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ASTRONOMY AND ASTROPHYSICS

Evolved, single, slowly rotating … but magnetically active

The G8-giant HR 1362 = EK Eridani revisited

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Abstract. We rediscuss the unusual case of the slowly rotating late-type giant HR 1362, which exhibits a very unusual high level of magnetic activity. New BVRI photometry from two robotic telescopes from 1991 through 1998 together with previously published photometric data gives a very precise photometric period of 306.9±0.4 days. With the aid of high-resolution (R=120,000) optical spectra and the Hipparcos parallax we redetermine the absolute parameters of HR 1362 and find it to be a single G8IV-III star of 14 $L_\odot$ and a mass of 1.85 $M_\odot$ with $T_{\rm eff}$=5125 K, $\log g$=3.25, and solar abundances. Lithium is not significantly different from solar and we obtain $\log n$(Li)=1.14 from a detailed spectrum synthesis including both isotopes at 6708 Å. $V \sin i$ and macroturbulence are determined from fits of disk-integrated models to the observed line profiles as well as their Fourier transforms and are 1.5±0.5 km s^{-1} and ≈5 km s^{-1}, respectively. The minimum radius from $v \sin i$ and $P_{\rm rot}$ is only then in agreement with the spectral classification and the bolometric luminosity from the Hipparcos parallax if the inclination of the stellar rotation axis is nearly 90°. We concur with the arguments of Stępień (1993) that HR 1362 is an evolved Ap star, and therefore the magnetic field is possibly of galactic origin rather than dynamo generated.

Key words: stars: activity – stars: individual: HR 1362 – stars: late-type – stars: rotation – stars: starspots

1. Introduction

HR 1362=EK Eri exhibits photometric variations with the unusually long period of ≈300 days. Its spectral lines are barely rotationally broadened indicating that the long photometric period could be the stellar rotation period. There is no evidence for duplicity, and yet the star shows strong magnetic activity when compared with the empirical rotation versus activity relation of other cool giants, including the RS CVn binaries (Strassmeier et al. 1990, 1994). HR 1362 has recently been detected as an extreme ultraviolet source by EUVE (Lampton et al. 1997) and by ROSAT (Kreysing et al. 1995).

Its spectral classification of G8 suggests a sufficiently deep outer convection zone for photospheric starspots and their magnetic fields to develop, although a search for optical flares in the Johnson U-band did not reveal any detectable events (Henry & Newsom 1996). The usual interpretation that the photometric period is the stellar rotation period made HR 1362 a test case for stellar dynamo theories because it is generally accepted that a dynamo process can not switch on if a critical angular velocity is not reached or, it ceases its operation once the star is slowed down due to the envelope expansion after hydrogen core exhaution. In any case, if the photometric period is indeed the rotation period, HR 1362 should not be magnetically active because even if the dynamo can operate for any non-zero rotation rate, it is expected to be extremely inefficient for very low rotation rates. We see three possible scenarios to get out of this puzzle. First, the photometric period may not be the rotation period but a spot-cycle period and the star is seen nearly pole on. Second, as put forward by Stępień (1993), the star is an evolved Ap star and its magnetic field is therefore thought to be of intergalactic (primordial) origin and not due to a dynamo process. How such a field topology would cause the observed 0.18-mag photometric amplitude remains to be determined. Third, an efficient small-scale turbulent dynamo could be in place that works even when the angular velocity $\Omega \to 0$.

In this paper we analyse 20 years of continuous V-band photometry, mostly obtained with our robotic telescopes at Fairborn Observatory in Arizona and, together with high-resolution (R=120,000), high-S/N optical spectra and the recent results from the *Hipparcos* mission, we rediscuss the physical properties of HR 1362 and derive its evolutionary status. The final section (Sect. 5) presents our conclusions.

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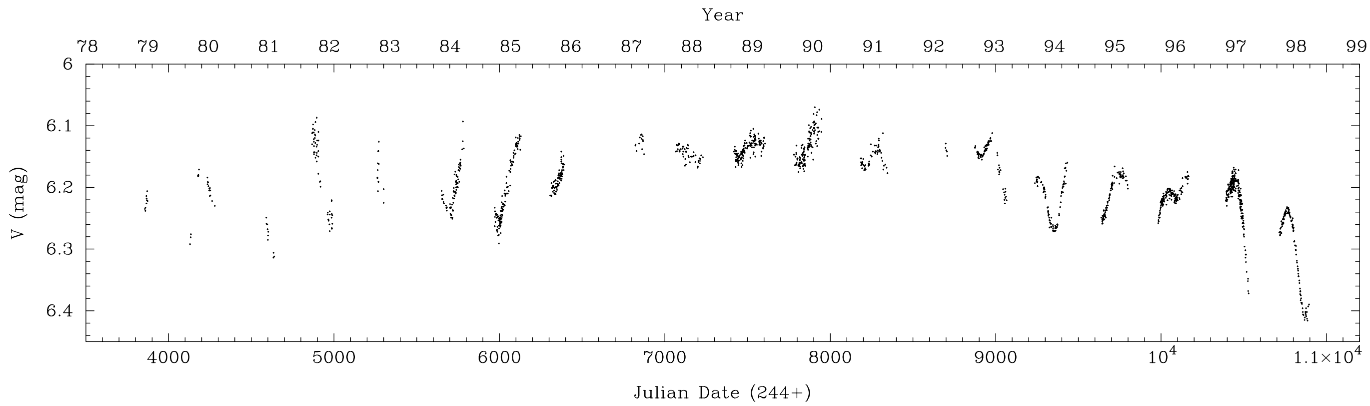

