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Solar and Astrophysical Dynamos and Magnetic Activity

Edited by

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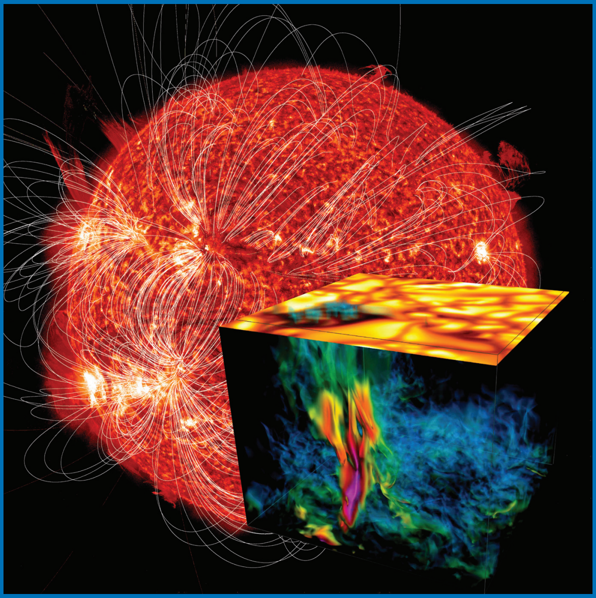

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SOLAR AND ASTROPHYSICAL DYNAMOS AND MAGNETIC ACTIVITY

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COVER IMAGE:

Image of the Sun in the Helium 304 Angstrom line and magnetic field lines from the Solar Dynamic Observatory data (source: SOHO/NASA), and numerical simulations of a self-organized magnetic field structure, which is formed below the solar surface and appears on the surface a dark 'pore' (see the paper by Irina Kitiashvili in these Proceedings).

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Preface

The origin of magnetic fields is one of the great, fundamental mysteries of astrophysics. Global magnetic fields in planets, in the Sun and other stars, in spiral galaxies and galaxy clusters are believed to be generated and maintained by a hydromagnetic dynamo, a process that converts turbulent kinetic energy into magnetic energy. The dynamo processes operate on drastically different scales, but are associated with common physical mechanisms, involving a complex interaction of rotation, turbulence and MHD instabilities.

The goal of this symposium was to discuss the most important results of recent studies of the cosmic dynamo processes: the origin and evolution of magnetic fields in various astrophysical objects from planets, to stars, galaxies, and clusters of galaxies; solar and stellar activity cycles; advances in dynamo theories and numerical simulations; dynamo and turbulence interlinks; similarities and differences between the solar and stellar activity of different scales; the driving mechanisms and triggers of solar and stellar magnetic relaxation phenomena; connections between the dynamo mechanisms in various objects; magnetogenesis; the current and future observational projects; and other hot topics related to the solar and astrophysical dynamos.

The Symposium has covered the state of our understanding of dynamo mechanisms in different astrophysical conditions, discussed new observational results, theoretical models, similarities and differences of the physical processes leading to magnetic field generation and formation of magnetic structures. It focussed on the link between theory and observation, and sought out the identification of critical problems for future observations and modeling. The symposium brought together observers and theorists of distinct fields of research which encouraged discussions and co-operations among solar, stellar, planetary, galactic and extragalactic astronomers. We believe it had helped in the development of new ideas regarding the fundamental dynamo processes and in understanding links between these processes and magnetic activity on various cosmic scales. The highlights of the Symposium from our point of view as well as, the open issues in the field are briefly addressed below.

In the solar dynamo context, remarkable and beautiful observations, particularly of sunspots that remind us Van Gogh's paintings, have been performed and important advances in numerical simulations have been achieved, however, fundamental questions remain to be solved, such as:

(*i*) What is the sunspot stability mechanism?

(*ii*) What are the implications for a shallow anchor depth of the sunspots (around 0.95 solar radius) to the solar dynamo action?

(*iii*) Is the magnetic helicity flux really a necessary requirement for large-scale dynamo to prevent quenching of the alpha-effect? What is the role of cross-helicity and Coronal Mass Ejections (CMEs) in this process?

Also, it is important to remark that the test field methods seem to be a powerful tool to determine non-local transport of the magnetic fields. With regard to numerical simulations of the large-scale solar dynamo, new developments combining the convective layer with a realistic corona are required in order to assess the role of the helicity flux.

Doppler and Zeeman-Doppler imaging techniques have been crucial for advancing the studies of magnetic activity in stars. More accurate determinations of differential rotation and meridional flow profiles are also in progress. Giant flares, possibly triggered by violent fast magnetic reconnection in the stellar coronas, have been observed in solar-like stars. An important statistical study has raised the following question: can such giant flares also occur in the Sun? If so, then what would be the consequences for the solar system environment?

Magneto-convection simulations of stellar dynamos have advanced considerably. The role of magnetic reconnection in the dynamo action, particularly in the outer convection layers, and also in diffusion/dissipation of small scale fields, is still an open theoretical issue that should be explored with the help of numerical simulations. Massive stars seem to have a near surface thin-convective layer that could be important for dynamo. The dynamo action in M-dwarf stars, on the other hand, seem to be similar to the geodynamo characterized by a strong dipole field, rapid rotation, and bistability.

Regarding to large-scale magnetic fields of the Milky-Way (MW), the astronomical-unit scale fields seem to be correlated with the kilo-parsec scale magnetic fields, in consistency with dynamo action. However, there are still strong debates about reversals the large-scale magnetic field from one spiral arm to the other. Are these reversals all realistic?

