ASTRONUM 2025

17th International Conference on Numerical Modeling of Space Plasma Flows

Madison, WI, USA

13-18 July 2025

Organized by:

- **Center for Space Plasma and Aeronomic Research in The University of Alabama in Huntsville, USA**
- **Physics Department in The University of Wisconsin-Madison, USA**
- **Maison de la Simulation (CEA/CNRS/Inria/UPS/UVSQ), Saclay, France will organize ASTRONUM-2025**

BOOK OF ABSTRACTS

ASTRONUM 2025
Madison, WI, July 13 – 18
AGENDA

	SUNDAY, JULY 13	
5:00 PM – 8:00 PM	**Registration – Fluno Center Mendota Hallway**	
6:00 PM – 8:00 PM	**Welcome Reception – FC Skyview Reception**	

	MONDAY, JULY 14	
7:30 AM - 6:00 PM	**Registration – FC Atrium**	
8:45 AM – 5:35 PM	**GENERAL SESSION – FC Auditorium**	
	CHAIR: Audit, E.	
9:00 AM - 9:25 AM	Stone, James	AthenaK: a performance-portable version of Athena++
9:25 AM - 9:50 AM	Banik, Uddipan	A novel theory for particle acceleration in collisionless plasmas: origin of the universal non-thermal distribution function
9:50 AM - 10:15 AM	Li, Hui	3D Dust Dynamics in Protoplanetary Disks: Implications for Planetesimal Formation
10:15 AM - 10:45 AM	**Morning Break - FC Atrium**	
	CHAIR: Fujimoto, K..	
10:45 AM - 11:10 AM	Giacalone, Joe	Hybrid simulations of the extremely fast shock and associated solar energetic particle event observed by Parker Solar Probe on 13 March 2023
11:10 AM - 11:35 AM	Büchner, Jörg	Kinetic Simulation of Particle Energization by Magnetic Reconnection in Collisionless Plasmas
11:35 AM - 12:00 PM	Matsukiyo, Shuichi	2D PIC simulation of pickup ion mediated oblique heliospheric termination shock
12:00 PM - 12:25 PM	Adhikari, Subash	Compressive Pressure-Strain Interaction in Kinetic Plasma Turbulence
12:30 PM - 1:45 PM	**Lunch Break – FC Dining Room**	
	CHAIR: Stone, J.	
1:45 PM - 2:10 PM	DeGrendele, Christopher	Hybrid ML-Numerical Solvers for Hyperbolic-Parabolic PDEs: Overcoming Timestep Constraints
2:10 PM - 2:35 PM	Lee, Youngjun	Enhancements in Solvers and Physics Capabilities in Flash-X
2:35 PM - 3:00 PM	Calder, Alan	Neutron Star Atmospheres
3:00 PM - 3:25 PM	Xu, Siyao	Energetic particle transport in turbulent plasma
3:35 PM - 3:55 PM	**Afternoon Break - FC Atrium**	
	CHAIR: Ricker, P.	
3:55 PM - 4:20 PM	Tchekhovskoy, Alexander	Bringing the scales in general relativistic magnetohydrodynamic simulations
4:20 PM - 4:45 PM	Hauck, Cory	A data-driven strategy for entropy-based moment closures
4:45 PM - 5:10 PM	Johnson, Grant	Solving the Plasma Kinetic Equation Numerically on Smooth Manifolds with Continuum Methods
5:10 PM - 5:35 PM	Singh, Divjyot	Converting H-AMR to Run GRRMHD Simulations on Intel GPUs with OpenCL
	SESSION ADJORNS	

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TUESDAY, JULY 15		
7:30 AM - 6:00 PM	**Registration – FC Atrium**	
9:00 AM – 5:35 PM	**GENERAL SESSION – FC Auditorium**	
CHAIR: Xu, S.		
9:00 AM - 9:25 AM	Zank, Gary	Magnetic Flux Ropes, Turbulence, and Chromospheric and Coronal Heating
9:25 AM - 9:50 AM	Beattie, James	Supersonic magnetized turbulence at Reynolds numbers over a million: implications for fundamental compressible turbulence theory and cold phase interstellar plasma
9:50 AM - 10:15 AM	Fraternale, Federico	Multi-Component MHD/Kinetic-Neutrals and Multifluid Modeling of the Outer Heliosphere and VLISM
10:05 AM - 10:30 AM	**Morning Break - FC Atrium**	
CHAIR: Zank, G. P.		
10:45 AM - 11:10 AM	Fujimoto, Keizo	Electron Heating in Turbulent Current Sheet During 3D Magnetic Reconnection
11:10 AM - 11:35 AM	Arshad, Talha	Adaptive Mesh Refinement for the Semi-Implicit Particle-in-Cell Model
11:35 AM - 12:00 PM	Chen, Yuxi	Suppressing spurious oscillations and particle noise in particle-in-cell simulations
12:00 PM - 12:25 PM	Choi, Dooyoung	Thickness and orientation of heliospheric current sheets at various heliosphere locations
12:35 PM - 1:30 PM	**Lunch Break – FC Dining Room**	
CHAIR: Dubey, A.		
1:45 PM - 2:10 PM	Comisso, Luca	Probing Particle Acceleration in Turbulence with First-Principles Kinetic Simulations
2:10 PM - 2:35 PM	Golant, Ryan	Intermittency and particle transport in fully-kinetic, large-amplitude turbulence
2:35 PM - 3:00 PM	An, Yifu	BATSRUS GPU: Faster-than-Real-Time Magnetospheric Simulations with a Block-Adaptive Grid Code
3:00 PM - 3:25 PM	Commerçon, Benoît	Numerical methods for dust dynamics applied to the ISM and star formation: status and perspective
3:35 PM - 3:55 PM	**Afternoon Break - FC Atrium**	
CHAIR: Boldyrev, S.		
3:55 PM - 4:20 PM	Caplan, Ron	Open-source Release of the Magnetohydrodynamic Algorithm outside a Sphere (MAS) model
4:20 PM - 4:45 PM	Issa, Danat	Probing Cosmic Pathways of Heavy Element Nucleosynthesis through State-of-the-art Simulations
4:45 PM - 5:10 PM	Wibking, Benjamin	Quokka: Exascale Radiation MHD for Star and Galaxy Formation
SESSION ADJOURNS		

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WEDNESDAY, JULY 16		
7:30 AM - 6:00 PM	**Registration – FC Atrium**	
9:00 AM - 5:35 PM	**GENERAL SESSION – FC Auditorium**	
CHAIR: Lazarian, A.		
9:00 AM - 9:25 AM	Pogorelov, Nikolai	Global Structure of the Heliosphere
9:25 AM - 9:50 AM	Munakata, Kazuoki	Sidereal cosmic-ray anisotropy at TeV energies modeled with data from the Tibet ASgamma experiment
9:50 AM - 10:15 AM	Zhang, Ming	A physics-based data-driven model for solar energetic particle radiation forecasting
10:05 AM - 10:30 AM	**Morning Break - FC Atrium**	
CHAIR: Caplan, R.		
10:45 AM - 11:10 AM	Provornikova, Elena	MHD simulations of CME emergence into the inner heliosphere with displacement of the heliospheric magnetic field
11:10 AM - 11:35 AM	Baratashvili, Tinatin	Icarus: Advanced Techniques for Heliosphere Modelling
11:35 AM - 12:00 PM	Singh, Talwinder	HelioCubed: Inner Heliosphere Simulations with 4th order accuracy on a Cubed Sphere Grid
12:00 PM - 12:25 PM	Shen, Fang	Modeling and Prediction of Earth-affecting Solar Transients Based on Multiple Observations and Machine Learning Techniques
12:35 PM - 1:30 PM	**Lunch Break – FC Dining Room**	
CHAIR: Li, H.		
1:45 PM - 2:10 PM	Vishniac, Ethan	Magnetic Helicity Conservation and the Turbulent Cascade
2:10 PM - 2:35 PM	Medvedev, Mikhail	Modeling pair cascade in AGN jets
2:35 PM - 3:00 PM	Lazarian, Alex	Energy spectra and kinetic energy dominance in subAlfvenic turbulence
3:00 PM - 3:25 PM	Ho, Ka Wai	Dust Coagulation in Athena++: Application to Hydrodynamical Instabilities and Future Possibilities
3:35 PM - 3:55 PM	**Afternoon Break – FC Atrium**	
CHAIR: Lee, D.		
3:55 PM - 4:20 PM	Radice, David	Neutron Star Merger Simulations
4:20 PM - 4:45 PM	Balsara, Dinshaw	An Anisotropic Model of the Heliospheric Interface
4:45 PM - 5:10 PM	Steinberg, Elad	Deterministic semi-Implicit Compton Scattering coupled to Hydrodynamics
5:10 PM - 5:35 PM	Li, Yuan	Probing Intracluster Medium Turbulence Near and Below Coulomb Mean-Free-Path Scales with Cool Filaments
SESSION ADJOURNS		
6.30 PM - 9:00 PM	**Group Dinner – FC Skyview Reception**	

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THURSDAY, JULY 17		
7:30 AM - 6:00 PM	**Registration – FC Atrium**	
9:00 AM – 5:10 PM	**GENERAL SESSION – FC Auditorium**	
	CHAIR: Vishniac, E.	
9:00 AM - 9:25 AM	Zhdankin, Vladimir	Turbulent Dissipation in Relativistic Collisionless Plasmas
9:25 AM - 9:50 AM	Audit, Edouard	Modeling supernova ejecta on exascale systems
9:50 AM - 10:15 AM	Hanawa, Tomoyuki	4th Order Accurate Poisson Equation for the Adaptive Mesh Refinement
10:05 AM - 10:30 AM	**Morning Break - FC Atrium**	
	CHAIR: Baratashvili, T.	
10:45 AM - 11:10 AM	Hegde, Dinesha	SuryaBench: Full-Resolution Benchmark Dataset from the Solar Dynamics Observatory for Machine Learning Applications in Heliophysics
11:10 AM - 11:35 AM	Liu, Weihao	Modeling the 2017 September 10 Solar Energetic Particle Event as Observed on Mars and at 1 au
11:35 AM - 12:00 PM	Michael, Adam	Towards a Novel Treatment of the Magnetotail Transition Region
12:00 PM - 12:25 PM	Toth, Gabor	Non-adiabatic Shock Heating in Multi-ion Magnetohydrodynamic Simulation
12:35 PM - 1:30 PM	**Lunch Break – FC Dining Room**	
	CHAIR: Hanawa, T.	
1:45 PM - 2:10 PM	Ricker, Paul	Toward self-consistent subgrid modeling of black hole feedback
2:10 PM - 2:35 PM	Mewes, Vassilios	Neutrino Radiation Hydrodynamics with Flash-X+thornado
2:35 PM - 3:00 PM	Hu, Yue	Cosmic ray transport in partially Ionized and turbulent medium
3:00 PM - 3:25 PM	Boldyrev, Stanislav	Particle Acceleration in relativistic Alfvenic turbulence
3:35 PM - 3:55 PM	**Afternoon Break - FC Atrium**	
	CHAIR: Provornikova, E.	
3:55 PM - 4:20 PM	Holmstrom, Mats	Stellar wind interactions with resistive obstacles
4:20 PM - 4:45 PM	Lee, Dongwook	Enhancing shock-capturing numerical methods for relativistic flows
4:45 PM - 5:10 PM	Kim, Tae	Kinetic Interstellar Pickup Ion Model of the Multi-Scale Fluid-Kinetic Simulation Suite
5:10 PM - 5:35 PM	J. E. Leake	Data-Driven Magnetohydrodynamical Simulations of Solar Active Regions
	SESSION ADJOURNS	

AGENDA

FRIDAY, JULY 18		
9:00 AM – 11.25 AM	**GENERAL SESSION – FC Auditorium**	
Chair: Pogorelov, N. V.		
9:00 AM - 9:25 AM	Rau, Shiau-Jie	Influence of the donor star evolutionary stage on common envelope evolution
9:25 AM - 9:50 AM	Vartanyan, David	Core-Collapse Supernovae: A Theoretical Study for the Transient Sky
9:50 AM - 10:15 AM	Wilhelm, Rostislav-Paul	High fidelity simulations of the multi-species Vlasov-Maxwell system with the Numerical Flow Iteration
10:15 AM - 10:40 AM	Melon Fuksman, David	New and upcoming radiative transfer and adaptive mesh refinement in the PLUTO code
10:40 AM - 10:10 AM	**Morning Break - FC Atrium**	
11:10 AM - 11:25 AM	**Farewell Adress (N. V. Pogorelov)**	

