Activity report based on CPU time and storage used on PDC and NSC of 2025/2026

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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.

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 $\mathrm{cm}^9\,\mathrm{s}^{-4}$, but for the Hall cascade, the dimensions are $\mathrm{cm}^{13}\,\mathrm{s}^{-4}$, which has consequences on the decay [461]. The same scaling is also well obeyed when the turbulence is initially highly anisotropic [468]. 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.

We have now also shown that the evolutionary tracks form isochrones in a diagram of magnetic field strength versus length scale. Visualizations of electric current density at different times along evolutionary tracks are shown in Figure 1.

482. Brandenburg, A., Cielo, M., Iarygina, O., & Vazza, F.: 2026, "Isochrones in primordial magnetic field evolution," *Astron. Astrophys.*, DOI: 10.1051/0004-6361/202661355 (arXiv:2606.10863)

475. Gurgenidze, M., Long, A. J., Roper Pol, A., Brandenburg, A., & Kahniashvili, T.: 2026, "Primordial magnetic field from chiral plasma instability with sourcing," *Phys. Rev. D* **114**, 023542

473. Zhang, J., & Brandenburg, A.: 2026, "Resistive scaling in the magnetic helicity-driven inverse cascade," *Astrophys. J.* **997**, 308

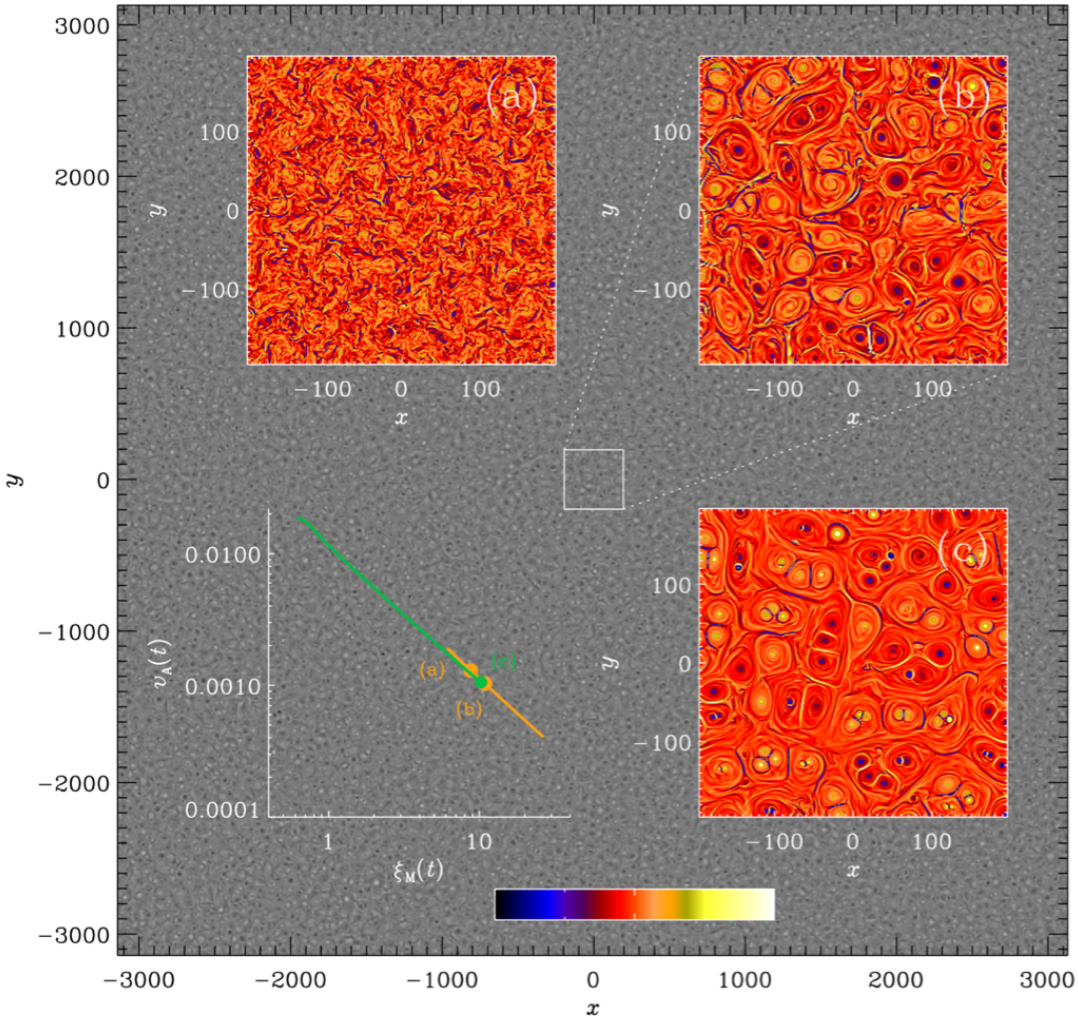

Figure 1: Visualizations of electric current density at different times along evolutionary tracks shown in the lower left inset. Taken from Ref. [482].

