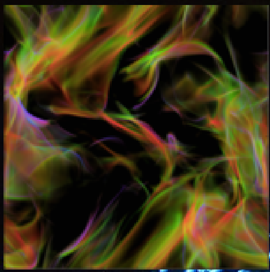

MIST2023 :
Cosmic turbulence and Magnetic fields: physics of baryonic matter across time and scales

25-29 Sep 2023 Cargèse (France)

ABSTRACTS

MONDAY 25 SEPTEMBER	
	R: Review talks (35') I: Invited talks (20') C: Contributed talks (15') P: Poster Lightning Presentations (1', 1 slide)
08:45-9:00	Welcome address
Session I - Gas Physics, Star Formation and Galaxy Evolution - Chair: Alba Vidal Garcia	
R	Pillepich A. - Simulating galaxies and their gaseous haloes with the Illustris TNG simulations and beyond
R	Decarli R. - Cosmic evolution of the densities of molecular gas and star formation rate *(video talk)*
C	Rauch M. – Turbulence and temperature in the inter-galactic medium at high redshift
10:30-11:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: William Matthaeus	
R	Kunz M. – Plasma physics in the intracluster medium
R	Brüggen M. – The role of non-thermal constituents in the multiphase circumgalactic medium and observational results from LOFAR, VLA and MeerKAT *(video talk)*
I	Chen H.-W. – Turbulent velocity field in the diffuse circumgalactic medium around quasars
12:30 - 15:00	LUNCH
Session I - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Olga Alexandrova	
R	Velli M. – Solar wind turbulence as seen by Parker Solar Probe *(video talk)*
R	Sorriso-Valvo L. - Scaling laws for the energy transfer in space plasma turbulence
I	Chandran B. - Stochastic heating in collisionless plasmas *(video talk)*
16:30-17:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: Annick Pouquet	
I	Semenov V. – Capturing Turbulence with Numerics: a Simple Method for Modeling Unresolved Turbulence in Galaxy Simulations
C	Reichherzer P. – Reflecting on cosmic ray transport: the role of micro-mirrors in the intra-cluster medium
C	Böss L. – Galaxy cluster simulations with a spectral cosmic ray model
C	Churazov E. – The Coma cluster in X-rays *(video talk)*
DISCUSSION 1 - The (many) roles of turbulence in galaxy evolution Chairs: Romain Teyssier, Edith Falgarone	
19:30	Welcome drink
TUESDAY 26 SEPTEMBER	
Session I - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Amitava Bhattacharjee	
R	Pouquet A. – Stronger local dissipation with stronger waves? The case of turbulence in fluids and plasmas
R	Matthaeus W. – Overview on dissipation in collisionless plasma
C	Li H. - Understanding the temporal and spatial properties of compressible MHD turbulence
10:30-11:00	Coffee Break & Poster Viewing
Session II - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Hitesh Kishore Das	
R	Bhattacharjee A. – Current Sheets and the Plasmoid Instability: Mediators of Fast Magnetic Reconnection and Turbulence
R	Fielding D. - Plasmoid instability in the multiphase interstellar medium
I	Schöber J. - Origin and evolution of cosmic magnetic fields
12:30 - 15:00	LUNCH
Session I - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Matthew Kunz	
R	Schekochihin A. - MHD turbulence: a biased review
R	Stone J. – Numerical models of turbulence at exascale
C	Hosking D. – Are cosmic voids filled with reconnecting magnetic fields from the early universe?
P	**Poster ligthning presentations**
16:30-17:00	Coffee Break & Poster Viewing
Session II - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Alexander Schekochihin	
R	Pfrommer C. - Magnetic dynamos and the roigin of the far-infrared-radio correlation in galaxies *(delivered by Timon Thomas)*
I	Lemoine M – Fermi acceleration in magnetized turbulence
C	Lübke J. – Beyond quasilinear theory: investigating non-Gaussian magnetic turbulence models and charged particle transport
C	Kempski P. – On the hunt for a new theory of cosmic ray transport
DISCUSSION 2: Collisional versus non-collisional approaches: when and where? Chairs: Olga Alexandrova and Ralf Klessen	
WEDNESDAY 27 SEPTEMBER	
Session I - Gas Physics, Star Formation and Galaxy Evolution - Chair: Vadim Semenov	
R	Schinnerer E. - The star formation process on cloud scales: insights from PHANGS
R	Federrath C. - Control of star formation by turbulence, magnetic fields and feedback *(video talk)*
I	Meidt S. - Structure and turbulence on the Jeans scale in gas disks
10:30-11:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: Blakesley Burkhart	
I	Agertz O. – The connection between star formation, gravity and turbulence in the insterstellar medium
C	Vazquez-Semadeni E. – The role of gravity, turbulence, cooling and magnetic fields during cloud formation

C	Fensch J. – Universality of gravitation-driven isothermal turbulence in galactic disks
C	Whittingham J. – The impact of magnetic fields in cosmological galaxy mergers
C	Scannapieco E. – What governs the density evolution of turbulent media?
12:30	LUNCH
	FREE AFTERNOON
THURSDAY	
28 SEPTEMBER	
Session I - Gas Physics, Star Formation and Galaxy Evolution - Chair: Enrique Vazquez-Semadeni	
I	Péroux C. – Cold gas in circum-galactic media
I	Oh P. – The entrainment of magnetized and molecular gas in galactic winds
I	Godard B. – The turbulent interface of the warm and cold neutral media
C	Das H. – Magnetic fields and turbulence: piecing together the multiphase puzzle
10:30-11:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: Fabrizio Arrigoni Battaia	
I	Verhamme A. – Lyman alpha emission from galaxies: simulations and MUSE GTO Deep surveys results
I	Burkhart B. – How supermassive black holes ignite the intergalactic medium: tales from the low-redshift Lyman-alpha forest
I	Vidal-Garcia A. – Molecules in the circumgalactic medium of starburst galaxies at cosmic noon
C	Ramesh R. – The role of turbulence and magnetic fields in the circumgalactic medium of galaxies *(video talk)*
12:30 - 15:00	LUNCH
Session I - Gas Physics, Star Formation and Galaxy Evolution - Chair: Evan Scannapieco	
R	Miville-Deschênes M.-A. – New observational perspectives on turbulence of the multi-phase diffuse interstellar medium
I	Jelic V. – Faraday tomography at low-radio frequencies *(video talk)*
I	Bracco A. – LOFAR depolarization canals *(video talk)*
I	Hily-Blant P. – Statistical and dynamical signatures of turbulent dissipation in a diffuse molecular cloud
16:30-17:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: Marc-Antoine Miville-Deschênes	
R	Guillard P. – Multiphase shocked inter-galactic medium in the Stefan's Quintet *(video talk)*
I	Kreckel K. – Stellar feedback diagnosis: Metal mixing in nearby galaxies *(delivered by Eva Schinnerer)*
I	Villa-Velez J. – Warm H2 in galaxies *(delivered on-line by Pierre Guillard)*
DISCUSSION 3: How to reconcile observations and simulations of turbulence in multiphasic media? Chairs: François Boulanger, Fabrizio Arrigoni Battaia	
Time TBC: 19h ?	CONFERENCE DINNER
FRIDAY	
29 SEPTEMBER	
Session I - Turbulence, Plasmas, Magnetic Fields and Cosmic Rays - Chair: Drummond Fielding	
C	Berlok T. – Magnetic field amplification in galaxy clusters with AREPO
C	Zhou M. – Generation and amplification of magnetic fields in a collisionless plasma
C	Cerri S. – Turbulent regimes from interactions of 3D Alfvén waves / kinetic-Alfvén- waves packets
C	Mirabel F. – Turbulence and magnetic fields in the formation of black holes and Pop-III stars at cosmic dawn
C	Ji S. – The impact of turbulence, magnetic fields and cosmic rays on the circumgalactic medium: from kpc to AU scales *(video talk)*
10:30-11:00	Coffee Break & Poster Viewing
Session II - Gas Physics, Star Formation and Galaxy Evolution - Chair: Jeremy Fensch	
I	Kim C.-G. – Feedback regulated star formation: The TIGRESS simulations (and related topics)
I	Zaroubi S. – Constraining the intergalactic medium at z ≈ 9.1 using LOFAR Epoch of Reionization observations *(video talk)*
C	Lancaster L. – The effects of MHD turbulence and photo-ionized gas on the dynamics of wind-driven bubbles
C	Steinwandel U. – On the physical nature of multiphasic galactic outflows
12:30 - 15:00	LUNCH
15:00 Closing lecture (TBA)	
DISCUSSION 4: What have we learned? Chairs: Pierre Lesaffre + Lorenzo Perrone	
16:00	END OF THE MEETING
POSTERS	
Berat, J.	Faraday tomography of mock observations of diffuse interstellar medium
Bisschoff B.	Modeling the large-scale structure and neutral hydrogen content of the universe
Biswas S.	Shear dynamo action in non-helical base flows
Dumond, P.	On the radial profile of filaments formed in a turbulent context
Ewart R.	Non-thermal particle acceleration and power-law tails via relaxation to universal Lynden-Bell equilibria
Gilabert T.	The role of viscosity in galaxy clusters
Hosking D.	Metastability of magnetically supported atmospheres
Kempf, J.	Dynamical properties and detectability of the magneto-thermal instability
Moseley E.	Modeling the impact of MHD turbulence on dust transport and evolution in the intracluster medium
Perrone L.	Whistler suppression of the magneto-thermal instability in galaxy clusters
Perrone L.	The Role of Scientists in a Planetary Crisis
Rappaz Y.	Merger trees and dynamo in the weakly collisional plasma of galaxy clusters
Thomas T.	Galactic winds and cosmic rays in CRISPy galaxies

ORAL PRESENTATIONS

In chronological order

Simulating galaxies and their gaseous haloes with the IllustrisTNG simulations and beyond

Annalisa Pillepich*[1]

[1]Max Planck Society (GERMANY) – Germany

Abstract

I will give an overview of the IllustrisTNG simulations, a suite of cosmological large-volume magneto-hydrodynamical models for the formation and evolution of galaxies that represent the current modeling frontier from dwarf galaxies to the most massive galaxy clusters. I will also present a number of spin-off projects that have been undertaken using the IllustrisTNG galaxy formation model, with a particular focus on TNG-Cluster, which simulates about 100 truly massive 10ˆ15 solar mass galaxy clusters. I will hence focus on the results that we have been extracting from these simulations and that showcase the tight interplay between feedback originating from the innermost regions of galaxies and the thermodynamical, ionization, chemical, magnetic, and kinematical properties of the circum-galactic and intra-cluster media. Within the IllustrisTNG model, such results are based on model simplifications such as ideal MHD, an effective treatment of the ISM, and subgrid stellar and SMBH feedback, whose limitations need to be discussed and quantified.

