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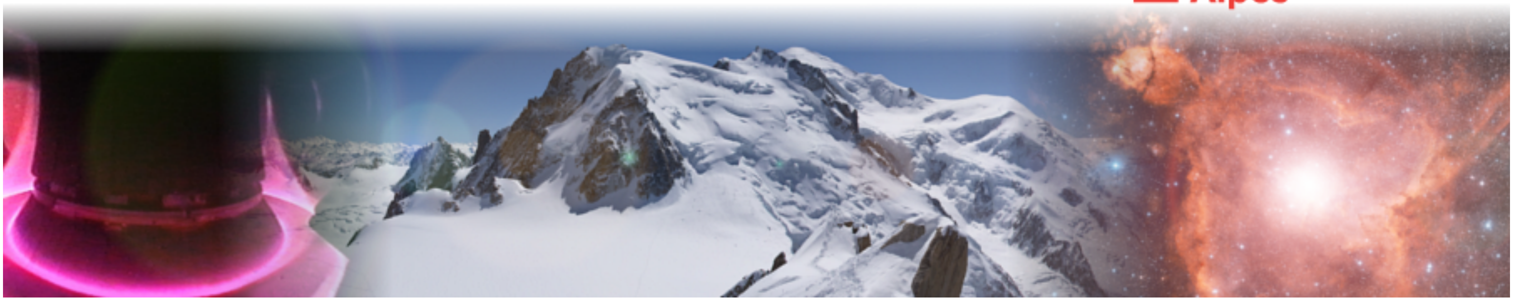

The expanding universe of plasma physics

ORAL CONTRIBUTIONS ABSTRACT BOOK

Anabella Araudo

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Particle acceleration and magnetic field amplification in the termination shocks of AGN jets. When observational astronomy meets plasma physics

It has been suggested that relativistic shocks in extragalactic sources may accelerate the highest energy cosmic rays. The maximum energy to which cosmic rays can be accelerated depends on the structure of magnetic turbulence near the shock but recent theoretical advances indicate that relativistic shocks are probably unable to accelerate particles to energies much larger than a PeV. We study the hotspots of powerful radiogalaxies, where electrons accelerated at the termination shock emit synchrotron radiation. The turnover of the synchrotron spectrum is typically observed between infrared and optical frequencies, indicating that the maximum energy of non-thermal electrons accelerated at the shock is < TeV for a canonical magnetic field of ~100 micro Gauss. Based on theoretical considerations we show that this maximum energy cannot be constrained by synchrotron losses as usually assumed, unless the jet density is unreasonably large and most of the jet upstream energy goes to non-thermal particles. We test this result by considering a sample of hotspots observed with high spatial resolution at radio, infrared and optical wavelengths. We present the famous radiogalaxy Cygnus A as a case study.

Prasanta Bera

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A perturbation study of axisymmetric strongly magnetic degenerate stars : the case of super-Chandrasekhar white dwarfs

In the presence of a strong magnetic field a stellar equilibrium configuration, aided by the Lorentz force, can support a larger mass than a non-magnetic one. This has been considered a possible explanation of the super-Chandrasekhar mass white dwarfs giving rise to over-luminous Type-Ia supernovae. We present here linear and non-linear perturbation studies of such strongly magnetized configurations and show that axisymmetric configurations with poloidal or toroidal fields are unstable. The numerical evolution of the perturbations shows instability after about an Alfven crossing time. This time scale is very short for the magnetically supported super-Chandrasekhar mass white dwarfs. Uniform rotation about the symmetry axis can reduce the growth rate but can not stabilize the super-massive configurations. It is concluded that long-lived super-Chandrasekhar mass white dwarfs supported by magnetic field are unlikely to occur in Nature.

Pallavi Bhat

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Origin of large-scale magnetic fields in MRI simulations

Magneto-rotational instability (MRI) drives turbulence in accretion disks. Large-scale fields in such systems are important for facilitating jets, nonlocal transport of angular momentum and understanding the MRI saturation. In shearing box simulations of MRI, we find large scale dynamo action during early MRI growth phase, a previously unidentified feature. The large scale modes are characterized by small horizontal wavenumbers growing exponentially before turbulence and high wavenumber fluctuations arise. We compute the terms in the mean field equations to identify the individual contributions to large scale field growth using different types of averaging. We discuss the potential implications of these new results for understanding the large scale MRI dynamo saturation and turbulence.

