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Cosmic turbulence and magnetic fields: Physics of Baryonic Matter Across Time and Scales

Abstracts

Large-scale turbulence in action in multi-phase intergalactic gas in pairs and groups of galaxies.

Philip N. Appleton * [1]

[1] Infrared Processing and Analysis Center – United States

Understanding how large-scale driven turbulence (on scales of 1-5 kpc) might affect galaxy evolution is vitally important if we are to understand why star formation is so inefficient in galaxies over cosmic time. I will present examples of turbulence and shocks in large-scale intergalactic gas in the local Universe where we believe that turbulence continues to suppress star formation despite high molecular surface-densities. I will concentrate on recent observations of the massive gas bridge between the two galaxies in the Taffy system where we see evidence for a multi-phase turbulent medium with energy arising from shocks on many scales from fast shocks producing X-rays and optical emission lines in diffuse gas to powerful slow shocks in warm molecular gas. Our recent ALMA observations have revealed a myriad of dense molecular filaments which have peculiar characteristics - being likely transient structures in a highly turbulent medium. VLA observations are scheduled which will further explore the nature of a magnetic connection between the galaxies. The bridge structure may be an example of how all three kinds of MHD turbulence (toroidal, compressive and current-driven) may be operating to significantly reduce star formation in this system which has recently undergone a major "wet" collision, but is not producing stars.

*Speaker

Reconstructing the three-dimensional density distribution of observed, strongly-magnetised, turbulent molecular clouds

James Beattie * [1], Christoph Federrath [1]

[1] Research School of Astronomy and Astrophysics [Canberra] – Australia

Molecular clouds (MCs) are extremely dynamic, with magnetic fields, turbulent motions and gravity all playing significant roles in the time-evolution and star formation rate (SFR) of the clouds. At the heart of almost every MC SFR model is the three-dimensional (3D) density probability density function (PDF) and the turbulent Mach number, $\mathscr{M}$. The 3D density PDF is used to encode all the dynamics from the cloud into the SFR models. However, observations of MCs only ever access the 2D column density and 3D information is lost, or is hard to reconstruct because of the strong anisotropies in the clouds due to the presence of strong, ordered magnetic fields. In this talk we present a new method for reconstructing the 3D density PDF, from the 2D column density, for both isotropic and anisotropic clouds, with no *a priori* assumption of the 3D distribution. Furthermore, $\mathscr{M}$, sets the width of the 3D density PDF, and also parameterises the critical density for MCs to collapse into protostellar cores, which eventually form stars. Typically $\mathscr{M}$ is measured using the full-width-half-max of CO lines. However, we show that one can use the number of filamentary structures, one of the fundamental building blocks of MCs, in the column density of the cloud to measure $\mathscr{M}$, with application on *Herschel* space telescope data. Our new method also provides a canonical relation between the SFR and the number of filaments in MCs.

*Speaker

3D chemical structure of the turbulent diffuse interstellar medium

Elena Bellomi * [1,2], Benjamin Godard [1,2], Patrick Hennebelle [3], Valeska Valdivia [3], Maryvonne Gerin [1]

[1] Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique (LERMA), ENS, Sorbonne Université, Observatoire de Paris, CNRS : UMR8112, France
[2] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France
[3] Astrophysique Interactions Multi-Echelles (AIM) – CEA, Université Paris-Diderot, CNRS : UMR7158 – Service d'astrophysique, L'Orme des Merisiers, Gif-sur-Yvette, France

The multiphase structure of the local interstellar medium is controlled by the thermal instability whose effects a priori depend on the radiation field, turbulence, gravity and magnetic field. We study the coupled physical and chemical states of the local interstellar medium with numerical simulations including thermal processes, out-of-equilibrium chemistry of atomic and molecular hydrogen, self-shielding, and extinction. The simulations are post-processed with a chemical code which computes the steady-state of 149 species, giving access to the 3D chemical structure of the gas. The statistical chemical properties of the multiphase medium are simultaneously compared to the observations of ten different chemical species over a sample of hundreds of lines of sight extending up to a distance of 3 kpc around the Sun. Our parametric study shows that the statistics of the H-H_2 transition gives a strong constraint on the local mean density and radiation field but loosely depends on gravity and the level of turbulence. On the other hand, CH and CI are found to be tracers of the local pressure and the presence of self-gravitating dense clumps along the lines of sight. CH, CH^+, OH, HCO^+, and CO are finally strongly affected by warm and out-of-equilibrium H_2 and trace the mass and the volume filling factor of both the unstable phase and the cold neutral medium.

*Speaker

Resolving shock heating, turbulence and the baryon cycle in high redshift massive galaxies

Jake Bennett * [1], Debora Sijacki [1]

[1] Institute of Astronomy, University of Cambridge (IoA) – United Kingdom

Recent cosmological galaxy formation simulations have found that potentially copious amounts of gas do not shock heat in the circumgalactic medium and virialise, but instead deliver cold gas from the cosmic web directly onto galaxies. This significantly changes how galaxies are built up, leading to high central mass deposition rates and hence requiring strong feedback to prevent excessive star formation. However, these simulations typically do not focus their numerical resolution on resolving structure accretion shocks, potentially leading to so-called 'in-shock cooling'. Using novel computational methods within the moving mesh code AREPO, we can now target numerical resolution to more accurately resolve accretion shocks on-the-fly. This allows us to run full cosmological simulations of high redshift massive galaxy assembly, with a reduced impact from 'in-shock cooling', to investigate how gas is cooled and heated as it streams from cosmic filaments onto the forming galaxies.
Furthermore, high resolution at accretion shocks will allow us to more robustly capture the generation of vorticity in the wake of curved shocks to estimate how much of the gas energy budget is stored in turbulent motions. The predictions of this work will be directly relevant for future observations by JWST and SKA. This method can also be further generalised to target increases in the spatial resolution within the circumgalactic medium of galaxies, hence allowing not only cosmic inflow but also galaxy outflow multi-phase structure and clumpiness to be captured accurately. This can then be compared against future ALMA and MUSE observations.

*Speaker

Cosmic Rays and Interstellar medium turbulence dynamics

Loann Brahimi * [1], Alexandre Marcowith , Benoit Commerçon , Yohan Dubois

[1] Laboratoire Univers et particules de Montpellier (LUPM), CNRS : UMR5299, Université de Montpellier, France

Cosmic Rays can modify the properties of magnetised interstellar turbulence by the effect of the gradient of their pressure. Global effects over galactic scales are well known. In this study we rather concentrate on intermediary galactic scales of a few tens of parsecs. Using a bi-fluid method we calculate the necessary conditions on the diffusion of Cosmic Rays to modify the mean properties of magnetohydrodynamic turbulence, in particular in case of fresh injection of particles by supernovae.

*Speaker

Challenges in The Hot and Relativistic Universe

Andrei Bykov * [1]

[1] Ioffe Institute, Saint Petersburg – Russia

Non-thermal and relativistic components, which are connected in the symbiotic way with the matter through the stochastic and regular magnetic fields play essential role in the evolution of galaxies and clusters of galaxies. The extremely energetic events associated with the collapse of massive stars, merging of compact relativistic stars, and accretion processes of different scales lead to acceleration of particles up to ultra-relativistic regimes, emission of broad spectra of electromagnetic radiation, and also emission of neutrinos and gravitational waves. Shocks, turbulence and magnetic reconnection are playing a crucial role in the formation of the hot and non-thermal populations as it is observed in the Earth magnetosphere, heliosphere and many astrophysical objects. We review the complex multi-scale processes in collisionless cosmic shocks of different strengths, combining the detailed microscopic view of the collisionless shock structure with the back-reaction effects of the accelerated particles on the fast outflows. These processes are responsible for the efficient conversion of the kinetic and magnetic energies of the outflows into the observed high energy radiation. We discuss the spectacular appearance of the non-thermal phenomena in supernovae, gamma-ray bursts, pulsar wind nebulae, starburst regions and clusters of galaxies.

