Activity report based on time used on PDC and C3SE since October 2015

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During the reporting period, Ms Sarah Jabbari has submitted and successfully defended her PhD thesis with the title "Origin of solar surface activity and sunspots" (May 20, 2016), in addition to Mr Xiang-Yu Li, who defended his licentiate thesis (also) on May 20, 2016. Both thesis projects are based on calculations that have been done on Beskow and Hebbe.

We have continued investigating 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). Bidya Karak (former post-doc at Nordita) has been doing spherical shell simulations of convection with magnetic fields. Xiang-Yu Li has been doing simulations of condensation and coagulation processes in the meteorological context. Sarah Jabbari has been doing large-scale simulations of turbulence in spherical shells and found the spontaneous formation of magnetic spots. Together with Master Students and visitors, Axel Brandenburg has been doing simulations with radiative transfer and ionization included. He has also been doing hydromagnetic simulations in the cosmological context.

For all calculations, we use the Pencil Code, which is hosted by Google Code[1] The code has now been moved to `https://github.com/pencil-code`. Below, I describe the research outcome by quoting published papers since October 2014 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 Sunspot formation and NEMPI

The discovery of remarkably strong magnetic spots reported in our 2014 report have now been verified in global spherical shell simulations [325].

348. Jabbari, S., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2016, "Sharp magnetic structures from dynamos with density stratification," *Mon. Not. Roy. Astron. Soc.*, submitted

336. Jabbari, S., Brandenburg, A., Mitra, D., Kleeorin, N., & Rogachevskii, I.: 2016, "Turbulent reconnection of magnetic bipoles in stratified turbulence," *Mon. Not. Roy. Astron. Soc.* **459**, 4046–4056

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

[1] The Pencil Code was written by Brandenburg & Dobler (2002) as a public domain code.

