COMMISSION 25. STELLAR PHOTOMETRY AND POLARIMETRY
PHOTOMETRIE ET POLARIMETRIE STELLAIRES

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1. INTRODUCTION.

The outstanding feature of the last triennium was most certainly the abrupt generalisation of the use of array detectors, particularly CCDs (charge coupled devices). The latter pervade all subdivisions of instrumental astronomy. The gains achieved by their high quantum efficiency, their stability, their capability of delivering immediately recordable signals which can be processed by appropriate computational means, have been the cause of spectacular progress regarding the photometric precision of weak signal measurements.

The applications made in stellar- or surface photometry and polarimetry, high- and low resolution spectroscopy, astrometry, are innumerable. Every aspect of experimental research is concerned by these new detectors (at least 60% of the IAU commissions are concerned!). New developments have been made regarding either the number of pixels (chips having 2000 x 2000 pixels have been announced) or lower noise levels at signal readout which thus improve the signal to noise ratio for weak sources and shorten integration times.

Since the evolution of the characteristics of these detectors is not guided by the sole needs of astronomers, we encounter discontinuities regarding the availability of chips having already excellent properties. The varying specifications adopted by the commercial manufacturing companies force renewals which are not always beneficial.

Apart from this infatuation for CCDs, one should not lose sight of the performances already attained by other types of bi-dimensional detectors which are particularly adapted for very weak extended sources. Devices using combinations of elements such as image intensifiers, multichannel plates, CCDs, resistive anodes, etc.. allow the counting of incident photons and their X-Y localisation in the focal plane. The quantum efficiency, resolution and limiting acquisition frequency of these IPCSs (image photo-counting system) have also been improved.

A difficulty which is still in want of a satisfactory solution is the storage of these data. Astronomy makes much use of data centres where classified collections of photographic spectra and stellar fields are kept in view of being available for purposes different to those originally intended. Setting up and coordinating the storage of these "frames" and their instrumental characteristics is a challenge which must be met in regard of future generations.

The continued use of more traditional detectors such as the photographic plate and the photomultiplier (PM), and the quest for improvements of their performances have been but slightly affected by the new techniques. If the disappearance of the AAS photo-bulletin is regrettable it is, on the other hand, satisfying to note that several large scale projects based on the use of hypersensitised photographic plates are still been either continued or newly started. We may point out the following:

- The forthcoming completion of the blue and red atlases of the southern sky made jointly by ESO and SRC.
- The starting of a second version of the POSS in blue, red and IR making use of modern emulsions.

Among the greater efforts undertaken in photoelectric photometry (UBVRI, uvby, Walraven, Geneva) one must mention the acquisition of photometric data necessary for the HIPPARCOS mission. This astrometric satellite conceived by ESA will measure the proper motions of about 100 000 stars and a large number of parallaxes.

The present report has no intent of being exhaustive; it does not represent a summary of Astron & Astrophys abstracts, which is so useful for our community (we take the opportunity here to thank its promoter, prof. W. Fricke, and wish him a profitable retirement). The editors, I.S. McLean for sections 2.1.3. and 3. and F. Rufener for the rest, hope that they have commented on the prominent events with sufficient fairness. To know more about those who have marked the "good old days", one should read (40.004.005) where the early stages of photoelectric photometry are related.

2. ADVANCES IN PHOTOMETRY TECHNIQUES.

2.1 Instrumentation.

2.1.1 Few channel photometers.

The analysis of the properties of PMs used as precision instruments has led Rosen & Chromey to trace the fatigue effects on pulse-counting photometry (39.034.006), Hildebrandt & Lange to determine counting losses (39.036.034), Ebbets to characterise signal to noise rate from pulse-counting devices in presence of various noises (41.034.039), Lamarre to investigate the photon noise in the far IR domain (41.034.090) and Raouff & al to revisit the noise power spectrum (42.036.104). Stecklum investigates stellar scintillation using photon counting statistics (39.082.059). The consultation of the proceedings of the San Diego workshop (40.012.062) is recommended.

