# The OmegaWhite Survey for Short Period Variable Stars VI. Open Clusters 

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#### Abstract

Using light curves with $\sim 3$ min cadence and a duration of 2 hrs made using the OmegaWhite survey, we present the results of a search for short-period variable stars in the field of 20 open clusters. We identified 92 variable stars in these fields. Using a range of cluster member catalogues and Gaia EDR3 data, we have determined that 10 are cluster members and 2 more are probable members. Based on their position on the Gaia HRD and their photometric periods, we find that most of these are $\delta$ Sct stars. We obtained low-resolution optical spectroscopy of some of these cluster members and field stars. We discuss the cluster variable stars in the context of $\delta$ Sct stars in other open clusters.


Key words: stars: oscillations - Galaxy: open clusters and associations - stars: variables: $\delta$ Scuti - Stars: distances

## 1 INTRODUCTION

Open star clusters (OCs) contain a few tens to over a thousand stars which are gravitationally bound and form and evolve in the Galactic disc. They are important components of the Milky Way and efficient tools for studying it. For example, young OCs have been used to map the Galactic rotation curve, determine the structure of spiral arms, study mechanisms of star formation and test stellar evolution models, whilst the structure and evolution of our Galaxy have been traced from the distribution of old OCs (Friel 1995). Moreover, since the cluster members are resolved, they can be studied individually, and hence, the cluster parameters (such as distance and age) can be determined with a higher accuracy for OCs than for single field stars. Consequently, a study of the population of OCs can trace the large scale structure of our own Galaxy (e.g. Piskunov et al. 2006, Wu et al. 2009). Additionally, since the stars in an OC formed at the same time and hence have the same age and metallicity, OCs have been used for studying stellar evolution (e.g. Vandenberg 1985).

Because the age of OCs can be determined, it is interesting to verify if the variable stars properties alter as a function of age. Gilliland et al. (1991) studied stars in the core of the old OC M67 searching for solar-like $p$ mode oscillations. Although they did not find any such oscillations, a set of new variable stars was found. Similarly, Hartman et al. (2008) conducted the Deep MMT (formerly Multiple Mirror Telescope) transit survey of the intermediate-age OC M37, aiming to find transiting exoplanets. They found 1445 variable stars, almost all

[^0]being new discoveries, many being rapidly rotating stars, but also including a sample of pulsating stars.

Since these earlier surveys, the study of OCs has been transformed through space missions such as Kepler, K2, TESS and wide field ground based surveys. For instance, using K2 data, Rebull et al. (2016) determined the rotation period of stars in OCs of different ages and hence better understand how stellar rotation period changed over time. TESS has also been used to search for variability of stars in OCs and search for exoplanets around stars in OCs (e.g. Bouma et al. 2019). Although the Next-Generation Transit Survey (NGTS) has a main goal of discovering exoplanets, it has also been used to determine the rotation rates of stars in open clusters (e.g. Gillen et al. 2020).

The OmegaWhite (OW) Survey was a wide field highcadence survey whose prime aim was to identify short period variable stars in the Galactic plane. The main goal was to find rare ultra-compact binary systems such as the AM CVn stars (Solheim 2010) which have orbital periods of $5-70$ min. The strategy and the pipeline of the OW survey were outlined in Macfarlane et al. (2015, hereafter Paper 1), with a detailed analysis of a large data set containing images of $134 \mathrm{deg}^{2}$ in Toma et al. (2016, Paper 2). A number of papers have followed which report populations of sources or individual short period variables. Additionally, Macfarlane et al. (2017, Paper 3) showed that followup photometry of variable stars identified in the OW survey were confirmed with the same period, proving that the OW strategy is successful. In this paper we report on a study which aimed to identify short period variable stars in OCs.

## 2 OVERVIEW OF THE OMEGAWHITE SURVEY

Full details of the OW survey and the data reduction process are outlined in Papers 1 and 2. Briefly, the OW survey used OmegaCAM (Kuijken 2011) mounted on the ESO VLT Survey Telescope (VST, Capaccioli \& Schipani 2011). A set of images with exposure times of 39 s (with a mean cadence of 2.7 min ) were taken of a $1 \mathrm{deg}^{2}$ field for 2 hr . Fields were within 10 deg of the Galactic plane. Photometry was obtained for stars in the field using difference imaging (Wozniak 2000). Variable stars were initially identified using the Lomb Scargle periodogram (Lomb 1976, Scargle 1982) and a manual verification phase was done to vet these variable candidates. Colour information derived from ugriH $\alpha$ filters was also obtained for many fields using the VPHAS+-DR2 catalogue (Drew et al. 2016). The data for this study use the same fields analysed in Paper 2 (i.e. $134 \mathrm{deg}^{2}$, observed between 2011-2015).

## 3 VARIABLE STARS IN OPEN CLUSTER FIELDS

Determining which stars in the field of an OC are cluster members is a difficult and often protracted task. Kharchenko et al. $(2012,2013)$ used the catalogue of Roeser et al. (2010) which provided 2MASS photometry and proper motions for 900 million stars to identify more than 3000 clusters and determine their key properties. They also give the probability that individual stars are cluster members. A similar study used UCAC4 data to determine the membership of stars in 1876 OCs (Sampedro et al. 2017). Since these studies, Gaia is now a key source for parallax and proper motion information (Gaia Collaboration et al. 2018a, 2021). This allowed Cantat-Gaudin et al. (2018) and Cantat-Gaudin \& Anders (2020) to determine cluster properties and to give probabilities of whether a star is a cluster member. We now discuss how we found variable stars in the cluster fields.

### 3.1 Identifying variable stars

We cross-matched the Milky Way Star Clusters Catalogue (MWSC, Kharchenko et al. 2013) with the OW on-sky footprint outlined in Paper 2. We identified 20 OCs whose angular radius (see Table 1) fully overlapped the OW survey. These are young, intermediate and old OCs, spaning a wide range of ages between 1.0 Myr and 2 Gyr. Although almost all of our 20 OCs have unknown metallicity, NGC 6583 has an abundance of $[\mathrm{Fe} / \mathrm{H}]=+0.370 \pm 0.03$ in the MWSC catalogue (Kharchenko et al. 2013) and a value of $[\mathrm{Fe} / \mathrm{H}]=$ $+0.370 \pm 0.04$ reported by Heiter et al. (2014) and Netopil et al. (2016); it is also one of the most metal rich clusters studied (Magrini et al. 2010).

We initially selected all the stars which were within the angular diameter of each cluster, and then selected those that were identified as candidate variable stars using the procedures set out in Paper 2. Light curves were obtained for 47422 stars and 217 candidate variable stars ( 0.45 percent) were identified. These candidates were then passed through our manual verification stage (Paper 2). We are confident that 92 of these are bona fide variable stars, for which details and
light curves are shown in Appendix A (Table A1) and Appendix B (Figures B1, B2, B3, B4, B5), respectively. Examples of spurious variables include stars which had diffraction spikes rotating through their point spread function over the 2 hr of observation (see Paper 2 for further details). We also note that since we use the Lomb Scargle periodogram to automatically detect variable stars, the period we determine is less certain for periods which are comparable to the duration of the light curve.

### 3.2 Variable stars as cluster members

The next stage sets out to determine which of the variable stars we have identified in the field of OCs were bona fide cluster members. We have used a number of catalogues from the literature and incorporate recent data derived from Gaia.

Kharchenko et al. (2005) define a probability of a star being a cluster member as the measure of the deviation from the mean proper motion of the cluster. They give three types of probabilities: the most probable cluster members are stars with a kinematic probability, $P_{k i n} \geqslant 61$ percent (i.e. stars that deviate within less than $1 \sigma$ from the mean). Those with probabilities within $14 \leqslant P_{k i n}<61$ percent are only possible members, in the interval $(1 \sigma, 2 \sigma)$. The remaining are field stars not associated with the OC.

Cantat-Gaudin et al. $(2018,2020)$ determine a probability, $P_{\text {memb }}$, that a star is member of an OC based on their Gaia DR2 parallax and proper motion data. We also use the membership catalogue of Sampedro et al. (2017) which is based on UCAC4 data and have three 'yes' or 'no' flags based on different criteria for membership.

