Publications of the Department of Astronomy — Beograd, № 6, 1976.

GENERAL PROPERTIES OF THE AP STARS

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Abstract — The general properties (surface temperature, luminosity, rotational velocity, frequency of binaries, atmospherical chemical composition, variability) are summarized, together with the main theories proposed for explaining the phenomenon of the A-type peculiar stars.

The purpose of this review is to summarize the general properties of the peculiar A-type stars and especially the results of the atmospheric abundance determinations, in order to make them comparable with the predictions of the various theories, and to emphasize which are the basic differences between the sub-groups of Ap stars (Si-, Mn-, cool-Ap) and the Am stars (metallic-line stars).

The main characteristics of Ap and Am stars are summarized in Table 1. We point out the following facts:

Groups of stars presenting no measurable magnetic field (like the Mn- and the Am-stars) are not light — or spectrum-variable, while the other groups (Si- and cool-Ap stars) showing magnetic fields ranging from few hundreths of gauss to 35 kilogauss are generally spectrum-variable and light-variable.

The Ap- and Am-stars cover a large range of ages, from less than 10^6 y to more than 5×10^9 or 10^{10} y. Hence the peculiarity is not due to evolutionary effects.

The region of the HR diagram where they are found is characterized by the following properties of the stellar atmospheres: no atmospheric unstability due to radiation pressure and mass loss, to convection or pulsation is present in that region; in addition the peculiar stars are slow rotators as compared with normal stars in the same region of the diagram. Hence, whichever is the reason producing the chemical atmospherical peculiarities, these are not destroyed by mixing with the matter in the interior. It is therefore very important to check carefully the boundaries of the region in the HR diagram where Ap and Am stars are placed, in order to be sure that no peculiar star is a pulsating star or a fast rotator (Breger, 1969, 1970). It should be very important to observe by multicolor photoelectric photometry a large number of stars classified Bp or Ap, or Am in order to study their light variability and to ascertain if in some cases this might be explained by pulsation. At present it seems that spectrum-variability and magnetic field variations are explicable by the model of the oblique rotator, while the light variation is probably correlated with blanketing variations.

Table 1

	Ap Mn	Ap Si Si — Cr — Eu	Am
Range in θ_e	0.26 — 0.56		0.54 — 0.75
„ „ log g	3.5 — 4.4		3.5 — 4.4
B—V	— 0.15 (Mn) (≤ 0.00) Si	— 0.05 (~ 0.00 ÷ + 0.25 (Sr Cr Eu)	+ 0.2 ÷ + 0.35
V sin i	≤ 90	≤ 90	≤ 90
Microturbulence	normal	for their θ_e	and log g
Percentage of spectr. binaries	40%	20%	90%
Percentage of vis. binaries		Like normal stars	
Magnetic fields	?	probably always present (from few 100 g to 35 Kg)	?
Variability in light	no?	yes	only 2 cases known
RV	no?	yes	no, except for orbital motion
field	no field meas.	yes	no field measurable
line intensity	no?	yes	no
Age	$\leq 10^8 \div > 10^{10}$ (halo stars)		$\leq 3.10^8$ to 10^{10} (M 67)
Abundance peculiarities	defect of He in Mn, Si stars Defect of *O* Excess of Mn, Si Fe peak (X10 to 100) Excess of heavy elements (X100 to > 1000) and Rare Earths Mn stars excepted		Defect of Sc, Ca (X10) Excess of Fe peak (X10) Excess of heavy elements and Rare Earths (X10)

Frequency of Ap, Am stars: about 15% of normal stars of the same color.

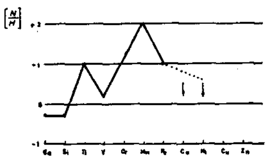
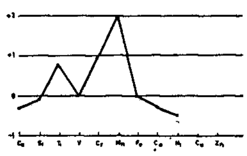
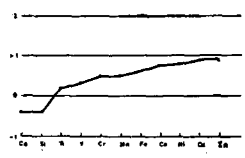
There is also need for spectroscopic studies of population II stars classified as Ap or Am (Klemola, 1962; Graham et al. 1973) by means of high spectral resolution spectra.

The atmospherical abundance peculiarities can be summarized as follows: a general defect of the light elements, an excess of the elements of the iron peak, and a strong excess of heavy elements and rare earths. However the various groups present a different behavior, which is sketched in Table 2.

Several theories have been proposed in order to explain the characteristics of the Ap stars and Am stars. The slow rotation is explicable by the presence of the magnetic field which interacting with the interstellar matter can act as a braking factor; for Am stars, which do not have a measurable field, we suppose that the braking is due to the interaction with the companion; a reasonably hypothesis

