A1.1.4 Objective 4: Connections to geospace: *material and magnetic field output of the Sun*

The solar wind, the embedded magnetic field, and eruptive perturbations in the form of CMEs drive the variations in the space surrounding the Earth and other planets. The dynamic connections between Sun and geospace are a cornerstone of the ILWS program. To understand how the Sun's variability affects life and society, we must understand how the products of this variability are transported into and through the heliosphere, and how they interact with the Earth's magnetic field and atmosphere. The AIA investigation is expected to make substantial quantitative advances in many areas relevant to this problem. At the foundation of this expectation lies the improved understanding of the global coronal field and its extension into the heliosphere. In objectives 2 and 3 we discussed this for the pathways for escape of energetic particles into the heliosphere, the irradiance that affects the ionosphere and below, and the triggering of flares and CMEs. Here we focus on the magnetized solar wind and its perturbations.

The solar wind flows out radially into the heliosphere dragging along the magnetic field lines that are forced "open" within the first few radii from the Sun. The successes of simple concepts such as the potential-field source-surface (PFSS) model suggest that more realistic and detailed models should explain why this is. What determines which field lines will open? Why does the PFSS work as well as it does? The latter is particularly interesting because the PFSS model does not incorporate field dynamics. How is field opened, and how is it closed again as the connections evolve? This must have something to do with the properties of the solar wind, which we know depends on the field geometry and strength (often parameterized using the field expansion between low atmosphere and where the field becomes essentially radial). But although that dependence is empirically constrained, we still need to learn what determines the physical properties of the solar wind.

The eruptive coronal mass ejections perturb the background solar wind. How do they evolve through the coronal field? How do they couple into, and propagate through the heliosphere on their way to the Earth and the other planets?

In parallel to the above research topics, the AIA data products are designed to make an immediate contribution to space weather studies; data, catalogs, analysis software, and archive will be easy to use. The easy-to-use data and software systems (based on our YOHKOH, TRACE and SOHO experience) will make the AIA observations very useful for the world-wide solar physics community. Moreover, this approach will enable scientists from other fields within the ILWS community to easily access and use AIA data in their analysis of heliospheric and geospace data. In addition, the AIA investigation will develop and maintain an event catalog that is updated as data are received. Rapid brightenings, early rises of CME filaments, and other activity diagnostics will be listed on the web within minutes. All images will be inspected visually within 24 h in order to (a) augment the event catalog with filament and sigmoid developments, flare properties, flux emergence sites, wave phenomena, and other products requested by interested parties, and (b) create experience and intuition in researchers that stimulates the exploration of new avenues and discovery of new phenomena in traditional solar physics areas as well as in the wider ILWS context. To achieve this, the AIA team will explore how to best include heliospheric and geospace data in the daily assessment of events.

Main tasks for Objective 4:

1. **Dynamic coupling of corona and heliosphere**
2. **Solar wind energetics**
3. **Propagation of CMEs and related phenomena**
4. **Vector field and velocity**

Co-investigators Fuselier and Mikic are responsible for coordinating this research objective. With input from the user community, the AIA team team will help develop space-weather and solar-physics products relevant to the study of connections to geospace.

Task 4A: Dynamic coupling of corona and heliosphere

Major goals and significance The dynamic coupling of the closed corona to the open field reaching into the heliosphere can be observed using the sensitive AIA telescopes. On the scale of supergranulation, the network field is replaced every few days in a continual process of flux emergence in ephemeral regions flux and cancellation due to collisions between opposite polarities [53]. This process forces magnetic reconnection in addition to those associated with the smaller-scale granular driving. TRACE observations of the corona above quiet-Sun regions hint at a multitude of dynamic structures, particularly in exposures of minutes or more [1]. The sensitivity of the AIA will allow us to observe these structures with much shorter exposure times, and hopefully reveal how this field couples to the that in the heliosphere, particularly in the open-field configurations of coronal holes at the base of the fast solar wind.

Technical approach and methodology The combination of HMI, AIA, and (ground- or space-based) coronagraph observations with modelling efforts will deepen our understanding of the interface between corona and heliosphere. Currently, the heliospheric field is readily approximated by a source-surface potential-field model and Parker spiral. This involves various poorly-testable, pragmatic corrections [54, 55, 56]. Detailed observations of the field geometry, in particular in the first few tenths of the solar radius above the limb where the field is strong, will help us understand these corrections, and the role currents and field dynamics play. This will improve the fast but simple source surface modelling and guide the more advanced MHD modelling.

One key tool in this is a surface dispersal model (already developed by our team, [57]), that simulates the evolution of photospheric field near the limb where it is hard to observe, and on the backside of the Sun. Combined with HMI magnetograms of the visible hemisphere, and seismological proxies for flux on the backside of the Sun (with assigned polarities) this provides a good approximation of the entire surface field needed as a basis for global coronal modelling.

