COMMISSION 25: STELLAR PHOTOMETRY AND POLARIMETRY

Photométrie et Polarimétrie stellaire

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1. PHOTOMETRY

(Prepared by C. Sterken)

1.1. INTRODUCTION

This is a summary of the essential work that was published since the previous report (Young 1994), Reports on Astronomy Vol XXIIA, 229–238. This summary is not a complete review, and it certainly does not cover papers that appeared during the last couple of months. References are in terms of volume and reference number in Astronomy and Astrophysics Abstracts, and papers with no such citation numbers are given with their full bibliographic reference.

1.2. INSTRUMENTATION

Anyone overviewing the work published during the last couple of years cannot fail to see the increasing proportion of CCD-based papers compared to the ones related to photomultiplier photometry. CCD techniques are increasingly applied in time-series photometry of variable stars. Many papers dealing with CCD detectors and related to photometric applications are gathered in IAU Symp. 167 *New developments in array technology and applications* , eds. A.G. Davis Philip, K. A. Janes & A. R. Upgren (Kluwer 1995).

Besides the migration towards this array detector, there is another tendency that is bound to make photometry effectively much more difficult for the years to come: the increasing occurrence of straightforward decommissioning and closing of telescopes of the 50cm to 1m class. Those telescopes have been the working horses for photometric research since the 1950s, and one cannot stress enough that this situation endangers the further development and expansion of the trade of photometry, not to speak of the value of such telescopes in monitoring variable stars, nor of the great loss for education and training purposes. It is even so that large observatories are not willing to keep even one single photometric instrument on their sites, thus eliminating all possibilities of determining basic quantities such as, for example, nightly extinction coefficients. At the same time active photometrists keep providing lists of CCD-based standard-star magnitudes and colour indices and go on organising and distributing standardised methods of data reduction. Sparks of hope arise among supporters of Crawford's Global Network of Automatic Telescopes (GNAT) crusade, but one needs not be a pessimist to conclude that the future for photometry is rather grim.

1.3. REDUCTION PACKAGES

Harmanec et al. 1994 (61.002.020) report on a global reduction of almost 50 000 UBV measurements obtained at Hvar and Skalnaté Pleso Observatories, and present reliable magnitudes and colours on the non-variable (i.e. comparison) stars in a photometric system that very nearly matches Johnson's original UBV system.

CCD photometry and its reduction for stars to $V \sim 18 - 20$ receive profound attention by Jønch-Sørensen 1994 (62.113.042, .113.028)

1.4. SYNTHETIC PHOTOMETRY

A great deal of work seems to be going on in synthetic photometry. Bell et al. 1994 (61.113.041) and Paltoglou & Bell 1994 (61.113.042) give transformation equations between synthetic and observational UBV and Washington systems in a model-independent way. Morossi et al. 1994 (62. 113.050), 1995 (63.113.018) present synthetic DDO indices derived from Kurucz model fluxes. Synthetic photometry techniques are also applied by Colina & Bohlin 1994 (62.113.014) in absolute flux calibration of optical spectrophotometric standards.

1.5. PHOTOMETRIC SYSTEMS

McGregor et al. 1991 (61.113.009) describe the MSSO near-infrared photometric system via the required lists of defining standard star measurements, and filter transmission properties. They give the transformation relations between their system and other near-infrared photometric systems.

In a notorious workshop of the Vatican Observatory (*The MK system at 50 years: a powerful tool for astrophysical insight*, 62.012.096), numerous papers related to photometry and photometric systems were presented, specifically by Cramer, Crawford, Golay, Hauck, Lloyd Evans, Nicolet, Olsen, Davis Philip and other prominent photometrists.

The Conference to honour Cousins in his 90th birthday was a great success, and the Proceedings (63.012.084) contain many good papers on standardisation ($UBVRI$ & $JHKL$, CCD photometry, photographic photometry, transformation problems).

1.6. EXTINCTION

An excellent service is provided by Geneva Observatory under impulse of G. Burki, who distributes at ESO's WWW site a continuous update of Geneva $UBVB_1B_2V_1G$ atmospheric extinction coefficients. These data are determined by the Geneva method, and are obtained with CCD (with extension to RI) and PMT detectors.

Grebel & Roberts 1995 (63.113.016–017) present two important papers on heterochromatic extinction, treating the dependence on stellar temperature, surface gravity and metallicity on interstellar, respectively, atmospheric extinction.

