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# COMMISSION B6 — ASTRONOMICAL PHOTOMETRY AND POLARIMETRY

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## TRIENNIAL REPORT 2015-2018

## 1. Photometry

### 1.1. *All-sky photometric survey with* Gaia

The *Gaia* ESA satellite has routinely operated since July 2014 performing a continuous all-sky scan and observing all point-like sources down to $G \sim 20.7$ mag, with $G$ being the broad passband associated to the white light. Besides $G$, *Gaia* is performing low-resolution spectrophotometry (with corresponding integrated $G_{BP}$ and $G_{RP}$ bands, two broad passbands in the blue and red part of the optical spectrum). The mean rate of observations is of about 70 million a day, meaning 630 million photometric $G$ measurements, 70 million BP and 70 million RP spectra a day. Photometric alerts are issued at a rate of about 6 a day. An extension of the mission until end of 2020 was approved by ESA in 2017.

Two major steps have been achieved:

- In September 2016, the Data Processing and Analysis Consortium published the first release of data (*Gaia*-DR1). The catalogue includes positions and $G$ magnitudes of 1.143 billion sources. *Gaia* is a self-calibrated instrument using as many as possible constant sources to define the mean instrument (from observations in the whole focal plane and along time). The calibration model is described by Carrasco et al. (2016). The content and validation of the photometric data in Gaia-DR1 can be found in van Leeuwen et al. (2017) and Kaastra (2017). More detailed information is provided at the *Gaia*-DR1 web pages `https://www.cosmos.esa.int/web/gaia/dr1`. For the brightest stars, $G < 12$, the photometric accuracy is estimated to be limited to a calibration floor of ∼3 mmag for the individual CCD transits; the quoted standard uncertainties on the mean $G$-band magnitudes at the bright end vary by an order of magnitude due to not fully converged calibrations; over the range $G = 12 - 17$, the distribution of photometric standard uncertainties as a function of magnitude shows two bumps at $G \sim 13$ and $G \sim 16$ due to not fully converged calibrations. Zero-point of $G$ photometry was computed on the basis of a set of Spectrophotometric Standard Stars (SPSS, Pancino et al. 2012). The $G$ passband determination can be found in Apellaniz (2007) and Weiler et al. (2018).
- In April 2018, the second release of data (*Gaia*-DR2) occurred. It includes $G$-band photometry for about 1.5 billion sources and $G_{BP}$ and $G_{RP}$ for about 1.1 billion sources.

Including 22 months of observations and improved calibrations, the precisions and accuracies are better than in *Gaia*-DR1. $G$ magnitudes precisions vary from around 1 mmag at the bright ($G < 13$) end to around 20 mmag at $G = 20$. $G_{BP}$ and $G_{RP}$ magnitudes have precisions varying from a few mmag at the bright ($G < 13$) end to around 200 mmag at $G = 20$. The description of the data processing can be found in Riello et al. (2018) and of the properties of the data in Evans et al. (2017). Near very bright sources, in crowded regions, and at the faint end ($G > 19$) of the survey, the photometric measurements from the blue and red photometers suffer from an insufficiently accurate background estimation and from the lack of specific treatment of blending and decontamination from nearby sources. *Gaia*-DR2 is supplemented by light curves of more than 500 000 stars. Zero-points and passbands shape were computed as well on the basis of the same set of SPSS that in DR1.

Despite the limitations of *Gaia*-DR1 and DR2, the *Gaia* photometry is the most accurate and homogeneous all-sky survey to date, and the reference for many current and future on-ground and space projects. In parallel to the DR1 and DR2 publications, Abbott (et al. 2018) discuss in depth the problem of passband determination and formulate it in a basic functional analytic framework. Given a set of calibration sources, the passband can be described with respect to the set of calibration sources as the sum of two functions, one which is uniquely determined by the set of calibration sources, and one which is entirely unconstrained. The constrained components for the *HIPPARCOS*, *Tycho*, and *Gaia*-DR1 passbands were determined, and the unconstrained components were estimated. The work to finalize the calibration of the SPSS has continued with the explanation of the instrumental effects (Altavilla et al. 2015) and the monitoring of the short-term variability (Marinoni et al. 2016).

