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Two new bright Ae stars*

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Abstract. Two newly identified Ae stars, ν Cyg and κ UMa, were discovered in the course of the Magnetic Survey of Bright main sequence stars (Monin et al. 2002). We present their Hα profiles along with measurements of their equivalent width and parameters of emission features. Emission in the Hα line of ν Cyg is variable on a time scale of 3 years. κ UMa exhibits weak emission which is rather stable. The emission is thought to arise from a circumstellar disk, and we have estimated the size of that disk.Both new emission stars are IRAS sources. Their IR color excesses are consistent with those of classical Ae stars. Thus, ν Cyg and κ UMa appear not to belong to the class of Herbig Ae/Be stars. We argue that the frequency of Ae stars may be underestimated due to the difficulty of detection of weak emission in some A stars.

Key words. stars: emission line, Be – stars: individual: ν Cyg – stars: individual: κ UMa

1. Introduction

Ae (A–emission) stars are believed to be cooler counterparts of classical Be stars (Jaschek & Andrillat 1998). They have similar observational properties: emission in hydrogen lines, IR excess compared to the IR brightness expected from the stellar photosphere, photometric and spectral variability on timescales from days to years, and linear polarization. In general, the phenomena that are observed in Ae stars are less spectacular than, but similar to, Be phenomena. One example is the behavior of emission features. Be stars exhibit emission in different spectral lines. The number of lines in emission and its strength decreases when one goes from late Be to early Ae stars (Jaschek et al. 1991). In stars later than A0, only Hα and sometimes Hβ are seen in emission (Jaschek et al. 1980).

The group of Ae stars is almost 10 times less numerous than the group of the hotter Be counterparts (Zorec & Briot 1997). To enhance the probability of finding such stars, different selection criteria are used, for example, anomalous IR emission (Jaschek et al. 1991), variability (Irvine 1979), or fast rotation (Ghosh et al. 1999).

In the course of the Magnetic Survey of Bright Main Sequence stars (Monin et al. 2002) we obtained high resolution spectropolarimetry of 21 A type stars with visual magnitude $m_V < 4$. There was only one known Ae star in our sample, γ UMa, indicated as an Ae star in the Bright Star Catalogue (BSC; Hoffleit & Jaschek 1982); it did not show detectable emission in our observations. However, inspection of Stokes I profiles of 21 A type stars resulted in the discovery two new Ae stars, ν Cyg and κ UMa. In this paper we discuss these stars.

2. The data used

The Magnetic Survey of Bright Main Sequence Stars is being carried out using the coudé échelle spectrograph CEGS of the 1m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS). The spectra cover the range from 4000 to 9000 Å, with a resolving power of $R \simeq 40\,000$. The main goal of this project is to obtain high quality polarimetric spectra in order to detect new weakly magnetic stars among both rapidly and slowly rotating main sequence stars. As a byproduct of these observations, we obtain very high signal-to-noise Stokes I profiles which, because of their very precise residual intensities, are suitable for other purposes. During reduction, we pay special attention to the spectral normalization especially in orders containing broad hydrogen lines (see description of the data reduction procedure by Monin et al. 2002). Here let us briefly review the normalization technique. In most of the spectral orders we use a smoothing-and-clipping high-frequency filter (Shergin et al. 1996). It filters effectively absorption lines whose width is small as compared to the width of the spectral order. After the lines are removed the continuum can be placed easily. The algorithm takes the noise level into account. These orders are used then to determine the underlying continuum in orders containing broad hydrogen lines. We interpolate the continuum flux in several

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* Based on observations collected at the 1 m telescope of the Special Astrophysical Observatory (Nizhnij Arkhyz, Russia).

Table 1. Basic observational properties (according to the BSC) of the two bright Ae stars discovered during the Magnetic Survey.

Name	HR	HD	V	$B-V$	Sp	$v \sin i$, km s^{-1}
κ UMa	3594	77327	3.60	0.00	A1Vn	219
ν Cyg	8028	199629	3.94	0.02	A1Vn	241

Table 2. Observation log. The columns, respectively, list the name, the UT and Julian dates, the exposure time $t_{\rm exp}$, the peak signal-to-noise ratio per pixel.

