PHOTOMETRIC SYSTEMS FOR FUTURE SURVEY SATELLITES

V. Straizys and E. Høg

1 Institute of Theoretical Physics and Astronomy, Goštauto 12, Vilnius 2600, Lithuania
2 Copenhagen University Observatory, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark

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Abstract. The photometric aspects of the workshop “Future Possibilities for Astrometry in Space”, organized by RGO and ESA in June 1995, are reviewed. The Strömvil or the Vilnius medium-band systems, defined for survey satellites of the GAIA type, would make it possible to obtain spectral classes (or temperatures), absolute magnitudes (or surface gravities), metallicities, peculiarity types and interstellar reddenings for all stars down to 16th or 17th mag. This huge data bank would generate extremely important studies of the structure and evolution of our Galaxy and other nearby galaxies.

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

1. INTRODUCTION

At the beginning of the 21st century, the European Space Agency is planning to launch an astrometric scanning survey satellite, GAIA (Global Astrometric Interferometer for Astrophysics), which is described by Lindegren & Perryman (1994, 1995). The project was proposed by a group of astronomers (Lindegren et al. 1993) as a concept for a cornerstone mission within the European Space Agency’s “Horizon-2000 Plus” scientific program. This mission is expected to give positions, parallaxes and proper motions of some 50 million objects down to $V = 15$ mag with an accuracy of better than 10
microarcseconds. Additionally, the satellite will be able to measure the brightness of stars in a multicolor photometric system in order to determine temperatures, gravities, absolute magnitudes, metallicities, interstellar reddenings and distances of the same and even fainter stars.

A workshop organized jointly by the Royal Greenwich Observatory and the European Space Agency on “Future Possibilities for Astrometry in Space” was held at Cambridge, U.K., on June 19–21, 1995. Here we discuss the photometric part of the project as it was presented at the workshop.

2. PHOTOMETRIC EQUIPMENT OF GAIA

It is planned that the GAIA satellite will contain three pairs of off-axis telescopes of diameters 55 cm scanning the sky along great circles. Each pair of telescopes will make interferometric (coherent) position measurements using CCD chips placed in the central part of the 1° to 1.6° field. The outer part of the unvignetted field will be used for incoherent imaging, employing eight CCD chips placed in the focal plane behind the filters and operating in the Time Delayed Integration mode. The expected scale of the focus is 18 arcsec/mm for $D = 55$ cm and $F = 11.46$ m telescopes.

To make the photometric results most useful, one should use an optimum photometric system, allowing to classify stars of all spectral types in terms of surface temperatures, gravities, metallicities and peculiarity types in the presence of various interstellar reddening. For this purpose, the medium-band photometric systems are most effective since they combine the sufficient light and the sufficient sensitivity to different spectral features.

In 1994, one of the authors (Høg 1994, 1995) proposed an eight-color system consisting of four passbands of the Strömgren system ($u, v, b, y$) supplemented by the ultraviolet Walraven’s magnitude $W$ at 320 nm, two narrow-band passbands measuring the H$\beta$ line and the broad-band infrared passband $I$ at 800 nm. It was shown that a pair of 70 cm telescopes during a 2.5 year mission gives predicted standard errors of $\lesssim 0.01$ mag for a solar-type star down to the following limiting magnitudes $V$: in the $I$ passband down to 19th mag, in the $v, b, y$ passbands down to 17th mag, in the H$\beta$ passband down to 15th mag and in the $W$ passband down to 14th mag (Høg 1995). Thus, the limiting magnitude of the complete system is set up by the narrow-band H$\beta$ and the ultraviolet passbands.
At the Cambridge workshop, Straizys & Høg (1995) proposed another system for a survey satellite, which in an optimum way provides the completely photometric classification of stars of all normal spectral types as well as of a number of peculiarity groups. The system consists of the $u,v,b,y$ passbands of the Strömgren system, of the $P$, $Z$ and $S$ passbands of the Vilnius system and the above-mentioned infrared passband. Four passbands of the Strömgren system and three passbands of the Vilnius system form the Strömvil system proposed by Straizys, Crawford & Philip (1996) for classification of faint stars affected by interstellar reddening. The scientific justification of diverse passbands of the Strömvil system is given both by Straizys & Høg (1995) and Straizys et al. (1996). The Vilnius system and its classification possibilities are described in two monographs of one of the authors (Straizys 1977, 1992).

The Strömvil system is capable of classifying stars in spectral classes and luminosities (or determining their temperatures and surface gravities) everywhere in the HR diagram. Also, the system is able to identify metal-deficient dwarfs and giants, Am and Ap stars, emission line stars of different spectral classes, carbon and barium stars, white dwarfs and a number of types of unresolvable binaries. All this can be done in the presence of interstellar reddening, the color excess being one more parameter being determined. This property of the system is most important in the case of survey photometry down to 16th mag or fainter, since the majority of such faint stars (most of them are also distant) are expected to be considerably reddened, especially at low galactic latitudes.

The infrared passband, added to the Strömvil system, makes it possible to form a blanketing-free color index suitable for temperature determination for late-type stars. The infrared passband may be taken from the $R,I$ system of Cousins (1980) with a mean wavelength of 812 nm and a half-width of 166 nm.

