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Aloy, Miguel-Angel	***Gravitational Wave Signals in Black Hole Forming Core Collapse*** Miguel-A. Aloy, University of Valencia, Spain. Pablo Cerdá-Durán, University of Valencia, Spain. Martin Obergaulinger, University of Valencia, Spain. Nicolas DeBrye, University of Valencia, Spain. José A. Font, University of Valencia, Spain. We present general relativistic numerical simulations of collapsing stellar cores. Our initial model consists of a low metallicity rapidly-rotating progenitor which is evolved in axisymmetry with the latest version of our general relativistic code CoCoNuT, which allows for black hole formation and includes the effects of a microphysical equation of state (LS220) and a neutrino leakage scheme to account for radiative losses. The motivation of our study is to analyze in detail the emission of gravitational waves in the collapsar scenario of long gamma-ray bursts. Our simulations show that the phase during which the proto-neutron star (PNS) survives before ultimately collapsing to a black hole is particularly optimal for gravitational wave emission. The high-amplitude waves last for several seconds and show a remarkable quasi-periodicity associated with the violent PNS dynamics, namely during the episodes of convection and the subsequent nonlinear development of the standing-accretion shock instability (SASI). By analyzing the spectrogram of our simulations we are able to identify the frequencies associated with the presence of g-modes and with the SASI motions at the PNS surface. We note that the gravitational waves emitted reach large enough amplitudes to be detected with third-generation detectors such as the Einstein Telescope within a Virgo Cluster volume at rates <~ 0.1 yr-1.
Amano, Takanobu	***Robust Handling of Low Density Regions in Hybrid Simulations*** Takanobu Amano, University of Tokyo, Japan Katsuaki HIgashimori, University of Tokyo, Japan Keisuke Shirakawa, University of Tokyo, Japan We present a new method for plasma hybrid (particle ions and fluid electrons) that may extend its applicability and improve the robustness. We incorporatefinite electron inertia effect with a method different from the conventional approach. The finite electron inertia correction is directly introduced as a correction to the electric field rather than the magnetic field. It is shown that the resulting equation in the low density limit (or in a pure vacuum) reduces to the Laplace equation for the electric field, indicating there is no difficulty in handling a vacuum region. One-dimensional numerical experiments confirm that the method can easily handle a pre-existing vacuum regions, as well as extremely low density regions that is produced as a result of self-consistent nonlinear development of the system. We argue that the present method significantly improves the robustness without losing the advantages of the original hybrid model.
Audit, Edouard	***3D Simulations of Convection-Pulsation Coupling in Cepheids*** Edouard Audit, CEA / Maison de la Simulation, FRANCE Cepheids are giant stars from the instability strip of the Hertzsprung-Russel diagram. They display periodic variations of luminosity (and radius) linked to the period-luminosity relationship used to calculate star distances in the Local Group. This variability was explained by Eddington (1917) through the kappa-mechanism, an excitation mechanism of stellar oscillations that is related to sharp changes of opacity in ionization regions. This bump in opacity periodically blocks the escape of emerging radiation, leading to unstable oscillation modes. The blue edge of the classical instability strip (where stars have higher surface temperature) is rather well-known and explained (Chiosi et al. (1993) ; Beaulieu et al. (1995)) but cold Cepheids close to the red edge present a convective zone at their surface that affects their pulsation properties. we studied the coupling between this surface convection and the radial pulsations triggered by the kappa-mechanism around the ionization region of the star, using the HERACLES code. Previous work had shown the the convection stabilizes in 2D the radial oscillations excited by the kappa mechanism. But the filling factor of 3D convection plumes tend to be smaller than 2D filling factor (3D structures are short-lived and smaller than their 2D counterparts) and we have shown that 3D convection does not quench the radiative pulsations, leading to an efficient 3D kappa-mechanism. Using our results, we then show that Stellingwerf's 1D Cepheid model agree with the nonlinear simulations better than does Kuhfuß ' model when convection is involved.

Balsara, Dinshaw	***Multidimensional Riemann Solvers With Self-Similar Internal Structure*** Dinshaw S. Balsara (dbalsara@nd.edu), University of Notre Dame A study of the MHD and Relativistic MHD systems reveals that multidimensional upwinding plays a very important role in their numerical solution. To that end, we have designed multidimensional Riemann solvers that indeed offer the requisite multidimensional upwinding. As is the case for one-dimensional Riemann solvers, retaining substructure in the Riemann fan is important for obtaining low dissipation methods. In this talk, I explain the formulation of multidimensional Riemann solvers. I also introduce recent work on introducing substructure in the multidimensional Riemann solvers.
Beresnyak, Andrey	***On the parallel spectrum of MHD Turbulence*** Andrey Beresnyak, Los Alamos National Laboratory, USA The spectrum of perturbations in the solar wind is anisotropic, in particular the globally isotropized spectrum was found to be different from the spectrum measured parallel to the local mean magnetic field. The standard Goldreich-Sridhar model predicts k^-2 parallel spectrum which follows from the critical balance argument. While some measurements are consistent with this, till this day there is a considerable debate on the subject, with some criticizm directed at the critical balance argument itself, as being a conjecture based on the uncertainly relation. I will argue that the k^-2 parallel spacial spectrum is simply the omega^-2 Lagrangian frequency spectrum of strong turbulence. As Alfven waves propagate exactly along magnetic field lines, the measurement of the spectrum along field line is equivalent to the measurement of the frequency spectrum. Given this, it is better to view critical balance as inevitable and rigorous consequence of strong Alfvenic turbulence, rather than a conjecture. I also tested this idea using high-resolution simulations, in particular I verified not only the k^-2 parallel spectrum, but also the fact that the cutoff of the parallel spectrum is the Kolmogorov timescale multiplied by Alfvenic speed, not Kolmogorov lengthscale. I hope that this result will conclude the debate on the nature of the parallel spectrum.
Bisikalo, Dmitry	***Precessional density wave as a reason of turbulence in accretion disks of non-magnetic close binary stars*** D.V. Bisikalo, E. P. Kurbatov, P. V. Kaygorodov Institute of astronomy of the RAS, Russia 3D numerical simulations demonstrate the formation of precessional spiral density waves in accretion disks of close binary stars. The precessional wave causes the appearance of strong density and velocity gradients in the disk. Linear stability analysis shows that the presence of the radial velocity gradient leads to instability of radial modes. The perturbation becomes unstable if the radial velocity variation is of the same order or greater than the sound speed on the perturbations characteristic wave scale. The unstable perturbations rapidly grow with time and give rise the turbulization of the accretion disk. The obtained viscosity (0.01 in terms of Shakura-Sunyaev parameter) is in agreement with observations.

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Blies, Patrick	***ANTARES -- A Numerical Tool for Astrophysical RESearch*** Patrick Blies, University of Vienna, Austria Hannes Grimm-Strele, University of Vienna, Austria Natalie Happenhofer, University of Vienna, Austria Friedrich Kupka, University of Vienna, Austria Eva Mundprecht, University of Vienna, Austria Herbert Muthsam, University of Vienna, Austria Florian Zaussinger, BTU Cottbus, Germany My talk will give an overview of the relatively young ANTARES code, a numerical code originally conceived for stellar hydrodynamics that has been developed mainly at the University of Vienna. Up to now, it has been used in very highly resolved simulations of solar granulation, in 2D simulations of pulsating stars and in 2D and 3D simulations of semiconvection, among others. I am going to review its main fields of application, highlight the underlying numerical methods and talk about the most recent additions: the implementation of a parallelized multigrid solver for a generalized non-linear Helmholtz equation in 2D and the usage of curvilinear grids for high Mach number flows.
Chen, Ke-Jung	***Cosmic Impact of the First Binaries*** Volker Bromm, UT Austin USA We present the cosmological simulations of impact of the first binaries. Recent studies of the first star formation suggest that those stars tend to form into binaries or multiple stellar systems instead of single stars, so the first stars could be less massive than we originally thought. It implies the first stars would die as score collapse supernovae instead of pair-instability supernovae, both of them are very different in nucleosynthesis yields and explosion energies. We use the well-tested massively-parallel combined N-body and smoothed-particle hydrodynamics code Gadget-2, modified to include detailed cooling, chemistry, and radiative transfer of primordial gas to study the impact of the first binaries. We take realistic Pop III stellar models and their nucleosynthesis products as initial inputs for our cosmological simulations and trace the transport of supernova metals that can significantly affect the chemical enrichment in the primordial intergalactic medium. In this talk, we discuss the impact of the first binaries to the early Universe and their observational signatures for the forthcoming James Webb Space Telescope.
Chen, Ke-Jung	***Simulating the First Cosmic Explosions: Explosion and Mixing of Pair-Instability Supernovae*** Stan Woosley, UC Santa Cruz, USA Alexander Heger, Monash University, Australia Ann Almgren, LBNL, USA Weiqun Zheng, LBNL, USA We present multidimensional simulations of the thermonuclear supernovae from massive primordial stars. Numerical and theoretical study of the primordial star formation in the early Universe suggest that these stars could have been very massive. These primordial stars may have died as energetic thermonuclear supernovae, so-called pair-instability supernovae (PSNe). We model the explosion of PSNe by using a new radiation-hydro code, CASTRO and find the fluid instabilities driven by nuclear burning and hydrodynamics during the explosion. For red supergiant models, amplitudes of these instabilities are sufficient to break down the spherical symmetry of the supernova ejecta.
Cho, Jungyeon	***Turbulence and Origin of Cosmic Magnetic Fields*** Jungyeon Cho, Chungnam National University, Korea Turbulence is believed to play important roles in the origin of cosmic magnetism. Here I will focus on the growth of cosmic magnetic fields by turbulent motions. It is well known that turbulence can efficiently amplify a week seed magnetic field. First, I will briefly summarize growth of uniform seed magnetic fields in turbulence. Second, I will demonstrate that growth of localized seed magnetic fields in turbulence is very fast. Our numerical results show that fast magnetic diffusion followed by a usual small-scale dynamo enables fast growth of a localized seed field. This results show that, regardless of the shape of the seed fields, fast magnetization is possible in turbulent systems, such as large-scale structure of the universe or galaxies. I will also present recent progress in this field.

