FM9
Solar Irradiance: Physics-Based Advances

https://doi.org/10.1017/S1743921319004526 Published online by Cambridge University Press

Astronomy in Focus - XXX
Proceedings IAU Symposium No. XXX, 2018
M. T. Lago, ed.

doi:10.1017/S1743921319004526

FM9 - Solar Irradiance: Physics-Based Advances

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Keywords. Sun: irradiance, TSI, variability, MHD, radiative transfer; Stars: variability; instrumentation: radiometry, photometry

1. The Importance of Understanding Solar Variability

Solar irradiance varies on all timescales at which it has ever been observed and possibly also on multi-decadal to century timescales. Knowledge of the magnitudes and timescales of this variability extends to many fields other than solar, including Earth-climate modeling, stellar-variability studies, and exoplanet detection. The terrestrial atmospheric and climate systems respond to variations in solar radiative output on timescales from days to decades, and there is also evidence for solar influences on climate over longer timescales. Stellar astronomers have been comparing variability of the Sun with that of other lower main sequence stars to determine how typical the Sun's solar activity cycle is. The magnitude and timescales of stellar variability can limit the detectability of exoplanets via transit methods relying on precision photometry. Understanding the physics behind solar variability helps assess the resulting effects on the Earth as well as the causes of similar stellar brightness variations and thus even the habitability of exoplanets.

2. Recent Improvements in Solar-Irradiance Understandings

Currently available empirical and semi-empirical models of solar-irradiance variability and some of the measurements of this variability have discrepancies that limit knowledge particularly of the long-term changes in the Sun's radiative output. Fortunately, recent advances in modeling and observing the solar atmosphere make it possible to create a new generation of significantly more realistic physics-based irradiance models. Benefitting from the enormous recent progress in solar observations and models, it is now possible to develop a new generation of irradiance models based on the current state-of-the-art in solar physics. In particular, these advances in understanding solar variability include:

• *3D magneto-hydrodynamic* (MHD) simulations of flows and magnetic fields in the near-surface layers of the Sun and stars have reached a high level of realism, and can now reproduce many sensitive observational tests. These simulations make it possible to replace 1D representations of the solar atmosphere with realistic 3D simulations and also enable assessment of the contributions of granulation to short-term solar-irradiance variability.

• New time-efficient *radiative transfer codes* and approaches have been developed. These allow calculated emergent spectra from 3D MHD cubes to account for effects from millions of atomic and molecular lines as well as deviations from local thermodynamic equilibrium, giving more accurate estimates of outgoing radiation as a function of position on the solar disk.

• *New atomic and molecular data* allow more reliable computation of the opacities in the solar atmosphere. The irradiance variability in the UV, violet, blue, and green spectral domains is fully controlled by millions of the Fraunhofer lines. Recent advances in laboratory astrophysics and in collecting the data (e.g. a major upgrade of the Vienna atomic line database, which now also includes molecular data) make possible significantly more accurate calculations of solar-irradiance variability.

• *Surface flux transport models* (SFTMs) now more realistically simulate the evolution of the large-scale surface magnetic field over the solar cycle. This allows reconstructing the evolution of the solar surface magnetic field and irradiance over long timescales, which is crucial to understanding the pre-anthropogenic solar contributions to climate change, from which natural sensitivities of climate can be estimated.

• *Irradiance-monitoring instrument improvements* are providing more stable long-term measurements, helping constrain the range of possible secular variations in the Sun's radiative output, as well as better short-term sensitivity, which can help refine solar-irradiance models using other indicators of solar activity.

• *High-resolution imagery of magnetic features* on the solar surface, which are the main driver of solar irradiance variability, from recent solar missions such as the Solar Dynamics Observatory (SDO), STEREO, SUNRISE, HINODE, etc. SDO in particular provides frequent space-based magnetograms, which are needed inputs to the newest physics-based solar-irradiance models.

With these recent advances in understanding solar-irradiance variations, we organized a dedicated focus meeting to summarize such physics-based advances and enable discussions between the many research areas involved in these improved understandings.

3. Focus Meeting 9

Focus Meeting 9, titled "Solar Irradiance: Physics-Based Advances," brought together researchers from around the world to discuss new insights, measurements, and models related to solar-irradiance variability. After an introduction session highlighting the prominent questions in the fields of Earth climate's sensitivity to solar variability, solar-surface magnetic features causing solar-irradiance variability, and the brightness variability of Sun-like stars, the meeting included the following four primary sessions:

• Session 1: Available Solar-Irradiance Data Sets and Models
• Session 2: Brightness Contrasts of Solar-Surface Magnetic Features
• Session 3. Structure and Evolution of Solar-Surface Magnetic Fields
• Session 4. Extrapolating Solar Models to Sun-like Stars

This chapter in the IAU General Assembly XXX proceedings summarizes but a few of the presentations and posters from this focus meeting to provide a sample of the many diverse presentations at the meeting itself.

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