Shocks, Reconnection, and Particle Acceleration in Plasma-fluids

June 20-21, 2013

Centre Blaise Pascal, ENS Lyon, France

Shocks, Reconnection, and Particle Acceleration in Plasma-fluids

Description

The acceleration of non-thermal particles in large scale flows is of prime importance in astrophysics and beyond. Cosmic accelerators can energize particles up to 10^{20} eV. The flux of high-energy cosmic rays has a strong impact on Earth, on its climate and weather.

However, accelerators embedded in large scale MHD flows within astrophysical objects still remain enigmatic in various ways. The aim of the workshop is to bring together people of different communities and approaches: modelers of large scale flows, scientists scrutinizing fundamental processes, people who are deriving observable signatures, and numerical specialists. We also aim at bringing together the French with the European community and strengthen the collaboration between them, specially emphasizing the Rhône-Alpes region.

The first day concentrates on theoretical questions of plasma physics, particle acceleration, magnetic reconnection, and turbulence in plasma fluids. This includes open questions of how to model these phenomena and how to realize such models numerically.

The second day presents results of modeling concrete astrophysical objects: microquasars and X-ray binaries, pulsars and their winds, gamma-ray bursts, solar wind, supernova remnants and superbubbles, the interstellar medium.

Scientific/Organizing committee

- Rolf WALDER, CRAL, École normale supérieure de Lyon, France
- Alexandre MARCOWITH, LUPM, Université Montpellier 2, France
- Andrei BYKOV, Ioffe Institute, Russian Academy of Sciences, St. Petersburg, Russia
- Christophe WINISDOERFFER, CRAL, École normale supérieure de Lyon, France
- Mickaël MELZANI, CRAL, École normale supérieure de Lyon, France

Administrative coordination

- Samantha BARENDSON, Centre Blaise Pascal, ENS de Lyon, France

Practical information

Lunchs

June 20 – 13:05 & June 21 – 12:30

Brasserie Le Métropole
25 Place des Pavillons
69007 Lyon
+33 4 72 76 21 71

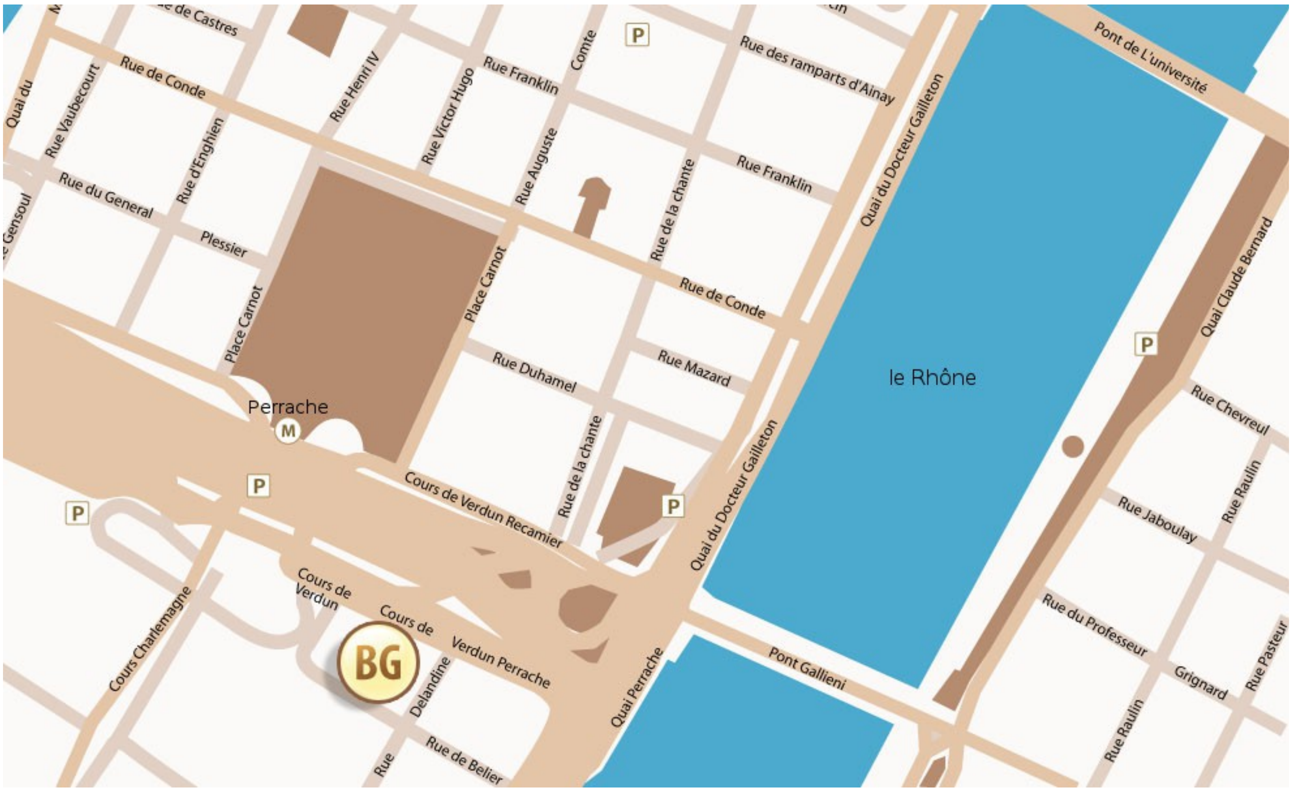
5 min walking from ENS.