Fig. 1. Long-term V light curve of HR 1362 from 1978 through early 1998. Note the small amplitude when the system is brightest in around 1987–1991 and the large amplitude when the system is faintest. Such a behavior indicates that starspots could be the cause of the light variability.

2. New observations and photometric history

2.1. Photometry

Photometry prior to 1990 was previously analysed by Strassmeier et al. (1990) and consisted of data from various sources including Lloyd-Evans & Koen (1987), Derman et al. (1989), Boyd et al. (1985) and Strassmeier & Hall (1988). New Johnson BV-band photometry was gathered with the 0.4m Vanderbilt/TSU robotic telescope (VU/TSU APT, Henry 1995) at Fairborn Observatory between 1991 and 1998. From late 1996 on, $V(RI)_c$ photometry was additionally obtained with Amadeus, one of the two 0.75m Vienna Observatory "Wolfgang-Amadeus" twin automatic photoelectric telescopes (W-A APT, Strassmeier et al. 1997a). Both telescopes are now located at Fairborn Observatory in Washington Camp in southern Arizona. Since 1991, 1232 new V-data points were acquired by the two APTs as well as 975 B and 286 RI observations, each the mean of three measurements of the variable and the comparison star. The W-A APT data were transformed to the Johnson-Cousins $V(RI)_c$ system and used HD 27179 (V=$5\overset{m}{.}95$, B-V=1.078, V-I=1.0, ESA 1997; V=$5\overset{m}{.}94$, B-V=1.08, U-B=0.94, Nicolet 1978) as the comparison star and HD 27861 as the check star. The VU/TSU-APT data were transformed to the Johnson UBV system and used the same comparison and check stars. Previous differential data from the literature were shifted to the absolute scale by adding the brightness of the comparison star. The standard error of a nightly mean from the overall seasonal mean for the VU/TSU-APT data significantly improved from 1992 on and was thereafter – for both APTs – between $0\overset{m}{.}004$–$0\overset{m}{.}002$ in V and B, and $0\overset{m}{.}005$ in R_c and I_c.

2.2. Spectroscopy

Spectroscopic observations were obtained at Kitt Peak National Observatory (KPNO) with the coudé feed telescope during runs in December 1997 and January 1998, and at the Canada-France-Hawaii telescope (CFHT) in October 1997. The KPNO data were obtained either with a 800^2 TI CCD (TI-5 chip, 15 μ pixels) or a 3000×1000 CCD (Ford F3KB chip, 15 μ pixels) with grating A, camera 5 and the long collimator resulting in a resolving power of 38,000 at 6420 Å with the TI-5 CCD, and 32,000 with the F3KB CCD. The CFHT spectra were obtained with the Gecko coudé spectrograph and the Loral 2048^2 CCD (15 μ pixels) with an effective resolving power of 120,000 at 6710 Å. The signal-to-noise ratio of these spectra is 500:1. Representative plots of the wavelength regions of interest are shown later in Fig. 4. All data were reduced with IRAF and included bias subtraction, flat fielding and optimized aperture extraction. To ensure an accurate wavelength calibration, frequent Th-Ar comparison spectra and spectra of bright radial-velocity standards were obtained nightly.

3. The light-curve variability and its periodicity

Fig. 1 shows all V-band photometry of HR 1362 since the discovery of its light variability in 1978 by Lloyd-Evans & Koen (1987). These data have been subjected to a least-squares periodogram analysis. After removing the long-term trend in the average light level by prewhitening with three periods of 5995, 2211, and 1217 days, a single strong minimum of the squares of the residuals is obtained with a period of 306.9$\pm$0.4 days (Fig. 2). We then divided and performed a period search on two parts of the V-band data, one prior to JD 2,446,500 with 369 data points and one after JD 2,448,500 with 725 data points. Note that these two sets are the large-amplitude parts from Fig. 1 and bracket the low-amplitude, high-brightness state in the years 1987 through 1991. Thus, they might represent two different spot cycles. The photometric periods from these two intervals, each about 2500 days long, were 311$\pm$5 days and 294$\pm$2 days, respectively.

