

COMMISSION 25. STELLAR PHOTOMETRY AND POLARIMETRY
PHOTOMETRIE ET POLARIMETRIE STELLAIRES

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I. Introduction

This triennium has in general not been one of spectacular new developments in photometric or polarimetric techniques; rather, existing techniques have been improved and are being exploited by more observatories than before. For this reason, the previous report (31.113.097) should be consulted for a broad survey of the subject, while the present has the character of a progress report.

Memorable events were the successful launch and operation of the infrared point source survey satellite IRAS (Ref. 1); the publication of massive photometric catalogues in the Strömrgren system (34.002.029), Geneva system (30.002.008 and 31.002.064), DDO system (31.002.003) and the ANS ultraviolet system (32.002.001); the appearance of a Standard Star Newsletter (Ref. 2) and the distribution of Supplement 3 of the Catalogue of Photometric Sequences (Ref. 3).

Space telescope is beginning to make its influence felt (32.012.013 and Ref. 4): apart from stimulating ground-based calibration work at high precision, the most immediate benefit to general practice of our craft will probably be the experience gained with CCD detectors at a precision useful for general photometry. Some of the work elsewhere is of similar photometric quality, but implementing the array detectors for precise spectrophotometric work is in general proceeding more slowly than we hoped for 3 years ago. Progress in this field is often reported first in the series "Instrumentation in Astronomy, published as separate volumes of the Proceedings of the Society of Photo-Instrumentation Engineers (SPIE).

Major observatories are beginning to accept the premise that the polarization option should be present on all suitable instruments. However, "clean" polarization treatment as an important design aim for the future Very Large Telescopes has not yet become fully integrated into the design process for these telescopes. It will be up to our Commission (among others) to press for this.

The present report is based mainly on the classical optical wavelength region; the limits to our interest are vague, but for this report we have concentrated on those spectral regions where classical technology is used. The report was prepared jointly by Rufener and Tinbergen, with input from the Organising Committee. In one or two special cases, we refer to literature more recent than June 1984. To allow each section to be read independently, a small amount of redundancy has been allowed to remain, both in the text and in the references. As far as possible, references are in the system of Astronomy and Astrophysics Abstracts.

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1. Astrophys. J. 278, L1, 1984.
2. L.E. Pasinetti (ed.) Standard Star Newsletter (Osservatorio Astronomico di Brera, 22055 Merate, Italy).
3. A.N. Argue, E.W. Miller and H. Warren, Supplement 3 of the Catalogue of Photometric Sequences, 1983 (Dept. of Physics, Ricks College, Rexburgh, Idaho).

photometry in particular (for example, R.E. Schild, P.A.S.P. 95, 1021). However, we should be cautious and keep in mind the difficulties that could limit its range of action (see section IV). It is stressed that:

- a) care must be taken with regard to the preservation and conformity of the definition of the instrumental passbands;
- b) these observations must be connected via secondary faint standard sequences that are sufficiently well known.

These two requirements are necessary but not sufficient. Careful study of the performance of each "chip" is necessary which could lead to the maximum adaptation of application and reduction methods. S. Djorgovski exposed these problems in an excellent article (Proceedings of the NASA/SDSU Workshop on Improvements in Photometry, San Diego, June 1984, W. Borucki & A. Young, eds.).

STRÖMGREN PHOTOMETRY

This photometric system has found wide application in the study of galactic populations. The introduction to the comprehensive catalogue of E.H. Olsen (34.002.029) sets out the problems linked to the homogenization of observational data. The difficulties encountered arise both from measurements obtained with instrumental systems defined either by filters or by slots on the spectrum and from the heterogeneity of the selection of standard stars. This remarkable work underlines the importance of the stability of instrumental definition and the choice of the sequence of standard stars for maintaining the significance of the photometric parameters. Using synthetic photometric simulations, J. Manfroid illustrates these problems in the study "On photometric standards and colour transformation" (IAU Symposium 111, 1984). A. Ardeberg and H. Lindgren have prospected the aptitude of this system for the study of stars later than F (31.113.096; 32.113.025).

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OTHER SYSTEMS

Photometric systems with intermediate or narrow passbands (Walraven, Geneva system, Vilnius, DDO etc.) have been used actively during the last three years. Efforts are now being made to obtain photometric measures for stars which are presently candidates appearing in the Input Catalogue of the future European astrometric satellite Hipparcos.

The last issue available (raw computerprint) of the "Catalogue of stars measured in the Geneva Observatory photometric system" contains 150.000 measurements in seven colours for approximately 23.000 stars which have been collected over the last 25 years. A comparative study is being made of the [V] magnitude scale of this catalogue with Johnson's V-band definition, which is very close.

