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SEARCHING FOR A VARIABILITY OF INTERSTELLAR REDDENING IN THE LINE OF SIGHT OF NGC 4833

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Abstract. The globular cluster NGC 4833 lies near the galactic plane. It is known to exhibit a strong differential reddening caused by several galactic interstellar clouds in its line of sight. Based on two optical observation runs made in 2006 within and separated by a 6-month interval, we intend to detect the photometric variations (colors and magnitudes) of stars in NGC 4833 due to the varying interstellar reddening.

Keywords: dust, extinction, globular cluster NGC 4833

1 Introduction

Light passing through clouds of atomic and/or molecular hydrogen is significantly obscured by the dust they contain. One of the main questions in the study of the Interstellar Medium (ISM) is the size of the smallest structure of these neutral clouds. This structure could be hierarchical or fractal, extending down to AU-sized clumps. Pfenniger et al. (1994) proposed that the baryonic dark matter associated with galaxies might consist of tiny cold gas clouds. They based this suggestion on galaxy dynamics and evolution, emphasizing the astrophysical appeal of dark matter in this form. Pfenniger & Combes (1994) further proposed that the fractal structure seen in CO at large scales might extend down to AU scales, and could be associated with the outer Milky Way disk, as seen in CO and HI. The extreme properties of these elementary cloudlets in the coldest cases (3K) would be: $10^9 cm^{-3}$; column density, $10^{24} cm^{-2}$; size, 30 AU; and mass, $10^{-3} M_{\odot}$. Since then, significant evidence has been accumulated for the existence of AU-sized structures in the cold ISM, or the existence of molecular gas not detected by CO emission. One of the latest examples is the spectroscopic results of Boissé et al. (2013), which further reinforce the proposal that there are few-AU structures in the ISM. We therefore propose to measure variable extinction towards the NGC 4833 globular cluster, using BVI photometry. We report photometric observations of several hundreds of stars in NGC 4833, repeated over a 6-month interval. Our goal is to look for magnitude variations over time, among these stars. Indeed, as NGC 4833 lies at a distance of 6500 pc from the Sun, it moves $\simeq 8.04\, mas.yr^{-1}$, equivalent to $52\, AU.yr^{-1}$ and more than 4 AU per month. Therefore, within a six-month period, NGC 4833 moves about 26 AU, which is comparable to the size of the small-scale structures of the ISM.

2 Observations and Data Reductions

Photometric observations of NGC 4833 were performed at La Silla, Chile, with the ESO Multi-Mode Instrument (EMMI). Two observation runs separated by a 6-month interval were done. The first run was performed on January 20-22, 2006, and the second on July 15-17, 2006. For each run, four stellar fields (F_1, F_2, F_3, F_4) around NGC 4833 were selected. Each stellar field was observed using three exposure times: 60s, 420s and 900s (filter B); 12s, 90s, and 600s (filter V); and 6s, 40s and 200s (filter I). Bias, dome and sky flat-fields were collected in the usual way.

For photometry reduction, we used the DAOPHOT II Stetson (1994) crowded-field photometry package. Using stars common to all filters, we compiled a BVI photometry list, keeping only those stars which errors do not exceed 0.05 mag and spatial restraint of 0.2 pixels.

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3 Highlighting Color Variations Within Six Months

3.1 Color magnitude diagrams

We assembled B-V and V-I color magnitude diagrams (CMDs hereafter) as shown in Fig.1. For each observation, the magnitudes of stars measured depended on atmospheric extinction. It is well-known that this extinction is a function of spectral type. Thus, in this study, we restricted our targets to the same luminosity class (dwarfs) and to a short temperature interval ($0.50 \leq (B-V) \leq 1.0$). Accordingly, 5,800 dwarfs, well-identified at epoch 0 and 1, satisfied these criteria. The probability of star membership will be discussed in an upcoming paper by Itam-Pasquet at al (in preparation).

