ASTRONUM 2011

6th INTERNATIONAL CONFERENCE ON NUMERICAL MODELING OF SPACE PLASMA FLOWS

JUNE 13-17, 2011 - VALENCIA, SPAIN

BOOK OF ABSTRACTS

Author: Daniela Alic

Title: Novel techniques in the numerical modeling of relativistic astrophysical plasmas.

Abstract: The study of black holes dynamics in an ambient magnetic field is important for a variety of astrophysical phenomena. In this talk, I will present novel approaches in the numerical simulations of the force-free approximation for tenuous plasma. These techniques are inspired from the treatment of the current and related stiff terms in a relativistic resistive MHD approach. As a direct application, I will show results obtained from a numerical study of the Blandford-Znajek mechanism, in which the electromagnetic field extracts energy from an orbiting black hole binary and leads to emission along jets.

Author: Miguel Angel Aloy

Title: Powering short GRBs by mergers of moderately magnetized neutron star merger.

Abstract: We explore the implications of the process of formation of low-density funnels of magnetized plasma during the process of merger of two neutron stars with initially low magnetization. In particular, we consider the impact on the production of short gamma-ray bursts that such funnels may probably have. The formation of the aforementioned structures has been considered as a necessary condition to boost ultrarelativistic jets after the formation of a hyperaccreting black hole system. We will conclude that the fact that low-density channels are naturally formed from rather generic initial merger conditions suggests that the formation of ultrarelativistic jets can be a genuine feature of mergers of magnetized neutron stars.

Author: Takanobu Amano

Title: Kinetic and self-consistent numerical modeling of the terrestrial inner magnetosphere

Abstract: A new kinetic and self-consistent numerical model for energetic (1-300 keV) ring-current particles in the terrestrial inner magnetosphere is presented. We have derived a closed set of nonlinear equations that incorporates the self-consistent coupling between the electromagnetic field and ring-current particles whose dynamics are approximated by their guiding-centers. A new numerical simulation code for solving a reduced Vlasov equation in five-dimensions as well as Maxwell equations is developed. We demonstrate that the present model is capable of describing the propagation of magnetohydrodynamic (MHD) waves as well as the kinetic transport of ring-current particles, both of which are essential for realistic inner magnetospheric modeling.

Author: Tahar Amari

Title: Reconstructing algorithms for the solar coronal magnetic field

Abstract: The low solar corona is dominated by the magnetic field which is created inside the sun by a dynamo process and then emerges into the atmosphere. This magnetic field plays an important role in most structures and phenomena observed at various wavelengths such as prominences, small and large scale eruptive events, and continuous heating of the plasma, and therefore it is important to understand its three-dimensional properties in order to elaborate efficient theoretical models. Unfortunately, the magnetic field is difficult to measure locally in the hot and tenuous corona. But this can be done at the level of the cooler and denser photosphere, and several instruments with high resolution vector magnetographs are currently available (THEMIS, Imaging Vector Magnetograph (IVM), the Advanced Stokes Polarimeter (ASP)), SOLIS, HINODE , Solar Dynamics Observatory (SDO), or will be shortly available and future programmed missions such as , SOLAR-ORBITER. This has lead solar physicists to develop an approach which consists in *reconstructing* the coronal magnetic field from boundary data given on the photosphere. We will present our recent progress and results to solve this problem at the scale of active region or larger ones such as full sun scale.

Author: Edouard Audit

Title: A numerical model for multigroup radiation hydrodynamics

Abstract: We present a multigroup model for radiation hydrodynamics to account for variations of the gas opacity as a function of frequency. The entropy closure model (M_1) is applied to multigroup radiation transfer in a radiation hydrodynamics code. In difference from the previous grey model, we are able to reproduce the crucial effects of frequency-variable gas opacities, a situation omnipresent in physics and astrophysics. We also account for the energy exchange between neighbouring groups which is important in flows with strong velocity divergence. These terms were computed using a finite volume method in the frequency domain. We first present test of the radiative transfer aspect of the method, its global consistency (reversion to grey model) and comparaison against a well established kinetic model. We then present the coupling of the multigroup radiative transfer to the hydrodynamics through a second series of tests. Finally, the model was linked to a database of opacities for a Xe gas in order to simulate realistic multigroup radiative shocks in Xe. The differences with the previous grey models are discussed.

Author: Dmitry Bisikalo

Title: Gaseous flows in the inner part of the circum-binary disk of the T Tauri star.

Abstract: We present results of 2D and 3D numerical simulations of the matter flow in the circum-binary disk of a binary T Tauri star. It is shown that two bow shocks caused by the supersonic motion of the binary components in the gas of the disk are formed in the system having parameters typical for T Tauri stars. These bow shocks significantly change the flow pattern. In particular, the shocks lead to re-distribution of the angular momentum in the system. In the inner region of the system the velocity distribution is far from the Keplerian one and the flow structure is mainly governed by the bow shocks. Presence of the stationary bow shocks leads to formation of a gap, rarefied region in the circum-binary disk having a radius $\sim 3A$ for systems with the zero eccentricity and $\sim 3.2A$ for systems with the larger eccentricity. We also show that the redistribution of the angular momentum due to the bow shocks leads to occurrence of two matter flows propagating from the inner edge of the circum-binary disk to the components. Further redistribution of this matter between the components is discussed.

Author: Stanislav Boldyrev

Title: Universal scaling laws in magnetohydrodynamic turbulence.

Abstract: Solar wind turbulence is often studied in the framework of magnetohydrodynamics (MHD). Based on phenomenological modeling and numerical simulations, we consider universal scaling laws that exist in strong incompressible MHD turbulence. We address second-order correlation functions such as the energy spectrum and cross helicity, and discuss to what extent the results of numerical simulations of MHD turbulence can be used to fit observational data.

Author: Joerg Buechner

Title: Large-scale fluid-based and kinetic simulations of Solar Plasmas.

Abstract: Solar plasmas are rich in their structure and dynamics - nowadays well observed by ground based and space telescopes. Due to their complex structure and inhomogneity, however, their description and theoretical investigation requires numerical simulations which bridge over many orders of magnitude of spatial and temporal scales. We report about current approaches addressing the multiscale nature of solar magnetic reconnection processes.

Author: Blakesley Burkhart

Title: Bridging the Gap: Connecting ISM Turbulence Theory and Observations.

Abstract: MHD Turbulence is a critical component of the current paradigms of star formation, particle transport, magnetic reconnection and evolution of the ISM. Progress on this difficult subject is made via numerical simulations and observational studies. However, due to limitations of resolution, scale discrepancies, and complexity of the observations, the best approach for connecting numerics to observations is not always obvious. I will advocate for an approach that invokes the synergetic use of statistical techniques to understand the underlying physics of turbulent astrophysic

Author: Jonathan Carroll-Nellenback

Title: Seeing to the Forrest: AstroBEAR 2.0, Distributed Trees, Multi-level Updates & a Highly Parallelized AMR Multiphysics Code.

Abstract: In my talk I will discuss new results in the development of AstroBEAR, a highly parallelized, patch based, AMR MHD code with support for self-gravity, diffusion, and several heating and cooling source terms. AstroBEAR conserves mass, momemtum, and energy across all AMR boundaries and uses constrained transport to conserve magnetic divergence. AstroBEAR's elliptic and parabolic solvers utilize the highly parallel hypre library developed at LLNL, and the hyperbolic solver implements an unsplit CTU+CT Gudonov scheme (Gardiner and Stone 2008)

Author: Gwangson Choe

Title: Interactive Evolution of a Transiently Enhanced Ring Current and the Earth's Magnetosphere.

Abstract: The dynamical evolution of the Earth's magnetosphere loaded with a transiently enhanced ring current is investigated by numerical magnetohydrodynamic simulation. Two cases with different values of the initial ring current are considered. In one case, the initial ring current is strong enough to create a magnetic island in the magnetosphere. The magnetic island readily reconnects with the earth-connected ambient field and is destroyed as the system approaches a steady equilibrium. In the other case, the initial ring current is not so strong, and the initial magnetic field configuration bears no magnetic island, but a wake of bent field lines, which is smoothed out through the relaxing evolution of the magnetosphere. The relaxation time of the magnetosphere is found to be about five to six minutes, over which the ring current is reduced to about a quarter of its initial value. Before reaching a steady state, the magnetosphere is found to undergo an overshooting expansion and a subsequent

contraction. Fast and slow magnetosonic waves are identified to play an important role in the relaxation toward equilibrium.

Author: Andrew Cunningham

Title: Isothermal Magnetized Bondi Accretion

Abstract: We have carried out a numerical study of the effect of large scale magnetic fields on the steady state rate of accretion from an isothermal gas onto a resistive point mass. The simulations for this study use very general and simple initial conditions and avoid complications arising from boundary conditions by keeping the boundaries far from the accreting object. Our simulations leverage the adaptive refinement methodology to attain high spatial fidelity close to the accreting object. Our results are particularly relevant to the problem of star formation from magnetized molecular cloud where thermal energy radiated away on timescales much shorter than the dynamical time for accretion. Our simulations show convergence toward finite accretion rate with vanishing accreting object radius regardless of magnetic field strength. We find that large scale magnetic fields reduce the accretion rate by 30% to 98% over a range of magnetic field strengths thought to be relevant to star formation.

Author: Lars Kristen Selberg Daldorff

Title: Fourier VlasovMaxwell solver in four-dimensional phase space

Abstract: We present an algorithm for solving the time-dependent Vlasov-Maxwell system of equations in the four-dimensional phase space (two spatial and two velocity dimensions) using a Fourier method in velocity space. One Vlasov equation is solved for each particle species, from which the charge and current densities are calculated as sources for the Maxwell equations. The code has been parallelized by means of domain decomposition and the transpose method. We present a case study where the code has been used for investigating the excitation of a forced low frequency ion wave mode that does not obey any linear sound dispersion relation, but is driven by the nonlinear interaction with an electron beam.

Author: Luca del Zanna

Title: Parametric decay of Alfven waves: on the role of solar wind expansion

Abstract: Nonlinear wave-wave interactions of large-amplitude Alfven waves with compressible modes, in particular parametric decay, are likely to be important in determining the radial evolution of the normalized cross helicity, as observed in the fast solar wind. In this talk I will review both MHD and hybrid numerical simulations performed by the group in

Florence and I will present preliminary results obtained with the so-called Expanding Box Model, a technique to take into account the effects of the solar wind expansion while retaining Cartesian geometry and periodic boundary conditions. The results show that the expansion can strongly modify the properties of the decay, depending on the competition between the relative timescales.

Author: Turlough Downes

Title: Multifluid magnetohydrodynamic turbulence in weakly ionised astrophysical plasmas

Abstract: Many astrophysical plasmas, such as molecular clouds and accretion disks around young stellar objects, are weakly ionised and are threaded by dynamically significant magnetic fields. Such systems inevitably display behaviour which can not be modelled adequately by ideal magnetohydrodynamics (MHD), at least on length scales below some threshold. In this talk we present the results of recent studies of fully multifluid MHD turbulence performed using the HYDRA code and we discuss the influence of each of ambipolar diffusion and the Hall effect on the properties of this turbulence.