Archie Bott

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Experimental demonstration of turbulent magnetic field amplification on OMEGA

The phenomenon of magnetic field amplification due to the motion of turbulent plasma has been investigated in a series of experiments on the OMEGA facility at the University of Rochester (NY). Plasma jets driven by intense laser irradiation are passed through asymmetric grids, and then collided head on, leading to developed turbulence. Images from a framing camera detecting plasma soft X-ray emission have been used to provide information about the density spectrum, calculated using suitable filtration techniques. The bulk velocity, electron and ion temperatures are diagnosed via Thomson scattering – this has allowed for proper characterisation of the plasma regime. Polarimetry and proton radiography have enabled independent measurement of the magnetic field strength and morphology; both give a consistent picture of the magnetic field properties. The results presented here lend support to the theoretical expectations that turbulent plasma at high magnetic Reynolds numbers can maintain sustained field amplification – an effect believed to be responsible for the magnetic fields universally observed in various astrophysical environments, from stars to the intra-cluster medium.

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Interaction of parallel and oblique Alfvén waves

The nonlinear interaction of two parallel Alfvén wave packets in uniform plasma generates density cavities in the medium and parallel electric fields in the direction to the wave propagation (Mottez 2012, 2015). In this study, we have shown that the interaction of a third Alfvén wave packet with the two initial waves gives rise to powerful accelerated electron beams in the parallel direction. We have also investigated the interaction of two sinusoidal Alfvén waves in oblique propagation in a uniform medium. The analytic expression of the electric field shows clearly the contribution of two distinct terms; one corresponds to the parallel propagation, the other corresponds to the oblique propagation.

Maria Victoria del Valle

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Turbulence-induced magnetic fields in shock precursors

Galactic cosmic rays are believed to be mostly accelerated at supernova shocks. However, the interstellar magnetic field is too weak to efficiently accelerate galactic cosmic rays up to the highest energies, i.e. 1015 eV. A stronger magnetic field in the pre-shock region could provide the efficiency required. A mechanism has been proposed in which the cosmic ray pressure gradient forms the shock precursor and drives turbulence, amplifying the magnetic field via the small-scale dynamo (Beresnyak, Jones & Lazarian 2009). Key ingredients for the mechanism to operate are the inhomogeneities present in the interstellar medium. In this work we explore the magnetic field amplification in different interstellar medium conditions through 3D magnetohydrodynamic numerical simulations.

Camilia Demidem
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Corrugation of relativistic magnetized shock waves

Collisionless shock waves, as encountered e.g. in supernovae remnants, pulsar wind nebulae or gamma-ray bursts, are generically considered as promising sites for particle acceleration to high energies. One of the key ingredients of a successful Fermi acceleration process is the generation of an intense magnetized turbulence, but how it is produced remains poorly understood, all the more so in the magnetized and/or relativistic regime. In this context, I study through relativistic MHD simulations how a shock front reacts to incoming upstream perturbations. I compare the corrugation pattern for low amplitude waves to that predicted by a recent linear analytical calculation and I verify in particular the existence of a resonant response of the corrugation to incoming waves for some specific part of wave vector space. I also investigate the non-linear regime, which lies out of range of the linear theory.

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Fully-Kinetic Versus Reduced-Kinetic Modelling of Collisionless Plasma Turbulence

Abstract: We report the results of a direct comparison between kinetic models in two-dimensional collisionless plasma turbulence. In particular, we examine the differences among the simulations produced using three prominent kinetic models: the fully-kinetic, the hybrid-kinetic, and the gyrokinetic model. The simulations are carried out using the so-called Orszag-Tang vortex as initial condition, covering the range of scales from the tail of the inertial range down to electron scales at a reduced ion-to-electron mass ratio of 100. The results are analysed for two different ion beta ratios and for variable turbulence fluctuation strengths.

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Disruption of sheetlike structures in Alfvénic turbulence by magnetic reconnection