We notice an increasing interest for photometers capable of high frequency sampling of signals from rapidly varying objects such as cataclysmic variables or stellar occultations (40.034.057; Bouchet & Guttierrez, Messenger, 45; Pfau at Jena university observatory). This aim is achieved by the complex photometer built in München by Barwig & al which also records 5 colours (UBVRI) on 3 channels (2 stars and one sky-background) simultaneously (38.034.119; Astron & Astrophys 175, 327). The performances of this instrument (MCCP) are unique for the monitoring of weak rapidly variable objects. It uses the transmission of light by fibre optics in a most astute manner. Other photometers also make use of this device as well as differential measurement techniques (39.034.021; 42.034.066; 42.034.218 to 223). An interesting solution is the use of photo-diodes as detectors (37.034.056; 40.012.062; 42.036.085). Provided that the necessary precautions are taken to conserve the passbands, such a technique could be applied to the measurement and monitoring of the brightest stars, as proposed by Crawford (42.113.022).

Much effort has been devoted to the development of photometers for the near- and far infrared (38.034.012; 38.034.166-167; 39.034.030; 39.034.062; 40.034.175-176).

The following references concern new equipment, several of which have been described by our Russian colleagues (39.034.43; 39.034.168; 40.034.058; 40.034.071; 40.034.196-197; 42.034.058). Particular care is taken regarding the conservation of the passbands and long term stability in Young's photometer (42.034.069). Mégevand (Thesis 2190, Geneva University) has presented the concept of a photometer which does rapid sampling of the 7 Geneva colours simultaneously in the star-field and in the 6 background-fields surrounding it. The latter two instruments use the statistical tests presented by Bartholdi & al (37.036.111).

2.1.2 Two dimensional or array photometry.

This rapidly evolving field has several orientations. To gather information on this subject one must consult the main conference proceedings and the following review articles:

- Proceedings of SPIE (The International Society of Optical Engineering) vols: 445, 501 and 627 of the conferences held at London, San Diego and Tucson (38.012.098; 40.012.047; 42.012.092).
- CCD in Astronomy by C.D. Mackay in Annu. Rev. of A & A vol. 24, 255 (42.034.051).
- An enthusiastic review by J.A. Tyson: Low-light-level CCD imaging in astronomy (42.034.162).

The use of CCDs is extensively described by the references given in the above mentioned reviews. I would nevertheless like to point out some works concerning sensitisation in the near UV (40.034.081; 41.034.030) and the applications of CCD cameras using rapid-sampling (37.036.142; 41.034.010; 41.034.041; 42.034.227; 42.036.100). This technique allows the time-resolution of flux variations. The descriptions of CCD cameras are often concise and not detailed enough for the reproduction of similar equipment. One must however welcome the presentation by Gunn & al (PASP 99, 618) who give us a detailed description of the state of development of the Palomar Observatory camera, thereby allowing the astronomical community to profit by their 10 years of experience. Walker (38.113.002) has shown that an accuracy of 1 mmag is possible for the repeated photometry of standard stars.

The processing of information obtained via array detectors has been the object of numerous publications, several of which are in the proceedings of an international workshop held at Erice on data analysis in astronomy (40.012.096), or in the ESO-OHP workshop held at Saint-Michel (June 1986): The optimisation of the use of CCD detectors in Astronomy. Software packages have been developed and distributed abroad. We may mention IRAF (KPNO, Tucson), DAOPHOT (DAO, Victoria) and MIDAS (ESO, München). These systems contain specialised software, such as that necessary to deconvolve crowded fields (FOCAS, ROMAFOT). The analysis of performances achieved has been discussed (41.036.045; K. Mighell in Messenger 47). A review of the methods based on maximum entropy image restoration in astronomy is to be found in (42.036.060).

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A.N. Argue reports as follows: Argue et al have made CCD observations with the 1.0 m Kapteyn Telescope at la Palma of over 3000 binary stars, mostly with separations less than 5 arcsec, selected by J. Dommanget (Obs. Royal de Belgique) as part of the HIPPARCOS project. Reductions are being carried out using M.J. Irwin's "Automatic Analysis of crowded fields" program (40.036.256) .

