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Analysis of the hyperfine and isotopic structure of Ga II in the optical spectrum of κ Cnc and HR 7775

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Abstract. Spectra of the HgMn stars κ Cnc and HR 7775 have been analyzed, under the assumption of local thermodynamic equilibrium (LTE), with respect to the abundance and isotopic mixture of gallium. The primary purpose of the investigation was to level the contradictory results obtained using spectral lines in different spectral regions (Smith 1996). The analysis has been performed by Ga II lines in the optical region including hyperfine and isotopic components from new Fourier Transform Spectrometer measurements (Karlsson & Litzén 2000). Gallium has, for both stars, been determined to be overabundant by two orders of magnitude compared to the sun, using oscillator strengths derived by Ryabchikova & Smirnov (1994). The difference in abundance obtained using spectral lines in the UV and the visual spectral region is unexplainable by accounting for hyperfine and isotopic structure. Astrophysical log gf values have been determined for the Ga II 5p $-$ 5d transitions at 5360, 5363 and 5421 Å.

Key words: atomic processes – line: profiles – stars: abundances – stars: chemically peculiar – stars: individual: κ Cnc, HR 7775

1. Introduction

The astrophysically rare element gallium (Z=31) has earlier been studied with respect to its abundance in normal and chemically peculiar (CP) stars. In the sun its abundance is listed as log N_{Ga}=+2.9 (Anders & Grevesse 1989) on a scale where log N_H=12, and it is believed to be the lightest element to have a substantial contribution to its abundance arising from the slow neutron caption process (s-process) of nucleosynthesis. Other contributions to its abundance arise from more energetic processes (e and r-processes). Among the CP stars the spectrum of Ga II is particularly strong in some members of the HgMn and He-weak subclasses. The line enhancements represent abundances of up to four orders of magnitude over the solar value when simply interpreted by homogeneous model atmospheres. However, as for many other spectrum anomalies exhibited by CP stars the line enhancements are believed to result from atmospheric processes, such as diffusion, rather than from nucleosynthetic origins.

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Abundance analyses performed by using spectral lines in the optical region (Adelman 1989; Lanz et al. 1993) have resulted in a different value than that obtained with the Ga II and Ga III resonance lines in the UV (Takada-Hidai et al. 1986; Smith 1996). This has recently been referred to as "The Gallium problem" (Dworetsky et al. 1998). The most appealing explanation for the discordant results has been the need for hyperfine structure (hfs) of spectral lines located in the optical wavelength region (Dworetsky et al. 1998).

Smith used the resonance lines of Ga II and Ga III in the UV for studies of several objects and found the gallium abundance to be lower using these lines compared to results from other investigations in the visible. For some objects included in Smith's work the abundance obtained from individual spectral lines deviates much from the average value, especially if only a moderate enhancement of gallium is observed compared to the sun. Smith determined an average value for the gallium abundance in κ Cnc to be log N_{Ga}=6.6 from UV lines which is 0.6 dex below the value presented by Adelman (1989) from optical region Ga II lines.

Dworetsky et al. attempted to equalize the difference observed by Smith by investigating spectral lines in the optical wavelength region and utilizing a limited incorporation of the hfs. They used the Ga II 4d $-$ 4f transitions (4251 $-$ 4262 Å) in addition to the Ga II 5s $-$ 5p transition at 6334 Å and were able to match the result by Smith. Their abundance result is an averaged value of five spectral lines, where a systematic decrease in abundance is observed when lines at longer wavelengths are used. The hfs was estimated by including an incomplete set of hyperfine components based on experimentally measured wavelengths (Bidelman & Corliss 1962), except for Ga II λ6334 where the structure was adopted from Lanz et al.

