Online Advanced Study Program on Helicities in Astrophysics and Beyond

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Abstract booklet

2020-09-25 13:00:00

Speaker: David MacTaggart

Authors: David MacTaggart, Chris Prior

Magnetic winding – a key to unlocking topological complexity in flux emergence

The solar atmosphere is composed of highly complex magnetic field structures. It has long been appreciated that the topological complexity of these magnetic fields is fundamental to the dynamics of the solar atmosphere. Magnetic helicity, an invariant of ideal magnetohydrodynamics that combines information on magnetic flux with the underlying field line topology, is the main quantity that is currently used to study topological complexity in the solar atmosphere. In this talk, we show that the underlying topological description of open magnetic fields (and their helicity) can be described in terms of magnetic field line winding, similar to the role of Gauss linkage for closed magnetic fields. We describe how helicity and winding are related and give examples of how they behave differently. In particular, for examples of flux emergence, we show that magnetic winding can detect topological complexity in magnetic fields much more clearly than helicity. We will conclude by arguing that magnetic winding flux should be measured in observations together with helicity flux, in order to provide a much more complete picture of the topology of emerging magnetic fields. For extra or preparatory reading, the following papers are recommended, preprints of which can be found at http://www.maths.gla.ac.uk/~dmactaggart/publications.html
Magnetic winding - a key to unlocking topological complexity in flux emergence (J. Phys. Conf. Ser.)
Magnetic winding: what is it and what is it good for? (Proc. Roy. Soc. A)
Helicity and winding fluxes as indicators of twisted flux emergence (Geophys. Astrophys. Fluid Dyn.)
Interpreting magnetic helicity flux in solar flux emergence (J. Plasma Phys.)

2020-09-25 14:00:00

Speaker: J. K. Thalmann

Authors: J. K. Thalmann, L. Linan, K. Moraitis, X. Sun, E. Pariat, G. Valori, M. Gupta, K. Dalmasse

Magnetic helicity as indicator for solar eruptivity

A full understanding of the physics behind explosive solar phenomena is, to date, still missing. Related research still searches for reliable indicators of upcoming flare activity and also for the respective potential to evolve into a coronal mass ejection. The latter is essential for any attempt to predict the induced Space Weather on Earth. Until present, no single observation- or model-based parameter has been singled out as a promising candidate to unambiguously characterize the flaring potential of solar

active regions, yet a helicity-based parameter attracted recent attention. The so-called helicity ratio quantifies the fraction of non-potential magnetic helicity in the active-region corona associated to present intense electric currents. It can be shown that indeed, the helicity ratio marks the eruptive potential of solar active regions. The relative success using this quantity, however, strongly depends on the quality of the underlying 3D nonlinear force-free coronal magnetic field model, based on real observations. In particular, we find distinctly different characteristic pre-flare levels of the helicity ratio prior to eruptive and confined flares. The helicity ratio appears to be insensitive for the magnitude of an upcoming flare, though it reflects a response timely related to the occurrence of eruptive flares, representing the signature of the ejection of magnetized plasma carrying strong electric currents from the active-region corona via an associated coronal mass ejection.
Related publications:
Thalmann, J. K., et al., ApJ, 880, L6, 2019 (arXiv:1907.01179);
Thalmann, J. K., et al., ApJ, 887, 64, 2019 (arXiv:1910.06563);
Thalmann, J. K., et al., accepted for publication in A&A, 2020 (arXiv:2009.05287)

2020-10-16 13:00:00

Speaker: Philippa Browning

Authors: Philippa Browning

Helicity-conserving relaxation in unstable and merging twisted magnetic flux ropes

