Activity report based on time used on PDC and C3SE of 2017 and 2018

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In this activity report, I describe and list some highlights of the 17 papers of 2018 and the 10 papers of 2017 that all acknowledge SNAC. The science covered in these papers extends from the early Universe to solar magnetic fields and even the initiation of rain in turbulent clouds. This lead to the PhD thesis of Xiang-Yu Li, who finished in September 2018. The underlying simulations required extensive amounts of computing time and Beskow was the only machine capable of these.

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`. 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. The papers of 2017 are listed separately as most of them were already mentioned and described in more detail in the activity report of the previous period.

1 Gravitational waves and early universe magnetic fields

An important upcoming activity involves the computation of the stochastic gravitational wave background from the Big Bang. Those can be measured in future with LISA and the pulsar timing array (PTA). Our first paper on the numerical method is described in Ref. [383]. We have also discovered and characterized the dynamo effect in decaying helical turbulence; see Ref. [380] and Figure 1, where we show the temporal growth at intermediate times and a new property of the subsequent decay law: a scaling of the magnetic energy $\mathcal{E}_{\rm M}(t) \propto t^{-p_{\rm M}}$ with $p_{\rm M} \approx 0.5$, which is even slower than for helical turbulence and therefore important for maintaining detectable signatures of early universe turbulence. Already last year, using numerical simulations, we showed for the first time the occurrence of a turbulent chiral magnetic cascade in the early universe [352]. This lead to new follow-up work this year; see Refs. [388], [375], and [364]. We have also studied in detail the magnetic fields generated during the electroweak phase transition [359] and during inflation [358]. Those works appeared late in 2017 and were not mentioned in the previous report. We have also discovered distinct classes of hydrodynamic and magnetohydrodynamic turbulent decay [344], as already mentioned in the previous report.

388. Schober, J., Brandenburg, A., & Rogachevskii, I.: 2018, "Chiral fermion asymmetry in high-energy plasma simulations," *Geophys. Astrophys. Fluid Dyn.*, submitted (arXiv:1808.06624)

383. Roper Pol, A., Brandenburg, A., Kahniashvili, T., Kosowsky, A., Mandal, S.: 2018, "The timestep constraint in solving the gravitational wave equations sourced by hydromagnetic turbulence," *Geophys. Astrophys. Fluid Dyn.*, submitted (arXiv:1807.05479)

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

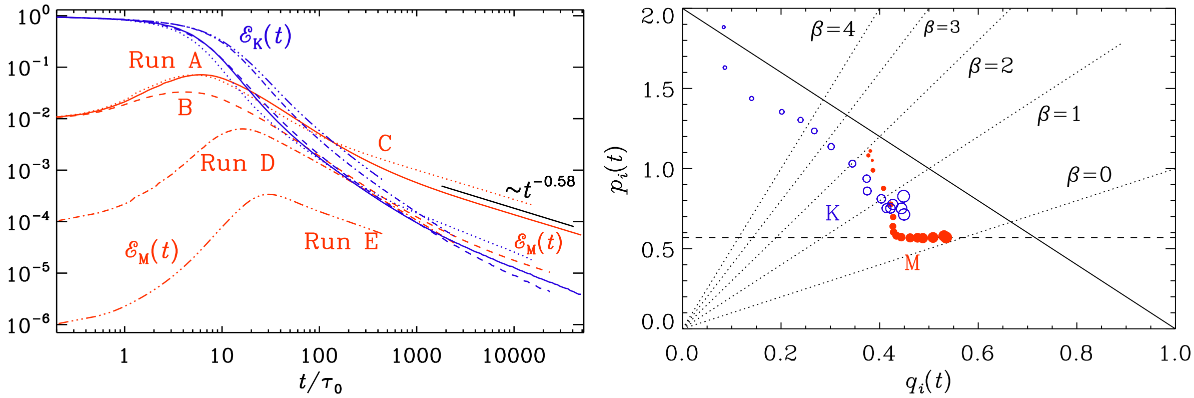

Figure 1: Left: Evolution of kinetic energy (blue) and magnetic energy (red) for zero initial helicity (solid), maximally positive helicity (dashed), and maximally negative helicity (dotted) for strong (Runs A–C), intermediately strong (dot-dashed, Run D) and weak initial field (triple dot-dashed, Run E) of zero helicity. Right: pq diagram for Run A for kinetic (blue open symbols) and magnetic (red filled symbols) energy spectra. Near the end of the run (larger symbols), the solution evolves along the $p_{\rm M}=0.58$ line (dashed) and $q_{\rm M}\approx 0.55$ with $\beta_{\rm M}=p_{\rm M}/q_{\rm M}-1\approx 0.05$ is found at the end of the run. Smaller (larger) symbols denote earlier (later) times.