Finally we used Gaia EDR3 data (Gaia Collaboration et al. 2021) to compare the distance of each star with the cluster distance. We used the photogeometric distance determined by Bailer-Jones et al. (2021) and also the 16 th and 84 th percentile of the photogeometric distance as the spread of distance. For the distance of each cluster, we assumed an uncertainty of 20 percent given in Kharchenko et al. (2013); they quote an external uncertainty on the distance of 11 percent but no internal error. Those stars which were clearly closer or more distant than the OC (for instance many stars in the field of ESO 430-18 were significantly more distant than the cluster distance of 870 pc ), we classified them as not cluster members. For the cases which were more marginal, we classified them as probably not members.

With these different criteria to hand, we assessed whether a star was a cluster member or field star. We classed a star as a cluster member if all our criteria indicated it was a real member. For those cases where the majority of the criteria suggested cluster membership, we indicate in Table A1 a 'Probable' membership. In some cases, there was a lack of evidence to give a more conclusive indication of membership probability. In the case of the shortest period star we found, the $29.8 \min \delta$ Sct OW J180753.62-220904.4 (see Figure 2 and Table 3), there is some uncertainty on the age of the OC ASCC 93, (1.3 Myr given by Kharchenko et al. 2013, 16 Myr by Sampedro et al. 2017). However, since $\delta$ Sct stars are older than the age of this cluster, this star is not associated with the OC ASCC 93.

Out of the 92 variable stars, we identified 10 as cluster members and other 2 as probable members. We classified 6 as probably not members, 68 as not cluster members and
the remaining 6 stars have unknown membership status. To summarise, 12 out of 92 variable stars have the highest probabilities to be physically members of open clusters, and we consider them as cluster members during the rest of this paper.

### 3.3 Variable stars on the Gaia HRD

We also used Gaia EDR3 to place the variable stars on the Hertzsprung-Russell Diagram (HRD), again using the photogeometric most likely distance determined by Bailer-Jones et al. (2021). We then deredden the $(B P-R P), M_{G}$ values using the 3D-dust maps derived from Pan-STARRS1 data (Green et al. 2019) and the relationship between $E(B-V)$ and $E(B P-R P)$ and $A_{G}$ and $E(B P-R P)$ outlined in Andrae et al. (2018). For those stars just off the edge of the Pan-STARRS1 field of view (stars with $\delta<-30^{\circ}$ ) we take the nearest reddening distance relationship. We show the resulting Gaia HRD along with stars within 50 pc , which we assume have no significant reddening, in Figure 1. We find that the majority of stars which are variable and cluster members have likely evolved off the main sequence implying that the variability is due to stellar pulsations. Field variable stars are located close to the main sequence (down to early M type), evolved off the main sequence, but also blueward of the upper main sequence which may indicate they contain evolved stars. (Due to fields being close to the Galactic plane and due to the nature of how we deredden the $(B P-R P), M_{G}$ values, there is some uncertainty in their location on the Gaia HRD).

## 4 SPECTROSCOPIC IDENTIFICATION OF VARIABLE STARS

As part of the OW follow-up programme, we acquired lowresolution spectra of 12 variable stars found within the angular radius of the OCs to help determine their nature (only three were subsequently found to be OC members). The stars were observed between April to May 2016 using the Spectrograph Upgrade-Newly Improved Cassegrain (SpUpNIC, Crause et al. 2019) mounted on the 1.9 m telescope at the South African Astronomical Observatory in Sutherland. The G7 grating was used which has a wavelength range of 5600 $\AA, 300$ lines per mm and a resolving power of $\sim 700$. The observing log is given in Table 2. The spectra were then reduced and flux and wavelength calibrated using the same standard techniques described in Macfarlane et al. 2017 (Paper 3).

### 4.1 Identification of stellar types

Based on the shape of their light curves, their periods and location on the Gaia HRD, we expect that most of the 12 stars, which we obtained spectra for, are likely $\delta$ Sct stars which have an A - F spectral type. We made a preliminary determination of the stars spectral type by comparison with the JHC spectral atlas (Jacoby et al. 1984).

The spectra of the variable stars are shown in Appendix C (Fig. C1, C2). In Figure C1a, we compare one of our stars with A and F stars from the JHC atlas, as an example. Thus, we find that ten stars have an A spectral type because they


Figure 1. The position of variable stars in the region of open clusters in this study in the Gaia $(B P-R P)_{o}, M G_{o}$ plane. We differentiate those which we regard as cluster members and probably members (shown as red stars), those we regard as field stars or probable field stars (pink dots) and those for which we are unable to determine whether they are members or not (green squares). The smaller dark dots are stars within 50 pc of the Sun which we assume are not affected by reddening.


Figure 2. The spectrum of the short-period $\delta$ Sct-like variable star, OW J180753.62-220904.4, which has a 66 percent chance to be a member of the open cluster ASCC 93. The spectrum was flux and wavelength calibrated. The dashed lines indicate spectral lines and the shaded areas atmospheric telluric bands (Papers 3, 4). The spectrum indicates that our star is an A4V type, confirming it to be a $\delta$ Sct pulsator.
exhibit strong H Balmer lines and weak Ca II lines (Figure C1b); we show one example spectrum in Figure 2. Two stars, OW J080659.2-300022.2 and OW J180319.05-215901.8, have unusual spectra, but the presence of Hydrogen Balmer lines, indicate that these are typical A - F stars, possibly affected by interstellar reddening (Figure C2).

Table 1. The 20 open clusters in this study. The first two columns give the ID number in the MWSC catalogue (Kharchenko et al. 2013) and the cluster name. They are followed by the ESO semester when the data was taken in and the internal OW field name. Next, the sky coordinates (J2000) of the cluster centre, the angular radius of the cluster extent, the distance, the $E_{B-V}$ and the cluster age are all taken from the MWSC. Last, the number of variable stars found in the angular area of each cluster is given. An asterisk indicates the clusters that were found in Cantat-Gaudin et al. (2018, 2020)'s catalogues.

| $\begin{aligned} & \hline \text { MWSC } \\ & \text { ID } \end{aligned}$ | Cluster <br> Name | $\begin{aligned} & \hline \text { ESO } \\ & \text { Sem } \end{aligned}$ | $\begin{gathered} \text { OW } \\ \text { Field } \end{gathered}$ | $\begin{gathered} \hline \text { RA } \\ (\mathrm{deg}) \\ \hline \end{gathered}$ | $\begin{gathered} \hline \text { Dec } \\ (\mathrm{deg}) \end{gathered}$ | r $(\operatorname{arcmin})$ | $\begin{gathered} \mathrm{d} \\ (\mathrm{pc}) \end{gathered}$ | $\begin{aligned} & \mathrm{E}_{B-V} \\ & (\mathrm{mag}) \end{aligned}$ | $\begin{aligned} & \log \mathrm{t} \\ & (\mathrm{yr}) \end{aligned}$ | \# Variable stars |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1392 | Turner 12 | 88 | 3a | 119.5 | -29.3 | 7.5 | 4500 | 0.73 | 8.5 | 0 |
| 1420 | ESO 430-09 | 88 | 3 b | 120.6 | -29.8 | 4.8 | 2270 | 0.21 | 8.5 | 2 |
| 1432 | NGC 2533* | 88 | 4 a | 121.8 | -29.9 | 8.4 | 2960 | 0.46 | 8.4 | 6 |
| 1345 | Teutsch 25 | 88 | 11a | 117.1 | -27.9 | 4.2 | 2840 | 0.42 | 9.3 | 0 |
| 1383 | NGC 2483 | 88 | 12a | 118.9 | -27.9 | 6.9 | 1650 | 0.35 | 7.6 | 7 |
| 2668 | ESO 520-20 | 91 | 17b | 265.9 | -24.7 | 4.5 | 2040 | 2.33 | 9.2 | 2 |
| 2690 | Dutra-Bica 44 | 91 | 18a | 266.6 | -24.9 | 4.2 | 2260 | 2.41 | 9.1 | 0 |
| 2791 | Teutsch 14a* | 93 | 85a | 270.9 | -22.1 | 9.6 | 2110 | 1.50 | 8.5 | 7 |
| 2814 | ASCC 93 | 93 | 85b | 272.0 | -22.3 | 9.9 | 1830 | 0.58 | 6.1 | 1 |
| 2845 | NGC 6573 | 93 | 86a | 273.4 | -22.1 | 5.7 | 3030 | 1.06 | 8.8 | 3 |
| 2860 | NGC 6583* | 93 | 86b | 274.0 | -22.1 | 6.0 | 1750 | 0.56 | 9.0 | 9 |
| 2708 | Dutra-Bica 51 | 93 | 100b | 267.4 | -31.3 | 3.3 | 1350 | 3.12 | 6.0 | 0 |
| 2613 | Antalova 3 | 93 | 103a | 262.7 | -32.2 | 6.6 | 2590 | 1.35 | 8.4 | 1 |
| 1273 | Haffner 11 | 94 | 34b | 113.8 | -27.7 | 6.0 | 5160 | 0.42 | 8.9 | 0 |
| 1426 | ESO 430-14 | 94 | 40b | 120.9 | -31.4 | 7.8 | 2860 | 0.83 | 7.2 | 15 |
| 1391 | FSR 1342* | 94 | 40a | 119.5 | -31.5 | 7.2 | 3630 | 0.94 | 8.3 | 2 |
| 1208 | Ivanov 6 | 94 | 107a | 111.1 | -24.6 | 6.0 | 2430 | 1.15 | 6.6 | 0 |
| 1279 | Riddle 5 | 94 | 108b | 114.2 | -24.7 | 3.6 | 2710 | 0.90 | 8.8 | 2 |
| 1431 | ESO 430-18 | 94 | 114b | 121.8 | -30.8 | 17.4 | 870 | 0.0 | 8.9 | 32 |
| 1425 | Ruprecht 51 | 94 | 114a | 120.9 | -30.7 | 5.7 | 2530 | 0.56 | 8.8 | 3 |