END OF CONFERENCE

ASTRONUM 2025
Madison, WI, July 13-18

TALKS BY PARTICIPANT

Adhikari, Subash	Monday, July 14	12:00 PM - 12:25 PM	Compressive Pressure-Strain Interaction in Kinetic Plasma Turbulence
An, Yifu	Tuesday, July 15	2:35 PM - 3:00 PM	BATSRUS GPU: Faster-than-Real-Time Magnetospheric Simulations with a Block-Adaptive Grid Code
Arshad, Talha	Tuesday, July 15	11:10 AM - 11:35 AM	Adaptive Mesh Refinement for the Semi-Implicit Particle-in-Cell Model
Audit, Edouard	Thursday, July 17	9:25 AM - 9:50 AM	Modeling supernova ejecta on exascale systems
Balsara, Dinshaw	Wednesday, July 16	4:20 PM - 4:45 PM	An Anisotropic Model of the Heliospheric Interface
Banik, Uddipan	Monday, July 14	9:25 AM - 9:50 AM	A novel theory for particle acceleration in collisionless plasmas: origin of the universal non-thermal distribution function
Baratashvili, Tinatin	Wednesday, July 16	11:10 AM - 11:35 AM	Icarus: Advanced Techniques for Heliosphere Modelling
Beattie, James	Tuesday, July 15	9:25 AM - 9:50 AM	Supersonic magnetized turbulence at Reynolds numbers over a million: implications for fundamental compressible turbulence theory and cold phase interstellar plasma
Bhattacharjee, Chinmoy		Poster	Gravitomagnetic Vorticity and Enstrophy Generation in Accretion Disk: Implications for Plasma Flow Stability
Boldyrev, Stanislav	Thursday, July 17	3:00 PM - 3:25 PM	Particle Acceleration in relativistic Alfvenic turbulence
Büchner, Jörg	Monday, July 14	11:10 AM - 11:35 AM	Kinetic Simulation of Particle Energization by Magnetic Reconnection in Collisionless Plasmas
Calder, Alan	Monday, July 14	2:35 PM - 3:00 PM	Neutron Star Atmospheres
Caplan, Ron	Tuesday, July 15	3:55 PM - 4:20 PM	Open-source Release of the Magnetohydrodynamic Algorithm outside a Sphere (MAS) model
Chen, Yuxi	Tuesday, July 15	11:35 AM - 12:00 PM	Suppressing spurious oscillations and particle noise in particle-in-cell simulations
Choi, Dooyoung	Tuesday, July 15	12:00 PM - 12:25 PM	Thickness and orientation of heliospheric current sheets at various heliosphere locations
Comisso, Luca	Tuesday, July 15	1:45 PM - 2:10 PM	Probing Particle Acceleration in Turbulence with First-Principles Kinetic Simulations
Commerçon, Benoît	Tuesday, July 15	3:00 PM - 3:25 PM	Numerical methods for dust dynamics applied to the ISM and star formation: status and perspective
Crawford, Chris		Poster	Transition from Vortical to Alfvénic-like Fermi Electron Acceleration in Magnetic Reconnection with Increasing Guide Field
DeGrendele, Christopher	Monday, July 14	1:45 PM - 2:10 PM	Hybrid ML-Numerical Solvers for Hyperbolic-Parabolic PDEs: Overcoming Timestep Constraints
Dubey, Anshu		-	
Fraternale, Federico	Tuesday, July 15	9:50 AM - 10:15 AM	Multi-Component MHD/Kinetic-Neutrals and Multifluid Modeling of the Outer Heliosphere and VLISM
Fujimoto, Keizo	Tuesday, July 15	10:45 AM - 11:10 AM	Electron Heating in Turbulent Current Sheet During 3D Magnetic Reconnection
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Hanawa, Tomoyuki	Thursday, July 17	9:50 AM - 10:15 AM	4th Order Accurate Poisson Equation for the Adaptive Mesh Refinement
Hauck, Cory	Monday, July 14	4:20 PM - 4:45 PM	A data-driven strategy for entropy-based moment closures

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Henadhira Arachchige, Kalpa Harindra Perera	Tuesday, July 15	17:10 AM - 17:35 AM	Machine Learning Approach to Coronal Hole Detection within Solar Cycles and Solar Wind Model Validation
Ho, Ka Wai	Wednesday, July 16	3:00 PM - 3:25 PM	Dust Coagulation in Athena++: Application to Hydrodynamical Instabilities and Future Possibilities
Holmstrom, Mats	Thursday, July 17	3:55 PM - 4:20 PM	Stellar wind interactions with resistive obstacles
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Issa, Danat	Tuesday, July 15	4:20 PM - 4:45 PM	Probing Cosmic Pathways of Heavy Element Nucleosynthesis through State-of-the-art Simulations
Johnson, Grant	Monday, July 14	4:45 PM - 5:10 PM	Solving the Plasma Kinetic Equation Numerically on Smooth Manifolds with Continuum Methods
Kim, Tae	Thursday, July 17	4:45 PM - 5:10 PM	Kinetic Interstellar Pickup Ion Model of the Multi-Scale Fluid-Kinetic Simulation Suite
Lazarian, Alex	Wednesday, July 16	2:35 PM - 3:00 PM	Energy spectra and kinetic energy dominance in subAlfvenic turbulence
Leake, James	Thursday, July 17	5:10 PM - 5:35 PM	Data-Driven Magnetohydrodynamical Simulations of Solar Active Regions
Lee, Youngjun	Monday, July 14	2:10 PM - 2:35 PM	Enhancements in Solvers and Physics Capabilities in Flash-X
Lee, Dongwook	Thursday, July 17	4:20 PM - 4:45 PM	Enhancing shock-capturing numerical methods for relativistic flows
Li, Hui	Monday, July 14	9:50 AM - 10:15 AM	3D Dust Dynamics in Protoplanetary Disks: Implications for Planetesimal Formation
Li, Yuan	Wednesday, July 16	5:10 PM - 5:35 PM	Probing Intracluster Medium Turbulence Near and Below Coulomb Mean-Free-Path Scales with Cool Filaments
Liu, Weihao	Thursday, July 17	11:10 AM - 11:35 AM	Modeling the 2017 September 10 Solar Energetic Particle Event as Observed on Mars and at 1 au
Matsukiyo, Shuichi	Monday, July 14	11:35 AM - 12:00 PM	2D PIC simulation of pickup ion mediated oblique heliospheric termination shock
Medvedev, Mikhail	Wednesday, July 16	2:10 PM - 2:35 PM	Modeling pair cascade in AGN jets
Melon Fuksman, David	Friday, July 18	10:15 AM - 10:40 AM	New and upcoming radiative transfer and adaptive mesh refinement in the PLUTO code
Mewes, Vassilios	Thursday, July 17	2:10 PM - 2:35 PM	Neutrino Radiation Hydrodynamics with Flash-X+thornado
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Provornikova, Elena	Wednesday, July 16	10:45 AM - 11:10 AM	MHD simulations of CME emergence into the inner heliosphere with displacement of the heliospheric magnetic field
Radice, David	Wednesday, July 16	3:55 PM - 4:20 PM	Neutron Star Merger Simulations
Rau, Shiau-Jie	Friday, July 18	9:00 AM - 9:25 AM	Influence of the donor star evolutionary stage on common envelope evolution
Ricker, Paul	Thursday, July 17	1:45 PM - 2:10 PM	Toward self-consistent subgrid modeling of black hole feedback
Roley, Karin		Poster	Modeling Particle Acceleration in Magnetic Reconnection with Machine Learning-Driven Sub-grid Physics

TALKS BY PARTICIPANT

Shen, Fang	Wednesday, July 16	12:00 PM - 12:25 PM	Modeling and Prediction of Earth-affecting Solar Transients Based on Multiple Observations and Machine Learning Techniques
Singh, Divjyot	Monday, July 14	5:10 PM - 5:35 PM	Converting H-AMR to Run GRRMHD Simulations on Intel GPUs with OpenCL
Singh, Talwinder	Wednesday, July 16	11:35 AM - 12:00 PM	HelioCubed: Inner Heliosphere Simulations with 4th order accuracy on a Cubed Sphere Grid
Steinberg, Elad	Wednesday, July 16	4:45 PM - 5:10 PM	Deterministic semi-Implicit Compton Scattering coupled to Hydrodynamics
Stone, James	Monday, July 14	9:00 AM - 9:25 AM	AthenaK: a performance-portable version of Athena++
Tchekhovskoy, Alexander	Monday, July 14	3:55 PM - 4:20 PM	Bringing the scales in general relativistic magnetohydrodynamic simulations
Toth, Gabor	Thursday, July 17	12:00 PM - 12:25 PM	Non-adiabatic Shock Heating in Multi-ion Magnetohydrodynamic Simulation
Vartanyan, David	Friday, July 18	9:25 AM - 9:50 AM	Core-Collapse Supernovae: A Theoretical Study for the Transient Sky
Vishniac, Ethan	Wednesday, July 16	1:45 PM - 2:10 PM	Magnetic Helicity Conservation and the Turbulent Cascade
Wang, Bingbing		Poster	One dimensional analytical solutions of the transport equations for incompressible magnetohydrodynamic (MHD) turbulence
Wang, Xiangyu		Poster	Acceleration of ultrahigh-energy cosmic rays in the early afterglows of gamma-ray bursts: Concurrence of jet dynamics and wave-particle interactions
Wibking, Benjamin	Tuesday, July 15	4:45 PM - 5:10 PM	Quokka: Exascale Radiation MHD for Star and Galaxy Formation
Wilhelm, Rostislav-Paul	Friday, July 18	9:50 AM - 10:15 AM	High fidelity simulations of the multi-species Vlasov-Maxwell system with the Numerical Flow Iteration
Xu, Siyao	Monday, July 14	3:00 PM - 3:25 PM	Energetic particle transport in turbulent plasma
Zank, Gary	Tuesday, July 15	9:00 AM - 9:25 AM	Magnetic Flux Ropes, Turbulence, and Chromospheric and Coronal Heating
Zhang, Ming	Wednesday, July 16	9:50 AM - 10:15 AM	A physics-based data-driven model for solar energetic particle radiation forecasting
Zhdankin, Vladimir	Thursday, July 17	9:00 AM - 9:25 AM	Turbulent Dissipation in Relativistic Collisionless Plasmas

SCHEDULE OF TALKS

Monday, July 14: 12:00:00 PM - 12:25:00 PM
Presenter: Adhikari, Subash

Compressive Pressure-Strain Interaction in Kinetic Plasma Turbulence

Subash Adhikari, University of Delaware, Newark, DE 19716
Yan Yang, University of Delaware, Newark, DE 19716
William H. Matthaeus, University of Delaware, Newark, DE 19716

Using kinetic particle-in-cell (PIC) simulations of plasma turbulence, we revisit the pressure-strain interaction [1] and in particular we focus on the recent decomposition of pressure-strain interaction into compressive and incompressive parts [2]. It is evident in the literature that the pressure dilatation is clearly due to plasma compressions, but in this study we explore the local dynamics of the remaining anisotropic part, often called Pi-D, and examine the contributions due to compressive, non solenoidal velocities of the particle species. The compressive contribution to Pi-D can play a significant role in turbulent systems with low plasma beta even though the initial conditions are incompressible-like. Compressive ingredient of Pi-D is locally shown to be anticorrelated with both incompressive Pi-D and pressure dilatation. In addition, we show conditional statistics for these components of pressure-strain interaction at regions of localized current, vorticity and rate of strain tensor.
[1] Y. Yang, W. H. Matthaeus, T. N. Parashar et al, “Energy transfer, pressure tensor, and heating of kinetic plasma,” Phys. Plasmas 24, 072306 (2017).
[2] S. Adhikari, Y. Yang, and W. H. Matthaeus, “Revisiting compressible and incompressible pressure-strain interaction in kinetic plasma turbulence,” Under review in Physics of Plasmas, arXiv:2503.11825 (2025).

Tuesday, July 15: 2:35:00 PM - 3:00:00 PM
Presenter: An, Yifu

BATSRUS GPU: Faster-than-Real-Time Magnetospheric Simulations with a Block-Adaptive Grid Code

Yifu An, University of Michigan, USA
Yuxi Chen, University of Michigan, USA
Hongyang Zhou, University of Michigan, USA
Alexander Gaenko, University of Michigan, USA
Gábor Tóth, University of Michigan, USA

BATSRUS, our state-of-the-art extended magnetohydrodynamic code, is the most used and one of the most resource-consuming models in the Space Weather Modeling Framework. It has always been our objective to improve its efficiency and speed with emerging techniques, such as GPU acceleration. To utilize the GPU nodes on modern supercomputers, we port BATSRUS to GPUs with the OpenACC API. Porting the code to a single GPU requires rewriting and optimizing the most used functionalities of the original code into a new solver, which accounts for around 1% of the entire program in length. To port it to multiple GPUs, we implement a new message passing algorithm to support its unique block-adaptive grid feature. We conduct weak scaling tests on as many as 256 GPUs and find good performance. The program has 50-60% parallel efficiency on up to 256 GPUs, and up to 95% efficiency within a single node (4 GPUs). Running large problems on more than one node has reduced efficiency due to hardware bottlenecks. We also demonstrate our ability to run representative magnetospheric simulations on GPUs. The performance for a single A100 GPU is about the same as 270 AMD "Rome" CPU cores, and it runs 3.6 times faster than real time. The simulation can run 6.9 times faster than real time on four A100 GPUs.