A definite answer has still to wait for higher resolution Faraday rotation measures (RMs) based on pulsar observations with new instruments like the Low Frequency Array (LOFAR), and the future ones, like the Square Kilometre Array (SKA). Regarding the advances in the MW large-scale dynamo theories, current results suggest a model with overlapping disk and halo dynamos, which would allow for both dipole and quadrupole dynamo components. Further studies are in progress.

Observational and theoretical advances of the Large and Small Magellanic Clouds seem to point to a pan-Magellanic field of tidal origin. Is this the dominant dynamo mechanism operating in the Magellanic clouds? Three-dimensional MHD simulations will help to answer this question.

In a more general context of galactic dynamos, another open issue is to assess the importance of turbulence induced by cosmic rays and/or pure supernova remnants on the galactic dynamos. In the more diffuse Intra-Cluster Medium (ICM) of galaxies, small-scale turbulent dynamos should operate in order to amplify seed magnetic fields provided, for instance, by Active Galactic Nuclei (AGN) and galactic winds, and maintain them. However, the collisionless nature of these very low density environments seem to require a collisionless-fluid description for an appropriate treatment of kinetic effects in the turbulent dynamo action. A good news is that recent theoretical/numerical studies indicate that a collisionless dynamo provides results similar to a (collisional) MHD dynamo action in the ICM conditions. Studies of dynamo action in primordial mini-halos seem to indicate that the chemical composition plays a fundamental role in the growth of the primordial fields.

This symposium has explored the interconnections between the dynamos and turbulence which is ubiquitous in the Universe and a key to understanding magnetic phenomena. In our view, the biggest difficulty one faces in this regard is the lack of a solid MHD turbulence theory, which is particularly critical for the late, non-linear dynamo saturation phase. Also, we do not yet understand the role of magnetic reconnection in the turbulent dynamo, diffusion/dissipation of small-scale fields, and magnetic flux transport.

Concerning the new and coming instruments and experiments to measure cosmic fields the news are stimulating. Several new solar instruments and telescopes are currently in operation (New Solar Telescope, GREGOR) or being constructed (Advanced Technology Solar Telescope, European Solar Telescope), space missions (Solar Dynamics Observatory, Hinode, STEREO) and several new plasma laboratory experiments on dynamo, magnetic reconnection, etc., are in progress in Madison, Princeton, Grenoble, New Mexico, and other places. A potential upgrade of the Pierre Auger Cosmic Ray Observatory for cosmic rays detection, which are tracers of cosmic magnetic fields, is also under discussion. At radio/millimeter wavelengths the LOFAR (Low Frequency Array) is the current

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most sensitive radio observatory at low observing frequencies, until the next generation of large array radio telescopes, the Square Kilometre Array (SKA) which should come online around 2020. Three-dimensional Faraday rotation tomography will map the large scale galactic and extragalactic magnetic fields more precisely than ever. Other current projects include Murchison Widefield Array (MWA), Australian Square Kilometre Array Pathfinder (ASKAP) and the Planck satellite. The later has measured the cosmic microwave background polarized radiation. Currently, the foreground component of the diffuse polarized radiation in the sky is being separated from the background cosmic component. When ready these maps will provide new improved information on the galactic magnetic field structure.

Gamma-ray astronomy can put constraints on the intergalactic magnetic field, i.e., the magnetic field in the space between clusters of galaxies and in the voids which are empty of galaxies. The very weak fields recently inferred from gamma ray observations with the Fermi satellite will be probed with higher sensitivity with the coming Cherenkov Telescope Array (CTA). Besides the higher sensitivity at the largest energies, it will cover a significantly larger high-frequency range than any current gamma-ray observatory. It is planned to be in operation around 2018. If confirmed, the presence of non-null magnetic fields in the voids will point to the very existence of primordial magnetic fields, as it would be very challenging to explain the fields in such voids by purely astrophysical processes.

We would like to thank the International Astronomical Union, the National Astronomical Observatories (Beijing, China), the Local Organizing Committee for the support and brilliant organization of this Symposium. We thank all participants for the extremely interesting presentations and discussions, and would like to mention the winners of the Best Poster Competition:

• Susanta Kumar Bisoi & Janardhan Padmanabhan, ‘Asymmetry in the periodicities of solar photospheric fields: A probe to the unusual solar minimum prior to cycle 24’.

• Yang Guo & Mingde Ding, ‘Tests and applications of nonlinear force-free field extrapolations in spherical geometry’.

• Daniel Brito de Freitas & Jose Renan De Medeiros, ‘A nonextensive approach for the angular momentum loss rate in low-mass stars’.

• Christina Burge & Eduard Kontar, ‘Non-collisional pitch angle scattering and hard X-ray observations of solar flares’.

• Qiao Song, Jun Zhang, Shuhong Yang & Yang Liu, ‘Flares and non-potentiality of AR 11158’.

We believe that the main goals of this Symposium have been achieved. The chapters of these Proceedings present an updated overview of the current status of this field of research and in the coming years, we hope that this book may serve as guideline both to seniors and new researchers in this fascinating and interdisciplinary field of knowledge.

Elisabete de Gouveia Dal Pino, Alexander G. Kosovichev, and Yihua Yan, co-chairs SOC
Beijing, August 31, 2012

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