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History of the Δa photometric system

H. M. Maitzen[1], E. Paunzen[2] and M. Netopil[1,2]

[1] *Institute for Astrophysics, University of Vienna, Türkenschanzstraße 17, 1180 Vienna, Austria, (E-mail: hans.michael.maitzen@univie.ac.at)*

[2] *Department of Theoretical Physics and Astrophysics, Masaryk University, Kotlárská 2, 611 37 Brno, Czech Republic*

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Abstract. We review the invention of the Δa photometric system, which provides an efficient method to detect magnetic chemically peculiar stars, but also some other groups such as emission-line or metal-weak objects. Besides the investigation of numerous field stars, the photometric system was also applied to various stellar aggregates, from nearby Galactic open clusters over globular clusters up to field populations and clusters in the Large Magellanic Cloud. The study of star cluster members clearly provides the basis to improve knowledge connected with evolutionary topics. We discuss some results that were made during the four decades long history of Δa photometry.

Key words: stars: chemically peculiar – stars: emission-line, Be – stars: evolution – open clusters and associations: general – techniques: photometric

1. Introduction

Following a suggestion of K. D. Rakos in March 1969, a photoelectric mission at the 60 cm Bochum telescope at ESO-La Silla by HMM was devoted to a photometric variability search in Johnson UBV for objects in the catalogue of magnetic stars by Babcock (1958). During this two months run from the middle of May until July, 1969 the ApSi(Cr) star CS Vir (HD 125248) with already known 9 d photometric period was included to check the capability of the observing equipment. It had, however, not yet been observed in UBV and our results were astonishing: U and B confirmed the published period with roughly sinusoidal light curves, but in V a double wave variation appeared (Maitzen & Rakosch, 1970). This finding prompted us to refine the photometric filter coverage of the visual spectral range by including Strömgren $uvby$ and Hβ wide and introducing two middle band filters g_1 and g_2 centered on 5030 and 5240Å, respectively. A subsequent run at the Bochum telescope revealed the presence of two flux depressions in v and g_2 (Maitzen & Moffat, 1972). While the former had already been known as metallicity enhancement from Strömgren photometry, the latter was so far present in a similar way only in the Ap-star HD 221568 observed by Kodaira (1969) who found flux depressions in its continuum at 4200, 5300 and 6300Å. The need for examining other magnetic stars in our new filter system became imminent.

2. Creating the Δa system

Further photoelectric missions on La Silla confirmed what had been found for CS Vir. Therefore it was advisable to compare the flux depression at 5240Å (g_2) with the arithmetic mean of the adjacent filters g_1 and y, expressed in magnitudes, by the definition:

$$a = g_2 - \frac{g_1 + y}{2} \tag{1}$$

Applying this to so-called normal stars (non-magnetic, non-peculiar) their photometry resulted in a slow, approximately linear increase with colour index (e.g. $b - y$) over the upper main sequence range. Standard deviations from this "normality line" are typically of the order of a few mmag. It turned out that nearly all of the well-known magnetic peculiar stars are lying above this line by more than 3σ (typically >10 mmag). This was the reason to create a new peculiarity index Δa defined as

$$\Delta a = a - a_{\mathrm{normal}} \tag{2}$$

where the second term refers to the a-value on the normality line corresponding to the colour of the peculiar star. Thus, the Δa-system was established after numerous observations in the first half of the 1970s (Maitzen, 1976). Its potential was evident: while the classical Ap-stars were detected by spectroscopy, limiting research to the immediate neighbourhood of the Sun, photometry would enable statistical research and much larger distances to be reached.

According to the definitions of chemically peculiar (CP) stars by Preston (1974) it is obvious that strong global magnetic fields are only present among CP2 (classical Ap-stars) and CP4 (He-weak stars, part of them). CP1 (Am-stars) and CP3 (HgMn-stars) lack those fields, and Δa has peculiar positive values only for the magnetic stars. The question arises: does a significant positive Δa mean that the star is a peculiar magnetic one? With high probability yes, but there is an impurity effect due to Be-stars which undergo their variation from their shell phase through normal and then to the emission line phase. This goes parallel from significant positive to significant negative Δa-values, e.g. for Pleione (Maitzen & Pavlovski, 1987). Negative Δa is also a characteristic for a large fraction of λ Bootis stars. The detection efficiency of Δa for different stellar groups has been discussed by Paunzen et al. (2005), confirming that almost all magnetic CP stars can be detected by Δa. It is therefore also a valuable pre-selection tool for spectroscopic or polarimetric follow-up observations.

