EVOLUTIVE STAGE OF THE Am-TYPE STARS

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ABSTRACT

A photometric criterion (the m parameter) deduced from the Geneva 7-colour photometry provides good Am-candidates. In the classical magnitude versus colour diagrams of clusters, the Am-stars tend to lie above the main sequence. The following points will be examined: (a) the validity of the photometric criterion according to recent spectral classifications; (b) the evolutive stage of field Am-type stars from their absolute magnitude and binarity.

Key words: Space astrometry; Stars: Am; Stars: evolution; Techniques: Geneva photometry.

1. INTRODUCTION

The classification of late A- and early F-type stars is mainly based on three types of lines:

(a) Sp(H): Hydrogen lines;

(b) Sp(K): Ca^+ K line;

(c) Sp(m): Various metallic lines.

If a serious discrepancy is present and Sp(H) $\leq$ Sp(K) $\leq$ Sp(m), the star is classified as Am.

Photometry is able to provide good Am candidates. Nicolet & Cramer (1981) defined a reddening-free m parameter in the Geneva photometry.

Until the results of Hipparcos were available, the only means of obtaining information about the evolutive stage of the Am stars was via Am stars belonging to open clusters. At the beginning of the 1980s, it was known that the Am cluster members lie slightly above the main sequence.

The purpose of the present investigation was to confirm or to infer corresponding properties for the field stars.

2. GENEVA PARAMETERS

The seven Geneva pass-bands of Rufener & Nicolet (1988) are given in Figure 1. Note that the U, B and V Geneva filters are different from their homonyms in the classical Johnson system. For example, $U_{\rm Gen}$ is narrower that $U_{\rm Johnson}$ and does not intersect the Balmer discontinuity.

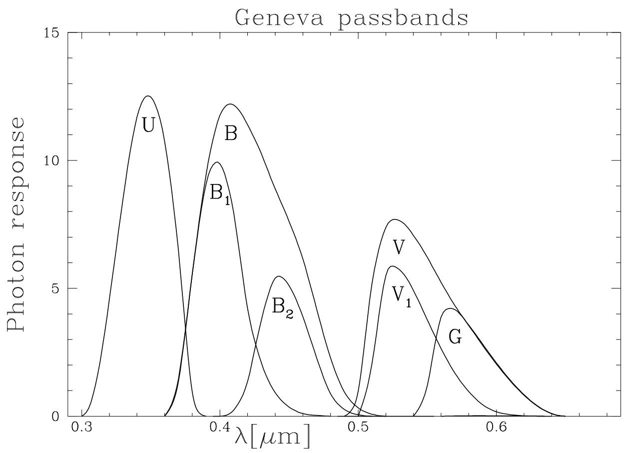

Figure 1. The 7 Geneva passband functions. The U, B and V Geneva filters are different from their homonyms in the classical Johnson system. If appropriate, Geneva indices are distinguished by square brackets, such as [U–B], [B–V], etc. $U_{\rm Gen}$ is narrower than $U_{\rm Johnson}$. The support of the (broad) B filter is the sum of the (intermediate) B_1 and B_2 filters. Therefore B does not provide a lot of additional information. The same remark applies to V relative to V_1 and G.

We clearly see that the broad B filter is to some extent the sum of the intermediate pass-band B_1 and B_2 filters. The same is true for V considered as the 'sum' of V_1 and G. The essential amount of information is provided by the five intermediate filters U, B_1, B_2, V_1 and G. The supplement of information by the broad B and V filters is negligible.

Five independant filters give four independant colour indices: $U - B_1$, $B_1 - B_2$, $B_2 - V_1$ and $V_1 - G$ for example are a *basis* of the photometric space. Any other colour index is a linear combination of indices of the basis.

A linear definition of reddening-free parameters, rigorous for monochromatic (and therefore non-physical) fluxes, is acceptable for narrow, and even intermediate filters. From four colour indices, three

