Astron. Astrophys. 324, 998–1004 (1997)

ASTRONOMY
AND
ASTROPHYSICS

On the comparison between spectroscopic and photometric metallicity measurements in active solar-type stars*

F. Favata[1], **G. Micela**[2], **S. Sciortino**[2], **and F. Morale**[2]

[1] Astrophysics Division – ESA/ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands (fabio.favata@astro.estec.esa.nl)
[2] Istituto e Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy

Received 18 December 1996 / Accepted 25 February 1997

Abstract. We present spectroscopic determinations of the Fe abundance in a sample of K-type stars selected from the X-ray flux-limited *Einstein* Extended Medium Sensitivity Survey. These stars have been shown to have a low value of the m_1 Strömgren photometric index implying low metal abundances, similar to the abundance observed in Pop. II stars. Yet these cool stars are not expected to be metal-poor, being most likely young and thus metal-rich. Based on an equivalent width-based abundance analysis which uses high resolution spectra in the region around the Li I 6707.8 Å doublet, we show that none of the stars investigated shows any evidence for low metal abundances. Rather, all have solar or even slightly super-solar abundances. Thus, for very active K stars, photometric metallicity determinations appear to be strongly biased, with the stars appearing to be of much lower metallicity than they actually are. The stars in our sample are estimated to be coeval or younger than those of the Pleiades. If, as we argue, the bias in the photometric indices depends purely on the high activity level of these stars, it is then likely that all stars sufficiently young to have similar activity levels would display similar photometric anomalies. We then predict that a non-negligible fraction of the disk population K-type stars are expected to show comparable anomalies in their photometric indices. These stars will masquerade as Pop. II stars in photometric surveys, and significantly contaminate Pop. II star samples selected on the basis of photometric properties alone, down to quite faint magnitudes.

Key words: stars: abundances – stars: late-type

1. Introduction

It has recently been shown by Morale et al. (1996) – hereafter M96 – that K-type stars selected from an X-ray flux limited survey (the *Einstein* Extended Medium Sensitivity Survey, EMSS, Gioia et al. 1990) show low values of the m_1 photometric index. The m_1 index is a combination of magnitudes in the Strömgren photometric system which measures the blanketing in the UV region of the spectrum, and which has been extensively calibrated, for dwarfs, as a metallicity indicator. Given that the m_1 index is, at fixed metallicity, dependent on the effective temperature of the star, the color-independent δm_1 index is normally used, defined as $\delta m_1 = m_{1[\mathrm{Hyades}]} - m_{1[\mathrm{obj}]}$, i.e. the difference in the m_1 index between the object under investigation and a standard main sequence, in this case that of the Hyades. Large values of the δm_1 index are typical of low-metallicity (i.e. halo) stars. While the same extensive calibration is not available for giant stars, all the evidence, based for example on synthetic photometry from model atmospheres (Gustafsson & Bell 1979) shows that the m_1 index can also be used as a metallicity indicator in giants, although with a different calibration.

The large δm_1 values which have been measured for the K stars from the EMSS (see Fig. 2 of M96) are comparable to the values observed in low metallicity stars, with some stars having implied metallicity as low as those of halo stars. As already noted by M96, all the available evidence (such as the lithium abundance and the rotational speed) about the nature of the K stars detected in the EMSS, and in particular about the single stars, i.e. the ones not belonging to tidally locked binary systems, points toward them being young objects, either still contracting toward or recently arrived on the main sequence (Favata et al. 1993). The evolutionary status of stars in tidally locked binaries (i.e. RS CVn-type binaries) is less clear, as they typically contain at least one evolved component, and could thus be much older.