Author: Michael Dumbser

Title: Very High Order PNPM Schemes on Unstructured Meshes for Classical and Relativistic MHD Equations

Abstract: In this talk we present a new unified approach of general P_NP_M schemes on unstructured meshes in two and three space dimensions for the solution of classical and relativistic MHD equations. The new P_NP_M approach uses piecewise polynomials u_h of degree N to represent the data in each cell. For the computation of fluxes and source terms, another set of piecewise polynomials w_h of degree $M \geq N$ is used, which is computed from the underlying polynomials u_h using a reconstruction or recovery operator. The P_NP_M method contains classical high order finite volume schemes ($N = 0$) and high order discontinuous Galerkin (DG) finite element methods ($N = M$) just as two particular special cases of a more general class of numerical schemes. Our method also uses a novel high order accurate one–step time discretization, based on a local space–time discontinuous Galerkin predictor, which is also able to solve PDE with stiff source terms. We show that our method is asymptotic preserving for a linear model system. We will show applications of our new approach to the ideal classical MHD equations as well as its extension to viscous and resistive classical MHD equations. Since our numerical schemes are also able to deal with stiff source terms, we also show some recent applications to the resistive relativistic MHD equations.

Author: Sergey Dyadechkin

Title: Introduction of curvilinear coordinates in FMI HYB hybrid model

Abstract: Hybrid approach treats ions as the particles and electrons as a massless, charge neutralizing fluid. Such an approach is very useful to study the cosmic plasma interaction with non-magnetized and magnetized planetary object than the effect of ionsf́inite gyroradius is significant. The HYB hybrid model has been developed at the Finnish Meteorological Institute (FMI) over ten years and has been used successfully to describe how the flowing plasma interacts with various solar system bodies: Mercury, Venus, the Moon, Mars, Saturnian moon Titan and asteroids.

However, one limitation factor of the HYB model is that it assumes cube shaped grid cells. Taking into account that planetary worlds are not Cartesian, developing a curvilinear (spherical and cylindrical) coordinate version of the model would allow a more precise representation of the real situation. Important advantages of curvilinear grid compared with a Cartesian grid, are: 1) A better grid resolution, because the grid size decreases automatically near the obstacle (the planetary surface) and 2) Natural boundary conditions for the obstacle, because the planetary surface overlaps r-constant surface of the grid.

We represent the recent achievements in the curvilinear grid development project and illustrate the usage of the new model by example test runs. The final aim of the project is to get 3D curvilinear Hybrid code, which can be implemented to the different branches of plasma physics: planetary physics, solar physics, astrophysics.

Author: Samuel Falle

Title: Comparison between AMR and SPH

Abstract: The most widely used computational methods for astrophysical fluid dynamics are SPH (Smoothed Particle Hydrodynamics) and grid codes using AMR (Adaptive Mesh Refinement). The relative merits of these methods have been hotly disputed for a number of years, but in the end the only way to settle this is to compare them for a range of problems for which one has a good idea of the correct solution. I will discuss comparisons between the SPH code, SEREN, and the Godunov-type AMR code, MG for a number of test problems, such as Kelvin-Helmholtz, radiative shocks, moving polytropes and a simple model of the Santa Barbara cluster formation problem.

Author: Vladimir Florinski

Title: Heliospheric modeling on geodesic grids

Abstract: We report a new model of the global heliosphere based on a hexagonal geodesic grid. The model is designed to simulate a flow of partially ionized plasmas in the solar system and beyond. The geodesic grid, produced by a recursive subdivision of an icosahedron, is free from polar singularities inherent in spherical polar grids. This property makes the model more efficient to study the transport and acceleration of cosmic rays in the global heliosphere. The code employs a Lagrange multiplier method to control the divergence of the magnetic field. Representative solutions and magnetic field topologies relevant to cosmic-ray transport are demonstrated.

Author: José A. Font

Title: Numerical relativity simulations of the Papaloizou-Pringle instability in black hole-torus systems.

Abstract: Astrophysical systems formed by a black hole surrounded by a thick accretion disk or torus are promising candidates for the central engine of gamma-ray bursts (GRBs), and also possible outcomes of the collapse of supermassive stars to supermassive black holes (SMBHs). In this talk we discuss recent results of three-dimensional numerical simulations in full general relativity of such type of systems where it is shown that an $m = 1$ nonaxisymmetric Papaloizou-Pringle instability grows for a wide range of self-gravitating tori orbiting black holes. Our simulations provide for the first time gravitational waveforms for the growth and nonlinear saturation of the Papaloizou-Pringle instability along with detectability estimates. In particular, it is found that the resulting nonaxisymmetric structure in the torus persists for a timescale much longer than the dynamical one, becoming a strong emitter of large amplitude, quasiperiodic gravitational waves. Our results indica! te that both, the central engine of GRBs and newly formed SMBHs, can be strong gravitational wave sources observable by forthcoming ground-based and spacecraft detectors. If such signals were eventually detected, there would be a solid confirmation about the nature of the mechanism responsible for gamma-ray bursts.

Author: Xueshang Feng

Title: Recent Progress and Future Avenue of 3D Solar Storm Modeling by SIP-CESE-MHD Model

Abstract: The objective of this talk is to present new extensions of our Solar-Interplanetary space-time conservation element and solution element (CESE) model (SIP-CESE MHD model) (Feng et al., ApJ, 2007) to adaptive mesh refinement (AMR) implementation under six-component grid system (Feng et al., ApJ, 2010). By transforming the governing MHD equations from the physical space (x, y, z) to the computational space () while retaining the form of conservation (Jiang, Feng, Solar Physics, 2010), the SIP-AMR-CESE MHD model is implemented in the reference coordinates by utilizing the parallel AMR package PARAMESH. Meanwhile, here is also included the volumetric heating source terms derived from the topology of the magnetic field expansion factor and the minimum angular separation (at the photosphere) between an open field foot point and its nearest coronal hole boundary. In this paper, we present the preliminary results of applying the SIP-AMR-CESE MHD model for modeling the! solar wind background of different solar activity phases by comparison with SOHO observations and other spacecraft data from OMNI. Our numerical results show overall good agreements in the solar corona and in interplanetary space with these multiple spacecraft observations.

Author: Sebastien Galtier

Title: MHD turbulence and the solar wind

Abstract: The solar wind has been widely analyzed during the last 40 years and one of the major conclusions is that it is a highly turbulent medium with fluctuations of the density, magnetic and velocity fields over a broad range of frequencies; these fluctuations possess many properties expected of fully developed MHD turbulence. For that reasons the interplanetary medium is seen as a unique laboratory for investigating several fundamental questions on turbulence. In this talk I will discuss about some of these questions which are: the role of anisotropy, dispersive and compressible effects on MHD turbulence. I will use both analytical and numerical simulations to illustrate my presentation.

Author: Urs Ganse

Title: Numerical challenges in kinetic simulations of three-wave interactions

Abstract: Generation of radio bursts in CME foreshock regions and turbulent cascades in the solar wind are assumed to be results of three-wave interaction processes of dispersive plasma modes. Using our Particle in Cell code ACRONYM, we have studied the behaviour of kinetic wavemodes in the presence of beamed electron populations, with a focus on type II radio burst emission processes. We will discuss the numerical challenges in generating and analyzing self-consistently evolving wave coupling processes with a PiC-Code, and present preliminary results of said project.

Author: Kai Germaschewski

Title: Extending global magnetosphere simulations beyond MHD

Abstract: The global magnetosphere model OpenGGCM has recently been enhanced to include the Hall term in a generalized Ohmś Law and take advantage of heterogeneous processor architectures. We will present a study of magnetic reconnection at the dayside magnetopause in the transition from resistive to Hall-dominated reconnection, and investigate the impact on occurrence of flux transfer events.

Global modeling provides important insight on the dynamics of Earthś geospace environment as a whole, however it is important to realize that fluid models are limited in the kinetic features they capture. While for the foreseeable future global kinetic simulations will remain computationally far out of reach, kinetic models hold promise to enhance our understanding of local physics that can be use to enhance to global models. In the second part of the presentation, we will introduce computational features of a new particle-in-cell code, PSC, including a new approach to solve the load balancing problem on massively parallel machines and use of GPU technology to accelerate the particle advance.

Author: Bruno Giacomazzo

Title: Magnetized Binary Neutron Star Mergers

Abstract: Binary neutron stars (BNSs) are among the most powerful sources of gravitational waves that will be detected by ground-based interferometers, such as advanced Virgo and LIGO, and they are also thought to be behind the central engine of short gamma-ray bursts. Since BNSs are often magnetized it is necessary to solve the full set of general relativistic magnetohydrodynamic (GRMHD) equations in order to accurately follow the last stages of inspiral, merger and the eventual formation of a black hole surrounded by a torus of magnetized matter. I will report on some recent results obtained using our fully GRMHD

code Whisky in simulating the merger of magnetized equal-mass binary neutron star systems. I will in particular describe how magnetic fields can affect the gravitational wave signal emitted by these sources and their possible role in powering short gamma-ray bursts.

Author: Melvyn Goldstein

Title: Nonlinear interactions of Alfvnic fluctuations in a spherically expanding solar wind

Abstract: Using our spherical global three-dimensional MHD code, we have performed time-dependent simulations to investigate the evolution of large amplitude Alfvn waves as they enter the solar wind from the solar corona and evolve in an expanding solar wind. The motivation is to study turbulent dynamics in the solar wind from about 0.2 R to 1.5 AU. The initial condition is a steady state, self- consistent solution of the MHD equations that fills the simulation domain. Alfvnic wave packets with varying perpendicular scales are introduced on the surface of the inner boundary. The simulation shows significant latitude-dependent evolution of the initial fluctuations that appears to be driven, in part, by proximity to the heliospheric current sheet and the velocity gradients between fast and slow wind. In addition, we investigate how the non-linear interactions between the fluctuations affect the two-dimensional power spectra and correlation functions.

Author: Tomoyuki Hanawa

Title: Dynamical Stability of Galactic Shocks

Abstract: We discuss both physical and numerical instabilities of galactic shocks. First we show a two-dimensional hydrodynamical simulation of a one-dimensional stationary flow with a standing shock as an example of the numerical instability. Although the flow is proven to be stable analytically, the shock front and the post-shocked flow are strongly perturbed in the numerical simulation even when the pre-shocked flow is unperturbed. The model flow is isothermal and should be vorticity free if the initial flow is so. However, significant amount of the vorticity is produced at the shock front in the numerical simulation. The instability is more serious, when the shock is stronger. This numerical instability is similar to the wiggle instability which appears in recent numerical simulations of galactic shocks. It is proved that an isothermal one-dimensional flow with a standing shock is unstable when the post-shocked flow is accelerated. We discuss the possibility that the classical Fujimoto-Roberts solution of the Galactic shock is unstable since the post-shocked flow is accelerated in their solution. We also discuss the cure for the the numerical instability.

Author: Carlos Hidalgo

Title: Influence of 3D physics on plasma rotation and transport in fusion plasmas

Abstract: Scenario development in fusion devices, important for ITER to reach the foreseen plasma performance, depends on multi-scale transport phenomena that are far from being fully understood. In particular, the magnitude of radial transport in magnetic confinement devices for controlled nuclear fusion suffers spontaneous bifurcations when specific system parameter values are exceeded. The mechanism governing the development of this bifurcation is still one of the main scientific conundrums facing the magnetic fusion community after more than twenty years of intense research. Furthermore, toroidal field ripple and the application of magnetic perturbations break the axi-symmetry of fusion plasmas thereby modifying plasma properties. These have to be determined in order to be able to access the power loadings on material surfaces in future fusion devices such as ITER. This paper deals with the physics of plasma rotation and transport in fusion plasmas showing the importance of both mean and fluctuating radial electric fields, the detection of long-range correlations consistent with the theory of zonal flows, and the role of magnetic topology. These findings are in line with the expectation that multi-scale interactions are a crucial ingredient of complex dynamics in many non-equilibrium systems.

