

**MIST2025 - Cosmic turbulence and Magnetic fields:
physics of baryonic matter across time and scales**
29 Sep-3 Oct 2025 Cargèse (France)

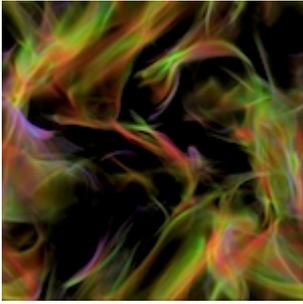
BOOK of ABSTRACTS

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| MONDAY | |
| 29 SEPTEMBER | |
| Notes : | R: Review talk (35' = 25' + 10') I: Invited talk (25' = 20' + 5') C: Contributed talk (15' = 12' + 3') |
| 08:50-9:00 | Welcome address - Marc-Antoine Miville-Deschênes and Edith Falgarone |
| 9:00-10:25 | Session I - Astro: Star Formation and ICM - Chair: Bruce Elmegreen |
| 09:00 R | Schinnerer, Eva [MPIA, Heidelberg, Germany] <i>Molecular gas and the star formation process on cloud scales in nearby galaxies</i> |
| 09:35 R | Hennebelle, Patrick [AIM, CEA, France] <i>What regulates star formation in Galaxies? Turbulence, magnetic field and stellar feedback</i> |
| 10:10 C | Fournier, Martin [University of Hamburg, Germany] <i>The XMagnet Project: Probing Intracluster Medium Turbulence with Exascale MHD Simulations</i> |
| 10:25-10:55 | Coffee Break |
| 10:55-12:20 | Session II - Plasmas - Chair: Olga Alexandrova |
| 10:55 R | Bhattacharjee, Amitava [Princeton University, USA] <i>Universal kinetic distribution functions for collisionless plasmas: implications for stellar coronal heating and dark matter halos</i> |
| 11:30 R | Ewart, Robert [Oxford University, UK] <i>Relaxation to universal non-Maxwellian equilibria in a collisionless plasma</i> |
| 12:05 C | Effenberger, Frederic [Ruhr University, Bochum, Germany] <i>Energetic Particle Transport in Structured and Multiscale Plasma Turbulence: Bridging Observations, Theory, and Simulation</i> |
| 12:30-14:45 | LUNCH - Free time |
| 14:45-16:20 | Session III - Astro: Star Formation, Turbulence - Chair: Eva Schinnerer |
| 14:45 R | Beattie, James [Princeton University, USA] <i>So long Kolmogorov: the forward and backward turbulence cascades in a supernovae-driven, multiphase interstellar medium</i> |
| 15:20 R | Elmegreen, Bruce [Retired, USA] <i>Turbulence Connections to Star Formation</i> |
| 15:55 I | Miville-Deschênes, Marc-Antoine [ENS Paris, France] <i>Multi-phase turbulence in the Solar neighbourhood, from hundreds of pc to milli-pc scales</i> |
| 16:20-16:45 | Coffee Break |
| 16:50-18:05 | Session IV - Plasmas : High-beta plasmas, Solar Wind - Chair: William Matthaeus |
| 16:50 R | Kunz, Matthew [Princeton University, USA] <i>High-beta turbulence in clusters and consequences for cosmic ray diffusion and energization</i> |
| 17:25 I | Servidio, Sergio [University of Calabria, Italy] <i>Relaxation Processes in Astrophysical Plasma Turbulence</i> |
| 17:50 C | Choudhury, Prakriti [University of Oxford, UK] <i>Modeling transport in weakly collisional, high beta plasmas</i> |
| 18:05-18:30 | Lightning presentation of 12 posters (1 slide, 1' each) - - Chair: Pierre Lesaffre |
| 19:00 | WELCOME DRINK |
| TUESDAY | |
| 30 SEPTEMBER | |
| 09:00-10:25 | Session I - Plasmas: Solar wind - Chair: Sergio Servidio |
| 09:00 R | Matthaeus, William [University of Delaware, USA] <i>Turbulence "pressure cooker" and its impact on acceleration of the solar wind and the energization of suprathermal particles</i> |
| 09:35 I (OL) | Sorriso-Valvo, Luca [ISTP/CNR, Bari, Italy] <i>Emergence of two inertial-range dynamical regimes in solar wind turbulence</i> |
| 10:00 I | Alexandrova, Olga [Observatoire de Paris, France] <i>Coherent structures across the turbulent cascade in the solar wind</i> |
| 10:25-10:55 | Coffee Break |
| 10:55-12:20 | Session II - Astro: Galactic disks - Chair: Ralf Klessen |
| 10:55 R | Pichon, Christophe [IAP, France] <i>Galactic Disk Emergence and Resilience</i> |
| 11:30 I (OL) | Tacconi, Linda [MPE, Munich, Germany] <i>The Structure and Dynamics of Galaxies over Cosmic Time</i> |
| 11:55 I | Semenov, Vadim [CfA, Harvard University, USA] <i>Turbulent Formation of First Galaxies and Galactic Disks</i> |

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| 12:30-14:45 | LUNCH - Poster viewing - Free time |
| 14:45-16:25 | Session III - Plasmas: Reconnection - Chair: Amitava Bhattacharjee |
| 14:45 R | Ji, Hantao [PPPL, USA] <i>Magnetic reconnection: experiments and theory</i> |
| 15:20 R | Stawarz, Julia [Notrthumbria University, UK] <i>The interplay between magnetic reconnection and turbulence</i> |
| 15:55 C | Ghosh, Subham [Asia Pacific Center for Theoretical Physics, Korea] <i>Magnetic Reconnection: An Alternative Explanation of Radio Emission in Galaxy Clusters</i> |
| 16:10 C | Rodriguez Montero, Francisco [KAVLI Cosmological Studies, Chicago, USA] <i>The formation of a metastable cosmic ray corona in Milky Way analogues</i> |
| 16:25-16:45 | Coffee Break |
| 16:55-18:10 | Session IV - Astro: ICM, CGM, QSO halos - Chair: Anne Verhamme |
| 16:55 I | Chen, Hsiao-Wen [University of Chicago, USA] <i>Resolving turbulence drivers in the diffuse circumgalactic medium</i> |
| 17:20 I | Zhuravleva, Irina [University of Chicago, USA] <i>Direct Measurements of Gas Kinematics in the Intracluster Medium: First Results from XRISM</i> |
| 17:45 I (OL) | Péroux, Céline [ESO, Garching, Germany] <i>The Multi-Scale Multi-Phase Circumgalactic Medium: Observed and Simulated</i> |
| 19:00-20:15 | Public outreach conference (in French) by Katia Ferrière: <i>Les champs magnétiques dans l'univers</i> |
| WEDNESDAY | |
| 1 OCTOBER | |
| 09:00-10:20 | Session I - Astro: Feedback, CR - Chair: Philipp Girichidis |
| 09:00 R | Pfrommer, Christoph [Leibniz-Institut für Astrophysik Potsdam (AIP), Germany] <i>The role of cosmic ray feedback in galaxy formation</i> |
| 09:35 C | Kjellgren, Karin [University of Heidelberg, Germany] <i>The impact of cosmic rays in Milky Way-like galaxies and their gamma-ray signatures</i> |
| 09:50 C (OL) | Tan, Joanne [MPIA, Germany] <i>Imprints of Feedback on the Cosmic Evolution of Gas and Metals in the IllustrisTNG Simulations</i> |
| 10:05 C | Perrone, Lorenzo Maria [Leibniz-Institut für Astrophysik Potsdam (AIP)] <i>Characterizing turbulence injection by cold fronts and mergers in cosmological simulations of galaxy clusters</i> |
| 10:20-10:50 | Coffee Break |
| 10:50-12:15 | Session II - Astro: Disks - Chair: Matthew Kunz |
| 10:50 R | Lesur, Geoffroy [IPAG, Grenoble, France] <i>Hydro, MHD, dust-gas dynamics in proto-planetary disks</i> |
| 11:25 I | Latter, Henrik [Cambridge University, UK] <i>MHD turbulence and dynamos in accretion disks</i> |
| 11:50 I (OL) | Fensch, Jérémy [CRAL, ENS-Lyon, France] <i>Giant clumps at cosmic noon</i> |
| 12:30-13:30 | LUNCH |
| 14:00-20:00 | BOAT TRIP / Free afternoon |
| THURSDAY | |
| 2 OCTOBER | |
| 09:00-10:25 | Session I - Astro: ISM turbulent plasma - Chair: Marc-Antoine Miville-Deschênes |
| 09:00 R | Ferrière, Katia [IRAP, Toulouse, France] <i>Plasma turbulence in the ISM</i> |
| 09:35 I | Haverkorn, Marijke [Radboud University, The Netherlands] <i>Magnetic fields from low-frequency radio polarimetry (i.e. the Faraday rotation sky) and optical polarimetry</i> |
| 10:00 I | Ocker, Stella [Caltech, Pasadena, USA] <i>Probing cosmic turbulence with fast radio bursts</i> |
| 10:25-10:55 | Coffee Break |
| 10:55-12:15 | Session II - Astro: First stars, shocks - Chair: Mordecai-Mark Mac Low |
| 10:55 I | Klessen, Ralf [University of Heidelberg, Germany] <i>Formation and Properties of the First Stars</i> |
| 11:20 I | Guillard, Pierre [IAP, France] <i>Turbulent mixing and H2 excitation in the Stephan's Quintet shocked circumgalactic medium</i> |
| 11:45 C | Vigoureux, Guillaume [LPENS, Paris, France] <i>A model of SNR expansions in the Milky Way: the hidden ionization factor</i> |
| 12:00 C | Whittingham, Joseph [Leibniz Institute for Astrophysics, Potsdam, Germany] <i>Zooming-in on radio relics: Solving five major problems with density turbulence</i> |

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| 12:30-14:00 | LUNCH - Poster viewing - Free time |
| 14:00-15:00 | DISCUSSION: Climate Change - Chairs: Perrone, Elmegreen, ... |
| 15:00-16:15 | Session III - Astro: Star Formation, Turbulence, B - Chair: Patrick Hennebelle |
| 15:00 R | Vazquez-Semadeni, Enrique [UNAM, Mexico] <i>The Turbulent Support (TS) and Global Hierarchical Collapse (GHC) models for molecular clouds compared: differences, convergence, and myths</i> |
| 15:35 I | Mac Low, Mordecai-Mark [AMNH, New-York, USA] <i>Galactic Dynamos and the Magnetic-Field to Density Relationship</i> |
| 16:00 C | Whitworth, David [IRA, Mexico] <i>On the relation between magnetic field strength and gas density in the interstellar medium: A multiscale analysis</i> |
| 16:15-16:45 | Coffee Break |
| 16:45-17:35 | Session IV - Astro: Faraday RM, B, CR, intermittency - Chair: Geoffroy Lesur |
| 16:45 I | Girichidis, Philipp [ITA, University of Heidelberg, Germany] <i>Magnetic fields in simulations of Milky Way-like galaxies</i> |
| 17:10 I | Lesaffre, Pierre [ENS Paris, France] <i>The Intermittency of Turbulence in MHD Simulations</i> |
| 18:00-19:15 | Public outreach conference (in French) by Pierre Guillard: L'histoire de l'évolution des galaxies : la révolution JWST |
| 19:30 | CONFERENCE DINNER |
| FRIDAY | |
| 3 OCTOBER | |
| 09:00-10:20 | Session I - Astro: Lyman alpha, Turbulence - Chair: Hsiao-Wen Chen |
| 09:00 I | Verhamme, Anne [Université de Genève, Switzerland] <i>Lyman-alpha to probe Lyman-continuum escape from galaxies</i> |
| 09:25 C | Chang, Seok-Jun [MPA, Germany] <i>Radiative transfer of Hydrogen Lyman Alpha in Turbulent Gas</i> |
| 09:40 C | Manzoni, Daniele [Scuola Normale Superiore di Pisa, Italy] <i>Lyman-alpha radiation pressure feedback at Cosmic Dawn with LYDION</i> |
| 09:55 I | Levrier, François [ENS Paris, France] <i>The anisotropic nature of interstellar turbulence as unveiled through JWST observations of the Pleiades nebula</i> |
| 10:20-10:50 | Coffee Break |
| 10:50-12:15 | Session II - Astro: CGM, ICM, CR transport - Chair: Christoph Pfrommer |
| 10:50 C | Adam, Remi [OCA, France] <i>Probing intracluster medium turbulence from deep imaging of Sunyaev-Zel'dovich fluctuations</i> |
| 11:05 C | Chen, Mandy [Caltech, USA] <i>Unveiling Turbulence Drivers in Quasar Halos: Insights from IFS Observations</i> |
| 11:20 C | Hidalgo Pineda, Fernando [MPIA, Germany] <i>From a Spherical Cow to a Herd: Modelling Multiphase Galactic Outflows</i> |
| 11:35 C | Kaul, Ish [University of California, Santa-Barbara, USA] <i>Magnetized infalling cold clouds and streams in the CGM</i> |
| 11:50 C | Jolly, Jean-Baptiste [MPE, Germany] <i>NOEMA3D: Inflowing Gas at Subgalactic Scales in Massive Star Forming Galaxies at $z=1-2$</i> |
| 12:05 C | Lübke, Jeremiah [ITP, Bochum, Germany] <i>Modeling Cosmic Ray Transport: Magnetized vs. Unmagnetized Motion in Structured Magnetic Turbulence</i> |
| 12:30-15:00 | LUNCH - Poster viewing - Free time |
| 15:00-16:20 | Session III - Astro-Plasmas: ICM, RM, Dynamos - Chair: James Beattie |
| 15:00 I (OL) | Nelson, Dylan or Lehle, Katrin [University of Heidelberg, Germany] <i>Magnetic fields in the intracluster medium with TNG-Cluster: properties, morphology, and tangential anisotropy</i> |
| 15:25 C (OL) | Najmudeen, Bijas [University of Manchester, UK] <i>BISTRO: Magnetic Fields Regulate Star Formation in the Western CMZ</i> |
| 15:40 C | Irshad P., Muhammed [TIFR, India] <i>Turbulent dynamos in a collapsing cloud</i> |
| 15:55 C | Kempf, Jean-Maël [IRAP, Toulouse France] <i>Numerical simulations of a turbulent dynamo effect in a global stratified model of the intracluster medium</i> |
| 16:10-16:20 | CLOSING REMARKS - Speakers: Christoph Pfrommer and Edith Falgarone |
| 16:20-16:45 | Coffee Break |