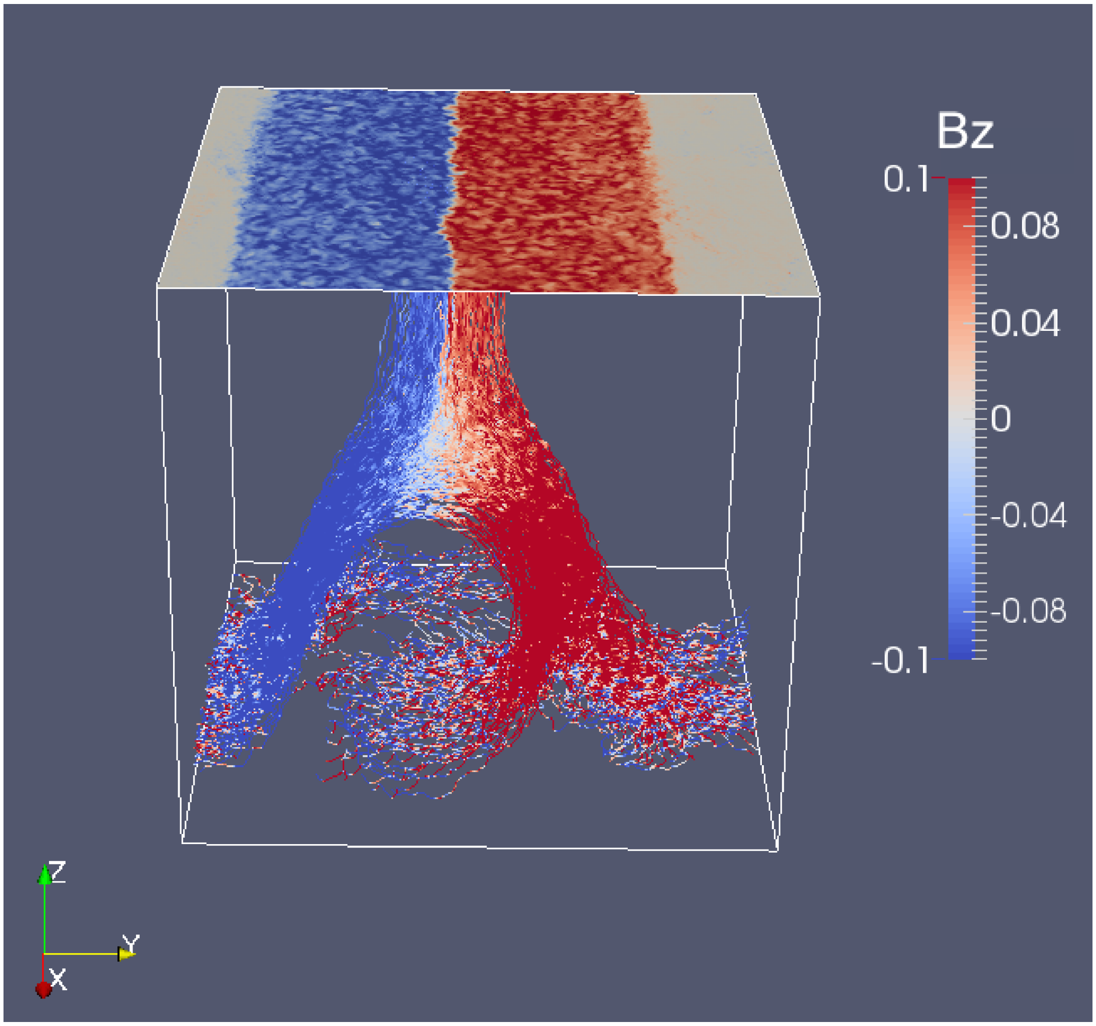

Figure 1: Three-dimensional visualization of vertical magnetic field, B_z at the surface (color-coded) together with three-dimensional volume rendering of the vertical component of the magnetic field; see [336] for details.

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 recent discovery of magnetic spots (Summer 2013) has been followed up with more realistic simulations to see whether real sunspots can be produced this way (see previous section).

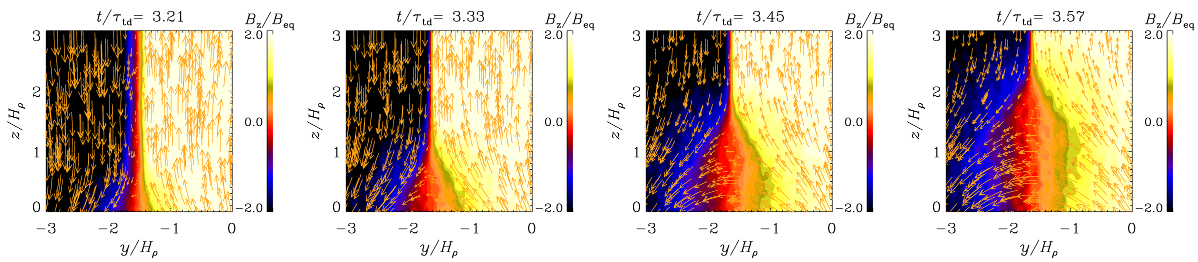

Figure 2: Time evolution of $\overline{B_z}/B_{\rm eq}$, together with $\overline{B_y}/B_{\rm eq}$ and $\overline{B_z}/B_{\rm eq}$ vectors; see [336] for details.

2 Radiation hydrodynamics simulations

We have engaged in radiation hydrodynamics simulations and discovered that the local stability properties of hydrostatically stratified layers are solely determined by the coefficients in the opacity law [319]. The deeper layers are therefore a priori stably stratified. These effects are modified further by ionization effects [329].

329. Bhat, P., & Brandenburg, A.: 2016, "Hydraulic effects in a radiative atmosphere with ionization," *Astron. Astrophys.* **587**, A90

This work is in preparation of doing realistic simulations of sunspot formation,

3 Dynamo action in the Sun

The small-scale magnetic field of the Sun does not vary much over the course of the solar cycle. It might even show some anti-correlation with the large-scale magnetic field. To understand this, we have performed simulations of turbulent dynamos in different parameter regimes and found that the solar behavior can be reproduced as a result of a suppression of small-scale dynamo action. The work is now published [328].

328. Karak, B. B., & Brandenburg, A.: 2016, "Is the small-scale magnetic field correlated with the dynamo cycle?" *Astrophys. J.* **816**, 28

4 Particles in Turbulence

Using direct numerical simulations, it is shown that heavy inertial particles (with Stokes number St) in inhomogeneously forced statistically stationary turbulent flows cluster at the minima of turbulent kinetic energy. Two turbulent transport processes, turbophoresis and turbulent diffusion together determine the spatial distribution of the particles. The ratio of the corresponding transport coefficient – the turbulent Soret coefficient – increases with St for small St, reaches a maxima for St=10 and decreases as $\mathrm{St}^{0.33}$ for large St.

- Mitra, D., Haugen, N. E. L., & Rogachevskii, I.: 2016, "Turbulent Soret Effect," *J. Fluid Mech.*, in press, arXiv:1603.00703