Special issue on current research in astrophysical magnetism

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EDITORIAL

Special issue on current research in astrophysical magnetism

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Much of what Hannes Alfvén envisaged some 70 years ago has now penetrated virtually all branches of astrophysical research. Indeed, magnetic fields can display similar properties over a large range of scales. We have therefore been able to take advantage of the transparency of galaxies and the interstellar medium to obtain measurements inside them. On the other hand, the Sun is much closer, allowing us to obtain a detailed picture of the interaction of flows and magnetic fields at the surface, and more recently in the interior by helioseismology. Moreover, the solar timescales are generally much shorter, making studies of dynamical processes more direct.

This special issue on current research in astrophysical magnetism is based on work discussed during a one month Nordita program *Dynamo, Dynamical Systems and Topology* and comprises papers that fall into four different categories (A)–(D).

(A) *Papers on small-scale magnetic fields and flows in astrophysics*

1. E M de Gouveia Dal Pino, M R M Leão, R Santos-Lima, G Guerrero, G Kowal and A Lazarian
   Magnetic flux transport by turbulent reconnection in astrophysical flows
2. Philip R Goode, Valentyna Abramenko and Vasyl Yurchyshyn
   New solar telescope in Big Bear: evidence for super-diffusivity and small-scale solar dynamos?
3. I N Kitiashvili, A G Kosovichev, N N Mansour, S K Lele and A A Wray
   Vortex tubes of turbulent solar convection

The above collection of papers begins with a review of astrophysical reconnection and introduces the concept of dynamos necessary to explain the existence of contemporary magnetic fields both on galactic and solar scales (paper 1). This is complemented by observations with the new Big Bear Solar Observatory telescope, allowing us to see magnetic field amplification on small scales (paper 2). This in turn is complemented by realistic simulations of subsurface and surface flow patterns (paper 3).

(B) *Papers on theoretical approaches to turbulent fluctuations*

4. Nathan Kleeorin and Igor Rogachevskii
   Growth rate of small-scale dynamo at low magnetic Prandtl numbers
5. Erico L Rempel, Abraham C-L Chian and Axel Brandenburg
   Lagrangian chaos in an ABC-forced nonlinear dynamo
6. J E Snellman, M Rheinhardt, P J Käpylä, M J Mantere and A Brandenburg
   Mean-field closure parameters for passive scalar turbulence

Research in dynamo theory has been actively pursued for over half a century. It started by trying to understand the large-scale magnetic fields of the Sun and the Earth, and subsequently also in galaxies. Such large-scale fields can nowadays be understood in terms of mean-field dynamo theory that explains the possibility of large-scale field generation under anisotropic conditions lacking mirror symmetry. However, even when none of this is the case, dynamos can still work, and they are called small-scale dynamos that were referred to in paper 2. This was studied originally under the assumption that the flow is smooth compared with the magnetic field, but in the Sun the opposite is the case. This is because viscosity is much smaller than magnetic diffusivity, i.e., their ratio, which is the magnetic Prandtl number, is small. In that case the physics of small-scale dynamos changes, but dynamos still exist even then (paper 4). Tracing the flow lines in nonlinear small-scale dynamos is important for understanding their mixing properties (paper 5). Turbulent mixing is a generic concept that applies not only to magnetic field, but also to passive scalars which are often used as a prototype for studying this. Turbulence simulations have helped tremendously in quantifying the ability of turbulent flows to mix, but the more we know, the more complicated it becomes. It turns out that spatial and temporal coupling is an important consideration for allowing accurate comparison between numerical simulations and mean-field theory (paper 6).

(C) *The large-scale solar cycle*

7. V V Pipin and D D Sokoloff
   The fluctuating α-effect and Waldmeier relations in the nonlinear dynamo models[1]
8. Radostin D Simitev and Friedrich H Busse
   Solar cycle properties described by simple convection-driven dynamos

The mean-field concept has helped us constructing detailed models of the solar cycle and to make comparison with observed features of the solar 11-year cycle. One such feature is the Waldmeier relation between growth time and amplitude of the cycle, and there is another relation for the declining part of the cycle. These relations reflect nonlinear aspects of the model and therefore constitute an important test of the model (paper 7). While mean-field theory is a useful concept for modeling solar activity, it must eventually be tested against fully three-dimensional simulations. At present, such simulations are often quite idealized, because only the large scales of the turbulent convection of stars can be resolved. Nevertheless, numerical simulations begin to show many properties that are also seen in the Sun (paper 8).

(D) *Flow and dynamo properties in spherical shells*

9. Maxim Reshetnyak and Pavel Hejda
   Kinetic energy cascades in quasi-geostrophic convection in a spherical shell
10. Radostin D Simitev and Friedrich H Busse
    Bistable attractors in a model of convection-driven spherical dynamos

As the rotation speed is increased, the flow becomes more strongly constrained by the Coriolis force. In a spherical shell, such a flow is additionally constrained by gravity, or at least by the geometry of the domain. Such flows are called geostrophic. Only now are we beginning to learn about the subtle properties of the kinetic energy cascade in such flows (paper 9). Turbulent systems are highly nonlinear and it is in principle possible to find multiple solutions of the equations even for the same boundary and initial conditions. For turbulent systems, we can only ask about the statistical properties of the solutions, and the question of multiple solutions is then less obvious. However, in turbulent dynamos in convective shells, a nice example has been found where this is possible. A detailed account of this is given in paper 10.

Most of the participants of the Nordita program were able to stay for the full month of the program, allowing them to think about new ideas that will be reflected not only in papers on the short term, but also in new projects and collaborations on a larger scale in the years to come. We therefore thank Nordita for providing a stimulating atmosphere and acknowledge the generous support.

[1] This paper has been published as V V Pipin and D D Sokoloff 2011 *Phys. Scr.* **84** 065903.