*Speaker

Dynamical effect of cosmic rays on the interstellar medium and galactic winds

Yohan Dubois * [1]

[1] Institut d'Astrophysique de Paris (IAP), Sorbonne Université, CNRS : UMR7095, Paris, France

I will show recent results of MHD simulations including cosmic rays (CR) in the adaptive mesh refinement code RAMSES. I will quickly review the modeling of CR anisotropic diffusion, streaming instability, and their acceleration at shocks, and show how the physics of CRs and their transport shape the structure of the dense gas in the turbulent interstellar medium, and how they substantially modify the properties of large-scale galactic winds.

*Speaker

An analytical stochastic representation of 3D MHD turbulence

Jean-Baptiste Durrive * [1], Katia Ferrière [1], Pierre Lesaffre [2], Francois Boulanger [2]

[1] Institut de recherche en astrophysique et planétologie (IRAP), Université Toulouse III Paul Sabatier, Observatoire Midi-Pyrénées, CNRS: UMR5277, Toulouse, France
[2] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

An analytical model for fully developed three-dimensional incompressible turbulence was recently proposed in the hydrodynamics community. It consists in a random field represented by means of a stochastic integral, which, with only a few parameters, shares many properties of empirical and numerical turbulence: power-law behaviour of the moments of velocity increments (i.e. the structure functions) in the inertial range, intermittent corrections (i.e. non-Gaussianity), existence of energy transfer across scales (i.e. the cascade), long-range-correlations, dissipation at small scales, the correct vorticity alignment properties and the geometry of the velocity gradient tensor (i.e. the teardrop shape of the RQ-plane). In our work, we suggest a generalisation to the magnetised case, based on the dynamics of the kinematic regime of incompressible MHD turbulence. The formulae we provide constitute a physically motivated 3D model of a turbulent velocity field and magnetic field coupled together. Several free parameters enter the description, which are useful to confront the model with the data. We also provide a python code to generate realisations of these fields quickly, as a complementary tool to numerical simulations.

*Speaker

The turbulent Galaxy via information field theory

Torsten Ensslin * [1], Reimar Leike [1], Sebastian Hutschenreuter [1]

[1] Max-Planck-Institut für Astrophysik, Germany

The complex interstellar medium (ISM) is probed via various measurements of emission and absorption processes. Turning these diverse measurements into a coherent picture of the turbulent structures and an estimate of their spatial power spectra is non-trivial. Information field theory (IFT) is the mathematical framework that permits to do so. Here, IFT is briefly introduced and recent results of IFT-based methods on the Galactic ISM are presented. In particular, the 3D structure of local dust clouds and the interplay of electron density and magnetic field orientation in the nearby Milky Way are investigated.

*Speaker

Feedback and Turbulence in Galaxy Formation

Claude-André Faucher-Giguère * [1]

[1] Northwestern University – USA

I will review some basic problems in galaxy formation, focusing on the observed inefficiency of star formation on both cosmological and galactic scales. I will then present results from the FIRE cosmological simulations, which indicate that feedback from stars can resolve the main issues for galaxies up to about L*. The feedback processes that regulate star formation do so, in part, via the excitation of turbulence in the interstellar medium and the circumgalactic medium. I will conclude by outlining analytic arguments that allow us to understand the results that emerge from the complex simulations in simple terms.

*Speaker

Hydro simulations of cosmic dawn

Anastasia Fialkov * [1]

[1] Institute of Astronomy – United Kingdom

Reionization is a multi-scale problem. At the mid-point of reionization bubbles of ionized gas measure few tens of comoving mega parsecs, while the sources of ionization are stars inside galaxies. Despite the large dynamic range of the problem, high-resolution hydro simulations of reionization are making tremendous progress including detailed physics and producing testable predictions. However, many of the processes that lead to reionization are still poorly understood resulting in large modelling uncertainties. To grasp variations in reionization history hybrid approaches are used that allow scanning the space of potential signals. In my talk I will summarize the status of the field.

*Speaker

Understanding Galaxy Evolution with Dusty Starburst Galaxies at High Redshift

Hai Fu * [1]

[1] The University of Iowa – USA

We are constantly intrigued by how dramatically galaxies evolve when we probe closer to the cosmic dawn. Ten billion years ago, galaxies were forming stars ten times more fiercely than they do today. Thanks to wide-area (sub)millimeter surveys, we have identified a rare sample of gravitationally lensed or hyperluminous starbursts at the peak epoch of cosmic star formation. I will show how high-resolution multi-phase observations have improved our understanding of these unusual galaxies. I will also present quasar absorption-line observations that constrain the halo-scale gas supply of such dusty starburst galaxies. By contrasting with other galaxy populations, these observations shed important light on the evolution of massive galaxies.

*Speaker

The evolution of star-forming galactic disks – Galactic velocity dispersions: from feedback to gravitational instabilities

Reinhard Genzel * [1], Hannah Uebler, Natasha Foerster Schreiber, Linda Tacconi

[1] Max-Planck-Institut fur extraterrestrische Physik – Garching, Germany

Following an introduction of the cosmic evolution of star forming galaxies from z=2.5 to 0, we will present the current observational knowledge of the evolution of sub-galactic velocity dispersion in star forming, main sequence disks. The data for this investigation come mainly from the SINS and KMOS-3D surveys of ionized gas, but we also include the molecular gas as it is currently known. We show that sub-galactic scale velcoity dispersions depend mainly on redshift. We show that high-z star forming disks are globally gravitationally unstable, such that the redshift scaling is plausubly understood as a direct consequence of this global Toomre instability and the larger gas accretion rates and gravitational energy conversion from gas accretion and radial transport. In contrast z=0 disks are not globally unstable and the velocity dispersions are feedback driven. We close by pointing out the interconnectedness of the global baryon gas regulator, gas transport and bulge formation, and thr dark matter fractions in high-z disks galaxies.

*Speaker

The chemistry and dynamics of the turbulent ISM including cosmic rays

Philipp Girichidis * [1], Daniel Seifried, Thorsten Naab, Tim-Eric Rathjen, Stefanie Walch, Maria Werhahn

[1] Leibniz-Institut fuer Astrophysik, Potsdam (AIP) – Potsdam, Germany

We simulate the chemical evolution and the dynamics of the present-day magnetized interstellar medium using high-resolution three-dimensional magneto-hydrodynamical simulations. We include a chemical network to actively follow the abundances of ionized, atomic and molecular hydrogen as well as CO and free electrons. Dense regions are shielded from the interstellar radiation field. We follow the formation of star clusters and include stellar winds, radiation and supernova (SN) feedback from the clusters. We also include cosmic rays (CRs) as a relativistic fluid, which are dynamically coupled to the gas dynamics as well as coupled to the chemical network via the CR ionization rate. CRs are injected together with stellar winds and SNe. We find that magnetic field can delay the formation of dense molecular gas leaving more gas in a diffuse state. This warm diffuse gas can be lifted out of the galactic disk by the CR pressure reducing the available gas for subsequent star formation. Besides the dynamical effect of the CR pressure we present the effect of the spatially and temporally varying CR ionization rate on the chemical composition in molecular clouds. To better connect the simulations to observations we post-process the CRs in different observable radiative bands. We also investigate the orientation of gaseous structures with respect to the magnetic fields and analyse the nature of turbulent motions in different phases of the gas.

*Speaker

Molecules and Turbulence: following the energy trail

Benjamin Godard * [1,2]

[1] Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique (LERMA), ENS, Sorbonne Université, Observatoire de Paris, CNRS : UMR8112, France

[2] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

Because it is predominantly heated by the UV radiation field, the diffuse interstellar medium has long been thought to behave like a photo-dissociation region (PDR). This view is indeed successful in explaining many chemical properties of the cold gas (T $<$ 100 K). Yet, for the last 30 years, absorption spectroscopy has revealed a gas with a chemical richness that is unexpected from the sole predictions of PDR-type models. Since their production pathways are protected by highly endo-energetic reactions, it has been proposed that several of these species are nothing else but a signature of another powerful energy source, such as the dissipation of magnetized turbulence or the turbulent transport at the interface between warm and cold phases.

