Challenges in Modelling Solar Magnetism and Dynamo Action
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Abstract:
This is a proposal to gather world experts, with many residing in Europe, for an ESF Science Meeting via the Astrosim network on numerical simulations of solar magnetism and dynamo action. We seek to understand how the turbulent Sun achieves its convective transport of heat and angular momentum, establish its large scale flows and how it generates, amplifies, stores and redistributes magnetic fields. The resolution of such complex and challenging questions requires focused and sustained efforts over multiple years to build more realistic global dynamical solar simulations.

Scientific objectives:
We are in an *era of fundamental discovery* about the overall dynamics of the solar interior and its ability to generate magnetic fields through dynamo action. This has come about partly through guidance and challenges to theory being provided by helioseismology as we now observationally probe the interior of the Sun with high accuracy (SoHO) and by high resolution observations of the surface magnetic fields of the Sun (SoHO, Hinode). It also rests on our increasing ability to conduct simulations of the crucial solar turbulent and magnetic processes by using the latest generation of supercomputers. We intend if this proposal is funded to organize an international workshop to gather the world experts in solar turbulence and magnetism in order to progress further in our understanding of the inner working of our star.

Indeed the Sun is a magnetic star whose variable activity has profound effects on our technological society on Earth. This activity can damage satellites in space and power grids on the ground, and interrupt communications. Thus there is keen interest in being able to forecast the behaviour of the magnetic structures and its 22-yr cycle. Yet this has proved to be difficult, since the eruption of new magnetic flux through the solar surface appears to have a dominant role in the evolution of the atmospheric field configurations, as does the shuffling of field foot points by the subsurface turbulence, but recent encouraging progresses have been realized (Dikpati & Gilman 2006). The *origin of the solar magnetic fields* must rest with dynamo processes occurring deep within the star (Parker 1993, Ossendrijver 2003, Brun et al. 2004). Within the convection zone, complex interactions between compressible turbulence and rotation of the star serve to redistribute angular momentum and heat so that a strong differential rotation is achieved. Further, since the fluid is highly electrically conducting, currents will flow and magnetic fields must be built, leading to a likely nonlinear feedback on the dynamics. Yet there are many puzzles about the dynamo action that yields the large range of spatial and temporal scales of the observed fields, which as the underlying turbulence, can be ordered on some scales and chaotic on others.
We have achieved significant progress with our studies of highly nonlinear models of *elements of the solar dynamo*, and propose to continue our effort to build a more realistic dynamical model of the Sun. The *solar interface dynamo* paradigm is based on a number of underlying processes or building blocks:

(a) An α-mechanism: The generation of the background weak poloidal field, either by cyclonic turbulence within the convection zone or by breakup of active regions.

(b) A β-mechanism or turbulent transport: The transport of the weak poloidal field from its generating region to the region of strong shear, the tachocline, by either magnetic pumping by turbulent plumes or by large scale meridional circulations.

(c) An ω-mechanism: The organization and amplification of the magnetic field by differential rotation, particularly by large-scale rotational shear in the tachocline, into strong, isolated magnetic structures that are toroidal in character.

(d) Magnetic buoyancy: The rise and transport of the large-scale toroidal field by magnetic buoyancy into and through the convection zone to be both shredded and recycled or to emerge as active regions.

These essential processes have been identified mainly by intuition built on 2-D models, such as mean-field models and thin flux tube calculations. We thus wish to discuss the *fully nonlinear* 3-D versions of these processes in order to bridge 2-D and 3-D modelling efforts in a more coherent picture and to improve our understanding of solar magnetism. For the last decade the study of solar and stellar magnetic activity has been a field of fast development, in particular in Europe that possesses a large community of both plasma (fluid) physicists and specialists in dynamo theory, experts on the structure, evolution and dynamics of stars, as well as front edge observations and experimental facilities. Thanks to that strong community and to excellent theoretical work, more accurate observations and very recently high performance global MHD numerical simulations a coherent picture for solar and stellar magnetism is starting to emerge.

We believe that the ESF Science Meeting within the Astrosim network provides a real opportunity to organize a meeting whose purpose is to identify the strengths and weaknesses of the current 2-D mean field and 3-D MHD solar simulations and to bridge the gap between them and with the latest observational constraints, with the ultimate goal of improving our knowledge on solar magnetism and dynamics.

Meeting Programme:

The meeting will last 4 days from Monday the 14^{th} of April 2008 until Thursday the 17^{th}. After a day devoted to the latest observational evidences of solar magnetism and dynamics, the time will be devoted mostly to discussion in order to address questions such as: What are the missing elements of either 2-D mean field or 3-D MHD simulations? How these simulations can be improved by new development or by beneficiating from improvement coming from the complementary or alternative approaches? How close to observations are the latest simulations? What do the observers need from the theoretician/modellers and vice and versa? In each morning and afternoon sessions half the time will be devoted to contributed talks that will critically summarize the current state-of-the-art in a given sub theme of the solar magnetism (the dynamics of the solar tachocline, the solar convection, flux emergence, dynamo action, prediction of the next solar cycle etc…). Then in the second half of each session, the various speakers of each session will be asked to form a panel to which any participants of the workshop could ask a question to or raise an issue to be discussed among the panel members and all the participants. We hope by organizing such open discussions at the end of every session while the subject at hand is still fresh in everybody's mind to pin down what are the advantages and disadvantages of one simulation over another or what could be done to improve their realism and quality in order to match the latest high quality observations.