Analysis of Central Variable Stars in the Globular Cluster NGC 6205

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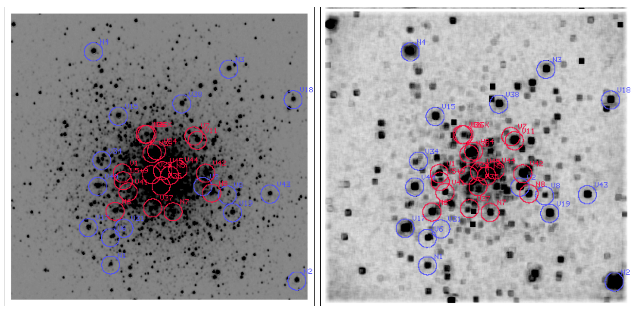
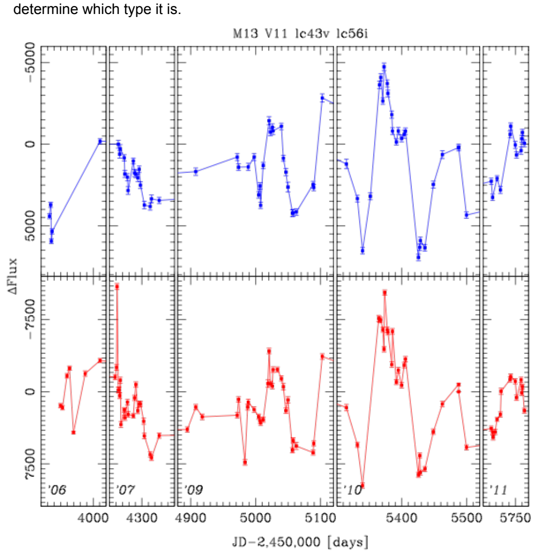


(Above) Circled in both images are all of the variable stars we detected with a high level of certainty in the cluster. The stars circled in red are the central stars that are analyzed in this poster (the outer stars are studied in another work). **(Left)** Pictured here is the *I*-band (near infrared) reference image of NGC 6205, which is the image used for the subtraction process, and shows the cluster more or less as seen through a telescope, but with brightness inverted. **(Right)** This image is the variable image, or the result of the subtraction process. A star's "brightness" in this image is not magnitude as pictured at left, but the amount of variability, or flux change, that the star has. Square "stars" in the subtracted image mask out image defects, while round "stars" correspond to variable objects; close visual inspection of each "star" can determine which type it is.



(Above) Pictured here is the known variable star V11, the brightest star in NGC 6205. The top plot shows how the star's flux through the V filter changes, and the bottom plot shows variations in flux through the *I* filter. V11 is an irregular long-period variable star (LPV) of relatively high △Flux, which is the amount of energy output by the star per unit area per second. This star is a pulsating red giant star, which means its pulsation is due to the instability of the gas in exterior layers. Though V11 varies irregularly, our rough estimate of this star's period is *P* = 101 days. Previous studies only had continuous data over the course of several months, similar to the first box of data points, which to short to estimate the star's period. Our large amount of data allows us to see the complex behavior of this star in much greater detail.

Abstract

Stars that vary in brightness over time are referred to as variable stars, and globular clusters provide a very good opportunity to study these stars due to their large star density, and consistent distance and composition. NGC 6205, or M13, has approximately 300,000 stars over a diameter of about 145 light-years, making it an ideal area to observe. Pulsating variable stars can have a very wide range of brightness and period, but most can be broken into two general classifications of having a regular period (Cepheids, RR Lyrae, etc.) or an irregular period (Mira, T Tauri, etc.) of variability. Our research presents new findings and classifications of the variable stars contained in NGC 6205 through our large collection of data taken over 5 years, a much longer study than has previously been done on this cluster.

Observations

From 2006 to 2011, observations were taken on over 100 nights by various students using the CCD camera on BGSU's 0.5m telescope. Images were taken in groups of 4 in the V-band (green) and 4 in the I-band (near-infrared) filters, using exposure times of 120 and 60 seconds, respectively. Multiple images allowed for more reliable data (see below), and the long span of these observations allowed for new insights in the behavior of these stars.