The precise evolutionary state of the young single solar-type stars selected in X-ray surveys is still a matter of debate (see Micela et al. 1997 and Favata et al. 1997c for a more extensive discussion of the issue), and it is unclear what fraction is still genuinely in the pre-main sequence stage and what fraction is composed of young main sequence stars, with ages similar to the Pleiades or to the Hyades. The debate has recently been fueled by the large numbers of putative PMS stars being found among the optical counterparts to soft X-ray sources from the ROSAT All Sky Survey (RASS). According to these RASS-based results (see Alcalá et al. 1995 and the following series of papers), most of the sources found in soft X-ray surveys should

Send offprint requests to: F. Favata
* Based on observations collected at the ESO La Silla observatory

be PMS stars, with very few already on the main sequence. This has recently been shown not to be true for sources in the EMSS by Micela et al. (1997), who show, on the basis of precise distances derived from the Hipparcos parallaxes, that most of the stellar sources found in the EMSS are actually main sequence stars. In any case, whatever their precise evolutionary status, the high abundance of lithium which is typically observed in these stars (Favata et al. 1993, Tagliaferri et al. 1994, Schachter et al. 1996) is not compatible with ages approximately older than the Hyades. This is further confirmed by the fact that K-type stars with high levels of lithium similar to the ones found in X-ray samples are very rare in volume limited samples of stars in the same mass range (Favata et al. 1996, Favata et al. 1997b), in which older stars are found to be prevalent. On the basis of all known facts on galactic chemical evolution, stars of such young age are expected to show metallicities similar to or higher than solar, with low metallicity stars being essentially absent at these ages.

Thus, the observed high values of δm_1 in the K-type stars from the EMSS are not in agreement with their expected range of metallicities. M96 considered it unlikely that the high δm_1 in these stars could be entirely due to a low abundance, and showed that there is a strong observed correlation between δm_1 and the level of activity as measured by $f\mathrm{x}/f_\mathrm{v}$, the ratio between the the X-ray and optical apparent magnitudes. Such correlation is indicative of an activity-related effect, but, due to the lack of independent abundance measurements of EMSS stars, M96 could not assess if and in which measure the observed effect was due to a mixture of real abundance effects and activity-induced changes in the m_1 index.

To determine to what extent the observed δm_1 excess can be attributed to stellar activity or to actual metal deficiency, and thus to help constrain the evolutionary status of the solar-type stars detected in X-ray surveys, we have determined the photospheric iron abundance in a sample of K stars from M96, using high-resolution spectra in the red spectral region and an equivalent width analysis using Kurucz model atmospheres. This type of analysis should be less influenced by the possible effects of chromospheric activity, and should therefore help to determine the "true" photospheric abundances of the target stars.

2. The observed sample

Ideally, one would want to study, for the present work, all the K-type stars from the EMSS, and determine their photospheric metal abundance without introducing any selection criteria. However, to be able to perform as accurate an equivalent width analysis as possible, we have decided to discard stars whose spectral characteristics make it difficult to derive the effective temperature, or to reliably measure the equivalent width of the weak Fe I lines from which the abundance is derived. Thus, all SB2 binaries (which constitute a fairly large fraction of the stars in the EMSS) have been discarded, given the difficulty of assigning effective temperatures to each component. Also stars with high rotation speed (again numerous in an activity-selected sample such as the EMSS), which washes out the weak lines and thus makes the type of abundance analysis discussed here impossible to perform, were discarded. Furthermore, to perform a direct comparison, we have chosen to study here only the stars for which the photometry has been presented by M96.

The K-type stars for which the photometry is presented in M96 appear to be clearly separated, on the basis of the value of their c_1 index, in main-sequence and giant-branch stars. Both the main-sequence and the giant-branch stars from M96 show a large δm_1 excess with respect to the respective loci of solar-metallicity normal main sequence and giant stars. As discussed earlier, the lithium abundance of several of the low surface-gravity stars in M96 is much too high for them to be normal (or even active) giants, and they are thus likely to be pre-main sequence stars, still contracting toward the main sequence. The c_1 index for the high activity EMSS stars does not appear (unlikely the m_1 index) to be perturbed by the high activity levels, and the reliability of the discrimination between main sequence and low-gravity stars for EMSS stars on the basis of c_1 has been confirmed using the recently available Hipparcos parallaxes (Micela et al. 1997). Both main-sequence and low surface gravity stars have been included in the present sample.

The restrictive selection criteria discussed above leaves us with a samples of five stars. While the resulting sample is admittedly small, the purpose of the present work is not to produce a statistically complete and unbiased study of the metallicity in activity-selected solar-type stars. Rather, the aim has been to derive reliable metallicities for some of the active stars which show apparent large metal under-abundances, and thus study the relationship between photometric and spectroscopic abundance determinations in active stars. The target stars, together with their main characteristics and with the results of the abundance analysis, are listed in Table 1.