*Speaker

Cosmic evolution of the densities of molecular gas and star formation rate

Roberto Decarli*[1]

[1]INAF-Osservatorio di Astrofisica e Scienza dello Spazio – via Gobetti 93/3, I- 40129 Bologna, Italy

Abstract

The cosmic history of star formation shows that galaxies emerging from the dark ages formed progressively more and more stars per unit cosmic volume, until a peak age around redshift z_˜2. After that, the star formation rate in a cosmological volume dropped by nearly one order of magnitude down to the present age. While this overall picture has been established via decades of multi-wavelength campaigns, a fundamental understanding of what causes this evolution is still lacking. The study of the multi-phase interstellar medium, i.e., the fuel for star formation in galaxies, can shed light on the history of cosmic star formation. The content of neutral gas (HI) is usually measured via absorption studies of the Ly-a line against the spectra of background sources. The molecular gas content, on the other hand, can be quantified using campaigns of dust and/or molecular gas emission at mm wavelengths. Molecular deep fields, i.e., sensitive "blind" observations of continuous patches of the extragalactic sky, have only recently become technically feasible, and provided the first direct constraints on the molecular gas budget up to z_˜3. In this talk, I will review the status of these investigations and outline what we can expect in the near future with the next generation of facilities.

*Speaker

Turbulence and temperature in the general IGM at high redshift

Michael Rauch*[1]

[1]Carnegie Institution for Science – United States

Abstract

I propose to discuss the status of turbulence and temperature measurements in the general intergalactic medium at high redshift, as measured by QSO absorption lines, and resolve some longstanding issues that have led to apparently contradictory measurements of turbulence and gaseous small scale structure in the literature.

*Speaker

Plasma physics of the intracluster medium

Matthew Kunz*[1]

[1]Princeton University – United States

Abstract

I will provide a brief tutorial on some aspects of plasma physics that are fundamental to understanding the dynamics and energetics of the intracluster medium (ICM). For brevity, I will focus solely on its thermal plasma component – its stability, viscosity, conductivity, and ability to amplify magnetic fields to dynamical strengths via turbulence and other plasma processes – and provide an overview of some of the theoretical tools and techniques used to elucidate this physics. Observational context will be woven throughout the narrative, from constraints on the strength and geometry of intracluster magnetic fields and the effective viscosity and conductivity of the ICM, to lessons learned from spacecraft data taken in the hot, dilute solar wind. The promise of future X-ray missions to probe intracluster turbulence and discover the impact of small-scale plasma physics, coupled with sensitive, high-resolution radio observations of synchrotron-emitting plasma that reveal the properties of intracluster magnetic fields and particle-acceleration mechanisms, are likely to establish galaxy clusters as the premier cosmic laboratories for deciphering the fundamental physics of hot, dilute plasmas.

*Speaker

The role of non-thermal constituents in the multiphase CGM and observational results from LOFAR, VLA and MeerKAT

Marcus Bruggen*[1]

[1]University of Hamburg – Germany

Abstract

Recent advances in radio observations have shed new light on the cosmic ray and magnetic field distributions in the circumgalactic medium. As a result, we now have good constraints on cosmic ray transport mechanisms (streaming vs diffusion) and transport parameters as well as profiles of magnetic fields that extend into the far CGM. Correlations between various galactic properties and radio spectral properties tell us about the role of non-thermal constituents in the multi-phase CGM. We report a series of recent results from LOFAR, the VLA and MeerKAT. The observations will be complemented by analytical and numerical work on the non-thermal CGM.

*Speaker

Observational constraints on the turbulent circumgalactic medium

Hsiao-Wen Chen*[1]

[1]The University of Chicago – United States

Abstract

The circumgalactic medium (CGM) and intergalactic medium (IGM) contain fuel for future star formation and a record of past feedback. They are uniquely sensitive to the physics of baryonic flows. Diffuse, ionized plasmas such as the CGM are expected to be turbulent, because of the expected high Reynolds number, and the presence of turbulence and the degree of such turbulence have profound implications for the thermal and dynamic properties of the gas. I will present recent empirical findings on the tuburlent CGM around galaxies and quasars. Using a combination of 1D absorption spectroscopy and 3D line intensity maps, we are able to measure the velocity structure function to constrain the the velocity fluctuations as a function of spatial scale in the diffuse CGM. In most cases, we find that the velocity structure functions are surprisingly consistent with expectations from the Kolmogorov relation. I will discuss the implications of our findings as well as the future prospect.

*Speaker

Scaling laws for the energy transfer in turbulent plasmas

Luca Sorriso-Valvo*[1,2] and Raffaele Marino

[1]KTH Stockholm – Sweden
[2]Istituto per la Scienza e la Tecnologia dei Plasmi – Italy

Abstract

One characteristic trait of space plasmas is the multi-scale dynamics resulting from nonlinear transfers and conversions of various forms of energy. Routinely evidenced in a range from the large-scale solar structures down to the characteristic scales of ions and electrons, turbulence is a major cross-scale energy transfer mechanism in space plasmas. At intermediate scales, the fate of the energy in the outer space is mainly determined by the interplay of turbulent motions and propagating waves. More mechanisms are advocated to account for the transfer and conversion of energy, including magnetic reconnection, emission of radiation and particle energization, all contributing to make the dynamical state of solar and heliospheric plasmas difficult to predict. The characterization of the energy transfer in space plasmas benefited from numerous robotic missions. However, together with breakthrough technologies, novel theoretical developments and methodologies for the analysis of data played a crucial role in advancing our understanding of how energy is transferred across the scales in the space. In recent decades, several scaling laws were obtained providing effective ways to model the energy flux in turbulent plasmas. Under certain assumptions, these relations enabled to utilize reduced knowledge (in terms of degrees of freedom) of the fields from spacecraft observations to obtain direct estimates of the energy transfer rates (and not only) in the interplanetary space, also in the proximity of the Sun and planets. Starting from the first third-order exact law for the magnetohydrodynamics by Politano and Pouquet (1998), we present a detailed review of the main scaling laws for the energy transfer in plasma turbulence and their application, presenting theoretical, numerical and observational milestones of what has become one of the main approaches for the characterization of turbulent dynamics and energetics in space plasmas.

*Speaker

Capturing Turbulence with Numerical Dissipation: a Simple Alternative to Large Eddy Simulations for Galaxy Formation

Vadim Semenov*[1]

[1]Harvard-Smithsonian Center for Astrophysics – United States

Abstract

Star formation and feedback in galaxies are sensitive to the turbulent properties of actively star-forming regions, which cannot be resolved even in state-of-the-art simulations. The modeling of star-forming and feedback can be significantly improved by explicit modeling of subgrid turbulence, e.g., following the Large Eddy Simulations (LES) methodology. As I will show, such a turbulence-based model for star formation and feedback is favored by the observed decorrelation between young stars and dense molecular gas in the ISM on sub-kiloparsec scales. In my talk, I will present an approach alternative to LES, where the explicitly modeled subgrid turbulence is sourced by the local numerical dissipation. Such a model is motivated by the generic property of turbulent flows that the dissipation rate is independent of viscosity and instead is set by the energy cascade rate, implying that local numerical dissipation can be treated as a reasonable model for the rate of energy transfer from resolved to subgrid scales. I will show that such a model can capture multiple non-trivial features of small-scale turbulence in idealized decaying supersonic turbulence tests. In galaxy formation simulations, this model predicts the distribution of turbulent velocities in cold and dense supersonic ISM which is close to the results of an explicit LES model, without requiring any explicit closure relations for the source terms.

*Speaker

Reflecting on Cosmic Ray Transport: The Role of Micro Mirrors in the Intracluster Medium

Patrick Reichherzer*†[1], Archie Bott[1], Robert Ewart[1], Gianluca Gregori[1], and Alex Schekochihin[1]

[1]Department of Physics, University of Oxford – United Kingdom

Abstract

The transport of cosmic rays (CRs) in the Intracluster Medium (ICM) is essential for understanding the formation and evolution of galaxy clusters and their influence on the thermal and non-thermal properties of the ICM. Understanding CR transport is crucial for interpreting gamma-ray emissions from these clusters. In this study, we will examine the transition between microscale and macroscale physics relevant for CR transport in the ICM. Specifically, we consider the mirror-instability and (near-) resonant scattering of CRs in magnetostatic turbulence. Using numerical simulations, we demonstrate the importance of kinetic micro-instabilities and quantify their impact on CR diffusion coefficients across various spatial scales. We find that micro-mirrors dominate the CR transport up to TeV energies.

*Speaker

†Corresponding author: patrick.reichherzer@physics.ox.ac.uk

Galaxy Cluster simulations with a spectral Cosmic Ray model

Ludwig Böss*[1], Klaus Dolag , and Ulrich Steinwandel

[1]Ludwig Maximilian University [Munich] – Germany

Abstract

Non-thermal emission from relativistic electrons gives insight into the strength and morphology of intra-cluster magnetic fields, as well as providing powerful tracers of structure formation shocks.
Emission caused by Cosmic Ray (CR) protons on the other hand still challenges current observations and is therefore testing models of proton acceleration at intra-cluster shocks.
Large-scale simulations including the effects of CRs have been difficult to achieve and have been mainly reduced to simulating an overall energy budget, or tracing CR populations in post-processing of simulation output and has often been done for either protons or electrons.
We use an efficient on-the-fly Fokker-Planck solver (Böss+2023) to evolve distributions of CR protons and electrons within every resolution element of our simulation.
The solver accounts for CR acceleration at intra-cluster shocks, based on results of recent PIC simulations, re-acceleration due to shocks and MHD turbulence, adiabatic changes and radiative losses of electrons.
We apply this model to zoom simulations of galaxy clusters, recently used to show the evolution of the small-scale turbulent dynamo on cluster scales (Steinwandel, Böss et. al. 2021).
For these simulations we use a spectral resolution of 48 bins over 6 orders of magnitude in momentum for electrons and 12 bins over 6 orders of magnitude in momentum for protons.
In this talk I will give a brief overview of the CR model and its application to study radio halos, radio relics and gamma-ray emission in galaxy clusters.

*Speaker

The Coma cluster in X-rays

Eugene Churazov*[1]

[1]Max Planck Institute for Astrophysics – Germany

Abstract

The Coma cluster is one of the closest and brightest massive galaxy clusters. It hosts the whole range of phenomena characteristic of rich clusters, excluding a cool core and prominent signatures of the AGN Feedback, which are likely erased by the ongoing merger. The proximity of the Coma cluster combined with deep X-ray observations provides a detailed view of perturbed ICM, merger-driven shocks, and sites of particle acceleration.

*Speaker

STRONGER LOCAL DISSIPATION WITH STRONGER WAVES? THE CASE OF FLUID AND MHD TURBULENCE

Annick Pouquet*[1,2]

[1]National Center for Atmospheric Research (NCAR) – Boulder, CO, United States
[2]Laboratory for Atmospheric and Space Physics (LASP) – 1234 Innovation Drive, Boulder, CO 80303-7814, United States

Abstract

With large Reynolds numbers, fluids and plasmas in astrophysical bodies need a source of dissipation, beyond particle acceleration at small scales. Turbulence offers a clear possibility through nonlinear coupling and the systematic formation of strong localized gradients, for example in the form of self-amplified strain, and current and vorticity sheets and filaments. A review of why and how it happens physically in complex nonlinear systems is briefly presented, starting from basic considerations.
The role of waves is then analyzed in this context and it is shown that the localized dissipation in such systems can be, in some cases and by some measure, stronger than for fully developed turbulence. It is also briefly mentioned how exact laws involving energy and helicity conservation can be of help in measuring the dissipation in such flows, as done for example in the solar wind.