Author: Gregory Howes

Title: Gyrokinetic Simulations of Solar Wind Turbulence

Abstract: Although turbulence in the solar wind has been studied for more than four decades, only recently has the "dissipation range" of solar wind turbulence become a focus of the heliospheric physics community. To explore the physical mechanisms responsible for the dissipation of the turbulent fluctuations in the nearly collisionless solar wind, one must abandon fluid approaches to modeling the turbulence and adopt a kinetic description. For some time, there has been significant effort focused on employing a gyrokinetic formalism to study the dissipation of turbulence in the solar wind, taking advantage of sophisticated numerical techniques developed for use in the fusion community. Here I will report on some of the most recent successes of this effort, in particular the first three-dimensional, nonlinear gyrokinetic simulation of plasma turbulence resolving scales from the ion to electron gyroradius with a realistic mass ratio, where all damping is provided by resolved physical mechanisms. The resulting energy spectra are quantitatively consistent with a magnetic power spectrum scaling of -2.8 as observed using in situ spacecraft measurements of the dissipation range. The collisional ion heating is measured at sub-ion-Larmor radius scales, which provides the first evidence of the ion entropy cascade in an electromagnetic turbulence simulation.

Author: Vladislav Izmodenov

Title: Modeling of partly ionized non-equilibrium solar wind/LISM plasma interactions

Abstract: We present first results of a 3D kinetic-MHD numerical model of the solar wind interaction with the local interstellar medium which has been recently advanced by taking into account non-equilibrium local behavior of the velocity distribution function of the charged particles. In this model, all charged particles are divided into several co-moving types. The coldest type, with parameters typical of original solar wind protons, is considered in the framework of fluid approximation. The hot pickup proton components created from interstellar H atoms and heliospheric ENAs by charge exchange, electron impact ionization and photoionization are treated kinetically. The charged components are considered self-consistently with interstellar H atoms, which are described kinetically as well. To solve the kinetic equation for H atoms we use the Monte Carlo method with splitting of trajectories. Solar and interstellar magnetic fields are taken into account in the model.

Author: Pekka Janhunen

Title: New PIC simulation results of solar wind electric sail

Abstract: The solar wind electric sail (electric sail, E-sail) is a new and potentially revolutionarily efficient method of interplanetary propulsion. The E-sail taps the momentum flux of the solar wind with the help of long, thin, highly positively charged and centrifugally stretched tethers. The technical development of the E-sail is proceeding well and two CubeSat missions ESTCube-1 and Aalto-1 are under construction. They are to be launched in late 2012 and 2013, respectively.

According to estimations, a full-scale E-sail could weigh about 100 kg and produce 1 N thrust at 1 AU. The thrust would scale as 1/r where r is the distance from the sun and the thrust direction could be vectored by about 30 degrees away from radial by inclining the sail. In a multi-asteroid touring mission, for example, such an E-sail would produce 300 MNs total impulse over a 10-year mission which would be equivalent of burning 100 tonnes of chemical propellant. In such or equivalent mission, then, the E-sail would be 100-1000 times more efficient than the present state of the art methods i.e. chemical rockets and ion engines.

The elementary process of the E-sail is the interaction of the solar wind plasma stream (typically 1-100 cm-3 fully ionised proton plasma flowing at 300-800 km/s) with a thin tether biased to 20-40 kV. We have used a new parallelised electrostatic PIC code to compute the behaviour of the solar wind around the tether and to predict the thrust per unit length of the tether in average solar wind at 1 AU. Here we will present these new results and discuss the challenges involved in reaching accurate thrust estimation by time-dependent explicit PIC simulation.

Author: Yanfei Jiang

Title: A new 3D radiation MHD code - beyond diffusion approximation

Abstract: We have developed a novel numerical method to integrate the equations of radiation magnetohydrodynamics in 3D using Athena. This method solves the radiation moment equations in the mixed frame, without invoking any diffusion-like approximations. The moment equations are closed using a variable Eddington tensor whose components are calculated from a formal solution of the transfer equation using the method of short characteristics. The method is valid over a wide range of regimes, including both optically thick and thin flows, and ratios of the radiation and gas pressure from 10^{-4} to 10^{4}. We present results from an extensive test suite that includes convergence of radiation modified acoustic waves in all parameter regimes, radiating shock tests up to Mach numbers that produce radiation pressure dominated postshock flows, and the evolution of shear layers due to radiation viscosity. We present some preliminary applications of the method to the Rayleigh-Taylor instability in a radiation-supported atmosphere, and the photon bubble instability in accretion disks. We use the results of our tests and applications to gauge the accuracy of flux-limited diffusion, especially in optically thin flows.

Author: Hyesung Kang

Title: Nonthermal Radiation from Weak Cosmological Shocks

Abstract: Shock waves form in the intergalactic medium as a consequence of accretion, merger, and turbulent motion during the structure formation of the universe. They not only heat baryonic gas but also govern non-thermal processes through the acceleration of cosmic rays (CRs), production of magnetic fields, and generation of vorticity. Suprathermal particles are known to be produced as an inevitable consequence of the formation of collisionless shocks in tenuous plasmas and they can be further accelerated to become CRs via diffusive shock acceleration (DSA). The presence of nonthermal particles, especially electrons, in clusters of galaxies, has been inferred from observations of synchrotron emission from diffuse radio halos and relics. We have calculated the emissions from CR electrons accelerated at weak plane shocks with quasi-parallel magnetic fields, using time-dependent DSA simulations, including energy losses via synchrotron emission and Inverse Compton scattering. Observational implications of these calculations will be discussed.

Author: Homa Karimabadi

Title: Recent Advances in Kinetic Simulations and Analysis Techniques

Abstract: We present our latest advances in kinetic plasma simulations and the strategies that we have developed, including data mining and computer vision algorithms, to extract physics from the resulting massive data sets. The simulations have led to a number of breakthrough results in the areas of magnetic reconnection, flux rope interactions, particle acceleration, and magnetospheric physics. We will show highlights of our research in these areas.

Author: Rony Keppens

Title: Dusty circumstellar environments: numerical simulations with MPI-AMRVAC

Abstract: I will highlight the latest results obtained on multi-dimensional modeling of circumstellar environments, where stellar outflows interact mutually or with the surrounding interstellar environment. We first present findings in pure gas dynamic scenarios, where optically thin radiative losses combined with supersonic outflows cause complex instability dominated circumstellar bubbles. We comment on single star, as well as on binary system scenarios. In the latter, we study the morphology of the collision front between the stellar winds of binary components in long period binary systems, where distinctly different instabilities manifest themselves on the leading versus the trailing parts of the collision front (with respect to the orbital motion). We conclude with presenting interaction scenarios for dust-loaded stellar outflows, specifically for moving red giant stars. This includes a detailed treatment for dust grains in the stellar wind, accounting for drag forces between dust and gas. Our simulations allow to deduce how dust grains of varying sizes become distributed throughout the circumstellar medium. All results were obtained using the highly parallel, flexible MPI-AMRVAC code, able to handle Newtonian to relativistic gas dynamic scenarios, up to mag- netized plasmas. Therefore, the code has been extended by coupling the hydro and magnetohydrodynamic modules to (possibly multiple) pressureless dust species. Algorithmic strategies will be discussed, applicable to these and similar parallel, grid-adaptive numerical simulations.

Author: Woong-Tae Kim

Title: Gas Dynamics in Central Regions of Barred Galaxies: Two-Dimensional Hydrodynamic Simulations

Abstract: The inner parts of barred galaxies contain substructures such as off-axis shocks, nuclear rings, and nuclear spirals, which may affect nuclear star formation and activities of central black holes (BHs) by controlling the mass inflow rate. We investigate the formation of such substructures and mass inflows using high-resolution, grid-based hydrodynamic simulations. The gaseous medium is assumed to be infinitesimally-thin, isothermal, and non-self-gravitating. To explore various galactic environments, we vary the gas sound speed as well as the BH mass. In a quasi-steady state, nuclear rings shrink in size as the sound speed increases, while become independent of the BH mass, suggesting that ring position is not determined by the Lindblad resonances. Nuclear spirals persist only when either the sound speed is small or the BH is very massive. While the mass inflow rate toward the galaxy center in models with low sound speed is quite small because of the presence of narrow nuclear rings, it becomes large enough to power a central BH in Seyfert galaxies. We present the detailed properties of the bar substructures and discuss their astronomical implications.

Author: Kenta Kiuchi

Title: Gravitational waves and neutrino emission from the merger of binary neutron stars

Abstract: Numerical simulations for the merger of binary neutron stars are performed in the framework of full general relativity incorporating a finite-temperature (Shenś) equation of state and neutrino cooling for the first time. It is found that for this stiff equation of state, a hyper massive neutron star (HMNS) with a long lifetime ($\gg$10 ms) is the outcome of the total mass $\leq 3.0\ M_{\odot}$. It is also shown that the typical total neutrino luminosity of the HMNS is $4 - 6 \times 10^{53}$ ergs/s and the effective amplitude of gravitational waves from the HMNS is $4 - 6 \times 10^{-22}$ at $f = 2.2 - 2.5$ kHz for a source distance of 100 Mpc. We also present the neutrino luminosity curve when a black hole is formed for the first time.

Author: Richard Klein

Title: Radiation Hydrodynamic AMR Simulations of High Mass Star Formation: The Effects of Feedback in Cores to Clusters

Abstract: The formation of massive stars remains one of the most significant unsolved problems in astrophysics, with implications for the formation of the elements and the structure and evolution of galaxies. It is these stars, with masses greater than 8-10 solar masses, that eventually explode as supernovae and produce most of the heavy elements in the universe,

dominate the energy injection into the interstellar medium of galaxies and by injecting both heavy elements and energy into the surrounding medium, shape the evolution of galaxies. High mass star formation poses a major theoretical challenge: How is it possible to sustain a sufficiently high mass accretion rate into a protostellar core despite the radiation pressure on the accreting envelope? I will first summarize our work on the first 3D simulations of massive star formation that resolve this longstanding problem using our high resolution 3D magneto-radiation-hydrodynamic adaptive mesh refinement code ORION, identifying 2 new mechanisms that efficiently solve the problem of the Eddington barrier to high mass star formation. By including the feedback effects of radiation pressure, protostellar radiation heating and protostellar outflows, I will discuss our work on stellar multiplicity. I will then present the first simulations of the effects of radiation feedback from high mass protostars on the universality of the IMF across a wide range of environments. Finally, I will present the first simulations of the formation of high mass clusters with radiation feedback.

Author: Vladimir Kolobov

Title: Simulations of weakly ionized plasmas with adaptive Cartesian mesh

Abstract: Many problems of plasma physics are characterized by the presence of large gradients of plasma parameters in localized domains (streamers, filaments, ionization fronts, etc). For such problems, the ability to dynamically adapt the mesh resolution to local plasma properties can substantially increase the accuracy and efficiency of simulations. We will describe our new plasma simulation tool with Adaptive Mesh Refinement (AMR) using octree Cartesian mesh. We have already demonstrated our approach for simulation of streamer development with a minimal plasma model (Poisson solver, drift- diffusion electron transport, immobile ions, and local field ionization) [1]. Recently, we developed new capabilities including ion drift, electron energy balance, and simple external circuit [2]. Having added ion transport to the minimal plasma model, we simulated low-pressure discharges controlled by ion drift to the walls. We have illustrated that fluid model with account for electron thermal conductivity can reproduce qualitatively the complicated structure of the cathode region in DC discharges observed in experiments. In particular, the nonmonotonic distribution of the electrostatic potential was formed with two field reversals in the plasma region and a sharp maximum of plasma density in the vicinity of the first field reversal near the cathode sheath. The electron temperature reached a minimum in the Faraday Dark Space, near the second field reversal. Careful examination shows deficiencies of the fluid model, which operates in terms of an average electron and cannot describe the complicated structure of the electron energy distribution function observed in the cathode region. After all, we have shown that fluid plasma models previously developed for the traditional meshing techniques can be extended for the adaptive Cartesian mesh [3]. The new tool has been applied to studies of microplasmas. We simulated dynamics of gas breakdown between two wires of radius 100 nm separated by a 1 μm distance. A voltage of amplitude 0.2-4 kV was applied between

the wires to initiate a pulsed breakdown induced by field emission of electrons from the cathode. The dynamics of gas breakdown were studied using dynamically adaptive Cartesian mesh to resolve the propagation of fast ionization front at different gas pressures above atmospheric. New physics learned by using the new AMR code will be discussed. We will also describe some computational issues including parallel computations with dynamic load balancing among processors.