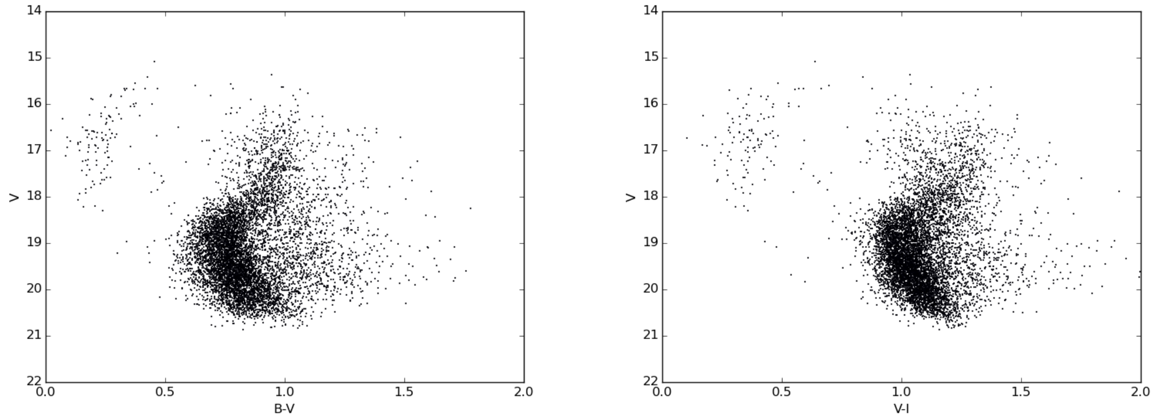

Fig. 1. Left: (B-V) CMD of NGC 4833. **Right:** (V-I) CMD of NGC 4833.

3.2 (B-V) Color maps

(B-V) color variations can be expressed as follows: $\Delta(B-V) = (B-V)_{jan} - (B-V)_{jui}$, and errors related to these variations are written as: $\delta(\Delta(B-V)) = \delta(B-V)_{jan} + \delta(B-V)_{jui}$. We built a (B-V) variation map (see Fig.2, left panel), selecting only stars which satisfied: $\Delta(B-V) > \delta(\Delta(B-V))$. In Fig.2, the right panel represents the same map as in the left panel does, but it includes the position of stars in order to weigh variations. The center of the map displays an area of high weight including with many variation clumps, suggesting that these variations are not homogeneous.

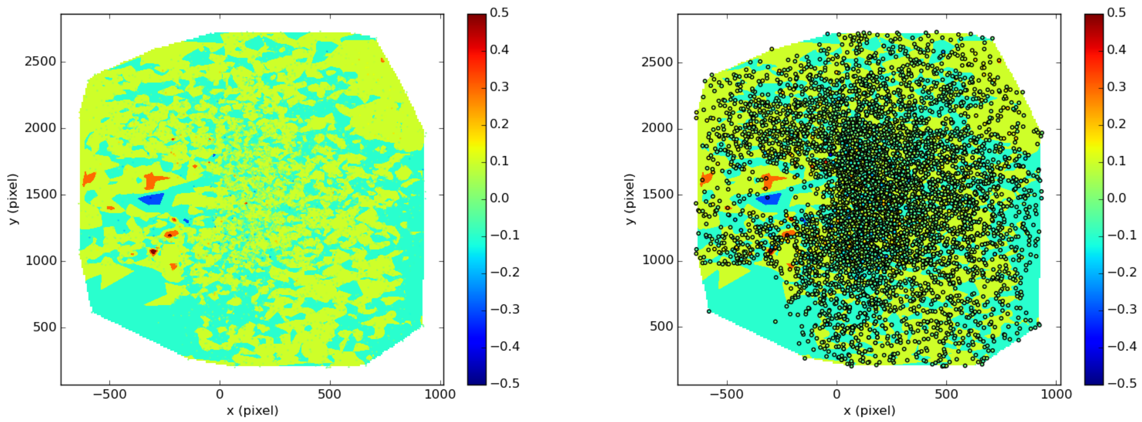

Fig. 2. Left: Map of (B-V) variations. **Right:** Map of (B-V) variations with stars. The X-axis and the Y-axis represent the pixel coordinates of stars.