### 1.2. *Dark Energy Survey*

In January, the Dark Energy Survey (DES) was released with the coadded images and catalogs from its first 3 years of operations (Abbott et al. 2018). These data are calibrated to uniformity of c. 0.7 percent (0.007 mag) RMS over the 5000 sq deg of the DES footprint (Burke et al. 2018), and the DES photometric system is tied to the AB system via the HST CalSpec standard C26202 at the c. 1 percent level. A set of c. 22 million calibrated standard stars in the DES photometric system within the DES footprint was one of the outputs of this effort, and this set will be described in a future paper.

The southern sky candidate DA white dwarf followup effort continues. The goal is to use the modeled spectra of the confirmed DA white dwarfs as spectrophotometric calibrators for large current and future surveys and instruments. With a particularly successful observing season behind us, we now have spectra for nearly 200 candidate DA white dwarfs and followup imaging (to obtain*u*-band data and to monitor candidates for any signs of variability) for roughly 500 targets.

### 1.3. *SDSS-ugriz standard star system*

The SDSS-*ugriz* standard star system for the entire sky is being refined and readied for publication. This will be an outgrowth of Smith et al. (2002), the original standards paper for the northern hemisphere and equator. The initial set of southern hemisphere standards has been use for about 10 years We have refined the list, selected the best of the potential standards and are preparing it for publication. See $http://www-star.fnal.gov/Southern_ugriz/New/index.html$.

1.4. *Optical Region Spectrophotometry*

S. Adelman, A. Gulliver, G. Hill, and B. Smalley expect that their 0.5-m ASTRA Spectrophotometric Telescope System will be completed before the IAU General Assembly so that they can report on how well it is operating and show examples of its results. It is designed to obtain flux calibrated spectra at classification dispersion. From these fluxes variability studies of the continuum spectra can be performed and the strongest lines can be measured. The resolution is 7 Angstroms in second and 14 Angstroms in first order. The wavelength range is approximately $\lambda\lambda$ 3300-9000. Initially they plan to use about 10 minutes/hour to observe Vega and secondary standard candidates. It will observe from the New Mexico Skies Observatory, near Mayhiil, NM, USA.

## 2. Polarimetry

2.1. *Introduction*

Polarimetry continues to be a very active field, be it in terms of research papers, meetings, instruments and research programs. This was particularly true from November 2015 through February 2018, period to which this modest report refers to. The area of optical high angular resolution continues to progress very rapidly, while the sub-mm band is also growing fast. The simultaneous use of various bands to approach a problem has become commonplace. Below we highlight some areas where research in polarimetry has been very active. Then, after reviewing some of the progress in polarimetric instrumentation, we mention meetings that took place or will take place in the near future, including those in the forthcoming IAU GA 2018 in Vienna, as well as the Astropol 2019 currently being planned.

2.2. *Areas of Research*

Here we outline some areas in which polarimetry has been playing a major role. The links provided in the Instrumentation and Meetings sections below provide more details on the research being done, as well as references to papers and projects that are being carried out. The mm and sub-mm polarization all-sky data made public by the Planck satellite has continued to generate a large number of papers in the refereed journals. These include works related to both Galactic foreground and Extragalactic and Cosmology physics.

In the field of the Interstellar Medium (ISM), Molecular Clouds and Star Formation, topics of research have included: Observations and Theory of grain alignment, ISM magnetic field structure and its role in Star Formation, magnetized turbulence and pre-stellar cores. Data spanned bands from the optical/NIR to the sub-mm. The relation between the Solar System's heliosphere and the magnetic field of the Solar neighborhood have been under scrutiny with optical polarimetry, with the Voyager 1 spacecraft and the IBEX experiment playing a crucial role.

