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ASTRONOMY AND ASTROPHYSICS

A spectroscopic study of the magnetic chemically peculiar star ν Fornacis

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Abstract. The magnetic chemically peculiar star ν Fornacis is known to be a periodic magnetic and luminosity variable. In the framework of the Oblique Rotator Model, ν For presents a mainly dipolar magnetic field, whose symmetry axis is tilted with respect to the rotational axis, non solar abundances and a non homogeneous distribution of elements on the stellar surface. The variability period is the stellar rotational period. Thus, spectral variabilities are also expected for this star.

By analysing the Hipparcos photometry and data from the literature, the luminosity period of ν For has been found equal to 1.89232 days. This value also represents the variability of the effective magnetic field measurements available in the literature.

To investigate the, up to now unknown, spectroscopic behaviour of ν For, we have performed time-resolved spectroscopy of this star in the 400–600 nm range. The equivalent widths are found to be also variable with the previous period and have been used to derive abundances.

Phase relations, between light, spectral and magnetic variabilities have been established. According to the hypothesis that light variations are due to a non-homogeneous distribution of elements on the stellar surface and high metallicity regions are responsible for blocking of ultraviolet flux and its redistribution towards the visible wavelengths, iron is the main origin of the light variability.

Key words: stars: abundances – stars: chemically peculiar – stars: individual: HD 12767 – stars: magnetic fields

1. Introduction

According to the Oblique Rotator Model, proposed by Babcock (1949) and Stibbs (1950), a magnetic Chemically Peculiar (CP) star consists of: a mainly dipolar magnetic field, whose axis is tilted with respect to the rotational one; non solar chemical abundances; and a non homogeneous distribution of elements on the stellar surface. In such a picture, the period of the observed magnetic, photometric and spectral variability is the stellar rotational period.

ν Fornacis (= HD 12767= HR 612= HIP 9677) was classified as an A0 silicon star by Bidelman & Böhm (1955), its photometric variability was discovered by Renson & Manfroid (1978) and the presence of a magnetic field suggested by Babcock (1958). Measurements of the effective magnetic field were obtained by Borra & Landstreet (1980).

In the previous picture of a CP star, ν For is also expected to present spectral variations. With the aim to determine their behaviour and relate spectral, light and magnetic variability, we have obtained time resolved spectra of ν For.

2. Observations and data reduction

Spectra of ν For have been obtained with the 2.1 m telescope at CASLEO with the REOSC echelle spectrograph that is *on loan from the Institut d'Astrophysique de Liège*. The spectra were acquired from January 16 to 24 and December 5 to 11, 1995. The S/N achieved was between 100 and 250. Details on observation and data reduction methods are given in Leone et al. (1997). Equivalent widths have been measured by a Gaussian fit of spectral lines after having removed possible continuum slope. Following Leone et al. (1995), we have estimated the error in the measured equivalent width by the relation:

$$\Delta EW = \frac{1}{2}\left(2\frac{v_e \sin i}{c}\lambda\right)\frac{1}{S/N} \qquad (1)$$

where the quantity in brackets is the total extension of the line as deduced from the rotational broadening. We have assumed the value $v_e \sin i = 50\,\mathrm{km\,s^{-1}}$ given by Leone & Manfrè (1996). Typically, $\Delta EW = 15$ mÅ.

3. Abundances

Leone & Manfrè (1996) have determined the effective temperature and gravity of ν For by spectrum synthesis analysis of the

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Table 1. Logarithm of the average abundances ($log(N/N_{Tot})$) and logarithm of the relative standard deviations of ν For. The standard deviations take into account the periodic variability of the abundances. When possible, abundances are compared with the values for B main sequence stars derived by Adelman (1986) and Gies & Lambert (1992) and with solar abundances (Kurucz priv. comm.).

Element	N. lines	ν For	A& B stars		Sun
			Adelman	Gies & Lambert	
He	1	-2.56± 0.23	-1.13	-1.04	-1.05
C	3	-4.45± 0.19	-3.45	-3.76	-3.48
Ne	1	-2.82± 0.07	-4.10	-3.99	-3.95
Mg	3	-5.55± 0.22	-4.30		-4.46
Si	4	-4.08± 0.30	-4.44	-4.38	-4.49
Cl	2	-4.61± 0.23			-6.54
Ca	1	-5.58± 0.38	-5.88		-5.68
Cr	3	-5.43± 0.11	-5.95		-6.37
Fe	5	-3.58± 0.19	-4.41	-4.24	-4.37
Ni	1	-4.21± 0.12	-6.61		-5.79

H_β region taking into account the effect of the enhanced metallicity. The ATLAS9 (Kurucz 1993) model atmosphere, whose H_β line profile matches the observations, has: T_{eff} = 13400 K, $\log g$ = 3.85 and a metal opacity scale equal to ten times the solar value.