Dinner

June 20 – 19:00

Brasserie Georges
30 Cours de Verdun Perrache
69002 Lyon Perrache
+33 4 72 56 54 54

Metro « Perrache »



Metro Map

plan métro-tram de Lyon
SYTRAL
MÉTRO - TRAMWAY
CUIRE
HENON
CROIX-ROUSSE
CROIX-PAQUET
HÔTEL DE VILLE
Louis Pradel
GARE DE VAISE
VALMY
GORGE DE LOUP
FOURVIÈRE
VIEUX LYON
Cathédrale St-Jean
MINIMES
Théâtres Romains
ST JUST
CORDELIERS
BELLECOUR
AMPÈRE
Victor Hugo
PERRACHE
Suchet
Sainte-Blandine
Montrochet
mise en service en 2005
MUSÉE DES CONFLUENCES
IUT-FEYSSINE
Croix-Luizet
INSA-Einstein
La Doua-Gaston Berger
Université Lyon 1
Condorcet
Le Tonkin
CHARPENNES
Charles Hernu
MASSÉNA
FOCH
RÉPUBLIQUE-Villeurbanne
GRATTE-CIEL
FLACHET
CUSSET
LAURENT BONNEVAY
Collège Bellecombe
BROTTEAUX
Thiers-Lafayette
Part-Dieu-Servient
Moncey-Mairie du 3ème
Saxe-Préfecture
PART-DIEU
Vivier Merle
Liberté
PLACE GUICHARD
GUILLOTIÈRE
Saint-André
Rue de l'Université
SAXE-GAMBETTA
GARIBALDI
SANS-SOUCI
MONPLAISIR-LUMIÈRE
GRANGE BLANCHE
Ambroise Paré
Vinatier
Essarts-Iris
Boutasse-Camille Rousset
Hôtel de Ville-Bron
Les Alizés
Rebufer
Quai Claude Bernard
Centre Berthelot
JEAN MACÉ
Garibaldi-Berthelot
Route de Vienne
Jet d'eau Mendès France
Jean XXIII Maryse Bastié
Villon
Bachut Mairie du 8ème
LAËNNEC
MERMOZ PINEL
PARILLY
Parilly-Université
Europe-Université
Porte des Alpes
Parc Technologique
Hauts de Feuilly
Salvador Allende
Alfred de Vigny
St-Priest-Hôtel de Ville
Esplanade des Arts
Jules Ferry
Cordière
ST-PRIEST BEL-AIR
PLACE JEAN JAURÈS
DEBOURG
STADE DE GERLAND
GARE DE VÉNISSIEUX
Saône
Rhône
Métro
PERRACHE L. BONNEVAY
CHARPENNES STADE DE GERLAND
HÔTEL DE VILLE CUIRE
GARE DE VAISE GARE DE VÉNISSIEUX
Tramway
PERRACHE IUT - FEYSSINE
PERRACHE ST-PRIEST
Agence commerciale TCL
Parc relais TCL
Gare SNCF
Navette aéroport
Office de tourisme
Accessibilité
parmi les 90 stations du réseau métro-tramway, seules les 8 stations suivantes ne sont pas encore accessibles :
Ampère, Cordeliers, Foch, Gratte-ciel, Flachet, Brotteaux, Croix-Paquet et Henon