1.7. TRANSFORMATION

Olsen 1995 (63.113.019) comments on the systematic differences between two of the *uvby* systems when extended to late-type metal-deficient stars. Joner et al. 1995 (63.113.022) consider the zero-points of six sets of $uvby\beta$ photometry. They found R.A. and Decl.-dependent offsets amounting to several $0\overset{\mathrm{m}}{.}001$. Straizys & Lazauskaite 1995 (62.113.030) document on the conformity errors in setting up U bands in CCD photometry.

1.8. CALIBRATION

Mégessier 1995 (63.113.020) gives a thorough discussion of the accuracy of visible and near-infrared absolute flux calibrations, and constrains the visible monochromatic flux of Vega within $\pm 0.7\%$. Smalley & Dworetsky 1995 (63.113.013) calibrate fundamental atmospheric parameters ($T_{\rm eff}$, $\log g$) for B, A and F stars from $uvby\beta$ photometry.

1.9. STANDARD STARS

Secondary photometric standards for the Thuan-Gunn and Johnson-Kron-Cousins systems are presented by J orgensen 1994 (62.113.021). Stellar-classification standards in the Vilnius system are given by Bartkevicius & Lazauskaite 1994 (62.113.030). Intrinsic colour indices in the Vilnius system are given by Sudzius & Bobinas 1994 (62.113.005).

1.10. BOOKS

A most important book has just appeared: *The measurement of starlight*, J.B. Hearnshaw (Cambridge Press 1996): a very well-documented monograph dealing with all historical aspects of photometry going from visual magnitude estimates to the newest array detectors. A work every photometry student (even every photometrist) should read at least once.

2. POLARIMETRY

(prepared by J. Landstreet)

2.1. INTRODUCTION

Polarimetry continues to grow as a technique that can provide useful information and constraints on the geometrical organization of complex objects; on the nature, location, and sizes of scattering particles; and on magnetic field structures. There are now well over a dozen polarimeters in active service, some at major national observatories; and polarimetry is gradually ceasing to be a specialized technique understood only by a few, and is becoming a generally available tool. Because polarization of most objects is small, less than 1% and sometimes less than 0.01%, polarimetric measurements require far more photons per measurement than most photometric observations. Polarimetry is therefore often carried out on large telescopes, and does not suffer in the same way as photometry from the steady loss of small telescopes now occurring in the world (see C. Sterken's report above).

Below I offer a rather haphazard overview of some polarimetric observing programmes and the corresponding modelling efforts, as well as referring to reviews. In this section, the references are generally given in abbreviated, rather than *Astronomy & Astrophysics Abstracts* notation, as I do not find it convenient to look up articles via the *A & A Abstracts* myself, and suspect this may be true for many others.

2.2. CLOUDS IN STAR-FORMING REGIONS; PRE-MAIN-SEQUENCE STARS

Polarimetry is now frequently used to help understand the geometrical organization of clouds in star-forming regions and of circumstellar material and jets in the vicinity of young stars, since scattering of stellar radiation by irregularly distributed clouds can easily lead to net linear polarization. In some cases polarization by magnetically aligned grains is also implicated. Polarimetry of young objects is increasingly carried out in the near-IR.

Several reports of polarimetric studies of Herbig Ae/Be stars are presented in *The Nature and evolutionary status of Herbig Ae/Be stars: proceedings of the First International Meeting*, ed Pik Sin The et al (PASP Conference Series, 1994); see particularly articles by Piirola et al, Yudin, Grinin et al, and Bastien et al, as well as the review by Grinin in that volume.

Young stellar objects have been studied with polarimetry by Walther et al 1993 (ApJ, 418, 310); Casale 1996 (MNRAS, 277, 1385); Colome et al 1996 (ApJ, 461, 909); Casement & McLean 1996 (ApJ, 462, 797); and Chrysostomou et al 1996 (MNRAS, 278, 449). Pre-main sequence stars were observed by Hutchinson et al 1994 (A&A, 285, 883).

Disks around stars such as β Pic indicate that such stars may still be rather young. Imaging polarimetry of β Pic itself is described by Wolstencroft et al 1995 (Ap Space Sci, 224, 395), while the dusty and organically rich circumstellar environment of the solar-type star SAO 206462 is studied by Coulson & Walther 1995 (MNRAS, 274, 977).

2.3. CIRCUMSTELLAR ENVIRONMENT OF HOT STARS

It has been known for more than two decades that the radiation from hot emission line stars is often linearly polarized due to the presence of circumstellar material, either in a massive wind, as occurs in Wolf-Rayet stars, or in material which has to some extent taken up residence around the star, as in Be stars. This has been a field in which considerable activity has occurred in the past trimester.