The intermittency that is one characteristics of such flows is also analyzed through the joint behavior of normalized third and fourth-order moments (skewness S and kurtosis K). A K(S) scaling is observed which is in rough agreement with previous results for a variety of systems, including the planetary boundary layer, climate re-analysis data, fusion plasmas and the Solar Wind, as well as in galaxies (1). These relationships may be related to nonlocal interactions between coherent structures in the inertial and near dissipative ranges, and display a transition for the scaling of dissipation once the Kolmogorov small-scale turbulence range is sufficiently developed.
(1) A. Pouquet, D. Rosenberg, R. Marino and P. Mininni: {*Intermittency scaling for mixing and dissipation in rotating stratified turbulence at the edge of instability.*} *Atmosphere, Special Issue in the honor of Jack Herring. Volume **14**, 1375, August 2023.*

*Speaker

Overview of Dissipation in Collisionless Plasma

William Matthaeus*[1]

[1]University of Delaware – United States

Abstract

Turbulent cascade leading to dissipation and heating are usually considered to be of great importance in space and astrophysical plasmas. This connection is straightforward when collisions are strong in a magnetized plasma, and standard closures provide simple representations of dissipation in terms of coefficients of viscosity and resistivity. In the opposite limit of weak collisions, the same underlying physical effects that lead to dissipation are present, but the simple approximations to describe them, the closures, are not available in general. But how different are these relationships when collisions are absent? We review a formalism based on the Vlasov-Maxwell equations that demonstrates the pathways of energy conversion among different forms. We highlight the production of internal energy by pressure-strain and pressure-dilatation interactions. These terms can also be scale filtered to study transfer across scales. Here we inquire as to whether the collisionless case admits statistical relationships analogous to the viscous and resistive closures found in collisional plasma theory. We employ kinetic PIC simulation, as well as MMS observations in the magnetosheath, to examine analogous viscous-like and resistive-like scalings in the weakly collisional regime. Of the many potential implications, the identification of pressure strain as the fundamental plasma dissipation function leads to improved understanding of the partitioning of internal energy between protons and electrons, at least over a limited range of parameters. Still numerous questions remain. We conclude with a few remarks concerning remaining issues including the role of Boltzmann entropy in collsionless turbulence.

*Speaker

Understanding the Temporal and Spatial Properties of Compressible MHD Turbulence

Hui Li*[1], Kaho Yuen[1], and Huirong Yan[2]

[1]Los Alamos National Laboratory – United States
[2]Deutsches Elektronen-Synchrotron (DESY) – Germany

Abstract

We will discuss recent results on 4D FFT analysis (temporal plus 3D spatial) of compressible MHD turbulence. Most fluctuation power is found to have nearly zero or very low frequencies with finite wavenumbers. They do not follow the dispersion surfaces of linearized MHD waves, though a very small fraction of the power is observed to fall within the expected dispersion relations for Alfven, Slow and Fast modes. We propose a new interpretation on how to understand the temporal behavior in MHD turbulence. The temporal response of any particular wavenumber is shown to be a Lorentzian in frequency. Its profile peaks at the eigen-frequency of a given wave mode but has very broad wings extending to both low and high frequencies. We quantify how this new approach can be used to explain the turbulence simulation results. Such a new theory also allows a new approach to obtain scaling relationships in wavenumber space for compressible turbulence. Implications for understanding the solar wind turbulence, particularly the density variations and particle transport in the low beta regime will be discussed as well.

*Speaker

Current Sheets and the Plasmoid Instability: Mediators of Fast Magnetic Reconnection and Turbulence

Amitava Bhattacharjee*†[1]

[1]Princeton Plasma Physics Laboratory, Princeton University – United States

Abstract

Current sheets are localized regions of the plasma in which the current density can become singular in the zero-dissipation limit. While the critical role of such structures in mediating fast reconnection and turbulence has been recognized for some time, the universal nature of the plasmoid instability of these structures in high-Lundquist-number plasmas and its role has become a subject of significant interest relatively recently. Enabled by sophisticated computer simulations and analytical theory and tested by observations, the plasmoid instability has transformed our understanding of magnetic reconnection and inspired new research in space, astrophysical, and laboratory plasmas. In this talk, I will review the evolution of our understanding in systems where closed field lines exist (such as in a torus) and those where they may not (such as in stellar coronae and compact astrophysical objects where field lines may be line-tied). Even the definition of magnetic reconnection in the latter class of systems remains a contested issue. In turbulent systems characterized by the formation of thin current sheets, the onset of the plasmoid instability is shown to interrupt the inertial range and introduce new power laws for the dissipation range and produce coherent structures that play an essential role in particle acceleration and heating in non-relativistic as well as relativistic regimes. Despite the progress made in theory and observations, many open questions remain. Some of them will be discussed.

*Speaker
†Corresponding author: amitava@princeton.edu

Plasmoid Instability in the Multiphase Interstellar Medium

Drummond Fielding*[1]

[1]Center for Computational Astrophysics, Flatiron Institute – United States

Abstract

Despite the central importance of the interstellar medium (ISM) to many astrophysical systems a robust theory of the interplay of thermal instabilities, turbulence, and magnetic fields remains elusive. I will present a new suite of high resolution 3D MHD simulations of thermally unstable turbulent systems representative of the ISM. Throughout these simulations large current sheets unstable to the plasmoid instability form regularly. This instability enables rapid magnetic reconnection and leads to the formation of plasmoids, which manifest in 3D as flux ropes. I will demonstrate that thermal instabilities can promote the plasmoid instabiltiy and that resulting plasmoids form in three distinct environments: (i) within cold clumps, (ii) at the asymmetric interface of the cold and warm phases, and (iii) within the warm, volume-filling phase. I will end with a brief discussion of the role of the plasmoid instability in setting the magneto-thermal phase structure of the ISM and the scattering of cosmic rays, as well as potential observational probes of these important plasma processes.

*Speaker

Numerical Models of Turbulence at Exascale

James Stone*[1]

[1]Institute for Advanced Study [Princeton] – United States

Abstract

Probing the properties of turbulence in astrophysical plasmas in the nonlinear regime often requires numerical methods. The emergence of exascale computing systems in the past year has increased the computing resources available for such studies by an order of magnitude. A new performance-portable version of the Athena++ AMR MHD code that can run on virtually any existing computer architecture (including GPU accelerated exascale systems) will be described, along with preliminary results from a variety of projects currently underway using this new code. These include a study of MRI-driven turbulence in radiation-dominated accretion flows around black holes, (very preliminary) studies of MRI-turbulence in the local shearing box that have the potential to reach ultra-high resolution, and a new study of MHD turbulence in the weakly ionized phases of the ISM that solves the two-fluid (ions and neutrals) equations directly. The ability to achieve much higher scale separation in these applications promises to enable new insights into astrophysical turbulence.

*Speaker

Origin and evolution of cosmic magnetic fields

Jennifer Schober*[1]

[1]Ecole Polytechnique Federale de Lausanne (EPFL) – Switzerland

Abstract

Magnetic fields are observed on virtually all astrophysical scales of the modern Universe, from planets and stars to galaxies and galaxy clusters. Observations of blazars suggest that even the intergalactic medium is permeated by magnetic fields. Such large-scale fields were most likely generated very shortly after the Big Bang and therefore are a unique window into the physics of the very early Universe.

In my talk, I will review theoretical models of magnetogenesis and confront these with observational constraints. I will address the possible origin of magnetic fields in the very early Universe, during inflation and the cosmological phase transitions, as well as their pre-recombination evolution in decaying magnetohydrodynamical (MHD) turbulence. Finally, I will present results from high-resolution numerical simulations that show an efficient amplification of magnetic energy due to the so-called chiral anomaly, a standard model effect that necessarily leads to an extension of the MHD equations at high energies.

*Speaker

MHD turbulence: a biased review

Alexander Schekochihin*[1]

[1]University of Oxford – United Kingdom

Abstract

The last several years have seen significant, and intellectually exciting, progress in the theory of MHD turbulence. The refrain of this progress is the definitive intertwining of turbulence and reconnection physics in all interesting contexts: tearing-mediated inertial-range cascade in MHD with a guide field (1 and references therein), reconnection-controlled decay of MHD turbulence (2), tearing-limited dynamo saturation (3), etc. I tried to give a long, detailed account of the subject in (1) — an account that could be useful as a tutorial and was, therefore, deliberately biased towards a particular logical (and chronological) narrative. In this talk, I will attempt a different (and perhaps more difficult) task, viz., to explain how several distinct (and distinctive) intellectual threads of MHD turbulence theory pursued by different groups of researchers over the last few decades are coming together in the emerging overall narrative: the critical-balance phenomenology (Goldreich & Sridhar, Boldyrev, Beresnyak, Loureiro, Chandran, Mallet...), the focus on selective decay and coherent structures (Matthaeus, Pouquet...), the school of stochastic reconnection (Lazarian, Vishniac, Eyink...). What are sometimes perceived as mutually exclusive approaches seem to me to be different viewing angles of the same picture — rather a beautiful one, and one we can all be quite proud of. (1) A. A. Schekochihin, "MHD turbulence: a biased review," J. Plasma Phys. 88, 155880501 (2022) (e-print arXiv:2010.00699)

(2) D. N. Hosking and A. A. Schekochihin, "Reconnection-controlled decay of magnetohydrodynamic turbulence and the role of invariants," Phys. Rev. X 11, 041005 (2021) (e-print arXiv:2012.01393)

(3) A. K. Galishnikova, M. W. Kunz, and A. A. Schekochihin, "Tearing instability and current-sheet disruption in the turbulent dynamo," Phys. Rev. X. 12, 041027 (2022) (e-print arXiv:2201.07757)

*Speaker

Are cosmic voids filled with reconnecting magnetic fields from the early Universe?

David Hosking[*†1] and Alex Schekochihin[2]

[1]Princeton University – United States
[2]University of Oxford – United Kingdom

Abstract

It has been suggested that the weak magnetic field hosted by the intergalactic medium (IGM) in cosmic voids might be a relic from the early Universe. If so, the strength and coherence length of fields in voids could be "predicted" from reasonable assumptions about the properties of the primordial field at its genesis, provided the evolution of the fields in the intervening time were understood. Inversely, cosmological models of primordial magnetogenesis could be constrained by precise observations of the fields in voids. In this talk, I shall argue that magnetically dominated turbulent decay — as would be expected to follow magnetogenesis at a phase transition — takes place on the timescale on which energy-containing magnetic structures reconnect, and conserves the random fluctuation level of magnetic helicity in large volumes. This theory implies that relics of primordial magnetic fields would be stronger by several orders of magnitude than predicted by previous models — in particular, we find consistency between the observational constraints on fields on voids and the hypothesis that those fields are relics of a net-non-helical magnetic field generated at the electroweak phase transition.