Program

June 20, 2013		
08:45 – 09:15	Break	Welcome coffee and croissants
09:15 – 09:20	Speech	Opening - Rolf Walder, SOC
09:20 – 10:05	Speech	Physics of shocks generating high energy cosmic phenomena - **Guy Pelletier**
10:05 – 10:35	Speech	RMHD simulations of non-resonant Streaming instability near relativistic shocks - **Fabien Casse**
10:35 – 11:05	Speech	The influence of frequency-dependent radiative transfer on the structures of radiative shocks - **Neil Vaytet**
11:05 – 11:20	Break	Coffee break
11:20 – 12:05	Speech	Electrostatic shocks in astrophysics, in the laboratory and in particle-in-cell simulations - **Mark Dieckmann**
12:05 – 12:35	Speech	Differences between PIC, real, and Vlasov-Maxwell plasmas - **Mickaël Melzani**
12:35 – 13:05	Speech	Implicit PIC - **Giovanni Lapenta**
13:05 - 14:30	Break	Lunch - Brasserie Métropole
14:30 – 15:15	Speech	Multi-scale, multi-physics simulation of microquasars - first results - **Rolf Walder**
15:15 – 16:00	Speech	High energy process in accretion disk coronae - **Alexandre Marcowith**
16:00 – 16:30	Break	Coffee break
16:30 – 17:00	Speech	Numerical 3D-hydrodynamic modelling of colliding winds in massive star binaries: particle acceleration and gamma-ray emission - **Klaus Reitberger**
17:00 – 17:45	Speech	Flow collision zones: ubiquitous and - anisotropically, inhomogeneously – turbulent - **Doris Folini**
17:45 – 18:15	Speech	TBD - Romain Cohet
19:00 – 22:00	Break	Dinner - Brasserie Georges
June 21, 2013		
08:30 - 09:00	Break	Welcome coffee and croissants
09:00 - 09:45	Speech	Kinetic range plasma turbulence, reconnection and particle energization- what we can learn from large scale kinetic simulations and observations within our heliosphere - **Sandra Chapman**
09:45 - 10:15	Speech	Electron Dynamics in 3D Coronal Magnetic Reconnection Regions - **Gisela Baumann**
10:15 - 10:45	Speech	Explosive tearing mode reconnection in relativistic plasmas: application to the Crab flares - **Hubert Baty**
10:45 - 11:15	Break	Coffee break
11:15 - 11:45	Speech	PIC simulations of relativistic magnetic reconnection in ion-electron plasmas - **Mickaël Melzani**
11:45 - 12:15	Speech	3D Kinetic Magnetic Reconnection: getting ready for the MMS mission - **Giovanni Lapenta**
12:30 - 14:00	Break	Lunch - Brasserie Métropole
14:00 - 14:30	Speech	3D relativistic hydro models for SS433: virtual views on precessing jets - **Rémi Monceau-Baroux**
14:30 - 15:15	Speech	Hydrodynamic simulation of GRB afterglow - **Zakaria Meliani**
15:15 – 15:45	Speech	Gamma-ray emision from binaries - **Guillaume Dubus**
15:45 – 15:50	Speech	Closing Remarks - Rolf Walder
15:50 – 18:00	Break	Happy Hour

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Physics of shocks generating high energy cosmic phenomena

Guy PELLETIER
Insitute de Planétologie et d'Astrophysique de Grenoble, France

Two kinds of challenge raise in high energy astrophysics :i) the generation of very powerful spectra of suprathermal particles or photons, as for instance the Gamma Ray Burst emissions, ii) the generation of spectra of high energy particles that extend to Ultra High Energies (a few 1020eV). Strong collisionless shocks with turbulence, possibly accompanied by reconnection sites, are expected to be the sources of these phenomena, by developing a Fermi process through scattering off self-generating turbulence. From the point of view of physics, the main task is to understand and to quantify the triptych that involves the formation of a collisionless shock, the generation of suprathermal particles and the generation of turbulence interdependently. Non relativistic shocks and relativistic shocks have different properties in this respect and different efficiencies in accounting for the high energy challenges. Whereas the generation of MHD turbulence is expected at non-relativistic shocks, generation of intense micro-turbulence is expected at relativistic shocks (however with probably an MHD component also in the long term). A special focus on relativistic shocks with their micro-turbulence will be addressed, including a view on the nonlinear structure and an estimate of the radiative performance.

