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Am Stars: Abundances, ages, pulsations, and binarity

G. Catanzaro

Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Catania, Via Santa Sofia 78, I-95123 Catania, Italy e-mail: `giovanni.catanzaro@inaf.it`

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Abstract. In this paper I will discuss some recent studies on the chemically peculiar stars of the metallic subgroup, the so-called Am objects. In particular, I will discuss some observational aspects linked to their abundances pattern, their ages, some new discoveries regarding pulsations, and finally the incidence of Am stars in binary or multiple systems.

Key words. Stars: abundances – Stars: chemically peculiar – Stars: binaries: spectroscopic – Stars: atmospheres

1. Introduction

The Chemically Peculiar stars of the main sequence are stars that show anomalies in the strength of spectral lines if compared with objects of the same effective temperature. According to Preston (1974), they have been divided into 4 main classes (spectra basis):

- CP1 – non-magnetic metallic-lined (Am)
- CP2 – magnetic (Ap)
- CP3 – mercury manganese stars (HgMn)
- CP4 – helium peculiar

Among them, the Am sub-group shows Ca II K-line too early for their hydrogen line types, while metallic lines appear too late, such that the spectral types inferred from the Ca II K- and metal lines differ by five or more spectral subclasses. Moreover, The marginal Am stars (denoted with Am:) are those whose difference between Ca II K- and metal lines is less than five subclasses. The commonly used classification for this class of objects includes three spectral types prefixed with *k*, *h*, and *m*, corresponding to the K-line, hydrogen lines and metallic lines, respectively. Regarding abundances, their typical pattern show underabundances of C, N, O, Ca, and Sc and overabundances of the Fe-peak elements, Y, Ba, and of rare earth elements (Catanzaro et al. , 2019a).

It is commonly believed that the strength of the metal lines is due to the interplay between gravitational settling and radiative acceleration in an A-type star where the magnetic field should be weak or absent. In this scenario, the Am stars should rotate slower than about 120 km s^{-1} to allow radiative diffusion to compete with meridional circulation (see, e.g. Charbonneau , 1993, and references therein).

The abundance anomalies observed in AmFm stars are believed to be caused by atomic diffusion below the superficial convection zone. The process by which these anomalies, which are produced in deep layers, propagate toward the stellar surface is well understood. However, it depends on quantities which

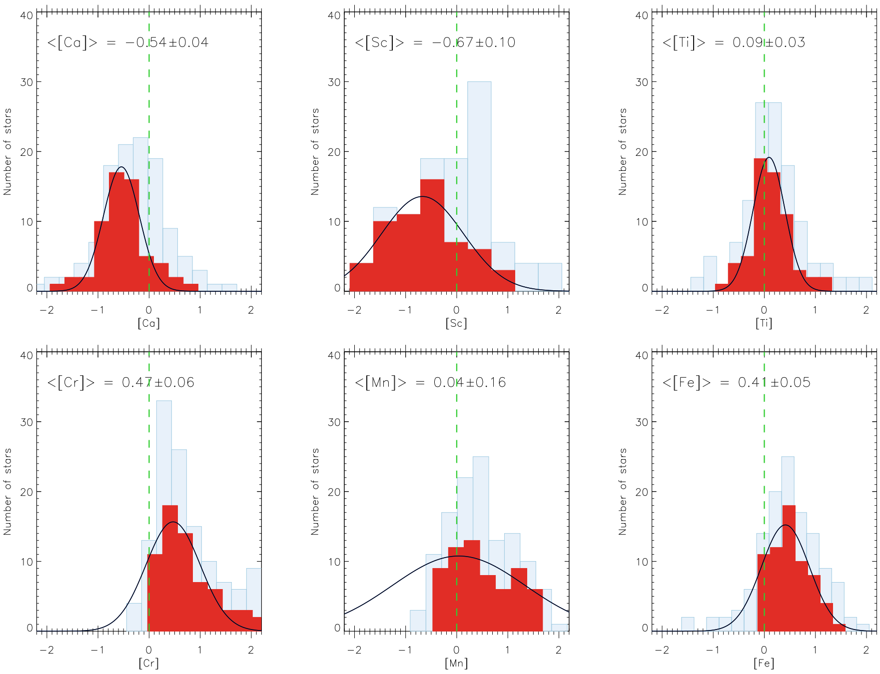

Fig. 1. Distributions of the abundances of the elements: Ca, Sc, Ti, Cr, Mn, and Fe. Light blue histograms represent the element distribution for all the suspected CP stars. Red histograms refer to the selected Am stars, overimposed gaussian fits. We reported also the center and FWHM of the gaussians, and the solar abundances were taken from Grevesse et al. (2010) as dashed vertical lines. (Figure adapted from Catanzaro et al. (2019a))