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Author: Alexei Kritsuk

Title: Comparing Numerical Methods for Isothermal Magnetized Supersonic Turbulence

Abstract: Many astrophysical applications involve magnetized turbulent flows with shock waves. Ab initio star formation simulations require a robust representation of supersonic turbulence in molecular clouds on a wide range of scales imposing stringent demands on the quality of numerical algorithms. We employ simulations of supersonic super-Alfvenic turbulence decay as a benchmark test problem to assess and compare the performance of nine popular astrophysical MHD methods actively used to model star formation. The set of nine codes includes: ENZO, FLASH, KT-MHD, LL-MHD, PLUTO, PPML, RAMSES, STAGGER, and ZEUS. These applications employ a variety of numerical approaches, including both split and unsplit, finite difference and finite volume, divergence preserving and divergence cleaning, a variety of Riemann solvers, a range of spatial reconstruction and time integration techniques. We present a comprehensive set of statistical measures designed to quantify the effects of numerical dissipation in these MHD solvers. We compare power spectra for basic fields to determine the effective spectral bandwidth of the methods and rank them based on their relative effective Reynolds numbers. We also compare numerical dissipation for solenoidal and dilatational velocity components to check for possible impacts of the numerics on small-scale density statistics. Finally, we discuss convergence of various characteristics for the turbulence decay test and impacts of various components of numerical schemes on the accuracy of solutions. The nine codes gave qualitatively the same results, implying that they are all performing reasonably well and are useful for scientific applications. We show that the best performing codes employ a consistently high order of accuracy for spatial reconstruction of the evolved fields, transverse gradient interpolation, conservation law update step, and Lorentz force computation. The best results are achieved with divergence-free evolution of the magnetic field using the constrained transport method, and using little to no explicit artificial viscosity. Codes which fall short in one or more of these areas are still useful, but they must compensate higher numerical dissipation with higher numerical resolution. This paper is the largest, most comprehensive MHD code comparison

on an application-like test problem to date. We hope this work will help developers improve their numerical algorithms while helping users to make informed choices in picking optimal applications for their specific astrophysical problems.

Author: Harald Kucharek

Title: Hybrid Simulations for the Evolution of Ion Distributions and the Associated ENA Production at the Termination Shock

Abstract: Since launch in 2008 the interstellar Boundary Explorer IBEX provided several sets of sky maps in the light of Energetic Neutral Atoms ENAs. All of these maps include a features in the sky which where unexpected and which are not yet understood. The most prominent feature is the so-called Ribbon, which is currently under intensive investigation. ENAs are of interstellar origin, which charge exchange with energetic ions at the Termination Shock (TS) or in the heliosheath. During that process the interstellar neutral exchange its charge with a fast moving ion and this ion becomes a fast moving energetic neutral atom. The energy of the ENA is therefore the original energy of the charged component. The ion distributions at the TS are generated by turbulence and wave particle interaction and vice versa. The efficiency of the ENA production depends on the charge exchange rate and the phase space density. The ENA intensity observed by IBEX at Earths orbit depends on the peak loca! tion of the distribution in phase space. If one assumes that the source of the observed ENAs is localized at the TS most likely on its global shape. Hybrid simulations appear to be a useful tool following ion distributions at the perpendicular shocks and to study their behavior. We performed a number of hybrid simulations using different shock normal angles and investigated the spatial evolution of solar wind protons and pickup ion distributions through the shock under the impact of self-generated turbulence.

Author: Katarzyna Kulpa-Dybel

Title: The effect of supernova rate on magnetic field evolution in barred and ringed galaxies.

Abstract: We present three-dimensional (3D) global numerical simulations of the cosmic ray driven dynamo in barred and ringed galaxies. We study the evolution of the interstellar medium of barred and ringed galaxies in the presence of non-axisymmetric component of the potential, i.e. the bar and/or the oval. The three main components of the interstellar medium, i.e. magnetic field, gas and cosmic rays are dynamically coupled. The magnetohydrodynamical dynamo is driven by cosmic rays, which are continuously supplied to the disk by supernova (SN) remnants. No magnetic field is present at the beginning of simulations but one-tenth of SN explosions is a source of a small-scale randomly oriented dipolar magnetic field, energy of which corresponds to the Crab Nebula total magnetic energy. In all models we assume that 10% of 10^{51}erg SN kinetic energy output is converted into CR

energy, while the thermal energy from SN explosions is neglected. Additionally, to examine the effect of SN frequency on magnetic field amplification we performed several simulations for different SN rates.

The main result is that the cosmic ray driven dynamo can amplify weak magnetic fields up to a few μG within a few Gyr in barred and ringed galaxies. In the case of the fastest amplification the e-folding time is equal to 104Myr and the magnetic field reaches equipartition at time $t \sim 1.8$Gyr. A completely random initial magnetic field evolves into large scale structures. In most models the even (quadrupole-type) configuration of the magnetic field with respect to the galactic plane can be observed. Only in one model the odd (dipole-type) symmetry is obtained.

The modelled magnetic field configuration resembles maps of the polarized intensity observed in barred and ringed galaxies. For instance, magnetic arms between gaseous spiral and the bar are observed in most of the barred galaxy simulations. Only in one model, with very high star formation rate, no magnetic arms can be identified in gaseous arms or in the interarm area. Moreover, magnetic field reversals are visible in barred and ringed galaxies simulations. Depending on the model they can be observed during the whole simulation time or appear from time to time.

Author: Sebastian Lange

Title: MHD turbulence in the heliosphere and diffusion of peaked turbulent modes

Abstract: The understanding of MHD-turbulence within the heliosphere is crucial for the mechanism of charged particle transport. Furthermore the particles also interacts with the MHD-Plasma. This is observed during solar energetic particle events. The highenergetic charged particles from this ejection are streaming through the surrounding plasma, depositing their energy to discrete wavemodes. This will lead to an energy spectrum which follows the typical -5/3 law disturbed by a peak-structure. The question is how this scenario will evolve. Regarding Kolmogorovs thesis the peak will diffuse isotropically, whereas Goldreich and Sridhar predict an anisotropic behaviour distinguished by parallel and perpendicular direction to the magnetic backgroundfield. We will present results of a 3D pseudospectral MHD-code concerning this matter and will discuss mechanisms of paricle transport.

Author: Giuseppe Lanzafame

Title: Semi-Lagrangian implicit integrations in SPH modelling: a model of the accretion disc in a microquasar

Abstract: Current explicit integration techniques in fluid dynamics are deeply limited by the Courant-Friedrich-Lewy condition of the time step progression, based on the adopted spatial resolution coupled with the maximum value between the kinetic velocity or the signal

transmission speed in the computational domain. Eulerian implicit integration techniques, even though more time consuming, can afford to perform stable computational fluid dynamics even if such explicit limitation is very short, paying only the price of a very small inaccuracy in the calculations, without suffering of such a strict (sometimes very strict) temporal limitation. In this paper, we present a simple and effective way to perform Lagrangian Smooth Particle Hydrodynamics (SPH) implicit integrations without any Jacobian matrix inversion operations. Applications to SPH accretion disc simulation around a massive black hole (MBH) in a binary stellar system is shown, together a comparison to the same result obtained according to the traditional explicit integration techniques. Some simple tests in the case of 1D blast waves are also shown.

Author: Giovanni Lapenta

Title: 3D Kinetic modelling of plasma microinstabilities in macroscopic processes

Abstract: The need to handle the coupling between microscopic and macroscopic processes in plasma physics is ubiquitous. The wide difference in mass between electrons and ions and the great change in time and space scales between large-scale magnetohydrodynamic processes and small-scale kinetic effects pose a great challenge to the simulation of plasma physics problems. The traditional approach has been to try to derive reduced models of the full first principle physics model and solve them considering only the scales of interest. We present a different point of view, based on using first principle methods for each scale, relying on coupling different physics approaches for each scale, fluid for the macroscopic and kinetic for the microscopic. The implicit moment model relies on numerical methods that can effectively average the smallest scales within correct kinetic treatment while focusing on large-scale structures. The application of this approach will be presented in light of the new EC funded project SWIFF (swiff.eu) to study new methods for micromacro coupling in space physics. Swiff encompasses 7 centers in 5 european countires and is coordinated by Giovanni Lapenta.

Author: Alex Lazarian

Title: To what extent magnetic fields are frozen in astrophysical fluids?

Abstract: Astrophysical fluids are definitely turbulent and turbulence is known to change many properties of fluids. How about the concept of magnetic fields being nearly perfectly frozen in? Magnetic reconnection induced by turbulence allows efficient diffusion of magnetic field and fluids and makes the strict traditional concept of fields perfectly frozen in plasma only applicable to laminar fluids. Instead, in turbulent fluids reconnection-induced diffusion allows efficient mass and flux transport. I shall discuss the deep relation between magnetic reconnection and turbulence as well as implications of reconnection diffusion both for astrophysics and numerical codes.

Author: Dongwook Lee

Title: Development of a Jacobian-Free Newton-Krylov implicit solver in FLASH

Abstract: We present an ongoing progress to develop efficient high-order numerical algorithms and methodology for simulating stiff systems of differential equations on large scale parallel computer architectures using FLASH, a multiphysics code framework used widely in the astrophysics community. In this presentation, we discuss a fully implicit solver based on a Jacobian-free Newton-Krylov (JFNK) approach with an appropriate preconditioner such as ILU based on an (restrictive) additive Schwartz preconditioner approach. We will also show our preliminary results for advective and diffusive systems using the implicit solver.

Author: Bo Li

Title: Modeling the multi-component solar wind: a few numerical aspects and potential applications to stellar winds

Abstract: Intrinsically multi-dimensional and involving the transition from the collision-dominated to collisionless regime, the solar wind proves challenging to model in a number of numerical aspects. In this talk we present a consistent numerical scheme that efficiently handles the multi-component and multi-dimensional nature of the solar wind, and readily incorporates such effects as wave heating and field-aligned electron heat flux. The scheme conserves the mass, momentum and energy of the system to a high accuracy, allowing a direct comparison of results along flow tubes with one-dimensional computations. We examine the difficulties associated with the introduction of a third species, namely alpha particles, into a proton-electron wind. This difficulty originates from the occurrence of an ion gyro-frequency in a fluid system, and can be readily resolved by adopting an operator-splitting approach whereby this gyro-frequency is treated with the classical Buneman scheme, w! hich is in extensive use in particle simulations. While this is easy to implement and proves satisfactory, we also devised an analytical approach to eliminate this gyro-frequency whereby one can easily investigate such effects as low-frequency toroidal Alfven waves, with solar rotation being the zero-frequency limit, on the solar wind. These latter effects are likely to play a role in the dynamics of radiatively driven winds from late O or early B stars as well.