[*]Speaker
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Magnetic dynamos and the origin of the far-infrared-radio correlation in galaxies

Christoph Pfrommer*[1], Maria Werhahn[2], Rüdiger Pakmor[2], and Philipp Girichidis[3]

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[2]Max-Planck-Institut für Astrophysik – Germany
[3]Heidelberg Universität – Germany

Abstract

The discovery of the far-infrared-radio correlation in galaxies over more than half a century ago has puzzled many astrophysicists: while the calorimetric theory for the radio emission is a simple and attractive explanation, it predicts radio synchrotron spectra that are much too steep in comparison to observations. Moreover, the super-linear slope of the relation raises questions about the saturation level of the magnetic dynamo in galaxies. Using magneto-hydrodynamic simulations of forming galaxies, I will show that gravitational collapse of the proto-galaxy generates turbulence at the corrugated accretion shock, which drives a small-scale magnetic dynamo. As the shock propagates outwards, supernova explosions and the shear associated with the fast rotating galactic disk and the hot halo plasma inject additional turbulence and continuously drive multiple small-scale dynamos, which exponentially amplify weak seed magnetic fields until saturation with the turbulence. Modeling the steady-state spectra of cosmic ray protons and electrons, we find that our simulated star-forming and star-bursting galaxies with saturated magnetic fields match the global far-infrared-radio correlation across four orders of magnitude. In combination with analytical arguments, this solves the long-standing question of the origin of the far-infrared-radio correlation and enables us to address the physical cause of its scatter. Moreover, we show how calorimeter theory can be reconciled with the observed flat radio spectra in starburst galaxies by additionally considering free-free absorption and emission at low and high radio frequencies, respectively.

*Speaker

Particle acceleration in astrophysical, magnetized turbulent plasmas

Martin Lemoine*†[1]

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Abstract

How magnetized turbulent plasmas can accelerate charged particles to high energies represents a long-standing question with far-reaching implications for high-energy and multi-messenger astrophysics. It indeed goes back to the seminal works of Enrico Fermi (1949, 1954) and nowadays, it is commonly invoked to model the generation of non-thermal particle spectra in a broad variety of astrophysical sites, including extreme, relativistic sources. Our understanding of particle acceleration in turbulent plasmas has known substantial progress in recent years, mostly spurred by large-scale, kinetic numerical simulations. This talk will address those developments and discuss a theoretical picture to describe the physics at play, based on non-resonant interactions between particles and velocity structures. This model, which can be seen as a modern implementation of the original Fermi scenario, appears supported by recent numerical simulations of turbulence in the semi- and fully-relativistic regime. It also brings to light an interesting connection between the properties of intermittency of the turbulence and the spectrum of accelerated particles. I will discuss those features then conclude with some possible applications and extensions, regarding notably the influence of intermittency on spatial (parallel) transport.

*Speaker

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Beyond Quasilinear Theory: Investigating Non-Gaussian Magnetic Turbulence Models and Charged Particle Transport

Jeremiah Lübke*[1], Frederic Effenberger[2], Horst Fichtner[2], and Rainer Grauer[1]

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Abstract

Quasilinear theory has dominated the description of charged particle transport in magnetic turbulence since the 1960s. While it leads to important insights, one should keep in mind that it characterizes the turbulent magnetic field solely by the power spectrum, which has lead to a wide range of models describing the magnetic field by a simple self-similar random field with a prescribed two-point correlation structure. That this is not sufficient for a more realistic model can be concluded from magneto-hydrodynamic (MHD) simulations and solar wind observations that exhibit multifractal behaviour and coherent structures such as current sheets. Recently, there has been an increased interest in the transport of charged particles in non-Gaussian random magnetic fields as well as MHD fields, yet the exact processes are not yet fully understood. We investigate how certain features of such fields modify the transport behaviour by comparing test particle simulations in simple self-similar random fields, unstructured multifractal random fields, a variant of the minimal multi-scale Lagrangian mapping procedure, and full 3D MHD fields. The statistics and the structures of the employed fields are studied via their structure functions, pair dispersion of fieldlines, and partial variance of increments along virtual spacecraft trajectories.

*Speaker

On the hunt for a new theory of cosmic ray transport

Philipp Kempski*†[1], Drummond Fielding[2], and Eliot Quataert[1]

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[2]Center for Computational Astrophysics, Flatiron Institute – United States

Abstract

Relativistic cosmic rays (CRs) may play an important role in the evolution of galaxies and clusters by driving galactic winds and heating diffuse gas. As a result, "CR feedback" has become a key ingredient in galaxy evolution models. However, a fundamental limitation of these models is that the nature of CR feedback is a very strong function of the assumed CR transport model. In this presentation, I will argue that popular existing transport models are full of theoretical uncertainties and are generally not in good agreement with CR spectra measured close to Earth. This suggests that the microphysical theory of CR propagation needs to be revisited. I will discuss possible new models of CR transport that may help bridge the gap between theory and observations.

*Speaker
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The Star Formation Process on Cloud-Scales: Insights from PHANGS

Eva Schinnerer*[1]

[1]MPIA – Germany

Abstract

Where do stars form and how is their formation regulated across galactic disks are two important questions for our understanding of stellar mass growth in galaxies. High angular observations of nearby galaxies now regularly reach scales of the star-forming units, namely Giant Molecular Clouds (GMCs) and HII regions, resolve their population properties, and hence allow us to sample the time evolution of the star formation process in nearby galaxies. The *PHANGS* (Physics at High Angular resolution in Nearby GalaxieS) collaboration is collecting such cloud-scale data to gain new insights on the molecular gas reservoir (ALMA), dust & embedded star formation (JWST), young stellar clusters (HST) and stellar feedback (VLT/MUSE) and their role in the matter cycle in galaxies. I will introduce the *PHANGS* and present a few highlights from the collaboration research relevant to the theme of the workshop.

*Speaker

Control of star formation by turbulence, magnetic fields, and feedback

Christoph Federrath*[1]

[1]Australian National University – Australia

Abstract

The dynamics and structure of the interstellar medium is controlled by turbulent MHD flows. In this talk, I will try to motivate and link the statistics and physics of MHD turbulence to the physics of star formation, and discuss the role of stellar feedback as well. I will also present results from the largest turbulence simulations ever run, and how they may be relevant for ISM turbulence physics and star formation. Webpage: https://www.mso.anu.edu.au/_˜chfeder/index.html

*Speaker

Structure and turbulence on the Jeans scale in gas disks

Sharon Meidt*[1]

[1]Universiteit Gent [Ghent] – Belgium

Abstract

Galactic orbital motions on the scales of giant molecular clouds represent a source of kinetic energy that is capable of opposing the gravitational collapse of material in the outer cloud envelope. I will discuss the implications of these motions for environmentally-varying cloud properties observed in nearby galaxies with PHANGS-ALMA. Then I will discuss the importance of gravitational instability for converting these motions into turbulence, based on a reassessment of the stability of rotating gas disks. Taking into account their 3D nature, gas disks embedded in background stellar disks become unstable even after passing the Toomre stability threshold, on scales closer to the turbulent Jeans length (100s of pc) than predicted in 2D (a few kpc). The rich, filamentary web structures observed in new extragalactic PHANGS- JWST/MIRI images of the dusty ISM appear on these intermediate 100s of pc scales, suggesting that gravitational instability is a pervasive process shaping the ISM of nearby galaxies and driving turbulence on these scales.

*Speaker

The roles of gravity, turbulence, cooling, and the magnetic field during cloud formation

Enrique Vazquez-Semadeni*[1], Vianey Camacho[2], Guido Granda-Muñoz[2], and Gilberto Gómez[2]

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[2]Instituto de Radioastronomia y Astrofisica, UNAM – Mexico

Abstract

The respective roles of gravity, cooling, turbulence, and the magnetic field in the formation of clouds and clumps in the interstellar medium (ISM) remain an open issue. I discuss here numerical results on the complex interplay between these agents. Every new generation of density fluctuations (generically, "clumps") requires compressions in their parent medium, which may be produced by turbulent, thermal and/or large-scale gravitational agents, but not by local self-gravity. Local self-gravity becomes increasingly dominant as the density increases, and gradually begins to drive the kinetic and magnetic energy of the clumps. The observed correlation between field strength (B) and density (rho) can be understood simply in terms of a superposition of nonlinear Alfven, slow, and fast waves, for each of which the field scales differently with density. Self-gravity can additionally affect the correlation at high densities. In a clump sample from a numerical simulation of multi-scale cloud contraction, the kinetic energy Ek scales as the gravitational energy Eg to the -0.86 power, while the magnetic energy Em scales as Eg to the -0.66 power, suggesting that, once self-gravity becomes dominant, it drives the kinetic and magnetic energies of the clumps. The shallower dependence of Em with Eg may arise from the fact that only motions perpendicular to the magnetic field can inject energy into it. Finally, during the formation of clouds by supersonic compressions along the magnetic field in the diffuse ISM, the field is bent at the shock, and the curvature amplified by the compressive velocity gradient towards the cloud, generating a shearing motion around the formed cloud. Therefore, the field is dragged and shaped by the dominant force or inertial motion. However, it also has the effect of inhibiting the development of turbulence by the various instabilities, therefore playing a passive-active role during cloud formation.

*Speaker

The connection between star formation, gravity and turbulence in the ISM

Oscar Agertz*[1]

[1]Lund Observatory – Sweden

Abstract

The gas velocity dispersion is observed to increase with the star formation rate (SFR) of a galaxy, but it is yet not established whether this trend is driven by stellar feedback or gravitational instabilities. In this talk I will discuss what simulations of entire disc galaxies can teach us about the drivers behind ISM turbulence. Our simulations show that disc galaxies can reach the same levels of turbulence regardless of the presence of stellar feedback processes, indicting that this is an outcome of the way disc galaxies regulate their gravitational stability. However, I will demonstrate that large-scale turbulence driving is only sustainable if dense star forming gas is continuously disrupted and redistributed back to larger scales by small-scale stellar feedback processes. Only in this situation can a realistic ISM can develop where density and energy spectra of the ISM, as well as GMC mass functions closely match observations. Finally, I will argue that because the warm and cold ISM can feature dramatically different levels of turbulence, care must be taken when inferring properties of the ISM from diffuser gas tracers (e.g. Halpha) versus cold molecular tracers (e.g. CO).

*Speaker

Universality of gravitation-driven isothermal turbulence in galactic disks

Jeremy Fensch*†[1], Frédéric Bournaud , Noé Brucy , Yohan Dubois , Patrick Hennebelle , and Joakim Rosdahl

[1]CRAL – Université de Lyon, ENS de Lyon – France

Abstract

Star formation in galaxies is very inefficient and the origin of this inefficiency is one of the main open questions in the field of galaxy evolution. The main physical process was initially though to be cloud disruption via star formation feedback. However, recent numerical simulations have shown that feedback energy release is not sufficient for galaxies with gas column densities typical of high-redshift galaxies (see e.g. Brucy et al., 2020). The paradigm is currently shifting towards a higher role of turbulence for more gas-rich galaxies, turbulence being mostly injected by gas accretion and disk dynamics. However, due to the huge spatial range involved, it is difficult to numerically probe the effect of turbulence from its injection scale down to its effect on star formation, typically at ~0.1 pc.