3. Open cluster survey in Δa

After establishing the Δa-system by field stars relatively near to the Sun, the 1980s were devoted to the search of peculiar/magnetic stars in open clusters using the photoelectric technique (see for details and references Paunzen et al.,

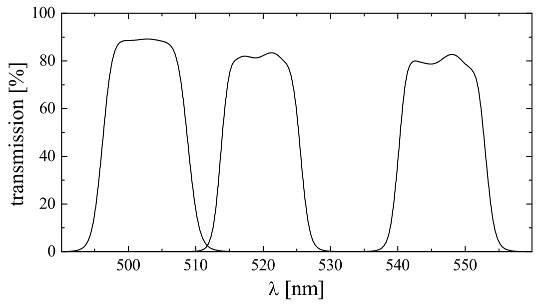

Figure 1. The Δa filters were adjusted over the years to improve the efficiency of the system, the currently last one is shown here.

2014b). Due to the lower magnitude limit (one star at one time) this way the closer galactic clusters were observed, altogether 48 of them. This situation changed dramatically with the transition of Δa to CCD observations as of 1995. 47 open clusters were published so far with this technique, increasing the galactic surrounding for this investigation enormously. These are presented in a series of papers (the currently last one by Netopil et al., 2007) and in studies of two individual open clusters (Netopil et al., 2005; Cariddi et al., 2018). As a result, about 100 Ap cluster stars were detected, their mass distribution resembling in general that of the field stars. The formation of Ap stars turns out to be more efficient in the range of objects with masses of 3–4 $M_\odot$, reaching a maximum value near five percent of all stars (Netopil et al., 2014).

4. Δa photometry of globular clusters

After the discovery of chemical abundance variations especially on the Blue Horizontal Branch of globular clusters observations were undertaken in order to verify whether similar effects as on the main sequence where quiet atmospheres are present would produce measurable consequences to be registered also by Δa. Paunzen et al. (2014a) presented an analysis of three globular clusters in this photometric system and find that about 3 per cent of the stars lie in abnormal regions in the diagnostic diagrams. A comparison with published abundances for few horizontal-branch stars yields an excellent agreement. Therefore, the observations provide very promising results, which will serve as a solid basis for follow-up observations.

5. CP stars in the Large Magellanic Cloud

Some fields in the Large Magellanic Cloud (LMC) were subject to Δa photometry and clearly deviating Δa-objects were found, both above and below the normality line of field and cluster stars. Hence the first extragalactic chemically peculiar stars of the upper main sequence were discovered this way, but also Be-stars, detected by Δa-photometry (Paunzen et al., 2006). Spectroscopic confirmation took place for a classical magnetic CP2 star (NGC 1866-1005) and the Be-star NGC 1866-257 using the Si-doublet λ4128/31Å and the Hβ line, respectively, using the 6.5 m Magellan II telescope at Las Campanas (Paunzen et al., 2011). However, the derived occurrence of classical chemically peculiar stars in the LMC is only about half the value found in the Milky Way, while the age and mass distributions apparently do not differ from those of CP stars in galactic open clusters. For some of the detected CP stars in the LMC photometric timeseries data are available from the Optical Gravitational Lensing Experiment (OGLE)-III survey. Paunzen et al. (2013) only found two objects that may show some weak rotationally modulated light variations. This can be explained by the absence of photometric spots of overabundant optically active chemical elements, a behaviour which is probably caused by different conditions during the star formation in the LMC and the Galaxy.

6. Detection by serendipity

An unexpected success was reached by the application of Δa-photometry to the list of Ap stars by Renson et al. (1991). One object (Renson 31250), later denominated HIP 60350 in the Hipparcos/Tycho catalogue, had an entry as "A5m:" and with a visual magnitude of about 11 mag one of the faintest object therein. A positive Δa mean obtained from an (insufficient) number of individual measurements suggested possible peculiarity. It was therefore observed spectroscopically for spectral classification at the Figl Observatory for Astrophysics of the Vienna University. It turned out that its late A-type was wrong and that this star, exhibiting He-4026Å, was an early B-type object with unusual red shifted radial velocity of $+210\,\mathrm{km\,s^{-1}}$. Together with the proper motion results of Hipparcos a galactocentric velocity of about $600\,\mathrm{km\,s^{-1}}$ resulted, hence identifying HIP 60350 as fastest star of the Galactic disc moving in the direction to the Andromeda Galaxy (Maitzen et al., 1998), detected thanks to a chance value of Δa!

7. Conclusions

We reviewed the invention of the Δa photometric system and achievements that were made in CP star research based on this efficient detection tool. It was applied to several environments, from Galactic field stars and open clusters to globular clusters or stellar populations in the LMC. Cluster stars certainly provide a unique opportunity to study evolutionary topics thanks to the tight constraints on the age. However, we still lack of homogeneous cluster parameters for numerous objects (see discussion by Netopil et al., 2015). For many open clusters of the Δa survey these were already derived (Netopil & Paunzen, 2013) and upcoming data releases of the Gaia satellite mission will allow thorough membership analyses for a proper identification of cluster member stars. This will significantly improve our knowledge of the evolutionary status of CP stars. Nevertheless, more CP star detections in clusters are desirable and we continue our efforts using the Δa system.

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