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Commercon, Benoit	***Adaptive-time-stepping for implicit schemes on AMR grids and application to radiation-hydrodynamcis*** Benoit Commercon, CRAL ENS Lyon, France Vincent Debout, LESIA Observatoire de Paris, Paris Romain Teyssier, ITP University of Zurich, Switzerland We present a new method for implicit adaptive time-stepping on adaptive mesh-refinement grids. We implement it in the radiation-hydrodynamics solver we designed for the RAMSES code for astrophysical purposes and, more particularly, for protostellar collapse. I will present the different types of boundary conditions (Dirichlet, Neumann, and Robin) that are used at the interface between levels and present our implementation of the new method in the RAMSES code. I will the present classical tests and applications for protostellar collapse.
de Gouveia Dal Pino, Elisabete	***Star Formation and the Turbulent Transport of Magnetic Flux: A New Paradigm*** E. M. de Gouveia Dal Pino (University of Sao Paulo, Brazil) R. Santos-Lima (University of Sao Paulo, Brazil) Alex Lazarian (University of Wisconsin, USA) Marcia R. M. Leao (University of Campinas, Brazil) Gustavo Guerrero (Federal University of Minas Gerais, Brazil) Greg Eyink (Johns Hopkins University, USA) Currently, there is no doubt that MHD turbulence and star formation are interconnected. In this regard, an important question that is not fully understood yet is how the magnetic fields are transported in this process. When clouds collapse gravitationally to form stars, some magnetic flux transport is required, otherwise the new born stars would have magnetic fields several orders of magnitude larger than the observed ones. Also, the magnetic flux that is dragged in the late stages of the formation of a star can remove all the rotational support from the accretion disk that grows around the protostar thus preventing the formation of a proto-planetary disk. The efficiency of the mechanism which is often invoked to allow the transport of magnetic fields in the different stages of star formation, namely, the ambipolar diffusion, has been lately put in check. We here discuss an alternative mechanism for magnetic flux transport which is based on turbulent magnetic reconnection. We review recent results obtained from 3D MHD numerical simulations that indicate that this mechanism is very efficient for decoupling and remove away magnetic flux from inner denser regions of collapsing clouds in the different stages of star formation - from core collapse to disk formation. We also present results of test field models that allow the evaluation of the diffusion coefficient of this mechanism which confirm the theoretical predictions.
Endeve, Eirik	***Positivity-Preserving Discontinuous Galerkin Methods for Supernova Neutrino Transport*** Eirik Endeve, Oak Ridge National Laboratory, USA Cory Hauck, Oak Ridge National Laboratory, USA Yulong Xing, Oak Ridge National Laboratory, USA Anthony Mezzacappa, University of Tennessee, Knoxville, USA We are developing numerical methods for simulation of neutrino transport in core-collapse supernovae. By employing a conservative formulation of the general relativistic Boltzmann equation, we aim to develop methods that are (i) high-order accurate for computational efficiency, (ii) robust in the sense that the phase space density f preserves the maximum principle of the physical model (i.e., f\in[0,1] for fermions), and (iii) applicable to evolution in curved spacetimes, which results in gravity-induced frequency shift and angular aberration. Our approach is based on the Runge-Kutta discontinuous Galerkin method, which has many attractive properties, including high-order accuracy on a compact stencil and correct asymptotic behavior in the diffusion limit. We have developed a high-order, maximum-principle-satisfying scheme for the 6+1-dimensional phase space advection problem. We describe the numerical method and show results from implementations in spherical and axial symmetry. Our tests demonstrate that the method is high-order accurate and strictly preserves the maximum principle on f. We also demonstrate the ability of our method to accurately include effects of a strong gravitational field.

Ermishkin, Maxim	***A Three-Dimensional Numerical Study of Supernova Remnant Interaction with Inhomogeneous Interstellar Medium*** M.V. Ermishkin, S.T. Surzhikov, Institute for Problems in Mechanics of the RAS, Russia Magnetohydrodynamic (MHD) interaction between the supernova remnant (SNR) and the interstellar medium (ISM) has been studied using a three-dimensional numerical model. The inhomogeneity of the ISM is introduced by one or two diffusion gas clouds located near the SNR. The gas cloud has a spherical shape and consists of two layers. The inner spherical layer with radius of 1.6 pc consists of cold dense gas (concentration n = 40 1/cc, temperature T = 80 K). The outer shell with radius of 2.1 pc consists of gas heated by ultraviolet radiation propagating in the ISM. In this layer of the cloud concentration and temperature are n = 0.25 1/cc, T = 8 000 K. Parameters of the SNR correspond to explosion of Ia type supernova star. The direction of magnetic field in the ISM is constant. In the work two different cases of state of the ISM are investigated: n = 0.001 1/cc, T = 1000 000 K and n = 1 1/cc, T = 10 000 K. Numerical solutions begin at the time when the shell of the SNR reaches the distance of 2 pc. The numerical model has been developed using the ideal MHD model of plasma. The numerical solution has been performed using the numerical method based on different limiters. Our findings suggest that for considered values of the ISM characteristics there are two different scenarios of evolution of both the SNR and the gas cloud. In first case when density of cloud is much higher than density of shock wave of the SNR the processes of cloud's compression and strong mixing of the surrounding medium are observed. If densities of the cloud and the shock wave are comparable the cloud is destroyed. The influence of the cloud on the shock wave is much smaller in this case. The impact of the magnetic field and radiation cooling has been also discussed.Results of the investigation suggest that inhomogeneities of the ISM could be an important factor responsible for asymmetry of radiation intensity images in a number of observed supernova remnants.
Fang, Shen	***Toward Understanding the Sun-to-Earth Evolution of the 2012 July 12-16 Coronal Mass Ejection Using Three-dimensional MHD Simulation*** Fang Shen, State Key Laboratory of Space Weather, Center for Space Science and Applied Research, Chinese Academy of Sciences, CHINA Chenglong Shen, School of Earth and Space Sciences, University of Science and Technology of China, CHINA Jie Zhang, School of Physics, Astronomy, and Computational Sciences, George Mason University, USA Phillip Hess, School of Physics, Astronomy, and Computational Sciences, George Mason University, USA Yuming Wang, School of Earth and Space Sciences, University of Science and Technology of China, CHINA Xueshang Feng, State Key Laboratory of Space Weather, Center for Space Science and Applied Research, Chinese Academy of Sciences, CHINA Hongze Cheng, School of Earth and Space Sciences, University of Science and Technology of China, CHINA Yi Yang, State Key Laboratory of Space Weather, Center for Space Science and Applied Research, Chinese Academy of Sciences, CHINA Dynamic process of coronal mass ejections (CMEs) in the heliosphere is the key information for us to evaluate the CMEs' geo-effectiveness and to improve the accurate prediction of CME induced Shock Arrival Time (SAT) at Earth's environment. We present a three-dimensional (3D) magnetohydrodynamic (MHD) simulation of the evolution of the CME in a realistic ambient solar wind for the July 12-16, 2012 event by using the 3D COIN-TVD MHD code. A detailed comparison between the observations and the simulation results from our model is made, including time-elongation maps for the positions of Stereo A and Stereo B. In the validation study, we find that our 3D COIN-TVD MHD model, with the magnetized plasma blob as the CME driver, is able to re-produce relatively well the real 3D nature of the CME and their evolution in the inner heliosphere; and also provide a relatively satisfactory comparison with the ACE spacecraft observations at the L1 point.

