Scientific usage of the Pencil Code

Pencil Code Steering Committee

- Terms of Reference [previous revision 1.26 of 2018]
- Minutes

General links related to the Pencil Code

- GitHub page
- Code of Conduct
- List of Committers

Other links related to the Pencil Code

- travis-ci.com (automatic test result after each check-in)
- SpecialIssue (in *Geophys. Astrophys. Fluid Dyn.* **114**, 1-281)
- Scientific usage of the Pencil Code (DOI:10.5281/zenodo.3466444) [ADS]
- Pencil Code paper (JOSS), copy of the manual, nordita page
- Github: https://github.com/pencil-code/website/blob/master/doc/manual.pdf
- Github: https://github.com/pencil-code/website/blob/master/doc/citations.pdf
- Pencil Code Newsletter: 2021/1, Back Issues

1 2021arXiv210506042L 2021/05
Thresholds for Particle Clumping by the Streaming Instability
Li, Rixin; Youdin, Andrew

2 2021arXiv210501539H 2021/05
Spectral characterisation of inertial particle clustering in turbulence
Haugen, N. E. L.; Brandenburg, A.; Sandin, C. *and 1 more*

3 2021MNRAS.503.1290S 2021/05 cited: 5
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4 2021arXiv210411112Z 2021/04
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5 2021arXiv210407588P 2021/04
Inferring magnetic helicity spectrum in spherical domains: the method and example applications
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6 2021arXiv210403192H 2021/04
Spectrum of turbulence-sourced gravitational waves as a constraint on graviton mass
He, Yutong; Brandenburg, Axel; Sinha, Aditya

7 2021ApJ...911..110B 2021/04 cited: 4
Relic Gravitational Waves from the Chiral Magnetic Effect
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Testing the Jeans, Toomre, and Bonnor-Ebert Concepts for Planetesimal Formation: 3D Streaming-instability Simulations of Diffusion-regulated Formation of Planetesimals
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9 2021ApJ...910L..15G 2021/04 cited: 1
Small-scale Dynamo in Supernova-driven Interstellar Turbulence
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10 2021A&A...648A..52L 2021/04 cited: 3
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Park, Kiwan; Cheoun, Myung-Ki

23 2021arXiv210203168V 2021/02

Hunting down the cause of solar magnetism

Viviani, M.; Prabhu, A.; Warnecke, J. *and 4 more*

24 2021arXiv210200982Z 2021/02 cited: 1

Stellar X-rays and magnetic activity in 3D MHD coronal models

Zhuleku, J.; Warnecke, J.; Peter, H.

25 2021PhRvR...3a3193K 2021/02 cited: 3

Circular polarization of gravitational waves from early-Universe helical turbulence

Kahniashvili, Tina; Brandenburg, Axel; Gogoberidze, Grigol *and 2 more*

26 2021MNRAS.501.3074B 2021/02 cited: 2

Inverse energy transfer in decaying, three-dimensional, non-helical magnetic turbulence due to magnetic reconnection

Bhat, Pallavi; Zhou, Muni; Loureiro, Nuno F.

27 2021MNRAS.501..467Z 2021/02 cited: 7

Streaming instability with multiple dust species - I. Favourable conditions for the linear growth

Zhu, Zhaohuan; Yang, Chao-Chin

28 2021JOSS....6.2807P 2021/02 cited: 17

The Pencil Code, a modular MPI code for partial differential equations and particles: multipurpose and multiuser-maintained

Pencil Code Collaboration; Brandenburg, Axel; Johansen, Anders *and 35 more*

29 2021ApJ...907...83V 2021/02 cited: 1

Interaction of Large- and Small-scale Dynamos in Isotropic Turbulent Flows from GPU-accelerated Simulations

Väisälä, Miikka S.; Pekkilä, Johannes; Käpylä, Maarit J. *and 3 more*

30 2021arXiv210108749B 2021/01

Numerical Study of Trailing and Leading Vortex Dynamics in a Forced Jet with Coflow

Bhatia, Bharat; De, Ashoke

32 papers of 2021 alone

31 2021ApJ...907...43H 2021/01
A Proper Discretization of Hydrodynamic Equations in Cylindrical Coordinates for / Simulations
Hanawa, Tomoyuki; Matsumoto, Yosuke

32 2021A&A...645A.141V 2021/01 cited: 2
Physically motivated heat-conduction treatment in simulations of solar-like stars: ef dynamo transitions
Viviani, M.; Käpylä, M. J.

33 2020arXiv201206343B 2020/12
Generation of mean flows in rotating anisotropic turbulence: The case of solar nea shear layer
Barekat, A.; Käpylä, M. J.; Käpylä, P. J. *and 2 more*

34 2020ApJ...905..179K 2020/12 cited: 3
On the Existence of Shear-current Effects in Magnetized Burgulence
Käpylä, Maarit J.; Vizoso, Javier Álvarez; Rheinhardt, Matthias *and 2 more*

35 2020MNRAS.498.4230R 2020/11 cited: 9
The Lagrangian hydrodynamics code MAGMA2
Rosswog, S.

36 2020ApJ...903..148L 2020/11 cited: 2
Dust Growth by Accretion of Molecules in Supersonic Interstellar Turbulence
Li, Xiang-Yu; Mattsson, Lars

37 2020arXiv201202064O 2020/10
Chaotic transients and hysteresis in an α^2 dynamo model
Oliveira, Dalton N.; Rempel, Erico L.; Chertovskih, Roman *and 1 more*

38 2020arXiv201007046B 2020/10
Turbulent radiative diffusion and turbulent Newtonian cooling
Brandenburg, Axel; Das, Upasana

39 2020PhRvD.102h3512R 2020/10 cited: 38
Numerical simulations of gravitational waves from early-universe turbulence
Roper Pol, Alberto; Mandal, Sayan; Brandenburg, Axel *and 2 more*

40 2020JPhCS1640a2005G 2020/10
The Supercomputing Simulation of Instability and Shock Waves in Gas Giant
Gornova, Alisa; Kulikov, Igor; Chernykh, Igor

41 2020DPS....5210301H 2020/10
Vortex Dynamics in the Polar Atmosphere of Jupiter
Hyder, A.; Lyra, W.; Chanover, N. *and 2 more*

42 2020A&A...642A..66W 2020/10 cited: 4
Rotational dependence of turbulent transport coefficients in global convective simulations of solar-like stars
Warnecke, J.; Käpylä, M. J.

43 2020ApJ...901...54K 2020/09 cited: 20
Turbulence Sets the Length Scale for Planetesimal Formation: Local 2D Sim Streaming Instability and Planetesimal Formation
Klahr, Hubert; Schreiber, Andreas

44 2020ApJ...901...18B 2020/09 cited: 1
Hall Cascade with Fractional Magnetic Helicity in Neutron Star Crusts
Brandenburg, Axel

45 2020zndo...3961647A 2020/08 cited: 2
Pencil Code
Axel Brandenburg, on behalf of the Pencil Code Collaboration

46 2020MNRAS.496.4749B 2020/08 cited: 2
Application of a helicity proxy to edge-on galaxies
Brandenburg, Axel; Furuya, Ray S.

47 2020ApJ...898..112P 2020/08 cited: 1
Negative Magnetic Diffusivity β Replacing the α Effect in the Helical Dynamo
Park, Kiwan

48 2020zndo...3466444B 2020/07 cited: 1
Scientific usage of the Pencil Code
Brandenburg, Axel

49 2020PhRvD.102b3536B 2020/07 cited: 5
Primordial magnetic helicity evolution with a homogeneous magnetic field fro
Brandenburg, Axel; Durrer, Ruth; Huang, Yiwen *and 3 more*

50 2020ApJ...898...60R 2020/07 cited: 4
A Simple, Entropy-based Dissipation Trigger for SPH
Rosswog, S.

51 2020JPlPh..86c9018R 2020/06
Electrodynamics of turbulent fluids with fluctuating electric conductivity
Rüdiger, G.; Küker, M.; Käpylä, P. J.

52 2020ApJ...896L..14B 2020/06 cited: 2
Hemispheric Handedness in the Galactic Synchrotron Polarization Foreground
Brandenburg, Axel; Brüggen, Marcus

53 2020ApJ...896...86C 2020/06 cited: 1
Stabilizing Effect of Magnetic Helicity on Magnetic Cavities in the Intergalactic Medium
Candelaresi, Simon; Del Sordo, Fabio

54 2020ApJ...895...91G 2020/06 cited: 16
Requirements for Gravitational Collapse in Planetesimal Formation—The Impact of Scal by Kelvin-Helmholtz and Nonlinear Streaming Instability
Gerbig, Konstantin; Murray-Clay, Ruth A.; Klahr, Hubert *and 1 more*

55 2020PhRvD.101j3028S 2020/05 cited: 6
Generation of chiral asymmetry via helical magnetic fields
Schober, Jennifer; Fujita, Tomohiro; Durrer, Ruth

56 2020MNRAS.494.1180G 2020/05 cited: 2
On the spatial and temporal non-locality of dynamo mean-field effects in supersonic inte turbulence
Gressel, Oliver; Elstner, Detlef

57 2020PhRvF...5d3702S 2020/04 cited: 10
Saturation mechanism of the fluctuation dynamo at $Pr_M \geq 1$
Seta, Amit; Bushby, Paul J.; Shukurov, Anvar *and 1 more*

58 2020ApJ...892..106M 2020/04 cited: 4
Exploring Bistability in the Cycles of the Solar Dynamo through Global Simulations
Matilsky, Loren I.; Toomre, Juri

59 2020ApJ...892...80B 2020/04 cited: 5
The Turbulent Stress Spectrum in the Inertial and Subinertial Ranges
Brandenburg, Axel; Boldyrev, Stanislav

60 2020arXiv200307997S 2020/03
On the saturation mechanism of the fluctuation dynamo at $\mathrm{Pr}_M \geq 1$
Seta, Amit; Bushby, Paul J.; Shukurov, Anvar *and 1 more*

80-32+1 = 49 papers of 2020

61 ☐ 2020PhRvE.101c3102B 2020/03
Statistics of relative velocity for particles settling under gravity in a turbulent flow
Bhatnagar, Akshay

62 ☐ 2020IAUGA..30..295K 2020/03 cited: 3
Magnetism in the Early Universe
Kahniashvili, Tina; Brandenburg, Axel; Kosowsky, Arthur *and 2 more*

63 ☐ 2020GApFD.114..235B 2020/03 cited: 3
Driving solar coronal MHD simulations on high-performance computers
Bourdin, Philippe-A.

