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*Research Note*

# New variable stars in open clusters

## I. Methods and results for 20 open clusters[⋆]

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**Abstract.** We present high precision CCD photometry of 1791 objects in 20 open clusters with an age of 10 Myr to 1 Gyr. These observations were performed within the $\Delta a$ photometric system which is primarily used to detect chemically peculiar stars of the upper main sequence. Time bases range from 30 min up to 60 days with data from several nights. We describe the time series analysis reaching a detection limit of down to 0.006 mag for apparent variability. 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, hence they are interesting targets for follow-up observations.

**Key words.** Galaxy: open clusters and associations: general – stars: variables: general

## 1. Introduction

The detection of variable members of open clusters is very important since these objects have fairly well known astrophysical parameters, such as luminosity and effective temperature. Several theories (e.g. pulsational and evolutionary models) can be tested with these variable stars.

In the literature, a huge amount of papers dedicated to the search for new variable stars in open clusters can be found. In general, two different kinds of surveys are conducted: 1) the search for special types of variables (Viskum et al. 1997; Jerzykiewicz et al. 2003) or 2) selected open clusters are searched for all kinds of variable objects (Kafka & Honeycutt 2003; Mochejska et al. 2003).

Our search for new variable stars in open clusters is a serendipitous result from already published CCD $\Delta a$ photometry (Bayer et al. 2000; Paunzen & Maitzen 2001, 2002; Paunzen et al. 2002, 2003). The intermediate-band, three-filter $\Delta a$ system investigates the flux depression at 5200 Å found for magnetic chemically peculiar objects (Maitzen 1976). Our 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).

We describe the way to define the variability limit and present all bona-fide variable stars within the Hertzsprung-Russell-diagram. Four objects are probably not members of the corresponding open clusters. We give a discussion about the possible nature of the detected variability.

## 2. Observations and reductions

The observations of the open clusters were performed with the Bochum 61 cm (ESO-La Silla), the Helen-Sawyer-Hogg 61 cm (UTSO-Las Campanas Observatory) and the Complejo Astronómico el Leoncito (CASLEO) 2.15 m telescopes. The characteristics of the instruments can be found in Bayer et al. (2000) and Paunzen et al. (2002).

The basic reductions (bias-subtraction, dark-correction, flat-fielding) were carried out within standard IRAF routines. For all frames we applied a point-spread-function (PSF) fitting within the IRAF task DAOPHOT (Stetson 1987).

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**Table 1.** Open clusters observed at ESO and UTSO in 1995 (upper panel) as well as CASLEO in 1998 and 2001 (lower panel). The ages ($\log t$) and distance moduli ($V_0 - M_V$) were taken from the literature. The limit of apparent variability (Limit) is according to Sect. 3. The errors in the final digits of the corresponding quantity are given in parentheses.