To lift this technical lock, I developed a new method in the RAMSES code, which allowed me to self-consistently trace the self-generated isothermal turbulence cascade injected by galactic dynamics down to 0.1pc (see Fensch et al., 2023, A&A, arXiv: 2301.13221). We are able to resolve both sub-pc scales locally within the full galaxy via an encapsulated zoom technique on a kpc-sized region. The first results obtained on isothermal disks is that the gravitationally-induced turbulence cascades isotropically following Burgers' scalings down to the resolution limit (0.1 pc). The cascade is the same for gas-poor spiral and gas-rich clumpy disks, as well as the power spectrum of the gas surface density and the mass spectrum of gravitationally bound structures, despite different Mach number, morphology and dynamics. These results suggest an universality of gravitationally-driven isothermal turbulence in galactic disks.

Last, I will present preliminary results from a PRACE project (PI Fensch), using the same method, on the effect of gas cooling and star formation feedback on the turbulence cascade and structure formation.

*Speaker

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The impact of magnetic fields on cosmological galaxy mergers

Joseph Whittingham*†[1], Martin Sparre[2], Christoph Pfrommer[1], and Ruediger Pakmor[3]

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[2]University of Potsdam = Universität Potsdam – Germany
[3]Max-Planck-Institut für Astrophysik – Germany

Abstract

During a galaxy merger, strong tidal interactions inject turbulence whilst simultaneously compressing and shearing the gas. In gas-rich mergers, these effects are expected to substantially amplify the galactic magnetic field, which may in turn result in a significant dynamical back reaction. We have investigated this effect by running a series of high-resolution magnetohydrodynamic (MHD) zoom-in simulations of major mergers between disc galaxies. In this talk, I will present some of the key results from these simulations, and will show how MHD simulations produce merger remnants with systematically different morphologies and sizes compared to their hydrodynamic analogues. I will also discuss how the amplified magnetic fields are able to have this impact, and what observations would be consistent with our findings.

*Speaker
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What governs the density evolution of turbulent media?

Evan Scannapieco*[1]

[1]Arizona State University – United States

Abstract

Simulations of isothermal turbulence uncover a normal distribution of log density (s), whose variance depends on Mach number and the nature of the forcing. This distribution is often invoked to model star formation, and a similar distribution arises in non-isothermal turbulence such as may exist in the circumgalactic medium. Yet little is known about the changes in log density (ds/dt) that lead to these results. I will describe a suite of simulations that for the first time measure the distribution of ds/dt and its temporal correlation as a function of flow properties. Then I will show how these results give rise to the observed density distribution and suggest how they can be applied to improve our understanding of astrophysical turbulence on interstellar and circumgalactic scales.

*Speaker

On which scales are circumgalactic metals mixed?

Celine Peroux*†[1,2]

[1]Laboratoire d'Astrophysique de Marseille (LAM) – CNRS : UMR7326, Aix Marseille Université, INSU – Pôle de l'Étoile Site de Château-Gombert 38, rue Frédéric Joliot-Curie 13388 Marseille cedex 13, France

[2]European Southern Observatory – Germany

Abstract

We have now mounting evidences that the circumgalactic medium (CGM) of galaxies is polluted with metals processed through stars. The fate of these metals is however still an open question and several findings indicate that they remain poorly mixed. A powerful tool to study the CGM low-density gas is offered by absorption lines in quasar spectra although limited to 1-dimension. This talk will report the use of close-by bright extended galaxies with fortuitous intervening foreground MgII absorbers along their sightlines. MUSE observations allow us for the first time to spatially resolve kpc-scales in absorption in the plane of the sky over a continuous area. Early results indicate a high efficiency of the metal mixing on kpc-scales and put new observational constraints on turbulent mixing in cosmological simulations.

*Speaker

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The Entrainment of Magnetized and Molecular Gas in Galactic Winds

Peng Oh*[1]

[1]UC Santa Barbara – United States

Abstract

Due to significant progress in the last _˜ 5 years the entrainment of atomic gas, T _˜ 10ˆ4 K gas in galactic winds– which I will briefly review – is now fairly well understood. However, dusty molecular gas which is overdense relative to the wind by 4-5 orders of magnitude is also seen outflowing in galactic winds. This is much harder to understand. We present the first simulations showing successful survival, entrainment and growth of T _˜ 10-100K dusty gas, and discuss the underlying physics. Superfically, despite markedly different gas morphology, the entrainment of clouds in the MHD case is similar to the hydrodynamic case. We show that in fact there are critical underlying differences in the gas physics, and draw parallels with the solar corona.

*Speaker

Origin of high pressure Carbon in the diffuse interstellar medium

Benjamin Godard*[1,2], Guillaume Pineau Des Forêts[2,3], and Shmuel Bialy[4]

[1]Laboratoire de physique de l'ÉNS - ENS Paris – Centre National de la Recherche Scientifique – France
[2]Observatoire de Paris – Observatoire de Paris-Université PSL – France
[3]Institut d'astrophysique spatiale – Institut National des Sciences de l'Univers, Université Paris-Saclay, Centre National de la Recherche Scientifique, Centre National d'Études Spatiales [Paris] – France
[4]Technion - Israel Institute of Technology [Haifa] – Israel

Abstract

The diffuse interstellar medium is full of chemical mysteries. One of those is the presence of substantial amounts of neutral Carbon at high pressure (one to two orders of magnitude above the mean pressure) in all directions in the galaxy (Jenkins & Tripp 2011). We propose that this feature results from the propagation of high velocity shocks (40 km s$ˆ{-1}$ < V_S < 200 km s$ˆ{-1}$) in the warm neutral medium. Such shocks, which incidentally induce phase transition between the warm neutral medium and the cold neutral medium, provide all the necessary conditions to explain optical observations including the excitation conditions and the line profiles of CI. The comparison between models and observations leads to a precise estimation of the distribution of the injection rate of mechanical energy at large scale (few tens of pc). This distribution is found to be in excellent agreement with the expected distribution of injection rates induced by supernovae explosions in the solar neighborhood and show a puzzling similarity with the distribution of the kinetic energy transfer rate deduced from CO observations (Hennebelle & Falgarone 2012, Miville-Deschênes et al. 2017). This work provides a new evidence of the connection between the injection mechanisms and the transfer of energy in the turbulent cascade that develops across the warm and cold phases of the interstellar medium.

*Speaker

Magnetic Fields and Turbulence: Piecing Together the Multiphase Puzzle

Hitesh Kishore Das*[1]

[1]Max Planck Institute for Astrophysics – Germany

Abstract

It is well-known that astrophysical mediums are multiphase and turbulent in nature. At first glance, these two properties don't seem to fit well together, as a turbulent medium would tend to mix a multiphase medium into a homogeneous one. This dilemma can be alleviated by radiative cooling which can cause new, cold material to form again. But, a big piece in the puzzle is still missing: magnetic fields. Magnetic fields drastically change the nature of dynamical processes in a turbulent multiphase medium, and it has been shown that magnetic fields prevent the mixing of multiphase gas. This suppression of mixing can affect the cold gas growth or survival at small scales and the surface brightness of the low density gas and the baryon cycle in larger scales. In this talk, I will present our recent results from our study of small-scale MHD turbulence simulations to understand the effects of magnetic fields on multiphase gas. I will show evidence confirming the effects of magnetic fields in turbulent radiative mixing layers while also showing the surprising lack of change in many outcomes from larger turbulent box simulations. I will explain this dichotomy in the light of the physics of turbulence and mixing and how magnetic fields alter the previous picture.

*Speaker

Lyman-alpha emission from galaxies: simulations and MUSE GTO Deep surveys results

Anne Verhamme*[1]

[1]Observatory of Geneva – Switzerland

Abstract

I will first review the main results obtained since 2919, the last occurence of this conference, from the MUSE GTO collaboration, on the study of the circum galactic medium of galaxies through their Lyman-alpha properties, and the observation of other resonance lines (Maseda+20, Kusakabe+20, 22, Leclercq+22, Vitte+23, Bacon+21). I will then describe our recent achievements in simulating mock resonant line observations from virtual galaxies and their link with the physical properties of the scattering medium, as well as comparisons with observations (Mauerhofer+21, Garel+21, Maji+22, Blaizot+23, Gazagnes+23).

*Speaker

How Supermassive Black Holes Ignite the Intergalactic Medium: Tales from the Low Redshift Lyman-alpha Forest

Blakesley Burkhart*[1]

[1]Rutgers University – United States

Abstract

The Lyman-α forest is a key diagnostic for the state of diffuse baryons in the intergalactic medium (IGM) and for fundamental cosmological parameters. At high redshift (i.e., z $\geq$ 2) the Lyman-α forest is observed in optical wavelengths from ground-based observatories and has been used to constrain small-scale cosmic structure, the dark matter distribution, the IGM gas temperature, and the evolution of the ultraviolet ionizing background (UVB) radiation. However, the low redshift (z_˜0.1) Lyman-α forest, observed from space-based UV instruments such as HST COS, has challenged the most advanced cosmological simulations. In this talk, I will show how active black hole (AGN) feedback can be at least as important (or more!) as the UVB for setting the amount and distribution of neutral gas in the low redshift IGM. The AGN feedback signatures appear in the neutral gas statistics beginning around z_˜1, thus possibly affecting 21-cm intensity mapping programs that target this redshift range (e.g., HIRAX). These findings herald a significant paradigm shift for cosmological simulations and observations that target the low redshift IGM and suggest that cosmological simulations should develop AGN feedback models with both galaxies and the IGM in mind.

*Speaker

CH+(1-0) in z_˜2-6 starburst galaxies: probes of extended reservoirs of multi-phasic turbulent gas

Alba Vidal Garcia*[1]

[1]OAN – Spain

Abstract

Submillimetre-selected galaxies at redshifts $z \sim 2$ to 6 are among the most intensely star-forming galaxies in the universe. The way they accrete their gas to form stars at such high rates is still a controversial issue. We have detected the CH+(1-0) line in emission and/or in absorption in all the gravitationally lensed starburst galaxies observed so far with ALMA in this redshift range (1,2).
The unique spectroscopic and chemical properties of CH+ allow this transition to highlight the sites of dissipation of mechanical energy. The absorption lines reveal the intermittent dissipation in massive turbulent reservoirs of diffuse molecular gas extending far out of the galaxies (_˜20 kpc). The broad emission lines with widths up to a few thousands of km/s, arise in myriad molecular shocks powered by the feedback of star formation (3,4,5) and, in one case, an active galactic nucleus (6).

The CH+(1-0) lines therefore probe the sites of prodigious energy releases in the circum-galactic medium (CGM) of these starburst galaxies. Mechanical energy is stored in turbulent motions of molecular gas before being radiated away and lost. These turbulent reservoirs therefore act as extended buffers of mass and energy over timescales of a few tens to 100 Myr.

In comparison, the CH+(1-0) line observed in one nearby starburst galaxy with Herschel/HIFI suggests that the turbulent luminosity of the CGM increases faster than the SFR as z increases, a possible signature of the increased importance of gravitational infall in feeding the CGM turbulence at higher z.