64 ☐ 2020GApFD.114..213C 2020/03 cited: 4
Testing Alfvén wave propagation in a "realistic" set-up of the solar atmosphere
Chatterjee, Piyali

65 ☐ 2020GApFD.114..162B 2020/03 cited: 2
The time step constraint in radiation hydrodynamics
Brandenburg, Axel; Das, Upasana

66 ☐ 2020GApFD.114..130R 2020/03 cited: 9
The timestep constraint in solving the gravitational wave equations sourced by hydromagnetic turbulence
Roper Pol, Alberto; Brandenburg, Axel; Kahniashvili, Tina *and 2 more*

67 ☐ 2020GApFD.114...77G 2020/03 cited: 5
Modelling supernova-driven turbulence
Gent, F. A.; Mac Low, M. -M.; Käpylä, M. J. *and 2 more*

68 ☐ 2020GApFD.114...58Q 2020/03 cited: 1
Convergence properties of detonation simulations
Qian, Chengeng; Wang, Cheng; Liu, JianNan *and 3 more*

69 ☐ 2020GApFD.114...35A 2020/03 cited: 4
Treatment of solid objects in the Pencil Code using an immersed boundary method and overset grids
Aarnes, Jørgen R.; Jin, Tai; Mao, Chaoli *and 3 more*

70 ☐ 2020GApFD.114....8K 2020/03 cited: 7
Sensitivity to luminosity, centrifugal force, and boundary conditions in spherical shell convection
Käpylä, P. J.; Gent, F. A.; Olspert, N. *and 2 more*

71 ☐ 2020A&A...635A.110E 2020/03 cited: 12
Pebble drift and planetesimal formation in protoplanetary discs with embedded planets
Eriksson, Linn E. J.; Johansen, Anders; Liu, Beibei

72 ☐ 2020arXiv200203638B 2020/02 cited: 4
Piecewise quadratic growth during the 2019 novel coronavirus epidemic
Brandenburg, Axel

73 ☐ 2020MNRAS.491.4702Y 2020/02 cited: 5
Morphological signatures induced by dust back reaction in discs with an embedded planet
Yang, Chao-Chin; Zhu, Zhaohuan

74 ☐ 2020JPlPh..86a9010B 2020/02 cited: 1
The nature of mean-field generation in three classes of optimal dynamos
Brandenburg, Axel; Chen, Long

75 ☐ 2020MNRAS.491.1043N 2020/01 cited: 5
Magnetohydrodynamical origin of eclipsing time variations in post-common-envelope binaries for solar mass secondaries
Navarrete, Felipe H.; Schleicher, Dominik R. G.; Käpylä, Petri J. *and 3 more*

76 ☐ 2020JAtS...77..337L 2020/01 cited: 3
Condensational and Collisional Growth of Cloud Droplets in a Turbulent Environment
Li, Xiang-Yu; Brandenburg, Axel; Svensson, Gunilla *and 3 more*

77 ☐ 2020IAUS..354...65G 2020 cited: 1
Global simulations of stellar dynamos
Guerrero, G.

78 ☐ 2020ApJ...889...55B 2020/01 cited: 1
Magnetic Helicity Dissipation and Production in an Ideal MHD Code
Brandenburg, Axel; Scannapieco, Evan

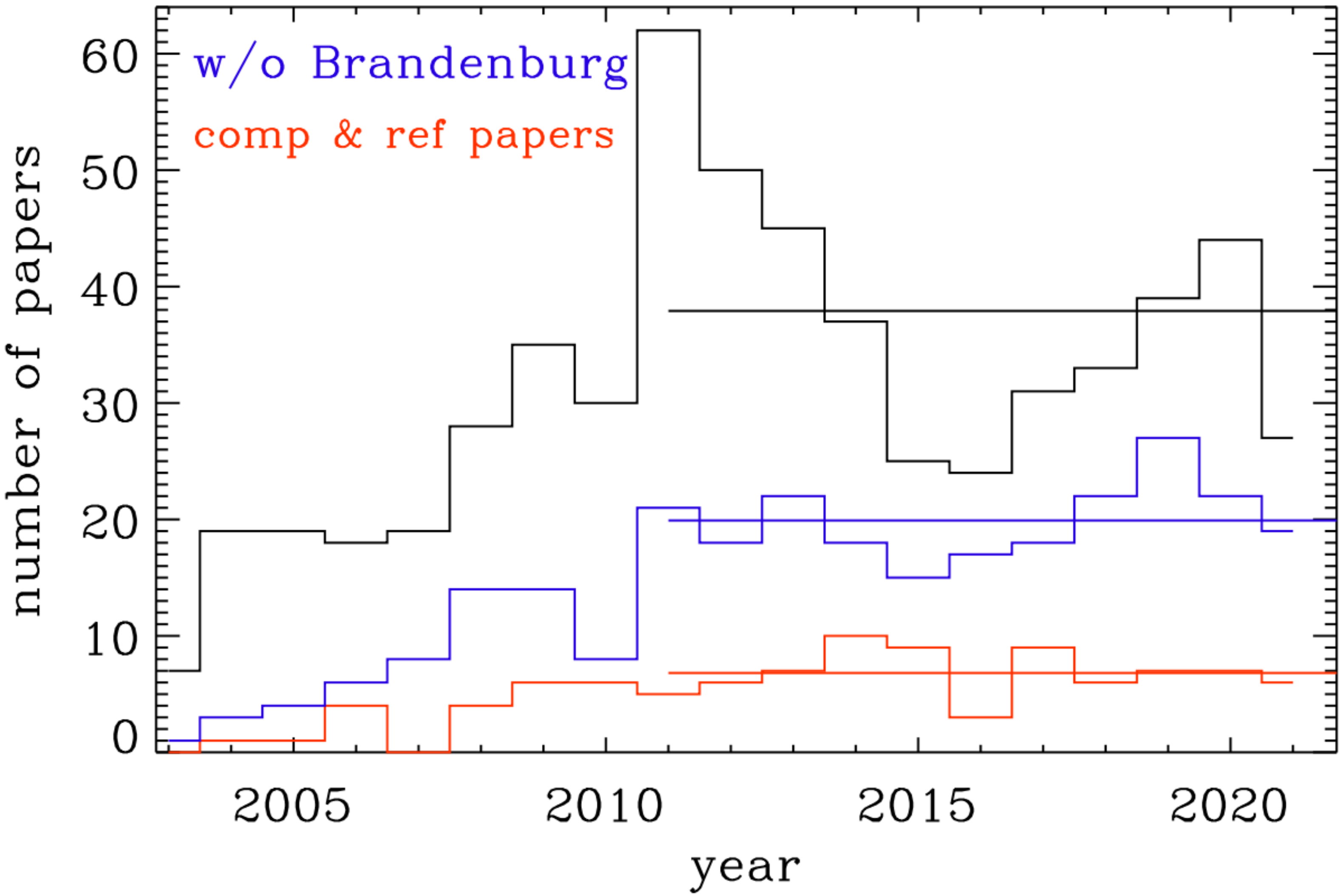
79 ☐ 2020AAS...23530422H 2020/01
Simulating the Orbital Evolution of a Black Hole Embedded in an Active Galactic Nucleus Disk
Hernandez, B.; Mac Low, M.; Goodman, J. *and 3 more*

80 ☐ 2020A&A...633A.113A 2020/01 cited: 7
3D numerical simulations of oscillations in solar prominences
Adrover-González, A.; Terradas, J.

81 ☐ 2019MNRAS.490.5788M 2019/12 cited: 6
Small-scale clustering of nano-dust grains in supersonic turbulence
Mattsson, L.; Fynbo, J. P. U.; Villarroel, B.

