

Activity report based on CPU time and storage used on PDC and NSC of 2024/2025

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In this activity report, we describe and list some highlights of the 19 papers that all acknowledge NAISS. Out of those, 2 are submitted. For the calculations, we use the PENCIL CODE, which is hosted on github <https://github.com/pencil-code>. The Pencil Code Collaboration consists of currently 38 developers who have published their effort in JOSS, the Journal of Open Source Software **6**, 2807 (2021).

Here and below, the 3-digit numbering of the papers coincides with that of Brandenburg's full list of publications on <https://axelbrandenburg.github.io/pub/node1.html>. All the papers quoted below acknowledge NAISS, PDC, and/or NSC.

1 Turbulent decay and Hosking integral

It is commonly thought that gravitational collapse during star and galaxy formation could lead to turbulence. However, it now turns out that the amplification of turbulence is just a consequence of the local shrinking of the volume which contained initial perturbations. Using a suitable transformation, we were able to show that the underlying turbulence is actually still decaying, although the magnetic field can still be amplified if its energy is still below the kinetic energy [470].

In this connection, it was of interest to study the fate of what is called acoustic turbulence, where the vorticity is initially vanishing. It turns out that in the presence of a sufficiently strong magnetic field, acoustic turbulent energy can be converted into vorticity [463].

A major development of the last few years concerns the Hosking integral. It is the correlation integral of the magnetic helicity density. It is conserved and gauge-invariant. Dimensional arguments allow us to determine the power laws of the decays with and without magnetic helicity, and simulations yield the numerical prefactors that are arguably universal [459]. In MHD, the dimensions of the Hosking integral are $\text{cm}^9 \text{s}^{-4}$, but for the Hall cascade, the dimensions are $\text{cm}^{13} \text{s}^{-4}$, which has consequences on the decay [461]. The same scaling is also well obeyed when the turbulence is initially highly anisotropic [468]; see Figure 1. We have now also studied the reality of inverse cascading in simulations of Hall turbulence in spherical shells representing neutron star crusts [460].

An important application of decaying turbulence is to the evolution of primordial magnetic fields during the radiation era of the early universe. The turbulent decay stops near the time of recombination after the gas motions have been damped away and the magnetic becomes frozen into the plasma. Remarkably, once we know on which track the field evolves, the endpoints in the diagnostic diagram describe a universal line versus length scale [455]. This line of endpoints depends on some open questions concerning turbulent reconnection and the physics of radiative damping.

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Figure 1: Visualizations of one component of the magnetic field on the periphery of the computational domain at different times for Roberts field I (top) and Roberts field II (bottom). Taken from Ref. [468].

The conservation of the Hosking integral is not restricted to an initial k^4 spectrum [441], but can also occur for shallower spectra [450]. Furthermore, a non-vanishing mean fermion chirality along with dynamo action can be obtained just from inhomogeneous chemical potential fluctuations [452].

- 470. Brandenburg, A., & Ntormousi, E.: 2025, “Magnetic field amplification during a turbulent collapse,” *Astrophys. J.* **990**, 223
- 468. Brandenburg, A., Yi, L., & Wu, X.: 2025, “Inverse cascade from helical and nonhelical decaying columnar magnetic fields,” *J. Plasma Phys.* **91**, E113 arXiv:2501.12200
- 463. Brandenburg, A., & Scannapieco, E.: 2025, “Magnetically assisted vorticity production in decaying acoustic turbulence,” *Astrophys. J.* **983**, 105
- 461. Vachaspati, T., & Brandenburg, A.: 2025, “Spectra of magnetic fields from electroweak symmetry breaking,” *Phys. Rev. D* **111**, 043541
- 460. Dehman, C., & Brandenburg, A.: 2025, “Reality of inverse cascading in neutron star crusts,” *Astron. Astrophys.* **694**, A39
- 459. Brandenburg, A., & Banerjee, A.: 2025, “Turbulent magnetic decay controlled by two conserved quantities,” *J. Plasma Phys.* **91**, E5
- 455. Brandenburg, A., Neronov, A., & Vazza, F.: 2024, “Resistively controlled primordial magnetic turbulence decay,” *Astron. Astrophys.* **687**, A186
- 452. Schober, J., Rogachevskii, I., & Brandenburg, A.: 2024, “Chiral anomaly and dynamos from inhomogeneous chemical potential fluctuations,” *Phys. Rev. Lett.* **132**, 065101

2 Dynamo action in the Sun and Galaxies

To connect our early Universe simulations discussed above with the later cosmological evolution, we have now performed simulations of large-scale structure formation with realistic magnetic fields [457]. Using direct numerical simulations of rotating stratified turbulence, we studied in [464] the resulting magnetic helicity fluxes in α -type dynamos. Those magnetic helicity fluxes have also been studied in isolation and we conformed that they drive an inverse k^{-1} cascade, but with a dimensionless prefactor that scales with the Lundquist number [476]. We also studied the interaction between α -type dynamos and the magnetorotational instability [471].