All the spectra used in the course of the present work have been acquired using the CAT 1.4 m telescope at the ESO La Silla observatory in July 1991 and September 1992, with the Coudé Echelle Spectrometer (CES). The short camera with the RCA CCD (ESO #9) was used, yielding an effective resolution of about 50 000. The spectra were originally obtained with the main purpose of deriving the lithium abundance in the target stars, and are therefore centered on the Li I 6707.8 Å line. The data reduction procedure has been described in detail in Favata et al. (1993), to which the reader is referred for details. The five spectra used in the present work are shown in Fig. 1; their signal-to-noise ratio ranges between 60 and 120.

3. The abundance determination

The Fe abundance has been derived, for the stars described in the present work, using the same approach and techniques described in detail in Favata et al. (1997a) – hereafter F97 – to which the reader is referred for details. Here, we will only present a brief summary of the analysis procedure.

For the abundance determination, we used 11 Fe I lines present in the $\simeq 40$ Å wide spectra (which are centered around the Li I 6707.8 Å line). The choice of the lines is discussed in F97, together with the rationale for excluding some low excita-

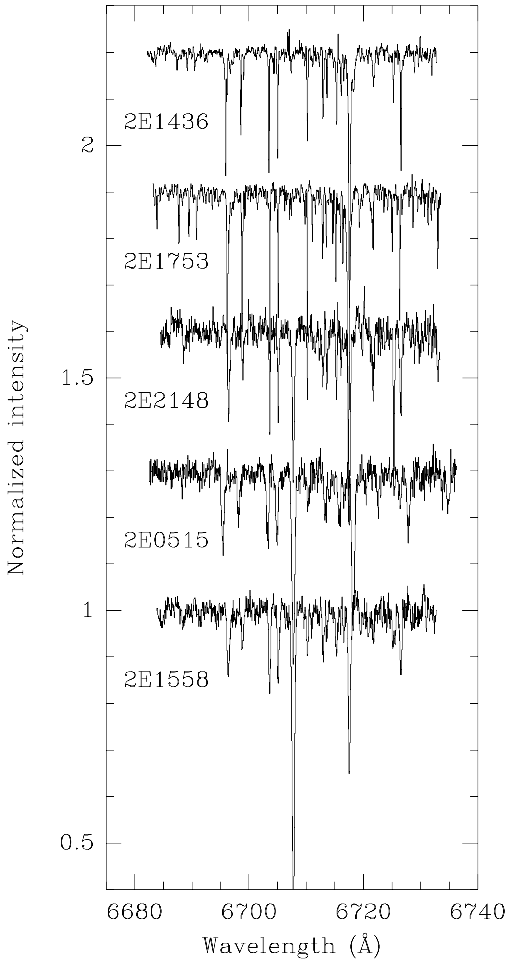

Fig. 1. The high resolution spectra which have been used for the abundance analysis discussed in the present paper. The two bottom spectra are from the two low surface gravity stars in the sample, which also have the most intense Li I line.

tion Fe I lines present in the same spectral region which, in cool dwarfs, yield anomalously low abundances. For the abundance determination, we used the solar $\log gf$ values determined in F97 on a solar spectrum obtained with the same instrument configuration, so that the derived abundance are to be considered as relative to the solar abundance. The equivalent width of the Fe I lines was measured using the IRAF *splot* package, and the abundance was determined using the WIDTH9 code and model atmospheres at the appropriate effective temperature and surface gravity computed using the ATLAS9 code (Kurucz 1993). Note that in all of the target stars it was not possible to measure all the lines used in F97, as some of the Fe I lines are blended with neighboring lines from other elements, and thus can only be accurately measured in stars with very low rotation rates (while the objects studied here all have a moderate rotation speed) and in spectra of very good signal-to-noise. The actual number of Fe I lines used in the analysis ranges from 6 to 8, and is indicated, for each object, in Table 1, together with the derived Fe abundance, relative to the solar value, and the dispersion of the values obtained for the individual lines in the same object.

The effective temperature of each star was determined using the Strömgren photometry of M96, and using the calibration of Alonso et al. (1996). This calibration gives the effective temperature as a function of the $b-y$ and c_1 indices as well as of the abundance [Fe/H] itself. Given that the abundance is the quantity to be determined, the effective temperature has to be derived, if necessary, in an iterative way (which however, given that all the target stars are of near-solar metallicity, has not been necessary).

