. The horizontal axis is the frequency in d^{-1}. The lower plot details the peak area

into a multitude of aliases. The very narrow extrema are easily missed or discarded if the frequency resolution is not sufficient.

On the other hand the 1996 observations give a poor resolution. As they were always performed at approximately the same hour, powerful 1-day aliases do appear. These observations show some evidence toward variations with a period of about 10 days, with aliases, particularly at $0\overset{d}{.}9$ and $1\overset{d}{.}1$. These are the only strong features common to both Renson and chi-square analyses, and they are obvious only for the $U-B$ index. The upper panel of Fig. 1 shows Renson's periodogram plotted for $U-B$. The narrow peak at frequency $\nu = 0.273$/d ($P = 3\overset{d}{.}66$) is spurious and does not show up in the chi-square analysis.

In the 20-year data set including all Geneva data, the one-day aliases have disappeared, and a single peak stands out rather clearly among a forest of aliases at $P = 9.7076 \pm 0.0030$ d ($\nu = 0.10301$/d) according to Renson's method (lower panel of Fig. 1), or $P = 9.7084 \pm 0.0040$ d ($\nu = 0.10300$/d) according to the chi-square analysis.

The spectroscopic data relative to the Fe II line are relatively noisy because of (1) the faintness of the star and (2) a strong blending, especially on the blue side. Thanks to a few additional observations (Mathys et al., in preparation) and the revision of some older measurements, a periodicity can be derived which appears to be compatible with the photometric data. We find $P = 9.7133 \pm 0.0080$ d ($\nu = 0.10295$/d) according to Renson's method (Fig. 2), or $P = 9.7078 \pm 0.0100$ d ($\nu = 0.10301$/d) according to the chi-square analysis.

The problem of the blending of the Fe II line can be avoided by measuring a Nd III line ($\lambda\,6145$ Å), conveniently placed in the spectral range covered by the CES data. In this case, three split line components are observed, and the cleanest measurements correspond to the wavelength shift between the bluest two. The derivation of the value of the mean magnetic field modulus from this wavelength difference is based on unpublished theoretical values of the Landé factors of the levels between which the transition takes place, kindly communicated to us by Dr. J.-F. Wyart. With those values, the Zeeman pattern of the line does not depart significantly from a triplet, which is particularly suitable for determination of the field modulus (see Sect. 4.2.1 of Mathys 1989).

Here too, a periodicity can be derived which agrees neatly with the other data: $P = 9.7100 \pm 0.0080$ d ($\nu = 0.10299$/d) according to Renson's method (Fig. 3), or $P = 9.7091 \pm 0.0080$ d ($\nu = 0.10300$/d) according to the chi-square analysis.

The weighted average of the various period estimates is $P = 9.7085 \pm 0.0021$ d ($\nu = 0.103003$/d).

3. Analysis of the variations

Ap stars are normally characterized by very regular periodic brightness variations which can be fitted by simple Fourier series:

Table 2. Parameters of the least-squares fits for HDE 318107. The first seven lines are the Geneva photometric indices. The last two lines correspond to the mean magnetic field modulus as deduced from Fe II and Nd III. The error on each parameter is indicated in parentheses. σ is the scatter around the least-squares fit. r is the total range of the analytical curve. S/N is the signal-to-noise ratio defined as the total range divided by the scatter

HDE 318107	$P = 9\overset{\mathrm{d}}{.}7085$	$t_0 = 2\,440\,000.000$						
	A	B_1	B_2	ϕ_1	ϕ_2	σ	r	S/N
V	9.358 (0.0003)	0.0049 (0.0007)	0.0015 (0.0007)	5.90 (0.12)	1.82 (0.37)	0.0072	0.0106	1.48
$U-B$	1.118 (0.0003)	0.0133 (0.0007)	0.0019 (0.0007)	4.72 (0.04)	5.30 (0.34)	0.0070	0.0273	3.92
$V-B$	0.936 (0.0003)	0.0049 (0.0007)	0.0004 (0.0007)	4.42 (0.12)	3.34 (1.35)	0.0068	0.0098	1.44
$B1-B$	0.861 (0.0003)	0.0006 (0.0007)	0.0003 (0.0007)	2.77 (0.99)	0.07 (1.91)	0.0053	0.0014	0.27
$B2-B$	1.511 (0.0003)	0.0039 (0.0007)	0.0025 (0.0007)	4.69 (0.13)	4.11 (0.26)	0.0070	0.0110	1.57
$V1-B$	1.647 (0.0003)	0.0050 (0.0007)	0.0020 (0.0007)	4.57 (0.11)	3.46 (0.29)	0.0079	0.0115	1.47
$G-B$	2.052 (0.0003)	0.0072 (0.0007)	0.0015 (0.0007)	4.53 (0.08)	3.69 (0.43)	0.0091	0.0153	1.67
$\langle H\rangle$(Fe II)	14957 (56)	1345 (106)	641 (106)	3.68 (0.08)	1.06 (0.16)	360	2987	8.28
$\langle H\rangle$(Nd III)	14469 (53)	1633 (113)	1383(112)	3.53 (0.06)	2.37 (0.08)	659	5275	8.01