The use of polarimetry to constrain properties of the massive winds of W-R stars was reviewed by Moffat in *The Impact of Long-Term Monitoring on Variable Star Research*, ed Sterken and de Groot (Kluwer, 1994), p 117; Moffatt and his collaborators at the Université de Montréal have amassed an

impressive amount of polarization data for W-R stars. Schulte-Ladbeck 1994 (Ap & Space Sci, 221, 347) reviews the results obtained so far from polarimetry of hot stars; she has been a major participant in the first UV measurements of polarization using WUPPE. In the same issue, Brown 1994 (Ap & Space Sci, 221, 357) reviews the theory of Spectropolarimetry of hot circumstellar gas. Two other useful reviews of this field are in the proceedings of the meeting on *Wolf-Rayet stars, binaries, colliding winds, evolution*, ed van der Hucht and Williams (Kluwer, 1995), of observations by Antokhin (p 87) and of wind modelling by Brown & Richardson (p 186).

2.4. POLARIMETRY OF MAGNETIC A AND B STARS

Polarization measurements, both of single (metallic or Balmer) spectral lines, and of broad spectral bands, play a key role in measurements of stellar magnetic fields. G. Mathys has been carrying out a major programme of spectropolarimetric observations of southern magnetic A and B stars, and has shown that several moments of a general stellar magnetic field are constrained by such data. See Mathys 1994 (A&A Suppl, 108, 547) and 1995 (A&A, 293, 733; and 293, 746). Leroy has recently concluded a major study of the linear polarization variations of a number of cool northern magnetic A stars; a catalogue of his data is in Leroy 1995 (A&A Suppl, 114, 79). These data provide valuable constraints on the transverse component of a stellar magnetic field, a quantity heretofore virtually unmeasured. Modelling of such data is discussed in several recent papers by Landi Degl'Innocenti, Landolfi, Leroy and their collaborators, particularly Bagnuolo et al 1995 (A&A, 295, 459) and Leroy et al 1995 (A&A, 301, 797). An indication of the kind of modelling of the structure of a stellar magnetic field that is now possible by combining several kinds of data may be seen in Wade et al 1996 (A&A, 313, 209).

2.5. GIANT STARS

Because of mass loss, evolved stars sometimes display linear polarization due to scattering from circumstellar material. I have not found any recent review of this subject, but some articles indicative of ongoing interest are the following. Rao & Raveendran 1993 (A&A, 274, 330) and Rosenbush 1995 (Astr Nachrichten, 316, 213) have studied R CrB systems. In *Luminous High-latitude Stars* ed D D Sasselov (PASP Conference series, 1993), articles by Kastner & Weintraub (p 151) and by Nook (p 167) report observations relevant to such stars. The bizarre object η Car was studied by Aitken et al 1995 (MNRAS, 273, 359) and by Falcke et al 1996 (A&A, 306, L17). Polarimetry is one kind of data utilized by Gehrz et al 1995 (ApJ, 439, 417) in a large study of the massive binary system RY Scu.

2.6. CATACLYSMIC BINARIES AND AM HER SYSTEMS

Close binary systems containing a magnetic white dwarf, often with mass transfer onto the degenerate star, are being identified in ever greater numbers. In such systems the magnetic field of the white dwarf is often revealed by strong linear and/or circular polarization of continuum light.

These stars have been extensively reviewed by Brian Warner in his recent book *Cataclysmic Variable Stars* (Cambridge, 1995), over one-quarter of which is devoted to magnetic CV's. They have also figured in a number of recent meetings for which the proceedings are now available, including *Cataclysmic variables : proceedings of the conference held in Abano Terme, Italy*, ed A. Bianchini et al (Kluwer, 1995), the *Cape Workshop on Magnetic Cataclysmic Variables*, ed D A H Buckley & B Warner (PASP Conference Series, 1995), and in *White Dwarfs : Proceedings of the 9th European Workshop on White Dwarfs*, ed D Koester & K Werner (Springer, 1995).

Correspondingly, a number of groups continue to observe and model these exotic systems. Several polarimeters are active in this endeavour, especially the polarimeter of the Nordic Optical Telescope (see for example Hakala et al 1993, MNRAS, 263, 61; and Singh et al 1995, ApJ, 453, L95). Other polarimeters active in this field include that of the University of Arizona (Schmidt et al 1995, ApJ, 441, 414), the Hatfield polarimeter (Bailey et al 1995, MNRAS, 272, 579) and the University of Cape Town instrument (Buckley & Shafter 1995, MNRAS, 275, L61).

2.7. BOOKS

An excellent book that should be of interest to all observational polarimetrists has recently appeared. I refer, of course, to Jaap Tinbergen's *Astronomical Polarimetry*, just published by Cambridge (1996). This book discusses the various methods of describing polarization in light, and the many subtle aspects of actually measuring polarization (mainly of visible light and the radio region, but with discussions of UV, X-ray, and even γ-ray polarimetry)) in a very clear fashion.