Recent laboratory measurements of the Ga II spectrum (Karlsson & Litzén 2000) have provided a complete set of hyperfine and isotope components for the spectral lines corresponding to the 5s $-$ 5p and 5p $-$ 5d transitions, which are located in the red spectral region. The 4d $-$ 4f transitions used by Dworetsky et al. have also been analyzed by Karlsson & Litzén, but due to large configuration interaction in the 4f levels it is at this time only possible to experimentally estimate the isotopic and hyperfine structures using the Fourier Transform Spectrometer technique. The shift between the outermost hyperfine components for the 4d − 4f transitions is reasonably large and without considering the line structure, their use will increase the uncertainty of the result. The Ga II lines in the red spectral region have a simpler structure, therefore wavelengths can be derived individually for each component and the hyperfine constants derived unambiguously.

In this study spectral lines from Ga II are investigated with a complete set of experimentally determined hyperfine and isotopic components. We have chosen to analyze spectra of κ Cnc and HR 7775 in the visible region to investigate the abundance and isotopic mixture of gallium in a further attempt to reconcile the "Gallium problem".

2. Observational data

We have used a spectrum of κ Cnc obtained with the ESO New Technology Telescope (NTT) at La Silla, Chile, provided by G. Mathys (ESO). The material consists of a continuous spectrum between 4100 and 6700 Å acquired with a resolving power of R = $\frac{\lambda}{\Delta\lambda}$ = 60000. Spectra for the HgMn star HR 7775 and a second set of observation material for κ Cnc were obtained with the Nordic Optical Telescope (NOT) at La Palma, Canary Islands, using the SOviet FINnish (SOFIN) high resolution spectrograph (Tuominen et al. 1999) at a resolving power of 60 000. The data obtained with the two telescopes are considered to be comparable in quality.

The Bright Star Catalogue (Hoffleit & Jascheck 1982) lists κ Cnc as a multi-star system, consisting of three objects. A recent study (Ryabchikova et al. 1998) shows the flux ratio between the primary and secondary components to be approximately 11.5 in the V band, while the faint third component is assumed to make an insignificant contribution to the spectrum. The bright companion seems to be a relatively fast rotator and spectral lines from it are smeared out in the spectrum and show only features from the very strong lines Ca II H & K and Mg II λ4481 in addition to the spectral lines of hydrogen and helium. The Mg II line from the secondary component is observable in our spectrum and is used to determine the components relative velocity and the corresponding wavelength shift.

HR 7775 is also known to be a multiple star system. A fainter close companion was detected by the Hipparcos satellite at a distance of 0.68 arcsec. Our high resolution SOFIN spectrum was obtained using a slit width of 0.7 arcsec (Wahlgren et al. 2000). We have chosen to treat the spectrum of HR 7775 as originating from a single star due to the unknown nature of the binary orbit and the high likelihood that the close companion lies outside the aperture.

3. Atomic data

Laboratory spectra of gallium were recorded with the Fourier Transform Spectrometer (FTS) at the Atomic Spectroscopy Laboratory in Lund. The spectra were obtained using a hollow-cathode discharge as a light source and covered the region 12 500–50 000 cm^{-1} (8000–2000 Å). All Ga II lines showing significant hfs and isotopic shift (IS) were analyzed by means of a computer code, where a function consisting of co-added gaussians was fitted to the observed feature. Parameters included in the fitting process were the magnetic dipole and electric quadrupole hyperfine constants, A and B respectively, and the central wavelength. The electric quadrupole constant, B, was found to be insignificant during the line fitting process. Wavelengths for the hfs components of a transition were therefore derived from the magnetic dipole constant and the central wavelength. The fitting process is not applicable for the 4d − 4f transitions due to severe perturbations of the hyperfine structure by configuration interaction. For those transitions the hyperfine and isotopic structure were estimated by measuring the wavelengths and the intensities for all resolved features in the FTS spectrum. A more comprehensive report of the laboratory measurements will be published elsewhere (Karlsson & Litzén 2000).

