European Research Council
Executive Agency
Department B: Scientific Department

Project No: 227952

Project Acronym: AstroDyn

Project Full Title: Astrophysical dynamos

ERC GRANT

Mid-Term Activity Report

Period covered: from 1 February 2009 to 31 July 2011

Start date of project: 1 February 2009

Principal Investigator name: Axel Brandenburg

Host Institution name: NORDITA

Date of preparation: 28 September 2011

Date of submission: 28 September 2011

Duration: 2.5 years

Grant Mid-Term Activity Report

GENERAL INFORMATION

Project No:	227952
Project acronym:	AstroDyn
Project full name:	Astrophysical dynamos
Period number:	30 months
Period covered - start date:	1 February 2009
Period covered - end date:	31 July 2011
Project start date:	1 February 2009
Project duration [months]:	60 months
Principal Investigator name:	Axel Brandenburg
Host Institution name:	Nordita
Date of submission:	28 September 2011
Are there any ethical issues associated with your project, as specified in the Description of Work and other granting documents?	☐ Yes, all relevant documents have been sent already ☐ Yes, all pending documents included with this report ☒ No

Summary of the major achievements since the start of the project[1]

Sunspots cover a small fraction of the solar surface. They have kilogauss magnetic fields and it has commonly been believed that these fields continue in the form of long flux tubes beneath the surface. This therefore suggests that the Sun's magnetic field might be in what is known as a "fibril" state. This was never borne out by simulations. Instead, dynamo simulations suggest that, when a large-scale dynamo operates, the magnetic field tends to be volume filling and thus nearly diffusive (Käpylä et al. 2009). Current thinking also places dynamo action in the tachocline beneath the convection zone where flux tubes with a strength of 100,000 gauss have been postulated. An important goal of the AstroDyn project has therefore been to examine scenarios in which the magnetic field is generated throughout the convection zone. This field would be much weaker (around 300 gauss) and active regions and sunspots would be produced locally near the surface.

Just recently, new turbulence simulations have shown that near the surface, where the density drops sharply, turbulence effects can lead to an instability that spontaneously concentrates magnetic flux through a negative effective magnetic pressure instability (NEMPI); see Brandenburg et al. (2011). This new result supports our suggestion that the solar dynamo may operate throughout the convection zone, and that sunspot formation occurs as a surface phenomenon. Our discovery comes as a result of a broad group effort undertaken within this ERC project, allowing us to investigate the possibility of a negative effective magnetic pressure first in a range of dedicated simulations in various setting (with and without stratification, with and without convection). We have now started applying these findings to solar conditions with realistic radiation transport putting thus our revised understanding of solar magnetic activity on a firm basis.

Our project builds heavily upon the publicly available PENCIL CODE,[2] so all the code development done during the early phase of the project is to the benefit of a broader community and, conversely, the project gains from work done by other colleagues. The number of people able to check in changes to the code is around 70 and 10 of them have the status as owner. As a result of the new developments, we have now performed high resolution simulations in spherical geometry to study the effects of changing rotation and density stratification, and its effect on the dynamo.

Another crucial achievement resulting from the AstroDyn project concerns the α effect in convective turbulence. At the time when the project started, there were suggestions that α goes to zero in the limit of large magnetic Reynolds numbers even for kinematically weak magnetic fields. There were obvious questions concerning the degree of scale separation and the amount of stratification, because α should be proportional to the local stratification gradient and hence might be absent for weak stratification. In the mean time the situation has changed dramatically in that several results from our group now show conclusively that α does exist

[1] References given in the text refer to the list of refereed papers below

[2] `http://pencil-code.googlecode.com/`

also in convection both at weak and strong stratification. The components of both the α tensor and the turbulent diffusivity tensor are integral kernels and not just coefficients as was all too often assumed previously. Significant progress in this direction has been made by developing the test-field method, which was another major milestone of our project. The determination of turbulent transport coefficients has now been extended to determine the turbulent viscosity tensor as well as other contributions such as the anisotropic kinetic alpha effect and the Λ effect. In addition, we have identified pitfalls in determining the correct α effect using the more traditional imposed-field method. Our work has led to new possibilities for determining magnetic helicity fluxes both in mean-field and in direct simulations, which in turn has led to the realization that diffusive magnetic helicity fluxes can be more important than previously thought. While the progress has been significant, our work has also shown that the magnetic helicity fluxes are still small compared with microscopic diffusion unless the magnetic Reynolds number exceeds values around 10,000 (Candelaresi et al. 2011).