380. Brandenburg, A., Kahniashvili, T., Mandal, S., Roper Pol, A., Tevzadze, A. G., & Vachaspati, T.: 2018, "The dynamo effect in decaying helical turbulence," *Phys. Rev. Fluids*, submitted (arXiv:1710.01628)

375. Schober, J., Brandenburg, A., Rogachevskii, I., & Kleeorin, N.: 2018, "Energetics of turbulence generated by chiral MHD dynamos," *Geophys. Astrophys. Fluid Dyn.*, DOI: 10.1080/03091929.2018.1515313 (arXiv:1803.06350)

364. Schober, J., Rogachevskii, I., Brandenburg, A., Boyarsky, A., Fröhlich, J., Ruchayskiy, O., & Kleeorin, N.: 2018, "Laminar and turbulent dynamos in chiral magnetohydrodynamics. II. Simulations," *Astrophys. J.* **858**, 124

359. Brandenburg, A., Kahniashvili, T., Mandal, S., Roper Pol, A., Tevzadze, A. G., & Vachaspati, T.: 2017, "Evolution of hydromagnetic turbulence from the electroweak phase transition," *Phys. Rev. D* **96**, 123528

358. Kahniashvili, T., Brandenburg, A., Durrer, R., Tevzadze, A. G., & Yin, W.: 2017, "Scale-invariant helical magnetic field evolution and the duration of inflation," *J. Cosmol. Astropart. Phys.* **12**, 002

Papers quoted already in the 2017 activity report:

352. Brandenburg, A., Schober, J., Rogachevskii, I., Kahniashvili, T., Boyarsky, A., Fröhlich, J., Ruchayskiy, O., & Kleeorin, N.: 2017, "The turbulent chiral magnetic cascade in the early universe," *Astrophys. J. Lett.* **845**, L21

344. Brandenburg, A., & Kahniashvili, T.: 2017, "Classes of hydrodynamic and magnetohydrodynamic turbulent decay," *Phys. Rev. Lett.* **118**, 055102

2 Sunspot formation and NEMPI

Sunspots reveal properties of the underlying magnetic field through their geometrical arrangement in three- and four-spot configurations. This was revealed through our work in Ref. [379]. We have now performed simulations showing the spontaneous flux concentrations from the negative effective magnetic pressure instability beneath a radiative stellar surface [361]. We have also studied the formation of magnetic bipoles in rotating turbulence with coronal envelope [377]. Our work on the identification of sharp magnetic structures from dynamos with density stratification was published already last year [348].

379. Bourdin, Ph.-A., & Brandenburg, A.: 2018, "Magnetic helicity from multipolar regions on the solar surface," *Astrophys. J.*, in press (arXiv:1804.04160)

377. Losada, I. R., Warnecke, J., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2018, "Magnetic bipoles in rotating turbulence with coronal envelope," *Astron. Astrophys.*, in press (arXiv:1803.04446)

361. Perri, B., & Brandenburg, A.: 2018, "Spontaneous flux concentrations from the negative effective magnetic pressure instability beneath a radiative stellar surface," *Astron. Astrophys.* **609**, A99

Paper of 2017 mentioned in previous activity report:

348. Jabbari, S., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2017, "Sharp magnetic structures from dynamos with density stratification," *Mon. Not. Roy. Astron. Soc.* **467**, 2753–2765

3 Dynamo action in the Sun

Linear polarization, as characterized by the Stokes Q and U parameters, is coordinate-dependent. A coordinate-independent characterization is provided by the parity-even and parity-odd E and B mode polarizations that are routinely used in cosmology Kamionkowski et al. (1997). Their cross-correlation can also reveal information about magnetic helicity, but only if the system is inhomogeneous Bracco et al. (2018). This was shown in our new work of Ref. [386] using data of numerical simulations; see Figure 2.

We have also continued using simulations to reveal subsurface properties of the Sun's magnetic field using simulations [389]. Its small-scale [366] and large-scale [365] properties have been subjects of separate investigations earlier this year.