Name	Date	JD - 2 450 000	$t_{\rm exp}$, min	S/N Hα/Hβ
κ UMa	Apr., 2000	1658.34	80	340/280
	Dec., 2000	1892.54	60	430/320
ν Cyg	Aug., 1996	326.84	60	260/130
	Jul., 1999	1362.50	80	370/200

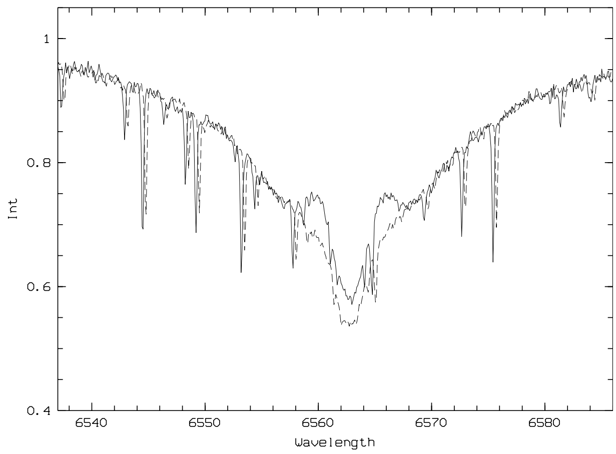

Fig. 1. Hα profiles of ν Cyg obtained in 1996 (solid line) and in 1999 (dashed line). The spectra have been corrected to a heliocentric reference frame. The sharp lines are telluric absorption lines.

adjacent orders. A low degree (2nd or 3rd order) polynomial interpolation is applied. We check how the algorithm works. For that we reconstruct the continuum in spectral orders containing narrow lines only. Reconstructed continuum is compared to the continuum obtained with the use of the high-frequency filter. Usually, the systematic difference is only 1% of the continuum flux or less. Normalized Hα line profiles of the same star obtained with different spectrograph setup are also agree to within 1%. Finally, from the comparison of observed and synthetic profiles of the Hα line in spectra of normal A type stars, we find that the difference does not exceed 1%. The Stokes I spectrum has high quality and it is suitable, for example, for comparison with synthetic spectra, and, because of its high spectral resolution, for searches for and detailed studies of weak emission features (which are generally undetectable at low resolution).

Two new Ae stars, ν Cyg and κ UMa, were found among the targets of the Magnetic Survey. The basic observational properties of these stars are listed in Table 1. Below we discuss them in detail.

3. New Ae stars

Figure 1 shows Hα profiles in spectra of ν Cyg obtained during 1996 and 1999. The spectra have been shifted to the heliocentric reference frame, but have not been corrected for the radial velocity of the star. A double-peaked emission inside the absorption Hα core is clearly seen in the 1996 data. In 1999 Hα had an absorption profile, but the broadening does not seem consistent with the high rotational velocity of 240 km s^{-1} listed in the BSC. This apparently low $v \sin i$ may well be a consequence of infilling of the line core by undetected emission.

A similar distortion of the line profile which may be due to the presence of weak emission is seen in Hα of another A1Vn star from the survey list, κ UMa (see Fig. 2). The Hα line profile slope changes abruptly on the flanks of the absorption core, at about ±5 Å from the line center. Ghosh et al. (1999) did not detect emission in this star during their search for new Be stars among An/Bn stars; however, their survey was undertaken using low spectral resolution and they may have therefore missed Ae/Be stars with weak emission. In our spectra of κ UMa the Hα line core is also much narrower than is expected from its BSC rotational velocity of 219 km s^{-1}. The star was observed in April, 2000, and again eight months later. From comparison of the two spectra it appears that the emission is rather stable.