Author: Shengtai Li

Title: High-Order Divergence-Free AMR Method for MHD Flows

Abstract: We present a higher-order (> 2) divergence-free adaptive mesh refinement (AMR) method for magneto-hydrodynamic simulations. We include two types of time integration. The first one is to use the multi-stage Runge-Kutta method with natural continuous extension (RK-NCE). Using RK-NCE, we can obtain the higher-order intermediate solution for the fine grid if local time step is used for finer block of the grid. The second time integration is to use Lax-Wendroff time integration, which replaces the time derivatives with spatial derivatives. A higher-order divergence-free space-time reconstruction polynomial is used to interpolate the solution at the coarse cells to the fine cells. Several issues at the coarse-fine interface are addressed to preserve the high-order accuracy. Numerical examples are presented to demonstrate the effectiveness of our method.

Author: Richard Lovelace

Title: Numerical Modeling of Jets from Accretion Disks

Abstract: We have carried out axisymmetric and 3D MHD simulations of the formation of astrophysical jets from the disk-magnetosphere boundary of a rotating magnetized star. The jets are found to occur under conditions where the magnetosphere is strongly compressed by the accretion disk. We use a Godunov-type code in spherical and cubed sphere coordinates. Simulations show, that the magnetic flux is strongly compressed at the disk-magnetosphere boundary and matter is ejected into the jet from this boundary driven by the magnetic force. The flow is collimated by the toroidal magnetic field of the jet. We also investigated non-symmetric and one-sided jets which emerge from the disk-magnetospere boundary of magnetospheres which are not symmetric about the equatorial plane. We consider as an example the superposition of dipole and quadrupole field components of different strengths.

Author: Jonathan Mackey

Title: Radiation-MHD simulations of pillars and globules in HII regions

Abstract: The effects of initially uniform magnetic fields on the formation and evolution of dense pillars and cometary globules at the boundaries of HII regions are investigated using 3D radiation-magnetohydrodynamics simulations. It is shown that for weak and medium field strengths an initially perpendicular field is swept into alignment with the pillar during its dynamical evolution, matching magnetic field observations of the "Pillars of Creation" in M16 and also some cometary globules. A strong perpendicular magnetic field remains in its initial configuration and also confines the photoevaporation flow into a bar-shaped dense

ionised ribbon which partially shields the ionisation front and would be readily observable in recombination lines. A simple analytic model is presented to explain the properties of this bright linear structure. These results show that magnetic field strengths in star-forming regions can in principle be significantly constrained by the morphology of structures which form at the borders of HII regions. The parallel scaling of different raytracing/microphysics algorithms is also discussed.

Author: Mordecai-Mark Mac Low

Title: MHD simulations of a supernova-driven ISM and the warm ionized medium using a positivity preserving ideal MHD scheme

Abstract: We present new 3D magnetohydrodynamic (MHD) simulations of a supernova-driven, stratified interstellar medium. These simulations were run using the Waagan et al. (2011) positivity preserving scheme for ideal MHD implemented in the Flash code. The scheme is stable even for the Mach numbers approaching 100 found in this problem. We have previously shown that the density distribution arising from hydrodynamical versions of these simulations creates low-density pathways through which Lyman continuum photons can travel to heights $|z| > 1$ kpc. This naturally produces the warm ionized medium through photoionization due primarily to O stars near the plane. However, our earlier models reproduce the peak but not the width of the observed emission measure distribution. Here, we examine whether inclusion of magnetic fields and a greater vertical extent to the simulation domain produce a gas distribution that better matches the observations. We further study the change of magnetic energy over time in our models, showing that it appears to reach a steady state after a few hundred megayears, presumably supported by a turbulent dynamo driven by the supernova explosions. (The same algorithm was used to show dynamo amplification during the gravitational collapse of a turbulent gas core by Sur et al. 2010 and Federrath et al. 2011.)

This work was partly supported by NASA/SAO grant TM0-11008X and by NSF grant AST-0607512. The software used in this work was in part developed by the DOE NNSA-ASC OASCR Flash Center at the University of Chicago.

Author: Stefano Markidis

Title: Global Particle-in-Cell Simulations of Magnetospheres

Abstract: Kinetic simulations of the magnetosphere formation with implicit moment Particle-in-Cell method are presented. The goals of this work are to overcome the limitations of previous global Particle-in-Cell simulations and enable simulations of interaction of solar wind with magnetized planets with more realistic simulation parameters. The implicit moment Particle-in-Cell method satisfies the CFL condition and it is stable against the finite grid in-

stability on grid spacings larger than the Debye length. Thus, simulations of magnetospheric dynamics are now possible with realistic solar wind velocity to light velocity ratio $v_s w/c$, realistic thermal velocities, and increased ion to electron mass ratio. Moreover, because of the use of realistic $v_s w/c$ and thermal velocity values, the particle dynamics results classical, and the relativistic treatment is not necessary as in other global simulations.

In this talk, the implicit moment Particle-in-Cell method is first reviewed. Its application to the global simulations of magnetospheres, the initial simulation set-up and the boundary conditions are then discussed. Finally, the preliminary results of 2D3V simulations of the Mercurys magnetosphere formation are presented. Simulations are completed with the characteristic values of solar wind at Mercurys aphelion (0.47 AU). The ion to electron mass ratio is 256. Mercurys magnetic moment is scaled down and its radius (RM) is decreased to maintain the real magnetopause stand-off distance. The first results of global simulations are represented in Figures 1 and 2 showing the pseudocolor plots of ion density and the x component of electron current on the x(from the Mercurys center toward the sun)-z(from South to North Mercurys pole) plane.

Author: Yosuke Matsumoto

Title: Multiscale simulations of the Kelvin-Helmholtz instability

Abstract: We have recently shown by 2D MHD simulations of the Kelvin-Helmholtz instability (KHI) in a highly asymmetric density layer in a large simulation domain that rapid formation of a plasma mixing layer can be achieved by forward and inverse energy cascades of the KHI [Matsumoto and Seki, 2010]. The forward cascade is triggered by the growth of the secondary Rayleigh-Taylor instability (RTI) [Matsumoto and Hoshino, 2004, 2006] excited during the nonlinear evolution. The inverse cascade is accomplished by a nonlinear coupling of the fastest growing mode of the KHI and other unstable modes. One of remaining issues, which is not treated accurately in the MHD simulation, is the mixing process itself; the mixing of plasmas is due to the numerical dissipation implicitly or explicitly added in the simulation.

To understand all the mechanisms ranging from the dissipating scale to the scale of the largest vortex in a self-consistent manner, we have carried out 2D fully kinetic particle-in-cell (PIC) simulations of the KHI. We focus on dissipation scales by changing kinetic parameters of the ion-to-electron mass ratio (M/m) and the ratio of the electron plasma to gyro frequencies (wpe/Wge), while the normalized macroscopic parameters (beta, Mach number, etc.) are fixed. As results, we found that the secondary RTI is responsible for a dissipation mechanism in the scale of k*rge 0.6, indicating that the secondary RTI is a kind of the lower-hybrid drift instability[Winske, 1988]. The energy transported down to scales smaller than the ion gyro radius is proportional to $(M/m)^{1.3}$ and $(wpe/Wge)^{2.4}$.

Author: Colin McNally

Title: Phurbas - Adaptive Lagrangian Meshless Magnetohydrodynamics

Abstract: We present Phurbas, an adaptive Lagrangian meshless code for magnetohydrodynamics. Phurbas uses a meshless method with a point-based discretization where the governing equations are solved in the form with Lagrangian (or comoving) derivatives. The algorithm is Lagrangian in the sense that the discretization points move with the fluid and hence the time step is not limited by the Eulerian Courant-Friedrichs-Lewy condition. Local third order least-squares polynomial fits are calculated around each point from the values of neighboring points to provide spatial derivatives. Simulated quantities and point positions are advanced in time with a second order predictor-corrector scheme. Phurbas is spatially adaptive. A target resolution can be specified for each point in space, with points being added and deleted as needed to meet this target. Point addition and deletion is based on a local void and clump detection algorithm. Novel stabilization operators are used to filter high-frequency modes and provide diffusion in shocks. A set of non-adaptive Lagrangian tracer particles may be used to follow fluid elements. Globally conserved quantities are maintained constant by differentially correcting regions of large change. We have parallelized the code by modifying the framework provided by GADGET-2 (Springel 2005). Agreement with a set of standard test problems, including 1e-6 amplitude linear MHD waves, magnetized shock tubes, and Kelvin-Helmholtz instabilities is demonstrated. Finally we demonstrate agreement with analytic predictions of linear growth rates for magnetorotational instability in a cylindrical geometry, as well as following its non-linear development. Our efforts with Phurbas are initially aimed at problems in protoplanetary disks where the novel features of the algorithm are particularly advantageous.

Author: Zakaria Meliani

Title: Two-shell collisions in the GRB afterglow phase

Abstract: Strong optical and radio flares often appear in the afterglow phase of Gamma-Ray Bursts (GRBs). It has been proposed that colliding ultra-relativistic shells can produce these flares. Such consecutive shells can be formed due to the variability in the central source of a GRB. We perform high resolution 1D numerical simulations of late collisions between two ultra-relativistic shells in order to explore these events. We examine the case where a cold uniform shell collides with a self-similar Blandford and McKee shell in a constant density environment and consider cases with different Lorentz factor and energy for the uniform shell. We produce the corresponding on-axis light curves and emission images for the afterglow phase and examine the occurrence of optical and radio flares assuming a spherical explosion and a hard-edged jet scenario. For our simulations we use the Adaptive Mesh Refinement version of the Versatile Advection Code (AMRVAC) coupled to a linear radi! ative transfer code to calculate synchrotron emission. We find steeply rising flare like behavior for small

jet opening angles and more gradual rebrightenings for large opening angles. Synchrotron self-absorption is found to strongly influence the onset and shape of the radio flare.

Author: Andrea Mignone

Title: Adaptive Mesh Computations with the PLUTO code for Astrophysical Fluid Dynamics

Abstract: The PLUTO code for adaptive grid computations of classical and (special) relativistic magnetized flows is illustrated. The current release of the code exploits the distributed infrastructure of the Chombo library for multidimensional parallel computations over block-structured, adaptively refined grids. The adopted formulation relies on a conservative, finite-volume approach where all the primary flow quantities are discretized at the cell-center in a fully dimensionally unsplit way. The current implementation extends the second-order unsplit time stepping scheme to non-ideal dissipative terms including viscosity, resistivity and anisotropic thermal conduction as well as an efficient treatment of point-local, potentially stiff source terms over hirearchical nested grids. The solenoidal condition of magnetic field is enforced by augmenting the MHD/RMHD equations with a generalized Lagrange multiplier (GLM) providing, at the same time, propagation and damping of divergence errors through a mixed hyperbolic/parabolic explicit cleaning step. Efficiency and robustness are shown through multidimensional benchmarks and applications to problems of astrophysical relevance.

Author: Francesco Miniati

Title: Resistive generation of intergalactic magnetic field at cosmic dawn

Abstract: Magnetic fields are truly ubiquitous in cosmic plasmas and various physical processes are likely responsible for their origin. However, recently observed magnetic fields in voids of galaxies with strengths $\geq 10^{-18}$ G or so are a challenge for typical astrophysical mechanisms and processes in the early universe seem the only alternative. In this talk I will present a model in which intergalactic magnetic fields are generated by cosmic-ray particles produced by the first generation of galaxies and stars that are also responsible for reionization of the universe is presented. Such cosmic-ray particles escape from the parent galaxy into the intergalactic medium where they induce return currents. Given the finite resistivity of the intergalactic plasma, an electric field is required to sustain such return currents. It can be shown that under general conditions the electric field is rotational and a magnetic field is generated. I will present numerical simulations of structure formation that include self-consistently the resistive source of magnetic field and show that magnetic fields of order 10^{-17} G can be generated throughout intergalactic space. I will briefly discuss the role Bell instability.