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| 16:50 | END OF CONFERENCE |
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| | LIST OF POSTERS |
| | Callies Edouard: <i>Impact of the ambipolar diffusion on the formation of filament in the diffuse ISM through MHD instabilities</i> |
| | Dumond Pierre: <i>A mass invariant in a compressible turbulent medium</i> |
| | Duong Tuan Anh: <i>Tracing Magnetic Fields Along Star-Forming Filaments from Dust Polarization Data: First results from the B-FUN project with NIKA2-POL</i> |
| | Elmegreen Bruce: <i>TBD</i> |
| | Ewart Robert: <i>Cosmic-ray transport in inhomogeneous media</i> |
| | Gazol Adriana: <i>On the regulation of the cold neutral medium mass fraction by magnetic field</i> |
| | Gruenwald Gudrun: <i>Solving the Six-Dimensional Vlasov--Maxwell System with Active Flux and Splitting Methods</i> |
| | Gry Cecile: <i>A diffuse cloud seen from within: deformation, shock and turbulence ?</i> |
| | Ko Eunhee: <i>Dynamical heating by superbubbles and the cusp-core transformation</i> |
| | Kordt Aron: <i>Feedback from the First Stars: Imprints of Low-Energy Pair-Instability Supernovae in Second-Generation Stars</i> |
| | Guerrero-Gamboa Ruben: <i>The Role of Magnetic Fields in Turbulence Amplification and Gravitational Collapse</i> |
| | Kumar Vinay: <i>Magnetic Reconnection in 3D and Its Role in Turbulent Dynamo Saturation</i> |
| | Meenakshi Moun: <i>Modeling CRE evolution in AGN jets and winds: A radio spectral analysis</i> |
| | Perrone Lorenzo Maria: <i>TBD</i> |



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TALKS

Molecular gas and the star formation process on cloud scales in nearby galaxies

Eva Schinnerer*¹

¹MPIA – Germany

Abstract

Star formation is a vital process for stellar mass growth during the evolution of galaxies. Our understanding of where stars form and how their formation is regulated across galactic disks is surprisingly incomplete. Cloud-scale observations that resolve the sites of recent (or future) star formation and allow for sampling the time evolution of the star formation process have become possible with instruments such as ALMA, HST, VLT/MUSE and recently JWST. Comprehensive surveys such as PHANGS (Physics at High Angular resolution in Nearby GalaxieS) enabling the study of the molecular gas reservoir, dust and embedded star formation, young stellar clusters and stellar feedback at comparable resolution have provided first robust insights how molecular gas properties and the subsequent star formation depend on environment. I will summarise our current understanding of molecular gas properties and the star formation process based on cloud scale observations of nearby galaxies and provide an outlook on the insights that JWST observations can bring.

*Speaker

What regulates star formation in Galaxies? Turbulence, magnetic field and stellar feedback

Patrick Hennebelle*¹

¹Astrophysique Interactions Multi-échelles (AIM) – CEA, Université Paris VII - Paris Diderot, INSU, CNRS : UMR7158 – Service d’astrophysique Orme des Merisiers F-91191 GIF SUR YVETTE CEDEX, France

Abstract

Understanding what regulates star formation in galaxies is a fundamental question in astrophysics. However, a simple estimate of the star formation rate (SFR) that a galaxy like ours should have overpredicts the observed SFR by nearly two orders of magnitude. Over the past 50 years, three main explanations have been proposed to account for these low observed SFRs: magnetic fields, turbulence, and stellar feedback. While it is likely that all three mechanisms play some role, their relative contributions to regulating the SFR remain a subject of debate.

Stellar feedback appears to produce SFRs consistent with observations for Milky Way-type galaxies. However, it is far less clear whether stellar feedback alone can explain the SFR in gas-rich galaxies.

In this talk, I will discuss the various simulations which have been recently performed to investigate the SFR and show their success and their failure.

I will present a new analytical model based on gravo-turbulent theory to compute the SFR. This model, which has been rigorously tested against a series of numerical simulations, includes turbulent dispersion and predicts that when the size of the system is smaller than the turbulent Jeans length, the SFR is significantly reduced.

This model, which can be used as a subgrid model in large-scale simulations that do not resolve the small-scale interstellar medium, provides a clear explanation of how turbulence, in conjunction with stellar feedback, may contribute to regulating star formation in galaxies.

*Speaker

The XMagnet Project: Probing Intracluster Medium Turbulence with Exascale MHD Simulations

Martin Fournier^{*1}, Marcus Bruggen², and Philipp Grete³

¹Universität Hamburg = University of Hamburg – Germany

²University of Hamburg – Germany

³Michigan State University (USA) (MSU) – Department of Physics Astronomy Michigan State University Biomedical Physical Sciences 567 Wilson Road, Room 3248 East Lansing, MI 48824, United States

Abstract

Understanding the physics of the intracluster medium (ICM) is key to building a consistent model of its thermal regulation. The ICM is a multiphase environment shaped by turbulence, magnetic fields, radiative cooling and the effect of supermassive black holes. Capturing the full dynamical range of these processes requires large-scale simulations. In this talk, I will present the XMagnet project—a suite of high-resolution MHD simulations of AGN feedback in a cool-core galaxy cluster, run on Frontier, the first academic exascale supercomputer. After introducing our simulation setup, I will discuss key insights from a velocity structure function (VSF) analysis of the hot and cold gas phases. By comparing projected VSFs obtained from mock optical and X-ray observations with their unprojected counterparts, I will show that observational biases significantly affect the interpretation of VSFs in nearby cool-core clusters and must be taken into account when attempting to constrain turbulence in the ICM.

^{*}Speaker

Universal kinetic distribution functions for collisionless plasmas: implications for stellar coronal heating and dark matter halos

Amitava Bhattacharjee*¹ and Uddipan Banik*

¹Princeton University – United States

Abstract

We develop a self-consistent quasilinear theory for the relaxation of electromagnetic kinetic plasmas, and demonstrate that the mean distribution functions of both electrons and ions tend to relax to a universal v^{-5} tail. Large-scale electromagnetic fields efficiently accelerate the unscreened, fast particles but not the screened, slow ones. This non-thermal tail may arise in the solar corona from electromagnetic turbulence despite collisions, allowing suprathermal particles to escape the sun's gravity (velocity filtration) and inverting the temperature profile with temperatures rising to a million degrees Kelvin. The same theoretical framework can be applied to predict universal density profiles which appear to emerge from self-gravitating systems such as cold dark matter halos.

*Speaker

Relaxation to universal non-Maxwellian equilibria in a collisionless plasma

Robert Ewart*¹

¹Department of Astrophysical Sciences, Princeton University, Peyton Hall, Princeton, 08544, USA – United States

Abstract

Statistical mechanics can be extended to describe collisionless plasmas undergoing relaxation due to violent, turbulent, evolution. Such collisionless systems naturally conserve extra invariants that endow the system with a partial ‘memory’ of its prior conditions, but this memory is imperfect on long time scales due to the development of a turbulent cascade to small scales, which breaks the precise conservation of phase volume. The equilibria are still determined by the short-time collisionless invariants, but the invariants themselves are driven to a universal form on long time scales by the nature of the turbulence in phase space. We review large amplitude phase-space turbulence in collisionless plasmas confirming it with high resolution PIC simulations. Implications for quasilinear and turbulent collision operators are discussed.

*Speaker

Energetic Particle Transport in Structured and Multiscale Plasma Turbulence: Bridging Observations, Theory, and Simulation

Frederic Effenberger*¹

¹Ruhr-University Bochum – Germany

Abstract

Energetic particles in astrophysical plasmas, both in the heliosphere and in a variety of cosmic environments, interact with turbulence that is magnetised, intermittent, and inherently multiscale. Understanding how these turbulent structures govern particle transport and acceleration is key to interpreting cosmic ray propagation, space weather phenomena, and high-energy radiation signatures. Here, I report on initial results of our ISSI Team #24-608 that brings together experts in space plasma turbulence, particle transport modeling, and spacecraft data analysis to develop the next generation of physically realistic test-particle simulations. These models incorporate turbulence features constrained by heliospheric in-situ observations from Parker Solar Probe and Solar Orbiter, as well as numerical simulations resolving coherent structures like current sheets and flux ropes across broad dynamical ranges. We investigate the role of such intermittency and structure in modifying classical diffusion coefficients and enabling anomalous transport regimes. Our approach aims to move beyond idealised turbulence assumptions, providing testable predictions for particle fluxes and anisotropies in the heliosphere and beyond. These developments offer new perspectives on energetic particle dynamics across cosmic environments, with implications for galaxy-scale feedback processes and magnetised turbulence from star-forming regions to the intergalactic medium.

*Speaker

So long Kolmogorov: the forward and backward turbulence cascades in a supernovae-driven, multiphase interstellar medium

James Beattie^{*1,2}

¹Department of Astrophysical Sciences [Princeton] – United States

²Canadian Institute for Theoretical Astrophysics – Canada

Abstract

The interstellar medium (ISM) of disk galaxies is turbulent, and yet the fundamental nature of ISM turbulence, the energy cascade, is not understood in detail. In this talk, I report upon high-resolution simulations of a hydrodynamical, gravitationally stratified, supernova (SNe)-driven, multiphase ISM to probe the nature of a galactic turbulence cascade. Through the use of velocity flux transfer functions split into interactions between compressible and incompressible modes, I will show that there exists a large-to-small-scale cascade in both compressible and incompressible modes, when mediated by an additional incompressible mode. But the incompressible cascade is highly non-local. Moreover, there is a compressible mode mediated component of the incompressible cascade that proceeds in the opposite direction – an inverse cascade from small-to-large scales. The cascade feeds flux into scales well beyond the scale height, energizing the winds and fueling the direct cascades. Both the strongly non-local and the inverse incompressible cascades happen on scales that have a power law incompressible velocity spectrum, highlighting how degenerate the spectrum is to the true underlying physical processes. I will directly show that the inverse cascade comes from incompressible modes interacting with expanding SNe remnants (SNRs) and that incompressible modes are generated, to leading order, via baroclinic, highly corrugated cooling layers between warm and hot plasma in these SNRs. I will use these simulation measurements to outline a complete phenomenology for SNe-driven turbulence in a galactic disk, generated from SNR cooling layers, and highlight the strong deviations that SNe-driven turbulence has from the conventional Kolmogorov model.

*Speaker

Turbulence Connections to Star Formation

Bruce Elmegreen*¹

¹Retired from IBM Research – United States

Abstract

Turbulence in the ISM gives it a correlated structure that is reflected in the positions and motions of the stars it forms. Turbulent pressure that balances the weight of the gas is also more strongly correlated with the star formation rate than any other obvious variable. These observations suggest a fundamental role for turbulent pressure that points to a specific sequence of processes that initiates star formation on the cloud scale. Other processes that are correlated like turbulence operate on a galactic scale. These larger-scale processes can be studied with power spectra. Recent results on galaxy power spectra using HST and JWST images suggest a different origin for large and small-scale correlated motions, but they offer no clue yet for how much large-scale motion generated by galactic gravity cascades to small-scale motion where it mixes with turbulence generated by star-formation feedback. Power spectra have also been used recently to measure the thickness of M51, which corroborates the indirect measurement of thickness made from turbulent pressure.

*Speaker

Multi-phase turbulence of the diffuse interstellar medium, from hundreds of pc to milli-pc scales

Marc-Antoine Miville-Deschenes*¹

¹Laboratoire de Physique de l'École Normale Supérieure – Centre National de la Recherche Scientifique,
Institut national des sciences de l'Univers – France

Abstract

The ways in which diffuse interstellar matter condenses to form stars is still puzzling, especially in the early phases of the condensation process. Most of the interstellar matter in Milky-Way type galaxies is in the HI, the diffuse neutral atomic gas, where cooling and magnetized turbulence act together to form small scale filamentary clouds, without any significant help from self-gravity. The star formation efficiency in galaxies is likely to depend on this cloud formation process that is still poorly understood. In this talk I will review the specificity of interstellar turbulence in this magnetized and multi-phase case. I will also present several recent observations from the radio to the optical that are allowing to image the properties of turbulence in the diffuse ISM of the Milky Way and the Magellanic Cloud, at scales from hundreds of pc down to milli-pc scales.

*Speaker

High-beta turbulence in galaxy clusters and consequences for thermal stability and cosmic ray-diffusion

Matthew Kunz*¹

¹Princeton University – United States

Abstract

Many estimates of viscosity in the ICM rely on the assumptions that Coulomb collisions determine the kinematic viscosity, and that viscous stresses are isotropic and Laplacian in nature. These assumptions, however, fail to explain X-ray observations of multi-scale density fluctuations, which suggest that ICM turbulence cascades to scales significantly smaller than the Coulomb-collisional viscous scale. This discrepancy has been interpreted as indicating a kinematic viscosity that is at least a factor of ten (if not more) smaller than the conventional Spitzer viscosity. Yet, the ICM is not a hydrodynamic fluid; it is a weakly collisional, magnetized plasma, and it is therefore subject to various non-equilibrium effects, such as anomalous scattering and anisotropic viscous stresses. In particular, small-scale instabilities driven by anisotropy in the thermal pressure scatter plasma particles, increasing the effective scattering rate and reducing the kinematic viscosity. Additionally, weakly collisional plasmas exhibit a magnetic field-aligned bias in their viscosity, which can be exploited by turbulent self-organization ("magneto-immutability") to decrease viscous dissipation further. To better capture the ICM plasma's weakly collisional nature, we present a theory of turbulence in the ICM that leverages both of these effects, where small-scale instabilities reduce the effective viscous scale to the Alfvén scale, below which self-organization affords a robust, nearly conservative cascade that extends down to the scale of ion-Larmor radii. To verify the predictions of this theory, we present results from a high-resolution, weakly collisional "Landau-fluid" simulation of super-Alfvénic turbulence, with parameters chosen that approximately match the ICM of the Coma cluster. Beyond interpreting observations of suppressed viscosity in the ICM, the results of the simulation are also used to argue for a thermally stable source of viscous heating that promotes multi-phase gas in the ICM, and to inform new studies on the propagation and (re-)acceleration of cosmic rays in galaxy clusters. In particular, we explain how the same plasma microphysics responsible for reducing the thermal mean free path in the ICM enhances the confinement of sub-TeV cosmic rays.