For the surface gravity we used a value of 4.5 for the main-sequence stars and a value of 3.5 for the low-surface gravity stars. While the surface gravity of the low-gravity objects is likely to have significant uncertainties, up to 0.5 dex, as shown in F97 this leads to an additional uncertainty in the derived abundance of at most 0.1 dex, which therefore does not change the results of the present work in any significant way. The microturbulence was held constant at 1 km/s, a reasonable approximation for the relatively cool stars discussed here.

The scatter in the abundance determination derived from each individual spectral line is $\simeq 0.10$ dex, a value typical for this type of abundance analysis in late-type dwarfs (see F97). We find no evidence for the spectroscopic abundance analysis to be in any way affected by the high activity levels of these stars, as the abundances derived from each individual line do not appear to show systematic dependences on any of the line parameters.

Of the five stars discussed here, three are on the main sequence, while two have lower surface gravity, as measured on the basis of their c_1 index. The three main sequence K dwarfs in the sample all have measurable lithium abundances, ranging between 1.6 and 0.0 dex, on the usual scale in which N(H) is 12.0 (Favata et al. 1993). Such lithium abundances are typical of young main sequence stars, i.e. of age similar to the Pleiades, and are incompatible with their being significantly older, as already at the age of the Hyades lithium is significantly more depleted in K dwarfs.

The photometric abundance, is derived using the δm_1 index reported by M96 and the calibration of Olsen (1984), which has a typical scatter, for the spectral types of interest here, of $\simeq 0.25$ dex. The two most active of the three dwarfs have photometrically derived abundances (-2.4 and -0.8) which would require them to be classified as metal-poor, yet their spectroscopic abundance is $\simeq +0.05$. The less active object (with and $f_{\rm X}/f_{\rm V}$ of -3.26) shows compatible photometric and spectroscopic abundances, thus confirming the statement of M96 that the apparent metal deficiency is activity-induced, and making it likely that the activity level at which the effect starts to be relevant is $f_{\rm X}/f_{\rm V} \simeq -3$. The slightly over-solar Fe abundance derived spectroscopically for all three dwarfs is typical of young main sequence stars, again confirming their evolutionary status.

The two lower surface gravity stars have been chosen from the larger sample of EMSS star, also on the basis of their not having a (visible) binary companion. They have quite large photospheric lithium abundances (i.e. 2.70 and 3.10), which in such

Table 1. The stars for which the spectroscopic abundance has been determined in the course of the present work. The spectral type listed is the one derived from the Strömgren photometry by M96 (also shown in the table). The photometric metallicity reported in the table is derived from the data of M96, using, for the main sequence stars, the calibration of Olsen (1984), while for giant stars the calibration of Gustafsson & Bell (1979) was used.

EMSS name	Other name	Spectral type	$b-y$	m_1	c_1	$T_{\rm eff}$	Photom. [Fe/H]	Spectr. [Fe/H]	# of lines	N(Li)	$f_{\rm X}/f_{\rm V}$ (log)
2E0515.4−0710	–	K0III	0.640	0.260	0.488	4570	−2.0	+0.16 ± 0.11	7	+2.70	−2.22
2E1436.8−2628	SAO 182743	K4V	0.605	0.554	0.194	4570	−0.8	+0.06 ± 0.10	7	−0.05	−2.74
2E1558.4−2232	–	K0III	0.651	0.335	0.422	4250	−1.0	+0.10 ± 0.10	6	+3.10	−2.19
2E1753.5+1830	GJ 698	K5V	0.666	0.722	0.115	4280	0.0	+0.10 ± 0.09	8	+0.75	−3.26
2E2148.2+1420	–	K3V	0.581	0.415	0.172	4520	−2.4	+0.12 ± 0.06	7	+1.60	−2.40

cool stars are only compatible with their being very young, and therefore their low surface gravity can be easily explained as due to their being still contracting toward the main sequence. Their slightly over-solar abundances are also in line with this hypothesis. While no extensive observational calibrations of the δm_1 index in terms of [Fe/H] are available in the literature, it was already evident in M96 that their δm_1 is anomalous with respect to a "solar-abundance giant sequence" which M96 had derived using a small number of normal giants. The two low-gravity stars discussed here lie well above the normal giant sequence of M96. We have derived a photometric metallicity estimate, for them, placing them on the theoretical $m_1$versus $b-y$ diagram of Gustafsson & Bell (1979) (their Fig. 21), which is constructed from synthetic photometry derived from their extensive set of model atmospheres for red giants. The position of our low-gravity stars in this diagram also implies metallicities which are typical of halo stars.