Table 2

Summary of the main differences in abundances (relative to normal stars and not to Fe)

	a) Hot Ap stars in the same θ_e and g range			b) Cool peculiar stars in same θ_e and g range	
	Si stars (magnetic field present; spectrum-variability present)	Mn stars (no magnetic field; no spectrum-variability		cool Ap stars (magnetic field present; spectrum-variability present	Am stars (no magnetic field; no variability
He	deficient	deficient			
CNO	probably deficient, few data	normal? no sufficient data	CNO	O deficient, no other data	C deficient no other data available
Mg	normal? (however UV observations suggest it is deficient)	deficient or normal (UV observations suggest it is deficient)	Mg	normal (UV observations of one case confirms normality)	defect
Si	excess	normal	Si	normal or excess	normal or slight defect
Ca	defect or normal	defect	Ca	normal or slight excess	defect
Sc	defect or normal	normal	Sc	normal or slight excess	defect
Fe peak	Fe enhanced by a factor of ~ 10	Fe normal	Fe peak	Fe enhanced by a factor of ~ 10	Fe enhanced by a factor ~ 3
	Schematic abundances:  Cr Mn			Schematic abundances:  Cu and Zn are probably deficient since their lines were not observed in Ap	
Sr, Y, Zr	enhanced by factors 30 to 50	enhanced by factor ~ 30	Sr, Y, Zr	Sr enhanced by a factor ~ 100 Y ~ normal Zr enhanced by a factor ~ 100 Sr% $\simeq$ Zr $\geq$ Y	Sr enhanced by a factor of ~ 10 to 5 Y enhanced by a factor of ~ 5 Zr enhanced by a factor of ~ 4 to 2 Sr $\gtrsim$ Y > Zr
RE	They are all enhanced, with the exception of Ba, by factor ~ 10^3—10^4	no enhancement	RE	Ba normal; excess of other RE increases with atomic number; excess by a factor 10^2—10^3	all RE are enhanced by a constant factor of 10 to 30 absent
Rare elements (f. i. P, S, Ga, Hg, U)	Present in several Si stars	Present in several Mn stars	Hg and other rare heavy elements	present	

since more than 90% of Am stars are members of close binary systems (as compared with 40% for normal A-type stars). It is not easy to explain the slow rotation of Mn-stars which have no measurable field and have a percentage of binaries comparable to that of the normal stars.

Two groups of theories have been proposed in order to explain the production of the chemical peculiarities: nuclear theories, and physical separation theories. Burbidge and Burbidge in 1954 suggested that nuclear reactions can occur in the atmospheres where the strong variable magnetic fields might act as particle accelerators. However this theory is not acceptable because of severe difficulties with the energies requested and because the variability of the field is not real but due to the rotation of the star, and hence only an effect of different aspect. In 1965 Fowler, Burbidge, Burbidge and Hoyle suggested that the Ap stars were evolved objects and that their atmospheres were mixed with the gas of the interior, enriched by nuclear reactions occurred during the stellar life. This hypothesis does not hold anymore, because we know that a large majority of Ap and Am stars are very young. Since the characteristics of the old population II Ap stars are very similar to those of the young stars of the same color (see for instance Sargent and Searle, 1967, 1968; Stalio, 1974) it is probable that the same mechanism produces the peculiarities in both groups. Brancazio and Cameron (1967) have computed the effects that spallation by cosmic rays can produce on the atmospherical chemical composition. They conclude that the effect should be to deplete the atmosphere of heavy elements, i.e. a result just opposite to the observations.

The physical separation theories are more promising, and especially that suggested by Michaud (1970), based on the possibility that diffusion can occur in quiet atmospheres like those of the Ap stars. Michaud is able to show that the elements which are found to be in defect diffuse downward under the effect of gravitation, while those which are found in excess are pushed up by radiation pressure. The prevalence of radiation pressure over the gravitational force depends on the absorption coefficient of the ion and on its abundance. Havnes and Conti in 1971 have proposed another theory, suggesting that the interaction of the stellar magnetosphere with the interstellar matter permits to accrete ions in a differential way: easily ionizable gas, like the rare earths, is accreted in a higher percentage than difficulty ionizable gas, like helium.

In conclusion, a very large amount of information on Ap and Am stars has been collected; however we need more photometric and spectroscopic observations, in order to check the results with the predictions of the theories. The diffusion theory seems that one which explains the larger number of facts, but still many details are not clear. Moreover it is very difficult to understand how diffusion can occur, and how microturbulence does not mix the atmosphere, also in relatively quiet atmospheres like those of the Ap and Am stars.

REFERENCES

Brancazio, P. J. and Cameron, A. G. W., 1967 Canadian J. Phys. *45*, 3297.

Breger, M., 1969 Astroph. J. Suppl. *19*, 99.

Breger, M., 1970 Astroph. J. *162*, 597.

Burbidge, G. R. and Burbidge, E. M., 1954 Astroph. J. Suppl. *1*, 431.

Fowler, W. A., Burbidge, E. M., Burbidge, G. R. and Hoyle, F., 1965 Astroph. J. *142*, 423.

Graham, J. A. and Slettebak, A., 1973 Astron. J. *78*, 295.

Havnes, O. and Conti, P. S., 1971 Astron. & Astroph. *14*, 1.

Klemola, A. R., 1962 Atsron. J. *67*, 740.

Michaud, G., 1970 Astroph. J. *160*, 641.

Sargent, W. L. W., and Searle, L., 1967 Astroph. J. *150*, L 33.

Sargent, W. L. W. and Searle, L., 1968 Astroph. J. *152*, 443.

Stalio, R., 1974, Astron. & Astroph. *31*, 89.