4 Searching for Variations of Magnitudes Based on Variable Interstellar Reddening (VIR)

4.1 Methodology

We aim to check if photometric variations follow a simplified model of interstellar extinction. Indeed, in this model, we consider that the galactic extinction curve is constant over time. Each star observed at epoch 1 (first observing run) was directly compared to the same star observed at epoch 2 (second observing run). If time variations are due to Variable Interstellar Reddening (VIR hereafter), one expects that the following VIR-test is satisfied:

$$|\Delta(B)| = 1.4 * |\Delta(V)| \pm \eta \tag{4.1}$$

$$|\Delta(I)| = 0.6 * |\Delta(V)| \pm \eta \tag{4.2}$$

with $\Delta(\lambda_F) = m_1(\lambda_F) - m_2(\lambda_F)$ and a parameter η, which determines the robustness of the test and will be defined in the following section.

4.2 Discarding intrinsic variable stars

Kopacki (2014) listed the well known variable stars in NGC 4833 and placed them in a CMD, allowing us to verify that candidates are not known as intrinsic variable stars. In our selected region of the CMD, mostly binary variable stars (especially WUMa-type ones) are found among dwarfs. In fact, Milone et al. (2012) measured the fraction of binary stars in NGC 4833, and found a low value of 0.058 ± 0.006. In other words, out of the 5,800 stars selected among dwarfs in NGC 4833, only 336 might statistically be binaries. In order to further lower this number, we chose η so that binaries could not verify equations 4.1 and 4.2. We randomly selected two different phases from the B, V and I light curves of several WUMa stars, and checked if the magnitude variations between the two phases satisfied equations 4.1 and 4.2. After 50,000 simulations for each WUMa, we chose $\eta = 0.3$ to design a robust VIR test at which binaries fell under a small ratio $< 5\%$.

4.3 VIR test results for NGC 4833' stars and error discussion

The formula of error for our VIR-test can be expressed as follows:

$$E(\frac{\Delta(\lambda_F)}{\Delta(\lambda_V)}) = \frac{\Delta(\lambda_F) * E(\Delta(\lambda_V)) + \Delta(\lambda_V) * E(\Delta(\lambda_F))}{(\Delta(\lambda_V))^2} \tag{4.3}$$

Of the 5,800 stars selected in the CMD, only 46 had an error ratio $< \eta = 0.3$ mag (see Fig.3). Thus, we could only apply the VIR-test (equations 4.1 and 4.2) to 46 stars, which is too small a statistic to be significant. Furthermore, none of the 46 stars passed the VIR-test. Therefore, with this method, because of the high error values of magnitude ratios, we could not verify if photometric variations were compatible with a VIR.