A particularly striking example is the recent discovery of CH^+ in absorption and emission in bright sub-millimeter galaxies at the peak of the star formation history. In absorption, CH^+ traces large halos of diffuse and turbulent media. Conversely, the broad line profiles seen in emission (linewidths $>$1000 km s^{-1}) likely trace a turbulent gas bred in the wake of galactic outflows.

In this talk, I will present several chemical and kinematics properties of molecular lines observed in absorption in the galactic diffuse medium and in absorption and emission in starburst galaxies at high redshift, and discuss how these properties can be linked to the cascade and dissipation of interstellar turbulence.

*Speaker

Correlations and energy transfer in compressible isothermal and adiabatic MHD turbulence

Philipp Grete * [1], Kris Beckwith , Brian W. O'shea

[1] Michigan State University (MSU) – Department of Physics & Astronomy, USA

Compressibility, magnetic fields and turbulence are all thought to be important factors to varying degrees in many astrophysical processes and terrestrial experiments. However, our understanding of their joint effect, even in its simplest description (i.e., compressible magnetohydrodynamic turbulence), is still scarce. One step towards a more comprehensive picture is a better understanding of the governing energy dynamics, e.g., looking at the interplay between kinetic and magnetic energy via different mediators such as advection, magnetic tension or magnetic pressure. Here, we present an extension of established shell-to-shell energy transfer analysis methods to the compressible MHD regime. We apply this analysis to numerical simulations in both the subsonic and supersonic regimes. This allows us to illustrate how varying degrees of compressibility influence the energy dynamics within and between kinetic and magnetic energy reservoirs. For example, we show that compression acts against a magnetic energy cascade (scale-local magnetic to magnetic energy transfer). Moreover, we present how magnetic tension becomes overall less important with increasing sonic Mach number. Finally, we show how different correlations, such as the observationally relevant correlation between density and magnetic field strength, are affected by different equations of state.

*Speaker

Is accretion-driven turbulence a key process for galaxy growth?

Pierre Guillard * [1], Matt Lehnert [2], François Boulanger , Guillaume Pineau des Forêts [3]

[1] Institut d'Astrophysique de Paris (IAP) – Université Pierre et Marie Curie, CNRS : UMR7095, Paris, France
[2] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France
[3] Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique (LERMA), ENS, Sorbonne Université, Observatoire de Paris, CNRS : UMR8112, Paris, France

Spitzer and Herschel infrared spectroscopy has revealed a population of nearby galaxies with weak star formation and unusually bright emission lines (e.g. [CII], H_2), with very broad linewidths. The line luminosities are greatly in excess of that expected by photoelectric heating of the gas, suggesting that they are powered by the dissipation of turbulent kinetic energy. This discovery of large masses of gas not associated with star formation reveal the potentially important, but largely unexplored, role that turbulence plays in the energetics and formation of multiphase gas on galactic scales. Is this relevant for filamentary gas accretion onto halos of galaxies? I will discuss a toy model in which some of the gravitational potential energy is transferred into gas accretion streams as they penetrate deeper into halos of young galaxies, and part of that energy is dissipated through a turbulent cascade in the warm infalling gas. We have modeled the excitation of the [CII] line as gas is cooling isobarically during its transition from the warm ionized to cold neutral medium. We find that the contribution of [CII] to the total gas cooling rate is increased to 30% and that this [CII] luminosity fraction is largely independent of metallicity. This may explain the recent ALMA detections of [CII] line emission from very high-redshift galaxies, that is not co-spatial with their UV-continuum and have ratios of [CII] to infrared luminosity that are higher than that expected from star formation.

*Speaker

Zooming-in in the star formation process: from intermediate galactic scale to self-gravitating cores and below

Patrick Hennebelle * [1]

[1] Astrophysique Interactions Multi-échelles, CEA, Université Paris Diderot, CNRS : UMR7158, Gif sur Yvette, France

Star formation is a complex multi-physics and multiscale process, which requires the development of adequate zooming strategies. This is particularly important to properly study the star formation rate and the initial mass function. During the talk I will present an attempt to self-consistently describe both the intermediate and the small scales (i.e. the prestellar dense cores) within the Galaxy. In particular, it is argued that the core mass function, thought to be at the origin of the initial stellar mass function (IMF), presents a slope that is similar to the Salpeter one but that the peak is a consequence of the finite resolution of the numerical simulation. A solution for this problem will be proposed. More specifically we argue that the peak of the IMF is a direct consequence of the so-called dust opacity limit that occurs during the collapse at high density.

*Speaker

The turbulent dissipation structures of diffuse molecular ISM

Pierre Hily-Blant * [1]

[1] Université Grenoble Alpes, CNRS, IPAG, Grenoble, France

Turbulence in molecular clouds should have little in common with laboratory flows which are incompressible and subsonic. Yet, observations of molecular clouds have shown that the statistical properties of the velocity field are surprisingly similar to those obtained in laboratory experiments, a characteristic which may reflect the properties of the forcing on large scales. On the other hand, observations of molecular clouds can also provide a glance at the structures populating the far-wings of the probability distribution of the velocity increments. Interferometric maps of dissipation regions of turbulence reveal structures visible in velocity space only. In this talk, we focus on observational studies of turbulence in molecular clouds, showing the spatial and kinematic coherence of dissipation structures from the parsec to the milli-parsec scale. We close up with a few perspectives offered by the JWST in combination with the ALMA interferometer.

*Speaker

Feedback regulated star formation

Chang-Koo Kim * [1]

[1] Department of Astrophysical Sciences, Princeton, USA

Gravity is a one-way force. In the ISM, any supporting pressure force against gravity would be dissipated and radiated away in relatively short turbulence dissipation and cooling time. As a result, star formation could be a runaway process, unless continuous turbulence driving and heating. Massive, young stars provide prodigious amounts of energy and momentum during their lifetime as winds and radiation and at death as supernovae. These efficient stellar feedback processes replenish pressure and momentum flux and provide support against the gas weight. The feedback regulated star formation naturally gives rise to correlations between star formation rates and galactic conditions and makes large scale star formation efficiency low. In this talk, I will broadly review galactic scale self-regulation theories and numerical simulations that provide quantitative calibration.

*Speaker

Intermediate velocity shock waves: probing turbulent cascades

Andrew Lehmann * [1], Benjamin Godard[2], Guillaume Pineau des Forêts[2], Edith Falgarone [1]

[1] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France
[2] Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique (LERMA), ENS, Sorbonne Université, Observatoire de Paris, CNRS : UMR8112, Paris, France

Observations of galactic superwinds, supernova remnants and protostellar outflows reveal a common anomaly of the detection molecules that would be destroyed by such high velocity shocks (up to _˜1000 km/s). A picture has emerged of large-scale outflows triggering a turbulent cascade in a multiphase medium with significant mechanical energy dissipating in molecular shocks at much lower velocities ($<$ 50 km/s). Modeling these shocks is key to understanding the energetics of this process and also to generate observables.
We update the Paris-Durham shock model, a state-of-the-art magnetohydrodynamic shock code developed with a focus on molecular chemistry, in order to account for the self-generated UV field produced in shocks at these velocities. In these shocks there is significant excitation of atomic hydrogen, with a large flux of Lyman α and Lyman β photons escaping ahead of the shock to heat, ionize and drive molecular chemistry in a large slab of pre-shock gas. We discuss how Lyman α observations combined with tracers of the warm pre-shock gas and shock-heated gas constrain properties of the turbulent gas reservoirs surrounding young starburst galaxies.

*Speaker

Observations of the multiphasic large scale environment of galaxies at high redshift

Matt Lehnert * [1]

[1] Institut d'Astrophysique de Paris (IAP), Université Pierre et Marie Curie, CNRS : UMR7095, Paris, France

The baryon content of galaxies is thought to be a balance between rates of gas accretion and its angular momentum content, star formation, and outflows. I discuss two particular aspects of this baryon cycle using data from ALMA, ATCA, and JVLA showing very extended halos and disks in atomic and molecular gas and dust in high redshift galaxies. This low surface brightness emission is frequently missed in interferometric surveys due to lack of sensitivity and filtering out the extended emission. These reservoirs contain a significant fraction of the gas mass, are multiphased, and carry a significant amount of angular momentum and turbulent energy. I discuss the implications and impact of these results on our understanding of galaxy evolution and how the baryon cycle in galaxies is likely regulated.

