Imaging dense globular clusters like M3 and M15

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Abstract

The objective for this study will be to explore new photometric methods for amateur telescope observations of 'cluster variables' and globular clusters using CCD photometry. Amateur telescope photometric observations of 'cluster variables' in globular clusters are limited because of dense, crowded star fields. However, with improvements in CCD photometric methods, there are opportunities to observe cluster variables, such as RR Lyrae and SX Phoenicis type stars, through time series analysis of multiple exposures of whole cluster images.

Traditional methods for determining light curves in 'field' RR Lyrae and SX Phoenicis type stars require selection of comparison and perhaps check stars to perform differential photometry; i.e. subtraction of flux density measures between a non-variable (comparison star) and the variable star as they change in magnitudes over time. We explore the possibility of measuring the variable star's periodicity in areas, or sections of a globular cluster, to sort different stellar type 'cluster variables' within each section of the cluster. There are areas or regions of a globular cluster which 'pulsate' at a variable rate which is representative of 'cluster variables' that make up that region. For example: we have detected different variability periods within the 'core' of a cluster compared to the outer circumference areas of the cluster. .

Introduction:

Amateur astronomers can not always discriminate individual star luminosities within the dense star fields of globular clusters like M3 or M15. In this paper we'd like to propose methods and techniques for the analysis of aggregating different cluster region's flux densities (luminosity). Then by comparing the regional average flux densities we can estimate the luminosity differences between core and outer regions of the globular clusters.

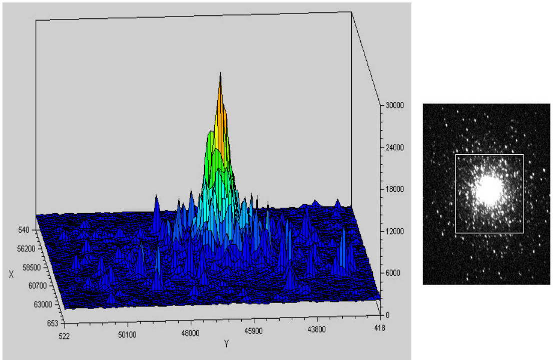

Illustration 1: Creating a flux density map of the Globular Cluster M 15.

We use a Visual Basic interface to Maxim DL software libraries to extract the statistics of the flux densities of the core areas and the outer regions of the Globular Clusters. Then using time series analysis of the different regions surrounding the clusters, we determine the aggregate periodicity within those regions. At this time, selection of the core area is based on visual inspection, see *Illustration 1*.

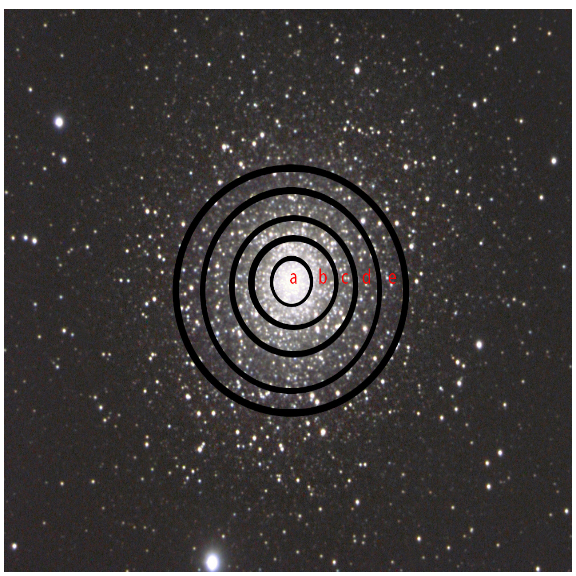

Illustration 2: Selecting different regions for analysis.