4. What causes the photometric anomalies?

The spectroscopic abundance analysis presented here shows no signs of possible anomalies (such as systematic differences in the abundances derived from individual lines), and the equivalent widths of the Fe I lines in the spectra is not compatible with the abundances being significantly sub-solar. We thus consider the spectroscopic determination of [Fe/H] as reliable, and consider the photometric abundance determination as anomalous. The m_1 index is defined as $m_1 = (v-b)-(b-y)$ (the Strömgren band-passes used in M96 are listed for convenience in Table 2), and it essentially measures the blanketing of the continuum in the violet region of the spectrum due to the crowding of metallic lines. The large number of lines in a metal-rich star reduces the energy flux in the violet region of the spectrum considerably, and thus produces a different m_1 index with respect to a metal-poor star, where the violet continuum is relatively undisturbed. In the very active stars discussed here the energy output in the violet region of the spectrum appears to be as large as in a metal-poor star, as if it were not disturbed by the absorption of the metallic lines. However, M96 detect no perturbations in the c_1 index in the same stars. Given that the c_1 index is also influenced by changes in flux in the v band ($c_1 = (u-v)-(v-b)$), the same effect which produces the change in m_1 must prevent the equivalent change to appear in the c_1 index, i.e. the flux increase in the v band must be matched by a corresponding flux increase in the u band which balances out in the c_1 index.

Table 2. The band-passes of the Strömgren filter set used by M96

Band	Center (Å)	Width (Å)	Actual band limits (Å)
u	3505	330	3324–3686
v	4110	170	4006–4222
b	4685	183	4572–4801
y	5488	235	5376–5636

One possible explanation of the observed shift in m_1 is offered by current models of photospheres and chromospheres of active stars. Houdebine et al. (1996) (hereafter H+96) have recently computed such models for M-type dwarfs. While their models are for a cooler effective temperature than the stars we are discussing here, they still provide a useful insight in the possible mechanisms which may be determining the m_1 shift. From Fig. 1 of H+96 it is evident that the v-band continuum is little affected by increasing stellar activity, while the continuum in the u-band (which is blue-ward of the Balmer jump) shows a strong activity dependence. At the same time, though, the v-band contains the Hδ line at 4102 Å, which, in very active stars, becomes an emission feature. One possible explanation is thus that the observed m_1 shift in very active stars is essentially due to the flux increase in the v band due to Hδ emission, which is fully balanced, in the c_1 index, by the simultaneous u-band continuum increase.

A qualitative estimation of the effect of activity, again using the models of H+96, supports this interpretation. The observed δm_1 changes for the very active stars in our sample are of $\simeq 0.3$ mag, i.e. roughly a factor of two in flux in the v band. Given the $\simeq$ 170 Å band-pass of the v filter, this implies an Hδ line flux of ~ 2 dex the continuum flux, where the line flux is integrated over the line width, while the continuum flux is expressed in $\mathrm{erg\,cm^{-2}\,s^{-1}\,\AA^{-1}}$. Inspection of Fig. 1 of H+96 shows that this is the typical expected flux increase for Balmer lines in very active stars. At the same time the same plot shows that the Balmer continuum (and thus the u-band flux) also increases, by a factor of ~ 4 for the most active model, i.e. by the right amount to counter-balance the shift in the v-band flux in the c_1 index and thus to leave c_1 undisturbed.

Inspection of Fig. 5 of H+96 shows that the ratio between the Hα flux and the Balmer continuum chromospheric flux is however not constant, but is rather also function of the activity level. This implies that, if the explanation discussed here for the δm_1 change is right, later-type stars, in which the contrast between the photospheric and chromospheric u-band continuum will be different, could, in addition to the same type of δm_1 shift, also show changes in their c_1 index.