Oscillator strengths have been taken from Ryabchikova & Smirnov (1994). The values for the 4d − 4f transitions in the blue spectral region are based on lifetimes measured with the beam-foil technique. No experimental data for the lifetimes of the 5p and 5d levels are at the present time available. The oscillator strengths for the spectral lines in the red wavelength region are based on extrapolated lifetimes from the 4f levels. The branching fractions for all levels are, with a few exceptions, set by Ryabchikova & Smirnov to be 1.0, which is too large a value due to the multiplicity of the deexcitation possibilities. The oscillator strengths for the 5p − 5d transitions at 5360 and 5421 Å are determined astrophysically by Ryabchikova & Smirnov and compared in Table 1 with corresponding values from this work. The log gf values in our analysis are obtained with a complete set of hyperfine and isotopic components, which partly can explain the discrepancy between the log gf values observed for the λ5421 line.

4. Spectrum analysis

Our analysis is performed by synthetic spectrum fitting using the program SYNTHE (Kurucz 1993) with complete IS and hfs of Ga II incorporated into the atomic line input. The primary target is κ Cnc, whose spectrum has been analyzed for all strong Ga II lines in the optical region. κ Cnc has been observed on two occasions at the same phase and the results obtained by using different data sets are comparable. The κ Cnc stellar system is analyzed with stellar atmosphere parameters adopted from Ryabchikova et al., with $\mathrm{T_{eff}}$ = 13200 K and log g= 3.7 for the primary star and $\mathrm{T_{eff}}$ = 8500 K and log g = 4.0 for the secondary. The stellar parameters are obtained by fitting spectrophotometry and hydrogen line profiles, considering a mass ratio between the primary and secondary component of $\frac{M_\mathrm{A}}{M_\mathrm{B}}$=2.2$\pm$0.1. The projected equatorial rotational velocity, $v \sin i$, for the primary object was determined to be less than 7 $\mathrm{km\,s^{-1}}$ by synthetic spectrum fitting of sharp Fe II lines while the corresponding value for the secondary component was derived similarly by using Mg II λ4481 to be of the order of 40 $\mathrm{km\,s^{-1}}$. Fe II lines were used for the primary component since they do not show any significant hfs or IS, while the Mg II λ4481 was the only usable feature from the secondary component in our stellar spec-

Table 1. Ga II lines used in this analysis.

λ^{a} (Å)	Configuration	$\log gf^{b}$	HR 7775[c]	κ Cnc[d]	κ Cnc[e]	w^{f}	$\log gf^{g}$
4251.149	4d $^3D_1$ − 4f $^3F_2$	0.35	6.90		7.50	1	
4254.075	4d $^3D_2$ − 4f $^1F_3$	−0.23	7.00		7.25	3	
4255.722[h]	4d $^3D_2$ − 4f $^3F_3$	0.68	6.70		7.00	2	
4262.019	4d $^3D_3$ − 4f $^3F_4$	0.98	6.50		7.30	1	
5338.240	5p $^3P_0$ − 5d $^3D_1$	0.43	≤6.50	6.70	6.70	3	
5360.402	5p $^3P_1$ − 5d $^3D_2$	0.42	6.90			–	0.42
5363.585	5p $^3P_1$ − 5d $^3D_1$					–	0.06
5416.318	5p $^3P_2$ − 5d $^3D_3$	0.64	6.80	6.95	7.00	3	
5421.275	5p $^3P_2$ − 5d $^3D_2$	0.55				–	−0.05
6334.069	5s $^3S_1$ − 5p $^3P_2$	1.00	6.40	7.15	7.15	2	
6419.239	5s $^3S_1$ − 5p $^3P_1$	0.57	≤6.60	7.05	7.05	3	
6455.923	5s $^3S_1$ − 5p $^3P_0$	−0.08	6.90		7.10	3	

[a] Central wavelength from Karlsson & Litzén.
[b] Ryabchikova & Smirnov (1994).
[c] $\log N_{Ga}$ based on NOT data, JD=2451002.618, 2451003.622 and 2451003.637.
[d] $\log N_{Ga}$ based on NOT data, JD=2449706.554 (ϕ=0.962) and 2449706.592 (ϕ=0.968).
[e] $\log N_{Ga}$ based on NTT data, JD=2450115.657 (ϕ=0.952).
[f] Weighting parameter (1–3) for κ Cnc, NTT data.
[g] Astrophysical $\log gf$ values determined in this work, from κ Cnc assuming $\log N_{Ga}$=7.1.
[h] 4d $^3D_2$ − 4f $^3F_2$, λ4255.937, $\log gf$=−0.32 is included in this feature.