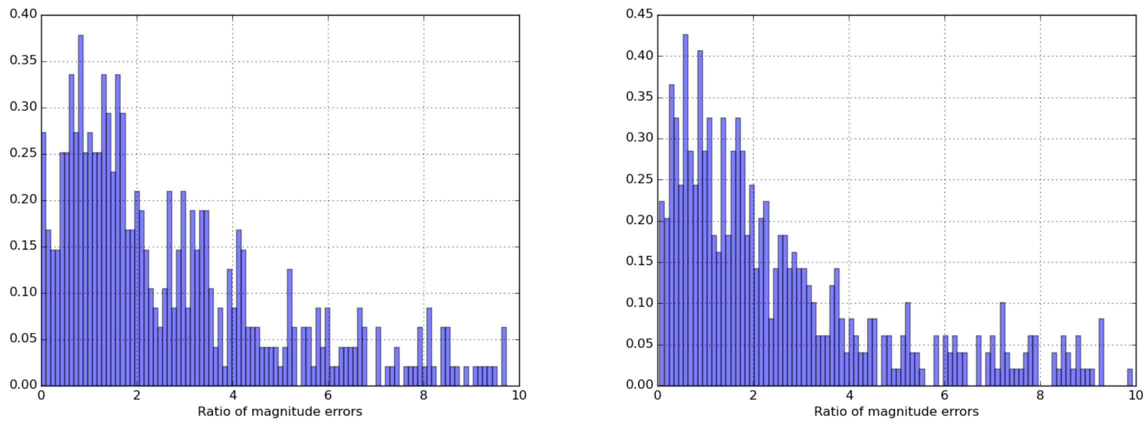

Fig. 3. Histograms of ratio of magnitude errors with $\lambda_F = B$ (see equation 4.3 and left panel) and with $\lambda_F = I$ (right panel).

4.4 Confidence in results

In the following, we assume that all stars are members of NGC 4833. In order to show that the photometric variations of magnitudes do not occur by chance, we want the distribution of magnitude variations over a period of 6 months (called "data" hereafter) to fit within a known distribution. Thusly, we are able to compute the occurrence likelihood of each magnitude variation. Kolmogorov-Smirnov and Wilcoxon statistic tests yield a significant p-value for a logistic distribution with $\mu = -0.001 \pm 0.0005$ and $s = 0.026 \pm 0.0002$ (see Fig.4). For variations $> |0.05|$ mag the probability that they are not due to chance is $> 86\%$, which is significant.

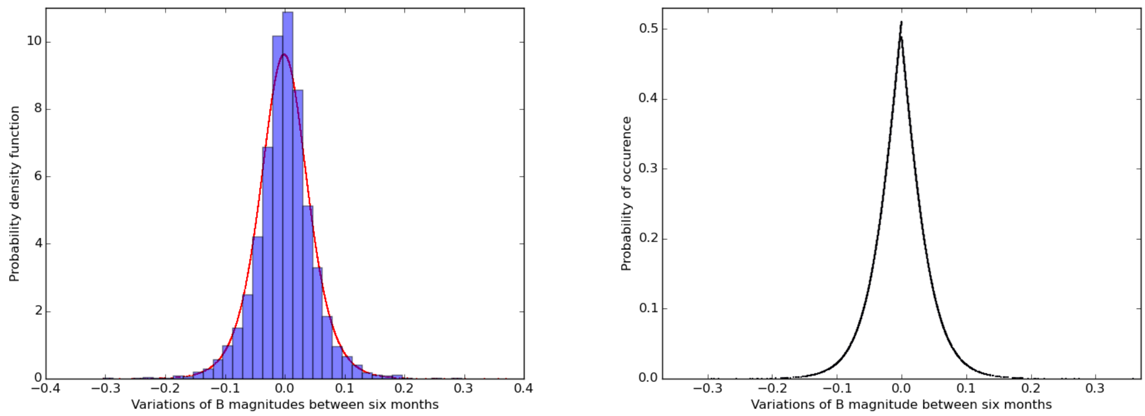

Fig. 4. Left: Fit of a logistic distribution of our data with $\mu = -0.001 \pm 0.0005$ and $s = 0.026 \pm 0.0002$. **Right:** Probability of occurrence (on y-axis) of a variation in magnitude within six months (on x-axis).

5 Conclusions

The study of the NGC 4833 globular cluster, is particularly relevant because it lies behind dusty regions. We believe that the interstellar medium in the foreground, is composed of large and small structures of several AUs. Because of these structures and of NGC 4833's velocity, variations of the reddening over time may occur. The magnitude error ratios are too high to determine if the variations are compatible with a VIR, but statistical analysis shows that the likelihood that variations $> |0.05|$ are not due to chance is $> 86\%$. Moreover, the (B-V) color map of NGC 4833 highlights variations with time. In future work, we will plan to compare our data to that of Melbourne et al. (2000), who carried out optical observations of NGC 4833 in 1995. The comparison will give us an opportunity to extend our study of this cluster to a time span of 11 years. In addition, we will create a model based on a given structure and a dynamic of clouds in the foreground to constrain the existence of these photometric and color variations.

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