SCHEDULE OF TALKS

Tuesday, July 15: 11:10:00 AM - 11:35:00 AM
Presenter: Arshad, Talha

Adaptive Mesh Refinement for the Semi-Implicit Particle-in-Cell Model

Talha Arshad, University of Michigan, USA
Yuxi Chen, University of Michigan, USA
Gabor Toth, University of Michigan, USA

The particle-in-cell (PIC) method is a fundamental tool for modeling plasma kinetic processes, but its high computational cost remains a challenge. Adaptive mesh refinement (AMR) offers a promising approach to enhance efficiency by dynamically adjusting resolution based on plasma dynamics. In this work, we present a novel AMR algorithm tailored for a semi-implicit PIC solver. Our implementation supports multiple refinement levels with flexible refinement ratios while ensuring numerical stability and accuracy. A carefully designed electric field solver minimizes resolution interface artifacts, and a specialized algorithm preserves Gauss's law in the whole domain, including refinement level interfaces. Particles can move across resolution changes so that the distribution function is consistent among all grid levels. To maintain computational efficiency, we employ particle splitting and merging techniques to ensure uniform particle-per-cell distribution. Benchmark tests, including a two-dimensional double current sheet reconnection problem, demonstrate the effectiveness of our method, achieving accurate solutions with significant computational speed-up compared to uniform high-resolution grids. These advancements pave the way for more efficient large-scale plasma simulations.

Thursday, July 17: 9:25:00 AM - 9:50:00 AM
Presenter: Audit, Edouard

Modeling supernova ejecta on exascale systems

Edouard Audit, CEA / Maison de la Simulation
Lou Roussel-Hard, CEA / Maison de la Simulation and IAP
Luc Dessart, IAP
Thomas Padioleau, CEA / Maison de la Simulation
Yushan Wang, CEA / Maison de la Simulation
Enzo Roaldes, CEA / Maison de la Simulation

Exascale systems offer great opportunities for the numerical astrophysics community and also raise important technical challenges, especially for legacy codes and for code sustainability and portability. I will present recent technical development and performance improvement of the Heracles++ code developed using the Kokkos library. Then I will present results of supernova ejecta modelling done with this code developed using the Kokkos library. I will concentrate on red super-giants explosion and the influence of Ni clumping.

Wednesday, July 16: 4:20:00 PM - 4:45:00 PM
Presenter: Balsara, Dinshaw

An Anisotropic Model of the Heliospheric Interface

Dinshaw S. Balsara, Univ. of Notre Dame
Vladimir Florinski, University of Alabama, Huntsville
Gary Zank, University of Alabama, Huntsville
Shishir Biswas, Univ. of Notre Dame

We present a pioneering model of the interaction between the solar wind and the surrounding interstellar medium that includes the possibility of different pressures in directions parallel and perpendicular to the magnetic field. The outer heliosheath region is characterized by a low rate of turbulent scattering that would permit development of pressure anisotropy. The effect is best seen on the interstellar side of the heliopause, where a narrow region develops with an excessive perpendicular pressure resembling a plasma depletion layer typical of planetary magnetspheres. The theory and some implementation aspects of such an anisotropic plasma model will also be discussed if time permits.

Monday, July 14: 9:25:00 AM - 9:50:00 AM
Presenter: Banik, Uddipan

A novel theory for particle acceleration in collisionless plasmas: origin of the universal non-thermal distribution function

Uddipan Banik, IAS Princeton, USA
Amitava Bhattacharjee, Princeton University, USA

There is ample evidence for non-thermal (non-Maxwellian) power-law distribution functions in astrophysical as well as laboratory plasmas in the collisionless/kinetic regime. In particular, there is a preponderance of v^-5 velocity (v) distribution and E^-2 energy (E) distribution in collisionless plasmas such as the ion population of the solar wind. I am going to present a novel self-consistent theory for particle acceleration based on the perturbed Vlasov-Maxwell equations for multi-species plasma that is a huge improvement upon the conventional Parker transport equation and can explain the origin of the universal power-law distribution function. I will show how an electromagnetically driven collisionless plasma always relaxes to an E^-2 energy distribution and a v^-(d+2) universal power-law (d = number of dimensions), which corresponds to v^-5 in 3D, as long as the electromagnetic drive acts predominantly on scales larger than the Debye length in a nearly uncorrelated fashion. This result is independent of the detailed fluctuation power spectrum. Stronger Debye shielding of slower particles reduces their effective charge and suppresses their acceleration in a universal manner relative to unshielded faster particles, ultimately resulting in the universal power-law distribution.

Wednesday, July 16: 11:10:00 AM - 11:35:00 AM
Presenter: Baratashvili, Tinatin

Icarus: Advanced Techniques for Heliosphere Modelling

Tinatin Baratashvili, Centre for amthematical Plasma-Astrophysics, KU Leuven, Belgium
Stefaan Poedts, Centre for amthematical Plasma-Astrophysics, KU Leuven, Belgium; Institute of Physics, University of Maria Curie-Skłodowska, ul. Radziszewskiego 10, 20-031 Lublin, Poland

Coronal Mass Ejections (CMEs) are the main drivers of interplanetary shocks and space weather disturbances. CMEs propagate in the solar wind and interact with its magnetic field. This interaction can modify the CME magnetic field configuration. One of the key parameters that determines the geo-effectiveness of the CME is its internal magnetic configuration. Strong CMEs directed towards Earth can severely impact our planet, and their prediction can mitigate possible damage. Thus, efficient space weather prediction tools are necessary to produce timely forecasts for the CMEs' arrival times at Earth and their strength upon arrival.
We recently obtained a complete 3D MHD modelling chain from Sun to Earth using COCONUT to reconstruct the coronal model and Icarus to model the inner heliosphere. COCONUT (Perri et al. 2022) is a 3D global MHD model that covers the domain from the solar surface to 0.1 AU. The model is coupled to the heliospheric models EUHFORIA and Icarus. The implemented source terms, such as radiative losses, thermal conduction, and approximated coronal heating, allow a bi-modal solar wind configuration at the outer boundary, making the model suitable for space weather purposes (Baratashvili et al.2025).
The novel heliospheric model Icarus (Verbeke et al. 2022, Baratashvili et al. 2025), implemented within the framework of MPI-AMRVAC (Xia et al. 2018), introduces new capabilities to model the heliospheric solar wind and actual CME events. Ideal MHD equations are solved in the co-rotating reference frame with the Sun. Advanced techniques, such as adaptive mesh refinement and gradual radial grid stretching, are implemented to optimise the simulations. The most significant advantage of the AMR in MPI-AMRVAC is that one can design the refinement criteria according to the purpose of the simulation run.
Using these advanced techniques, we explore the evolution and propagation of magnetised CME models. We also systematically compare different AMR configurations to evaluate simulation accuracy, efficiency, and execution time. Modelled solar wind profiles are validated against in situ observations to assess the performance and predictive capability of Icarus in heliospheric simulations.

SCHEDULE OF TALKS

Tuesday, July 15: 9:25:00 AM - 9:50:00 AM
Presenter: Beattie, James

Supersonic magnetized turbulence at Reynolds numbers over a million: implications for fundamental compressible turbulence theory and cold phase interstellar plasma

James R. Beattie, Princeton University, United States of America
Amitava Bhattacharjee, Princeton University, United States of America
Christoph Federrath, Australian National University, Australia
Ralf Klessen, University of Heidelberg, Germany
Salvatore Cielo, Leibniz Supercomputing Center of the Bavarian Academy of Sciences and Humanities, Germany

Supersonic magnetohydrodynamic (MHD) turbulence is a ubiquitous state for many astrophysical plasmas, including thin, cool accretion disks and the interstellar medium of our galaxy. However, even the basic statistics of this type of turbulence remains uncertain. In this talk I will present results from supersonic MHD turbulence simulations at unparalleled resolutions, with plasma Reynolds numbers of over a million and grids up to 10080^3. In the kinetic energy spectrum we find a break between the scales that are supersonic and dominated by kinetic energy, with spectral index -2 (Burgers turbulence), and those that become strongly magnetized and subsonic, with spectral index -3/2. At magnetic Reynolds number of greater than 10^5, we find a power law emerging in the magnetic energy spectrum with spectral index -9/5, unexplained by any modern Rm asymptotic turbulence theory. On the strongly magnetized scales, the plasma tends to self-organize into locally aligned states across all primitive variables and their curls, depleting the nonlinearities in a scale-dependent that is inconsistent with the dynamical alignment theories. Both of these aspects challenge the tenets of magnetohydrodynamic turbulence theories and help to describe a new phenomenology for supersonic turbulence.

Thursday, July 17: 3:00:00 PM - 3:25:00 PM
Presenter: Boldyrev, Stanislav

Particle Acceleration in relativistic Alfvenic turbulence

Stanislav Boldyrev, University of Wisconsin-Madison, USA

Alfvenic turbulence is common in astrophysical plasmas and plays a crucial role in heating the plasma and energizing particles within it. At small kinetic scales, this turbulence creates intermittent current sheets and can be affected by the tearing instability or charge starvation effects. We discuss recent findings on relativistic particle acceleration in Alfvenic turbulence, presented in [1-3]. We argue that the relative strength of turbulent magnetic fluctuations, compared to the guiding magnetic field, determines the energy spectrum of the accelerated particles. Furthermore, this relationship influences the distribution of the particles' pitch angles, which may impact the radiative signatures of astrophysical objects.
1. C. Vega, S. Boldyrev, V. Roytershteyn, Particle Acceleration in Relativistic Alfvenic Turbulence, ApJ, 971, 106, 2024;
2. S. Boldyrev, N. Loureiro, Tearing-mediated Alfvenic Turbulence in a Relativistic Plasma, ApJ, 979, 232, 2025;
3. C. Vega, S. Boldyrev, V. Roytershteyn, Anisotropic particle acceleration in Alfvenic turbulence, ApJ, 985, 231, 2025.
This work was supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under award number DE-SC0024362.

Monday, July 14: 11:10:00 AM - 11:35:00 AM
Presenter: Büchner, Jörg

Kinetic Simulation of Particle Energization by Magnetic Reconnection in Collisionless Plasmas

Joerg Buechner, Technical University Berlin, Institute for Physics and Astronomy, Germany

Magnetic Reconnection is a major mechanism of energizing plasmas and particles at the expense of stored magnetic energy. To understand the energization of charged particles of different-mass by reconnection in hot, collisionless (e.g. astrophysical) plasmas the details of their kinetic behavior, the built-up of electric fields and the particle response have to be considered self-consistently. Since the underlying physical processes are essentially non-linear, for this sake numerical simulations have to be carried out. We review the results of appropriate numerical simulations, taking into account the consequences for the energization of different mass ions and electrons in reconnection processes and illustrate them by comparing their results with in situ observations in solar system plasmas.

SCHEDULE OF TALKS

Monday, July 14: 2:35:00 PM - 3:00:00 PM
Presenter: Calder, Alan

Neutron Star Atmospheres

Alan Calder, Stony Brook University, USA
Lourenzo Colleyn-De Sousa, Stony Brook University, USA
Zach Medin, LANL, USA

Neutron stars in accreting systems during quiescent or burst phases are well-modeled as a hot blackbody. An atmosphere of accreted material can shift the observed spectrum away from the Planck spectrum, and quantifying these effects is critical to interpreting X-ray observations of these objects. We present a study testing Zcode, developed by Zachary Medin at LANL, for simulating radiation transfer in X-ray bursting neutron star atmospheres. These tests demonstrate good agreement in the behavior of the outgoing spectrum's color-correction factor with previous models and theoretical expectations. We also show how the model calculates time-independent atmospheric snapshots, each iteratively refined, and uses them to progressively converge toward the correct atmospheric state. We calculated outgoing fluxes across different optical depths and explored the physical explanations for deviations from a pure blackbody spectrum, attributed to frequency-dependent opacity sources. We also assess the influence of Compton scattering on redistributing photon energies. Ultimately, our findings verify the model's methods and motivate further exploration of different parameters.

Tuesday, July 15: 3:55:00 PM - 4:20:00 PM
Presenter: Caplan, Ron

Open-source Release of the Magnetohydrodynamic Algorithm outside a Sphere (MAS) model

Ronald M. Caplan, Predictive Science Inc, USA
Jon. A. Linker, Predictive Science Inc, USA
Zoran Mikic, Predictive Science Inc, USA
Roberto Lionello, Predictive Science Inc, USA
Pete Riley, Predictive Science Inc, USA
Cooper Downs, Predictive Science Inc, USA
Viacheslav Titov, Predictive Science Inc, USA
Tibor Torok, Predictive Science Inc, USA
Miko Stulajter, Predictive Science Inc, USA

Since its initial creation over three decades ago, the Magnetohydrodynamic Algorithm outside a Sphere (MAS) Fortran code has, and continues to be, used extensively for
solar corona and heliospheric research. It integrates the time-dependent resistive thermodynamic magnetohydrodynamic equations in three-dimensional spherical coordinates, and runs efficiently on high-performance computing architectures.
Over the years, the code has continually been developed and improved with new physics models, features, algorithms, and computational advancements.
MAS has been available for use by the community for several years through the Corona-Heliosphere (CORHEL) (and more recently the CORHEL-CME) models available for runs-on-demand at NASA's Community Coordinated Modeling Center (CCMC).
With the recent focus on open science initiatives along with the increasingly wide-spread access to high-performance computational resources, we are pleased to present the first public open-source release of the MAS code.
The recommended method of using MAS remains to be the CORHEL models hosted at the CCMC, while the primary use of the public source code is for reference and/or advanced users/developers.

