Looking for a definitive answer for age dependency in Ap stars

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Abstract

For many decades the evolutionary status of the magnetic Ap stars has been controversial. Today there are two working hypotheses and their observable consequences: 1) The peculiarities arise shortly after the stars arrive on the MS and then the frequency of Ap stars in cluster is constant with cluster age; or 2) The peculiarities show up slowly during the stars life on the MS and then the frequency of Ap stars in cluster depends upon cluster age.

We are studying the frequencies of Ap stars in open clusters of different ages to decide which models best represents the observed frequencies. We found 27 Ap stars among 371 stars in the spectral range of B7V to A9V in 18 open clusters. We combine the clusters in 3 groups by age and we found frequencies of Ap stars of 5.1%, 6.1% and 9.4%, for the group 1, 2 and 3, respectively. We compare statistically the observed frequencies with the models and we found a weak evidence that a model 2 is better than model 1. With the simulations we conclude that we will need at least 900 stars per group to reach a definitive answer for the dependency upon age for Ap stars.

Introduction to the problem

The evolutionary status of the Ap stars is still a matter of debate. There are two working hypotheses and their observable consequences:

Hypothesis		Observable Consequence
1) The peculiarities arise shortly after the stars arrive on the MS.	→	1) Frequency of Ap stars is constant with cluster age.
2) The peculiarities show up slowly during the stars life on the MS.	→	2) Frequency of Ap stars depends upon cluster age.

How to tell?

We are studying the frequencies of Ap stars in open clusters of different ages to decide which model best represents the observed frequencies.

Observations

We have obtained classification spectra of 470 stars between late B, A and early F–type stars in 18 open clusters. In each cluster we have observed all the stars with unreddened colors in the range $-0.16 \leq$ B – V $\leq +0.30$. We used two criteria to determine which cluster to observe. First, the apparent distance modulus $(m - M)_0 \leq 11$; the distance to reach a S/N = 100 in less than 20 minutes. Second, the cluster age had to be less than $10^{8.8}$years; the age A stars leave the main sequence. The data have been reduced and analyzed with IRAF using standard methods. Table 1 lists the sumary of telescopes/instruments used.

Table 1:

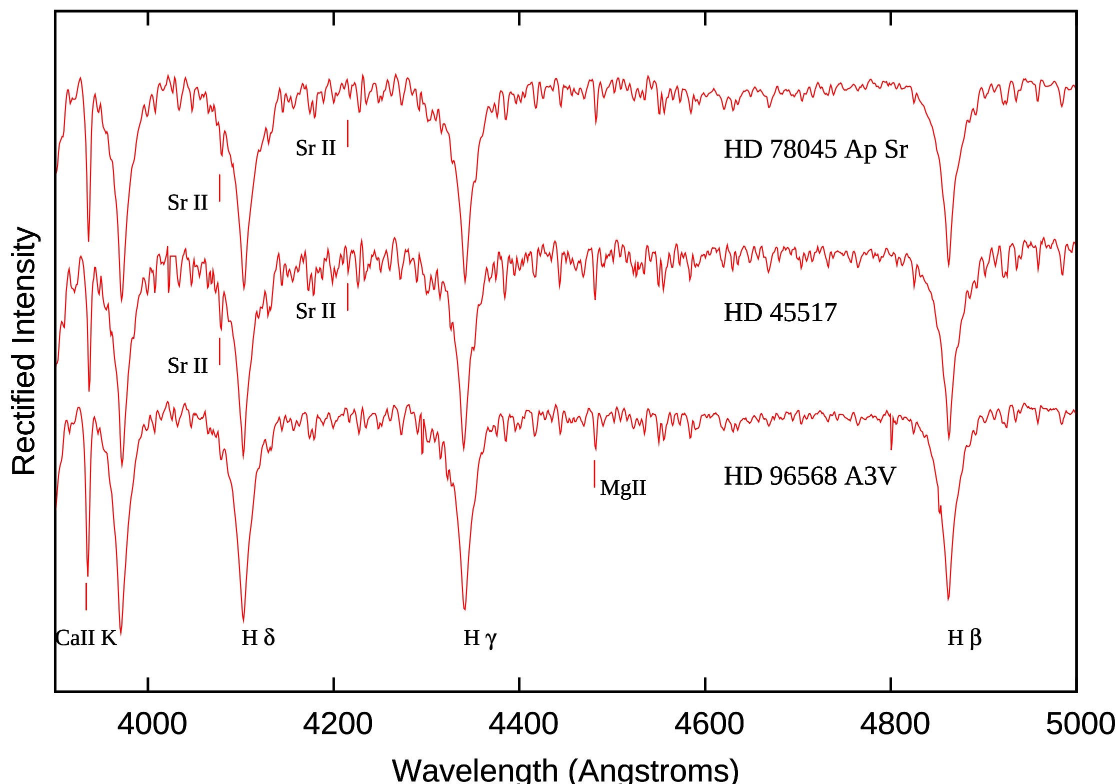
Dates	Telescopes	CCD	grating (g/mm)	$\lambda_{central}$ (Å)	$\Delta\lambda$ (Å)
04–06 Mar. 2000	LNA 1.6m	#106 (Loral 1024x1024)	1200	4500	2
27–30 Mar. 2002	ESO 1.52m	#38 (Loral 2688 x 512)	1200	4600	2
02–05 Mar. 2002	CTIO 1.5m	Loral1K#1 (Loral 1200 x 800)	600	4700	3
18–21 Dec. 2002	ESO 1.52m	#38 (Loral 2688 x 512)	1200	4600	2
21–25 Aug. 2002	McDonald 2.1m	CCD1 (Loral 1024x1024)	600	4600	3