Although we suspect that emission is responsible for the peculiar line profiles of ν Cyg and κ UMa, the distortion may also be due to binarity. In principle, the superposed absorption profiles from two companions in a binary system may be mistakenly considered as an emission. When the observed separation between absorption cores is small the profiles are not seen separately, and the combined profile may not correspond to any reasonable single-star model. Binarity often occurs among Ae stars (see Jaschek & Andrillat 1998). We investigated the literature and found that both two new Ae stars are indeed binaries. One may suggest that the Hα profile in Fig. 2 simply comprise two profiles that have different width. If this is the case, we expect other hydrogen lines to have similar shapes. On the other hand, if emission is responsible for the distortion, its strength should decrease rapidly to higher order hydrogen lines. Weak emission appearing at Hα should therefore not be found at Hβ. We checked other lines in the spectra of κ UMa and did not find any signs of the line profile distortion observed in Hα. For example, Fig. 2 shows the profile of Hβ in the spectrum of κ UMa which is free from any profile distortion similar to that observed in Hα. In fact, the Hβ profile is neither fully consistent with the synthetic profile superposed in Fig. 2, nor is it fully symmetric. However, the weakness of these effects relative to those found in the Hα profile strongly supports our conclusion that the Hα profile peculiarities are not due to binarity, but rather result from emission.

The presence of two stars allows us to derive the dynamical parallax, and therefore to estimate the distance to the system. κ UMa has an orbital period of 35.61 ± 0.06 yr and a semi-major axis of 185 ± 2 mas (Barnaby et al. 2000). Assuming masses of the components to be the same and equal to 3 $M_{\rm sun}$, the calculated value of the dynamical parallax is ≈9 mas. The trigonometric parallax obtained with HIPPARCOS, 7.7 ± 0.83 mas (Perryman et al. 1997), is consistent with this value.

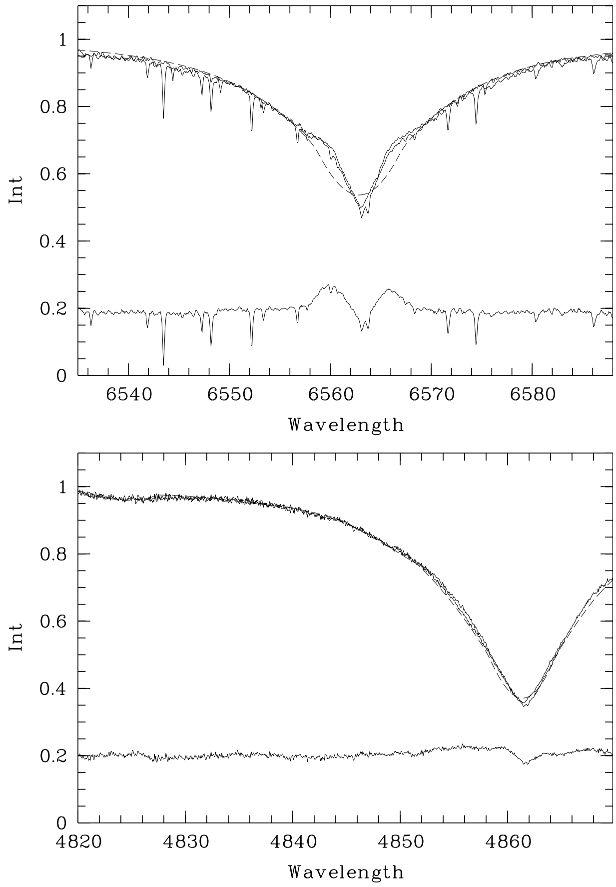

Fig. 2. Hα (top panel) and Hβ (bottom panel) profiles of κ UMa along with the subtracted residual spectrum (observed – synthetic) shifted upward by 0.2 for display purposes. Two spectra, obtained in April 2000 and in December 2000, are plotted. The spectra coincide. Solid line – observed spectra Dashed line – synthetic spectrum (see text). Weak emission is seen in the Hα profile residual, and it is absent in the Hβ profile residual. The sharp core of Hβ is likely due to the secondary companion. The core is shifted by approximately 20 km s^{-1} toward longer wavelength. Similar radial velocity is expected for the secondary from the orbital parameters given by Barnaby et al. (2000).