3. REPORT OF THE WORKING GROUP ON INFRARED ASTRONOMY

(Prepared by E. F. Milone)

The Working Group has continued to pursue the improvement of IR passbands following the recommendations of the joint meeting of Commissions 25 and 9 at the Baltimore IAU (Milone 1989). The work has also continued to be funded by research grants from the University of Calgary and Canadian NSERC. As previously noted, the passbands of the Johnson JHKLMNQ broadband photometric system along with atmospheric window transmissions were calculated by MODTRAN, and used a series of stellar flux models from Kurucz (1991 private communication) to probe the atmospheric extinction under different water vapor, height, and airmass conditions. The curvature of the resulting extinction line describes the sensitivity of each response function to variations in water-vapor extinction. On the basis of our simulations, and an extensive set of experiments to optimise S/N without seriously degrading the reproducibility and transformability, and subject to field trials, we recommended a set of passband s which should improve both extinction and standardization from all sites, and enable transformable infrared photometry from lower altitude sites than is currently the case, at least for the shorter wavelength passbands. The basis for the work, the procedures, and the recommendations were summarized in Young, Milone, and Stagg (1993, 1994), and in Milone, Young and Stagg (1993, 1995); a paper presenting the extinction curves is in preparation. The importance of the new passbands for studies of binary stars in clusters was reviewed briefly in Milone (1996).

Since the previous report, a small subcommittee of the working group, viz., A. T. Young and Milone, has continued to work on the problem, and has computed the emission expected through each of the tested passbands. First, the atmospheric model used for numerical simulations was upgraded to a recent release of MODTRAN3. Second, numerical experiments confirmed that the new filters have two orders of magnitude less emission in the iK passband over the traditional K filter and more than one order of magnitude improvement over one of the better K filters, in use at the RAO. The experiments also indicated a reduction in emission of 1/3 over the Wainscot-Cowie filter, and nearly a factor 2 improvement over the 2Mass filter for the U.S. Standard atmosphere at a site at 2 km altitude. For the L passbands, the improved iL filter was a factor 6 better than a modern L filter, which is cut somewhat to the red of the original Johnson L filter.

Filters within the specifications of the Young et al. (1994) recommendations have been produced by Custom Scientific of Phoenix and are now available for purchase and testing. Six of these filters (iz, iH, iJ, iK, IL, and iLp) were placed in a dewar equipped with an InSb detector at the Rothney Astrophysical Observatory of the University of Calgary and were undergoing testing in Fall, 1996. Initial trials indicated that the filters were successful at reducing the sensitivity of IR photometry to water vapour, but more trials were needed to check the behaviour of these filters compared to versions of the Johnson filters, and the reliabilty, i.e., self transformation, under different atmospheric conditions. Future acquisition and testing of longer passband filters (iM, iN, in, and iQ) are planned. The WG would like to express its appreciation to David Marcus of Custom Scientific for undertaking the manufacture of these new filters, at reasonable cost, and for extensive discussion and helpfulness. Andy Young provided improvements to the draft versions of this report.

References

Milone E.F. (ed.), 1989, Infrared Extinction and Standardization (Lecture Notes in Physics, Vol. 341). Springer-Verlag, Berlin.

Milone, E.F., Stagg, C.R., and Young, A.T., 1995. "Towards Robotic IR Observatories: Improved IR Passbands", in 'Robotic Observatories', ed. M. F. Bode. (Chichester: Praxis; New York: John Wiley & Sons), pp. 117-124.

Milone, E.F., 1996. "Concluding Postscript" in 'The Origins, Evolution, and Destinies of Binary Stars in Clusters', eds. E.F. MIlone and J.-C. Mermilliod. ASP Conference Series, 90, 505.

Milone, E.F., Stagg, C.R., and Young, A.T. 1993. "Improved IR Passbands for Ground-based Photometry: An Aid to Calibration Efforts" in 'Astronomical Infrared Spectroscopy: Future Astronomical Directions', ed. S. Kwok, ASP Conference Series, 41, 395-396.

Young, A.T., Milone, E.F., and Stagg, C.R. 1993. "Improvements to Infrared Photometry" in 'Stellar Photometry - Current techniques and Future Developments', eds., C. J. Butler and I. Elliott. (Cambridge: University Press), pp. 235-241.

Young, A.T., Milone, E.F., and Stagg, C.R., 1994. "On Improving Infrared Passbands", Astronomy & Astrophysics Suppl., 105, 259-279.