Feng, Xueshang	***A New 3D Solar Wind Model in Spherical Coordinates with Dual-time Step*** Xueshang Feng, SIGMA Weather Group, State Key Laboratory for Space Weather, Center for Space Science and Applied Research, Chinese Academy of Sciences, CHINA In this paper, we introduce a new three dimensional magnetohydrodynamics numerical model to simulate the steady state solar wind ambient from the solar surface to 215 Rs or beyond, and the model adopts a splitting finite volume scheme based on a six-component grid system in spherical coordinates. By splitting the magnetohydrodynamics equations into a fluid part and a magnetic part, a finite volume method (Ziegler, JCP, 2004; Ziegler, JCP, 2011) is used for the fluid part and the constrained-transport method that can maintain the divergence-free constraint on the magnetic field is used for the magnetic induction part. This new model of second order in space and time is validated in modeling the large-scale structure of solar wind. The numerical results for Carrington rotation 2064 show its capability of producing structured solar wind in agreement with observations. Furthermore, the MHD equations are solved at each physical time step by advancing in pseudo time. As an independently developed three-dimensional MHD code, the present scheme combined with dual time technique has demonstrated the accurateness and robustness through numerical experiments of solar wind ambient during different solar activities from minimum to maximum. The use of dual time stepping is beneficial in the computation since the use of dual time stepping allows the physical time step not to be limited by the corresponding values in the smallest cell and to be selected based on the numerical accuracy criterion. The capability of modeling strong magnetic field (small plasma beta region) is validated because of the admittance of enlarged CFL condition. The pseudo time iteration steps required for convergence depend on the CFL number and grid numbers. In our tests, under enlarged CFL number 50, 15 pseudo time iterations are need to meet the assigned tolerance, compared to the CFL number 0.5 that will takes 100 iterations. In a pseudo-time, additional acceleration techniques, such as multigrid (Kifonidis, 2012, AA), time-derivation preconditioning (Turkel, 1999, AnRFM), should be used without changing the properties of the physical-time in order to explore fast computational speed. These considerations, combined with the present method's application to the numerical simulation of solar corona looks promising in pursuing small plasma beta simulation as well as computational speedup.
Fujimoto, Keizo	***Kinetic Modeling of Collisionless Magnetic Reconnection in Three Dimension*** Keizo Fujimoto, National Astronomical Observatory, Japan One of the main issues on magnetic reconnection processes is the mechanism breaking the frozen-in condition around the x-line and providing the electric resistivity in collisionless plasmas. It has been recognized empirically in magnetohydrodynamic simulations that the Petschek-type fast reconnection can be achieved only when an intense resistivity arises locally near the x-line. However, the generation mechanism of the resistive effects in collisionless plasmas is poorly understood in the kinetic framework. The present study focuses on the 3D dissipation mechanism in a quasi-steady period for the anti-parallel configuration. Large-scale 3D particle-in-cell simulations with adaptive mesh refinement have revealed that a current-aligned electromagnetic mode produces turbulent electron flow that facilitates the transport of the momentum responsible for the current density. It is found that the electromagnetic turbulence is drastically enhanced in association with plasmoid formations and has a significant impact on the dissipation at the x-line. The linear analyses indicate that the mode is driven by the flow velocity shear across the current layer rather than the relative drift velocity between the electrons and ions. The kinetic simulations as well as the linear analyses suggest the importance of turbulence in dissipation processes of 3D collisionless reconnection.

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Goldstein, Melvyn	***Three-Fluid Solar Wind Model with Eddy Viscosity*** Melvyn L. Goldstein, NASA Goddard Space Flight Center Arcadi V. Usmanov, NASA GSFC and Univ. of Delaware William H. Matthaeus, Univ. of Delaware We describe a three-fluid, three-dimensional magnetohydrodynamic (MHD) solar wind model that incorporates turbulence transport, eddy viscosity, turbulent resistivity, and turbulent heating. The solar wind plasma is modeled as a system of co-moving solar wind protons, electrons, and interstellar pickup protons, with separate energy equations for each species. Numerical steady-state solutions of Reynolds-averaged solar wind equations coupled with turbulence transport equations for turbulence energy, cross helicity, and correlation length are obtained by the time relaxation method in the corotating with the Sun frame of reference in the region from 0.3 to 100 AU. The model equations include the effects of electron heat conduction, Coulomb collisions, photoionization of interstellar hydrogen atoms and their charge exchange with the solar wind protons, turbulence energy generation by pickup protons, and turbulent heating of solar wind protons and electrons. The turbulence transport model is based on the Reynolds decomposition and turbulence phenomenologies that describe the conversion of fluctuation energy into heat due to a turbulent cascade. In addition to using separate energy equations for the solar wind protons and electrons, a significant advance is that the turbulence model uses an eddy viscosity approximation for the Reynolds stress tensor and the mean turbulent electric field. The approximation allows the turbulence model to account for driving of turbulence by large-scale velocity gradients. Using either a dipole approximation for the solar magnetic field or synoptic solar magnetograms from the Wilcox Solar Observatory for assigning boundary conditions at the coronal base, we apply the model to study the global structure of the solar wind and its three-dimensional properties, including embedded turbulence, heating and acceleration throughout the heliosphere.
Hanawa, Tomoyuki	***Wiggle instability revisited: the role of bulk viscosity*** Tomoyuki Hanawa, Chiba University, Japan The wiggle instability, which appears in the numerical models of galactic spiralshocks, is reexamined by taking account of the bulk viscosity. The numerical models hitherto have not taken account of the bulk viscosity explicitly, asfar as the author knows. However it provides a dominant term in the pressure tensor in the transition layer of a strong shock, if we take account of a small but finite amount of the viscosity. Although the transition layer is very thin in reality, it is artificially broadened by limited resolution in numerical models. Thus the bulk viscosity should be enhanced according tothe resolution to reproduce the pressure tensor properly in the broadened shock transition region. I have made several numerical experiments in order to examine the validity of the argument mentioned above. The enhancedbulk viscosity provides seemingly smooth density and velocity profiles in the transition layer. As a result, the profiles depend little on theangle between numerical cell boundary and the shock front. A stationaryplane shock wave is heavily distorted if the wave front is inclined withrespect to the cell boundary and the bulk viscosity is not taken intoaccount. Also the odd-even instability is cured by the bulk viscosity.The wiggle instability disappears when the bulk viscosity is enhanced in the regions of converging flow. The enhanced bulk viscosity doesnot affect the growth of the Kelvin-Helmholtz instability. These resultssupport the above mentioned hypothesis. We also argue the location ofthe galactic shock on the basis of the wiggle instability free models.
Hansteen, Viggo	***Numerical modeling of the solar chromosphere and corona; what has been done? what should be done?*** Viggo Hansteen, University of Oslo, Norway A number of increasingly sophisticated numerical simulations spanning the solar atmosphere from below the photosphere in the convection zone to far above in the corona have shed considerable insight into the role of the magnetic field in the structure and energetics of the Sun's outer layers. This development is strengthened by the wealth of observational data now coming on-line from both ground and space based observatories. In this talk we will concentrate on the successes and failures of the modeling effort thus far and discuss the inclusion of various effects not traditionally considered in the MHD description such as time dependent ionization, non-LTE radiative transfer, and generalized Ohm's law.

Holmstrom, Mats	***A Hybrid Model for the Interaction Between the Solar Wind and Planets Implemented in FLASH*** Mats Holmstrom, Swedish Institute of Space Physics, Kiruna, Sweden A hybrid plasma solver treats ions as particles and electrons as a fluid. Here we present a hybrid solver for the interaction between the solar wind and planets. The parallel solver is implemented in the FLASH open source software framework. We discuss the implementation of different model features, such as permanent magnetic fields, internal resistivity of the obstacle (planet), low density regions, particle collisions, and ionospheric chemistry. Examples are shown for the plasma interactions of the Moon, Jupiter's moon Callisto and Mars.
Hotta, Hideyuki	***Solar differential rotation maintained by small- and large- scale convection*** Hideyuki Hotta, High Altitude Observatory, USA Matthias Rempel, High Altitude observatory, USA Takaaki Yokoyama, University of Tokyo, Japan The sun is rotating differentially. Helioseismology has revealed the detailed structure of the solar differential rotation. One of the most important features is the near surface shear layer (NSSL). It is thought that the solar differential rotation is maintained by the turbulent thermal convection. Around the NSSL, the time scale of the thermal convection drastically changes. This means that the influence of the rotation on the convection changes too. In order to reproduce the NSSL by the numerical calculations, we must prepare a huge number of grids and integrate large number of time steps for covering the broad spatial and temporal scales. This requirements for the NSSL is achieved using our recent efficient numerical method and the supercomputer K in Japan. In the calculation, the global scale and the supergranulation scale convection is established simultaneously. Then the solar like NSSL is partially reproduced. Around the NSSL, the convection transports the angular momentum radially inward and generates the poleward meridional flow. This poleward meridional flow generates the positive correlation of radial and latitudinal velocities, i.e. Reynolds stress. The inertial force by the Reynolds stress is balanced with the Coriolis force in the NSSL.
Inutsuka, Shu-Ichiro	***Dynamics of Interstellar Medium:*** ***Theory, Methodology, and Implications*** Shu-ichiro Inutsuka, Nagoya University, Japan Tsuyoshi Inoue, NAO, Japan Kazunari Iwasaki, Nagoya University, Japan Yusuke Tsukamoto, Nagoya University, Japan Numerical simulation of the phase transition dynamics of interstellar medium requires magnetohydrodynamics (MHD) description of very different length scales from sub-pc “Field length” to galactic scale First part of this review talk is focused on the various techniques to improve the accuracy of the numerical scheme based on method of characteristics. The description includes two-fluid MHD that describes ambipolar diffusion, Riemann Solver in MHD and the evolutionary condition of intermediate shocks in MHD. MHD of interstellar medium is remarkably different from that of simple barotropic gas owing to the phase transitions between cold phase and warm phase (and hot phase) that trigger variety of instabilities. Identifications of distinct instabilities in various stages provide us important clues for understanding the saturation levels of turbulent energies and rates of formation and destruction of cold clouds, such as HI clouds and molecular clouds. Recent progress in this line of numerical simulations is reviewed and implications are outlined.