Table 2. The observing log of follow-up spectra obtained for 12 variable stars found in the angular area of 20 open clusters that overlap OmegaWhite fields. The survey ID, cluster name, date of observation, exposure time, airmass and the slitwidth are listed for each star.

| OW Star ID | Cluster | Date-obs | Exp <br> sec | Airmass | Slitwidth <br> $\prime \prime$ |
| :--- | :--- | :--- | :--- | :---: | :---: |
| OW J080659.21-300022.2 | NGC 2533 | $30-04-2016$ | 1800 | 2.31 | 1.80 |
| OW J080706.92-295626.7 | NGC 2533 | $30-04-2016$ | 1500 | 1.83 | 1.80 |
| OW J080711.98-294621.7 | NGC 2533 | $02-05-2016$ | 2100 | 1.19 | 1.05 |
| OW J080721.21-294516.6 | NGC 2533 | $01-05-2016$ | 1800 | 1.08 | 1.50 |
| OW J180319.05-215901.8 | Teutsch 14a | $03-05-2016$ | 900 | 1.06 | 1.50 |
| OW J180753.62-220904.4 | ASCC 93 | $01-05-2016$ | 1200 | 1.04 | 1.80 |
| OW J181329.36-220502.4 | NGC 6573 | $02-05-2016$ | 900 | 1.01 | 1.80 |
| OW J181531.53-220755.3 | NGC 6583 | $02-05-2016$ | 900 | 1.03 | 1.80 |
| OW J080554.11-305750.0 | ESO 430-18 | $03-05-2016$ | 2400 | 1.15 | 1.50 |
| OW J080603.57-305142.5 | ESO 430-18 | $30-04-2016$ | 1800 | 1.49 | 2.10 |
| OW J080603.79-305050.5 | ESO 430-18 | $02-05-2016$ | 1800 | 1.08 | 1.50 |
| OW J080635.21-305741.5 | ESO 430-18 | $01-05-2016$ | 1200 | 1.24 | 1.50 |

### 4.2 Identification of stellar types using the equivalent width ratios

To refine the spectral type of the 12 variable stars we determined the equivalent width (EW) of the Ca II line (K, 3933 $\AA$ ) and $\mathrm{H} \epsilon(3970 \AA$ ) for identification (c.f. Jaschek \& Jaschek 1990). We modified the EW method used in Paper 3. For our 12 stars, we measured the EWs of Ca K and the $\mathrm{Ca} \mathrm{H}+\mathrm{H} \epsilon$ doublet because the K line changes significantly from one A subtype to the other. We used the interactive tool splot in IRAF (Tody 1993) for the measurements. We obtained a calibration curve using as reference all the A1V up to F4V main sequence stars given by Jacoby et al. (1984). The same two Ca lines were measured and the EW ratios determined for these reference stars. Lastly, we fit the measured ratios as a function of spectral type using an exponential function. The results of these steps are shown in Figure 3. The intersection
of each line with the curve indicates the likely spectral type of our variable stars, from A0V to A8V; see also Table 3.

In most cases, there is a good agreement between the spectral type assigned using the JHC atlas and the EW approach. However, one star OW J080706.92-295626.7, is identified as an A3V star by the EW ratio, although the visual comparison places it as an earlier A0/A1V star. Further, OW 080659.2300022.2 is thought to have A8V spectral type from the EW ratio, but approximately F4V from its location in the Gaia HRD (Figure 1). The OW J180319.05-215901.8 (bottom spectrum in Figure C2) is so affected by reddening that the Ca lines are not visible and hence we could not measure the EW ratio for this star. Thus we cannot tell if it is an A or F star.

Table 3. A sample of 12 variable stars found overlapping the area of 20 open clusters with follow-up low-resolution spectra available. The survey ID, the cluster name, and the MWSC kinematic membership probability are given first (Kharchenko et al. 2013). Next, the membership probability obtained from Gaia-DR2 data published by Cantat-Gaudin et al. (2018) is listed. The empty spaces indicate that there were no data in the catalogue for those particular stars. The equivalent width ratios of the Ca II lines (i.e. $\mathrm{Ca} \mathrm{K} /(\mathrm{Ca} \mathrm{H}+\mathrm{H} \epsilon)$ ), the estimated spectral types and the cluster membership are given in the last three columns. See text for details.

| Star ID | Cluster | $\mathrm{P}_{\text {kin }}$ <br> $(\%)$ | $\mathrm{P}_{M e m b}$ <br> $(\%)$ | EW Ratio <br> $(\mathrm{Ca} \mathrm{K/} \mathrm{Ca} \mathrm{H+H} \epsilon)$ | Spectral type <br> JHC + EW | Cluster member? |
| :--- | :--- | ---: | :--- | :--- | :--- | :--- |
| OW J080659.21-300022.2 | NGC 2533 | 0.0 | 70.0 | $0.256 \pm 0.093$ | reddened A8V | Cluster member |
| OW J080706.92-295626.7 | NGC 2533 | 78.4 | 80.0 | $0.133 \pm 0.034$ | A3V | Cluster member |
| OW J080711.98-294621.7 | NGC 2533 | 9.2 | 50.0 | $0.208 \pm 0.029$ | A7V | Field star |
| OW J080721.21-294516.6 | NGC 2533 | 66.7 | 50.0 | $0.270 \pm 0.043$ | A8V | Field star |
| OW J180319.05-215901.8 | Teutsch 14a | 54.4 | 10.0 | Ca lines invisible | reddened A/F | Field star |
| OW J180753.62-220904.4 | ASCC 93 | 65.5 |  | $0.141 \pm 0.016$ | A4V | Field star |
| OW J181329.36-220502.4 | NGC 6573 | 63.2 |  | $0.169 \pm 0.012$ | A5V | Field star |
| OW J181531.53-220755.3 | NGC 6583 | 14.1 | 90.0 | $0.231 \pm 0.026$ | A7V/A8V | Cluster member |
| OW J080554.11-305750.0 | ESO 430-18 | 0.0 |  | $0.178 \pm 0.022$ | A6V | Field star |
| OW J080603.57-305142.5 | ESO 430-18 | 13.1 |  | $0.143 \pm 0.012$ | A4V | Field star |
| OW J080603.79-305050.5 | ESO 430-18 |  |  | $0.266 \pm 0.069$ | A8V | Field star |
| OW J080635.21-305741.5 | ESO 430-18 | 0.0 |  | $0.073 \pm 0.004$ | A0V/A1V | Field star |



Figure 3. The data points represent the measured EW ratio (Ca $\mathrm{K} /(\mathrm{CaH}+\mathrm{H} \epsilon))$ for a set of reference A stars from the JHC atlas (Jacoby et al. 1984). The EW ratio curve is obtained by fitting the data points with an exponential function. The measured EW ratios of the 11 variable stars in open clusters are displayed as horizontal lines.