Author: Takashi Minoshima

Title: Multi-Moment Advection scheme for Vlasov simulations

Abstract: We present a new numerical scheme for solving the advection equation and its application to Vlasov simulations. The Vlasov simulation, which directly discretizes the Vlasov equation on grid points in phase space, has been proposed for an alternative method of the Particle-In-Cell (PIC) method. The Vlasov simulation is expected to have higher accuracy than the PIC method, because it is free from the statistical noise inherent to the PIC. However, due to the difficulty of solving the advection equation in multidimensions, no standard scheme for the Vlasov simulation has been established thus far. We propose an advection scheme, in which not only point values of a profile but also its zeroth to second order piecewise moments are treated as dependent variables, for better conservation of the information entropy. We have developed one- and multi-dimensional schemes and show that they provide quite accurate solutions within reasonable usage of computational resources compared to other existing schemes. The multi-dimensional scheme can accurately solve the solid body rotation problem of a gaussian profile for more than hundred rotation periods with little numerical diffusion. This is crucially important for Vlasov simulations of magnetized plasmas. Applications of the schemes to electrostatic and electromagnetic Vlasov simulations are presented with some benchmark tests.

Author: Takahiro Miyoshi

Title: On numerical shock instabilities of Harten-Lax-van Leer-type approximate Riemann solvers

Abstract: Numerical shock instabilities of Harten-Lax-van Leer (HLL)-type approximate Riemann solvers for hydrodynamics (HD) and magnetohydrodynamics (MHD) are investigated. From numerical experiments of the shock instabilities of the HLL-Contact (HLLC) method for HD and the HLL-Discontinuities (HLLD) method for MHD, we infer that the instabilities may be suppressed by adding a sufficient numerical dissipation to the shear wave not the contact wave. Therefore, in this paper, new robust HLL-type methods for HD and MHD which can resolve the contact discontinuity are constructed by selectively adding a sufficient numerical dissipation to the tangential momentum. In the new methods, the carbuncle phenomenon in the blunt body problem cannot be observed.

Author: Sergey Moiseenko

Title: Magnetorotational processes in core-collapse supernovae

Abstract: We discuss results of 2D simulations of MR mechanism of supernova explosion. We show that due to the differential rotation in collapsed iron core of the massive star initial magnetic field is amplifying with the time. MR instability develops and leads to the exponential growth of all components of the magnetic field. The supernova explosion energy found in our simulations corresponds to the theoretical estimations and results of observations. The simulations were done by specially developed imlicit completely conservative operator-difference scheme in Lagrangian variables on triangular grid of variable structure.

Author: Fernando Moreno-Insertis

Title: 3D-modeling of the emergence of magnetized plasma from the solar interior

Abstract: The emergence of magnetized plasma from the solar interior into the atmosphere is at the root of some of the best-known structures and phenomena in the Sun. Magnetic flux emerging from the deep interior leads to the formation of sunspots and active regions. On smaller space- and timescales, flux is emerging continually also outside of active regions (in the so-called quiet Sun): the quiet solar photosphere is teeming with magnetic concentrations on a large range of sizes and with total unsigned magnetic flux in excess of that contained in active regions. On the other hand, the emergence of flux from the interior causes large perturbations in the solar atmosphere, that, in some cases, lead to spectacular eruptions (X Ray jets, flares, coronal mass ejections).

The physical understanding of these processes is advancing quickly at present thanks to the possibility of three-dimensional numerical modeling of solar domains that include the top layers of the solar interior, the photosphere, low atmosphere and up to several tens of Megameters in the corona. Those models include magnetohydrodynamical and radiation transfer aspects. Fundamental progess is being achieved, e.g., in the modeling of the formation of active regions, the launching of spicules, the ejection of X-Ray jets in the corona. In this review I will summarize a number of those modeling efforts based on state-of-the-art numerical codes that use massively parallel supercomputing installations.

Author: Bernhard Müller

Title: Recent Advances in Simulations of Core-Collapse Supernovae

Abstract: We discuss some of the recent results obtained by our group at MPA in the field of core-collapse supernova physics on the basis of a comprehensive modeling approach covering the evolution of the supernova from the collapse to the breakout of the shock from

the stellar surface. In particular, we present the first multi-dimensional general relativistic neutrino hydrodynamics simulations of supernova explosions, conducted as a part of our continuing efforts to provide more accurate predictions for the gravitational wave signal. We also elaborate on the numerical and computational challenges of multi-dimensional neutrino transport. Moreover, we discuss 3D simulations of the shock propagation through the stellar envelope, focusing on ejecta anisotropies and their implications for neutron star kicks and spins.

Author: Hans-Reinhard Müller

Title: Direct modeling of neutral helium in the heliosphere

Abstract: Several years of neutral measurements by IBEX-Lo have yielded direct observations of interstellar neutral helium and oxygen. There are strong indications for the presence of secondary neutral helium and oxygen created in the heliosphere. A detailed calculation method based on Keplerian orbits has been developed to characterize helium distribution functions throughout the heliosphere while accounting for loss and production of neutral particles along their path. Both the method and some results will be presented.

Author: Wolf-Christian Müller

Title: Surprises in the theory of anisotropic magnetohydrodynamic turbulence

Abstract: A new approach toward the analysis of high-Reynolds-number direct numerical simulations of incompressible magnetohydrodynamic (MHD) turbulence subject to a strong mean field has led to unexpected results: the scaling of one dimensional spectra taken along rays passing through the origin of Fourier space is independent of the rays' orientation with respect to the mean magnetic field direction; the spectral amplitude variation with respect to the angle between a ray and the mean magnetic field can be eliminated by normalization with an angle-dependent dissipation wavenumber. Thus the anisotropy of MHD turblence permeated by a strong mean magnetic field does *not* appear as direction dependent scaling but rather as a direction dependent Reynolds number. These findings invalidate present phenomenologies which are based on the critical balance argument.

Author: Chung-Sang Ng

Title: Large-Scale High-Lundquist Number Reduced MHD Simulations of the Solar Corona using GPU Accelerated Machines

Abstract: We have recently carried out a computational campaign to investigate a model of coronal heating and current-sheet formation in three-dimensions using reduced magnetohydrodynamics (RMHD). Our code is built on a conventional scheme (pseudo-spectral, semi-implicit) and is parallelized using MPI. The current investigation requires very long time integrations using high Lundquist numbers, where the formation of very fine current layers challenge the resolutions achievable even on massively parallel machines. We present here results of a port to Nvidia CUDA (Compute Unified Device Architecture) for hardware acceleration using graphics processing units (GPUs). In addition to a brief discussion of our general strategy, we will report code performance on several machines that span a variety of hardware configurations and capabilities. These include a desktop workstation with commodity hardware, a dedicated research workstation equipped with four Nvidia C2050 GPUs, as well as several large-scale GPU accelerated distributed memory machines: Lincoln/NCSA, Dirac/NERSC, and Keeneland/NICS.

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Author: Ken-ichi Nishikawa

Title: Simulation of Relativistic Jets and Associated Self-consistent Radiation

Abstract: Plasma instabilities are responsible not only for the onset and mediation of collisionless shocks but also for the associated acceleration of particles. We have investigated particle acceleration and shock structure associated with an unmagnetized relativistic electron-positron jet propagating into an unmagnetized electron-positron plasma. Cold jet electrons are thermalized and slowed while the ambient electrons are swept up to create a partially developed hydrodynamic-like shock structure. In the leading shock, electron density increases by a factor of about 3.5 in the simulation frame. Strong electromagnetic fields are generated in the trailing shock and provide an emission site. These magnetic fields contribute to the electrons transverse deflection and, more generally, relativistic acceleration behind the shock. We have calculated, self-consistently, the radiation from electrons accelerated in the turbulent magnetic fields. We found that the synthetic spectra depend on the Lorentz factor of the jet, its thermal temperature and strength of the generated magnetic fields. We are currently investigating the specific case of a jet colliding with an anti-parallel magnetized ambient medium. The properties of the radiation may be important for understanding the complex time evolution and/or spectral structure in gamma-ray bursts, relativistic jets in general, and supernova remnants

Author: Jean-Philippe Nominé

Title: PRACE Research Infrastructure: Petascale Computing Resources for European Scientists

Abstract: The most powerful supercomputers in Europe are offered to European researchers in academia and industry, as the PRACE Research Infrastructure launched the third call for access to its resources on May 2nd, 2011. Three petascale supercomputers are offering more than 650 million core hours for applicants, as well as 17 national HPC systems with more than 50 million core hours. We will present PRACE recent history and current statute, its organization, missions and perspectives.

Author: Martin Obergaulinger

Title: MHD simulations of non-rotating stellar core collapse with neutrinos

Abstract: Sufficiently strong magnetic fields may affect the dynamics of a collapsing stellar core and the subsequent phases potentially leading to a core-collapse supernova explosion. Since the field of the progenitor core is most likely rather weak, such effects require efficient field amplification. The absence of (rapid) rotation limits the range of promising amplification mechanisms, eliminating, e.g., the winding of the fields lines by differential rotation or the magneto-rotational instability. To assess the importance of some of the remaining processes, we have performed MHD simulations of the collapse and the first several hundred milliseconds post-bounce. The simulations follow the coupled evolution of the gas, the magnetic field, and the neutrino radiation. We solve the energy-dependent two-moment system of neutrino transport, i.e., the equations for neutrino energy and momentum closed by a simple analytic Eddington factor closing the system. We find that magnetic fields typically observed in neutron stars can be by a combination of the effects of flux-freezing compression and amplification by non-radial fluid flow such as convection and the standing accretion shock instability (SASI).

Author: Manel Perucho Pla

Title: ICM reheating by relativistic jets

Abstract: Galactic jets are powerful energy sources reheating the intracluster medium in galaxy clusters. Their crucial role in the cosmic puzzle, motivated by observations, has been established by a great number of numerical simulations missing the relativistic nature of these jets. We present the first relativistic simulations of the very long term evolution of realistic galactic jets. The runs have been performed in the supercomputer Mare Nostrum, using tipically up to 128 processors and adding up to 200,000 hours of calculation per simulation.

Unexpectedly, our results show no buoyant bubbles, but large cocoon regions compatible with the observed X-ray cavities. The reheating is more efficient and faster than in previous scenarios, and it is produced by a long lasting shock wave able to survive for several hundreds of Myrs. Therefore, most of the clusters should exhibit weak shocks confining X-ray cavities, whose detection becomes an observational challenge.

Author: Viviane Pierrard

Title: Coupling the plasmasphere model with the ionosphere

Abstract: The plasmasphere is the extension of the ionosphere at higher altitudes. A three dimensional physical dynamic model of the plasmasphere has been developed at BISA. The velocity distribution functions of the particles in the plasmasphere are obtained from the kinetic approach. The position of the plasmapause, the limit of the plasmasphere, is determined by the interchange instability mechanism and depends on the level of geomagnetic activity. The dynamics of the plasmasphere is mainly determined by the convection electric field combined with the corotation electric field. Different empirical models have been used and their results are compared. The highly dynamic region of the plasmasphere is disturbed during geomagnetic storms and substorms, with formation of a sharp plasmapause closer to the Earth and generation of a plume in the afternoon MLT sector.The deformation of the plasmasphere during quiet and disturbed geomagnetic periods is illustrated and compared with observations of IMAGE and CLUSTER satellites. The plasmasphere model has been coupled with the IRI ionospheric model to determine the composition, the number density and the temperature in the plasmasphere. Correspondence exists between the plasmapause position and the F region ionospheric trough. Coincident observations of middle and top ionosphere, satellite tomography, radar measurements and plasmapause observations are used to investigate the conditions when the F region trough is associated with the plasmapause. Moreover, the plasmaspheric region has direct influence on other regions of the magnetosphere. For instance, radiation belt energetic particle populations are very sensitive to the core plasmasphere distribution and specifically to the position of the plasmapause.