| Designation | | $N_S$ | $N_V$ | $N_F$ | $N_N$ | JD (start) | $\Delta t$ [d] | Limit [mag] | $\log t$ | $V_0 - M_V$ |
|---|---|---|---|---|---|---|---|---|---|---|
| NGC 2439 | C0738−315 | 115 | 3 | 18 | 4 | 2 449 816.51736 | 7.995 | 0.022 | 7.30 | 13.00(10) |
| NGC 2489 | C0754−299 | 53 | 1 | 13 | 4 | 2 449 818.57083 | 34.937 | 0.012 | 8.45 | 10.80(10) |
| NGC 2567 | C0816−304 | 34 | – | 17 | 4 | 2 449 818.61111 | 44.868 | 0.012 | 8.43 | 11.10(10) |
| NGC 2658 | C0841−324 | 84 | 1 | 12 | 3 | 2 449 817.56597 | 18.026 | 0.018 | 8.50 | 12.90(15) |
| Melotte 105 | C1117−632 | 122 | – | 15 | 2 | 2 449 816.61111 | 3.072 | 0.010 | 7.77 | 11.30(10) |
| NGC 3960 | C1148−554 | 32 | – | 17 | 3 | 2 449 828.60625 | 59.865 | 0.014 | 8.88 | 11.10(20) |
| NGC 5281 | C1343−626 | 16 | 1 | 55 | 6 | 2 449 816.78125 | 48.010 | 0.008 | 7.04 | 10.60(15) |
| NGC 6134 | C1624−490 | 82 | 2 | 32 | 6 | 2 449 821.75069 | 18.003 | 0.010 | 8.84 | 9.80(15) |
| NGC 6192 | C1636−432 | 64 | – | 38 | 6 | 2 449 822.79583 | 44.949 | 0.006 | 7.95 | 11.15(20) |
| NGC 6208 | C1645−537 | 15 | – | 12 | 2 | 2 449 880.69236 | 2.010 | 0.020 | 9.00 | 10.00(15) |
| NGC 6396 | C1734−349 | 48 | 2 | 18 | 5 | 2 449 821.88958 | 31.939 | 0.014 | 7.40 | 10.60(15) |
| NGC 6451 | C1747−302 | 41 | 2 | 12 | 2 | 2 449 883.78125 | 0.988 | 0.010 | 8.30 | 11.65(20) |
| NGC 6611 | C1816−138 | 45 | 2 | 42 | 5 | 2 449 849.79306 | 38.989 | 0.016 | 6.48 | 11.65(10) |
| NGC 6705 | C1848−063 | 275 | 1 | 43 | 5 | 2 449 822.86250 | 59.911 | 0.014 | 8.40 | 11.65(20) |
| NGC 6756 | C1906+046 | 33 | 3 | 38 | 5 | 2 449 823.90069 | 53.944 | 0.008 | 8.11 | 12.60(15) |
| NGC 3114 | C1001−598 | 181 | 7 | 50 | 4 | 2 451 138.82296 | 2.979 | 0.022 | 8.48 | 9.60(15) |
| Collinder 272 | C1327−610 | 45 | 2 | 22 | 1 | 2 452 144.48472 | 0.020 | 0.008 | 7.11 | 11.85(15) |
| Pismis 20 | C1511−588 | 178 | 2 | 80 | 2 | 2 452 143.52872 | 1.045 | 0.022 | 6.70 | 12.55(20) |
| NGC 6204 | C1642−469 | 268 | 3 | 55 | 1 | 2 452 143.63456 | 0.067 | 0.020 | 8.30 | 10.40(25) |
| Lyngå 14 | C1651−452 | 60 | 3 | 70 | 1 | 2 452 144.58135 | 0.087 | 0.008 | 6.00 | 12.05(15) |

$N_S$: number of investigated stars; $N_V$: number of variable objects; $N_F$: number of frames; $N_N$: number of nights; $\Delta t$: time base of the observations.

All observations were done in the intermediate-band, three-filter $\Delta a$ system. It consists of the filters $g_1$ ($\lambda_C$ = 5000 Å, bandwidth = 130 Å), $g_2$ (5220 Å, 130 Å) and $y$ (5500 Å, 230 Å). The filter transmission curves and more details about the actual photometric system can be found in Maitzen et al. (1997) and Kupka et al. (2003).

## 3. Temporal analysis and results

The temporal analysis of our photometric data is especially sophisticated since the overall time bases range from 0.020 to 60 days with 12 to 80 data points per individual cluster (Table 1). The smallest time resolution is about one minute with typically six frames within 30 min. As a consequence of the points discussed in the following, we do not present any light curves.

A classical time series analysis such as a Fourier technique (Handler et al. 2003) cannot be performed since it is not optimized for sparse data sets with widely different time bases. We have used the following approach to get a statistically solid limit for variability.

