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DIVISION E / COMMISSION E1 / WORKING GROUP SOLAR IRRADIANCE

CHAIR **Greg Kopp**
VICE-CHAIR **Alexander Shapiro**

TRIENNIAL REPORT 2015-2018

1. Introduction

The Commission E1 "Solar Irradiance" Working Group (WG-SI) was created following a Joint Commission Meeting at the IAU General Assembly in Honolulu in 2015. That GA XXIX meeting included a focus meeting titled "Brightness Variations of the Sun and Sun-Like Stars" with the resulting publication in Krivova, Kopp, Shapiro, and Unruh (JSWSP 2017). From that FM13, it was apparent that while the total solar irradiance (TSI) variability on multiple-day and 11-year timescales is relatively well constrained, there were several issues, particularly regarding the newer spectral solar irradiance (SSI) measurements, that our WG-SI could address:

1. The magnitude (primarily in the UV part of the spectrum) and the phase (mainly in the visible) of the 11-year solar-cycle SSI variations were highly controversial.
2. Reliable estimates of uncertainties in many irradiance datasets were missing.
3. There are no direct irradiance measurements prior to the satellite era to help constrain the variability of solar irradiance on centennial timescales, so an alternative was needed for Earth climate studies.
4. Coordinated efforts for data inter-comparisons between various independent measurements as well as between measurements and models were needed.

Some of these issues are best addressed at the instrument level, while others benefit from comparisons between data and solar models or between solar and stellar observations. The WG-SI brought together experts representing all these diverse fields. The results of this working group will be summarized at Focus Meeting 9, "Solar Irradiance: Physics-Based Advances" at the upcoming IAU GA XXX in Vienna, Austria in 2018.

2. Developments within the past triennium

Understanding solar variability involves diverse scientific and instrumentation fields, including solar-variability measurements, solar-irradiance modeling, and knowledge of the causes of variability of the Sun and/or stars. Interactions between these disciplines can help explain the many causes of solar variability.

Refinements to the instrument-measurement record, particularly those from the NASA SORCE mission's SSI instruments, have reduced the magnitude of some of the previously-suspect trends in solar irradiances over the last few years. Initial SSI results from the Spectral Irradiance Monitor (SIM) on this mission suggested an out-of-phase behavior of the visible- and NIR-wavelength irradiances with the solar cycle as well as more extreme solar variability at UV wavelengths than other instruments or models measured. More recent SIM measurements during Solar Cycle 24, however, are not so extreme in the UV and follow this recent solar-cycle phase better in the visible, likely due to better corrections for instrument degradation during this later era. These newer data and improved instrument corrections help address Item #1 above.

Two of the WG-SI's members, Kopp and Werner, have launched new TSI-measuring space-borne instruments and compared the results from those with other on-orbit TSI instruments. These instrument-comparison efforts involving the Total Irradiance Monitor (TIM) on the NASA Total and Spectral Solar Irradiance Sensor (TSIS) and the NorSat1 Compact and Lightweight Absolute Radiometer (CLARA), as well as efforts from a NASA Solar Irradiance Science Team (SIST) effort led by WG-SI chair Kopp, help refine agreement of and uncertainties in on-orbit solar-irradiance measurements, addressing Items #2 and 4 above. That SIST effort involves the creation of a new "Community Consensus" TSI composite that will combine the measurements of all the space-flight TSI instruments into a single composite for use by climate and solar researchers, further addressing Items #2 and 4.

A new physics-based solar-irradiance model, SATIRE-3D (Yeo et al. 2017), which combines improvements in solar magneto-hydrodynamics (MHD) and the most stable TSI instrument record, that from the SORCE TIM, fits the TSI measurements extremely well, indicating a better physical understanding of the causes of solar variability as being almost completely due to solar-surface magnetic features. Similar solar-irradiance models can help extend the 40-year space-borne measurement record to historical time ranges needed for Earth-climate studies via correlations with solar-variability proxies such as sunspot number, sunspot area, Ca K, Mg II, and F 10.7, as needed for Item #3. Additionally, WG-SI chair Kopp is a member of a newly-selected ISSI team that is reviewing and refining the 400-year-long sunspot data-record, including new reconstructions such as the statistical, non-linear comparison approach of Chatzistergos et al. (2017). These efforts provide better knowledge of historical solar variability and help address Item #3.

Observations of stellar variability can indicate how typical the observed solar variations are on solar-rotational and solar-cycle timescales, and can perhaps even indicate the likelihood of solar variations on long-term timescales via statistical samplings of many thousands of stars. Recent improvements in understanding of solar and stellar dynamos help explain the physical processes behind solar-cycle and longer-term variations. Shapiro et al. 2017 show via power spectra using MHD simulations and solar-irradiance models that observed irradiance variability on timescales longer than days is almost completely due to the two competing solar-surface magnetic features of sunspots and faculae. Recent work by WG-SI chair Shapiro and his student has greatly increased the speed of solar- and stellar-atmosphere opacity calculations to improve radiative-transfer and MHD-based estimates of solar and stellar brightness. And a new method based on power spectra of photometric-brightness time series helps determine stellar-rotational periods, to which which many stellar parameters such as age, temperature, mass, and brightness are linked. These improvements utilize newly-available data of hundreds of stars from the Kepler mission as well a baseline of high-cadence solar-irradiance data from the WG-SI members.

One key aspect of our group's effort has been on interdisciplinary communications, needed to bring together the diverse solar/stellar and observational/modeling fields represented. The WG-SI has initiated a newsletter to the group's members to provide coordination and interactions. We have also created a website summarizing the group's goals to improve inter-disciplinary communications. The FM9, "Solar Irradiance: Physics-Based Advances," at the upcoming IAU GA XXX in Vienna, Austria in 2018 will bring together experts from around the world to discuss the latest research in each of the areas explaining the causes of solar variability. That meeting is focused on the improvements to our understanding of the physical causes of variability in the solar irradiance, including advances in radiative transfer, MHD, and solar- and stellar-dynamo processes, as well as updates on measurements of solar and stellar variability. Proceedings from FM9 will be published in a consolidated topical issue journal, similarly to how the 2015 IAU GA XXIX FM13 on solar variability was summarized in a topical issue of the *Journal of Space Weather and Space Climate* (JSWSC), published in 2017 with this WG's chairs, Shapiro and Kopp, as two of the issue's four editors.

3. Closing remarks

One item that has become apparent with this WG's interdisciplinary efforts is the benefit of understanding solar variability on long timescales via overlap with stellar-variability studies. Efforts to further improve such interdisciplinary studies between the solar- and stellar-variability communities are planned for a future IAU working group by the WG-SI's chairs.

Greg Kopp and Alexander Shapiro
chairs of Working Group "Solar Irradiance"

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