Ivan, Lucian	***A High-Order Solution-Adaptive CENO Finite-Volume Scheme for MHD on Multi-Block Cubed-Sphere Grids*** Lucian Ivan, Department of Applied Mathematics, University of Waterloo, Canada Hans De Sterck, Department of Applied Mathematics, University of Waterloo, Canada Clinton P.T. Groth, University of Toronto Institute for Aerospace Studies, Canada Accurate, efficient and scalable high-performance computing (HPC) methods for massively-parallel computational clusters are highly desirable for large-scale scientific computing applications, especially for problems exhibiting spatial and temporal multi-resolution scales and non-trivial geometries. For global magnetohydrodynamics (MHD) modelling, high-accuracy approaches could significantly reduce the grid requirements, thereby enabling more affordable yet accurate predictions. Key challenges in MHD space physics are related to providing accurate and efficient discretizations on spherical domains, maintaining solenoidal magnetic fields and capturing shocks. This talk provides an overview of the development and application of a fourth-order finite-volume discretization procedure in combination with a parallel solution-adaptive algorithm for solution of hyperbolic conservation laws on three-dimensional cubed-sphere grids. Numerical results to illustrate current capabilities of the multi-dimensional high-order, solution-adaptive, cubed-sphere computational framework are discussed.
Joos, Marc	***Magnetohydrodynamic Turbulence in Accretion Discs: A Test Case for Petascale Computing in Astrophysics*** Marc Joos, CEA - Service d'Astrophysique, France Sébastien Fromang, CEA - Service d'Astrophysique, France Angular momentum transport in accretion discs is one of the major issues of modern astrophysics and is crucial to understand as various astrophysical problematics as black hole dynamics or planet formation. Angular momentum transport relies on magnetohydrodynamic turbulence, responsible for the non-linear evolution of the magneto-rotational instability (MRI). 3D simulations are essential to determine the physical properties of the flow resulting from this instability. In particular, angular momentum transport rate induced by the MRI is difficult to estimate, depending on dissipation rates which are linked to viscous and resistive scales. These dissipation scales are very different and to simulate flows with such properties is very challenging. We recently realized a simulation with the higher viscous dissipation coefficient ever reach on a BlueGene/Q. We discuss the challenges encountered in this context and the developments realized regarding efficient parallel Input/Output, hybridation and porting on GPGPU.
Kaeppeli, Roger	***Well-balanced Schemes for Gravitationally Stratified Media*** Roger Kaeppeli Seminar for Applied Mathematics, ETH Zurich Switzerland The Euler equations with gravitation are an example of a system of conservation laws with source terms. These systems allow steady state solutions where the flux divergence is exactly balanced by the source term. Standard high-resolution finite volume schemes have troubles to maintain this equilibrium at the discrete level. This results in spurious waves that can obscure the phenomenon of interest. The failure of standard schemes is particularly flagrant in under-resolved regions, which are generally unavoidable in multi-dimensional simulations. The main reason for the failure of standard schemes is due to the fact that the equilibrium cannot be represented by simple polynomial functions. Therefore, the commonly employed reconstruction techniques, based on piece-wise polynomials, lead to non-zero truncation errors. These errors are at the origin of the spurious waves. Schemes that preserve exactly some discrete version of the steady states of a system of conservation laws with source terms are termed as well-balanced. Well-balanced schemes for the Euler equations with gravitation have been developed for isentropic and isothermal stratifications. In this talk we present new schemes capable of resolving exactly arbitrarily entropy or temperature stratified equilibria. We present a second-order well-balanced reconstruction technique based on a local discrete representation of hydrostatic equilibrium. We demonstrate the performance of our well-balanced reconstruction on a series of astrophysically relevant problems: the propagation of waves in the solar atmosphere, self-gravitating proto-neutron stars in core-collapse supernovae and convection inside stars.

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Kawai, Soshi	***A new divergence-free-preserving high-order scheme for magnetohydrodynamics*** Soshi Kawai, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan. In this presentation, we present a new strategy that is very simple, divergence-free, high-order accurate, yet has an effective discontinuous-capturing capability for simulating magnetohydrodynamics (MHD) with shock waves. The new strategy is to construct artificial diffusion terms in a physically-consistent manner, and to build into the induction equations in a conservation law form at a partial-differential-equation level. We analytically derive the form of physically-consistent artificial diffusion terms that act as a diffusion term only in the curl of magnetic field to capture numerical discontinuities in the magnetic field while not affecting the divergence field (thus maintaining divergence-free constraint). The method is based on finite difference method with co-located variable arrangement, and we show that any linear finite difference scheme in an arbitrary order of accuracy can be used to discretize the modified governing equations to ensures the divergence-free and the global conservation constraints numerically at the discretization level. The proposed method is inherently divergence-free both ideal and resistive MHD, with and without shock waves, and also both inviscid and viscous flows.
Khazanov, George	***Kinetic Theory of Superthermal Electrons in the Ionosphere-Magnetosphere System*** George V. Khazanov, NASA, USA The superthermal electrons (SE) are the major energy contributor to the ionosphere and inner magnetosphere system via the Coulomb collision processes. The SE escape from the ionosphere to the magnetosphere is controlled by strong Coulomb coupling with the thermal plasma distribution along the entire magnetic field line. The thermal plasma distribution along the field line, in turn, is controlled by electron and ion temperature distributions that are mostly determined by SE heating of the thermal electrons. We have especially emphasized the proper Coulomb collision description of the SE interaction with the thermal plasma that must be performed using the Landau collision term. This issue will be discussed in detail in this talk based on the analysis of some cases in which such a description is crucial.
Kim, Yonghwi	***Gaseous Structures and Mass Drift in Spiral Galaxies : Effects of Spiral Arms and Magnetic Fields*** Yonghwi Kim, Seoul National University, Korea Woong-Tae Kim, Seoul National University, Korea Stellar spiral arms and magnetic fields in disk galaxies play important roles in the formation of gaseous substructures such as spurs/feathers as well as mass inflow/outflows in the radial direction. We present the results of our recent magneto-hydrodynamic simulations that study nonlinear responses of self-gravitating and/or magnetized gas to an imposed stellar spiral potential in galactic disks with differing arm strength, pattern speed, and magnetic field strength. We find that the extent and shapes of gaseous arms as well as the radial mass drift rate depend rather sensitively on the arm pattern speed. Magnetic fields not only reduce the peak density of galactic spiral shocks but also transport angular momentum additionally via magnetic pressure and tension forces. We quantify the relative contribution of shock dissipation, external torque, and self-gravitational torque to the total mass inflow rate, and demonstrate that the distributions of line-of-sight velocities and spiral-arm densities can be a useful diagnostic tool to distinguish whether the spiral pattern is rotating fast or slow. We also present physical interpretations of our results and discuss astronomical implications of our findings.
Kiuchi, Kenta	***Magnetized binary neutron star merger simulations on K*** Kenta Kiuchi, Yukawa Institute for Theoretical Physics, Japan We performed numerical relativity-magneto hydrodynamical simulations of binary neutron star merger on the Japanese supercomputer K. The grid resolution of 70 m is highest among the binary neutron star merger simulations done so far and we did an in-depth resolution study to figure out the amplification mechanism of magnetic fields during the binary neutron star merger. We found the Kelvin-Helmholts instability developed in the shear layer at the merger significantly amplifies the magnetic field. A hyper-massive neutron star formed after the merger is subject to the non-axisymmetric magneto-rotational instability. These two amplification mechanisms do not work with an insufficient resolution. The star collapses to a black hole and a formed accretion disk is strongly magnetized a priori. We found a coherent toroidal magnetic field inside the disk and not a coherent poloidal field above the black hole even after 60 ms after the black hole formation.

Klein, Richard	***Multi-Physics Feedback Zoom-in Simulations with Realistic Initial Conditions of the Formation of Star Clusters: From Large Scale Magnetized Clouds to Turbulent Clumps to Cores to Stars*** Richard I. Klein, UC Berkeley, Dept. of Astronomy, and Lawrence Livermore National Laboratory At present there have been a few radiation-hydrodynamic simulations, that are capable of reproducing the observed IMF over an about 2 decade range in stellar masses. In addition to reproducing the IMF without a prescribed equation of state, these simulations also reproduce a number of other properties of observed young star systems, such as the mass-dependent fraction of stars in binary and multiple systems. However, all simulations of the IMF to date rely on highly-idealized initial conditions (IC's). Existing simulations typically begin with a gas clump density and radius comparable to the typical densities and sizes of nearby newborn star clusters. Current approaches, however, do not properly capture the density and velocity structure that would result from the formation of such a protocluster gas clump within a GMC, during which energy and mass are continually accreted from larger scales – perhaps often along a filament. To address this crucial challenge to the development of a predictive theory of star formation, I will present new simulations of the formation of star clusters starting with turbulence driven on the larger scales of small GMC's and evolving to the formation of turbulent clumps down to molecular cores and to stars that include the fully coupled effects of magnetic fields, protostellar outflows, and radiation transport. To achieve the large dynamical range required we employ new zoom-in AMR simulations with our multi-physics AMR code ORION, of selected regions within our new large-scale turbulent MHD simulations of the formation of IRDCs. In the talk I will discuss the different stages of the zoom-in simulations at different scales leading to star formation within these large clouds beginning with the properties and formation of extended massive braided filamentary dark clouds with density profile similar to observations. I will then discuss and compare the properties of our turbulent clumps with observations of cloud clumps with Zeeman magnetic field measurements. I show that the magnetic properties of the cloud clumps from our simulations match very well with the observations, including the formation of a power law relation between magnetic field strength $\|B\|$ and volume density n(H) with the power index α very close to the value of 0.65 deduced from a Bayesian analysis of observed cloud clumps as well as the probability distribution function of the observed B/n(H)^\alpha. These strong field AMR simulations provide us self-consistent and realistic turbulence ICs of magnetized filamentary molecular clouds for high-resolution zoom-in star cluster formation simulations with radiation feedback and outflows after dense clump cores are formed inside the clouds. Upon collapse of the dense clumps, we perform the next stage of AMR zoom-in simulations on a small segment of the long dark filament. The size of the zoom-in region is large enough for the study of the effects of the radiation and outflow feedback from newly forming young stars and clusters on the dense surrounding molecular cloud environment. Finally, I will discuss the effect of realistic initial conditions on the formation of the resultant IMF from these large to small-scale simulations.
Kritsuk, Alexei	***Energy Cascade and Scaling in Supersonic Turbulence*** Alexei Kritsuk, UCSD, USA Rick Wagner, SDSC, USA Michael Norman, SDSC, USA Supersonic turbulence plays an important role in a number of extreme astrophysical and terrestrial environments, yet its understanding remains rudimentary. We use data from a three-dimensional simulation of supersonic isothermal turbulence to reconstruct an exact relation derived analytically from the Navier--Stokes equations (Galtier & Banerjee, 2011, PRL, 107, 134501). Our analysis supports a Kolmogorov-like inertial energy cascade in supersonic turbulence previously discussed on a phenomenological level. A new approximate scaling relation for supersonic turbulence is derived and validated. This relation has a remarkable property to asymptotically converge to the 4/5 law at Mach numbers below unity and also capture correct asymptotic behavior at high Mach numbers. Moreover, it allows one to derive Larson's relations observed in molecular clouds from first principles, supporting their interpretation in terms of supersonic turbulence.