*Speaker

Relaxation Processes in Astrophysical Plasma Turbulence

Sergio Servidio*¹

¹Dipartimento di Fisica, Università della Calabria, 87036 Rende – Italy

Abstract

Turbulence in classical fluids is characterized by persistent structures that emerge from the chaotic landscape. We investigate the analogous process in plasma turbulence via observations, theory, and simulations. In particular, by using high-resolution, kinetic simulations, we observe the formation of long-lived vortices with a profile typical of macroscopic, magnetically dominated force-free states. Inspired by the Harris pinch model for inhomogeneous equilibria, we describe these metastable solutions with a self-consistent kinetic model, starting from an explicit form of the particle velocity distribution function. Turbulence is mediated by the long-lived structures, accompanied by transients in which such vortices merge and form self-similarly new metastable equilibria. This process can be relevant to the comprehension of various phenomena, going from the formation of coherent structures in the heliosphere to the emergence of plasmoids in the vicinity of massive compact objects.

*Speaker

Modeling transport in weakly collisional, high beta plasmas

Prakriti Pal Choudhury*¹ and Archie Bott¹

¹University of Oxford – United Kingdom

Abstract

There is significant evidence from X-ray observations that the suppression of energy and momentum transport (heat conduction and viscosity) in the intracluster medium is a few orders of magnitude below what can be explained by the perpendicular suppression in a tangled magnetic field using classical transport theory. The possible culprit is the class of microinstabilities triggered by the velocity-space anisotropies due to macroscopic gradients in fluid properties, in presence of magnetic field. This could be generally true in the intergalactic, intragroup and the hot-dilute medium around any galaxy. A fluid closure for electrons/ions in such a medium is not possible without a clear understanding of the saturation of these microinstabilities. There have been several explorations in recent years using collisionless particle-in-cell simulations of temperature-gradient or perpendicular-to-parallel pressure-anisotropy driven microinstabilities, notably heat-flux driven whistlers and negative (positive) pressure anisotropy driven firehose (mirror), which regulate the velocity-space anisotropy by resonant/non-resonant scattering and diffusion of particles. However, most simulations suffer from crucial limitations regarding computational feasibility and/or physical details. In this work, we propose a novel mapping of the problem of global inhomogeneities and gradients in plasma to a local periodic, homogeneous particle-in-cell box. Using particle-in-cell simulations, we demonstrate that we can study macroscopic gradient driven microinstabilities in a generalized framework that addresses several past limitations, particularly the issue of intractible scale separation. In addition, this framework opens the possibility to model collective transport phenomena. In this talk, I aim to expand on the motivation, framework, and key results from this approach so far.

*Speaker

Turbulence ”pressure cooker” and its impact on acceleration of the solar wind and the energization of suprathermal particles

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Abstract

Since the works of Kraichnan and Iroshnikov (1) it has been recognized that overlapping Elsasser fields of opposite types gives rise to nonlinear couplings and turbulence in an incompressible magnetohydrodynamics (MHD) medium. This is a fundamental property in dynamo theory and astrophysics, emphasized e.g., in the monographs by Moffatt and Parker (2). A key consequence of overlap is emergence of regional mean values of the mean turbulence electric field, the ”emf” in mean field dynamo theory (3). This quantity is central in the Reflection Driven Turbulence model (aka WTM) for coronal heating in open field regions (4) where non-WKB reflection of ”outward” Elsasser fluctuations triggers and sustains the heating process. While MHD turbulence in general involves both Elsasser fluctuations, reflection from Alfvén speed gradients can enhance nonlinear activity and turbulence effects. Related examples are found in the generation of the Jovian aurora (5) and the thinning of current sheets and subsequent rapid reconnection (6). Here we point out two potentially important applications of these ideas. First, the heliospheric current sheet (HCS) and the fragmented Alfvén zone (AZ) as observed by the Parker Solar Probe (PSP), are prime candidates for generation of stronger turbulence and emf at more or less fixed locations, due to multiple encounters with Alfvén speed gradients and enhanced likelihood of Elsasser ”collisions”. Furthermore, these geometries may be favorable for maintaining this emf in given locations for extended periods of time due to stagnation of propagation effects. Second, these regions of enhanced emf are likely sources of energization of suprathermal particles, such as the ”glow” seen by PSP near several HCS encounters or enhancements near identifiable flux tubes. (7). We suggest that enhanced turbulence emf, along with trapping or entrainment due to turbulence topology in these special regions may provide a ”pressure cooker” for systematic generation of suprathermal particles in the range of tens of keV or higher. IMAP, supplemented by the L1 constellation should provide ample opportunity to investigate this possible mechanism for particle energization near 1 au, while PSP/ISOIS and Solar Orbiter may enable related investigations in the inner heliosphere (8).

(1) Kraichnan *Phys Fluids* 8 , 1385 (1965); Iroshnikov *Soviet Astron.* 7. 566 (1964)

(2) Moffatt, *Magnetic Field Generation in Electrically Conducting Fluids*, (Cambridge, 1978); Parker, *Cosmical Magnetic Fields: Their Origin and Activity* (Oxford, 1979)

*Speaker

- (3) Krause, Fritz, and K-H. Rädler. *Mean-field magnetohydrodynamics and dynamo theory*. Elsevier, 2016
- (4) Matthaeus et al, ApJ 523, L93 (1999)
- (5) Saur et al, GRL, 30, 1260 (2003)
- (6) Sakai et al, Solar Phys, 91, 103 (1984)
- (7) Desai et al, ApJ 985, L38 (2025); Tessein et al, GRL 43, 3620 (2016)
- (8) Cohen et al, "A IMAP's role in understanding particle injection and energization throughout the heliosphere", SSR (submitted)

Emergence of two inertial-range dynamical regimes in solar wind turbulence

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²Istituto per la Scienza e la Tecnologia dei Plasmi – Italy

Abstract

The solar wind has represented for decades a unique environment for in-situ experimental studies of collisionless plasma turbulence. Since the early spacecraft observations, power-law spectra of magnetic field and plasma velocity have been interpreted in the framework of Kolmogorov-like phenomenology, including several developments accounting for anisotropy, expansion, and variable Alfvénicity of the fluctuations. In the Alfvénic solar wind, the paradigm is a multi-range spectrum, including: a large-scale energy injection range, with a $\sim 1/f$ spectrum; a mesoscale turbulent inertial range, dominated by nonlinear interactions, and with variable spectral index often in the range 1.5-1.7; by sub-ion and sub-electron steeper spectra, where field-particle interactions overlap to the turbulent nonlinear energy transfer. Models of solar wind turbulence rely on such paradigm. However, recent observations are unveiling a more complex scenario, in which the inertial range is in fact composed of two sub-ranges separated by a sharp spectral break. Intermittency parameters such as the kurtosis and third-order laws confirm this scenario. The break separating the two ranges evolve radially, with a Kolmogorov-like spectrum taking over a more Boldyrev-like one as the wind expands. This explains the apparent gradual evolution of the single-range spectrum. While the observation of such double scaling range is robust and convalidated by data analysis, its origin and implications are yet to be fully understood.

*Speaker

Coherent structures across the turbulent cascade in the solar wind

Olga Alexandrova*¹

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Abstract

Solar wind is an excellent laboratory to study astrophysical plasma turbulence in a wide range of scales, and for different conditions (plasma beta can vary between 0.01 to 100). One of the inherent properties of a turbulent cascade is intermittency, which is due to presence of coherent (or intermittent) structures. Coherent structures are high amplitude events localized in space and living longer than any random fluctuation. Considering solar wind at 1 au, we find different types of structures, such as current sheets and Alfvén vortices in fast solar wind (> 500 km/s) and compressive vortices, magnetic holes, solitons and shocks in slow wind (~ 300 km/s). Their scale goes from fluid (MHD) to ion kinetic scales (100 km). Considering high resolution data of ESA/Cluster mission, we could detect vortex like events at electron scales (~ 1 km). Closer to the Sun, from ~ 10 to 35 solar radii, signatures of intermittent events are also observed with NASA/Parker Solar Probe mission. A statistical study at 0.17 au shows presence of embedded coherent structures from MHD down to kinetic scales. Alfvén vortices appear dominant at all scales in contrast to the widespread view of dominance of current sheets, which are rare in our statistics. Alfvén vortex seems to be an important building bloc of solar wind turbulence.

*Speaker

Galactic Disk Emergence and Resilience

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Abstract

Thin stellar discs dominate the star-forming population of the Universe, yet their remarkable stability and efficiency remain among the most persistent puzzles in galaxy formation. I will argue that thin discs emerge and persist naturally through dynamical self-regulation, driven by the interplay between gravitational wakes, coherent gas inflows, and star formation.

Once a stellar disc becomes sufficiently massive to resist disruption, it enters a *homeostatic* state where orbital heating-driven by perturbations-is precisely balanced by cooling from new stars formed on nearly circular orbits. This loop maintains discs close to marginal gravitational stability, enabling them to remain thin, long-lived, and highly efficient at converting gas into stars. I will show that this self-regulated *attractor* state explains the ubiquity, resilience, and tightness of observed galaxy scaling relations, such as the Tully-Fisher and Kennicutt-Schmidt laws, without recourse to any finely tuned feedback prescriptions. I aim to shift the field of galaxy formation from empirical calibration to a first-principles, gravity-driven theory, and establish discs as benchmarks for self-organised criticality.

*Speaker

Recent Observational Advances in Understanding Galaxy Evolution

Linda Tacconi*¹

¹MPE – Germany

Abstract

Deep and increasingly complete multi-wavelength look-back surveys provided a wealth of information about the formation and evolution of galaxies over cosmic time. With the advent of sensitive ground-based adaptive optics assisted integral field instruments, submm interferometers like ALMA and NOEMA, and JWST in space the emphasis is shifting from assembly populations censuses to understanding the internal physical and dynamical processes driving galaxy evolution. In this presentation, we will review results from some spatially resolved, multi-wavelength studies of star-forming galaxies, focusing on the epochs associated with the peak ($z \sim 1-3$) of star formation, but including the newest results at higher redshifts as well. We discuss the latest results on the incidence and prevalence of rotating, turbulent disks with redshift, but emphasize the interesting kinematics present once signatures of rotation are removed from these galaxies. We know that star-forming galaxies contained were much more gas rich at earlier cosmic epochs than at the present time. Disk fragmentation and instabilities are efficient in driving the internal galaxy dynamics in such gas rich environments. We will show examples of galaxies exhibiting strong inflow signatures in their disks, sometimes along bars and spiral arms. Taken together with deep imaging, the emerging kinematic observations show that disk fragmentation and instabilities, as well as powerful star formation and AGN driven outflows strongly influence the evolution of disks and central bulges.

*Speaker

Turbulent Formation of First Galaxies and Galactic Disks

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Abstract

Our paradigm of galaxy formation has been transformed by JWST, ALMA, and recent Galactic archaeology surveys with Gaia, which suggest that disk galaxies, including our Milky Way (MW), form surprisingly early, $z > 4$, and prevail throughout the cosmic history. I will present insights into the early disk formation from new high-resolution cosmological zoom-in simulations with detailed modeling of turbulent ISM focusing on the first few Gyr of a close MW analog. These simulations suggest that the stellar disk of the MW progenitor could form extremely early, around $z \sim 6$, still exhibiting chemo-kinematic properties consistent with the local MW observation. We find that the modeling of locally variable star formation efficiency (SFE) coupled with the small-scale ISM turbulence is crucial for early formation and survival of galactic disks. Such a model introduces a qualitatively new channel of the global star formation rate (SFR) variability caused by chaotic fluctuations in the average SFE due to changes in the ISM turbulence, which, in our simulation, dominates the short-term SFR variability. The average SFE stays low, close to $\sim 1\%$ per freefall time, and its variation decreases when the gas disk forms, leading to only mild effects of stellar feedback on the early disk, enabling its survival. Our findings underscore the critical role of modeling a turbulent cold ISM and turbulence-regulated star formation and feedback in driving early SFR variability and early disk formation.

*Speaker

Magnetic reconnection: past, present, and future

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²Princeton Plasma Physics Laboratory – United States

Abstract

Magnetic reconnection is considered as one of most fundamental plasma processes across the Universe responsible for explosive release of magnetic energy to particles. It plays a pivotal role in electron and ion heating, particle acceleration to high energies, energy transport, and self-organization. The relevant phenomena range from solar flares, coronal heating, solar wind interactions with planets' magnetospheres including Earth's, star formation in molecular clouds, to explosions on magnetars and pulsars including Crab Nebula, as well as to disruptive phenomena in laboratory fusion plasmas. This talk concisely reviews the history of magnetic reconnection research starting from solar flares since 1950s and summarizes the status of our current understanding. Emphasis will be given on the prospect of solving multi-scale reconnection problem, including the anticipated role of the FLARE project which just began its operation.

*Speaker

The Interplay Between Magnetic Reconnection and Turbulence

Julia Stawarz^{*1}, Paulina Quijia Pilapana¹, Jeffersson Agudelo Rueda¹, Patricio A. Munoz^{2,3}, Naoki Bessho⁴, Riddhi Bandyopadhyay, Takuma Nakamura⁵, Stefan Eriksson⁶, Daniel Graham⁷, Jörg Büchner, Alexandros Chasapis⁸, James Drake⁹, Mike Shay¹⁰, Robert Ergun, Hiroshi Hasegawa¹¹, Yuri Khotyaintsev^{12,13}, Marc Swisdak¹⁴, and Victoria Wilder

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⁹University of Maryland, College Park – United States

¹⁰Univ Delaware – United States

¹¹Japan Aerospace Exploration Agency [Tokyo] – Japan

¹²Uppsala Universitet [Uppsala] – Sweden

¹³Swedish Institute of Space Physics, Uppsala – Sweden

¹⁴Department of Physics [Maryland] – United States

Abstract

Alongside magnetic reconnection, turbulence is another fundamental nonlinear plasma phenomenon that plays a key role in energy transport and conversion across a wide range of heliospheric and astrophysical plasmas. From a numerical, theoretical, and observational perspective there is a long history of exploring the interplay between these two phenomena in space plasma environments; however, recent high-resolution, multi-spacecraft observations have ushered in a new era of understanding this complex topic. The interplay between reconnection and turbulence is both complex and multifaceted, and can be viewed through a number of different interrelated lenses - including turbulence acting to generate current sheets that undergo magnetic reconnection (*turbulence-driven reconnection*), magnetic reconnection driving turbulent dynamics in an environment (*reconnection-driven turbulence*) or acting as an intermediate step in the excitation of turbulence, and the random diffusive/dispersive nature of the magnetic field lines embedded in turbulent fluctuations enabling so-called *stochastic reconnection*. In this talk, I will give a brief overview of the ways in which

^{*}Speaker

observations from NASA's Magnetospheric Multiscale (MMS) mission have been providing new insight into these different facets of the interplay between turbulence and magnetic reconnection. I will further discuss in detail new insights into turbulence-driven reconnection that have been gained through observations of the shocked solar wind plasma downstream of Earth's bow shock, focusing on the use of machine learning to aid in identifying magnetic reconnection and the role that reconnection plays in dissipating energy in turbulent plasmas.

