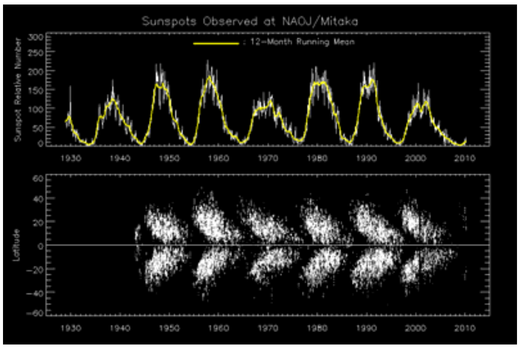
1. SOLAR-C Mission Science Goals

1.1 Origin of Solar Magnetism

1.1.1 Solar Magnetic Cycle

The solar magnetic cycle is one of the greatest puzzles in astrophysics. Similar magnetic cycles have been observed in other stars; and the turbulent dynamo that controls these cycles is a key to understanding the cosmic magnetism. It has been known for centuries that the number of sunspots changes quasi-periodically with 11-year cycle, forming the famous “butterfly” diagram (Figure 1 and Figure 2).



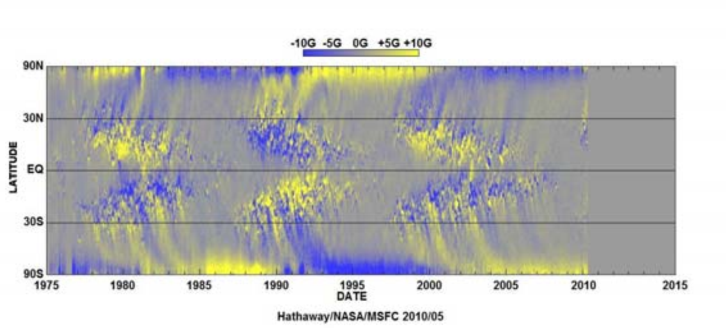


Figure 1: (left): Sunspot numbers and sunspot butterfly diagram (NAOJ)
Figure 2: (right): Averaged surface magnetic field strength (courtesy of D. H. Hathaway)

Many recent solar dynamo models are based on the so-called “flux-transport” paradigm whereby the advection of magnetic flux by the axisymmetric flow in the meridional plane regulates the period and amplitude of the activity cycle. Most flux-transport models attribute the generation of mean poloidal field to the emergence and subsequent dispersal of photospheric active regions by the combination of poleward circulation and turbulent diffusion in the upper convection zone, known as the “Babcock-Leighton” mechanism. The reversal of the global poloidal field occurs as opposite-signed field from lower latitudes converges on the polar regions. However, how this process couples to the dynamics and magnetic topology of the deeper convection zone is currently unknown. Recent *Hinode* observations reveal the polar field is highly structured, with magnetic field concentrations reaching 1kG, which is not captured by mean-field models. How the polar “magnetic landscape” changes with the solar cycle is one of the most critical questions for understanding the nature of solar magnetism. The magnetic field evolution is intimately coupled to the flow field, including convection, differential rotation, and the mean meridional flow. In particular, the latitudinal bands of photospheric magnetic activity reflected in the solar butterfly diagram (Figure 1 and Figure 2) are closely linked to systematic variations in the differential rotation known as “torsional oscillations” (Figure 3). A surprising result from helioseismology is that the depth and strength of these flows increase in the near-polar regions. Furthermore, models of surface flux transport indicate that the polar field strength is sensitive to variations in the amplitude and structure of the high-latitude meridional flow. However, reliable measurements of the magnetic and flow fields in the near-polar regions are currently lacking.

There is a huge gap in our knowledge of the polar magnetism and dynamics, preventing us from understanding the basic mechanisms of solar magnetic activity, and developing physics-based forecasts of the solar activity and cycles.

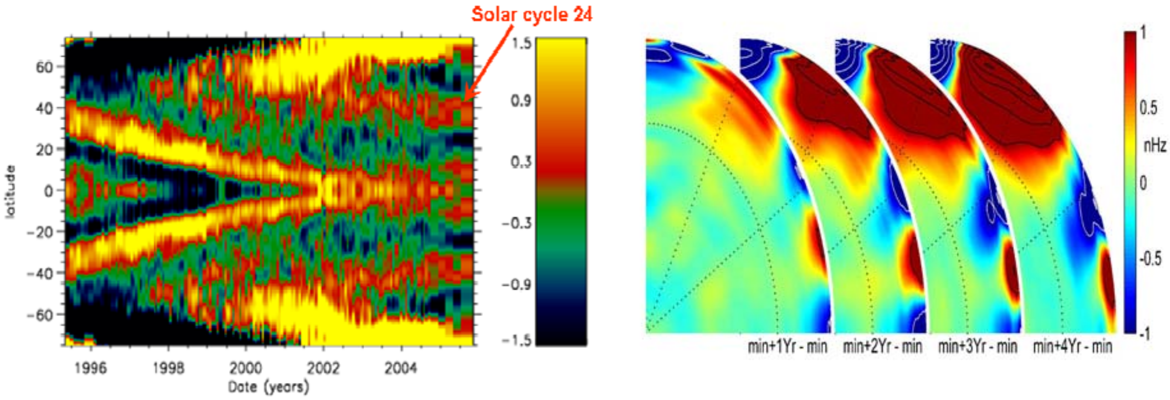
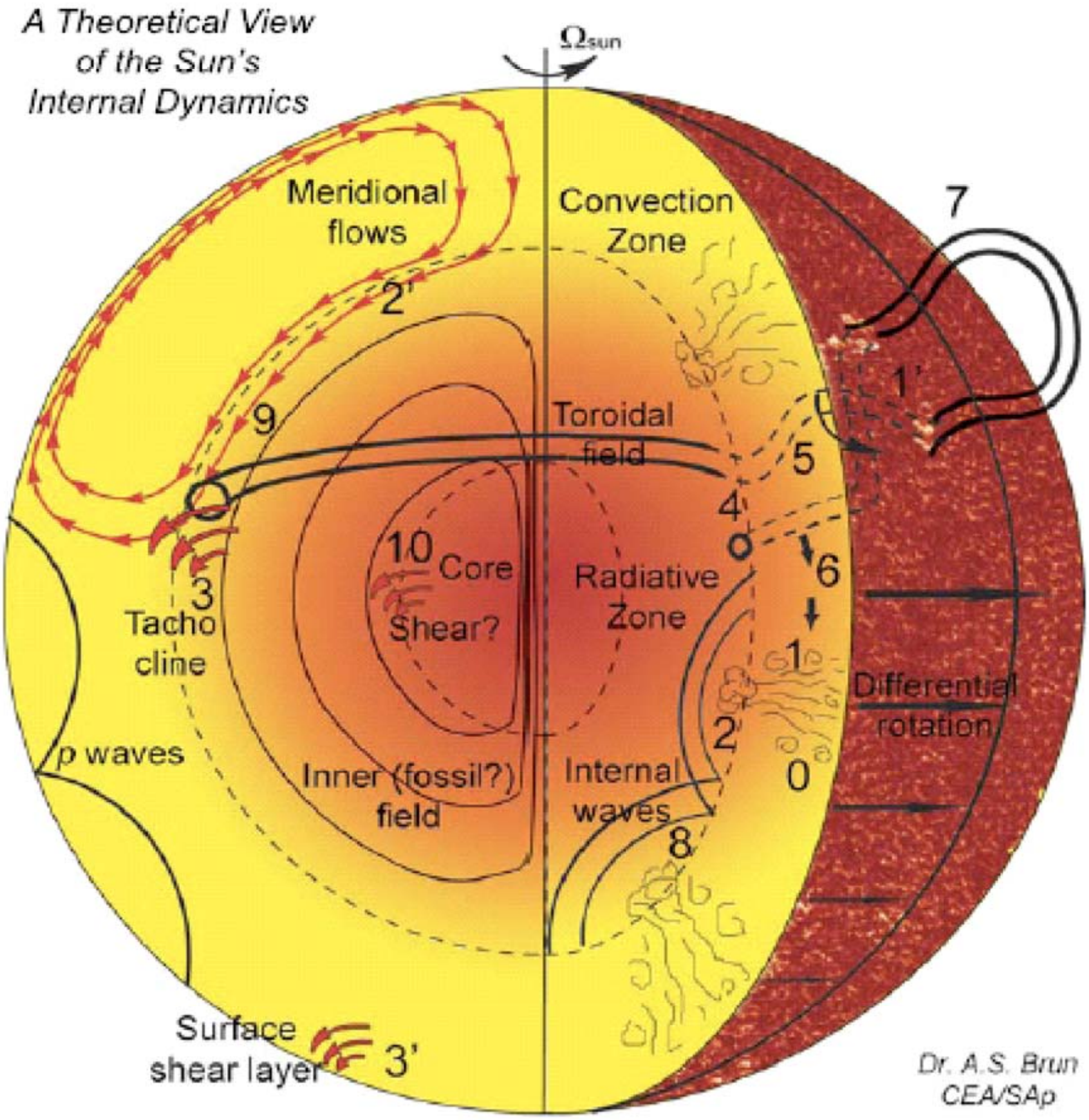


Figure 3: Systematic variations in angular velocity known as torsional oscillations, illustrating their latitudinal and temporal variation several Mm below the photosphere (left) and their subsurface structure in the meridional plane (right; figure adapted from Vorontsov et al. 2002).