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Kucharek, Harald	***Multi-Dimensional Multi-Species Hybrid Simulations for Instabilities and Wave Turbulence at the Termination Shock.*** H. Kucharek, University of New Hampshire, NH, USA. K. V. Gamayunov, Florida Institute of Technology, FL, USA. H-R. Mueller, Dartmouth College, Hanover, FL, USA N. Pogorelov, University of Alabama in Huntsville, Huntsville, AL, USA. The Interstellar Boundary Explorer (IBEX) provided several all sky images in the light of Energetic Neutral Atoms (ENAs). These images showed a ribbon feature which was unexpected and which formation mechanism is still unknown. Aside from the Ribbon feature the distributed ENA flux shows temporal variations that are unexplained, in particular at solar wind energies. ENAs are of heliospheric origin, and a product of charge exchange of interstellar neutrals with energetic ions at the Termination Shock (TS), in the heliosheath, the heliopause, or even beyond. Therefore, the energy and the phase-space distribution is therefore the original energy of the energetic ions. Their temporal evolution and energetization is a product of wave-particle interactions. ENA intensity observed by IBEX at Earth's orbit depends on all kinetic processes at different scales (ion and MHD scales) at the TS and in the heliosheath. Hybrid simulations, which included all kinetic processes self-consistently on the ion level, are a proven to be a very powerful tool to investigate wave-particle interaction, turbulence, and phase-space evolution of pickup and solar wind ions (such as H+, He+ and He2+). We performed 2D and 3D multi-species hybrid simulations for an ion/ion beam instability to study the temporal evolution of ion distributions, their stability, and the associated ENA generation under the influence of self-generated, self-consistent waves in the heliosheath. We investigated the energetization of ions downstream of the TS, the turbulence, and growth rate of instabilities in the heliosheath. All these processes are critical to understand the intensity and the spectral properties of ENA distributions at IBEX orbit.
Lembege, Bertrand	***3D global particle-in-cell simulations of the solar wind-terrestrial magnetosphere interaction: analysis of the cusp region*** B. LEMBEGE, LATMOS-CNRS, France D.S. CAI, IISE, Univ. Tsubuka, Japan A. ESMAEILI, Univ. Tsubuka, Japan K. NISHIKAWA, NSSTC, UAH, USA The interaction of the solar wind with the terrestrial magnetosphere is analyzed with the help of a three-dimensional (3D) global full electromagnetic particle-in-cell (PIC) simulations, in the configuration where the Interplanetary Magnetic Field (IMF) is northward. The present study is mainly focussed on the cusp region and associated particle momenta dynamics. Within the present context, this work represents to our knowledge- the first numerical simulation for analyzing the cusp dynamics within a full consistent 3D kinetic and electromagnetic approach. The main goals of the study are : (i) to retrieve the main features of the cusp known until now in order to validate the use of 3D PIC 'global' simulations, (ii) to compare with previous results obtained with 3D MHD simulations, (iii) to complete the updated global view of the cusp thanks to the present use of 3D PIC simulation and not accessible by MHD approach, (iv) to compare with statistical results of experimental CLUSTER mission. In particular we will focuss on recent features of the cusp evidenced experimentally by CLUSTER mission (the Alfven Transition Layer or ATL) and not retrieved by MHD and hybrid approach, which completes the features of the outer edges of the cusp.
Li, Shengtai	***Long-Term Simulations of Rossby Vortex Instability in Proto-planetary Disks with Dead Zone*** Shengtai Li, Los Alamos National Lab, USA Hui Li, Los Alamos National Lab, USA The ALMA has revealed images of large asymmetries in the distribution of millimeter sized dust in proto-planetary disks. These large-scale asymmetries has been related to the excitation of Rossby wave/vortex instability (RWI/RVI). Using our high resolution and fast simulation tool (LA-COMPASS), we have performed both 2D and 3D simulations to investigate the generation and sustainability of RWI vortex in proto-planetary disks with dead zone. We find the vortex can be sustained for a long time (even for the life time of the disk). We also investigate the vortex extended length in azimuthal direction and vortex width in radial direction, both of which depend on the width and depth of the dead zone. A comparison with ALMA observation is also provided.

Loring, Burlen	***A screen space GPGPU surface LIC algorithm for parallel interactive exploration of large composite datasets*** H. Karimabadi, Department of Electrical and Computer Engineering, University of California, San Diego, USA V. Rortershteyn, Department of Electrical and Computer Engineering, University of California, San Diego, USA W. Daughton, Los Alamos National Laboratory, USA The standard way to visualize streamlines of a vector field is to seed some points and integrate to trace curves that are instantaneously tangent to the velocity vector. Although useful, this approach can be cumbersome when interactively exploring a dataset. For example, the technique is inherently local and unless feature locations are know apriori it's difficult to select an effective set of seed points. An alternative technique called ”line integral convolution” or LIC, which convolves noise with a vector field producing streaking patterns that follow vector field tangents, has the advantage that a very detailed view of the streamlines over the entire computational domain is found in one step without the need to explicitly specify a set of seed points. However, the technique is computationally expensive and the quality of the results are highly data dependent. In the case of screen space LIC on arbitrary surfaces, which is fast enough for interactive use, the results are highly sensitive to a number of run time parameters such as scene lighting, camera position, orientation, screen resolution, and other view related parameters. As a result of these issues the technique often produces low contrast and low dynamic range images, making flow patterns difficult to discern and pseudo-coloring with scalar fields challenging. This work presents a GPGPU screen space surface LIC algorithm specifically tailored for the parallel interactive visualization and exploration of large composite datasets. Interactivity is achieved through an efficient parallel load balancing and compositing algorithm that simultaneously reduces inter-process communication and redundant computation. New shading algorithms that address variability introduced by data dependence and produce high contrast flow patterns and high dynamic range pseudo-coloring across a wide variety of input data and viewing parameters are presented. We show results from the visual analysis of a PIC simulation of turbulence in a hot magnetized plasma.
Masset, Frederic	***Planet-Disk Interaction on the GPU: the FARGO3D code*** Frederic Masset, UNAM, Mexico Pablo Benitez Llambay, Cordoba Observatory, Argentina In a first part I will present the new HD-MHD code FARGO3D. It is a finite difference code in three geometries. It has orbital advection (aka FARGO) implemented for hydrodynamics and MHD. It can run indifferently on (clusters of) CPUs or GPUs. Simple syntax rules allow users to implement their own modules in C, and have them translated automatically to CUDA by a python parser, so as to effortlessly run them on GPUs. In a second part I will present an ongoing project with FARGO3D aimed at linking the tidal torque felt by a protoplanet in a laminar, magnetized two dimensional disk, to the torque expectancy felt by the same planet in a three dimensional disk subject to MHD turbulence.
Meyrand, Romain	***3D direct numerical simulations of incompressible Hall MHD: Application to solar wind turbulence.*** Meyrand Romain, LPP, France Describing the sub-ion scale behavior of weakly collisional magnetized plasmas, such as the solar wind, necessitates a priori a detailed understanding of the kinetic physics in a turbulent regime. The complexity of such an approach however limits the theoretical developments and forces numerical experiments to be restricted to low Reynolds numbers. During this presentation I will show how we can take advantage of the relative simplicity of fluids models and the high precision of pseudo spectral methods to tackle the problem of turbulence in solar wind by 3D direct numerical simulations massively parallelized at high Reynolds numbers. I will highlight the existence of a spontaneous breaking of chiral symmetry in incompressible isotropic Hall MHD turbulence, as well as the existence of a new regime called ion MHD (IMHD). A new turbulence regime of 3D EMHD turbulence under the presence of a strong external magnetic field will be presented, as well as some recent result about weak incompressible Hall MHD turbulence. Implications for solar wind turbulence will be discussed.