In a comparison of 4 globular clusters Pritzl, Barton and Smith A. Horace (2000) discuss the individual photometry methods for determining RR Lyrae stars and their metalicity using period luminosity ratios. Corwin and Carney (2001) also discuss the metallicity ratios of the RR Lyrae stars of M3 and determine that the period luminosity of the 'core' is on average less than period luminosity of the stars in the outer regions of the cluster. However, they do this by discriminating almost every RR Lyrae light curve within the cluster. Amateur telescopes (under 40 cm apertures) will have a difficult time doing this in these distant dense star fields.

Sandage (2006) utilizes color transformations of many observations using the *B – V* colors to calibrate the metallicity and temperature of the RR Lyrae stars when determining their metalicity ratios.

Instrumentation & Data:

For the M15 observations there were 3 different instruments from 3 observatories. "Galileo Observatory" and Stouraitis Dimitrios used an 80mm Semi-Apo refractor with SXV-H9 camera at prime focus at a Paramount Equatorial and a C-14 as a guide scope with a DMK 21AU04AS camera. At the "Elizabeth Observatory" we used an 80mm Semi-Apo refractor also, but with ATIK-IC mono camera (both cameras SXV-H9 & ATIK-IC are cooled at -20c from the environment temperature). All data have been corrected by Dark – Flat & Bias frames obtained before, in the middle and after the end of every observation. In all cases there has also been a record of all the atmospheric data (wind, temperature, humidity etc.)

The Bareket Observatory used a ST8XE CCD camera, C14 OTA (working at f/8.7 with special custom corrector-reducer lenses), Paramount ME external guided; as the remote Internet based system (ACP) to image the M3 globular cluster. The observatory also has temperature sensor auto-focus capabilities, cloud sensor, observatory fish eye camera etc. This is so students are able to observe the system during use. There are a variety of filters at the CFW: LRGB, BV (Schuller photometric), HA, SII, OIII and spectra grating for spectroscopy measurements. All filters are research grade.

Methods:

Our images of M3 from Ido Bareket and M15 from Iakovos Strikis were taken with a luminescence and clear filter, respectively. At this time we do not use color differences to determine the periods of RR Lyrae stars within these clusters. However, it still may be possible to estimate different periods of the RR Lyrae stars should they be 'synchronized' in some fashion for different regions of the clusters.

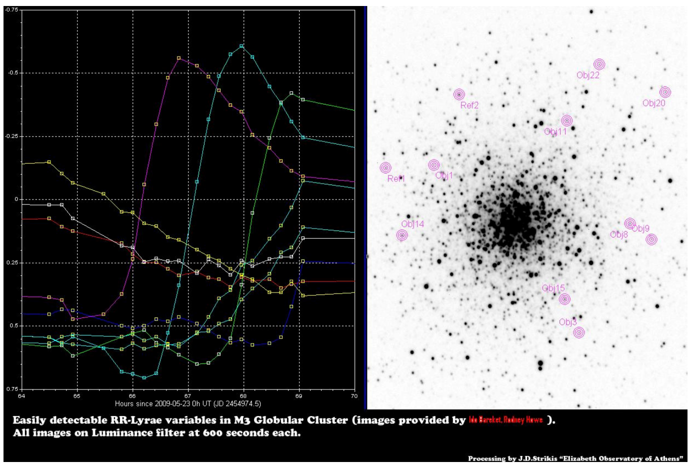

Illustration 3: A look at the phase similarities of 20 randomly selected RR Lyrae variables in the outer regions of M3. This was done using 32 images over 3 consecutive nights.

The only individual stellar differential photometry that we could do on the M3 RR Lyrae stars was in the outer region of the cluster. See *Illustration 3*.

Once it was determined there might be some phase relationship in these outer region RR Lyrae stars, the question was what phenomena might be responsible, and could we use aggregate average flux density differences between the inner core regions and the outer RR Lyrae stars to understand the apparent synchronized periods.

A Visual Basic program that interfaced the Maxim DL libraries was developed to calculate the area average and standard deviations and minimum, maximum flux densities given coordinate picks within each stacked image exposure (see reference section).

Table 1: Shows an example of each image in the series, which has the following data elements.