1.1.2 Generation and Emergence of Magnetic Field

In astrophysical objects, dynamo action can exist in plasmas with a seed magnetic field and flow fields. However, sufficient conditions for dynamos are not well-determined. For solar and stellar physics it is particularly important that dynamo processes can result in a cyclic behavior. Mean-field MHD theories of solar and stellar dynamos predict the cyclic behavior, which resembles the observed properties such as the butterfly diagram for sunspot formation zone and polar field polarity reversals. However, our understanding of the underlying physical processes is still schematic Parker’s standard α-Ω mechanism that has been applied to the Sun and a wide range of other astrophysical objects, stars, galaxies, interstellar medium.

The current global dynamo models involve several building blocks mainly known by their representation in mean-field electrodynamics: One is the α-effect that generates the poloidal field from the mean poloidal or toroidal field by a turbulent cyclonic flows (Item 1 in Figure 4), or by a disintegration of the surface active region fields. (Items 1’, 4, and 5 in Figure 4). The other is the Ω-effect that generates the toroidal field from the mean poloidal field by shear motions in the differential rotation. These two effects couple with each other to re-generate the toroidal and poloidal fields in repetition. The locations of each effect are now considered to be separated in the interior, so that , in addition to these field stretching mechanisms, the transport of the fields are also important ingredients: (Items 3 and 3’ in Figure 4). The three different transport mechanisms generally considered are active transport toward the surface by means of magnetic buoyancy (rising flux tubes, formation of active regions), turbulent transport in the convection zone (turbulent pumping, turbulent diffusion) and transport by the large scale meridional flow (flux transport dynamo; Figure 5).



0: Turbulent convection (plumes); 1: Generation/self-induction of poloidal B field ("α-effect") or 1': Tilt of active region; 2: Turbulent pumping of B field in tachocline or transport of B field by meridional flows from CZ into tachocline (single for multi-cells flow?); 3: Field ordering into toroidal structures by large-scale radial and latitudinal shear in tachocline ("Ω-effect"); 3': Surface shear layer or subsurface weather; 4: Toroidal field becomes unstable to m=1 or 2 longitudinal instability (Parker instability); 5:Rise and rotation of twisted toroidal structures; 6: Recycling of weak field in CZ; 7: Emergence of bipolar structures at the surface; 8: Internal waves propagating in RZ and possibly extracting angular momentum; 9: Interaction between dynamo induced field and inner field in the tachocline along with shear, turbulence, waves, etc.; 10: Instability of inner field and shearing via Ω-effect at nuclear core edge? Is there a dynamo loop realized in RZ?

Figure 4: Solar internal dynamics and dynamo

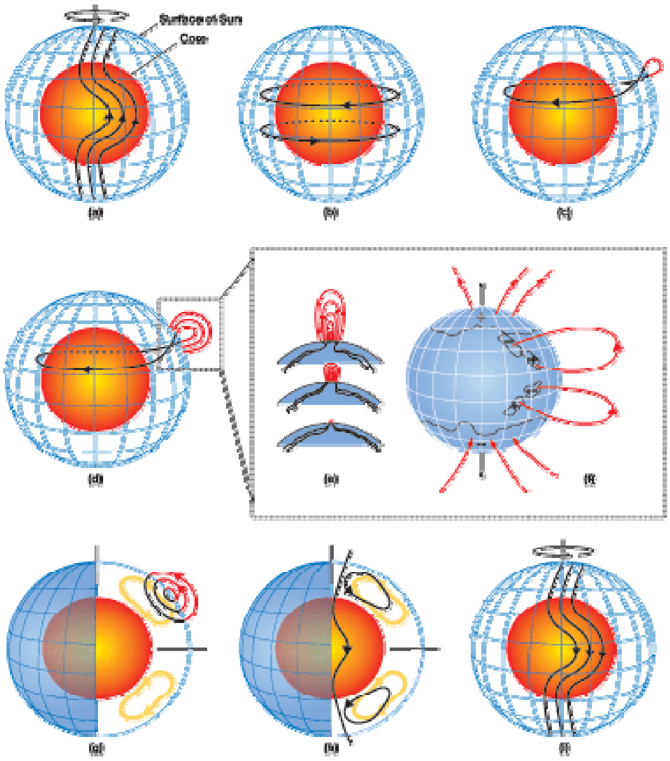


Figure 5: Flux transport dynamo (adapted from Dikpati and Gilman 2006)

The success of this beautiful theory hinges on the turbulent properties, magnetic and kinetic helicities and diffusivity. However, direct numerical simulations, developed during the past decade, revealed significant limitations, such as the catastrophic helicity quenching, which severely restricts the magnetic field growth. The potential solution is in studying the helicity balance including large-scale circulations and helicity loss through coronal mass ejections. This study requires detailed observations of the solar interior, magnetic field and coronal dynamics over the whole solar cycle. It is particularly important to understand the mechanism of the cyclic polar field reversals revealed in synoptic ground-based observations during the past three sunspot cycles. Because the Sun's axis is almost perpendicular to the ecliptic our knowledge of the polar magnetic field structure and dynamics is very poor.

The best opportunity to gain this knowledge can be provided by the out-of-ecliptic SOLAR-C mission. It will provide an important insight into the structure of polar magnetic fields and the mechanism of polarity reversals. The polar fields are largely unipolar, and it was believed that the polarity reversals result from a diffusion or circulation process of magnetic flux transport from the low-latitude zone where the flux emerges. However, recent high-resolution observations from *Hinode* showed that the polar fields are highly structured, and, while the mean polar field is only a few Gauss, the field in these elements is very strong. This discovery challenges the flux transport models, and opens a new opportunity of studying the relationships between the structuring and global field reversals. The out-of-ecliptic mission will also improve our knowledge of the large-scale convection, differential rotation and meridional circulation, which are the key ingredients of dynamo models.

In terms of magnetic-field observations, compared to ultra high-resolution vector-magnetograms obtained in the ecliptic plane, SOLAR-C has advantages in longer observation periods, more global view of the polar regions, and capability of providing simultaneous flow-field observation in and below the photosphere, to facilitate study of interaction between plasma flow and magnetic fields. Potential disadvantages are that part of the polar regions that lie on the Earth-side may be observed with higher resolution from the ecliptic plane, and the lack of vector magnetogram capability from the spectro-polarimetry by an imaging polarimeter. If, however, as *Hinode* is finding out, the polar fields primarily comprise relatively large, predominantly vertical kG-field patches, these disadvantages may not be so important.

1.1.3 Dynamics of the Solar Convection Zone and Tachocline

The differential rotation, meridional circulation, turbulent α-effect, and turbulent transport terms (turbulent diffusion and magnetic pumping) that form the basis of the solar dynamo models ultimately arise from turbulent solar convection. Stellar observations confirm that convection breeds magnetism; late-type stars such as the Sun with convective outer envelopes exhibit vibrant magnetic activity whereas more massive stars with convectively stable envelopes are generally less active. Thus, understanding solar convection and the mean flows it generates is an essential prerequisite to understanding solar magnetism.

Determination of the solar internal rotation profile and near-surface meridional circulation by means of global and local helioseismology, in the past three decades, has revolutionized solar dynamo theory. Rotational shear has long been an essential ingredient in all solar dynamo models, as the principle generation mechanism for the global-scale toroidal magnetic flux (Ω-effect) that ultimately emerges from the solar interior to form active regions. More recent flux-transport dynamo models have further identified flux advection by the mean meridional circulation as a key factor in the establishment of cyclic magnetic activity. In particular, the poleward advection of emergent toroidal flux from lower latitudes may account for the polarity reversals of the polar field and thus the cyclic reversals of the global dipole moment. Possible correlations between the high-latitude meridional flow speed and activity patterns such as cycle amplitude and duration are necessary to distinguish among various dynamo paradigms. Regardless of the dynamo mechanism, surface flux transport models indicate that the strength and distribution of the polar magnetic field (crucial for coupling to the heliosphere) is sensitive to the amplitude and structure of the high-latitude meridional circulation. Determination of the differential rotation and the meridional circulation in the polar regions will thus provide unprecedented insights into the dynamics of the convection zone, the operation of the solar dynamo, and the solar-terrestrial interaction, bringing the helioseismology revolution to its ultimate fruition.

Observations of the solar photosphere reveal a hierarchy of convective motions, from solar granulation (L~1 Mm) to supergranulation (L~35 Mm). Deeper in the convection zone convective length and time scales increase as a consequence of the larger density and pressure scale heights.