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

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

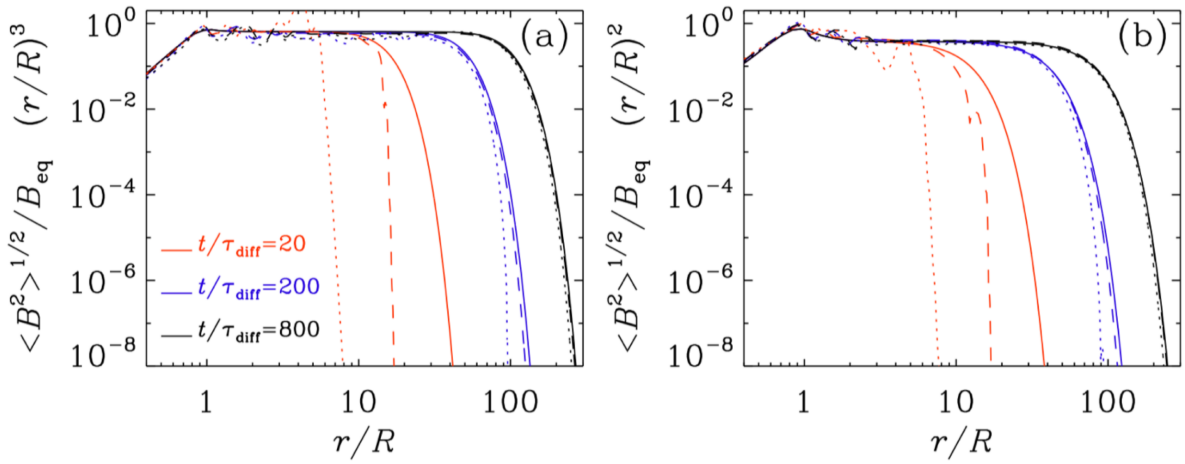

Figure 2: Radial dependence of dipolar (left) and quadrupolar (right) toroidal magnetic fields with distance from the galaxy. On sufficiently short timescales, the displacement current cannot be neglected; see the dotted and dashed lines. Taken from Ref. [474].

1 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. 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].

474. Brandenburg, A., Ghosh, O., Vazza, F., & Neronov, A.: 2026, "Magnetic field spreading from stellar and galactic dynamos into the exterior," *Astrophys. J.* **1002**, 165

472. Ghosh, O., Brandenburg, A., Caprini, C., Neronov, A., & Vazza, F.: 2026, "Can astrophysical sources magnetize the voids?" *Phys. Rev. D* **113**, 023523

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," *Astrophys. J.* **993**, 22

464. Brandenburg, A., & Vishniac, E. T.: 2025, "Magnetic helicity fluxes in dynamos from rotating inhomogeneous turbulence," *Astrophys. J.* **984**, 78

To assess the magnetization of the voids between galaxy clusters, we have revisited recent suggestions that magnetic fields in the outskirts of galaxies can pollute the voids. While we have found that quadrupolar toroidal magnetic fields, expected in galaxies, do indeed spread faster (see Figure 2), they are still confined by a magnetosphere [474] and cannot expand into the voids [472].