Circumstellar matter is a field of study which continues to profit from polarimetric observations. While angularly unresolved stellar envelopes continued to be studied, optical/NIR direct polarimetric imaging with large telescopes has definitely come of age. Debris and protoplanetary disks have been prime targets, while dusty nebulae illuminated by nearby stars have also been observed. In this area, sub-mm polarimetry with ALMA and other interferometers and polarimeters should become mainstream. Solar and stellar magnetic fields continued to be an area of intense activity. In particular, stellar magnetic fields continued to profit from the existing high spectral resolution polarimeters and tools such as Least Squares Deconvolution. Exoplanet polarimetry, either by reflection or by transit, both proposed in more detail about a decade ago or so, is a technique that also seems valuable for exoplanet work.

Finally, CMB polarimetry and the search for the B-mode polarization pattern continues to be the next great challenge in the field of Cosmology, particularly with the possible detection of B-modes from inflation with the BICEP2 instrument. While BICEP2 and Planck data showed that Galactic dust plays a larger role than anticipated, the race is still on for that conclusive detection.

### 2.3. *Polarimetric Instrumentation*

This period saw the coming of age of important polarimetric instrumentation that have been or are being added to the suite available to users. The links below should help with providing both much more detail and the current capability of the instruments. In the mm and sub-mm domain, the latest improvements of the polarimetric capability of ALMA, first implemented in its Cycle 3 (2015-16), will undoubtedly have increased impact in the coming years. Future cycles should see most of the current limitations of the ALMA polarimetric mode lifted. At the James Clerk Maxwell Telescope, POL-2, the polarimeter that uses the SCUBA-2 detector, has been commissioned at 850 $\mu$m (2016) and also at 450 $\mu$m (2018). A survey to study B-fields In STar-forming Region Observations (BISTRO) by a large consortium from East Asian countries, the UK and Canada is ongoing. In the meantime, several cosmological projects aiming at the difficult detection of the B-mode polarization signal in the Cosmic Background Radiation, either on the ground or via balloon, are taking place or nearing data collection (BICEP2/Keck Array/BICEP3, CMB-S4, Spider, LSPE-SWIPE). Cosmic magnetic fields on the cosmic scale will be one of the main goals of the Square Kilometer Array (SKA), whose construction is slated to begin in 2018.

In the optical/NIR domain, GPI, the Gemini Planet Imager, a extreme adaptive optics imaging polarimeter, continues to provide diffraction-limited imaging between 0.9 and 2.4 $\mu$m. At Gemini North, a community supported proposal for commissioning the GPOL polarimeter in the near future has met with success. At the ESO/VLT observatory, SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch) continues to be an incredibly productive instrument, with several hundred papers in the past 2-3 years. Two of the three instruments that are fed by the adaptive optics forefront unit have polarimetric capabilities: IRDIS provides dual-polarization imaging in the NIR and ZIMPOL provides classical imaging and differential-polarimetric imaging in the visible with resolution better than 30 mas. Circumstellar disks, eventually affected by putative planets, remain a prime field of study with SPHERE, but recent imaging of stellar atmospheres have been equally impressive.

In contrast to these high angular resolution instruments, the era of optical/NIR polarimetric surveys seems to have arrived. The Galactic Plane Infrared Polarization Survey (GPIPS), an H-band (1.65 $\mu$m) survey of the Northern (l = 18 - 56, b = 1) Plane, is readying its 4th data release. In the optical (V-band), SOUTH POL will cover the Southern Sky from the pole up to $\delta$ = -15, with an expected accuracy of 0.1percent at V 15. The SOUTH POL polarimeter has just seen first light in mid-November of 2017 at CTIO, Chile. At the University of Hiroshima, SGMAP, a Northern optical all-sky survey is also being proposed. These surveys, complemented by the sub-mm surveys and observations, will undoubtedly provide an unprecedented view of the Universe in polarized light. Areas such as Star Formation, Molecular Cloud structure and evolution, Stellar Envelopes, GRB, Galactic Structure, AGN and Cosmology will benefit tremendously.