Both results lead to a distance to the system of approximately 110–120 pc. According to HIPPARCOS photometry, the visual magnitudes of the primary and the secondary are, respectively, 4.16 ± 0.11 and 4.54 ± 0.16.

ν Cyg also has a close companion. According to the HIPPARCOS archive, the companion is 2.3 mag fainter than the Ae primary whose visual magnitude is 4.07 ± 0.01. The orbital parameters of this system are not known. Therefore, the distance to the system, 109 ± 6 pc, was calculated using only the trigonometric parallax.

Using the calculated distances and visual magnitudes, the absolute magnitudes can also be determined. These are -1.4 and -1.0 for the primary and the secondary of κ UMa, respectively, and -1.3 and 1.2 for the primary and the secondary of ν Cyg. The absolute magnitudes of the κ UMa components and the ν Cyg primary appear to be almost one magnitude higher than those of normal A1 dwarfs and correspond to those of giants. Jaschek & Andrillat (1998) point out that the absolute magnitudes of Ae and A-type shell stars exceeds the mean value for normal dwarfs.

In order to further confirm the weak emission in Hα of κ UMa we have computed synthetic Hα and Hβ line profiles. The atmospheric parameters used to compute these profiles were derived from several sources. Malagnini et al. (1982) obtained the value of 9600 K for the combined effective temperature of the components of κ UMa by comparison of UV spectra with Kurucz models. These authors claim that the value they derived should be accurate within 200 K. This is consistent with the temperature we obtain from $uvby\beta$ photometry taken from Gray & Garrison (1987), $T_{\rm eff} = 9640 \pm 200$ K, using the calibration by Moon & Dworetsky (1985). From the $uvby\beta$ photometry, we also computed $\log g = 3.3 \pm 0.1$, indicative of a giant, and supporting the derived absolute magnitudes. Although these results are suggestive, we stress that they correspond to the combined spectrum of the κ UMa primary and secondary. These conclusions should be robust if the spectral types of the components are similar.

κ UMa and ν Cyg have similar distances and visual magnitudes of their primaries. Therefore, both primaries must have similar absolute magnitudes. Note that the secondary in κ UMa must also have the absolute magnitude that is comparable to that of the primary (their visual magnitudes are similar). In the case of ν Cyg, the photometry is dominated by the colors of the primary – the contribution of the secondary is negligibly small. The combined colors of κ UMa and ν Cyg do not differ significantly (Gray & Garrison 1987). This is possible if the primary and the secondary in κ UMa have similar colors. Together with similar absolute magnitudes it leads to similar temperatures and gravities.

Comparison of observed and calculated hydrogen line profiles also supports the above conclusion. Except for the core, which is distorted by emission, the Hα profiles of ν Cyg and κ UMa are fully similar. The difference between the profiles is less than the estimated errors due to improper spectral normalization. As discussed in Sect. 2, at Hα these errors do not usually exceed 1%. The same is true for the Hβ profiles, but the agreement is somewhat poorer. Taking into account that the contribution of the secondary in ν Cyg is small, one may suggest that both companions in κ UMa have similar hydrogen line profiles.

Taking into account the apparent similarity of the physical parameters of the components of κ UMa, we adopted the value 9600 K for the effective temperature, 3.3 for the logarithmic surface gravity, a microturbulence value equal to 4 km s^{-1} and a solar abundance.

A synthetic spectrum of κ UMa has been calculated using the code SPECTRUM (Gray and Corbally 1994). SPECTRUM uses a Kurucz atmosphere model as input. The synthetic spectrum has been convolved with the rotational profile of desired width and limb darkening factor (the latter is assumed to be equal to 0.4).