I.A. Glass reports that B.C. Carter of the South African Astronomical Observatory has obtained a new set of 156 JHKL standards of very high quality. These have been compared to previous standards published by Elias et al. (A.J. 87, 1029, 1982) on the C.I.T. - Cerro Tololo system, with those of Allen & Cragg (M.N. 203, 777, 1983) on the A.A.O. system and with Engels et al. (A. & Ap. Suppl. 45, 5, 1981) as well as Johnson's and his own much older lists. It is found that the consistency of the C.I.T. and Carter standards is the best, the r.m.s. differences being 0.01 or less at JHK. The A.A.O. system is only slightly worse, and the Engels et al. system much worse, the r.m.s. differences being .043 at J and .023

each at H and K (all comparisons after taking care of systematic transformations).

SYNTHETIC PHOTOMETRY

This subject has developed due to the particular interest of a precise confrontation between the fluxes predicted by the most accurate models, the photometric observations and the latest spectrophotometric data tied to the energy distribution of a black body. In this context the spectrophotometric atlas by J.E. Gunn & L.L. Stryker (33.002.042) and the list by I.N. Glushneva (34.113.009) are particularly useful. The following could be undertaken in the course of these numerical experiments:

- a) search for and control of the best description of the pass bands defining each photometric system;
- b) estimate of the effects caused by deviating natural (instrumental) systems;
- c) calibration of photometric parameters from models and confrontation with empirical calibrations;
- d) detection and analysis of inconsistencies;
- e) application to the computation of appearances for stellar populations considered globally.

This enumeration is far from being exhaustive and shows the large variety of possible applications. A "joint meeting" on this technique is planned during our next assembly.

MISCELLANEOUS

The extensive use of computer-controlled microdensitometers exploring photographic plates whose sensitivity was enhanced by physico-chemical treatment gives access to an enormous amount of information. Development and refinement of software codes for evaluation are in continuing progress. The nature of the source is determined by shape-recognizing algorithms (stars, globular clusters, galaxies etc.) Even the most refined photometry will remain dependent on the definition of the instrumental systems and on the homogeneity of the emulsions and their treatment (an important reference: 33.012.059).

In recent years several new photometers have been described (29.034.031; 30.034.027; 30.034.054; 30.034.068). Special mention should be made of differential photometers which were conceived to make accurate measurements of the magnitude difference between two stars even if the sky is not of photometric quality (30.034.015; 34.034.087). A very interesting attempt in this direction is the development of RADS (rapid alternate detection system) which was tested by E.F. Milone et al. (32.031.675; 34.036.104). This instrument was conceived to measure successively during a rapid sampling cycle not only the two stars to be compared but also their neighbouring sky background. If we disregard the sensitivity variation caused by the shifting of the pupil's image on the detector, this method has the advantage of taking into account the variations of the sky brightness which are often anti-correlated to extinction variations. The statements and remarks made by J.F. James (30.031.002) gave rise to a pointed and justifiable reaction by A.T. Young et al. (*Quart. Jour. Royal Astr. Soc.* 25, 56).

A new way of detecting variability has been found by performing rapid sampling (29.034.050; 29.113.013; 33.034.066) or by lowering the detection threshold by a maximum increase of the "signal-to-noise" ratio of the measurements (D.W. Kurtz, 32.122.022). In this respect see also the article by F.L. Deubner & J. Isserstedt (34.113.012). Also related to this field are the measurements of D. Dravins (32.031.642) on photon statistics with nanosecond resolution.

Several articles have been written concerning statistical discussions for a better way of measuring photometric quantities. M. Claudius & R. Florentin-Nielsen (30.031.505) discuss the optimum choice of integration, I.R. King (33.036.017) studies the accuracy of measurement of star images on a pixel array. P. Bartholdi et al. (*Astron. Astrophys.* 134, 290) show that the application in real-time of statistical evaluation criteria in association with measurements obtained by rapid sampling lead to objective quality criteria, thus allowing filtering of accidental anomalous recordings.

The systematic application of computer processing has brought about a new approach to problems of reduction outside the atmosphere and the relation to standard stars. General procedures have been proposed and criticized (W.E. Harris et al., 30.031.558; D.M. Popper, 31.031.555; J. Manfroid & A. Heck, 33.036.025).

The eruption of the Mexican volcano El Chichon in April 1982 contaminated the stratosphere with a huge quantity of dust and particles of sulfuric acid. Called "the dust cloud of the century", it has significantly increased atmospheric extinction over the entire planet. The following increases were recorded by the Geneva Observatory photometric station at La Silla (ESO): $\Delta k_U = .070$; $\Delta k_B = .055$; $\Delta k_V = .045$. The decrease in this additional extinction has been slow and lasted until 1984.