(1) Falgarone et al. 2017

(2) Vidal-García et al. in prep

(3) Godard et al. 2019

(4) Lehmann et al. 2020

(5) Lehmann et al. 2021

(6) Vidal-García et al. 2021

(7) Li et al. 2019
(8) Frayer et al. 2018

*Speaker

The role of turbulence and magnetic fields in the circumgalactic medium of galaxies

Dylan Nelson*[1]

[1]Heidelberg University – Germany

Abstract

I will discuss the role of turbulence and magnetic fields in cosmological magnetohydrodynamical simulations of galaxy formation. Specifically, the large-volume IllustrisTNG simulations allow us to capture the interplay of feedback, halo-scale turbulence, and magnetic field amplification. I will focus on the circumgalactic medium (CGM) – the diffuse gaseous halos surrounding galaxies. This is the interface regime between gas accretion from the cosmic web, and feedback-driven outflows, which come together to form the multi-scale, multi-phase CGM. I will discuss the complex dynamics of this baryonic reservoir, the relative properties of the cool _˜10ˆ4 K phase versus the hot _˜10ˆ6-8 K phase, and the corresponding observational signatures. I will outline the computational challenges and the outlook for future high-resolution galaxy formation simulations which aim to resolve the wide range of scales needed to understand the role of turbulence and magnetic fields in the circumgalactic medium of galaxies.

*Speaker

New observational perspectives on turbulence of the multi-phase diffuse interstellar medium

Marc-Antoine Miville-Deschenes*[1]

[1]Astrophysique Interprétation Modélisation – Commissariat à l'énergie atomique et aux énergies alternatives, Institut National des Sciences de l'Univers, Université Paris-Saclay, Centre National de la Recherche Scientifique, Université Paris Cité, Commissariat à l'énergie atomique et aux énergies alternatives : UMR$_{E9}$005, $CentreNationaldelaRechercheScientifique$: $UMR_7158, UniversitéParisCité : UMR_7158 - -France$

Abstract

The diffuse interstellar medium of galaxies is composed of a cloud / inter-cloud medium where cold (80K) neutral clouds are formed out of a warm (6000K), volume filling, medium. Even though the 21 cm emission is well detected in emission over the entire sky, most of the knowledge on the HI has been built using absorption measurements on a limited number of sight-lines crossing radio sources. Indeed the 21 cm emission is quite complex on most lines of sight, with a mixture of components of various widths reflecting the large temperature distribution of matter. It is only very recently, with the development of new data analysis techniques, that the different phases of the HI could be separated from the emission data themselves, opening the possibility to map-out each phase and finally study their multi-scale properties. With new high-resolution, high-sensitivity and high-mapping speed facilities like ASKAP and MeerKat, we witness the beginning of a new era of Galactic 21 cm emission exploration. In parallel, low-surface brightness surveys in the optical-NIR, aimed at capturing extra-galactic features, are revealing again dust scattering of Galactic cirrus, opening the possibility to map ISM structure down to 1 arcsec over wide areas. In this talk I will present recent results based on the use of new spectral decomposition methods applied to 21 cm data as well as new observations of high-Galactic structures in the optical. In particular I will discuss the properties of turbulence of the warm phase, the variability of the cloud formation efficiency in the diffuse ISM the Milky Way+halo and in the outskirt of the Small Magellanic Cloud, and the very small scale structure of the ISM as revealed by new optical mapping of cirrus clouds.

*Speaker

Faraday tomography at low-radio frequencies

Vibor Jelić*[1] and Ana Erceg[1]

[1]Ruder Boskovic Institute – Croatia

Abstract

The Galaxy's interstellar medium is a complex structure consisting of multiphase gas and dust permeated by cosmic rays and magnetic fields. While the Galactic magnetic field is relatively weak, it is the key to structure organisation in the Galaxy. However, detecting and reconstructing its 3D configuration is challenging, mainly because magnetic field observations are limited to specific tracers probing only a single magnetic field component. One way to study the line-of-sight component of the magnetic field is through linearly polarised synchrotron emission observations, which are affected by Faraday rotation. To analyse these observations, a technique called rotation measure synthesis is used. It decomposes the polarised synchrotron emission by the amount of Faraday rotation it has experienced, allowing us to do so-called Faraday tomography. The rotation measure synthesis will be reviewed during this talk, and the power of Faraday tomography will be demonstrated on low-frequency radio observations.

*Speaker

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Gas and dust structures at pc-scale in nearby galaxies with JWST: probing the dissipation of feedback-driven mechanical energy

Pierre Guillard*[1,2]

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Abstract

The JWST has the capability to image gas and dust structures in nearby galaxies, at resolutions below the Toomre-unstable length (a few kpc), the turbulent Jeans length (a few hundred pc), and the disk scale height (tens of pc) for the closest objects. The combination of JWST data with tracers of molecular gas at high spectral resolution with ALMA offer the possibility to constrain how mechanical and radiative feedback processes interact with the surrounding multiphase gas reservoir, and impact the rate and location of star formation. In this talk we describe the pc-scale structures in nearby galactic disks and the Stephan's Quintet galaxy collision. We then discuss how we can use these data to constrain the interactions between the different phases of the ISM, as well as the rate of dissipation of the kinetic energy injected by feedback processes into the molecular phase.

*Speaker

Metal mixing in nearby galaxies

Kathryn Kreckel[*†1]

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Abstract

Gas-phase metallicities track the growth of stellar mass and the pollution from massive stars into the interstellar medium (ISM), providing a unique tracer of galaxy evolution. With new VLT/MUSE optical integral field spectroscopy, the PHANGS team now has a wealth of emission line maps that trace different ionization sources and physical conditions at the 50pc spatial scales needed to isolate individual ionized regions (e.g. HII regions, supernova remnants, planetary nebulae) from surrounding diffuse ionized gas. I will present our most recent results measuring the gas phase oxygen abundances for 24,000 HII regions across 19 galaxies in the PHANGS-MUSE survey. We move beyond simple radial gradients to search for signatures of azimuthal abundance variations. Regions with enhanced abundances have high ionization parameter and are associated with younger star clusters and higher molecular gas densities, indicating a correlation between recent star formation and locally enriched material. We further place quantitative constraints on the mixing scale within the ISM. We find correlations between metallicity variations, gas turbulence and SFR, driven principally by dilution rather than pollution, demonstrating the role of mixing in regulating the ISM.

[*]Speaker

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Energy budget of galaxies: shocks and PDRs in 3C 326

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Abstract

Shocks are ubiquitous in the interstellar medium (ISM) as a result of a variety of astrophysical phenomena such as outflows, supernovae, jets among others. The perturbations created by these phenomena traverse the ISM, disturbing and changing the thermal, chemical, and physical characteristics of the environment. Therefore, understanding the underlying physics of shocks provides us with a powerful tool to study how the mechanical energy is dissipated in extragalactic sources. We show preliminary results of a project focused on the interpretation of H2 molecular emission (e.g., pure rotational and ro-vibrational transitions) in radiogalaxies observed with the Spitzer IR Spectrograph and VLT/SINFONI imaging spectroscopy. The emission is assumed to be produced by ensembles of shocks/PDRs inside the observation beam. Particularly, we studied the radio galaxy 3C 326, a galaxy with low star formation (0.07 M/yr) and large amounts of H2 (3.5x10ˆ9 M). The fitting method is based on the H2 lines, Herschel/PACS (CII)158 μm and (OI)63 μm. In this galaxy, the mechanical and UV power are found to be mostly reprocessed by the diffuse medium (i.e., nH = 10-100 cmˆ-3) contrary to what is expected in extragalactic sources. The derived mechanical power seems to be independent of the medium that reprocesses this energy. A fit with both shocks and PDRs is needed to reproduce the observed fluxes. This is a novel method that allows us to obtain the mechanical and UV contribution from observations while being consistent with the total energy budget of the source. We hope to apply this method to a larger sample of galaxies. This study opens a door to understanding energy dissipation in extragalactic sources produced by ensembles of shocks/PDRs in a multi-wavelength context being a key point to exploit and interpret future JWST observations and to put constraints on feedback and dissipation processes.

*Speaker

Magnetic field amplification in galaxy clusters with AREPO

Thomas Berlok*[1,2], Christoph Pfrommer[2], Ewald Puchwein[2], Rüdiger Pakmor[3], Martin Sparre[2], Joe Whittingham[2], Larissa Tevlin[2], and Lorenzo Perrone[2]

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[2]Leibniz Institute for Astrophysics Potsdam – Germany
[3]Max Planck Institute for astrophysics – Germany

Abstract

I will discuss the amplification of magnetic fields by the turbulent dynamo in the intracluster medium of galaxy clusters. I will show results from cosmological, high resolution, non-radiative zoom-in MHD simulations that were performed with the moving mesh code AREPO. Using these simulations, we have found criteria for obtaining a converged magnetic field at a given redshift and distance to the cluster center. I will present power spectra and curvature statistics for the magnetic field in order to demonstrate that its amplification to _˜μG values is done by the turbulent small scale dynamo. The presented simulations will be part of an upcoming galaxy cluster simulation suite that will investigate the effects of including a sophisticated momentum-driven AGN jet feedback, cosmic rays and a treatment of the weakly collisional intracluster medium using Braginskii viscosity. I am leading the effort to include Braginskii viscosity in these upcoming simulations and will present how we have implemented the comoving Braginskii equations in AREPO.

*Speaker

Generation and amplification of magnetic fields in a collisionless plasma

Muni Zhou*†[1], Vladimir Zhdankin[2], Matthew Kunz[1], Nuno Loureiro[3], and Dmitri Uzdensky[4]

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[2]Flatiron Institute – United States
[3]Massachusetts Institute of Technology – United States
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Abstract

Astronomical observations suggest pervasive micro-gauss magnetic fields in our Galaxy and in the intracluster medium (ICM) of galaxy clusters. It is widely believed that such dynamically important magnetic fields are produced by plasma dynamos acting upon some "seed" magnetic fields. However, a complete understanding of this process in a weakly collisional plasma is still lacking. We report a first-principles numerical and theoretical study of plasma dynamo in a fully kinetic framework. By applying an external mechanical force to an initially unmagnetized plasma, we develop a self-consistent treatment of the generation of "seed" magnetic fields, the formation of turbulence, and the inductive amplification of fields by fluctuation turbulent dynamo. The driven large-scale motions in an unmagnetized, weakly collisional plasma are subject to strong phase mixing which leads to the development of thermal pressure anisotropy. The Weibel instability is thus triggered and produces the filamentary, micro-scale "seed" magnetic fields. The plasma is thereby magnetized, enabling the stretching and folding of the fields by the plasma motions and the development of pressure-anisotropy instabilities. The scattering of particles off these microscale magnetic fluctuations provides an effective viscosity, regulating the field morphology and turbulence. During this process, the seed fields are further amplified by the fluctuation dynamo until reaching the equipartition with the turbulent flow. The saturated state of the dynamo and its contrast to a MHD dynamo will also be discussed.

