ASTRONUM 2018
ORAL ABSTRACTS

Audit, Edouard	***Numerical Simulations of Super-Luminous Supernovae*** Edouard Audit, CNRS, France We have studied super-luminous supernovae of various origin using numerical simulations. We have performed 1D and 2D Eulerian multi-group radiation-hydrodynamics using the HERACLES code and 1D non-Local-Thermodynamic-Equilibrium (non-LTE) radiative transfer post-processing with CMFGEN. Such studies are a key element to interpret numerous observations. We will present several results obtained and more specifically recent results on super-luminous type II SNe powered by magnetar.
Bacchini, Fabio	***Advanced Algorithms for Special and General Relativistic Particle Simulations*** Fabio Bacchini, KU Leuven, Belgium Bart Ripperda, KU Leuven, Belgium Alex Chen, Princeton University, USA Lorenzo Sironi, Columbia University, USA Relativistic particle methods are an extremely powerful tool for modeling astrophysical plasma phenomena. In the special relativistic limit, kinetic Particle-in-Cell (PiC) codes are a widely employed mean of obtaining insights on the microscopic dynamics characterizing high-energy processes such as magnetic reconnection and beam-plasma instabilities. Here, we present the latest advances on exactly energy-conserving, fully implicit methods for PiC simulations of relativistic plasmas. We review the numerical details of the implementation of such methods in high-performance, parallelized frameworks and provide proofs of the quality of the obtained results. Furthermore, we extend the numerical techniques to handle curved spacetimes, allowing for the simulation of charged, massive particles around black holes and neutron stars. With the obtained tools, we foresee a direct extension of the special relativistic PiC method to general relativistic simulations of kinetic processes.
Balsara, Dinshaw	***Geodesic Mesh MHD : A New Paradigm for Computational Astrophysics and Space Physics Applied to Spherical Systems*** Vladimir Florinski, UAH, USA Sudip Garain, UND, USA A majority of astrophysical systems tend to be spherical. The same is true for problems in space physics. Even so, simulations of such systems tend to be done on logically Cartesian meshes. The r-theta-phi meshes that are often used have a few major deficiencies: a) They don't cover the sphere uniformly, b) The coordinate singularity on-axis results in a loss of accuracy, c) The timestep is seriously diminished. All these problems are associated with using an inadequate coordinate system for doing the calculation. As astrophysicists and space physicists actively take on the issues of MHD turbulence, it becomes increasingly important to have high orders of accuracy. High accuracy schemes are the only way of reducing the dissipation and dispersion that should be held down in turbulence simulations. In this work we show that an excellent alternative is available. The most isotropic covering of the sphere comes from icosahedrally generated geodesic meshes. The elements of such a mesh are inherently curved and we show that isoparametric mapping provides an extraordinarily accurate re-mapping strategy for the sphere. We show that divergence-free MHD calculations can be done on such meshes with no loss of on-core processing efficiency or parallelism. To improve accuracy we use a combination of: a) WENO methods, b) A re-formulation to support high order divergence-free reconstruction of magnetic fields, c) Multidimensional Riemann solvers, d) Higher order timestepping to match the spatial accuracy. The resulting capability achieves provably high order of accuracy and high levels of parallelism. Several stringent test problems are presented and a few frontline applications are shown to highlight the utility of our approach.
Barkov, Maxim	***3D Dynamics and Morphology of Bow-shock Pulsar Wind Nebulae*** Maxim Lyutikov, Purdue University, USA Bow-shock pulsar wind nebulae (PWNe) show a variety of morphological shapes. We attribute these variations to the intrinsic properties (relative orientation of the pulsar's spin, velocity, and magnetic inclination angle) - as well as the line of sight. We identify three basic types of bow-shock nebulae: (i) a ``rifle bullet'' (spin and velocity aligned); (ii) a ``frisbee'' (spin and velocity orthogonal, spin is in the plane of the sky) and (iii) a ``cart-wheel'' (like frisbee but the spin is perpendicular to the plane of the sky). Using 3D relativistic MHD simulations, as well as analytical calculations, we reproduce both the key morphological features of the bowshock PNEs, as well as variations are seen in different systems. Magnetic stresses within the pulsar wind strongly affect the overall structure, producing ``whiskers'', ``tails'', ``filled-in'' and ``mushroom" shapes, non-symmetric shapes etc. On the other hand, the ISM inhomogeneities, as well as the anisotropy of the wind luminosity, produce only mild variations of the PWN shape. In few cases we clearly identify the morphological structure - our results do not favor alignment of the pulsar spin and linear velocity. Our calculations of the underlying radiative process explain low synchrotron X-ray efficiency (in terms of the spin-down luminosity) and argue for energetically subdominant contribution of the IC processes.

ASTRONUM 2018
ORAL ABSTRACTS

Battarbee, Markus	***Global hybrid-Vlasov Simulations of the Earth's Magnetosphere: Vlasiator Results and Advances*** Markus Battarbee, University of Helsinki, Finland Urs Ganse, University of Helsinki, Finland Thiago Brito, University of Helsinki, Finland Maxime Grandin, University of Helsinki, Finland Tuomas Koskela, University of Helsinki, Finland Yann Pfau-Kempf, University of Helsinki, Finland Lucile Turc, University of Helsinki, Finland Sebastian Von Alfthan, CSC - IT Center for Science, Finland Minna Palmroth, University of Helsinki, Finland Vlasiator is an efficient global hybrid-Vlasov HPC code designed for simulating the Earth's magnetosphere and the near-Earth space environment including ion kinetic effects. This talk will first give an overview of recent published science results and then present a number of code improvements and design choices made in order to facilitate new science and future avenues of hybrid-Vlasov modelling.
Beresnyak, Andrey	***Reconnection in Hall-MHD Plasma*** Andrey Beresnyak, NRL, USA Magnetic reconnection is a process likely responsible for high-energy events in magnetically dominated environments. Does complex plasma physics play a role in this phenomena? Yes and no. We completed extensive parameter study of simulated high-resolution Hall-MHD reconnection. It has now become clear that similar to MHD reconnection it is a multi-scale process. Namely the system contain structures sized from current layer thickness down to electron scales. This is evident not only in the structure and spectra but also in the shape of the quasi-separatrix mixing layer where energy is released. Plasma effects certainly can affect the microscopic processes, such as acceleration to lower energies, but turns out it may affect even global energetics, such as the global reconnection rate when the turbulent current layer thickness is below 200 ion skin depths.
Bisikalo, Dmitry	***Influence of Stellar Radiation on the Flow Structure in Envelope of Hot Jupiter*** Dmitry Bisikalo, Alexander Cherenkov Institute of astronomy of the Russian Academy of Sciences Hot Jupiter exoplanets are subjected to extreme radiation of their parent stars. Photo- metric observations of the hot Jupiter transits with HST/STIS detected strong absorption in Lyman-alpha line, thus indicating the existence of an extended hydrogen envelope beyond the Roche lobe. Gas dynamic and MHD modeling shows that, if the dynamical pressure of the stellar-wind is high enough to stop the outflow from the vicinity of the inner Lagrangian point, a quasi-closed non-spherical envelope, bounded by the bow-shock of a complex shape, forms in the system. In this report we discuss the impact of stellar radiation pressure in Lyman-alpha line on gasdynamics in envelope of hot-Jupiter HD209458b, orbiting its solar-like type star. Simulations show that for HD 209458 b radiation pressure acts only on thin ”substellar” layer, locally changing dynamics, but total impulse in this absorbed line is not enough to have significant impact on gasdynamics, and therefore, evolution of atmosphere of this hot Jupiter. To have significant observable effect due to radiation pressure it is required to increase intensity of Lyman-alpha line by two order of magnitude.
Calder, Alan	***Thermonuclear (Type Ia) Supernovae and Progenitor Evolution*** Alan C. Calder, Stony Brook University, USA Donald E. Willcox, Stony Brook University, USA Dean M. Townsley, University of Alabama, USA Thermonuclear (type Ia) supernovae are bright stellar explosions with the unique property that the light curves can be standardized, allowing them to be used as distance indicators for cosmological studies. Many fundamental questions about these events remain, however. We provide a critique of our present understanding of these and present results of simulations assuming the single-degenerate progenitor model consisting of a white dwarf that has gained mass from a stellar companion. We present results from full three-dimensional simulations of convection with weak reactions comprising the A=23 Urca process in the progenitor white dwarf.

