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COMMISSION 25 — STELLAR PHOTOMETRY AND POLARIMETRY

PHOTOMÉTRIE ET POLARIMÉTRIE STELLAIRE

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

According to the IAU membership database, Commission 25 currently has 230 members from 40 countries. The Commission's membership represents 2.4% of the total IAU membership of 9658.

This report presents a small selection of the work of many members of the Commission during the triennium 2006 - 2008. During the current triennium considerable effort was devoted to updating the Commission's membership records. This was done by contacting members individually and requesting them to confirm or update their personal details. Many of the members' details were outdated or incorrect. The updated lists will be sent to the IAU Secretariat in Paris.

In 2007, the Commission's website was moved from its previous host site at the Vrije Universiteit Brussel to the South African Astronomical Observatory. The URL of the new Commission 25 website is `<iauc_25.saao.ac.za>`. We thank Chris Sterken for having established the Commission's website and for having maintained it for a number of years. The Commission plans to change the website to bring it more in line with the 'look and feel' of the official IAU website.

In January 2008 the community of photometrists was saddened by the news that Theo Walraven had passed away. He was a staff member, lecturer and professor at the Leiden Observatory from the 1940s until 1980. He began his career with Anton Pannekoek in Amsterdam working on variable stars and contributed in a fundamental way to our insight into variable stars (together with Paul Ledoux, with whom he wrote the famous article in the *Handbuch der Physik*). He also helped understand the synchrotron radiation in the Crab nebula (with Jan Oort). Highly talented in instrumentation, he developed the 'Walraven photometer' with its corresponding 'Walraven photometric system' on the 0.75 m 'Light collector' at the Leiden Southern Station, near Hartebespoortdam in South

Figure 1. Theodore (Fjeda) Walraven at the 50 cm Zunderman Telescope of the Leiden Observatory, sometime in the 1950s, where he did his extensive work on RR Lyrae stars, published in the *BAN*. Image courtesy of Leiden Observatory.

Africa. From the 1960s onward he and his wife Johanna, who was his close collaborator, lived with their family for most of the time at the Leiden Southern Station, with short visits to Leiden for teaching and developing new instrumentation. The instrument and telescope were moved to ESO in Chile in 1978/79, and the photometric system was in use until some quite some time after the decommissioning of the 'Walraven photometer' in 1991.

2. Photometry

2.1. *Photometric standards and calibration*

Work on photometric standards and calibration, which underpins all photometric applications, proceeded during the triennium under review. Many issues of standardization were discussed in the conference reviewed in more detail in Section 5 below. That conference also provided updates on the Strömvil system and the Walraven system.

Landolt (2007) published $UBVRI$ photoelectric observations of 109 stars around the sky, centered more or less at $-50°$ declination. The majority of the stars fall in the magnitude range $10.4 < V < 15.5$ and in the colour index range $-0.33 < (B-V) < +1.66$.

Rodgers *et al.* (2006) commenced a project to expand the DDO standard star list by integrating Landolt's equatorial standard star fields. The new primary DDO standard stars include the principal $UBVR_C I_C$ stars in the equatorial SA fields, with fainter stars becoming secondary standards for that field. They published preliminary results for the primary standard stars in SA fields 92 through 106, with magnitudes between $9.0 < M_{48} < 16.0$.

Smith *et al.* (2007) reported at the 2007 AAS meeting their progress on an extension of the $u'g'r'i'z'$ standard star network developed to support calibration of the Sloan Digital Sky Survey (SDSS). There were some limitations in the original system due to tailoring the network to support the survey goals, namely a lack of fainter and redder stars. Their latest work includes both fainter and redder stars. Clem *et al.* (2007) presented a new set of secondary standard stars for the $u'g'r'i'z'$ photometric system established in selected open and globular star clusters. These standards are calibrated to the original standard system defined by Smith *et al.* with an accuracy of 1% or better, extend as faint as $r' \sim 20$, and are concentrated in small regions of the sky. As a result, they can serve as viable calibrators of photometry obtained on large-aperture telescopes.

