Activity report based on time used on HPC2N, PDC, and Nordic HPC since October 2013

Axel Brandenburg (Nordita)

October 21, 2014

Since this year, we have started calculating helioseismic signatures from our simulations. This is the work of one of our post-docs hired on the *VR breakthrough research grant*, "Formation of active regions in the Sun" (2012-5797, January 2013 – December 2016, 4.2 MSEK). We have also continued work on the negative effective magnetic pressure instability (NEMPI), which led to the completion of one licentiate thesis (Sarah Jabbari) and another one will be defended on 5 December (Illa Losada). These calculations have been done on Lindgren.

For all calculations, we use the Pencil Code, which is hosted by Google Code[1]. Below, I describe the research outcome by quoting published papers since October 2013 in refereed journals. The numbering of the papers coincides with that of my full list of publications on `http://www.nordita.org/~brandenb/pub`. All the papers quoted below acknowledge SNAC and none of those papers were mentioned in the activity report of the previous period.

1 Helioseismology

One paper has now been published on this topic, where we calculate helioseismic signatures from our solar simulations. More work is in the pipeline and will also be an important aspect of our future activity.

316. Singh, N. K., Brandenburg, A., & Rheinhardt, M.: 2014, "Fanning out of the solar f-mode in presence of nonuniform magnetic fields?" *Astrophys. J. Lett.* **795**, L8

2 Sunspot formation and NEMPI

We have now found remarkably strong magnetic spots [313], where the magnetic field for spot formation comes from an underlying dynamo (Fig.1). The interaction between NEMPI and the dynamo has been studied in more detail on more idealized models [312].

313. Mitra, D., Brandenburg, A., Kleeorin, N., Rogachevskii, I.: 2014, "Intense bipolar structures from stratified helical dynamos," *Mon. Not. Roy. Astron. Soc.* **445**, 761–769

312. Jabbari, S., Brandenburg, A., Losada, I. R., Kleeorin, N., & Rogachevskii, I.: 2014, "Magnetic flux concentrations from dynamo-generated fields," *Astron. Astrophys.* **568**, A112

304. Losada, I. R., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2014, "Magnetic flux concentrations in a polytropic atmosphere," *Astron. Astrophys.* **564**, A2

[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 104; see `http://pencil-code.googlecode.com`.

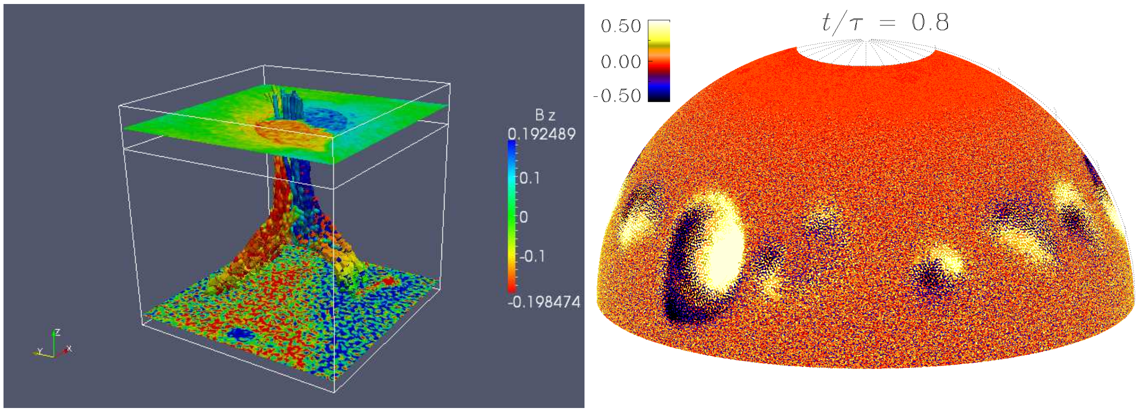

Figure 1: Visualization of δ-spot formation in a Cartesian domain (left) [314] and in a sphere (right, Jabbari et al., 2014, in preparation).

301. Brandenburg, A., Gressel, O., Jabbari, S., Kleeorin, N., & Rogachevskii, I.: 2014, "Mean-field and direct numerical simulations of magnetic flux concentrations from vertical field," *Astron. Astrophys.* **562**, A53

To understand the significance of this work, it should be emphasized that 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 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). An important result was the direct detection of NEMPI in direct numerical simulations; see my activity report of 2011. The new discovery of magnetic spots (Summer 2013) needs to be followed up with more realistic simulations to see whether real sunspots can be produced this way.

3 Dynamo action in spherical shells

Differential rotation in stars is caused by anisotropic convection in stars, and the solution can be either such that the equator is faster or slower than the poles. It now turns out that this depends on wether or not one allows for magnetic fields to be generated [322]. Our new results therefore now supersede earlier ones where magnetic fields where not allowed to be generated (Käpylä et al., 2014).