Several metallic lines were examined in order to obtain the projected rotational velocity ($v \sin i$). Due to fast rotation the metallic lines are shallow, with relative intensity less than 8%. Only 8 lines are deeper than 2%. With the given S/N ratio weaker lines are not measurable. We determine $v \sin i$ by

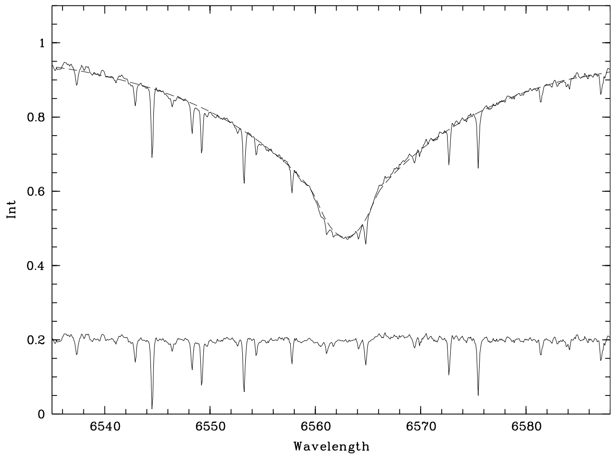

Fig. 3. Same as Fig. 2, but for the normal A star α Lac. The sharp lines are telluric absorption lines.

comparing with a synthetic line profile. The values obtained for TiII+FeII λ 4534, FeII λ 4550, FeII λ 4556, and SiII λ 4556 are consistent with each other within $10\,\mathrm{km\,s^{-1}}$. The average value is $190\,\mathrm{km\,s^{-1}}$. Note that the SiII λ 4556 line is only 2% deep. We could not fit adequately three strong blends, λ 4923, 5018, and 5169. They might be affected by non-LTE effects. They consist of lines of neutral Fe and Mg that may be formed in conditions far from LTE. We exclude these blends from our analysis. In Apr., 2000 the MgII λ 4481 line gives a higher value of $v \sin i$, $210\,\mathrm{km\,s^{-1}}$ against $190\,\mathrm{km\,s^{-1}}$ in Dec., 2000, which we believe is due to errors in spectra normalization. In Apr., 2000 the MgII λ 4481 line appears in an order where the spectrograph response function makes a short bend. In that part of the order the continuum normalization may be less accurate. Since most of measurable metallic lines agree with the value of $v \sin i = 190\,\mathrm{km\,s^{-1}}$ in the rest of this work we use this value.

Figure 2 presents superimposed observed and synthetic Hα and Hβ profiles for κ UMa. Residual spectra (observed minus synthetic) are also shown. A weak double-peaked emission feature is seen in the residual spectrum well inside the core of Hα. After the subtraction of the synthetic profile, the equivalent width of the emission component is 0.3 Å. In fact, weak emission of comparable strength was detected also in the spectra of ν Cyg in 1999. The emission strength of ν Cyg decreased by a factor of 2 between 1996 and 1999.

To illustrate that the features seen in the residual spectra are not likely a result of poor determination of the atmospheric parameters (and therefore poor correspondence between the observed and synthetic profiles in the absence of emission), in Fig. 3 we present observed, synthetic and subtracted residual spectra of the normal A star α Lac (A1V). The synthetic spectrum for α Lac was calculated with the following parameters: $T_{\mathrm{eff}} = 9500$, $\log g = 4.0$, and $v \sin i = 130\,\mathrm{km\,s^{-1}}$. The temperature and gravity were estimated from the spectral type. $v \sin i$ was taken from the BSC. It is seen from Fig. 3 that the mean intensity in the subtracted spectrum of α Lac is around zero. The calculated model appears to fit the observed spectrum of a normal A dwarf very well if the spectrum contains no emission.

Table 3. Hα measurements. EW is the equivalent width of Hα (including emission). EW_{em} – the equivalent width of the emission measured in the residual spectrum (see text and Fig. 2). ΔV_{peak} is the peak-to-peak separation of the emission. The central position of peaks was measured by fitting a Gaussian.