We propose a mechanism whereby the intense, sheet-like structures naturally formed by dynamically aligning Alfvénic turbulence are destroyed by magnetic reconnection at a scale \lambda_D, larger than the dissipation scale predicted by models of intermittent, dynamically aligning turbulence. The reconnection process proceeds in several stages: first, a linear tearing mode with N magnetic islands grows and saturates, and
then the X-points between these islands collapse into secondary current sheets, which then reconnect until the original structure is destroyed. This effectively imposes an upper limit on the anisotropy of the structures within the perpendicular plane, which means that at scale \lambda_D the turbulent dynamics change: at scales larger than \lambda_D, the turbulence exhibits scale-dependent dynamic alignment and a spectral index approximately equal to -3/2, while at scales smaller than \lambda_D, the turbulent structures undergo a succession of disruptions due to reconnection, limiting dynamic alignment, steepening the effective spectral index and changing the final dissipation scale. The scaling of \lambda_D with the Lundquist (magnetic Reynolds) number S_L depends on the order of the statistics being considered, and on the specific model of intermittency; the transition between the two regimes in the energy spectrum is predicted at approximately \lambda_D \sim S_L^{-0.6}$. The spectral index below \lambda_D is bounded between -5/3 and -2.3. The final dissipation scale is at S_L^{-3/4}, the same as the Kolmogorov scale arising in theories of turbulence that do not involve scale-dependent dynamic alignment.

François Orain

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Edge MHD instabilities and their interaction with magnetic perturbations in tokamaks

Reaching high confinement regimes while limiting the heat flux on plasma facing components is a key issue in current and future tokamaks. The understanding and control of MHD instabilities, occurring at the plasma edge and inducing quasiperiodic plasma relaxations, is therefore crucial. Towards this end, the dynamics of instabilities called ELMs (Edge Localized Modes) and their mitigation by magnetic perturbations (MPs) are studied with the non-linear MHD code JOREK.
After briefly presenting the theoretical understanding of ELMs, their dynamics, observed in modeling and showing features qualitatively comparable to experimental observations, will be described: linear growth of the instabilities, non-linear mode coupling, formation and transport of filamentary structures. Then the ELM control by externally applied MPs will be presented. MPs are likely to induce magnetic reconnection at the plasma edge and to drive external modes capable to couple with ELMs and therefore induce a constant transport rather than a violent relaxation.

Adnane Osmane

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Fundamental plasma physics in planetary radiation belts: new perspectives after the Van Allen Probes.

Recent observations in the Earth's radiation belts of nonlinear electrostatic structures (double layers, electron solitary holes, large-amplitude whistlers), with electric fields two orders magnitude larger than previously measured, has hinted at alternative routes through which planetary radiation belts' acceleration can take place. In this communication we will review how recent in situ measurements have forced us to shift our focus from large-scale processes occurring on timescales of days, to local and small-scale mechanisms affecting the radiation belt's dynamics on timescales of a few hours. A theoretical description of small-scale processes will be presented with a focus on the sub-critical nature of associated instabilities. Our results should be of relevance to acceleration mechanisms in other planetary radiation belts in which ultra-relativistic electrons are commonly produced.

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Generation of seed magnetic fields above Electroweak scale and Biermann Battery process

Arun Kumar Pandey and Jitesh R. Bhatt

The origin of large scale magnetic field is a much discussed problem in the modern astronomy and cosmology. The origin of the magnetic fields in the galaxies and clusters are still unknown.
It is widely assumed that, magnetic Fields in the astronomical objects such as stars, galaxies etc., exist because of the amplification of seed magnetic field generated during some early Universe Magnetogenesis process. In a recent work, the authors of ref. [PRL.111.051303], showed that the primordial magnetic field can be generated in the early Universe at the time of recombination era, on purely linear scales through vorticity induced by scale-dependent temperature fluctuations, or equivalently, a spatially varying speed of the sound of the gas. The idea was that the residual free electrons left over after recombination tap into the vorticity to generate magnetic field through Biermann battery. Not too long ago, generation of magnetic field via quantum chiral anomaly attracts much attention as it explains apart from generation of seed magnetic fields, but also explain some other observed phenomenon like baryon asymmetry in the early universe. It was realized that, in the early Universe, above electronic scale, there can be chiral asymmetry due to some mechanism at temperature than the EW temperature T > 100GeV. And because of the chiral asymmetry, the well known MHD equations get modified. At temperature T > 100 GeV, weak reactions are fast enough to establish local thermal equilibrium, in the background of long range electromagnetic fields. In such a case, one can define, a space time dependent chemical potentials for the left handed and right handed particles. In our work, we found that under such limitations, an Biermann Battery kind of term

can arise, which don't need any seed field. Our calculations showed that, at a length scale of cosmological interest, sufficiently large magnetic field can be generated via this process.

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Particle acceleration in solar flares: merging magnetic islands in forced reconnection.

Abstract: There are many proposed mechanisms for particle acceleration in flares, but no single model is able to fully reproduce the range of observed spectra and fluxes from solar flares. It is therefore likely that there are multiple acceleration mechanisms operating as part of a multi-stage process.