AIA and coronagraph data, combined with such models, will allow the study of evolving coronal holes as parts of the heliospheric field. Team members with expertise in MHD modelling and field geometry studies will address this coupling. Such modelling capabilities will be exercised and refined starting with the SOLAR-B and STEREO missions. They will yield their full potential during SDO, when full-disk data enable us to cover scales from active regions to the entire corona.

Science data requirements Needed are high S/N observations of all coronal EUV wavelengths, possibly taking extra long exposures to see the faint, high-arching structures. Sequences at a cadence of $\sim 30\,$s or better are needed to study the evolving field. Comparison with HMI magnetograms and full-sphere field models are needed to compare observed field geometries with models.

Science team roles and responsibilities S. Fuselier (magnetospheric and ionospheric physics, manager of the space-physics department at LMMS/LMATC), N. Hurlburt (data management), Z. Mikic (MHD modelling of corona-heliosphere coupling), P. Scherrer (field extrapolation, comparison with results from Wilcox Solar Observatory modelling), and C. Schrijver (global modelling of coronal field).

Required resources Force-free and other field models are needed as part of this task.

Task 4B: Solar wind energetics

Major goals and significance The solar wind is accelerated within approximately 10 solar radii. Comparisons with in-situ measurements in the heliosphere (usually near the Earth, but also from, e.g., the interplanetary spacecraft and the out-of-ecliptic Ulysses mission) suggest that the wind density and velocity are determined by the geometry of the field near the Sun. The wind velocity has been found to anti-correlate with the so-called expansion factor, i.e., with the ratio of field strengths near the solar surface and at the distance of the source surface [58, 59, 60]. It may be that other parameters are involved [61], but testing such dependences requires a combination of the near-Sun field models with a wind propagation model that includes stream interactions. That combination of models also will help validate the field models for the highest domains of the solar corona that are too faint to observe directly and must be studied indirectly by comparing the model geometries and wind properties to observations in the low corona and within the distant heliosphere.

Technical approach and methodology The findings from task 1A are to be combined with heliospheric models of the solar wind, and then compared to in-situ measurements of wind properties.

Science data requirements Required are high S/N images of the solar corona at all AIA EUV wavelengths, perhaps requiring extra long exposures to see the faint, high corona. Combination with ground- or space-based coronagraphs (including STEREO imagery) will help validate the coronal field models. In-situ measurements of the solar wind, at least near Earth (as in the Sun-Earth L1 point) are needed at low temporal resolution for comparison with models. Coupling of coronal-field and heliospheric-wind models is needed to test and validate the high-coronal field and solar wind models jointly, as they cannot be independently verified.

Science team roles and responsibilities S. Fuselier (magnetospheric and ionospheric physics, manager of the space-physics department at LMMS/LMATC), N. Hurlburt (data management), Z. Mikic (MHD modelling of corona-heliosphere coupling), P. Scherrer (field extrapolation, comparison with results from Wilcox Solar Observatory modelling), and C. Schrijver (global modelling of coronal field).

Required resources Successful work on this task requires heliospheric models for the solar wind and embedded field.

Task 4C: Propagation of CMEs and related phenomena

Major goals and significance The high-cadence AIA images will enable the study of CMEs and associated (shock, blast, and other) waves that are launched into the heliosphere. CME-related shock waves [62, 49] likely play a significant role in the generation of solar energetic particles from within the heliosphere [63]. The calibrated AIA images covering a wide range of temperatures will, moreover, enable us to estimate the mass involved in an ejection (as already applied to SXT, EIT and TRACE observations, [64, 49]), and - for prominence eruptions - provide the acceleration profile of CME-related structures to be compared with coronagraph data higher up. Combination with coronagraph data may allow us to estimate velocities and field-strength evolution in the initial phase of CMEs, both important to the severity of related geo-magnetic storms [65]. The AIA images will also elucidate whether the short-term coronal dimming during CMEs [66] is a consequence of a change in density (related to field evolution) or temperature (reflecting expansion or modified heating) or both. Moreover, the AIA images not only better clarify the relation of dimming with flux ropes or magnetic clouds observed in-situ but also (combined with magnetic field extrapolations) reveal the origin of the magnetic field in interplanetary coronal mass ejections.

Another important aspect is that SOHO's LASCO frequently observes matter falling back to the Sun, even from eruptions that reach beyond 6 solar radii [67]. TRACE observations of erupting filaments often show such material falling back in dark, absorbing streams in the early phases of CMEs. What determines what fraction of the CME mass falls back? What does that mean for its geo-effectiveness? We will study these processes by combining observations of erupting filaments seen in emission in He II 304Å, in absorption in the EUV channels, and in scattered light in available coronagraph data.

In order to study the potential geo-effectives of eruptions, we need to constrain the field orientation, the mass content, (evolution of) the speed, and any associated EUV irradiance changes.

Technical approach and methodology Compare eruptions with MHD (or other) models of the evolving coronal field. Combine the observations of the near-Sun conditions with models for the propagation of perturbations through the background solar wind, and compare the results with the in-situ observations of CMEs passing by the Earth's magnetosphere.