Mezzacappa, Anthony	***An Update on the Two- and Three-Dimensional Core Collapse Supernova Simulations of the "Oak Ridge" Group, and Future Plans*** Anthony Mezzacappa, University of Tennessee, USA Stephen W. Bruenn, Florida Atlantic University, USA Eric J. Lentz, University of Tennessee, USA W. Raphael Hix, Oak Ridge National Laboratory, USA O.E. Bronson Messer, Oak Ridge National Laboratory, USA J. Austin Harris, University of Tennessee, USA Eric J. Lingerfelt, Oak Ridge National Laboratory, USA Eirik Endeve, Oak Ridge National Laboratory, USA Konstantin N. Yakunin, University of Tennessee, USA John M. Blondin, North Carolina State University, USA Pedro Marronetti, National Science Foundation, USa We present an update on the two- and three-dimensional simulations of core collapse supernovae being carried out by the "Oak Ridge" group. Our two-dimensional simulations have now progressed to 1.2-1.4 seconds after stellar core bounce, long enough to characterize important quantities such as the explosion energy and the 56Ni mass produced, and to compare both with observations. We also present an update on our ongoing three-dimensional simulation, which has reached a critical stage, approximately 300 ms after stellar core bounce, prior to the potential onset of explosion. Finally, we discuss our overall near- and long-term strategy, spanning the peta- and exa- scales.
Moesta, Philipp	***Modeling Magnetorotational Core-Collapse Supernovae in Three Dimensions*** Philipp Mösta, Caltech, USA Sherwood Richers, Caltech, USA Christian D. Ott, Caltech, USA Roland Haas, Caltech, USA Anthony L. Piro, Caltech, USA Kristen Boydstun, Caltech, USA Ernazar Abdikamalov, Caltech, USA Christian Reisswig, Caltech, USA Erik Schnetter, Perimeter Institute, Canada I present results of new three-dimensional (3D) general-relativistic magnetohydrodynamic simulations of rapidly rotating strongly magnetized core collapse that we have performed in the last year. These simulations are the first of their kind and include a microphysical finite-temperature equation of state and a leakage neutrino heating/cooling scheme that captures the overall energetics correctly. Our results show that the 3D dynamics of magnetorotational core-collapse supernovae are fundamentally different from what was anticipated on the basis of previous 2D simulations. A strong bipolar jet that develops in a simulation constrained to 2D is crippled by a spiral instability and fizzles in full 3D. Our analysis suggests that the jet is disrupted by an m = 1 kink instability of the ultra-strong toroidal field near the rotation axis. A completely new flow structure develops as highly magnetized plasma funnels push out the shock in polar regions, creating wide secularly expanding lobes
Nakamura, Sho	***Development of a HLL approximate Riemann solver for magnetohydrodynamics including Cosmic-Ray effects*** Sho Nakamura, Tohoku University, Japan We developed a new numerical magnetohydrodynamic (MHD) solver in which effects of the Cosmic-Ray(CR) pressure is taken into account when the speeds of the fast magneto-acoustic wave are calculated in the Harten-Lax-van Leer (HLL) Riemann solver. The sound speed in usual HLL Riemann solver is replaced by the effective sound speed which is combined thermal gas and CRs. Diffusive propagation of the CR is also solved. To treat diffusion term of the CR as flux term, diffusion of the CR is solved by explicit method. In this presentation, we explain the fundamentals of our method and show results of test problem.

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Ng, Chung-Sang	***From the Parker Model to Turbulent Heating of the Solar Corona*** C. S. Ng, Geophysical Institute, University of Alaska Fairbanks, USA T. J. Dennis, Geophysical Institute, University of Alaska Fairbanks, USA We present results from a series of three-dimensional simulations investigating the heating in solar coronal loops of various lengths, based on the equations of reduced magnetohydrodynamics, following up on our recent simulations of the Parker model of coronal heating [Ng et al., Astrophys. J., 747, 109, 2012]. We study the time-averaged energy dissipation rate <W> as a function of the length of the loop L. We confirm that in the limit of small L (L << V_A*T_c, where V_A is the Alfven speed based on the parallel magnetic field and T_c is the correlation time of the random photospheric motions), <W> agrees well with the scaling derived from the Parker model. In the other limit of L >> V_A*T_c, we show that <W> is given by the photospheric Poynting flux required to launch Alfven waves. In the intermediate range of L ~ V_A*T_c, <W> is well described by a scaling based on the Kolmogorov turbulence energy cascade, rather than the Iroshnikov-Kraichnan cascade. We also show that <W> can be modeled by combining the Parker heating and the Alfven wave launching power for all range of L. This work is supported by a NSF grant AGS-0962477.
Obergaulinger, Martin	***Magnetic Field Amplification in Non-Rotating Stellar Core Collapse*** Martin Obergaulinger, Universitat de València Thomas Janka, Max-Planck-Institut für Astrophysik Miguel Ángel Aloy Torás, Universitat de València We present results of simulations of core collapse using a code for the coupled evolution of the equations of magnetohydrodynamics and neutrino transport. We find that during collapse, flux-freezing compression amplifies the pre-collapse field by a few orders of magnitude, and after bounce hydrodynamic instabilities in the region behind the stalled shock wave such as convection and the standing accretion shock instability add another factor of up to roughly 10 to the amplification. The magnetic energy never reaches equipartition with the internal energy, but strong initial fields modify the post-shock flows and support the revival of the shock wave.
Oran, Rona	***Heavy Ion Composition in the Fast and Slow Solar Wind: Results from a Global MHD Model Coupled to a Charge Evolution Code*** Federico Nuevo, ,1. Instituto de Astronomía y Física del Espacio (IAFE), CONICET-UBA, CC 67 - Suc 28, (1428) Buenos Aires, Argentina. 2. Facultad de Ciencias Exactas y Naturales (FCEN), Universidad de Buenos Aires. Alberto Vásquez,1. Instituto de Astronomía y Física del Espacio (IAFE), CONICET-UBA, CC 67 - Suc 28, (1428) Buenos Aires, Argentina. 2. Facultad de Ciencias Exactas y Naturales (FCEN), Universidad de Buenos Aires. Rich Frazin, University of Michigan Igor Sokolov, University of Michigan Ward Manchester, University of Michigan Tamas Gombosi, University of Michigan The mechanisms responsible for the formation of the slow solar wind are a subject of vigorous debate in the heliospheric community. Heavy ion composition in the solar wind is an important observable that allows us to study the wind's evolution. The final "freeze-in" distributions measured in-situ at 1AU and beyond depend on the plasma conditions along the wind trajectory close to the Sun, and are known to be significantly different when measured in either the fast or slow solar wind. As such, heavy ion charge states have played an important role in testing the various theories concerning the formation of the fast and slow wind, and in determining the source region of the slow solar wind. In this talk, we will present results from a global MHD model of the solar atmosphere, in which the wind is heated and accelerated by Alfven waves. The global model results are used to drive a charge state evolution code along open magnetic field lines at all heliographic latitudes. The resulting charge state distributions for O, C, and Fe are compared to in-situ Ulysses measurements at 1-2AU as well as to high resolution spectra observed in the lower corona. We find that the large scale latitudinal variation of the O+7/O+6, C+6/C+5 ratios as well as the average charge state of Fe are captured by the model. In particular, the observed increases of these quantities in the slow (steady) solar wind compared to the fast wind are reproduced. We demonstrate that these increases are associated with a higher plasma density at the base of open field lines whose foot-points are located near the boundary of the coronal holes. We show that this density enhancement as predicted by the model is consistent with EUV tomographic reconstructions of the lower corona. We discuss the possible interpretations and implications of our results to our understanding of solar wind formation.