The most recent $BV(I)_c$ photometry from 1997 September through 1998 April is used to search for short-term changes possibly due to intrinsic variations of the spot distribution or any other short-period (few days) and low-amplitude signal. Note that the light curve shown in Fig. 3 covers the entire observing season, i.e. 187 consecutive nights, and was obtained with a sampling of up to three points per night. These data were first prewhitened with the obvious 294-day period from

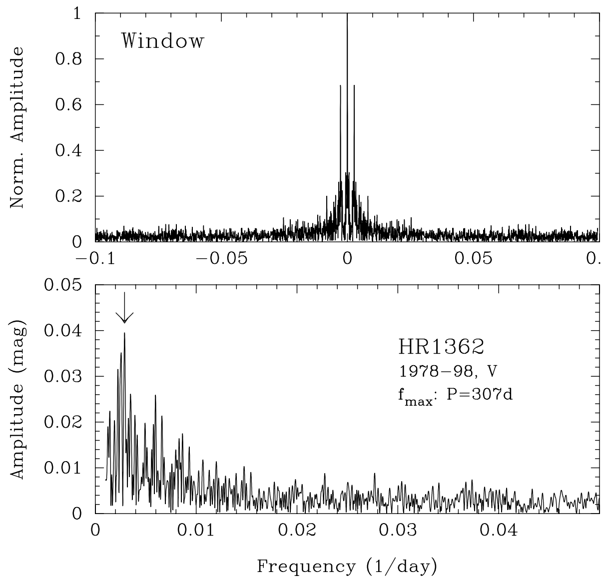

Fig. 2. Periodogram from the combined V-band data of HR 1362 from 1978–1998 (*lower panel*). The *upper panel* shows the window function with aliasing periods centered around multiples of one year.

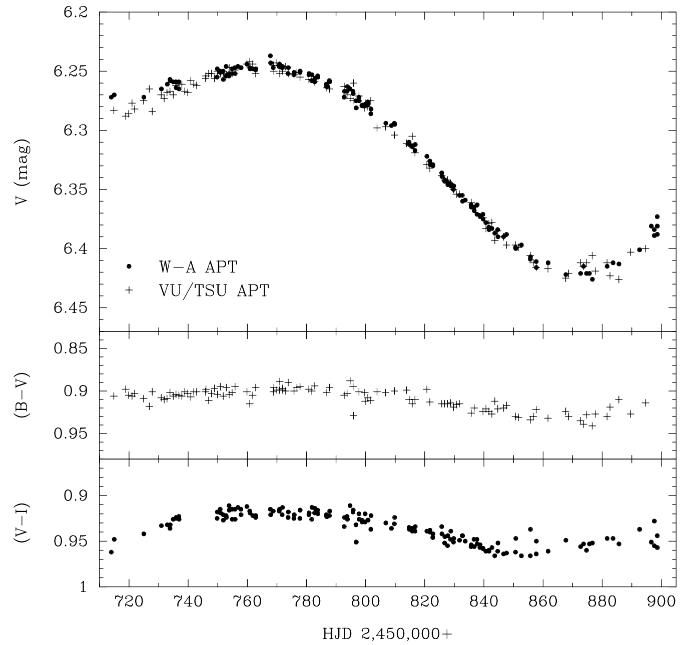

Fig. 3. (*Top*): The V magnitude observations during the entire observing season 1997/98. $(Middle)$: the B-V color and, (*bottom*): the V-I$_c$ color variations. The fact that the star becomes redder when fainter agrees with the cool starspot model.

the Fourier analysis and then again subjected to a least-squares period search up to the Nyquist frequency. No significant variability above a noise level of 4 mmag in the frequency domain was found.

On the seasonal time scale, the 1997/98 V magnitudes and colors are clearly correlated. The star becomes redder when it is fainter (see Fig. 3), in agreement with the (cool) starspot hypothesis. The peak-to-peak V, V-I, and B-V amplitudes were $0\overset{\mathrm{m}}{.}178\pm0.005$, $0\overset{\mathrm{m}}{.}050\pm0.003$, and $0\overset{\mathrm{m}}{.}040\pm0.003$, respectively, and we note that such a relatively large V-I amplitude is typically only seen for the most active and most spotted stars (e.g. Cutispoto 1997, Strassmeier et al. 1997b). The relation between long-term and short-term variability in a sample of 104 solar-type stars was recently investigated by Lockwood et al. (1997). They found that most of the stars with short-term variations greater than 3 mmag also have long-term variations but not vice versa. The most plausible explanation suggested by Lockwood et al. was spot development and evolution on stars whose rotation axes lie nearly in the line of sight, resulting in a loss of a significant rotational-modulation signature.