*Speaker

Dissipation of compressible MHD turbulence

Pierre Lesaffre * [1]

[1] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

The interstellar medium (ISM) is very hostile, but surprisingly fertile for molecules. Dissipation bursts of turbulence might help produce and excite molecules, but their observational characterisation so far remains elusive. The ISM is a complex multi-phase and multi-physics medium. Nevertheless, leaving aside gravitation, cosmic rays and radiation, one ISM phase may be considered as a magnetised isothermal gas. Thus we focus here on generic aspects of dissipation in decaying isothermal MHD turbulence. We take unprecedented care at resolving and controlling dissipation and we reveal how one can estimate locally the dissipation induced by numerical schemes.

In our simulations, we integrate observable quantities such as Stokes parameters which characterise magnetic fields and centroid velocities which characterise dynamics. We find strong dissipation lies on sheets, which project as ridges on the plane of the sky where they are seen edge-on. These filaments are revealed by contours of the increments of integrated observables.

The statistics of plane of sky increments of the observables reflect the intermittency of turbulence. We strive at identifying the nature of each dissipative structure. We detect slow, intermediate and fast shocks, Alfvénic discontinuities, and we attempt to estimate their relative weight in the dissipative budget.

Finally, in a 2D decaying turbulence numerical experiment with chemistry and cooling (unmagnetised), we show how individual planar shocks can account for the global molecular yields induced by the dissipation. This strengthens our goal to build a coherent picture of turbulence dissipation by means of a statistical description of dissipative structures.

*Speaker

The Reduced Wavelet Scattering Transform, a comprehensive statistical description of the non-Gaussian ISM

François Levrier * [1]

[1] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

The ubiquitous filamentary patterns that are observed in the interstellar medium (ISM) are the result of the interplay between turbulence, magnetic fields and gravity. These patterns are examples of the highly non-Gaussian structures that emerge naturally from non-linear physical processes. As our understanding of the magnetized ISM largely relies on the comparison of observations with numerical MHD simulations and phenomenological models, we need an adequate statistical description of non-Gaussian, filamentary structures. Such a description would provide a way to quantify the impact of the physical parameters on the statistical properties of the emerging structures. In this talk, I will present the Reduced Wavelet Scattering Transform (RWST), a low-variance statistical description of non-Gaussian physical processes. This description has been obtained through a reduction of the Wavelet Scattering Transform (WST) of Mallat et al., by fitting its angular dependencies while distributing the associated information into a few functions whose physical meaning are identified. I will present the results obtained with the RWST on different physical fields (fBm synthetic processes, column density maps from MHD simulations, and astrophysical observations of dust total intensity emission), discuss the physical interpretation of the different components of the RWST, and show how realistic syntheses can be obtained from very few statistical descriptors.

*Speaker

Cosmic Dawn II : galactic photon budget and CGM

Joseph Lewis * [1], Pierre Ocvirk [1]

[1] Observatoire astronomique de Strasbourg – Université de Strasbourg, CNRS: UMR7550 – Strasbourg, France

A growing consensus seems to point towards the ionising UV light of galaxies having been the main driving force behind the reionisation process. I analysed the ionising photon contribution of galaxies to the intergalactic medium, and its relation to galactic properties such as mass and star formation. This study was carried out using the Cosmic Dawn II simulation, a new, massive, fully-coupled radiation-hydrodynamics simulation of galaxy formation during the Epoch of Reionization (EoR), performed with RAMSES-CUDATON, as an update of Cosmic Dawn I (Ocvirk et al. 2016), and was complemented by follow up simulations including metals and their relevant physics. I computed the amount of escaping ionising photons from the dark matter haloes during and before the EoR. I found that dark matter halos between 10^9 $M_\odot$ and $5\,10^{10}$ $M_\odot$ host galaxies that produce more than 80% of the ionising photons between z=8 and z=6. Less massive haloes are too dim, whereas brighter haloes are too few, dense, and opaque in their cores to provide a more significant contribution. As redshift decreases past z=8, this dominant mass interval moves to higher masses.

*Speaker

Radio continuum emission in the bridges of collisional galaxy systems

Ute Lisenfeld * [1], Heinrich Völk [2]

[1] Universidad Granada – Spain
[2] Max-Planck-Insitut fuer Kernphysik – Germany

Collisional galaxy systems, like the so-called Taffy galaxies, UGC 12194/5, and UGC 813/6, are systems where two spiral galaxies collide face-on. In the collision the diffuse parts of the two interstellar media interact supersonically and produce a bridge of shocked atomic and molecular gas and of radio continuum emission between them. The radio continuum emission of the bridge constitutes almost half of the total emission of the system and has the consequence that the system is radio loud by a factor of about two with respect to the FIR-radio correlation.
We propose that the radio continuum emission in the bridge is produced by diffusive shock acceleration in the shocks that compress and mutually decelerate the respective interstellar media. We present a simple model for the acceleration of relativistic particles in these shocks and calculate the resulting radio emission and its spectral index and show that the predictions are in agreement with the observations.
This process discussed is likely to take place in other systems as well, as in galaxy clusters or galaxy groups.

*Speaker

Multiphase Circumgalactic Medium: The Impact of Galactic Winds and Radiative Cooling

Cassandra Lochhaas * [1,2]

[1] Space Telescope Science Institute – USA
[2] Ohio State University, Columbus – USA

The circumgalactic medium (CGM) is closely linked to galaxy formation and evolution, but difficult to characterize observationally and typically poorly resolved in cosmological simulations. I will first present my analytic model for a galactic wind-blown bubble and show that it produces cool gas within the CGM of Milky Way-like galaxies, consistent with observations. I will then discuss my analysis of recent spherically-symmetric, idealized, high-resolution simulations of the CGM to characterize the gas pressure, turbulent and radial velocities, and degree of thermal and effective dynamic pressure support in the overall CGM as well as in its high- and low-temperature phases. I will present our findings that higher-mass halos contain a CGM mostly formed of a hot gas halo in hydrostatic equilibrium out of which cold gas condenses and falls onto the central galaxy, while lower-mass halos' CGM is not in hydrostatic equilibrium, has a wider spread of properties at a given galactocentric radius, does not have a clear separation of hot and cold phases, and is dominated by bulk motions. These results promote the idea that there is no "average" CGM and care must be taken when simulating the CGM. I will also briefly discuss how I plan to bring similar types of analyses to the FOGGIE (Figuring Out Gas and Galaxies in Enzo) high-resolution, fully cosmological CGM simulations to explore how the properties of the CGM differ from those in idealized simulations.

*Speaker

Tracing the origin and fate of magnetic fields in galaxies

Sergio Martin-Alvarez * [1]

[1] University of Oxford , Oxford, United Kingdom

Magnetic fields are one of the most fascinating puzzles in the picture of galaxy formation. Recognised important throughout many astrophysical scenarios, they often stand as a major source of uncertainty. In galaxy evolution, one of the major unknowns is which mechanisms generate microGauss magnetic fields in the ISM. Three main alternative pictures stand as possible drivers of their evolution: either magnetic fields are of strong primordial origin and amplified by dynamos or produced by stars or AGN and subsequently fed to the ISM, and possibly further out into the intergalactic medium, polluting the cosmic magnetic field. While each picture appears self-sufficient, current studies struggle to shed light on how these different mechanisms interact or whether one dominates over the others. I present in this talk our first scientific results using our new algorithm designed to answer these questions by following how magnetic fields from different origins co-evolve. I apply the code to a cosmic zoom-in MHD RAMSES simulation where magnetic fields are sourced simultaneously as an ab-initio primordial field and by magnetised stellar feedback to study the origin of galactic magnetic fields. The two sources are followed separately. I discuss which magnetic source dominates the energy budget in the galaxy and in different parts of its ISM. I review some signatures of these fields and how the stellar-generated field pollutes the primordial magnetic field in the environment. I will finally briefly present our new cosmological radiative transfer-magnetohydrodynamical SPHINX simulations of the epoch of reionization.