* All observations done with Cassegrain Spectrographs

Spectral Classifications

The spectra have S/N $\sim$ 100, and were classified on the MK System. A set of MK standards and a set of "well-known" peculiar stars were observed to help with the classifications. The classification was done without knowledge of the program star name (i.e. blind). After classification we did statistical analysis only on stars classified in the range of B7V to A9V. Our classification is listed in the journal of observations.

Figure: Example of the classification procedure. Comparison of the program star HD 45517 which belongs to the open cluster NGC 2232 with the MK standard HD 96568 A3V and a "well-known" peculiar star Ap HD 78045 A3 Sr. The features that lead to its classifications as an Ap Sr are indicated in the figure.



Journal of Observations

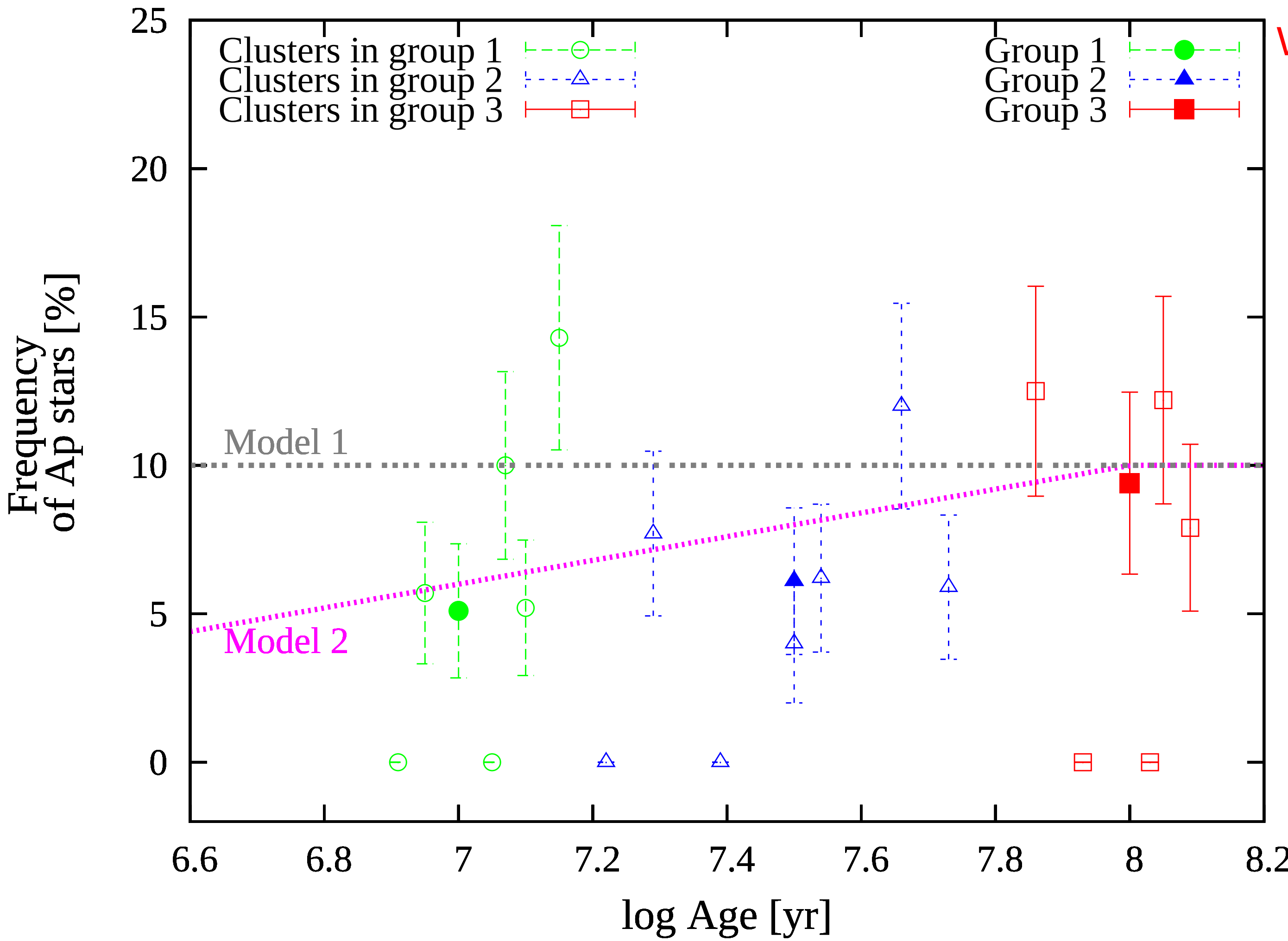
Clusters Names	# Observed Objects	# Objects B7V–A9V	Ap	fAp Ap/A	Log Age log(yr)	RA DEC (1950)	m – M (mag)	E(B–V)	Observ.	obs-date (month/year)
Group 1										
NGC2362	34	22	0	0.0%	6.91	07 18 – 24 57	10.71	0.095	ESO	DEC/02
NGC2264	45	35	2	5.7%	6.95	06 40 +09 53	9.12	0.051	CTIO	MAR/02
NGC1502	14	5	0	0.0%	7.05	04 07 +62 19	9.57	0.759	McD	AUG/02
NGC2169	12	10	1	10.0%	7.07	06 08 +13 57	10.11	0.199	ESO	DEC/02
NGC2343	22	19	1	5.2%	7.10	07 08 – 10 37	10.12	0.118	ESO	MAR/02
NGC5281	15	7	1	14.3%	7.15	13 46 – 62 55	10.23	0.225	CTIO	MAR/02
Total	142	98	5	**5.1%**	**7.0**					
Group 2										
IC2395	13	8	0	0.0%	7.22	08 42 – 48 09	9.24	0.066	ESO	DEC/02
NGC7160	18	13	1	7.7%	7.29	21 53 +62 36	9.48	0.375	McD	AUG/02
NGC4103	23	10	0	0.0%	7.39	12 06 – 61 15	11.06	0.294	CTIO	MAR/02
IC2602	33	25	1	4.0%	7.50	10 42 – 64 24	6.04	0.024	LNA	MAR/00
Trumpler 10	18	16	1	6.2%	7.54	08 47 – 42 27	8.14	0.034	ESO	DEC/02
IC2391	27	25	3	12.0%	7.66	08 40 – 53 02	6.21	0.008	ESO	DEC/02
NGC2232	19	17	1	5.9%	7.73	06 28 – 04 50	7.78	0.030	ESO	DEC/02
Total	151	114	7	**6.1%**	**7.5**					
Group 3										