IMPORTANT PUBLICATIONS

The "proceedings" of several meetings contain interesting descriptions and numerous references in direct relation with our Commission's activities:

- Instrumentation for astronomy with large optical telescopes, IAU colloquium 67 (32.012.059).
- Second ESO Infrared workshop, Garching (32.012.060).
- Solid State Imagers for Astronomy, SPIE 290 (32.012.098).
- Proceedings of the second New Zealand symposium on photoelectric photometry, Auckland (33.012.049).
- Proceedings of the workshop on astronomical measuring machines, Edinburgh (33.012.059).
- Instrumentation in Astronomy IV, SPIE 331 (33.012.085).
- Proceedings of the NASA/SDSU Workshop on improvements in photometry, San Diego, 1984 (W. Borucki and A.T. Young, ed.)

Some recent books are useful for consultation:

- Software for Photometric Astronomy, by S. Ghedini (32.003.041)
- Astronomical photometry, by A.A. Henden and R.H. Kaitchuck (32.003.056)
- Low light level detectors in astronomy, by M.J. Eccles, M.E. Sim, K.P. Tritton (34.003.061).
- Microcomputers in Astronomy (R.M. Genet, A.M. Genet, ed.) (34.003.069).
- Advances in photoelectric photometry. Vol. 1 (R.C. Wolpert, R.M. Genet, ed.) (34.003.160). Completed by vol. 2, published in 1984.

The last two references were published under the auspices of the very active group I.A.P.P.P. (International Amateur-Professional Photoelectric Photometry Group) which also publishes interesting communications.

Mention should be made of the remarkable activity of the data centres which collect and make available the most recent catalogues in computerized form: "Astronomical Data Center at NASA Goddard Space Flight Center, Greenbelt, Maryland, USA" and the "Centre de données stellaires (CDS), Strasbourg, France". The updating of these catalogues is indicated in the "Bulletin d'information du CDS". In this field, B. Hauck draws our attention to:

- "Homogenous catalogue of red and infrared magnitudes in the photoelectric photometric system of Kron (magnetic tape), G. Jasiewicz (31.002.066).
- "Le catalogue général des données photométriques", B. Hauck (31.002.022).
- "Early-type MK standard stars in the Strömgen 4 color and Geneva photometric systems", A.G. Davis Philip, B. Hauck, Proceedings at the MK classification workshop, Toronto, June 1983.
- "UBV data 1976-1982: a complete supplement to the General Catalogue", J.-C. Mermilliod (34.002.121).
- "Photometric data", B. Hauck, Proceedings of colloquium on astronomical catalogues, Tbilisi, September 1984.
- "Photometric data files", B. Hauck, J.-C. Mermilliod, M. Mermilliod, Proceedings of International Course on Data Handling in Astronomy and Astrophysics, Trieste, July 1984.
- "Collection of data for stars in open clusters", J.-C. Mermilliod, Proceedings of International Course on Data Handling in Astronomy and Astrophysics, Trieste, July 1984.

-- "uvby, β photoelectric photometric catalogue new version with 60044 records concerning 40487 stars", B. Hauck, M. Mermilliod, to be published.

III. Advances in polarimetry techniques

Polarization modulation has become the accepted technique for adding polarimetric capability to an instrument with photoelectric detectors. The highest precision reported for this technique is about 0.003%, used in phase-locked linear polarimetry for detecting non-linear pulsation in a Beta Cephei star (29.122.165). Several new modulation polarimeters, with various precision levels, are described in the literature of the last three years (30.031.521, 30.034.023, 30.032.617, 32.034.155, 32.034.073 or Ref. 1, 34.034.030, 30.034.008, 32.034.004, 34.034.107 and Ref. 12, p. 238; the last four of these are for the infrared, the fifth last is a scanning spectropolarimeter).

The modulation technique is particularly necessary and exacting for array polarimeters (whether area or spectro-polarimeters), where calibration of all polarimetric effects for every elementary detector would be particularly cumbersome. An imaging polarimeter is described in Ref. 13. The Lick Cassegrain spectropolarimeter is in full production (Ref. 2); a high-dispersion Coudé spectropolarimeter has been implemented on the same telescope (Ref. 12, p. 62). Two new array polarimeters are described in Ref. 3; results are reported in 34.125.001, 34.158.002 and Ref. 4; precision approaches 0.1%.

The polarimeter in the Space Telescope's Faint Object Spectrograph is described in Ref. 14. Best precision of a few tenths of a percent is predicted. Both of the imaging cameras and the High Speed Photometer on Space Telescope also have polarimetric capability.