- 476. Zhang, J., & Brandenburg, A.: 2025, “Resistive scaling in the magnetic helicity-driven inverse cascade,” *Astrophys. J.*, submitted (arXiv:2509.21141)
- 471. Brandenburg, A., Larsson, G., Del Sordo, F. & Käpylä, P. J. 2025 Magneto-rotational instability in a solar near-surface mean-field dynamo 10.3847/1538-4357/ae03c4 (arXiv:2504.16849)
- 464. Brandenburg, A., & Vishniac, E. T.: 2025, “Magnetic helicity fluxes in dynamos from rotating inhomogeneous turbulence,” *Astrophys. J.* **984**, 78
- 457. Mtchedlidze, S., Domínguez-Fernández, P., Du, X., Carretti, E., Vazza, F., O’Sullivan, S. P., Brandenburg, A., & Kahniashvili, T.: 2024, “Intergalactic medium rotation measure of primordial magnetic fields,” *Astrophys. J.* **977**, 128

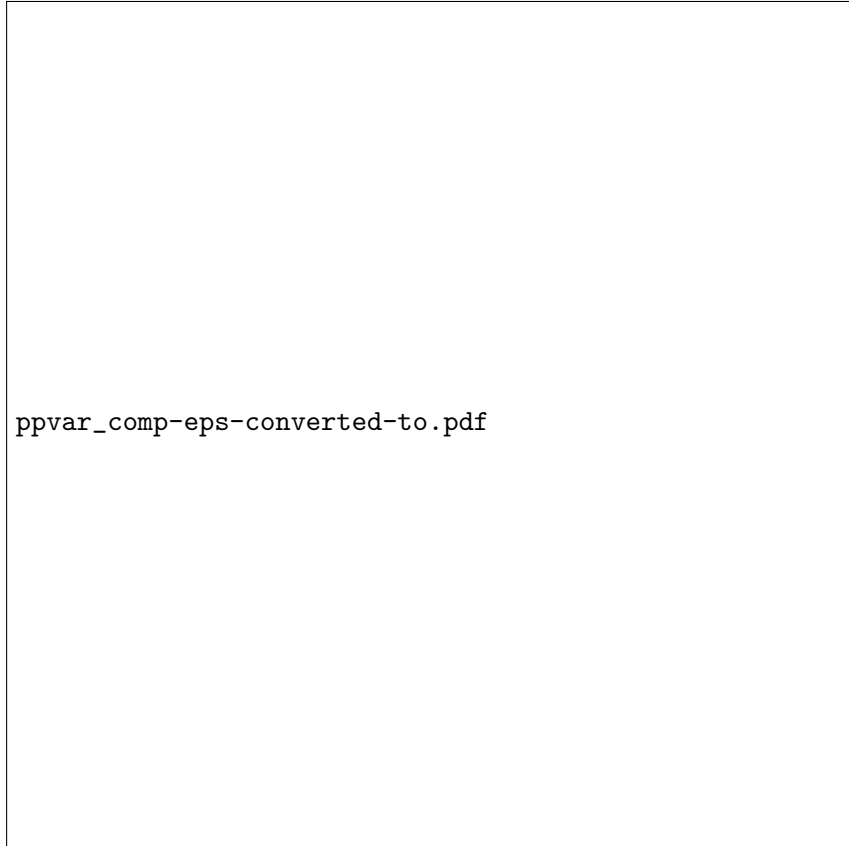


Figure 2: Visualizations of field lines of in the x - z plane on top of a color-scale representation of $\overline{B}_y$, where blue (red) shades refer to negative (positive) values. Taken from Ref. [471].