RMHD simulations of non-resonant Streaming instability near relativistic shocks

Fabien CASSE[1], Alexandre MARCOWITH[2] & Rony KEPPENS [3]
[1.] Laboratoire Astroparticule & Cosmologie, Université Paris Diderot, France
[2.] Laboratoire Univers et Particules Montpellier, France
[3.] Centre for mathematical Plasma Astrophysics , KU Leuven, Belgium

In this talk, I will present some recent simulations using the relativistic MHD framework to study the influence of electrical cosmic-ray charge upon MHD waves propagating in the precursor of a shock. After describing the structure of the upstream medium of a shock, I will show that in the most likely configuration, magneto-sonic waves are destabilized by the external charge while Alfven waves remains unaffected. RMHD simulations will be presented describing the magneto-acoustic wave amplification. Simulations will cover the whole shock velocity range from the non-relativistic to the ultra-relativistic shock regime.

The influence of frequency-dependent radiative transfer on the structures of radiative shocks

Neil VAYTET
Ecole normale supérieure de Lyon, France

Radiative shocks are shocks in a gas where the radiative energy and flux coming from the very hot post-shock material are non-negligible in the shock's total energy budget, and are often large enough to heat the material ahead of the shock. Many simulations of radiative shocks, both in the contexts of astrophysics and laboratory experiments, use a grey treatment of radiative transfer coupled to the hydrodynamics. However, the opacities of the gas show large variations as a function of frequency and this needs to be taken into account if one wishes to reproduce the relevant physics.

We have performed radiation hydrodynamics simulations of radiative shocks in Ar using multigroup (frequency dependent) radiative transfer with the HERACLES code. The opacities were taken from the ODALISC database.

We show the influence of the number of frequency groups used on the dynamics and morphologies of subcritical and supercritical radiative shocks in Ar gas, and in particular on the extent of the radiative precursor. We find that simulations with even a low number of groups show significant differences compared to single-group (grey) simulations, and that in order to correctly model such shocks, a minimum number of groups is required. Results appear to eventually converge as the number of groups increases above 50. We were also able to resolve in our simulations of supercritical shocks the adaptation zones which connect the cooling layer to the final post-shock state and the precursor.

Electrostatic shocks in astrophysics, in the laboratory and in particle-in-cell simulations

Mark Eric DIEKMANN
Dept of Science and Technology (ITN), Linköping University, Norrköping, Sweden

Non-relativistic electrostatic shocks in collision-less plasma form when two unmagnetized plasma clouds collide at a speed that exceeds significantly the local ion acoustic speed. Such a collision results in a pair of shocks, the forward and reverse shocks, which move into opposite directions. Such shocks are now routinely generated in laser-plasma experiments, they can be modeled in multi-dimensional particle-in-cell simulations and analytic models of such structures exist, at least under idealized assumptions. Such shocks are typically not considered to be representative of supernova remnant shocks. The maximum Mach number of such shocks is limited to values well below those of SNR shocks. I will describe in my talk how electrostatic shocks form and how they are sustained in a self-consistent way. An overview of recent related laser-plasma experiments and simulations is given. I will then discuss how the shock-reflected ion beam can pre-heat the upstream plasma by means of instabilities or through the ambipolar electrostatic field of a plasma density gradient. It is discussed how this pre-heating could reduce the ion acoustic Mach number of SNR shocks to a value that allows the latter to be stable even in the absence of supporting magnetic fields.

Differences between PIC, real, and Vlasov-Maxwell plasmas

Mickaël MELZANI, Rolf WALDER, Christophe WINISDOERFFER, Doris FOLINI
Centre de Recherche Astrophysique de Lyon, Ecole Normale Supérieure de Lyon, France

The widespread use of particle-in-cell (PIC) codes for studying plasmas out of equilibrium calls for a deep understanding of the PIC model, and of its relations with a real plasma and with the Vlasov-Maxwell description.

The PIC model lies on two building blocks. The first stems from the capability of computers to handle only up to ~ 10^{10} particles, while real plasmas contain from 10^4 to 10^{20} particles per Debye sphere: a coarse-graining step must be used, whereby of the order of $p \sim 10^{10}$ real particles are represented by a single computer "superparticle". The second is field storage on a grid with its subsequent finite superparticle size.

We introduce the notion of coarse-graining dependent quantities, i.e. physical quantities depending on p. They all derive from the plasma parameter Λ, that we show to behave as $\Lambda \propto 1/p$. Important applications include the PIC collision- and fluctuation-induced thermalization times, that scale with the number of superparticles per grid cell and are a factor $p \sim 10^{10}$ smaller than in real plasmas, and the level of electric field fluctuations, that scales as $1/\Lambda \propto p$. We show how large superparticle sizes of the order of the Debye length modify these scalings.

We investigate the extent to which these unphysically large parameters alter the PIC plasma physics with two main examples: the rapid thermalization of plasmas with two different temperatures, and the blurring of the linear spectrum of the filamentation instability. In the latter case, the fastest growing modes do not dominate the total energy because of a high level of fluctuations, and effective growth rates measured on the totalenergy can differ by more than 50% from the linear cold predictions.