4. Absolute parameters for HR 1362

4.1. Brightness and luminosity

The trigonometric parallax obtained by Hipparcos (ESA 1997) constrains HR 1362 to a distance of 63±3 pc. With the brightest, i.e. presumably unspotted, V magnitude of $6\overset{\mathrm{m}}{.}08\pm0.01$, observed in 1981 and again in 1990, the absolute visual magnitude of HR 1362 is $M_{\rm V} = +2\overset{\mathrm{m}}{.}01\pm0.10$. Interstellar absorption was considered to be $A_V = R\,E_{\rm B-V} \approx 0.07$ from an average of the b-y excess of $0\overset{\mathrm{m}}{.}012$(:) measured by Eggen (1989), and in B-V of $0\overset{\mathrm{m}}{.}03$ given by Eggen & Iben (1989). R was adopted to be 3.20 for $E_{\rm b-y}$, and 3.39 for $E_{\rm B-V}$, to account for the bandwidth effect. The absolute brightness of $+2\overset{\mathrm{m}}{.}0$ clearly confirms the giant IV-III luminosity classification already suggested in our previous paper (Strassmeier et al. 1990). The dereddened Hipparcos B-V color of $0\overset{\mathrm{m}}{.}878\pm0.002$ obtained from transforming $E(b-y)$ to $E(B-V)$ and adopting the average of the two values of $0\overset{\mathrm{m}}{.}023$, indicates a G7IV-III star with $T_{\rm eff}$ of 5140 K according to the tables of Gray (1992), or 5260 K according to the more recent color-temperature transformation of Flower (1996). With a bolometric correction of B.C.=−0.206 from Flower (1996), the bolometric magnitude is $+1\overset{\mathrm{m}}{.}80$, and with an absolute magnitude for the Sun of $M_{\rm bol,\odot} = +4\overset{\mathrm{m}}{.}64$ (Schmidt-Kaler 1982), the luminosity of HR 1362 must be approximately 14 $L_\odot$. Table 1 summarizes the absolute parameters some of which are determined in the following sections.

4.2. Space-motion components

With the Hipparcos parallax and an average radial velocity from the literature (6.6 km s^{-1}; see Strassmeier et al. 1990) we redetermine the (U,V,W) space-motion components relative to the Sun in a right-handed coordinate system to be –4.0±0.9, –31.4±1.1, +9.1±1.2 km s^{-1}. These velocities supersede the ones given by Eggen (1989) and place HR 1362 in the (U,V)-diagram within the borders representative for young disk stars. As such, HR 1362 is not likely to be a FK Comae-type member of the old HR 1614 moving group as suggested by Eggen (1989) and Eggen & Iben (1989). Having space motions similar to the (U,V) velocities of the Pleiades supercluster additionally argues for its relative youth.

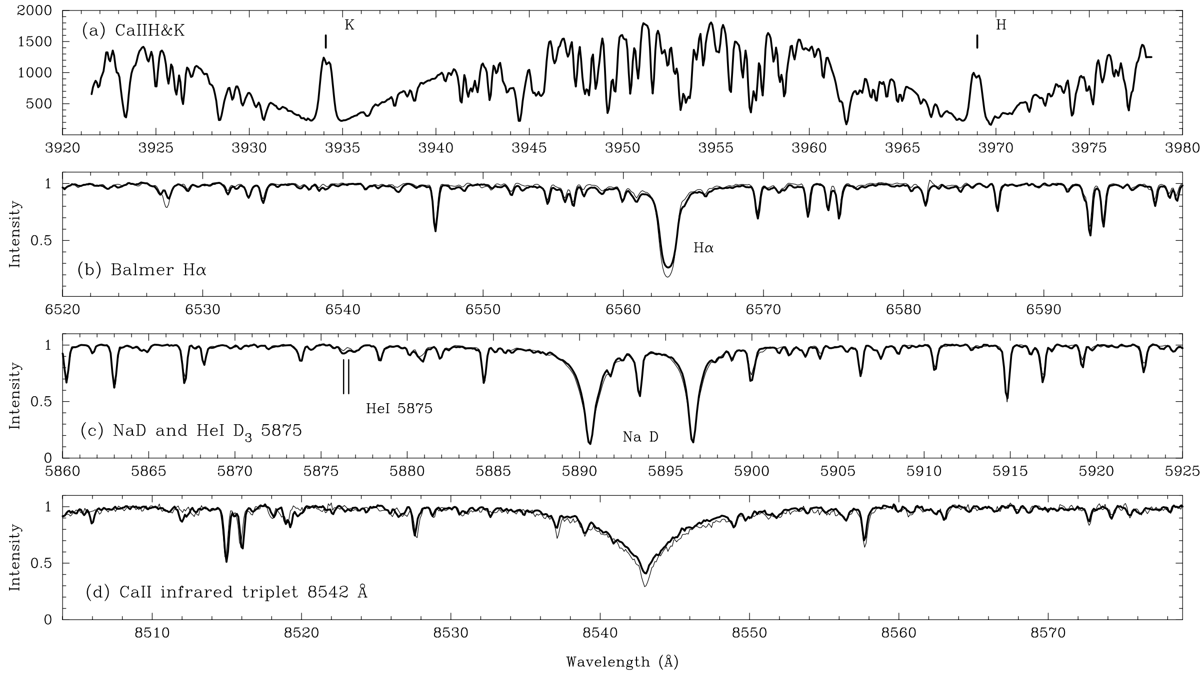

Fig. 4a–d. Representative spectra of HR 1362 for several wavelength regions of interest (thick lines). **a** the singly ionized calcium H and K lines at 3934 and 3969 Å, **b** the Balmer Hα line, **c** the NaD and He I doublet, and **d** the calcium infrared triplet line at 8543 Å. The thin lines are spectra of the MK-standard star 11 LMi classified as G8IV-V (Keenan & McNeil 1989). The strong H&K emission is obvious but also note the filled in line cores of Hα and Ca II 8542.