New simulations have now demonstrated the enhancement of small-scale turbulent dynamo by large-scale shear [357]. Using simulations with the test-field method, we have discovered a new contribution of kinetic helicity to turbulent magnetic diffusivity [356]. In preparation for a new observational technique to measure magnetic helicity in the solar corona, we have now demonstrated quantitatively the compensation of Faraday depolarization by magnetic helicity in the solar corona [351]. Simulations have also been used to verify an analytic solution of an oscillatory migratory α^2 stellar dynamo [346].

389. Singh, N. K., Raichur, H., Käpylä, M. J., Rheinhardt, M., Brandenburg, A., & Käpylä, P. J.: 2018, "f-mode strengthening from a localized bipolar subsurface magnetic field," *Geophys. Astrophys. Fluid Dyn.*, submitted (arXiv:1808.08904)

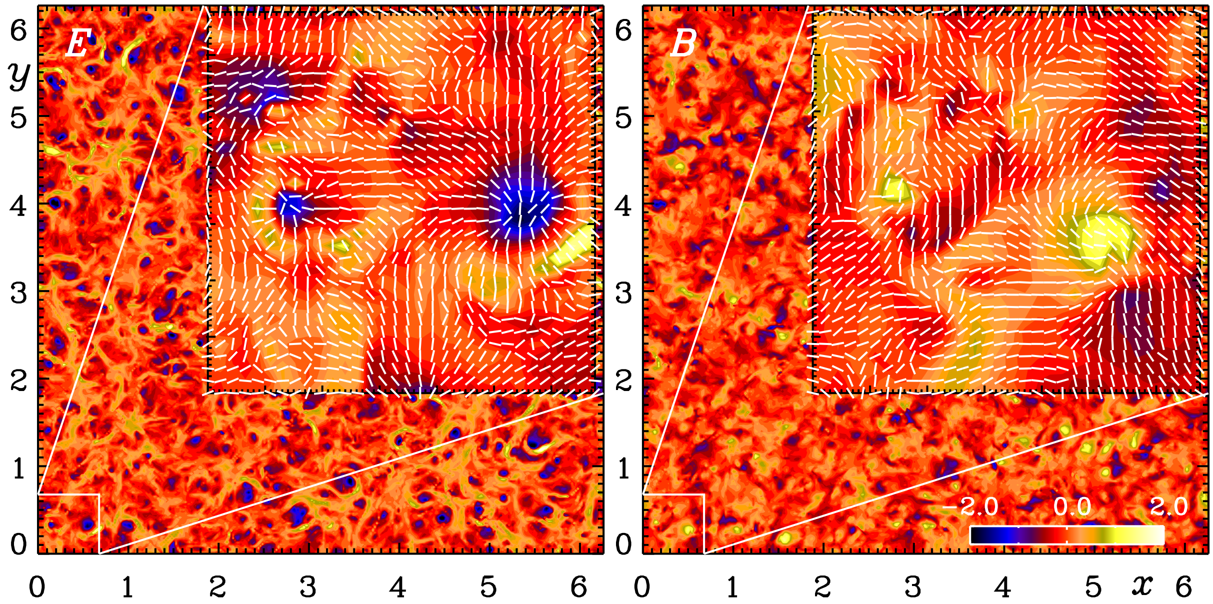

Figure 2: E-mode (left) and B-mode (right) polarization for isotropic fully helical magnetohydrodynamic turbulence using an xy slice of E and B from [344] (their Figures 4d–f, for a magnetic Prandtl number of 100). Dark (light) shades indicate negative (positive) velocity. In each panel, the insets show an enlarged portion where we also show the E and B polarization vectors.

386. Brandenburg, A., Bracco, A., Kahniashvili, T., Mandal, S., Roper Pol, A., Petrie, G. J. D., Singh, N. K.: 2018, "E and B polarizations from inhomogeneous and solar surface turbulence," *Astrophys. J.*, submitted (arXiv:1807.11457)

366. Käpylä, P. J., Käpylä, M. J., & Brandenburg, A.: 2018, "Small-scale dynamos in simulations of stratified turbulent convection," *Astron. Nachr.* **339**, 127–133

365. Brandenburg, A., & Chatterjee, P.: 2018, "Strong nonlocality variations in a spherical mean-field dynamo," *Astron. Nachr.* **339**, 118–126