Magnetic flux transport by supergranulation and granulation may contribute to the cyclic reversal of the large-scale poloidal field by working in concert with the meridional circulation. Not only does convection influence magnetism, but the converse is also true; magnetism can influence the structure of convection and investigating the nature of this nonlinear feedback provides valuable insight into both phenomena. In particular, the structure and evolution of supergranulation in polar coronal holes, where a net unipolar flux permeates the photosphere, may be significantly different than that at lower latitudes where the flux distribution exhibits mixed polarity. The Lorentz force tends to decrease convective length scales but magnetically-induced enhancements in radiative cooling may counteract this effect. Careful observations over extended time intervals (at least hundreds of days for reliable statistics) at high latitudes are needed to elucidate the subtle nonlinear feedbacks between solar convection, magnetism, and radiation.

Observational signatures of giant cells are notoriously difficult to glean from photospheric observations but the unique high-latitude vantage point offered by SOLAR-C will provide new opportunities. The maintenance of mean flows by global convective motions is expected to produce thermal gradients between the equator and pole that may be detectable by helioseismic inversions or photospheric irradiance measurements (Section 1.2.3). Furthermore, theoretical and numerical models predict a change in morphology between global convective motions at high and low latitudes in rotating spherical shells. The transition between polar and equatorial convective modes occurs near the so-called tangent cylinder, a cylindrical surface aligned with the rotation axis and tangent to the base of the convection zone. This tangent cylinder intersects with the solar surface at about 45° latitude. Possible changes in the subsurface flow fields inferred from local helioseismic inversions inside and outside the tangent cylinder may provide a valuable and previously unexploited observational signature of the elusive but extremely important giant cells. *Hinode* measurements have already revealed a systematic high-latitude alignment of supergranules that may reflect the underlying influence of giant cells. Polar observations may also reveal other phemonema such as inertial waves or precessing convective modes with longitudinal wavenumber $m=1$, as seen in some numerical simulations.

Convective and meridional flows that converge toward the poles are accelerated in a prograde sense by means of the Coriolis force which can in some circumstances establish a cyclonic polar vortex. The presence of a polar vortex remains controversial in current helioseismic inversions but is exhibited by some numerical simulations. Coordinated helioseismic determinations of the differential rotation and meridional flow at high latitudes will settle this issue, at least in the upper convection zone, and will provide important constraints to global convection simulations, enhancing our understanding of angular momentum transport.

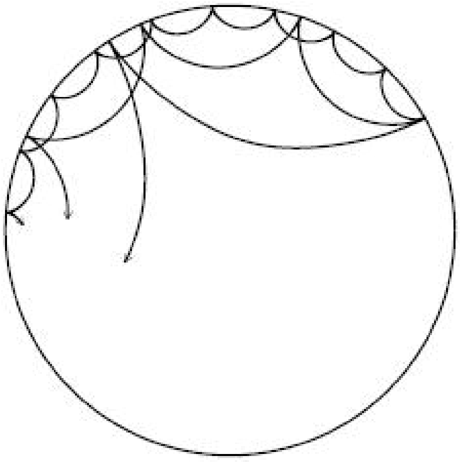
Like the polar regions, the base of the solar convection zone is an unexplored frontier of essential importance to the operation of the solar dynamo. This is where photospheric active regions originate, as the strong shear, convective pumping, and mild stratification promote the generation of coherent toroidal magnetic flux structures which buoyantly destabilize and rise. Flux-transport dynamo models attribute the duration of the solar cycle to the equatorward flow speed near the base of the convection zone. Furthermore, recent theoretical and numerical models indicate that the differential rotation profile throughout the solar convection zone is influenced by thermal and mechanical coupling to the tachocline. SOLAR-C will enable fundamental breakthroughs in our understanding of solar internal dynamics and magnetism by probing the base of the convection zone through the innovative and powerful technique of stereoscopic helioseismology (Section 1.1.4).

1.1.4 Probing the Solar Interior

In our effort to understand the mechanism behind the solar activity cycle, it is important that we study the solar interior observationally. The only method known to us is helioseismology, which enables us to measure thermal structure and flows in the solar interior. In this subsection a very brief introduction to helioseismology is given, to provide background for further discussions in Section 2.

The solar 5-minute oscillations, discovered by Leighton et al (1962), were later identified as manifestation of the global acoustic eigenoscillations, excited by acoustic emission by turbulent convective motions. These eigenmodes are results of acoustic waves generated in the upper convection zone travelling around the sun, some of which interfere with themselves constructively and become resonant modes, whose properties are sensitive to the structure of the sun (Figure 6). This motivated effort to develop methods of probing the solar interior based on precisely measured eigenfrequencies.

In helioseismology, we start from observing surface wavefield, preferably by Doppler velocity measurement, which is known to suffer less noise compared to intensity fluctuation measurement (by a factor of 5 or more is not uncommon). The wavefield is then characterized by Fourier (in temporal domain)/Spherical Harmonic (in spatial domain) analyses, to produce eigenfrequencies as the primary product. The eigenfrequencies are then analyzed, typically by inversion methods, to estimate various quantities that affect wave propagation. One good example is adiabatic sound-speed distribution, and another is differential rotation in the sun (Figure 7), which is now measured in low- to mid-latitude convection zone and deeper into the radiative zone, but not at high-latitudes and in the central region of the sun. The limitations are mainly coming from an insufficient number of eigenmodes that sample these regions. The profile of the solar differential rotation depicted in Figure 7 gave observational constraints to solar dynamo theory. In fact, it contradicted columnar rotation profiles which were generally believed to be the case for the sun, and understanding of dynamo were based on.



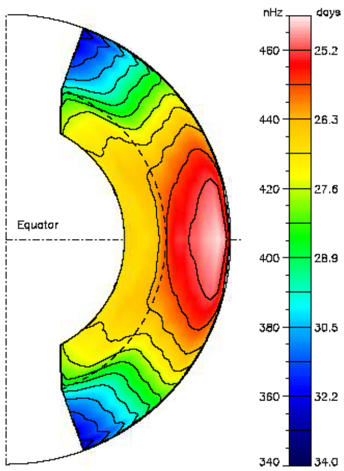
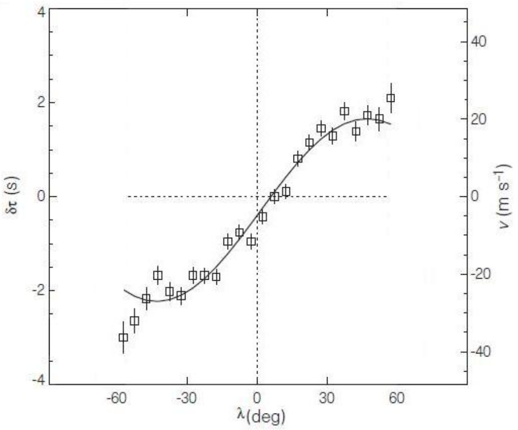


Figure 6. (left): Acoustic ray paths for various modes. Each of these paths, after a trip around the sun, eventually overlap with itself, and if it is found to be constructively interfering with itself, it becomes a resonant eigenmode. Different modes have different paths, and therefore sample different parts of the sun.

Figure 7. (right): Differential rotation of the sun measured by (global) helioseismology (adapted from Thompson et al 1996).



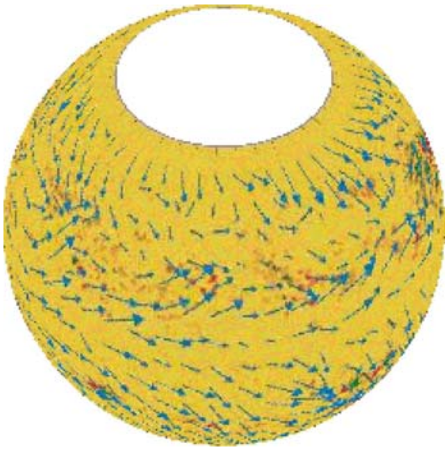


Figure 8. (left): Meridional flow speed measured by local helioseismology (adapted from Giles et al 1997)
Figure 9. (right): Subsurface local flows measured by a local helioseismology technique (adapted from Haber et al 2002).

Building on these successes, in recent years, a new subfield of *local* helioseismology is developing. As in the old version of helioseismology (often called *global* helioseismology), local helioseismology does start from measuring wavefields. In local helioseismology, however, we do not measure (global) eigenfrequencies. Instead, we measure those quantities that characterize *local* propagation of the waves, such as wave travel times between a pair of surface points (for example, two bouncing points along a ray path in Figure 6), power distribution (in wavenumber-frequency space) of local wavefield, etc. Unlike in global helioseismology, these measurements provide bases for probing *localized* and *asymmetric* structure of the sun, not constrained by the symmetric manner in which global modes sample the sun, as signified by symmetries of eigenfunctions.

Meridional circulation has thus been measured (Figure 8) by a time-distance method, and solar subsurface 'weather' patterns (local flowfields) are now routinely measured by local power spectrum analyses (Figure 9). Once again, the high-latitude regions are missing as, once beyond about 60° off the disc centre, foreshortening and projection degrade the local wavefield measurement significantly, although these parts are of great interest. Deeper layers are also difficult to access, because of the following. As we see in Figure 6, probing a deeper layer requires measuring wavefields at (at least) two regions on the sun that are apart by a great distance, in which case at least one, possibly both, of the region tends to be rather close to the limb, and therefore suffers from projection and foreshortening. One possible way to resolve this difficulty is *stereohelioseismology*, in which multiple helioseismic observations from different view angles are used to observe wavefields without significant degradation due to projection and foreshortening.