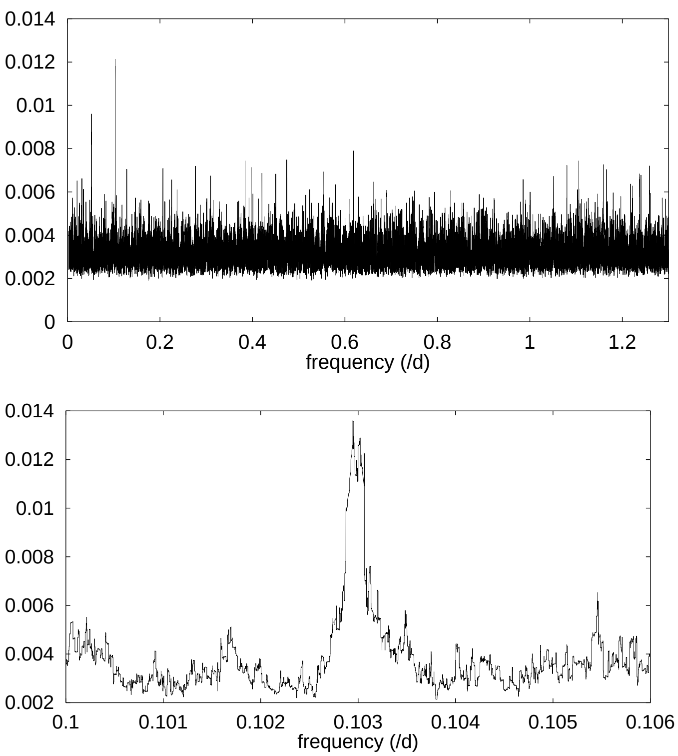

Fig. 3. Renson's periodograms for the measurements of the mean magnetic field modulus of HDE 318107 deduced from the wavelength shift between the blue components of the line Nd II $\lambda\,6145$. The parameter plotted is Renson's $1/\theta_1$. The horizontal axis is the frequency in d^{-1}. The lower plot details the peak area

$$m(t) = A + \sum_{i=1}^{I} B_i \cos\left(\frac{2\pi i\,(t-t_0)}{P} + \phi_i\right) \tag{1}$$

where m is the magnitude, P the fundamental period, I the total number of harmonics — generally 2 are sufficient —, t the time and t_0 the origin of time. The magnetic variations are also often smooth though, in some cases, large departures from harmonicity may exist (Mathys et al. 1997). The mean modulus