ASTRONUM 2018
ORAL ABSTRACTS

Caplan, Ronald	***GPU-Acceleration of an Established Solar MHD code using OpenACC*** Ronald M. Caplan, Predictive Science Inc, USA Jon, A. Linker, Predictive Science Inc, USA Zoran Mikic, Predictive Science Inc, USA Cooper Downs, Predictive Science Inc, USA Tibor Torok, Predictive Science Inc, USA The advent of GPU accelerators have had a notable impact on high-performance computing across many disciplines. They can provide high performance with low cost/power, which has lead them to become a primary compute resource on many of the largest supercomputers. For some problems, they also have the potential to achieve supercomputer performance "in-house" on a single server with a modest number of GPUs. The biggest hurdle in taking advantage of GPU-computing (especially for long-established/large programs) is the need to write/modify code to be able to efficiently run on the GPUs. While in the past, this required complete re-writes of code, this can now be achieved using portable, comment-based APIs such as OpenACC. Here, we present our experience of implementing multi-GPU acceleration into our Solar MHD code (MAS) using OpenACC in a fully portable, single-source manner. Our preliminary implementation is focused on MAS running in "zero-beta" mode. While valuable on its own, the main goal of this first step is to pave the way for a full thermodynamic MHD implementation. We describe the implementation methodology and some of the many challenges faced, including determining and testing the applicability of our algorithms to GPU-computing. "Time-to-solution" performance results of running a production-level flux rope eruption simulation on multi-CPU and multi-GPU systems are shown. We find that the GPU-accelerated MAS code has the ability to run small-to-medium sized "zero-beta" simulations on a single multi-GPU server at speeds previously requiring multiple server-nodes of a supercomputer.
Chen, Yuxi	***Improving the robustness and accuracy of high-order schemes*** Yuxi Chen, University of Michigan, USA Gabor Toth, University of Michigan, USA We noticed that the fifth-order monotonicity preserving scheme (MP5) produces significant oscillations behind a standing or slowly moving shock. Our further studies suggest that even the first- and second-order upwind schemes generate such downstream oscillations. But the oscillations in the low-order schemes are less severe and more localized than in the high-order scheme due to the high numerical dissipation. Previous work suggests that the momentum spike at the shock creates the oscillatory wave structures. It is difficult, if not impossible, to design an algorithm to eliminate this generation mechanism. Numerical dissipation can be explicitly added to the equations to suppress the oscillations, but it is hard to suppress the oscillations while keeping the sharp shock structure. Since the low-order schemes control the oscillations reasonably well, we design an adaptive algorithm to detect the location of the shock and apply a low-order scheme to the cells next to the shock while using the MP5 scheme for the rest of the domain. We will describe the adaptive algorithm and show its performance for 1D and 2D test problems and 3D magnetosphere simulations as well.
Chu, Ran	***Realizability-Preserving DG-IMEX Methods for Neutrino Transport*** Ran Chu, University of Tennessee, Knoxville, USA Eirik Endeve, Oak Ridge National Laboratory, USA Cory D. Hauck, Oak Ridge National Laboratory, USA Anthony Mezzacappa, University of Tennessee, Knoxville, Oak Ridge National Laboratory, USA To simulate multidimensional neutrino transport in nuclear astrophysics applications, physical, realizability-preserving discontinuous Galerkin implicit-explicit (DG-IMEX) methods are studied. Here we present how to build an accurate and robust DG-IMEX method that works with the two-moment method, which evolves moments of a phase space distribution function f. More precisely, a DG-IMEX method that is streaming accurate (2nd -order), diffusion accurate, and realizability-preserving (preserving physical bounds on the evolved moments) is proposed. To balance efficiency and accuracy, IMEX methods treat the collision terms on the right hand side of the Boltzmann transport equation (local interaction terms) implicitly and the advection terms on the left hand side explicitly. The PARSD method, one family of the above methods with optimizable timestep restriction, is built as an example. The details of our mathematical model, the numerical method, including the derivation of the IMEX coefficients based on appropriate constraints, and numerical results are presented.

ASTRONUM 2018
ORAL ABSTRACTS

Endeve, Eirik	***Towards Discontinuous Galerkin Methods for Supernova Simulations*** Eirik Endeve, Oak Ridge National Laboratory, USA Ran Chu, University of Tennessee, Knoxville, USA Cory Hauck, Oak Ridge National Laboratory, USA Anthony Mezzacappa, University of Tennessee, Knoxville, USA We are developing algorithms for simulations of core-collapse supernovae — coupling solvers for hydrodynamics, neutrino transport, and gravity. Aiming to employ compatible high-order methods in all sectors, the hyperbolic hydro and transport equations are discretized with the discontinuous Galerkin (DG) method, while elliptic equations for the gravitational field are discretized with a continuous finite element method. The hyperbolic solvers are implemented in the Toolkit for High-ORder Neutrino rAD-hydrO (thornado). In this talk, we discuss the hyperbolic solver for neutrino transport in thornado, which employs a multi-group two-moment model, where the spectral particle density and flux — angular moments of a positive phase space distribution function — approximates the radiation field in a computationally tractable manner. Since neutrinos are fermions, and subject to Pauli's exclusion principle, the neutrino distribution function is constrained by both lower and upper bounds, which put algebraic constraints on the moments. We discuss a DG method for the fermionic two-moment model which maintains these constraints.
Fambri, Francesco	***High Order Path-Conservative ADER Discontinuous Galerkin Schemes Applied to the GRMHD Equations and to a Novel First Order Formulation of the CCZ4 System of the 3+1 Einstein Equations*** Francesco Fambri, Laboratory of Applied Mathematics, University of Trento, Italy Michael Dumbser, Laboratory of Applied Mathematics, University of Trento, Italy Olindo Zanotti, Laboratory of Applied Mathematics, University of Trento, Italy In this talk we present a new class of high-order accurate numerical algorithms for solving the equations of general-relativistic ideal magnetohydrodynamics in curved spacetimes, as well as a new strongly hyperbolic first order formulation of the Einstein equations based on the conformal and covariant Z4 system (CCZ4) with constraint-violation damping, referred to as FO-CCZ4. The solution of the fully coupled GRMHD+CCZ4 system is matter of nearly next future research. As CCZ4, the FO-CCZ4 formulation combines the advantages of the BSSNOK formulation with the suppression of constraint violations given by the damping terms, but being first order in time and space is particularly suited for a discontinuous Galerkin implementation. The presented novel formulation has been obtained by making careful use of first and second order ordering constraints. A proof of strong hyperbolicity is given for a selected choice of gauges via an analytical computation of the entire eigenstructure of the FO-CCZ4 system. The resulting governing FO-CCZ4 PDE system is written in fully non-conservative form and requires the evolution of 58 unknowns. A key feature of our formulation is that the first order CCZ4 system decouples into a set of pure ODEs and a reduced hyperbolic PDE system that contains only linearly degenerate fields. The (GRMHD and FO-CCZ4, separately) governing partial differential equations are solved via a new family of fully-discrete and arbitrary high-order accurate path-conservative discontinuous Galerkin (DG) finite-element methods combined with adaptive mesh refinement (AMR) and time accurate local timestepping (LTS). In order to deal with shock waves and other discontinuities or singularities (e.g. singularities arising in the center of black holes), the high-order DG schemes are supplemented with a novel a-posteriori subcell finite-volume limiter, which makes the new algorithms as robust as classical finite-volume methods at shocks and discontinuities, but also as accurate as unlimited high-order DG schemes in smooth regions of the flow. We validate the correctness of the formulation and the corresponding discretization through a series of numerical tests in one, two and three spatial dimensions. We also present preliminary results on the evolution of binary black hole systems. To the best knowledge of the authors, these are the first successful 3D simulations of moving punctures ever carried out with high order discontinuous Galerkin schemes using a first order formulation of the 3+1 Einstein equations of general relativity. Finally, we present a performance and accuracy comparisons between Runge-Kutta DG schemes and ADER high-order finite-volume schemes, showing the higher efficiency of DG schemes. In particular, a recent (strong) scaling study of the presented ADER-DG schemes has been carried out for the FO-CCZ4 equations, from 720 up to 180'000 cores on the Hazel-Hen supercomputer in Stuttgart, Germany: we have experienced an MPI-parallel efficiency greater than 93%.
Felker, Kyle	***Fourth-Order Accurate Ideal MHD in Athena++*** Kyle Gerard Felker, Princeton University, USA James Stone, Princeton University, USA We present a fourth-order accurate finite volume method for the solution of ideal magnetohydrodynamics (MHD) that uses a constrained transport (CT) formulation to prevent the onset of numerical monopoles. The method is implemented in the Athena++ code and compared to the existing second-order scheme for accuracy, robustness, and computational efficiency. We examine the arithmetic intensity and data locality tradeoffs in vectorized, parallel domain-decomposed simulations performed on several multicore architectures. The advantages of the fourth-order method are evaluated within the context of multidimensional MHD problems of varying smoothness.

ASTRONUM 2018
ORAL ABSTRACTS

Feng, Xueshang	***A New Approach for Magnetic Field Divergence-free in MHD Simulation*** Xueshang Feng, Chinese Academy of Sciences, CHINA In multidimensional MHD simulations, it is difficult to satisfy the divergence-free constraint . The violation of the divergence constraint is due to the nonphysical intermediate state within a numerical discontinuity profile. Since this violation may frequently lead to severe stability problems, researchers have tried to enforce the divergence-free constraint in their MHD formulations such as the projection method, constraint transport method, eight-wave solution method, and hyperbolic divergence cleaning method. In this talk, we propose a new approach for magnetic field divergence-free in MHD simulation. By combining with least squares reconstruction, here is proposed a divergence-cleaning approach. This method can be applied to any numerical scheme with a K-exact polynomial reconstruction. The divergence-cleaning method is employed for 3D MHD with a rotated-hybrid scheme in the finite-volume frame. The rotated-hybrid scheme is devised by decomposing a cell-face normal vector into two orthogonal directions and combining the Roe solver, a full-wave solver, and the Rusanov solver, a fewer-wave solver, into one based on a rotated Riemann solver approach. To validate and demonstrate the capabilities of the rotated-hybrid scheme for MHD, we perform an Orszag-Tang MHD turbulence problem and a numerical study for the steady-state coronal structures of Carrington rotation (CR) 2098 in 2010 during solar rising phase.
Florinski, Vladimir	***Modeling of Heliospheric Plasma Processes on Geodesic Meshes*** V. Florinski, University of Alabama in Huntsville, USA D. S. Balsara, University of Notre Dame, USA S. Garain, University of Notre Dame, USA We present a new modeling framework for space and astrophysical plasma processes based on geodesic spherical meshes. A geodesic triangulation of a sphere, obtained by a recursive division of an icosahedron, avoids the singularities of polar coordinates and features a desirably narrow distribution of arc lengths and face areas. A triangulated mesh has two important advantages over the commonly used dual (hexagonal) tesselations: it is easy to decompose into triangular blocks (sectors) and is amenable to mesh refinement. Currently, the framework is capable of solving MHD problems with up to fourth order spatial accuracy. The talk will focus on mapping techniques for spherical frustum zones, conservative reconstruction and stencil operations, and decomposition and parallelization. Representative solutions will be shown for the problem of a magnetized stellar wind from a rotating star.
Fraternale, Federico	***The Inertial Range of Turbulence in the Inner Heliosheath and in the Local Interstellar Medium*** F. Fraternale, Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, Italy N. V. Pogorelov, Space Science Department, University of Alabama in Huntsville, USA J. D. Richardson, Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, USA D. Tordella, Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, Italy The governing mechanisms of magnetic field annihilation in the outer heliosphere is an intriguing topic. It is currently believed that the turbulent fluctuations pervade the inner heliosheath (IHS) and the local interstellar medium (LISM). Turbulence, magnetic reconnection, or their reciprocal link may be responsible for magnetic energy conversion in the IHS. As 1-day averaged data are typically used, the present literature mainly concerns large-scale analysis and does not describe inertial-cascade dynamics of turbulence in the IHS. Moreover, lack of spectral analysis make IHS dynamics remain critically understudied. Our group showed that 48-s MAG data from the Voyager mission are appropriate for a power spectral analysis over a frequency range of five decades, from 5e-8 Hz to 1e-2 Hz [Gallana et al., JGR 121 (2016)]. Special spectral estimation techniques are used to deal with the large amount of missing data (70%). We provide the first clear evidence of an inertial-cascade range of turbulence (spectral index is between -2 and -1.5). A spectral break at about 1e-5 Hz is found to separate the inertial range from the energy-injection range (1/f energy decay). Instrumental noise bounds our investigation to frequencies lower than 5e-4 Hz. By considering several consecutive periods after 2009 at both V1 and V2, we show that the extension and the spectral energy decay of these two regimes may be indicators of IHS regions governed by different physical processes. We describe fluctuations' regimes in terms of spectral energy density, anisotropy, compressibility, and statistical analysis of intermittency. In the LISM, it was theorized that pristine interstellar turbulence may coexist with waves from the IHS, however this is still a debated topic. We observe that the fluctuating magnetic energy cascades as a power law with spectral index in the range [-1.35, -1.65] in the whole range of frequencies unaffected by noise. No spectral break is observed, nor decaying turbulence.

