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Round table discussion of session G: MHD convection and dynamos

Juri Toomre

JILA & Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder CO 80309-0440, USA. email: jtoomre@jila.colorado.edu

Abstract. Vigorous discussion ensued about conditions under which both small-scale and global-scale dynamo action would be realized within real stars where the flow fields are expected to be highly turbulent and the magnetic Prandtl numbers small. Our nearest star reminds us that intricate boundary-layer phenomena may have to also be considered, such as the presence of a tachocline of rotational shear at the base of the solar convection zone revealed by helioseismology, which suggests that an interface dynamo may be at work to produce the observed 22-year cycles of large-scale magnetic activity.

Keywords. Magnetic fields, Sun: magnetic fields, stars: magnetic fields, (magnetohydrodynamics:) MHD

The discussion panel consisted of the following speakers: A. Brandenburg, F.H. Busse, R. Cameron, A. Getling, and A.S. Brun. It was chaired by J. Toomre.

1. Intricate flow fields and smoother magnetic fields

Fluid turbulence associated with convection in stars is expected to be very complex in structure and character, and so it continues to be realized in the latest three-dimensional compressible convection simulations carried out on massively parallel supercomputers. However, in studying conditions under which sustained dynamo action can be achieved, most MHD simulations have found it necessary to use magnetic Prandtl numbers that are greater than unity ($P_m \sim 5$, say), rather than the very small values thought to be representative of the ratio of molecular viscosity to magnetic diffusivity within stars. Within such modelling, the magnetic field structures are somewhat simpler than the velocity or vorticity fields, for the greater magnetic diffusivity leads to smoother fields. There has been substantial debate recently about whether magnetic dynamo action can be achieved at small P_m when the flows are fully turbulent, leading to what may be termed small-scale dynamos. Some argue that this may require the magnetic Reynolds number R_m to become very large, even approaching infinity, as P_m attains values of order 10^{-8} or smaller, whereas others suggest that the required R_m for sustained dynamo action will asymptote to a large but finite value.

2. Small-scale and global-scale stellar dynamos

In the spirit of the broader discussions in the community, there were differing positions taken by the panelists about whether small-scale dynamo action would be realized in stars. All agreed that global-scale magnetic fields are expected to be produced by large-scale dynamo action, provided rotation and sphericity could play suitable roles in simulations that captured a sufficiently large range of scales. However, some thought that the very large R_m required for small-scale magnetic fields to be generated directly by the velocity fields suggest that in many stars such dynamos would not be able to operate. Others disagreed, favoring the position that more moderate asymptotic values for R_m would likely allow direct generation of both small and large-scale magnetic fields in most stars. These are issues that may be resolved through simulations with sufficient spatial resolution that should be feasible within the next few years given the rapid advances in supercomputing.

3. Solar interface dynamo and tachocline

It was agreed that some of these topics were rather abstract given what we now know about our nearest star and its magnetism. This should give us some pause when broadly identifying the types of dynamos operating in stars. Namely, the sun seems to possess small-scale dynamo action in the upper portions of the convection zone that leads to the chaotic eruption of intense fields. The sun must also be operating what is now thought to be a global-scale interface dynamo to produce the remarkable 22-year cycles of orderly larger-scale magnetic activity. Strong fields erupt as sunspot pairs which follow surprisingly well-defined rules. In the interface dynamo, the sites of generation of toroidal and poloidal fields are spatially separated, and there must be feedbacks between these two field components. Poloidal field generated by cyclonic turbulence within the bulk of the convection zone, or by break up of active regions, are pumped downward to the tachocline of rotational shear (deduced from helioseismology) at its base. The differential rotation stretches such poloidal field into strong toroidal structures, which may succumb to magnetic buoyancy instabilities and rise upwards to pierce the photosphere as curved structures that form the observed active regions. The strong toroidal field, twisted somewhat by the effect of rotation to regenerate a strong poloidal component, is either shredded by the turbulent convection, or emerges through the surface as sunspot pairs. These are complex dynamical elements now being studied in detail through various simulations, reminding us that we are still quite some way from having a comprehensive global model for the solar dynamo. Many other stars may involve large-scale dynamos that share many of the intricacies involved in such interface dynamos, and thus we must be cautious as we try to assign far simpler mechanism to explain the origins of stellar magnetism.