

# Long Period Variable Stars in Globular Cluster M5

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## Background

Long period variable stars (LPVs) are stars that vary in size and brightness over periods of greater than 10 days. They have numerous implications on stellar structure and evolution and provide important constraints on theoretical stellar evolution models. Globular clusters are particularly valuable because they allow for multiple variables to be controlled – such as composition, age, and distance of the stars inside the cluster. With this knowledge, any variation from one LPV to another is representative of only the difference in the stars' evolutionary stage. Previous research done on LPVs has been mostly achieved with photographic plates – causing the overcrowded cluster centers to be underrepresented. Recent improvements in charged-coupled device (CCD) detectors and digital photometric methods necessitate a more complete survey of LPVs in globular clusters.

## Calibration

The LPV data were calibrated from instrumental to standard magnitudes using the Stetson (2000) list of standard magnitudes of non-variable comparison stars in the cluster. To do this, we used the instrumental magnitude ( $\gamma$ ) of the variable, 6-9 well-chosen comparison stars, and the slope ( $m$ ) value from the linear fit of the CURFIT plot (see Figure #1) of  $\gamma_{us} - V_s$  vs  $(V - I)_s$  (subscript 'us' is data we obtained, while 's' is Stetson standard data). An intercept value ( $b$ ) is also obtained but later subtracts away. Using this information and the set of equations to the right, we can find  $(V - I)_v$  values and subsequently  $V_v$  and  $I_v$  values – the standard magnitudes of our variables (the median standard magnitude from the 6-9 comparison stars is ultimately used). The comparison stars were chosen based on their magnitude, proximity to the candidates, crowding (or lack thereof), and color (mostly red with some blue options for the Cepheids).

$$\begin{aligned} \gamma_v - V_v &= m(V - I)_v + b && \text{Subscript v = variable star's value} \\ \gamma_c - V_c &= m(V - I)_c + b && \text{Subscript c = comparison star's value} \end{aligned}$$

Subtracting from each other yields

$$(\gamma_v - \gamma_c) - (V_v - V_c) = m[(V - I)_v - (V - I)_c]$$

Solving for  $V_v$

$$V_v = (\gamma_v - \gamma_c) + V_c - m[(V - I)_v - (V - I)_c]$$

Doing likewise for  $I$  gives

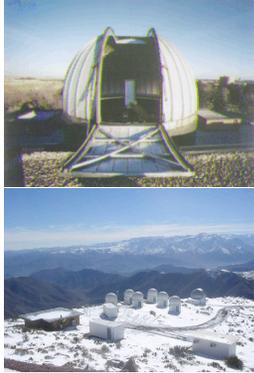
$$I_v = (\gamma_v - \gamma_c) + I_c - m[(V - I)_v - (V - I)_c]$$

Subtracting  $V_v - I_v$  for  $(V - I)_v$

$$(V - I)_v = [(\gamma_v - \gamma_c) - (I_c - I_v) + (V_c - I_c) - (m - m')(V - I)_c] / (1 + m - m')$$

## Data Collection

Data collection began in BG in 2007 and continued in 2009 and 2010. BGSU's 0.5 meter telescope and CCD camera were used to obtain different length exposures in the V-band (green) and I-band (near IR). Along with these data, the 0.4 meter PROMPT remote telescope array at Cerro Tololo Inter-American Observatory near La Serena, Chile was used in 2011 to obtain similarly exposed images. These images were easily requested and retrieved online through the SKYNET client.



## Image Processing

- Trim:** undesirable edges are trimmed off.
  - Zero:** bias images are taken at beginning of night – images with no exposure, just base level readout.
  - Dark:** thermal agitation creates a dark current – a readout not created from star photons.
  - Flats:** also taken at beginning of night – images of the inside of the dome in both V and I to show dust rings, variations in sensitivity and in electronics, and partial shadowing of the camera's light path called vignetting.
  - Illuminate:** sky flats are taken similar to dome flats and are used to correct for dome's curved shape on the dome flats.
- During the course of processing, the Zero and Dark images are subtracted from the cluster images, the Dome flats are divided from the cluster images, and the Illumination correction image is multiplied by to create the fully processed cluster image ready for photometry.

## Variable Star Detection

We used the program DAOPHOT to find likely LPV candidates. DAOPHOT is able to locate all the stars on each image and compare each one individually to its counterpart on the other images. From this, DAOPHOT calculates each star's variability index ( $\Lambda$ ) – all stars will have some base level variability due to image quality fluctuations between images. Stars with unusually large  $\Lambda$  are flagged as LPV candidates for further investigation. From here we can make instrumental light curves to provide confirmation of variability and characterize the nature of the variability. We found 31 LPV candidates with this method.