Several types of image photo-counting systems (IPCS) have been improved and tested. Their intrinsic limitation remains the frequency that each pixel can sustain for a reliable detection to be made (number of photons and X-Y coordinates). These devices are best adapted for weak and extended sources. We may mention Mepsicron (37.034.068), the Multi-Anode Multichannel Array or MAMA (38.034.088; 41.034.161), the proposal by Shectman (42.034.121) or that of Hickson (PASP, 98, 622). The problems related to noise reduction (41.034.168) and the statistical properties of these detectors have also been tackled (42.034.164).

The ability of electronography to achieve high resolution, the large number of pixels and the easy storage of the information continue to interest French (CFHT, Hawaï) and Russian (41.034.047) groups. A good example of the performances that can be attained was presented by Blecha (37.036.143).

Improvements regarding the hypersensitising of photographic plates have extended their possibilities of application. The IAU colloquium 78: Astronomy with Schmidt-type telescopes (37.012.077) and the Edinborough workshop (38.012.067) have examined their potentiality. The photometric-reading of glass-based emulsions has been reviewed by Pierre (41.036.171). The atlases have been discussed in the introduction.

2.1.3 Near Infrared - New Techniques (section by I.S. McLean)

In the past three years near infrared astronomy has undergone a major revolution of staggering importance to the subject. The cause has been the advent of two-dimensional solid-state detector arrays; the infrared analogue of silicon CCDs. A number of major observatories have established "common-user" or "facility" instruments, i.e. cameras and/or array spectrometers including:

- the U.K. Infrared Telescope Unit of the Royal Observatory, Edinburgh,
- the National Optical Astronomy Observatories at Kitt Peak and Cerro Tololo,
- the European Southern Observatory,
- many independent institutes (such as the Institute of Astronomy, University of Hawaii, the Steward Observatory, University of Arizona, Rochester University and many others) have constructed their own instruments.

Of course, it is early days yet, the array formats are still relatively small (64 x 64 approximately), but the sensitivity per pixel is at least as good as the best single-element IR sensors. In the near infrared the current front-runner is the 62 x 58 Indium Antimonide array from SBRC, but recent arrays of Mercury-Cadmium-Telluride (HgCdTe) from Rockwell International also appear very promising. Long-wavelength systems employing extrinsic Silicon photoconductor arrays from Aerojet Electrosystems, SBRC and others have been used by groups at Berkeley, Goddard and UCSD. Depending on the dopant, these arrays are sensitive to approximately 30μm.

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European manufacturers are also participating in these developments. For example, SAT and LETI-LIR (France) and Battelle (Germany) companies are involved in providing array detectors for the ESA Infrared Satellite Observatory (ISO) and Mullards (UK) are making HgCdTe arrays with 3.5 μm cut-offs. For reference to the latest developments see SPIE volumes 627, 782 and "Infrared Astronomy with Arrays" eds. C.G. Wynn-Williams and E.E. Becklin, University of Hawaii, Institute of Astronomy (1987).

It seems likely that IR photometry with panoramic detectors will now encounter problems similar to those already faced by optical astronomers using CCDs. The discussions on standardisation planned for the Baltimore General Assembly should therefore include photometry with infrared arrays. Some effort by this commission to stimulate discussions on standardisation would therefore be very valuable.

2.1.4 Automatic photoelectric telescopes (APT).

The dynamic activity of the IAPPP (International Amateur Professional Photometry) has brought forth an interesting series of communications where Boyd, Genet and Hall (37.036.026) have presented a new and low-priced application of the APT concept which had already been conceived and tried out in the sixties. The successive improvements and the demonstration of the efficiency of the new concept have been described in (38.032.029; 40.032.005; 42.036.082). The scientific motivations and the operation of several APT have been the object of a meeting of which the proceedings have already been published (IAPPP commun. 25). This effort which tends to orient the use of small telescopes to the systematic monitoring of well defined objects is full of promise.

2.2. Extinction.

Atmospheric extinction, its measurement and the limitations it imposes on the photometric accuracy of ground-based observations have been discussed during specialised workshops in Paris (38.012.078) and San Diego (40.012.062). Our Russian colleagues have re-examined the optimisation of methods of reduction outside the atmosphere for wide- and intermediate band photometries (39.036.083; 39.113.026; 39.113.034; 42.036.071). For ground-based observations in the far-IR we can mention (42.082.085). Several retrospective analyses have given a description of the short-, mean- and long-term variations of atmospheric extinction in the visible range and have evaluated the role of volcanic eruptions, particularly that of El Chichón (42.082.029; 42.082.044; 42.082.045; 42.082.083).