Fujimoto, Keizo	***Electromagnetic Turbulence in the Reconnection Current Layer*** Keizo Fujimoto, Beihang University, China Magnetic reconnection a focal phenomenon in space and astrophysics, enabling explosive energy release of the magnetic field energy into plasma kinetic energy. The reconnection process is supported by the magnetic dissipation around the x-line. However, the mechanism generating the dissipation has been poorly understood for collisionless plasmas where the binary Coulomb collisions are negligibly small. Recent observations in space and laboratory have shown intense wave activities in the reconnection region, which might have an impact on the dissipation at the x-line. The present study has carried out large-scale particle-in-cell simulations with the adaptive mesh refinement to investigate the wave activities in the thin current layer formed during anti-parallel reconnection. The 3D simulations suggest that the electromagnetic waves dominate near the x-line, consistent with the observations. However, the intensity is dependent on the system size and timing. The findings are 1) the turbulence intensity increases significantly associated with plasmoid ejections, 2) the intensity also increases with the system size in the current density direction, and 3) the current sheet width increases with the turbulence intensity, but there is an upper limit. We will present in this talk the generation mechanism of the electromagnetic turbulence and the impact on the reconnection process.
Gaburro, Elena	***Well Balanced Arbitrary-Lagrangian-Eulerian Finite Volume Schemes on Moving Nonconforming Meshes for the Euler Equations of Gasdynamics with Gravity*** Elena Gaburro, University of Trento, Italy Michael Dumbser, University of Trento, Italy Manuel J. Castro, University of Malaga, Spain In this work we present a novel second order accurate well balanced Arbitrary-Lagrangian-Eulerian (ALE) finite volume scheme on moving nonconforming meshes for the Euler equations of compressible gasdynamics with gravity in cylindrical coordinates. The main feature of the proposed algorithm is the capability of preserving many of the physical properties of the system exactly also on the discrete level: besides being conservative for mass, momentum and total energy, also any known steady equilibrium between pressure gradient, centrifugal force and gravity force can be exactly maintained up to machine precision. Perturbations around such equilibrium solutions are resolved with high accuracy and with minimal dissipation on moving contact discontinuities even for very long computational times. This is achieved by the novel combination of well balanced path-conservative finite volume schemes, that are expressly designed to deal with source terms written via nonconservative products, with ALE schemes on moving grids, which exhibit only very little numerical dissipation on moving contact waves. In particular, we have formulated a new HLL-type and a novel Osher-type flux that are both able to guarantee the well balancing in a gas cloud rotating around a central object. Moreover, to maintain a high level of quality of the moving mesh, we have adopted a nonconforming treatment of the sliding interfaces that appear due to the differential rotation. A large set of numerical tests has been carried out in order to check the accuracy of the method close and far away from the equilibrium, both, in one and two space dimensions. Finally, nontrivial test problems in a rotating Keplerian gas disk shows the greatly reduced dissipation and the significant improvements of the new scheme on moving contact discontinuities compared to classical non well balanced Eulerian methods on fixed grids.
Giacalone, Joe	***Pitch-Angle Scattering of Charged Particles in an Irregular Magnetic Field with Constant Magnitude*** Joe Giacalone The transport of charged particles in irregular magnetic fields has important applications in astrophysics and heliophysics; and despite several decades of study, there remain significant gaps in our understanding. For one, observational estimates of the mean-free path of cosmic rays in the (turbulent) interplanetary magnetic field are considerably larger – by a factor of 10 – than the prediction of so-called quasi-linear theory. One possible solution to this discrepancy relates to the properties of the assumed fluctuating magnetic field in that most of its power is in wave modes that do not efficiently scatter the particles' pitch angle. A field with no variation is its magnitude would be one example. By having no variation in the magnetic-field magnitude, there is no magnetic mirroring, and particles would not efficiently scatter through 90-degrees pitch angle. There are numerous spacecraft observations of the interplanetary magnetic field that reveal a larger variation in the individual components of the field and considerably less variation in the magnitude. However, constructing kinematic models of irregular magnetic fields that both satisfy Maxwell's equations and have constant magnetic field magnitude is difficult. In this talk, I will review some recent work on this problem, and present results from recent numerical calculations of the pitch-angle diffusion coefficient and mean-free path of scattering of charged particles in a conceptually simple 1D model with these properties. Results from these calculations are compared to those from 1D-slab and 3D-isotropic turbulence models.

ASTRONUM 2018
ORAL ABSTRACTS

Glines, Forrest	***Simulations of Thermal Heating from Active Galactic Nuclei in Galaxy Clusters*** Forrest Glines, Michigan State University, USA Brian W. O'Shea, Michigan State University, USA G. Mark Voit, Michigan State University, USA Observations from the last decade have revealed the existence of cool-core clusters, galaxy clusters with a cooling time much shorter than the dynamical time. Recent work suggests that clusters may be thermally stable due a central heating mechanism such as an active galactic nucleus (AGN) that prevents cooling. Previous analytical work in one dimension has shown that thermal heating from a central AGN with a power-law radial profile, where the heating exceeds cooling at near and far radii but not in an intermediate region, may produce a stable cluster with an isentropic entropy profile in the core and an isothermal profile outside the cluster. To test this, we simulated idealized galaxy clusters using the ENZO code with thermal heating from a central AGN. Thermal heating as a function of radius was injected proportional to the radius to a fixed exponent in (-3,-2] for each run. Total thermal feedback was set equal to the total rate of cooling in the cluster. Thermal feedback with a conic angular dependence was also explored. However, the purely thermal feedback was not enough to achieve thermal stability and each simulation collapsed due to overcooling. These results support previous work showing that some kinetic feedback through a jet may be necessary for self-regulating AGN activity.
Grete, Philipp	***As a Matter of Force - Systematic Biases in Idealized Turbulence Simulations*** Brian W. O'Shea, Michigan State University, USA Kris Beckwith, Sandia National Laboratories, USA Physical processes in astrophysical systems typically encompass a very large dynamical range in space and time, which is not accessible by direct numerical simulations. Thus, idealized subvolumes are often used to study small scale effects including the dynamics of magnetized turbulence. These turbulent boxes require an artificial driving in order to mimic energy injection processes. In this presentation, we show and quantify how the autocorrelation time of the driving and its normalization systematically change properties of the flow. This includes, for example, the slope of the power spectrum, energy transfer dynamics, and the correlation between density and magnetic field strength. Given that these differences introduce a systematic bias in observable such as the line of sight magnetic field, we conclude that special care needs to be taken in interpreting results of idealized simulations.
Grosheintz, Luc	***High-order Well-balanced Finite Volume Methods for Euler Equations with Gravity*** Luc Grosheintz, Seminar of Applied Mathematics, ETH Zurich Hydrostatic equilibria are a common class of stationary solutions to the Euler equations with gravity. It's the force-balance of pressure and gravity. While the force-balance may be exact on the continuous level, this is typically no longer the case for Finite Volume Methods (FVM) at the discrete level. We will present a novel high-order FVM which maintains hydrostatic equilbria to machine precision. Further, we will present out progress towards balancing non-stationary equilibria. Examples of non-stationary equilibria are rotating fluids where pressure gradient, gravity and inertial force balance. We've implemented well-balanced schemes for structured and unstructured grids. We will show astrophysically relevant examples using these novel schemes.
Hanawa, Tomoyuki	***Total Energy Conservation Including Self-Gravity*** Tomoyuki Hanawa, Chiba University Total energy of an astronomical system is of our great interest, since the evolution of the system depends on it. Hence we solve the hydrodynamical equations taking account of the conservation in numerical simulations of astrophysical objects. However, gravitational energy is often taken into account as a source term and the total energy including gravity is not guaranteed. This paper shows that the conservation of total energy can be achieved down to the round off error if the Poisson equation is adequately discretized and the gravitational energy release is evaluated properly. In order to achieve the total energy conservation, we should define the gravity not at the cell center but on the cell surface. The gravity defined on the cell surface has normal and tangential components. The former is obtained by applying the Gauss's theorem to the Poisson equation, while the latter is constrained by the condition of rotation free. The second order finite difference scheme gives an appropriate gravity for an uniform grid but not for a block-structured grid with oct-tree. An alternative for solving the Poisson equation on the block-structured grid is given in this talk.