Our work has shed light on issues concerning the importance of using open boundary conditions for the magnetic field. This helped resolving the question of the dependence of the onset of the magneto-rotational instability on the value of the magnetic Prandtl number. In now turns out that with open boundary conditions the onset is independent of the magnetic Prandtl number.

Another important cornerstone of the project has been the modeling of features like coronal mass ejection (CME) above the surface of a dynamo region such as the solar surface. We have analyzed the nature of the expelled magnetic field in simulations that couple to a simplified representation of the lower solar wind. The magnetic field above the surface resembles real CMEs. Further detailed comparisons with actual coronal mass ejections will be beneficial. We have already extended our earlier work on a simpler Cartesian model of a force-free outer layer above the turbulence zone to full spherical domains and also cases where the turbulence is driven by convection. This work has been extremely beneficial in connection with another project on the determination of magnetic helicity in the solar wind (Brandenburg, Subramanian, Balogh, & Goldstein 2011), which yielded results that were initially quite puzzling, but that then turned out to be plausible and entirely comparable with our CME simulations.

Our work has also produced off-spin in other fields connected with astrobiology, turbulent combustion, and data assimilation used for weather prediction and now many other things. This is evidenced by some of the publications that have already appeared and are listed below (Babkovskaia et al. 2011; Brandenburg, Haugen, & Babkovskaia 2011) and others that will appear later.

Publishable brief summary of the achievements of the project

The goal of the astrophysical dynamo project (AstroDyn) is to improve our understanding of the origin of magnetic fields in various astrophysical settings. Of particular importance has been the Sun's magnetic field. The field and its variations manifest themselves through sunspots on the solar surface, through strong outbursts called coronal mass ejections, and through changes in the interplanetary magnetic field. They control space weather conditions that are relevant for the safety of astronauts and the operation of micro-electronics on board spacecrafts.

The AstroDyn project rests on four pillars that form also the topics of four PhD projects carried out within AstroDyn. Two of them are relevant to the physics at the solar surface (sunspots and active regions out of which spots emerge) and above (coronal mass ejections), and two are about the physics of the dynamo (especially its nonlinear saturation) and about dynamos in other bodies such as the Galaxy. The following two major achievements should be highlighted:

(i) a new process for the formation of active regions (and ultimately sunspots) has been proposed and detected in simulations,

(ii) coronal mass ejection-like phenomena have been shown to emerge self-consistently above the surface of a global dynamo simulation covering both interior and exterior regions,

(iii) systematic twist (helicity) has been detected in the solar wind away from equatorial plane, and its surprising properties were found to be in agreement with new results from global and local simulations,

(iv) new formulae for the vorticity production in the Galactic dynamo have been derived and tested numerically, and

(v) a controversy regarding large-scale dynamo action driven by convection has been resolved.

Among those, the direct verification of the negative effective magnetic pressure instability in turbulence simulation has been of particular excitement. This instability spontaneously produces flux concentrations as a result of the collective action of many turbulent eddies on scales encompassing many turbulent correlation lengths. This phenomenon has not been seen before, because it requires a large computational domain compared with the size of turbulent eddies, long run times, and a magnetic field strength that lies in a suitable interval. This work is significant because it supports the notion pursued in our group that solar activity may be a shallow phenomenon. This accomplishment has been the result of a broad group effort undertaken within this ERC project.

Other important accomplishments of members of our group concern the construction of a self-consistent model of coronal mass ejections and its usefulness in the interpretation of magnetic helicity measurements in the solar wind by members of our group.

Major problems/difficulties

Scientific problems: none

Technical problems: none

Support provided by the Host Institution: A delay in our financial report of July 2010 occurred due to several personnel changes in our administration. The situation has now stabilized and no further problems are being anticipated.

Other: The budget came under increased pressure because of changes in the relative exchange rate. The Euro is now buying us much less than originally planned for.