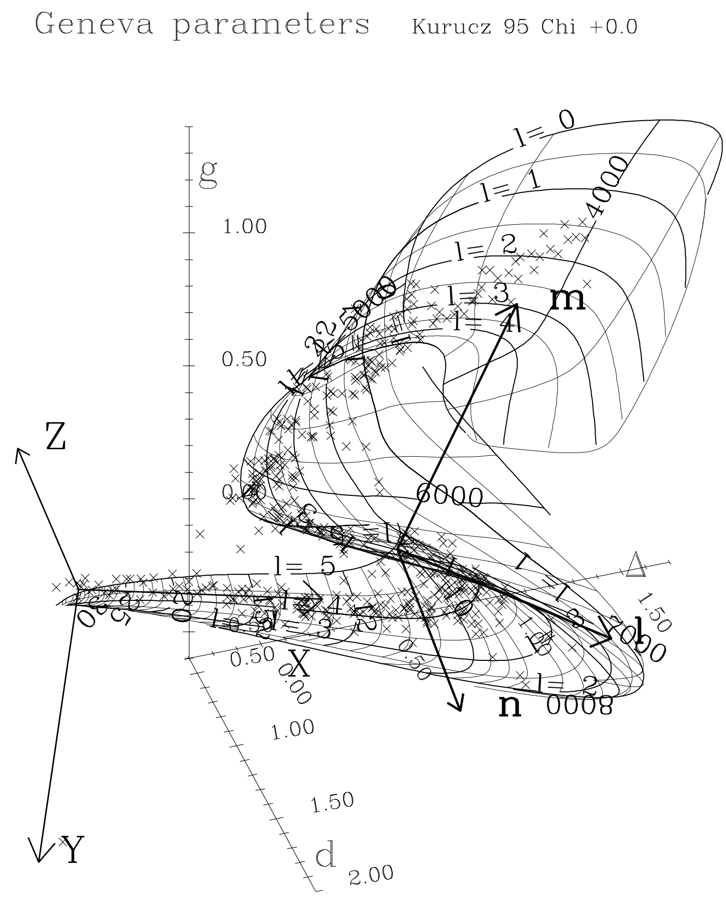

Figure 2. The X, Y, Z (Cramer & Maeder,1979) set of parameters is isometric to the set d, Δ, g. X, Y, Z is especially suitable for the study of hot stars. The set l, m, n is also isometric to d, Δ, g, i.e. it can be obtained from unitary geometric transforms (such as translations, rotations, symmetries) of d, Δ, g. Moreover l, m, n are parallel to the principal axes of the set of the late A and early F-type stars. Iso-log(g) and iso-$T_{\rm eff}$ *lines derived from the Kurucz (1993) fluxes are traced.*

such independant parameters can be deduced:

$$\begin{aligned} d &= (U - B_1) - 1.430\,(B_1 - B_2) \\ \Delta &= (U - B_2) - 0.832\,(B_2 - G) \\ g &= (B_1 - B_2) - 1.357\,(V_1 - G) \end{aligned}$$

In the 3-dimensional d, Δ, g parameters space, Nicolet & Cramer (1981) noticed that photometric boxes (Nicolet 1981) or neighbourhoods around Am-type stars contained a high rate of Am stars, but that d, Δ, g did not allow by themselves an easy prediction for this phenomenon. Another index should therefore exist.

3. l, m, n PARAMETERS

Let E be a set of points in a n-dimensional euclidian space. It is always possible to define n *principal axes* of the distribution of these points. Figure 2 shows two examples: (a) X, Y, Z parameters defined by Cramer & Maeder (1979) for the O, B and early A-type stars:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} +0.3788 \\ -0.8288 \\ -0.4572 \end{pmatrix} + \begin{pmatrix} +0.5476 & +0.8288 & +0.1145 \\ +0.7286 & -0.4051 & -0.5523 \\ +0.4414 & -0.3859 & +0.8257 \end{pmatrix} \begin{pmatrix} d \\ \Delta \\ g \end{pmatrix}$$

Axis X is clearly sensitive to the Balmer discontinuity and provides, for these stars, an excellent parameter for $T_{\rm eff}$. Y, containing a large coefficient for the $B_1 - B_2$ index, is sensitive to the H_γ, $H_\delta \ldots$ Balmer lines and provides an excellent parameter for the gravity $\log(g)$, thus for the absolute magnitude of B-stars. But such calibrations are not valid for solar type and cool stars.

(b) l, m, n parameters for late A and early F-type stars:

