

CCD OBSERVATIONS IN THE VILNIUS PHOTOMETRIC SYSTEM

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Abstract. Setting up the Vilnius photometric system with CCD detectors is extremely important for investigation of galactic structure since the system makes it possible to determine completely by photometric means spectral classes, absolute magnitudes, metallicities and peculiarity types of stars, even when affected by interstellar reddening. The paper describes the first observations made in the Vilnius system with CCD detectors at the Kitt Peak National Observatory and the US Naval Observatory Flagstaff Station. The paper also describes available software for the photometric classification of stars and investigations planned with the VATT telescope on Mt. Graham in Arizona. Some recommendations for users of CCD cameras for stellar photometry are given.

Key words: methods: observational – techniques: photometric – instrumentation: CCD detectors – stars: fundamental parameters

1. CCD VILNIUS PHOTOMETRY ACCOMPLISHED

The Vilnius seven-color photometric system provides the means to classify stars in two or three dimensions in the presence of interstellar reddening. The setting up of the system with panoramic

detectors, such as CCDs, make it extremely effective in investigations of stellar populations and interstellar extinction in galactic areas up to large distances.

The first CCD photometry in the Vilnius system was obtained with the 0.9 m telescope of the Kitt Peak National Observatory in 1986. The RCA chip gave a 5×7 arcmin field and provided the seven filter measurements of most all the stars to a limiting $V = 17$ mag (Boyle et al. 1990a,b, 1992; Smriglio et al. 1991). Despite single exposures, low sensitivity in the ultraviolet and the high read-noise of the CCD, we were able to obtain all six color indices for the 231 stars in two fields near the globular cluster M 56 in Lyra and 193 stars near the globular cluster M 71 in Sagitta. This was the first time that Vilnius photometry and the two-dimensional classification of stars were accomplished to this faint limit. Photometric spectral and luminosity classes, absolute magnitudes, interstellar reddenings and extinctions and distances of the stars were determined.

Besides determining the distance dependence of interstellar reddening, it was possible also to analyse statistically the cloudy structure of interstellar dust in these directions (Smriglio et al. 1993, 1994, 1995, 1996). We have learned that interstellar reddening is “patchy” even in the small scale areas of 30 square arcmin size. From this we have determined that there appear to be small dust clouds of $1 - 10$ pc in size and $7 - 8$ clouds per kpc in number out to 1.2 kpc distance. Such clouds cause reddening of about 0.03–0.04 mag in E_{b-y} .

We have been encouraged by the success in obtaining this CCD photometry. But of course we and anyone else who uses the data must respect the photometric error limitations and not expect more information than what the measurements can support. For the stars fainter than 15th mag, our CCD photometry was not of sufficient accuracy to provide reliable absolute magnitudes, metallicities and other parameters of stars. For this, better CCD quality, longer or more numerous exposures were required.

2. PHOTOMETRIC CLASSIFICATION OF STARS

The completely photometric classification of stars in the MK system is performed using several software packages developed both in the Institute of Theoretical Physics and Astronomy in Vilnius and in Astronomical Institute of the Rome University “La Sapienza”. In the Rome institute, the software package called Automated Stellar

Classification Access and Reporting (ASCAR) is in use. This package contains two classification techniques:

(a) A comparison method which finds the best match between the program star and a standard star of the reference catalogue. For this, the General Photometric Catalogue of Stars Observed in the Vilnius System (Straizys and Kazlauskas 1993) containing about 8000 stars is used. Smriglio et al. (1990) showed that the predicted spectral classes and luminosities are in good agreement with MK classification from the literature.

(b) A Graphic Interactive Classification (GIC) method which uses diagrams based on the reddening-free Q -parameters calibrated in terms of spectral classes and absolute magnitudes (Straizys 1992). As a by-product of classification of normal stars, one can identify a number of peculiar objects, such as Be, Am, Ap, subdwarfs, metal-deficient giants, carbon and barium stars, white dwarfs, horizontal-branch stars, unresolved binaries, etc. An estimate of the classification errors is given in Smriglio et al. (1992).

A number of facilities are also available in ASCAR for determination of color excesses, absolute magnitudes, interstellar reddening and metallicity.

In the Vilnius Institute, other versions of software for the classification of stars are available. They include the LYGINT software package, based on a comparison of reddening-free Q -parameters of the program and standard stars (A. Kazlauskas, unpublished), the KLANOR software package using a number of reddening-free Q , Q -diagrams and several methods of comparison of Q -parameters (K. Zdanavičius, unpublished) and the CLASS software package based on a three-dimensional (spectral class, absolute magnitude and color excess) fitting of the observed color indices of the program star with those from a bank of standard stars (Vansevičius and Bridžius 1994).