Information you would only want to share with ERCEA

The ERC grant has been a major boost for the personal career of the PI and also for the status of his institute. As one can see from his full list of publications[3] that all acknowledge the ERC grant, the total output of publications has been 65, of which 50 are in refereed journals. Of the refereed papers, 12 are first-author papers of the PI, and 5 of those are single-authored papers, giving evidence that the grant has allowed the PI to remain fully research active while mentoring now a group of 4 PhD students and a total of 4 post-docs with the help of an assistant professor, a 2 year visiting professor, and a total of about 100 visitors, many of whom have contributed to the research output of the project; see also `http://www.nordita.org/~brandenb/AstroDyn/` for the web size of these activities.

The administrative burden on the PI has been relatively light and it is important to keep it that way in the future.

List of keywords :

Solar physics – astrophysical fluid dynamics – magnetohydrodynamics – turbulence – dynamo theory – sunspots

[3] `http://www.nordita.org/~brandenb/pub/node1.html`

APPENDIX 1. Publications

PDF files of all publications can be downloaded from `http://norlx51.nordita.org/~brandenb/tmp/papers.zip`. This zip folder with 109 Mbytes contains the following list of 65 files:

```
Babk+Haug+Bran11.pdf           Hubb+Bran09.pdf
Bran09_boulder.pdf             Hubb+Bran10.pdf
Bran09_sofia.pdf               Hubb+Bran11.pdf
Bran10_euler.pdf               Hubb+DSor+Kapy+Bran09.pdf
Bran11_chandra.pdf             Hubb+Rhei+Bran11.pdf
Bran11_naxos.pdf               Kahn_etal10.pdf
Bran11.pdf                     Kapy_etal10b.pdf
Bran11_prandtl.pdf             Kapy_etal10.pdf
Bran+Cand+Chat09.pdf           Kapy_etal11b.pdf
Bran+DSor09.pdf                Kapy+Korp11.pdf
Bran_etal10.pdf                Kapy+Korp+Bran10b.pdf
Bran_etal11.pdf                Kapy+Korp+Bran10.pdf
Bran+Hau+Babk11.pdf            Kem+Bran+Ji11.pdf
Bran+Kapy+Korp11_nice.pdf      Kem+Bran+Klee+Roga11_naxos.pdf
Bran+Klee+Roga10.pdf           Kem+Rran+Klee+Roga11.pdf
Bran+Nord11.pdf                Mada+Bran10.pdf
Bran+Subr+Balo+Gold11.pdf      Mitra_etal10b.pdf
Cand+Bran11_naxos.pdf          Mitra_etal10c.pdf
Cand+Bran11.pdf                Mitra_etal10.pdf
Cand+DSor+Bran10.pdf           Mitra_etal11.pdf
Cand+DSor+Bran11_naxos.pdf     Radl+Bran10.pdf
Cand+Hubb+Bran+Mitra11.pdf     Radl_etal11.pdf
Chat+Bran+Guer10.pdf           Ray+Mitr+Perl+Pand11.pdf
Chat+Guer+Bran11.pdf           Rhei+Bran10.pdf
Chat+Mitra+Bran+Rhei11.pdf     Rue+Kit+Bra11.pdf
Chat+Mitra+Rhei+Bran11.pdf     Sur+Bran09.pdf
DSor+Bran10b.pdf               Verm+Bran09.pdf
DSor+Bran11b.pdf               Warn+Bran10b.pdf
DSor+Bran11.pdf                Warn+Bran10c.pdf
DSor+Cand+Bran10.pdf           Warn+Bran10.pdf
Guer+Chat+Bran10.pdf           Warn+Bran+Mitra11b.pdf
Guer_etal11.pdf                Warn+Bran+Mitra11.pdf
Guer+Kapy11.pdf
```

Alternatively, papers can also be downloaded from `http://www.nordita.org/~brandenb/pub/node1.html`.