Name	JD + 2 450 000	EW, Å	EW_{em}, Å	ΔV_{peak}, $\mathrm{km\,s^{-1}}$
κ UMa	1658.34	10.62	0.27	294
	1892.54	10.11	0.40	282
ν Cyg	326.84	9.79	0.97	245
	1362.50	10.68	0.51	253

All measured parameters of the Hα emission features observed in the spectra of κ UMa and ν Cyg are presented in Table 3. This table gives the equivalent width of Hα (EW), the equivalent width of the emission (EW_{em}) and the peak-to-peak separation of the emission (ΔV_{peak}). Note that telluric absorption features were extracted and did not affect the calculations of the equivalent width. The equivalent widths of Hα reported in Table 3 are close to those obtained by Jaschek & Andrillat (1998) for Ae and A type shell stars.

It is generally accepted that the emission lines observed in Ae/Be stars are produced in a gaseous disk rotating around the central star. The profile of the emission lines is double-peaked. According to the theory developed by Huang (1972), in a case of uniform density distribution within the disk, the profile has a maximum at $v = \pm v_{\mathrm{out}} \cdot \sin i$, where v_{out} is the velocity corresponding to the outermost parts of the disk. Therefore, the separation between the peaks, ΔV_{peak}, contains information about the size of the emission disk as well as the inclination. The radius of the disk R_{disk} depends on the rotation law and can be calculated from the following equation (Jaschek & Jaschek 1992):

$$\frac{R_{\mathrm{disk}}}{R_*} = \left(\frac{2v \sin i}{\Delta V_{\mathrm{peak}}}\right)^{\gamma}$$

where R_* is the photospheric radius, $\gamma = 1$ for rotation with conservation of angular momentum ($R_{\mathrm{disk}} \propto v_{\mathrm{out}}^{-1}$) and $\gamma = 2$ for Keplerian rotation ($R_{\mathrm{disk}} \propto v_{\mathrm{out}}^{-2}$). Using the data from Table 1 and Table 3 we calculated the radius of the disk. In case of κ UMa it is found to be between $1.5 \pm 0.1\ R_*$ and $2.1 \pm 0.4\ R_*$ (γ is between 1 and 2). The radius of the disk of ν Cyg is between $1.9 \pm 0.2\ R_*$ and $3.7 \pm 0.6\ R_*$. Radii of disks in Ae and Be stars have similar sizes, 2–4R_* (Ghosh et al. 1999; Jaschek and Jaschek 1992). Thus, the sizes of the disks of these two new Ae stars have values typical of Ae/Be stars.

4. IR properties

Both ν Cyg and κ UMa were detected with IRAS (see Table 4). In the table we present the IRAS number and the stellar magnitude in V and 12 μm. A color correction was applied when we calculated broadband magnitudes from the IRAS fluxes. We followed the color correction scheme presented in the IRAS Explanatory Supplement. A color correction factor for a 10 000 K blackbody was assumed.

A large fraction of A type stars observed by IRAS show infrared excess (Jaschek et al. 1991). The IR excess is thought

Table 4. IR data: the visual magnitude, the stellar magnitude at 12 μm calculated from the IRAS flux, and the ($V - 12\ \mu$m) color excess.

Name	IRAS	V	[12]	(V–[12]) – (V–[12])$_0$
κ UMa	09002+4721	3.60	3.46	–0.03
ν Cyg	20553+4058	3.94	3.83	0.00

to arise from a circumstellar disk. In classical Ae/Be stars the excess is due to free-free emission from plasma in a gaseous disk. Herbig Ae/Be stars, on the other hand, exhibit IR excess which is due to thermal emission from hot and/or cool circumstellar dust (Waters & Waelkens 1998). These two groups are well separated on ($V - 12\ \mu$m) color excess versus temperature diagram (Hillenbrand et al. 1992). In particular, Herbig Ae/Be stars show an IR excess which is several magnitudes larger than is found for classical Ae/Be stars of a given temperature. Around 10 000 K classical Ae stars exhibit an excess close to zero, while it is from 3 to 10 mag for Herbig Ae/Be stars.