Steady over last 10 years

- Not all references use the code in their paper
- 38 papers/year use Pencil Code
- Plus 7 paper/year quote Pencil Code for comparison
- 20 papers/year of the 38 are without myself
- Range 15-27/year



As of May 2021, the PENCIL CODE *has been used for a total of 592 research papers; see Figure 1; 277 of those are papers (47%) are not co-authored by Brandenburg. In addition, 97 papers reference it for code comparison or other purposes (see the red line).*

1 ☐ 2021arXiv210506042L 2021/05

Thresholds for Particle Clumping by the Streaming Instability

Li, Rixin; Youdin, Andrew

2 ☐ 2021arXiv210501539H 2021/05

Spectral characterisation of inertial particle clustering in turbulence

Haugen, N. E. L.; Brandenburg, A.; Sandin, C. *and 1 more*

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Inferring magnetic helicity spectrum in spherical domains: the method and example applications

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10 ☐ 2021A&A...648A..52L 2021/04 cited: 3

Coagulation of inertial particles in supersonic turbulence

Li, Xiang-Yu; Mattsson, Lars

Both C15 and Y17 used (different versions of) the `Pencil` code, while we use `ATHENA`. A detailed code comparison test (which is not our goal) would be needed to attribute any differences to the algorithms, and we note that both codes have been extensively tested. Nevertheless, this study motivates specific tests of non-linear SI convergence for a range of codes.

All our past simulations (Schreiber & Klahr 2018; Klahr & Schreiber 2020) as well as those in the present paper have been performed with the Pencil Code (Brandenburg 2001), which solves for the gas density ρ_g with a finite difference version of the following set of equations in the shearing sheet approximation

Brandenburg, A. 2001, ApJ, 550, 824, doi: 10.1086/319783

Johansen, A., & Bitsch, B. 2019, A&A, 631, A70, doi: 10.1051/0004-6361/201936351

Johansen, A., Henning, T., & Klahr, H. 2006a, ApJ, 643, 1219

Johansen, A., Klahr, H., & Henning, T. 2006b, ApJ, 636, 1121

Johansen, A., Mac Low, M.-M., Lacerda, P., & Bizzarro, M. 2015, Science Advances, 1, 1500109, doi: 10.1126/sciadv.1500109

Johansen, A., Oishi, J. S., Mac Low, M.-M., et al. 2007, Nature, 448, 1022, doi: 10.1038/nature06086

Johansen, A., & Youdin, A. 2007, ApJ, 662, 627

Johansen, A., Youdin, A., & Mac Low, M.-M. 2009, ApJ, 704, L75, doi: 10.1088/0004-637X/704/2/L75

However, all simulations in Klahr & Schreiber (2020) were two-dimensional and radial and vertical diffusion are known to have unequal relative strengths if driven by the SI (Johansen & Youdin 2007; Schreiber & Klahr 2018). Thus, in the present paper, we study the SI in a three dimensional box, measure radial and vertical diffusion and then switch on self-gravity to check for gravitational collapse for different total mass content (pebbles plus gas) in the box.

11 2021arXiv210317238B 2021/03 cited: 1

PySDM v1: particle-based cloud modelling package for warm-rain microphysics and aqueous chemistry

Bartman, Piotr; Arabas, Sylwester; Górski, Kamil *and 5 more*

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Brandenburg, Axel; Clarke, Emma; He, Yutong *and 1 more*

Selected relevant recent open-source developments

The SDM algorithm implementations are part of the following open-source packages (of otherwise largely differing functionality):

- `libcloudph++` in C++ (Arabas et al., 2015; Jaruga & Pawlowska, 2018) with Python bindings (Jarecka et al., 2015);
- `SCALE-SDM` in Fortran, (Sato et al., 2018);
- `PALM LES` in Fortran, (Maronga et al., 2020);
- `LCM1D` in Python/C, (Unterstrasser et al., 2020);
- `Pencil Code` in Fortran, (Brandenburg et al., 2021);
- `NTLP` in Fortran, (Richter et al., 2021).
- `superdroplet` in Python (`Cython` and `Numba`), C++, Fortran and Julia (https://github.com/darothen/superdroplet);

List of links directing to SDM-related files within the above projects' repositories is included in the `PySDM` README file.

Python packages for solving the dynamics of aerosol particles with discrete-particle (moving-sectional) representation of the size spectrum include (both depend on the `Assimulo` package for solving ODEs):

- `pyrcel`, (Rothenberg & Wang, 2017);
- `PyBox`, (Topping et al., 2018).

11 ☐ 2021arXiv210317238B 2021/03 cited: 1

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Pebble trapping in vortices: three-dimensional simulations

Raettig, Natalie; Lyra, Wladimir; Klahr, Hubert

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Pekkilä, Johannes; Väisälä, Miikka S.; Käpylä, Maarit J. *and 2 more*

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Baehr, Hans; Zhu, Zhaohuan

19 ☐ 2021A&A...647A..18J 2021/03

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Jakab, P.; Brandenburg, A.

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Can we observe the QCD phase transition-generated gravitational waves through pulsar timing arrays?

Brandenburg, Axel; Clarke, Emma; He, Yutong *and 1 more*

B. Bangalore DNS database

The DNS data were computed adopting the Pencil code.[66] A computational domain of $19.18 \times 4.8 \times 4.8$ mm^3 was discretized using a uniform mesh of $960 \times 240 \times 240$ nodes.

A lean (the equivalence ratio $\Phi = 0.81$) and slightly preheated ($T_u = 310$ K) hydrogen–air flame was studied using a detailed reaction mechanism (9 species and 21 reactions) by Li *et al.*[67] and mixture-averaged transport coefficients, which depended on temperature. The simulation conditions (flame IIS in the third line in Table I, where IIS is an abbreviation of Indian Institute of Science) are associated with the thin reaction zone regime[65] of turbulent burning.

As discussed in detail elsewhere,[56,57] results reported in the following were averaged over transverse planes and various instants (54 snapshots stored, each 5 μs over the time period 1.401 ms $\leq t \leq$ 1.566 ms).

65N. Peters, "The turbulent burning velocity for large-scale and small-scale turbulence," J. Fluid Mech. **384**, 107 (1999).

66N. Babkovskaia, N. E. L. Haugen, and A. Brandenburg, "A high-order public domain code for direct numerical simulations of turbulent combustion," J. Comput. Phys. **230**, 1 (2011).

67J. Li, Z. Zhao, A. Kazakov, and F. L. Dryer, "An updated comprehensive kinetic model of hydrogen combustion," Int. J. Chem. Kinet. **36**, 566 (2004).

21 2021arXiv210211110N 2021/02 cited: 1

Origin of eclipsing time variations: contributions of different modes of the dynamo-generated magnetic field

Navarrete, Felipe H.; Käpylä, Petri J.; Schleicher, Dominik R. G. *and 2 more*

22 2021arXiv210203500P 2021/02

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Park, Kiwan; Cheoun, Myung-Ki

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Hunting down the cause of solar magnetism

Viviani, M.; Prabhu, A.; Warnecke, J. *and 4 more*

24 2021arXiv210200982Z 2021/02 cited: 1

Stellar X-rays and magnetic activity in 3D MHD coronal models

Zhuleku, J.; Warnecke, J.; Peter, H.

25 2021PhRvR...3a3193K 2021/02 cited: 3

Circular polarization of gravitational waves from early-Universe helical turbulence

Kahniashvili, Tina; Brandenburg, Axel; Gogoberidze, Grigol *and 2 more*

26 2021MNRAS.501.3074B 2021/02 cited: 2

Inverse energy transfer in decaying, three-dimensional, non-helical magnetic turbulence due to magnetic reconnection

Bhat, Pallavi; Zhou, Muni; Loureiro, Nuno F.

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Streaming instability with multiple dust species - I. Favourable conditions for the linear growth

Zhu, Zhaohuan; Yang, Chao-Chin

28 2021JOSS....6.2807P 2021/02 cited: 17

The Pencil Code, a modular MPI code for partial differential equations and particles: multipurpose and multiuser-maintained

Pencil Code Collaboration; Brandenburg, Axel; Johansen, Anders *and 35 more*

29 2021ApJ...907...83V 2021/02 cited: 1

Interaction of Large- and Small-scale Dynamos in Isotropic Turbulent Flows from GPU-accelerated Simulations

Väisälä, Miikka S.; Pekkilä, Johannes; Käpylä, Maarit J. *and 3 more*

30 2021arXiv210108749B 2021/01

Numerical Study of Trailing and Leading Vortex Dynamics in a Forced Jet with Coflow

Bhatia, Bharat; De, Ashoke

2. Numerical Methodology

2.1. Governing equations and solver details

The Pencil code[20], an open source code is invoked and modified as per our needs to solve the fully compressible conservation equations of mass, momentum, and energy, which are recast as:

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Pencil: Finite-difference Code for Compressible Hydrodynamic Flows

Show affiliations

Brandenburg, Axel; Dobler, Wolfgang

The Pencil code is a high-order finite-difference code for compressible hydrodynamic flows with magnetic fields. It is highly modular and can easily be adapted to different types of problems. The code runs efficiently under MPI on massively parallel shared- or distributed-memory computers, like e.g. large Beowulf clusters. The Pencil code is primarily designed to deal with weakly compressible turbulent flows. To achieve good parallelization, explicit (as opposed to compact) finite differences are used. Typical scientific targets include driven MHD turbulence in a periodic box, convection in a slab with non-periodic upper and lower boundaries, a convective star embedded in a fully nonperiodic box, accretion disc turbulence in the shearing sheet approximation, self-gravity, non-local radiation transfer, dust particle evolution with feedback on the gas, etc. A range of artificial viscosity and diffusion schemes can be invoked to deal with supersonic flows. For direct simulations regular viscosity and diffusion is being used. The code is written in well-commented Fortran90.