The same Fig. 1 of H+96 also shows that the chromospheric continuum is likely to be visible, although as a minor effect, also in the v band. This may produce, in addition to the strong increase in the Hδ flux, an additional (albeit perhaps negligible from a photometric point of view) increase in m_1 index. However this may not explain the reduction in the equivalent width of the absorption lines in this region, for which marginal evidence has been found by Basri et al. (1989) in active solar-type stars in the spectral region 3800–5300 Å. They in fact report that in active stars some spectral lines appear to be filled-in with respect to their shape in inactive standard stars. However, they also report that not all lines appear to be filled-in, so that the degree of (eventual) fill-in must depend in a complex way on the line parameters. It is not obvious, also, how much this effect will depend on the spectral region being studied. Thus, at the same time some additional fill-up of individual spectral lines (perhaps from chromospheric emission from the same atomic species) appears to be present.

Both causes, which produce similar effects in the photometric observations of real stars, are likely to be at work in the objects discussed here, although the first seems likely to be dominant. In the above interpretative framework the activity levels required to produce the necessary photometric shifts are consistent with the observed X-ray luminosities. If the Balmer fluxes required to produce the increase in the v-band flux are scaled using the observed flux-flux relationships between Balmer line and X-ray fluxes (as for example Eq. 6 of Rutten et al. 1989 or Fig. 16a of Fleming 1988), the equivalent X-ray luminosities are of order $\sim 10^{30}\,\mathrm{erg\,s^{-1}}$, which is the typical X-ray luminosity of the more active EMSS stars (see Micela et al. 1997).

5. Photometric surveys

The Sloan Digital Sky Survey (SDSS), which is scheduled to start in the near future, will employ medium-band photometry (with a filter system using bands wider than the ones used in the Strömgren system, and rather similar to the bands of the Johnson-Morgan-Cousins system, Fukugita et al. 1996) to separate the astronomical objects detected in the survey into different categories, which will then be the target of spectroscopic observations. While the main aim of the survey is to collect a large number of spectra of galaxies, and thus to perform a large-scale redshift survey, several types of galactic stars will also be subject to study. In particular, Pop. II stars will be actively searched for in the SDSS. The results of the present work show that, for K stars, young and active single stars will masquerade as Pop. II stars in the photometric data, and will therefore significantly contaminate any sample selected on the basis of photometric information only, with active dwarfs appearing as metal-poor dwarfs, and both active K giants and K-type PMS stars appearing as Pop. II K giants.

No sufficiently well-tested model of the changes brought on the spectrum of a cool star by the high levels of activity are available, and therefore a precise assessment of the type of contamination will require an observational campaign of a similar sample of stars conducted within the same photometric system used for the SDSS. It is nevertheless reasonable to assume, given also that similar effects in terms of apparent metal deficiency have been observed in the Johnson system by Amado & Byrne (1997), that activity will induce effects on the metallicity indicators used in the SDSS similar to the ones discussed here.

To quantitatively estimate what the impact of young active stars masquerading as Pop. II objects in the SDSS will be, we have done some simple modeling. We have assumed that all K dwarfs of ages $\lesssim 10^8$ yr will be sufficiently active to display significant shifts in their metallicity indicators, and used a simple Galaxy model (i.e. the one of Bahcall & Soneira 1980, modified to allow separation of the observed star counts in age-homogeneous groups, cf. Micela et al. 1993) to estimate the relative number of real Pop. II stars and young K dwarfs as a function of magnitude and Galactic latitude. The results of the computation are shown in graphical form in Fig. 2, where the number of stars brighter than a certain apparent visual magnitude V is plotted, both for true Pop. II K type dwarfs, and for Pop. I K-type dwarfs younger than $\simeq 10^8$ yr, the age at which their activity level is expected to drop significantly below $f\mathrm{x}/f_\mathrm{v} \simeq -3$.

It is evident from Fig. 2 that young K dwarfs will dominate, at high galactic latitude, over Pop. II K-dwarfs, at all magnitudes brighter than $\simeq 17$, and still at magnitude 19 their number density will be $\simeq 10\%$ of the number density of true Pop. II dwarfs. At lower galactic latitudes the situation is proportionally much worse, with young K-type dwarfs dominating all the way down to magnitude 20.