Photographic and electronographic area polarimeters are described in 29.034.001 and 34.034.019 respectively; a precision of a few percent is reported for these on objects only a little above sky background.

Solar spectropolarimetry with a resolution of 500000 is reported in Refs. 5 and 6. Though such resolutions may never be applied to stars, the demonstration that there are no fundamental problems with polarimetry using a Fourier transform spectrometer is valuable for Very Large Telescopes, which after all is where our future lies. Another point of great interest for precision spectropolarimetry using the Very Large Telescopes is the design of the Large European Solar Telescope, which has an intermediate focus for mounting the polarization modulator (Ref. 7), ensuring that polarization capability is not compromised by transfer optics.

A very worthwhile discussion of future instrumental possibilities is given in Ref. 8, which also has its roots in solar polarimetric practice.

Polarised spatial interferometry is discussed in Ref. 9.

An X-ray polarimeter of the "classical" Behr 2-beam type is described in 30.032.509; the best precision reported is 0.2%

Instrument-theoretical considerations are the subject of 33.034.026 (polarimeter design), 34.036.035 (Stokes parameter statistics), Refs. 10 and 11 (retarder design).

Observations suitable for polarization standards are reported in 32.034.004 (UBVRIJHK), 32.116.016 (UBVR, 0.75; very precise degree and angle of polarization), Ref. 15 (UBVRI) and 33.131.147 (UBVRIJ). These are valuable additions to the bibliography in 29.031.614 and 31.113.097 sec IIIb.

Discussions of polarimetric accuracy required for particular scientific objectives, though valuable for polarimetric practice, are not mentioned here; they are considered to be the province of other Commissions.

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3. I.S. McLean, *Proc.S.P.I.E.* 445, (Instrumentation in Astronomy V), p. 547, 1984.

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7. LEST Foundation Annual Report 1983, p. 16.
8. J.O. Stenflo, *Applied Optics* 23, 1267, 1984.
9. F. Vakili, *Proc. S.P.I.E.* 445 (Instrumentation in Astronomy V), 484, 1984.
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12. *Bull. Amer. Astron. Soc.* 16, 1984.
13. J.A. Tyson and R.W. Lee, *Proc. S.P.I.E.* 290 (Solid State Imagers in Astronomy), 144, 1981.
14. R.G. Allen, J.R.P. Angel, *Proc. S.P.I.E.* 331 (Instrumentation in Astronomy IV), p. 259, 1982.
15. T. Korhonen, V. Pirola and A. Reiz, *ESO Messenger* no. 38, December 1984, p. 20.

IV. Detector developments

There is little doubt that array detectors of some kind will eventually take over from the single-pixel detectors now used for precise work. The take-over, however, is a gradual process; more and more problems are encountered as the required precision is raised. Very broadly speaking, the best array detector practice has now reached 0.01 mag in photometry and 0.1% in polarimetry (0.001 and 0.005% respectively for single detectors). Whenever this precision of the array detectors is sufficient and the multiplex advantage vital to the programme contemplated, the array detectors are the indicated path to progress (see, for instance, Ref. 1).

Imaging a field rather than a single point with photometric precision introduces extra problems such as ghosts (Ref. 2); recording such images is further complicated by pixel-to-pixel variation of both gain factors and offsets. On the other hand, the availability of many parallel detectors offers the possibility of intercomparing the registrations of the same source by different element detectors and thus constructing an internally consistent calibrated image; progress in this field is considerable, but does not seem to have approached any fundamental limits yet and often suffers from ad hoc simplifications.

The problem, of course, is that in general both the zero offset and gain of elemental detectors are not identical and are functions of position of the element, wavelength, temperature, polarization, etc., and that some of these functional dependences are coupled. Decoupling and calibrating them in a relative sense are the keys to successful photometry. The most "decoupled" situations would seem to be sky images in narrow bands excluding night-sky lines and spectrophotometry of single point objects, while "objective prism" images constitute the most complex situation and are least likely to yield reliable precision results (both these and broadband direct images are of course of great interest for their efficient acquisition).

Calibration sources are sometimes artificial, at other times the sky itself; in both cases it needs to be demonstrated that the spectral content and evenness of illumination are appropriate to the problem. From the point of view of our Commission, reports of array detector work should be read with the above considerations in mind.

To get an impression of the problems involved and the complexity of the solutions, good "student texts" are 34.002.043, Ref. 7 and Ref. 8 (the advanced student may proceed to Ref. 15, p. 2, Refs. 4, 5 and 6, probably to his complete bewilderment). The fundamental solution to our problems will be homogeneous array detectors, but for the moment this is wishful thinking at almost all levels of precision.