1.1.5 Prediction of Solar Cycles

Prediction of the solar sunspot cycles is not only of great practical importance, it also represents an ultimate test for our understanding of solar magnetism. So far, our predictions based on the α-Ω dynamo were not successful even with the input from helioseismology. The most successful prediction of the previous solar cycle was made using measurements of polar magnetic field of the Sun (Figure 10). The polar magnetic field reaches the maximum strength during the sunspot minima, and it correlates very well with the maximum sunspot number of the following solar cycle. In addition, it has been established long ago that a close correlation exists between the strength of geomagnetic indexes measured during the solar minima with the following sunspot maxima. This correlation is probably caused by the high-speed solar wind from the polar regions.

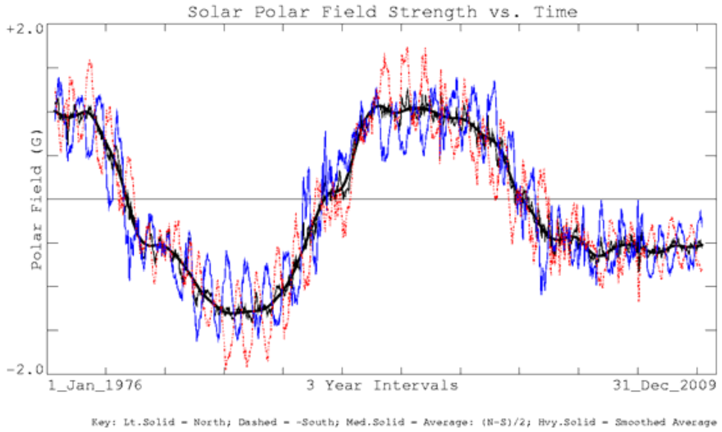


Figure 10. Evolution of solar polar magnetic fields (solid: north and dashed: -south)

However, how the polar magnetic field strength is translated into the future sunspot number is completely unknown. It has been suggested that this may correspond to the transformation of the global dipole magnetic field into the toroidal magnetic field of sunspots by the differential rotation (Ω-mechanism of the dynamo). However, the physics of this transformation and also the mechanism, which determines the polar magnetic field strength, are unknown.

Thus, for developing physics-based forecast of solar activity it is extremely important to investigate the structure and evolution of the polar magnetic fields, mechanisms of the magnetic flux transport and interaction between the old and new magnetic fluxes. The SOLAR-C observations will provide direct measurements of magnetic fields and flows, which will be incorporated into the dynamo models and data assimilation procedures for predicting the solar magnetic cycles. In addition, it is well-known that the solar 11-year cycles have a complicated structure with periods of very high activity. It will be very important to investigate the correlation between these periods and the preceding polar dynamics.

1.1.6 Scientific Questions to be Solved by SOLAR-C

We set the following four fundamental questions toward the understanding the solar magnetism and 11-year activity cycle related issues that are tackled by SOLAR-C.

Q1) How is the global, cyclic, solar magnetic field generated?
Q2) What is the nature of flows in the polar regions of the Sun and how do they interact with magnetism?
Q3) How does the radiative energy output of the Sun depend on latitude?
Q4) How does magnetic activity shape the structure and evolution of the polar solar corona and how does it affect the Earth?

The relation between these questions and what targets should be observed with the science payload is shown in Table 1. The detailed description on the background is shown in the following sections.

Table 1: Summary of scientific questions, targets and the required observations.

Key Questions	Section	Observation Targets; overview	Observation Targets in detail	Instruments / Measurements	Scientific objectives/Background in brief	Importance / Difficulty
Q1: How is the global cyclic, solar magnetic field generated ?	1.2.1	T1) Dynamical coupling between magenetic fields and flows	* Surface meridional circulation beyond latitudes of 60 degrees * Surface magnetism * Polar magnetic field reversal * Cyclic variation of above variables	* Doppler for Local HS * Magnetic (longitudinal)	* Possible correlations between the hihg-latitude meridional flow speed and magnetic activity patterns are necessary to distinguish between different dynamo paradigms. * Determining the differential rotation profile close to the poles will provide	important / definite
Q2: What is the nature of flows in the polar regions of the Sun, and how they vary with magnetic field?	1.2.2	T2) Photospheric magnetic flux distribution and evolution in the polar regions	* Transport of magnetic flux by super-granular flows in the polar region * Differential rotaion in the polar regions	* Magnetic (vector) * Granular patterns	* Constrain the amplitude of turbulent flux dispersal from models that describe the surface evolution of magnetic field, that limit the processes rebuilding the poloidal field from troidal field. * Small versus large scale dynamo	moderate / definite
			* non-axisymmetric flows	* Doppler for Local HS	* Limit the efficiency of poloidal field generation	important / definite
			* Jet-like flow associated with the flux tubes in the tachocline * Flows associated with flux emergence	* Doppler for Global HS from additional vantage points	* Possible limitation for the field structure and amplitude in the solar convection zone	very important / very difficult
			* Near-surface super-granular-scale convection in the polar regions * Global convection, giant cell	* Doppler for Local HS * Magnetic (longitudinal)	* Progress into understanding convective transport and the establishment of mean flows in the deep convection zone.	important / difficult
			* Meridional counter flow * Thermal structure in the convection zone	* Doppler for Global HS from additional vantage points	* Unprecedented insights into the dynamics of the deep convection zone.	very important / very difficult
Q3: How does the radiative energy output of the Sun depends on latitude?	1.2.3	T3) High-precision measurement of total solar irradiance	* Continuous measurement of the total solar irradiance from various solar latitues	*Total irradiance	*Understand the irradiance variation against latitude *Understand the irradiance variation in stellar activity cycles	very important / definite
Q4: How does magnetic activity shape the structure and evolution of the polar solar corona and how does it affect the Earth ?	1.2.4	T4) Structure and dynamics of the high-latitude solar corona and solar wind	* Imaging and spectroscopy in EUV emission lines for outer solar atmosphere * White-light imaging of heliospheric structures between the Sun and Earth * In-situ measurements of the solar wind and particles (including cosmic rays)	*EUV Imager *EUV Imaging Spectrograph *Heliospheric Imager (optional) *In-situ instruments (optional; not clearly defined yet)	*Progress of understanding the variation of polar coronal structures in a solar cycle *Progress of understanding polar region dynamics in outer solar atmosphere *New view by direct imaging of innter heliosphere from a vantage point *Progress in understanding the	important/ definite

1.2 Exploration of Solar Interior and Solar Magnetic Activity

The primary goal of the SOLAR-C mission is to understand the origin of solar magnetic activity by observing the magnetism and dynamics of the polar regions that are currently inaccessible for direct observation. In Section 1.1 we identified four key scientific questions tackled by SOLAR-C. They are summarized in Table 1. Here we describe each of the observational targets in turn and what scientific impact they are likely to have.

1.2.1 Q1: How is the global, cyclic, solar magnetic field generated?

Understanding the origin, distribution, topology, and evolution of magnetic flux near the solar poles is essential for understanding the origins of cyclic magnetic activity, for predicting the amplitude and duration of future cycles, and for assessing the impact of solar variability on the Earth. Coupling between magnetic fields and flows in the polar regions governs the polarity reversal of the global dipole moment and shapes the magnetic topology of the overlying corona. The magnetic flux emanating from polar coronal holes fills the heliosphere and accelerates the fast component of the solar wind, thus regulating the interaction between the Sun and planetary space environment. Further progress requires high-latitude magnetograms, Dopplergrams, and helioseismic imaging.

Synoptic observations of solar magnetic fields have shown evidence that the magnetic flux at the following (westward) edge of bipolar active regions is systematically transported toward the poles, where it encounters poloidal flux of the opposite sign generated by the previous cycle. As low-latitude flux continues to accumulate, the magnetic polarity of the polar regions reverses, leading to a corresponding reversal in the global dipole moment. ***However, how the process of the polarity reversal actually occurs in detail and how it couples to the deeper convection zone is unknown.*** What processes determine the distribution of surface and subsurface polar flux before and after a reversal? This fundamental issue can and will be resolved by means of a magnetograph viewing the pole from an inclination much greater than the 7° provided by the ecliptic.

High-latitude magnetic field measurements are also needed to quantify the energy and flux budget of the dynamo, the multipolar structure of the mean poloidal field, and the efficiency of poloidal field generation by means of the Babcock-Leighton mechanism. Evidence for non-axisymmetric structure in large-scale fields with low longitudinal wavenumber (m=1-3) might reflect the presence of MHD shear instabilities. Measurements of the high-latitude magnetic field in the solar photosphere are of fundamental importance for the understanding of the magnetic topology of the solar corona and its dynamical coupling to the solar interior, particularly with regard to small-scale flux emergence and coronal heating.

