

# The a Research Group

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## Abstract:

We give a summary of more than 25 years of research within the three filter, intermediate-band,  $a$  photometric systems. It investigates the flux depression at 5200Å, found for magnetic chemically peculiar (CP) objects. Starting with photoelectric measurements it has steadily developed introducing new and more efficient filters as well as the modern CCD technique. Up to now, more than twenty papers were devoted to search for new CP stars in our Milky Way up to distances of 5000 pc and even in the Large Magellanic Cloud. In the latter, the first extragalactic CP stars were detected. In addition, we have presented theoretical isochrones and synthetic colors from the newest available stellar atmospheres. The theoretical predictions agree very well with observations allowing not only to determine the reddening and age of open clusters from our photometry but also to investigate the flux depression at 5200Å in more detail. As an outlook, we present a new approach to search for chemically peculiar horizontal branch stars in globular clusters and to detect stellar variability of various objects observed during our photometric observations.

## The tool of $a$ -photometry

Photometry offers an easy possibility for investigation of larger samples of CP stars, especially through the discovery of characteristic broad band absorption features, the most suitable of them located around 5200Å. Nearly three decades ago, Maitzen (1976) introduced the narrow-band, three filter  $a$  photometric system, slightly changed within the last years, in order to investigate the flux depression at 5200Å. It samples the depth of this flux depression by comparing the flux at the center (5205Å -  $g_2$ ), with the adjacent regions (5027Å -  $g_1$  and 5509Å -  $y$ ) using band-widths of 222Å ( $g_1$ ), 107Å ( $g_2$ ) and 120Å ( $y$ ). The respective index was introduced as:

$$a = \frac{g_1 - y}{g_2 - y}$$

Since this quantity is slightly dependent on temperature (increasing towards lower temperatures), the intrinsic peculiarity index had to be defined as  $a = a - a[(b - y) / (B - V)]$ ;  $(g_1 - y) / (g_1 - y)$  (the difference between the individual  $a$ -values and the  $a$ -value of non-peculiar stars of the same colour - the "normality line"). It was shown (e.g. Vogt et al., 1998, A&AS, 130, 455) that virtually all peculiar stars with magnetic fields (CP2 stars) have positive  $a$ -values up to 0.075 mag whereas Be/Ae and Bootis stars exhibit significant negative ones (Maitzen & Pavlovski 1989a,b). The index  $(g_1 - y)$  shows an excellent correlation with  $(b - y)$  and can be used as an index for the effective temperature. An  $y$  versus  $(g_1 - y)$  diagram (= color-magnitude diagram) for a cluster can then easily sort out non-members. Assuming that all stars exhibit the same interstellar reddening, peculiar objects deviate from the normality line more than 3 (see Figure 1).

## Open cluster survey

The survey for CP stars in open clusters using photoelectric photometry (one star at one time) has so far delivered data for objects usually no more distant than 1000pc from the sun. A series of fourteen papers were devoted to 1240 stars in 38 open cluster fields. In 1995 a survey in open clusters using CCD technology was initialized. Up to now a photometry of 23 open clusters are published in a series of 5 papers. Within the investigated sample of nearly 2600 stars, more than 20 CP candidates and 11 Bootis stars were found.

Our search for new variable stars in open clusters is a serendipitous result from already published CCD  $a$  photometry. The observations span widely different time intervals (0.02 to 60 days) yielding different possibilities for detecting the whole set of variations. We want to emphasize that these observations are not optimized for the detection of variable stars but are able to find even very low amplitude variables (the typical detection limit reached is between 0.006 and 0.022 mag). In total, we have detected 35 variable objects of which four are not members of their corresponding clusters. The variables cover the entire Hertzsprung-Russell diagram.