Iijima, Haruhisa	***Radiation MHD Simulations on Solar Chromospheric Jets*** Haruhisa Iijima, Nagoya University, Japan Takaaki Yokoyama, The University of Tokyo, Japan The solar chromosphere is filled with small jetting structure. Due to the inhomogeneous distribution of the magnetic field on the solar photosphere, chromospheric jets have a variety of appearance. The small gas pressure scale height near the solar surface causes a sharp transition from the plasma energy dominated convection zone to the magnetic energy dominated chromosphere. The radiation magnetohydrodynamic simulation is an important tool for the quantitative understanding of the solar atmosphere. Our radiation MHD code, RAMENS, includes the effect of the three-dimensional radiative transfer, the field-aligned stiff thermal conduction, and the non-ideal equation of states. We report our current understanding on the formation process of solar chromospheric jets and future perspective.
Juno, James	***A Quadrature and Matrix-free Discontinuous Galerkin Algorithm for (Plasma) Kinetic Equations*** James Juno, University of Maryland College Park, USA Ammar Hakim, Princeton Plasma Physics Lab, USA Jason TenBarge, Princeton University, USA William Dorland, University of Maryland College Park, USA Within the various niches which compose the field of plasma physics, there is growing excitement about the possibility to measure particle distribution functions, which provide a complete description of the dynamics and non-equilibrium thermodynamics of a weakly collisional plasma. From ongoing observational missions in space, such as the Magnetospheric Multiscale Mission (MMS), to terrestrial laboratory experiments, such as the Large Plasma Device (LAPD) and the Facility for Laboratory Reconnection Experiments (FLARE), to satellite missions set to launch in the near future, such as the Parker Solar Probe (PSP), every facet of the field is moving towards the "final frontier" of our understanding of a weakly collisional plasma's evolution: the particle distribution function. As such, it is imperative to develop computational tools to support and help us understand the plethora of experimental and observational distribution function data. The challenges inherent in the simulation of a weakly collisional plasma are large. The governing system of equations, the Vlasov-Maxwell system, is a high dimensional transport equation: six dimensions plus time. While the particle in cell (PIC) method, a Lagrangian discretization of the system which advances “macroparticles" along characteristics, has been fruitful over the years in elucidating collisionless dynamics, analysis of the distribution function from a PIC solution presents its own set of difficulties due to the counting noise inherent to the algorithm. With computational power ever increasing, and algorithms becoming more advanced, our focus is thus on deriving a direct discretization of the Vlasov-Maxwell system, which would permit more careful analysis of the distribution function required for a large variety of plasma physics conditions and parameters. In this talk, we present a novel algorithm for the numerical solution of the Vlasov-Maxwell system of equations which uses high order discontinuous Galerkin finite elements to discretize the system on a phase space grid. The resulting numerical method is robust and retains a number of important properties of the continuous system, such as conservation of mass and energy. In addition, we will discuss a number of discoveries concerning the computational implementation of the algorithm which bring the cost of directly discretizing the Vlasov-Maxwell system down tremendously. Careful analysis of the distribution function from standard turbulence and reconnection benchmarks reveals a high signal to noise ratio, making the algorithm ideal for analysis of the underlying non-equilibrium thermodynamics.

Kadowaki, Luis H.S.	***A Statistical Study of Fast Magnetic Reconnection in Turbulent Accretion Disks*** Luis H.S. Kadowaki, IAG-USP, Brazil Elisabete M. de Gouveia Dal Pino, IAG-USP, Brazil James M. Stone, Princeton University, USA Fast magnetic reconnection events can play an important role in accretion disks systems. A potential model to explain the transition between the High/Soft and Low/Hard X-ray states observed in high-mass X-ray binaries (HMXBs) and Active Galatic Nuclei (AGNs) can be attributed to fast magnetic reconnection induced in the turbulent corona of accretion disks. According to this model, the power released by fast reconnection between the magnetic field lines arising from the inner accretion disk and the lines anchored into the compact source could accelerate relativistic particles in a first-order Fermi process and produce the observed non-thermal high-energy emission. In this talk, we will discuss the results of three-dimensional local magnetohydrodynamic (MHD) and global general-relativistic MHD (GRMHD) simulations of accretion disks around black holes, whose turbulence is naturally driven by MHD instabilities, such as the magnetorotational instability (MRI) and the Parker-Rayleigh-Taylor instability (PRTI). Our simulations revealed the development of a nearly steady-state turbulence driven by both instabilities. We have performed a detailed statistical analysis to identify the presence of current sheets in the turbulent regions of both the corona and the disk. We then determined the magnetic reconnection rates in these locations obtaining average reconnection velocities in Alfven speed units of the order of 0.1-0.2, which are consistent with the predictions of the theory of turbulence-induced fast reconnection.
Kaneko, Takafumi	***Reconnection-Condensation Model for Solar Prominence Formation*** Takafumi Kaneko, Nagoya University, Japan Takaaki Yokoyama, The University of Tokyo, Japan We propose a reconnection-condensation model in which topological change in a coronal magnetic field via reconnection triggers radiative condensation, resulting in prominence formation. Solar prominences are cool dense plasma clouds in the hot tenuous corona. The origin of cool dense plasmas and the mechanism of their mass maintenance are long term issues in solar physics. Radiative cooling condensation (thermal instability) is a promising process to supply mass for prominences. Yet the triggering mechanism of condensation is unclear. In observations, prominences always appear along polarity inversion lines, suggesting that cancelation or reconnection must be related to radiative condensation. We propose a reconnection-condensation model and demonstrate it using three-dimensional magnetohydrodynamic (MHD) simulations including nonlinear anisotropic thermal conduction and optically thin radiative cooling. Thermal conduction is explicitly solved using a super time-stepping method with second-order accuracy (Meyer et al., 2014) and a flux limiter for anisotropic conduction (Sharma & Hammett, 2007). MHD equations are solved by four-stage Runge-Kutta method and a fourth-order central finite difference method with artificial viscosity (Rempel 2014). In our simulations, a flux rope is created by reconnection via converging footpoint motion. By elevation of dense coronal plasmas and topological change in coronal magnetic fields, radiative condensation is triggered inside the flux rope. Our results show clear link between reconnection and radiative condensation. Recently, we improved the model to include dynamic fine structures by the Rayleigh-Taylor instability. We found that mass condensation rate is enhanced to balance with mass drainage rate by coupling with the Rayleigh-Taylor instability. This result support the previous observational findings of mass maintenance in prominences.

Klein, Richard	***The Formation of Massive Clusters From High Redshift to the Present Day Universe*** Richard I. Klein, UC Berkeley and Lawrence Livermore National Laboratory, USA PS Li, UC Berkeley, USA Christopher McKee, UC Berkeley, USA Massive stars lie at the center of the web of physical processes that has shaped the universe as we know it, governing the evolution of the interstellar medium of galaxies, producing a majority of the heavy elements, and thereby determining the evolution of galaxies. A significant fraction of all stars form in massive clusters, which will be observable throughout the visible universe with JWST. In this talk, I shall present first results of the formation of clusters of stars across cosmic time, both of moderate mass, such as the Orion Nebula Cluster (ONC), and of high mass, such as the super star clusters (SSC) seen in starburst galaxies, starting with high mass cluster formation in our present day universe. These simulations are carried out using newly developed advanced techniques in our radiation-magneto-hydrodynamic AMR code ORION, for radiative transfer with both ionizing and non-ionizing radiation that accurately handles both the direct radiation from stars and the diffuse infrared radiation field that builds up when direct radiation is reprocessed by dust grains. Our simulations include relevant feedback effects such as radiative heating, radiation pressure, photodissociation and photoionization, protostellar outflows, magnetic fields and turbulence. The challenge in simulating the formation of massive stars and massive clusters is to include all these feedback effects self-consistently as they occur collectively. I will first present our recent results on cluster formation on moderate scales over the dynamic range of ~ 5pc down to 28 au for a period of 350,000 yr, including magnetic fields, turbulence and both radiative and outflow feedback from the protostars. At the end of the simulation, the star formation efficiency in the cluster is 4.3 % and the star formation rate per free-fall time is ≈ 0.04, within the range of observed values. The total stellar mass increases quadratically in time, whereas the number of protostars in the cluster increases as $\sim t^{1.5}$. We find that the density profile around most of the simulated protostars is $\sim \rho \propto r^{(-1.5)}$. At the end of the simulation, the protostellar mass function approaches the Chabrier stellar initial mass function. We infer that the time to form a star of median mass 0.2 Msun in the cluster is about 140,000 yr from the median mass accretion rate. We find excellent agreement in our simulations with the protostellar luminosities observed in recent large cluster samples and a theoretical estimate, and we conclude that the classical protostellar luminosity problem is resolved. The multiplicity of the stellar systems in the cluster simulation agrees, to within a factor of 2, with observations of Class I young stellar objects; most of the simulated multiple systems are unbound. Bipolar protostellar outflows are launched using a subgrid model, and extend up to 1 pc from their host star. The mass-velocity relation of the simulated cluster outflows is consistent with both observation and theory. I shall then present our first results on massive cluster formation starting at scales ~ 100 pc. and forming massive SSC clusters of ~ 1 million solar masses using multiple zoom-in refinements with AMR and including all of the above mentioned coupled physics. I shall discuss how we chose self-consistent initial conditions for massive cluster formation simulations, and show preliminary results of the properties of the massive SSC clusters and ONC type clusters that form. Key questions we are addressing include how effectively is radiation trapped within the cluster and how does stellar feedback affect the formation of Orion-scale clusters and SSC.
Kolobov, Vladimir	***Kinetic Solvers with Adaptive Mesh in Phase Space for Low-Temperature Plasmas*** Vladimir Kolobov, UAH, USA Robert Arslanbekov, CFDRC, USA Dmytro Levko, CFDRC, USA Simulations of low-temperature plasma require coupled kinetic solvers and electromagnetics. One method for reducing computational cost of mesh-based kinetic solvers is to use adaptive mesh in phase space (AMPS). Another method is to reduce dimensionality of kinetic solvers using a problem symmetry. In the present paper, we will describe the implementation and application of 1d2v kinetic solvers with AMPS and coupling to Poisson solver for electric field. Collisions of charged particles with neutrals are described using spherical coordinates in velocity space. For transport in configuration (physical) space, we use Cartesian, cylindrical or spherical coordinate systems depending on problem type. Collisions are divided into two types. Boltzmann-type collisions are associated with a large change of particle momentum – they are described by an integral operator in velocity space. Fokker-Planck-type collisions are associated with small changes of momentum. They are described by Fokker-Planck-type differential operators in velocity space. We solve Boltzmann-Fokker-Planck (BFP) kinetic equation using Finite Volume method with octree Cartesian mesh, without splitting physical and velocity spaces. As a result, mesh adaptation in velocity space triggers mesh adaptation in physical space. This creates some difficulties for calculation of particle density and coupling kinetic solvers to Poisson solver for calculation of electrostatic field. Details of the implementation and application of the BFP-Poisson solvers with adaptive Cartesian mesh in phase space will be discussed for applications to space and laboratory plasmas.