322. Karak, B. B., Mantere, M. J., Käpylä, P. J., & Brandenburg, A.: 2014, "Mono-stable hydromagnetic stellar differential rotation," *Astron. Astrophys.*, submitted (arXiv:1407.0984)

4 Dynamo action, helicity, and vorticity in Cartesian domains

We have demonstrated for the first time that inverse transfer is possible even in the absence of magnetic helicity; see Figure 2. We have performed now dynamo simulations demonstrating that very strong dissipation events are possible [311], that fields can be generated by the battery

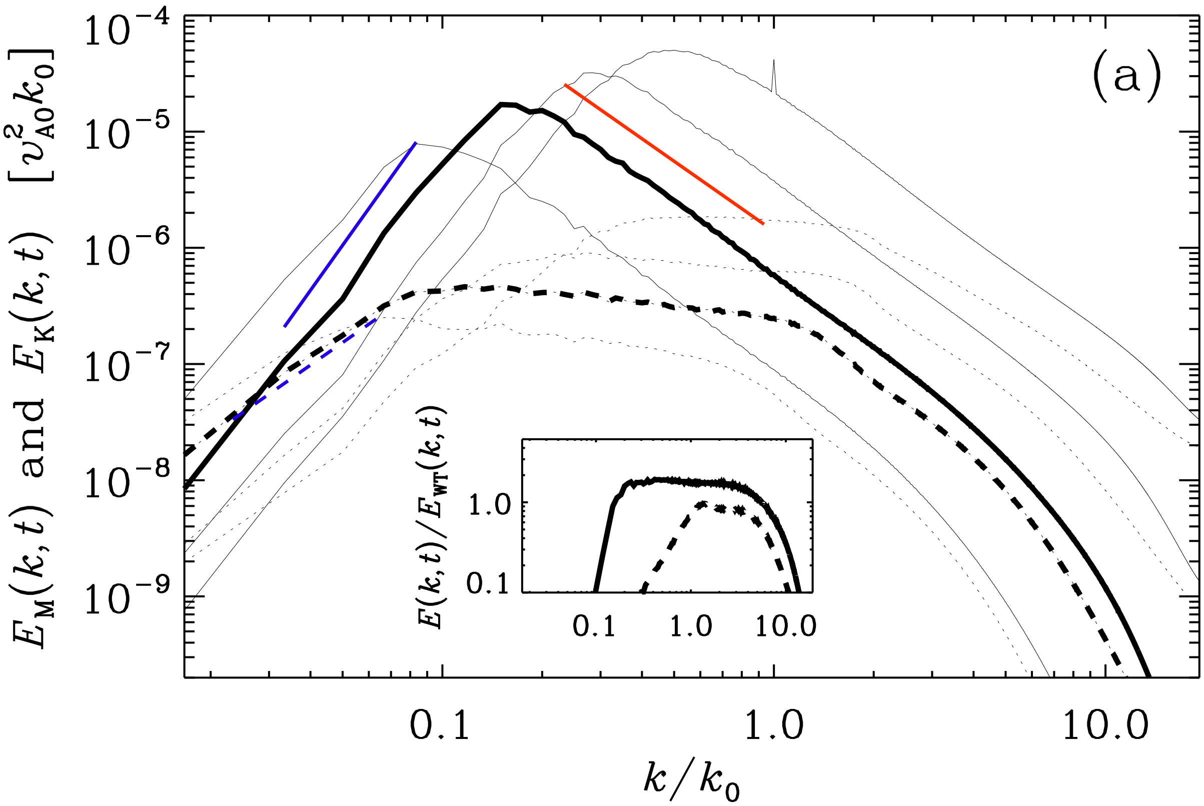

Figure 2: (Color online) Magnetic (solid lines) and kinetic (dashed lines) energy spectra for Run A at different times. The straight lines indicate the slopes k^4 (solid, blue), k^2 (dashed, blue), and k^{-2} (red, solid). Resolution 2304^4 using 9216 processors on Lindgren.

term [310], and that the ratio of kinetic to magnetic energy dissipation depends sensitively on the magnetic Prandtl number [308]. If these fields are helical, this leads to marked signatures in polarized emission [305].

320. Brandenburg, A., Kahniashvili, T., & Tevzadze, A. G.: 2014, "Nonhelical inverse transfer of a decaying turbulent magnetic field," *Phys. Rev. Lett.*, submitted (arXiv:1404.2238)

311. Candelaresi, S., Hillier, A., Maehara, H., Brandenburg, A., & Shibata, K.: 2014, "Superflare occurrence and energies on G-, K- and M-type dwarfs," *Astrophys. J.* **792**, 67

310. Modestov, M., Bychkov, V., Brodin, G., Marklund, M., & Brandenburg, A.: 2014, "Evolution of magnetic field generated by the Kelvin-Helmholtz instability," *Phys. Plasmas* **21**, 072126

308. Brandenburg, A.: 2014, "Magnetic Prandtl number dependence of the kinetic-to-magnetic dissipation ratio," *Astrophys. J.* **791**, 12

305. Brandenburg, A., & Stepanov, R.: 2014, "Faraday signature of magnetic helicity from reduced depolarization," *Astrophys. J.* **786**, 91

5 Turbulent transport coefficients

To analyze the nature of dynamo action, we continue using the test field method to determine the α effect and turbulent diffusivity [314]. A completely new dynamo mechanism has been discovered that works based on the time delay between magnetic field changes and the response in the mean electromotive force [306]. An α effect emerges also from just shear and stratified turbulence [302] and could therefore be tested in the laboratory.

314. Karak, B. B., Rheinhardt, M., Brandenburg, A., Käpylä, P. J., & Mantere, M. J.: 2014, "Quenching and anisotropy of hydromagnetic turbulent transport," *Astrophys. J.* **795**, 16

306. Rheinhardt, M., Devlen, E., Rädler, K.-H., & Brandenburg, A.: 2014, "Mean-field dynamo action from delayed transport," *Mon. Not. Roy. Astron. Soc.* **441**, 116–126

302. Rüdiger, G., & Brandenburg, A.: 2014, "The alpha-effect in a turbulent liquid-metal plane Couette flow," *Phys. Rev. E* **89**, 033009

References

Käpylä, P. J., Käpylä, M. J., & Brandenburg, A.: 2014, "Confirmation of bistable stellar differential rotation profiles," *Astron. Astrophys.* **570**, A43