Table 1. Astrophysical data for HR 1362

Parameter	Value
Spectral type	G8IV-III
Distance (Hipparcos)	63±3 pc
M_V	+2.^{m}01±0.10
Luminosity	13.6±1.3 $L_\odot$
$\log g$	3.25±0.25
$T_{\rm eff}$	5125±50 K
(B-V)$_{\rm Hipparcos}$	0.^{m}901±0.002
(V-I)$_{\rm Hipparcos}$	0.^{m}92±0.04
A_V	0.07 (adopted)
$v \sin i$	1.5±0.5 km s^{-1}
Photometric period	306.9±0.4 days
Min. radius (from $P\, v \sin i$)	8.7±2.9 $R_\odot$
Radius (from Hipparcos)	4.7±0.3 $R_\odot$
Mass	1.85 $M_\odot$
$\log n$(Li)	1.14±0.04
Fe,Ca,V abundance	solar

4.3. Effective temperature and gravity

Detailed synthesis of a high S/N, $\lambda/\Delta\lambda$=120,000 CFHT spectrum is used to determine the lithium abundance, the effective temperature, gravity, and the rotational broadening of HR 1362. Model atmospheres are taken from the grid provided by Kurucz (1993) and atomic line data are from VALD (Piskunov et al. 1995). Unfortunately, some of the wavelengths and $\log gf$-values in the 6700-Å region are still significantly in error, especially when very small lines ($W_\lambda \leq$20 mÅ) or e.g. silicon lines are to be synthesized. A fit to the solar spectrum from the standard Kurucz (1991) model ($T_{\rm eff} = 5777$ K, $\log g = 4.44$, Y=0.1) with $v_{\rm micro} = 1.0\,{\rm km\,s^{-1}}$ and the abundances from Grevesse & Anders (1991) was used to verify and/or correct the appropriate $\log gf$ values.

Once the correct line list was generated, we computed synthetic spectra from a grid of ($T_{\rm eff}$,$\log g$)-models with 5000, 5125, 5250 K and 3.0, 3.25, and 3.5 to refine these two parameters. Microturbulence was assumed to be 2.0 km s^{-1} for HR 1362. The best fit from a comparison in the 6690–6740 wavelength region is obtained with the 5125 and 3.25 model and solar abundances. Typical uncertainties are ±50 K in $T_{\rm eff}$ and ±0.25 in $\log g$. On this basis we suggest that a G8IV-III classification is most appropriate. This also agrees with the fact that a slightly cooler but higher gravity atmosphere ($T_{\rm eff} = 5000$/$\log g = 3.5$) results in a better fit of the photospheric absorption line profiles than a hotter but lower-gravity (5250/3.0) model. Furthermore, a single blue-wavelength exposure shows a moderately strong Sr II 4077-Å line typically indicative of a normal giant to subgiant spectrum (Gray & Garrison 1989).

4.4. Lithium abundance

The nominal Kurucz (1993) $\log gf$ values for ^{6}Li and ^{7}Li are -0.009 and -0.309, respectively, and a fit to the solar 6707.8-Å spectral region with these gf's results in the relatively low solar lithium abundance of 1.00. The solar photospheric Li abundance listed by Grevesse & Anders (1991) is 1.16±0.1, and a value

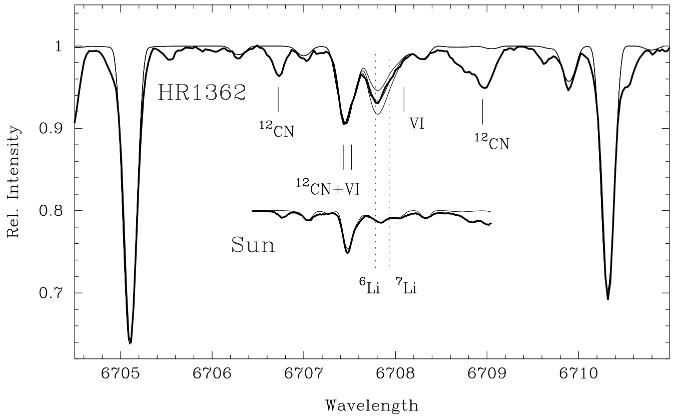

Fig. 5. Spectrum synthesis for the Li I lines at 6707.8 for HR 1362 and the Sun (insert below). The thick line is the observed spectrum and the thin lines are synthetic spectra for three values of lithium abundance; $\log n$(Li)= 1.04 (top line), 1.14 (middle line), and 1.24 (bottom line). The solar spectrum has been offset by -0.2 in continuum for better visibility. The combined equivalent width of ^{6}Li and ^{7}Li for HR 1362 is 21 mÅ as compared to $\leq$ 5 mÅ for ϵ Eri (K2V) and 3 mÅ for the Sun.