trum. Spectral line profiles are generated with different values of $v \sin i$ and $\log N_{Ga}$. The best fit provided the value of the rotational velocity. Line broadening mechanisms such as radiative, Stark and Doppler effects are included in the analysis via the damping constants derived by the SYNTHE program. Stellar models were calculated using the LTE approximation with the ATLAS9 (Kurucz 1993) program under the assumption of no turbulent velocity.

The spectrum of the HgMn star HR 7775 has been investigated for comparison. However, a detailed analysis of the line profiles is not possible due to the weakness of the Ga II spectrum. For HR 7775 we used a stellar atmosphere model with T_{eff} = 10750 K, $\log g$= 4.0 and $v \sin i$= 2 km s^{-1}, where all stellar parameters are from Wahlgren et al. (2000). The effective temperature and the surface gravity are based on Strömgren photometry using indices from Hauck & Mermilliod (1980).

The 5p − 5d transitions correspond to energy levels with small hyperfine constants, consequently we are not able to see any structure in these spectral features and the analysis is limited to abundance determination. Even if a spectral line profile does not show any signs of being affected by hfs or IS, it is of great importance to use line structure data in the analysis. As shown in Fig. 1, a difference of approximately 0.5 dex is observed if the hfs and IS are neglected.

The 5s − 5p transitions at 6334, 6419 and 6456 Å have a larger separation between the hyperfine and isotopic components which allows us to do a detailed analysis of structure and intensities of individual components. The wavelength separations for the individual components forms a broad spectral line with a peculiar line profile, which as shown in Fig. 2 might be interpreted as blends from unknown features.

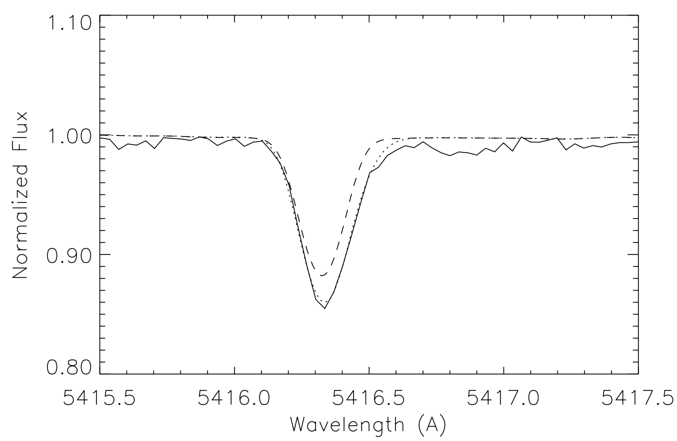

Fig. 1. Abundance analysis using Ga II λ5416 in κ Cnc. Solid curve: observed profile. Synthetic spectra are generated with (dotted) and without (dashed) hfs/IS. Both synthetic spectra are computed for an abundance of $\log N_{Ga}$=7.00. The difference in depth for the two spectra correspond to a difference in abundance of 0.5 dex.

Gallium has two stable isotopes with a terrestrial abundance ratio of 60:40 (^{69}Ga:^{71}Ga). The separation of the spectral lines from different isotopes is small compared to the shift due to the nuclear moment, therefore it is difficult to achieve information about the isotopic mixture in an object. However, Ga II λλ6419 and 6334 present line profiles indicating a different isotopic mixture than the terrestrial. Since the hyperfine constants for ^{69}Ga are smaller than corresponding values for ^{71}Ga, the outermost components will both be members from the latter. When the isotopic mixture is altered from 60:40 to 80:20, the spectral line becomes narrower by approximately 25 mÅ and agrees better with the observed profile. The change in line profile can-