According to Taylor (1974), a magnetised plasma undergoing turbulent reconnection relaxes towards minimum magnetic energy state, conserving magnetic helicity. I will present an overview of some advances in modelling helicity-conserving relaxation of twisted magnetic flux ropes, in which relaxation is triggered by onset of the ideal kink instability or through the merger of multiple flux ropes. The work focuses on explaining how solar flares are triggered and accelerate charged particles to high energies, and how the solar corona is heated to high temperatures, but applications to laboratory plasmas will also be mentioned. Reconnection in kink-unstable flux ropes leads to plasma heating and particle acceleration as the magnetic field relaxes to a field well approximated by a Taylor state. Building on idealised models of relaxation in cylindrical flux ropes, a more realistic model of an unstable twisted coronal loop can be developed, representing a confined solar flare. 3D MHD simulations show that an avalanche of heating events in stable twisted flux ropes may be triggered by instability of a single unstable flux rope. The energy release predicted by a relaxation model agrees well with these simulations, and a similar model describes flux rope merger in a spherical tokamak device.

2020-10-30 13:45:00

Speaker: Maxim Dvornikov

Authors: Maxim Dvornikov

Magnetic helicity in rotating neutron stars consisting of electroweakly interacting inhomogeneous matter

We study chiral fermions electroweakly interacting with a background matter having the nonuniform density and the velocity arbitrarily depending on coordinates. The dynamics of this system is described approximately by finding the Berry phase. The effective action and the kinetic equations for right and left particles are derived. In the case of a rotating matter, we obtain the correction to the anomalous

electric current and to the Adler anomaly. Then we study some astrophysical applications. Assuming that the chiral imbalance in a rotating neutron star vanishes, we obtain the rate of the magnetic helicity change owing to the interaction of chiral electrons with background neutrons. The characteristic time of the helicity change turns out to coincide with the period of the magnetic cycle of some pulsars.
Reference: Nuclear Physics B vol. 955, p. 115049 (2020)

2020-10-08 13:00:00

Speaker: Anthony Yeates

Authors: Anthony Yeates

Does a potential magnetic field contain helicity?

Potential field (current-free) extrapolations are widely used as minimum-energy models for the Sun's coronal magnetic field. They are often thought of as helicity free, being the reference field with respect to which the commonly-used "relative helicity" is measured. But if we consider the global solar atmosphere, the relative helicity does not give a complete description of the magnetic topology. Indeed, I will show that even potential fields can contain local concentrations of magnetic helicity, when the latter is defined in a meaningful sense. I will illustrate how this "minimal" helicity is distributed in space and time over the solar cycle. For more see
A.R. Yeates, The minimal helicity of solar coronal magnetic fields, ApJ Letters 898, L49, 2020
https://iopscience.iop.org/article/10.3847/2041-8213/aba762
or https://arxiv.org/abs/2007.10649.

2020-10-16 14:00:00

Speaker: Fabio Del Sordo

Authors: Simon Candelaresi and Fabio Del Sordo

The stabilizing effect of helical magnetic fields on intergalactic cavities

We investigate the effect of magnetic helicity on the stability of buoyant magnetic cavities as found in the intergalactic medium. In these cavities we insert helical magnetic fields and test whether or not helicity can increase their stability to shredding through the Kelvin-Helmholtz instability and, with that, their lifetime. This is compared to the case of an external vertical magnetic field that is known to reduce the growth rate of the Kelvin-Helmholtz instability. By comparing a low-helicity configuration with a high-helicity one with the same magnetic energy, we find that an internal helical magnetic field stabilizes the cavity. This effect increases as we increase the helicity content. Stabilizing the cavity with an external magnetic field requires instead a significantly stronger field at higher magnetic energy. We conclude that the presence of helical magnetic fields is a viable mechanism to explain the stability of intergalactic cavities on timescales longer than 100 Myr.
Reference: https://iopscience.iop.org/article/10.3847/1538-4357/ab8dc0

2020-10-08 14:00:00

Speaker: Franck Plunian

Authors: Franck Plunian, Andrei Teimurazov, Rodion Stepanov, Mahendra K. Verma

Inverse cascade of energy in helical turbulence

Using direct numerical simulation of hydrodynamic turbulence with helicity forcing applied at all scales, a near-maximum helical turbulent state is obtained, with an inverse energy cascade at scales larger than the energy forcing scale and a forward helicity cascade at scales smaller than the energy forcing scale. In contrast to previous studies using decimated triads, our simulations contain all possible triads. By computing the shell-to-shell energy fluxes, we show that the inverse energy cascade results from weakly non-local interactions among homochiral triads. Varying the helicity injection range of scales leads to necessary conditions to obtain an inverse energy cascade.