1.1 Journal articles

In press:

- Kemel, K., Brandenburg, A., & Ji, H.: 2011, "A model of driven and decaying magnetic turbulence in a cylinder," *Phys. Rev. E*, in press (arXiv:1106.1129)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Kem+Bran+Ji11.pdf`

- Guerrero, G., Rheinhardt, M., Brandenburg, A., & Dikpati, M.: 2011, "Plasma flow vs. magnetic feature-tracking speeds in the Sun," *Monthly Notices Roy. Astron. Soc.*, in press (arXiv:1107.4801)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Guer_etal11.pdf`

- Brandenburg, A.: 2011, "Nonlinear small-scale dynamos at low magnetic Prandtl numbers," *Astrophys. J.*, in press (arXiv:1106.5777)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran11.pdf`

- Hubbard, A., Rheinhardt, M. & Brandenburg, A.: 2011, "The fratricide of $\alpha\Omega$ dynamos by their α^2 siblings," *Astron. Astrophys.*, in press (arXiv:1102.2617)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Hubb+Rhei+Bran11.pdf`

- Rädler, K.-H., Brandenburg, A., Del Sordo, F., & Rheinhardt, M.: 2011, "Mean-field diffusivities in passive scalar and magnetic transport in irrotational flows," *Phys. Rev. E*, in press (arXiv:1104.1613)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Radl_etal11.pdf`

- Ray, S. S., Mitra, D. Perlekar, P. & Pandit, R.: 2011, "Dynamic multiscaling in two-dimensional fluid turbulence," *Phys. Rev. Lett.*, in press (arXiv:1105.5160)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Ray+Mitr+Perl+Pand11.pdf`

Published:

- Brandenburg, A., Kemel, K., Kleeorin, N., Mitra, D., & Rogachevskii, I.: 2011, "Detection of negative effective magnetic pressure instability in turbulence simulations," *Astrophys. J. Lett.* **740**, L50
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran_etal11.pdf`

- Chatterjee, P., Mitra, D., Rheinhardt, & M. Brandenburg, A.: 2011, "Alpha effect due to buoyancy instability of a magnetic layer," *Astron. Astrophys.* **534**, A46
  ERC funding is acknowledged; arXiv version is open access.
  File: `Chat+Mitra+Rhei+Bran11.pdf`

- Warnecke, J., Brandenburg, A., & Mitra, D.: 2011, "Dynamo-driven plasmoid ejections above a spherical surface," *Astron. Astrophys.* **534**, A11
  ERC funding is acknowledged; arXiv version is open access.
  File: `Warn+Bran+Mitra11.pdf`

- Chatterjee, P., Mitra, D., Brandenburg, A., & Rheinhardt, M.: 2011, "Spontaneous chiral symmetry breaking by hydromagnetic buoyancy," *Phys. Rev. E* **84**, 025403
  ERC funding is acknowledged; arXiv version is open access.
  File: `Chat+Mitra+Bran+Rhei11.pdf`

- Guerrero, G., & Kp̈ylä, P. J.: 2011, "Dynamo action and magnetic buoyancy in convection simulations with vertical shear," *Astron. Astrophys.* **533**, A40
  ERC funding is acknowledged; arXiv version is open access.
  File: `Guer+Kapy11.pdf`

- Käpylä, P. J., & Korpi, M. J.: 2011, "Magnetorotational instability driven dynamos at low magnetic Prandtl numbers," *Monthly Notices Roy. Astron. Soc.* **413**, 901–907
  ERC funding is acknowledged; arXiv version is open access.
  File: `Kapy+Korp11.pdf`

- Candelaresi, S., & Brandenburg, A.: 2011, "Decay of helical and non-helical magnetic knots," *Phys. Rev. E* **84**, 016406
  ERC funding is acknowledged; arXiv version is open access.
  File: `Cand+Bran11.pdf`

- Brandenburg, A.: 2011, "Chandrasekhar-Kendall functions in astrophysical dynamos," *Pramana J. Phys.* **77**, 67–76
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran11_chandra.pdf`

- Käpylä, P. J., Mantere, M. J., Guerrero, G., Brandenburg, A., & Chatterjee, P.: 2011, "Reynolds stress and heat flux in spherical shell convection," *Astron. Astrophys.* **531**, A162
  ERC funding is acknowledged; arXiv version is open access.
  File: `Kapy_etal11b.pdf`