Koshkarov, Oleksandr	***A Framework for Microscopic/Macroscopic Simulations of Magnetized Plasmas*** Gian Luca Delzanno, Los Alamos National Laboratory, USA Vadim Roytershteyn, Space Science Institute, USA Gianmarco Manzini, Los Alamos National Laboratory, USA Many problems in plasma physics require the solution of the Vlasov-Maxwell (VM) or Vlasov-Boltzmann equations. These equations are extremely hard to solve numerically because of their high dimensionality, nonlinearities and the huge spatial and temporal scale separation. While several reduced methods have been developed in certain limits, a comprehensive approach capable of obtaining accurate solutions in all parameters regimes remains elusive. We will present a spectral method for the VM equations based on a decomposition of the plasma phase-space density in Hermite or Legendre modes. Its most important feature is that, with a suitable spectral basis, the low-order moments correspond to the typical fluid moments (mass, momentum, energy) of the plasma, while the kinetic/microscopic physics can be retained by adding more moments. With the 'built-in' fluid/kinetic coupling, the method might offer an optimal way to perform accurate simulations of macroscopic phenomena including microscopic physics. The method features favorable numerical properties, such as spectral convergence and exact conservation laws in the limit of finite time step. A comparison between the Particle-In-Cell (PIC) and the spectral method on standard electrostatic test problems shows that the spectral method can be orders of magnitude faster/more accurate than PIC for some problems. Furthermore, we have recently developed a hybrid simulation approach that couples the spectral method with a PIC technique. The goal is to combine the accuracy typical of spectral methods, with the flexibility of PIC in dealing with complex distribution functions that might otherwise require a large number of moments for convergence. The application of the spectral/PIC method to the problem of the interaction of a weak beam with a background plasma will be discussed, showing the potential of the hybrid method in terms of computational efficiency and accuracy.
Krueger, Daniel	***Improving Radiative Transfer in ANTARES*** Daniel Krueger, Goettingen University, Germany Nadiia Kostogryz, Max-Planck-Institut fuer Sonnensystemforschung Goettingen, Germany Damian Fabbian, Goettingen University, Germany Friedrich Kupka, Goettingen University, Germany An important part of realistic stellar hydrodynamics simulations is radiative transfer. Numerical methods which yield accurate results are usually very expensive and can easily encounter stability problems. The ANTARES framework uses ray integration based solvers with short characteristics methods to compute the radiative heating and cooling rate. This class of solvers is unfortunately very expensive and can lead to unphysical artifacts in low-density areas of stellar atmospheres. Thus, developing ways to avoid these artifacts without drastically reducing the accuracy of the code would be highly beneficial. Therefore, two further methods have been implemented into the ANTARES framework. In order to reduce artifacts we implemented the Delo-Bezier method as described by de la Cruz Rodriguez and Piskunov (2013). This method is strictly positive definite and monotonic as the radiative transport equation requires. It is used both for calculation of optical depth and for calculation of intensity. First results show that ANTARES runs more stably and that with this method the amplitude of the artifacts in the radiative flux is reduced. Additionally, the time needed for calculations stays roughly the same. Another approach to reduce artifacts and additionally speed up simulations is to develop a 3D nongrey Eddington approximation of radiative transfer solver. For the grey case a similar solver was presented by Tanner et al. (2012), achieving an increase in speed of a factor of 10 with an associated error not larger than 10 percent in comparison to one of the most simplified solvers based on ray integration. We expect our solver to give at least the same benefit in speed-up without leading to larger errors, being as far as we know, the first attempt for the nongrey case.

Lembege, Bertrand	***Microturbulence within the Front of a Quasi-Perpendicular Supercritical Shock: Two Stream Instabilities Analyzed with 2D Full PIC Simulation.*** Bertrand Lembège, LATMOS-UVSQ, France Laurent Muschietti, LATMOS-UVSQ, France & SSL, UC Berkeley, USA Viktor Decyk, Phys. Dept., UCLA, USA Supercritical quasi-perpendicular shocks in collisionless plasmas are characterized by the presence of a noticeable fraction of ions that are reflected off of the shock front and form a foot upstream of the shock ramp. These ions which carry a significant amount of energy are the source of microturbulence within the shock front itself and play a key role in transforming the directed bulk energy (upstream) into thermal energy (downstream). For quasi-perpendicular shock geometries, the speed of the reflected ions is mostly directed at 90° to the magnetic field. Streaming instabilities can develop, which are excited by the relative drifts between incoming ions, reflected ions, and electrons across Bo within the shock's foot. Recent linear dispersion analysis and 1D full particle simulations (Muschietti et Lembege, Ann. Geophy., 2017) has identified three types of emissions: (i) one which is the oblique extension of ECDI (electron cyclotron drift instability) defined initially for 90°, and (ii) two types of whistler waves propagating respectively in quasi-perpendicular domain and at strongly oblique angles. Herein, 2D full particle simulations are performed in order to analyze how these different waves can coexist and possibly couple one each other, and to determine the resulting waves emission in their linear and nonlinear stage. Main results will be extracted for a possible comparison with high resolution wave measurements issued from the recent MMS mission.
Li, Shengtai	***Numerical Simulations for Laboratory Astrophysics using FLASH*** Shengtai Li, Theoretical Division, Los Alamos National Laboratory, USA Hui Li, Theoretical Division, Los Alamos National Laboratory, USA Kirk A. Flippo, Physics Division, Los Alamos National Laboratory, USA In this talk, we will present results of numerical simulations for different laboratory astrophysics experiments on Omega laser facility. The FLASH code developed at Flash Center of University of Chicago will be used in all the simulations. The FLASH code has been extended with numerous capabilities to allow it to simulate laser-driven High Energy Density Physics (HEDP) experiments. We will show results of generation of hydrodynamics instability and magnetic field via Biemann battery term, and how the magnetic fields get amplified by the turbulence-dynamo effect. The research is supported by the Los Alamos Laboratory Directed Research and Development (LDRD) fund.
Linker, Jon	***Coupled MHD-Focused Transport Simulations for Modeling Solar Particle Events*** Jon A. Linker Predictive Science Inc. USA Ronald M. Caplan Predictive Science Inc. USA Nathan Schwadron University of New Hampshire USA Matthew Gorby University of New Hampshire USA Cooper Downs Predictive Science Inc. USA Roberto Lionello Predictive Science Inc. USA Tibor Torok Predictive Science Inc. USA Janvier Wijaya Predictive Science Inc. USA Solar Particle Events (SPEs) are an important space weather phenomena. The largest SPEs are typically associated with M or X-class solar flares and fast coronal mass ejections (CMEs). The acceleration and transport of solar energetic particles (SEPs) is intimately tied to the evolution and propagation of coronal mass ejections (CMEs) and their associated shock waves. We have developed STAT (SPE Threat Assessment Tool) to simulate SPEs by combining MHD simulations of CMEs with models of SEP acceleration and transport. The CME simulations start from realistic models of the corona developed with CORHEL (Corona-Heliosphere), a suite of models and tools for characterizing the solar and heliospheric environment for specific time periods. The time evolving MHD fields are used to drive solutions of the focused transport equation performed with the Energetic Particle Radiation Environment Module (EPREM). EPREM is a component of EMMREM (Earth-Moon-Mars Radiation Environment Module). We describe the philosophy and challenges for both the MHD simulations of CMEs and the focused transport simulations of particles, and demonstrate novel diagnostic techniques for combining the MHD and particle data from the simulations.

Liu, Yi-Hsin	***Orientation, Stability and Spread of Asymmetric Magnetic Reconnection X-line*** Yi-Hsin Liu, Dartmouth College, USA Tak Chu Li, Dartmouth College, USA Michael Hesse, University of Bergen, Norway Masha Kuznetsova, NASA-Goddard Space Flight Center, USA Ari Li, Los Alamos National Laboratory, USA The orientation, stability, and spread of the reconnection x-line in asymmetric geometry are studied using three-dimensional (3D) particle-in-cell simulations. We initiate reconnection at the center of a large simulation domain to minimize the boundary effect. The resulting x-line has sufficient freedom to develop and spread along an optimal orientation, and it remains laminar. Companion 2D simulations indicate that this x-line orientation maximizes the reconnection rate. The divergence of the non-gyrotropic pressure tensor breaks the frozen-in condition, consistent with its 2D counterpart. We then design 3D simulations with one dimension being short to fix the x-line orientation, but long enough to allow the growth of the fastest growing oblique tearing modes. This numerical experiment suggests that reconnection tends to radiate secondary oblique tearing modes if it is externally (globally) forced to proceed along an orientation not favored by the local physics. The development of oblique structure easily leads to turbulence inside small periodic systems. The implication of this work to magnetospheric, solar and astrophysical plasmas will be discussed.
Markidis, Stefano	***An Adaptive Fluid-Kinetic PIC Method*** Stefano Markidis, KTH, Sweden Vyacheslav Olshevsky, KU Leuven, Belgium Chaitanya P. Sishtla, KTH, Sweden Steven W. Chien, KTH, Sweden Giovanni Lapenta, KU Leuven, Belgium Erwin Laure, KTH, Sweden Particle-in-Cell (PIC) methods are widely used for fluid and kinetic plasma modeling. While both the fluid and kinetic PIC approaches have been successfully used to target either kinetic or fluid simulations, little was done to combine fluid and kinetic particles under the same computational framework. This work proposes to combine both fluid and kinetic within the same computational model with the possibility of adapting from fluid to kinetic particles in time and space. We design and implement the new PIC method, and test it against the Landau damping of Langmuir and ion acoustic waves, two stream instability and sheath formation. We unify the fluid and kinetic PIC method under one common framework comprising both fluid and kinetic description, providing a tool for adaptive fluid-kinetic simulations of plasmas.