are not directly observed: the mass-loss flux and the exact position of convections zones.

Vick et al. (2013) studied the effect of mass loss on internal and surface abundances of A and F stars in order to see how this mechanism compete with atomic diffusion regarding the formation of abundance anomalies. Unfortunately, the current observational constraints did not allow them to conclude if that mass loss is to be preferred over turbulent mixing (induced by rotation or otherwise) in order to explain the AmFm phenomenon.

Alecian et al. (2013) studied in detail Scandium, which is systematically underabundant at the surface of AmFm stars, as a key element in understanding the interplay between atomic diffusion and the stellar structure. Their results are compatible with the scenario where the scandium depletion is created below the hydrogen convection zone.

Most Am stars appear to be members of binary systems with periods between 2 and 10 days (e.g. Smalley et al. , 2014).

The most comprehensive list of peculiar stars to date is *“The General Catalogue of Ap, Am and HgMn stars”* by Renson & Manfroid (2009). In this catalog are listed 8205 stars. Among these stars, 3652 are Ap (or probable), 4299 Am (or probable), and 162 HgMn (or probable). Moreover, 2314 stars are doubtful since most of them were classified only photometrically and not yet confirmed spectroscopically. An important step toward the comprehension of the CP phenomenon is the correct classification of these stars.

2. Abundaces of Am stars

In Catanzaro et al. (2019a) we presented the first results of a spectroscopic campaign

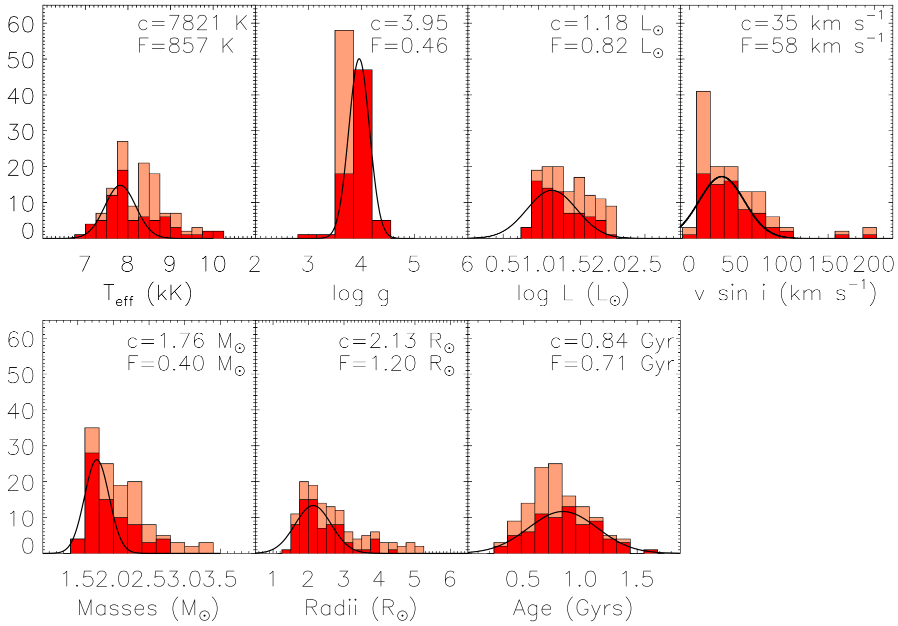

Fig. 2. Histograms for the distribution of temperatures, gravities, luminosities, rotational velocities, masses, radii, and ages for all the stars of our sample (orange histograms) and for the Am sub-sample (red histograms). Each box reports also the values for the center and FWHM of the gaussian fit overimposed (black lines).

devoted to observing as many suspected CP stars as possible. The observations have been carried out with the 1-meter class telescope of the Catania Astrophysical Observatory which is fiber linked with the Catania Astrophysical Observatory Spectropolarimeter (CAOS). CAOS has a resolution R = 45000 in the spectral range between 3600 Å and 10000 Å, and allow obtaining spectra with signal-to-noise ratio ≈ 60 with $T_{exp} = 45$ min for a V = 10 magnitude star.