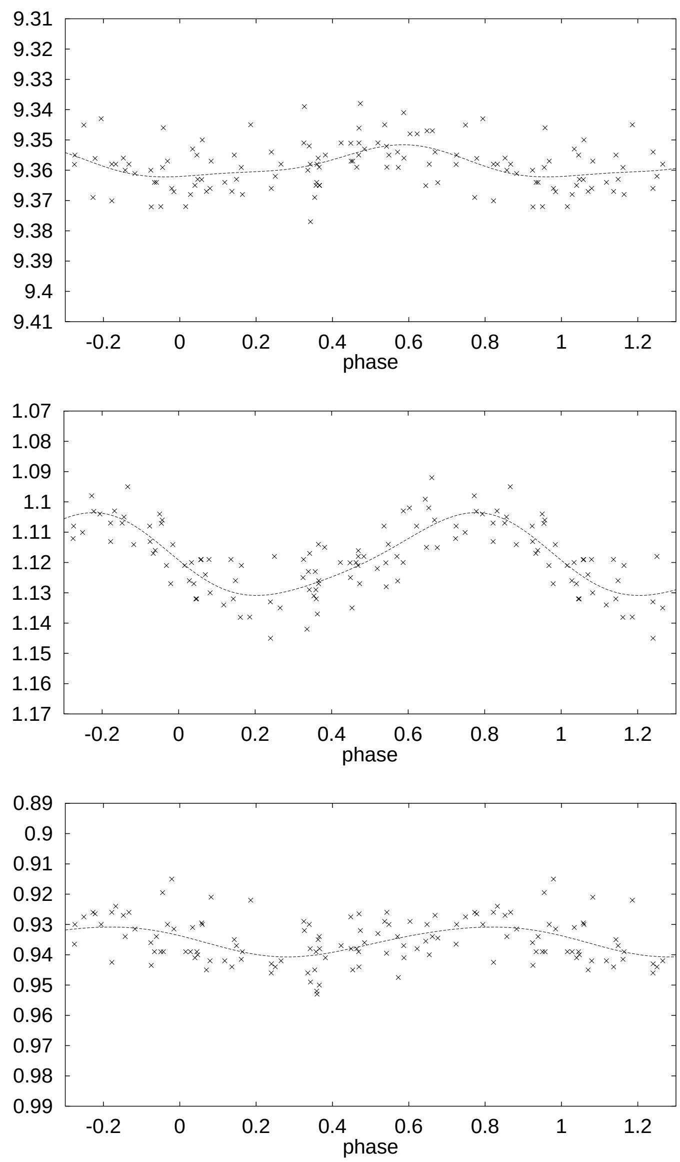

Fig. 4. Phase diagrams for the Geneva photometric indices of HDE 318107, V, $U-B$, $V-B$. Time origin is JD 2 440 000,0. The curves are second-order Fourier series

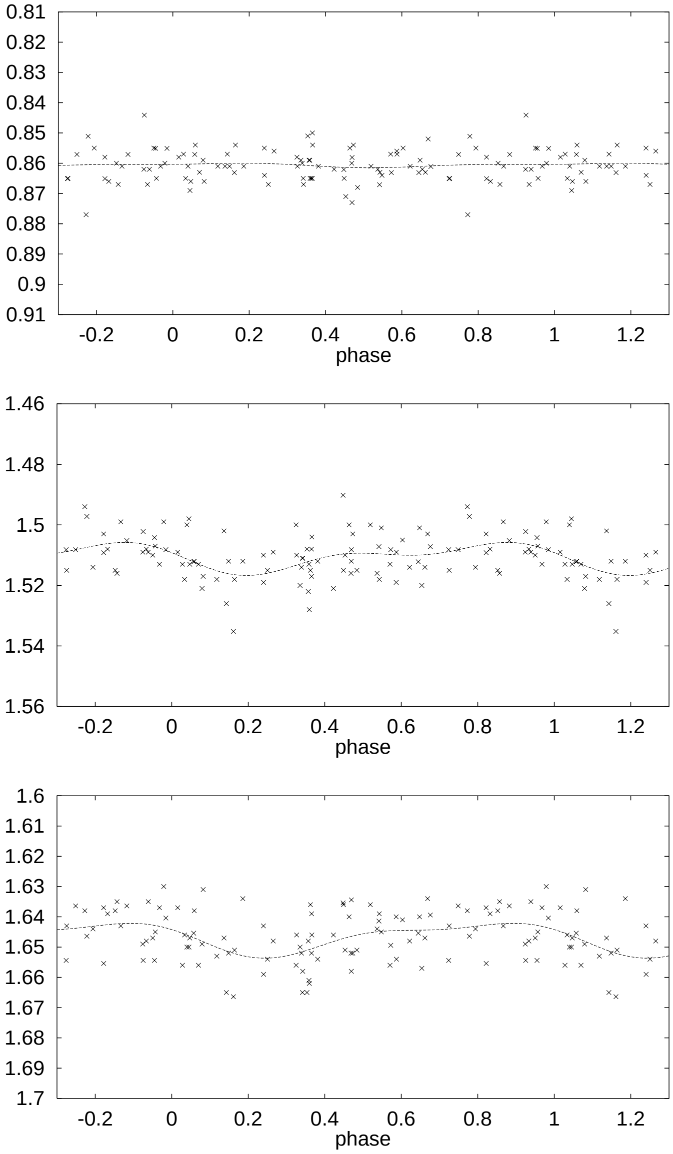

Fig. 5. Phase diagrams for the Geneva photometric indices $B1 - B$, $B2 - B$, $V1 - B$