Publication:	Astrophysics Source Code Library, record ascl:1010.060
Pub Date:	October 2010
Bibcode:	2010ascl.soft10060B
Keywords:	Software

31 ☐ 2021ApJ...907...43H 2021/01

A Proper Discretization of Hydrodynamic Equations in Cylindrical Coordinates for /
Simulations

Hanawa, Tomoyuki; Matsumoto, Yosuke

32 ☐ 2021A&A...645A.141V 2021/01 cited: 2

Physically motivated heat-conduction treatment in simulations of solar-like stars: e
dynamo transitions

Viviani, M.; Käpylä, M. J.

33 ☐ 2020arXiv201206343B 2020/12

Generation of mean flows in rotating anisotropic turbulence: The case of solar nea
shear layer

Barekat, A.; Käpylä, M. J.; Käpylä, P. J. *and 2 more*

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On the Existence of Shear-current Effects in Magnetized Burgulence

Käpylä, Maarit J.; Vizoso, Javier Álvarez; Rheinhardt, Matthias *and 2 more*

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The Lagrangian hydrodynamics code MAGMA2

Rosswog, S.

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Dust Growth by Accretion of Molecules in Supersonic Interstellar Turbulence

Li, Xiang-Yu; Mattsson, Lars

37 ☐ 2020arXiv201202064O 2020/10

Chaotic transients and hysteresis in an α^2 dynamo model

Oliveira, Dalton N.; Rempel, Erico L.; Chertovskih, Roman *and 1 more*

38 ☐ 2020arXiv201007046B 2020/10

Turbulent radiative diffusion and turbulent Newtonian cooling

Brandenburg, Axel; Das, Upasana

39 ☐ 2020PhRvD.102h3512R 2020/10 cited: 38

Numerical simulations of gravitational waves from early-universe turbulence

Roper Pol, Alberto; Mandal, Sayan; Brandenburg, Axel *and 2 more*

40 ☐ 2020JPhCS1640a2005G 2020/10

The Supercomputing Simulation of Instability and Shock Waves in Gas Giant

Gornova, Alisa; Kulikov, Igor; Chernykh, Igor

P, and $\boldsymbol{v}$ in order to save extra computational cost for computing wave amplitudes. This simple and easy method works in the Cartesian coordinates but may not in the cylindrical coordinates. In the latter, a part of the changes in the radial and azimuthal components of the velocity may be ascribed to those in the unit vector. Such changes are eliminated in the covariant derivative (see, e.g. Mitra et al. 2009). We should use the covariant derivative to check the monotonicity of the velocity. This procedure is implemented in the Pencil Code (Pencil 2018). As noted in Mitra et al. (2009) and the manual of the Pencil Code, we should also use the covariant derivative of the magnetic field in the MHD to exclude the change because of the curvature of the coordinates. The velocity and magnetic field in the local Cartesian grid are easier to compute than the covariant derivative; yet, the accuracy is of a higher order.

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A Proper Discretization of Hydrodynamic Equations in Cylindrical Coordinates for A Simulations

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Oliveira, Dalton N.; Rempel, Erico L.; Chertovskih, Roman *and 1 more*

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Roper Pol, Alberto; Mandal, Sayan; Brandenburg, Axel *and 2 more*

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The Supercomputing Simulation of Instability and Shock Waves in Gas Giant

Gornova, Alisa; Kulikov, Igor; Chernykh, Igor

1. Introduction

For the last twenty years, from a wide range of hydrodynamic methods two main approaches have been used for non-stationary solutions of astrophysical problems. They are the Lagrangian SPH method [1, 2] (Smoothed Particle Hydrodynamics) and Eulerian methods within adaptive meshes, or AMR [3] (Adaptive Mesh Refinement). On the basis of the SPH method the following simulation packages were developed: Hydra [4], Gasoline [5], GrapeSPH [6], GADGET [7]. With the Eulerian methods (in some case with adaptive mesh refinement) the following packages were implemented: NIRVANA [8], FLASH [9], ZEUS [10], ENZO [3], RAMSES [11], ART [12], Athena [13], Pencil Code [14], Heracles [15], Orion [16], Pluto [17], CASTRO [18], GAMER [19]. The packages BETHE-Hydro [20], AREPO [21], CHIMERA [22], GIZMO [23] and PEGAS/GPUPEGAS/AstroPhi [24, 25, 26] are implemented using a combination of Eulerian and Lagrangian methods.

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Hyder, A.; Lyra, W.; Chanover, N. *and 2 more*

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Rotational dependence of turbulent transport coefficients in global convective dynamo simulations of solar-like stars

Warnecke, J.; Käpylä, M. J.

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Turbulence Sets the Length Scale for Planetesimal Formation: Local 2D Simulations of Streaming Instability and Planetesimal Formation

Klahr, Hubert; Schreiber, Andreas

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Hall Cascade with Fractional Magnetic Helicity in Neutron Star Crusts

Brandenburg, Axel

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Pencil Code

Axel Brandenburg, on behalf of the Pencil Code Collaboration

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Application of a helicity proxy to edge-on galaxies

Brandenburg, Axel; Furuya, Ray S.

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Negative Magnetic Diffusivity β Replacing the α Effect in the Helical Dynamo

Park, Kiwan

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Scientific usage of the Pencil Code

Brandenburg, Axel

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Primordial magnetic helicity evolution with a homogeneous magnetic field from inflation

Brandenburg, Axel; Durrer, Ruth; Huang, Yiwen *and 3 more*

50 ☐ 2020ApJ...898...60R 2020/07 cited: 4

A Simple, Entropy-based Dissipation Trigger for SPH

Rosswog, S.

Software and Data Availability. The source code used for the simulations of this study, the PENCIL CODE (Brandenburg & Dobler 2010), is freely available on https://github.com/pencil-code/. The DOI of the code is https://doi.org/10.5281/zenodo.3961647 (Brandenburg 2020b). The simulation setup and the corresponding data are freely available on https://doi.org/10.5281/zenodo.3951873 (Brandenburg 2020a).

Software and Data Availability. The source code used for the simulations of this study, the PENCIL CODE (Pencil Code Collaboration et al. 2021), is freely available on https://github.com/pencil-code/. The doi of the code is 10.5281/zenodo.2315093 (Brandenburg 2018). The simulation setup and the corresponding data are freely available from doi:10.5281/zenodo.4448211, see also http://www.nordita.org/~brandenb/projects/GWfromCME/ for easier access.

The Astrophysical Journal, 898:60 (14pp), 2020 July 20 Rosswog

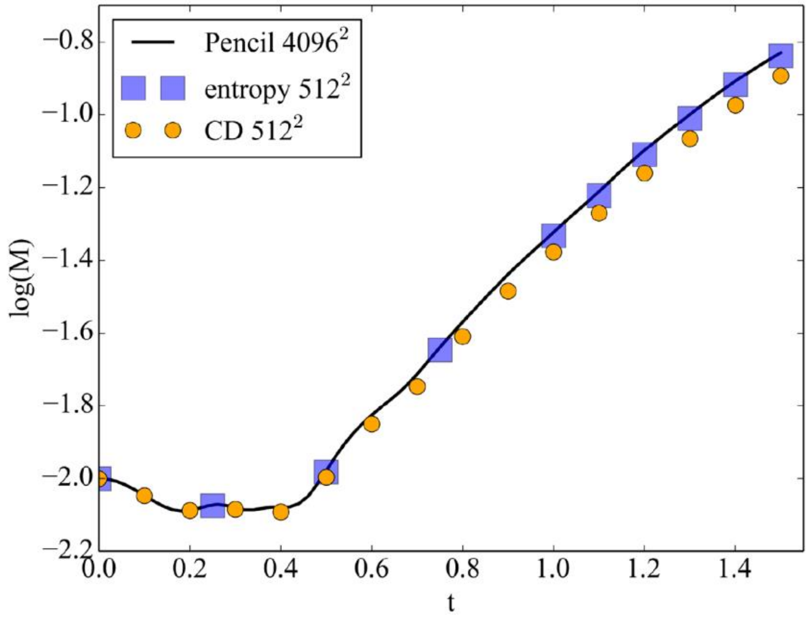

Figure 11. Kelvin–Helmholtz rate calculated as in McNally et al. (2012). The growth rate with the suggested entropy trigger is shown as blue squares ("entropy"), with the $d(\nabla \cdot v)/dt$ -trigger as orange ("CD"). As reference solution we take a high resolution (4096^2 grid cells) simulation from the Pencil code.