Julian Date and Time	**2454997.29229167**
Average Flux Density of selected area	**9496.799**
Pixels selected	**X0, Y0, X1, Y1**
Image Name	**M3-N1-C001-Luminance(1)**

A table of values for each area average and standard deviation of flux densities are created with the Visual Basic program and the output is analyzed with a set of R statistical routines designed to cross correlate the time series of the selected areas (Riggs (2008). For Example: stacked time series comparisons of inner core, core, outer region of the cluster, and the entire image are calculated showing both positive and negative periods correlations.

Using the R statistical package's Auto-Regressive Integrated Moving Average (ARIMA) library we look at the average flux density for each image to get a rough estimate of the selected area's periodicity. (Riggs, 2008) Then we do pair wise comparisons of these periods by cross correlations and Loess smoothing (*Illustration 4 and 6*). Which show how the core area may have less variability than the outer regions of the M3 globular cluster, and a negative slope for M15?

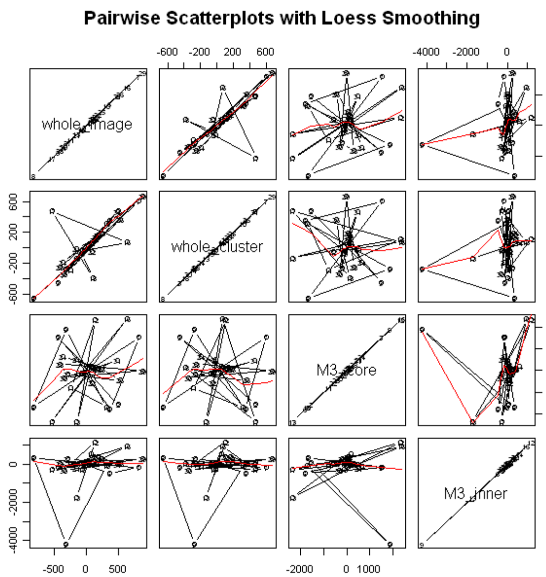

Illustration 4: Pair wise comparisons of average flux densities between the image, outer region, core and inner core. For M3 the inner core shows less periodicity than the outer regions of the cluster.

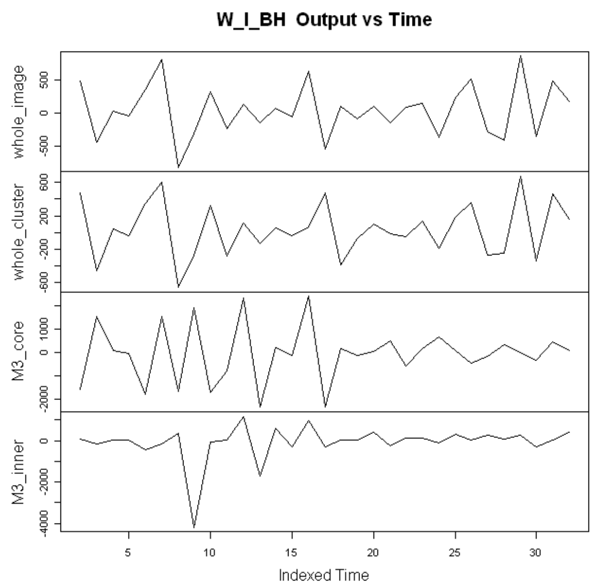

Illustration 5: Shows each of the selected areas of M3 for 3 nights of 32, 8 minute exposures and their 'period variability' of the stacked images. Note how the M3_core and M3_inner core areas show considerable differences in periods between themselves and the whole cluster, (which includes the 20 random RR Lyrae stars in Illustration 3).

Results:

What we've noticed for both M3 and M15 globular clusters is that the core region has very different period fluctuations than any other part of the globular cluster. Given this paper's limitations of looking at only two dense clusters it is not reasonable hypothesize why this should be so. However, we do note that there may be longer (over days) periodicity within the inner core regions, perhaps not related to RR Lyrae periodicities.