*Speaker

Who needs turbulence? Cascade, intermittency and Reynolds number in solar wind-like plasmas

William H. Matthaeus * [1]

[1] University of Delaware – USA

Turbulence in plasmas such as the solar wind is generally thought to proceed in a similar way to the fluid case (1,2) with however additional channels available, especially at kinetic scales (3). An overview of the plasma cascade process is presented here, describing the sequence of processes from large scales, through an inertial range, and finally leading to small scale dissipation. Generation of non-Gaussianity and formation of coherent structures occurs progressively in the inertial range, a phenomenon familiar in viscous-resistive MHD. In the plasma case, kinetic effects and dissipation are concentrated in coherent structures of several types, including both current and vorticity structures. An important feature, well known in hydrodynamic turbulence, is that the spatial concentration of these structures, measured by the kurtosis, increases with Reynolds number. For weakly collisional plasma, a similar conclusion emerges, based on the notion of ?effective Reynolds number? computed from inertial range bandwidth, without regard to specific dissipation processes (4). We present evidence for these properties of cascade, based on both kinetic simulation and analysis of spacecraft data in the solar wind and magnetosheath. (1) Matthaeus , W.H. & Velli, M. Space Sci Rev, 160: 145 (2011) (2) Matthaeus, W., et al. arXiv:1903.06890 (3) Yang, Y., et al. MNRAS 482, 4933?4940 (2019) (4) Parashar, T. et al., ApJ Letters, 884:L57, 2019

*Speaker

Cloud-scale molecular gas kinematics in nearby galaxies, and a bottleneck to star formation

Sharon Meidt * [1]

[1] Universiteit Gent, Ghent, Belgium

The kinematics of molecular gas on cloud scales are a sensitive probe of the boundary conditions for star formation. Until recently, such measurements were only available for cloud populations within the Local Group (including our own Milky Way). But now, new survey capabilities are expanding our view of gas motions to a greater diversity of galactic environments, providing unprecedented constraints on the process of star formation in prototypical 'star forming main-sequence' galaxies. These observations hold the key to building a full picture for the characteristic inefficiency of star formation. The complex array of motions revealed by the PHANGS/ALMA survey suggests a more dynamic view of the star-forming medium than the idea of cold, dense gas organized into discrete virialized objects. Strong deviations from approximate virialization consistently occur in environments with high shear, short orbital times and deep stellar potential wells, suggesting that the gas in these regions is strongly coupled to the galactic potential. I will summarize the evidence for a direct link between gas dynamical state and the efficiency of star formation from both observations and simulations. Then I will describe a new model for how the coupling of molecular gas to the galactic potential acts as a bottleneck for star formation, adopting a 3D model of motions relevant for gas embedded in a disk. This framework suggests that, in concert with feedback, the galaxy can act to both stop star formation once it has begun and prevent it from starting in the first place.

*Speaker

Pre-stellar core formation from dense shocked regions in supersonic isothermal magnetoturbulence

Philip Mocz * [1]

[1] Princeton University – USA

In this talk, I describe the dense structures in supersonic isothermal turbulence which ultimately form pre-stellar cores by self-gravity. Compressible turbulence establishes a network of transient dense shocks that sweep up material and have a density profile described by balance between ram pressure of the background fluid versus the magnetic and gas pressure gradient behind the shock. These rare, densest regions of a turbulent environment can become Jeans unstable and collapse to form pre-stellar cores. Using numerical simulations of magnetogravo-turbulence, we study the structural properties and collapse of dense shocks as a function of magnetic field strength. In the regime of a weak magnetic field, the collapse is isotropic. Strong magnetic field strengths lead to significant anisotropy in the shocked distribution and collapse occurs preferentially parallel to the field lines. Our work provides insight into analysing the magnetic field topology and density structures of young protostellar collapse.

*Speaker

Stratification and turbulence in the intracluster medium

Rajsekhar Mohapatra * [1], Christoph Federrath [1], Prateek Sharma [2]

[1] Research School of Astronomy and Astrophysics, Canberra, Australia
[2] Indian Institute of Science, Bangalore, India

The Active Galactic Nuclei (AGN) feedback model is an attractive solution to the cooling flow problem in the intracluster medium (ICM). However, the exact mechanism by which AGN jets transfer energy to the ICM is unclear. Recently, a lot of attention has been paid to the role of turbulent heating in arresting the cooling of the ICM gas. AGN jets and the motion of galaxies and haloes through the intracluster medium can drive turbulence in the ICM. When this turbulence dissipates at viscous scales, it is supposed to heat up the ICM gas and prevent runaway cooling of the ICM gas. In our work, we study the impact of turbulence driving length scale, the level of turbulence heating and the strength of background stratification on the different statistical properties of ICM gas. We perform high resolution hydrodynamic simulations of homogeneous isotropic turbulence and stratified turbulence. We include radiative cooling and global thermal balance in some of our simulations. We derive the scaling relations between density and pressure fluctuations, rms Mach number and the strength of background stratification (Richardson number) and compare our results to recent observations. From our homogeneous isotropic turbulence simulations, we get an upper bound of $<= 10$ % on the level of turbulence heating in the ICM.

*Speaker

Atomic and molecular hydrogen along quasar/GRB lines of sight

Pasquier Noterdaeme * [1]

[1] Institut d'Astrophysique de Paris (IAP) – Université Pierre et Marie Curie, CNRS : UMR7095, Paris, France

Absorption spectroscopy towards bright background sources has proven to be a very sensitive technique to probe the gas in the distant Universe. Damped Lyman-alpha (DLA) systems, in particular, have widely been used as blind probe of neutral gas in and around galaxies. Indeed, the evolution of their column density distribution, kinematics and chemical enrichment provide strong constraints for models of galaxy formation and evolution. However, it becomes more and more evident that the majority of DLAs only probe warm diffuse gas in the outskirts of galaxies. In this talk, I will synthesize progress concerning the detection and characterization of colder and molecular-rich phases in absorption and discuss how these phase bring unique information on the ISM in the overall population of high redshift galaxies.

*Speaker

Characteristic Scales in the Circum-galactic Medium

Peng Oh * [1]

[1] University of California, Santa Barbara – USA

In recent years, observations of the circum-galactic medium (CGM) have uncovered a large reservoir of T$\sim 10^4$K, photo-ionized gas in the much hotter halos of galaxies. Inflowing cold gas in galactic halos helps fuel star formation, whilst outflowing cold gas is our primary observational marker of feedback. However, the formation and survival of dense cold gas in the atmospheres of galaxy halos is still poorly understood. For instance, we do not yet understand how cold gas can be entrained in a hot wind, as is observed; most simulations indicate it should be shredded by hydrodynamic instabilities. The small scale structure of the cold gas is also poorly understood; galaxy formation simulations show CGM properties which are not converged numerically, and it is not clear what scales need to be resolved to achieve convergence. In this talk I will highlight some recent progress on these questions.

*Speaker

Grain growth and the age of dark clouds

Laurent Pagani * [1], Charlene Lefevre [2], Hiroyuki Hirashita [3], Pierre Lesaffre [4]

[1] Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (LERMA), Université Pierre et Marie Curie, Observatoire de Paris, CNRS : UMR8112, Paris, France
[2] Institut de RadioAstronomie Millimétrique (IRAM), CNRS: UPS2074, Grenoble, France
[3] ASIAA, Taipeh, Taiwan
[4] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

Grains are limited in size distribution as long as they remain in the diffuse medium, but start to grow once inside clouds by accretion of volatiles and coagulation of grains between them. Magnetic field and turbulence are the main drivers to make grains grow to large irregular shapes which are significantly impacting their optical properties. In particular, large abundance of fluffy and porous aggregates up to a few μm in size is predicted in pre-stellar cores in order to reproduce mid-infrared scattering, as revealed by the coreshine phenomenon detected in Spitzer images (Steinacker et al. 2010, Pagani et al. 2010, Lefèvre et al. 2014, 2016). We are now modelling the growth of the grains through hydrodynamical models of cloud contraction towards prestellar cores, starting from realistic grain size distributions (like MRN). Though our model relies on a streamline approach, we can introduce a description of turbulence decay to follow more closely the evolution of the grain growth. Our goal is to compare the resulting grain size properties with observations to deduce the dynamical time needed to reach sizes inferred from scattered light. To allow the comparison, the modelled grain size population is processed with SIGMA, the new grain properties estimator for irregular grown grains (Lefèvre et al. submitted.). Dynamical growth time brings new constraints on the age of dark clouds which can be cross-checked with the time it takes for deuteration to occur in the same clouds, which is another irreversible process.