With this model atmosphere, we have identified the lines in our spectra by using SYNTHE (Kurucz & Avrett 1981) and the atomic line list given by Kurucz (1993). Equivalent widths have been converted to abundances by using WIDTH9 (Kurucz & Avrett 1981) with the exception of the HeI587.6 and MgII448.1 nm lines which have been analysed according to Leone & Lanzafame (1998) and Leone et al. (1997) respectively.

Microturbulent velocity measured by forcing the unblended iron lines to give a single abundance value is equal to 2.9 km s^{-1} with a 0.8 km s^{-1} standard deviation. This value is slightly larger than the microturbulent velocity measured by Leone & Manfrè (1996) (2.1 km s^{-1}) and coincident with the value measured by Leone et al. (1997). The large value of the standard deviation is probably due to the line desaturation induced by the variable magnetic field.

Average derived abundances and associated standard deviations are listed in Table 1.

By comparing the derived abundances of ν For with the values of main sequence A and B-type stars given by Adelman (1986) and Gies & Lambert (1992), within errors: helium, carbon and magnesium are under-abundant; silicon, calcium and chromium abundances are not peculiar and the other considered elements are over-abundant.

The derived abundances for silicon and iron are close to the values given by Leone & Manfrè (1996): $\log(N_{Si}/N_{Tot}) = -4.01$ and $\log(N_{Fe}/N_{Tot}) = -3.36$.

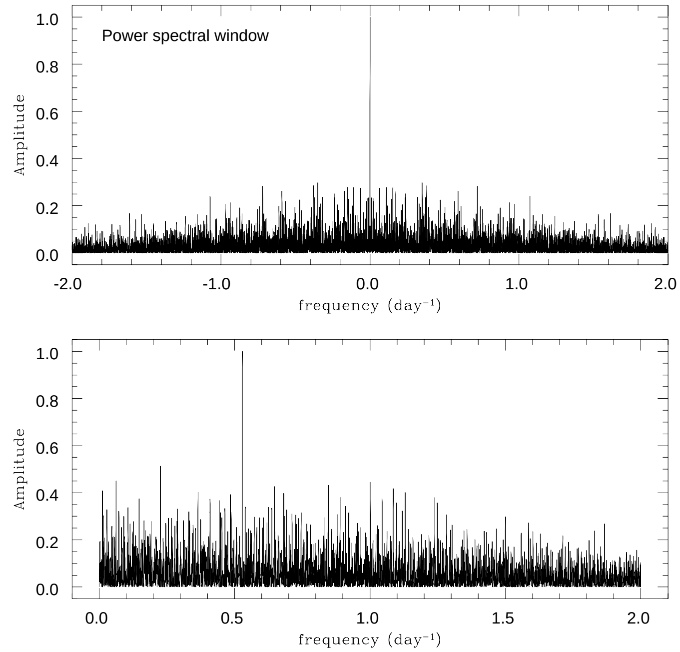

Fig. 1. Deeming (1975) power-spectrum of Hipparcos data and associated spectral window. Amplitudes have been normalised to the maximum value.

