Activity report based on time used on HPC2N, PDC, and NSC since October 2010

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To achieve the ultimate goal of understanding the origin of magnetic fields in the Sun and other astrophysical settings we have performed both direct turbulence simulations of such systems as well as mean-field calculations. In addition, we have been able to utilize the test-field method to determine turbulent transport coefficients from direct simulations. These coefficients are then used in mean-field models which enable us to make predictions that can then be tested with direct simulations. Particularly noteworthy is the detection of a negative effective magnetic pressure instability from direct numerical simulations. This has become possible through detailed exploratory work that led us to perform simulations in the right parameter regime. Based on this breakthrough, more papers will appear in the next year.

Most of the calculations have been carried out using the Pencil Code (`http://www.nordita.org/software/pencil-code`), which is now being hosted by Google Code (`http://pencil-code.googlecode.com`)[1]. In the following I describe the research outcome by quoting published papers since October 2010 in refereed journals. The numbering of the papers coincides with that of my full list of publications on `http://www.nordita.org/~brandenb/pub`.

1 Negative effective magnetic pressure instability

It is generally believed that the solar dynamo operates in the shear layer beneath the convection zone. This idea faces several difficulties that might be avoided in distributed solar dynamos shaped by near-surface shear. In that scenario, active regions would form due to large-scale (mean-field) instabilities in the near-surface shear layer. One candidate has been the negative effective magnetic pressure instability (NEMPI). Until recently, this possibility remained uncertain, because it was based on results from mean-field calculations using turbulent transport coefficients determined from direct numerical simulations (DNS). A breakthrough has now been achieved through the direct detection of this instability in simulations. For details see `http://norlx51.nordita.org/~brandenb/tmp/Byaver/` as well as our latest paper:

246. Brandenburg, A., Kemel, K., Kleeorin, N., Mitra, D., & Rogachevskii, I.: 2011, "Detection of negative effective magnetic pressure instability in turbulence simulations," *Astrophys. J. Lett.* **740**, L50

2 Turbulent transport coefficients

The test-field method is now a well developed tool. It has been applied to the nonlinear regime in flows driven by magnetic buoyancy [245,243,225] and to flows with magnetic background

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[1] The Pencil Code was written by Brandenburg & Dobler (2002) as a public domain code. The current number of project members on the google page is 41.

turbulence [220]. Of particular excitement has been the discovery of cross helicity production in a stratified layer with a vertical magnetic field [233].

245. Chatterjee, P., Mitra, D., Rheinhardt, & M. Brandenburg, A.: 2011, “Alpha effect due to buoyancy instability of a magnetic layer,” *Astron. Astrophys.* **534**, A46

243. Chatterjee, P., Mitra, D., Brandenburg, A., & Rheinhardt, M.: 2011, “Spontaneous chiral symmetry breaking by hydromagnetic buoyancy,” *Phys. Rev. E* **84**, 025403R

233. Rüdiger, G., Kitchatinov, L. L., & Brandenburg, A.: 2011, “Cross helicity and turbulent magnetic diffusivity in the solar convection zone,” *Solar Phys.* **269**, 3–12

225. Brandenburg, A., Chatterjee, P., Del Sordo, F., Hubbard, A., Käpylä, P. J., & Rheinhardt, M.: 2010, “Turbulent transport in hydromagnetic flows,” *Phys. Scr.* **T142**, 014028

220. Rheinhardt, M., & Brandenburg, A.: 2010, “Test-field method for mean-field coefficients with MHD background,” *Astron. Astrophys.* **520**, A28

3 Dynamo action in spherical shells

Our simulations of astrophysical flow in spherical shells are now well developed and have led to detailed measurements of the resulting differential rotation in simulations driven by convection [238]. Particularly important is the development of what looks like coronal mass ejections above a spherical surface [244]. This work is now being extended to flows driven by convection. We shall also allow for the development of what corresponds to a solar wind in the outer parts.