2020-11-05 13:00:00

Speaker: Christopher Prior

Authors: Christopher Prior, Zack Sierzega and Jeff Wereszczynski

Using writhing to characterise DNA topology (with a little help from solar physics).

The buckling/writhing/kinking of a twisted tube is a phenomenon crucial in solar physics, e.g CME's and solar flaring, and on a vastly different scale in DNA supercoiling experiments. Both phenomena occur when a sufficiently twisted tube deforms in order to shed this entanglement, the degree of twisting which can be shed is controlled by a quantity called the writhing. As I will explain this quantity is far more important in DNA modelling than solar physics applications, but the mathematical tools to correctly characterise it were actually developed in a solar physics context. I have spent the last year co-authoring a paper which politely makes this point to the DNA community. To be constructive I have also co-authored a python package (WASP) to correctly calculate it. I will introduce the (correct) writhe measure through instructive examples and then demonstrate how it can be applied to numerical DNA experiments to highlight writhing can characterize the effect of various extraneous molecules on the DNA molecule's topology. If time permits I will also introduce the exciting topic of writhe fingerprinting and how it can be used to help predict protein structure. An introduction to protein structure fingerprinting is given in https://pubs.acs.org/doi/abs/10.1021/acs.jctc.9b01010 The results to be reported in the talk are given in this paper https://www.biorxiv.org/content/10.1101/2020.09.17.301309v1

2020-10-30 13:00:00

Speaker: Semikoz Victor

Authors: Semikoz V.B., Sokoloff D.D.

Effects of P-noninvariance in the magnetic field generation of the celestial bodies

We study generation of magnetic fields in MHD modified in relativistic plasmas when accounting for Abelian anomalies arising in the Standard Model (SM) of particle physics. In particular, this approach is relevant to MHD applications in a hot plasma of the early Universe, or a degenerate ultra-relativistic electron gas in supernovae as the progenitors of neutron stars as well. A special case is the possibility for generation of primordial magnetic fields (PMF) by the relic neutrino-antineutrino asymmetry, $n_{\ u} - n_{\\bar{\ u}}$, which arises through the same anomalies in SM and obeys the well-known upper bound from the Big Bang Nucleosynthesis. The P and CP symmetries as the main rules in the quantum electrodynamics (QED) both in vacuum and plasma, manage MHD helicity parameter which, in its turn, is responsible for the PMF instability in QED plasma.

1) V.B. Semikoz and D.D. Sokoloff, "Large -scale magnetic field generation by alpha-effect driven by collective neutrino -plasma interaction", Phys.Rev.Lett. 92 (2004) 131301 [arXive:astro-ph/0312567].
2) V.B. Semikoz and D.D. Sokoloff, "Large-scale cosmological magnetic fields and magnetic helicity", Int.J.Mod.Phys. D 14 (2005) 1839-1854 .
3) V.B. Semikoz, D.D. Sokoloff and J.W.F. Valle, "Is the baryon asymmetry of the Universe related to galactic magnetic fields?", Phys.Rev.D80 (2009) 083510 [arXive: 0905.3365 (hep-ph)].
4) P.M. Akhmet'ev, V.B. Semikoz and D.D. Sokoloff, "Flow of hypermagnetic helicity in the embryo of a new phase in the electroweak phase transition", Pisma Zh.Eksp.Teor.Fiz. 91 (2010) 233 [arXive:1002.4969 (astro-ph)].
5) V.B. Semikoz, D.D. Sokoloff and J.W.F. Valle, "Lepton asymmetries and primordial hypermagnetic helicity evolution" JCAP 1206 (2012) 008 [arXive: 1205.3607 (astro-ph)].
6) Maxim Dvornikov, V.B. Semikoz and D.D. Sokoloff., "Generation of strong magnetic fields in a nascent neutron star accounting for the chiral magnetic effect", Phys. Rev. D 101 (2020) 083009.