Since we only have a limited amount of available data, all observations were added and analysed together. For each frame we get a "standard mean magnitude" as the weighted mean photometric value (the weights are the measurement errors according to the PSF reduction technique) of all objects (variable and non-variable). The mean atmospheric extinction within the corresponding 700 Å decreases slightly with $\lambda$ and may vary during the time of our observations (Schuster & Parrao 2001). Furthermore, the quantum efficiency of CCD detectors increases towards the red region. We are therefore confronted with different zero points for the different standard mean magnitudes. The light curve of an "overall standard star" was used as comparison in the further analysis.

As a final step, differential light curves of each individual object in comparison to the "overall standard star" were generated. For all differential light curves, a mean magnitude and its standard deviation were calculated. We define an object as variable if

- its standard deviation from the mean exceeds nine times the overall standard deviation of the cluster;
- at least three data points exceed three times its standard deviation.

The first term is only the formulation of the statistical significance whereas the second guarantees that bad measurements or possible misidentifications do not affect our conclusions. The mean values are between 0.006 and 0.022 mag (Table 1). As a test, a phase dispersion minimization analysis (Stellingwerf 1978) was performed yielding the same statistical significance of variability. But the very unfavourable spectral window of the data sets prevents a definite conclusion about the true periods.

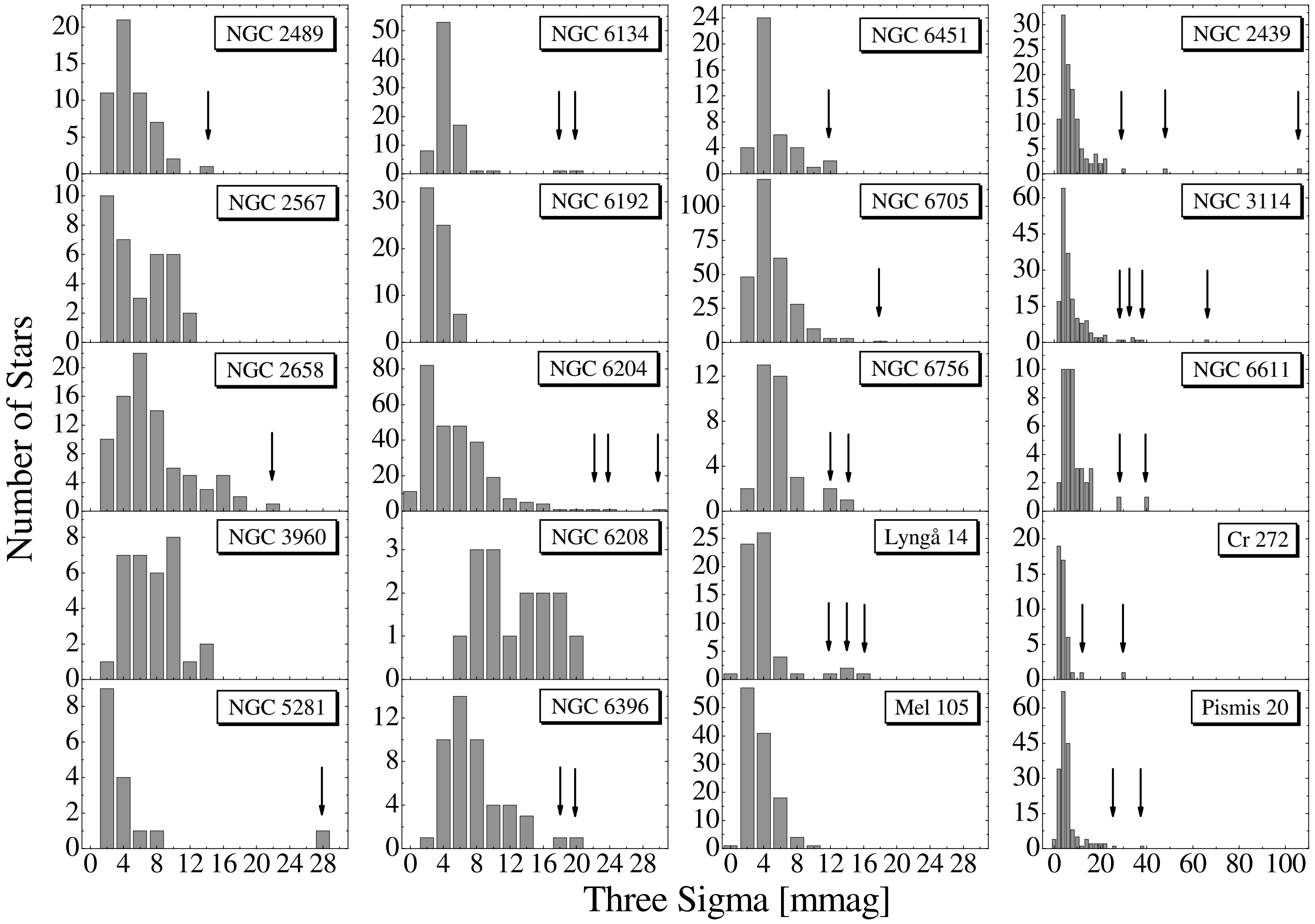