Magnetic Reconnection: An Alternative Explanation of Radio Emission in Galaxy Clusters

Subham Ghosh*¹ and Pallavi Bhat¹

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Abstract

From observations, we see non-thermal radio emission with spectral index from flux density ranging from 1 to 3, extended over a large region (\sim megaparsec) in galaxy clusters, which contain largely collisionless plasma. To explain this, the electrons should be energized or accelerated. One explanation is that the energy released during a merger event could be channeled to accelerate electrons through turbulence or shock. However, the efficiency of these mechanisms are low.

We, therefore, look for another particle acceleration mechanism: magnetic reconnection in collisionless plasma. Reconnection sites form naturally due to fluctuation dynamo operating in the turbulent intra-cluster medium (ICM), producing strong magnetic fields that reverse on short length scales. The plasma in the ICM being non-relativistic (temperature $\sim 10^8$ K), we aim to explore particle acceleration due to reconnection using particle-in-cell (PIC) simulation for non-relativistic plasma. During magnetic reconnection, the magnetic energy gets converted to particles' kinetic energy. Driven by the tearing instability, magnetic reconnection begins by giving rise to magnetic islands and x-points, where the inductive electric field gets generated and accelerate the particles. Soon after the saturation of the tearing instability, the plasmoid instability takes over and enhances the reconnecting electric field. Thus, magnetic energy gets converted to electrons kinetic energy. We find that the initial non-relativistic thermal electrons with the temperature of the galaxy cluster, become relativistic and non-thermal as they go through magnetic reconnection sites. The resulting non-thermal electron energy spectra matches with that inferred from the observed radio spectra of galaxy clusters. Furthermore, our estimate of the achievable maximum energy (or corresponding Lorentz factor $\sim 10^5$) of the electrons due to reconnection-driven acceleration, interestingly aligns well with observations. The synchrotron luminosity of the accelerated electrons from our model is in agreement with the observed value ($\sim 10^{41}$ ergs/s) as well. This supports reconnection as an efficient particle acceleration mechanism in the ICM.

*Speaker

The formation of a metastable cosmic ray corona in Milky Way analogues

Francisco Rodriguez Montero*¹

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Abstract

Despite the many successes of cosmological galaxy formation and evolution simulations, they commonly implement baryonic feedback in a phenomenological manner by calibrating "boosting" parameters, which somewhat diminishes their predictive power and restricts their usefulness in interpreting observational data. An alternative approach is to improve the modelling of feedback processes from first principles, by self-consistently including components which have by-and-large been overlooked. One of these alternatives has been to model cosmic rays (CRs) injected by supernova shocks, which has been seen to have a drastic effect on the evolution of Milky Way-like galaxies and the thermal state of their interstellar medium (ISM). Given their slow-cooling properties, they can efficiently transport stellar-injected energy from the ISM to the large scales of the circum-galactic medium (CGM). Using a suite of high-resolution cosmological zoom simulations of a Milky Way analogue including magnetic fields and CR injection via supernovae, we have explored the role of CR feedback in the thermo-dynamical state of the CGM. While simulations without CRs present the classical, cold filamentary accretion at high redshift, strong feedback in the CR simulation disrupts these inflows well beyond the virial region, resulting in lower-density material approaching the inner halo. This deceleration of streaming inflows creates a reservoir of low-velocity gas at a distance between 0.3 and 0.5 times the virial radius. We have determined that this reservoir of low-velocity gas is predominantly warm ionised gas supported by CR pressure gradients, continuously heated by the UV background. We term this newly characterised region of the CGM the meta-stable CR corona. Based on this new understanding of the dynamical properties of inflows and the CGM in the presence of CRs, we present criteria for the stability of cosmological accretion shocks taking into account CR heating and transport, as well as a CR+thermal gas mixture. We present how these results can be used to extend current models of galaxy formation to take into account the multi-scale impact of CRs across cosmic time.

*Speaker

Resolving turbulence drivers in the diffuse circumgalactic medium

Hsiao-Wen Chen*¹

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Abstract

The circumgalactic medium (CGM) and intergalactic medium (IGM) 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. The amplitude and spectrum of this turbulence have profound implications for the sources that drive the thermal and dynamic properties of the gas. Recent work has begun to constrain the turbulent energy spectrum in the diffuse CGM, using both velocity–size relations and velocity–structure–function measurements of scale-dependent fluctuations. In this talk I will (i) assess observational and analysis systematics that can bias these inferences (e.g., bulk motions, projection effects, beam smearing, line blending, thermal broadening), and (ii) synthesize current constraints on the dominant drivers and injection scales of CGM turbulence across galaxy environments, distinguishing the roles of stellar feedback, AGN, and cosmological accretion.

*Speaker

Direct Measurements of Gas Kinematics in the Intracluster Medium: First Results from XRISM

Irina Zhuravleva*¹

¹University of Chicago – United States

Abstract

The X-ray Imaging and Spectroscopy Mission (XRISM) provides high-resolution spectra of extended X-ray sources, enabling the first direct studies of bulk flows and turbulence in the intracluster medium (ICM). In its first two years, XRISM has observed several of the brightest galaxy clusters, offering new insights into gas dynamics and energy transfer during feedback from central supermassive black holes and cluster mergers. In this talk, I will present results on the detection of multiple turbulence drivers and their role in AGN feedback, the first direct measurements of hot gas velocity power spectra, and the reconstruction of line-of-sight cluster mergers together with turbulence produced by mergers. I will conclude by comparing these direct measurements with indirect probes of velocity cascades inferred from density fluctuations in X-ray images.

*Speaker

The Multi-Scale Multi-Phase Circumgalactic Medium: Observed and Simulated

Celine Peroux*¹

¹European Southern Observatory – Germany

Abstract

These are exciting times for studies of galaxy formation and the growth of structures. New observatories and advanced simulations are revolutionising our understanding of the cycling of matter into, through, and out of galaxies. This talk will first describe a basic framework to convert measurements of the gas properties observed in absorption spectra into global estimates of the condensed (stars and cold gas) matter mass densities. We will then review our current understanding of the cycling of baryons from global to galactic scales, in the so-called circumgalactic medium. These results will be complemented by recent findings of hydrodynamical cosmological simulations. The final parts will be dedicated to future prospects, identifying new techniques and up-coming facilities as well as key open questions.

*Speaker

Cosmic ray feedback in galaxy formation

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Germany

Abstract

Understanding the processes underlying galaxy formation is one of the most important challenges in astrophysics. Unresolved questions include the disconnect between the short time scale of gas collapse on small scales and the long time scale for galaxy evolution, as well as the mechanism responsible for ejecting mass, momentum, and energy out of galaxies (or preventing their infall) in a way that matches the observed scaling relations. Recent progress strongly suggests that cosmic rays may play a crucial role in controlling these processes in and around galaxies. However, the strength of cosmic ray feedback depends very sensitively on the dynamical coupling of cosmic rays to the background plasma. I will review how cosmic rays interact with and propagate through the magnetised plasma in the interstellar and circumgalactic media. In particular, I will highlight a new insight into how cosmic rays drive plasma waves unstable in such a way that they can scatter off the waves, thereby regulating the cosmic rays' transport speed and momentum transfer to the ambient plasma. I will then demonstrate that cosmic rays play a decisive role in the formation and evolution of spiral galaxies by providing feedback that regulates star formation and drives gas out in galactic winds. This implies that cosmic rays dominate the pressure of the circum-galactic medium, raising the question whether this impacts thermal instability and precipitation of the cooling gas onto galaxies which would enable future star formation. Comparing cosmic ray spectra of electrons and protons to observational data and studying the correlation of the far-infrared emission with gamma-ray and radio emission from galaxies enables us to test the cosmic ray feedback models. This argues that a complete understanding of galaxy formation necessarily includes these non-thermal components.

*Speaker

The impact of cosmic rays in Milky Way-like galaxies and their gamma ray signatures

Karin Kjellgren*¹

¹University of Heidelberg (ITA) – Germany

Abstract

Cosmic rays (CRs), with their substantial energy density, play a key role in galaxy evolution, and shaping the interstellar medium (ISM). Accelerated in supernova (SN) shocks, CRs propagate along magnetic field lines, distributing energy and momentum throughout the galaxy. This process ionizes and heats the gas, drives large galactic outflows by creating pressure gradients, and regulates star formation. Observationally, the influence of CRs is revealed via the emission of gamma radiation.

We perform high-resolution magnetohydrodynamical simulations of Milky-Way-like galaxies, in which we follow individual massive stars and include self-consistent stellar feedback such as SNe and CRs, dynamically coupled to the MHD equations. We model the multi-phase interstellar medium using a non-equilibrium chemical network that includes hydrogen and carbon species, allowing us to take into account the relevant cooling and heating processes and compare the simulations to observations. Additionally, we investigate how the galactic magnetic field influences CR transport by varying the initial field strength between a weak setup (3nG) where the field is allowed to evolve self-consistently under the influence of the (CR-driven) magnetic dynamo, and a strong setup (3μG) that results in CGM field strengths more in line with cosmological simulations. This allows us to explore how and where CRs can alter magnetization in the disk as well as the CGM.

We present the effects of thermal and CR feedback on the galactic structure and gas dynamics across different ISM phases. We find that CRs convert fountain flows into sustained galactic outflows - absent in the MHD-counterparts - driving mass loss from the entire disk and magnetize the CGM. We analyze these outflows in terms of energy loading and their impact on vertical structure. Additionally, we back up our simulations with post-processed, multi-wavelength gamma-ray emission from both CR protons and electrons, enabling direct comparisons to observational features in the Milky Way.

*Speaker

Imprints of Feedback on the Cosmic Evolution of Gas and Metals in the IllustrisTNG Simulations

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¹Max Planck Institute for Astrophysics – Germany

²Max Planck Institute for Astrophysics – Germany

Abstract

Metal absorption lines are powerful tools for probing the gas content in the universe and illuminating the gas flows around galaxies. Absorption that arises from different ionization states of chemical elements provides insight into various gaseous structures and environments - low-ionization lines trace the cooler, denser regions near galaxies, while high-ionization lines illuminate the hotter, more diffuse regions of the universe. I generate a suite of synthetic quasar absorption-line observations from the TNG100 cosmological simulation across redshifts from $z = 5$ to the present to examine the cosmic evolution of multiphase gas and metal absorption lines. Using these, I compute the absorber path densities for low- (e.g., MgII), intermediate- (e.g., SiIII), and high-ionization species (e.g., CIV, OVI) and find that TNG100 qualitatively reproduces observed trends - the path densities of different ions evolve with redshift at different rates. Path densities of high-ionization species also peak at lower redshifts compared to their low-ionization counterparts. Quantitatively, TNG100 slightly overpredicts the path densities of various metal absorbers, suggesting an excess of metal-enriched gas at all redshifts considered, though the excess varies across ions. This excess remains when we implement different UV backgrounds to generate metal absorption lines. I further explore this discrepancy using mock absorption-line observations of the CGM of selected galaxies. They reinforce the idea that TNG100 may be overproducing metal absorbers, potentially due to an overly efficient metal redistribution via galactic outflows. I show that these results potentially reflect the implementation of feedback mechanisms - such as AGN-driven winds or supernova feedback - in TNG100 and their implications for modeling gas flows in galaxy evolution. I also discuss potential model refinement to achieve better agreement with observations.

*Speaker

Characterizing turbulence injection by cold fronts and mergers in cosmological simulations of galaxy clusters

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Abstract

Defining what is turbulence and what is not in the ICM of galaxy clusters is inherently ambiguous, as the plasma is radially stratified, and continuously stirred at different scales. This poses a serious problem in the interpretation of both observations and numerical simulations, since the strength and the properties of turbulence are fundamental ingredients of many physical processes, such as the magnetic dynamo and cosmic ray acceleration. Previous techniques to disentangle turbulence from bulk flows include spherical averaging and multi-scale iterative filtering, though both come with limitations.

In this talk I propose a more holistic approach, combining spatial filters that extract fluctuations at a given scale with local power spectra to analyse the evolution of cluster turbulence throughout their history. Our pipeline - which has been parallelized to take advantage of modern GPUs - is applied to massive ($M_{200,c} > 10^{15} M_{\text{sun}}$) galaxy clusters from PICO-Clusters, a new suite of high-resolution cosmological zoom-in simulations using the moving mesh code Arepo with the IllustrisTNG galaxy formation model.

With this approach it is possible to quantify the injection of turbulence, e.g. by cold fronts and cluster mergers, as well as to identify the respective contribution of turbulent fluctuations and bulk flows to emission line broadening in the central regions of galaxy clusters.

These observables can be probed by XRISM and next-generation X-ray telescopes, allowing us to connect high-resolution cosmological simulations to observations.

^{*}Speaker

Hydrodynamical turbulence in protoplanetary discs

Geoffroy Lesur^{*1}

¹nothing – Argentina

Abstract

I will present our current understanding of hydrodynamic turbulence in the cold, weakly ionized regions of protoplanetary discs. In this context, three hydrodynamic instabilities are of particular interest: the vertical shear instability (VSI), the convective overstability (COS), and the zombie vortex instability (ZVI). I will review their physical mechanisms and current theoretical status, before focusing on recent results concerning the nonlinear saturation of the VSI. Finally, I will discuss how turbulence driven by the VSI may be interpreted within the broader framework of critically balanced rotating turbulence.