## 5 NATURE OF THE VARIABLE STARS

We show details of the 92 variable stars in Table A1 and their location on the Gaia HRD in Figure 1. We have identified 12 stars as either being cluster members or probable members i.e. with a high membership probability and we consider them as cluster members from now on (their details are outlined in Table 4 and the light curves are shown in Figure 4); six are members of the cluster NGC 6583; four are members of NGC 2533; one is a probable member of ESO 430-18 and the remaining a probable member of NGC 2483. Considering the shape of their light curves and colours, these cluster stars are $\delta$ Sct pulsators (Breger 1979, 2000), although we cannot rule out some of them being SX Phe stars, which are their metal poor counterparts (Nemec \& Mateo 1990). High-resolution spectra are necessary to study the metal lines in order to differentiate between these two types.

We obtained spectra for three stars which we consider cluster members. OW J181531.53-220755.3 in NGC 6583 is an A7/A8V star (Figure C1b) consistent with it being a low am-
plitude $\delta$ Sct. OW J080706.92-295626.79 in NGC 2533 is an A3V star and the light curve looks like that of a low amplitude $\delta$ Sct pulsator. The analysis outlined in $\S 4.2$ suggested that OW J080659.21-300022.2 (i.e. top spectrum in the Figure C 2 ) is a A 8 V star, although the shape of its continuum pointed to it being reddend. However, its position on the Gaia HRD is consistent with the spectral type F4V: both spectral types point to a $\delta$ Sct classification. Overall, the position of these variables in the Gaia HRD indicates that they are either main sequence stars, or have evolved off the main sequence, which is consistent with them being $\delta$ Sct stars.

We have classified two stars as probable cluster members. OW J075556.7-275026.1 in NGC 2483 is a $\delta$ Sct (there has been a debate about whether NGC 2483 is a genuine cluster, e.g. Fitzgerald \& Moffat 1975). It has a position on the dereddened Gaia HRD consistent with a late F spectral type. OW J080237.1-294217.4 in ESO 430-09 does not have a Gaia $(B-R)$ colour but has a dereddend $\mathrm{MG}_{o}$ consistent with a late K spectral type.

Of the remaining stars, 6 have insufficient information to assess their membership, with the remaining 74 being not or probably not cluster members. Figure 1 shows that many of the field variable stars (and those with no membership information) are pulsating stars with a smaller number being hotter than the main sequence implying they would be evolved stars (this part of the Gaia HRD includes hot subdwarf stars, $\mathrm{sdO} / \mathrm{Bs}$, located blue-ward of the horizontal branch, around $M_{G} \sim 5 \mathrm{mag}$, as shown by Gaia Collaboration et al. 2018b, Geier et al. 2019, Dal Tio et al. 2021).

In Papers 2 and 3 we showed that the amplitude of the periodic modulation (which is derived using the Lomb Scargle Periodogram) could be used to help determine the nature of the variable sources. In Fig. 5 we show the amplitude as a function of period. Of the 12 OC members, 11 have an amplitude consistent with typical low amplitude $\delta$ Sct stars. One star, OW J075556.7-275026.1, a member of NGC 2483, has an amplitude of 0.14 mag and could be a high-amplitude $\delta$ Sct star (HADS, Rodríguez et al. 1996, Alcock et al. 2000, Garg et al. 2010). We note 30 more stars showing high amplitudes that could be HADS. Of these, five stars which we cannot determine if they are cluster members might be HADS based on their amplitude and location on the Gaia HRD. The re-


Figure 4. The light curves of the 12 variable stars that we found to be members or highly probable members of the 20 open clusters found overlapping the set of OW fields. For each, we list the cluster name and its survey name. Further details are given in Table 4.
maining are field stars. Nevertheless, those stars with high amplitudes could also be eclipsing binary stars or compact pulsators, although we note that some stars showing high amplitudes (e.g. OW J080610.3-304739.1, Fig. B4) are artificially high due to some spurious data points.

We now use the VPHAS+ colour information (Drew et al. 2014,2016 ) to confirm the variable star classification of the cluster member stars and identify other stars which may have interesting properties. We show the stars in the $(g-r),(u-g)$ and $(r-i),(r-H \alpha)$ planes in Fig. 6. The cluster members have colours consistent with being reddened stars of A-F spectral type, confirming that they are $\delta$ Scutis. The redder stars at the bottom right in the ugr diagram could also be eclipsing and/or contact binaries. One field star, OWJ 073646.1-244016.9, is significantly bluer than the main sequence and has $r-H \alpha=1.0$ indicating $\mathrm{H} \alpha$ emission and
therefore it is worthy of follow-up spectroscopy (it is located near the lower part of the main sequence in Fig. 1).

## $6 \delta$ SCUTI STARS IN OPEN CLUSTERS

Rodríguez (2002)'s compilation of $\delta$ Sct stars in 22 OCs shows 84 stars with periods of typically $1-3 \mathrm{hrs}$. The age of the OCs are widely varied, with Rodríguez (2002) noting $3 \delta$ Sct stars in the $\alpha$ Per cluster (age $\log t / \mathrm{y} \sim 7.7$, Kharchenko et al. 2013), and $4 \delta$ Sct stars in Melotte $71(\log t / y \sim 9.0$, Kharchenko et al. 2013). Chang et al. (2013) in their statistical survey of Galactic $\delta$ Sct stars identify nearly 100 such variables as OC members. Using K2, Rebull et al. (2016) report eight pulsator-like stars in the Pleiades $(\log t / y \sim 8.2)$ of which five are clear $\delta$ Sct stars with periods $\lesssim 2.4 \mathrm{hrs}$ with three more with similar periods $\sim 7.2 \mathrm{hrs}$. More recently,


Figure 5. The period-amplitude diagram of the variable stars reported here in log scale. The cluster members and probably members are shown as red stars, the field stars and probable field stars are shown as blue dots and the green squares are the stars with unknown membership status.

Durgapal et al. (2020) searched for variable stars in four OCs using a 1.0 m ground based telescope and found $5 \delta$ Sct stars, 4 in King $7(\log t / y \sim 8.9)$ and 1 in King $5(\log t / y \sim 9.1)$; their periods are in the range of $3.1-5.0 \mathrm{hrs}$.

To compare, we found a small number of $\delta$ Sct stars, only 12, in four open clusters (NGC 2533, NGC 6538, NGC 2483 and ESO 430-09) from our sample of 20 (§5).

NGC 2533 is an intermediate age cluster of 250 Myr old and NGC 6583 is old ( 1 Gyr ). Although we noted earlier the debate on whether NGC 2483 was a real OC, its age appears to be young ( 40 Myr ). The periods we found for these cluster members are between 60-125 min.

The $\delta$ Scuti stars are located in the lower part of the Instability Strip (Rodríguez et al. 2000), and therefore follow a period-luminosity (PL) relation that has been studied in detail over the years: since the beginning by Leavitt \& Pickering (1912) who discovered the Classical Cepheids, up to McNamara (2011), Ziaali et al. (2019), Poro et al. (2021) who updated the PL relation for $\delta$ Scutis. Although $\delta$ Sct stars can show variations on multiple periods, our data are not sensitive enough to detect them because of the short duration of the OW light curves.

We now use the periods measured from the OW photometry to determine the absolute magnitude of the $\delta$ Sct stars indicated in Table 4 using the PL relationship derived by Ziaali et al. (2019) based on Gaia DR2 data. In addition we use the relationship between $G$ and $V$ using equation 1 of Montalto et al. (2021) to convert $M_{V}$ to $M G$. We estimate the error on the $M G_{o}$ using the uncertainties on the distance estimate from Gaia DR3 and add an additional 0.1 mag to
take into account the uncertainty of dereddening $M G$. We show the resulting predicted values of $M G_{o}$ based on the period luminosity relationship in Figure 7. The agreement between the predicted and measured values of $M G_{o}$ is reasonably good once the uncertainties are taken into account. The one star which shows a significant departure from predictions is OW J075556.7-275026.1 which we have classed as a probable cluster member. We note that Poretti et al. (2005) find that $\delta$ Sct stars which are pulsating in the first overtone rather than the fundamental frequency have shorter periods by a factor of 0.775 which implies they would be fainter by $\sim$ 0.3 mag: this would give a better fit to the predicted absolute magnitude for around half the stars in Figure 7.