2020-11-05 14:00:00

Speaker: Simon Candelaresi

Authors: Simon Candelaresi, Gunnar Hornig

Magnetic helicity in periodic domains

While magnetic helicity is a well-defined quantity for fields that ar well confined within the domain, for fields with a net magnetic flux through the domain we show it is not well defined. This is linked to the fact that a magnetic vector potential A does not exist, s. t. curl(A) = B. We show case doubly and triply periodic domains and show that helicity can lead to fundamental contradictions. In one example we show that by a simple gauge transformation we can set the helicity to zero.

References:

M. A. Berger, J. Geophys. Res.-Space 102, 2637 (1996) DOI: 10.1029/96JA01896
E. Panagiotou, J. Comput. Phys. 300, 533 (2015) DOI: 10.1016/j.jcp.2015.07.05
P. G. Watson and I. J. D. Craig, J. Geophys. Res.-Space 106,15735 DOI: 10.1029/2000JA000418

2020-12-11 13:30:00

Speaker: Avishek Ranjan

Authors: Avishek Ranjan, P. A. Davidson, U. R. Christensen, J. Wicht

On the generation and segregation of kinetic helicity in geodynamo simulations

Kinetic helicity (referred to as helicity, hereafter) the inner product of velocity and vorticity, is considered an important ingredient for the maintenance of a dipolar magnetic field in the geodynamo. Outside the tangent cylinder-an imaginary cylinder which circumscribes the inner core—a spatial segregation of helicity has been observed in several simulations, being negative in the north and positive in the south. Such a segregation pattern is important for a dynamo that relies on the α-effect. However, the origin of this pattern in these simulations is poorly understood. In this paper, we use three strongly forced numerical dynamo solutions to study the various sources of helicity, including those due to buoyancy (H_T), Coriolis, Lorentz and viscous forces. We find a strong spatial correlation between the segregation pattern of helicity and H_T both in the instantaneous and the time-averaged results. Our results show that, outside the tangent cylinder, H_T is dominated by the product $-u_z\,\partial T/\partial\varphi$, where u_z is the vertical velocity component and T is the temperature perturbation. It is known that when inertial waves are launched from a localized buoyant anomaly, H_T takes the same sign as the local helicity. We conjecture that this is the reason for the spatial correlation between H_T and helicity in our simulation results. The flow in our simulations being strongly turbulent, this effect seems to be a statistical one and manifests itself most clearly in the averaged quantities.

Reference: A. Ranjan, P. A. Davidson, U. R. Christensen, J. Wicht, On the generation and segregation of helicity in geodynamo simulations, Geophys. J. Int. (2020) 221, 741–757, doi: 10.1093/gji/ggaa011

2020-12-17 14:00:00

Speaker: Teissier, J.-M.

Authors: Teissier J.-M., Müller, W.-C.

<u>Magnetic helicity inverse transfer in supersonic isothermal MHD turbulence</u>

Magnetic helicity is an ideal invariant of the magnetohydrodynamic (MHD) equations which exhibits an inverse transfer in spectral space. Up to the present day, its transport has been studied in direct numerical simulations only in incompressible or in subsonic or transonic flows. Inspired by typical values of the turbulent root mean square (RMS) Mach number in the interstellar medium, this work presents some aspects of the magnetic helicity inverse transfer in high Mach number isothermal compressible turbulence, with RMS Mach number up to the order of ten: 1) a clear Mach-number dependence of the spectral magnetic helicity scaling but an invariant scaling exponent of the co-spectrum of the Alfvén velocity and its curl, 2) the approximate validity of a dynamical balance relation found by incompressible turbulence closure theory, 3) a characteristic structuring of helically-decomposed nonlinear shell-to-shell fluxes that can be disentangled into different spectrally local and non-local transfer processes.