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Hemispheric Handedness in the Galactic Synchrotron Polarization Foreground

Brandenburg, Axel; Brüggen, Marcus

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Stabilizing Effect of Magnetic Helicity on Magnetic Cavities in the Intergalactic Medium

Candelaresi, Simon; Del Sordo, Fabio

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Requirements for Gravitational Collapse in Planetesimal Formation—The Impact of Scales Set by Kelvin-Helmholtz and Nonlinear Streaming Instability

Gerbig, Konstantin; Murray-Clay, Ruth A.; Klahr, Hubert *and 1 more*

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Generation of chiral asymmetry via helical magnetic fields

Schober, Jennifer; Fujita, Tomohiro; Durrer, Ruth

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On the spatial and temporal non-locality of dynamo mean-field effects in supersonic interstellar turbulence

Gressel, Oliver; Elstner, Detlef

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Saturation mechanism of the fluctuation dynamo at $\mathrm{Pr_M} \geq 1$

Seta, Amit; Bushby, Paul J.; Shukurov, Anvar *and 1 more*

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Exploring Bistability in the Cycles of the Solar Dynamo through Global Simulations

Matilsky, Loren I.; Toomre, Juri

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The Turbulent Stress Spectrum in the Inertial and Subinertial Ranges

Brandenburg, Axel; Boldyrev, Stanislav

60 2020arXiv200307997S 2020/03

On the saturation mechanism of the fluctuation dynamo at $\mathrm{Pr_M} \geq 1$

Seta, Amit; Bushby, Paul J.; Shukurov, Anvar *and 1 more*

II. BASIC EQUATIONS AND NUMERICAL MODELLING

To study the fluctuation dynamo action in a turbulent flow driven by a prescribed random force, we solve the equations of magnetohydrodynamics, using the Pencil code [53]. The computational domain is a triply periodic cubic box of nondimensional width $L = 2\pi$, with 256^3 or 512^3 grid points. The equations are solved with sixth-order finite differences in space and a third-order Runge–Kutta scheme for the temporal evolution. The governing equations are

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0, \tag{1}$$

$$\frac{\partial \mathbf{b}}{\partial t} = \nabla \times (\mathbf{u} \times \mathbf{b}) + \eta \nabla^2 \mathbf{b}, \tag{2}$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\frac{\nabla p}{\rho} + \frac{\mathbf{j} \times \mathbf{b}}{c\rho} + \nu\left(\nabla^2 \mathbf{u} + \frac{1}{3}\nabla(\nabla \cdot \mathbf{u}) + 2\mathbf{S} \cdot \nabla \ln \rho\right) + \mathbf{F}, \tag{3}$$

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Astronomy & Astrophysics

3D numerical simulations of oscillations in solar prominences

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ABSTRACT

Context. Oscillations in solar prominences are a frequent phenomenon, and they have been the subject of many studies. A full understanding of the mechanisms that drive them and their attenuation has not been reached yet, however.
Aims. We numerically investigate the periodicity and damping of transverse and longitudinal oscillations in a 3D model of a curtain-shaped prominence.
Methods. We carried out a set of numerical simulations of vertical, transverse and longitudinal oscillations with the high-order finite-difference Pencil Code. We solved the ideal magnetohydrodynamic equations for a wide range of parameters, including the width (w_x) and density (ρ_{p0}) of the prominence, and the magnetic field strength (B) of the solar corona. We studied the periodicity and attenuation of the induced oscillations.
Results. We found that longitudinal oscillations can be fit with the pendulum model, whose restoring force is the field-aligned component of gravity, but other mechanisms such as pressure gradients may contribute to the movement. On the other hand, transverse oscillations are subject to magnetic forces. The analysis of the parametric survey shows, in agreement with observational studies, that the oscillation period (P) increases with the prominence width. For transverse oscillations we obtained that P increases with density and decreases with B. For longitudinal oscillations we also found that P increases with ρ_{p0}, but there are no variations with B. The attenuation of transverse oscillations was investigated by analysing the velocity distribution and computing the Alfvén continuum modes. We conclude that resonant absorption is the mean cause. Damping of longitudinal oscillations is due to some kind of shear numerical viscosity.
Conclusions. Our model is a good approximation of a prominence body that nearly reproduces the observed oscillations. However, more realistic simulations that include other terms such as non-adiabatic processes or partially ionised plasmas are necessary to obtain better results.

Key words. Sun: filaments, prominences – Sun: oscillations – methods: numerical

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Yang, Chao-Chin; Zhu, Zhaohuan

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The nature of mean-field generation in three classes of optimal dynamos
Brandenburg, Axel; Chen, Long

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Magnetohydrodynamical origin of eclipsing time variations in post-common-envelope binaries for solar mass secondaries
Navarrete, Felipe H.; Schleicher, Dominik R. G.; Käpylä, Petri J. *and 3 more*

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Condensational and Collisional Growth of Cloud Droplets in a Turbulent Environment
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Brandenburg, Axel; Scannapieco, Evan

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Simulating the Orbital Evolution of a Black Hole Embedded in an Active Galactic Nucleus Disk
Hernandez, B.; Mac Low, M.; Goodman, J. *and 3 more*

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3D numerical simulations of oscillations in solar prominences
Adrover-González, A.; Terradas, J.

81 2019MNRAS.490.5788M 2019/12 cited: 6
Small-scale clustering of nano-dust grains in supersonic turbulence
Mattsson, L.; Fynbo, J. P. U.; Villarroel, B.

The code we used to solve the MHD equations is the Pencil Code[1]. It is a publicly available model that uses sixth-order finite-difference schemes. High-order derivative schemes, such as the one used in the Pencil Code, reduce the numerical dissipation, but to obtain consistency in numerical solutions, the code needs small amounts of diffusion to damp out the modes near the Nyquist frequency (Brandenburg 2003). For this reason we introduced a simplified second-order hyperviscosity term (see Haugen & Brandenburg 2004) and a shock viscosity term at the equation of motion. We did not use artificial viscosity in the other equations. The hyperviscosity is proportional to a diffusion coefficient. This coefficient should be as small as possible but sufficient to reduce the wiggles in the results. In addition, to avoid wiggles, we used fifth-order upwind derivatives for the advection terms $\boldsymbol{u}\cdot\nabla\ln\rho$ and $\boldsymbol{u}\cdot\nabla s$. The time step is a third-order Runge–Kutta scheme.

The Pencil Code uses three layers of ghost points to implement boundary conditions. In this work, closed boundary conditions were applied (see Terradas et al. 2016). This means that line-tying conditions were imposed at all the boundaries of the computational box. A line-tying boundary condition sets the three components of the velocity to 0, the normal component of the magnetic field is kept constant, and the density and entropy variables have their spatial derivatives be null. This condition imposed at the bottom boundary is crucial to mimic the purely reflecting conditions of the photosphere and to obtain the magnetic support. Because the Pencil Code uses the magnetic vector potential instead of the magnetic field, to fix the magnetic component perpendicular to the boundary, we applied to the three components of $\mathbf{A}$ the condition of antisymmetry relative to the boundary value that vanishes the second derivative of $\mathbf{A}$. The numerical domain consists of a box of $180 \times 144 \times 90$ mesh points. The dimensions of the box are 100 Mm in the x-direction, 80 Mm in the y-direction, and 50 Mm in the vertical component. In this way, we imposed an equidistant grid of 556 km.

[1] http://pencil-code.nordita.org/

Unknown connections

- Well-known for helicity studies

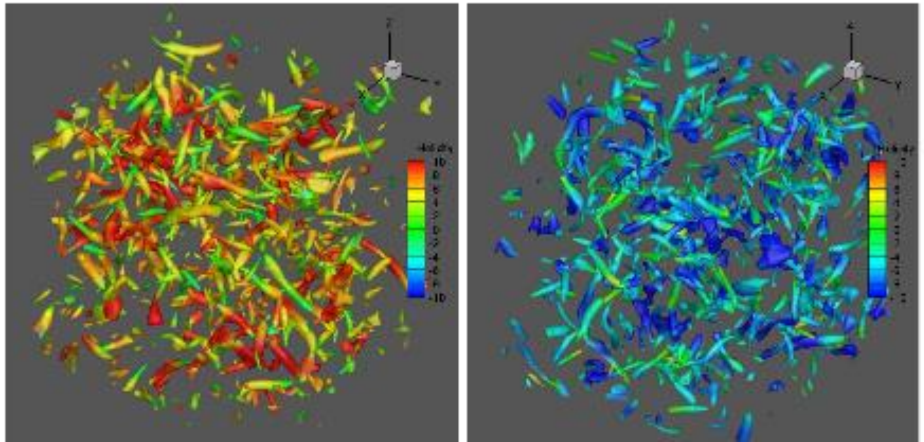
We based our helical and non-helical compressible turbulence analyses on a set of well-controlled direct numerical simulations with periodic boundary conditions. Two programs, the Pencil Code and the OpenCFD, known (the former already worldwide[15] and the latter mainly in China[16], so far) respectively in the astrophysics and aerodynamics communities, have been used for tests. Helicity controlling techniques, with or without helicity injection, say, have been well-developed, as partly already implemented in typical incompressible and compressible turbulence simulation open-source softwares[17]. The discretization grid numbers used are up to 1024^3, and for statistical steady state statisitcs, long time integrations up to 5 large-eddy turnover times were performed. Such typical 'massive' simulations resolve reasonably well into the details of flow structures, with visibly separated energy-containing, inertial, bottleneck and dissipation regimes in the power