It thus appears that photometric selections of K-type Pop. II dwarfs are bound to be deeply contaminated by young and active Pop. I K-dwarfs all the way down to faint limiting magnitudes. While our model calculation is based on simple but realistic assumptions, and are thus to be considered as indicative, the predicted magnitude of the effect is very large, and it will then most likely significantly affect real surveys.

Estimating the magnitude of the contamination for giant stars is more difficult, because the data on the fraction of giants which will be sufficiently active are less reliable than for dwarf stars. Making the simple assumption that 1% of the field giants have activity levels higher than $f\mathrm{x}/f_\mathrm{v} \simeq -3$ (a number compat-

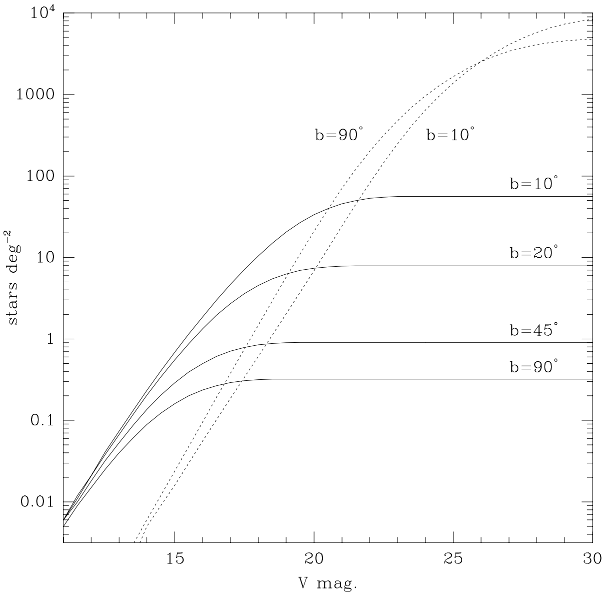

Fig. 2. The number of stars brighter than apparent visual magnitude V, plotted against the magnitude itself, at a number of different galactic latitudes and galactic longitude $l = 90°$. The number of young main sequence Pop. I K dwarfs (ages 10^7–10^8 yr), which, due to their high activity level, would masquerade as Pop. II dwarfs in photometric surveys is plotted using continuous lines, while the number of genuine Pop. II K dwarfs is plotted using dashed lines. The cross-over between the number of true Pop. II dwarfs and the number of masquerade disk dwarfs between magnitudes 17–20 (depending on the Galactic latitude) is due to the small scale height of the young stars in the disk. Thus, the region in which Pop. II dwarfs dominate is the one in which the observations are deep enough as to "exit" the Galaxy's disk. The computation has been performed assuming a constant star formation rate throughout the lifetime of the disk, and stars younger than 10^7 yr have been ignored as discussed in the text.

ible with the results of Maggio et al. 1990), and repeating the computation described above for giant stars, the potential contamination from single active giants appears to be small, and thus most likely negligible.

Less clear is the potential contaminant effect of "field PMS" stars (such as the two low-gravity stars discussed in the present paper), which would likely also masquerade as Pop. II giants. Given that very little is currently known about their space distribution and density, we refrain from any modeling approach. They could, however, also be a potential problem, and their contaminating effect will need to be reassessed when their space distribution will have been better understood.

6. Conclusions

We have used an abundance analysis based on high resolution spectra in the red region of the spectrum to show that the X-ray selected dwarfs discussed by M96 are metal-rich stars, both main sequence and pre-main sequence (the ones with low surface gravity). Their metallicity is typically solar or super-solar, and therefore the m_1 anomaly reported by M96 appears to be *entirely* due to the high level of stellar activity. While M96 had already noted that the observed m_1 anomaly could not be due solely to an actual very low metal abundance, they could not exclude that it was due to a mixture of real abundance peculiarity (even if not so large as implied by the observed δm_1) and activity effects. Here, we show that the observed m_1 anomaly is not in any way related to actual metallicity effects, but it is solely due to the influence of stellar activity.

That stellar activity could influence photometric metallicity estimates has been suspected since almost two decades, based on observations of the Sun (Giampapa et al. 1979), and some observational evidence had been accumulated for active binaries (Gimenez et al. 1991). Also, AB Dor (a young, active star very similar to the stars in our sample) has been shown to have an anomalously low value of the m_1 index by Jetsu et al. (1990). While M96 have shown such anomaly to be widespread (and present essentially in all the K-type stars in the EMSS), here we show that it is a pure activity effect, with no contribution from eventual real abundance peculiarities.