*Speaker

MHD turbulence and dynamos in accretion disks

Henrik Latter^{*1}

¹University of Cambridge [UK] – United Kingdom

Abstract

I will review turbulence and magnetic field generation in the fully ionised plasma swirling around, and accreting onto, compact objects, such as white dwarves, neutron stars, and black holes. The magnetorotational instability (MRI) will be the star of the show, but the talk will touch on other dynamo mechanisms, such as the gravitoturbulent dynamo. After my take on the modern simulation landscape, the main topics to be covered comprise (a) theories of MRI saturation, (b) large-scale dynamo waves, (c) the nature of the MRI's small-scale dissipative structures and the partition of heating between ions and electrons, (d) the MRI's relationship to thermal instability, convection, and gravitational instability, and (e) the behaviour of the MRI in weakly collisional (or collisionless) settings.

*Speaker

Giant clumps at cosmic noon

Jeremy Fensch*¹

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Abstract

Most of the massive star-forming galaxies from the cosmic peak of star formation (from $z=3$ to $z=1$, coined ‘cosmic noon’) show several giant star-forming clumps, of masses up to 10^8 - 10^9 solar masses spanning around 1 kpc and forming stars at a rate of a few M_{\odot} /year. Signs of migration of these structures towards galaxy centres suggest that they are not transient features. It is therefore important to understand if star formation proceeds differently in giant clumps, which harbour an environment for star formation that is very different from that of local molecular clouds in terms of gas surface density, turbulence, star formation and feedback clustering.

Using parsec-scale numerical simulations, I will show how these giant clumps may arise, either by violent disc instabilities in isolated gas-rich disks and also mergers of moderately gas-rich galaxies. The formation and evolution of clumps via these channels have a very low sensitivity to stellar feedback prescriptions, as long as the disk is gas-rich enough. In particular, I will show to what extent the too low gas fraction in galaxies obtained in most of the latest cosmological simulations may lead to missing the formation of these clumps and their subsequent impact on galaxy evolution.

Last, I will show how gravity-driven turbulence cascades down from star-forming clouds down to the sub-parsec level, using a self-consistent zoom-in method in isolated disk simulations tracing the self-generated supersonic turbulence cascade over four decades in spatial scales. The main results from isothermal disks with gas and stars is that gravitational instabilities inject turbulence which cascades isotropically following Burgers’ scaling down to the resolution limit (0.1 pc). The cascade, and density statistics, are the same for spiral and clumpy disks, despite different Mach number, morphology and dynamics, pointing towards a universality of gravitationally-driven isothermal turbulence in galactic disks. We further show that the results are not affected by including magnetic fields, stellar feedback and thermal instabilities.

*Speaker

Plasma turbulence in the ISM

Katia Ferrière^{*1}

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Midi-Pyrénées, Université Paul Sabatier (UPS) - Toulouse III – France

Abstract

The interstellar medium is a multi-scale, multi-phase, magnetized, partially ionized, and highly turbulent medium. In this talk, I will address both theoretical and observational aspects of plasma turbulence in the interstellar medium. I will successively consider radio wave propagation through a plasma and radio polarized emission. For each, I will first provide a theoretical framework in the form of a few basic equations, which will enable me to define useful diagnostic tools of plasma turbulence; I will then show how these tools have been utilized to detect and interpret observational signatures of plasma turbulence, and what astronomers have learned from them regarding the nature, the sources, and the dissipation of turbulence in the interstellar medium.

^{*}Speaker

Observing turbulent magnetic fields in the interstellar medium

Marijke Haverkorn^{*1}

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Abstract

Magnetized interstellar turbulence is exceedingly complex: it is compressible, non-gaussian, and spatially intermittent, its properties depending on environment. Observational characterization of turbulent magnetic fields is equally complicated due to the indirect nature of magnetic field measurements, and the dependence of the observables on other interstellar components such as cosmic ray, gas and dust distributions.

A wealth of recent observations and correlation studies with other interstellar components show convincingly that descriptions of the Galactic magnetic field in terms of power laws and correlation scales are much too oversimplified, as theoretical studies also indicate. I will present some of these recent observational efforts to characterize turbulent magnetic fields in the interstellar medium of the Milky Way and discuss some of the puzzling results.

^{*}Speaker

Probing cosmic turbulence with fast radio bursts

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Abstract

Fast radio bursts (FRBs) are dispersed and scattered by plasma density fluctuations along the line-of-sight, making them sensitive probes of diffuse ionized gas across interstellar, circumgalactic, and intergalactic media (ISM/CGM/IGM). FRB measurements can indirectly constrain the spectral index, amplitude, and inner scale of the density fluctuation power spectrum, making them highly complementary to more direct probes of velocity and magnetic field fluctuations in turbulent plasmas. In this talk I will discuss how FRB propagation effects are unveiling cosmic plasmas at extremely small (sub-au) spatial scales in both interstellar and circumgalactic media, and how they may be used in tandem with quasars to constrain the turbulent dynamics of ionized gas in these environments. I will illustrate how techniques developed through decades of study of Galactic pulsars are now being routinely applied to FRB surveys, which will soon add FRBs to the landscape of probes that trace the evolution of ISM and CGM turbulence over cosmic time.

*Speaker

The First Stars: Formation, Properties, Impact

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Abstract

The first generation of stars, often called Population III (or Pop III), form from metal-free primordial gas at redshifts $z \sim 30$ and below. They dominate the cosmic star formation history until $z \sim 20$ -15, at which point the formation of metal-enriched Pop II stars takes over. I review current theoretical models for the formation, properties and impact of Pop III stars, and discuss observational constraints. I argue that primordial gas is highly susceptible to fragmentation and Pop III stars form as members of small clusters with a logarithmically flat mass function. Feedback from massive Pop III stars plays a central role in regulating subsequent star formation, but major uncertainties remain regarding its immediate impact. Direct observations of Pop III stars in the early Universe remain extremely challenging, whereas stellar archeological surveys allow us to constrain both the low-mass and the high-mass ends of the Pop III mass distribution. Observations suggest that most massive Pop III stars end their lives as core-collapse supernovae rather than as pair-instability supernovae. I also speculate about the formation of supermassive stars, which under very specific circumstances can get as massive as several 100.000 solar masses and can become the seeds of the supermassive black holes observed in the high-redshift universe.

*Speaker

Turbulent mixing and shock excitation in the molecular circum-galactic medium of Stephan's Quintet

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Abstract

Understanding the survival mechanisms of cold clouds in the circum-galactic medium of galaxies is key to comprehending how galaxies acquire the gas needed for star formation and how the CGM remains a complex, multi-phase medium over time. I will present JWST infrared spectroscopy of molecular hydrogen in the intra-group medium of Stephan's Quintet, where two multiphase gas flows are colliding at a relative velocity of 700 km/s. This is an exceptional and nearby laboratory to study the origin and survival of cold gas in a shocked, tidally-stripped material in the group halo, where the exquisite spectral and spatial resolution of the JWST MRS allows us to probe the morpho-kinematics of the ionized and warm molecular gas on the scale of giant molecular clouds.

*Speaker

A model of SNR expansions in the Milky Way : the hidden ionization factor

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Abstract

Supernova remnants (SNRs) are major drivers of turbulence in the Milky Way and play a central role in the exchange of mass and energy between the different phases of the interstellar medium (ISM). Yet, despite their importance, very few tracers of old, radiative SNRs have been identified, and their contribution to the global ionization of the ISM remains largely unquantified.

Following the identification of a potential tracer of old radiative SNRs (1), we performed detailed modeling of SNR evolution and their interaction with the surrounding medium using the Paris Durham shock code. The code was recently extended to compute the production of multi-ionized species, as well as both continuum emission and line emission across more than one million radiative transitions (2). To quantify the global impact of SNRs on the thermochemical state of the ISM and derive the statistical properties of potential tracers, we developed a Galaxy-wide distribution model that accounts for both core-collapse and thermonuclear supernovae, and incorporates key features such as spiral arms, Galactic flaring, and the variation of star formation rate, ambient density, UV radiation field, and magnetic field with galactocentric distance.

As a first application, the results of the model were compared with two infrared Galactic surveys of the fine-structure lines of N⁺ observed by COBE (3) and the Herschel Space Telescope (4). The analysis shows that SNRs make an unavoidable contribution to N⁺ emission along random lines of sight. Preliminary results indicate that at least 30% of the N⁺ in the Galaxy is produced by SNRs, primarily through collisional processes, suggesting that SNRs may be a significant source of ionization in Milky Way-like galaxies. This finding is remarkably robust, showing only a weak dependence on the specific parameters governing the SNR distribution.

(1) Godard, B., Pineau des Forêts, G., et al. 2024b, *A&A*, 689, A25

(2) Godard, B., Pineau des Forêts, G., et al. 2024a, *A&A*, 688, A169

(3) Bennett, C. L., Fixsen D. J., et al. 1994, *ApJ*, 434, 587

(4) Goldsmith, P. F., Yildiz, U. A., et al. 2015, *ApJ*, 814, 133

*Speaker

Zooming-in on radio relics: Solving five major problems with density turbulence

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Abstract

Radio relics are Mpc-sized regions of emission that can be found at the periphery of merging galaxy clusters. They are generally understood to result from synchrotron emission produced by shock-accelerated electrons. However, whilst the standard paradigm is agreed upon, a series of problems continue to challenge our understanding. In particular, we note the following five major problems: i) the so-called "Mach number discrepancy", where radio-derived Mach numbers are higher than their X-ray equivalents, ii) the inferred existence of microgauss magnetic fields, which cannot be achieved by standard shock compression scenarios alone, iii) the apparent contradiction of cooling models with observations, iv) the existence of varied, often filamentary, small-scale morphology, and finally v) the "critical Mach number" problem, where particle-in-cell (PIC) simulations appear to contradict the very existence of radio relics! We use a hybrid approach to solve these problems; first identifying typical shock conditions in cosmological simulations, before using the results to inform a series of idealised shock-tubes, which can be run with substantially higher resolution. We post-process our simulations with the cosmic ray electron spectra code, CREST, and the emission code, CRAYON+, thereby creating mock radio data ab-initio. Through this strategy, we have identified that upon running into an accretion shock, merger shocks generate a dense, shock-compressed sheet, which then interacts with upstream density fluctuations in the intracluster medium (ICM). In this talk, I will show how this scenario generates a Mach number distribution at the shock front and excites Rayleigh-Taylor-generated velocity turbulence at the contact discontinuity. I will then show how this directly leads to solutions for the five aforementioned problems. Finally, I will show how the upstream fluctuations imprint themselves on the relic morphology, providing the intriguing possibility that we may use radio relics, in turn, to study the turbulent properties of the ICM.

*Speaker

The Turbulent Support (TS) and Global Hierarchical Collapse (GHC) models for molecular clouds compared. Differences, convergence, and myths.

Enrique Vazquez-Semadeni*¹

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Abstract

I will present a detailed comparison between the "turbulent support" (TS) and "global hierarchical collapse" (GHC) theoretical models for molecular clouds and star formation, as a basis for the interpretation of observations and simulations. After a brief historical recap of the origins of both models, I will discuss their fundamental premises and interpretation of molecular cloud properties, scaling relations, energy balance, and star formation activity. The fundamental distinction is that TS assumes that giant molecular clouds (GMCs), on scales 10-100 pc are supported against collapse by turbulent motions, and interprets the widths of molecular lines exclusively as turbulence that opposes gravity. Instead, GHC incorporates a description of GMC-scale infall motions and accretion at all scales onto and inside the clouds, which allows the clouds and their substructures to evolve, increasing their masses, sizes, and star formation rates (SFRs). Also, it explicitly considers that the total velocity dispersion and the kinetic energy E_k include compressive motions (of either gravitational or inertial origin) that do not oppose gravity but rather work together with it. In consequence, values of the virial parameter ($\alpha_v = 2E_k/E_g$) up to ~ 3 can be considered as indicative of significant gravitational binding. In relation to the SFR, in TS it is determined by parameters of the turbulence, which is considered as an external agent, and therefore the SFR is not subject to secular evolution. Under GHC, instead, the main parameter regulating the evolution of the SFR is the accretion rate onto the cloud and the gravitational contraction, causing the SFR to first increase over time, until feedback begins to reduce it, by destruction of the local collapse flow. Finally, under TS, hub-filament systems (HFSs) are a consequence of turbulent compressions, while under GHC they are the result of anisotropic gravitational contraction from the cloud scale. Several strategies to discriminate between the two scenarios are outlined.

*Speaker

Interactions of Small-Scale and Large-Scale Dynamos in the Interstellar Medium

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Abstract

Observational evidence of near-equipartition magnetic fields at high redshift demonstrates that dynamo generation of fields must proceed quickly. We use numerical simulations of a shearing box with the Pencil Code, a high-order finite difference code, to study the supernova-driven interstellar medium (ISM). Turbulence drives a small-scale dynamo (SSD) that proceeds at different rates in the different thermal phases of the ISM and grows in direct proportion to the local vorticity. The SSD saturates at a few percent of equipartition with kinetic energy. Growth rates of a few megayears or less occur in well resolved models of the SSD, suggesting that galaxies are effectively born magnetized. Differential rotation drives a large-scale dynamo (LSD) that also derives energy from the turbulent flow, and approaches saturation within 1 Gyr. Our local models of the LSD tend to produce a stronger mean field than observed, suggesting that global effects contribute to observed fluctuating fields. The observed relationship between density and magnetic fields is best reproduced by global models that include dynamo activity.

*Speaker

On the relation between magnetic field strength and gas density in the interstellar medium: A multiscale analysis

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Abstract

The magnetic field strength to gas density relation in the interstellar medium is of fundamental importance. We present and compare Bayesian analyses of the B-n relation for two comprehensive observational data sets: a Zeeman data set and 700 observations using the Davis-Chandrasekhar-Fermi (DCF) method. Using a novel hierarchical Bayesian analysis I will present a general, multi-scale broken power-law relation, $B = B_0(n/n_0)^\alpha$, with $\alpha = \alpha_1$ for $n < n_0$ and α_2 for $n > n_0$, and with B_0 the field strength at n_0 for both the Zeeman data and DCF data. I will examine the new results and data and how it relates to scales in the ISM, specifically in relation to gravity and core formation. We performed a similar analysis on nineteen numerical magnetohydrodynamic simulations covering a wide range of physical conditions from protostellar disks to dwarf and Milky Way-like galaxies, completed with the Arepo, Flash, Pencil, and Ramses codes. I shall discuss how, by using these numerical simulations we can see what physical processes drive the relationship and push us to better understand the interplay between magnetic fields and the ISM, and how the roles of turbulence and gravity are important.