### References

Bailey, S.I. 1917, AHCO 78, 132  
 Smith, H. A., et al. 2010, AJ 139, 2302  
 Stetson, P.B. 2000, PASP 112, 925

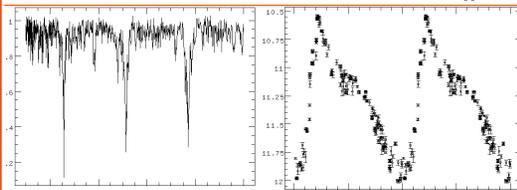
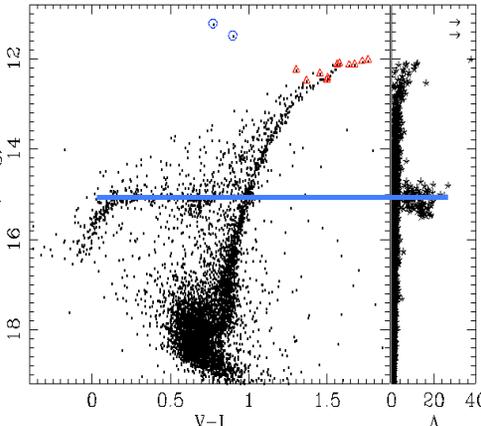
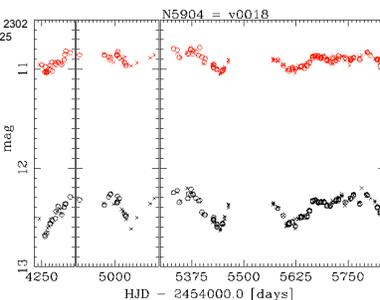
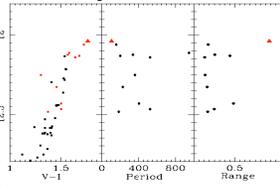
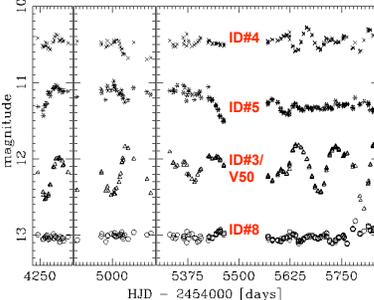


Figure #4

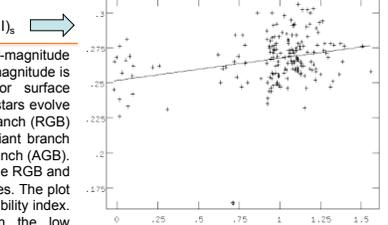


The plot to the left is a sample light curve of ID#18 broken into 2007, 2009, 2010 BG data, then a seasonal gap when the cluster was not visible before the 2011 PROMPT data. The red points are infrared data while the black are visible. Notice the curves are similar in shape, but have different amplitudes.



To the left are several example V-band light curves for four of the LPVs. In truth, these four stars have very similar magnitudes around 12.3, but were shifted to fit all four on one plot.

To the right is an image of NGC 5904, or M5 – a globular cluster 24,500ly from the Sun – taken with BGSU's 0.5m telescope and CCD. All 31 LPV candidates are circled and marked with their ID. These candidates were a product of DAOPHOT and were chosen based on their brightness and large variability indexes – this list was ultimately narrowed down even further once light curves were made and it became clear some were not LPVs.



## Conclusions

- Variability in M5 has been studied in the past – LPV V50 (our ID#3) was detected by S.I. Bailey in 1917, over 100 RR Lyrae stars have been well studied by larger telescopes (which we detected but did not analyze), and the two Cepheids we detected have also been well studied.
- Out of the 31 variable candidate stars, we found 10 new LPVs along with the two Cepheids and V50. To find a given star's period, phase dispersion minimization (PDM) was used to locate best possible period that fit to the data. Figure #2 shows the plot theta vs. period that PDM creates – a low theta value indicates a best fit period. We can then focus on this point and have the program create a plot of the data using that period. In Figure #3, the best period has been selected and the data 'folded' to create a light curve that displays two full cycles of the variability of one of the Cepheids as an example. Combining the periods and light curves we noticed the LPVs are irregular, with small scale variation along larger beats.
- Bailey found V50 using photographic plates and determined it had a period of 106 days. Our data and modern period finding technique found the same star to have a period of  $106 \pm 0.06$  days; Bailey's data with our period finding technique found a period of  $105.253 \pm 0.003$  days.
- Our data on the two Cepheids will also be analyzed by Dr. Smith at Michigan State University to further his analysis of these stars' slowly changing periods; his results will be included in the journal article resulting from our data. We found V42 to have a period of  $25.715 \pm 0.01$  days, while Smith found it to be  $25.735 \pm 0.015$  days. For V84, we found the period to be  $26.81 \pm 0.01$  days, Smith found it to be  $26.93 \pm 0.02$  days. One possible reason for the slight differences between our periods and Smith's are these stars' changing periods – Smith's data sets ended in 2006 and 2005, respectively, while our data sets ended in 2011. The shapes of our light curves are very similar to Smith's with ranges very close to his. The mean V magnitudes we obtained are  $V42 = 11.221$  and  $V84 = 11.489$ , both with error  $\pm 0.0035$ . Smith found the magnitudes to be 11.19 and 11.42, respectively, both with error  $\pm 0.03$ . Our mean magnitude for V42 falls within error of Smith's value, but we found V84 to be slightly fainter than Smith.
- Figure #4 shows three plots: first the tip of the giant branch on the CMD, next V magnitude vs. Period, then V magnitude vs. Range – LPVs are marked on the CMD and V50 is marked by a large triangle. By looking at the CMD and Figure #4, we see not all stars become variable during the giant phase. This indicates that factors other than evolutionary stage affect variability – such as age or composition. Both other plots do not indicate any obvious relation between magnitude and period or range.