Author: Nikolai Pogorelov

Title: Modeling Nonstationary Heliosphere with the Multi-Scale Fluid-Kinetic Simulation Suite

Abstract: Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS) is developed to simulate flows of magnetized, partially ionized plasma experiencing collisions with neutral atoms. The suite self-consistently combines a module to solve ideal MHD equations using high-resolution, shock-capturing numerical schemes and adaptive mesh refinement, a direct simulation Monte Carlo module to analyze the transport of neutral particles in the process of their interaction with ions, and a module for solving the FokkerPlanck equation describing the transport of pick-up ions (PUIs), which are born when the core plasma ions exchange charge with neutral atoms. There is also a module implementing the PUI-generated turbulence and its interaction with the core plasma. MS-FLUKSS is built on the Chombo framework, which ensures efficient parallelization and dynamic load balancing on petascale supercomputers.

In this talk, we present numerical results of nonstationary problems of the solar wind interaction with the local interstellar medium: solar cycle effects with the solar input from Ulysses measurements, propagation of the corotating interaction regions and coronal mass ejections, the evolution of the heliospheric current sheet, time-evolution of the energetic neutral particle fluxes, etc. Numerical results are compared with the Ulysses, Voyager, and Interstellar Boundary Explorer data.

Author: David Radice

Title: Discontinuous Galerkin methods for general relativistic hydrodynamics

Abstract: I will present the general formulation of the equations of general relativistic hydrodynamics needed for the application of discontinuous Galerkin (DG) methods and present a proof-of-concept 1D, DG, code for general relativistic hydrodynamics, which we used to test these methods for relativistic hydrodynamics. I will also show the results obtained in some representative tests.

Author: Joachim Raeder

Title: Multi-scale Physics in the Magnetosphere

Abstract: In 30 years of magnetosphere simulations, the most important consideration has remained the same: resolution, resolution, resolution. Magnetospheric processes are of inherent multi-scale nature, that is, small-scale processes control the large-scale flow and field topology, while the large-scale flows feed back on the small-scale processes. Sometimes localization techniques such as AMR can be used to resolve the small-scale processes; however, in some situation, like turbulent flows, only a brute force approach helps. We will present several examples where new physics emerges as the numerical resolution of the simulation increases, in particular Flux Transfer Events (FTEs) at the magnetopause, ideal MHD ballooning modes in the tail, and dipolarization fronts during substorms.

Author: Luciano Rezzolla

Title: Modelling the dynamics of compact-object binaries in general relativity

Abstract: The detection of gravitational waves is eagerly expected as one of the most important scientific discoveries of the next decade. A worldwide effort is now working actively to pursue this goal both at an experimental level, by building ever sensitive detectors, and at a theoretical level, by improving the modelling of the numerous sources of gravitational waves. Much of this theoretical work is made through the solution of the Einstein equations in those nonlinear regimes where no analytic solutions are possible or known. I will review how this is done in practice and highlight the considerable progress made recently in the description of the dynamics of binary systems of black holes and neutron stars. I will also discuss how the study of these systems provides information well beyond that contained in the gravitational waveforms and opens very exciting windows on the physics of black holes and on the relativistic astrophysics of GRBs.

Author: Marina Romanova

Title: Global Simulations of MRI-driven Accretion onto Magnetized Stars

Abstract: We present results of global axisymmetric and full 3D MHD simulations of disk accretion onto rotating magnetized stars with a tilted dipole magnetic field. Godunov-type codes in cylindrical and cubed-sphere geometry are used. Axisymmetric simulations show that the disk-magnetosphere interaction is different in cases of aligned and anti-aligned fields of the star and the disk. In case of aligned fields, the magnetic flux is accumulated at the disk-magnetosphere boundary and accretion onto the star is episodic. 3D simulations show that matter of the disk may possibly penetrate through the field lines of the external magnetosphere due to interchange instability. In all cases, reconnection also acts as an efficient mechanism of diffusivity in penetration of the disk matter through external layers of the magnetosphere towards the stellar surface.

Author: Ilia Roussev

Title: Global MHD Modeling of CMEs and Related Shock Waves Originating from Complex Active Regions

Abstract: The physical causes of coronal mass ejections (CMEs) have been debated by the solar community for over three decades now. The vast majority of proposed models agree that CMEs are the result of catastrophic loss of mechanical equilibrium or stability of the coronal magnetic field due to changes in the distribution of magnetic flux elements at the photosphere. These models usually involve idealized physical circumstances with either

dipolar or quadrupolar underlying magnetic field geometries. The real Sun, however, demonstrates cases far more sophisticated than those idealized configurations. Therefore, studying the actual magnetic field geometries involved during CMEs is crucial for understanding the dynamical time scales of the eruption, acceleration profiles, etc. By means of fully compressible 3-D magnetohydrodynamic simulations, we have investigated the CME events that took place on Apr 21 and Aug 24 of 2002. We have used high-resolution MDI data to set realistic boundary condition for the magnetic field at the Sun. The loss of equilibrium and subsequent eruption have been achieved by stretching and twisting the opposite polarity feet of a newly emerged magnetic dipole in the vicinity of the source region of the CME. As the result of reconnection at 3-D null points, magnetic flux and helicity are transferred from the compact flux system containing the emerged dipole to the larger-scale flux systems in the neighboring active regions. The CME dynamics have been found to proceed in a manner different than that predicted by earlier models, yielding fast CME events with properties similar to those of the observed ones. This talk summarizes the simulated dynamics of the CMEs and associated shock waves, and their comparison with observations. We discuss the influence of the global magnetic field on the geometry of the CME-driven shock waves, and the possible implications for the production of solar energetic particles.

Author: Dongsu Ryu

Title: Relativistic MHD Codes for Adiabatic and Isothermal Flows

Abstract: Building relativistic magnetohydrodynamic (MHD) codes based on upwind schemes is still challenging, partly because the eigenstructure for relativistic MHDs has not yet been analytically given. In this talk, we present an analytic form of the eigenvalues which is complicated but yet tractable, and show that the eigenvectors are expressed in a relatively simple form with the eigenvalues. We show test results with a preliminary version of code for isothermal flows which is simpler than that for adiabatic flows.

Author: Wolfram Schmidt

Title: Modeling unresolved processes in the turbulent multiphase interstellar medium

Abstract: Large-scale simulations of idealized disk galaxies or galaxies from cosmological initial conditions play a prominent role in computational astrophysics. A key problem in these simulations is that turbulence, the thermal structure of the interstellar medium, star formation, and the interaction of stars with their environment cannot be fully resolved. In particular, turbulence below the grid scale is produced by external driving (energy transfer from larger, resolved scales) and by internal driving (unresolved thermal instabilities and stellar feedback). Customarily applied models focus on particular processes, while neglecting others (e.g., only internal, but no external driving). Although this seems to be a pragmatic

approach, such models are hard to justify on physical grounds because of the dynamical coupling between the various processes in the interstellar medium. I give an outline of a model of compressible turbulence in a warm and a cold gas phase with separate thermal budgets, including simple descriptions of star formation and feedback. This model can be used to explore the effects of the input physics and can be incorporated in astrophysical simulations as a subgrid scale model.

Author: Sergio Servidio

Title: Numerical experiments of magnetic reconnection in two-dimensional turbulence

Abstract: The nonlinear dynamics of magnetic reconnection in turbulence is investigated through high resolution numerical simulations, in a two-dimensional geometry. In order to study the problem of reconnection in turbulence, Magnetohydrodynamic (MHD) and Hall MHD equations are solved with high-accuracy pseudo-spectral codes. Systematic analysis of these numerical simulations reveals the presence of a large number of X-type neutral points, where magnetic reconnection locally occurs. We examine the statistical properties of this ensemble of reconnection events that are spontaneously provided by turbulence. The associated reconnection rates are distributed over a wide range of values and scales with the geometry of the diffusion region. In this complex scenario of multiple-reconnection events, the contribution of the Hall term plays a very important role. Results from hybrid-Vlasov kinetic simulations are discussed as well. This general description of reconnection has broad applications, going from laboratory plasmas to astrophysical flows, where generally turbulence is present.

Author: Fang Shen

Title: 3-D MHD Simulation of the Two CMEs Propagation and Interaction Using Successive Magnetized Plasma Blobs Model

Abstract: A three-dimensional (3D) time-dependent, numerical magnetohydrodynamic (MHD) model is used to investigate the evolution and interaction of two CMEs in the nonhomogeneous ambient solar wind. The background solar wind is constructed based on the self-consistent source surface with observed line-of-sight of magnetic field and density from the potential field source surface of 2.5 R_s to the Earths orbit (215 R_s) and beyond. The two successive CMEs occurring on 2001 March 28 and forming a multiple magnetic cloud (multi-MC) in interplanetary space are chosen as a test case, in which they are simulated by means of two high-density, -velocity and -temperature magnetized plasma blobs model, and successively ejected into the nonhomogeneous background solar wind medium along different initial launch directions, respectively. The dynamical propagation and interaction of the two CMEs between 2.5 and 220 R_s are investigated. Our simulation results show that, although

the two CMEs are separated by 10 hours, the second CME is able to overtake the first one, and cause compound interactions and an obvious acceleration of the shock. At L1 point near the Earth, the two resultant magnetic clouds in our simulation are consistent with the observations by ACE. In this validation study, we find that this 3D MHD model, with the self-consistent source surface as initial-boundary conditions and the magnetized plasma blob as CME model, is able to reproduce and explain some of the general characters of the multiple magnetic clouds observed by satellite.

Author: Aaron Skinner

Title: A two-moment radiation hydrodynamics module in Athena using a Godunov method

Abstract: We describe a module for the Athena code that allows the equations of radiation hydrodynamics to be solved. For simplicity, we use the grey equations without scattering. We adopt the local Eddington tensor based on the M1 closure of a two-moment radiation model which describes the diffusion and streaming limits well. The radiation variables are updated via a combination of Godunov-type transport, explicit updates of most source terms, and a simplified implicit iterative update of stiff source terms. Our algorithm conserves total energy and momentum and is parallelized with MPI. To reduce computational costs, we update the radiation variables by sub-stepping on a hydrodynamic timescale and by using an adaptive reduced speed of light. Finally, we present a suite of standard and novel tests in one, two, and three dimensions designed to validate the code for both the pure radiation and radiation hydrodynamics in the diffusion and streaming limits, as well as inte! rmediate regimes. These tests, which include radiation hydrodynamic waves, shocks, and equilibria show that the method produces accurate results and second-order convergence in most regimes. The code is suitable for a wide variety of astrophysical applications and will ultimately be made freely available on the Web.

Author: Felix Spanier

Title: Hybrid simulations of charged particle motion in the heliosphere

Abstract: The transport of charged particles in turbulent media has been a major question in cosmic ray and space physics. Since the beginning of this research field analytical theories had to include severe simplifications to allow for a solution. The quasi-linear theory has been the analytical theory of choice for several decades and is not able to explain the available observations of solar energetic particles. There have been also a number of numerical approaches for this problem also, which have made mostly assumptions about the turbulent spectrum. We present a hybrid approach to the problem solving the MHD equations for the background medium and the equation of motion for testparticles simultaneously. This approach allows the direct calculation of Fokker-Planck coefficients and the mean free path

from particle tracks. We will discuss the application of this model to solar energetic particles and compare with obervations. Also the advantages and pitfalls of this method shall be clarified.