3 Turbulent transport in helical turbulence

In an earlier paper of 2017, we found that in helical turbulence, the effective magnetic diffusivity is reduced relative to the nonhelical value. We now found out that the helicity effect on the turbulent passive scalar diffusivity works in the opposite sense and leads to an enhancement [467]. This turns out to be related to the fact that the turbulent velocity field increases with the kinetic helicity [466].

- 466. Rogachevskii, I., Kleeorin, N., & Brandenburg, A.: 2025, “Theory of the kinetic helicity effect on turbulent diffusion of magnetic and scalar fields,” *Astrophys. J.* **985**, 18
- 465. Brandenburg, A., Käpylä, P. J., Rogachevskii, I., & Yokoi, N.: 2025, “Helicity effect on turbulent passive and active scalar diffusivities,” *Astrophys. J.* **984**, 88

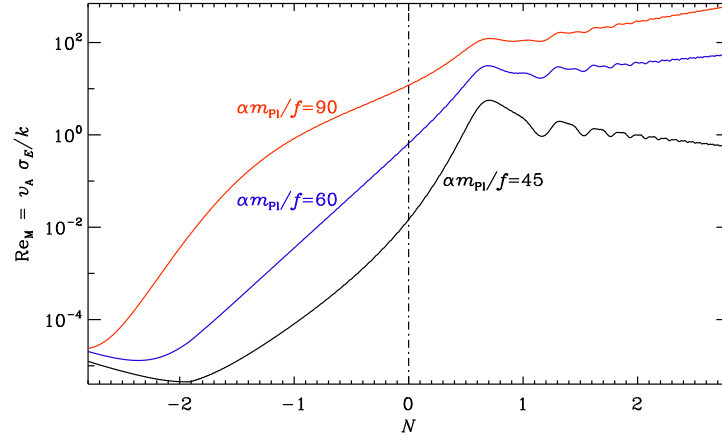


Figure 3: Magnetic Reynolds number versus the number of e -folds N for different coupling parameters $\alpha m_{\text{PI}}/f = 45$ (black), 60 (blue), and 90 (red). Taken from Ref. [472].

4 Backreaction of axion dynamics during inflation

We have recently explored the effects of backreaction on a model of axion-SU(2) inflation, where we found the emergence of a novel attractor, supported by the backreaction of super-horizon gauge field modes on the rolling axion [454]. This novel backreaction-supported attractor was found numerically. The strength and correlation length of the resulting helical magnetic fields depend on the inflationary Hubble scale. For suitable parameter choices we find that the strength of the resulting magnetic fields having correlation lengths around 1 Mpc, consistent with the required intergalactic magnetic fields for explaining the spectra of high energy γ rays from distant blazars [460].

- 472. Iarygina, O., Sfakianakis, E. I., & Brandenburg, A.: 2025, “Schwinger effect in axion inflation on a lattice,” *Phys. Rev. Lett.*, submitted (arXiv:2506.20538)
- 467. Sharma, R., Brandenburg, A., Subramanian, K., & Vikman, A.: 2025, “Lattice simulations of axion-U(1) inflation: gravitational waves, magnetic fields, and scalar statistics,” *J. Cosmol. Astropart. Phys.* **05**, 01

- 458. [Brandenburg, A.](#), Iarygina, O., Sfakianakis, E. I., & Sharma, R.: 2024, “Magnetogenesis from axion-SU(2) inflation,” *J. Cosmol. Astropart. Phys.* **12**, 057
- 454. Iarygina, O., Sfakianakis, E. I., Sharma, R. & [Brandenburg, A.](#): 2024, “Backreaction of axion-SU(2) dynamics during inflation,” *J. Cosmol. Astropart. Phys.* **04**, 018

5 Gravitational waves and early universe magnetic fields

An important 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. We have continued studying the chiral magnetic effect and have now calculated the resulting GW production [453]. The accuracy of the so-called sound-shell model of gravitational wave production is examined in [453], where we also find a new source of departures. In [442], we computed the effects of departures from general relativity on the spectrum of turbulence-sourced gravitational waves.

- 453. [Brandenburg, A.](#), Clarke, E., Kahniashvili, T., Long, A. J., & Sun, G.: 2024, “Relic gravitational waves from the chiral plasma instability in the standard cosmological model,” *Phys. Rev. D* **109**, 043534

Academic achievements

Master’s student Gustav Larsson successfully defended his thesis on 16 June 2025

PhD student Yutong He has successfully defended his PhD thesis on 4 June 2024.