SCHEDULE OF TALKS

Tuesday, July 15: 11:35:00 AM - 12:00:00 PM
Presenter: Chen, Yuxi

Suppressing spurious oscillations and particle noise in particle-in-cell simulations

Yuxi Chen, University of Michigan, USA
Hongyang Zhou, Boston University, USA
Gabor Toth, University of Michigan, USA

Particle-in-cell (PIC) simulations are essential for studying kinetic plasma processes, but they often suffer from statistical noise, especially in plasmas with fast flows. We have also found that the typical central difference scheme used in PIC codes to solve Maxwell's equations produces spurious oscillations near discontinuities, which can lead to unphysical solutions. In this work, we present numerical techniques to address these challenges within the semi-implicit PIC code FLEKS, which is based on the Gauss's Law-satisfying Energy-Conserving Semi-Implicit Particle-in-Cell method (GL-ECSIM). First, we introduce a Lax-Friedrichs-type diffusion term with a flux limiter into the Maxwell solver to suppress unphysical oscillations near discontinuities. Second, we propose a novel approach for calculating the current density in the comoving frame, which significantly reduces particle noise in simulations with fast plasma flows. Numerical tests are presented to demonstrate the effectiveness of these methods in mitigating spurious oscillations and noise in shock and magnetic reconnection simulations.

Tuesday, July 15: 12:00:00 PM - 12:25:00 PM
Presenter: Choi, Dooyoung

Thickness and orientation of heliospheric current sheets at various heliosphere locations

Dooyoung Choi, Chungbuk National University, South Korea
Dae-Young Lee, Chungbuk National University, South Korea
Kyung-Eun Choi, University of California, Berkeley, USA
Sungjun Noh, Los Alamos National Laboratory, USA
Kyung-Chan Kim, Chungbuk National Unverisyt, South Korea

We analyze the characteristics and structure of heliospheric current sheets (HCSs) using Voyager 2 spacecraft in-situ observations at two distinct distance ranges: from 1 to 33.6 au which spanning Earth to near Neptune) and within the heliosheath (approximately 90-120 AU). Structural fitting was performed using a one-dimensional Harris sheet model. In the 1-33.6 AU range, 188 HCS crossings were identified between 1977 and 1990, while 34 crossings were identified in the heliosheath between 2008 to 2018. The occurrence time of these HCSs correlate with the sunspot cycle: more crossings were detected during sunspot maximum than during sunspot minimum. Quantitatively, HCSs in the 1-33.6 AU region exhibited a mean thickness of 3.3×105 km, whereas those in the heliosheath ranged from 4.5×106 km to 1.5×107 km. In both regions, the measured thickness exceeds the local proton inertial length, suggesting a low likelihood that identified HCSs serve as efficient sites for magnetic reconnection. The normal vectors to the HCS planes were predominantly oriented perpendicular to the Parker spiral magnetic field in both distance ranges, although a subset of HCSs showed significant tilt angles. During HCS crossings in both regions, we observed a decrease in magnetic field magnitude and an increase in proton density relative to background values. Discontinuity analysis revealed that cases showing features of rotational discontinuities were not uncommon. Finally, by comparing our results with previous studies of HCS thickness at various heliospheric locations, we confirm a clear trend of increasing sheet thickness with heliocentric distance.

Tuesday, July 15: 1:45:00 PM - 2:10:00 PM
Presenter: Comisso, Luca

Probing Particle Acceleration in Turbulence with First-Principles Kinetic Simulations

Luca Comisso, Columbia University, USA

Turbulence is regarded as a potential driver of nonthermal particle acceleration in space and astrophysical plasmas. In this talk, I will present recent insights from first-principles particle-in-cell (PIC) simulations that, thanks to significant computational advances, can bridge the gap between microscopic kinetic scales and macroscopic MHD scales. We show that large-amplitude turbulence in strongly magnetized plasmas produce a substantial population of nonthermal particles with a power-law energy distribution that is independent of microscopic kinetic scales. We identify reconnecting current sheets occurring within the turbulent domain as key sites for particle injection from the thermal pool. In these regions, parallel electric fields arising from magnetic reconnection initiate electron acceleration, whereas perpendicular electric fields govern ion energization. The accelerated electrons develop pronounced pitch-angle anisotropy, with most electrons preferentially moving along the local magnetic field. This anisotropy has important consequences for interpreting synchrotron emission from the accelerated particles, which I will discuss. These results offer new insight into the microphysical processes that govern particle acceleration in turbulent, magnetized plasmas, with broad relevance to heliospheric and astrophysical environments.

SCHEDULE OF TALKS

Tuesday, July 15: 3:00:00 PM - 3:25:00 PM
Presenter: Commerçon, Benoît

Numerical methods for dust dynamics applied to the ISM and star formation: status and perspective

Benoît Commerçon, CRAL, France
Léodasce Sewanou, CRAL, France
Guillaume Laibe, CRAL, France
Ugo Lebreuilly, CEA Saclay, France

Dust grains are the building blocks of planet formation. Dust evolves from galactic scales down to protoplanetary discs through its dynamical interaction (drag) with the gas. Understanding the coupled evolution of gas and dust across these scales is of primary importance.
I will briefly review the different models used to handle dust dynamics in grid-based codes. I will present an application of dusty turbulence in molecular clouds performed with the RAMSES code, comparing results from a mono-fluid model (Lebreuilly et al. 2019) with those from a model treating dust as Lagrangian super-particles (Commerçon et al. 2023).
Next, I will describe ongoing developments at CRAL in Lyon aimed at improving the scalability and performance of RAMSES within the SPACE EuroHPC Center of Excellence. Finally, I will present a new GPU-based implementation of dust multi-fluid dynamics using the SHAMROCK code (David-Cléris et al. 2025).

Monday, July 14: 1:45:00 PM - 2:10:00 PM
Presenter: DeGrendele, Christopher

Hybrid ML-Numerical Solvers for Hyperbolic-Parabolic PDEs: Overcoming Timestep Constraints

Christopher DeGrendele, University of California, Santa Cruz
Ashesh Chattopadhyay, University of California, Santa Cruz
Dongwook Lee, University of California, Santa Cruz

This work presents a novel hybrid numerical methodology for solving partial differential equations (PDEs) characterized by the co-existence of hyperbolic and parabolic terms. A well-known bottleneck in conventional numerical schemes is the parabolic stability constraint, which mandates severely restricted timesteps or necessitates the adoption of computationally expensive implicit solvers in practical astrophysics simulations. We demonstrate that the strategic integration of a Deep Neural Network (DNN) within a numerical solver provides an efficient means to overcome this restrictive parabolic timestep, thereby enabling the evolution of both hyperbolic and parabolic dynamics at the hyperbolic timestep limit. Our investigation contrasts DNNs with Fourier Neural Operators (FNOs) as candidate neural network architectures, revealing that FNOs exhibit markedly superior stability, attributable to their inherent design for mitigating high-wavenumber errors. We further provide a linear stability analysis to precisely delineate the operational regimes and potential instabilities of our ML-enhanced models. Preliminary studies on the Burgers-Diffusion equation and the Euler's equations with heat conduction serve to validate the efficacy of our proposed framework.

SCHEDULE OF TALKS

Tuesday, July 15: 9:50:00 AM - 10:15:00 AM
Presenter: Fraternale, Federico

Multi-Component MHD/Kinetic-Neutrals and Multifluid Modeling of the Outer Heliosphere and VLISM

Federico Fraternale, Center for Space Plasma and Aeronomic Research, The University of Alabama in Huntsville, USA
Nikolai V. Pogorelov, Department of Space Science and Center for Space Plasma and Aeronomic Research, The University of Alabama in Huntsville, USA
Ratan K. Bera, Center for Space Plasma and Aeronomic Research, The University of Alabama in Huntsville, USA

The interaction between the solar wind (SW) and the local interstellar medium (LISM) involve a vast range of particle populations, energy distributions, and spatial scales. Capturing this system's global structure, interpreting near-Earth observations, and probing the pristine LISM thousands of au away demand sophisticated, multi-component and three-dimensional models.
We present the latest version of our 3D MHD-plasma/kinetic-neutrals model, which treats pickup protons, electrons, and singly/doubly charged helium ions as separate, self-consistently coupled fluids. In this model, He^+, He^{2+}, and H^+ ions interact with kinetically treated H and He atoms through six charge-exchange processes and photoionization. We describe its implementation, including new analytic fits for the charge-exchange cross-section data, optimized for energetic neutral atom modeling.
Focusing on the outer heliosheath - the region of modified LISM shaped by the heliosphere and solar dynamics - we show how suprathermal ions, when self-consistently incorporated under a strong-scattering assumption, alter the hydrogen/helium wall structure, atom filtration, and background plasma. Using 40 years of data-driven boundary conditions at 1 au (based on IPS, OMNI, and Ulysses data), we simulate shocks and pressure fronts transmitted across the HP to the broad VLISM region with Cartesian grids at unprecedented resolution and time span, using a multifluid approach. The results are discussed in the context of Voyager observations.

Tuesday, July 15: 10:45:00 AM - 11:10:00 AM
Presenter: Fujimoto, Keizo

Electron Heating in Turbulent Current Sheet During 3D Magnetic Reconnection

Keizo Fujimoto, Beihang University, China
Yinan Liu, Beihang University, China
Jinbin Cao, Beihang University, China

Origin of high-energy particles is a key issue in space plasmas as a source of cosmic rays and non-thermal plasmas in space and astrophysical environments. Magnetic reconnection is one of the promising processes that can produce energetic particles through the release of magnetic field energy. This study has focused on electron acceleration and heating mechanism in reconnection by means of large-scale particle-in-cell simulations in the 3D system. The simulations show that the overall electron temperature is much higher in 3D case than in 2D case, in particular, around the reconnection x-line and magnetic islands. The electron heating is attributed to the intense electric field induced by the electromagnetic turbulence. The electromagnetic turbulence is spontaneously driven in the 3D current sheet by the flow shear instabilities. The accelerated electrons are efficiently scattered by the turbulence, resulting in the strong electron heating. In this talk, we will present the 3D simulation results to show how the electrons are accelerated and heated in the magnetic islands and diffusion region.

Monday, July 14: 10:45:00 AM - 11:10:00 AM
Presenter: Giacalone, Joe

Hybrid simulations of the extremely fast shock and associated solar energetic particle event observed by Parker Solar Probe on 13 March 2023

Joe Giacalone, University of Arizona

On March 13 2023, Parker Solar Probe was located about 0.23AU from the Sun and encountered a shock driven by a coronal mass ejection that was described as " … one of the fastest in situ shocks ever recorded". The shock was moving nearly along to the average upstream magnetic field - and example of a quasi-parallel shock. We have performed a self-consistent hybrid simulation of this shock which is applicable for comparison with observations in the very near vicinity of the shock. The simulation includes the formation of a high-energy tail from the heated distribution of plasma behind the shock, and the acceleration of particles to high energies, which exceed a few MeV. Based on our comparisons between the simulations and observations we find that the shock was likely moving considerably slower than was initially estimated, and the efficiency of the acceleration of particles at the shock was quite low – less than 5% - which is consistent with the shock having an Alfven Mach number of about 3-4. This is much less than initially estimated. We discuss these comparisons and their implications.

Tuesday, July 15: 2:10:00 PM - 2:35:00 PM
Presenter: Golant, Ryan

Intermittency and particle transport in fully-kinetic, large-amplitude turbulence

Ryan Golant, Columbia University, USA
Lorenzo Sironi, Columbia University & Center for Computational Astrophysics, USA
Philipp Kempski, Princeton University

Large-amplitude magnetized turbulence is generically intermittent, populated with sparse, intense structures like sharp field-line bends, current sheets, reconnection plasmoids, and — in the kinetic picture — Larmor-scale fluctuations due to anisotropy-triggered instabilities. Recent work has sought to quantify the impact of these intermittent structures on particle transport, separately looking at the roles of field-line bends and of micro-mirror fluctuations. In this talk, I will present a comprehensive picture of intermittency and particle transport in fully-kinetic, large-amplitude turbulence based on an extensive suite of particle-in-cell simulations spanning a wide range of weak initial field strengths. While the statistics of field-line curvature in these kinetic simulations show reasonable agreement with previous MHD results, the presence of Larmor-scale fluctuations and a greater degree of tearing yield subtle but significant deviations from MHD. These results may have implications for the confinement of MeV and GeV cosmic rays and for the re-acceleration of fossil electrons in galaxy clusters.

Thursday, July 17: 9:50:00 AM - 10:15:00 AM
Presenter: Hanawa, Tomoyuki

4th Order Accurate Poisson Equation for the Adaptive Mesh Refinement

Tomoyuki Hanawa, Chiba University, Japan

Improving the accuracy of gravity is important for better numerical simulations of astrophysics. For a given mass distribution, we can evaluate the gravity by the Poisson equation. If the discretization is higher order, the gravity is more accurate in general. On the other hand, we can increase the resolution by adopting the Adaptive Mesh Refinement (AMR) so that a dense compact object is covered with a finer grid. However, the current AMR solver is limited to second-order accuracy. In this talk, I show the method to solve the Poisson equation on the AMR grid with 4th-order accuracy in space. The method includes the quadratic interpolations in the directions normal and tangential to the coarse-fine level boundary. The interpolation normal to the level boundary ensures the matching of the gravity on the level boundary.