We also stress that a PIC plasma bears differences with the Vlasov-Maxwell description, which models a phase-space fluid with $\Lambda = +\infty$ and no correlations.

Multi-scale, multi-physics simulation of microquasars - first results

Rolf WALDER[1], Doris FOLINI[1,3], Mickaël MELZANI[1], Christophe WINISDOERFFER[1] & Jean M. FAVRE[2]
[1.] Centre de Recherche Astrophysique de Lyon, CRAL ENS-Lyon, France
[2.] Swiss Supercompute Center, CSCS Lugano, Switzerland
[3.] Institute for Atmospheric and Climate Science, IACETH, ETH Zürich, Switzerland

Microquasars are complex objects, the description of which demands for a comprehensive approach, comprising a fluid dynamics point of view as well as particle aspects and the decisive role of photons, especially in the vicinity of the accreting black hole. On top of that, as will be highlighted in this presentation, relevant interactions in these objects take place over a multitude of scales. First pure hydrodynamical full-scale simulations of such systems will be presented: from the circum-binary scale down to the scale of the gravitational radius of the black hole. For wind-accreting high mass systems like Cyg X-1, it is discussed under what conditions, on what scale, and how what kind of accreting structure is formed and what their characteristics are. It will be shown that the answer to these questions strongly depends on the wind speed, but also on the interplay of different scales of the accretion flow. In particular, scales in the vicinity of the black hole are important for the stability of the global accretion flow within the Bondi-Hoyle scale. It is further discussed on what scales the flow is unlikely to reach thermodynamical equilibrium and touch on the related issue of particle acceleration.

High-energy processes in accretion disk coronae

Alexandre MARCOWITH[1], Renaud BELMONT[2] & Julien MALZAC[2]
[1.] Laboratoire Univers et Particules Montpellier, France
[2.] Institut de Recherche en Astrophysique et Planétologie (IRAP)

Accretion disks around compact objects are known as X- and Gamma-ray emitters. The non-thermal radiation is likely produced in a hot corona associated with the accretion disk. As in the solar corona energetic particles can be accelerated at different sites and radiate efficiently. To investigate the different spectral states observed in these objects we have developed a numerical tool that dynamically couple energetic leptons (electron/positron), photons and magneto-hydrodynamic slab-type waves plus a thermal population of protons. We present here the first results of this code adapted to the conditions that prevail around galactic black holes.

Numerical 3D-hydrodynamic modelling of colliding winds in massive star binaries: particle acceleration and gamma-ray emission

Klaus REITBERGER[1], Ralf KISSMANN[1], Anita REIMER[2], Guillaume DUBUS[3] & Olaf REIMER[1]
[1.] Institut für Astro und Teilchenphysik, University of Innsbruck, Austria
[2.] Institute for Astro- and Particle Physics, Innsbruck University
[3.] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)

Massive stars in binary systems (as WR140, WR147 or η Carinae) have long been regarded as potential sources of high-energy γ-rays. The emission is thought to arise in the region where the stellar winds collide, thereby producing accelerated particles which subsequently emit γ-rays.
This scenario is supported by recent observations of η Carinae with the Fermi Large Area Telescope. To address the underlying emission mechanisms in a quantitative way, numerical simulations that incorporate hydrodynamics, the acceleration of charged particles as well as subsequent γ-ray emission are necessary.
Hydrodynamical models have been presented in the past which describe the dynamics of the wind-collision region and the ensuing thermal emission up to X-ray energies. Consequently, we present a 3D-hydrodynamical model with the aim of describing high-energy γ-ray emission. Our model incorporates the line-driven acceleration of the winds, gravity, orbital motion and the radiative cooling of the shocked plasma, as well as the diffusive shock acceleration of charged leptons in the wind collision region and the subsequent γ-ray emission via relativistic bremsstrahlung and anisotropic inverse Compton radiation towards the observer. First results regarding wind structure, particle and γ-ray spectra will be shown.