- Brandenburg, A., Subramanian, K., Balogh, A., & Goldstein, M. L.: 2011, "Scale-dependence of magnetic helicity in the solar wind," *Astrophys. J.* **734**, 9
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran+Subr+Balo+Gold11.pdf`

- Del Sordo, F., & Brandenburg, A.: 2011, "Vorticity production through rotation, shear, and baroclinicity," *Astron. Astrophys.* **528**, A145
ERC funding is acknowledged; arXiv version is open access.
File: `DSor+Bran11.pdf`

- Brandenburg, A., & Nordlund, Å.: 2011, "Astrophysical turbulence modeling," *Rep. Prog. Phys.* **74**, 046901
ERC funding is acknowledged; arXiv version is open access.
File: `Bran+Nord11.pdf`

- Rüdiger, G., Kitchatinov, L. L., & Brandenburg, A.: 2011, "Cross helicity and turbulent magnetic diffusivity in the solar convection zone," *Solar Phys.* **269**, 3–12
ERC funding is acknowledged; arXiv version is open access.
File: `Rue+Kit+Bra11.pdf`

- Mitra, D., Moss, D., Tavakol, R., & Brandenburg, A.: 2011, "Alleviating α quenching by solar wind and meridional flow," *Astron. Astrophys.* **526**, A138
ERC funding is acknowledged; arXiv version is open access.
File: `Mitra_etal11.pdf`

- Brandenburg, A., Haugen, N. E. L., & Babkovskaia, N.: 2011, "Turbulent front speed in the Fisher equation: dependence on Damköhler number," *Phys. Rev. E* **83**, 016304
ERC funding is acknowledged; arXiv version is open access.
File: `Bran+Hau+Babk11.pdf`

- Candelaresi, S., Hubbard, A., Brandenburg, A., & Mitra, D.: 2011, "Magnetic helicity transport in the advective gauge family," *Phys. Plasmas* **18**, 012903
ERC funding is acknowledged; arXiv version is open access.
File: `Cand+Hubb+Bran+Mitra11.pdf`

- Hubbard, A., & Brandenburg, A.: 2011, "Magnetic helicity flux in the presence of shear," *Astrophys. J.* **727**, 11
ERC funding is acknowledged; arXiv version is open access.
File: `Hubb+Bran11.pdf`

- Brandenburg, A.: 2011, "Dissipation in dynamos at low and high magnetic Prandtl numbers," *Astron. Nachr.* **332**, 51–56
ERC funding is acknowledged; arXiv version is open access.
File: `Bran11_prandtl.pdf`

- Chatterjee, P., Guerrero, G., & Brandenburg, A.: 2011, "Magnetic helicity fluxes in interface and flux transport dynamos," *Astron. Astrophys.* **525**, A5
ERC funding is acknowledged; arXiv version is open access.
File: `Chat+Guer+Bran11.pdf`

- Babkovskaia, N., Haugen, N. E. L., Brandenburg, A.: 2011, "A high-order public domain code for direct numerical simulations of turbulent combustion," *J. Comp. Phys.* **230**, 1–12
ERC funding is acknowledged; arXiv version is open access.
File: `Babk+Haug+Bran11.pdf`

- Brandenburg, A., Chatterjee, P., Del Sordo, F., Hubbard, A., Käpylä, P. J., & Rheinhardt, M.: 2010, "Turbulent transport in hydromagnetic flows," *Phys. Scr.* **T142**, 014028
ERC funding is acknowledged; arXiv version is open access.
File: `Bran_etal10.pdf`

- Guerrero, G., Chatterjee, P., & Brandenburg, A.,: 2010, "Shear-driven and diffusive helicity fluxes in $\alpha\Omega$ dynamos," *Monthly Notices Roy. Astron. Soc.* **409**, 1619–1630
ERC funding is acknowledged; arXiv version is open access.
File: `Guer+Chat+Bran10.pdf`

- Chatterjee, P., Brandenburg, A., & Guerrero, G.: 2010, "Can catastrophic quenching be alleviated by separating shear and α effect?" *Geophys. Astrophys. Fluid Dyn.* **104**, 591–599
ERC funding is acknowledged; arXiv version is open access.
File: `Chat+Bran+Guer10.pdf`