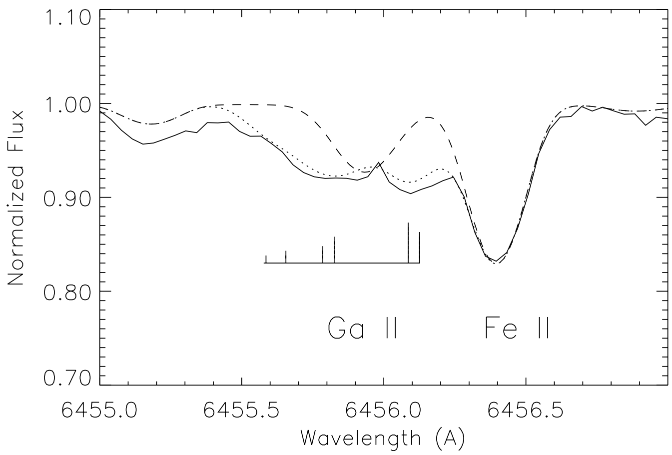

Fig. 2. Analysis of the isotopic mixture using Ga II λ6419 in κ Cnc. Solid curve: observed profile. Synthetic spectrum generated with hfs/IS, log N_{Ga}=7.10 (dotted) is compared with a single line profile at 6455.9 Å, generated without hfs/IS, log N_{Ga}=6.50 (dashed).

not be reproduced by broadening mechanisms such as rotation or turbulent velocity since different isotopic mixtures affect the individual components differently. The effect is noticeable for both Ga II $\lambda\lambda$6419 and 6334 in the κ Cnc spectrum. Spectra obtained with a very high resolving power (R=200 000) will not give additional information due to the magnitude of the rotational velocity. We have calibrated the wavelength scale in this region with Fe II lines, due to their insignificant hfs and IS. The wavelength calibration is set to an accuracy of $\pm$10 mÅ, based on errors in the determination of the iron line wavelengths (S. Johansson, private communication) and the synthetic spectrum fitting.

The analysis of the Ga II 4d $-$ 4f transitions between 4251 - 4262 Å was performed by including an estimated hyperfine and isotopic structure. The wavelength calibration for these transitions was made with Mn II lines with a complete set of hyperfine components (Holt et al. 1999), with the same accuracy as for the iron line calibration. The increased line density compared to the red spectral region complicates the analysis and most Ga II lines seem to be blended with other features. The spectra of κ Cnc and HR 7775 both present an asymmetric line profile for Ga II λ4251 and even though the objects are not similar in spectral type or chemical composition this might imply that the line is disturbed by a common unknown feature. The Ga II λ4255 feature is a mixture of the 4d $^3D_2$ $-$ 4f $^3F_3$ and the 4d $^3D_2$ $-$ 4f $^3F_2$ transitions, each with their own set of hyperfine and isotopic components included in our analysis. The log gf values for the two involved transitions have been summed, where for 4d $^3D_2$ $-$ 4f $^3F_2$, log gf=$-$0.32 has been used. This value is calculated from the Multi Configuration Hartree Fock (MCHF) program (Froese Fischer et al. 1997), but due to configuration mixing it is associated with large errors. However, it is in agreement with the value of log gf=$-$0.30 used by Dworetsky et al. Ga II λ4262 is blended with Cr II λ4261.9 in its blue wing, which might explain its deviation from the average gallium abundance.

The average abundance of gallium, $\langle \log N_{Ga} \rangle$, in κ Cnc is determined based on the results for individual Ga II lines from the NTT spectrum. The result for each spectral line has been weighted with respect to its credibility in the abundance analysis considering line blending and the accuracy of the line profile fitting. The uncertainty of the oscillator strengths have not been considered during this process. A maximum value (3) for the weighting parameter corresponds to a nicely fitted unblended spectral line. The astrophysical log gf values are based on the result $\langle \log N_{Ga} \rangle$= 7.1 from the NTT data.