Monday, July 14: 4:20:00 PM - 4:45:00 PM
Presenter: Hauck, Cory

A data-driven strategy for entropy-based moment closures

Cory Hauck, Oak Ridge National Laboratory

In this talk, I will present recent work on entropy-based moment closures for kinetic radiation transport equations. Despite their elegant mathematical structure, entropy-based moment closures face severe implementation challenges that have limited their wide-spread use. In the current work we leverage the fact that many of the important properties of these closures are ensured by the existence of a convex moment entropy that is inherited from the kinetic entropy of the radiation transport equation via the closure. It turns out that convex approximations of the moment entropy can preserve many such properties, and we propose a data-driven strategy to generate convex approximations using neural networks. We prove rigorous results about the resulting closures for the case of linear kinetic equations equipped with a Maxwell-Boltzmann entropy, and we present numerical results to demonstrate the acceleration provided by the data-driven approach.

Thursday, July 17: 10:45:00 AM - 11:10:00 AM
Presenter: Hegde, Dinesha

SuryaBench: Full-Resolution Benchmark Dataset from the Solar Dynamics Observatory for Machine Learning Applications in Heliophysics

Dinesha V. Hegde, Department of Space Science & CSPAR, UAH, USA
Sujit Roy, Earth System Science Center (ESSC), UAH & NASA MSFC, USA
Amy Lin, ESSC, UAH, USA
Talwinder Singh, Georgia State University, USA
Vishal Gaur, ESSC, UAH, USA
Rohit Lal, ESSC, UAH, USA
Johannes Schmude, IBM Research, USA
Marcus Freitag, IBM Research, USA
Nikolai Pogorelov, Department of Space Science & CSPAR, UAH, USA
Manil Maskey, NASA MSFC, USA
Rahul Ramachandran, NASA MSFC, USA,
and the HelioFM team.

NASA's Solar Dynamics Observatory (SDO) continually captures extensive (~1.5 TB/day), high-quality, multi-instrument solar data, turning heliophysics into a data-intensive discipline. This vast observational record offers a unique opportunity to leverage machine learning (ML) techniques to tackle persistent challenges in solar and heliospheric physics. However, seamless application of SDO data requires specialized preprocessing to homogenize observations from multiple instruments. To fully exploit the highest-quality data available from SDO, we introduce SuryaBench, a full-resolution, ML-ready benchmark dataset comprising systematically curated multi-channel imagery from the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI), spanning more than a solar cycle from 2010 to 2024. We preprocess the data to correct roll angles, adjust for orbital effects, normalize exposures, and compensate for instrument degradation over time. We also co-align AIA and HMI imagery in time and space to reconcile their different resolutions, ensuring a consistent dataset suitable for ML tasks. We will present early results of applying SuryaBench to train our heliophysics foundation model, Surya, demonstrating its potential to advance data-driven heliophysics research.

Tuesday, July 15: 5:10:00 PM - 5:35:00 PM
Presenter: Henadhira Arachchige, Kalpa Harindra Perera

Machine Learning Approach to Coronal Hole Detection within Solar Cycles and Solar Wind Model Validation

Kalpa HENADHIRA ARACHCHIGE, CEA Paris-Saclay, FRANCE
Barbara PERRI, CEA Paris-Saclay, FRANCE
Sacha BRUN, CEA Paris-Saclay, FRANCE

Coronal Holes (CHs) are the major source of origin of the fast solar wind, which is its most geo-effective component. Identifying the coronal hole configuration and the large-scale structures of the solar corona enables prediction of the solar wind at 1 AU, thus allowing validation of solar wind models in reference to 1 AU observations. In this work, we contribute to the WindTRUST project, which aims to fill the gaps in France's ability to predict and protect against the most intense solar events, and we are dedicated to improving numerical simulations of the Sun-Earth system and its interaction with the Parker spiral. We focus on developing a solar wind model validation pipeline based on coronal hole EUV observations. Specifically, we use SDO/AIA images for 193˚A and composite images (171˚A, 193˚A, & 211˚A), under different solar conditions within solar cycle 24. CHs are detected by identifying the darker regions, which correspond to the low-density and low-temperature regions of the solar corona. Therefore, based on the intensities in the EUV wavelengths, the threshold value corresponding to the segmentation of CH regions requires optimization. Based on CH contour observations, we develop a machine learning algorithm to determine the optimized threshold value for a fixed time within solar cycle 24. To this end, we use the EZSEG algorithm and the opencv-python library to trace the CH contours, and the optimized threshold values are identified by matching the observed CH area on the solar disk at that time with the CH contour area detected using these two methods. The machine learning algorithm is trained using solar indices data and data from large-scale events such as solar flares and Coronal Mass Ejections during solar cycle 24. Once we identify the optimized threshold values for the CH contours in the SDO/AIA images, we validate them using a diagnostic test with the CH contours produced from the Potential Field Source Surface (PFSS) model (non-MHD) and the WindPredict (WP) model (Polytropic and Alfv´en Wave) (MHD). Subsequently, we repeat the above systemic procedure to develop a comprehensive automatic validation tool, extending it to include solar cycles 23 and 25 using SoHO, STEREO, and SolO EUV images of the solar corona. Finally, we couple the machine learning model and the validation pipeline to develop an automation tool for solar wind predictions at 1 AU.

Wednesday, July 16: 3:00:00 PM - 3:25:00 PM
Presenter: Ho, Ka Wai

Dust Coagulation in Athena++: Application to Hydrodynamical Instabilities and Future Possibilities

Ka Wai Ho, UW-Madison/ KITP/ New Mexico Consortium, USA
Hui Li, Los Alamos National Laboratory, USA
Shengtai Li, Los Alamos National Laboratory, USA

Dust coagulation plays a fundamental role in planet formation and the evolution of protoplanetary disks, yet its coupling with hydrodynamical processes remains computationally challenging to model. We present the implementation of a dust coagulation module in Athena++, built upon its existing multi-dust framework, enabling self-consistent simulations of dust growth dynamics coupled with gas hydrodynamics. Our framework incorporates particle-particle collision kernels, fragmentation thresholds, and size-dependent aerodynamic drag, allowing for the simultaneous evolution of multiple dust species across a wide size distribution. We apply this implementation to investigate the role of dust coagulation in hydrodynamical instabilities, with particular focus on the streaming instability and vertical shear instability in the radial-vertical (R-Z) plane of protoplanetary disks. Our preliminary results demonstrate that dynamic dust growth significantly modifies the onset conditions and nonlinear evolution of these instabilities. The coagulation process creates a feedback loop where clumping enhances local dust growth, which in turn affects the gas-dust coupling and alters the instability dynamics.
We will also discuss the possibility of extending this framework to couple with other existing Athena++ modules, including chemistry and radiation transport. These capabilities will enable comprehensive studies to tackle frontier problems in planet-forming disks, including ice-line chemistry effects and radiation feedback from evolving dust opacity. This integrated approach bridges the gap between microphysical dust processes and macroscopic disk evolution. Our work provides a crucial computational tool for understanding the early stages of planet formation in the era of high-resolution ALMA and JWST observations.

Thursday, July 17: 3:55:00 PM - 4:20:00 PM
Presenter: Holmstrom, Mats

Stellar wind interactions with resistive obstacles

Mats Holmstrom, Swedish Institute of Space Physics, Kiruna, Sweden.

The modeling of the interactions of planets with stellar winds has a spherical obstacle to the flowing plasma. Boundary conditions are prescribed at this spherical inner boundary. If we want to include the finite conductivity of the obstacle in the model we have to take an approach without any such boundary conditions on the electromagnetic fields.
Here we present how we have implemented this in a hybrid model, allowing the same code to model passive absorbers, like the Moon, and induced magnetospheres, like Venus.
Difficulties in details of the implementation, and solutions, are presented.

Thursday, July 17: 2:35:00 PM - 3:00:00 PM
Presenter: Hu, Yue

Cosmic ray transport in partially Ionized and turbulent medium

Yue Hu, Institute for Advanced Study, 1 Einstein Drive, Princeton, NJ 08540, USA

Understanding cosmic ray (CR) diffusion in partially ionized media is essential yet challenging due to the complex interplay between turbulence and ion-neutral interactions.
We present high-resolution 3D two-fluid simulations that explicitly treat ions and neutrals to investigate CR superdiffusion in turbulent, partially ionized environments. Our study explores how ion-neutral decoupling and the associated damping of turbulence affect CR propagation under both transonic and supersonic conditions. We find that ion-neutral decoupling leads to significant damping of velocity, density, and magnetic field fluctuations at small scales, resulting in spectral slopes steeper than the Kolmogorov and Burgers expectations. The damping of magnetic fluctuations reduces pitch-angle scattering and thereby increases CR parallel mean free paths. Consequently, CR perpendicular transport exhibits two distinct superdiffusive regimes: (1) a scattering-dominated regime with displacement scaling as t^3/4, and (2) a scattering-free regime governed by magnetic field line wandering, with displacement scaling as t^3/2. These results highlight the critical role of two-fluid physics in modeling CR transport in partially ionized regions such as molecular clouds and dense interstellar clumps, where conventional single-fluid approaches may fail to capture key transport behaviors.

Tuesday, July 15: 4:20:00 PM - 4:45:00 PM
Presenter: Issa, Danat

Probing Cosmic Pathways of Heavy Element Nucleosynthesis through State-of-the-art Simulations

Danat Issa, Northwestern University/CIERA, USA
Ore Gottlieb, Flatiron Institute, USA
Brian Metzger, Columbia University/Flatiron Institute, USA
Jonatan Jacquemin-Ide, University of Colorado Boulder, USA
Francois Foucart, University of New Hampshire, USA
Matthew Liska, Georgia Tech, USA
Goni Halevi, Illinois Institute of Technology, USA
Alexander Tchekhovskoy, Northwestern University/CIERA, USA

The origin of the visible matter that surrounds us remains one of the most enduring mysteries in physics. The groundbreaking detection of a binary neutron star merger in 2017, observed through both gravitational and electromagnetic waves, marked the dawn of multimessenger astronomy. This milestone opened an unprecedented window into the physics of matter under extreme conditions and transformed our understanding of such cataclysmic events. Similarly, collapsars, massive stars whose cores collapse into accreting black holes, might also be capable of producing a rich array of multimessenger signals. To fully harness the scientific potential of these transient phenomena, we urgently need robust theoretical models that link the central engine to observable signatures. Yet, no such comprehensive models currently exist. I will present self-consistent models of collapsars, for which I developed a general relativistic neutrino-transport magnetohydrodynamic code, nuH-AMR. These models will be instrumental in interpreting current observations and guiding observational strategies for ground and space missions.

Monday, July 14: 4:45:00 PM - 5:10:00 PM
Presenter: Johnson, Grant

Solving the Plasma Kinetic Equation Numerically on Smooth Manifolds with Continuum Methods

Grant Johnson, Princeton University, USA
James Juno, Princeton Plasma Physics Laboratory, USA
Ammar Hakim, Princeton Plasma Physics Laboratory, USA

A major challenge in plasma kinetic simulations is accurately resolving atmospheres around neutron stars and energy dynamics within the ergosphere of Kerr black holes. These regions form extreme density gradients and require fine velocity space resolution; both are not easily captured by particle schemes. Kinetic continuum schemes on the other hand are particularly well suited to handle these cases but have traditionally been considered prohibitively expensive. Recent developments in applying high-order schemes such as discontinuous Galerkin (DG) have made them realizable and led to a renewed interest in kinetic continuum methods. We present a Hamiltonian-based framework for the static spacetime kinetic system and illustrate how to represent it with a modal DG algorithm. The resulting method conserves energy and density, handles general coordinate systems, and is asymptotic preserving (AP) in the limit of high collisionality. Additionally, for some restricted choices of brackets, upwind fluxes result in monotonic entropy growth and L2 decay, increasing simulation stability. We have implemented this scheme in the Gkeyll code base, and benchmarks on both non-relativistic and relativistic problems have shown excellent agreement with existing code and analytic results. We have further demonstrated this implementation holds the theoretical properties of the scheme, such as conservation laws and AP. This framework provides a first-principles modeling of astrophysical systems previously limited by particle noise. Future work is aimed at implementing the static spacetime general relativistic Vlasov-Maxwell-BGK system in Gkeyll with the target of simulating extreme environments around compact objects.

Thursday, July 17: 4:45:00 PM - 5:10:00 PM
Presenter: Kim, Tae

Kinetic Interstellar Pickup Ion Model of the Multi-Scale Fluid-Kinetic Simulation Suite

Tae K. Kim, University of Alabama in Huntsville, USA
Nikolai V. Pogorelov, University of Alabama in Huntsville, USA
Federico Fraternale, University of Alabama in Huntsville, USA

Created by charge exchange between the solar wind (SW) and interstellar neutral atoms that freely penetrate into the heliosphere, interstellar pickup ions (PUIs) gradually decelerate the SW with a drag provided by mass loading. Furthermore, PUI-driven turbulence is the predominant source of energy injection into the SW flow that is most likely responsible for the steady rise in SW temperature measured by the Voyager 2 and New Horizons spacecraft beyond 20-30 AU. Hence, it is important to account for the charge exchange process and PUIs to model the SW evolution in the outer heliosphere. Using the Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS), which is a suite of numerical codes for modeling the flows of partially ionized plasma, PUIs can be either approximated as a single, isotropic mixture with the SW or treated as a separate fluid. In this work, we consider a kinetic treatment of PUIs as an alternative, more realistic approach than the fluid treatment of PUIs. We describe the current implementation of a kinetic PUI model in MS-FLUKSS and present some preliminary results.