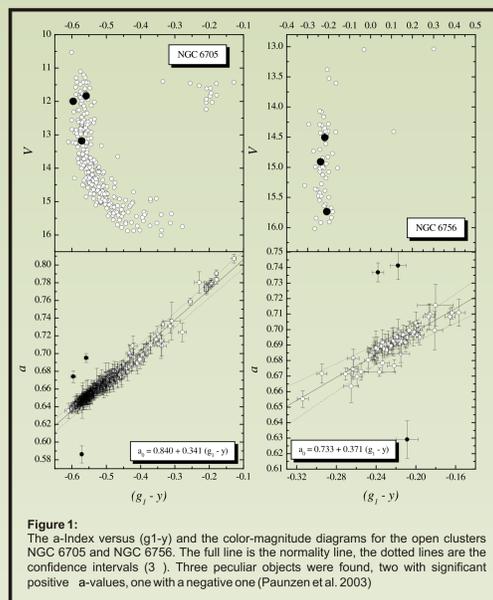


Figure 1: The  $a$ -index versus  $(g_1 - y)$  and the color-magnitude diagrams for the open clusters NGC 6705 and NGC 6756. The full line is the normality line, the dotted lines are the confidence intervals (3). Three peculiar objects were found, two with significant positive  $a$ -values, one with a negative one (Paunzen et al. 2003)

## Extragalactic CP stars

The first extragalactic classical chemically peculiar stars more than 100 years after the discovery of this group were detected (Maitzen et al. 2001). Using the tool of CCD  $a$ -photometry, eight definite positive detections in the globular-like stellar cluster NGC 1866 and its surrounding in the Large Magellanic Cloud were made. More than 1950 objects down to 20.5 mag were observed. Furthermore we found three objects with significantly negative  $a$ -values indicating either an Ae/shell or Bootis nature. The overall percentage of chemically peculiar stars for NGC 1866 (1.5%) seems lower than for the majority of open clusters in our Milky Way whereas the incidence within the LMC field is decisively less (0.3%).

## Selected publications of our research group:

- Photoelectric filter photometry of the flux depression at 5200Å in Ap-stars Maitzen H.M., 1976, A&A, 51, 223
- A photoelectric investigation of Ap-stars in open clusters. I - NGC 2516 and NGC 1662 Maitzen H.M., Hensberge H., 1981, A&A, 96, 151
- Photoelectric photometry of peculiar and related stars. II Delta-a-photometry of 339 southern Ap-stars Maitzen H.M., Vogt N., 1981, A&A, 123, 48
- Delta a photometry of Be/shell stars Maitzen H.M., Pavlovski K., 1989a, A&AS, 77, 351
- Delta a photometry of lambda Bootis stars Maitzen H.M., Pavlovski K., 1989b, A&A, 219, 253
- Photoelectric search for peculiar stars in open clusters - Part XIV NGC 1901, NGC 2169, NGC 2343, CR 132, NGC 2423 and NGC 2447 Maitzen H.M., 1993, A&AS, 102, 1
- First CCD Measurements in the Delta a System for Detecting CP2 Stars Maitzen H.M., Paunzen E., Rode M., 1997, AA, 327, 636
- CP2 stars in clusters: deep Delta a-photometry Maitzen H.M., Rode M., Paunzen E., 1998, CoSka, Vol. 27, No. 3, p. 213
- Statistics on the spectral classification of CP2 stars in the Southern Sky Rode M., Maitzen H.M., Paunzen E., 1998, CoSka, Vol. 27, No. 3, p. 255
- CCD photometric search for peculiar stars in open clusters I. NGC 2169, Melotte 105 and NGC 6250 Bayer C., Maitzen H.M., Paunzen E., Rode-Paunzen M., Sperl M., 2000, A&AS, 147, 99
- On the detection of the first extragalactic classical chemically peculiar stars Maitzen H.M., Paunzen E., Pintado O.I., 2001, A&A, 371, L5
- CCD photometric search for peculiar stars in open clusters II. NGC 2489, NGC 2567, NGC 2658, NGC 5291 and NGC 6208 Paunzen E., Maitzen H.M., 2001, A&A, 373, 153
- CCD photometric search for peculiar stars in open clusters III. NGC 2439, NGC 3960, NGC 6134, NGC 6192 and NGC 6451 Paunzen E., Maitzen H.M., 2002, A&A, 385, 867
- CCD photometric search for peculiar stars in open clusters IV. Collinder 272, Pismis 20, Lynga 14, NGC 6396 and NGC 6611 Paunzen E., Pintado O.I., Maitzen H.M., 2002, A&A, 395, 823
- On the evolutionary status of chemically peculiar stars of the upper main sequence Pöhl H., Maitzen H.M., Paunzen E., 2003, A&A, 402, 247
- The 5200Å flux depression of chemically peculiar stars: I. Synthetic Delta a photometry - the normality line Kupka F., Paunzen E., Maitzen H.M., 2003, MNRAS, 341, 849
- Theoretical isochrones for the Delta a photometric system Claret A., Paunzen E., Maitzen H.M., 2003, A&A, 412, 91
- CCD photometric search for peculiar stars in open clusters V. NGC 2099, NGC 3114, NGC 6204, NGC 6705 and NGC 6756 Paunzen E., Pintado O.I., Maitzen H.M., 2003, A&A, 412, 721
- New variable stars in open clusters. I. Methods and results for 20 open clusters Paunzen E., Zwintz K., Maitzen H.M., Pintado O.I., Rode-Paunzen M., 2004, A&A, 418, 99
- The cool CP and lambda Bootis stars Kupka F., Paunzen E., Maitzen H.M., Ilev, I.Kh., 2004, MNRAS (in press)

