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Precise astrometry from half-century long observations of star cluster M 15

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This paper uses five epoch archival images to determine the individual positions of stars in M 15 star cluster.

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1 Introduction

The total number of photographic plates observed worldwide with professional telescopes until late-twentieth century is estimated to be more than two million images (Tsvetkov et al. 1997, 2012). The use of this resource can provide us with a great opportunity to register changes in the objects, either in position or brightness. The selected object for this study is NGC 7078 – one of the oldest (13.2 Gyr, McNamara et al. 2004) and most metal poor globular clusters ($[Fe/H] = –2.40$, Sneden et al. 1997) known in the Milky Way. Kharchenko et al. (2013) estimate the proper motions for this cluster to be $pmRA = –0.46$, $pmDEC = –4.98$ mas/yr.

2 The data

The images were taken with the Pulkovo observatory Normal Astrograph on photographic plates 160 by 160 mm (see Kiseleva, Khrutskaya 2007, www.puldb.ru). Observations made as early as September 1909 are available, but with lower quality. For this work only the best-quality plates of M 15 were used, which have identical orientation and positioning. A full list of the plates considered in this paper is in Table 1.

The plates were scanned with EPSON Expression 10000XL, resolution 1600 dpi giving full frame of approx. 8000 by 8000 pixels. In this study we cropped the scanned images to use only the central 3000 by 3000 pixels. This ensures a good coverage of the cluster and its surrounding background.

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Table 1 List of plates used.

Plate number	Exposure date	Exposure time
PULKOVO-241	1935 11 22	60 s
PULKOVO-419	1937 10 23	60 s
PULKOVO-8791	1968 09 30	35 s
PULKOVO-12289	1979 12 08	40 s
PULKOVO-12659	1980 08 08	60 s

3 Methods

On the five epoch images a standard PSF photometry is done in IRAF with package *daophot*. Using tens of reference stars we successfully construct PSF from every individual image – an elliptical Moffat function, linearly varying in both directions. We let the background to be locally fit during photometry and fine centering of the PSF on the star also to ensure the best possible positions of the stars.

We apply a data quality constraint on the photometry catalogues to avoid false detections. Only stars with no error during photometry are used, with sharpness more than –2 and χ less than 8. Sky level of the background is determined individually for each star in a ring away from the peak. In majority of the stars agreement is reached within the 8–9 fitting iterations. The resulting catalogues from PSF photometry for each image is between 1600 and 3100 stars depending on the plate quality.

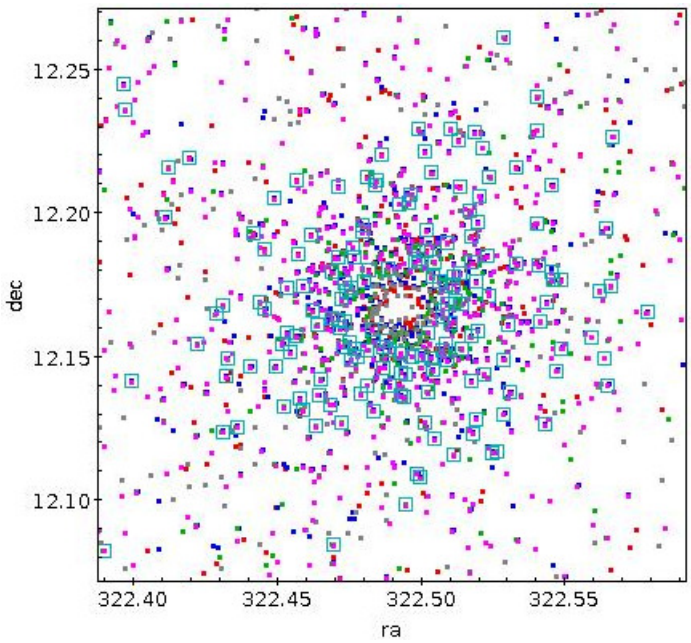


Figure 1 Sky plot of five epoch images photometry files in degrees. Common stars identified in all five epochs are plotted with blue squares.

Matching stars to be present in all five epoch photometry is done based on both position and magnitude of the stars, to eliminate false matches. A star needs to be detected within 3 arcseconds radius in all five images to be confirmed a match. At the end we have a catalogue of 270 stars, identified in all five epoch images.

The central region of the cluster and the five epoch photometry catalogues are plotted on Fig. 1. The matched common stars in all five epochs are marked with blue squares. In the central regions of the cluster there are no stars identified due to crowding and overlapping. We are able to detect positions of the outer regions of the cluster as well as field stars.

4 Results

Figure 2 shows the positions of the stars with respect to the reference image, PULKOVO-419, of the other four epoch images. We derive the mean differences in *RA*, *DEC* in arcseconds as follows: PULKOVO-241: 0.522,0.14 arcsec, PULKOVO-8741: –0.736, –0.95 arcsec, PULKOVO-12289: –0.366, –1.29 arcsec, PULKOVO-12659: –0.419, –1.00 arcsec. When we convert the individual shifts of the stars to proper motions, having the exact the time of observation, these values are in agreement within the error with the literature (Kharchenko et al. 2013).

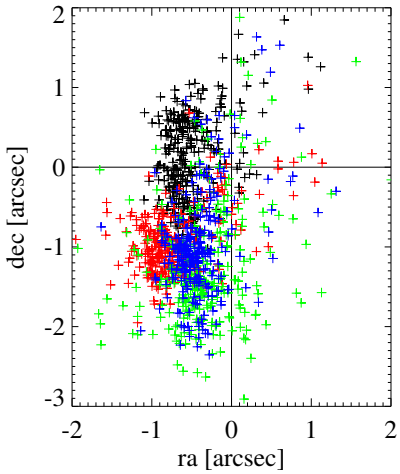


Figure 2 Positions of individual stars with respect to PULKOVO-419.

In this paper we apply PSF photometry on archival photographic plate images of the cluster M 15. We show that it is possible to successfully acquire accurate positions and brightness of stars in various epoch observations.

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