NGC2422	20	16	2	10.5%	7.86	07 36 –14 29	8.45	0.070	ESO	MAR/02
NGC3228	11	11	0	0.0%	7.93	10 21 –51 43	8.68	0.028	CTIO	MAR/02
Collinder258	13	12	0	0.0%	8.03	12 27 –60 46	10.38	0.160	ESO	MAR/02
NGC2516	88	82	10	12.2%	8.05	07 58 –60 45	8.06	0.101	CTIO	MAR/02
NGC3114	45	38	3	7.9%	8.09	10 02 –60 07	9.80	0.069	ESO	MAR/02
Total	177	159	15	**9.4%**	**8.0**					
Grand total	470	371	27	7.3%	7.5					

Statistical tests

We found 27 Ap stars among 371 stars in the spectral range of B7V to A9V. To investigate if there is a dependence upon age of the Ap phenomenon, we combine the clusters in 3 groups by age and computed the frequencies of occurrence of Ap stars for each group (see Journal of observations and Figure 2). In order to test the significance of the differences in the frequencies, a 2×3 contigency table test for independence was built. The χ^2 value computed is 1.7, which corresponds to a confidence level of 60% to reject the hypothesis of independence.

We compare statistically the observed frequencies with two simple models for the frequency of Ap stars. Model 1: frequency of Ap stars is constant with the stellar age, and their value is the frequency of the field (10%). Model 2: frequency of Ap stars is zero until logt=5.5, and after that threshold, increases linearly with age until logt=8.0, when the frequency becomes constant and equals the field frequency (10%). To test which model best represents the observed frequencies an F-test based on the ratio of chi-squares of model 1 to model 2 was applied. An F value of 6.23 was found, corresponding to P_{F_1} = 25% and P_{F_2} = 75%. This result is a weak evidence that model 2 better than model 1.

Results



Which model best represents the observed frequencies of Ap stars (f_{Ap})?

Model 1

f_{Ap} is constant with age

$\times$

Model 2

f_{Ap} is age dependent

F – Test

We apply F test to compare

$\chi^2_{model\ 1} \times \chi^2_{model\ 2}$

$P_1 = 25\%$ and $P_2 = 75\%$

We are not able to decide between the models.