2.3. Photometric systems (some references limited to basic aspects).

2.3.1 Broad band systems.

South African colleagues, Cousins first and Menzies & Lang later have collected large pieces of work for standard stars of UBV(RI)c (38.113.049; 38.113.050; 40.113.060). Stobie proposes faint galactic reference stars in 8 fields (39.113.038). Many transformation equations for VRI have been gathered by Taylor (41.036.021). In the USSR an effort to establish an instrumentally well defined and homogeneous WBVR system is related in (39.113.050)

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by Khaliullin & al. Lanz gives a general catalogue of the Johnson UBVRI (42.002.036). The basics of JHKLM is reviewed by Glass (39.113.022). Standard stars for the L and M filter bands are proposed (38.113.022) and absolute calibrations are given in this range (39.113.027; 39.113.028).

2.3.2 uvby & β.

Several publications gather lists of standard stars. Perry and Crawford for the bright stars (42.002.048), Kilkenny, Menzies and Cousins for the E regions (42.113.015; 42.113.019; 41.113.061). Secondary standards near the south galactic pole are proposed in (37.113.040). Philip (39.113.011) has collected faint secondary standard stars for use with large telescopes. A preliminary uvby calibration for G & K type stars is given by Olsen (38.113.014). Manfroid and Heck analyse the accuracy of reduction procedures (37.036.036). Using numerical simulations, Manfroid computes synthetic observations filtered through standard passbands and reduced via the usual transformations. He compares these with those obtained for mismatched passbands. Large deviations are found for objects outside the zone where $0 < b-y < .4$ (38.113.034). More recently, Manfroid and Sterken have strikingly confirmed these effects due to a mismatch by comparing observations of a same sample of stars made with non-identical instrumental systems at the same observatory (Astron & Astrophys, in press). Similar work has also been undertaken by Reimann & Boehm (Astron. Nachr. submitted). Hauck & Mermilliod have compiled a new edition of the uvby,β photoelectric catalogue with 40 484 entries (39.002.016).

2.3.3 Others.

Relationships between stellar magnitudes and photon fluxes are given by Ralys for the Vilnius photometric system (38.113.061). For the same system, an automated two-dimensional classification has been issued from photographic plates (42.113.018). Cramer investigates relations between the β-index and Geneva photometry for B-type stars (38.113.036). A new description of the passbands of the Geneva system, calibrated from recent spectrophotometric data for α Lyr, allows the latest edition of the Geneva photometric catalogue (≈ 28 000 stars) to be used as a low resolution absolute spectrophotometry (Nicolet and Rufener, Astron. & Astrophys. suppl. in press). Luminosity classification with the Washington system is re-examined by Geisler (38.113.026).

2.4. Synthetic photometry and energy distributions.

In the same sense as the points of view expressed during the joint meeting at New-Delhi concerning this subject (42.012.020), synthetic analyses of photometric systems had already been carried out by the Vilnius group (37.113.001-003). The properties of the U filter of UBV and those of the uvby,β system have been reviewed by Bessel, Howell and Lester & al respectively (41.113.034; 41.113.039; 42.113.002). As a by-product from the Geneva passbands evaluation (Nicolet & Rufener, Astron. & Astrophys., in press) a small correction is proposed for the absolute calibration of the Gunn & Stricker spectrophotometric catalogue (33.002.042). Among the new absolute spectrophotometric data we may mention those of Kiehling for stars of type F and later (39.113.063; Astron. & Astrophys. Suppl. 69, 465), those of Taylor (37.113.026) and

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Filipenko & Greenstein for faint spectrophotometric standards useful with large optical telescopes (38.113.017). Calibrations of Vega in the IR (40.113.048; 40.113.057) from 5 to 100 μm have served to fix the instrumental responses of IRAS. Synthetic colours of the Sun (37.113.020) and the optimisation of an ideal photometric system have been discussed this way (41.113.059).