A complete understanding of how a polar field reversal occurs and what physical processes give rise to the solar activity cycle can only be obtained by considering magnetic field measurements within the context of the global and local flows that generate them. This is addressed in question Q2, Section 1.2.2.

1.2.2 Q2: What is the nature of the flows in the polar regions of the Sun and how do they interact with magnetism?

As alluded to in Sections 1.1.2 the dynamical origins of solar magnetic activity can only be fully investigated by considering correlations between multiple observables. The most important correlations are clearly those between the flow and the magnetic fields. Magnetic induction by convection, differential rotation, and meridional circulation is responsible for the magnetic activity patterns we see and the back-reaction of the Lorentz force on mean and fluctuating flows provides an important diagnostic of subsurface dynamics. Investigating such interactions lies at the heart of nearly all of the scientific objectives of the SOLAR-C mission.

Differential rotation and meridional flow in polar regions

Details of differential rotation and meridional flow in polar regions are currently unknown. Differential rotation is inferred from global acoustic oscillations, which are not very sensitive to the structure in high latitudes and in addition they do not allow for a discrimination between contributions from the southern and northern hemisphere. Meridional flows are inferred from Doppler measurements as well as local helioseismic techniques. Both approaches yield only reliable data to latitudes of about 60° since resolution is limited due to foreshortening and, in the case of helioseismic measurements, the signal to noise ratio is reduced due to the line-of-sight projection of the p-mode Doppler signal.

Existing helioseismic measurements of differential rotation suggest sharp spatial and temporal variations, including the possibility of a subsurface poleward jet (polar jet), but these measurements can be confirmed only by observing the polar regions directly, from an out-of-ecliptic orbit and by local helioseismology, which is free from the constraints of global helioseismology. The zeroth-order structure of the meridional flow is approximately described by a single cell pattern with poleward flow near the surface (and maybe in equatorward at the bottom). An additional flow cell with opposite direction in polar regions has been inferred from some measurements, but is still strongly debated. In addition to their dynamo implications differential rotation and meridional flow have compelling diagnostic value in understanding the dynamics of the deep solar convection zone. Particularly significant are possible correlations between zonal flows, meridional flows, magnetic flux, and thermal variations.

The most well established signature of dynamical coupling between the zonal and meridional flows, magnetic fields, and thermal gradients is that of the solar torsional oscillations. These are alternating bands of east-west zonal flow that evolve in close correspondence with the solar activity cycle (Figure 3). Two components are evident from the data, including a low-latitude branch that propagates equatorward in conjunction with bands of magnetic activity and a high-latitude branch that propagates poleward on a comparable time scale. The high-latitude branch is stronger and deeper than the low-latitude branch and may arise from distinct dynamical influences. Correlated meridional flows and thermal signatures are known for the low-latitude branch but are currently undetectable for the high-latitude branch. Variations of the meridional flow with the solar cycle induced by magnetic or thermal forcing also have important consequences for determining the strength and distribution of the polar field and the timing of polarity reversals. Coordinated observations of the meridional flow and the magnetic field in the polar regions will provide quantitative estimates of flux transport and will thus elucidate the physical mechanisms that underlie cyclic solar activity.

The vantage point of SOLAR-C will provide an unprecedented opportunity to observe such correlations and in particular their phase relationships, providing important constraints to theoretical and numerical models of the solar convection zone and dynamo by exploring a part of the Sun that is virtually unknown.

Tachocline dynamics/stereoscopic measurements

In order to observationally constrain the subsurface location of dynamo activity it is necessary to detect either field-induced perturbations of the sound speed or related flow fields. Sunspots and related bipolar active regions in the solar photosphere are thought to originate from the buoyant destabilization and subsequent emergence of strong, coherent toroidal magnetic flux structures that are generated deep in the solar interior, most likely in the tachocline or the lower convection zone. Some theoretical and numerical models predict that such concentrated toroidal flux structures may support coincident zonal jets of fluid as large as 100 m/s that help stabilize them against magnetic tension and buoyancy. Although direct detection of such deep-seated toroidal magnetic flux structures may be beyond the sensitivity of helioseismic inversion techniques, the zonal jets they induce may be detectable by stereoscopic helioseismology in which coordinated observations using SOLAR-C and another instrument such as HMI or GONG would provide the very long baselines needed to measure the relatively long-wavelength modes that sample the deep interior with local helioseismology.

Currently one of the most pressing issues concerns the strength of the subsurface toroidal fields that ultimately emerge to produce photospheric active regions; current estimates range from 10 to 100 kG. The predicted amplitudes of associated zonal jets increase with the strength of the field, and are potentially only detectable toward the higher end of the estimated range (100 kG). Detections or even upper limits of this order for zonal flows and toroidal field strengths in the deep convection zone and tachocline could have a dramatic impact on dynamo models.

Stereoscopic helioseismology will also allow us to improve measurements of the meridional flow in the deep convection zone. Such measurements are challenging but extremely important, since the meridional flow speed at the base of the convection zone largely sets the 22-year period of the solar activity cycle, according to current flux-transport dynamo models. Given the paucity of current data, any limit imposed on structures, speed, etc. by observations would be of great importance. For example, determining the depth at which the flow shifts from poleward to equatorward would improve current estimates of the speed of the return flow at the base of the convection zone based on mass conservation. The density contrast of 100 between the lower (0.7R) and upper (0.96R) convection zone implies values of order several m/s, which would be extremely difficult to measure directly, even with a stereoscopic method.

In addition, the tachocline might also play a central role in determining the structure of differential rotation throughout the convection zone (deviation from Taylor-Proudman state, in which the rotation rate remains constant along the direction parallel to the rotation axis). Here additional constraints on the thermal structure, especially latitudinal temperature variations are crucial. Current attempts to measure such variations using the GONG and MDI data will be greatly improved by supplemental data from the unique perspective of SOLAR-C. The required accuracy is substantial, since models predict only a few Kelvin variation, as compared with a background temperature of about 2 million K at the base of the convection zone. Yet, if magnetic effects can be properly taken into account, local helioseismic inversions and irradiance measurements (Sec. 1.2.3) may be able to provide some estimate of the pole-equator temperature difference in the solar surface layers, if not in the deep convection zone.

Stereoscopic techniques will also benefit global helioseismic inversions, which are currently impeded by incomplete sampling of the solar surface. Observations from a single vantage point only sample one side of the Sun rather than the entire spherical surface on which spherical harmonic functions would form an orthogonal set. Multiple vantage points would greatly improve spatial coverage. In case of SOLAR-C, with its position in the orbit around the Sun synchronous with Earth, for maximizing the telemetry rate, the increase in spatial coverage is not so great but it still offers an increase particularly when its heliographic latitude is high.

Determining the differential rotation, the meridional flow, and convective patterns in the upper convection zone at high latitudes will be achieved by applying well-established local helioseismology techniques previously confined to lower latitudes. Probing deeper layers will be done by a novel technique of stereoscopic helioseismology from multiple vantage points.

1.2.3 Q3: How does the radiative energy output of the Sun depend on latitude?

The main goal of the proposed SOLAR-C Luminosity and Irradiance Monitor (LIM) is to address the basic question, ‘How precisely do we know the luminosity of the Sun?’ A more detailed description of the science goals can be summarized by the following four fundamental questions related to the radiative output of the Sun:

- *Are the solar irradiance variations observed from Earth due to flux redistribution in space or due to solar luminosity variations?*
- *Is the radiant output at the poles different from the values we observe in the ecliptic?*
- *What is the latitudinal temperature gradient?*
- *Why is the variability in irradiance of the Sun a factor of three smaller than that of sun-like stars?*

The first three questions arise because up to now, the irradiance was observed exclusively from the in-ecliptic vantage point. The fourth question was first asked by Lockwood et al. (1992) who noted that compared with Sun-like stars, the irradiance variations induced by the solar cycle appear to be smaller than in Sun-like stars. It has been proposed that this exceptional property of the Sun is due to our equator-on viewing angle (Lockwood et al. 1997, Radick 1998) but it is not yet clear whether this explanation can fully account for the observed difference (Knaack et al. 2001).

The observational answers to these fundamental questions require measurements of the solar radiative output at higher heliospheric latitudes than what an ecliptic-bound mission can provide. Observations from the SOLAR-C Plan-A platform will allow us to verify the view-point hypothesis. SOLAR-C Plan-A is the only planned mission that intends to fly a radiometer out of the ecliptic. On average, stars are seen from a latitude of 30º. A trend in the solar irradiance level as SOLAR-C LIM approaches this inclination will allow us to confirm or reject the view-point hypothesis. This measurement will also be possible check the reliability of TSI models at the Maunder minimum era that were reproduced using various indices with basic data of cosmogenic isotope that record the past solar magnetic activity. This is of vital importance in the future TSI prediction for the Earth’s environment.

Reproducing the solar luminosity is the ultimate requirement to all stellar evolution models. In other words, the total solar irradiance is used to calibrate models of stellar evolution. The energy production in the core of a main-sequence star is balanced by the radiant emission at the stellar surface. Since the energy production rate as well as the radiant emission strongly depend on the temperature of the core and surface, respectively, accurate measurements of the solar luminosity provides a direct link to the temperature not only at the solar surface but also in the solar core.