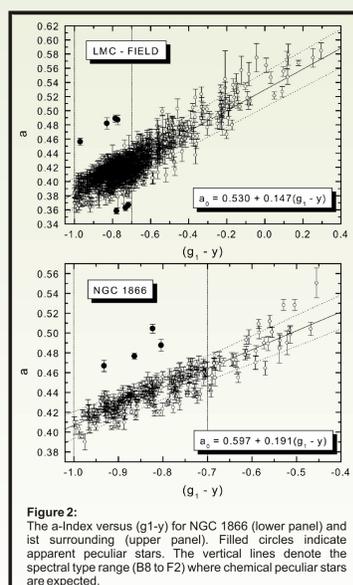


Figure 2: The  $a$ -index versus  $(g_1 - y)$  for NGC 1866 (lower panel) and its surrounding (upper panel). Filled circles indicate apparent peculiar stars. The vertical lines denote the spectral type range (B8 to F2) where chemical peculiar stars are expected.

## Evolutionary status of CP stars of the upper main sequence

For many decades the evolutionary status of the CP stars has been controversial. Oetken (1984, AN, 306, 187) concluded that the CP2 (magnetic CP stars) phenomenon appears at the late stages of the main sequence evolution. Hubrig et al. (2000, A&A, 539, 352) found that the distribution of CP2 stars of masses below three solar masses in the Hertzsprung-Russell-diagram differs from that of the "normal" stars in the same temperature range at a high level of significance: magnetic stars are concentrated toward the center of the main sequence band. The results of the Hipparcos mission on the other hand do not support the mentioned above findings. Gomez et al. (1998, A&A, 336, 953) presented the Hertzsprung-Russell-diagram of about 1000 CP stars in the solar neighbourhood using astrometric data from Hipparcos satellite as well as photometric and radial velocity data. Most CP stars lie on the main sequence occupying the whole width of it (about 2 mag), just like "normal" stars in the same range of spectral types.

We have investigated four young (age not more than 100 Myr) open clusters with known CP2 members. The peculiarity of these objects was established via photometric as well as spectroscopic data. We have derived effective temperatures and luminosities for these objects and calibrated ages as well as masses with the help of standard evolutionary models taking the overall metallicities of the individual clusters into account.

All investigated objects are members of their open cluster with ages between 10 and 140 Myr corresponding to a relative age of 0.05 and 0.36 of their main sequence life-time. This clearly proves that the observable CP2 phenomenon occurs already well before a star has reached 30% of its life-time on the main sequence (Pöhl et al. 2003)

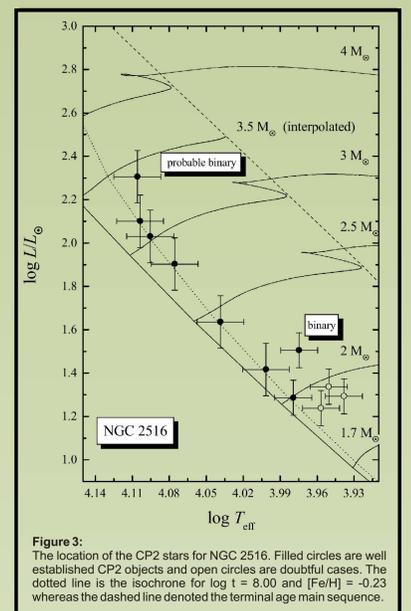


Figure 3: The location of the CP2 stars for NGC 2516. Filled circles are well established CP2 objects and open circles are doubtful cases. The dotted line is the isochrone for  $\log t = 8.00$  and  $[Fe/H] = -0.23$  whereas the dashed line denoted the terminal age main sequence.

