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COMMISSION E1 SOLAR RADIATION AND STRUCTURE

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Commission E1 WG **Solar Irradiance**

TRIENNIAL REPORT 2015-2018

1. Introduction

The IAU Commission "Solar Radiation and Structure" covers observational and theoretical aspects of the quiet Sun radiation, structure and variability. The range of scientific topics of the Commission "Solar Radiation and Structure" is defined as "quiet- Sun" studies to distinguish these from the impulsive solar activity covered by the Commission E2, although there are close interconnections between these two major parts of heliophysics and the two Commissions keep close collaboration within the framework of Division E, to ensure exchange of relevant information, promote connections and avoid redundancy.

The primary goals of the Commission are to investigate and understand the solar composition, the interior structure and dynamics, the mechanism of the solar magnetic cycles, the structure and dynamics of the solar atmosphere, the physics of magnetic structures, the sources of solar irradiance and long-term variability. The Commission topics also include synoptic observing programs, observational, data analysis and modelling techniques, and coordination of international observing campaigns, space and ground-based observations.

The following sections briefly review the Commission activity during 2015–2018 and some of the highlights in the field. As always, this report mainly focuses on the topics of interest of the Commission Organising Committee and is by no means exhaustive.

2. Organisational activities 2015–2018

During the last triennium, Commission E1 proposed and organised a number of IAU meetings. During the last IAU General Assembly in Honolulu, USA (August 2015), the IAU Symposium 320 "Solar and Stellar Flares and Their Effects on Planets" and the Focus Meeting 13 "Brightness variations of the Sun and Sun-like stars" profited from the broad international and interdisciplinary audience attracted by the general assemblies. The meetings were attended by solar, stellar and exo-planetary research communities and stimulated active discussions.

The IAU Symposium 327 “Fine Structure and Dynamics of the Solar Atmosphere” in Cartagena de Indias, Colombia (October 2016) focussed on the processes shaping the multi-scale structure of the solar atmosphere, its magnetic coupling and dynamics, energy release and explosive events. Special attention was paid to new observational diagnostics, such as high-resolution imaging spectroscopy and spectropolarimetry, and state-of-the-art theoretical models and numerical simulations, providing a platform for developing new coordinated observing and theoretical programs.

Comission E1 also contributed to the organisation of the IAU Symposium 328 “Living around Active Stars” in Maresias, Brazil (October 2016), which addressed the activity of stars, such as our Sun, including the influence of this activity on stellar environments. The symposium emphasised the high interdisciplinarity of this topic and thus urgent necessity of the coordinated effort by solar, stellar, planetary, atmospheric and climate physicists, as well as astobiologists to allow further efficient progress in our understanding of solar and stellar environments.

The IAU Symposium 340 “Long-term datasets for the understanding of solar and stellar magnetic cycles” in Jaipur, India (February 2018) co-organised and actively supported by the commission, accentuated the scientific heritage of historical observational archives, and the necessity of preserving, exploitation and continuation of the long-term observational programmes.

At the forthcoming General Assembly in Vienna, Austria (August 2018), Commission E1 and the commission working group ”Solar Irradiance” organise the Focus Meeting 9 “Solar Irradiance: Physics-Based Advances”. The meeting aims at stimulating the communication and collaboration between the irradiance community and researchers working in the fields of solar and stellar MHD simulations, radiative transfer, and surface-flux transport, in order to incorporate recent advances in these fields into the next generation of solar irradiance models. Another meeting taking place during the General Assembly in Vienna and supported by the commission is the Focus Meeting 12 “Calibration and Standardization Issues in UV-VIS-IR Astronomy”. It aims at initiating a coordinated worldwide effort to establish new standard sources, data formats and software packages to be used by many astronomers for different projects, rather than individual specific projects, as it is currently often done.

3. Commission Working Group

As proposed at the last General Assembly in Honolulu, Commission E1 initiated establishment of the Working Group ”Solar Irradiance”. The proposal was submitted and approved by the Division E in October 2015. Among the issues addressed by the WG activities are the magnitude of the solar cycle variability in the UV, the uncertainties in irradiance measurements, understanding and reconstruction of solar variability and irradiance for the pre-satellite period, coordinated efforts for intercomparisons between various measurements and models. The WG “Solar Irradiance” organises the Focus Meeting 9 at the forthcoming General Assembly in Vienna (see Sect. 2). A more detailed description of the WG activities is given in a separate report by the WG.