Leggett *et al.* (2006) presented near-infrared JHK photometry of 115 stars. Of these, 79 are faint standard stars drawn from the UKIRT Faint Standards and the Las Campanas standards (but see Milone & Young (2007) and references therein for comments about such 'standardization'). The average brightness of the sample in all three bandpasses is 11.5 mag, with a range between 10 and 15.

Kilkenny *et al.* (2007) presented homogeneous and standardized $UBV(RI)_C JHK$ photometry for over 100 M-type stars selected on the basis of apparent photometric constancy. Most of the stars have a substantial number of $UBV(RI)_C$ observations and could prove useful as red supplementary standards.

2.2. *Photometric studies of the near-Earth space environment*

Photometric techniques have also been used to study space debris, an issue of growing concern to users of near-Earth space. Several papers were presented at the *Advanced Maui Optical and Space Surveillance Technologies Conferences,* held in Wailea, Maui (HI, USA), 10-14 September 2006 and 12-15 September 2007.

A satellite's spectrum has two components: reflected sunlight and blackbody radiation. Hamilton (2006) discussed the use of the extended Strömgren system, $uvbyH_\beta Ca$, as a self-calibrating method of subtracting out reflected sunlight. While the blackbody radiation contribution is weak, it does not have the H_β and Ca II H and K absorption features. Hamilton argues that the signal-to-noise ratio of the blackbody radiation to the solar radiation may be detectable, and that this information may be used for satellite characterization. If so, this would provide a complement to radar-based studies of satellites in the near-Earth orbital environment.

Seitzer *et al.* (2007) presented results of a 14-night study at CTIO to detect and follow-up space debris in geostationary orbit. In this project one telescope was dedicated to survey operations, while a second telescope was used for follow-up observations for orbits and colors. The goal was to obtain orbital and photometric information on every faint object found with the survey telescope. Their survey concentrated on objects fainter than $R = 15$ mag, reaching a limiting R magnitude of 18.0 for a S/N of 10.

2.3. *New space-based and ground-based instruments*

A number of new instruments, both ground-based and space-based, were commissioned during the triennium under review. The list of instruments mentioned here is indicative of the current developments, and is not meant to be a comprehensive review.

Canada's *MOST* (Microvariability and Oscillations of STars) satellite is currently the smallest dedicated space-based photometer in operation. It has been collecting photometric time-series data for asteroseismology of main sequence stars and planetary transit observations since 2003. Huber *et al.* (2008) present *MOST* time series photometry of the rapid oscillations in the roAp star 10 Aql showing the presence of three pulsation frequencies in this star. Miller-Ricci *et al.* (2008) present transit observations of the exoplanet system HD 189733. Another space photometry mission that entered operation during the triennium is *CoRoT*, launched in December 2006. Barge *et al.* (2008) report the detection of the first planet discovered by *CoRoT*. The planet orbits a mildly metal-poor G0V star of magnitude $V = 13.6$ in 1.5 d.

EPOXI is a NASA Discovery Program Mission of Opportunity using the *Deep Impact* fly-by spacecraft. The EPOCh (Extrasolar Planet Observation and Characterization) is a 30-cm visible imager being used to gather photometric time series of known transiting exoplanet systems from January through August 2008. Christiansen *et al.* (2008) present an overview of the project and some preliminary results from observations of six systems.

Earth-bound telescopes are constrained by the diurnal cycle to observe targets for only a fraction of each day, except at the poles, where it is possible to acquire long and continuous photometric time series. Strassmeier *et al.* (2008) present stellar time-series optical photometry from Dome C in Antarctica and analyze approximately 13 000 CCD frames taken in July 2007. They conclude that Dome C in Antarctica can be used successfully for uninterrupted time-domain studies of long duration.

New ground-based instruments under development include the ASTRA spectrophotometer (Adelman *et al.* 2007). The soon-to-be-completed ASTRA spectrophotometer uses an automated 0.50-m telescope with a spectrograph that has a CCD as a detector and produces data with bandpasses of 7 or 14 Å. Once it becomes operational this instrument is expected to produce high-quality fluxes through at least the $\lambda\lambda$ 3300-9000 Å region for application to a wide variety of astrophysical problems.