244. Warnecke, J., Brandenburg, A., & Mitra, D.: 2011, “Dynamo-driven plasmoid ejections above a spherical surface,” *Astron. Astrophys.* **534**, A11

238. Käpylä, P. J., Mantere, M. J., Guerrero, G., Brandenburg, A., & Chatterjee, P.: 2011, “Reynolds stress and heat flux in spherical shell convection,” *Astron. Astrophys.* **531**, A162

4 Dynamo action, helicity, and vorticity in Cartesian domains

Successful small-scale dynamo action has now been shown to exists for magnetic Prandtl numbers down to 0.01 [247]. The ratio of kinetic to magnetic energy dissipation is found to be proportional to the square root of the magnetic Prandtl number, which has previously been found for large-scale dynamo action at low magnetic Prandtl numbers and has in another paper [228] been confirmed for large magnetic Prandtl numbers. In large-scale dynamos with sufficient scale separation, the inverse energy transfer is now show to scale with magnetic Reynolds number to the 1/2 power [239]. Magnetic helicity and its fluxes have been investigated in [222,229,230,241], and they have now also been shown to lead to plasmoid ejections [221]. This work is also relevant to galaxies, but there the flows are driven by potential forces leading to very little vorticity [235].

247. Brandenburg, A.: 2011, “Nonlinear small-scale dynamos at low magnetic Prandtl numbers,” *Astrophys. J.* **741**, 92

241. Candelaresi, S., & Brandenburg, A.: 2011, “Decay of helical and non-helical magnetic knots,” *Phys. Rev. E* **84**, 016406

239. Brandenburg, A.: 2011, “Chandrasekhar-Kendall functions in astrophysical dynamos,” *Pramana J. Phys.* **77**, 67–76

235. Del Sordo, F., & Brandenburg, A.: 2011, “Vorticity production through rotation, shear, and baroclinicity,” *Astron. Astrophys.* **528**, A145

230. Candelaresi, S., Hubbard, A., Brandenburg, A., & Mitra, D.: 2011, “Magnetic helicity transport in the advective gauge family,” *Phys. Plasmas* **18**, 012903

229. Hubbard, A., & Brandenburg, A.: 2011, “Magnetic helicity flux in the presence of shear,” *Astrophys. J.* **727**, 11

228. Brandenburg, A.: 2011, “Dissipation in dynamos at low and high magnetic Prandtl numbers,” *Astron. Nachr.* **332**, 51–56

222. Hubbard, A., & Brandenburg, A.: 2010, “Magnetic helicity fluxes in an α^2 dynamo embedded in a halo,” *Geophys. Astrophys. Fluid Dyn.* **104**, 577–590

221. Warnecke, J., & Brandenburg, A.: 2010, “Surface appearance of dynamo-generated large-scale fields,” *Astron. Astrophys.* **523**, A19

5 Mean-field models

Mean-field models provide an excellent tool to make predictions that can then be tested using direct simulations. Such work has established that large-scale field generation requires magnetic helicity fluxes to reach magnetic fields of equipartition strength. We confirm that magnetic helicity fluxes can alleviate catastrophic quenching [223,224,227]. This is also true of fluxes due to a solar wind and meridional flows [232].

232. Mitra, D., Moss, D., Tavakol, R., & Brandenburg, A.: 2011, “Alleviating alpha quenching by solar wind and meridional flow,” *Astron. Astrophys.* **526**, A138

227. Chatterjee, P., Guerrero, G., & Brandenburg, A.: 2011, “Magnetic helicity fluxes in interface and flux transport dynamos,” *Astron. Astrophys.* **525**, A5

224. Guerrero, G., Chatterjee, P., & Brandenburg, A.,: 2010, “Shear-driven and diffusive helicity fluxes in $\alpha\Omega$ dynamos,” *Monthly Notices Roy. Astron. Soc.* **409**, 1619–1630

223. Chatterjee, P., Brandenburg, A., & Guerrero, G.: 2010, “Can catastrophic quenching be alleviated by separating shear and α effect?” *Geophys. Astrophys. Fluid Dyn.* **104**, 591–599

6 Other work

Some of our latest results have now been reviewed in [234]. We have also applied the Pencil Code to simulating turbulent combustion of hydrogen and oxygen [226]. Some of those results can be understood by considering the Fisher equation [231].

234. Brandenburg, A., & Nordlund, Å.: 2011, “Astrophysical turbulence modeling,” *Rep. Prog. Phys.* **74**, 046901

231. Brandenburg, A., Haugen, N. E. L., & Babkovskaia, N.: 2011, "Turbulent front speed in the Fisher equation: dependence on Damköhler number," *Phys. Rev. E* **83**, 016304

226. Babkovskaia, N., Haugen, N. E. L., Brandenburg, A.: 2011, "A high-order public domain code for direct numerical simulations of turbulent combustion," *J. Comp. Phys.* **230**, 1–12