Flow collision zones:
ubiquitous and - anisotropically, inhomogeneously - turbulent

Doris FOLINI[1], Rolf WALDER[1] & Jean M. FAVRE[2]
[1.] École normale supérieure, Lyon, CRAL, UMR CNRS 5574, Université de Lyon, France
[2.] Swiss National Supercomputing Center, CSCS Lugano, Switzerland

Colliding supersonic flows are ubiquitous in astrophysics and play an important role in a wide range of objects, from O-star winds to molecular clouds, galactic sheets, or γ -ray bursts. We investigate characteristics of supersonically turbulent flow collision zones by numerically solving the Euler equations for the case of 3D isothermal plane parallel head on colliding flows, assuming symmetric settings (both flows have equal parameters) and upwind Mach-numbers $3 < Mu < 43$.
The turbulence within the collision zone is driven by the incoming upstream flows, whose kinetic energy is partly thermalized and spatially modulated by the confining shocks of the collision zone. Numerical results are in line with analytical self-similarity arguments for collision zone mean properties. The spatial scale of modulation grows with the collision zone. Independent of the upstream Mach number Mu , the mean density ρm is proportional to the upstream density ρu , with $\rho m \approx 20\rho u$. For the root mean square Mach number (Mrms) we have $Mrms \approx 0.25Mu$. Deviations towards lower turbulence are found as the collision zone thickens, for small Mu , and in the center of the collision zone. The turbulence is inhomogeneous.
The turbulence is also strongly anisotropic. The component transverse to the upstream flow remains subsonic on average, even in the central regions of the collision zone. Line of sight effects thus may play a role in observations. The anisotropy carries over to other quantities, like the density variance - Mach number relation. The density probability function is not log-normal. Structure functions are widely different if computed either along a line of sights perpendicular or parallel to the upstream flow. Structure functions are consistent with results from homogeneous, isotropic, stationary, driven 3D supersonic turbulence if computed over a multitude of directions and if restricted to the central regions of the collision zone.
Overall, our results show that turbulence characteristics of 3D isothermal collision zones typically deviate markedly from the characteristics of homogeneous, isotropic, stationary, driven 3D supersonic turbulence. This should be kept in mind when interpreting sturbulence characteristics derived from observations.

Kinetic range plasma turbulence, reconnection and particle energization: what we can learn from large scale kinetic simulations and observations within our heliosphere

Sandra CHAPMAN[1] with E. Leonardis[1],G. Gogoberidze[4], B. Hnat[1], K, Kiyani[1], K. Osman[1], A. J. Turner[1,] William S. Daughton[2], Vadim Roytershteyn[3], Homayoun Karimabadi[3]

[1.] Centre for Fusion, Space and Astrophysics, University of Warwick, Coventry, United Kingdom

[2.] Los Alamos Lab., Los Alamos, NM, United States

[3.] SciberQuest, Inc., Del Mar, CA, United States

[4.] Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia

Satellite observations of plasma parameters in-situ suitable for the study of turbulence and reconnection in the solar wind cover timescales from below ion kinetic scales up to days, providing a 'laboratory' to explore the fundamental physics. High resolution imaging of line of sight emissions from the solar corona also provide the first opportunity to study the spatio-temporal dynamics of turbulence and reconnection. Recent large scale self-consistent fully kinetic simulations in three dimensions are able to begin to capture both dynamic reconnection and self-generation of turbulence. Central to the idea of using these natural systems as physics laboratories, are methods that allow direct quantitative comparison between the predictions of theory and simulation, and the observations. Critically, theoretical predictions, and data analysis methods, must come together in a manner in which uncertainties can be well understood, and thus different theoretical scenarios can be distinguished unambiguously. In this talk I will present methods and recent results that quantify turbulence in these kinetic simulations of reconnection, in quiescent solar prominences, and in the solar wind, and how the statistical scaling of the turbulence relates to particle acceleration.

Electron Dynamics in 3D Coronal Magnetic Reconnection Regions

Gisela BAUMANN[1,2], Åke NORDLUND[1], Klaus GALSGAARD[1], Troels HAUGBOELLE[1] & Jacob Trier FREDERIKSEN[1]
[1.] Niels Bohr Institute, University of Copenhagen, Danemark
[2.] Kiepenheuer-Institut für Sonnenphysik, Germany

The presented work focuses on the acceleration mechanism of non- thermal electrons in 3D magnetic reconnection regions of an active solar region in a pre-flare phase and on a coronal hole region producing a solar jet. Magnetohydrodynamics is a suitable theory for describing the solar plasma motion macroscopically. However, in order to investigate particle kinetics, a microscopic particle tracing method is needed to specify the motion of single particles in a self-consistent electromagnetic field. One numerical kinetic approach is a Particle-In-Cell simulation (PIC). The numerical plasma description of MHD and PIC methods are joined in the presented research, introducing one of the first models successfully interconnecting microscopic and macroscopic scales. Although this technique is still in the early stages of development and heavy numerical constraints limit the parameter choice, it provides a new numerical tool for investigations of systems covering a vast range of scales.
Making use of this new method combined with large numerical simulations of the solar atmosphere with a realistic magnetic field topology, particle acceleration up to non-thermal velocities is found to be caused by a systematic, slowly evolving electric field that builds up at the current sheet that separates two different magnetic connectivity domains.