Processing

In the fall of 2013 and spring of 2014, image processing was done using ISIS (Image Subtraction Using Spatially Variable Kernel) imaging software, which looks at the difference in flux of individual stars (Alard, 2000). This program was used for stars near the center of the cluster, as it functions very well in crowded areas of high star density. This allowed for us to locate variable stars based of their change in brightness (flux) over time. Our data, spanning 5 years, was first cleaned of bad pixels by combining the four images from each night into one image, and therefore averaging out the random background noise (e.g., from light pollution) and removing occasional, randomly-arriving cosmic rays hitting the CCD camera and light pollution. These were removed so they would not give us false readings in our analysis later on. The images were then trimmed, rotated and moved to a common center so each image would overlay cleanly with the other images. After our images had been combined, we chose the best image in terms of clarity and resolution to compare against the other images. The next steps in ISIS subtracted each image from this reference image, giving us images where stars with no variability would have no signal, while stars whose brightness varied by large amounts would have a strong signal. This allowed us to get a precise reading of which stars were variable, and how large of a flux range each has. We catalogued these stars, comparing them to previously found stars and making note of newly-discovered ones as well. We then created plots of each star's flux differences in V and I over time, and for stars with regular variability, a flux vs. phase graphs as well. This allowed us to understand and draw conclusions about each star's classification, regularity and period.

Conclusion

We confirmed the existence of 1 BL Herculis star, 7 LPVs, and 6 RRL stars in the center of the cluster as well as additionally discovering 3 LPVs and 1 RRL star. We were able to confirm and update to higher precision the periods of all these stars and note additional behavior over longer time scales. Long term studies of globular clusters are very important for classifying and understanding the variable stars that they contain. They are important as variability exists from protostars to asymptotic branch red giants, all of which are needed to understand how stellar evolution functions. Some of the processes that drive irregular variables are still not fully understood, and long term data is very important for these stars as their periods can change over months or years. We believe our data has yielded many good conclusions that help us better understand the nature of many bright variables in this cluster and many people were instrumental in making this study a success.

References

Alard, C., 2000, Astron. & Astrophys., 144, 363

Kopacki, G., Kolaczkowski, W. and Pigulski, A., 2002, Astron. & Astrophys., 541

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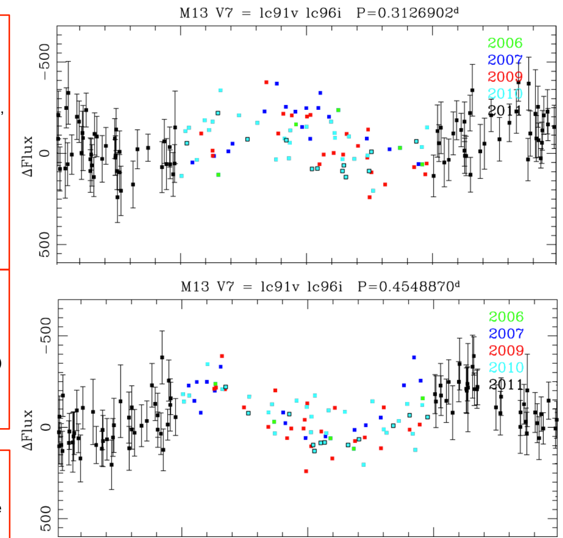
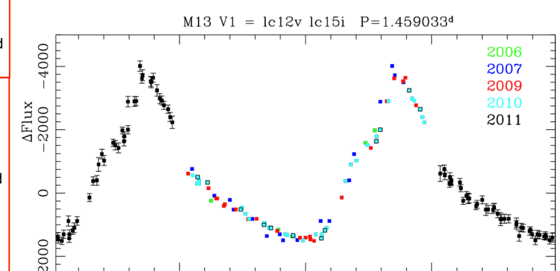


(Above) Many short period variable stars have a regular period, such as V7, the star pictured above, an RR Lyrae type variable star. RR Lyrae stars are red giant stars that have begun Helium fusion at their cores and have very short (<1 day) periods. Stars like this with regular periods can have their △Flux vs. Time graphs folded over themselves by their constant period to create △Flux vs. Phase (Φ) graphs, overlapping all of their data points onto one curve. The closer knit the curve of points, the better determined the period is, and with longer amounts of data, periods can be determined with greater accuracy. In our study, the RRL curves often have a large amount of scatter as their low △Flux leads to a low signal-to-noise ratio with the background star brightness. **(Top)** Here, our data is fitted with the old period, which was determined in 2002 (Kopacki et al). **(Bottom)** Using folding techniques in the ISIS system, we were able to determine a new period of *P* = 0.4548870 days, which better fit the data, giving us a tighter curve for this particular star.



(Above) Some stars have incredibly regular periods, such as V1, which is a BL Herculis star, a subset of type II Cepheid variables. These are old, metal poor stars about half the mass of the sun that are typically found in a galaxy's halo and globular clusters. These have short periods of only a few days due to their fluctuations between a larger, brighter state and a smaller, denser one. Our star had and incredibly close fit of *P* = 1.459033 days, confirming the originally discovered period with greater certainty (Kopacki et al, 2002). These stars are incredibly useful in determining distances between galaxies and our own galactic center due to their consistency in variability and brightness.