- Hubbard, A., & Brandenburg, A.: 2010, "Magnetic helicity fluxes in an α^2 dynamo embedded in a halo," *Geophys. Astrophys. Fluid Dyn.* **104**, 577–590
ERC funding is acknowledged; arXiv version is open access.
File: `Hubb+Bran10.pdf`

- Warnecke, J., & Brandenburg, A.: 2010, "Surface appearance of dynamo-generated large-scale fields," *Astron. Astrophys.* **523**, A19
ERC funding is acknowledged; arXiv version is open access.
File: `Warn+Bran10.pdf`

- Rheinhardt, M., & Brandenburg, A.: 2010, "Test-field method for mean-field coefficients with MHD background," *Astron. Astrophys.* **520**, A28
ERC funding is acknowledged; arXiv version is open access.
File: `Rhei+Bran10.pdf`

- Käpylä, P. J., Korpi, M. J., & Brandenburg, A.: 2010, "Open and closed boundaries in large-scale convective dynamos," *Astron. Astrophys.* **518**, A22
ERC funding is acknowledged; arXiv version is open access.
File: `Kapy+Korp+Bran10b.pdf`

- Käpylä, P. J., Brandenburg, A., Korpi, M. J., Snellman, J. E., & Narayan, R.: 2010, "Angular momentum transport in convectively unstable shear flows," *Astrophys. J.* **719**, 67–76

ERC funding is acknowledged; arXiv version is open access.
File: `Kapy_etal10b.pdf`

- Mitra, D., Tavakol, R., Käpylä, P. J., & Brandenburg, A.: 2010, "Oscillatory migrating magnetic fields in helical turbulence in spherical domains," *Astrophys. J. Lett.* **719**, L1–L4
  ERC funding is acknowledged; arXiv version is open access.
  File: `Mitra_etal10b.pdf`

- Madarassy, E. J. M., & Brandenburg, A.: 2010, "Calibrating passive scalar transport in shear-flow turbulence," *Phys. Rev. E* **82**, 016304
  ERC funding is acknowledged; arXiv version is open access.
  File: `Mada+Bran10.pdf`

- Kahniashvili, T., Brandenburg, A., Tevzadze, A. G., & Ratra, B.: 2010, "Numerical simulations of the decay of primordial magnetic turbulence," *Phys. Rev. D* **81**, 123002
  ERC funding is acknowledged; arXiv version is open access.
  File: `Kahn_etal10.pdf`

- Del Sordo, F., Candelaresi, S., & Brandenburg, A.: 2010, "Magnetic field decay of three interlocked flux rings with zero linking number," *Phys. Rev. E* **81**, 036401
  ERC funding is acknowledged; arXiv version is open access.
  File: `DSor+Cand+Bran10.pdf`

- Käpylä, P. J., Korpi, M. J., & Brandenburg, A.: 2010, "The α effect in rotating convection with sinusoidal shear," *Monthly Notices Roy. Astron. Soc.* **402**, 1458–1466
  ERC funding is acknowledged; arXiv version is open access.
  File: `Kapy+Korp+Bran10.pdf`

- Brandenburg, A.: 2010, "Magnetic field evolution in simulations with Euler potentials," *Monthly Notices Roy. Astron. Soc.* **401**, 347–354
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran10_euler.pdf`

- Mitra, D., Candelaresi, S., Chatterjee, P., Tavakol, R., & Brandenburg, A.: 2010, "Equatorial magnetic helicity flux in simulations with different gauges," *Astron. Nachr.* **331**, 130–135
  ERC funding is acknowledged; arXiv version is open access.
  File: `Mitra_etal10.pdf`

- Rädler, K.-H., & Brandenburg, A.: 2010, "Mean electromotive force proportional to mean flow in mhd turbulence," *Astron. Nachr.* **331**, 14–21
  ERC funding is acknowledged; arXiv version is open access.
  File: `Radl+Bran10.pdf`

- Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2010, "Large-scale magnetic flux concentrations from turbulent stresses," *Astron. Nachr.* **331**, 5–13
ERC funding is acknowledged; arXiv version is open access.
File: `Bran+Klee+Roga10.pdf`