Matsumoto, Tomoaki	***A Dynamical Model of the Heliosphere with the Adaptive Mesh Refinement*** Tomoaki Matsumoto, Hosei University/Princeton University, Japan Daikou Shiota, National Institute of Information and Communications Technology, Japan Ryuho Kataoka, National Institute of Polar Research, Japan Hiroko Miyahara, Musashino Art University, Japan Shoko Miyake, National Institute of Technology, Ibaraki College, Japan A change in the heliospheric environment plays an important role in the modulation of the galactic cosmic rays; the magnetic field structure and the speed of the solar wind affect the cosmic ray transport in the heliosphere. Since the heliospheric environment is affected by the solar wind activities, we have been developing a framework for simulating the heliosphere by using MHD simulations. The galactic cosmic rays are transported efficiently in the heliospheric current sheet (HCS), and it should be reproduced with a fine resolution in the model. We therefore utilized the adaptive mesh refinement (AMR) technique for improving the local resolution. In this talk, we present outline of our project and show the current status of the model development. The simulation code is based on SFUMATO code (Matsumoto 2007), which employs the block-structured AMR. The HLLD- scheme (Miyoshi 2007) was adopted for the MHD solver, and it was modified to have a third order of accuracy in space and second order in time. The time-dependent solar wind model is given by the inner boundary condition of the simulations. This model was ported from the space weather forecast system, SUSANOO (Shiota et al. 2014). It is based on the synoptic maps of the photospheric magnetic field provided by the Global Oscillation Network Group (GONG) project, the potential fields source surface (PFSS) model, and some empirical models for reconstructing the MHD parameters in the inner boundary condition. For refinement of the grid, two types of the criteria are adopted. The first criterion is the grid-refinement according to the distance between the AMR-block and the Sun. This criterion provides linear increase in a resolution according to the distance from the Sun. The second criterion is the grid-refinement according to the HCS. When the HCS is detected, the AMR-block is refined there. For a detector of the HCS, we have tested several refinement criteria, and found that the monitoring the local density was suitable for our model. Due to this criterion, the HCS is resolved by a fine resolution, and numerical diffusion is considerably reduced there. Moreover, the co-rotating interaction regions (CIRs) are resolved sharply because the slow winds exist near the HCS, and the CIRs are also covered by the fine grids.

Merkin, Slava	***High-Resolution Simulations of the Heliospheric Structure*** Kareem Sorathia, JHU/APL, USA John Lyon, Dartmouth College, USA Lars Daldorff, JHU/APL, USA Binzheng Zhang, University of Hong Kong, CHINA Micheal Wiltberger, NCAR/HAO, USA The large-scale structure of the heliosphere, particularly during solar minimum, is well-known: fast solar wind emanates from the polar coronal holes while slow wind forms a band surrounding the ecliptic plane. Equatorial coronal holes create streams of high-speed wind within the otherwise slow wind region creating stream interaction regions. The heliospheric current sheet – the structure separating the heliospheric magnetic fields of different polarities – is immersed in the slow wind band, and gets distorted when it is caught in the stream interactions. However, mesoscale structure of the heliosphere, at spatial scales of a fraction of the solar radius (1 Rs), is less well known because multi-point observations at these scales are essentially nonexistent while global heliosphere simulations have historically lacked the resolution to reproduce such structure. In the past few years we have used the Lyon-Fedder-Mobarry (LFM) magnetohydrodynamic (MHD) code, well-known for its very low numerical diffusion and high resolving power, to simulate the solar wind and heliospheric magnetic field at resolution inaccessible to previous models. In particular, we have demonstrated that mesoscale structure in the helispheric current sheet, such as folds and ripples, can be created by velocity shears abundant in the solar wind. Such structures are often observed in situ as heliospheric magnetic field polarity reversals, and are thought to be important for scattering energetic particles in the heliosphere. More recently, we have significantly upgraded the LFM code resulting in the creation of a new, even higher resolution, model dubbed Grid Agnostic MHD for Extended Research Applications (Gamera). In this presentation, we show Gamera simulations of the heliosphere on a grid with 5e8 grid cells resolving the heliospheric structure down to 0.2 Rs scale and demonstrate the emergent sub-structure within the stream interaction regions, which appears as characteristic vortices in the solar wind speed and heliospheric magnetic field, when viewed from Earth. Studying these and similar structures at such spatial scales may provide an important window into the heliospheric consequences of coronal features to be observed by the Parker Solar Probe and, in particular, distinguishing “fossil” heliospheric structure produced in the corona from structure self-generated in the solar wind. In addition, the heliospheric scales available to direction simulation now approach the correlation length in the solar wind and thus can be realistically used to drive magnetosphere simulations as well. Overall, this is the first time such structures have been shown to exist in the heliosphere, and thus these results provide a significant new insight into the real structure of the heliospheric magnetic field and solar wind.
Mezzacappa, Anthony	***The Core Collapse Supernova Mechanism: Where are we?*** Anthony Mezzacappa, University of Tennessee, Knoxville, USA Efforts by a handful of groups around the world resulting in increasingly sophisticated two- and three-dimensional multi-physics simulations of the core collapse supernova central engine have advanced the field beyond the drought of explosions to quantitative considerations of the characteristics of progenitors for which explosions are possible - e.g., progenitor mass; the robustness of the explosions obtained - i.e., their explosion energies; and the nucleosynthetic yields and gravitational wave and neutrino signals obtained. Yet much work remains, particularly in the context of three-dimensional modeling. I will present a brief overview of the status of the field, as well as present the status of the modeling efforts of the University of Tennessee - Oak Ridge National Laboratory supernova modeling effort.
Nagakura, Hiroki	***Radiation-Hydrodynamic Simulations of Core-collapse Supernovae with 6 Dimensional Boltzmann Neutrino Transport*** Shun Furusawa, RIKEN, Japan Hajime Togashi, RIKEN, Japan Kohsuke Sumiyoshi, Numazu College, Japan Shoichi Yamada, Waseda Univ, Japan Core-collapse supernovae (CCSNe) are intrinsically multi-scale, multi-physics and multi-dimensional phenomena. Because of the enormous complexity, the first-principles numerical simulations under realistic input physics are strongly required to uncover the explosion mechanism, predict observational signals (neutrinos, gravitational waves and electromagnetic waves) and prove physical state in extremely hot and dense matter of supernova core. With giving a brief overview of the current status of CCSNe study, I will talk about some essential methods of radiation-hydrodynamics with solving the first-principles 6-dimensional Boltzmann equations for neutrino transport, and then present recent results of our CCSNe simulations. I will also discuss some technical difficulties to handle multi-dimensional radiation-hydrodynamics, which would be also common issues for other fields. By sharing these problems, I hope to stimulate multidisciplinary collaboration in terms of radiation-hydrodynamic simulations among ASTRONUM participants.

Oran, Rona	***3D Hybrid Modeling of Asteroid Magnetospheres*** R. Oran, Massachusetts Institute of Technology, USA B. P. Weiss, Massachusetts Institute of Technology, USA M. de Soria-Santacruz Pich, Jet Propulsion Laboratory, California Institute of Technology, USA L. T. Elkins-Tanton, Arizona State University, USA I. Jun, Jet Propulsion Laboratory, California Institute of Technology, USA C. A. Polanskey, Jet Propulsion Laboratory, California Institute of Technology, USA J. B. Ream, Massachusetts Institute of Technology, USA C. T. Russell, University of California, Los Angeles, USA N. Z. Warner, Jet Propulsion Laboratory, California Institute of Technology, USA and the Psyche Team Asteroid (16) Psyche is a large (113 km radius) body likely made almost entirely of iron-nickel metal and is the object of the upcoming NASA Psyche mission (launch planned for 2022). Its composition suggests it may either be the core of a differentiated planetary body whose mantle was removed by collisions in the early solar system, or else is an unmelted, iron-rich accretional aggregate. A key test of the hypothesis that Psyche is a metallic core would be the identification of remanent magnetization due to ancient dynamo action. Dynamo evolution models in the presence of cooling in space suggest that Psyche would not be uniformly magnetized. The Psyche mission will measure magnetic fields in orbit around the asteroid using dual three-axis fluxgate magnetometers. The Psyche mission offers a unique opportunity to explore a yet-unknown type of magnetosphere: one created by the interaction of the solar wind with a small, airless, conducting body with a likely highly non-dipolar magnetic field. To study the range of possible magnetospheric environments of such a body, we simulated the interaction of the solar wind plasma with the body. Because the dimensions of the body are comparable to the solar wind proton gyroradii, hybrid simulations are required. Here we present a new three dimensional hybrid model of Psyche's magnetosphere developed using the HYB code. We modeled the shape of Psyche's magnetosphere assuming different intensities and patterns of magnetization to predict possible magnetic environments that the Psyche spacecraft may encounter. We compare the Psychean magnetosphere to the interaction of the solar wind with other types of asteroids, such as a non-magnetized metallic asteroid, or a non-metallic asteroids (such as a C-type asteroid). This range of simulated small body magnetospheres will enable us to constrain the nature of magnetization of (16) Psyche using the Psyche magnetometry measurements. This will address the hypothesis that the asteroid is the core of a differentiated body.
O'Shea, Brian	***Modeling the Milky Way: Challenges and Opportunities*** Brian O'Shea, Michigan State University I provide an overview of the current state-of-the-art in cosmological simulations of galaxy formation, focusing on the largest and most physically accurate simulations and what they can tell us about galaxy formation and evolution. I will also critically examine the future of galaxy formation simulations, including missing physics, numerical challenges, and opportunities for improved modeling.