## 7 CONCLUSIONS

Using data obtained from the OW survey, we have presented the results of a search for short period variable stars in the field of open clusters. The data set (covering $134 \mathrm{deg}^{2}$ in the Galactic Plane and Bulge) was cross-matched with the MWSC catalogue (Kharchenko et al. 2013), and catalogues based on Gaia data (Cantat-Gaudin et al. 2018, 2020) to find stars which are members of OCs. In a sample of 20 open clusters, we found 92 variable stars of which 12 are OC members, which have a range of ages. Based on spectroscopic observations and their location on the Gaia HRD, 12 of the variables are $\delta$ Sct pulsators. Of these, only 3 are physical members of open clusters.

The results from Gaia are allowing the membership of OCs to be much more reliably determined, and for new clusters to be identified (e.g. Ferreira et al. 2021). This coupled with observations from space missions such as Kepler and TESS (e.g. Nardiello et al. 2020) and ground based surveys such as NGTS (e.g. Gillen et al. 2020) or ZTF (e.g. Coughlin et al. 2021) will allow the photometric properties of cluster members to be studied without the contamination of field stars. In turn this will reveal how the properties of variable stars vary as a function of age in a direct manner.

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Figure 6. The colour-colour diagrams in the $u-g, g-r$ (left side) and $r-H \alpha, r-i$ (right side) planes for the sample of variable stars reported here. The colour information was taken from the VPHAS+-DR2 catalogue (Drew et al. 2016). The light grey small dots are all stars measured in the areas of the clusters. The black line represents the unreddened main-sequence derived by Drew et al. (2014). On this line we mark the position of B0V - M0V stars for reference. We indicate the variable stars found as cluster members as red star symbols; the green squares are stars with unknown membership probability and the blue dots are the field variable stars.

Table 4. Those variable stars which are members or highly probable members of OCs. We note the cluster they are associated with, the OC age, the period of the modulation in the OW light curve, the variable star type, the likelihood of the star being an OC member and the dereddended Gaia absolute $G \mathrm{mag}, M G_{o}$, and $(B-R)_{o}$ colour. Their light curves are shown in Figure 4.

| Name | Cluster | $\log \mathrm{t}$ <br> $(\mathrm{yr})$ | Period <br> $(\min )$ | Type | Members | $M G_{o}$ | $(B-R)_{o}$ |
| :---: | :--- | :--- | :---: | :--- | :--- | :--- | :--- |
| OW J080237.1-294217.4 | ESO 430-09 | 8.5 | 70.6 | G? | prob | 7.71 | - |
| OW J080659.2-300022.2 | NGC 2533 | 8.4 | 68.2 | A8/F4 - $\delta$ Sct | Y | 3.05 | 0.60 |
| OW J080713.1-295305.6 | NGC 2533 | 8.4 | 113.7 | $\delta$ Sct | Y | 1.64 | 0.59 |
| OW J080706.9-295626.7 | NGC 2533 | 8.4 | 121.5 | A3 $\delta$ Sct | Y | 2.52 | 0.53 |
| OW J080705.8-295140.8 | NGC 2533 | 8.4 | 133.4 | $\delta$ Sct | Y | 1.88 | 0.63 |
| OW J075556.7-275026.1 | NGC 2483 | 7.6 | 74.3 | $\delta$ Sct | prob | 3.90 | 0.88 |
| OW J181531.5-220755.3 | NGC 6583 | 9.0 | 60.6 | A7/A8 $\delta$ Sct | Y | 1.84 | 0.38 |
| OW J181535.4-220934.6 | NGC 6583 | 9.0 | 68.6 | $\delta$ Sct | Y | 1.95 | 0.50 |
| OW J181542.9-220949.7 | NGC 6583 | 9.0 | 74.7 | $\delta$ Sct | Y | 1.61 | 0.50 |
| OW J181556.6-221021.4 | NGC 6583 | 9.0 | 76.6 | $\delta$ Sct | Y | 1.29 | 0.63 |
| OW J181555.0-220953.6 | NGC 6583 | 9.0 | 82.4 | $\delta$ Sct | Y | 1.22 | 0.53 |
| OW J181545.5-220813.6 | NGC 6583 | 9.0 | 125.0 | $\delta$ Sct | Y | 1.49 | 0.66 |

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## DATA AVAILABILITY

The ESO data is available from the ESO archive. Light curves and optical spectra which are shown in the paper can be requested from the corresponding author.

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Figure 7. The solid line shows the period luminosity relation of Ziaali et al. (2019) where we have converted $M V$ to $M G$ (see the text for details). The data points indicate the observed $M G_{o}$ for those stars which have evidence they are $\delta$ Sct stars which are OC members. Apart from one star (the lowermost point) there is reasonable agreement with the stars observed $M G_{o}$ and that predicted by the period luminosity relationship, thereby strengthening their classification as $\delta$ Sct stars.

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Table A1: The catalogue of variable stars found in the angular areas of a set of 20 open clusters overlapping OmegaWhite fields. We show the stars distributed in each cluster and sort them according to their period measured by the Lomb Scargle periodogram ( $P_{L S}$ ). The star survey ID (that indicates the sky coordinates in hexadecimals, J2000) is given first, (he period and false alarm probability. For convenience and brevity, FAP is a notation used for $\log _{10}$ FAP here (See Paper 2 for details). The OmegaWhite photometry and the VPHAS+-DR2 (Drew et al. 2014, 2016) ugriHo colour indices are given afterwards. The kinematic membership probability obtained from the MWSC catalogue (Kharchenko et al. 2013), the membership probability obtained from Gaia DR2 data by Cantat-Gaudin et al. (2018), the UCAC4 memberships given by Sampedro et al. (2017), the distance obtained from Gaia data by Bailer-Jones et al. (2021), the Gaia photometry (Gaia Collaboration et al. 2021), the membership based on the distance, the total membership and an estimated type of variable star are given in the last columns.

