SCIENCE OBJECTIVES WITH SDO/HMI MAGNETOGRAMS

Yang Liu (*Stanford University*) *& HMI Team*

ABSTRACT: The primary goal of the Helioseismic and Magnetic Imager (HMI) investigation is to study the origin of solar variability and to characterize and understand the Sun's interior and the various components of magnetic activity. As unique capability, HMI will be able to observe the full-disk vector magnetic field continuously at a cadence sufficient to follow activity development. This observation, in combination with other data from SDO, is crucial for understanding and establishing connections from variability in the solar interior to variability in the solar atmosphere, and to the propagation of disturbances in the heliosphere. This will help understand solar variability and its effects, leading to reliable predictive capability, one of the key elements of the Living With a Star (LWS) program.

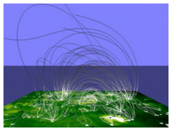
INTRODUCTION: The HMI science investigation addresses the fundamental problems of solar variability with studies in all interlinked time and space domains, including global scale, active regions, small scale, and coronal connections. One of the prime objectives of the LWS program is to understand how well predictions of evolving space weather can be made. The HMI investigation will examine these questions in parallel with the fundamental science questions of how the Sun varies and how that variability drives global change and space weather.

The capability of HMI to measure the vector magnetic field will provide continuous, seeing-free, uniform full disk vector magnetic field measurements with high spatial resolution and a reasonable cadence. The data will be used to measure free energy, stresses and helicity of the magnetic field, providing important input to many prime science objectives and tasks of SDO investigations. This also strengthens the LWS program tremendously, in particular, for studying magnetic stresses and current systems associated with impulsive events and evolving magnetic structures.

In the following, we present some of science objectives closely relative to the HMI magnetograms. These objectives fall into two categories: magnetic structures and evolutions on various scales, and magnetic energy and instability for solar transient events.

MAGNETIC STRUCTURES AND EVOLUTIONS ON VARIOUS SCALES.

1. EVOLUTION OF SMALL-SCALE STRUCTURES AND MAGNETIC CARPETIC.

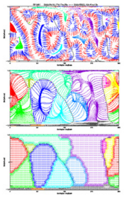


The quiet Sun is covered with small regions of mixed polarity, termed 'magnetic carpet', contributing to solar activity on short timescales. As these elements emerge through the photosphere, they interact with each other and with larger magnetic structures. They may provide triggers for eruptive events, and their constant interactions may be a source of coronal heating. They may also contribute to irradiance variations in the form of enhanced network emission.

HMI will allow global scale observations of the small-scale element distribution, their interactions, and the resulting transformation of the large-scale field.

Figure 1: Theoretical predictions for the structure and heating of the magnetic field above the solar surface using data for magnetic field from MDI are compared to the heating observed by EIT. The white magnetic field lines emanate from the magnetic carpet and form arches from one magnetic polarity to the other (Credit: LMSAL).

2. LARGE-SCALE CORONAL FIELD ESTIMATES.

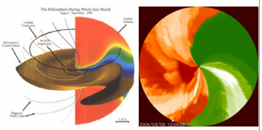


Models computed from line-of-sight photospheric magnetic maps have been used to reproduce coronal forms that show multi-scale closed field structures as well as the source of open field that starts from coronal holes but spreads to fill interplanetary space. Modeled coronal field demonstrates two types of closed field regions: helmet streamers that from the heliospheric current sheet and a region sandwiched between the like-polarity open field regions. There is evidence that most CMEs are associated with helmet streamers.

HMI will provide uniform magnetic coverage at a high cadence, and together with simultaneous AIA, STEREO coronal images will enable the development of coronal field models and study of the relationship between pre-existing patterns, newly opening fields, long distance connectivity, and CMEs.

Figure 2: The coronal open (colored dot areas) and closed (the areas consisting of blue-red field lines) field regions below 1.25 solar radius near maximum activity (CR1961) (top panel), the radial extension of the boundaries of open field regions to the source surface at 2.5Rs (middle panel), and the two kinds of boundary layers between open field regions at the source surface: bipolar (coincident with the black neutral line) and unipolar boundary layers (bottom panel) (Zhao & Webb, JGR, 108, 1234, 2003).

3. CORONAL MAGNETIC STRUCTURE AND SOLAR WIND.



MHD simulation and current-free coronal field modeling based on magnetograms are two ways to study solar wind properties and their relations with coronal magnetic field structure. These methods have proven effective and promising, showing potential in applications of real-time space weather forecasting. It has been demonstrated that modeling of the solar wind can be significantly improved with increased cadence of the input magnetic data.

By providing full-disk vector magnetic field data at high cadence, HMI will enable these models to better describe the distribution of the solar wind, coronal holes and open field regions, and how magnetic fields in active regions connect with interplanetary magnetic field lines.