*Speaker

Magnetic fields in simulations of Milky Way-like galaxies

Philipp Girichidis*¹

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Abstract

Magnetic fields play a central role in shaping the multiphase interstellar medium (ISM), regulating star formation, and mediating cosmic ray (CR) transport, yet their large-scale structure and observational signatures in galaxies remain incompletely understood. We present a suite of three-dimensional magnetohydrodynamical (MHD) simulations of Milky Way-like galaxies that include a non-equilibrium chemical network for accurate cooling, star formation, and supernova feedback, as well as CR physics. Our models allow us to investigate the amplification, strength, and structure of galactic magnetic fields in environments with and without CRs. We analyze magnetic field reversals in the disk plane and assess their relation to spiral structure, stellar feedback, and star formation activity. We further connect the simulated magnetic field morphology to observables by computing synthetic Faraday rotation measures, providing a direct comparison to Galactic observations. These results offer new insights into the interplay of magnetic fields, cosmic rays, and stellar feedback in shaping the ISM and highlight the importance of CRs for reproducing observed large-scale field structures in Milky Way-like galaxies.

*Speaker

The Intermittency of Turbulence in MHD Simulations

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Abstract

Intermittency measurements constitute an attempt to characterise the hidden order lying behind the apparent chaos of turbulent motions. I will review numerical experiments of isothermal MHD designed to assess how much geometrical projection can affect observational indicators of intermittency. I will present efforts to carefully identify the nature of the coherent structures (discontinuities such as shocks or current sheets) at the origin of the statistical anomalies probed by intermittency indicators. It appears that the macroscopic parameters of these discontinuities is to some degree insensitive to the dissipation coefficients. This is also supported by recent work with JB Durive on analytical solutions of Burgers equations. Finally, I will briefly present a multiscale synthesis technique able to generate turbulent fields which bear the proper intermittency characteristics at a much lower cost than full fledged numerical simulations.

*Speaker

Lyman-alpha to probe Lyman-continuum escape from galaxies

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Abstract

In the context of understanding cosmic reionisation, I will review the theoretical predictions and observational studies of the links between spectral and spatial distributions of the Lyman-alpha emission and Lyman continuum escape from galaxies.

*Speaker

Radiative transfer of Hydrogen Lyman Alpha in Turbulent Gas

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Abstract

Turbulence plays a crucial role in various astrophysical phenomena, from star formation to galaxy evolution, influencing the gas properties. Hydrogen Lyman Alpha ($\text{Ly}\alpha$) is one of the most prominent emission lines in diverse astrophysical environments. Due to its resonance nature, $\text{Ly}\alpha$ emission is highly sensitive to the properties of cold neutral gas and is widely used as a tracer of cold gas. While many radiative transfer simulations have been developed to extract physical information from $\text{Ly}\alpha$ emission, most adopt a simplified ‘microturbulence’ approximation, assuming a Gaussian velocity distribution without spatial correlations. In this work, we combine 3D Monte Carlo $\text{Ly}\alpha$ radiative transfer with hydrodynamic simulations to investigate how realistic, spatially correlated turbulence imprints itself on $\text{Ly}\alpha$ spectra. We find that such turbulence induces significant directional and temporal variations in the spectral shape. These results highlight the critical role of turbulent structure in shaping observable $\text{Ly}\alpha$ emission. In addition, I will discuss how to fully capture and treat optically thick turbulent gas in $\text{Ly}\alpha$ radiative transfer for large-scale simulations.

^{*}Speaker

Lyman-alpha radiation pressure feedback at Cosmic Dawn

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Abstract

Lyman-alpha ($\text{Ly}\alpha$) radiation pressure may be the dominant feedback mechanism during the Cosmic Dawn, when star-forming regions were denser and less metal-enriched than they are today. Therefore, accurately evaluating $\text{Ly}\alpha$ feedback in star and galaxy formation simulations is crucial for providing a realistic description of the high-redshift universe.

In this talk, I will discuss how $\text{Ly}\alpha$ radiation pressure regulates star formation. First, we developed a minimal shell model incorporating $\text{Ly}\alpha$ feedback for a central star cluster, validated through one-dimensional hydrodynamic simulations. From this, we derived upper limits on the star formation efficiency (SFE) of star-forming clouds imposed by $\text{Ly}\alpha$ feedback. Next, we constructed a framework to study the collective behavior of individual $\text{Ly}\alpha$ -driven bubbles around massive stars. By linking the volume filling factor to the star formation rate, we showed that the SFE remains below 35%, even for the most massive clouds. Finally, I'll present LYDION (LYman alpha DiffusION), a 1D $\text{Ly}\alpha$ radiative transfer solver based on the diffusion approximation. Compared to traditional Monte Carlo Radiative Transfer (MCRT) methods, LYDION is several hundred times faster, enabling efficient $\text{Ly}\alpha$ radiation hydrodynamics (RHD) simulations. I will conclude by discussing potential applications of LYDION—such as modeling H II region expansion around Population III stars—and its future development toward realistic star and galaxy formation simulations that incorporate $\text{Ly}\alpha$ radiation pressure feedback.

*Speaker

JWST imaging of the Pleiades: anisotropy of the turbulent energy cascade in the cold neutral medium

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Abstract

Studies of the interstellar medium often rely on magnetohydrodynamic (MHD) turbulence as an interpretive framework, making the statistical analysis of interstellar observations essential. In this work, we present a new perspective on diffuse interstellar matter through James Webb Space Telescope (JWST) NIRCcam observations of the Pleiades nebula. These data provide an unprecedented high-resolution view of the cold neutral medium (CNM), with a spatial resolution of 0.2 mpc (40 au). We apply two-dimensional Fourier analysis to characterize the structure of PAH emission in regions both near and farther from the star

*Speaker

Merope. To isolate the interstellar signal, stars and galaxies are removed, and an additional Fourier-space component—interpreted as a residual of the near-infrared cosmic background—is subtracted during the final data cleaning. The resulting PAH emission power spectra are strongly anisotropic and follow a break-free power-law, implying the absence of a characteristic scale for energy dissipation. The spectral slopes are -3.5 near Merope and -3 in the more distant region. Furthermore, the anisotropy in PAH emission is aligned with the magnetic field orientation inferred from Planck dust polarization data, with the degree of anisotropy remaining constant across scales. These results are considered in the context of interstellar turbulence potentially driven by the Pleiades stars. JWST observations thus provide a unique opportunity to confront theoretical models with data at physical scales where CNM turbulence decouples from thermal instability. Our findings support the view that the CNM energy cascade is anisotropic, consistent with expectations for subsonic MHD turbulence.

Probing intracluster medium turbulence from deep imaging of Sunyaev-Zel'dovich fluctuations

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Abstract

Understanding non-thermal intracluster medium (ICM) processes is becoming crucial for both cluster astrophysics and cosmology. Above all, turbulence is believed to be the main cause of the hydrostatic mass bias, limiting cluster cosmology, and is linked to the diffuse radio emissions via particle acceleration mechanisms that are not yet fully understood. The Sunyaev-Zeldovich effect (SZ) consists in the inverse Compton interaction between CMB photons and hot ICM electrons. It is a direct probe of the ICM thermal pressure. As turbulence is expected to drive pressure fluctuations, the SZ effect appears as a natural tool to investigate ICM turbulence, provided sufficient sensitivity and angular resolution is available. I will present constraints on the pressure fluctuation power spectrum in galaxy clusters using the NIKA2 SZ Large Program, a sample of 38 intermediate redshift clusters observed from the IRAM30m telescope at 18" resolution. Assuming scaling relations between pressure fluctuations and the 3D Mach number, we derive constraints on the turbulent to thermal pressure and the associated hydrostatic mass bias, finding about 15%. These results provide a step forward in the characterization of the physics of ICM turbulence.

*Speaker

Unveiling Turbulence Drivers in Quasar Halos: Insights from IFS Observations

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Abstract

The recent advent of high-throughput integral-field-unit spectrographs (IFS) has enabled unprecedented sensitivity in mapping low-density gas, opening new avenues for probing the dynamical states of the interstellar and circumgalactic medium (ISM and CGM). In this talk, I will present an investigation into turbulence and energy injection mechanisms in luminous quasar halos across redshifts from 0.5 to 3, leveraging data from VLT/MUSE and JWST/NIRSpec IFU. By analyzing velocity structure functions (VSFs) of the extended ISM and CGM, we demonstrate how AGN-driven outflows and jet-induced bubbles primarily inject energy at scales below 10 kpc, while larger-scale processes such as tidal interactions and galaxy mergers likely dominate energy injection further away from the central engine. In addition, elevated VSF amplitudes near halo centers reveal a stronger influence of AGN feedback in these regions. However, the overall turbulent energy contained in gas motions is subdominant in comparison to the quasar bolometric luminosity, suggesting inefficient energy coupling between quasar radiation and gas dynamics in the low-density halo environment. These findings provide empirical constraints on the scale-dependent mechanisms of energy injection and feedback in quasar systems, offering new insights into their role in shaping galaxy evolution across cosmic time.

*Speaker

From a Spherical Cow to a Herd: Modelling Multiphase Galactic Outflows

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Abstract

Galactic outflows crucially transfer baryons and energy across the ISM and CGM, affecting the stellar formation history and the distribution of metals. However, the survival of cold gas in these outflows remains uncertain due to the turbulent, multiscale nature of interactions between different gas phases. In this work, we extend the current understanding of outflow dynamics by bridging simplified "cloud-crushing" simulations with more realistic models of fractal ISM morphology. While previous wind tunnel simulations revealed a critical length scale of cold gas above which cooling dominates and multiphase survival is possible, such a scale does not exist in realistic ISM configurations. Using 3D AthenaPK simulations, we show how in such a setup this "survival criterion" maps to a fractal cold gas morphology. Specifically, we find a critical cold gas volume filling fraction in the ISM above which cold gas can survive and the emergent galactic winds are multiphase. Furthermore, we quantify how wind morphology, shaped by local ISM conditions, alters the kinematics and structure of outflows at large galactic distances. Our analysis of velocity structure functions and clump mass distributions of winds show dependencies on ISM conditions. This work shows critical links between galactic winds and the originating ISM, shedding light on the intricate processes that govern the baryonic cycle.

*Speaker

Magnetized infalling cold clouds and streams in the CGM

Ish Kaul*¹

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Abstract

The observed star formation and wind outflow rates in galaxies suggest cold gas must be continually replenished via infalling clouds or streams. Previous studies have highlighted the importance of cooling-induced condensation on such gas, which enables survival, mass growth, and a drag force which typically exceeds hydrodynamic drag. However, the combined effects of magnetic fields, cooling, and infall remain unexplored. Using 3d MHD simulations with radiative cooling I will show that for infalling clouds, magnetic fields aligned with gravity do not impact cloud growth or dynamics significantly, although stronger fields enhance survival. In contrast, even weak transverse magnetic fields can significantly slow cloud infall through magnetic drag. This effect arises when strong ‘draped’ fields form at the cloud’s peak infall velocity, just before it decelerates.

I will show that besides enhancing survival, slow infall increases total cloud mass growth compared to the hydrodynamic case, even if reduced turbulent mixing lowers the mass growth rate. Furthermore, I will show that streams often result in qualitatively different behavior. Mass growth and hence accretion drag are generally much lower in hydrodynamic streams. Unlike in clouds, aligned magnetic fields suppress mixing and thus both mass growth or loss. Transverse fields do apply magnetic drag and allow streams to grow. Overall, regardless of the efficacy of drag forces, streams are surprisingly robust in realistic potentials, as the destruction time when falling supersonically exceeds the infall time. I will also show how analytic models can reproduce these cloud/stream trajectories.

*Speaker

NOEMA3D: Inflowing Gas at Subgalactic Scales in Massive Star Forming Galaxies at $z \sim 1-2$

Jean-Baptiste Jolly^{*1}, Linda Tacconi², Reinhard Genzel^{2,3}, Natascha Forster-Schreiber², Karl Schuster⁴, and Roberto Neri⁵

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Abstract

In this talk I will present the first results from NOEMA3D, an ongoing IRAM-NOEMA ambitious legacy program with resolved observations of CO, (CI) and 1 mm dust continuum in a well-characterized sample of ~ 20 massive SFGs at $z \sim 1-2$, investigating the physical and kinematic processes that drive galaxy evolution on sub-galactic scales. With on-source integration times of 20-70 hours with the full 12-antenna array, NOEMA3D provides unequalled sensitivity and high spectral resolution cold gas maps of SFGs at this important epoch. More specifically, I will present high-resolution case-studies of molecular gas inflows along non-axisymmetric structures such as spiral arms or bars of galaxies, fueling nuclear star formation, bulge growth or efficiently feeding the central supermassive black hole.

^{*}Speaker

Modeling Cosmic Ray Transport: Magnetized vs. Unmagnetized Motion in Structured Magnetic Turbulence

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Abstract

Recently, the compatibility of conventional cosmic-ray transport theories with observational data has been questioned, sparking interest in the role of the fieldline geometry of turbulent magnetic fields. While magnetic turbulence is often viewed as a superposition of unstructured random fluctuations, both plasma simulations and observations of the solar wind as well as the interstellar medium suggest a complex and highly structured nature. To advance the understanding of cosmic-ray transport in realistic magnetic turbulence, we study the motion of test particles in snapshots of a high-resolution magnetohydrodynamic simulation, conditional on their gyro radii and experienced fieldline curvature. We identify two distinct transport modes: magnetized motion of particles tightly bound to coherent flux tubes and subjected to large-scale mirroring; and unmagnetized motion characterized by random scattering through chaotic regions of the magnetic field. We present a stochastic process for each case, describing magnetized motion by compound subdiffusion with long mean free paths and unmagnetized motion by using a Langevin approach with short mean free paths. Additionally, we propose a combined model consisting of a stochastic walker that alternates between the two modes and accurately reproduces test particle mean square displacements. We conclude by comparing our model with other non-classical transport descriptions and discuss the role of streaming cosmic rays. Although open questions remain, our approach highlights the impact of non-trivial turbulent geometry on cosmic-ray transport.