Pogorelov, Nikolai	***Multi-Scale Fluid-Kinetic Simulations Suite: Six Years with Blue Waters*** Sergey Borovikov, UAH, USA Phillip Colella, UC Berkeley, USA Tae Kim, UAH, USA Jacob Heerikhuisen, UAH, USA Igor Kryukov, Institute for Problems in Mechanics, Russian Academy of Sciences, Russia William Tang, Princeton University, USA Brian Van Straalen, UC Berkeley, USA Bei Wang, Princeton University, USA Mehmet Yalim, UAH, USA Gary Zank, UAH, USA Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS) is a collection of tools for solving magnetohydrodynamic (MHD) equations coupled with the kinetic Boltzmann equation and/or multiple systems of Euler gas dynamics equations. Solutions are obtained on adaptive mesh refinement (AMR) Cartesian or spherical grids. MS-FLUKSS turned out to be very suitable for the Blue Waters architecture. Moreover, collaboration with the Blue Waters team made it possible to introduce substantial improvements to the code. In particular, additional equations have been added to treat non-thermal ions as a separate fluid and a number of turbulence models implemented. Level-set equations are used to track surfaces that propagate through the computational region kinematically. The Petascale Application Improvement (PAID) program supported by the NSF through the Blue Waters project allowed us to switch to using GPUs for certain parts of MS-FLUKSS. In this presentation, we describe our major scientific results obtained on Blue Waters and present new, data-driven simulations relating the lower solar corona and heliosphere to the local interstellar medium.
Rempel, Matthias	***Simulations of Quiet Sun Magnetism: On the Role of Deep and Shallow Recirculation*** Matthias Rempel, HAO/NCAR Observations suggest that small-scale magnetic field in the solar photosphere is mostly independent from the strength of nearby network field as well as independent of the solar cycle. This supports the view that the origin of small-scale magnetism is due to a small-scale dynamo that operates independently from the large-scale dynamo responsible for the solar cycle. The saturation field strength and structure of the resulting magnetic field in the photosphere depends critically on the contributions from deep and shallow recirculation within the strongly stratified convection zone. In this talk we will discuss the consequences of deep and shallow recirculation for the structure of the quiet sun magnetic field in the photosphere ranging from sub-granular (less than 1 Mm) to super-granular (~ 30 Mm) scales. The presence of deep recirculation within the solar convection zone leads to the formation of granular scale magnetic flux sheets that are present in most downflow lanes in addition to a smaller scale turbulent magnetic field. The formation of such flux sheets can be studied in particular in "exploding granules", where new downflow lanes form in the center of an existing granule. We discuss how future high resolution observations of the deep solar photosphere with the Daniel K. Inouye Solar Telescope (DKIST) can further constrain small-scale dynamo action in the solar convection zone. Furthermore, deep recirculation leads to a magnetic flux imbalance on larger (super-granular) scales that can maintain a quiet Sun (mixed polarity) magnetic network solely through small-scale dynamo action. Such flux imbalance agrees well with that found in observations of quiet Sun network and plays a crucial role in maintaining a quiet Sun corona independent from the contributions of the large-scale dynamo responsible for the solar cycle.

Richers, Sherwood	***General Relativistic Monte Carlo Neutrino Radiation Transport*** Sherwood Richers, North Carolina State University, USA Hiroki Nagakura, Caltech, USA Christian Ott, Caltech, USA Joshua Dolence, Los Alamos National Lab, USA Kohsuke Sumiyoshi, Numazu College of Technology, Japan Shoichi Yamada, Waseda University, Japan The interactions between neutrinos and other matter is the dominant mechanism for energy and lepton number transport in core-collapse supernovae and neutron star mergers. The general-relativistic Boltmann equation that governs the transport of neutrinos in these systems is exceedingly expensive to solve numerically, making approximate transport methods the primary tool for many astrophysical simulations. I will discuss the Monte Carlo neutrino transport code Sedonu, which solves the full (steady-state) relativistic Boltzmann equation in three spatial dimensions. I will present the first multi-dimensional comparison of full Boltzmann neutrino transport methods in the context of core-collapse supernovae, and demonstrate that Sedonu and the discrete ordinates code of Nagakura, Shumiyoshi, and Yamada converge to the same result. I will also demonstrate the difficulties associated with using a more approximate two-moment method in the context of neutron star mergers, and will propose some improvements specific to this unique environment.
Riols, Antoine	***Turbulent Processes and Dust Dynamics in Protoplanetary Discs*** Antoine Riols, IPAG, France One of the most challenging problems in astrophysics is to understand how protoplanetary (PP) discs accrete. The magneto-rotational instability (MRI) has long been considered as the main source of turbulence and accretion in PP discs. However, the weak ionization of such objects prevents the MRI from being excited beyond 1 AU. Moreover, the low velocity dispersion observed in CO and strong sedimentation of millimetre dust measured in T-Tauri discs are in contradiction with predictions based on ideal MRI turbulence. By using shearing box simulations with the PLUTO code, we study two alternative mechanisms, which are the ambipolar-diffusion driven accretion and the gravitational instability. In particular, we compute the dust dynamics and settling in such flows and compare with current sub-millimetric observations of PP discs.
Ripperda, Bart	***Resistivity in General Relativistic Magnetohydrodynamics: An Application to Relativistic Reconnection and Particle Acceleration*** Bart Ripperda, Centre for mathematical Plasma Astrophysics, Belgium Lorenzo Sironi, Department of Astronomy, Columbia University, USA Oliver Porth, Institut fur Theoretische Physik, Germany Rony Keppens, Centre for mathematical Plasma Astrophysics, Belgium Resistivity plays a crucial role in the formation of current sheets, magnetic reconnection and the growth of plasmoids in relativistic magnetohydrodynamics (MHD). We have recently included resistivity in the general relativistic MHD (GRMHD) code BHAC. The code has also been improved with adaptive mesh refinement in combination with flux constrained transport to keep the field divergence-free. We present tests of the newly implemented methods in both special relativistic and general relativistic cases. To analyse particle acceleration, we adapted the code to evolve charged test particles according to the Lorentz force. We applied the resistive code to coalescing magnetic islands causing reconnection in magnetized plasma in 2D flat slabs in Minkowski spacetime. The low resistivity is resolved with very high accuracy due to the extreme resolutions obtained with adaptive mesh refinement. We applied both uniform resistivity and anomalous, spatiotemporally dependent resistivity based on the current density. We found that the plasmoid instability is triggered for Lundquist numbers of 20000 where it is not for Lundquist numbers of 10000. However, for anomalous resistivity with a background Lundquist number of 10000 and an enhanced resistivity in the current sheet, we find plasmoid formation. In all three setups we evolve charged test particles to determine acceleration sites and energy distributions. We find that electrons accelerate to non-thermal energies in the thin current sheets in all cases, and in the formed plasmoids in the cases liable to the plasmoid instability. The maximum Lorentz factor for the particles depends on the resistivity.

Roytershteyn, Vadim	***Fully Kinetic Simulations of Plasma Turbulence*** Vadim Roytershteyn, Space Science Institute, USA Gian Luca Delzanno, LANL, USA Typical space and astrophysical plasmas are weakly collisional, such that the dissipation of energy and momentum arises from microscopic collective processes operating at kinetic scales. Simulations of turbulence dynamics that faithfully describe kinetic process are thus of great interest. However, such simulations also present formidable challenges due to the presence of multiple characteristic scales in plasma, both spatial and temporal. We will discuss several examples of fully kinetic simulations drawn from solar wind turbulence studies and from the analysis of pickup-ion-generated turbulence. We will compare and contrast particle-in-cell (PIC) methodology, a robust and efficient, but also relatively inaccurate method with so-called transform approach that utilizes spectral expansion of the distribution function in Hermite basis. In contrast to PIC, the formulation of Hermite-transform method used in this study has exact conservation laws that enable long-term simulations. Furthermore, approximate, relatively computationally inexpensive models can be obtained with just a few coefficients. Such models are shown to be sufficient to reproduce frequencies and damping rates of basic modes at kinetic scales in magnetized plasma turbulence (kinetic Alfven and whistler). However, accurately capturing purely kinetic modes, such ion Bernstein modes, requires substantially high resolution.
Shen, Fang	***Three-Dimensional MHD Simulation of Interplanetary Solar Wind using a new Boundary Treatment: Comparison with In-situ Data at Earth*** Fang Shen, Zicai Yang, Yi Yang, Xueshang Feng, National Space Science Center, Chinese Academy of Sciences, China Fang Shen, Xueshang Feng, HIT Institute of Space Science and Applied Technology, China Jie Zhang, Department of Physics and Astronomy, George Mason University, USA Three-dimensional (3D) magnetohydrodynamics (MHD) numerical simulation is an important tool in the prediction of solar wind parameters. In this study, we improve our corona interplanetary total variation diminishing (COIN-TVD) MHD scheme by using a new self-consistent boundary treatment suitable for different phases of solar cycle, and apply it to simulate the background solar wind in the interplanetary space. The inner boundary of the model is set at 0.1 astronomical unit (AU) and six-component grid system is employed in the computation domain. The ideal MHD equations are solved by using the total variation diminution (TVD) Lax-Friedrich scheme, and the divergence of the magnetic field is eliminated by a diffusion method. This model uses magnetogram synoptic map images from the Global Oscillation Network Group (GONG) observation as input data. The empirical WSA relation is used to assign solar wind speed at the inner boundary, while density and temperature are specified according to the characteristics of satellite observation. There are five free parameters in the boundary conditions, which can be tuned to simulate the solar wind for different phases of solar cycle. We found that the number of multipole components included in the spherical harmonic expansion in the potential field source surface (PFSS) model, Lmax, has tremendous influence on the solar wind speed distribution, two free parameters in WSA model also have obvious effect on the speed distribution, and the other two free parameters obtained from the historical observational data are used to limit the magnetic field and density. This model is used to simulate the background solar wind from year 2007 to 2017, and we compare the modeling results with the ACE/WIND satellite observations. Visual comparison is proved to be a necessary addition to the quantitative assessment of the models' capabilities in reproducing the time series and statistics of solar wind parameters. Our model can capture the time patterns of solar wind parameters well at most time, and the simulated solar wind parameters (including speed, density, temperature, and the magnetic field strength) are in good agreement with the observations. Results show the improved COIN-TVD model with a new self-consistent boundary treatment can be used for prediction/forecast of solar wind parameters near Earth.