Wednesday, July 16: 2:35:00 PM - 3:00:00 PM
Presenter: Lazarian, Alex

Energy spectra and kinetic energy dominance in subAlfvenic turbulence

Alex Lazarian, UW-Madison, USA

I shall show that the spectra of kinetic and magnetic energies for subAlfvenic turbulence depend on the way the turbulence is driven. For magnetic driving of turbulence, the energies are in equipartition, and the spectra are similar. However, for velocity driving, the kinetic energy dominates the magnetic energy, and the spectral slopes are different. The peculiar properties of turbulence in the latter regime are explained well by the analytical theory I will present. The nature of driving can be determined from observations. I will discuss the astrophysical consequences of this finding.

Monday, July 14: 2:10:00 PM - 2:35:00 PM
Presenter: Lee, Youngjun

Enhancements in Solvers and Physics Capabilities in Flash-X

Youngjun Lee, Argonne National Laboratory, USA
Klaus Weide, The University of Chicago, USA
Wesley Kwiecinski, University of Illinois at Chicago, USA
Jared O'Neal, Argonne National Laboratory, USA
Johann Rudi, Virginia Tech, USA
Anshu Dubey, Argonne National Laboratory, USA

Flash-X, the new incarnation of FLASH, was released in 2022 with a new architecture and an orchestration system (ORCHA) to enable portability on heterogeneous platforms. Since then, we have enhanced several features in ORCHA, especially its interface with physics units in Flash-X. New physics capabilities relevant to astrophysics include a new implementation of compressible hydrodynamics solver, a genuinely multidimensionally high-order, Gaussian Process (GP) based method. We have also added more flexibility in its architecture to enable requirements such as multiple versions of the equation of state (EOS) in the same simulation. The integration of ORCHA with Flash-X is more robust and can be exercised with non-trivial simulations. In this presentation, we will present all the new and enhanced features of Flash-X, demonstrating ORCHA’s use for handling heterogeneity.

Thursday, July 17: 5:10:00 PM - 5:35:00 PM
Presenter: Leake, James

Data-Driven Magnetohydrodynamical Simulations of Solar Active Regions

James Leake, NASA Goddard Space Flight Center, USA
Lucas Tarr, National Solar Observatory, USA
Dylan Kee, NASA Goddard Space Flight Center, USA
Lars Daldorff, Catholic University of America, USA
Peter Schuck, NASA Goddard Space Flight Center, USA
Mark Linton, US Naval Research Laboratory, USA

We present results of a newly-developed method to incorporate observations of the solar photospheric magnetic field and plasma into MagnetoHydroDynamic (MHD) simulations of active region formation and eruption. This new method, which incorporates the method of characteristics, allows observed lower photospheric boundary data to be included in a physically and mathematically consistent manner, which also allows for missing data, instrument bias and uncertainty, and errors in methods used to infer the magnetic field, velocity, and plasma properties. We show rigorous tests of this method using previously run simulations of active regions from convection zone to corona as a ground-truth, and show how the frameworkncan be used to test other methods of data-driving. This method allows for the consistent driving of space weather models with the current best observations of the solar magnetic field, which is important for the advancement of space weather modeling.

Thursday, July 17: 4:20:00 PM - 4:45:00 PM
Presenter: Lee, Dongwook

Enhancing shock-capturing numerical methods for relativistic flows

Nathan Van Duker, University of California Santa Cruz, CA, USA

Improving accurate numerical modeling for relativistic simulations is a critical area of research. A key advancement in this field was the adaptation of modern high-resolution shock-capturing (HRSC) schemes, originally designed for non-relativistic flows, to incorporate relativistic effects. However, simply extending these Newtonian HRSC schemes to relativistic shock-capturing has proven challenging. Several studies have shown that achieving grid-convergent numerical solutions often requires impractically fine grid resolutions. This persistent challenge demands further in-depth investigation. In this presentation, we'll share our latest progress in enhancing shock-capturing numerical methods for relativistic flows. We'll start by highlighting common numerical issues encountered when solving 1D shock-tube problems using existing HRSC approaches, especially when relativistic tangential velocities are present. To address these deficiencies, we'll introduce our new hybrid method. This approach significantly improves the simulation of relativistic shock-tube solutions, delivering sharply resolved shock and contact waves.

Monday, July 14: 9:50:00 AM - 10:15:00 AM
Presenter: Li, Hui

3D Dust Dynamics in Protoplanetary Disks: Implications for Planetesimal Formation

Hui Li (LANL, USA)
Shengtai Li (LANL, USA)

Recent observations of protoplanetary disks have revealed that dust exhibits rich features (such as rings, gaps, and vortices) in disks. Understanding such features may hold the key to understanding planetesimal formation, which eventually leads to planet formation. Large-scale numerical modeling of the joint dynamics of gas and dust in such disks has shown great progress over the past decade. We have carried out 3D global gas+dust two-fluid simulations of disks to study several processes that regulate the gas and dust flows, together with the dust size evolution. In particular, we show that vortices in such disks can be an important site for concentrating dust and eventually lead to planetesimal formation. These extensive numerical studies are providing valuable understanding on how dust might behave in 3D realistic disks and offer critical insights on interpreting observations.

Wednesday, July 16: 5:10:00 PM - 5:35:00 PM
Presenter: Li, Yuan

Probing Intracluster Medium Turbulence Near and Below Coulomb Mean-Free-Path Scales with Cool Filaments

Yuan Li, University of Massachusetts Amherst, USA

The intracluster medium (ICM) is a weakly collisional, weakly magnetized plasma with an electron mean free path ranging from ~10 pc in cluster cores to ~10 kpc in their outskirts—comparable to the size of individual galaxies. Direct observations of ICM turbulence have long been challenging due to limitations in X-ray telescope resolution. Over the past few years, we developed a novel method to probe ICM turbulence using cool filaments as kinematic tracers. These filaments, observable with high-resolution optical/radio telescopes, are ubiquitous in cluster centers and also appear in the tails of jellyfish galaxies in cluster outskirts. By analyzing their velocity structure functions (VSFs) across multiple scales, we find that cluster cores exhibit anomalously steep VSFs, inconsistent with Kolmogorov turbulence. A small fraction of the systems show Kolmogorov-like VSFs on the smallest scales. This may reflect the dissipation of compressive modes and the beginning of a transition to Alfvenic turbulence. Jellyfish galaxy tails in outskirts display VSFs consistent with turbulence driven by Kelvin-Helmholtz instabilities. These measurements constrain ICM viscosity at trans- and sub-mean-free-path scales, probing regimes beyond current particle-in-cell (PIC) simulations yet now accessible to high-resolution MHD simulations of galaxy clusters. A precise characterization of ICM viscosity is critically needed in order to property model the plasma and large-scale structure formation of the universe.

Thursday, July 17: 11:10:00 AM - 11:35:00 AM
Presenter: Liu, Weihao

Modeling the 2017 September 10 Solar Energetic Particle Event as Observed on Mars and at 1 au

Weihao Liu, University of Michigan, USA
Igor V. Sokolov, University of Michigan, USA
Lulu Zhao, University of Michigan, USA
Nishtha Sachdeva, University of Michigan, USA
Ward B. Manchester IV, University of Michigan, USA
Tamas I. Gombosi, University of Michigan, USA

Solar energetic particles (SEPs) can pose significant radiation hazards to spacecraft and crewed missions, while also offering valuable insights into particle acceleration and transport processes in the heliosphere. On 2017 September 10, a major SEP event associated with a fast coronal mass ejection (CME) was observed at Earth, the Solar TErrestrial RElations Observatory-Ahead (STA), and missions at Mars, including the Mars Atmosphere and Volatile EvolutioN mission, the Mars Express mission and the Curiosity rover on Mars surface.
In this study, we apply the SOlar Wind with FIeld lines and Energetic particles (SOFIE) model to simulate the event described above. Our results show that the ambient solar wind is comparable along the Earth, STA and Mars trajectory during the 27-day Carrington rotation centered on 2017 September 10. Comparisons between SOFIE-simulated CME evolution and white-light coronagraph observations, including the CME height-time profiles, show good agreement. We also employ the shock-capturing tool to identify the evolving shock surface and its properties for accelerating particles during the onset phase. Simulated SEP time-intensity profiles and spectral characteristics at Earth, STA, and Mars are evaluated against observations. This work supports the validation of the SOFIE model and advances its predictive capabilities, particularly in the context of ongoing Mars exploration efforts.

SCHEDULE OF TALKS

Monday, July 14: 11:35:00 AM - 12:00:00 PM
Presenter: Matsukiyo, Shuichi

2D PIC simulation of pickup ion mediated oblique heliospheric termination shock

Shuichi Matsukiyo, Kyushu Univ., Japan
Yosuke Matsumoto, Chiba Univ., Japan

In the heliospheric termination shock, the average shock angle is believed to be close to perpendicular, where the shock angle is defined as the angle between the upstream magnetic field and the shock normal direction. However, due to solar wind turbulence, the local shock angle can become significantly oblique. This obliquity may play a critical role in the initial acceleration of pickup ions. In this study, we investigate kinetic structures of an oblique heliospheric termination shock and the initial acceleration process of pickup ions at the shock using a two-dimensional full particle-in-cell (PIC) simulation. We track the long-term evolution of oblique shocks (with shock angles ranging from 50 to 70 degrees), including solar wind electrons, ions, and pickup ions, using a simulation domain significantly larger in the shock-normal direction—2000 times the ion inertial length—than in previous studies.
Our simulation successfully reproduces the self-consistent generation of nonthermal pickup ions. The acceleration is found to be most efficient when the shock angle is 50 degrees. Pickup ions reflected at the shock propagate upstream and excite large-amplitude waves via resonant instabilities. These waves are convected downstream and interact with the shock front, leading to shock reformation and modifications of the downstream electromagnetic structure. Some pickup ions are accelerated to nonthermal energies on a timescale of approximately 100 inverse ion gyrofrequencies. Orbit analyses of the accelerated particles reveal that the shock surfing acceleration (SSA) mechanism operates in the early stages of acceleration, followed by shock drift acceleration. While SSA has been considered ineffective in a perpendicular heliospheric termination shock, the electrostatic potential associated with the upstream large-amplitude waves enable this mechanism to operate under oblique shock conditions.

Wednesday, July 16: 2:10:00 PM - 2:35:00 PM
Presenter: Medvedev, Mikhail

Modeling pair cascade in AGN jets

M.V. Medvedev, A. Ford, M. Sitarz

It is believed that rapidly spinning, supermassive black holes (BH) exist in centers of Active Galactic Nuclei and produce powerful relativistic jets via the Blandford-Znajek (BZ) mechanism. The BZ process, which taps the BH spin energy the electromagnetic Poynting flux, requires the presence of plasma to carry current. Since the BHs possess both inner and outer light cylinders, the magnetospheric plasma escapes the system on a dynamical time scale. Thus, it must be replenished. It has been proposed and demonstrated that the plasma is created _in situ_ via an electron-positron cascade.
Here, we numerically solve the model equations of the pair cascade and show that the cascade indeed forms and can populate the jet with lepton plasma. Certain interesting and useful scaling relations between the system parameters (mass, plasma density, x-ray intensity and spectrum, and others) are numerically obtained.

Friday, July 18: 10:15:00 AM - 10:40:00 AM
Presenter: Melon Fuksman, David

New and upcoming radiative transfer and adaptive mesh refinement in the PLUTO code

David Melon Fuksman, MPIA, Germany

I will present an overview of the relativistic and non-relativistic M1 radiative transfer modules included in the latest version of the PLUTO HD/MHD code, along with selected astrophysical applications. I will also outline an extension to three-temperature radiation hydrodynamics, which evolves separate energy components for dust, gas, and radiation. Next, I will introduce a novel multigroup half-moment radiative transfer scheme designed to eliminate beam-crossing artifacts in specific directions. In simulations of circumstellar disks, this method produces temperature distributions that are significantly closer to Monte Carlo radiative transfer results than those obtained with full-moment approaches such as M1 and flux-limited diffusion. Finally, I will discuss recent developments in the GPU-parallel version of PLUTO, focusing on the ongoing implementation of Adaptive Mesh Refinement.

SCHEDULE OF TALKS

Thursday, July 17: 2:10:00 PM - 2:35:00 PM
Presenter: Mewes, Vassilios

Neutrino Radiation Hydrodynamics with Flash-X+thornado

Vassilios Mewes, Oak Ridge National Laboratory, U.S.
Eirik Endeve, Oak Ridge National Laboratory, U.S.
Austin Harris, Oak Ridge National Laboratory, U.S.
Steven Fromm, Michigan State University, U.S.
Sean Couch, Michigan State University, U.S.
William Raphael Hix, Oak Ridge National Laboratory, U.S.
Bronson Messer, Oak Ridge National Laboratory, U.S.
Anshu Dubey, Argonne National Laboratory, U.S.
Anthony Mezzacappa, University of Tennessee, U.S.
Stephen W. Bruenn, Florida Atlantic University, U.S.