The abundance determined from the individual Ga II lines is presented in Table 1 together with the newly determined astrophysical log gf values for Ga II $\lambda\lambda$5360, 5363 and 5421. A complete list of those lines including wavelengths and effective log gf values for the hyperfine and isotopic components is presented in Table 2 for the case of the terrestrial isotopic mixture. The effective log gf values are scaled with respect to the relative abundance of the isotopes while the values for the individual hyperfine components are calculated assuming LS-coupling.

5. Conclusions

We have investigated the abundance of gallium in the visible spectrum of the κ Cnc and HR 7775 stellar systems. The complete isotopic and hyperfine structure have been incorporated for the lines in the red spectral region, while we used an estimated structure for the 4d $-$ 4f transitions in the blue. We have determined the average abundance of gallium in κ Cnc to be log N_{Ga}=7.1, which is 0.25 dex greater than proposed by Dworetsky et al. in an earlier analysis. The 0.6 dex discrepancy between the abundance based on spectral lines in the UV (Smith 1996) and the corresponding value from the optical region was earlier believed to be removed by including hyperfine structure for the spectral lines in the optical region. Our analysis shows that hfs is not responsible for the difference and another explanation must be found.

A change in effective temperature by $\pm$300 K or surface gravity by $\pm$0.1 will result in an insignificant change in the gallium abundance (Δlog N_{Ga} $<$ 0.03 and 0.01 dex, respectively). We have used a stellar atmosphere model with no turbulent velocity since HgMn stars are in general assumed to have quiet atmospheres, but if a little turbulent velocity is allowed (v_t=1 km s^{-1}) this would give an increased abundance of 0.02 dex. The luminosity ratio between the primary and secondary component is approximately 11.5 in the V band (Ryabchikova et al. 1998) and a value that differs by 10% will affect log N_{Ga} by less than 0.01 dex. A model where the binarity of κ Cnc is not considered will, however, give a decreased gallium abundance by approximately 0.15 dex. The estimated error introduced by the uncertainty of the primary star atmosphere model and the continuum placement is calculated to be less than 0.1 dex based on these values. The signal to noise of our data is good ($>$100) and the contribution to the abundance error is negligible. Line blending is included in the assigned weighting parameter for each line and if instead of this weighting scheme a straight average was used the gallium abundance

Table 2. Wavelengths and effective astrophysical log gf values for the hyperfine and isotopic components to Ga II λ5360, 5363 and 5421 Å, assuming a terrestrial (^{69}Ga:^{71}Ga; 60:40) isotopic mixture.

	4s5p ^{3}P$_1$ − 4s5d ^{3}D$_2$		4s5p ^{3}P$_1$ − 4s5d ^{3}D$_1$		4s5p ^{3}P$_2$ − 4s5d ^{3}D$_2$	
Isotope	λ (Å) [a]	log gf	λ (Å) [a]	log gf	λ (Å)[a]	log gf
^{69}Ga	5360.496	−1.902	5363.695	−0.718	5421.382	−1.515
	5360.469	−0.948	5363.613	−1.086	5421.343	−1.937
	5360.431	−0.300	5363.594	−1.086	5421.290	−1.527
	5360.411	−1.680	5363.512	−1.614	5421.263	−1.134
	5360.394	−1.874	5363.463	−1.119	5421.225	−1.615
	5360.367	−0.580	5363.451	−1.119	5421.223	−1.637
	5360.349	−0.981	5363.402	−1.818	5421.206	−1.469
	5360.333	−0.981			5421.179	−1.527
					5421.172	−1.673
					5421.156	−1.673
^{71}Ga	5360.520	−2.078	5363.725	−0.894	5421.409	−1.791
	5360.486	−1.124	5363.620	−1.262	5421.360	−1.013
	5360.437	−0.476	5363.597	−1.262	5421.293	−1.703
	5360.411	−1.856	5363.492	−1.790	5421.259	−1.310
	5360.391	−1.050	5363.430	−1.295	5421.210	−1.791
	5360.357	−0.756	5363.415	−1.295	5421.207	−1.849
	5360.334	−1.157	5363.353	−1.994	5421.186	−1.645
	5360.313	−1.157			5421.151	−1.703
					5421.142	−1.849
					5421.122	−1.849