Explosive tearing mode reconnection in relativistic plasmas: application to the Crab flares

Hubert BATY[1], Jérôme PÉTRI[1] & Seiji ZENITANI [2]
[1.] Observatoire de Strasbourg, Université Louis Pasteur, Strasbourg, France
[2.] National Observatory of Japan, Tokyo, Japan.

We investigate the possible role of Tearing mode in driving a fast magnetic reconnection process in relativistic plasmas. In particular, our resistive relativistic magnetohydrodynamic simulations of double current sheet system show an explosive phase associated with the nonlinear evolution of the magnetic islands. We discuss the consequences of such explosive reconnection dynamics to explain the MeV flares observed in the Crab pulsar nebula.

PIC simulations of relativistic magnetic reconnection in ion-electron plasmas

Mickaël MELZANI, Rolf WALDER, Christophe WINISDOERFFER, Doris FOLINI
Centre de Recherche Astrophysique de Lyon, École Normale Supérieure de Lyon

Magnetic field reconnection in relativistic ion-electron plasmas is a prime candidate to account for various high-energy events: for example flares in AGN jets, particle acceleration and transient jet production in microquasars, or high-energy emission in GRBs. With the help of two-dimensional particle-in-cell simulations, we present preliminary investigations of magnetic reconnection in a Harris current sheet where the magnetic field energy and the plasma thermal energy reach or exceed the particles rest mass energy.

We find fast reconnection, with a classical two-scale dissipation region where ions decouple from the magnetic field at an ion skin depth from the X-point, and the electrons at an electron skin-depth. These two zones are bounded by shocks, and the high resolution employed exhibits sharp transitions at various other locations.

We explicit the balance of terms in Ohm's law, and explain how to evaluate them in PIC simulations with relativistic particle distributions. We show that just as in non-relativistic simulations, the finite reconnection-induced electric field is allowed by bulk inertia in the ion region, and bulk plus thermal inertia in the electron region.

We also discuss particle acceleration, and find particles mainly accelerated by the reconnection-induced electric field.

3D Kinetic Magnetic Reconnection: getting ready for the MMS mission

Giovanni LAPENTA[1], A. Vapirev[1], V, Olshevskyi[1], S. Markidis[2], M. Goldman[3 &] D. Newman[3]
[1.] KU Leuven, Belgium
[2.] KTH, Sweden
[3.] University of Colorado, USA

We report on our work to provide theoretical support to the Magnetospheric Multiscale (MMS) Mission of NASA. We report on the results of applying our massively parallel 3D particle in cell code iPic3D [1] to the study of 3D reconnection.
Reconnection refers to the energy conversion process where magnetic field lines are broken and reconnected in a new configuration while electrons and ions are energized at the expense of the magnetic energy. The process has been extensively investigated in laboratory, in space and in astrophysical systems where it is believed to play a dominant role in shaping the development of energy in many events. The studies have preliminarily been in 2D assuming relatively idealized conditions.

Here we report on the new work where the role of the third dimension is investigated. We start from the typical 2D case and add the effects of the 3rd dimension in three steps.
First, we simply add the z-direction to a 2D run loading an initial system that simply replicates the same initial 2D state invariant of z, with the same initial perturbation also independent of z. This case is already extremely interesting showing the presence of key processes absent in 2D.Several regions of intense free energy are present (velocity shears, strong flows, density gradients) and elad to numerous instabilities. We will explain the relevance to existing observations and to the future MMS mission [2,3].

Next, we allow reconnection to develop freely an initially uncorrelated in the z dimension. Here we do not prescribe any perturbation and allow each z-plane to develop with only the spontaneous correlations naturally evolving in the system. In this case reconnection is vastly different from the 2D case leading to numerous reconnection sites that start to interact to form coherent structure: flox ropes and extended electron and ion diffusion regions.

Last, we initiate the system with configurations that are fully 3D and include to begin with a 3D topology with prescribed null lines and null points where the magnetic field is zero. The evolution is drastically different at null points and null lines.

In all three cases, we report on the evolution of the system focusing especially on:
1) the presence of instabilities,
2) the existence of non-MHD effects where electrons and ions display their kinetic nature and decouple from the frozen in condition.
3) the energetics of the process, investigating where and how energy is released.