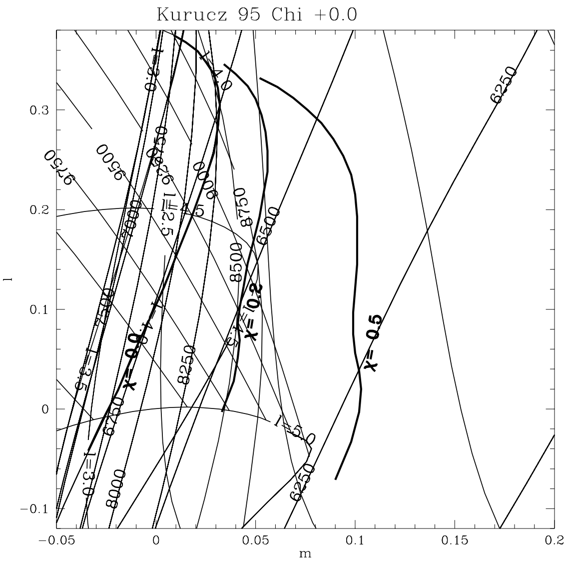

Figure 3. The iso-$T_{\rm eff}$ and iso-log(g) from Kurucz in the l versus m diagram. Temperatures are given simply by their values in K. The log(gravity) are given as l= .... For the dwarf stars (l = log(g)= 4.0), information of astrophysical interest is practically impossible to extract from the first principal l axis, here given as the ordinate. Broad lines are traced for dwarfs (log(g) = 4.0) and χ = [Me—H] = 0.0, 0.2 and 0.5. The second principal axis, m, is a good indicator for χ of the late A-type dwarfs and/or for log(g), i.e. indirectly the luminosity $L/L_\odot$.

$$\begin{pmatrix} l \\ m \\ n \end{pmatrix} = \begin{pmatrix} -1.080 \\ +0.340 \\ +0.352 \end{pmatrix} + \begin{pmatrix} +0.771 & +0.636 & -0.028 \\ -0.537 & +0.675 & +0.505 \\ -0.339 & +0.374 & -0.863 \end{pmatrix} \begin{pmatrix} d \\ \Delta \\ g \end{pmatrix}$$

The first axis l has unfortunately no clear astrophysical significance since the effects of differential extinction mimic almost exactly a cooling of $T_{\rm eff}$ for this category of stars. Without any intrinsic index like $(B_2 - V_1)_0$ or a reliable spectral type, it is very difficult to estimate $T_{\rm eff}$, as illustrated by Figure 3.

The second axis m, however, is a good indicator for chemical composition $\chi = [Me|H]$ for these stars. Am stars are obviously not simply overabundant A stars, but the diffusion process (see, for example, Alecian 1995) enhances the superficial abundance of heavy elements such as Ca.

4. CLUSTER Am STARS

Am stars have preferentially $m \geq 0.05$. Figure 5 shows this tendancy for members of the oldest clusters containing A-type stars before the red giant phase. Although Am stars cannot be crudely considered as overabundant stars, theoretical curves for dwarfs of $[Me|H]$ = 0.0, 0.2 and 0.5 were added in this plot.

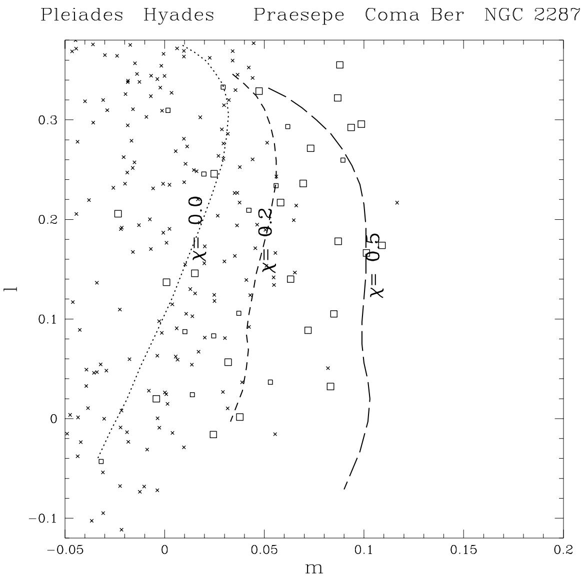

Figure 4. Cluster stars in a l versus m diagram. Stars classified as Am in the Renson (1992) list are plotted as large squares, the 'Am?' are small squares and other stars as crosses. The theoretical curves from the Kurucz (1993) fluxes, with log(g) = 4.0 (representative of the main sequence stars) and various χ or [Me—H] (0.0 is solar abundance) are superimposed.

Before Hipparcos the members of the closest clusters had both the best absolute magnitudes and the most reliable values for their ages. The lists of Ap and Am cluster stars by Renson (1992) are very valuable. The comparison of Figure 5 left (young clusters) and right (old clusters) shows that:

(a) the absolute magnitude of the Am stars is slightly brighter than the magnitude of stars having the same colour index. A possible explanation is the higher rate of binarity for the Am. Is that sufficient?

(b) the Am phenomenon is more frequent in the old clusters;

(c) the Am stars lie very often, but not always, above the main sequence.

It is well known that binarity enhances the Am phenomenon by slowing the rotation of the A dwarfs. Binarity also causes an increase of the luminosity up to a factor of two corresponding to a decrease of the absolute magnitude M_V by -0.75 raising the point in the plot.