[a] Karlsson & Litzén (2000)

would increase by 0.06 dex. We believe the uncertainty introduced by the oscillator strengths is unable to compensate for the differences in abundance. Experimental measurements for the optical lines will yield smaller log gf values since the branching fractions have been overestimated. This will result in an increased gallium abundance compared to the present value. However, we believe it will be a natural step towards solving "the Gallium problem" to experimentally determine necessary lifetimes and branching ratios to minimize the errors.

We find more appealing explanations than hfs/IS for the discordant abundance result to be the difficulties arising when the UV spectrum is analyzed. The line density in the region of the Ga II/ Ga III resonance lines is very high, which complicates the setting of the continuum level and an abundance analysis becomes more uncertain due to severe blending. Secondly, the investigation of gallium in the UV has been performed by using the Ga II and Ga III resonance lines, which are generally believed to be formed higher in the stellar atmosphere than transitions to higher states. If this is correct, then there is a possibility that the resonance lines are formed in a region where the approximation of LTE is not appropriate and our method in treating these lines with LTE-physics is insufficient.

Our investigation of Ga II λ 6334 and 6419 implies the isotopic mixture in κ Cnc to be altered compared to the terrestrial, but the stellar rotation prevents us from reaching a more accurate result. To investigate the isotopic mixture of gallium in chemically peculiar stars we must restrict ourselves to investigating stars with a low projected stellar rotation at high resolving power. Our synthetic calculations indicate that a projected rotational velocity less than 4 km s^{-1} is suitable for this kind of analysis, preferably observed with high resolving power (R≥100 000).

In addition to the results for κ Cnc, we have also determined the average gallium abundance for HR 7775 to be log N$_{Ga}$=6.7. This value is in agreement to within 0.1 dex with the result from Wahlgren et al. (2000) but 0.35 dex above the value obtained by Smith (1996). Unfortunately, the Ga II lines in the spectrum of HR 7775 are not as strong as in the spectrum of κ Cnc and even though HR 7775 is a slowly rotating star ($v \sin i \leq 2$ km s^{-1}) no further investigation of the line structure is possible.

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References

Adelman S.J., 1989, MNRAS 239, 487
Anders E., Grevesse N., 1989, Geochimica et Cosmochimica Acta 53, 197
Bidelman W.P., Corliss C.H., 1962, ApJ 135, 963
Dworetsky M.M., Jomaron C.M., Smith C.A., 1998, A&A 333, 665
Froese Fischer C., Brage T., Jönsson P., 1997, Computational Atomic Structure, Inst. of Phys. Pub., Bristol and Philadelphia
Hauck B., Mermilliod M., 1980, A&AS 40, 1
Holt R.A., Scholl T.J., Rosner S.D., 1999, MNRAS 306, 107
Hoffleit D., Jascheck C., 1982, The bright star catalogue, fourth edition, Yale University
Lanz T., Artru M.C., Didelon P., Mathys, G., 1993, A&A 272, 465

Karlsson H., Litzén U., 2000, J. Phys. B, in press
Kurucz R.L., 1993, Synthesis Programs and Line Data (Kurucz CD-ROM No.18)
Ryabchikova T., Smirnov Y.M., 1994, Astron. Rep 38, 70
Ryabchikova T., Kotchoukhov O., Galazutdinov G., Musaev F., Adelman S.J., 1998, Cont. Astron. Obs. Skalnaté Pleso 27, 258
Smith K.C., 1996 A&A 305, 902
Takada-Hidai M., Sadakane K., Jugaku J., 1986, ApJ 304, 425
Tuominen I., Ilyin I., Petrov P., 1999, in Astrophysics with the NOT, University of Turku, 47
Wahlgren G.M., Dolk L., Kalus G., et al., 2000, ApJ 539, in press