LETTER

Helicity hardens the gas

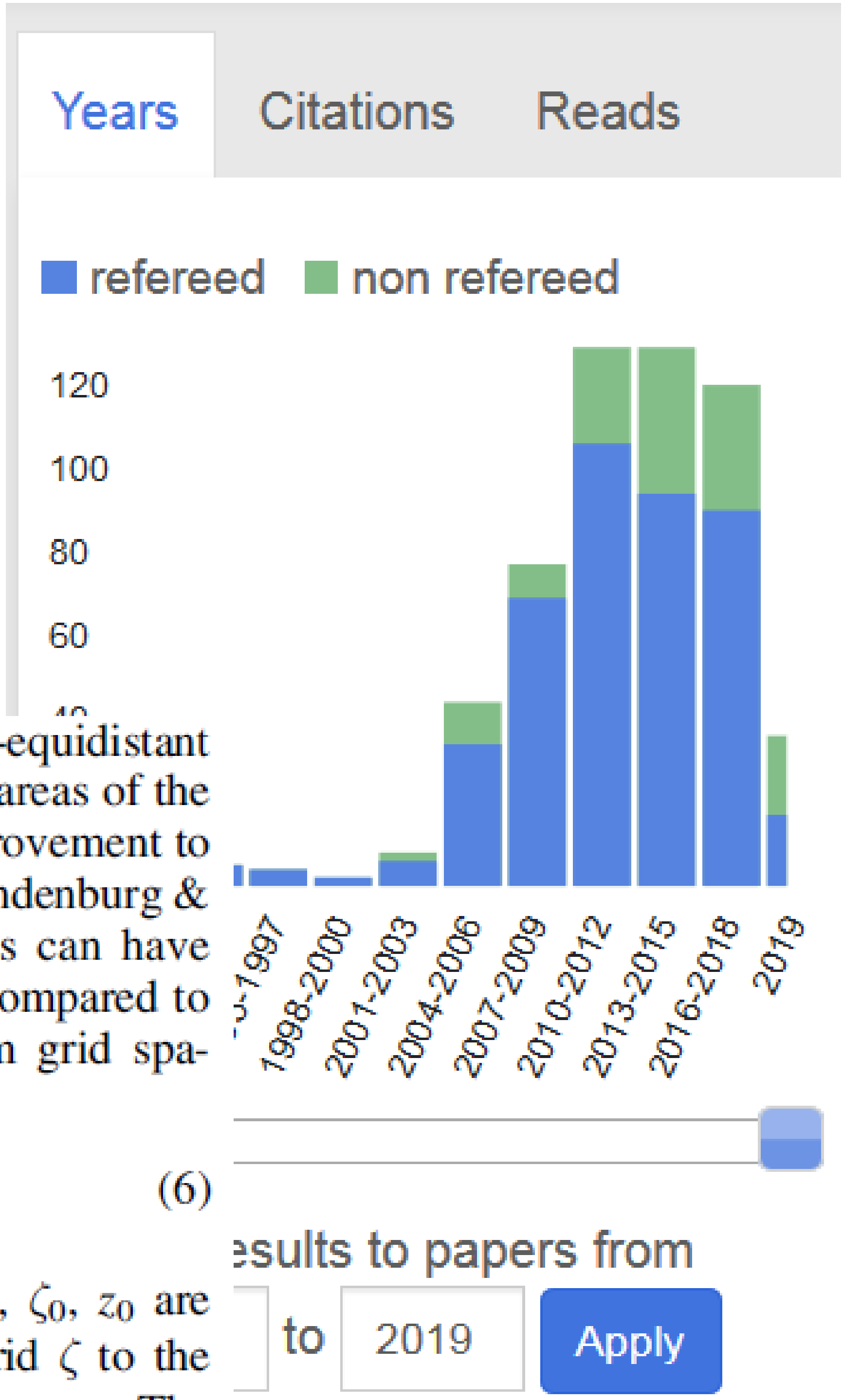
Jun Peng[1,2,*], Jin-Xiu Xu[3], Yan Yang[1,2,*] & Jian-Zhou Zhu[2]

A screw generally works better than a nail, or a complicated rope knot better than a simple one, in fastening solid matter, while a gas is more tameless. However, a flow itself has a physical quantity, helicity, measuring the screwing strength of the velocity field and the degree of the knottedness of the vorticity ropes. It is shown that helicity favors the partition of energy to the vortical modes, compared to others such as the dilatation and pressure modes of turbulence; that is, helicity stiffens the flow, with nontrivial implications for aerodynamics, such as aeroacoustics, and conducting fluids, among others.



ADS: full"Pencil Code"

- Pencil Code philosophy as inspiration to others
- Here just one example



The code has also been enhanced to use non-equidistant grids to allow for increased resolution in particular areas of the Milky Way, in this case around Geminga. This improvement to GALPROP is inspired by the the Pencil Code[5] (Brandenburg & Dobler 2002), where the use of analytic functions can have advantages in terms of speed and memory usage compared to purely numerical implementations for non-uniform grid spacing. The current run uses the grid function

$$z(\zeta) = \frac{\epsilon}{a} \tan\left[a(\zeta - \zeta_0)\right] + z_0 \qquad (6)$$

for all spatial coordinates $\zeta = x, y, z$, where ϵ, a, ζ_0, z_0 are parameters. This function maps from the linear grid ζ to the

Pencil Code Mile Stones

- 2004 First User Meeting
  - Annually since then
- 2016 Steering Committee
- 2020 Special Issue in GAFD
- 2020 Newletter
  - 4 newsletters since then
- 2020 Office hours
  - 4 since then
- NAG test results
- JOSS paper

The Journal of Open Source Software

The Pencil Code, a modular MPI code for partial differential equations and particles: multipurpose and multiuser-maintained

The Pencil Code Collaboration[1], **Axel Brandenburg**[1, 2, 3], **Anders Johansen**[4], **Philippe A. Bourdin**[5, 6], **Wolfgang Dobler**[7], **Wladimir Lyra**[8], **Matthias Rheinhardt**[9], **Sven Bingert**[10], **Nils Erland L. Haugen**[11, 12, 1], **Antony Mee**[13], **Frederick Gent**[9, 14], **Natalia Babkovskaia**[15], **Chao-Chin Yang**[16], **Tobias Heinemann**[17], **Boris Dintrans**[18], **Dhrubaditya Mitra**[1], **Simon Candelaresi**[19], **Jörn Warnecke**[20], **Petri J. Käpylä**[21], **Andreas Schreiber**[15], **Piyali Chatterjee**[22], **Maarit J. Käpylä**[9, 20], **Xiang-Yu Li**[1], **Jonas Krüger**[11, 12], **Jørgen R. Aarnes**[12], **Graeme R. Sarson**[14], **Jeffrey S. Oishi**[23], **Jennifer Schober**[24], **Raphaël Plasson**[25], **Christer Sandin**[1], **Ewa Karchniwy**[12, 26], **Luiz Felippe S. Rodrigues**[14, 27], **Alexander Hubbard**[28], **Gustavo Guerrero**[29], **Andrew Snodin**[14], **Illa R. Losada**[1], **Johannes Pekkilä**[9], **and Chengeng Qian**[30]

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Software

- Review
- Repository
- Archive

Editor: Arfon Smith

Reviewers:

- @zingale
- @rtfisher

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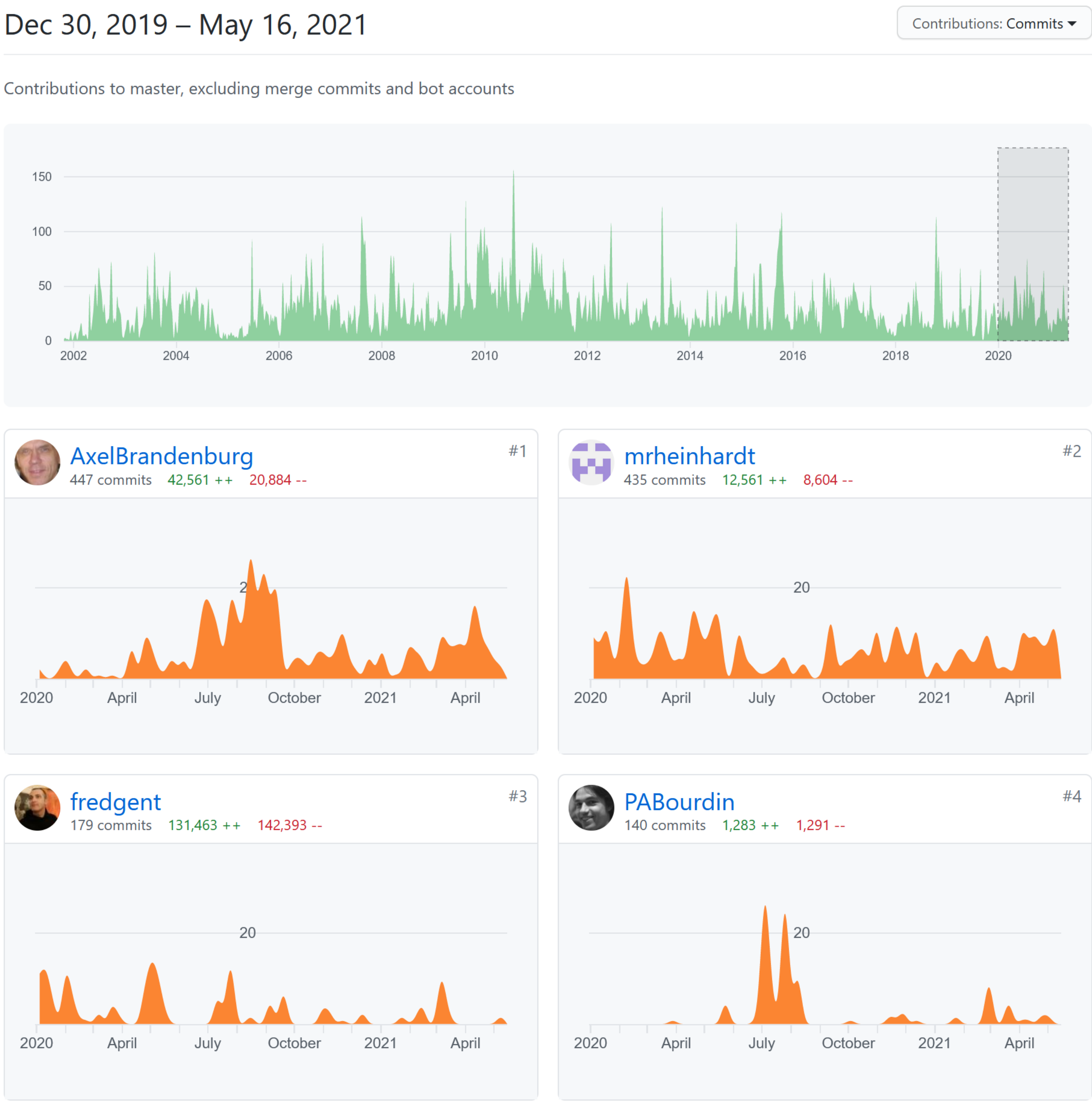
Summary