In that paper, the authors estimated effective temperature, gravity, rotational and radial velocities, and chemical abundances of principal elements for 126 stars. From this sample, they selected only the stars that show typical Am signatures in their chemical pattern (62 in total), and for them, they presented detailed chemical abundances. These results have been shown in Fig. 1, in which we report the distribution of abundances for 6 chemical elements useful for Am classification, i.e. calcium, scandium, titanium, chromium, manganese, and iron. In addition to the distributions, we computed the gaussian fit and reported in each box also the value for the center value and FWHM.

Furthermore in this paper, we have improved the luminosities of these stars by using new GAIA eDR3 distances (Gaia Collaboration et al. , 2021). In Fig. 2, we present a summary of our spectroscopic analysis. Each box shows the inferred distribution (in the form of histograms) for temperatures, gravities, luminosities, rotational velocities, masses, radii, and ages, both for the en-

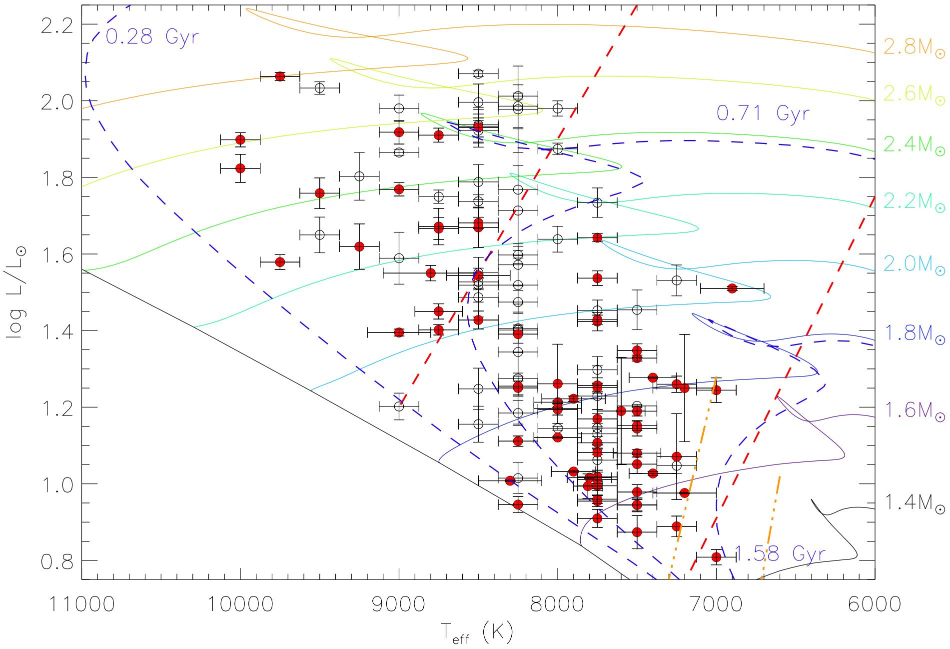

Fig. 3. HR diagram for all the stars investigated in this paper (with red-filled circles we indicated the Am stars). The red dashed lines show the δ Sct instability strip by (Breger & Pamyatnykh , 1998); the orange dash dot dot dot lines show the theoretical edges of the γ Dor instability strip by (Warner, Kaye & Guzik , 2003). The evolutionary tracks (colored lines) for the labeled masses, as well as the ZAMS (thick solid line), and the isochrones at 0.28, 0.71 and 1.58 Gyrs, are from Bressan et al. (2012) for $Z = 0.019$ (blue dashed lines).

tire sample (orange histograms) and for the Am sub-sample (red histograms). Masses, radii, and ages have been estimated by putting the stars in the HR diagram as shown in Fig. 3. We reported also the values for the center and the FWHM of the gaussian fit overplotted on each histogram.