- Käpylä, P. J., Korpi, M. J., Brandenburg, A., Mitra, D., & Tavakol, R.: 2010, "Convective dynamos in spherical wedge geometry," *Astron. Nachr.* **331**, 73–81
ERC funding is acknowledged; arXiv version is open access.
File: `Kapy_etal10.pdf`

- Hubbard, A., & Brandenburg, A.: 2009, "Memory effects in turbulent transport," *Astrophys. J.* **706**, 712–726
ERC funding is acknowledged; arXiv version is open access.
File: `Hubb+Bran09.pdf`

- Brandenburg, A.: 2009, "The critical role of magnetic helicity in astrophysical dynamos," *Plasma Phys. Control. Fusion* **51**, 124043
ERC funding is acknowledged; arXiv version is open access.
File: `Bran09_sofia.pdf`

- Sur, S., & Brandenburg, A.: 2009, "The role of the Yoshizawa effect in the Archontis dynamo," *Monthly Notices Roy. Astron. Soc.* **399**, 273–280
ERC funding is acknowledged; arXiv version is open access.
File: `Sur+Bran09.pdf`

- Hubbard, A., Del Sordo, F., Käpylä, P. J., & Brandenburg, A.: 2009, "The α effect with imposed and dynamo-generated magnetic fields," *Monthly Notices Roy. Astron. Soc.* **398**, 1891–1899
ERC funding is acknowledged; arXiv version is open access.
File: `Hubb+DSor+Kapy+Bran09.pdf`

- Brandenburg, A., Candelaresi, S., & Chatterjee, P.: 2009, "Small-scale magnetic helicity losses from a mean-field dynamo," *Monthly Notices Roy. Astron. Soc.* **398**, 1414–1422
ERC funding is acknowledged; arXiv version is open access.
File: `Bran+Cand+Chat09.pdf`

- Vermersch, V., & Brandenburg, A.: 2009, "Shear-driven magnetic buoyancy oscillations," *Astron. Nachr.* **330**, 797–806
ERC funding is acknowledged; arXiv version is open access.
File: `Verm+Bran09.pdf`

1.2 Publications in conference proceedings

- Brandenburg, A.: 2011, "Simulations of astrophysical dynamos," in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal

Pino, & A. Kosovichev, pp. 402–409
ERC funding is not acknowledged; arXiv version is open access.
File: `Bran11_naxos.pdf`

- Brandenburg, A., Käpylä, P. J., Korpi, M. J.: 2011, "From convective to stellar dynamos," in *Astrophysical Dynamics: From Stars to Galaxies*, ed. IAU Symp. 271, N. Brummell, A.S. Brun, M.S. Miesch, & Y. Ponty, pp. 279–287
ERC funding is acknowledged; arXiv version is open access.
File: `Bran+Kapy+Korp11_nice.pdf`

- Del Sordo, F., & Brandenburg, A.: 2011, "How can vorticity be produced in irrotationally forced flows?" in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal Pino, & A. Kosovichev, pp. 373–375
ERC funding is acknowledged; arXiv version is open access.
File: `DSor+Bran11b.pdf`

- Kemel, K., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2011, "Turbulent magnetic pressure instability in stratified turbulence," in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal Pino, & A. Kosovichev, pp. 473–475
ERC funding is acknowledged; arXiv version is open access.
File: `Kem+Bran+Klee+Roga11_naxos.pdf`

- Candelaresi, S., & Brandenburg, A.: 2011, "Magnetic helicity fluxes in $\alpha\Omega$ dynamos," in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal Pino, & A. Kosovichev, pp. 464–466
ERC funding is acknowledged; arXiv version is open access.
File: `Cand+Bran11_naxos.pdf`

- Warnecke, J., Brandenburg, A., & Mitra, D.: 2011, "Plasmoid ejections driven by dynamo action underneath a spherical surface," in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal Pino, & A. Kosovichev, pp. 306–309
ERC funding is acknowledged; arXiv version is open access.
File: `Warn+Bran+Mitra11b.pdf`