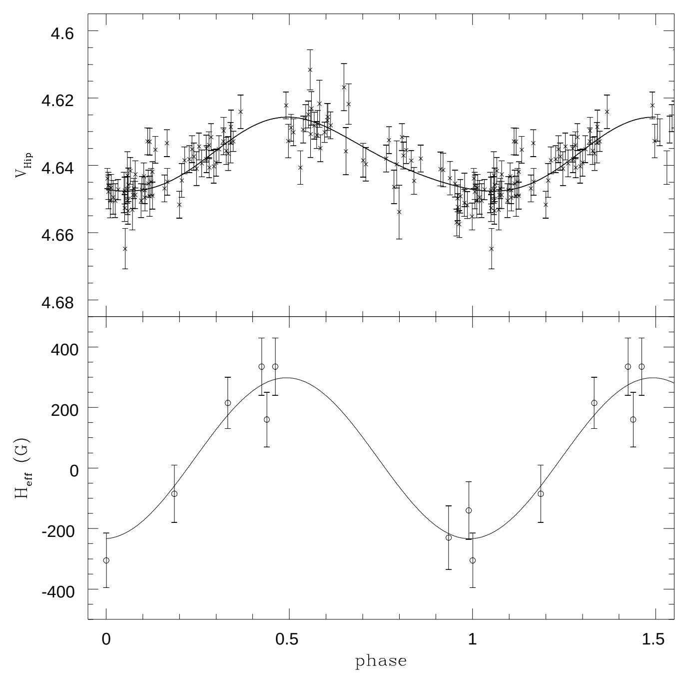

Fig. 2. Hipparcos photometry and effective magnetic field measurements by Borra & Landstreet (1980) phased with the ephemeris (3). Solid lines represent a fit of magnetic data assuming a sine function variation and a fit of magnitudes assuming a double wave variation (Eq. (2)).

4. Photometric, spectral and magnetic variability

According to Renson & Manfroid (1978), the photometric variability period of ν For is P = 1.89 days. Borra & Landstreet (1980) found their measurements of the effective magnetic field appear to be variable with the periods 1.877, 1.892 and 1.908. With this period, the photometric curves of Renson & Manfroid (1978) vary as the function (Mathys & Manfroid 1985):

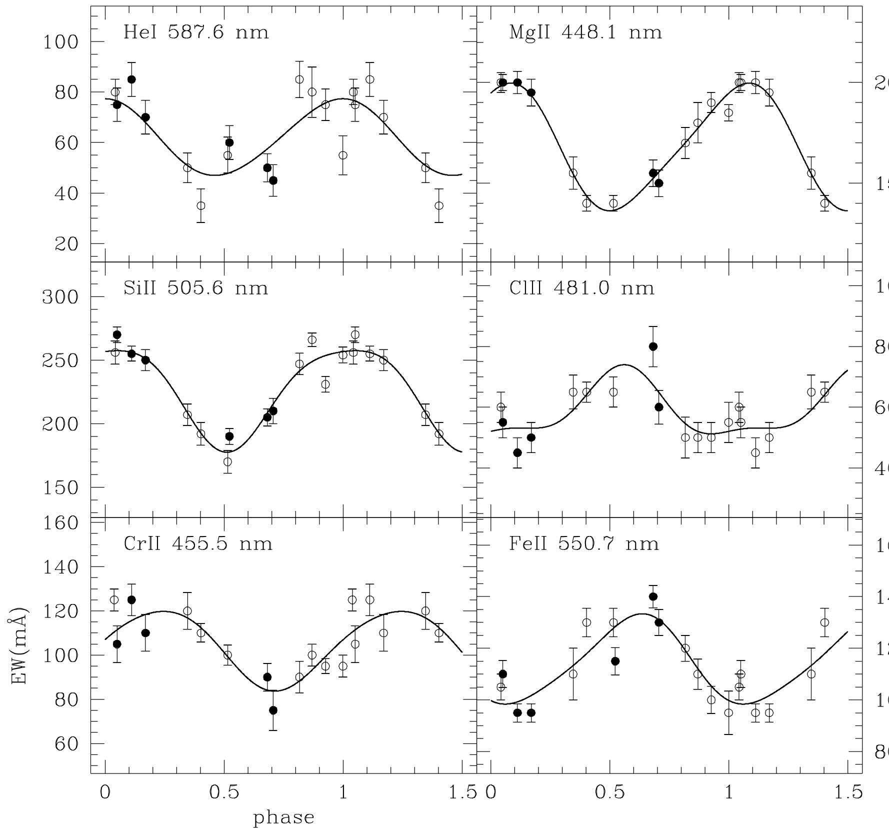

Fig. 3. Equivalent width variations. Open circles refer to January and filled circles to December 1995 observations. Errorbars are equal to two times the error in the equivalent width measurements as given by Eq. (1). Solid lines represent a fit of data assuming a double wave variation (Eq. (2)).

$$m = A_0 \;\; + A_1 \sin\left(2\pi\frac{(t-t_0)}{P} + \phi_1\right) \qquad (2)$$
$$\qquad + A_2 \sin\left(2\pi\frac{2(t-t_0)}{P} + \phi_2\right)$$

