Scientific rationale

Understanding the mechanism of the 11-year solar activity cycle is one of the central problems of solar physics. During the last 8 years observations from SOHO spacecraft have provided tremendous amount of new information about the physical processes in the solar interior and atmosphere associated with the solar cycle. The new data provide important constraints for theoretical models of solar dynamo and stimulate development of new ideas. These data also provide unique opportunity for testing the theoretical predictions. Therefore, exploring the new opportunities by an international team of specialists in data analyses, theory and modeling will be extremely beneficial for further progress in this field. In particular, we propose to investigate approaches to a synthesis of the helioseismic, magnetographic and coronal observations for developing a consistent model based on the current theoretical understanding of dynamo processes. The results of this research effort will have significant impact on planning future long-term observing programs and theoretical modeling.

Helioseismology has provided measurements of some key parameters of solar dynamo: differential rotation, meridional circulation, vorticity, and their variation during the current solar cycle. Many of these measurements are not explained by the dynamo theory and require new theoretical approaches. For instance, it is found that the migrating zonal flows – torsional oscillations, that follow the latitudinal activity belts, penetrate deep into the solar interior, particularly, in the near polar regions, and remain strong at the solar minimum. These measurements seem to be rule out the explanation of the torsional oscillations by a direct act of magnetic forces [*Schuessler*, 1981]. It could be that these flows are driven by changes in the convection energy flux caused by internal magnetic fields [*Spruit*, 2003], but this idea has to be modeled theoretically and tested in observations. At the moment, it is unclear how to do this. At the bottom of the convection zone, so-called tachocline, contrary to expectations from dynamo theories, no clear evidence for 11-year variations of solar rotation has been found. Instead, the observations show puzzling 1.3-year variations in the tachocline [*Howe et al.*, 2000]. A similar periodicity is found in the surface activity [*Krivova and Solanki*, 2002], but the relationship of this phenomenon to the tachocline variation is unknown.

A new significant element in recent investigations of the solar cycle is realization of the importance of non-axisymmetrical components of the solar dynamics and magnetism. It has been suggested that long-living complexes of activity, or `active longitudes`, play a fundamental role in the solar cycle. In particular, it is intriguing that the first active regions of a new solar cycle tend to appear in the same longitudinal zone as the last active regions of the previous cycle [*Benevolenskaya et al.*, 1999]. The non-axisymmetrical structures can be persistent over many cycles, and also are important in other stars with activity cycles [*Berdyugina and Usoskin*, 2003]. Observations of the solar corona in X-ray and EUV from Yohkoh and SOHO/EIT confirmed the existence of the previously observed by coronographs emission feature migrating towards the poles during the rising phase of the solar cycle, and revealed that these features represent footpoints of giant coronal loops connecting magnetic field of the following polarity of active regions with the polar field [*Benevolenskaya et al.*, 2001]. Since the polar field is formed during the previous solar cycle, these loops provide evidence of important topological changes in magnetic field that may be caused by reconnections in the corona. Recent advances of local area helioseismology and, particularly, time-distance helioseismology allow us to obtain detailed synoptic maps of subphotospheric flows and, thus, to study various non-axisymmetrical components of solar circulation [*Zhao and Kosovichev*, 2004].

The detailed observations of the solar cycle variations in the solar interior, surface magnetic field and solar corona provide a good basis for developing new approaches towards a consistent model of the solar cycle. Currently, the solar cycle models are mostly based on axisymmetrical mean-field theory. By adjusting free parameters these models can reproduce some features of the solar cycle [*Bonanno et al.*, 2002; *Dikpati et al.*, 2002; *Dikpati et al.*, 2004], but the basic understanding of the underlying physics is still missing.

We propose the following initial tasks for discussion and investigation:

- Physics of torsional oscillations and their relationship to magnetic fields
- Properties of non-axisymmetrical components and polar fields
- Role of reconnections in the solar corona
- Meridional circulation, differential rotation and magnetic flux transport
- Measurements and modeling of magnetic and kinetic helicity
- Formation of active regions
- Mechanism and role of 1-2 year variations in the solar cycle

The basic observational data that will be used for this project are synoptic maps of solar magnetic field available for cycles 21-23, synoptic maps of the corona and subphotospheric flows for cycle 23.

This project will be carried out during two one-week meetings at the ISSI in the spring and fall of 2005. The ISSI suits perfectly for this project because of the location and facilities which include a meeting room and access to workstations.

The results of this project will be published in a review article, or in several articles, and will represent a valuable discussion of the current state of this field and provide guidance for developing new approaches for data analysis and theoretical modeling.

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