^{*}Speaker

Magnetic fields in the intracluster medium with TNG-Cluster: properties, morphology, and tangential anisotropy

Dylan Nelson^{*1}

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Abstract

We characterize the magnetic field properties of 352 massive galaxy clusters from the TNG-Cluster magnetohydrodynamical cosmological simulation with a focus on central magnetic field morphology in cool-core (CC) vs non-cool-core (NCC) clusters. We present the central values and radial profiles of magnetic field strength and plasma parameter as a function of mass, cooling status and redshift. Compared to low-redshift observations, TNG-Cluster produces reasonable magnetic field amplitudes in the central regions of clusters spanning a range of 1-200 μG . We then discuss the main finding of this work: $z=0$ cool-core clusters have preferentially tangential magnetic fields at a characteristic scale of $\sim 0.1 r_{500c}$. These strongly tangential field orientations are specific to CCs. In contrast, across the full cluster population, magnetic fields show isotropic configurations at all radii and redshifts. As individual halos grow, the evolution of their magnetic field topologies is diverse: tangential features can be short-lived, persist over large cosmological time-scales, or periodically appear, vanish, and reappear towards $z=0$. We discuss the underlying physics and possible physical scenarios to explain the origin of these structures. We argue that both AGN feedback-driven outflows, and merger-driven sloshing motions, cannot explain the population-wide tangential bias in magnetic field orientation. Instead, we propose that the trapping of internal gravity waves is responsible for the tangentially biased magnetic field topologies that we find in cool-core TNG-Cluster halos, due to the strong entropy gradient in these clusters.

^{*}Speaker

BISTRO: Magnetic Fields Regulate Star Formation in the Western CMZ

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Abstract

The inner 100pc of the Central Molecular Zone (CMZ) of the Milky Way is characterized by extreme conditions—high gas densities, vigorous turbulence, and strong magnetic fields—that differ markedly from those in the Galactic disc. Yet, despite this abundance of dense gas, the star formation rate is observed to be roughly a factor of two lower than that in the disc, which is a long-standing puzzle. In our study, we use the 850 μ m polarized dust emission data from the JCMT BISTRO (B-fields In STar-forming Region Observations) survey, with a spatial resolution of 14.2, to probe the magnetic fields in a number of molecular clouds located in the western CMZ (spanning a $0.3\circ \times 0.2\circ$ area centered around $(l, b) = (359.608\circ, -0.037\circ)$ between the 20kms⁻¹ cloud and SgrC). Our analysis reveals that these clouds exhibit strong magnetic fields on the order of ~ 1 mG and are both magnetically subcritical and sub-Alfvénic. These characteristics indicate that magnetic fields provide significant support against gravitational collapse and turbulent compression. We, therefore, propose that the magnetic fields could play a dynamical role in stabilizing the molecular clouds, effectively suppressing star formation in these extreme environments. This magnetic field regulation may help to explain the observed low star formation efficiency in the western part of the CMZ despite its high gas density.

^{*}Speaker

TURBULENT DYNAMOS IN A COLLAPSING CLOUD

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Abstract

The amplification of magnetic fields is crucial for understanding the observed magnetization of stars and galaxies. Turbulent dynamo is the primary mechanism responsible for that but the understanding of its action in a collapsing environment is still rudimentary and relies on limited numerical experiments. We develop an analytical framework and perform numerical simulations to investigate the behavior of small-scale and large-scale dynamos in a collapsing turbulent cloud. This approach is also applicable to expanding environments and facilitates the application of standard dynamo theory to evolving systems. Using a supercomoving formulation of the magnetohydrodynamic (MHD) equations, we demonstrate that dynamo action in a collapsing background leads to a super-exponential growth of magnetic fields in time, significantly faster than the exponential growth seen in stationary turbulence. The enhancement is mainly due to the increasing eddy turnover rate during the collapse, which boosts the instantaneous growth rate of the dynamo. We also show that the final saturated magnetic field strength exceeds the expectation from considerations of pure flux-freezing or energy equipartition with the turbulence, scaling as $B\rho^{5/6}$, where ρ is the cloud density. Apart from establishing a formal framework for the studies of magnetic field evolution in collapsing (or expanding) turbulent plasmas, these findings have significant implications for early star and galaxy formation, suggesting that magnetic fields can be amplified to dynamically relevant strengths much earlier than previously thought.

*Speaker

Numerical simulations of a turbulent dynamo effect in a global stratified model of the intracluster medium

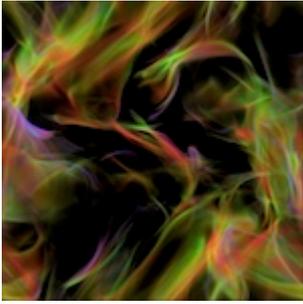
Jean-Maël Kempf^{*1} and François Rincon¹

¹Institut de Recherche en Astrophysique et Planétologie – IRAP-Toulouse – France

Abstract

X-ray observations of galaxy clusters show that those large-scale structures, located at the nodes of the cosmic web, host a very hot, diffuse, and ionised, gas, usually referred to as the intracluster medium (ICM). These observations unveil the subsonic turbulent nature of the gas flow, while the presence of microGauss-magnitude magnetic field can be deduced from complementary radio-observations. However, the questions of the origin and the structure of cluster’s magnetic fields are only moderately constrained from observations, and remain mostly open. In this respect, the small-scale fluctuation dynamo is a promising mechanism that converts the kinetic energy of the ICM flow into magnetic energy. This process is facilitated by the very large magnetic Prandtl number Pm found in galaxy clusters. In this work, we use IDEFIX to perform new numerical simulations of the self-excited dynamo effect, which is likely to amplify magnetic field up to strength at equipartition with the kinetic energy of the ICM velocity field responsible for its induction. These very-high resolution dynamo simulations, up to 1024^3 , in a spherical ICM model are unprecedented owing to their global, stratified, and very-high Pm regime. We explore a variety of physical effects. Different types of forcing are notably considered. The anisotropy of the transport processes with respect to the local direction of the magnetic field, typical of the strong magnetisation regime of the ICM plasma, are also accounted for in the Braginskii MHD regime simulated. In the limit of very high Pm , our simulations strongly suggest that a dynamo is always possible in galaxy clusters, despite their strong radial stratification. However, the orientation of the magnetic field depends on whether the turbulence is forced buoyantly through the magneto-thermal instability, or through an external artificial forcing mechanism aimed at mimicking large-scale cluster accretion or merger. Both forcing mechanisms lead however to common folded magnetic structures, that are reminiscent of the small-scale dynamo action. This anisotropy of the magnetic field, with respect to the radial direction of the gravity, is partly relaxed when the viscous transport is itself anisotropic.

^{*}Speaker



**MIST2025 - Cosmic turbulence and Magnetic fields:
physics of baryonic matter across time and scales**
29 Sep-3 Oct 2025 Cargèse (France)

POSTERS

Impact of the ambipolar diffusion on the formation of filament in the diffuse ISM through MHD instabilities

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Abstract

With the unprecedented resolution of the James Webb Space Telescope, we can now probe the fine structure of astrophysical environments where the decoupling between neutral and charged matter becomes significant. Observations showing the alignment of neutral material along magnetic field lines suggest that ambipolar diffusion may play a crucial role in shaping filamentary structures.

In this talk, we will present a new analytical study of the magnetic Rayleigh-Taylor instability (MRTI) in the incompressible, weakly ionized regime, modeled as a two-fluid system of neutrals and charges with different gravitational responses. This framework allows us to isolate the effects of ambipolar diffusion on mode growth.

We show that, unlike in the case of a magnetic field strictly within the interface, an **oblique field orientation** does not suppress all modes beyond a certain wavenumber. Instead, it leads to a **selection of preferred scales**, resulting in a distinct anisotropy in the instability development. This anisotropy is maximized in the intermediate coupling regime where ambipolar diffusion is strongest.

These results offer a novel perspective on how magnetic fields and partial ionization can structure astrophysical interfaces, with implications for interpreting the formation of filaments and stratified layers in various environments.

This work has been accepted for publication in *Astronomy & Astrophysics*. We will also present ongoing efforts to extend this analysis through dedicated numerical simulations, and we'll briefly discuss how this framework could be adapted to study other instabilities, such as the Kelvin-Helmholtz instability.

*Speaker

A mass invariant in a compressible turbulent medium

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Abstract

Supersonic compressible turbulence is ubiquitous in star-forming regions. However, predicting measurable statistical properties of the density fluctuations in this type of flow is a major challenge in physics due to the large non-linearities. In 1951, Chandrasekhar derived a mass invariant M_{inv} assuming statistical homogeneity and isotropy of the turbulent density field and stationarity of the background density. This invariant depends on the variance and correlation length of the density field. In this work, we perform high-resolution (2048^3) numerical simulations of homogeneous and isotropic compressible turbulence to test the validity of this invariant in a medium subject to decaying turbulence or to self-gravity. We study several input configurations, namely different Mach numbers and average gas densities to cover a range of star formation conditions. We confirm that M_{inv} remains constant during the decaying phase of turbulence and also for self-gravitating flows. We then present several applications of this invariant to improve our understanding of the statistics of compressible turbulence flows. First, it can be used to relate the deviation of the density probability distribution function of the density field from lognormal to its variance without any free parameters. Secondly, it enables us to predict the evolution of slope of the power spectrum of the density field with the Mach number in supersonic turbulence. These predictions are confirmed by comparison with numerical simulations. Finally, we discuss what can be learnt from this invariant regarding the statistics of the structures formed in star-forming regions and its link to the peak of the core mass function.

*Speaker

Tracing Magnetic Fields Along Star-Forming Filaments from Dust Polarization Data: First results from the B-FUN project with NIKA2-POL

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Abstract

We present an analysis of the plane-of-sky magnetic field structure within and around the OMC-1 filament in the Orion A molecular cloud, based on dust polarization data obtained with the NIKA2-POL camera at the IRAM 30m telescope. Our 1.15 mm continuum polarization maps, taken as part of the B-FUN large program, provide information on the magnetic field orientation at 11" (0.02 pc) resolution over a wide area, enabling us to clarify the correlation between the magnetic field structure and the filament properties/environment. A map of the plane-of-sky magnetic field strength is constructed with the Davis–Chandrasekhar–Fermi (DCF) method, using the local dispersions of polarization angles derived from the NIKA2-POL data in combination with a high-resolution column density map from Herschel, ArTéMiS, and NIKA2, as well as a velocity dispersion map derived from molecular (13CO, NH) line data. Our results show that the plane-of-sky magnetic field strength reaches values of several hundred microgauss in areas with well-ordered polarization angles, consistent with previous studies in this region. A new aspect of our work is the wider mapping coverage and the use of a more accurate method to estimate volume density as a function of position. We find that the mass-to-magnetic-flux ratio is significantly supercritical near BN-KL, only mildly supercritical along the OMC-1 filament, and magnetically subcritical in the outskirts of the filament.

These results contribute to clarifying the role of magnetic fields in the evolution of filaments and the origin of the star formation efficiency in dense molecular clouds.

^{*}Speaker

On the regulation of the cold neutral medium mass fraction by magnetic field

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Abstract

In the Galactic plane, the ratio of cold HI mass to total HI mass appears to remain roughly constant for Galactocentric radii between ~ 10 and ~ 20 kpc, despite differences in physical conditions. To explore the possible role of the mean magnetic field in the radial regulation of the cold HI mass fraction (CNM), we performed numerical simulations of 250 and 100 pc-sided turbulent cubic boxes including cooling functions and initial conditions tailored to model HI gas at galactocentric distances equal to 8.5, 11, 15, and 18 kpc. We find that, for these distances, the combined effect of the presence of magnetic field and a sufficiently large forcing scale is enough to keep the CNM mass fraction approximately constant between 11 and 18 kpc. When a radial reduction of the magnetic field is taken into account, this tendency is stronger and, in addition, the ratio between thermal and magnetic pressure, as well as the Alfvénic Mach number in the CNM, also remain approximately constant with galactocentric distance, suggesting the possibility that some properties of the CNM related to the magnetic field may also be approximately constant with galactocentric distance, while the properties of the hot HI gas have a radial dependence.

*Speaker

Solving the Six-Dimensional Vlasov–Maxwell System with Active Flux and Splitting Methods

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Abstract

Most space and astrophysical plasmas can be considered collisionless and are thus well described by the kinetic Vlasov equation in six-dimensional phase space, allowing for the modeling of non-equilibrium dynamics. This way, fast and small-scale kinetic effects such as wave-particle interaction can be captured, which have proven to be a driving factor in the macroscopic evolution of the plasma up to very large system scales. We present a novel scheme to solve the Vlasov–Maxwell system up to all of its six dimensions using operator splitting and the Active Flux (AF) method. AF is a modified Finite Volume method that evolves additional degrees of freedom located on the cell interfaces by a non-conservative method to compute high-order approximations to the numerical fluxes through the respective interface. Its compact stencil in both space and time is physically advantageous and facilitates parallelization. When comparing the proposed scheme to the state-of-the-art Positive and Flux Conserving method, it shows reduced dissipation and thus a better reproduction of important kinetic phenomena, even at significantly lower computing times.

*Speaker

A diffuse cloud seen from within: deformation, shock and turbulence ?

Cecile Gry*¹

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Abstract

The UV absorption spectrum of any nearby star bears the imprint of the diffuse local interstellar cloud (LIC) in which the Sun is embedded -only cloud to be observed from within. From the velocity measurements in all directions we derive the cloud bulk motion inside the Local Bubble relative to the Sun, and show that the cloud undergoes a compression in the direction of motion and an expansion in perpendicular directions. Column densities of atomic lines (MgII & FeII) evidence a metal abundance gradient from the front to the rear of the cloud.

Many sight-lines even the shortest ones exhibit secondary velocity component(s):

In half of the sight-lines covering half of the sky a component is present with a consistent blue-shift of -7 km/s relative to the LIC, that we interpret as evidence for a shock moving toward the cloud interior, possibly due to an enhancement of the external thermal pressure on one side of the LIC.

Other extra nearby secondary components could be kinematic disturbances inside the LIC. Could they be attributed to turbulence in the cloud ?

*Speaker

The Role of Magnetic Fields in Turbulence Amplification and Gravitational Collapse

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²Institute of Radioastronomy and Astrophysics – Mexico

Abstract

We investigate the amplification of turbulence during the gravitational collapse of prestellar turbulent cores through both analytical estimates and numerical simulations, comparing the hydrodynamic (HD) and magnetohydrodynamic (MHD) regimes. Analytically, we derive the ratio of one-dimensional velocity dispersion to gravitational infall velocity under the assumption of virial-like balance between kinetic and gravitational energies.