Looking at the figure we can conclude that the distribution of Am stars versus main astrophysical quantities is essentially the same as that of normal Am stars, with the exception of effective temperature, for which Am distribution reaches a peak at lower temperatures.

3. Do Am stars pulsate?

It has been believed for years that pulsation could not arise in Am stars such as diffusive settling and radiative levitation supposed to be responsible for the chemical anomalies (Michaud et al. , 1983, 1976; Michaud , 1970), contribute to depleting helium from the HeII ionization zone where the k-mechanism drives the pulsation of d Sct stars (Breger , 1970; Kurtz , 1976).

Nevertheless, many Am stars have been observed to pulsate (Kurtz , 1989; Henry & Fekel , 2005). Smalley et al. (2017) propose that a large part of the excitation occurs in the H/HeI ionization layer and is driven by turbulent pressure. Recent observations showed as some of them pulsate as δ Sct (P 2 hours), γ Dor (P $\sim$ 1 day), or roAp stars (P $\sim$ 5 min $\div$ 1 hour).

As part of the TESS Guest Investigator programs Cycles 2 and 3, Guzik et al. (2021) proposed observations in the 2-minute cadence of bright (visual magnitudes 7-8) Am stars to find out whether they pulsate and determine their pulsation frequencies. In their sample of 55 Am stars, they included the 32 Am stars found by Catanzaro et al. (2019a) placed inside the instability strips shown in Fig. 3. As a preliminary results, we find two δ Sct stars (HD 155316 and HD 211643) and two δ Sct/γ Dor hybrid (HD 8251 and HD 108449) candidates (Guzik et al. , 202).

More results are coming and in a forthcoming dedicated paper, we will show to the readers the complete set of pulsating Am stars found.

4. Am stars as extragalactic age indicators

Recently some authors discussed the possibility to use Am stars as extragalactic age indicators. Worthey (2015) suggested dating stellar populations in galaxies by using Chemically Peculiar stars in general, and Am in particular, since there are periods of time in which these stars contribute to the integrated light and other periods in which the contributions disappear. The method relies on the detection of the CP star features in the integrated spectral light of stellar populations, as long as the signal-to-noise ratio is high enough.

This possibility has been explored later by Catanzaro et al. (2022). With the aim to have the largest sample possible of Am stars with an estimation of the age, these authors build a sample of data by using both new and archived spectra (after having refined the luminosities). According to Worthey (2015), all their stars have an age between $\approx$ 310 Myrs and $\approx$ 1.58 Gyrs, with the distribution peaked at 0.86 ± 0.68 Gyrs.

In this paper, we compare the distribution of ages derived in the previous section with that from Worthey (2015) study. As we can see in Fig. 4, the results differ only in the peak of the distributions, which are younger by about 0.35 Gyrs. Also this study seems to confirm the first analysis by Worthey (2015).

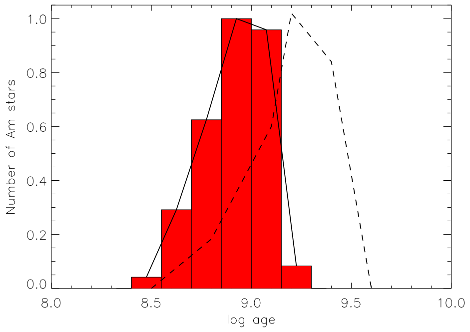

Fig. 4. Comparison between the age distribution of Am stars derived in this paper (red histograms-solid line) and the one derived by Worthey (2015) (dashed line).

5. Binarity

The development of chemical peculiarities is understood in the framework of atomic diffusion. One important question is what effect binarity has on the formation and evolution of CP stars. The presence of a companion can affect the stellar envelope due to tidal interactions. Tidal synchronization brakes the stellar rotation, leading to higher stability of the atmosphere layers, which in turn allows the generation of surface abundance anomalies. For Am stars, binarity appears to be a basic ingredient providing the conditions necessary for these peculiarities to develop.