McGraw *et al.* (2006) are working towards the development of the CCD/Transit Instrument with Innovative Instrumentation (CTI-II). This is a 1.8 m stationary, meridian-pointing telescope capable of millimagnitude photometry and milliarcsecond astrometry. It will also introduce new capabilities in faint object detection and characterization for low Earth orbit and geosynchronous transfer orbit satellites.

Another large ground-based instrument under development is the Advanced Liquid-mirror Probe of Astrophysics, Cosmology and Asteroids (ALPACA), an 8 m optical telescope destined for Cerro Tololo and designed to scan a strip of sky passing overhead and extending over 1000 square degrees (Crotts 2006). The imaging survey will be conducted in five photometric bands covering the optical region. It will allow photometric discrimination of many source types, including supernovae and asteroids, as well as photometric redshift determinations for galaxies and supernovae. The ALPACA is intended to operate over at least three years and is expected reach a cumulative point-source detection limit of about 28 mag at 10 sigma. ALPACA will deliver nightly photometry for many classes of variable and moving objects.

2.4. *Large-scale surveys*

A number of large-scale surveys announced major data releases during the period under review. The Sloan Digital Sky Survey announced its 5th data release (Adelman-McCarthy *et al.* 2007). It includes five-band photometric data for 217 million objects selected over 8000 square degrees. The COSMOS survey announced its 1st data release (Capak *et al.* 2007). They have published imaging data and photometry for the COSMOS survey in 15 photometric bands between 0.3 and 2.4 μm. These include data taken on the Subaru 8.3 m telescope, the KPNO and CTIO 4 m telescopes, and the CFHT 3.6 m telescope. Special techniques are used to ensure that the relative photometric calibration is better than 1% across the field of view. The absolute photometric accuracy from standard-star measurements is found to be 6%.

3. Infrared Working Group

A separate report for the WG-IR can be found in a subsequent chapter of this volume, so the report of the working group here will be brief. The work of the WG-IR during the current triennium was to promote further the benefits of the WG-IR filters as described by Young, Milone, & Stagg in 1994, and demonstrated in Milone & Young (2005). The increased signal-to-noise characteristics and lower extinction coefficients of the corresponding IRWG passbands were further elaborated in presentations to the meeting on standardization held at Blankenberge, Belgium, in May, 2006, and to a meeting of three amateur astronomy organizations (RASC, AAVSO, and ALPO) at Calgary, Canada in July, 2007. The written forms of these presentations can be found in Milone & Young (2007, 2008). The most important tasks at present are to expand the list of standards for the near-infrared part of this system (*iz*, *iJ*, *iH*, and *iK*) to more and fainter stars. This is a priority because of increasing interest by amateur astronomers in the infrared, a desire to obtain the increased variable-star precision that the IR offers, and because these (and perhaps the *iN* and *in* passbands in the relatively clean longer-wavelength 10 μ-m window) can permit meaningful data to be obtained at lower elevation sites.

To date, the filters needed to test the iM, iN, in, and iQ passbands have yet to be manufactured because of increasing filter manufacturing costs. Moreover, the iL and iL' passbands have not yet been tested because of technical problems at the one site where we have had sufficient time to test these filters, the Rothney Astrophysical Observatory. Photometrists with a keen interest in these developments, and who have access to facilities where these tests can be carried out, are urged to contact the chair of the working group.

4. Polarimetry

4.1. *Polarimetric studies - some highlights*

Significant progress has been made measuring magnetic fields in Herbig Ae and Be and other types of stars during the last four years. Polarimetry is used as an important tool for studying debris disks and disks around young stars.

Over the past few years polarimetric observations (e.g., Andersson & Potter 2007) have shown the importance of radiative alignment of dust grains in the interstellar medium. Consequently, more theoretical work has been carried out in this area (e.g., Hoang & Lazarian 2008; Lazarian & Hoang 2008).