*Speaker

Mapping the magnetic field of the diffuse ISM in 3D

Gina Panopoulou * [1], Kostas Tassis [2], Anthony Readhead [1]

[1] Caltech Department of Astronomy, Pasadena, USA
[2] University of Crete – Greece

One of the difficulties in determining the nature of MHD turbulence in the Milky Way's diffuse ISM has been the sparsity of observations that probe the magnetic field. The advent of Planck has jump-started our understanding in this field, by providing ample information on the morphology of the magnetic field as projected on the plane of the sky. The next step will be to extend this 2D knowledge to the third dimension - that along the line-of-sight. I will present an effort towards this goal: tomographic mapping of the magnetic field morphology using dust-induced starlight polarization. By combining information from a diverse set of observables, I will demonstrate how one can decompose the magnetic field orientation as a function of distance in the diffuse, cold medium. Finally, I will discuss what we can learn about MHD turbulence and other properties of the diffuse ISM from such an effort.

*Speaker

Energy dissipation in the Solar Wind : theoretical challenges

Thierry Passot * [1], George Miloshevich , Dimitri Laveder , Pierre-Louis Sulem

[1] Observatoire de la Côte d'Azur – CNRS : UMR7293, Université de la Côte d'Azur, Nice, France

The understanding of dissipation processes in a collisionless plasma such as the solar wind or the planetary magnetosheaths constitutes one of the major observational and theoretical challenges for space as well as many other astrophysical plasmas. It is believed to occur in two non-necessarily concomitant steps. Field-particle interactions, that can be resonant or non-resonant, first act to reversibly transfer energy from plasma flows and electromagnetic fluctuations to the particles. Such a process creates fine structures in velocity space, which enhance the efficiency of the very weak collisions, permitting, in a second step, to heat the plasma. The various processes involved in this scenario, including the role of intermittent turbulent structures, will first be briefly reviewed. We shall then focus on the role of Landau damping in space plasma turbulence, both at the level of observations and numerical modeling. The combined role of imbalance and electron Landau damping to steepen sub-ion Alfvénic turbulent magnetic spectra will also be discussed.

*Speaker

The Orion B project: from multi-lines observations to the physics of Giant Molecular Clouds

Jerome Pety * [1,2], Maryvonne Gerin [2], Jan Orkisz [1], Emeric Bron [2,3], Pierre Gratier [4], & The Orion-B Consortium

[1] Institut de RadioAstronomie Millimétrique (IRAM), CNRS: UPS2074, Grenoble, France
[2] Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (LERMA), Université Pierre et Marie Curie, Observatoire de Paris, CNRS : UMR8112, Paris, France
[3] Instituto de Fisica Fundamental-CSIC, Madrid, Spain
[4] Laboratoire d'Astrophysique de Bordeaux (LAB), CNRS : UMR5804, Université Sciences et Technologies - Bordeaux I, Floirac, France

The ORION-B project (Outstanding Radio-Imaging of OrioN B) currently uses the IRAM-30m/EMIR 3mm receiver to image a field of 5 square degrees, located near the southern edge of the Orion B molecular cloud. A total frequency bandwidth of 40 GHz is being observed with a spectral resolution of 195 kHz (0.6 km/s), a typical spatial resolution of 27" (i.e., 50 mpc or 104 AU at 400 pc, the distance of Orion B), and a typical sensitivity of 0.1 K. We succeeded to image the J=1-0 line of the isotopologues of CO as well as the 3mm lines of HCO^+, HCN, HNC, CN, CCH, C_3H_2, CS, SO, N_2H^+, SiO, H_2CO, CH_3OH, DCO^+ and many other weaker features.

I will here summarize some of the team recent results in order to show the potential of such datasets. First we show that it is possible to quantitatively infer the column density just from the collective analysis of the emission of the molecular lines (Gratier et al., in prep.). Second, the statistical analysis of the grid of chemical models allow us to propose more accurate predictors of the ionization fraction than the standard DCO^+/HCO^+ ratio (Bron et al., in prep.). Third, we characterize the ratio of compressive vs. solenoidal motions in the turbulent flow, and we relate this to the star formation efficiency in various regions of Orion B (Orkisz et al. 2017, Orkisz et al., in prep.).

*Speaker

Cosmic rays and magnetic fields in galaxies

Christoph Pfrommer * [1]

[1] Leibniz-Institut fur Astrophysik Potsdam (AIP), Potsdam, Germany

Understanding the physics of galaxy formation is an outstanding problem in modern astrophysics. Recent cosmological simulations have demonstrated that feedback by star formation, supernovae and active galactic nuclei appears to be critical in obtaining realistic disk galaxies and to slow down star formation to the small observed rates. However the particular physical processes underlying these feedback processes still remain elusive. In particular, these simulations neglected magnetic fields and relativistic particle populations (so-called cosmic rays). Those are known to provide a pressure support comparable to the thermal gas in our Galaxy and couple dynamically and thermally to the gas, which seriously questions their neglect. After introducing the underlying physical concepts, I will present our recent efforts to model cosmic ray physics and magnetic fields in galaxy formation. In particular, I will review cosmic ray acceleration at supernova remnants, how cosmic rays interact with the magnetized interstellar medium and propagate through galaxies. Finally, I will 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 form of galactic winds. In this process cosmic rays pressurize galactic halos, which modifies the cosmic accretion of priordial gas, the thermodynamic structure of the circumgalactic medium, and stellar and gaseous disk sizes. This argues that a complete understanding of galaxy formation necessarily includes these non-thermal components.

*Speaker

Dissipation in MHD turbulence

Annick Pouquet * [1,2]

[1] National Center for Atmospheric Research (NCAR) – Boulder, USA
[2] Laboratory for Atmospheric and Space Physics (LASP), Boulder, USA

How much dissipation occurs in a turbulent flow? In physical conditions which include waves (acoustic, Alfvén, gravity, inertial, whistler, ...), is the amount of energy being dissipated modified? And if so, can it be quantified?

This talk will review recent and not-so-recent results on dissipation in turbulent flows. I will first recall the origin of turbulent dissipation through local and non-local effects between widely separated scales, giving examples for both fluids and MHD. I will present models on the emergence of intermittency at large scales, and on the scaling of mixing and dissipation in the presence of waves (specifically, gravity waves), showing for example that the dissipation efficiency, estimated in terms of its dimensional expression, varies linearly with the Froude number, i.e. the ratio of the wave (Brunt-Vaissala) period to the eddy turn-over time, in an intermediate regime where waves and nonlinear eddies interact efficiently. If time permits, I will also discuss the link with intermittency and anisotropy of the small scales.