Papers quoted already in the 2017 activity report:

357. Singh, N. K., Rogachevskii, I., & Brandenburg, A.: 2017, "Enhancement of small-scale turbulent dynamo by large-scale shear," *Astrophys. J. Lett.* **850**, L8

356. Brandenburg, A., Schober, J., & Rogachevskii, I.: 2017, "The contribution of kinetic helicity to turbulent magnetic diffusivity," *Astron. Nachr.* **338**, 790–793

351. Brandenburg, A., Ashurova, M. B., & Jabbari, S.: 2017, "Compensating Faraday depolarization by magnetic helicity in the solar corona," *Astrophys. J. Lett.* **845**, L15

346. Brandenburg, A.: 2017, "Analytic solution of an oscillatory migratory α^2 stellar dynamo," *Astron. Astrophys.* **598**, A117

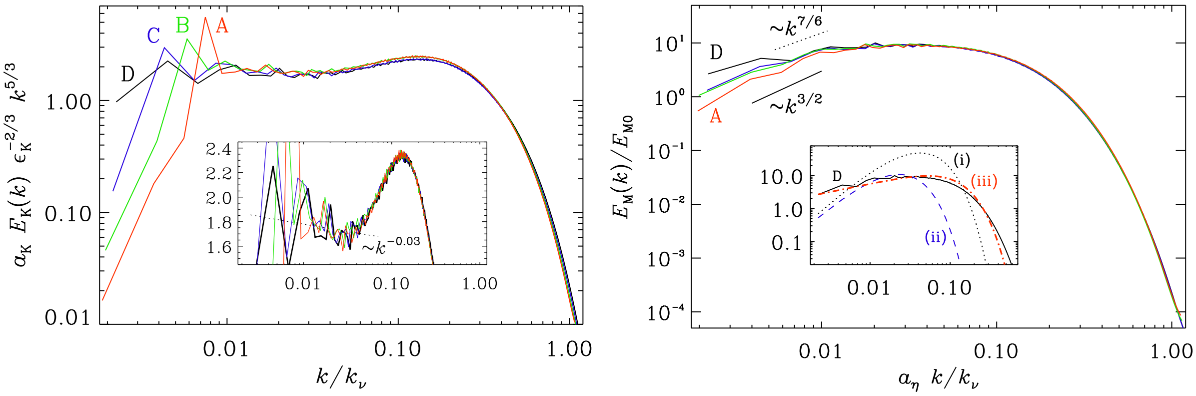

Figure 3: Left: Compensated kinetic energy spectra for all four runs. The inset shows the compensated spectra on a linear scale. The dotted line shows the theoretically expected inertial range correction proportional to $k^{-0.03}$. Right: Magnetic energy spectra for all four runs, time-averaged after compensating against the exponential growth, as explained in the text. The inset shows a comparison between the magnetic spectrum for Run D and the Macdonald function with different arguments explained in the text.

4 Particles in Turbulence

Based on our detailed studies of 2017 on Eulerian and modified Lagrangian approaches to multi-dimensional condensation and coagulation [349], we have completed 4 new papers on this subject. They show the importance of local energy dissipation in determining the speed of coagulation [373]. We also have performed work that includes the effects of condensation, in addition to coagulation [387]. We have also characterized the importance of fluctuations in dilute systems [390]. This lead to the PhD thesis of Xiang-Yu Li, who finished in September 2018.

390. Li, X.-Y., Mehlig, B., Svensson, G., Brandenburg, A., & Haugen, N. E. L.: 2018, "Fluctuations and growth histories of cloud droplets: superparticle simulations of the collision-coalescence process," *Quart. J. Roy. Met. Soc.*, submitted (arXiv:1810.07475)

387. Li, X.-Y., Brandenburg, A., Svensson, G., Haugen, N. E. L., Mehlig, B., & Rogachevskii, I.: 2018, "Condensational and collisional growth of cloud droplets in a turbulent environment," *J. Atmosph. Sci.*, submitted (arXiv:1807.11859)

376. Li, X.-Y., Svensson, G., Brandenburg, A., & Haugen, N. E. L.: 2018, "Cloud droplet growth due to supersaturation fluctuations in stratiform clouds," *Atmosph. Chem. Phys.*, DOI: 10.5194/acp-2018-644 (arXiv:1806.10529)