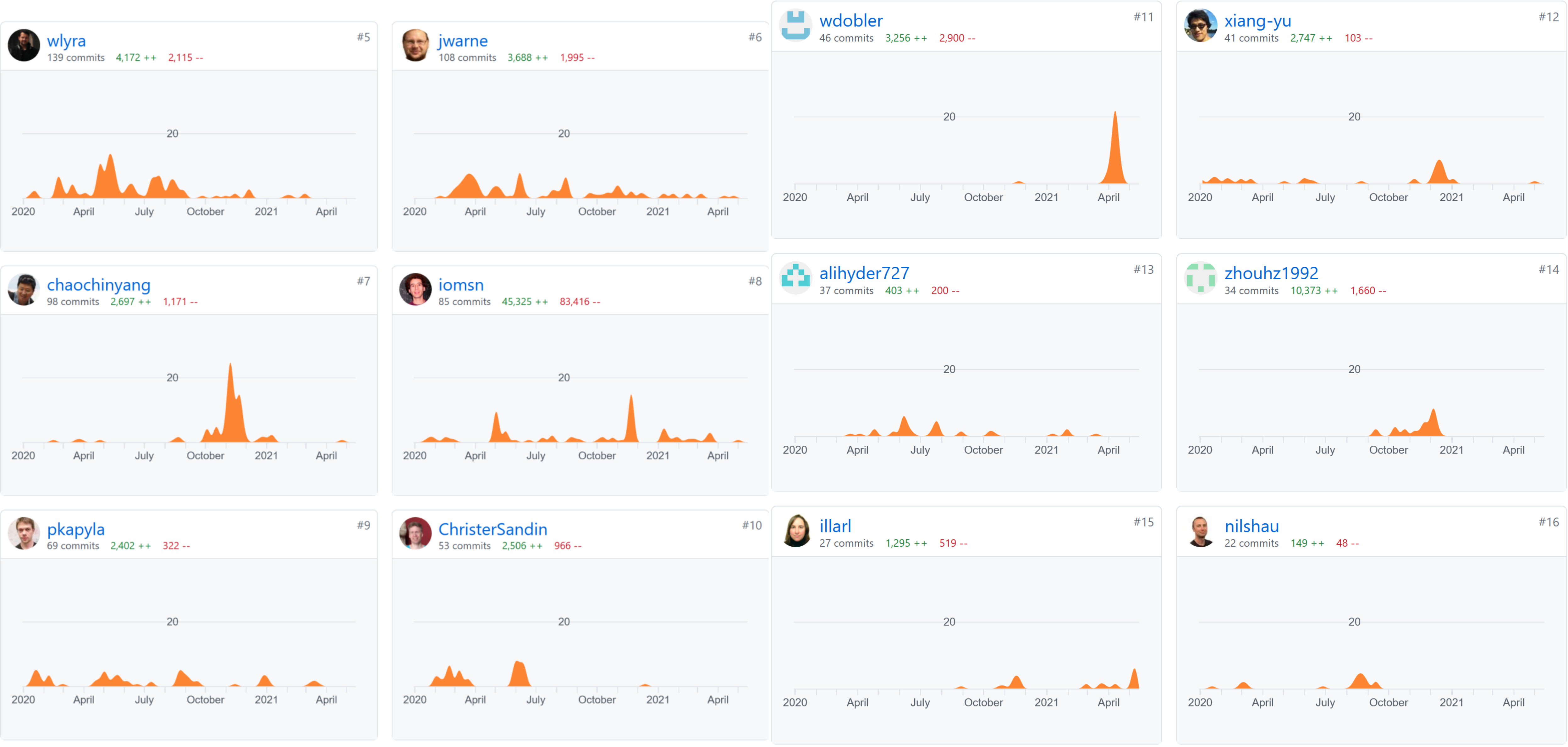
The Pencil Code is a highly modular physics-oriented simulation code that can be adapted to a wide range of applications. It is primarily designed to solve partial differential equations (PDEs) of compressible hydrodynamics and has lots of add-ons ranging from astrophysical magnetohydrodynamics (MHD) (A. Brandenburg & Dobler, 2010) to meteorological cloud microphysics (Li et al., 2017) and engineering applications in combustion (Babkovskaia et al., 2011). Nevertheless, the framework is general and can also be applied to situations not related to hydrodynamics or even PDEs, for example when just the message passing interface or input/output strategies of the code are to be used. The code can also evolve Lagrangian (inertial and noninertial) particles, their coagulation and condensation, as well as their interaction with the fluid. A related module has also been adapted to perform ray tracing

Coding activity since 2020 alone

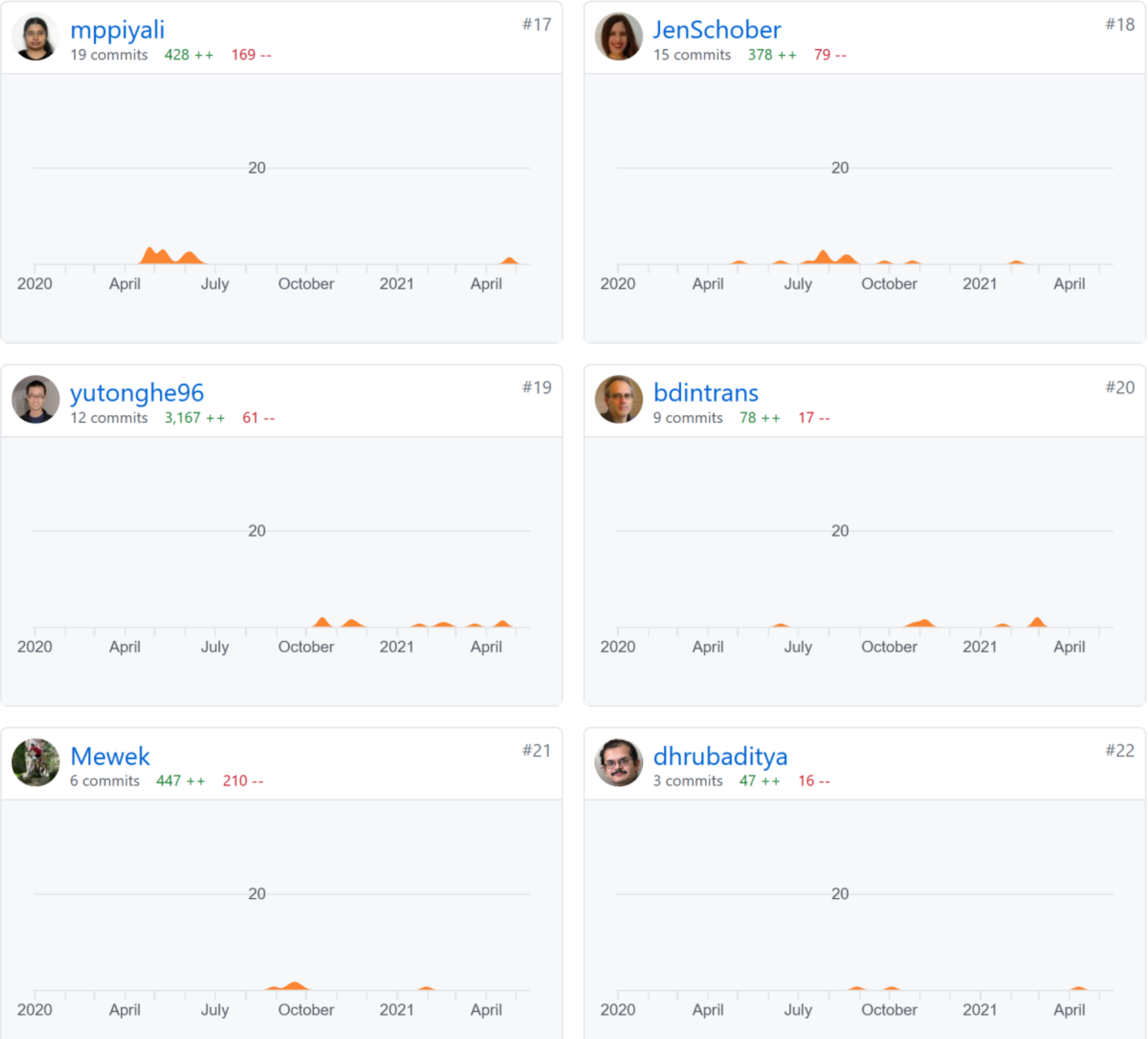
- Can select any interval on the GitHub site
- Can look for particular changes in temporal order