**Fig. 1.** Histograms of the three sigma standard deviations of all mean photometric values for the programme clusters; arrows indicate the bona-fide variable stars detected.

Figure 1 shows the histograms of the three sigma standard deviations of all mean photometric values of the observed cluster stars. The plotted standard deviations were normalized according to the errors of the photon noise. The influence of the number of data points on the detection limit is clearly visible (e.g. NGC 5281). We find no correlation between the amount of detected variable objects and the value of the detection limit.

### *3.1. Individual variables*

Table 2 lists the 35 bona-fide variable objects found in 15 open clusters. The photometric data for the Johnson *UBV* system were taken from WEBDA (accessible via `http://obswww.unige.ch/webda/`). Figure 2 shows the Hertzsprung-Russell diagram of these objects with the parameters listed in Table 2. The zero age main sequence (ZAMS hereafter) is taken from Schmidt-Kaler (1982). We are able to conclude from Table 2 and Fig. 2 that the following objects are *not* members of the corresponding open clusters because with the given $B-V$ color and reddening, they would lie significantly below the ZAMS (Fig. 2): Pismis 20 # 27, Lyngå 14 # 101 and NGC 6756 # 40. However, with a reddening close to zero, they are very close to the ZAMS indicating that these objects are foreground stars. NGC 6396 # 20 seems to be a highly reddened background star. All other objects are probably members of the corresponding clusters; although no further membership information was found in the literature. We have to emphasize that the errors of $B-V$ are of the order of 0.05 to 0.3 mag depending on the type of measurement technique (photographic, photoelectric or CCD).

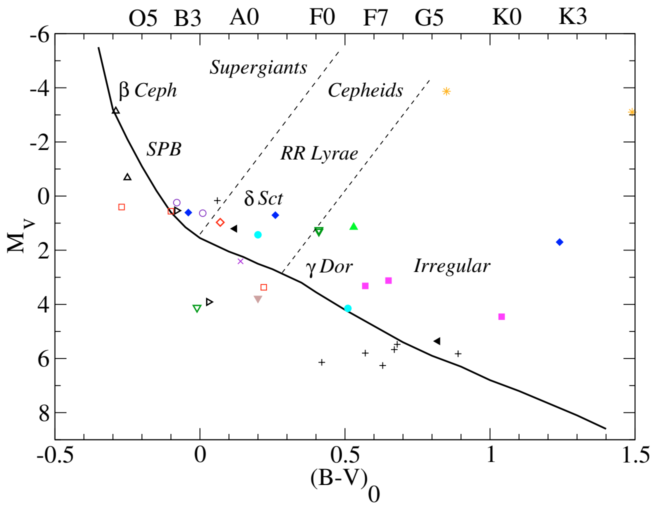

**Fig. 2.** The Hertzsprung-Russell diagram of the variable objects with the parameters listed in Table 2. The zero age main sequence is taken from Schmidt-Kaler (1982). The areas of different variable groups are indicated.