Forced magnetic reconnection requires an external process as a trigger and thus operates as part of a chain of perturbative processes in the plasma. Furthermore, many studies of particle acceleration deal with steady reconnection, yet this is unlike the conditions in flares, which are transient event. Forced reconnection has three stages: perturbation to the equilibrium, initial reconnection to form a chain of magnetic islands, and finally the islands begin to coalesce and form 'monster' islands. Previous studies of magnetic energy release and particle acceleration in flares have considered only the first two stages, but we now incorporate also coalescence.

To this end, we utilise 2D MHD simulations of forced magnetic reconnection using Lare2d with anomalous resistivity, and a long, periodic simulation domain which allows islands to move and coalesce. While forced reconnection models generally use a single sinusoidal disturbance, we consider the effect of multi-wavelength and localised disturbances, building towards more realistic models. The energy release and dynamics are investigated for different forms of external perturbations, focusing on the effects of merging magnetic islands. Test particles are introduced, allowing us to predict the energy spectra of non-thermal ions and electrons, as well as the spatial distributions and temporal evolution on non-thermal particle populations.

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Spontaneous current generation by ETG turbulence in tokamaks and cylindrical devices

Abstract:
Motivated by the observations and physics understanding of the phenomenon of intrinsic rotation[1] doubts were raised on the existence of intrinsic current in tokamaks. We investigated the possibility of non-inductive intrinsic current in sheared magnetic field geometry of tokamak and in shear-less straight field line geometry of cylindrical devices like LVPD. Ohm's law is generalized to include the effect of turbulent fluctuations in mean field approach. This clearly leads to the identification of sources and the mechanisms of non-inductive current drive by ETG turbulence.
It is found that in tokamak a mean parallel electro motive force (emf) and hence a mean parallel current can be generated by 1) the divergence of residual current flux density and 2) a non-flux like turbulent source from the density and parallel electric field correlations. Both residual flux and the non-flux source requires parallel wavenumber $\left\langle k_{||} \right\rangle$ symmetry breaking for their survival which can be supplied by various means like mean ExB shear, turbulence intensity gradient etc. It is found that the turbulence driven current is nearly 10% of the bootstrap current and hence can have significant influence on the equilibrium current density profiles and current shear driven modes.
The parallel wave number asymmetry vanishes when magnetic shear goes to zero and hence the above mechanism does not work in straight equilibrium magnetic field line geometry. Rather it is seen that $\left\langle k_y k_z \right\rangle$ symmetry breaking can produce a residual current density flux. Possible mechanism of such a symmetry breaking is explored. It turns out that a test current shear can asymmetrize the linear growth spectrum and hence the saturated turbulence spectrum in $k_y - k_z$ space. This produces a negative residual current density diffusivity and hence the test current

shear can grow, when it overcomes the positive ambient turbulent diffusivity, via modulational instability.

References
[1] J. E. Rice et al Nucl. Fusion {\bf 47} 1618 (2007);

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PIC simulations of relativistic collisionless shocks

Among other powerful relativistic astrophysical objects, gamma-ray bursts, blazars, pulsar winds provide an ideal environment to understand the acceleration mechanisms of high energy charged particles. These objects are characterized by relativistic outflows. The high-energy electromagnetic spectrum of these sources follows a power law distribution attributed to synchrotron and inverse Compton radiations of non-thermal particles. This non-thermal spectrum can naturally be linked to these outflows through a conversion of kinetic or Poynting flux in a non-thermal particle energy distribution in relativistic shocks. A deep insight of these phenomenon requires detailed simulations of collisionless shocks. The shock originates in the rise of a magnetic barrier. This barrier is constituted from turbulences arising in the shock precursor from electromagnetic instabilities. The non-thermal particles that propagate through the precursor will also be sources of instabilities affecting the shock. This leads to a multi-scale and non-linear problem. In PIC simulations, the particle acceleration can be studied.

Justin Walker

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MRI in the shearing box

I will discuss recent results of high-resolution, shearing-box simulations of the magnetorational instability (MRI). Turbulence within the incompressible, "small-shearing-box" limit seems exhibit certain universal properties, as well as an inertial range scaling of the energy spectrum that is consistent with strong magnetohydrodynamic (MHD) turbulence. The universality of the dynamo will also be discussed in the context of results that examined high Reynolds numbers and aspect ratio effects.