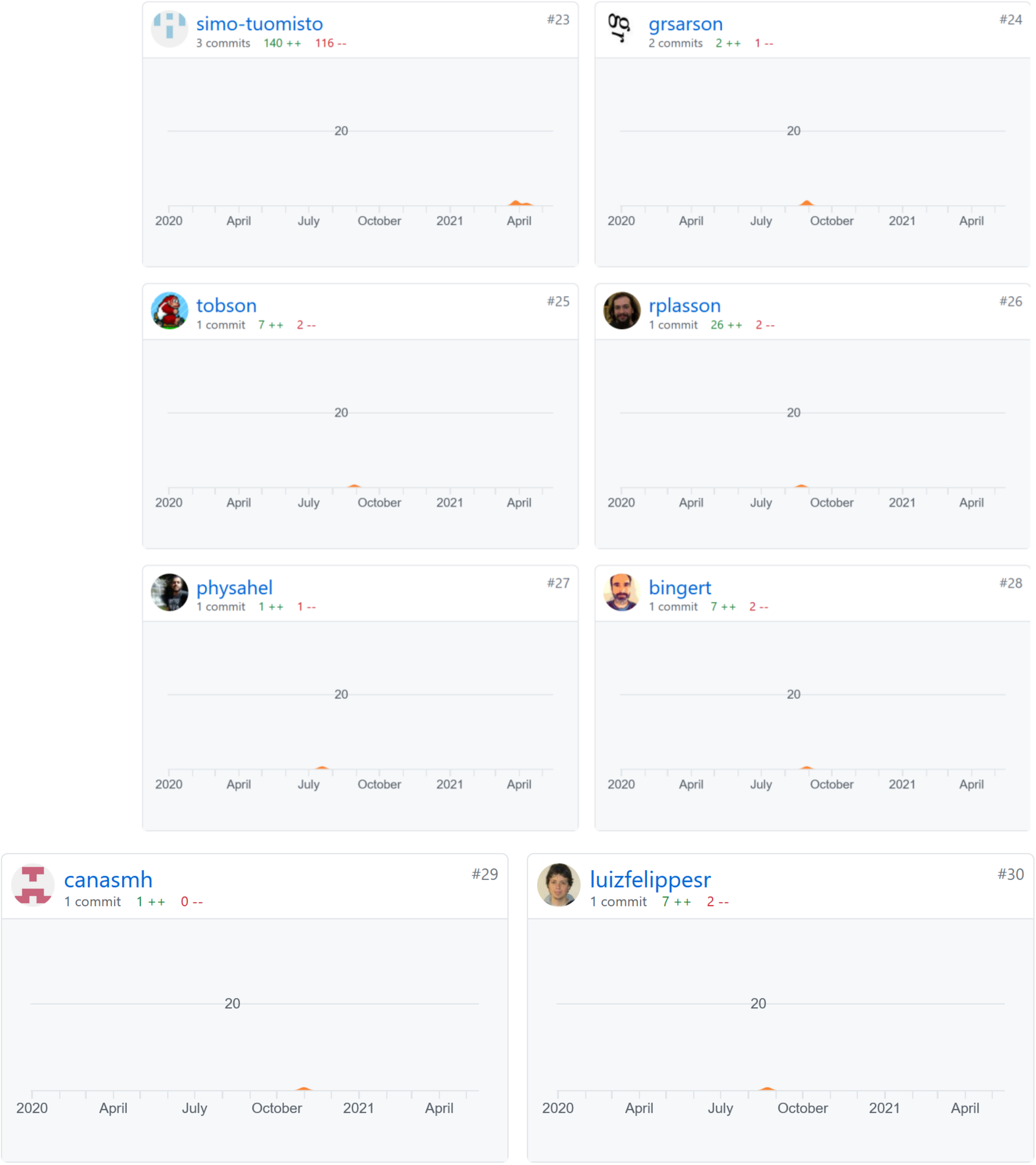


Sustained activity



H index of 17 since 2020





Public code

- Completely open: can one be scooped?
  - No evidence for this
- All intermediate developments transparent
  - Can trace mistakes, their source, and their consequences
  - No major problems encountered yet
- Bad papers can give negative feedback
  - Not really a concern

Usefulness of this code

- Fills a specific niche
- Maybe not useful for all purpose
- Now 20^{th} anniversary
- Main goal, to my mind, is to produce science
- Office hours can help new people to get help
- Nearly 20 owners: little hubs
- Users also do science w/o doing changes to the code

Significance

- You are not alone
  - Whatever you code, think of the others
- Backward compatibility
  - Don’t change default behavior of the code
  - Be very thoughtful if you do
- Prepare item for Newsletter about changes
  - Otherwise people would not know

Purpose of Meeting

- Understand what is going on
- New development
- Do changes that would otherwise not be done
- Examples: magnetic/meanfield, entropy, output
- New examples: spectral output from first time step

Run directories related to some past research projects

Isotropic homogeneous MHD turbulence

- Inverse transfer in non-helical MHD
- Classes of hydrodynamic and MHD decay
- The turbulent chiral - magnetic cascade in the early universe
- Dynamo effect in decaying helical t

Interstellar medium: cooling insta

- Thermal instability
- Random expansion waves
- Supersonic turbulence

Convection, ionization, & radiatior

- Cartesian convection with Kramers
- 1-D simulations with hydrogen ioni:
- The time step constraint in radiatic

Two-scale method of measuring magnetic helicity

- Large-scale helicity spectra

Coagulation

- Coagulation & condensation in turbulent flows
- Effect of turbulence on collisional growth of cloud droplets
- Cloud droplet growth due to supersaturation fluctuations in stratiform clouds

Miscellanea

- Spreading layer on neutron stars
- Test-field method for computing dynamo coefficients
- Strong nonlocality variations in a spherical mean-field dynamo
- Negative effective magnetic pressure instability
- Surface flux concentrations in a spherical α^2 dynamo

Other data

- Spectral magnetic helicity of solar active regions between 2006 and 2017

(last access: 16 December 2018) The DOI of the code is https://doi.org/10.5281/zenodo.2315093. The DNS setup and the corresponding data (Li et al., 2019) are freely available at https://doi.org/10.5281/zenodo.2538027.

The Pencil Code Newsletter

Issue 2020/1

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Contents

1 Preamble

During the June 2020 meeting of the Pencil Code Steering Committee (PCSC) it was decided that the

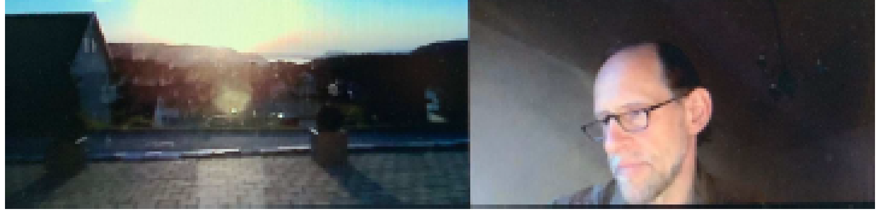

Figure 1: Axel's screenshot at the end of the PCSC meeting showing the view from Nils' window (Trondheim, Norway) and Matthias on the right on skype.

ing (PCUM) in Glasgow during 27–31 July 2020. If you forget the link, you can just say `pc_news` to get the link, which is `http://indico.fysik.su.se/event/6870/`; see Figure 2.

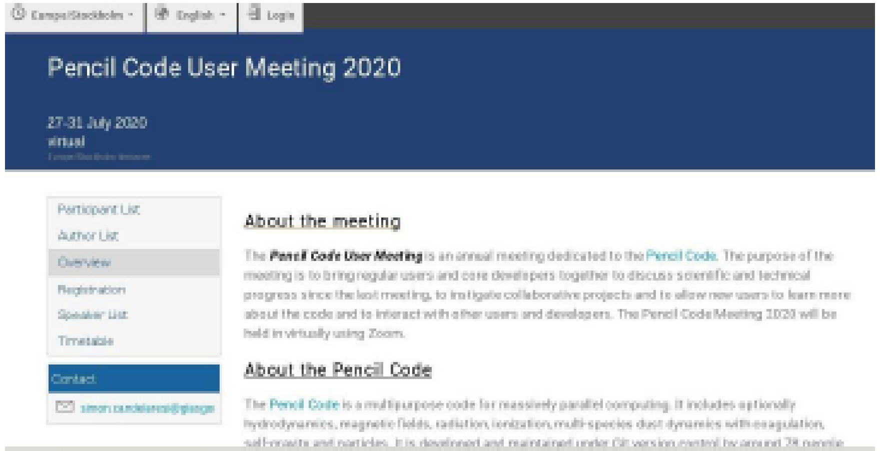

Figure 2: Web page where you can register for the meeting. Please register, even if you want to participate only in a few sessions.

Where in 20 years?

- Will the code still be used?
- By others than ourselves?
- Is our samples still up to the task?
- Usage of code/data DOI
- Other thoughts?

Conclusions

- This is the 17th User Meeting
- Much more to develop
- Thanks to Jennifer for organizing this meeting!
- And thanks to all for the collaboration
- I’m enjoying working with the code tremendously!
- Its great fun!
- It was a good decision in 2001 to go public