- Candelaresi, S., Del Sordo, F., & Brandenburg, A.: 2011, "Decay of trefoil and other magnetic knots," in *Advances in Plasma Astrophysics*, ed. Proc. IAU, Vol. 6, IAU Symp. S274, A. Bonanno, E. de Gouveia dal Pino, & A. Kosovichev, pp. 461–463
ERC funding is acknowledged; arXiv version is open access.
File: `Cand+DSor+Bran11_naxos.pdf`

- Kemel, K., Brandenburg, A., Kleeorin, N., & Rogachevskii, I.: 2011, "The negative magnetic pressure effect in stratified turbulence," in *Physics of Sun and Star Spots*, ed. IAU Symp. 273, D.P. Choudhary & K.G. Strassmeier, in press (arXiv:1010.1659)

ERC funding is acknowledged; arXiv version is open access.
File: `Kem+Rran+Klee+Roga11.pdf`

- Warnecke, J., & Brandenburg, A.: 2011, "Dynamo generated field emergence through recurrent plasmoid ejections," in *Physics of Sun and Star Spots*, ed. IAU Symp. 273, D.P. Choudhary & K.G. Strassmeier, in press (arXiv:1010.0218)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Warn+Bran10c.pdf`

- Del Sordo, F., & Brandenburg, A.: 2011, "Vorticity from irrotationally forced flow," in *Astrophysical Dynamics: from Stars to Galaxies*, ed. IAU Symp. 271, N. Brummell, & A.S. Brun, pp. 375–376
  ERC funding is acknowledged; arXiv version is open access.
  File: `DSor+Bran10b.pdf`

- Candelaresi, S., Del Sordo, F., & Brandenburg, A.: 2011, "Influence of Magnetic Helicity in MHD," in *Astrophysical Dynamics: from Stars to Galaxies*, ed. IAU Symp. 271, N. Brummell, & A.S. Brun, pp. 369–370
  ERC funding is acknowledged; arXiv version is open access.
  File: `Cand+DSor+Bran10.pdf`

- Warnecke, J., & Brandenburg, A.: 2011, "Recurrent flux emergence from dynamo-generated fields," in *Astrophysical Dynamics: from Stars to Galaxies*, ed. IAU Symp. 271, N. Brummell, & A.S. Brun, pp. 407–408 (arXiv:1008.5278)
  ERC funding is acknowledged; arXiv version is open access.
  File: `Warn+Bran10b.pdf`

- Mitra, D., Tavakol, R., Brandenburg, A., & Käpylä, P. J.: 2010, "Oscillatory migratory large-scale fields in mean-field and direct simulations," in *Solar and Stellar Variability: Impact on Earth and Planets, Vol.* **264**, ed. A. Kosovichev et al., CUP, pp. 197–201
  ERC funding is acknowledged; arXiv version is open access.
  File: `Mitra_etal10c.pdf`

- Brandenburg, A., & Del Sordo, F.: 2010, "Turbulent diffusion and galactic magnetism," in *Highlights of Astronomy, Vol.* **15**, ed. E. de Gouveia Dal Pino, CUP, pp. 432–433
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran+DSor09.pdf`

- Brandenburg, A.: 2009, "From fibril to diffuse fields during dynamo saturation," in *Solar-stellar dynamos as revealed by helio- and asteroseismology*, ed. M. Dikpati, Arentoft, T., Hernández, I. G., Lindsey, C., & Hill, F., Astron. Soc. Pac. Conf. Ser., Vol. **416**, pp. 433–442
  ERC funding is acknowledged; arXiv version is open access.
  File: `Bran09_boulder.pdf`

1.3 Books: monographs and edited books

Does not apply.

APPENDIX 2. Research Expeditions

Does not apply.

APPENDIX 3. Awards and recognitions

Does not apply.

APPENDIX 4. Patents, licencing, intellectual property

PENCIL CODE: `http://pencil-code.googlecode.com/`
Code license: GNU GPL v3
Years: 2001-2011
New revisions during grant period: r10328–r17707

APPENDIX 5. Dissemination to non-academic audience

- "Cycles of the Sun," Interview with Axel Brandenburg by British Publishers, January 2010 (`http://www.nordita.org/~brandenb/AstroDyn/material/Solar_Activity_10.pdf`)

APPENDIX 6. Other significant outputs/information

Does not apply.