Science data requirements In order to estimate the evolution of the innermost parts of CMEs, the AIA must see all temperatures to provide maximum observational constraints on the field evolution. Such complete vision of the coronal hot plasma will be helpful to estimate the near-solar velocity and mass, to trace the field structure, and to study the CME energetics. High cadence (~ 10 s), and high S/N to see the faint high structures is needed.

Science team roles and responsibilities S. Fuselier (magnetospheric and ionospheric physics, manager of the space-physics department at LMMS/LMATC), Z. Mikic (MHD modelling of corona-heliosphere coupling), N. Nitta (ICME studies), P. Scherrer (field extrapolation).

Required resources As under 1A, plus models of CME propagation through the heliosphere. In-situ solar wind plasma and magnetic field data, and magnetic field model for flux ropes.

Task 4D: Vector field and velocity

Major goals and significance Observations of the initial evolution of the field in a CME (including any unwinding of the large-scale helical field), will help modellers compute the further evolution through the heliosphere, including CME-wind and CME-CME interactions. Of particular importance here are the direction of motion of the CME front and the direction and magnitude of the heliospheric field with which it will interact en route to Earth. Important factors for heliospheric modellers include the initial velocity evolution of the CME close to the Sun, and the total mass contained within it, because these determine the interaction with the ambient heliospheric plasma. With this input, the heliospheric models need to estimate the $B_{\rm z}$ magnitude of the compressed field at the front interface of the CME as well as whether a shock forms before it reaches Earth. These properties define the strength of a geomagnetic storm and the intensity of the arorae [68]. Also important is the field orientation throughout the interior of the beginning CME, because that determines the recovery phase, including any substorms, of the geomagnetic field after the initial front passes. In order to provide the required input to heliospheric models, the evolution of the CME-related field and plasma needs to be observed and analyzed in the innermost corona observable with the AIA.

In a few cases, it may be possible to combine AIA image sequences with spectroscopic measurements from, SOLAR-B's EIS: together they provide the vector velocity that enables an accurate forecast of the geo-effectiveness of a CME. AIA, available coronagraphs, and hopefully STEREO observations can be combined to estimate 3-D velocity vectors.

Technical approach and methodology Measurements of the velocity profile of erupting filaments (and the surrounding corona field) are possible only projected against the plane of the sky. Combination with STEREO measurements, or with model MHD computations based on HMI vector-field measurements, should be made to study the evolution in three dimensions.

Calibrated intensities help constrain the mass contained in the CME.

Science data requirements High-cadence ($\sim 10\,\mathrm{s}$) observations at all coronal AIA wavelengths and in He II 304 Å. High S/N ratios at all corona temperatures to observe the evolution of faint loops high in the corona and around any erupting filament. Coordination with Solar-B EIS. Combination with STEREO observations and with ground-based coronagraph observations.

Science team roles and responsibilities S. Fuselier (magnetospheric and ionospheric physics, manager of the space-physics department at LMMS/LMATC), Z. Mikic (MHD modelling of corona-heliosphere coupling), P. Scherrer (field extrapolation).

Required resources MHD model of at least the propagation of CMEs through the innermost heliosphere, preferably out to Earth or beyond. Vector-field extrapolation models.

A1.1.5 Objective 5: Coronal seismology:
a new diagnostic to access coronal physics

Recent observations from SOHO and TRACE show a variety of oscillation modes in the transition region and corona. These observations opened up the promising new field of *coronal seismology*. By studying the properties, excitation, propagation and decay of these oscillations and waves, we can reveal fundamental physical properties of the solar transition region and corona, such as the magnetic field, density, temperature, viscosity, ...[69].

Examples of seismic responses of the corona have been found in large-scale coronal Moreton and EIT waves [70], in polar plumes, sunspot fields, upper transition region moss, and what appear to be ordinary loops. The whole gamut of MHD waves predicted by theoretical considerations has been observed. Perhaps most striking are the transverse oscillations seen by TRACE in association with $\sim 8\%$ of all C, M, and X-class flares observed [71, 72]. Longitudinal oscillations and waves have also been observed: in the upper transition region moss [73], and in coronal loops, both in cooler loops with TRACE [74] and in hot ($10^7\,\mathrm{K}$) loops with the SUMER spectrometer [75].

There are still many unresolved issues about these waves and oscillations. How do they get excited? Why does only a fraction of the observed flares lead to clear oscillations? Are longitudinal waves in coronal loops with 5 minute periods related to p-modes? How do any of these waves propagate? Which of the many possible theoretical mechanisms can explain the unexpectedly rapid decay of some of these waves? These are some of the questions that we need to answer before we can seismically probe coronal physics.

The AIA design will allow us to develop the necessary improved understanding of the properties and other unresolved issues of the observed waves. The high cadence of AIA will extend the parameter space to