| ID | $\begin{gathered} P_{L S} \\ (\mathrm{~min}) \end{gathered}$ | FAP | $\begin{array}{r} \mathrm{OWg} \\ (\mathrm{mag}) \end{array}$ | $\begin{array}{r} \text { Amp } \\ (\mathrm{mag}) \end{array}$ | $\begin{aligned} & g-r \\ & (\mathrm{mag}) \end{aligned}$ | $\begin{aligned} & u-g \\ & (\mathrm{mag}) \end{aligned}$ | $\begin{aligned} & \hline r-i \\ & (\mathrm{mag}) \\ & \hline \end{aligned}$ | $\begin{aligned} & \hline r-H \alpha \\ & (\mathrm{mag}) \end{aligned}$ | $\begin{array}{r} P_{k} \\ (\%) \\ \hline \end{array}$ | $\begin{aligned} & P_{M} \\ & (\%) \\ & \hline \end{aligned}$ | $P_{U 4}$ | $\begin{array}{r} \mathrm{d} \\ (\mathrm{pc}) \\ \hline \end{array}$ | $(B P-R P)_{o}$ | $M G_{o}$ | $\begin{gathered} \text { Mem } \\ \text { Dist? } \end{gathered}$ | Overall Mem? | Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ESO 430-09 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J080237.1-294217.4 | 70.6 | -4.8 | 16.5 | 0.018 | 0.87 | 0.43 | 0.46 | 0.24 | 99.1 |  |  | 3090 |  | 7.7 | Prob N | Prob | G? |
| OW J080234.2-294852.6 | 72.8 | -3.2 | 16.8 | 0.015 | 0.97 | 0.47 | 0.46 | 0.22 | 25.9 |  |  | 3130 | 0.59 | 2.8 | Prob N | Prob N | G ? |
| NGC 2533 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J080659.2-300022.2 | 68.2 | -3.1 | 16.5 | 0.014 | 0.82 | 0.39 | 0.42 |  | 0.0 | 70.0 |  | 2690 | 0.59 | 3.0 |  | Y | reddened A8 |
| OW J080711.9-294621.7 | 86.1 | -4.7 | 17.5 | 0.063 | 0.74 | 0.46 | 0.44 | 0.23 | 9.2 | 50.0 |  | 4650 | 0.65 | 2.8 | N | N | A7 $\delta$ Sct |
| OW J080721.2-294516.6 | 113.0 | -5.0 | 16.5 | 0.064 | 0.75 | 0.35 | 0.38 | 0.24 | 66.7 | 50.0 |  | 4960 | 0.58 | 1.7 | N | N | $\mathrm{A} 8 \delta \mathrm{Sct}$ |
| OW J080713.1-295305.6 | 113.7 | -2.6 | 14.6 | 0.018 | 0.62 | 0.45 | 0.34 | 0.23 | 11.3 | 90.0 | Y | 2680 | 0.59 | 1.6 |  | Y | $\delta$ Sct? |
| OW J080706.9-295626.7 | 121.5 | -4.5 | 15.5 | 0.023 | 0.66 | 0.35 | 0.35 | 0.15 | 78.4 | 80.0 | Y | 2630 | 0.53 | 2.5 |  | Y | A3 $\delta$ Sct |
| OW J080705.8-295140.8 | 133.4 | -4.2 | 15.7 | 0.043 |  |  |  |  | 72.9 | 60.0 | Y | 3150 | 0.63 | 1.9 |  | Y | $\delta$ Sct? |
| NGC 2483 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J075556.7-275026.1 | 74.3 | -3.8 | 16.5 | 0.144 | 0.8 | 0.33 | 0.4 | 0.27 | 96.8 |  |  | 2190 | 0.88 | 3.9 | Prob N | Prob | $\delta$ Sct? |
| OW J075531.4-275953.0 | 83.7 | -2.7 | 16.2 | 0.011 |  | 0.59 | 0.43 | 0.19 | 73.9 |  |  | 2520 | 0.68 | 2.9 | N | N | $\delta$ Sct? |
| OW J075554.5-280000.6 | 87.6 | -5.3 | 14.9 | 0.025 | 0.66 | 0.48 | 0.34 | 0.24 | 64.7 |  |  | 2380 | 0.61 | 2.1 | N | N | $\delta$ Sct? |
| OW J075542.2-275754.5 | 121.5 | -5.2 | 18.6 | 0.294 | 1.45 | 0.98 | 0.59 |  |  |  |  | 3480 | 1.14 | 4.2 |  |  | W UMa? |
| OW J075609.2-275655.3 | 124.2 | -4.1 | 16.7 | 0.101 | 0.65 | 0.45 | 0.39 | 0.22 | 56.8 |  |  | 3870 | 0.70 | 2.9 | N | N | $\delta$ Sct? |
| OW J075516.4-275227.5 | 128.4 | -3.7 | 19.2 | 0.287 | 1.27 | 1.04 | 0.57 | 0.39 |  |  |  | 3000 | 1.17 | 5.6 | N | N | W UMa? |
| OW J075518.8-275554.3 | 132.9 | -3.4 | 16.9 | 0.021 | 0.71 | 0.64 | 0.43 | 0.19 | 0.0 |  |  | 3950 | 0.58 | 2.9 | N | N | $\delta$ Sct? |
| ESO 520-20 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J174334.1-244707.3 | 71.1 | -2.8 | 14.3 | 0.008 | 0.94 | 0.56 | 0.75 | 0.26 | 6.4 |  |  | 760 | 0.40 | 2.5 | N | N |  |
| OW J174336.0-243928.9 | 97.8 | -3.0 | 15.7 | 0.009 | 1.03 | 0.44 | 0.72 | 0.26 | 0.5 |  |  | 1140 | 0.59 | 3.0 | N | N |  |
| Teutsch 14a |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J180303.1-221032.4 | 71.3 | -3.0 | 17.5 | 0.022 |  |  | 0.97 | 0.33 | 81.7 | 20.0 |  | 1960 | 0.91 | 1.9 |  | Prob N | $\delta$ Sct? |
| OW J180319.0-215901.8 | 79.2 | -3.6 | 17.0 | 0.023 |  |  | 1.19 | 0.44 | 54.3 | 10.0 |  | 3320 | 1.08 | -0.9 | N | N | A/F $\delta$ Sct? |
| OW J180403.1-221024.6 | 96.7 | -4.9 | 17.7 | 0.062 | 1.72 | 1.34 | 0.98 | 0.35 | 0.0 | 10.0 |  | 2430 | 0.97 | 1.4 |  | N | $\delta$ Sct? |
| OW J180400.3-220932.2 | 111.8 | -4.3 | 19.7 | 0.183 | 1.77 |  | 1.0 | 0.35 |  | 20.0 |  | 1910 | 1.25 | 4.2 |  | N | $\delta$ Sct? |
| OW J180407.3-220601.2 | 112.9 | -4.2 | 19.5 | 0.114 | 2.0 | 1.7 | 1.08 |  | 74.7 | 10.0 |  | 1860 | 1.15 | 3.1 |  | N | $\delta$ Sct? |
| OW J180321.9-220717.3 | 126.7 | -4.6 | 17.8 | 0.029 |  |  |  |  | 50.2 | 40.0 |  | 1530 | 1.20 | 1.9 |  | N | $\delta$ Sct? |
| OW J180259.5-220937.8 | 132.6 | -5.0 | 16.9 | 0.042 |  |  | 1.11 | 0.39 | 94.9 | 40.0 |  | 2860 | 1.24 | -0.1 |  | Prob N | $\delta$ Sct? |
| ASCC-93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J180753.6-220904.4 | 29.8 | -4.3 | 14.2 | 0.012 | 0.46 |  |  |  | 65.5 |  | Y | 1170 | 0.28 | 2.4 | N | Prob N | A4 $\delta$ Sct |
| NGC 6573 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J181329.3-220502.4 | 58.3 | -3.8 | 15.1 | 0.010 | 0.78 | 0.33 | 0.55 |  | 63.2 |  |  | 1380 | 0.60 | 3.0 | N | N | A5 $\delta$ Sct |
| OW J181325.9-220559.3 | 79.4 | -2.6 | 19.5 | 0.106 | 1.37 | 0.86 | 0.82 | 0.36 |  |  |  | 3360 | 0.95 | 3.9 |  |  |  |
| OW J181323.6-220633.4 | 82.0 | -2.8 | 20.3 | 0.273 | 1.5 | 1.32 | 0.86 | 0.4 |  |  |  | 3920 | 1.04 | 4.1 |  |  |  |
| NGC 6583 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J181531.5-220755.3 | 60.6 | -4.8 | 15.5 | 0.013 |  |  | 0.6 | 0.2 | 14.1 | 90.0 |  | 2080 | 0.38 | 1.8 |  | Y | A7/A8 $\delta$ Sct |
| OW J181538.4-221317.6 | 64.2 | -2.6 | 18.4 | 0.045 |  | 0.78 | 1.04 | 0.34 | 49.8 | 30.0 |  | 3690 | 1.20 | 3.0 |  | N | $\delta$ Sct? |
| OW J181602.3-220537.2 | 64.9 | -3.0 | 16.4 | 0.012 | 0.94 | 0.57 | 0.63 | 0.18 |  | 20.0 |  | 3020 | 0.50 | 1.7 | Prob N | N | $\delta$ Sct? |
| OW J181535.4-220934.6 | 68.6 | -3.6 | 15.5 | 0.009 | 0.81 | 0.56 | 0.6 | 0.2 | 18.4 | 100.0 |  | 2280 | 0.50 | 2.0 |  | Y | $\delta$ Sct |
| OW J181603.8-220421.9 | 72.4 | -3.4 | 17.5 | 0.023 | 1.11 | 0.76 | 0.72 | 0.21 |  | 10.0 |  | 2980 | 0.70 | 2.6 |  | N | $\delta$ Sct? |
| OW J181542.9-220949.7 | 74.7 | -2.6 | 15.0 | 0.007 | 0.8 | 0.59 | 0.6 | 0.19 | 0.0 | 80.0 |  | 2190 | 0.50 | 1.6 |  | Y | $\delta$ Sct? |
| OW J181556.6-221021.4 | 76.6 | -4.3 | 15.1 | 0.012 | 0.94 | 0.7 |  | 0.11 | 0.0 | 100.0 | Y | 2350 | 0.63 | 1.3 |  | Y | $\delta$ Sct? |
| OW J181555.0-220953.6 | 82.4 | -4.5 | 15.6 | 0.011 | 0.99 | 0.76 | 0.7 | 0.22 | 0.0 | 70.0 | Y | 2570 | 0.53 | 1.2 |  | Y | $\delta$ Sct? |
| OW J181545.5-220813.6 | 125.0 | -4.4 | 15.4 | 0.037 | 0.94 | 0.72 | 0.67 | 0.21 | 0.2 | 100.0 | N | 2320 | 0.66 | 1.5 |  | Y | $\delta$ Sct? |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ontinued | n next page... |

