Chapter 5

Summary, conclusions and future prospects

5.1 Introduction

By reviewing the main motivation for this study, it can be noted that a number of important goals were added to the initial motivation for the study. The initial motivation was to search for pulsating B-type variable stars in NGC 6204 and Hogg 22.

A sizeable data set firstly called for the automation of the data reduction process, photometry and periodic analysis, which were included in a reduction and photometry pipeline. Unguided observations and field rotations, due to the obliged removal of the CCD camera during the observation run, caused for additional corrections to be made to the data set before analysing the data. These corrections had to be made by creating a computer code which could calculate the rotation and translational movement of each image and map all stars to a fixed numbering system for identification in multiple images.

This expansion of the study by referring firstly to the setup of the new telescope and secondly to the software development can be seen in a positive light due to the fact that additional experience was gained, not only in the search for variable sources but also in the practical observational aspects, data reduction and periodic analysis of the data. From this practical point of view alone, any new periodic source found by analysing the data will contribute to the overall success of this study, where the main motivation should also be kept in mind.

After a brief summary of the work done in this study, concluding remarks will be made on the success of creating and implementing the reduction and photometry pipeline for the specific data set together with a discussion on possible improvements.

5.2   Summary

5.2.1   Observations

The data used in this study were collected over a period of 13 nights, where observations were done using B, V and I filter bands. By observing without a guiding system, difficulties in stabilising the target field for long periods of time were experienced. However, this did not influence individual image frames because of integration times shorter than 90 seconds. A total of 2164 image frames were taken during the observing run, which motivated for automation of the data reduction and photometry processes. In order to detect both long and short term periodicity, the observational strategy for this study relied on continuous V band observations with occasional filter changes to B and I bands.

5.2.2   Data reduction and photometry

The basic data reduction was done by using IRAF as explained in Chapter 3, where the field corrections were done by software created for inclusion in the photometry pipeline. After completion of the photometry pipeline, it was found that a scaling effect was present in the data from three nights. This scaling effect, which was consistent throughout the three nights, could however not be explained by any physical change in the telescope setup. The software that calculates the rotation and translational corrections to the image frames was found to be very sensitive to the scaling effect because of the fact that pixel distances were used in order to cross-correlate stars in different images.

Another drawback was experienced due to incomplete image header information from the first three nights. At the start of the observations, some information fields were not set by default to be written to the header file of each image. This was, however, corrected as soon as it was realised and was effective from the fourth night onward. These two problems could however be corrected for, after observing, but due to time constraints in data analysis and availability of computing facilities it was decided to exclude the scaled and incomplete image header data.

In total seven nights were successfully reduced and analysed by using the photometry pipeline from which differential photometry was obtained for all stars in the field. The differential photometry was done by using the average instrumental magnitude, of five reference stars in the field, as level against which other stars were compared.

5.2.3 Periodic analysis

After the successful implementation of the photometry pipeline on the data set, a number of new periodic sources were detected and identified.

Periodic analysis is a key process in order to correctly identify periodic sources from the data. Due to the unevenly spaced data set, it was necessary to use a technique, that is not sensitive to data sampled at inconsistent time intervals, which can be used to identify periodic signals from the data set. The Lomb-Scargle transform, which satisfies this condition, was used to extract frequencies from the light curve data of each star.

The important aspect of determining the significance of the extracted signal was addressed by creating a control time series from pure noise. This control time series was generated by using random noise from a Gaussian distribution at the same times as which the observations were done. The reason for using this control time series is to define the noise level and to be able to assign significance to extracted periodic signals. A level was defined by which the event of finding a frequency, in the periodogram, which originate from noise is less than 0.01%. However, it turned out that a number of 1562 sources showed significant periodicities when using this confidence level, where some sources included in this group were used as constant reference stars in the differential photometry process. Due to this aforementioned reason and the expected number of significantly varying stars in this type of stellar population, the confidence level was raised even higher to a normalised spectral power value higher than 5, as explained in Chapter 4, which corresponded with a number of 354 potential periodic stars. It turned out that this chosen level has an insensibly high confidence level, which indicates that the spectral power values should just be used as a reference to determine a sensible periodicity cutoff level.

High amplitude periodic sources were identified according to their extracted frequencies and light curve profiles which are shown in Chapter 4. This led to the identification of two possible β Cephei stars and numerous eclipsing binary stars.