373. Li, X.-Y., Brandenburg, A., Svensson, G., Haugen, N. E. L., Mehlig, B., & Rogachevskii, I.: 2018, "Effect of turbulence on collisional growth of cloud droplets," *J. Atmosph. Sci.* **75**, 3469–3487

Papers quoted already in the 2017 activity report:

349. Li, X.-Y., Brandenburg, A., Haugen, N. E. L., & Svensson, G.: 2017, "Eulerian and Lagrangian approaches to multidimensional condensation and collection," *J. Adv. Model. Earth Syst.* **9**, 1116–1137

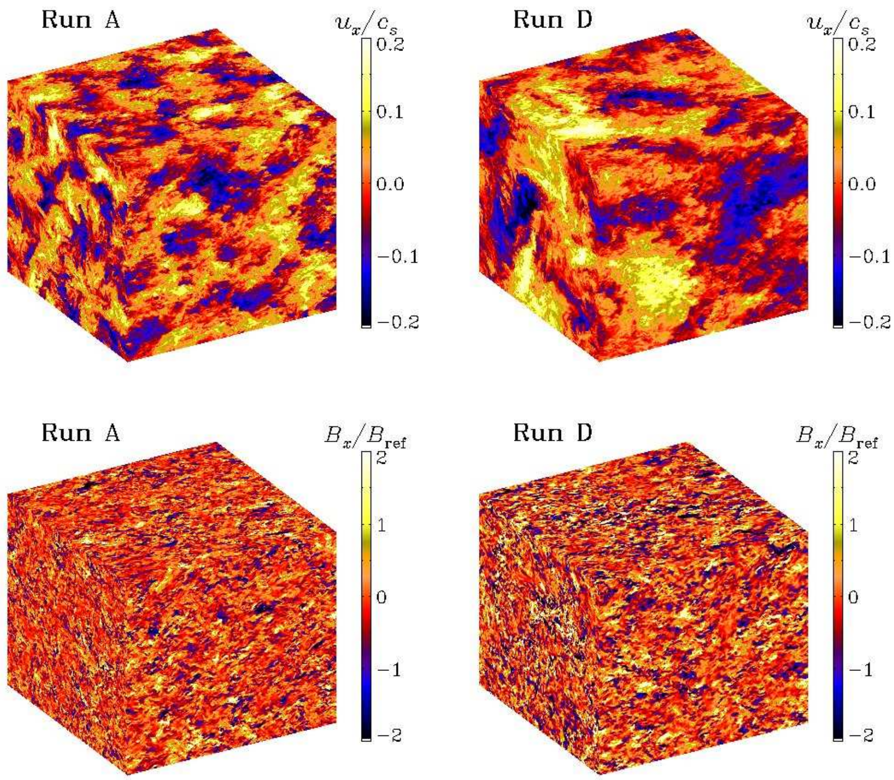

Figure 4: Visualizations of u_x (top) and B_x (bottom) for Runs A (left) and D (right) on the periphery of the domain at the last time of each run.

5 Small-scale dynamo and bottleneck in turbulence

As an additional off-spring of earlier work, we have completed this year a detailed investigation on varying the forcing scale in low Prandtl number dynamos [367]. It will provide an important benchmark for future studies.

367. Brandenburg, A., Haugen, N. E. L., Li, X.-Y., & Subramanian, K.: 2018, "Varying the forcing scale in low Prandtl number dynamos," *Mon. Not. Roy. Astron. Soc.* **479**, 2827–2833

Academic achievements

In September 2018, Dr Xiang-Yu Li successfully defended his PhD thesis at the University of Stockholm in the Meteorology department with Gunilla Svensson as the main supervisor. This project was supported by a grant from the Norwegian Research Council to Nordita with Brandenburg as the PI.

References

Bracco, A., Candelaresi, S., Del Sordo, F., & Brandenburg, A.: 2018, "Is there a left-handed magnetic field in the solar neighborhood? Exploring helical magnetic fields in the interstellar medium through dust polarization power spectra," *Astron. Astrophys.*, submitted 1807.10188

Brandenburg, A., & Dobler, W.: 2002, "Hydromagnetic turbulence in computer simulations," *Comp. Phys. Comm.* **147**, 471–475

Kamionkowski, M., Kosowsky, A., & Stebbins, A.: 1997, "A Probe of Primordial Gravity Waves and Vorticity," *Phys. Rev. Lett.* **78**, 2058–2061