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| ID | $\begin{gathered} P_{L S} \\ (\mathrm{~min}) \\ \hline \end{gathered}$ | FAP | $\begin{array}{r} \hline \mathrm{OWg} \\ (\mathrm{mag}) \\ \hline \end{array}$ | $\begin{array}{r} \mathrm{Amp} \\ (\mathrm{mag}) \\ \hline \end{array}$ | $\begin{array}{r} g-r \\ (\mathrm{mag}) \\ \hline \end{array}$ | $\begin{array}{r} u-g \\ (\mathrm{mag}) \\ \hline \end{array}$ | $\begin{array}{r} r-i \\ (\mathrm{mag}) \\ \hline \end{array}$ | $\begin{aligned} & \hline r-H \alpha \\ & (\mathrm{mag}) \\ & \hline \end{aligned}$ | $\begin{gathered} P_{k} \\ (\%) \\ \hline \end{gathered}$ | $\begin{aligned} & \hline P_{M} \\ & (\%) \\ & \hline \end{aligned}$ | $P_{U 4}$ | $\begin{array}{r} \mathrm{d} \\ (\mathrm{pc}) \\ \hline \end{array}$ | $(B P-R P)_{o}$ | $M G_{o}$ | $\begin{aligned} & \text { Mem } \\ & \text { Dist? } \end{aligned}$ | Mem Mem? | Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Antalova 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J173014.7-321035.4 | 99.5 | -2.6 | 18.0 | 0.031 | 1.65 | 1.36 | 1.09 | 0.39 | 9.8 |  |  | 1920 | 1.62 | 3.9 |  | N | $\delta$ Sct? |
| ESO 430-14 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J080309.0-312707.3 | 63.4 | -3.5 | 16.5 | 0.030 | 0.54 | 0.4 | 0.36 | 0.17 | 83.8 |  |  | 4270 | 0.02 | 1.8 | N | N | $\delta$ Sct? |
| OW J080343.1-312637.1 | 83.2 | -2.9 | 19.7 | 0.191 | 0.97 | 0.86 | 0.49 | 0.43 |  |  |  | 7580 | 0.82 | 2.8 | N | N | $\delta$ Sct? |
| OW J080338.5-312937.3 | 91.0 | -3.4 | 19.6 | 0.341 | 0.68 | 0.16 | 0.45 | 0.17 |  |  |  | 8980 | -0.02 | 2.8 | N | N | $\delta$ Sct? |
| OW J080340.2-312002.7 | 91.7 | -3.1 | 19.8 | 0.239 | 1.11 | 0.64 | 0.56 |  |  |  |  | 4960 | 0.63 | 4.2 | N | N | $\delta$ Sct? |
| OW J080335.9-312941.0 | 97.8 | -5.0 | 18.1 | 0.166 | 0.57 | 0.17 | 0.4 | 0.23 |  |  |  | 6960 | -0.06 | 1.9 | N | N | $\delta$ Sct? |
| OW J080349.1-313005.8 | 103.9 | -3.5 | 18.6 | 0.072 | 1.64 | 1.56 | 1.15 | 0.61 | 86.3 |  |  | 1000 | 2.02 | 6.4 | N | N |  |
| OW J080404.2-312130.6 | 110.7 | -3.5 | 21.3 | 0.689 | 1.01 |  | 0.59 | 0.43 |  |  |  | 9070 | 0.28 | 3.9 | N | N | W UMa? |
| OW J080342.0-312157.6 | 112.9 | -2.9 | 18.1 | 0.039 | 0.89 | 0.21 | 0.51 | 0.28 | 0.0 |  |  | 3170 | 0.46 | 3.8 |  | N | $\delta$ Sct? |
| OW J080345.4-312313.3 | 114.0 | -4.0 | 19.7 | 0.195 | 0.92 | 0.29 | 0.5 | 0.3 |  |  |  | 4980 | 0.49 | 4.2 | Prob N | Prob N | $\delta$ Sct? |
| OW J080402.5-312116.7 | 124.9 | -5.1 | 15.9 | 0.051 | 0.64 | 0.23 | 0.4 | 0.18 | 75.6 |  |  | 3220 | 0.20 | 1.8 |  | Prob N | $\delta$ Sct? |
| OW J080341.5-312617.2 | 127.6 | -4.7 | 20.2 | 0.469 | 1.17 |  | 0.53 |  |  |  |  | 5010 | 0.65 | 4.6 | N | N |  |
| OW J080357.1-312743.7 | 129.0 | -5.2 | 15.2 | 0.021 | 1.02 | 0.74 | 0.54 | 0.42 | 79.0 |  |  | 1120 | 0.88 | 4.1 | N | N | W UMa? |
| OW J080337.9-312248.7 | 130.4 | -3.8 | 17.2 | 0.031 | 0.72 | 0.14 | 0.44 | 0.25 | 47.3 |  |  | 3030 | 0.32 | 3.3 |  | N | $\delta$ Sct? |
| OW J080400.3-312627.4 | 131.9 | -4.1 | 19.7 | 0.220 | 1.61 |  | 0.79 | 0.47 |  |  |  | 1820 | 1.30 | 6.4 |  |  | W UMa? |
| OW J080357.2-312112.3 | 131.9 | -4.8 | 16.5 | 0.017 | 0.62 | 0.24 | 0.39 | 0.18 |  |  |  | 3050 | 0.24 | 2.5 |  |  | W UMa? |
| FSR 1342 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J075730.0-312747.8 | 92.3 | -3.3 | 20.5 | 0.381 | 1.36 |  | 0.86 | 0.38 |  | 20.0 |  | 4490 | 0.93 | 4.7 |  | N | $\delta$ Sct? |
| OW J075735.0-312802.1 | 128.1 | -4.5 | 16.6 | 0.033 |  | 0.87 | 0.67 | 0.35 | 86.6 | 40.0 |  | 3530 | 0.87 | 1.6 |  | Prob N | $\delta$ Sct? |
| Riddle 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J073645.9-244022.0 | 114.2 | -2.7 | 21.1 | 0.446 | 1.89 |  | 0.83 | 0.4 |  |  |  | 2260 | 1.32 | 6.4 |  |  | W UMa? |
| OW J073646.1-244016.9 | 119.2 | -4.5 | 20.0 | 0.297 | 1.61 | 0.18 | 1.64 | 0.97 | 0.0 |  |  | 270 | 2.52 | 10.5 | N | N | W UMa? |
| ESO 430-18 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OW J080759.0-303833.3 | 42.8 | -2.6 | 19.0 | 0.112 |  |  |  |  |  |  |  | 4540 | 0.99 | 4.2 | N | N |  |
| OW J080603.7-305050.5 | 43.7 | -2.7 | 17.5 | 0.016 | 0.64 | 0.32 | 0.44 | 0.23 |  |  |  | 4480 | 0.53 | 3.1 | N | N | A $8 \delta$ Sct |
| OW J080603.5-305142.5 | 44.6 | -4.0 | 16.7 | 0.022 | 0.46 | 0.25 | 0.35 | 0.2 | 13.1 |  |  | 4410 | 0.33 | 2.5 | N | N | A $4 \delta$ Sct |
| OW J080554.1-305750.0 | 52.1 | -4.2 | 17.1 | 0.024 | 0.56 | 0.43 | 0.36 | 0.17 | 0.0 |  |  | 4810 | 0.48 | 2.6 | N | N | $\mathrm{A} 6 \delta \mathrm{Sct}$ |
| OW J080610.3-304739.1 | 54.6 | -3.0 | 20.7 | 0.756 | 1.23 |  | 0.77 | 0.4 |  |  |  | 4570 | 1.22 | 5.8 | N | N | W UMa? |
| OW J080557.6-310024.3 | 56.2 | -3.4 | 20.6 | 0.544 | 1.53 |  | 0.73 | 0.41 |  |  |  | 2250 | 1.67 | 7.1 | N | N | W UMa? |
| OW J080635.2-305741.5 | 57.2 | -3.4 | 14.1 | 0.041 | 0.51 | 0.06 | 0.41 |  | 0.0 |  |  | 1800 | 0.40 | 2.0 | N | N | A0 $\delta$ Sct |
| OW J080658.9-305759.3 | 60.0 | -2.6 | 17.4 | 0.017 |  |  |  |  | 42.2 |  |  | 4860 | 0.48 | 2.7 | N | N |  |
| OW J080739.7-310319.7 | 60.9 | -2.8 | 17.3 | 0.020 |  |  |  |  |  |  |  | 6630 | 0.33 | 2.0 | N | N |  |
| OW J080715.2-304346.3 | 60.9 | -4.9 | 14.5 | 0.014 |  |  |  |  | 65.8 |  |  | 1940 | 0.42 | 2.4 | N | N |  |
| OW J080713.4-305003.7 | 61.2 | -2.6 | 17.1 | 0.016 |  |  |  |  | 20.1 |  |  | 3680 | 0.64 | 3.3 | N | N |  |
| OW J080703.8-303504.5 | 63.8 | -3.3 | 17.6 | 0.024 |  |  |  |  |  |  |  | 4950 | 0.47 | 2.9 | N | N | $\delta$ Sct? |
| OW J080639.9-310006.5 | 63.8 | -3.7 | 16.3 | 0.012 | 0.67 | 0.3 | 0.39 | 0.21 | 18.3 |  |  | 2770 | 0.56 | 3.1 | N | N |  |
| OW J080607.0-304226.5 | 64.5 | -3.1 | 20.7 | 2.719 | 1.28 |  |  |  |  |  |  | 3050 | 1.42 | 6.5 | N | N |  |
| OW J080701.7-310233.0 | 65.9 | -2.7 | 19.4 | 0.088 |  |  |  |  |  |  |  | 2980 | 1.14 | 5.5 | N | N |  |
| OW J080555.5-305724.0 | 66.2 | -3.0 | 19.7 | 0.114 | 0.84 | 0.31 | 0.52 | 0.36 |  |  |  | 6940 | 0.66 | 3.7 | N | N | G? |
| OW J080633.7-310345.1 | 68.9 | -3.5 | 20.4 | 0.306 | 1.55 |  | 0.79 | 0.44 |  |  |  | 2360 | 1.40 | 6.6 | N | N | W UMa? |
| OW J080735.2-303856.2 | 72.1 | -2.9 | 15.0 | 0.013 |  |  |  |  | 34.8 |  |  | 2840 | 0.71 | 1.9 | N | N |  |
| OW J080810.3-305419.3 | 81.8 | -3.0 | 16.7 | 0.016 |  |  |  |  |  |  |  | 4520 | 0.32 | 2.6 | N | N |  |
| OW J080611.6-305342.1 | 106.9 | -2.9 | 16.5 | 0.020 | 0.71 | 0.32 | 0.46 | 0.29 | 3.0 |  |  | 3210 | 0.68 | 3.0 | N | N | $\delta$ Sct? |
| OW J080635.7-305800.3 | 112.8 | -4.6 | 20.2 | 0.410 | 1.64 |  |  |  |  |  |  | 1580 | 1.56 | 7.2 | N | N |  |
| OW J080724.4-304202.6 | 123.1 | -3.9 | 21.0 | 1.549 |  |  |  |  |  |  |  | 1550 | 1.84 | 8.1 | N | N |  |
| OW J080643.6-310656.2 | 124.4 | -4.1 | 20.1 | 0.360 | 1.02 | 0.33 | 0.64 | 0.28 |  |  |  | 6750 | 0.85 | 4.5 | N | N | W UMa? |
| OW J080608.8-305836.1 | 125.6 | -3.9 | 20.7 | 0.506 |  |  | 0.72 |  |  |  |  | 6300 | 0.95 | 4.9 | N | N |  |
| OW J080717.0-305430.2 | 125.6 | -4.8 | 19.2 | 0.250 |  |  |  |  |  |  |  | 3750 | 0.96 | 4.8 | N | N | W UMa? |
| OW J080649.3-310443.9 | 125.6 | -3.8 | 16.8 | 0.020 | 1.07 | 0.36 | 0.61 | 0.36 | 55.6 |  |  | 5090 | 0.42 | 2.5 | N | N |  |
| OW J080605.1-305631.4 | 126.4 | -3.9 | 14.9 | 0.017 |  | 0.03 |  |  | 26.2 |  |  | 920 | 0.75 | 4.2 |  | N |  |
| OW J080815.2-305635.7 | 128.3 | -3.7 | 14.8 | 0.012 |  |  |  |  | 85.7 |  |  | 3280 | 0.21 | 1.9 | N | N |  |
| OW J080701.4-305427.6 | 129.6 | -4.1 | 15.8 | 0.017 |  |  |  |  | 44.2 |  | Y | 3350 | 0.35 | 2.4 | N | N |  |
| OW J080717.4-305414.2 | 129.6 | -3.6 | 15.9 | 0.012 |  |  |  |  | 2.0 |  |  | 4190 | 0.43 | 2.0 | N | N |  |
| OW J080700.5-305426.7 | 131.0 | -3.9 | 16.0 | 0.015 |  |  |  |  | 47.7 |  |  | 2030 | 0.72 | 3.7 | N | N | $\delta$ Sct? |
| OW J080606.3-305423.9 | 131.0 | -3.9 | 15.7 | 0.017 | 0.67 | -0.01 | 0.43 | 0.3 | 62.1 |  | Y | 3480 | 0.33 | 2.2 | N | N |  |
| Ruprecht 51 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |


| ID | $\begin{array}{r} P_{L S} \\ (\min ) \end{array}$ | FAP | $\begin{array}{r} \hline \mathrm{OWg} \\ (\mathrm{mag}) \end{array}$ | $\begin{array}{r} \text { Amp } \\ (\mathrm{mag}) \end{array}$ | $\begin{gathered} g-r \\ (\mathrm{mag}) \end{gathered}$ | $\begin{gathered} u-g \\ (\mathrm{mag}) \end{gathered}$ | $\begin{array}{r} r-i \\ (\mathrm{mag}) \end{array}$ | $\begin{aligned} & \begin{array}{l} r-H \alpha \\ (\mathrm{mag}) \end{array} \end{aligned}$ | $\begin{gathered} P_{k} \\ (\%) \end{gathered}$ | $\begin{aligned} & \hline P_{M} \\ & (\%) \end{aligned}$ | $P_{U 4}$ | $\begin{array}{r} \mathrm{d} \\ (\mathrm{pc}) \end{array}$ | $(B P-R P)_{o}$ | $M_{\text {O }}$ | $\begin{aligned} & \text { Mem } \\ & \text { Dist? } \end{aligned}$ | Mem Mem? | Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| OW J080337.0-303735.8 | 40.9 | -3.3 | 17.4 | 0.017 | 0.68 | 0.24 | 0.42 | 0.27 |  |  |  | 5420 | 0.56 | 2.6 | N | N |  |
| OW J080331.2-303442.0 | 55.4 | -3.1 | 17.5 | 0.034 | 0.88 | 0.4 | 0.48 | 0.27 | 1.5 |  |  | 3320 | 0.82 | 3.8 |  | N | $\delta$ Sct? |
| OW J080344.5-303536.5 | 74.8 | -3.2 | 14.4 | 0.013 |  |  | 0.28 |  | 62.8 |  |  | 2290 | 0.42 | 2.0 |  | N |  |

APPENDIX B: THE LIGHT CURVES OF VARIABLE STARS
APPENDIX C: IDENTIFICATION OF STELLAR TYPES USING THE JHC LIBRARY OF SPECTRA


Figure B1. The light curves of variable stars found in the angular areas of open clusters observed during the ESO Semesters 88 and 91. The stars are sorted according to their increasing periods, following the Table A1. The cluster name and the survey ID are given in the title of each light curve


Figure B2. As Fig. B1 for open clusters observed during ESO semester 93


Figure B3. As Fig. B1 for open clusters observed during ESO semester 94.


Figure B4. As Fig. B1 for open clusters observed during ESO semester 94 (cont).


Figure B5. As Fig. B1 for open clusters observed during ESO semester 94 (cont).


Figure C1. A set of spectra for variable stars observed in the angular area of 20 open clusters that overlap OmegaWhite fields. In the top image, we compare the spectrum of one OmegaWhite star (i.e. shown in black) with typical spectra of A and F stars (in blue) from the JHC atlas (Jacoby et al. 1984) - as an example. Thus, we conclude that our source is an early A star. The bottom figure shows that ten of our stars are common A type stars. The membership probability for each star is given in Table 3. See text for details.


Figure C2. Examples of spectra of variable stars observed in the angular area of 20 open clusters that overlap OmegaWhite fields. Two spectra of reddened A and A/F stars that look rather unusual are displayed. See text for details.


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