Latitudinal irradiance scans also allow assessment of latitudinal temperature gradients which might be linked to meridional flows.

1.2.4 Q4: How does magnetic activity shape the structure and evolution of the polar solar corona and how does it affect the Earth?

In addition to measurements of photospheric and subsurface motions and magnetic fields, it is the first opportunity to observe the outer solar atmosphere of the polar region in detail.

Coronal Structures and Activity in Polar Regions

The Japanese solar physics community monitored the brightness of the solar corona at a height above the solar limb by small ground-based coronagraphs for 60 years covering five 11-year solar activity cycles (Figure 11). In the space program, the whole Sun was monitored in soft X-ray observations by the 2nd Japanese solar mission, *Yohkoh*, from 1991 to 2001 (Figure 12).

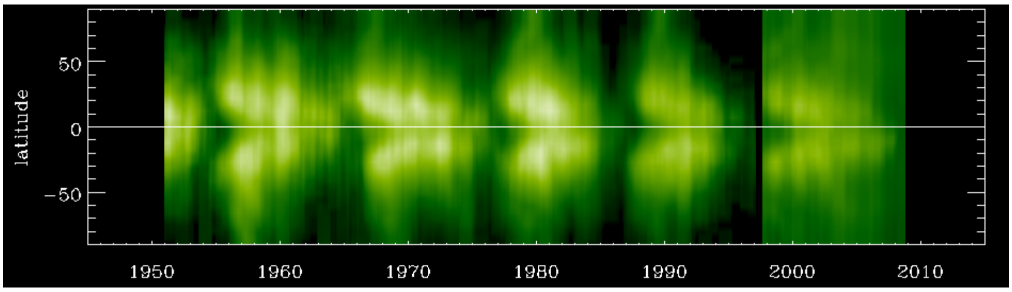


Figure 11. Coronal brightness variation in time-latitude diagram from the observation in the coronal green line (Fe XIV 5303) by the ground-based coronagraph at Norikura Solar Observatory (NAOJ)

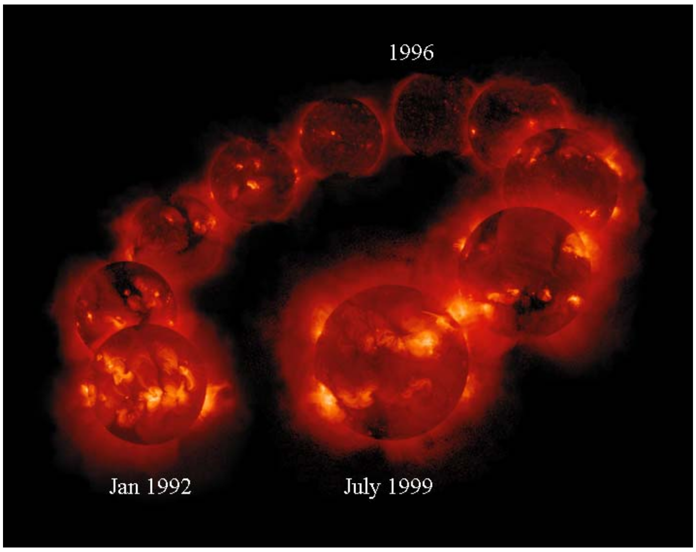


Figure 12. Cyclic variation of coronal structures in soft X-rays from *Yohkoh* (ISAS/JAXA)

Similar to the butterfly diagram of sunspot and surface magnetic fields, long-term coronal activity also shows the butterfly pattern in the time-latitude diagram. It has been well known since 1950's that there is a pole-ward migrating blanch in the diagram (Waldmeier 1957).

The polar regions of the Sun outside the solar maximum have a ray-like structure called 'polar plume.' The structure is well observed by white-light observations at the eclipse time or coronagraph observations in space. It is known from Skylab era that its electron temperature is slightly lower than the inter-plume region. The STEREO observations of polar regions with two view angles show where polar plumes observed with two coronal EUV imagers are rooted. However, the magnetic activity at the root could not be measured by a foreshortening effect by observing the polar region from the ecliptic plane, so that how these structures are formed has not been fully understood. Imaging observations of polar plumes from a vantage point in the SOLAR-C orbit will clearly address where and how they are formed. In addition to measurements of photospheric magnetic fields and imaging of transition region (TR) and corona, EUV imaging spectroscopy is of vital importance in revealing what basic processes are occurring at the roots of polar plumes and how plasmas in plumes move as results of the processes. One of the important measurements is to detect clear evidence of Alfvén waves in the polar plume or in inter-plume regions as we stress in the next sub-section of solar winds.

Near the solar maximum phase, the polar region is covered by many closed magnetic field structures with a ray-like shape at their tops, streamers. The phase of their appearance is near the time of polar magnetic field reversals. The coronal imaging observations from the SOLAR-C out-of-ecliptic orbit will clearly tell us how magnetic fields of these structures are connected at the photosphere and how these structures are formed near the solar maximum phase.

In addition to characteristic global magnetic structures in polar regions, small bipoles are also universally observed there. They were called X-ray bright points or coronal bright points that were first observed in an early sounding-rocket experiment with soft X-ray imaging telescopes. They are distributed all over the latitudes. From photospheric and coronal observations near the disk center, opposite magnetic polarities appear to be cancelling at the photospheric level beneath coronal bright points. It is believed that they are produced though magnetic reconnection in the corona by interaction between opposite magnetic polarities that have already seen above the photosphere, not as a direct emergence of a small bipolar structure. The elemental process occurring up to the mid latitudes is being investigated by *Hinode* with its high-spatial resolution in a narrow field of view. The small bipoles are replenished rapidly with time and the total magnetic flux exceeds those brought from the global magnetic activity showing a quasi-periodic activity of roughly 11 years. The occurrence frequency of the bright points measured in low-latitude regions is found to be roughly constant in contrast to the normal solar magnetic activity that has a quasi-periodic 11-year cycle. The low-amplitude or almost constant cyclic behavior may be the presence of a different dynamo action that locally functions. It is not clear at present that the emergence rate of such bipoles in polar regions is the same as that in low latitudes. A direct observation with less foreshortening effect from the out-of-ecliptic orbit with less overlap by foreground and background corona will clearly answer the behavior of small bipoles in polar regions.

Hinode high-cadence X-ray observations have shown that polar regions are more dynamic than expected from the extension of *Yohkoh* X-ray observations as revealed from a higher occurrence frequency of coronal jets (Cirtain et al. 2007). *Hinode* has also revealed from a high-resolution vector magnetic field measurement that the formation of coronal jets in a polar coronal hole is found to be associated with newly discovered photospheric kG concentration of polar magnetic fields through magnetic reconnection (Kamio et al. 2009). Such events may produce Alfvén waves that are thought to be important to the acceleration of the fast solar wind. EUV spectroscopy with enhanced sensitivity will reveal the coronal dynamics in polar region.

Solar Wind

Supersonic plasmas flow into interplanetary space from the Sun as the solar wind. Many in-situ observations in the ecliptic plane have shown that the speed of the solar wind ranges from 300 to 800 km/s. Timing analysis of the fast solar wind (600-800 km/s) with full-disk X-ray images and global open magnetic field structures of the Sun have revealed that polar coronal holes and those extended from polar regions to lower latitudes are the source of fast solar wind. The solar wind speed measured by Ulysses whose orbit is largely inclined to the ecliptic orbit clearly showed that there is a latitudinal variation in the solar wind speed and that the speed is bi-modal in the solar minimum phase, that is, the slow wind with outflow speed of 300-400 km/s in low latitudes and the fast wind of 600-800 km/s in high latitudes (McComas et al. 2003, 2008; Figure 13). It is also known from Ulysses that the slow solar wind also appears in the high-latitude region near the solar maximum phase (Figure 13). It is widely accepted that the fast solar wind is so fast that the speed cannot be explained by Parker's thermally driven wind model alone. An additional energy input needs to be given to the plasma flow. The interplanetary scintillation (IPS) observations show that the acceleration of the solar wind is almost finished within 30 solar radii.