### 2.4. *Meetings*

This period encompassed several important meetings related to polarimetry. Japanese astronomers played a pivotal role in the field of multi-wavelength polarimetry. The Cosmic Dust series, which originated as a session of the Asia-Oceania Geoscience Society in 2003, is now an yearly meeting on its own, with its last several editions being held at different venues in Japan. All of these have had contributions related to polarimetry, with plenty of time scheduled to allow interactions among participants. Hiroshima University has held the Cosmic Polarimetry from Micro to Macro Scales conference, in their Core of Research for the Energetic Universe series. The conference had talks covering polarization modeling, current and future instrumentation and results all across the electromagnetic (ELM) spectrum, from gamma-rays and hard/soft X-rays through optical/NIR and the sub-mm. The talks' slides can be downloaded from the above page and provide an impressive overview, sure to be of interest to researchers and students alike.

The forthcoming IAU XXX General Assembly in Vienna in 2018 will have meetings where polarization results will take part. The IAU Focus Meeting FM12 - Calibrations and Standardization Issues in UV-VIS-IR Astronomy will discuss the title topic across different techniques (spectroscopy, photometry and polarimetry). IAU Focus Meeting FM4 - Magnetic fields along the star-formation sequence will discuss polarimetry across the several physical scales involved in the star formation process. IAU Focus Meeting FM3 - Radio Galaxies: Resolving the AGN Phenomenon will discuss radio galaxies' properties and evolution across the ELM spectrum. IAU Focus Meeting FM8 - New Insights in Extragalactic Magnetic Fields will put together observational, theoretical and computational work to study magnetic fields on a cosmic scale, We close this report with the good news that the next meeting of the popular Astropol series, Astropol 2019, will take place in May hosted by the Hiroshima University, with support from other Japanese institutions. The previous meetings of the series were in 2004 (Hawaii), 2008 (La Malbaie, Quebec) and 2014 (Grenoble).

## References


Abbott, T. M. C., Abdalla, F. B., Allam, S., Amara, A., Annis, J., Asorey, J., Avila S., et al. 2018, adsabs.harvard.edu/abs/2018arXiv180103181A

Altavilla, G., Marinoni, S., Pancino, E., Galleti, S., Ragaini, S., Bellazzini, M., Cocozza, G,, Bragaglia, A., et al. 2015, AN, 336, 515

Burke, D. L., Rykoff, E. S., Allam,, S., Annis, J., Bechtol, K., Bernstein, G. M., Drlica-Wagner, A., et al. 2018, AJ, 155, 41

Carrasco, J.-M., Evans, D.-W., Montegriffo, P., Jordi, C., van Leeuwen, F., Riello, M., Voss, H., 2016, A&A, 595,7

Evans, D. W., Riello, M., De Angeli, F., Busso, G, van Leeuwen, F., Jordi, C. Fabricius, C., et al., 2017, A&A, 600, 51

Kaastra, J. S. 2017, A&A, 605, 51

Marinoni, S., Pancino, E., Altavilla, G., Bellazzini, M,, Galleti, S., Tessicini, G, Valentini, G., et al., 2016, MNRAS, 462, 3616

Pancino, E., Altavilla, G., Marinoni, S., Cocozza, G., J. M., Bellazzini, M., Bragallia, A, Federici, L., et al., 2012, MNRAS, 426, 1767

Riello, M. et al. 2018, in preparation

Smith, J. A.,Tucker, D. L., Kent, S., Richmond, M. W., Fukugita, M., Ichikawa,, T., Jorgensen, A. M., 2002, AJ, 123, 2121

van Leeuwen, F., Evans, D. W., De Angeli, F., Jordi, C., Bussi, G., Cacciari, C., Riello, M. et al., 2017, A&A, 599, 32

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