Author: Nikolaos Stergioulas

Title: Magneto-elastic oscillations and magnetar QPOs

Abstract: A number of long-lived quasi-periodic oscillations (QPOs) have been observed in the aftermath of giant bursts in soft-gamma-ray-repeaters (SQRs). We will discuss a model that interprets most of these QPOs as modulations of the magnetosphere due to magneto elastic oscillations of the magnetar. The model can explain the long lifetime of the QPOs (while crustal shear oscillations are damped on a very short timescale) as well as the near integer ratios of observed frequencies. Furthermore, our relativistic model predicts frequencies that only depend on the compactness of the star and the strength of the magnetic field, if the latter is a pure dipole. The influence of different magnetic field configurations will also be discussed.

Author: Tooru Sugiyama

Title: PIC calculation on GPGPU system

Abstract: We have performed the particle-in-cell (PIC) plasma simulation model on a GPGPU system. The algorithms which are frequently used for the PIC simulations on GPGPU system, use the particle sorting process in order to avoid the memory conflict on the calculation of the velocity moment. However, it requires hard efforts to write the simulation code, especially for FORTRAN code/user. This is because the code examples for C/C++ are mainly uploaded on CUDA Zone and other WEB sites. Here, we show a straight forward algorithm for the velocity moment calculation. It is based on the RETRY algorithm, which is major algorithm on the vector-type architecture like a SX super-computer. We discuss the calculation costs.

Author: Olga Toropina

Title: MHD Simulation of Bondi-Hoyle Accretion onto Magnetized Neutron Star

Abstract: We use axisymmetric MHD simulations to investigate the Bondi-Hoyle accretion onto a neutron star with a dipole magnetic field and interaction of supersonic neutron star with the interstellar medium. A non-magnetized star moving through the ISM captures matter gravitationally from the accretion radius Racc, and the mass accretion rate at high

Mach numbers was derived by Bondi, Hoyle and Lyttleton. In the presence of magnetic field of the star situation is more complex and depend on magnetospheric radius R_m. When $R_m > R_{acc}$, incoming ISM flow interacts directly with starś magnetosphere. When $R_m < R_{acc}$, matter is captured by the gravitational field of the star like in Bondi-Hoyle accretion onto non-magnetic star, then it is accumulated near the star and interacts with the magnetic field of the star. The magnetized star accretes matter at a lower rate than a non-magnetized star for the same parameters velocity; sound speed and Mach number. We found a structure of the flow for both cases, the mass accretion rate and its dependence on magnetic field of the star. In the case of small magnetic field we observed some instability of accretion flow and corresponding instability of mass accretion rate. This instability disappears with magnetic field increase.

Author: Gabor Toth

Title: Magnetohydrodynamics with Anisotropic Ion Pressure

Abstract: We study the magnetohydrodynamics (MHD) equations with anisotropic ion pressure and isotropic electron pressure under both the classical and semirelativistic approximations in order to develop a numerical model. The dispersion relation as well as the characteristic wave speeds are derived. In addition to the exact wave speed solutions, we also provide efficient approximate formulas for the semirelativistic magnetosonic speeds. The equations are discretized with the Rusanov and Harten-Lax-van Leer numerical schemes and implemented into the BATS-R-US MHD code. We perform a set of verification tests. The new code is applied to modeling the magnetosphere of the Earth. We compare the model results with various observations, including the ion pressure anisotropy data obtained by the Cluster and THEMIS satellites.

Author: Arcadi Usmanov

Title: Three-dimensional modeling of the solar wind: From the coronal base to the outer heliosphere

Abstract: We have developed a global fully three-dimensional magnetohydrodynamic solar wind model for the region that extends from the coronal base to 100 AU. The simulation domain consists of three spherical shell subdomains with computational boundaries between them placed at 20 solar radii and 0.3 AU. The location of the first boundary ensures that the flow at the boundary is both supersonic and super-Alfvénic. A steady-state solution in the innermost (coronal) region is obtained by the time-relaxation method. The solution uses a tilted dipole model or solar magnetograms as the boundary condition at the coronal base and includes a flux of Alfvén waves in the WKB approximation which provide additional acceleration for the coronal outflow in the open field regions. The intermediate region solution

is constructed by the integration of steady-state equations along radius using a marching scheme. The outer region solution (0.3-100 AU) is obtained again by time relaxation and takes into account turbulence transport and heating as well as flow deceleration, and other effects due to the interstellar pickup protons treated as a separate fluid. We use the model to simulate the global steady-state structure of the solar wind from the coronal base to the heliospheric boundary and compare the results with Ulysses and Voyager observations.

Author: Sven Van Loo

Title: Suppressing the star formation rate with magnetic fields

Abstract: Star formation affects galaxy evolution to such an extent that the early formation efficiency influences the ratio of the disc and spheroidal components in spiral galaxies. It occurs primarily in giant molecular clouds (GMCs), but is usually restricted to a small fraction of the volume of a GMC, as most stars form in or near relatively small clusters. This would seem to suggest that the processes setting the Galactic star formation rate are those that generate the dense clumps within GMCs. In contrast, the observationally inferred Kennicutt relation implies that the rate depends on a large-scale average of the column density of interstellar gas, which points to the importance of processes acting on scales larger than GMCs in regulating the Galactic rate.

An associated, important puzzle concerns the low efficiency of star formation in most environments. It usually happens at a rate much less than the gas mass divided by the free-fall time. Therefore, the star formation rate is probably directly regulated by processes like gravitational, thermal and magnetohydrodynamical instabilities and stellar feedback. I will discuss the formation and evolution of GMCs in a Galactic environment where I focus on the effect of the magnetic field. By combining the results of these simulations with data from photo-ionisation codes, synthetic emission maps and spectral line profiles can be produced. A direct comparison with observations from e.g. Herschel and ALMA will then provide invaluable information to both theory and observation of star formation.

Author: Shi Tsan Wu

Title: Modeling of Solar Active Region on the Basis of A Three-Dimensional, Time-Dependent Magnetohydrodynamic (MHD) Model

Abstract: A self-consistent, three-dimensional magnetohydrodynamic model together with time-dependent boundary conditions based on the method of characteristics at the source surface (photosphere) to accommodate the observation will be discussed. To illustrate this model, Active Region 11117 observed by SDO/HMI is chosen for the analyses in that the magnetic field structures and evolution of this action region will lead to the determination of the conditions for the initiation of a solar eruption. Specific physical parameters to be

simulated are non-potential magnetic field changes (i.e. change of magnetic flux (ϕ), the net electric current (I_N), the length of magnetic shear of the main neutral line (L_{ss}) and the flux normalized measure of the field twist . In addition the total current helicity (H_c) injected into the coronal and the photospheric surface velocity are also presented. We have found that all the non-potential magnetic field parameters are necessary conditions for a solar eruptive event, but a sufficient condition is reveal for this particular case. This sufficient condition is the "fragmentation of the length of magnetic shear of the main neutral line.

Author: Huirong Yan

Title: Cosmic Ray Transport in MHD Turbulence: large and small scale interactions

Abstract: Cosmic ray (CR) transport and acceleration is essential for many astrophysical problems, e.g., CMB foreground, ionization of molecular clouds and all high energy phenomena. Recent advances in MHD turbulence call for revisions in the paradigm of cosmic ray transport. We use the models of magnetohydrodynamic turbulence that were tested in numerical simulation, in which turbulence is injected at large scale and cascades to to small scales. I shall address the issue of the transport of CRs, both parallel and perpendicular to the magnetic field and show that the issue of cosmic ray subdiffusion is only important for restricted cases when the ambient turbulence is far from that suggested by numerical simulations. I also shall discuss the nonlinear growth of kinetic gyroresonance instability of cosmic rays induced by large scale compressible turbulence. This feedback of cosmic rays on turbulence was demonstrated an important scattering mechanism in addition to direct inte! raction with the compressible turbulence. We consider the nonlinear suppression due to the wave-particle scattering limit the energy range of CRs that can excite the instabilities and be scattered by the induced the slab waves. The feedback on large scale turbulence shall be also discussed.

Author: Helen Yee

Title: On Numerical Methods for Hypersonic Turbulent Flows

Abstract: This lecture discusses some of the key aspects for the design of suitable numerical meth- ods for hypersonic turbulent flows, including combustion, and thermal and chemical nonequilibrium flows. On the one hand, the physics of strong steady shocks and unsteady turbulence/shocklet interac- tions under the nonequilibrium environment is not well understood. On the other hand, standard and newly developed high order accurate (fourth-order or higher) schemes were developed for homoge- neous hyperbolic conservation laws and mixed hyperbolic and parabolic partial differential equations (PDEs) (without source terms). The appearance of the source terms in modeling non-equilibrium flow problems containing finite-rate chemistry or combustion poses additional numerical difficul- ties beyond that for solving

non-reacting flows. The majority of finite rate chemistry and thermal nonequilibrium simulations employ methods for homogeneous time-dependent PDEs with a point- wise evaluation of the source terms. The pointwise evaluation of the source term might not be the best choice for stability, accuracy and minimization of spurious numerics for the overall scheme. Moreover, hypersonic turbulent flows around re-entry space vehicles involve mixed steady strong shocks and turbulence with unsteady shocklets that poses additional numerical challenges. Proper control of numerical dissipation in numerical methods beyond the standard shock-capturing dissipation at discontinuities is an essential element for accurate and stable simulations of the subject physics. Unlike rapidly developing shock interaction flows, turbulence computations involve long time integrations. Improper control of numerical dissipation from one time step to another would be compounded over time, resulting in the smearing of turbulent fluctuations to an unrecognizable form. Stiffness of the source terms and material mixing in combustion poses additional computa- tional challenges. A well-balanced scheme, which can preserve certain non-trivial steady solutions of the governing equations exactly, may help minimize some of these difficulties. For stiff reactions, it is well known that the wrong propagation of discontinuities occurs due to the underresolved numerical solutions in both the space and time. Schemes to improve the wrong propagation of discontinuities for systems of stiff reacting flows remain as a challenge for algorithm development. Some of the recent algorithm developments for the aforementioned issues will be discussed.

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Author: Gary Zank

Title: The transport of low frequency turbulence in astrophysical flows: Governing model

Abstract: Numerous problems in space physics and astrophysics require a detailed understanding of the transport and dissipation of low frequency turbulence in an expanding magnetized flow. We employ a scale-separated decomposition of the incompressible MHD equations (based on an Elssasser description) and develop a moment hierarchy to describe the transport of the total energy density in fluctuations, the cross-helicity, the energy difference, and correlation lengths corresponding to forward and backward propagating modes and to the energy difference. The dissipation terms for the various transport equations are derived. One-point closure schemes are utilized. The technical elements of this work that distinguish it from previous studies are 1) the inclusion of the large-scale background inhomogeneous Alfvenic velocity VA at a level of detail greater than has been done before; 2) the introduction of a tractable slow time-scale closure to eliminate high frequency interferences terms that is likely to prove an useful approximation for practical problems related to the transport of turbulence in an inhomogeneous flow such as the solar wind or solar corona; and finally

3) we develop a simplified phenomenology for the energy difference that again may be useful for practical applications. This yields a highly nonlinear coupled system of 6 equations that describe the transport of turbulence in inhomogeneous sub-Alfvenic and super-Alfvenic flows.