2.5. Photometric faint star sequences.

Apart from the Catalogue of Photometric Sequences one can mention some other sources where sequences of very faint stars are established up to mv ≈ 22 (38.154.038; 38.154.040; 39.113.039; 39.113.061; 40.113.006; 40.113.061; 41.113.048). The method proposed by Jelley (42.034.146) can be a useful alternative.

2.6. Data Centres and Catalogues.

The steadily increasing activities of Data Centres(Strasbourg, Washington, Moscow) which are now as much appreciated as they are essential no longer need to be emphasised here. We may nevertheless mention the major contribution of the CDS in Strasbourg to the preparation of the Input Catalogue by the INCA consortium. This catalogue gathers precise data for ≈ 120 000 stars which can thus be observed during the astrometric mission of the HIPPARCOS satellite. The intersection of this catalogue with the available photometric data produces a list of ≈ 15000 stars without known magnitudes or colours. They are currently being observed with all the available photometric systems. This effort which is already 3/4 completed is being carried out by numerous observers.

From W.H. Warren Jr. (NASA Centre) we get a Report on Machine-Readable Photometric Catalogs Received or Modified in the Period 1 July 1984 through 30 June 1987. Numbers are in the international astronomical data centre numbering system used by Strasbourg and NASA data centres:

Num.	Description (limited to the title)
2092	Revised S201 Catalog of Far-Ultraviolet Objects.
2094	The Revised AFGL Infrared Sky Survey Catalog and Supplement.
2097	ANS Ultraviolet Photometry Catalogue of Point Sources.
2098	Catalog of Infrared Observations.
2101	A Catalogue of Photoelectric Magnitudes and Colours of Visual Double and Multiple Systems.
2106	A Search for Ultraviolet-Excess Objects.
2108	The Two-Micron Sky Survey: Nearest SAO Star and Locations on Palomar Sky Survey Prints.
2114	A Catalog of Ultraviolet Interstellar Extinction Excesses for 1415 Stars.
2115	Faint Blue Objects at High Galactic Latitude. Catalog of Objects in SA 28, 29, 55, 57, and 94.
2116	Photoelectric Photometric Catalogue in the Johnson UBVRI System.
2117	A Catalogue of Concentric Aperture UBVRI Photoelectric Photometry of Globular Clusters.
2118	UBVRI Photometric Standard Stars Around the Celestial Equator.
2119	Stellar Distribution Near the South Galactic Pole, Photographic V Magnitudes and B-V Colours of 640 Stars in Region I.

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2120 A Photometric and Spectrophotometric Investigation in a Region at the South Galactic Pole.
2121 Stellar Distribution Near the Selected Areas 127, 141 and 189.
2122 UBV Photoelectric Photometry Catalogue.
2123 UBV Photometry of Faint Stars (V > 14.5) in the Open Cluster M 67.
2124 Catalogue of UBV Photometry and MK Spectral Types in Open Clusters.
2125 IRAS Catalog of Point Sources.
2126 IRAS Serendipitous Survey Catalog (SSC).

2.7. **Books and Proceedings** (related to the field but not already mentioned).

37.003.082 Solar System Photometry Handbook (Genet).
38.003.002 Advances in photoelectric photometry, Vol. 2 (eds.: Wolpert & Genet).
38.012.037 Rapid variability of early-type stars. Proc. of the Hvar workshop.
40.012.038 Calibration of fundamental stellar quantities. Proc. IAU symposium 111, Como.
41.003.035 Photometric & polarimetric investigations of celestial bodies (ed. Morozhenko).
42.003.048 Méthodes physiques de l´observation (Léna).
42.012.006 Spectroscopic & photometric classification of population II stars (meeting at New Delhi).
42.012.053 Instrumentation and research programs for small telescopes. Proc. IAU symposium 118, Christchurch.