Often the presence of a stellar companion causes misclassification of the star, above all when the classification occurs only photometrically. In this framework, an enormous effort has been made from the observational point of view to acquire as much as possible spectroscopic data of Am stars belonging to multiple systems. The principal aim of these observations was to study the incidence and influence of binarity on the rise of Am peculiarity. The reader is referred to some papers published recently, i.g. (Catanzaro et al. , 2022) for Am stars in SB1 system (some examples have been adapted here in Fig. 5), or Catanzaro et al. (2019b) for a detailed study of the SB3 star HD 226766.

6. Conclusions

A-type metallic stars or Am stars are main sequence objects that show overabundance for what concern iron peak elements and underabundances of Ca and/or Sc. Since they are important in many aspects of modern astrophysics, in this paper we review some of those.

- Abundance pattern of Am stars shows an underabundance of almost 0.5 dex for calcium and/or scandium and an overabundance of titanium and manganese of about 0.1 dex and of about 0.5 dex for chromium and iron. Moreover, we concluded that the distribution of Am stars versus main astrophysical quantities is essentially the same as that of normal Am stars, with the exception of effective temperature, for which Am distribution reaches a peak at lower temperatures.
- TESS provided us high-quality data, thanks to which we found 4 out of 32 Am stars pulsating as δ Sct or hybrid δ Sct/γ Dor. More data are coming and a paper will be dedicated to this topic.
- In this study we have refined, by using distances from GAIA eDR3, the luminosities of the sample of Am stars already studied in Catanzaro et al. (2019a). By using evolutionary tracks we estimated ages and compare our results with those obtained in literature by Worthey (2015); Catanzaro et al. (2022). We confirmed that the distribution of ages of Am stars is very narrow, wide ≈ 0.4 Gyrs
- Most Am stars appear to be members of binary systems with periods between 2 and 10 days. To study the interplay between Am chemical anomalies and binariety we started years ago an observational campaign devoted to this topic. In our sample of Am stars we observed an incidence of $\approx 50\%$.

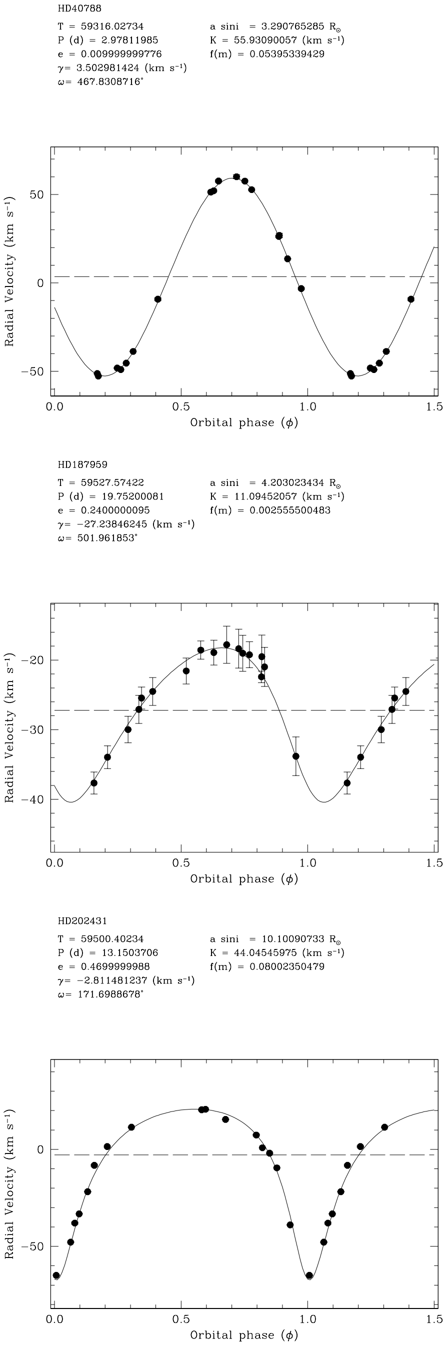

Fig. 5. Radial velocity curves and orbital parameters for three Am stars in Sb1 systems (adapted from Catanzaro et al. (2022)).

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