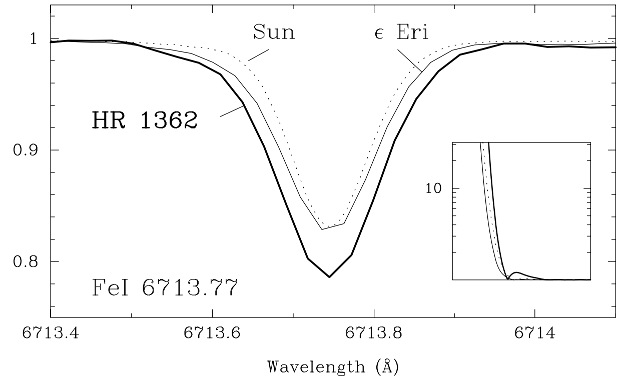

Fig. 6. A comparison of the unblended Fe I 6713.7-Å line profile of HR 1362 (G8IV-III, thick line) with ϵ Eri (K2V, thin line) and the Sun (dotted line). The spectral resolution for the HR 1362 and ϵ Eri spectra is 120,000 while the solar spectrum is from the NSO atlas and has R≈600,000. Obviously, the total line broadening for ϵ Eri is significantly smaller than for HR 1362 but its $v \sin i$ is larger because ϵ Eri is cooler and of higher gravity. The insert shows the Fourier transforms of the three line profiles after removal of the thermal and the instrumental profile, indicating smaller $v \sin i$ for HR 1362 compared to the Sun (2.0 km s^{-1}) and ϵ Eri (2.5 km s^{-1}).

of 1.00 would be outside their error limits. We thus adopted a solar abundance that is still within the errors of the Grevesse & Anders value but just lower than the nominal value by one half of its error bar, i.e. $\log n$(Li)$_\odot$=1.11. Then we altered the $\log gf$'s for ^{6}Li and ^{7}Li to find the best match to the observed solar spectrum. The best fitting synthetic spectrum was simply chosen by eye and is shown in the insert of Fig. 5 along with the observed solar spectrum from Kurucz et al. (1984). The required $\log gf$'s were -0.102 and -0.360 for ^{6}Li and ^{7}Li, respectively. Note that fixing the solar lithium abundance to 1.16 results in prohibitively large changes of the gf values, which indicates that wrongly synthesized blends cause the uncertainties. The wavelengths and transition probabilities for the ^{12}CN feature at 6707.529 and the Fe I 6707.443 line that both blend with the Li I line were taken from Gilroy (1989). Synthetic spectra of the lithium region are then compared to our CFHT spectrum of HR 1362. Fig. 5 shows a comparison with three values of the Li abundance. The best fit is achieved with $\log n$(Li)=1.14±0.04, very close to the nominal solar value. Although in general agreement with our result, the recent determinations by Randich et al. (1993) ($\log n$(Li)=1.05 with $T_{\rm eff}$=5100/$\log g$=3.7) and Fekel & Balachandran (1993) ($\log n$(Li)=1.0 with 5200/3.0) are in good agreement, being smaller by ≈0.1 dex, but are superseded because of our superior spectral resolution. However, intrinsic long-term variations of the lithium equivalent width of the order of, say, 10% are certainly possible and can not be excluded *a priori* unless the star is monitored continuously.

4.5. Rotational broadening and stellar radius

$V \sin i$ was also determined from spectrum synthesis using mainly moderately strong iron lines in the 6690–6740 Å region and an instrumental profile approximated by a Gaussian with the FWHM of weak Th-Ar comparison lines. Model profiles were then convolved with this Gaussian and verified by first fitting the solar spectrum. Macroturbulence is implicitely accounted for by integration over the visible hemisphere of Doppler-shifted local line intensities (for the procedure and a description of the synthesis code see Stift & Strassmeier 1995 and references therein). A model with $v_{\rm macro}$=5 km s^{-1} and $v_{\rm micro}$=2 km s^{-1} was adopted for HR 1362 according to average values suggested by Gray (1992) and yields $v \sin i = 1.5 \pm 0.5$ km s^{-1}. A second method made use of the information of the Fourier transform of the observed profiles and yields the ratio of $v \sin i/v_{\rm macro}$ following the recipes in Gray (1992). In this case, the instrumental profile and the thermal profile from an appropriate model atmosphere were divided out in the Fourier domain and the residual transform then compared with the disk integrated and transformed model profile. This procedure allows an estimate for the ratio $v \sin i/v_{\rm macro}$ of 0.5±0.3, its uncertainty being mostly due to the possible range of microturbulences and abundances of the thermal profile.