*Speaker

Deepening the understanding of cosmic-ray diffusion

Patrick Reichherzer * [1,2], Julia Becker Tjus [1,2], Ellen Zweibel [3,4], Lukas Merten [5,1,2], Moritz Pueschel [6]

[1] Theoretical Physics IV: Plasma-Astroparticle Physics, Faculty for Physics & Astronomy, Ruhr-Universitat Bochum, Germany
[2] Ruhr Astroparticle and Plasma Physics Center (RAPP Center), Germany
[3] Department of Astronomy, University of Wisconsin-Madison, USA
[4] Department of Physics, University of Wisconsin-Madison, USA
[5] Institute for Astro-Particle Physics, University of Innsbruck, Austria
[6] Institute for Fusion Studies, University of Texas at Austin, USA

Understanding the transport of energetic cosmic rays belongs to the most challenging topics in astrophysics. The complicated evolution of the cosmic-ray distribution can be modeled mathematically by a diffusive process in the limit of large times. Consequently, diffusion is of fundamental importance in the transport of cosmic rays through turbulence. We demonstrate the reduction of numerical artifacts for the calculation of the diffusion coefficient κ by providing important conditions for physical and numerical input parameters. Subsequently, we characterize the rigidity regimes of κ for arbitrary rigidities and guide fields, which we derive as a function of physical and numerical parameters. We show that at turbulence levels b/B above 5% of the total magnetic field, the approximation of an energy dependence $\kappa \propto E^{1/3}$ as predicted for a Kolmogorov spectrum within Quasi-Linear Theory does not hold. Consequently, a proper description of cosmic-ray propagation can only be achieved by using a turbulence-level dependent diffusion coefficient and can contribute to solving the Galactic cosmic-ray gradient problem.

*Speaker

The effects of local stellar radiation on non-equilibrium ISM chemistry and ISM line diagnostics

Alex Richings * [1]

[1] Institute for Computational Cosmology, Durham University – United Kingdom

The chemistry of ions and molecules in interstellar gas plays an important role in galaxy formation, as the abundances of different chemical species determine how quickly the gas can cool. Furthermore, understanding the gas chemistry is important for interpreting a wide range of ISM emission and absorption line diagnostics. Stellar radiation affects the ISM chemistry, as it ionises the gas and dissociates molecules. However, following the full 3D radiative transfer of stellar radiation in galaxy simulations can be computationally expensive. In this talk, I will present a suite of simulations of isolated disc galaxies, from dwarfs to Milky Way-mass galaxies, in which we couple an approximate treatment for the stellar radiation from individual star particles to a time-dependent chemical model that follows the evolution of 157 ions and molecules. I will compare these to simulations in which we assume a uniform interstellar radiation field, to demonstrate how including a local treatment for stellar radiation affects the evolution of the galaxy, the properties of the multi-phase ISM, and observable ISM line diagnostics. These simulations can also be used to test how ISM line diagnostics trace the physical conditions of the ISM, which is important for interpreting observations of these lines.

*Speaker

The many probes of the circum-galactic medium

Philipp Richter * [1]

[1] University of Potsdam – Germany

Main drivers of galaxy formation and evolution are the accretion of gas from the intergalactic medium and the ejection of metal-enriched material from galaxies due to star-formation activity and AGN feedback. As a result of these processes, galaxies are surrounded by massive envelopes of diffuse, multi-phase, highly turbulent gas: the so-called circumgalactic medium (CGM). In this talk, I will provide an overview on the various observational campaigns that aim at characterizing the spatial distribution of the CGM from low to high redshifts, its physical properties, its dynamics, and its baryon content.

*Speaker

A Stringent Limit on Primordial Magnetic Fields from the Cosmic Microwave Backround Radiation

Andrey Saveliev * [1,2], Karsten Jedamzik [3]

[1] Immanuel Kant Baltic Federal University, Russia
[2] Lomonosov Moscow State University, Russia
[3] Laboratoire Univers et Particules de Montpellier, Université Montpellier 2, CNRS: UMR5299, Montpellier, France

Primordial Magnetic Fields (PMFs), being present before the epoch of cosmic recombination, induce small-scale baryonic density fluctuations. These inhomogeneities lead to an inhomogeneous recombination process which alters the peaks and heights of the large-scale anisotropies of the Cosmic Microwave Backround (CMB) radiation. Utilizing numerical compressible MHD calculations, and a Monte Carlo Markov Chain analysis, which compares calculated CMB anisotropies with those observed by the WMAP and Planck satellites, we derive limits on the magnitude of putative PMFs. We find that the total remaining present day field, integrated over all scales, cannot exceed 47 pG for scale-invariant PMFs and 8.9 pG for PMFs with a violet Batchelor spectrum at 95% confidence level. These limits are more than one order of magnitude more stringent than any prior stated limits on PMFs from the CMB which have not accounted for this effect.

*Speaker

On the Measurement of the Helicity of Intergalactic Magnetic Fields Using Cosmic and Gamma Rays

Andrey Saveliev * [1,2], Rafael Alves Batista [3]

[1] Immanuel Kant Baltic Federal University – Russia
[2] Lomonosov Moscow State University – Russia
[3] University of Sao-Paulo – Brazil

The origin of the first magnetic fields in the Universe is a standing problem in cosmology. Intergalactic Magnetic Fields (IGMFs) may be an untapped window to the primeval Universe, providing further constraints on magnetogenesis. We demonstrate the feasibility of using gamma rays from electromagnetic cascades originating from TeV blazars and Ultra-High-Energy Cosmic Rays (UHECRs) to constrain the helicity of IGMFs by performing simulations of their propagation in simple magnetic field and source configurations. We show that the arrival directions of the respective particles may be used to measure the absolute value of the helicity and its sign.

*Speaker

Interpolation of turbulent magnetic fields and its consequences on cosmic-ray propagation

Leander Schlegel * [1], Antonius Frie [1], Patrick Reichherzer [1], Bjorn Eichmann [1], Julia Becker Tjus [1]

[1] Ruhr Astroparticle and Plasma Physics Center (RAPP Center) – Germany

Numerical simulations of the propagation of charged particles through magnetic fields solving the equation of motion often leads to the usage of an interpolation in case of discretely defined magnetic fields, typically given on a homogeneous grid structure. However, the interpolation method influences the magnetic field properties on the scales of the grid spacing and the choice of interpolation routine can therefore change the result. At the same time, it provides an impact, i.e. error, on the spatial particle distribution and the diffusion coefficient. We compare three different interpolation routines: trilinear, tricubic and nearest neighbor interpolation. Therefore, we optimize a given gridless turbulent reference field, to study in a ballistic and diffusive regime the error in the spatial particle distribution on the one hand and diffusion coefficient on the other hand. It is shown that the different interpolation routines have a significant impact on the resulting magnetic field properties, but the error on the particle propagation stays rather small. Here, a maximal error of about 10% occurs at about the transition between the ballistic and the diffusive propagation regime, which is almost independent of the chosen interpolation method.

*Speaker

The role of ISM turbulence in regulation of star formation in galaxies

Vadim Semenov * [1,2], Andrey Kravtsov [1], Nickolay Gnedin [1,3]

[1] Department of Astronomy and Astrophysics, Chicago, USA
[2] Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
[3] Fermi National Accelerator Laboratory, USA

Formation of stars on sub-parsec scales in galaxies is facilitated by highly-turbulent interstellar gas motions that extend to few 100 parsec scales. This turbulent cascade cannot be resolved in state-of-the-art galaxy formation simulations and therefore they model star formation and feedback by using subgrid prescriptions with parameters that are often tuned to reproduce observations. I will present results from a suite of isolated galaxy simulations in which we instead dynamically follow turbulent energy on unresolved scales and use a star formation model motivated by high-resolution simulations of turbulent giant molecular clouds. To model unresolved turbulence, we adopt a technique which have proved to be remarkably effective in aerospace engineering and simulations of terrestrial turbulent flows. Our galaxy simulations predict a distribution of star formation rates (SFR) that agrees with observations on a range of scales: from tens of parsec to kiloparsec and larger scales. Remarkably, this model can reproduce the observed linear correlation between the SFR and molecular gas surface densities on kiloparsec scale, while a commonly used prescription with a constant star formation efficiency per free-fall time above a fixed density threshold results in a significantly steeper relation. As I will show, these results can be understood using a physical model based on the mass conservation of gas as the gas cycles between star-forming, molecular, and diffuse states in the interstellar medium.

