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A Synoptic Variability Survey of M3

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Abstract. We present preliminary results from a synoptic photometric variability survey of the galactic globular cluster M3. These data consist of between 9 and 13 nights of data, the sampling allows a minimum detectable period of 10 minutes and is complete to $M_V \sim 21$.

1. Introduction

Since Pickering's discovery of the first globular cluster (i.e. RR Lyrae type) variable in M3, subsequent investigations have shown that this galactic globular cluster contains the largest homogeneous population of observationally accessible RR Lyrae stars; it is the best available laboratory for studies of RR Lyrae stars and related populations of variable stars, notwithstanding the recent revelation that Pickering's star was probably a Pop II Cepheid (Smith 1995 and references therein).

While M3 has been the subject of numerous observational campaigns, especially variability surveys (see Sawyer Hogg 1973), the availability of panoramic CCD cameras opens a new discovery space to variable star research in globular clusters; the high quantum efficiency of CCDs makes it possible to reach well down the main sequence in relatively short exposures. Furthermore, computational techniques now makes it possible to reduce and analyze massive datasets that constitute these surveys.

Carretta et al. (1998) and Kaluzny et al. (1998a) had undertaken variability surveys of M3 with CCD cameras, but the field of view of cameras available to those authors was relatively small, so their fields were a modest sample of M3 (see Fig. 1).

The scientific reasons for taking a synoptic view of the M3 variable population are many. A search for detached eclipsing binaries (DEBs) is motivated by a desire to obtain a direct, geometrical distance to M3 (Paczyński 1997). A search for close binaries is further motivated by the apparent discrepancy between the large number of blue stragglers in M3 and paucity of binaries. Since these observations extend well below the main sequence turn-off, they should yield a complete sample of variable stars to $m_V \sim 21$ which will include the rare SX Phe stars ($m_V \sim 17 - 18$ at the distance of M3).

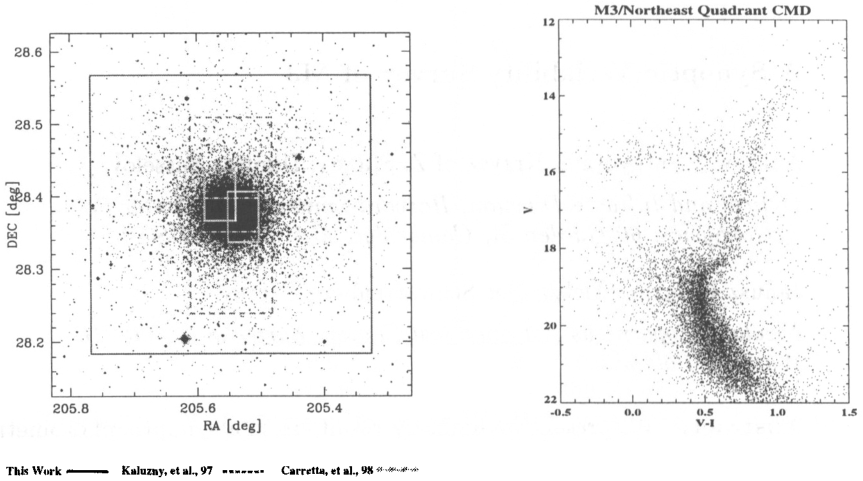

Figure 1. The left panel compares this survey with previous CCD surveys (Kaluzny et al. 1998a; Carretta et al. 1998). A color–magnitude diagram for Mosaic Northeast Quadrant appears in the right panel.

2. Observations and Data Reduction

The data for this survey were taken at the Smithsonian 1.2-m telescope on Mt. Hopkins, Arizona with the "4Shooter" camera. The focal plane of this camera consists of four 2K × 2K pixel back-side illuminated CCDs with 15μ pixels, which form a 4K × 4K pixel mosaic with a thin (1 arcmin) cruciform dead-band where the CCDs abut. The plate scale is 0.31 arcsec/pixel and the mosaic field of view is 25 × 25 arcmin. These parameters are well-matched to the angular size of M3 (with a core radius of 1.85 arcmin, see Fig. 1).

The telescope pointing was offset slightly from the core of M3 so that the core fell entirely in the Northeast quadrant and not in the "cracks" of the mosaic. 4Shooter data were obtained on nine nights in April and May of 1998. These runs were preceded by a four-night observing run in March 1998 with another camera (the "OneShooter") that is almost identical to the 4Shooter, except it only has a single CCD in the focal plane. These OneShooter observations were made to overlap the Northeast quadrant; there are 13 nights of data on the core and Northeast quadrant of M3.

Data were collected in B, V and I filters in a sequence $VVBVI$. A total of 287 V frames was collected, of which 201 were 4Shooter and 86 were OneShooter (in the case of the Northeast quadrant). The V exposures were 300 s long, whilst the B and I exposures were 420 s and 180 s respectively.