The Am phenomenon is more frequent for the Am stars leaving the main sequence, at least for the cluster members.

5. FIELD Am STARS

What is the predominant factor enhancing the rate of Am among the late A type stars: binarity? age? evolutive stage? With an accurate absolute magni-

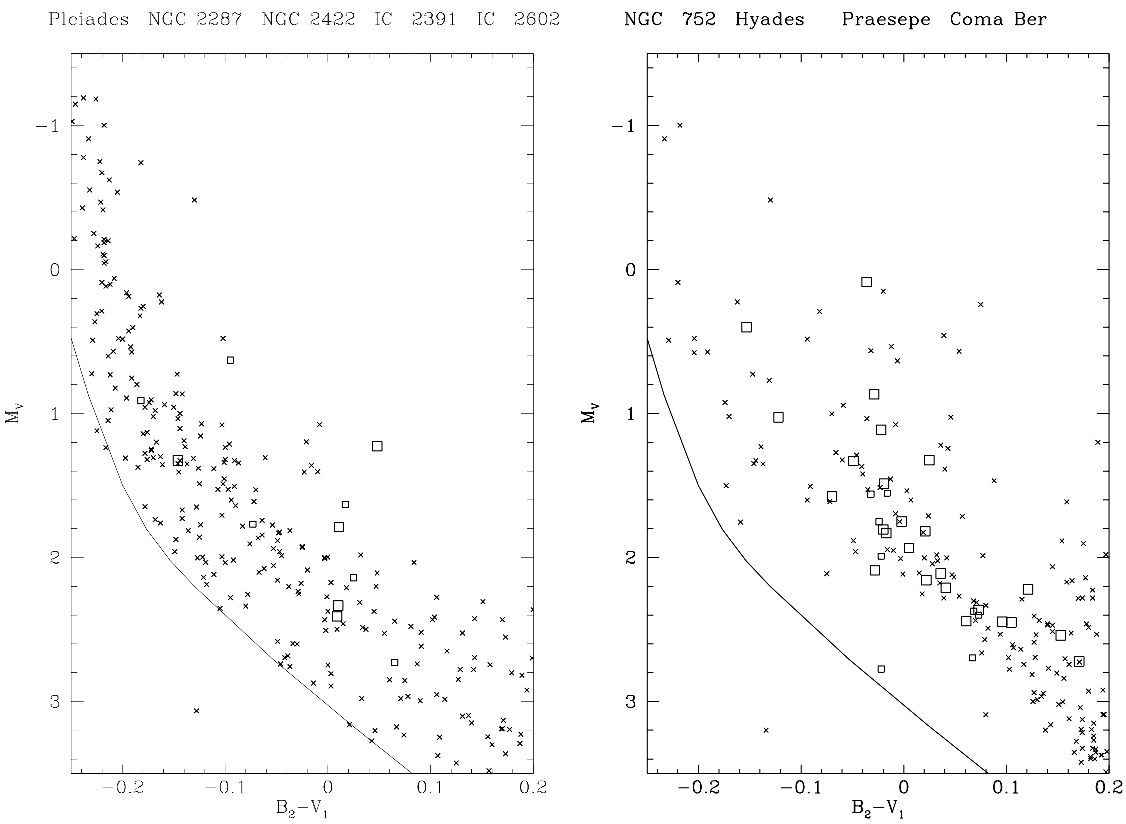

Figure 5. *M_V versus B_2–V_1 diagram for some young (left panel) and old (right panel) clusters. As in Figure 3, large squares are for Am stars, small squares for 'Am?' and crosses for the others. The line gives an approximate localization of the ZAMS and is used here as a reference.*

tude for field Am stars, we hoped to improve our knowledge concerning these causes.

On the basis of the m and l parameters a selection of confirmed and candidate Am field stars were submitted to Hipparcos (proposal 113) in order to estimate their M_V magnitudes and, hopefully, their evolutive stage directly from very accurate parallaxes expected from Hipparcos.

The absolute M_V magnitudes deduced from the Hipparcos parallaxes provide new information as seen in Figure 6 which is analogous to an HR diagram.

From the Schaller et al. 1992 models giving $T_{\rm eff}$ and $L/L_\odot$, $\log(g)$ was easily deduced via the Kurucz (1993) fluxes $B_2 - V_1$ and the bolometric correction for stars having $M/M_\odot = 1.7, /2.0$ and 2.5 and various ages. The path obtained for each mass is traced in Figure 6. Some ticks give the (theoretical) age.