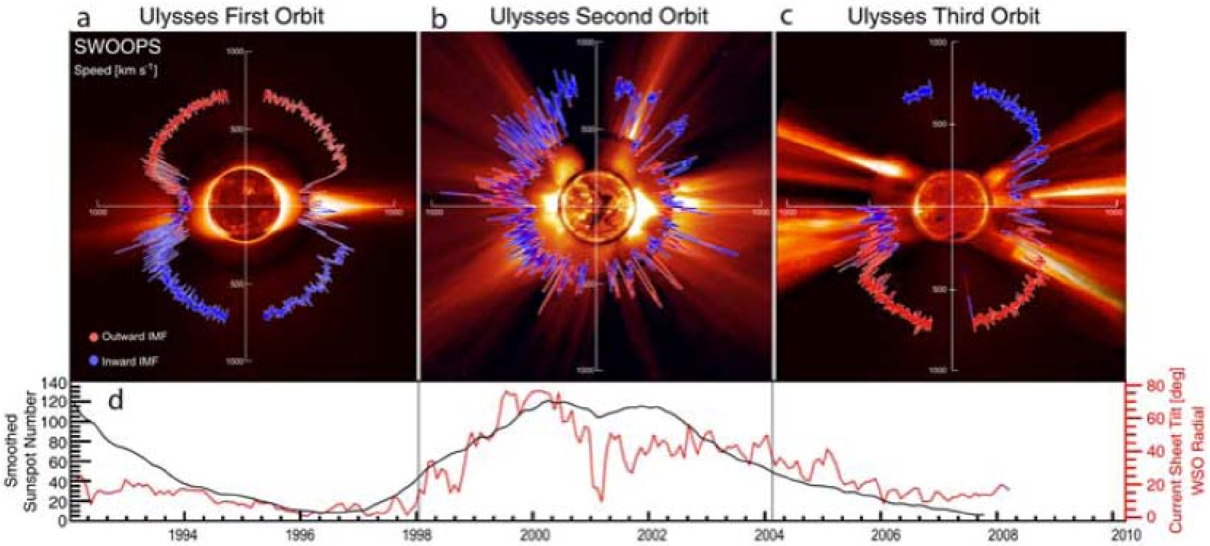


Figure 13. Solar wind velocity measurements by Ulysses (McComas et al. 2008)

There were two categorized candidates for the mechanisms of fast solar wind. One is a fast jet produced at the transition region or low corona, and the other is the acceleration by waves in the corona. The possibility of the former disappears after SOHO observations because the high-speed jet is not universally observed in the EUV imaging and spectroscopic observations in the transition region and low corona and because the acceleration of the flow speed at the location between the low corona and a distance of 30 solar radii becomes mandatory from the tracking of white-light coronal structure seen in the coronagraph (Sheeley et al. 1997) and from the evaluation of wind speed by Doppler dimming technique (Cranmer et al. 1999). The unexpectedly larger number of jets in polar coronal holes has been found by *Hinode* X-ray imaging observations (Cirtain et al. 2007; Figure 14). Although it may contribute to some fraction of the total mass with a million degree for the fast solar wind, it cannot explain the acceleration of the solar wind in the most inner heliosphere within 30 solar radii.

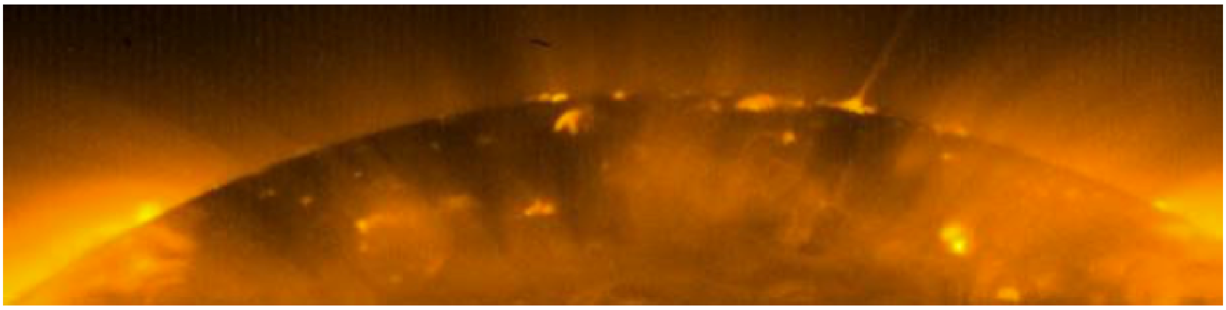


Figure 14. North polar coronal hole observed with *Hinode* XRT showing a coronal X-ray jet

One of the most promising mechanisms is acceleration of the wind plasma by Alfvén waves. The wave itself has normally been found in solar wind plasmas by in-situ measurements since the early space age (Belcher and Davis 1971). The source of the Alfvén waves is not well understood. It may be a wave simply produced by the photospheric motion of magnetic field structure by granule motions or a wave created by magnetic reconnection in the low corona. A high-speed solar wind is reproduced in Suzuki & Inutsuka (2005) by the photospheric lateral motion of the magnetic field. However, clear evidence of Alfvén wave with sufficient energy flux has not been found in the polar coronal hole. The wave signatures near the base of polar coronal holes that have been reported are mostly identified as slow-mode waves. One of the signatures for the presence of Alfvén wave near the base of the corona is enhanced line broadening of the coronal emission lines that are always observed in polar coronal holes. If it is found that this broadening is actually caused by Alfvén wave, where the energy flux of Alfvén waves created and what amount of energy flux Alfvén waves have could be understood. One way is to look at the polar region with an imaging spectrometer from various angles or to look at the same point stereoscopically with two imaging spectrometers that locates at different heliocentric latitudes. For this type of observation, higher spatial and spectral resolutions than those realized as SOHO SUMER and *Hinode* EIS is not required.

The solar wind is largely accelerated to the coronal sound speed near 2-3 solar radii and become supersonic beyond that point. In the upper part of the corona at a radial distance above ~2 solar radii, the hydrogen Lyman alpha line (H I) at 1216 Å shows a spectrum of very wide line width. This was first discovered by the sounding rocket experiment in l979 (Kohl et al. 1980). The emission mechanism is the resonance scattering of photons nearby the Lyman alpha wavelength by a small amount of neutral hydrogen in the corona, and was identified in Gabriel (1971). A similar line profile is seen in ionized oxygen resonance lines O VI at 1032 Å and 1037 Å (Figure 15). The number of scattered photons depends on the outflow speed of each hydrogen or ionized oxygen atom that absorbs a photon and re-emits. Faster plasmas scatter the smaller number of photons (Doppler dimming). The bulk flow speed of the solar wind plasma was evaluated from the scatted photons by SOHO UVCS in the inner corona that cannot be accessible by IPS observations. The cause of the largely enhanced line broadening is not fully understood. One definite contribution is from the line-of-sight component of the solar wind bulk outflow and the other is from the local mass motion of atoms. The local mass motion consists of the thermal Doppler motion and some additional mechanical motions. The latter contribution contains information of the heating and acceleration of solar wind plasmas.

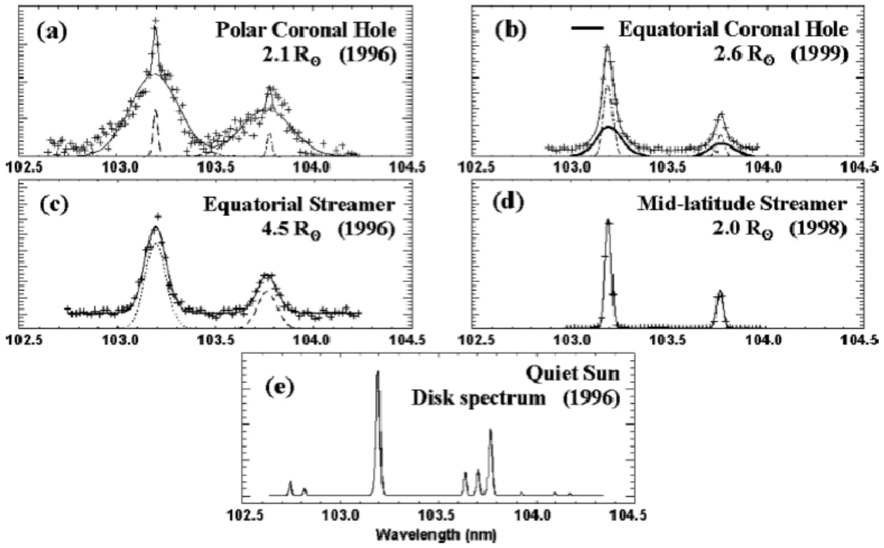


Figure 15. Enhanced emission-line broadening at observations above coronal holes with SOHO UVCS (from Kohl et al. 2006).

Largely enhanced emission-line widths have been found in O VI observations with SPARTAN and SOHO UVSC (Figure 15). The line width implies that there will be large ion mass motions perpendicular to the line-of-sight direction. It is sometime referred to be 100 MK at height above 2 solar radii, while the electron temperature at that height is about a million degree. The enhanced kinetic temperature is interpreted as a perpendicular motion of ions to the magnetic field line ($T_\perp$), and its highly anisotropic kinetic temperature ($T_\perp/T_{//}$ ~100 >>1) is due to the heating by some mechanisms. As a potential mechanism, the ion cyclotron resonance heating has been proposed (McKenzie et al. 1995; Cranmer et al. 200?). The mechanism requires a high-frequency Alfvén waves of 10^4 Hz in the corona, which cannot be expected by the low frequency (0.001-0.01 Hz) photospheric granule motions. The estimate of $T_\perp$ on O VI observations depends on the model outflowing atmosphere in polar coronal holes. A solution to satisfy the UVCS observation is possible for simple isotropic kinetic temperature ($T_\perp=T_{//}$) cases (Raouafi and Solanki 2006) and for reduced anisotropic ($T_{//} < T_\perp < 10\ T_{//}$) cases (Nakagawa 2007). Observations of polar coronal holes from different helio-latitude by the SOLAR-C Plan-A spacecraft from out-of-ecliptic orbit or stereoscopic measurements with a spacecraft in a low Earth orbit or at L_1 Lagrangian point will resolve this discrepancy and leads to correct understanding of motions of ionized atoms with different mass from hydrogen. The global magnetic-field structure inferred from the SOLAR-C magnetic field measurement and coronal imaging from a high-inclination vantage point will also become a help for understanding the magnetic structures in polar coronal holes as a model input.