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Pierrard, Viviane	***Kinetic Models for the Solar Wind and Other Space Plasmas*** Belgian Institute for Space Aeronomy 3 av. Circulaire Belgium Kinetic models are developed at BISA for the solar wind and for other space plasmas like the polar wind, the plasmasphere and the radiation belts of the Earth and other planets. The characteristics of the plasma are obtained by solving the evolution equation to determine the velocity distribution functions of its different particle species. The moments are obtained by integrating them over the velocity space. The kinetic description may distinguish between the partial density of the electrons and different ion species, individual species bulk speeds, parallel and perpendicular temperatures, up to parallel and perpendicular heat flow tensor components or even higher moments of the underlying velocity distribution function. The existence of non-Maxwellian features in the energy spectrum of particles and asymmetries in their pitch angle distributions can be studied, as well as the effects of Coulomb collisions, wave-particle interactions and turbulence. Illustrated mainly by the recent progress obtained for the solar wind model, we will also show other models of space plasmas obtained by using the kinetic approach. To determine the dynamics of specific regions in the terrestrial magnetosphere, these models also include the effects of the solar wind.
Pogorelov, Nikolai	***Mixing of the Interstellar and Solar Plasmas at the Heliospheric Interface*** Nikolai Pogorelov, Department of Space Science and CSPAR, University of Alabama in Huntsville Sergey Borovikov, CSPAR, University of Alabama in Huntsville Recent observations from the Voyager 1 spacecraft show that it penetrated into the local interstellar medium (LISM).This is quite surprising because no realistic, steady-state model of the solar wind (SW) interaction with the LISM gives the inner heliosheath width as narrow as 30 AU and the heliopause (HP) at 122 AU. This includes such models that assume a strong redistribution of the ion energy to the tails in the pickup ion distribution function. We show that the HP, which separates the SW from the LISM, is not a smooth tangential discontinuity, but rather a surface subject to Rayleigh-Taylor-type instabilities which can result in the LISM material penetration deep inside the SW. We also show that the HP flanks are always subject to a Kelvin—Helmholtz instability. The RT instability is considerably suppressed near the HP nose by the heliospheric magnetic field in steady-state models, but reveals itself in the presence of solar cycle effects and occasional magnetic field dissipation in the turbulent SW on the heliospheric side of the HP. We demonstrate that Voyager 1 may be in one of such instability regions and therefore observing plasma densities much higher than those in the pristine SW. Our results may be an explanation of the Voyager 1 early penetration into the LISM. They also show that there is a possibility that the spacecraft may start sampling the SW again before it finally leaves the heliosphere. Instabilities in the heliotail region are also discussed.
Price, Daniel	***The Marriage of Gas and Dust*** Daniel Price, Monash University, Australia Guillaume Laibe, University of St. Andrews, Scotland I will present our recent work on numerical methods for simulating two-fluid mixtures containing gas and dust. In particular, I will present our new method based on the "diffusion approximation for dust", appropriate to simulating small dust grains in the interstellar medium. I will also outline the relevance and analogies with multi-fluid MHD.
Radice, David	***Beyond 2nd Order Convergence in Simulations of Binary Neutron Stars*** David Radice, Caltech, USA Luciano Rezzolla, Frankfurt, Germany Filippo Galeazzi, Frankfurt, Germany The inspiral and merger of binary neutron stars (BNSs) is one of the most promising sources of gravitational waves (GWs) for future ground-based laser detectors such as LIGO, Virgo or KAGRA. GWs carry valuable information concerning the binary parameters as well as the equation of state of neutron stars. Extracting such information, however, requires the use of accurate models of GWs that can only be constructed using numerical-relativity simulations. Even though few high-quality BNSs waveforms have been computed in the past few years, substantial difficulties need to be addressed to be able to cover the parameter space of BNSs and produce reliable GWs templates. In this talk I present some recent progress in the modeling of BNSs in numerical relativity. In particular I will show how, with the use of higher-order numerical schemes, we were able to obtain GWs signals showing, for the first time, higher-than-second-order accuracy in the phase and amplitude evolution. Our results are also in excellent agrenment with the predictions of post-Newtonian theory almost up to the contact frequency of the binary.

Rossmanith, James	***A Mixed Fluid-Kinetic Solver for the Vlasov-Poisson System*** James Rossmanith, Iowa State University, Department of Mathematics, USA. Yongtao Cheng, University of Wisconsin, Department of Mathematics, USA. The dynamics of plasma can be simulated using kinetic or fluid models. Kinetic models are valid over most of the spatial and temporal scales that are of physical relevance in many application problems; however, they are computationally expensive due to the high-dimensionality of phase space. Fluid models have a more limited range of validity, but are generally computationally more tractable than kinetic models. One critical aspect of fluid models is the question of what assumptions to make in order to close the fluid model. A theoretically ideal but practically difficult to achieve model would combine positive aspects from both the kinetic and fluid models. In this work we develop and study an approach to hybridize fluid models with the Vlasov equation. The transfer of information from the kinetic to the fluid model (i.e., restriction) can be readily handled through the computation of moments. How to handle the transfer in the other direction (i.e., prolongation) is much less clear, and we consider a variety of approaches. The resulting model is discretized using a high-order discontinuous Galerkin scheme implemented in the freely available software package DoGPack. Through a variety of numerical test cases we demonstrate that the resulting numerical scheme is both asymptotic-preserving in regimes where collisions dominate and efficient in regimes where the plasma is collisionless.
Sandroos, Arto	***Vlasiator -- Global Kinetic Magnetospheric Modeling Tool*** Sebastian von Alfthan, Finnish Meteorological Institute, Finland Sanni Hoililjoki, Finnish Meteorological Institute, Finland Ilja Honkonen, Finnish Meteorological Institute, Finland Yann Kempf, Finnish Meteorological Institute, Finland Dimitry Pokhotelov, Finnish Meteorological Institute, Finland Minna Palmroth, Finnish Meteorological Institute, Finland We present Vlasiator, a novel simulation tool based on Vlasov's equation for modeling plasma processes in near-Earth space. In Vlasiator ions are represented with six-dimensional distribution functions self-consistently coupled with electromagnetic fields and, similarly to hybrid plasma simulations, electrons are modeled as a charge-neutralizing fluid. Vlasiator, however, is free of particle noise, allowing us to model, e.g., suprathermal particle distributions throughout the magnetosphere, and wave-particle interaction occurring upstream of Earth's bow shock in unprecedented detail. Global models based on Vlasov's equation have not received much attention in the past due to the huge computational requirements. For example, typical five-dimensional Vlasiator runs (two spatial coordinates, three velocity coordinates) require of the order of 1e12-1e13 phase-space cells, requiring large supercomputers to run efficiently. Dynamic creation of the phase-space mesh at runtime reduces the number of computed phase-space cells by a factor of 100, allowing us to run the code in contemporary supercomputers having 10k+ CPU cores with a two-level OpenMP-MPI parallelization scheme.
Sazykin, Stanislav	***Numerical Simulations of the Planetary Ionosphere-Magnetosphere Interactions*** Stanislav Sazykin, Rice University, U.S.A. Richard Wolf, Rice University, U.S.A. Thomas Hill, Rice University, U.S.A. One of the primary processes controlling the dynamics of plasma populations deep in the planetary magnetospheres is interchange instability, which, together with magnetic reconnection, comprises the two fundamental processes operating almost universally in planetary and astrophysical plasmas. In this paper, we describe recent efforts to simulate effects of interchange instability in the magnetospheres of Earth and Saturn. In the case of the terrestrial magnetosphere, flux tubes with reduced entropy are injected on the nightside as a consequence of reconnection in the magnetotail and subsequently undergoing interchange convective motion. On Saturn, the challenge is to explain the stability and longitudinal asymmetry of the plasma torus unstable to the rotational Rayleigh-Taylor instability. We present numerical simulations of both cases using the Rice Convection Model, which solves a special form of the Vlasov equation applicable to the inner magnetosphere approximation, coupled with a current closure equation appropriate for conducting ionospheres.

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Sisneros, Robert	***Visualizing the Big (and Large) Data from an HPC Resource*** Robert Sisneros, National Center for Supercomputing Applications, USA Supercomputers are built to endure painfully large simulations and contend with resulting outputs. These are characteristics that scientists are all too willing to test the limits of in their quest for science at scale. The data generated during a scientist's workflow through an HPC center (large data) is the primary target for analysis and visualization. However, the hardware itself is also capable of generating volumes of diagnostic data (big data); this presents compelling opportunities to deploy analogous analytic techniques. In this talk I will discuss some of the many ways in which visualization and analysis may be crammed into the scientific workflow as well as utilized on machine-specific data.
Sur, Sharanya	***Mixing in magnetized turbulent media*** Sharanya Sur, SESE, Arizona State University, USA Liubin Pan, CfA, Harvard University, USA Evan Scannapieco, SESE, Arizona State University, USA Turbulent motions are essential to the mixing of entrained fluids and are also capable of amplifying weak initial magnetic fields by dynamo action. In this talk, we consider the mixing of pollutants in the presence of an evolving magnetic field generated by dynamo action. We show that the scalar gradient field, which must be large for diffusion to operate effectively, is always aligned transverse to the magnetic field. This is true both in the early kinematic phase, when the field is dynamically unimportant, and in the late, saturated phase, when magnetic back reactions become strong enough to influence the flow. This occurs because the scalar gradient increases within the plane of compressive motion, but the magnetic field increases perpendicular to it. At late times the saturated magnetic field is strong enough to resist compressive motions making it harder for scalar gradients to grow and likely leading to the longer mixing times. Since both mixing and magnetic field amplification are driven by turbulent motions, our results are likely to have implications on intergalactic metal enrichment and thermal conduction in magnetized intracluster gas.
Surzhikov, Sergey	***Computational Physics of Small Meteors*** Sergey Surzhikov, Institute for Problems in Mechanics RAS, Russia The modern computational aerophysical models, which were developed for mathematical modeling of aerothermodynamics and radiative gas dynamics of re-entry space vehicles, have been applied for investigation of meteoric phenomena. Short analysis of general problems of meteoric physics is presented, as well as the typical compositions of meteoric bodies are discussed. Considerable attention has been given to investigation of the non-equilibrium physical-chemical processes accompanying move of a meteor of relatively small size at high altitudes, where the vibrational relaxation zone exceeds the size of meteoric body. Two-dimensional numerical model of the chemically non-equilibrium radiative gasdynamics of the ablating meteor body entering Earth atmosphere is presented. Meteoroid of non-spherical form with 2 cm cross-section radius is considered for velocity of 30 km/s at altitude 70 km. Numerical results for spectral emissivity of the ablating stone meteor moving into Earth atmosphere at hyperbolic velocity are presented and analyzed. Calculations were performed with the use of the radiative gasdynamic model taking into account most significant radiative mechanisms of absorption and emission in multigroup approximation.
Suzuki, Takeru	***Accretion disk winds driven by MRI turbulence*** Takeru K. Suzuki & Shu-ichiro Inutsuka (Nagoya University) MHD turbulence is ubiquitous in astrophysical accretion disks. MRI is one of the promising mechanisms that excite and sustain the turbulence. We have found by both local and global MHD simulations that such MRI-driven turbulence plays a role in not only the transport of angular momentum but also vertical outflows. In this talk, after introducing briefly our numerical implementation, we discuss physical properties of the vertical outflows and their astrophysical implication.