Using 3D simulations, we follow the time evolution of both turbulent and infall velocity components. In both HD and MHD cases, we find that turbulence initially decays, but is subsequently amplified by collapse, asymptotically approaching a virial-like state-even though the system remains far from equilibrium. In the MHD case, magnetic fields suppress turbulence generation, in agreement with previous findings. Stronger initial magnetic fields also slow down gravitational collapse, leading to varying ratios of turbulent-to-infall velocities. We propose and test a predictive expression for the collapse time delay as a function of the mass-to-flux ratio.

Finally, we explore the amplification of the magnetic field and its scaling with density during collapse, focusing on the intermediate radial region between the center and the radius of maximum infall speed. Our results have implications for the interpretation of observed velocity dispersions and magnetic field structures in star-forming regions.

^{*}Speaker

Dynamical heating by superbubbles and the cusp-core transformation

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Abstract

Recent JWST observations have revealed superbubbles (SBs)-cavity-shell structures distributed across the galactic disk-formed by successive supernova explosions. The potential fluctuations generated by SBs can dynamically heat galactic systems. Using the orbit-averaged Fokker-Planck equation, we investigate the role of SB-driven stochastic heating in the context of cusp-core transformation. This formalism describes the cumulative impact of weak, local encounters induced by stochastic noise sources. By modeling the expansion and collapse of SBs, along with their inhomogeneous spatial distribution, we derive diffusion coefficients linked to the power spectrum of SB-induced fluctuations. Furthermore, we find simple analytic scaling relations that provide an intuitive understanding of how diffusion efficiency depends on noise source and system parameters.

*Speaker

Feedback from the First Stars: Imprints of Low-Energy Pair-Instability Supernovae in Second-Generation Stars

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Abstract

The first stars are likely more massive than present-day stars, so they may frequently explode in a pair-instability supernova (PISN).

While observations of the first stars are pending, we can look for signatures of chemical enrichment by PISNe of the first stars in second-generation stars to bridge the gap between early star formation and metal-poor stellar archaeology.

Previous works focus on the upper end of the explosion energy range or integrate the chemical yields with an initial mass function.

Here, we test the sensitivity of the results by simulating feedback of stars whose explosion energy is at the lower end of the plausible range.

In a hydrodynamic simulation of a representative cosmological volume with AREPO, we follow the formation and explosion of massive first stars until the formation of second-generation stars in the early universe.

We present simulation results with a focus on the mechanical supernova feedback, chemical feedback including enrichment of the halo and inter-halo gas, and derive chemical signatures imprinted in second-generation stars.

^{*}Speaker

Magnetic Reconnection in 3D and Its Role in Turbulent Dynamo Saturation

Vinay Kumar*¹ and Pallavi Bhat¹

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Abstract

Magnetic reconnection plays a central role in converting energy and reorganizing magnetic fields in a wide range of astrophysical plasmas. In this presentation, I highlight two relatively unexplored aspects of reconnection that arise in different physical contexts. In the first part, we extend the classical tearing mode instability to three dimensions by introducing a modulation $g(y)$ along the invariant direction of a two-dimensional (2D) equilibrium. This setup mimics a flux tube-like structure and allows us to explore how breaking translational symmetry affects reconnection dynamics. Using a combination of linear theory and direct numerical simulations, we show that a tearing-like instability persists even in the absence of a guide field. The growth rate is suppressed compared to the 2D case by a factor of $\int \sqrt{g} dy / \int dy$, though the underlying scaling of the dispersion relation remains unchanged. The spatial modulation leads to nonuniform resistive layer properties, which in turn influence the structure and evolution of reconnection sites.

In the second part, we turn to the small-scale turbulent dynamo (SSD) and ask how reconnection might shape magnetic field evolution, particularly in the nonlinear regime. During the kinematic phase, when the Lorentz force is still weak, reconnection has little effect. However, as magnetic energy grows and nonlinear feedback sets in, we find that reconnection begins to restructure the magnetic field. We perform high-resolution magnetohydrodynamic simulations at large magnetic Prandtl and Reynolds numbers to characterize these effects and to identify possible observational signatures of reconnection-driven changes in the saturated dynamo. This has particular relevance for high- Pm astrophysical systems such as galaxy clusters and the intergalactic medium, where turbulent dynamos are believed to operate. Together, these results shed light on how three-dimensional reconnection processes influence both the onset of plasma instabilities and the long-term organization of magnetic fields in turbulent systems.

*Speaker

Magnetic Zooms: Testing how magnetic fields shape galaxy structure and star formation

Marin Jessy*¹

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Abstract

Giant Molecular Filaments, or "Galactic Bones," are long, narrow structures that trace spiral arms, and recent work shows that magnetic fields have a non-negligible impact on their dynamics. We use magnetohydrodynamical simulations with the moving-mesh code AREPO to model a Milky Way-like galaxy, incorporating magnetic fields self-consistently. By zooming into a spiral arm, we identify Bone-like filaments and analyse their magnetic properties. We compare simulated field strengths with observational estimates from surveys such as FIELDMAPS, and test different versions of the Davis–Chandrasekhar–Fermi (DCF) method to evaluate their accuracy in recovering field strengths from simulation data. Our results provide a theoretical benchmark for interpreting magnetic field measurements in large-scale galactic filaments.

*Speaker

Modeling CRE evolution in AGN jets and winds: A radio spectral analysis

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⁴School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne NE1 7RU – United Kingdom

Abstract

The evolution of cosmic ray electrons (CREs) in AGN-driven jets and winds is known to produce non-thermal radio emission. However, the detailed physical processes linking CRE evolution to this emission remain poorly understood. Additionally, in compact systems, distinguishing between the emission from jets and winds is often challenging due to both intrinsic similarities and observational limitations. *In our study, we investigate the in-situ evolution of CREs within collimated relativistic jets and non-relativistic wide-angled winds using 3D RMHD simulations.* Our results show that diffuse shock acceleration and radiative cooling processes significantly shape the local radio spectral properties in both cases. *In jets, CREs undergo multiple shock interactions as they travel along the jet spine towards the hotspot, eventually being advected back through the cocoon via backflows.* This repeated acceleration leads to flatter radio spectral indices near the hotspot, while spectral steepening is observed further out in the lobes due to radiative cooling - a well-known characteristic in both small- and large-scale jets. *In winds, however, CRE acceleration predominantly occurs at the Mach disk, with less frequent acceleration events in the surrounding cocoon.* Consequently, flatter spectral indices are confined near the Mach disk, while the cocoon exhibits comparatively steeper indices with distance. Notably, winds display a clear spectral steepening in the cocoon with increasing radio frequency, a trend less prominent in compact jets. The multiwavelength radio analysis of a large-scale jet suggests that the jet spine and hotspot seem to maintain detectable synchrotron emission up to high radio frequencies, whereas the emission from the surrounding cocoon becomes weaker due to radiative losses.

^{*}Speaker

Imprints of Feedback on the Cosmic Evolution of Gas and Metals in the IllustrisTNG Simulations

Joanne Tan*¹ and Thorsten Naab²

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Abstract

Metal absorption lines are powerful tools for probing the gas content in the universe and illuminating the gas flows around galaxies. Absorption that arises from different ionization states of chemical elements provides insight into various gaseous structures and environments - low-ionization lines trace the cooler, denser regions near galaxies, while high-ionization lines illuminate the hotter, more diffuse regions of the universe. I generate a suite of synthetic quasar absorption-line observations from the TNG100 cosmological simulation across redshifts from $z = 5$ to the present to examine the cosmic evolution of multiphase gas and metal absorption lines. Using these, I compute the absorber path densities for low- (e.g., MgII), intermediate- (e.g., SiIII), and high-ionization species (e.g., CIV, OVI) and find that TNG100 qualitatively reproduces observed trends - the path densities of different ions evolve with redshift at different rates. Path densities of high-ionization species also peak at lower redshifts compared to their low-ionization counterparts. Quantitatively, TNG100 slightly overpredicts the path densities of various metal absorbers, suggesting an excess of metal-enriched gas at all redshifts considered, though the excess varies across ions. This excess remains when we implement different UV backgrounds to generate metal absorption lines. I further explore this discrepancy using mock absorption-line observations of the CGM of selected galaxies. They reinforce the idea that TNG100 may be overproducing metal absorbers, potentially due to an overly efficient metal redistribution via galactic outflows. I show that these results potentially reflect the implementation of feedback mechanisms - such as AGN-driven winds or supernova feedback - in TNG100 and their implications for modeling gas flows in galaxy evolution. I also discuss potential model refinement to achieve better agreement with observations.

*Speaker

The Origin of the Depolarization in Giant Filament CFG024.00+0.48: Dust or Field?

Dawei Xi*¹ and Gary Fuller¹

¹University of Manchester – United Kingdom

Abstract

Understanding the role of magnetic fields in massive star formation regions is crucial for studying the evolution of giant filaments and massive star formation. In probing the plane of sky magnetic field morphology through dust polarization, it is important to understand the depolarization from dust grains and projection effects to study the 3D magnetic field. In this work we explore these issues using JCMT 850 μm dust polarization observation of the giant filament CFG024.00+0.48 (G24 hereafter). A clear polarization hole is detected in the south-west part of G24. To understand the origin of this polarization hole, we calculate the depolarization of the emission through dust misalignment based on the radiative torque theory and magnetic field projection effect by the inclination angle between the field and the line of sight. By estimating the relationship of the dust misalignment depolarization and the projection effect depolarization with intensity respectively, we are able to compare the relative depolarization level from two different mechanisms through the polarization-intensity power law index. As a result, we find that the origin of the polarization hole is basically caused by the depolarization from the dust misalignment. However in other clumps of the filament, we discover different relative relationships between the level of these two depolarization scenarios, which starts to reveal the complex 3D magnetic field morphology in the filament.

*Speaker

The impact of the cold gas fraction in the diffuse ISM on meter-wavelength polarized data

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Abstract

Observations of diffuse interstellar polarization at meter wavelengths reveal intricate Faraday depth structures, likely tracing interactions between magnetized plasma and neutral gas. A strong correlation with CNM filaments has been proposed, but not reproduced in simulations with low CNM fractions, suggesting the CNM content may shape Faraday structures.

We investigate whether the CNM fraction drives the correlation between Faraday structures and H i brightness temperature, as observed in the 3C196 field. Using numerical simulations with varying CNM content, we test the role of cold gas in coupling neutral structures to magnetized plasma, and assess the influence of turbulence and magnetic field topology.

We analyze 14 three-dimensional magnetohydrodynamic (MHD) simulations of Fourier-driven turbulence in 50 pc cubes, post-processed with the MOOSE code to generate synthetic synchrotron polarization and Faraday tomography. We compute spatial correlations between Faraday depth structures and phase-separated H i brightness temperature using the Histogram of Oriented Gradients (HOG) method and compare results with LOFAR observations, including instrumental effects.

The morphology correlation between H i and Faraday structures depends on the CNM mass fraction, turbulence and the mean magnetic field orientation. In simulations with strong turbulence ($v_{\text{RMS}} > 8 \text{ km s}^{-1}$) and high magnetic field strength ($B_{\text{RMS}} > 2.5 \mu\text{G}$), the correlation values match those observed with LOFAR, but the relative contributions of CNM and WNM differ from observations.

Our results show that CNM fraction alone is insufficient to explain the correlation with Faraday structures. Turbulence, magnetic field dynamics, and topology are also key factors, highlighting the need for a comprehensive approach to understanding the coupling between neutral gas and magnetized plasma in the diffuse ISM.

*Speaker

The (Limited) Effect of Viscosity in Multiphase Turbulent Mixing

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Abstract

Turbulent radiative mixing layers (TRMLs) play a fundamental role in the evolution of multiphase gas in astrophysical environments such as the circumgalactic (CGM) and intracluster medium (ICM). These layers regulate gas exchange between cold and hot phases, affecting cooling rates, turbulence, and overall energy transport. While most studies assume inviscid conditions, physical viscosity can significantly alter these processes by suppressing turbulence and modifying the energy exchange. In this work, we investigate the effects of viscosity on TRML evolution using idealized numerical simulations. We analyze how different cooling regimes are affected by viscosity, shaping the interface morphology, turbulence dynamics, and cooling efficiency. Our results have direct implications for understanding the life cycle of CGM gas, the efficiency of AGN-driven outflows, and the development of subgrid models for galaxy formation simulations.

*Speaker

illuminating the kinematics of the simulated circumgalactic medium

Joanne Tan*¹ and Thorsten Naab¹

¹Max Planck Institute for Astrophysics – Germany

Abstract

Modern absorption-line surveys of gas in the halos of nearby spiral galaxies reveal that the circumgalactic medium (CGM) - which plays a fundamental role in shaping galaxy evolution - is metal-enriched, ionized, multiphase in nature, and ubiquitously present. We generate synthetic quasar absorption-line observations of the simulated CGM to trace cosmic gas flows in high-resolution zoom-in simulations of present-day spiral galaxies with diverse merger histories. Using these, we explore the physical origins of observed absorption lines, for low (e.g., LyA, MgII), intermediate (e.g., SiIII, CIV), and high (e.g., NV, OVI) ions, and demonstrate that these simulations produce good agreement with recently reported observational results. In our simulations, low ions best trace the kinematics of gas inflows, while high ions best trace gas outflows. Supplementing existing measurements with a recently proposed observational marker - the equivalent-width co-rotation fraction - may not only permit the tracing of gas accretion, recycling, and outflows, but potentially also distinguish between the various modes of gas accretion onto galaxies. We show that the EW co-rotation fraction not only correlates with several properties of the absorbers, such as impact parameter, HI column density, and azimuthal angle, but also with galactic orientations. These correlations provide valuable insights into the gas flows surrounding galaxies, and are very distinct between mergers and non-mergers. This marker is particularly sensitive towards galaxies experiencing recent or ongoing mergers - kinematic coupling of the absorbers to their host galaxies is weaker than that in non-mergers. This coupling is also affected to varying extents for the different ions. Improved characterizations of these gas flows and kinematic coupling, enabled by new observational tracers for future measurements, will be necessary to understand the baryon cycle in evolving spiral galaxies and, ultimately, the future evolution of these galaxies.

*Speaker