The solar wind speed in the polar region changes in the solar cycle as shown in Figure 13. When the SOLAR-C spacecraft is in the final orbit, the spacecraft can see each polar region for a few months per year in a good condition above 30° from the solar equatorial plane. The change of flow speeds at the coronal base from the open magnetic-field region in each polar region can first be monitored during the rapid change in the polar reversal phase. The flow speed as a function of evaluated expansion factor of magnetic field structures in the polar region, which is considered to be a key factor for the fast wind speed, may be observed by SOLAR-C.

Coronal Mass Ejections & Disturbance

Coronal Mass Ejections (CMEs) are the most powerful source of the heliospheric disturbances and the primary cause of the geomagnetic storms. Understanding and predicting their initiation, evolution and interaction with the planetary atmosphere is one of the most important topics in solar physics and the space weather studies. The other source of geomagnetic disturbance is the Co-rotation Interaction Region (CIR), the large-scale plasma structures generated by the interaction of fast and slow solar winds. The recurrent MeV-ion events and the decrease of the galactic and anomalous cosmic ray intensity are also associated with CIR.

Initiation of CMEs and acceleration of the solar wind in the lower corona are being investigated in detail by *Hinode*, using the combination of photospheric and chromospheric observations by the SOT and coronal observations by the EIS and XRT. In order to investigate the later evolution of CMEs and CIRs in the inner heliosphere, it is necessary to have continuous imaging observation that covers from the outer corona to the interplanetary space.

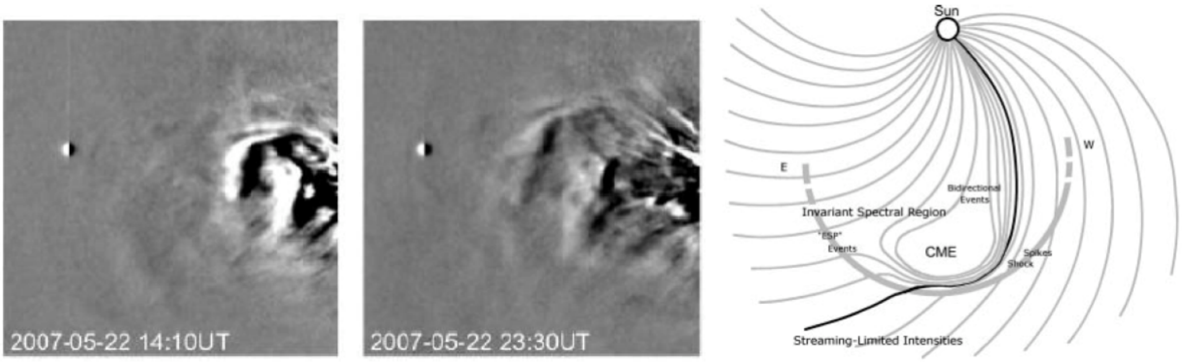


Figure 16. (Left and Middle) Evolution of a CME event observed with STEREO/HI-1 (from Harrison et al. 2009). (Right) Overhead view of the CME travel in the Sun-Earth interplanetary space (from Reames 1999)

The STEREO Heliospheric Imager instruments clearly demonstrated that CMEs and CIRs near 1AU and beyond can be detected by such instruments (left and middle panels in Figure 16; Harrison et al. 2009), and provided the first stereoscopic view of the solar corona and the inner heliosphere. With a STEREO/HI-like imaging instrument on board SOLAR-C/Plan-A, we will be able to obtain the first overhead view of the heliosphere, which has been often drawn as "cartoon models" by many researchers (right panel in Figure 16). It will allow us, for the first time, to investigate the evolution of CMEs and CIRs in the background Parker-spiral solar wind.

Combination of the context heliospheric image from SOLAR-C/IHI and the in-situ plasma measurement in the ecliptic by a spacecraft such as ACE, WIND, GEOTAIL and Cluster will be of great synergy. For example, the basic structure of CME is believed to be twisted flux rope that is either already formed before eruption or generated during the eruption by the post-eruptive reconnection (Forbes 2000). However, it has been pointed out that the interplanetary CMEs (ICME) observed by in-situ instruments at 1AU often show more complicated structure without well-defined flux rope (Richardson and Cane 2004). With the overhead view of the CMEs from SOLAR-C, we can tell where in the CME the in-situ instruments are observing, thus allowing the interpretation of the in-situ measurements in the global context.

The overhead view also has a great impact from the space weather point of view, as we will be able to see what part of the CMEs and CIRs are going to hit the Earth that allows more reliable prediction of the solar wind properties at the Earth.

Solar energetic particles (SEPs) associated with flares and CMEs and cause significant damage of the spacecrafts and disruptions of the human activities in the space. Moreover, acceleration of energetic particles is one of the most fundamental processes in the space and astrophysical plasmas. Understanding the production of SEPs and their propagation to the Earth is therefore one of the most important subject in the solar and heliospheric physics from both practical and academic points of view. Indeed, the solar corona, interplanetary space and the Earth's magnetosphere provide powerful and complementary laboratories for particle acceleration. While imaging of the solar corona shows the global change of the magnetic topology, in the magnetosphere, detail microscopic plasma processes can be observed by the in-situ measurements. On the other hand, with the out-of-ecliptic heliospheric imager and the other in-situ instruments, the interplanetary space provides a unique laboratory in which one can see both the global dynamics and morphology and the microscopic plasma processes.

Phenomenologically, SEP production can be classified into two categories, one associated with solar flare in the low corona (or more physically, magnetic reconnection), and the other associated with CME-driven interplanetary shocks. SEPs are usually observed at 1AU after they escape from the acceleration site and propagate, primarily along the interplanetary magnetic field, to the spacecrafts. Note that shock acceleration also is believed to be occurring in many astrophysical phenomena, such as generation of the galactic cosmic rays (GCRs) in the supernova shocks and gamma-ray bursts.

SOLAR-C/HI can address this issue by providing the global context of the interplanetary space in which acceleration and transportation occur. From the overhead view of the CMEs we can measure the mach number and, with an assumption of Parker-spiral-like ambient solar wind, the angle between the shock normal and the ambient magnetic field in the upstream. Also by assuming the Parker spiral, one can determine the magnetic connection of the shock front and the spacecrafts observing the SEPs in the ecliptic. Using this information and a model of SEP transportation, one can determine where in the CME shock the SEPs come from, thus allowing the comparison of the acceleration models and observations.

In-situ Measurements in the Inner Heliosphere

The past solar activity has been investigated by cosmogenic isotopes such as ^{14}C and ^{10}Be. These are created by the interaction between atoms in the Earth's atmosphere and cosmic rays in a certain energy range (~ a few GeV or below). These cosmic rays mostly arrive at Earth through the heliosphere during a course of a long travel in our galaxy. Due to the change of magnetic field structure in the heliosphere according to solar cycle variations, the number of the cosmic rays suffers from significant modulation. The transport process of cosmic rays in the heliosphere was first shed light on by Parker (1965). The theory describes the time evolution of the cosmic ray distribution function by processes of (1) convection and adiabatic energy change by solar wind velocity, (2) turbulent irregularities, and (3) gradient, curvature, and current-sheet drift. The basic formulation is still valid. However, there are uncertainties in various parameters.

Ulysses has executed the fist measurements of cosmic rays at high heliocentric latitude of 80°. It was expected that the cosmic ray intensity would increase an order of magnitude compared by the measurement near the ecliptic plane because the local interstellar cosmic rays can travel to the inner heliosphere along the magnetic field without significant modulation. In contrast to the theoretical expectation, Ulysses found that the cosmic rays increase only a few ten percents from ecliptic to the high latitude during the solar minimum. This indicates enhanced diffusion by turbulent irregularities in the high latitude. Thus, the transport model of cosmic rays in the heliosphere is not consistent with the Ulysses observations. The maximum inclination angle of 33° from the ecliptic plane in the SOLAR-C Plan-A orbit is smaller than that of 80° in the Ulysses orbit. However, a fast scan with a constant period of a half year at 1 AU distance from the Sun is an advantage in the SOLAR-C Plan-A orbit for the scan range from the northern maximum to southern maximum latitude, and may have an advantage of investigating how the particle counts vary with the solar activity cycle in a fixed observing condition. The measurement may produce unique data set to enhance the value of long-term data on the variation of cosmogenic isotopes that record the past solar activity. Without this measurement no progress is expected from observations for the transport of cosmic rays in the heliosphere in the coming decades.