References:
J.-M. Teissier and W.-C. Müller, https://arxiv.org/abs/2009.09374 J.-M. Teissier and W.-C. Müller, Journal of Physics Conference Series 1623 J.-M. Teissier http://dx.doi.org/10.14279/depositonce-9439

2020-12-11 13:00:00

Speaker: Sung-Hong Park

Authors: Sung-Hong Park, Kanya Kusano, K. D. Leka

<u>Magnetic Helicity Flux across Solar Active Region Photospheres: Hemispheric Sign Preference in Solar Cycle 24</u>

A hemispheric preference in the dominant sign of magnetic helicity has been observed in numerous features in the solar atmosphere: i.e., left-handed/right-handed helicity in the northern/southern hemisphere. The relative importance of different physical processes which may contribute to the observed hemispheric sign preference (HSP) of magnetic helicity is still under debate. Here, we estimate magnetic helicity flux (dH/dt) across the photospheric surface for 4,802 samples of 1,105 unique active regions (ARs) that appeared over an 8-year period from 2010 to 2017 during solar cycle 24, using photospheric vector magnetic field observations by the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). The estimates of dH/dt show that 63% and 65% of the investigated AR samples in the northern and southern hemispheres, respectively, follow the HSP. We also find a trend that the HSP of dH/dt increases from ~50-60% up to ~70-80% as ARs (1) appear at the earlier inclining phase of the solar cycle or higher latitudes; (2) have larger values of |dH/dt|, the total unsigned magnetic flux, and the average plasma flow speed. These observational findings support the enhancement of the HSP mainly by the Coriolis force acting on a buoyantly rising and expanding flux tube through the turbulent convection zone. In addition, the differential rotation on the solar surface as well as the tachocline alpha-effect of flux-transport dynamo may reinforce the HSP for ARs at higher latitudes.

Reference:

Park et al. 2020, ApJ, 904, 6 https://iopscience.iop.org/article/10.3847/1538-4357/abbb93/epub https://arxiv.org/abs/2010.06134

2020-12-03 13:30:00

Speaker: Olga Khabarova

Authors: Olga Khabarova, Helmi Malova, Roman Kislov, Lev Zelenyi, Vladimir Obridko, Alexander Kharshiladze, and Vladimir Kuznetsov

<u>Polar magnetic tornadoes – the structures that connect the Sun and the heliosphere</u>

Recent studies of the solar wind properties far above the ecliptic plane have allowed finding long-lived structures of a tornado type bounded by strong conic current sheets (CCSs). Polar magnetic tornadoes are observed in solar minimum within polar coronal hole flows up to 2-3 AU as seen from the Ulysses spacecraft (Khabarova et al. ApJ, 2017). CCSs are more stable and easily distinguishable in the Southern heliosphere than in the Northern heliosphere, although their solar sources do not display big phenomenological differences. TKey features of CCSs are (i) the decreased solar wind speed, and (ii) the high plasma beta. Further investigations have shown that a polar magnetic tornado is rooted at the Sun as a neutral line and rotates faster than the surrounding coronal hole. Properties of the CCSs, possible physical mechanisms leading to their formation, and perspectives of future studies are discussed.