Young, active K-type dwarfs will therefore masquerade as Pop. II dwarfs in photometric surveys. As we have shown, this is likely to be a major effect, with the number of "masquerade" stars being comparable or greater than the number of actual Pop. II stars down to quite faint magnitudes (i.e. $V \simeq 17$ at the Galactic pole, and $V \simeq 20$ at low Galactic latitudes). As shown by M96, the apparent m_1 deficit increases with color, being essentially absent for G stars and increasing strongly for the K dwarfs. While no stars cooler than spectral type K5 are present in the sample of M96, it is likely (also on the basis of theoretical models of the effects of chromospheric emission on the colors of cool dwarfs, see Houdebine et al. 1996) that the effect will be even stronger for the cooler stars, and thus that this masquerade effect would affect samples of M dwarfs even more. Large scale photometric surveys will thus need to take special precautions to avoid confusing young, active dwarf with Pop. II stars.

Acknowledgements. G. M. and S. S. acknowledge financial support from GNA-CNR, and MURST (Ministero della Università e della Ricerca Scientifica e Tecnologica). We have extensively used the Simbad database in the course of the present work, and the IRAF software system for the data reduction. We thank, for the many useful discussions and suggestions on the subject of this paper, R. Rosner, chair of the SDSS stellar survey working group, and R. Kurucz for providing the latest versions of his extensive library of software and data, as well as for much useful advice. We also thank M. Perryman for useful discussions based on an early version of the paper.

References

Alcalá J. M., Krautter J., Schmitt J. H. M. M. et al. 1995, A&AS, 114, 109
Alonso A., Arribas S., Martínez-Roger C. 1996, A&A, 313, 873
Amado P., Byrne P. B. 1997, A&A, in press
Bahcall J. N., Soneira R. M. 1980, ApJS, 44, 74
Basri G., Wilcots E., Stout N. 1989, PASP, 101, 528
Favata F., Barbera M., Micela G., Sciortino S. 1993, A&A, 277, 428
Favata F., Micela G., Sciortino S. 1996, A&A, 311, 951
Favata F., Micela G., Sciortino S. 1997a, A&A, in press

Favata F., Micela G., Sciortino S. 1997b, A&A, in press
Favata F., Micela G., Sciortino S. 1997c, A&A, in press
Fleming T. A. 1988, *Ph.D. thesis*, Univ. of Arizona
Fukugita M., Ichikawa T., Gunn J. E., Doi M., Shimasaku K. 1996, AJ, 111, 1748
Giampapa M. S., Worden S. P., Gilliam L. B. 1979, ApJ, 229, 1143
Gimenez A., Reglero V., de Castro E., Fernandez-Figueroa M. 1991, A&A, 248, 563
Gioia I. M., Maccacaro T., Schild R. et al. 1990, ApJS, 72, 567
Gustafsson B., Bell R. A. 1979, A&A, 74, 313
Houdebine E. R., Mathioudakis M., Doyle J. G., Foing B. H. 1996, A&A, 305, 209
Jetsu L., Vilhu O., la Dous C. 1990, A&AS, 85, 1127
Kurucz R. L. 1993, ATLAS9 stellar atmosphere programs and 2 km/s grid, CD-ROM No. 13
Maggio A., Vaiana G. S., Haisch B. M. et al. 1990, ApJ, 348, 253
Micela G., Sciortino S., Favata F. 1993, ApJ, 412, 618
Micela G., Favata F., Sciortino S. 1997, A&A, in press
Morale F., Micela G., Favata F., Sciortino S. 1996, A&AS, 119, 403
Olsen E. H. 1984, A&AS, 57, 443
Rutten R. G. M., Schrijver C. J., Zwaan C., Duncan D. K., Mewe R. 1989, A&A, 219, 239
Schachter J. F., Remillard R., Saar S. H. et al. 1996, ApJ, 463, 747
Tagliaferri G., Cutispoto G., Pallavicini R., Randich S., Pasquini L. 1994, A&A, 285, 272

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.