4. Developments within the past triennium

The research and observational highlights in the field in last triennium include (but by no means are limited to):

– Solar composition studies. This is still a highly debated problem (Steffen et al. 2015; Vagnozzi et al. 2017). New results reduce the disagreement of the solar model with helioseismology at the base of the convection zone but lead to a higher temperature of the solar core and to a disagreement with measurements of solar neutrinos. There were attempts to resolve the discrepancy of solar models with helioseismology by adjusting the opacity values at the base of convection zone (Bailey et al. 2015; Iglesias 2015), but further experiments are needed to resolve this important issue.

– New opacity calculations, e.g. Los Alamos OPLIB opacity tables or OPAS calculations (Colgan et al. 2016; Mondet et al. 2015).

– Studies of the global and local structure and dynamics of the Sun. These include attempts to detect solar gravity (g) modes by Fossat et al. (2017) or to resolve the important debate on the structure of the global circulation (Chen & Zhao 2017; Rajaguru & Antia 2015; Jackiewicz et al. 2015; Schad et al. 2015) and its variation with time (Komm et al. 2015, 2017; Kosovichev & Zhao 2016).

– Local helioseismology studies were focused on analysis of subsurface flow patterns associated with supergranulation and active regions (Greer et al. 2016; Woodard 2016; Švanda & Kozoň 2017).

– Helioseismic studies of sunspots and active regions (e.g., Cally et al. 2016; Felipe et al. 2017; Felipe & Khomenko 2017; Kosovichev et al. 2016).

– The mechanism of solar activity cycles remains enigmatic. Among the recent highlights are 3D numerical simulation studies (Guerrero et al. 2016; Beaudoin et al. 2016; Fan & Fang 2016; Chen et al. 2017), advances in the mean-field dynamo theory (Pipin 2017; Bekki & Yokoyama 2017; Pipin & Kosovichev 2018) and attempts of early predictions of the next solar cycle (Hathaway & Upton 2016; Cameron et al. 2016; Wang 2017; Kitiashvili 2016; Petrovay et al. 2018).

– Observational studies and simulations of the quiet Sun magnetic fields. The quiet Sun is filled with a small-scale turbulent magnetic field presumably maintained by a turbulent small-scale dynamo acting largely independently from the global solar dynamo responsible for the solar cycle (Borrero et al. 2017, and references therein). A complete understanding of the quiet-Sun magnetic fields is still missing, but significant progress in understanding has been done in observations thanks to the improved instrumentation and spatial resolution (Danilovic et al. 2016; Lagg et al. 2016; Lites et al. 2017; Smitha et al. 2017) and numerical simulations (Rempel 2014; Hotta et al. 2015; Hotta 2017; Khomenko et al. 2017; Kitiashvili et al. 2015).

– Investigation of the effect of the small-scale magnetic field on the assessment of the chemical composition of the Sun. When the state-of-the-art 3D MHD small-scale dynamo simulations (Rempel 2014) are employed in such studies, the effect of the small-scale magnetism is found to be small (Shchukina & Trujillo Bueno 2015; Shchukina et al. 2016).

– Development of the new generation of physics-based irradiance models. The state-of-the-art 3D MHD simulations have also been employed for modelling the variability of the total solar irradiance, for the first time ever without a recourse to the irradiance measurements (Norris et al. 2017; Yeo et al. 2017). The excellent agreement of the model with the measurements provides the final proof of the solar surface magnetism being the driver of the irradiance changes on time scales of days to decades.

– Discovery of the scattering polarization in the solar hydrogen Ly-alpha line. The Chromospheric Lyman-Alpha SpectroPolarimeter (CLASP) sounding rocket experiment, a result of an international collaboration between USA, Japan and Europe, was launched on 3 September, 2015. The spectro-polarimetric observations of the hydrogen Ly-alpha line (121.57 nm) with an unprecedentedly high polarization sensitivity Giono et al. (2016) allowed the discovery of the predicted Lyman-alpha scattering polarization pattern, showing conspicuous spatial variations on scales of the order of 10 arcseconds (Kano et al. 2017). Additionally, the scattering polarization was also discovered in the resonance line of Si III at 120.6 nm (Ishikawa et al. 2017). These observations help constraining theoretical models of the chromosphere–corona transition region and extrapolations of the magnetic field from photospheric magnetograms. The second flight of CLASP is foreseen for 2019, with the goal of measuring the linear and circular polarisation of the Mg II h & k lines in the solar atmosphere.