To check whether the new emission stars are classical Ae stars or belong to Herbig Ae/Be stars, we calculated their ($V - 12\ \mu$m) color excess (Table 4). Instead of $(V - 12\ \mu\mathrm{m})_0$ we used $(V - N)_0$ tabulated by Johnson (1966). The interstellar extinction for these stars is small at V and negligible at 12 μm.

On the ($V - 12\ \mu$m) color excess vs. temperature diagram both ν Cyg and κ UMa have been found to occupy the same region with classical Ae stars (with color excesses near 0; see Table 4. It is clear that they are not young pre-main sequence Herbig Ae/Be stars.

5. Discussion

In this study we demonstrated that weak emission ($EW < 0.5$ Å) is observed in the Hα lines of two new Ae stars, ν Cyg and κ UMa. The presence of weak emission introduces only a small distortion in the Hα line profile when it is seen in high resolution spectra ($R \simeq 40\,000$) and may be missed in spectra with lower resolution and/or signal-to-noise ratio. The distortion of the line profile can be revealed through comparison with a synthetic spectrum, provided that the atmospheric parameters of the star are accurately known.

The difficulty of detecting weak emission may result in underestimation of the fraction of emission-line stars. The strength of emission decreases with decreasing of temperature. This suggests that the fraction of stars with weaker emission may be higher for late B stars than for early B stars. The frequency of known Be stars also monotonically decreases from early to late B types (Zorec & Briot 1997). It may well be that effect is at least partly due to the systematic non-detection of weak emission Be stars.

The group of Ae stars seems to be continuation of Be stars toward lower temperatures. If one continues the observed frequency distribution of Be stars toward early A type stars, one would expect approximately 3% of A1–A2 type dwarfs to be classified as Ae. Zorec & Briot (1997) obtained the number of Ae stars by counts in different catalogues. From their data it appears that only 0.2% of A1–A2 stars have so far been identified as Ae stars. This rate is 15 times smaller than is predicted from an extrapolation of the distribution. It therefore seems that there is sharp cutoff in the distribution near the latest B subspectral types. It is interesting that a sudden change in the emission strength also occurs around A0 subspectral type (Andrillat et al. 1986). The emission becomes weaker in early A type stars, and it disappears completely in middle A type stars. However, weak emission is harder to detect, and so Ae stars, which are as a rule characterised by weak emission, may be missed more frequently than Be stars. This may lead to an underestimation of the frequency of Ae stars. Thus, the real frequency of Ae stars may be substantially higher than that found from simple counts in available catalogues.

6. Conclusion

Two new Ae stars, ν Cyg and κ UMa, have been discovered with the context of the Magnetic Survey of Bright Main Sequence stars. They both showed the presence of emission in the Hα line. No significant emission is seen in the Hβ line. ν Cyg exhibits double-peaked emission which is variable on a time scale of 3 years. The Hα line profile of κ UMa hosts weak emission. Its equivalent width is only 0.3 Å. Although such weak emission only slightly distorts the line profile, we were able to detect this small effect through comparison of observed and synthetic spectra. The emission is thought to arise from circumstellar disks, and using the derived parameters of the emission features we estimated the size of the disks.

We derived the absolute magnitudes of the new Ae stars, corrected for binarity. The Ae stars appear to be almost one magnitude more luminous in V than normal dwarfs of the same temperature. This supports the conclusion of Jaschek & Andrillat (1998) regarding the overbrightness of Ae and A type shell stars.

Both ν Cyg and κ UMa are IR sources that were detected with IRAS. Both exhibit IR fluxes typical of classical Ae stars. The newly-discovered emission stars are clearly not Herbig Ae/Be stars.

Lack of detection of weak emission similar to that which we have detected in κ UMa and in ν Cyg in 1999 should be taken into account when calculating the fraction of Ae and Be stars. This is especially important for Ae stars since they exhibit weaker emissions than their hotter counterparts. Counts in presently-existing catalogues may underestimate the true frequency of Ae stars.

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