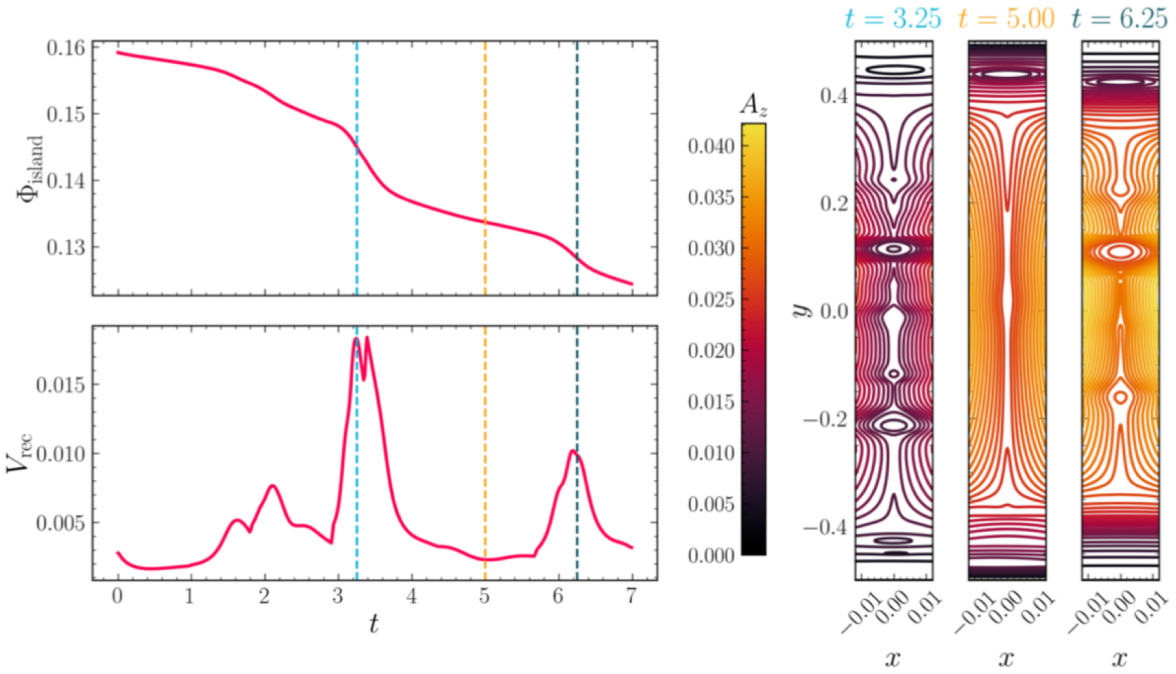

Figure 3: Temporal decay (upper left) and reconnection speed (lower left) in plasmoid-mediated reconnection (right). Taken from Ref. [483].

2 Plasmoid-mediated reconnection

Plasmoid-mediated reconnection is believed to be fast, but it was still believed to depend on the viscosity and thereby on the magnetic Prandtl nuumber. This question is important for computing the endpoints of cosmic magnetic field evolution. We have now shown that the reconnection speed is actually independent of the magnetic Prandtl nuumber [483]. The simulations have been carried out entirely on GPUs; see Figure 3 for visualizations.

483. Kumar, V., & Brandenburg, A.: 2026, "Magnetic Prandtl number dependence of plasmoid-mediated reconnection," *J. Plasma Phys.*, in press (arXiv:2605.18946)

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

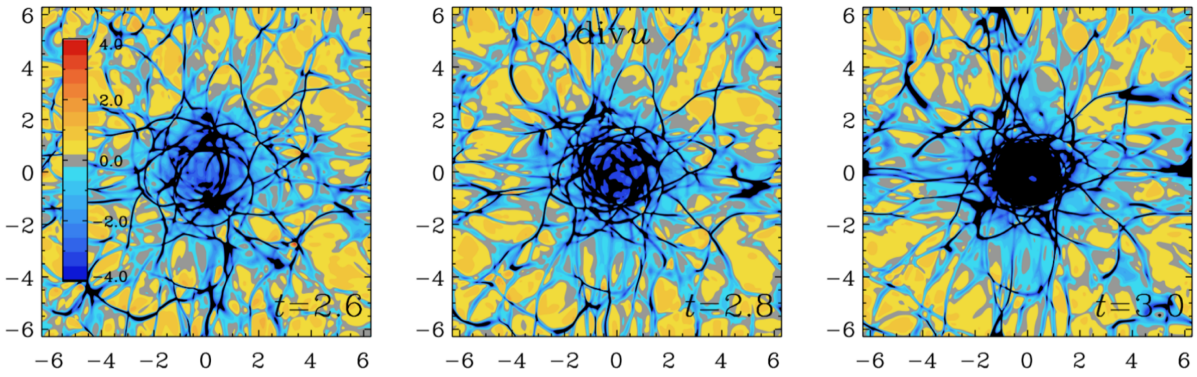

Figure 4: Visualizations of shocks produced during a turbulent collapse. Taken from Ref. [480].

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].

485. Iarygina, O., & Brandenburg, A.: 2026, "Primordial turbulence from inflation: a new inflaton-driven turbulent regime," *Phys. Rev. Lett.*, submitted (arXiv:2609.10326)

477. Iarygina, O., Sfakianakis, E. I., & Brandenburg, A.: 2026, "Schwinger effect in axion inflation on a lattice," *Phys. Rev. D* **114**, 063531

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

5 Self-gravitating turbulence and vorticity production

It is generally believed that vortical turbulence can be produced during a turbulent gravitational collapse. We have now shown that initially irrotational flows can produce vorticity through viscosity [480] and that any dynamo action is the result of vorticity that may be present initially or through viscous conversion [470]. Figure 4 shows the shocks produced during such a collapse, but shocks are already present initially. 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].

480. Brandenburg, A., Ntormousi, E., & Schober, J.: 2026, "No evidence of vorticity production from irrotational turbulent gravitational collapse yet," *Astrophys. J.* **1010**, 194

470. Brandenburg, A., & Ntormousi, E.: 2025, "Magnetic field amplification during a turbulent collapse," *Astrophys. J.* **990**, 223

463. Brandenburg, A., & Scannapieco, E.: 2025, "Magnetically assisted vorticity production in decaying acoustic turbulence," *Astrophys. J.* **983**, 105

Academic achievements

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