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Toriumi, Shin	***Emerging Magnetic Fields of Active Regions in the Sun*** Shin Toriumi, National Astronomical Observatory of Japan, Japan The formation of active regions (ARs) including sunspots is one of the most prominent magnetic activities in the Sun. Sometimes ARs may cause catastrophic phenomena known as flares and CMEs. Now it is widely accepted that the ARs are formed by emerging magnetic fields from the subsurface convective layer, i.e., flux emergence. Recently, aiming to investigate the dynamics of the flux emergence, we conducted 3D MHD simulations of the emerging magnetic fields from -20,000 km of the Sun. The rising fields temporarily undergo a deceleration before they appear at the visible surface, since an unmagnetized plasma is trapped between the rising fields and the surface layer. The magnetic fields, however, restart emergence further into the upper atmosphere due to the plasma instability. The entire evolution is therefore in a two-step way. In this presentation, we introduce the above numerical study as well as our recent observations of ARs in the actual Sun.
Toth, Gabor	***Magnetohydrodynamics with Embedded Particle-in-Cell Regions: MHD-EPIC*** Gabor Toth, University of Michigan, USA Lars Daldorff, University of Michigan, USA Tamas Gombosi, University of Michigan, USA Giovanni Lapenta, KU Leuven, Belgium Jorge Amaya, KU Leuven, Belgium Stefano Markidis, KTH, Sweden Jeremiah Brackbill, LANL, USA Computational models based on a fluid description of the plasma, such as magnetohydrodynamic (MHD) and extended magnetohydrodynamic (XMHD) codes are highly efficient, but they miss the kinetic effects due to the assumptions of small gyro radius, charge neutrality, and Maxwellian thermal velocity distribution. Kinetic codes can properly take into account the kinetic effects, but they are orders of magnitude more expensive than the fluid codes due to the increased degrees of freedom. If the fluid description is acceptable in a large fraction of the computational domain, it makes sense to confine the kinetic model to the regions where kinetic effects are important. This coupled approach can be much more efficient than a pure kinetic model. The speed up is approximately the volume ratio of the full domain relative to the kinetic regions assuming that the kinetic code uses a uniform grid. This idea has been advocated by Sugiyama et al [2007} but their coupling was limited to one dimension and they employed drastically different grid resolutions in the fluid and kinetic models. We describe a fully two-dimensional two-way coupling of a Hall MHD model BATS-R-US with an implicit Particle-in-Cell (PIC) model iPIC3D. The coupling can be performed with identical grid resolutions and time steps. We call this coupled computational plasma model MHD-EPIC (MHD with Embedded PIC regions). Our verification tests show that MHD-EPIC works accurately and robustly. We show a two-dimensional magnetosphere simulation as an illustration of the potential future applications of MHD-EPIC.
Van Straalen, Brian	***Astrophysics HPC Challenges: Chapter 2: Resilience*** Brian Van Straalen, Anshu Dubey, (LBNL) Andrew Chien, Hajime Fujita (U Chicago) Previously I have addressed the ASTRONUM community about the performance challenges that new computing architectures are imposing on our numerical methods and programming practices. Now I'd like to discuss resiliency. Even today large scale simulations must guard their progress with checkpoint files since total uptime with 40K+ cores is usually less than the wall clock time needed for a complete simulation. The next generation platforms will have faults at a rate that will affect every application. What are the options to mitigate this issue and what are the trade-offs?

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Wang, Liang	***Comparing Multi-Fluid Moment and Particle-In-Cell simulations of Collisionless Mangetic Reconnection*** Liang Wang, University of New Hampshire, USA Ammar Hakim, Princeton University/Princeton Plasma Physics Laboratory, USA Amitava Bhattacharjee, Princeton University/Princeton Plasma Physics Laboratory, USA Kai Germaschewski, University of New Hampshire, USA We introduce an extensible multi-fluid model that simultaneously evolves moments of the Vlasov-Maxwell equation for each species in the plasma. The five-moment limit of this model evolves a scalar pressure for each species, while the ten-moment limit evolves the full anisotropic, non-gyrotropic pressure tensor instead, both in a self-consistent manner. We first demonstrate, analytically and numerically, that the five-moment model reduces to the Hall MHD model under the assumptions of quasi-neutrality, infinite speed of light, and vanishing electron inertia. Then, we compare ten-moment and fully kinetic Particle-In-Cell simulations of a large scale GEM magnetic reconnection problem, and confirm the capability of the ten-moment model to evolve full electron pressure tensor largely correctly, using a simplified collisionless closure relation for the heat fluxes. We also briefly discuss a locally implicit algorithm implemented to eliminate the time step constraints from plasma frequency and quadratic dispersive modes, which greatly speeds up simulation performance.
Wu, Shi Tsan	***Analyses of Variability of Solar Wind during the CR1967, 2009,*** ***using a 3DSIP-AMR-CESE Magnetohydrodynamic Model*** S. T. Wu, The University of Alabama in Huntsville, USA Xueshang Feng, Center for Space Science and Technology, China Liping Yang, Center for Space Science and Technology, China We investigate the variability of solar wind properties (i.e. density, radial velocity and radial magnetic fields) during four Carrington rotations using a solar-interplanetary space-time conservation element and solution element (CESE) magnetohydrodynamic model (SIP-CESE MHD Model). In order to resolve the various spatial scales, the adaptive mesh refinement (AMR) procedure is implemented by the parallel AMR package PARAMESH(http://sourceforge.net/projects/paramesh). This model includes the volumetric heating source terms derived from the topology of magnetic field expansion factor and minimum angular separation (at the photosphere) between an open-field footpoint and its nearest coronal hole boundary to accommodate the acceleration of the solar wind. The numerical results of the solar wind properties of different solar-activity phases (i.e. various of Carrington Relation) are compared with SOHO observations and other spacecraft data from OMNI. These results show qualitative agreement in the solar corona and in interplanetary space with the multiple-spacecraft observations.
Yoo, Hyunju	***Effects of multiple-scale driving on turbulence statistics*** Hyunju Yoo, Chungnam National University, Korea Jungyeon Cho, Chungnam National University, Korea Turbulence is ubiquitous in astrophysical fluids such as the interstellar medium and the intracluster medium. In turbulence studies, it is customary to assume that fluid is driven on a single scale. However, in astrophysical fluids, there can be many different driving mechanisms that act on different scales. If there are multiple energy- injection scales, the process of energy cascade and turbulence dynamo will be different compared with the case of the single energy-injection scale. In this work, we perform three-dimensional incompressible/compressible magnetohydrodynamic turbulence simulations. We drive turbulence in Fourier space in two wavenumber ranges, $2 < k < \sqrt{12}$ (large scale) and $15 < k < 26$ (small scale). We inject different amount of energy in each range by changing the amplitude of forcing in the range. We present the time evolution of the kinetic and magnetic energy densities and discuss the turbulence dynamo in the presence of energy injections at two scales. We show how kinetic, magnetic, and density spectra are affected by the two-scale energy injections and we discuss the observational implications. In the case $\epsilon L < \epsilon S$, where ϵL and ϵS are energy-injection rates at the large and small scales, respectively, our results show that even a tiny amount of large-scale energy injection can significantly change the properties of turbulence. On the other hand, when $\epsilon L > \epsilon S$, the small-scale driving does not influence the turbulence statistics much unless $\epsilon L \sim \epsilon S$.

Zank, Gary	***Particle Acceleration Via Reconnection Processes In The Supersonic Solar Wind*** G.P. Zank, University of Alabama in Huntsville, Huntsville, USA J.A. le Roux, University of Alabama in Huntsville, Huntsville, USA G.M. Webb, University of Alabama in Huntsville, Huntsville, USA A. Dosch, University of Alabama in Huntsville, Huntsville, USA O. Khabarova, Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation RAS (IZMIRAN), Moscow, Russia An emerging paradigm for the dissipation of magnetic turbulence in the supersonic solar wind is via localized small-scale reconnection processes, essentially between quasi-2D interacting magnetic islands. The electric field generated by magnetic island merging can accelerate charged particles trapped in the vicinity of the merging region. Such merging magnetic islands observed near the reconnecting heliospheric current sheet may be a source of particle energization. We present observations of the process of island merging as the solar wind propagates from the ACE to WIND spacecraft, which were ~200 Re distant. We derive a gyrophase-averaged transport equation for particles experiencing pitch-angle scattering and energization in a super-Alfvenic flowing plasma experiencing multiple small-scale reconnection events. A simpler advection-diffusion transport equation for a nearly isotropic particle distribution is derived. Solving the steady-state isotropic transport equation with a fixed source yields a power law spectrum for the accelerated particles with index -(3 + MA)/2, where MA is the Alfven Mach number. By spatially and temporally averaging the observed values of MA from ~0.3 - ~ 6 AU in the ecliptic and high latitude solar wind, we find that the spectral index predicted from this acceleration mechanism ranges from ~ 4 at 0.3 AU to between 5 and 6 at 1 AU to ~ 6.5 - 7 beyond 1.5 AU. It is possible that the widely reported -5 power law spectral index observed in the quiet supersonic solar wind [Fisk & Gloeckler 2006, Mewaldt et al 2001] at 1 AU may be a natural consequence of particle acceleration associated with dissipative small-scale reconnection processes in a turbulent plasma.