Polarization of comets, asteroids and Trans-Neptunian objects as a function of phase angle reveals many properties of surfaces and dust grains. Berdyugina *et al.* (2008)

reported the first detection of polarized scattered light from an exoplanetary atmosphere for the short-period transiting planet orbiting HD 189733b.

Polarimetry, and in particular spectropolarimetry, provides key information about the structure of the inner regions in Seyfert and other active galaxies. Finally, CMB polarimetry, with recent *WMAP* results, the upcoming *Planck* mission and other planned future missions should provide a wealth of information on the early-Universe physics.

Landi Degl'Innocenti *et al.* (2007) presented a review of the current situation regarding polarimetric standardisation. Fossati *et al.* (2007) presented a consolidated analysis of the observations of standard stars for linear polarization obtained from 1999 to 2005 within the context of the calibration plan of the FORS1 instrument of the ESO VLT.

4.2. *New polarimetric instruments*

The South African Astronomical Observatory reports the completion of a new two-channel, High-speed Photo-POlarimeter (HIPPO) for the 1.9 m optical telescope of the South African Astronomical Observatory. The instrument makes use of rapidly counter-rotating (10 Hz), super-achromatic half- and quarter-waveplates, a fixed Glan-Thompson beam splitter and two photomultiplier tubes that record the modulated O and E beams. Each modulated beam permits an independent measurement of the polarisation and therefore simultaneous two-filter observations. All Stokes parameters are recorded every 0.1 sec and photometry every 1 millisecond. Post-binning of data is possible in order to improve the signal. This is ideal for applications such as measuring the rapid variability of the optical polarisation from magnetic Cataclysmic Variable stars. First light was obtained in February 2008.

The prime new optical application is direct imaging of exoplanets (which will be linearly polarized several tens of percent) against the (speckled) residual seeing image of the parent star (which, if within a few tens of parsec, will generally be polarized less than 0.1%). For a properly designed exoplanet polarimeter, this gives an advantage over photometry of a factor of order 1000. Various projects are underway and preliminary designs and concepts were presented at the 2008 SPIE conference in France and the Astronomical Polarimetry 2008 conference (see Section 5) in Canada. Examples are Planetpol (Hough *et al.* 2006), the Extreme Polarimeter (ExPo) (Jeffers *et al.* 2007), and the Gemini Planet Imager (Graham *et al.* 2007).

As the new large telescopes often have Nasmyth foci, the classical prescription for obtaining accurate optical and IR polarimetry needs to be modified. Tinbergen (2007) recently published a tutorial paper in PASP on the principles of Nasmyth focus polarimetry needed for such instruments.

5. Conferences

In May 2006, a meeting on *The Future of Photometric, Spectrophotometric and Polarimetric Standardization* was held in Blankenberge, Belgium. The meeting demonstrated convincingly the ongoing need for careful calibration for all ground-based as well as space-based projects that involve photometric measurement. Organized by former Commission 25 and Division IX president Chris Sterken, the meeting contained descriptions of many contemporary projects and the plans to calibrate instruments. Among those described were such surveys as the LSST, SDSS, Pan-STARRS, SkyMapper Southern Sky Survey, Dark Energy Survey, SNAP, and projects such as *Gaia*, CHORIZOS, OmegaCAM and the ASTRA spectrophotometer. Although most of these projects involved the visible region, the UV and IR were not neglected, with the former represented at least

down to the Lyα line in *HST* measurements, and an entire session devoted to the infrared. In addition to the calibration of instruments and a full discussion of absolute calibration, a number of photometric systems were described. These included the classic *UBVRI*, the Walraven *VBLUW*, *u'g'r'i'z'*, and the *IRWG* and Mauna Kea IR systems. Another entire session was devoted to polarimetry. Chris Sterken provided some telling examples of the need for calibration and standardization, both at the beginning and at the end of the meeting. The proceedings (Sterken 2007) were published in the ASP Conference Series and were dedicated to Arlo Landolt, former President of Division IX and of Commission 25, in recognition of his life's work of setting standards in photometry.