ASTRONUM 2018
ORAL ABSTRACTS

Sorathia, Kareem	***Mesoscale-Driven Acceleration and Losses of Energetic Particles in the Earth's Magnetosphere*** K. Sorathia, JHUAPL, USA A. Ukhorskiy, JHUAPL, USA V. Merkin, JHUAPL, USA Energetic particle populations play an important role in the near-Earth space environment, e.g., the particles comprising the ring current and radiation belts. These particles are non-thermal and not well suited to a fluid treatment, and instead more direct consideration of individual particle dynamics are necessary. The evolution of these populations is governed by the competing effects of production and loss processes. Traditional thinking has categorized these processes as either global, e.g. acting on magnetospheric scales, or local, e.g., acting on particle kinetic scales. Using a combination of high-resolution MHD and test particle simulations we show that mesoscale electrodynamic structures, flow features at the scale of roughly Earth radius that are between the kinetic and global scales, can play an important role in the production and losses of energetic particles (ions and electrons). Particle losses into the magnetosheath can be enhanced due to the boundary dynamics of the magnetopause, e.g. Kelvin-Helmholtz instability. Confined flow channels that form in the aftermath of localized magnetotail reconnection (bursty bulk flows) and corresponding magnetic signatures (dipolarization fronts), can more effectively transport and accelerate particles into the inner magnetosphere than large-scale convection. We will show the results of simulations demonstrating these processes and include several examples of spacecraft measurements showing signatures of the mesoscale-driven production and loss processes we discuss.
Toth, Gabor	***Generalized Lagrange Multiplier constrained Energy Conserving Semi-Implicit Particle-in-Cell Algorithm*** Gabor Toth, University of Michigan, USA Yuxi Chen, University of Michigan, USA The Energy Conserving Semi-Implicit Method (ECSIM) introduced by Lapenta (2017) has many advantageous properties compared to the classical semi-implicit and explicit PIC methods. Most importantly, energy conservation eliminates the growth of the finite grid instability. We have implemented ECSIM into our version of the iPIC3D code. The implementation is different and more efficient than the original approach. More importantly, we have addressed two major shortcomings of the original ECSIM algorithm: there is no mechanism to enforce Gauss's law and there is no mechanism to reduce the numerical oscillations of the electric field. A classical approach to satisfy Gauss's law is to modify the electric field and its divergence using either an elliptic or a parabolic/hyperbolic correction based on the Generalized Lagrange Multiplier method. This correction, however, violates the energy conservation property, and the oscillations related to the finite grid instability reappear in the modified ECSIM scheme. We explored an alternative approach: the particle positions are modified instead of the electric field in the correction step! Moving the particles slightly does not change the energy conservation property, while it can satisfy Gauss's law by changing the charge density. We found that this approach produces superior results compared to the original ECSIM algorithm. In some simulations, however, there are still some numerical oscillations present in the electric field. We attribute this to the simple finite difference discretization of the energy conserving implicit field solver that has no slope limiters that would eliminate the formation of new extrema. We have designed and tested a number of modifications that significantly reduce or eliminate these oscillations while only slightly violating the energy conservation properties. The amount of dissipation is controlled by adjustable parameters and the total energy of the system decreases, which guarantees that the finite grid instability does not show up. We will describe the new schemes and show some tests that demonstrate their properties.
Townsley, Dean	***Modeling Subgrid Combustion Processes in Simulations of Thermonuclear Supernovae*** Dean M. Townsley, University of Alabama, USA Broxton J. Miles, North Carolina State University, USA Alan C. Calder, Stony Brook University, USA While thermonuclear supernovae, observationally Type Ia, are widely depended upon for accurate measurements of the expansion history of the universe and contribute most of the iron in Earth abundances, many aspects of their origins remain unknown. Steadily improving simulations both expand and challenge our understanding of these events. While we know from the material ejected that these supernovae must come from the explosive incineration of a white dwarf star, exactly how and, more critically, why this explosion takes place and what type of stellar systems produce it are ambiguous. Computing the predicted results of proposed scenarios requires accurate and efficient numerical modeling of the combustion of carbon and helium-rich material on stellar scales in both the deflagration (subsonic) and detonation (supersonic) mode. I will discuss some techniques used to surmout the challenges met in computing accurate combustion dynamics and products for a star with dimensions of thousands of kilometers incinerated by reaction fronts with thicknesses as small as a micrometer.

Tricco, Terrence	***The Kelvin-Helmholtz Instability and SPH*** Terrence Tricco, Canadian Institute for Theoretical Astrophysics, University of Toronto, Canada There has been interest in recent years to assess the ability of astrophysical hydrodynamics codes to correctly model the Kelvin-Helmholtz instability. Smoothed particle hydrodynamics (SPH), in particular, has received significant attention on this matter. However, there has yet to be a clear demonstration that SPH yields converged solutions which are in agreement with other codes and methods. I will present SPH simulations of the Kelvin-Helmholtz instability using the test problems presented at last year's AstroNum that were put forward by Lecoanet et al (2016). I will demonstrate that SPH yields solutions which converge and quantitatively agree with grid-based methods.
van der Holst, Bart	***CME-Turbulence Interaction with 3-Temperature Plasma Instabilities*** Bart van der Holst, University of Michigan, USA Ward Manchester IV, University of Michigan, USA We examine the interaction between Alfven wave turbulence, plasma instabilities and temperature anisotropies in the environment of a fast coronal mass ejection (CME). The impact of a fast CME on the solar corona causes turbulent energy, thermal energy and dissipative heating to increase by orders of magnitude, and produces conditions suitable for a host of instabilities due to significant temperature anisotropy. We study these CME-induced effects with the recently developed Alfven Wave Solar Model, with which we are able to self-consistently simulate the turbulent energy transport and dissipation as well as isotropic electron heating and anisotropic proton heating. Furthermore, the model also offers the capability to address the effects of fire hose, mirror mode, and cyclotron instabilities on proton/electron energy partitioning, all in a global-scale numerical simulation. We find the turbulent energy greatly enhanced in the CME sheath with strong wave reflection at the shock, which leads to wave dissipation rates increasing by more than a factor of 100. In contrast, wave energy is greatly diminished by adiabatic expansion in the flux rope. Finally, we find proton temperature anisotropies are limited by plasma instabilities to a level consistent with solar wind observations.
Velli, Marco	***Plasma Physics of the Inner Heliosphere: Waves, Turbulence, Reconnection and Parker Solar Probe*** Velli, M. The magnetic field is fundamental to solar activity and shapes the interplanetary environment, as clearly shown by the full three dimensional monitoring of the heliosphere provided by the measurements of the Helios, Ulysses, SOHO, ACE, Wind, STEREO, Hinode, IRIS, SDO, and Voyager spacecraft. Magnetic fields are also the source for coronal heating and the very existence of the solar wind; produced by the sun's dynamo and emerging into the corona, magnetic fields become a conduit for waves, act to store energy, and then propel plasma into the heliosphere in the form of Coronal Mass Ejections (CMEs). In 2018 the Solar Probe Plus (PSP) mission will launch to carry out the first in situ exploration of the outer solar corona and inner heliosphere. Direct measurements of the plasma in the closest atmosphere of our star should lead to a new understanding of the questions of coronal heating and solar wind acceleration. I will describe the PSP scientific objectives and models of solar magnetic activity, coronal heating, and solar wind acceleration that PSP may confirm or falsify.
Woodward, Paul	***Moving the PPMstar code to Machines with GPU-accelerated Nodes for 3-D stellar Hydrodynamics Problems*** Paul Woodward, Univ. of Minnesota, USA HuaQing Mao, Univ. of Minnesota, USA We have been developing a new PPMstar code to support our research in convective boundary mixing in stellar interiors and its impacts upon stellar evolution and nucleosynthesis. The new code uses a relatively clean F90 expression that can be translated into CUDA by a python tool, enabling GPUs to be exploited if desired. The new code also is designed around an ultimate 3-level AMR capability, which is still in development. The code's new MPI messaging structure not only permits AMR to be introduced, but it also enables a resilient form of execution. Immediate visualization and production of partially analyzed data products as the code runs greatly reduce the amount of human labor. The code's redesign to enable the dynamic load balancing that AMR requires has the side effect of making very flexible code execution possible. These aspects of the code design and experience with and results of its use will be presented.

Zank, Gary	***Theory and Transport of Nearly Incompressible Magnetohydrodynamic Turbulence in the Solar Corona*** G.P. Zank, University of Alabama in Huntsville, USA L. Ashikhari, University of Alabama in Huntsville, USA P. Hunana, University of Alabama in Huntsville, USA S.K. Tiwari, Lockheed Martin, USA R. Moore, University of Alabama in Huntsville, USA D. Shiota, Nagoya University, Japan R. Bruno, INAF-IAPS-Rome, Italy D. Telloni, INAF-Torinio, Italy A new model describing the transport and evolution of turbulence in the quiet solar corona is described. In the low plasma beta environment, transverse photospheric convective fluid motions drive predominantly quasi-2D (non-propagating) turbulence in the mixed polarity "magnetic carpet," together with a minority slab (Alfvenic) component. We use a simplified sub-Alfvenic flow velocity profile to solve transport equations describing the evolution and dissipation of turbulence from 1 - 15 Rs (including the Alfven surface). Typical coronal base parameters are used, although one model uses correlation lengths derived observationally by Abramenko et al. 2013, and the other assumes values 10 times larger. The model predicts that 1) the majority quasi-2D turbulence evolves from a balanced state at the coronal base to an imbalanced state, with outward fluctuations dominating, at and beyond the Alfven surface, i.e., inward turbulent fluctuations are dissipated preferentially; 2) the initially imbalanced slab component remains imbalanced throughout the solar corona, being dominated by outwardly propagating Alfven waves, and wave reflection is weak; 3) quasi-2D turbulence becomes increasingly magnetized, and beyond ~6 Rs, the kinetic energy is mainly in slab fluctuations; 4) there is no accumulation of inward energy at the Alfven surface; 5) inertial range quasi-2D rather than slab fluctuations are preferentially dissipated within ~3 Rs, and 6) turbulent dissipation of quasi-2D fluctuations is sufficient to heat the corona to temperatures ~2 million degrees K within 2 Rs, consistent with observations that suggest the fast solar wind is accelerated most efficiently between ~2 - 4 Rs.
Zhang, Ming	***Solar Energetic Particle Transport in Coronal and Interplanetary Magnetic Fields*** Ming Zhang and Lulu Zhao, Florida Institute of Technology, USA Space weather forecast of radiation hazard from energetic solar events needs an accurate physical model of particle transport from the Sun to Earth and beyond. The model should include magnetic field and plasma conditions of the corona and interplanetary medium based on real-time measurements because they vary significantly from one solar event to another. Particle transport is governed by the magnetic field and plasma structures as well as their small-scale turbulent components, which drive particle scattering and diffusion. In this paper, we present a model of solar energetic particle propagation using focus transport equation with a data-driven coronal magnetic field. Behaviors of solar energetic particle escape to the interplanetary space and precipitation to the solar surface are analyzed. The results are used to explain observations of solar energetic particles and gamma-ray emission for solar flares and coronal mass ejections.
Zingale, Michael	***Modeling Type Ia Supernovae and X-ray Bursts*** Michael Zingale, Stony Brook University, USA We discuss the progress made in modeling Type Ia supernovae and X-ray bursts and what challenges remain. We show our current progress on both of these events, looking at a variety of different progenitor models for Type Ia supernovae and the burning dynamics in X-ray bursts, and outline our future goals. Numerical challenges will be discussed along with some new algorithmic ideas to overcome these issues.