*Speaker
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Turbulent regimes from interactions of 3D Alfvén-wave/kinetic-Alfvén-wave packets

Silvio Sergio Cerri*[1], Thierry Passot[1], Dimitri Laveder[1], Pierre-Louis Sulem[1], and Matthew W. Kunz[2]

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Abstract

A wide range of space and astrophysical systems host turbulent, magnetised plasmas. The turbulent cascade transfers energy from the injection to dissipation scales: how this transfer occurs and how turbulent fluctuations are dissipated feeds back on the macro-scale evolution and energetics of such systems. At large ("fluid") scales, the cascade is described by magnetohydrodynamic (MHD) turbulence, and the building blocks of its Alfvénic component are the interaction of counter-propagating Alfvén waves (AWs). At small ("kinetic") scales, the Alfvén-wave branch becomes dispersive and such cascade can be mediated by the interaction between both counter- and co-propagating kinetic-Alfvén-waves (KAWs). Another fundamental aspect of plasma turbulence is the formation of current sheets that typically undergo disruption through magnetic reconnection, which is a process that has been also suggested to potentially mediate the turbulent energy transfer at "small" scales.

In this talk, we report results from large-size, three-dimensional (3D) gyro-fluid simulations in which we revisit the problem of AW collisions as building blocks of the Alfvénic cascade at MHD scales. The interplay between AW interaction and magnetic reconnection is investigated depending on the turbulent regime that is present at the injection scales. We discuss three type of turbulent regimes that can arise from different large-scale conditions and their relevance in the context of solar-wind turbulence. We will also present preliminary results on kinetic-range turbulence arising from simulations of 3D KAW-packets interaction.

*Speaker

Turbulence and magnetic fields in the formation of black holes and Pop-III stars at cosmic dawn

Felix Mirabel*[1,2]

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[2]Instituto de Astronomia y Fisica del Espacio (IAFE) – Ciudad Universitaria. Buenos Aires, Argentina

Abstract

The existence of supermassive black holes (SMBHs) of 10ˆ9 solar masses in quasars when the universe was less than 10ˆ9 years old has been an intriguing puzzle since their discovery 20 years ago. How the seeds of these SMBHs have formed and grown so fast to become so large? Recently, has been found that turbulence in converging cold flows give birth to the first massive BH seeds by direct collapse, with no need of star formation. During the following gas accretion phase, strong shocks greatly amplify magnetic fields, and rapidly growing BHs launch relativistic magneto-hydrodynamic Jets and massive outflows, that in the high gas densities at cosmic dawn induce the formation of the first massive stars of PoP-III. Therefore, if BHs come first as new observations and new models suggest, the paradigm of PoP-III stars and BHs formation may have to be changed.

*Speaker

The impact of turbulence, magnetic fields and cosmic rays on the circumgalactic medium: from kpc to AU scales

Suoqing Ji*†[1]

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Abstract

Multiphase gas structure is ubiquitous in our universe. Recent observations suggest that large quantities of cool (10ˆ4 K) gas are detected in the circumgalactic medium (CGM) of galaxy halos, which extends up to a few times of galactic virial radius. In addition, warm gas at a few 10ˆ5 K is found to be tightly associated with the star-forming galaxies, but not the quenched ones. However, the origin and fate of such multiphase gas remain unclear. In this talk, I will discuss how magnetic fields, turbulent mixing layers and cosmic rays can play a crucial role in the formation and stability of the multiphase CGM.

*Speaker

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Turbulence, Magnetic Fields, and Thermodynamics of the ISM in Regulating Galactic Star Formation Rates

Chang-Goo Kim*[1]

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Abstract

Structure formation in the universe is not a one-way process solely driven by gravity. One profound piece of evidence is that, on galactic scales, star formation proceeds at a rate two orders of magnitude below the maximum set by pressureless collapse. Turbulence driven by energetic feedback is often believed to be a dominant player in preventing efficient gas consumption. However, the total stress supporting the overlying gas weight consists of thermal, turbulent, and magnetic components. Each stress component is a consequence of intricate coupling between feedback in different forms and interstellar medium (ISM) physics. To quantify the role of each stress in regulating pressure support and star formation rates (SFRs), we conduct a suite of simulations controlling physics ingredients – supernova (SN), UV radiation, and large-scale shear. We use a new extension of the TIGRESS numerical framework, called TIGRESS-NCR, to include non-equilibrium cooling and heating coupled with on-the-fly ray-tracing UV radiation transfer on top of well-tested SN feedback. The large-scale turbulent stress driven mainly by SN feedback dominates the total stress only in high-pressure environments. The thermal pressure dominates in low-pressure and low-metallicity environments. The magnetic component contributes to the level similar to or higher than turbulence unless either strong turbulence driver (i.e., SNe), rotation, or shear is absent. In a wide range of galactic parameter space, turbulence is not a dominant contributor to the total stress, implying that holistic modeling of ISM physics and feedback is necessary to regulate galactic star formation rates and shape the ISM.

*Speaker

The status of the LOFAR Epoch of Reionization Project

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Abstract

The main aim of the LOFAR EoR project is to statistically detect the 21-cm signal from the Epoch of Reionization between redshifts 6-11. The project obtained over 3000 hours of data so far on two main observational fields observing (NCP and 3C196). In this talk, I will give an overview of the recent progress in understanding and modeling the systems and the new upper limits of the power spectrum statistics. I will show preliminary results regarding the implications of these new upper limits on the physical properties of the IGM during the EoR.

*Speaker

The Effects of MHD, Turbulence, and Photo-Ionized Gas on the Dynamics of Wind-Driven Bubbles

Lachlan Lancaster*[1]

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Abstract

Star formation feedback is a key regulator of the growth and evolution of a galaxy's stellar population and drives powerful outflows that can determine the structure of gas on cosmological scales. This feedback, even in the so-called 'early' (pre-supernova) phase, also determines the formation of the first star clusters and plays a major role in the reionization of the universe. I will show how the presence of magnetic fields and turbulent flows can strongly impact the effects of star formation feedback and emphasize how different feedback mechanisms can work together to drive outflows. I will first focus on the way stellar wind-driven bubbles are affected by this physics, along with the presence of photo-ionized gas, by presenting a theory that determines how their evolution is changed by turbulent mixing. I will then comment on the similarities between these bubbles and those driven by supernovae before discussing the co-evolution of stellar wind-driven bubbles with their surrounding photo-ionized gas regions.

*Speaker

On the physical nature of multiphase galactic outflows

Ulrich Steinwandel*[1], Chang-Goo Kim[2], Greg Bryan[3], Eve Ostriker[4], Rachel Somerville[1], and Drummond Fielding[1]

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[3]Columbia University – United States
[4]Princeton University – United States

Abstract

Galactic winds are observed to be of multiphase nature and consist of cold, warm, and hot gas that can well be traced by HI and CO in the cold, H-alpha in the warm, and at the highest gas temperatures via photo-ionized metal species such as MgII or OIII or X-rays. While this presents a substantial challenge for outflow observations due to the fact that we need to invest in different techniques and instruments, the challenge with respect to the numerical modeling is equally hard due to the small-scale physics involved and the high resolution needed to resolve the launching and subsequent mixing of the gas further out in the CGM. I will present a set of high-resolution simulations (solar mass and sub-parsec) of isolated dwarf galaxies, targeted to understand the launching, evolution, and interaction of galactic winds with their host systems and their surrounding ambient medium. Our simulations include single star formation, non-equilibrium cooling, and chemistry as well as the resolved feedback from photo-ionizing radiation as well as supernovae. Consistent with a number of different outflow simulations we find that the warm wind (T around 1e4 K) is transporting most of the mass while the hot wind is responsible for the bulk of the energy budget in the wind (T around 5e5 K). At high altitudes (height z around 10 kpc) the hot starts to cool adiabatically and subsequently merges with the hot CGM. Our simulations are able to successfully reproduce the observed low mass loading factors observed in local dwarf galaxies and can recover their multiphase nature. However, the energy loading appears lower than predicted by some theoretical models, posing a joint challenge for analytic wind theory and direct numerical simulation which will be targeted in forthcoming work. Our paper can be found at https://ui.adsabs.harvard.edu/abs/2022arXiv221203898S/abstract

*Speaker

POSTERS

In alphabetical order of first author

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Faraday tomography of mock observations of diffuse ISM

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Abstract

Faraday tomography has been widely used in radiopolarimetry observations and has shown a new view of the whole sky with new structures as depolarization canals. To give an interpretative framework on this observations we need a comparison with numerical simulations. Using diffuse ISM MHD simulation, I apply RM-Synthesis on the output cubes of the simulation. This process allows us to do a deeper analysis of the structures, seen in fucntion of the Faraday depth. In particular, changing initial conditions as the turbulence forcing or the electron density could effectively change the Faraday structures. All those simulated Faraday cubes will eventually used as a database of a ML-algorithm to get physical parameters from each slice of any observationnal Faraday cube.

*Speaker

Modeling the large-scale structure and the neutral hydrogen content of the universe.

Brandon Bisschoff*[1], Yin-Zhe Ma*†[1], Ayodeji Ibitoye*[1], and Denis Tramonte*[1]

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Abstract

Studies on the rest frame 21 cm spectral emission line of neutral Hydrogen (HI; from the hyperfine spin-flip state transition) provides an interesting and novel way of studying the large-scale structure (LLS), baryon acoustic oscillations (BAO), cosmological models and galaxy dynamics and evolution. By modelling the distribution function of HI within dark matter halos and, consequently, the correlation power spectrum from this HI distribution function, it is possible to derive the HI content within galaxies, halos and the universe, and also the LLS of the universe. To achieve this goal we used the HALOMOD python package to carefully model the halo occupation distribution (HOD) for discrete and continuous HI tracers, and also the total HI-galaxy cross-power spectrum. This HI-galaxy cross-power was then fitted with the EMCEE python package to HI-galaxy cross-correlation data from the literature with redshifts between and scales between . The fit allowed to model the LLS of the universe, constrain the HOD parameters and derive several cosmological parameters, for e.g. the density fraction of HI and the average, minimum and maximum mass of HI per halo and galaxy. These results improve previous constraints on the structure and HI content of the universe, and also star and galaxy formation and evolution models.

*Speaker

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Shear dynamo action in non-helical base flows

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Abstract

The generation of small scale, mean or large scale magnetic fields in cosmos and in astrophysical bodies is an important problem in astrophysical plasmas. The dynamo mechanism is believed to be the key mechanism behind the existence of magnetic fields in various astrophysical bodies. Recently, the exact role of fluid helicity in the context of dynamo instability has been examined via direct numerical simulation.

Shear flows often coexist in astrophysical conditions and the role of flow shear on the onset of dynamo is only beginning to be investigated. The paradigm of investigation of the exponential growth of magnetic field caused by the interaction of small-scale velocity fluctuations and a flow shear; is commonly referred to as the "shear dynamo problem". In the present work, we have investigated the shear dynamo action using a kinematic dynamo model. For helical base flows, flow shear is shown to effectively suppress small-scale dynamo activity across a wide range of the magnetic Reynolds number. We report several new findings, when a non-helical flow is used as the base flow. Specifically, we find that in the absence of shear flows, the considered non-helical flow is unable to induce exponential amplification of magnetic energy. Interestingly, when the flow shear is introduced, it is found that the small scale non-helical base flow produces magnetic energy that grows exponentially with time. We obtain an algebraic (combination of linear and non-linear) scaling, for the growth rate of magnetic energy (gamma) with shear flow strength (S). Our numerical result for the dependence of gamma on S is found to generalize earlier analytical findings.