To determine the value of P, we have performed a least-square fitting with the previous function of the magnitudes ($V_{\rm Hip}$) of ν For measured with the Hipparcos satellite (European Space Agency 1997). The resulting period is 1.8925±0.0002 days, the given error represents the change on the period that increases the χ^2 of a unit. Almost the same period value (1.8924±0.0004) is obtained by using the Phase Dispersion Minimising routine distributed with IRAF package. Fig. 1 shows the Deeming (1975) power-spectrum graph of Hipparcos data and the associated spectral window. It is clear that aliases can be excluded. Peak position is at 1.8927 days, confirming the previous period value.

Unfortunately Renson & Manfroid (1978) photometric data have not been published, however from Mathys & Manfroid's (1985) fitting of these data, we find that on JD = 2 443 456.147 there was a photometric minimum. Thus, we adopted the ephemeris:

$$JD({\rm V_{Hip}(min)}) = 2\,443\,456.147 \;\; + \;\; 1.89232\,E \qquad (3)$$
$$\pm 0.150 \qquad \pm 0.00020$$

that is, within our fitting error, the period which forces the Hipparcos and Renson & Manfroid (1978) light curves to have the minimum at the same phase.

With this ephemeris, we have phased the Hipparcos photometry, the Borra & Landstreet (1980) measurements of the effective magnetic field (Fig. 2) and the equivalent widths, measured here, of the strongest lines (Fig. 3). We note that the light maximum shows the phase of the magnetic positive maximum.

As is expected for a magnetic chemically peculiar star, ν For is characterised by spectral variability. Fig. 3 shows the equivalent width variations, phased with the previous ephemeris. The variability of iron and chlorine lines is in phase with the light variability. In contrast, helium, magnesium, silicon and chromium lines are out of phase.

Borra & Landstreet observations were obtained from JD = 2 443 498.581 to 2 443 741.888. They were so close to the light minimum instant determined here that a negligible error (0.005) is expected for the phase relation between light curves and magnetic variation. Because of the time interval between Hipparcos photometry and our spectroscopic observations, a 0.1 error is possible for the previous phase relations between the light/magnetic and spectral variations.

5. Discussion and conclusion

By analysing the Hipparcos photometry of the magnetic silicon star ν For and forcing them to be in phase with Renson & Manfroid (1978) data, we have found that the variability period of ν For is 1.89232 days.

Time-resolved spectra have been obtained in the 400–600 nm range in January and December 1995 to investigate the spectral behaviour of this star. We have found that light curves are in phase with the magnetic field and with the strength of chlorine and iron lines. Out of phase is the variability of helium, magnesium, silicon and chromium lines.

In the hypothesis suggested by Leckrone (1974) that light variations are due to metal rich regions where the ultraviolet flux is blocked and then redistributed toward the visible range, we conclude that in the case of ν For, iron is the main factor in the flux redistribution.

Assuming that ν For is a rigid rotator, the angle i between the rotational axis and the line of sight, the stellar radius R_*, the equatorial rotational velocity ($v_{\rm e}$) and the rotational period are related by the equation:

$$v_{\rm e} \sin\, i = 50.6 \frac{R_* \sin\, i}{P}$$

for the project rotational velocity $50{\pm}5\,{\rm km\,s^{-1}}$ measured by Leone & Manfrè (1996) spectra, the stellar radius ($3.2{\pm}0.4{\rm R_\odot}$) given by North (1998) and the value of the rotational period determined here, we found that the rotational axis and the line of sight forms a $36^o \pm 9^o$ angle.

In the hypothesis of dipolar magnetic field, the angle (β) between the rotational axis and the dipole axis is given from the relation (Preston 1971):

$$\tan\beta \tan i = \frac{1-r}{1+r}$$

where r is the ratio of the minimum and maximum observed values of the effective magnetic field. The polar strength of the magnetic field (H_p) comes from Schwarzschild (1950) relation:

$$H_{\rm eff}(min, max) = 0.316 H_p \cos(\beta \pm i).$$

Borra & Landstreet (1980) measurements of the effective magnetic field with $r = -0.78$ are consistent with a $83^o \pm 3^o$ inclination of dipole axis with respect to the rotational axis and a polar magnetic field of ~ 1.3 kG.

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