There is a very good possibility we are seeing systematic issues with these data. However, these data are taken by different observatories; M3; Bareket Observatory, Israel, and M15; Elizabeth Observatory of Athens, Greece, at different times and under different conditions. Yet both sets of data show a distinct 'damping' of the variability in the core, and a different period within the core region when compared with the outer regions of the cluster.

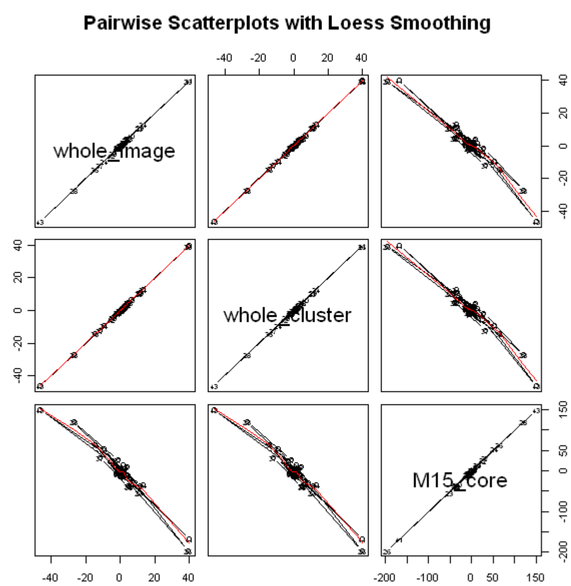

Illustration 6: The variability in the M15 pair wise comparisons is much less than in M3 (Illustration 4). The average flux density change shown here are for 46 images of M15 core.

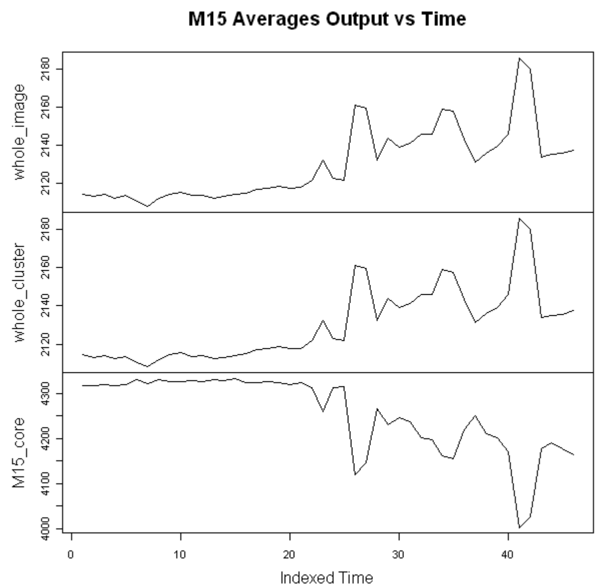

Illustration 7: The variability for all average flux densities increase over time, which is probably due to atmospheric effects over the observation period. However, that does not address the question of why the core flux densities should be decreasing while the rest of the cluster shows an increase in average flux density over the same set of stacked images.

Discussion:

Where Cross –Correlation analysis of these images may show temperature or mass-luminosity differences between aggregated dense stars in the core vs. less dense stellar interactions in the outer regions is a hypothesis to be tested with future work. There is also the question of whether the outer RR Lyrae stars are some how 'phase locked' with similar periodicities when compared to the different periods of core region stars. We'll only be able to test these hypotheses by analyzing more data of more globular cluster observations, and with different photometric color filters.

References

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M3 data courtesy of Ido Bareket, http://www.bareket-astro.com/movies/m3_variable_stars.html

M15 data courtesy of Iakovos Strikis, http://elizabethobservatory.webs.com/09contact.htm

Maxim DL software libraries: http://www.cyanogen.com/maximdl_dl.php

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ERROR: ioerror
OFFENDING COMMAND: readstring

STACK:

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