Pierre Bastien (University of Montreal) reports that the conference *Astronomical Polarimetry 2008 – Science from Small to Large Telescopes,* took place from 6 to 11 July 2008 at the Fairmont Le Manoir Richelieu, La Malbaie, in the wonderful Charlevoix region by the St-Lawrence River in Québec, Canada. The meeting attracted 97 keen participants and covered many topics. Refer to `<mars.astro.umontreal.ca/astropol2008/>` for a full list. This website also includes a text describing the scientific impact of polarimetry on theoretical astrophysics.

A whole day was spent on instrumentation for the optical and near-IR, far-IR and submillimetre spectral regions. Other sessions dealt with interstellar matter and molecular clouds, the galactic plane and star formation, stellar magnetic fields, circumstellar matter, the solar system and exoplanets, supernovae and extragalactic polarimetry, and CMB polarimetry. Some instrumentation highlights include an instrument that can measure polarization to 1 part in 10^6 and is now in use for exoplanets, imaging polarimetry with adaptive optics, high speed photo-polarimetry and a polarimeter for use with SCUBA-2 on the JCMT.

The need for faint polarized standard stars for large telescopes was raised. It was suggested to leave this to individual astronomers but that an effort should be made to collate all results in one place. Commission 25 was mentioned as an appropriate place to do so. The production of a database of optical stellar polarization data is currently in progress. All those interested in participating with observations are encouraged to contact Antonio Mario Magalhães, Univ. of Sao Paulo, Brazil. Polarimetry for large telescopes was a main topic of discussion. For some future telescopes, it is already too late to modify planned designs but in other cases, it is still possible to have an effect. For polarimetry, it is much better to design telescopes and instrumentation with the goal of doing polarimetry initially rather than producing add-ons to do polarimetry afterwards. A mission concept study for a future millimeter-wave satellite dedicated to CMB polarimetry was funded by NASA. Its use by astronomers working in other fields is strongly encouraged. This satellite would also be a perfect instrument for a polarization survey of the whole foreground sky. The proceedings of the Astronomical Polarimetry 2008 conference will be published in the ASP Conference Series.

As for future conferences, members of the Commission 25 are preparing a session on *Photometry: Past and Present* for the January 2009 meeting of the American Astronomical Society's History of Astronomy Division at Long Beach, California. The next astronomical polarimetry conference is planned to take place in 2012 in Nice, France.

6. Ongoing and future work of Commission 25

The various large-scale surveys are generating a flood of new standard stars and standard star observations. The Commission believes that some form of coordination among the various initiatives would be helpful to the astronomical community at large. The

Commission is thus planning to develop an IAU standard star database. The final product will be a one-stop location for all standard star data access. It would be a data depository and a gateway to the various recommended data servers via internet access. Such a database would be quality-controlled by a group of experts, so that observers could easily choose suitable and reliable standard stars that they need to use for their observations. The envisaged database should also be compatible with the Virtual Observatory (VO) data standards in order to take full advantage of the suite of data manipulating tools developed by the International VO Alliance.

Apart from providing reliable standard star data, the envisaged data base could also provide information on how to use those standards properly. It has been suggested that the Commission could also compile educational material in the form of a 'cookbook' on methods of doing and using photometry. In this regard the proceedings of the conference on *The Future of Photometric, Spectrophotometric and Polarimetric Standardization,* held in Blankenberge, Belgium in May 2006, would be particularly useful. A working group will take these ideas further at the next General Assembly. In keeping with this, it has been suggested that the Commission could consider organising a symposium on standardization topics across the electromagnetic spectrum.

With regard to polarimetry, the need for faint polarized standard stars for large telescopes was raised at the Astronomical Polarimetry 2008 meeting. It was suggested that Commission 25 would be an appropriate forum to collate all the results in one place. The OC of Commission 25 takes note of this suggestion and will liaise with the organisers of the conference to follow up on the recommendation.

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Peter Martinez
president of the Commission

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