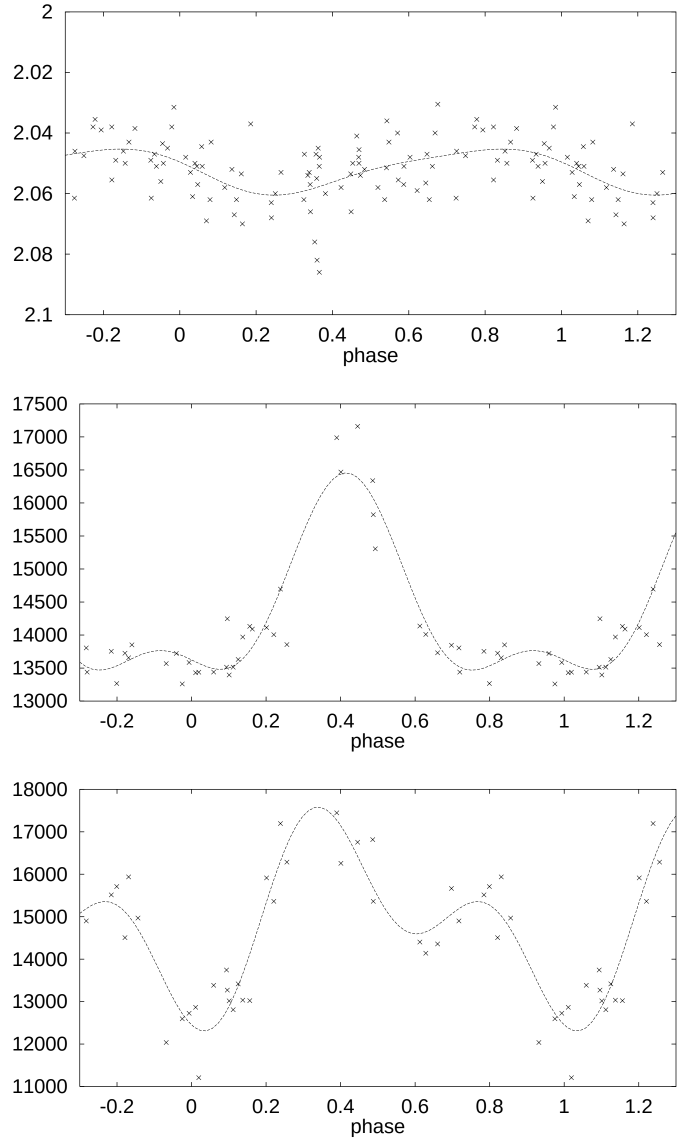

Fig. 6. Phase diagrams for the Geneva photometric index $G - B$, and for the mean magnetic field modulus deduced from Fe II and Nd III

$\langle H\rangle(t)$ obeys an equation similar to Eq. (1) with 2 or more components.

Least-squares fits show that a two-sine model is adequate for both photometric and magnetic measurements of HDE 318107. The corresponding parameters are listed in Table 2. The various phase diagrams (observations and analytical fit) are plotted in Figs. 4–6.

The phase diagrams show that variations do occur in most Geneva indices with total amplitudes between 0.01 and 0.03 mag. The only exception is $B1 - B$ which is often one of the least variable indices for Ap stars (see, e.g., Manfroid et al. 1998).

In the case of the mean field modulus, the two-sine approximation looks satisfactory, but the uncertainties on the measurements corresponding to the maximum of the field (around phase 0.4) are too large to allow us to decide whether a higher-order approximation is needed to represent the Fe II measurements. The Nd III data are adequately fitted by a second-order model, with a first harmonic significantly larger than for the Fe II data. The differences between the field modulus values determined from consideration of the Fe II and Nd III lines may presumably reflect different inhomogeneous distributions of these two ions over the stellar surface. However, for Nd III, the derived field values may also be affected by contributions to the line profile of hyperfine structure and of isotopic shifts (possibly also variable from point to point on the star), which have not been taken into account in the derivation of the field modulus. Discussion of these effects is beyond the scope of the present study.

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References

Burnet M., Rufener F., 1979, A&A 74, 54
Lindgren H., Gilliotte A., 1989, ESO Operating Manual No. 8
Manfroid J., Renson P., 1994, A&A 281, 73
Manfroid J., Mathys G., 1997, A&A 320, 497
Manfroid J., Burnet M., Renson P., 1998, A&AS 127, 201
Mathys G., 1989, Fundam. Cosmic Phys. 13, 143
Mathys G., 1994, Update to ESO Operating Manual No. 8
Mathys G., Hubrig S., Landstreet J.D., Lanz T., Manfroid J., 1997, A&AS 123, 353
North P., 1987, A&AS 69, 371
North P., Cramer N., 1981, Ap stars detected in open clusters by the Geneva photometry. In: Upper main sequence chemically peculiar stars, 23rd Liège Astrophys. Coll., p. 55
Renson P., 1978, A&A 63, 125
Renson P., 1980, A&A 92, 30