We have performed the above said studies using an in-house developed, multi-node, multi-card, well benchmarked GPU based 3D Magnetohydrodynamic solver (GMHD3D). Details of this study will be presented.

*Speaker

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On the radial profile of filaments formed in a turbulent context

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Abstract

Recent observations have exhibited that stars form preferentially along dense filaments (see e.g. Andre et al. 2019). A good comprehension of these structures is thus crucial to better constrain the star formation models. However, most of the observed characteristics of these filaments are still poorly understood. In particular, their radial profile is the subject of much debate because it appears much less steep that the one predicted by Ostriker (1964). Several models have been developed (Fiege & Pudritz 2000,Fischera & Martin 2012} to explain this profile highlighting the key role of magnetic field and external pressure. However, these studies consider that the structures are in equilibrium, a hypothesis that can be challenged: filaments are now often considered to be out of equilibrium because of an active accretion flow. Furthermore, the role of turbulence is not considered in these models.

Here, we propose that the radial profile of the filaments might directly arise from their turbulent origin. We compute the probability distribution of the shape of a 3D ellipsoid formed by lognormal density turbulent fluctuations and show that the average radial profile of the ellipsoid is very close to r^{-2} as widely observed. As the filaments seem to maintained in a quasi dynamical equilibrium by ongoing turbulent accretion flows, this profile should remain during the evolution. We also show that the most probable aspect ratio of structures formed in that turbulent context is about 4, of the same order as the values commonly observed in the interstellar medium. These first results suggest that a closer look to the turbulent origin of the filaments could help us to better understand their structure.

*Speaker

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Non-thermal particle acceleration and power-law tails via relaxation to universal Lynden-Bell equilibria

Robert Ewart*†[1,2], Michael Nastac[1,3], and Alexander Schekochihin[1,4]

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Abstract

Collisionless and weakly collisional plasmas often exhibit non-thermal quasi-equilibria. Among these quasi-equilibria, distributions with power-law tails are ubiquitous. It is shown that the statistical-mechanical approach originally suggested by Lynden-Bell (1967) can easily recover such power-law tails. Moreover, we show that, despite the apparent diversity of Lynden-Bell equilibria, a generic form of the equilibrium distribution at high energies is a 'hard' power-law tail (akin to those observed in cosmic ray sources). The shape of the 'core' of the distribution, located at low energies, retains some dependence on the initial condition but it is the tail (or 'halo') that contains most of the energy. Thus, a degree of universality exists in collisionless systems.

*Speaker

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Metastability of magnetically supported atmospheres

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[3]Princeton Plasma Physics Laboratory – United States

Abstract

The linear and nonlinear stability of a hydrodynamic atmosphere against adiabatic perturbations is determined by the well-known Schwarzchild criterion: an atmosphere is stable if its entropy increases with height. However, the generalisation of this criterion to atmospheres that are partially supported by magnetic pressure only guarantees linear stability. In this talk, I demonstrate that there exist "metastable" magnetised atmospheres, which are unstable to large perturbations despite being stable to small ones. I show how the density, pressure and magnetic-flux profiles of metastable atmospheres can be derived analytically, demonstrate their nonlinear relaxation using numerical simulations, and explain how the nonlinearly relaxed states can be determined theoretically using the statistical theory of "violent relaxation" originally developed in the context of stellar dynamics. I discuss possible applications of the metastability phenomenon to explosive releases of energy in astrophysical plasmas.

*Speaker
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Dynamical properties and detectability of the magneto-thermal instability in the intracluster medium

Jean Kempf*†[1], Francois Rincon , and Nicolas Clerc

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Abstract

Amongst the many plasma processes potentially relevant to the dynamics of the intracluster medium (ICM), turbulence driven at observable scales by magnetised buoyancy instabilities like the magneto-thermal instability (MTI) stands out in the outskirt of the ICM, where the background temperature decreases with radius.
We characterize the statistical properties of MTI turbulence in the ICM and assess whether such large-scale magnetised dynamics would be detectable with the future X-ray spectrometer X-IFU onboard ATHENA.
We make use of scaling laws derived by Perrone & Latter (2022a,b) to phenomenologically estimate the observable turbulent saturation levels and injection length of MTI turbulence for different ICM thermodynamic profiles, and perform a numerical simulation of the dynamics with Braginskii heat and momentum diffusion. We then use the simulation to construct synthetic observations of MTI turbulence with the X-IFU, using the SIXTE software.
In bright enough regions amenable to X-ray observations, the MTI drives mild turbulence: the measurable integrated temperature fluctuation and line-of-sight velocity field, which is essentially the azimuthal velocity component in cluster haloes, hardly exceeds 2% and 10 km/s respectively. We show that such moderate signals would be difficult to detect, even with X-IFU specifications. We also find that MTI turbulence develops at scales (_˜> 2Mpc), larger than the X-IFU field of view for local clusters, and is anisotropic in the direction of the gravity. If the fluctuation intensities were to be stronger than the current theoretical estimates, MTI fluctuations may be detectable and their anisotropy discernible with the X-IFU.
Finding direct signatures of magnetised plasma dynamics in the ICM, even at observable scales typical of the fluid MTI, remains challenging. However, this study only marks a first step in this direction. Several numerical and observational strategies are discussed to make further progress in the future.

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The Role of Viscosity in Galaxy Clusters

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Abstract

Viscosity is inherently related to turbulence, since it has a direct impact in how turbulent a plasma is. However, the impact of viscosity on the Intracluster Medium (ICM) is still under debate and it can be essential in mixing and turbulence processes and, therefore, the interaction of galaxies within galaxy clusters and the evolution of galaxies. For this reason, a deep study on the effect that viscosity has in the evolution of Galaxy Clusters from a numerical simulation point of view can give us a hint of gas properties and the dynamics going on in the ICM. The effect of viscosity is to suppress turbulence at small scales, producing morphological differences compared to inviscid simulations, differences in the way that shocks propagate and a strong effect in the dynamo amplification, which leads to weaker magnetic fields in Galaxy Clusters.

*Speaker

Modeling the impact of MHD turbulence on dust transport and evolution

Eric Moseley*†[1] and Romain Teyssier

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Abstract

Dust is critical to the transport of energy within and away from galaxies. Thus, by impacting both the evolution and transport of dust, magnetized turbulence can impact the evolution of galaxies fundamentally. To understand the impact of turbulence on grain dynamics on a fundamental level, we have implemented novel magnetohydrodynamic(MHD)-particle-in-cell(PIC) methods into the astrophysical fluid code RAMSES. Using this code, we use driven dusty turbulence simulations with a range of plasma beta and sonic Mach number to understand the factors that control the equilibrium grain velocity distribution. We present a simplified empirical model for these distributions based on the results of our simulations. Crucially, the grain charge-to-mass ratio has a profound impact on the dynamics of grains in a wide range of environments, a factor which has often been ignored in sub-grid and larger-scale models.

*Speaker

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Whistler suppression of the magneto-thermal instability in galaxy clusters

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Abstract

In the hot and dilute intracluster medium (ICM), kinetic plasma instabilities that are excited at the particles' gyroradius may play an important role in the transport of heat and momentum on macroscopic scales. Due to the extreme scale separation, current fluid simulations rely on subgrid models to describe the effect of microscale kinetic instabilities on the large-scale turbulence. In this work, we focus on the effect of the whistler instability, which is thought to suppress thermal conductivity in the ICM below the Spitzer value. We model its impact on the turbulence produced by the magneto-thermal instability (MTI), which may be active in the periphery of galaxy clusters, and relies on fast thermal conduction along magnetic field lines. We simulate MTI turbulence with a Boussinesq code, SNOOPY, and implement a closure for the thermal conductivity inspired from previous kinetic simulations of the whistler instability. Our subgrid model is characterized by a free parameter, which depends on the level of collisionality of the ICM, and on the nominal (Spitzer) efficiency of heat conductivity on cluster-wide scales. For modest suppression of the conductivity, the character of MTI-driven turbulence remains essentially unvaried, albeit with turbulent fluctuations of proportionally lower amplitude, in agreement with previous results. However, above a critical threshold, the MTI loses its ability to maintain equipartition-level magnetic fields through a small-scale dynamo, and the system enters a "death-spiral". For realistic physical parameters, we estimate the ICM to be marginally below this critical value. We finally study the effect of adding an external source of turbulence and find that it has a beneficial effect on the MTI by keeping the magnetic fields at equipartition levels, thus revitalizing the "dead" simulations. These results allow us to build a more comprehensive picture of how kinetic processes affect the plasma dynamics on astrophysical scales.

*Speaker

Merger trees and dynamo in the weakly collisional plasma of galaxy clusters

Yoan Rappaz*[1]

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Abstract

The intracluster medium (ICM) is the diffuse gas that fills the space between galaxies within galaxy clusters. It is primarily composed of plasma, which reaches virial temperatures of up to 10ˆ8 K due to highly-energetic mergers of dark matter subhalos. Under these conditions, the plasma is weakly collisional and therefore has an anisotropic pressure tensor with respect to the local direction of the magnetic field. This allows for the development of very fast, Larmor-scale, pressure-anisotropy-driven kinetic instabilities that alter the dynamics of magnetic field amplification.

The aim of our work is to study the growth rate of the magnetic field during the formation of a galaxy cluster, in which the turbulence is driven by successive mergers of dark matter halos. We also want to establish a redshift limit from which a dynamo process has to start to amplify the magnetic field up to equipartition with the turbulent velocity field.

Our model is based on 10ˆ3 merger trees obtained from the modified Galform algorithm (Parkinson et al. 2008), and we implement one-dimensional radial profiles for various plasma quantities. We also construct an effective model for the Reynolds number dependence on the magnetic fields over three different magnetization regimes (unmagnetized, magnetized "kinetic" and "fluid"), to mimic the effects of kinetic instabilities.

*Speaker

Galactic Winds and Cosmic Rays in CRISPy Galaxies

Timon Thomas*†1

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Abstract

The evolution of a given galaxy is determined by the physical processes influencing its interstellar medium. Alongside supernova explosions, radiation pressure and radiative heating, cosmic rays have been identified as an important feedback agent that is able to regulate star formation and shape the dynamics of the interstellar medium. Both cosmic rays (CRs) and the interstellar medium are tightly connected. Next to providing an additional pressure component counteracting gravity, CRs (partly) ionise and consequently heat neutral regions of the interstellar medium even if other heating mechanisms or ionising UV radiation are absent. On the other hand, the chemical composition and the magnetic field topology of the interstellar medium directly influence how CRs are transported along magnetic field lines. In my talk, I introduce the CRISP (Cosmic Ray and InterStellar Physics) framework which models the aforementioned processes to investigate their combined dynamics and their influence on galaxy evolution. I present the first simulations of idealized Milky Way-type galaxies which were performed using the CRISP framework. I focus my presentation on three points: 1) the heating race between the photoelectric effect and CRs in dense regions 2) how CRs are transported through neutral parts of the interstellar medium and 3) how they are working in unison with supernovae to drive highly structured and turbulent galactic winds.

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