Our best values for $v \sin i$ and $v_{\rm macro}$ are then 1.5±0.5 km s^{-1} and 5±1 km s^{-1}, respectively, in agreement with our previous estimate of 2±2 km s^{-1} and 3 km s^{-1} from much lower resolution KPNO spectra (Strassmeier et al. 1990) but significantly smaller than the $v \sin i$ of 6 km s^{-1} by Pallavicini et al. (1992) and $\leq$ 8 km s^{-1} by Randich et al. (1993) from ESO spectra. A recent CORAVEL measure is listed in the catalog of DeMedeiros et al. (1997) with 1.0±1 km s^{-1} and is formally consistent with our value but 50% smaller. Therefore, we first measured a spectrum of the well-studied K2-dwarf ϵ Eri ($T_{\rm eff}$=5000 K, $\log g$=4.6, $v_{\rm macro}$=2 km s^{-1}), taken at CFHT in the same night as HR 1362 with identical resolution and S/N, and obtained $v \sin i$ = 2.5±0.5 km s^{-1} in overall agreement with Gray's (1984) value of 2.2±0.6 and Fekel's (1997) value of 2.0±(0.5–1.0) km s^{-1} (Fig. 6 shows a comparison of the line broadening of the two stars). Again, these values are slightly out of tune with the nominal CORAVEL value for ϵ Eri of 1.5±2.0 km s^{-1}, but well within their relatively large error bars. This basically confirms our measuring procedures but also emphasizes the uncertainties once the stellar $v \sin i$ is approaching the solar value. We note that our error of 0.5 km s^{-1} is the rms from repeated measurements of several weak and moderately strong lines and takes into account an error of ±50 K and ±0.25 for $T_{\rm eff}$ and $\log g$, respectively but no Zeeman broadening. Also, no errors were assumed for the macro- and microturbulence and all synthesis was carried out with a fixed solar iron abundance of 7.67 (relative to $\log n({\rm H})$=12.00). Since ϵ Eri is a weakly active star, Gray (1984) included an approximate Zeeman broadening model and obtained a $v \sin i$ of 2.1 instead of 2.2, thus barely different. A similar effect could be expected for HR 1362.

If the long-term photometric period of 306.9 days is assumed to be the latitude-averaged rotational period, the value of $v \sin i$ = 1.5±0.5 km s^{-1} would confine the stellar radius to values larger than 9.1±3.0 R$_\odot$, whereas in case the shorter of the three periods is the actual rotation period, i.e. 294 days, the minimum radius would be 8.7±2.9 R$_\odot$. Only if $i \approx 90°$ are these radii approximately equal to those obtained from the optical spectral classification and the bolometric luminosity based on the Hipparcos parallax. The radius from the bolometric-luminosity – effective-temperature relation

$$\log R/R_\odot = \frac{1}{5}\left(42.26 - M_{\rm bol} - 10\log T_{\rm eff}\right) \quad (1)$$

is 4.7±0.3 R$_\odot$, thus smaller than the value from $v \sin i$ and the photometric period and formally not in agreement with it. This radius would correspond to an equatorial rotational velocity of 0.8 km s^{-1}. We note that the formal CORAVEL value of $v \sin i = 1 \pm 1$ (i.e. in terms of radius $R \sin i$=6±6 R$_\odot$) would be in very good agreement with the spectral classification and the bolometric luminosity but its error for $v \sin i$ was not determined specifically for HR 1362 but was estimated from the errors of other G and K stars in the sample of De Medeiros et al. (1997) having larger $v \sin i$'s than HR 1362 and is likely just a lower limit. Nevertheless, a G8IV-III star would be expected to have a radius of 5–8 R$_\odot$ and the hypothesis that the photometric light is modulated by the stellar rotation period seems plausible.

4.6. Evolutionary status and comparison with HD 181943

The adopted parameters of HR 1362, given in Table 1, place the star on the HR diagram as indicated by the cross in Fig. 7. The size of the cross corresponds to the uncertainties of the respective parameters.

Evolutionary tracks assuming solar metallicity taken from Schaller et al. (1992) for two different stellar masses are also plotted as solid lines. The position of HR 1362 relative to these tracks suggests a mass of 1.85 M$_\odot$ (formally ±0.05 M$_\odot$). When evolved backwards to the main sequence it falls into a region where several Ap stars with kiloGauss magnetic fields are observed (e. g. Hubrig et al. 1998). The present position of HR 1362, close to the base of the giant branch, indicates violent changes taking place in its internal structure; the mass of the convection zone increases rapidly as does also the total stellar moment of inertia (Sweigart et al. 1989, Rutten & Pylyser 1988). It is not clear how such changes influence the efficiency of the dynamo.

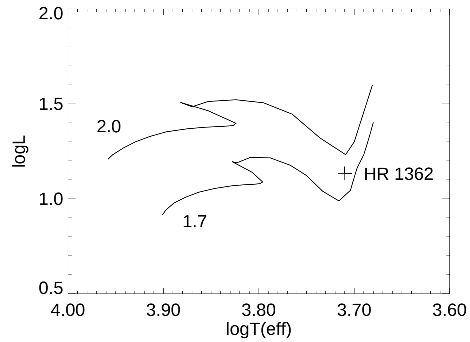

Fig. 7. The HR diagram with the position of HR 1362 marked as a cross with a size corresponding to uncertainties in the derived luminosity and effective temperature. Solid lines give evolutionary tracks taken from Schaller et al. (1992) for two stellar masses (indicated in the figure) with solar metallicity.