Neutrino-matter coupling via weak interactions is one of the most important physical mechanisms in the evolution of core-collapse supernovae (CCSN). The numerical modeling of these systems is an inherently multi-physics, multi-method and multi-scale problem. In this talk, we will describe the union of three codes to simulate CCSN: Flash-X+thornado+WeakLib, which evolve the fluid and gravity and provide the computational infrastructure (Flash-X), a code that evolves neutrino radiation hydrodynamics in a spectral two-moment model using the discontinuous Galerkin method (thornado), and a library that provides the equation of state and weak interaction opacity tables (WeakLib). We will describe the two-moment spectral neutrino transport in thornado, the mapping of fluid data in different representations (finite volume and discontinuous Galerkin), as well as our performance portability strategy using OpenMP/OpenACC offloading to harness heterogeneous exascale machines such as Frontier at the OLCF. We will present a detailed code comparison study with the Chimera code.

Thursday, July 17: 11:35:00 AM - 12:00:00 PM
Presenter: Michael, Adam

Towards a Novel Treatment of the Magnetotail Transition Region

Adam Michael, JHUAPL, USA
Sasha Ukhorskiy, JHUAPL, USA
Kareem Sorathia, JHUAPL, USA
Slava Merkin, JHUAPL, USA
Anthony Sciola, JHUAPL, USA
Harry Arnold, JHUAPL, USA

The formation and build-up of the ring current, one of the most important current systems affecting geospace, remains a major unsolved problem of magnetospheric physics. Ongoing work has shown that the transition region, connecting the stretched magnetotail to the dipole-dominated inner magnetosphere, is crucial to addressing this problem. This region not only delivers energy to the inner magnetosphere but the complex processes within, heat and accelerate the particles. Characterizing this region has been challenging due to the co-spatial, multi-scale nature of the problem, which involves resolving spatial scales spanning three orders of magnitude from large scale convection, azimuthally localized fast bursty bulk flows (BBFs), and energy-dependent drifts. Energy-dependent drifts are not included within global magnetohydrodynamic (MHD) models. Neither are fast flows described by ring current models that assume a quasi-static slow-flow approximation. Therefore, even simulations that couple the two models fail to capture the correct physical description of the region.
For this reason, treating the transition region requires a novel approach. In this talk, I will discuss recent work to use test particle simulations (CHIMP) as a bridge from the central plasma sheet in the MHD domain to the outer boundary of the inner magnetosphere model where energy dependent advection dominates. CHIMP not only characterizes and quantifies the transport and pressure carried by the supra-thermal ions but also computes phase space density to determine the particle flux entering the inner magnetosphere. This approach enables us to capture the feedback of non-adiabatic transport without implementing more computationally expensive methods such as MHD-PIC (particle-in-cell) approaches devised for some astrophysical applications.

Wednesday, July 16: 9:25:00 AM - 9:50:00 AM
Presenter: Munakata, Kazuoki

Sidereal cosmic-ray anisotropy at TeV energies modeled with data from the Tibet ASgamma experiment

K. Munakata, Shinshu University, Japan
The Tibet ASgamma collaboration

Various experiments have reported on the anisotropy in the arrival directions of galactic cosmic rays at the sidereal time frame, including underground muon telescopes and ground-based air-shower arrays. The sidereal anisotropy of the order of 0.1 % at TeV energies observed at the Earth has two distinct large-scale structures: a deficit region ranging from ~150◦ to ~240◦ in right ascension (so-called Loss-Cone) and an excess region from ~40◦ to ~90◦ (so-called Tail-In). Recent experiments with high statistics have shown the unexpected change in the amplitude and phase above ~100 TeV from those below ~100 TeV. In this presentation, we attempt to model the anisotropy at the heliospheric outer boundary at TeV energies by applying the idea of Liouville mapping with an MHD-model heliosphere to the experimental data from the Tibet ASgamma experiment.

Wednesday, July 16: 9:00:00 AM - 9:25:00 AM
Presenter: Pogorelov, Nikolai

Global Structure of the Heliosphere

Nikolai V. Pogorelov, The University of Alabama in Huntsville, USA
Federico Fraternale, The University of Alabama in Huntsville, USA
Gary P. Zank, The University of Alabama in Huntsville, USA
Ming Zhang, Florida Institute of Technology, USA

As the Sun moves through the local interstellar medium (LISM) it emits ions creating the heliosphere occupied by the plasma of solar origin. Determining the structure of the heliosphere is a fundamental question that can be answered only by numerical simulations based on sophisticated theoretical models. Apart from the physics involved in the interaction of fully ionized, collsionless solar wind (SW) with the partially-ionized, weakly collisional LISM, it is natural for a humankind to speculate about our place of habitat is seen from a distance, perhaps from a civilized star system. This is especially germane now in light of recently observed astrospheres that possess substantially different shapes and structures. We present simulations of the SW-LISM interaction in a very large computational box paying specific attention to modifications of the LISM properties caused by the presence of the heliosphere. Our results show that the heliosphere has a long, comet-like tail (the heliotail). The SW-LISM boundary is subject to instabilities affecting the plasma flow. A possibility is demonstrated of a quasi-parallel, slow-mode bow shock that affects some parts the LISM flow. We demonstrate that the complex heliospheric structure affects the distribution of plasma and magnetic field in the LISM resulting in a Galactic cosmic ray (GCR) anisotropy consistent with the Tibet air shower experiment. We also analyze the effect of turbulence on the length of the heliotail and its ultimate destruction. Finally, the role of anomalous and Galactic cosmic ray pressure gradients is discussed.

Wednesday, July 16: 10:45:00 AM - 11:10:00 AM
Presenter: Provornikova, Elena

MHD simulations of CME emergence into the inner heliosphere with displacement of the heliospheric magnetic field

Elena Provornikova, JHU APL, USA
Mark Linton, NRL, USA
Kalman Knizhnik, MORSE Corp., USA
Brian Wood, NRL, USA
Viacheslav Merkin, JHU APL, USA
Andrew McCubbin, JHU APL, USA

Observationally-constrained magnetohydrodynamic (MHD) simulations of the inner heliosphere are widely used to understand the dynamic structure of the solar wind between the Sun and Earth and the evolution of coronal mass ejections (CME) - the major drivers of space weather at Earth. A common approach in models of the inner heliosphere starting from 0.1 au from the Sun is to insert CMEs with analytically prescribed magnetic structures—for example, a magnetic spheromak—by superimposing the CME's magnetic field onto the heliospheric magnetic field. This ad hoc method is oversimplified because the superposition does not arise from a dynamic CME evolution in the solar corona. It also leads to an immediate alteration of the initial CME`s magnetic structure. In this work, we introduce a new, more physically accurate displacement method for the CME emergence into the inner heliosphere by dynamically bending the heliospheric magnetic field around the incoming CME, rather than superimposing fields. Using the GAMERA-Helio MHD model of the inner heliosphere (0.1-1 au) and a Gibson-Low model of a CME with an internal magnetic field, we demonstrate that the displacement method preserves the CME's internal structure. Moreover, the displacement method produces a current system around the CME consistent with prior coronal MHD simulations with a self-consistent CME initiation and evolution. The displacement approach represents a step forward in modeling CMEs in the inner heliosphere to study their evolution and impacts at Earth.

Wednesday, July 16: 3:55:00 PM - 4:20:00 PM
Presenter: Radice, David

Neutron Star Merger Simulations

David Radice, Penn State, USA

Neutron star mergers act as Nature's ultimate supercolliders, where two massive objects—each with approximately 10^{58} nucleons—collide at a quarter of the speed of light. These events generate gravitational waves and electromagnetic signals, probing matter under extreme conditions. In this talk, I will present new insights into the physics of neutron star mergers obtained from large-scale general-relativistic hydrodynamics simulations incorporating neutrino radiation. In particular, I will discuss the impact of neutrino-matter interactions on the dynamics of these systems and the results from recent calculations including idealized neutrino flavor transformation effects. I will also present our new, open-source, performance-portable numerical relativity infrastructure, built on top of the AthenaK code, and present some of our first results obtained with the new code.

Friday, July 18: 9:00:00 AM - 9:25:00 AM
Presenter: Rau, Shiau-Jie

Influence of the donor star evolutionary stage on common envelope evolution

Shiau-Jie Rau, University of Illinois, USA

Common envelope evolution is a crucial channel for binary systems to eject their envelope mass and lose angular momentum, resulting in clean, close binary systems. However, how much envelope mass CEE could eject is still unclear. In this project, we use 3D hydrodynamics simulations to study CEE for various donor star models, including red giant, early-AGB, and TP-AGB. Our TP-AGB model successfully ejected all its envelope gas for the first time. We track the mass ejection, orbital evolution, and recombination energy distributions. We also provide the density profile after CEE, which could be valuable for future post-CEE research.

Thursday, July 17: 1:45:00 PM - 2:10:00 PM
Presenter: Ricker, Paul

Toward self-consistent subgrid modeling of black hole feedback

Paul Ricker, University of Illinois, USA
Yinghe Celeste Lu, Cambridge University, UK
David Cruz Lopez, New York University, USA
Ferzem Khan, Ohio University, USA

Accretion onto black holes at the centers of galaxies and clusters takes place on scales of less than a milliparsec, yet the resulting feedback affects regions on kilo- to megaparsec scales. Including these effects in structure formation simulations thus requires subgrid modeling. Historically these models have been based on oversimplified physics, leading to significant differences between different treatments. I will discuss a new type of subgrid model that explicitly ties the physics of the accretion disk to the efficiency of jet, wind, and radiation feedback, enabling the model to track advances in general relativistic accretion disk modeling and naturally incorporate phenomena such as mode switching and precession.

Wednesday, July 16: 12:00:00 PM - 12:25:00 PM
Presenter: Shen, Fang

Modeling and Prediction of Earth-affecting Solar Transients Based on Multiple Observations and Machine Learning Techniques

Yi Yang, State Key Laboratory of solar activity and Space Weather, Beijing, China
Rongpei Lin, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
Yucong Li, Centre for Mathematical Plasma-Astrophysics, Department of Mathematics, KU Leuven, Belgium

Solar Transients, such as Coronal mass ejections (CMEs), constitute the major source of severe space weather events, with the potential to cause enormous damage to humans and spacecraft in space. It is becoming increasingly important to detect and track CMEs, since there are more and more space activities and facilities. In this presentation:
(1) Based on sequential solar observation, we developed a deep learning method that can automatically detect CMEs, which can warn the happening of CME events with a high accuracy;
(2) We derived the CME initial parameters of speed, angular width and central position angle, and by multiple view fitting GCS model, we also provided input parameters for CME propagation models, arrival time and speed, consistent with the interplanetary observations;
(3) We found that adding physical parameters of CME and background solar wind to traditional CNN model can obviously improve the prediction error of CME arrival time.

Monday, July 14: 5:10:00 PM - 5:35:00 PM
Presenter: Singh, Divjyot

Converting H-AMR to Run GRRMHD Simulations on Intel GPUs with OpenCL

Divjyot Singh, Northwestern University, USA
Koushik Chatterjee, University of Maryland, USA
Matthew Liska, Georgia Institute of Technology, USA
Kyle Parfrey, Princeton Plasma Physics Laboratory, USA
Alexander Tchekhovskoy, Northwestern University, USA

General relativistic radiative magnetohydrodynamics (GRRMHD) codes like H-AMR are at the forefront of modeling the extreme environments of compact objects, e.g., black holes and neutron stars. Graphical Processing Units (GPUs) have proven to be a critical tool in carrying out leadership-class simulations to probe accretion and jet physics. Advanced features of H-AMR, including adaptive mesh refinement, local adaptive time stepping, and load balancing, have been using CUDA that runs on NVIDIA GPUs. However, with Intel GPUs now powering the third fastest supercomputer in the world, Aurora at the Argonne National Laboratory, it is crucial for codes like H-AMR to support the Intel architecture. One way of achieving this is to integrate OpenCL support into the codebase. Here, I describe my work of adding OpenCL support to H-AMR. I discuss the challenges of porting stiff numerical differential equations solvers while preserving performance and accuracy. I will also present preliminary results comparing the accuracy and performance of the new code against the CUDA version for an isolated neutron star simulation. By bringing GRRMHD simulations to Intel GPUs, this work pushes the limits of high-resolution compact object simulations alongside next-generation architectures.

Wednesday, July 16: 11:35:00 AM - 12:00:00 PM
Presenter: Singh, Talwinder

HelioCubed: Inner Heliosphere Simulations with 4th order accuracy on a Cubed Sphere Grid

Talwinder Singh, Georgia State University, USA
Phillip Colella, Lawrence Berkeley National Laboratory, USA
Brian Van-Straalen, Lawrence Berkeley National Laboratory, USA
Chris Bozhart, Lawrence Berkeley National Laboratory, USA
Nikolai V. Pogorelov, University of Alabama in Huntsville, USA

We present HelioCubed, a high order magnetohydrodynamic (MHD) code designed for modeling the inner heliosphere. The code is designed to achieve 4th order accuracy both in space and in time. In addition, HelioCubed can perform simulations on mapped grids, such as those based on cubed spheres, which makes it possible to overcome stability limitations caused by the geometrical singularity at the polar axis of a spherical grid, thus enabling substantially larger time steps. HelioCubed has been developed using the high-level Proto library, ensures performance portability across CPU and GPU architectures, and supports back-end implementations, e.g., CUDA, HIP, OpenMP, and MPI. The code is compatible with the HDF5 library, which facilitates seamless data handling for simulations and boundary conditions. Our approach ensures that HelioCubed solves the MHD equations preserving the radial flow to machine round-off error even on cubed-sphere grids. Solar wind simulations can be performed using the boundary conditions provided by empirical or physics-based corona models. These capabilities make HelioCubed a versatile and powerful tool to advance heliophysics research and space weather forecasting.