3. CCD WORK IN PROGRESS

In 1993, we made CCD observations on the 1 m Ritchey telescope at the Flagstaff Station of the U.S. Naval Observatory. Its CCD camera gives a large field of view (23×23 arcmin) with a Tektronics 2048×2048 chip. We have made observations in the old open cluster M 67, the double open cluster NGC 1750/1758 and globular clusters M 3 and M 92.

Montgomery et al. (1993) have made extensive CCD photometry in M 67 with *UBVRI* broadband filters. Since the Vilnius *V*

passband of medium bandwidth measures almost the same magnitude as the broadband V over all spectral types to early M-type stars (Straizys 1992, p.488), we used 18 stars of the Montgomery et al. photometry to fit them with our measures in the Vilnius system. The fit is good with an rms dispersion of 0.014 mag over $12 < V < 14$ mag. In the same cluster, Montgomery et al. have identified 30 stars to be standards of high accuracy. Their color range is $-0.09 < B - V < 1.37$ and their brightness range is $9.96 < V < 13.90$. Photoelectric Vilnius photometry on this set of stars is in progress and will be useful for calibration purposes in future investigations. This cluster in Cancer is well placed for the northern hemisphere observing in the winter months. A preliminary HR diagram of M 67 in the Vilnius system was obtained (Boyle et al. 1994).

More CCD areas were observed with the same Flagstaff telescope in 1994: an area in the dark Pelican cloud, two areas in the Perseus dark clouds (near the young open cluster IC 348 and the reflection nebula NGC 1333), open clusters M 67 and NGC 1750/1758. The reductions and data analysis are in progress.

4. FUTURE PLANS

Encouraged by our success, we are starting an observational program for investigation of stellar populations in the Galaxy. Straizys, Boyle & Philip (1993) and Straizys & Philip (1994, 1995) have proposed a project for the investigation of stellar populations of the galactic disk. They point out that the Vilnius photometric system can probe galactic latitudes within 10 degrees of the galactic equator, the Zone of Avoidance. They refer to current models of the Galaxy and emphasize that now is the time for new observations to test and develop models of the thin and thick disks. The Vilnius or the Strömvil (Straizys, Crawford & Philip 1996) systems can determine purely photometrically space distribution functions of stars even in the directions affected by considerable interstellar reddening.

It is planned to use the 1.8 m Vatican Advanced Technology Telescope (VATT) to make observations for this project. We have expectations for success in these plans because: (1) the location of the telescope in Arizona, at altitude above 3000 m should give many nights of good observing including enhanced transparency in the ultraviolet; (2) ample telescope time should be available; (3) two CCD cameras are available, one with an 11×11 arcmin square field

and another with a 6×6 arcmin square field and with very high ultraviolet sensitivity and fine spatial resolution. More photoelectric photometry is needed for transformation of magnitudes and colors to the standard system. We expect this can be done by a set of standard areas situated at declination zones of about $+30$ deg and -30 deg (Philip, Boyle & Straižys 1996).

5. STEPS FOR PRECISE AND ACCURATE CCD PHOTOMETRY

Our experience suggests the following steps in observing and processing should be taken to assure precise and accurate CCD photometry.

(1) The filter transmission curves should be as close as possible to the curves of the standard filters to ensure an easy transformation to the standard system. See Straižys & Lazauskaitė (1995) and Roberts et al. (1995a,b) about matching the filters for CCDs.

(2) Flatfielding exposures should have high signal-to-noise per pixel and the same zero-point scale over the field. The uniform illumination pattern on the calibration flats must be somehow corrected for if it is different from the uniform illumination in the object exposures. Making ratios of flats in the same filter but obtained at different times or by different manners can reveal whether the flats have the same illumination pattern. The ratio must be constant over the field within the photon statistical error.

(3) Take more than one exposure on object frames and make a small shift of a few arcminutes in telescope position so that the same stars are measured on different areas of the CCD. This gives a test of the success in flatfielding. Has the goal of truly having just one zero-point all over the field been attained! Two or more measures give a better indication of the precision than just the theoretical estimate from errors of photon statistics, sky-noise and read-noise. As an alternative to off-setting the telescope, with an alt-azimuth telescope, such as the VATT, rotation of the derotator, e.g., 90 or 180 degrees between exposures on the same field and using matching flat fields might be convenient and useful.

(4) Observe at the lowest air-mass as possible.

(5) Assuming that photoelectric standards lie within the CCD fields observed, these standards must be appropriate for CCD calibration either for color transformation or simply setting zero-points.

What was measured in the beam passing through the aperture in the photoelectric photometry must be the same when a measurement is made in the synthetic aperture for the CCD. Often apertures for photoelectric photometers are large, e.g., 20 arcsec diameter, whereas the optimum synthetic aperture for the CCD measure is quite small, e.g., a few arcseconds. For doing 1 % photometry, appropriate photoelectric standards, measured in large apertures, should not have contaminating companion stars to five magnitudes fainter in that filter.

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