*Speaker

Magnetic fields in elliptical galaxies

Amit Seta * [1]

[1] Research School of Astronomy and Astrophysics ,The Australian National University – Australia

The existence of galactic magnetic fields is usually explained by a turbulent dynamo theory, of which the fluctuation dynamo theory forms a crucial part. However, an unambiguous observational confirmation of the fluctuation dynamo action in a galactic environment is still missing. This is because, in spiral galaxies, it is difficult to differentiate between the small-scale magnetic field generated by a fluctuation dynamo and those due to the tangling of the large-scale field. We propose that observing magnetic fields in elliptical galaxies would serve as a probe of the fluctuation dynamo action. We probe the magnetic fields in elliptical galaxies using existing observations of the Laing-Garrington effect, non-linear fluctuation dynamo simulations, and semi-analytical cosmological simulations. From simulations, we estimate the properties of the rotation measure distribution in terms of the properties of the random magnetic field and thermal electron number density and confirm them with analytical results. A convincing observation of magnetic fields in elliptical galaxies would help us better understand the theory of fluctuation dynamos.

*Speaker

Challenges: The Origin of Cosmic Magnetism

Kandaswamy Subramanian * [1]

[1] Inter-University Centre for Astronomy and Astrophysics, Pune, India

The universe is magnetized from stars to the large-scale coherent magnetic fields detected in galaxies and galaxy clusters, and even perhaps the intergalactic medium in voids. The standard picture for the origin of fields in all astrophysical systems involves turbulent dynamo amplification of a weak seed magnetic field. We first focus on the some specific challenges and intriguing questions which arise in the dynamo paradigm. The questions include, whether fluctuation dynamos generate coherent enough fields, can mean-field dynamos work in the presence of strongly growing fluctuations and can one have helical dynamos without initial helicity! A complementary paradigm which is that magnetic fields arise to some extent in the early universe will also be mentioned.

*Speaker

Plasma investigations of the connection between turbulence and cosmic-ray transport in the interstellar medium

Julia Tjus * [1]

[1] RAPP Center at Ruhr-Universität Bochum – Germany

Propagation of cosmic rays is described by diffusive motion in most astrophysical environments. For a proper modeling of this process, the diffusion tensor needs to be known in detail. In this work, we investigate the nature of the parallel diffusion coefficient κ for five different scattering regimes. We can show that the energy dependence of κ differs in these five energy ranges. The expectation of the typically applied fully diffusive motion only holds in a relatively small range of energy, where the latter is highly dependent on the simulation parameters. We also show that for turbulence levels that are above $\sim 5\%$ of the total magnetic field, the result of $\kappa \propto E^{1/3}$ expected from a Kolmogorov-type turbulence spectrum in the quasi-linear theory is not reached yet. Instead, the index is larger and increases toward higher energies. In this talk, we will summarize how we reach these results and put them into the astrophysical context. In particular, we focus on the importance of our findings with respect to the Galactic Interstellar Medium and the interpretation of recent gamma-ray measurements by Fermi.

*Speaker

Lyman alpha emission around galaxies at high redshift What can we learn about the turbulent ISM/CGM of galaxies from their Lyα emission ?

Anne Verhamme * [1]

[1] Observatoire de Genève, Université de Genéve – Switzerland

I will first briefly review the main results obtained by the MUSE collaboration on the Lymanα properties of high redshift galaxies. I will then describe the basics of Lymanα radiation transfer, and how Lyα spatial and spectral profiles may imprint velocity fields, column density, and porosity of the scattering medium. Finally, I will present the Monte Carlo radiation transfer code RASCAS that we are using to predict the Lyα properties of virtual galaxies, computed in the framework of the Sphinx project (https://sphinx.univ-lyon1.fr), and highlight some preliminary results.

*Speaker

CH^+ observations of starburst galaxies at the peak of cosmic star formation

Alba Vidal Garcia * [1]

[1] Laboratoire de Physique de l'ENS (LPENS), ENS, Université PSL, CNRS: UMR 8023, Sorbonne Université, Université Paris-Diderot, Paris, France

We present CH^+ (J=1-0) observations in 17 starburst galaxies at the peak of cosmic star formation. We detect CH^+ in absorption against their dust continuum emission in 16 of them, a high detection rate suggesting that the diffuse gas causing the CH^+ absorption is tied to the starburst phase. There are as many blue- and red-shifted absorptions that probe outflowing and inflowing gas motions respectively. These motions are ascribed to large scale turbulence. The absorption lines are deep and broad (average linewidth 400 km s^{-1}) and trace large column densities of CH^+ from which we derive the mass and kinetic luminosity of the reservoirs of turbulent diffuse gas. This luminosity correlates with the star formation rate indicating that turbulence is fed by feedback from star formation. The mass outflow rates are marginally sufficient to compensate the mass drain of the turbulent reservoirs due to star formation. Gas inflows from on-going mergers or cold stream accretion are therefore required for the gas mass feeding of the turbulent reservoirs. In one of the fields, comprising at least two bright submillimeter galaxies, Ly-α profiles have red wing velocities coinciding with those of CH^+ absorption, pointing to a co-spatial existence of the Ly-α emitting warm neutral medium and CH^+ absorbing cold neutral medium in the 20 kpc-scale environment of these galaxies. The infalling motion towards the starburst cores probed by the red-shifted CH^+ absorption against their dust continuum emission, is therefore shared by the Ly-α emitting medium.

*Speaker

MMS observations of thin current sheets in the solar wind

Alexander Vinogradov * [1], Ivan Vasko [2], Anton Artemyev [3], Egor Yushkov [1], Anatoly Petrukovich [1]

[1] Space Research Institute of the Russian Academy of Sciences, Russia
[2] Space Sciences Laboratory, University of California at Berkeley, USA
[3] University of California at Los Angeles, USA

Thin intensive current sheets play important role in solar wind dynamics. The MMS mission provides an opportunity to study the thin current sheets in the solar wind with high temporal and spatial resolution. Analyzing magnetic field data provided by the MMS mission during 2 days of November 2017, a detailed statistical analysis of current sheets is accomplished. The current sheets were detected using the PVI (Partial Variance of Increments) method. The applicability of curlometer is shown by comparing with current density estimates obtained using the "timing" method. In order to find the current sheet reference frame, we apply combination of the MVA (Minimum Variance Analysis) method and the timing method. Besides PVI, we investigated events with high-amplitude localized currents and magnetic field corresponding to 1D current sheet configuration. We completed the full statistics of current sheets and calculated the occurrence rate of high-amplitude current sheets. About 15% of current sheets were analyzed in the burst mode. Current sheets with an amplitude of up to 150 nA /m^2 and a thickness of up to 10 km were detected. To investigate the internal structure of the current sheets we performed epoch analysis of the characteristic plasma parameters of the current sheets. Three types of current sheets with different pressure balance across the sheet were detected.

*Speaker

21 cm Cosmology and the Epoch of Reionization

Saleem Zaroubi * [1,2]

[1] University of Groningen, Groningen, The Netherlands
[2] The Open University, Israel

21 cm Cosmology is a newly emerging field which attempts to explore the Universe through intensity mapping of neutral Hydrogen. A number of Radio telescopes are currently observing redshifted 21 cm from the Epoch of Reionization and are zeroing on the faint signal that emanates from this important period in the History of the Universe. One of the main telescopes that are carrying out such an experiment is the European LOFAR. In this talk I will review the current observational status of the high redshift 21 cm experiments and focus specifically on the results from LOFAR, as well as, the expectation from the upcoming SKA telescope.

*Speaker

Intermittency of magnetohydrodynamic and kinetic turbulence

Vladimir Zhdankin * [1]

[1] Department of Astrophysical Sciences, Princeton – USA

Intermittency plays a fundamental role in plasma turbulence by localizing a large fraction of the turbulent energy dissipation in coherent structures such as current and vorticity sheets. The statistical properties of these structures are thus of importance for modeling processes such as heating, non-thermal particle acceleration, and radiative signatures in a diverse range of astrophysical systems. I will first discuss measurements of the energetic, spatial, and temporal properties of dissipative structures in numerical simulations of magnetohydrodynamic (MHD) turbulence. I will then discuss current progress on understanding the role that intermittency has on energy dissipation in collision-less plasmas. In particular, I will discuss recent results on non-thermal particle acceleration and radiative beaming signatures from particle-in-cell simulations of relativistic plasma turbulence. These results have observational implications for high-energy astrophysical systems. Finally, I will point out future directions in building the connections between intermittency in MHD and kinetic settings.

*Speaker

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