In our communication at the Cambridge workshop (Straizys & Høg 1995), the precision of the Strömvil + $I$ photometry and the limiting magnitude were determined for the six GAIA telescopes of 55 cm diameter during a 5 year period of scanning. The predicted standard errors for stars of three spectral types, B0, G0 and M0, were computed. We found that down to $V = 14$ mag the precision of magnitudes for all eight passbands is better than $\pm 0.01$ mag for stars of all three spectral types. At $V = 16$ mag this is true only for the stars of spectral class G0 and earlier: for M0 stars the precision in the ultraviolet passbands with $\lambda_0 = 345$ nm and 374 nm is $\pm 0.05$. 

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and ±0.03 mag, respectively. However, the ultraviolet passbands in the Strömvil system are not needed for the classification of M-type stars.

3. ALTERNATIVE SYSTEMS

Photometric systems proposed for the GAIA mission were discussed by Pel (1995). He concludes that the Strömvil system appears to be very attractive for the project: the system does not contain any narrow-band magnitudes and provides three-dimensional classification for all spectral types. The system avoids the strong bandwidth effect, i.e. the dependence of the effective wavelengths on spectral type and interstellar reddening. This effect is very strong for broad passbands and reduces considerably the accuracy of the photometry. At the same time, Pel suggests two amendments to the Strömvil system: addition of one more ultraviolet passband with the mean wavelength shorter than that of the \( u \) passband and some more passbands “to fill some of the gaps between the Strömvil filters shortward of 600 nm”.

Favata & Perryman (1995) have discussed a possibility to place on the GAIA satellite some spectroscopic instrumentation for measurement of radial velocities, metallicities, two-dimensional spectral types and peculiarity types. In this respect, they discuss the interrelation between the photometric and spectroscopic observations. Since the GAIA-type mission will include a carefully optimized filter set for medium-band photometry, which will allow the determination of accurate effective temperatures and surface gravities, the low-resolution spectra would not be necessary to determine the same. However, the authors do not reject the usefulness of space-born spectroscopic three-dimensional classification of stars and for detection of new classes of peculiar objects.

An astrometric and photometric survey satellite mission is being developed by Russian astronomers. In the project AIST, described by Chubey et al. (1993) and Kopylov et al. (1995), it was decided to set up the original Vilnius photometric system. Later on, the mission was renamed STRUVE, the project being described in a comprehensive book published by the Pulkovo Observatory (Yershov et al. 1995). More details about the mission are given in communications by Kopylov & Gorshanov (1996a, b) in these proceedings. They suggest the Vilnius system be supplemented by four passbands: three of them are the ultraviolet passbands at 217.5, 267.5 and 282.5
nm and the fourth is the near infrared passband at 715 nm. The ultraviolet magnitudes give better possibilities for classification of stars earlier than F, especially, early B and O-type stars, peculiar stars of types Bp, Ap, Am, Be and further investigation of the interstellar extinction law in the ultraviolet. The passband at 715 nm, coinciding with one of the deepest TiO absorption bands, is important for identification and more precise classification of M-type stars of all luminosities. This passband was first proposed as one of the possible passbands of the Vilnius system in the early 1960's (Straižys & Zdanavičius 1965, Straižys 1977, 1992).

One more astrometric and photometric survey satellite, named FAME (The Fizeau Astrometric Mapping Explorer), is proposed for launch in 2000 in the United States (Seidelmann et al. 1995). It will contain two telescopes of 10 x 20 cm light collecting apertures. The primary purpose of the instrument is to compile a catalog of positions, proper motions and parallaxes for ~ 10 million stars down to ~ 15 mag. The detectors will be an array of eight CCD chips with 4000 x 1000 pixels in each. Together with astrometry, photometric observations of the same stars are planned. However, the photometric system is not chosen so far.

4. CONCLUSIONS

If the GAIA, STRUVE or FAME astronomical satellite missions will use the Vilnius or Strömvil systems, in the first decade of the 21st century astronomers will possess the catalogs of all stars down to 15–17th mag with their temperatures, luminosities, metallicities, peculiarity types and interstellar reddenings. For a precise calibration of the photometric data in terms of absolute magnitudes, a large number of stars with accurate parallaxes will be available from the same missions (Platais et al. 1995).

This huge data bank will be the basis for extremely important studies of the structure and evolution of the Galaxy as well as of the nearby galaxies. The problems to be solved with this catalog at hand are described in several papers of the Cambridge workshop (Perryman & Lindegren 1995, Murray 1995, Gilmore & Høg 1995, Turon 1995, van Leeuwen 1995, Straižys & Høg 1995). They include: HR diagrams for space volumes in different directions and heliocentric distances, variations of luminosity functions in different parts of the Galaxy, improvement of the Galaxy model, population differences in the spiral arms, the interarm regions, the thick disk and the central
bulge, the metallicity gradients in the disk and the halo, the ages of different populations, the interstellar extinction maps at different galactic latitudes and longitudes, distances and extinction properties of dust clouds, star-forming regions, open and globular clusters and many other problems.

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