– Solar chromospheric heating. Despite great progress in both observational and simulation methods, the mechanism of energy transport from the solar convection zone into the upper atmosphere, and the upper-atmospheric heating mechanism remain the main unresolved problems in solar and stellar structure. Ruderman et al. (2018); Khomenko (2017); Shelyag et al. (2016) analysed the role of non-ideal plasma effects and partial ionization in the solar atmospheric energy transport and chromospheric heating and showed that compressible and incompressible oscillations in solar magnetic fields are, indeed, able to provide sufficient energy to compensate chromospheric radiative losses.

– Development of spectropolarimetric tools, in particular in the UV and IR. Understanding of the magnetic field in the outer solar atmosphere is an important challenge in astrophysics, thus there is a need to identify, measure and interpret observable quantities sensitive to the magnetism of the upper chromosphere, transition region and corona. Trujillo Bueno et al. (2017) reported on diagnostic potential of spectropolarimetry in permitted spectral lines of the ultraviolet solar spectrum. Also, interest in the 10 830 Å spectral region has been growing over the last 15 years following advances in theory as well as in IR spectropolarimetric instrumentation. In particular, the following facilities are presently under development: the 4-m Daniel K. Inouye Solar Telescope (DKIST), the 4-m European Solar Telescope (EST), the 1.5-m GREGOR solar telescope and the Japanese Aerospace Exploration Agency mission Solar-C. The infrared instruments planned for DKIST will provide unprecedented IR observations with the highest spatial resolution possible from the ground. The GREGOR telescope hosts the GREGOR Infrared Spectrograph (GRIS), designed for spectropolarimetry in the 10 000–18 000 Å region.

– Investigation of the mechanisms at the origin and evolution of prominence-like tornadoes, e.g. using observations from EIS, AIA, THEMIS and IRIS (Mghebrishvili et al.

2015; Levens et al. 2015, 2016; Schmieder et al. 2017).

– Analysis of the magnetic flux ropes as a fundamental part of coronal mass ejections (Cheng et al. 2015; Liu et al. 2015; Piersanti et al. 2017; Heinzel et al. 2016). This type of investigation will certainly provide a useful basis for future observations provided by the METIS instrument on Solar Orbiter.

– Probing the chromosphere-corona mass cycle through coronal rain (Kohutova & Verwichte 2016).

– Formation of the helium spectrum (Giunta et al. 2015; Leenaarts et al. 2016). Using detailed non-LTE radiative transfer calculations, Leenaarts et al. (2016) identified two important mechanisms yielding strong spatial variations in that line's opacity, namely the spatially- structured emissivity of photons at wavelengths shorter than 504 Å (capable of ionising neutral helium) from hot material $T \approx 10^5$ K in the transition region, and the variations in the chromospheric electron density.

– Studies of magnetic loops and measurements of the plasma flow velocities (Ghosh et al. 2017; Harra et al. 2017; Sterling et al. 2017; Panesar et al. 2018; Kumar et al. 2018).

– Investigations of solar flares and magnetic energy release processes (Simões et al. 2015; Milligan 2015; Brosius et al. 2016; Gömöry et al. 2016; Lee et al. 2017; Heinzel et al. 2017; Jeffrey et al. 2017; Dzifčáková et al. 2018) using in particular Hinode/EIS, IRIS, and RHESSI observations. A new tool, the Solar Flare Finder, provides a way to identify which flares were observed by several user-selected instruments, and this gives an additional resource to researchers for planning detailed analysis of interesting events (Milligan & Ireland 2018).

5. Closing remarks

An extended version of this report, with more details on scientific highlights in fields of interest to Commission E1 as well as developments in the instrumentation is in preparation for "IAU Transactions". It will be completed at the end of the triennium, after the forthcoming General Assembly in Vienna, Austria in August 2018. Commission E1 will be contributing to the General Assembly activities through FM-9, FM-12 and the Division-E Days.

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president of the Commission

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