Seeing was typically 1.5 – 2.0 arcsec and the survey is complete to approximately $m_V = 21$ (see Fig. 2). Stars brighter than $m_V \sim 14$ are saturated.

Preprocessing through flat fielding was accomplished with the standard suite image processing tools in IRAF. Photometric reductions were done with the Warsaw-DIRECT pipeline (Kaluzny et al. 1998b; Stanek et al. 1998) which performs fits to the point spread functions of individual stars in each frame (i.e. PSF photometry). This pipeline is built in large part on the DAOPHOT photometric reduction package.

The subsequent processing consists of identifying variable stars using the Stetson variability index (J_S: Kaluzny et al. 1998b) and then determining the periods, if any are present, of the subsample of variable stars.

We have employed two different algorithms for period estimation: a modification of the Lafler–Kinman "string minimization technique" (Stetson 1996: Kaluzny et al. 1998b) and the "Analysis of Variance" (AoV: Schwarzenberg-Czerny 1999) approach. Neither algorithm is "perfect", i.e. one plainly succeeds in one case and fails in another, however the AoV approach seems to be more robust and only failed once for $\sim$ 300 periodic time series. While we may employ the expedient of running both algorithms on all our data and selecting the correct period by eye, the next generation of photometric surveys, which will produce far too many candidate periods for humans to winnow, will have to optimize these methods considerably.

3. Project Status and Future Directions

At present we have reduced the Northeast quadrant data and are nearing completion of the other three quadrants. While it is difficult to attest to the "completeness" of a variability survey given that detection sensitivity depend on the harmonic content of the light curve and sampling, it would appear that the current processing is quite robust to at least $m_V \sim 18.5$. This is demonstrated by the detection of an SX Phe star with very high signal to noise (see the phase-folded light curve in Fig. 2).

As of this writing, no population of hitherto undiscovered DEBs or other binaries has been revealed in these data. While this "missing link" may be due to a real lack of binaries, several issues of technique bear on this matter. Both the Lafler–Kinman and AoV period estimation algorithms perform better on the roughly sinusoidal light curves of pulsators than the "spiky" light curve characteristic of DEBs. We are exploring algorithms that might be more robust period estimators for DEB light curves to eliminate the possibility that this is merely a selection effect.

A second issue is that of the PSF fitting photometry itself. Although, the method autovalidates itself to at least $m_V \sim 18 - 19$ in the case of the SX Phe star mentioned above, somewhere near $m_V \sim 20$ there is evidence that the photometric error may result in light curves that are too noisy for period detection algorithms. Photometric reduction using Alard's image differencing software (Alard & Lupton 1998) apparently achieves signal to noise near the level of the photon counting statistics and has been used by two of us (Olech et al. 1999) for the detection of variable stars in the galactic globular cluster M55. Reprocessing by the image differencing method will make it possible to search for a faint population of DEBs well down the main sequence for an accurate determination of binarity in M3.

Acknowledgments. We thank Barbara Mochejska for producing the beautiful pseudo-color image of M3 that does not appear in these monochrome pro-

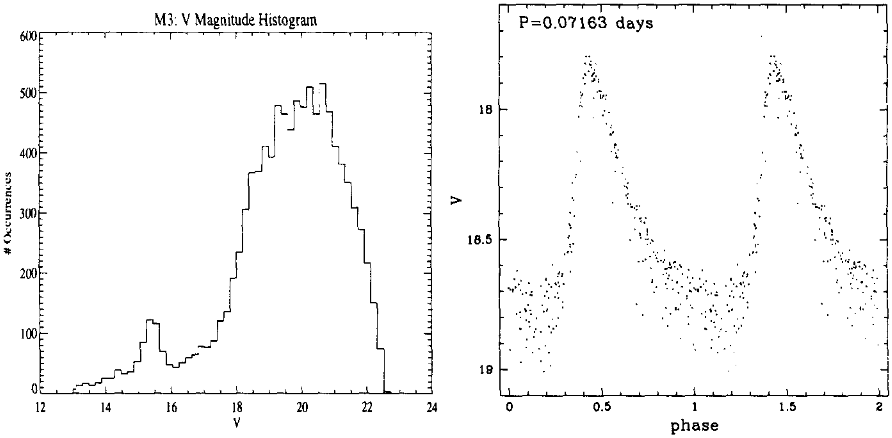

Figure 2. The left panel is a histogram of V magnitudes of all stars in the Northeast quadrant of this survey, showing photometric completeness to ~ 21. The right panel shows the high signal to noise phased light curve of an SX Phe star in the Northeast quadrant of this survey field.

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