**Table 2.** Photometric data for the Johnson $UBV$ system taken from WEBDA for the identified variable stars; the mean reddening values for the open clusters are according to the literature. The lower panel includes the four variable objects which are most probably not members of the corresponding cluster. The objects are numbered according to WEBDA or to our internal numbering system (marked with asterisks).

| Name | No. | $E(B-V)$ | $V$ | $B-V$ | $U-B$ |
|---|---|---|---|---|---|
| NGC 2439 | 128 | 0.37 | 14.72 | 0.33 | 0.22 |
| | 239 | | 14.84 | 0.63 | 0.41 |
| | 741 | | 15.91 | 1.61 | |
| NGC 2489 | 28 | 0.40 | 15.46 | 0.93 | 0.21 |
| NGC 2658 | 56* | 0.44 | 16.73 | 0.64 | |
| NGC 3114 | 14* | 0.07 | 15.51 | 0.75 | |
| | 143* | | 15.83 | 0.64 | |
| | 193* | | 15.70 | 0.74 | |
| | 233* | | 16.29 | 0.70 | |
| | 272* | | 16.17 | 0.49 | |
| | 273* | | 15.86 | 0.96 | |
| | 274* | | 10.19 | 0.13 | |
| Cr 272 | 1287 | 0.45 | 18.43 | 1.27 | |
| | 1297 | | 14.21 | 0.57 | |
| NGC 5281 | 1435 | 0.26 | 13.47 | 0.40 | |
| Pismis 20 | 28 | 1.25 | 16.04 | 1.17 | |
| NGC 6134 | 42 | 0.36 | 12.40 | 0.56 | 0.49 |
| | 662 | | 15.14 | 0.50 | |
| NGC 6204 | 92* | 0.45 | 16.17 | 1.49 | |
| | 150* | | 14.80 | 1.10 | |
| | 360* | | 14.99 | 1.02 | |
| Lyngå 14 | 115 | 1.48 | 14.99 | 1.38 | |
| | 150 | | 14.78 | 1.21 | |
| NGC 6396 | 1 | 0.97 | 9.79 | 1.82 | −0.06 |
| NGC 6451 | 199 | 0.70 | 14.06 | 0.62 | |
| | 716 | | 14.46 | 0.71 | |
| NGC 6611 | 198 | 0.85 | 13.21 | 0.60 | −0.06 |
| | 343 | 1.16 | 11.72 | 0.87 | −0.17 |
| NGC 6705 | 770 | 0.43 | 13.72 | 0.50 | 0.42 |
| NGC 6756 | 21 | 0.70 | 14.44 | 1.11 | |
| | 24 | | 14.50 | 1.11 | |
| Pismis 20 | 27 | ≈0 | 15.43 | 0.03 | |
| Lyngå 14 | 101 | ≈0 | 14.39 | 0.62 | |
| NGC 6396 | 20 | high | 10.62 | 2.44 | 2.63 |
| NGC 6756 | 40 | ≈0 | 15.01 | −0.01 | |

We have searched the literature to see if variable objects have been published for the investigated clusters in the past. Only NGC 6134 has so far been investigated in this respect by Rasmussen et al. (2002). These authors included also the data used in this work to show that the identified variable stars listed in Table 2 are indeed known $\delta$ Scuti type objects with the possibility of a $\gamma$ Doradus nature. Since the detection limit of variability for NGC 6134 is defined as 0.010 mag, we are confident that our method is valid for the given data sets.

None of the objects with a peculiar $\Delta a$ value shows evidence of variability.

Another important point is the type of variability. In Fig. 2 we have indicated the position of known variable star groups. Most of the objects seem to lie within the classical instability strip. Another large group is located within the area of the irregular variables (e.g. T Tauri objects). However, for an unambiguous conclusion about the true nature of the detected variability, follow-up observations are needed.

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