Figure 3:Left-MHD model of the solar corona and heliosphere driven by the observed line-of-sight photospheric magnetic field (Riley et al. JGR, 106, 15889, 2001). Right-solar wind seen from above the Sun's north pole. The red and green color scales show where the radial field is directed inward or outward, respectively. The brighter the color, the faster the wind. Wind speed is calculated based on a modified PFSS model-based Wang-Sheeley model (Credit: LMSAL).

4. DETERMINATION OF MAGNETIC CLOUD Bs EVENTS.

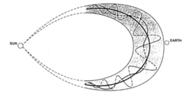


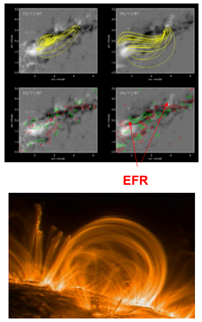
Figure 4: Highly idealized view of the proposed magnetic field line geometry of a 'typical' magnetic cloud on a global scale (Lepping et al. JGR, 95, 11957, 1990).

Potentially valuable information for geomagnetic forecasts--predictions of magnetic cloud Bs (southward field) events--may be obtained from the vector field measurements. Long intervals of large southward interplanetary magnetic field, Bs events, are believed to be one of the primary causes of intense geomagentic disturbances with the Bs component the more important quantity. It has been shown that magnetic orientation in `clouds' remains basically unchanged while propagating from the solar surface to Earth's orbit. This provides a plausible chain of related phenomena that should allow prediction to be made from solar observations of the geoeffectiveness of CMEs directed toward Earth.

Estimates of embedded Bs will be significantly improved by incorporating frequently updated vector field maps into coronal field models with the addition of coronal observations from AIA and STEREO.

MAGNETIC ENERGY AND INSTABILITY FOR SOLAR TRANSIENT EVENTS

1. COMPLEXITY AND ENERGETICS OF THE SOLAR CORONA.

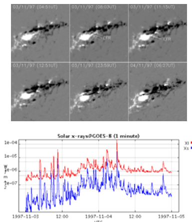


Observations have shown a variety of complex structures and eruptive events in the solar corona. However, categorizing complex structures has not revealed the underlying physics of the corona and coronal events. Two mechanisms have been proposed to buildup free energy in the corona: photospheric shear motions and emerging stressed magnetic flux; and both may, in fact, be at work on the Sun, but which plays the dominant role and how the energy injection is related to eruptive events is unknown. Magnetic helicity is an important characteristic of magnetic complexity and its conservation intrinsically links the generation, evolution, and reconnections of magnetic field.

HMI will provide data to allow estimations of injections of energy and helicity . Observations from AIA will show the subsequent response and propagation of complexity into the corona, relating the buildup of helicity and energy with energetic coronal events such as flares and CMEs.

Figure 5: top—emerging magnetic flux and corresponding changes in magnetic fields and electric currents. The computed non-linear force-free-field lines (yellow lines) are overplotted on the magnetograms., The color contours represent vertical currents. The emerging flux regions are marked by EFR. Bottom—TRACE observation of an active region at the edge of the Sun shows complex structures of the loops that connect one magnetic polarity to the other (Credit: LMSAL).

2. EMERGENCE OF MAGNETIC FLUX AND SOLAR TRANSIENT EVENTS.

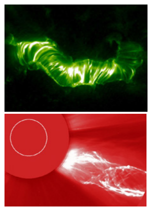


Emergence of magnetic flux is closely related to solar transient events. This suggests that magnetic flux emerging into the atmosphere interacts with pre-existing fields leading to loss of magnetic field stability. Observations of electric current and magnetic topology between newly emerging and pre-existing fields will likely lead to the understanding of why emerging flux causes solar transient events.

Vector polarimetry provided by HMI will enable these quantitative studies.

Figure 6: top—Time-series magnetograms of the active region AR8100. Magnetic flux emerged dramatically in this active region (marked as 'EFR'), and then elongated. Bottom—GOES observation shows increase of X-ray radiation during the procedure of emergence. Also shown are several major flares.

3. MAGNETIC CONFIGURATION AND MECHANISIMS OF SOLAR FLARES AND CMES.



Vector magnetic field measurements are needed to infer field topology and vertical current, both of which are essential to understand the flare/CME processes. Observations are required that can continuously track changes in magnetic field and electric current with sufficient spatial resolution to reveal changes of field strength and topology before and after the flare/CME.

HMI will provide these unique measurements of the vector magnetic field over the whole solar disk with reasonable accuracy and at high cadence.

Figure 7: Top--The post-flare arcades of the 2000 July 14 event seen in EUV wavelength taken by TRACE. Bottom—A CME clearly shows helical magnetic field structure, observed by the LASCO C2 coronagraph (Credits: TRACE & LASCO teams).