[1] Markidis, Stefano, and Giovanni Lapenta. "Multi-scale simulations of plasma with iPIC3D." Mathematics and Computers in Simulation 80.7 (2010): 1509-1519.
[2] Lapenta, Giovanni, et al. "Bipolar electric field signatures of reconnection separatrices for a hydrogen plasma at realistic guide fields." Geophysical Research Letters 38.17 (2011): L17104.
[3] S. Markidis, G. Lapenta, D.L. Newman, M.V. Goldman, L. Andersson, Three dimensional density cavities in guide field collisionless magnetic reconnection, Physics of Plasmas, 19, 032119, (2012).
[4] Vapirev, A. E., et al. "Formation of a Transient Front Structure Near Reconnection Point in 3D PIC Simulations." Journal of Geophysical Research: Space Physics (2013).

3D relativistic hydro models for SS433: virtual views on precessing jets

Rémi MONCEAU-BAROUX[1], Rony KEPPENS[1], Zakaria MELIANI[2] & Olivier PORTH[3]
[1.] Centre for mathematical Plasma Astrophysics, KU Leuven, Belgium
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Observations allow to look closer and closer into objects powering relativistic jets associated with accretion disks. This is also true for SS433, where observations down to the sub-parsec scale infer how an X-ray binary gives rise to a corkscrew patterned relativistic jet. Many simulations of jets associated with high energy astrophysical objects assume axisymmetry, allowing to cut down computational cost. Due to the inferred precessional motion of the SS433 jet, we aim for 3D simulations to accurately follow non axisymmetric processes, like the jet precession and its deflection by interstellar matter. XRB SS433 is well known through kilo-parsec scale observations with Chandra, showing its interaction with the supernova remnant W50, and on sub-parsec scale with VLA observations of its radio emission. We target the latter sub-parsec scale and focus on how the variation of the Lorentz factor of the injected matter influences the general jet dynamics. We visualize the 3D data, and also realize radio mappings, to compare our results with observations. For our study we use a relativistic hydrodynamic model assuming a baryonic jet. We solve the Euler equations in special relativity with a closure relation using a relativistic effective polytropic index. Our 3D simulations use an adaptive mesh refinement scheme [1]. We use parameters extracted from observations to impose thermodynamical conditions of the ISM and jet proper, i.e. period and angle of precession, bulk velocity and opening angle of the jet. Knowing the kinetic luminosity of the jet, we can estimate the ISM/jet density contrast, which varies with the adopted jet Lorentz factor. We then see how this affects its ISM interaction, by tracking the kinetic and thermal energy content, of the various ISM and jet regions. We follow and adjust the approach adopted in recent axisymmetric simulations [2] using a combination of tracers and local properties of the impacted medium. Our simulation follows simultaneously the evolution of the population of electrons which are accelerated by the jet. The evolving spectrum of these electrons, together with an assumed equipartition between dynamic and magnetic pressure, gives input for estimating the radio emission from our simulation. Ray tracing according to a direction of sight then realizes radio mappings of our data, which we can compare to VLA observations of SS433.

[1] R. Keppens et al., JCP 231, 718 (2012)
[2] R. Monceau-Baroux, R. Keppens & Z. Meliani, A&A 545, A62 (2012)

Hydrodynamic simulation of GRB afterglow

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We will present numerical investigation of the various evolutionary phases in the interaction of a relativistic shell with its surrounding cold interstellar medium (ISM). We do this for both 1D isotropic and full 2D jet-like fireball models. This is relevant for gamma-ray bursts (GRBs), and we demonstrate that, thanks to the AMR strategy, we resolve the internal structure of the shocked shell-ISM matter, which will leave its imprint on the GRB afterglow. We determine the deceleration from an initial Lorentz factor $\gamma = 100$ up to the almost Newtonian phase of the flow. We will discuss as well the 2D effect on the relativistic shell propagation.

Gamma-ray emision from binaries

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Several binaries are now established sources of high and very energy gamma-rays. A new class has been identified, gamma-ray binaries, with the particularity that most of their luminosity is emitted beyond 1 MeV. Other types of binaries detected in gamma-rays include microquasars, novae, colliding wind binaries. I'll discuss the origin of the gamma-ray emission in those systems. I'll describe how we try to model the orbital modulations that we observe, including in gamma-rays, emphasising the need to connect with relativistic (M)HD simulations. I'll explain how these binaries provide new information on pulsar physics, accretion- ejection and particle acceleration.

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