Figure 2: The frequencies of Ap stars (f_{Ap}) for groups of clusters is the number ratio of the sum of Ap stars in each group to the sum of stars in the spectral range of B7V to A9V in each group. The age each group of clusters is the mean age of the clusters.

How many stars?

How many stars do we need to get to the defi nitive answer?

To find out the number of stars needed in each cluster group to reach a definitive answer for the dependency upon age for Ap stars, we proceed with simulations of clusters based on the expected frequency of Ap stars for model 1 (with age dependency) and model 2 (with no age dependency).

Simulations

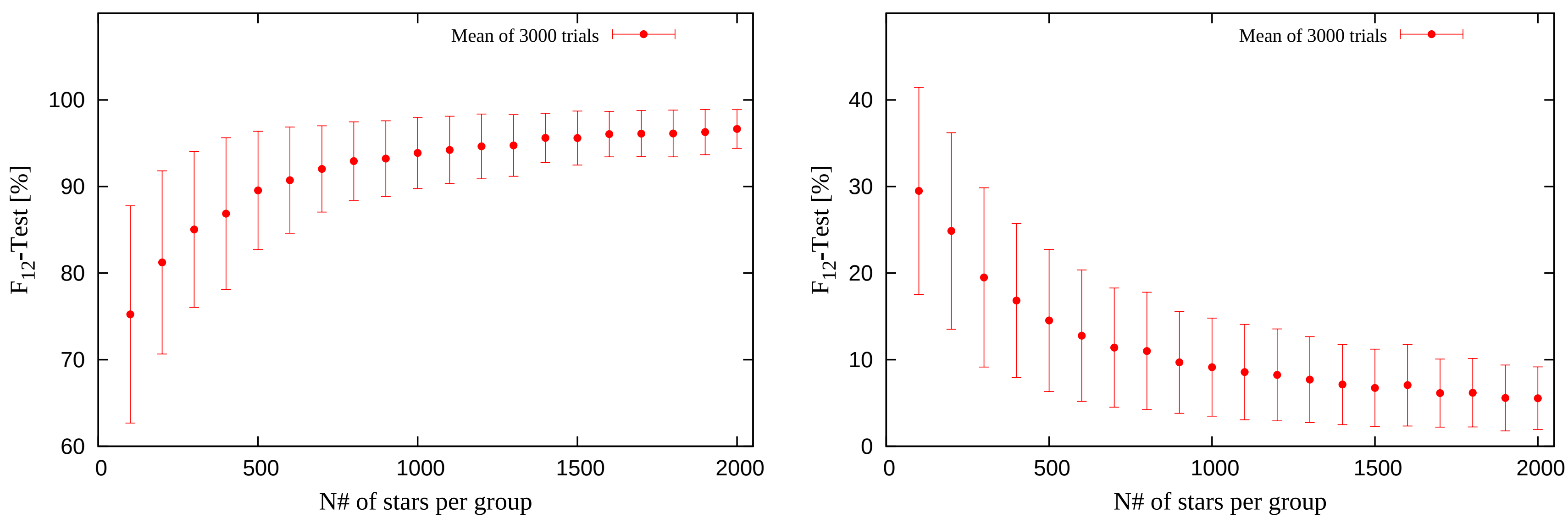
For each model, we produce 3000 trials for a fixed number of stars per group. In each trial we generate 3 groups of clusters with the same age of the clusters we observed, then we count the number of Ap stars in each group and compute the frequency of Ap stars. The number of stars per group varied from 100 to 2000 in steps of 100.

Results of the simulations

Figure 3: The result of simulations with group of clusters generated with age dependency (right) and no age dependency (left). To answer the question of how many stars we need, we applied an F-test (on the χ^2 of 3000 trials) for different numbers of stars per group. If the real f_{Ap} is age dependent (right), then we will need 900 stars per group to reach $P_{F_{12}} = 10\%$ and we can conclude that model 2 is significantly better than model 1. The same is true for no age dependence.

$$F_{12}\text{-Test} = \frac{\chi^2_{model1}}{\chi^2_{model2}}$$

With no age dependency — With age dependency



Conclusions

- We found 27 Ap stars among 371 stars in the spectral range of B7V to A9V.
- We combine the clusters in 3 groups by age and we found f_{Ap} of 5.1%, 6.1% and 9.4%, for the group 1, 2 and 3, respectively.
- We compare statistically the observed frequencies with two simple models for the frequency of Ap stars.

Model 1		Model 2
f_{Ap} is constant with age	X	f_{Ap} is age dependent

- We found a weak evidence that model 2 is better than model 1.
- With the simulations we conclude that we will need at least 900 stars per group to reach a definitive answer for the dependency upon age for Ap stars.

References

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