References:

Khabarova O.V., et al. 2017, High-latitude conic current sheets in the solar wind, The Astrophysical Journal, 836, 108, 1, https://doi.org/10.3847/1538-4357/836/1/108

2020-12-03 13:00:00

Speaker: Shin Toriumi

Authors: Toriumi, Shin

<u>Convective Flux Emergence Simulations of the Generation of Flare-prolific Active Regions</u>

It is known that massive solar flares are prone to occur in large-scale, complex-shaped, rapidly-evolving active regions. In this talk, we first summarize the key observational features of flaring active regions based on our Living Reviews article (Toriumi & Wang 2019). Then we introduce the recent efforts of our team to numerically model such active regions, especially on the series of state-of-the-art convective flux-emergence simulations with a very deep domain covering the whole convection zone (Toriumi & Hotta 2019). We discuss the importance of turbulent convection in generating the flare-prolific active regions.

Toriumi, S. & Wang, H. 2019, Living Reviews in Solar Physics, 16, 3 Toriumi, S. & Hotta, H. 2019, The Astrophysical Journal Letters, 886, L21

2020-12-15 12:00:00

Speaker: Jian-Zhou Zhu

Authors: Jian-Zhou Zhu

Compressible 'helical' turbulence: Fastened-structure geometry and statistics

Reduction of flow compressibility with the corresponding ideally invariant helicities, universally for various fluid models of neutral and ionized gases including the hydrodynamics, magnetohydrodynamics, extended magnetohydrodynamics and two-fluid models, can be argued statistically and associated to the geometrical scenario in the Taylor-Proudman theorem and its analogues. A 'chiral base field', rooted in the generic intrinsic local structure, as well as an 'equivalence principle' is explained and used to bridge the single-structure mechanics and the helical statistics. The electric field fluctuations may similarly be depressed by the (self-)helicities of the two-fluid plasma model, with the geometry lying in the relation between the electric and density fields in a Maxwell equation; however, the electromagnetic-wave analogy, in the fashion of Lighthill's acoustic analogy, appears not capable of directly shedding light on this issue: our fundamental results thus appear in this respect to be of clearer and more direct guiding-principle value for relevant applications in flow control (for noise reduction, say) and in astrophysics and controlled fusion, among others. Preliminary numerical results of direct numerical simulations will also be presented. In this talk, the speaker will revisit, deepen (with mechanics/geometry), verify (with direct numerical data) and extend (to plasmas) some earlier analyses in J.-Z. Zhu, J. Fluid Mech., 787, 440 (2016) and J.-Z. Zhu, Phys. Fluids 30, 031703 (2018), and the main content can also be seen in part of the following three works:
https://arxiv.org/abs/1910.04638;
https://arxiv.org/abs/1905.11783;
https://arxiv.org/abs/1901.00423.

2020-12-17 13:00:00

Speaker: P. F. Chen

Authors: Chen, Peng-Fei

Magnetic configuration and helicity of solar filaments

Solar filaments are an intriguing phenomenon in many senses, e.g., they are the key link between solar flares and coronal mass ejections, and they are tracers of nonpotential magnetic structures. It was believed that filaments are supported either by magnetic flux ropes or sheared arcades, the determination of which relied on sporadic measurements. In this talk, I will introduce how to determine the magnetic configuration of a filament simply from EUV images only. Similarly, several indirect methods have been proposed to determine the helicity of filaments from images only. In this talk, I will comment on these methods, and argue that the widely used method using filaments barbs, i.e., left-baring barbs correspond to positive helicity (or right-bearing barbs correspond to negative helicity), might not be correct.

References

1. Chen, P. F. et al. 2020, RAA, 20, 166
https://ui.adsabs.harvard.edu/abs/2020RAA....20..166C/abstract
2. Ouyang, Y.; Zhou, Y. H.; Chen, P. F. et al. 2017, ApJ, 835, 94

https://ui.adsabs.harvard.edu/#abs/2017ApJ...835...94O/abstract 3. Chen, P. F. et al. 2014, ApJ, 784, 50
https://ui.adsabs.harvard.edu/abs/2014ApJ...784...50C/abstract