5.2.4 Calibration of magnitudes

B and V band instrumental magnitudes from this study were calibrated to the standard system by using calibrated B and V band magnitudes from Forbes & Short (1996). This allowed for the construction of a colour magnitude diagram on which stars from both clusters could be identified. Extinction and distance corrected isochrones for both clusters were included on the colour magnitude diagram, where the cluster ages, interstellar extinction, and distances were obtained from the WEBDA database. By applying these

isochrones to the colour magnitude diagram, the two clusters can clearly be distinguished at the top end of the main sequence.

Together with the stars from this study, a number of 104 stars from the study of Forbes & Short (1996), were also included on this diagram. From the positions of the stars on the diagram, 12 stars from the study of Forbes & Short (1996) which were indicated as cluster stars, were identified to be field stars that belong to neither one of the two clusters.

5.3 Conclusions and future prospects

Assessment of the overall output from this study can be done by evaluating the success of four different aspects of this study:

- Capabilities of the telescope and instrumentation used in this study.

- Development and implementation of a reduction and photometry pipeline in automating the data analysis process.

- Periodic analysis of all sources in the data set.

- Identification and classification of periodic sources from the data

5.3.1 Telescope and instrumentation

The telescope together with the instrumentation used to obtain the data for this study proved to be capable tools in doing good quality optical research. For this particular study the large field of view, of the telescope-camera combination, was of great advantage due to the fact that the two clusters, NGC 6204 and Hogg 22, could be observed simultaneously despite their 6 arc minute separation distance.

A clear drawback experienced throughout this study was the unguided observations. However, currently a guiding system is installed, which eases the observational process considerably.

The unsolved problem of the scaling effect observed in the data, obtained from three specific nights, needs to be investigated thoroughly in order to eliminate it from future observing data.

5.3.2 Reduction and photometry pipeline

A considerable amount of time went into the creation and implementation of the reduction and photometry pipeline, which proved to be very successful in the analysis of the large data set under study. The pipeline was implemented on data from ten observing nights, where problems were experienced with three of the nights which were due to the scaling problem mentioned in the previous section. Although the reduction software performed very well on the data set it will, however, be advantageous to adapt the reduction computer code in such a way that scaling can be accommodated if experienced in a given data set.

The pipeline made use of the concept of a master list which contains all the sources in the field arranged according to magnitude. This technique proved to be very effective in creating a consistent numbering system for all sources in the field of study.

Differential photometry was done on all stars where the choice of the reference stars, used as constant stars, was found to be very important in obtaining good photometry accuracy. Therefore, careful inspection of the light curves needed to be done in order to choose the most constant stars to be used as reference stars.

5.3.3 Periodic analysis

Periodic analysis of any data set relies on a trustworthy definition of the noise level in the computed periodogram. The use of Gaussian noise to construct a distribution of the test statistic under the null hypothesis demonstrated to be ineffective in producing a reliable noise level for measuring significance of extracted frequencies against. This noise level was used in assigning significance to the highest power frequencies, from a periodogram, above a certain spectral power level. Although the integrity of the extracted frequencies and the relative spectral power between different frequencies were not compromised, the significance value assigned to each meaningful frequency was insensibly high. Therefore, in order to quantify the range of extracted meaningful frequencies, the normalised spectral power was used, as defined in Chapter 4, to give an indication of significance.

Daily alias frequencies were encountered in the periodograms, where the identification of alias frequencies in periodograms is very important in order to obtain the correct frequency for a specific source. The technique to identify these alias frequencies, that was used in this study, was applied with mixed success, which can be ascribed to the deviation from sinusoidal periodicity of periodic sources. This highlights the importance

of inspection of the periodogram together with the light curves of each source in order to identify the correct frequencies.

5.3.4 Identification and classification of periodic sources

In this study, the identification and classification of periodic sources were done with helpful insight from Prof Andrzej Pigulski together with resources from the AAVSO website. The highest amplitude periodic sources were identified from their light curve profile together with the most prominent extracted frequency. In the case of the two possible β Cephei stars, comparison to photometric results from Forbes & Short (1996), showed that the two candidates were of spectral type B where they were indicated on a two colour diagram from Forbes & Short (1996).

It can be concluded, in doing a general evaluation, that the different aspects, mentioned above, played a vital role in the main motivation for this study. Failure in any one of these supporting parts, would have resulted in an unsuccessful quest to search for pulsating stars in the open clusters under study. The importance of instrumentation, data analysis and interpretation of the data is evident from this study where the final output relied on all of these aforementioned research properties.