3. POLARIMETRY (by I.S. McLean).

3.1. Introduction.

The field of optical and infrared polarimetry (including photopolarimetry, spectropolarimetry and imaging polarimetry) has continued to grow and blossom over the current triennium. At our meeting in New Delhi we held a special session on polarimetry. One of the highlights of that meeting was the description of polarization facilities for the Hubble Space Telescope by Dr. Olivia Lupie. The tragic loss of the Space Shuttle Challenger, of course, has delayed the launch of the HST but much more work has now gone into the HST instrumentation including polarimetry modes. Similarly, more thought and more work has gone into understanding the effects and consequences on the measurement of polarization implied by the optical designs of the next generation of very large telescopes. Steve West of the University of Arizona has analysed the polarization effects associated with the Multiple-Mirror Telescope (MMT) and demonstrated that the problem is more benign than previously imagined at least for some applications. An analysis by Jaap Tinbergen shows that high precision photometry on VLTs can be affected by polarization effects, especially for full moon.

Much of the real progress in optical polarimetry over the past three years has been in the range and depth of astrophysical applications rather than in new instrumentation. This was evident in Delhi and the trend has strengthened. In the near infrared, however, there has been a colossal impact from the recent advent of solid-state imaging devices; several groups have lost no time in

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producing "infrared array polarimeters" (see below).

When considering the preparation of this report, it became evident to me that "astronomical polarimetry" is now such a fully-fledged subject, that to properly describe progress in this field one has to refer to the progress in a wide range of astrophysical topics, from interstellar dust to BL Lacs, from solar system studies to Seyfert galaxies, and many more. Alternatively, in describing the innovations in polarization instrumentation one finds that these largely stem from detector development, rather than from development of polarization optics. In many ways therefore, there is a huge overlap with the work of other commissions and, in particular, with Commission 9.

3.2. Instrument Developments.

Several new optical polarimeters have come into use in the past three years. One of these is the "Multi-Purpose-Fotometer (MPF)" at the La Palma Observatory. This instrument, designed by Jaap Tinbergen, is a 12-channel photopolarimeter operating with 6 beams. It is a superb, high precision instrument. Another multi-channel photopolarimeter has been built by V. Piirola. The CCD imaging photopolarimeter developed by Ian McLean at the Royal Observatory Edinburgh has been emulated by other groups. Dr. Joe Miller at Lick Observatory reports that he has converted the IDS spectropolarimeter to a CCD instrument. At the Anglo-Australian Observatory, Jeremy Bailey has upgraded the Pockels cell + IPCS spectropolarimeter (originally developed by Ian McLean) to work with a CCD camera. This innovation was beautifully timed to coincide with the discovery of SN1987a! Dr. James Hough, of Hatfield Polytechnic, England, together with Jeremy Bailey, have completed and commissioned a dual optical/IR photopolarimeter system capable of working from 0.3 - 2.5 μm using rotating superachromatic waveplates. In Arizona, Roger Angel and Steve West have developed a new form of retarder based on stress birefringence which, unlike the piezo-optic modulators invented by Jim Kent, operates at a low frequency. Steve has applied this technique to a near infrared array polarimeter. The new 62 x 58 infrared camera on UKIRT has been "adapted" to perform imaging polarimetry by Ian McLean. Many other optical and IR photopolarimeters have come into use or have been busily working e.g. the "Vatpol" developed by George Coyne, Director of the Vatican Observatory, is a robust, modern version of the classical "Minipol" originally pioneered by Kris Serkowski and Tom Gehrels at LPL (Tucson). A remarkable polarimeter-cum-telescope has been designed by Jim Kemp at Oregon to observe the Sun! Jim reports the astonishing polarization levels of 10^6 (i.e. 0.0001%)!

3.3. Astronomical Progress.

The only conference or workshop dealing specifically with polarimetry in this triennium was hosted by George Coyne at the Vatican Observatory, Castel Gandolfo in June 1987. This 2 week meeting included sessions of several days on the polarization properties and modelling of AM Her magnetic binaries, cool long period variables, symbiotic stars, early-type binaries (Wolf-Rayet, T Tauri etc.) and future prospects for polarimetry in astrophysics. The proceedings for this workshop are currently in preparation with a publication date of mid-88 being aimed for. The book will represent one of the most important contributions to the field of

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astronomical polarimetry in recent years since it will be a combination of review articles and new results covering the whole field of polarization from the circumstellar environment of stellar sources. It will turn out to be an excellent source book, the first for many years.

F.G. Rufener

President of the Commission

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