6. CONCLUSIONS

Binarity plays a role in the frequency of Am by slowing the rotation by tidal effects. The mixing, inhibiting the diffusion, due to differential rotation is less probable. But this role is not preponderant. Binarity can raise a point up to −0.75 magnitudes and we clearly see in Figure 6 that a majority of Am stars are raised by a higher value.

The age, by itself, has no preponderant effect, since stars with $M = 2.5\ M_\odot$ and an age $t = 5 \times 10^8$ years are clearly in a region of high density for Am in our HR diagram while 2.0 $M_\odot$ stars with the same age are not. At the time of the proposal, we hoped to be able to describe the kinematical history of the Am stars. An error of 1 km s^{-1} on the velocity $\vec{v}$ corresponds to an error of 700 pc for a $7 \cdot 10^8$ years age. But we see that the incertainties over the age are rather high and that is the main problem.

The evolutive stage seems to play the major role. North & Meynet, private communication (1996) computed the inertial momentum $I = \int \rho(r) r^2 \sin\vartheta d\vartheta\ dr$ for a set of evolutive models. The dilation of a dwarf star leaving the main sequence causes an increasing of $\log I$ by 0.5 dex or a factor three on I. In the (crude!) hypothesis of a rigid rotation of the star, $v_{\rm rot}$ is divided by 3 or so. The differential rotation (contradicting the rigid sphere hypothesis) is less probable at this stage.

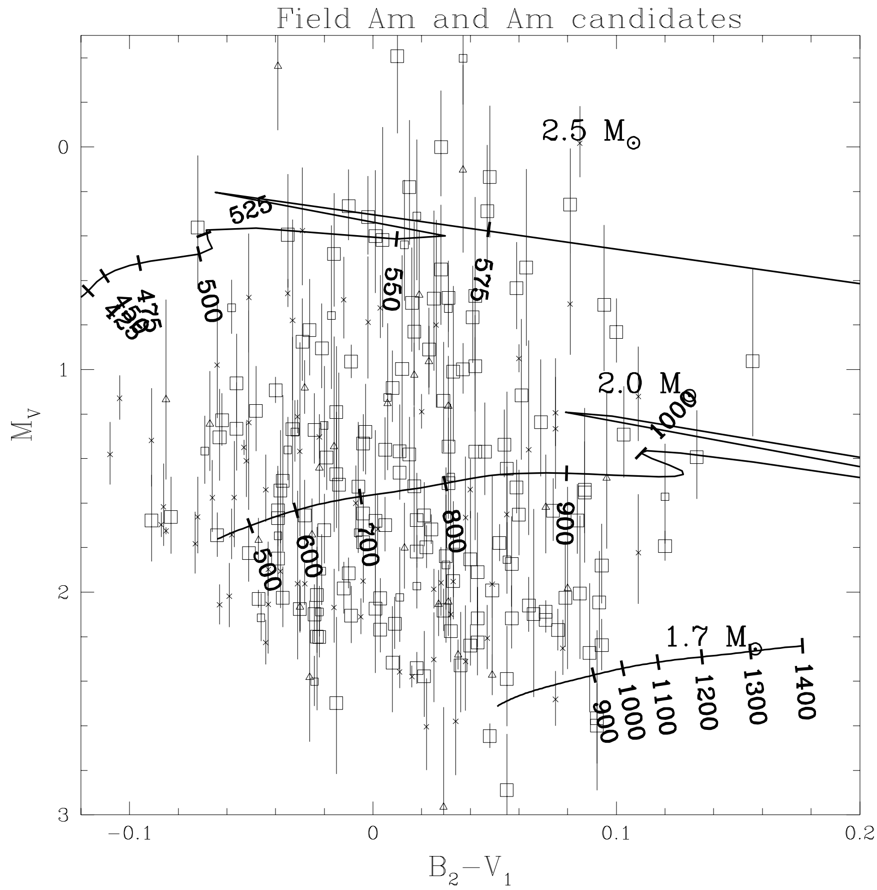

Figure 6. M_V versus B_2–V_1 diagram for field stars of the proposal. Large squares are for Am stars according to the CDS data base, small squares for stars classified by some, but not all authors, crosses for non-Am stars, small triangles for stars not classified. The vertical error bars come from the Hipparcos results. Note that they are slightly asymetric because the distance modulus m–M is not an affine function of the parallax π. The evolutive paths deduced from Schaller et al. (1992) for 1.7 $M_\odot$, 2.0 $M_\odot$ and 2.5 $M_\odot$ are traced. Theoretical ages in units of 10^6 years are also marked by ticks.

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