HR 1362 is not the only chromospherically active star with a very long photometric period. Hooten & Hall (1990) had found a period of 385 days for HD 181943. This period was recently revised to roughly 2,000 days by Fekel et al. (1995) who also reclassified it as a young K1V star with approximately the age of the Pleiades. However, the new Hipparcos parallax suggests an absolute magnitude 1.1 mag brighter than that adopted by Fekel et al. (1995), which then is no longer compatible with a K1V star but rather a slightly evolved K1V-IV star or more likely a pre-main sequence star shortly *before* arrival on the ZAMS. As opposed to HR 1362, the most likely inclination of the stellar rotation axis for HD 181943 is extremely low ($i \leq 12°$), and thus, the observed light variability can not be due to rotational modulation but must be due to some cyclic spot variation. Such variations are seen on almost every spotted star with a long enough photometric data base (compare with the many stars in the sample of, e.g., Strassmeier et al. 1997b). The light variation of HR 1362 is very smooth and very well defined as compared to HD 181943 where a seasonal scatter of $0\overset{\rm m}{.}05$ is present. Also, our light curves of HR 1362 do not contain a high-frequency signal due to an undetected (few days) period that could be interpreted as the true rotation period. Due to its low lithium abundance, approximately the solar value, a pre-main-sequence state for HR 1362 is very unlikely while, on the contrary, HD 181943 shows much stronger lithium (Strassmeier 1991).

5. Conclusions and discussion

From the data presented in this paper we can now put relatively stringent error bars on the photometric period and on the rotational velocity, while the Hipparcos parallax tightly restricts the luminosity. The remaining discrepancy between stellar radii from the rotational quantities and from the bolometric luminosity is primarily due the error in $v \sin i$, but also due to errors in the effective temperature, the unknown true "unspotted" magnitude (enters into $m_{\rm V} - M_{\rm V}$), and the amount of interstellar absorption. We conclude that the light variations of HR 1362 are caused by rotational modulation of a spotted photosphere and that the inclination of the stellar rotation axis must be near $i \approx 90^\circ$ to bring various parameters into agreement. Thus, HR 1362 remains a puzzle because it is overactive by two orders of magnitude for its rotation rate, when compared to other G and K giants in the Ca II H&K sample of Strassmeier et al. (1994). The combination of a relatively large photometric amplitude and $i \approx 90^\circ$ also suggests mostly low-latitude spots on the stellar surface and probably excludes an asymmetric polar spot since these spots can not significantly contribute to the rotational modulation because of the large foreshortening angle. Low-latitude spots are also in agreement with the observation that the smallest amplitudes are seen when the star is brightest and the largest amplitudes are seen when the star is faintest.

A very high level of chromospheric activity and a high coverage of a cool star by spots are indications of strong surface magnetic fields. Such fields are believed to be generated by the dynamo mechanism. Both, observations and theoretical parametric formulae suggest a scaling of the fields with surface rotation rate. This scaling is, however, invalid in case of HR 1362. If its field is dynamo originated, very special internal conditions (e.g. exceptionally high differential rotation) must play a dominating role in the field generation. But this possibility does not really solve the problem, which is then simply shifted to the question why such special conditions exist inside HR 1362 but are not present in an overwhelming majority of other, similar stars. While we cannot presently rule out this possibility, its acceptance involves a high degree of speculation.

On the other hand, the possibility that the surface magnetic field of HR 1362 is a relic of a much stronger magnetic field, existing already in the main-sequence evolutionary phase of this star, is more natural and in agreement with our present knowledge of properties of the upper main-sequence stars. Estimates indicate that about one A-type main-sequence star out of 10^2–10^3 possesses a strong (several kiloGauss in intensity) magnetic field of an approximately dipolar structure (Stępień 1993). The time scale for the Ohmic decay of such a field is much longer than the main-sequence stellar life time, hence it will survive at least until the giant phase although its structure becomes much more complicated due to an interaction with subphotospheric convection. If so, one giant out of 10^2–10^3 observed should show a high level of activity independent of its rotation rate. The existence of one anomalously strongly active star among slowly rotating giants with measured rotation rate and activity level is in agreement with this estimate. We conclude that this scenario is a more probable explanation for the rotation-activity puzzle of HR 1362.

Following the procedure applied by Stępień (1993) we can estimate the expected rotation period, $P_{\rm rot}$(MS), and the surface magnetic field, B(MS), of the main-sequence progenitor of HR 1362. We get $P_{\rm rot}$(MS)$\leq$1 month (inequality applies for a non-zero angular momentum loss between main sequence and the present state), and B(MS) $\approx$3 kG. Such values are not unusual among magnetic Ap stars.

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