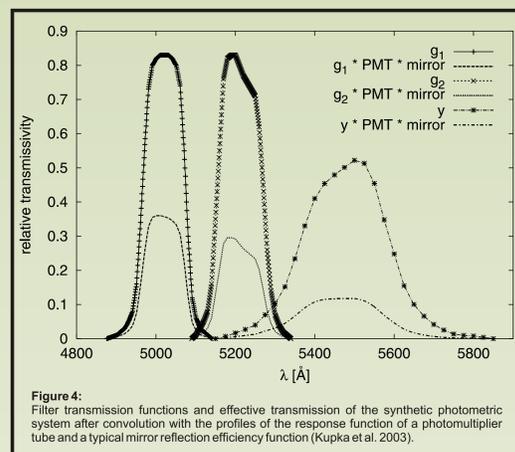


Figure 4: Filter transmission functions and effective transmission of the synthetic photometric system after convolution with the profiles of the response function of a photomultiplier tube and a typical mirror reflection efficiency function (Kupka et al. 2003).

## Theoretical Aspects

A synthetic photometric system was developed by Kupka et al. (2003) that can be used to explore the capability of model atmospheres with individual element abundances to predict photometric  $a$  magnitudes. The observed dependency of the  $a$ -index as a function of various colour indices sensitive to the effective temperature of stars as well as its average scatter expected from surface gravity variations within the main-sequence band is confirmed, also the behaviour of the normality line is well reproduced. Kupka et al. (2003) have also shown the metallicity dependence of the  $a$ -index. Thus,  $a$  photometry is a viable tool to identify CP stars in samples with metallicities slightly different from the solar ones and it is well suited to draw statistically meaningful conclusions about their distribution.

Kupka et al. (2004) present model atmospheres computed with individual abundances for a representative sample of CP stars and either confirm or redetermine their input parameters through comparisons with photometric, spectrophotometric and high resolution spectroscopic data. The final models obtained from this procedure were used to compute synthetic  $a$  indices which were compared with observations. We are able to reproduce the observed  $a$  values for CP1 (almost zero), cool CP2 (positive) and Bootis stars (negative) within a few mags.

Additionally, Claret et al. (2003) have investigated the capability of theoretical isochrones for the photometric  $a$  system to derive astrophysical parameters such as age, reddening and distance modules for open clusters. As a test, the published data of 23 open clusters were used to fit these isochrones with parameters from the literature. The fits show an excellent agreement between the observations and the theoretical grid. The observational data have been also fitted without knowledge of age, reddening and distance modulus, yielding an accuracy of 5 to 15% depending on the well known error sources of such a method.

## A new Approach

The existence of peculiar stars at the Blue Horizontal Branch was already shown by Behr et al. (1999, ApJ, 517, L135). He used high resolution spectra to determine elemental abundances of individual objects to prove the peculiarity. Our technique is capable to cover simultaneously all members of a globular cluster. A preliminary result of our photometric survey by means of M30, where a few peculiar stars were found with the aid of  $a$  photometry, is shown in Figure 5.

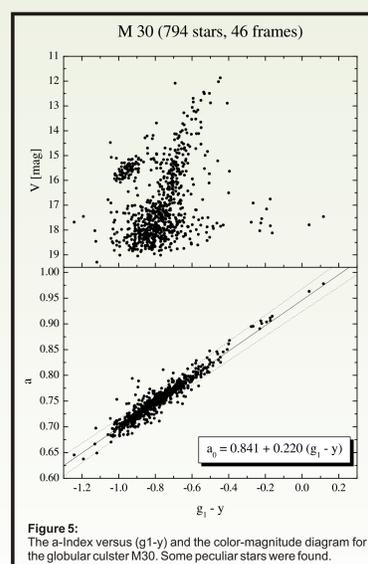


Figure 5: The  $a$ -index versus  $(g_1 - y)$  and the color-magnitude diagram for the globular cluster M30. Some peculiar stars were found.

Another capability of the  $a$  tool is to detect Novae. Only a small sample was investigated up to now, but the symbiotic nova PU Vulpeculae as well as the dwarf nova Z Cam show significant negative  $a$ -values up to 0.1 mag. Further observations on that topic are planned at the Figl-Observatory (Austria).