Wednesday, July 16: 4:45:00 PM - 5:10:00 PM
Presenter: Steinberg, Elad

Deterministic semi-Implicit Compton Scattering coupled to Hydrodynamics

Elad Steinberg, Hebrew University of Jerusalem, Israel
Itamar Giron, Hebrew University of Jerusalem, Israel

Compton scattering plays a crucial role in many high-energy astrophysical environments, from accretion flows around compact objects to radiation-dominated shocks. Traditional explicit numerical schemes for coupling Compton scattering to hydrodynamics often suffer from severe timestep constraints due to the strong coupling between radiation and matter at high optical depths. We present a new semi-implicit Compton scattering scheme that is fully integrated with astrophysical gas hydrodynamics. This method efficiently handles both the optically thin and thick limits, enabling stable evolution with large time steps. We validate the method with a suite of test problems. The results demonstrate significant improvements in stability and accuracy, making this scheme well-suited for multi-dimensional astrophysical simulations of radiative flows.

Monday, July 14: 9:00:00 AM - 9:25:00 AM
Presenter: Stone, James

AthenaK: a performance-portable version of Athena++

James Stone, Institute for Advanced Study, USA

AthenaK, a new version of the Athena++ AMR framework and physics solvers will be described. It adopts the Kokkos programming model to enable performance portability; AthenaK runs on virtually any hardware including CPUs, GPUs, and ARM processors. The code shows excellent weak scaling on up to 65,000 GPUs on the ORNL Frontier system, enabling calculations on exascale systems. In addition to solvers for Newtonian, special relativistic, and general relativistic hydrodynamics and MHD, the code incorporates many new capabilities. These include a new numerical relativity solver based on the Z4c formulation of the Einstein field equations and a new GRMHD solver in dynamical spacetimes enabling modeling of binary black hole and binary neutron star mergers, a relativistic radiation transport module for modeling luminous black hole accretion flows, and a particle module allowing studies of cosmic ray transport. Some results from applications of the code will be presented.

Monday, July 14: 3:55:00 PM - 4:20:00 PM
Presenter: Tchekhovskoy, Alexander

Bringing the scales in general relativistic magnetohydrodynamic simulations

Alexander Tchekhovskoy, Northwestern University, USA
Nicholas Kaaz, Northwestern University, USA
Aretaios Lalakos, California Institute of Technology, USA
Divjyot Singh, Northwestern University, USA
Danat Issa, Northwestern University, USA

Recent advancements in astrophysical fluid dynamics algorithms and hardware architectures have revolutionized the degree of realism with which we can model a wide range of astrophysical systems. However, even such advanced are woefully insufficient for enabling direct attacks on some of the most important systems, including accretion onto stellar-mass black holes in dying stars and super-massive black holes at the center of galaxies. This is because such systems include a vast scale separation both in space and time. I will discuss the recent progress in bridging the scales and outline future lines of attack on this problem.

Thursday, July 17: 12:00:00 PM - 12:25:00 PM
Presenter: Toth, Gabor

Non-adiabatic Shock Heating in Multi-ion Magnetohydrodynamic Simulation

Gabor Toth, University of Michigan, USA
Bart van der Holst, Boston University, USA
Judit Szente, Boston University, USA

Multi-ion magnetohydrodynamics (MHD) involves multiple ion fluids with an optional electron pressure equation. There are many systems that can be described by multi-ion MHD, for example, the solar wind consisting of hydrogen and helium ions, or the outer heliosphere consisting of thermal and pickup ions. Shocks are ubiquitous in the solar system, including shocks generated by coronal mass ejections (CMEs), corotating interactive regions (CIRs), bow shocks around planets, or the termination shock. While the multi-ion equations are well understood, the non-adiabatic heating at a shock in a multi-ion simulation is not easy to describe. One can write conservation laws for each ion fluid, but their interaction via various physical processes, many of those not captured by the multi-ion MHD equations, implies that those conservation laws are not individually satisfied. Following our previous approach for shock heating in extended MHD equations, we apply a similar methodology to the multi-ion MHD system. We note that we are only concerned with the energy equations here, and the momentum equations are handled as usual, which is probably an acceptable approximation for perpendicular shocks.
The first step is to solve for the total energy that includes all ion kinetic and thermal energies, the electron thermal energy and the magnetic energy. The total energy satisfies a pure conservation law, which means that a conservative numerical scheme will provide a proper weak solution across a discontinuity, such as a shock wave. The second step is to solve for the entropy densities of the ion fluids and the electrons. These entropy equations formally satisfy pure conservation laws, so a conservative numerical method will provide a well-defined weak solution, but those are physically incorrect, as they do not include the non-adiabatic heating. The third step is to form linear combinations of the entropy functions. The coefficients of the linear combination determine the ratio of the non-adiabatic heating deposited into the first fluid and the minor ion fluid (or the electrons). To further improve the scheme, we modify the weights to take into account the relative number densities of the ion fluids and electrons. We show that the new scheme behaves as designed. By properly setting the linear coefficients, the model can produce ion temperatures at the termination shock that are consistent with measurements.

SCHEDULE OF TALKS

Friday, July 18: 9:25:00 AM - 9:50:00 AM
Presenter: Vartanyan, David

Core-Collapse Supernovae: A Theoretical Study for the Transient Sky

David Vartanyan, Carnegie Institute of Science

The explosion mechanism of core-collapse supernovae - the vibrant neutrino-driven explosion of massive stars - presents an unsolved problem for over half a century. Recent improvements in high-performance computing and neutrino physics have enabled a new generation of multi-dimensional simulations of core-collapse supernovae that produce robust explosions. We present results of the largest multidimensional suite of simulations to-date, probing the global behavior of stellar explosion and the dependence on massive star progenitors. We discuss the joint detectability of correlated neutrinos and gravitational waves from such events, which will illustrate the dynamics of the remnant neutron star, the morphology of the explosion, and global stellar instabilities. These results galvanize synergistic observational and theoretical forays into core-collapse supernovae as Nature's astrophysical laboratories.

Wednesday, July 16: 1:45:00 PM - 2:10:00 PM
Presenter: Vishniac, Ethan

Magnetic Helicity Conservation and the Turbulent Cascade

Ethan Vishniac, Johns Hopkins University USA
Ka Wai Ho, LANL USA
Alex Lazarian, UW Madison, USA
Yossef Zenati, Johns Hopkins University, USA

Magnetic helicity is a robustly locally conserved quantity in the limit of small resistivity. Numerical effects typically violate this conservation law on relatively short time scales. Here I will present an algorithm for enforcing magnetic helicity conservation in a regular grid. Implementing this in a simulation of driven turbulence in a conducting fluid produces a large enhancement in the magnetic energy and its scale of organization. We compare this to the effect of increasing resolution in the absence of the correcting algorithm to argue that this is a real physical effect.

Tuesday, July 15: 4:45:00 PM - 5:10:00 PM
Presenter: Wibking, Benjamin

Quokka: Exascale Radiation MHD for Star and Galaxy Formation

Benjamin Wibking, Michigan State University, East Lansing, MI, USA
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Pak Shing Li, Shanghai Astronomical Observatory, Shanghai, China
Aditi Vijayan, Australian National University, Canberra, Australia

Quokka is a performance-portable, GPU-accelerated, adaptive mesh refinement (AMR) astrophysics radiation MHD code. Our code is 100% written in modern C++17 using template-based compile-time polymorphism, which enables us to run 40x faster on GPUs than CPUs. We also show our novel low-dissipation constrained-transport MHD method using a 7th-order PPM stencil that is fully compatible with first-order space-time flux-correction, and our novel asymptotic-preserving finite-volume multigroup radiation moment method. Finally, we demonstrate scaling of a self-gravitating AMR disk galaxy simulation to 1000+ nodes on Frontier and show the pre-exascale version of our planned exascale Milky Way simulation at 5 parsec uniform resolution.

Friday, July 18: 9:50:00 AM - 10:15:00 AM
Presenter: Wilhelm, Rostislav-Paul

High fidelity simulations of the multi-species Vlasov-Maxwell system with the Numerical Flow Iteration

R.-Paul Wilhelm, KU Leuven, Belgium
Fabio Bacchini, KU Leuven, Belgium
Sebastian Schoeps, TU Darmstadt, Germany
Melina Merkel, TU Darmstadt, Germany

When modeling nonthermal or rarefied plasma behavior, relevant e.g. for the solar wind, fluid dynamical models fail to capture the full range of relevant effects and therefore are only sufficiently accurate when used on a global scale. When local effects are important, in particular, if one is interested in effects on the electron scales, one has to resort to the kinetic description of plasmas - called the Vlasov-Maxwell system - as the assumption of equilibrium velocity distribution fails. Kinetic models describe the dynamics in entire phase space through modelling each particle species with an up to six-dimensional distribution function. While this in principle constitutes a first-principles model of the plasma dynamics, it is also very challenging to numerically simulate due to the "curse of dimensionality", the often turbulent and filamented structure of the distribution function, as well as the severe multi-scale nature of the dynamics involved.
Although modern high-performance computing now allows for ion-scale simulations using Particle-In-Cell (PIC) codes, the computational and memory costs of these simulations remain prohibitively high. Additionally, PIC methods suffer from noisy results, complicating data analysis. Grid-based approaches present a noise-free alternative but struggle with the multi-scale, filamented nature of the Vlasov system, making it difficult to extend these methods to the small scales required for accurate electron-scale simulations.
Recently, we suggested an alternative approach to solve the Vlasov-Maxwell system, which is based upon an iterative-in-time approximation of the characteristics. The entire evolution in time of the Vlasov system can be accurately described via only storing the time evolution of the electromagnetic fields and the initial data for the distribution function of each species. This omits the costly and error-prone intermediate storage of the six-dimensional distribution functions of the Vlasov system and only requires the storage of the smooth, lower-dimensional electromagnetic potentials.
In previous works we have shown that this approach is capable of solving the multi-species, electrostatic Vlasov system more accurately and efficiently than PIC approaches. In this work we show how this approach can be extended to the full Vlasov-Maxwell system, i.e., including the full range of electromagnetic forces. To this end we can employ an ansatz based upon the Hamiltonian splitting of the Vlasov-Maxwell system, similar to the electrostatic case, while now storing the electromagnetic potentials. We will discuss implications on stability of the extension, in particular, with regard to the choice of time-step size.

Monday, July 14: 3:00:00 PM - 3:25:00 PM
Presenter: Xu, Siyao

Energetic particle transport in turbulent plasma

Siyao Xu, University of Florida, USA
Saikat Das, University of Florida, USA

Energetic particle transport is of fundamental importance in space physics and astrophysics. The existing transport theories face difficulties in explaining observations. Different from the traditional modeling approach with linear magnetohydrodynamic (MHD) waves, recent studies using MHD and Particle-in-Cell (PIC) simulations with nonlinear turbulence reveal new transport properties of energetic particles. I will discuss our new findings on energetic particle transport based on both MHD and PIC simulations of turbulent plasma. The new transport mechanisms are promising in resolving the long-standing observational puzzles.

Tuesday, July 15: 9:00:00 AM - 9:25:00 AM
Presenter: Zank, Gary

Magnetic Flux Ropes, Turbulence, and Chromospheric and Coronal Heating

G.P. Zank, University of Alabama in Huntsville, USA
Xiaocan Li, Los Alamos National Laboratory, USA
M. Nakanotani, University of Alabama in Huntsville, USA
K. Khanal, University of Alabama in Huntsville, USA
L.-L. Zhao, University of Alabama in Huntsville, USA
L. Adhikari, University of Alabama in Huntsville, USA

The chromospheric and coronal heating problems are inextricably linked [Withbroe & Noyes, 1977, Withbroe, 1988]. A rate of energy dissipation of ~4 X 10^6 erg cm^-2 s^-1 is required to maintain the observed chromospheric temperature [Withbroe & Noyes, 1977]. By contrast, an energy deposition rate of 3 X 10^5 erg cm^-2 s^-1 is necessary to sustain the observed coronal heating above ~1.03 Rs [Withbroe, 1988], Rs being the radius of the Sun. Any mechanism(s) that heat the low solar atmosphere must therefore account for both the chromospheric and coronal heating rates, recognizing that the chromosphere is strongly mediated by radiative cooling and collisional thermal conduction, unlike the corona. A few models have attempted to incorporate both chromospheric and coronal heating but the question of how the chromosphere is heated, like that for coronal heating, is far from settled and whether the heating mechanisms for both regions are related or unrelated is an open question.
The dissipation of low-frequency MHD turbulence as a coronal heating mechanism has attracted considerable interest over the past decade thanks to the Parker Solar Probe (PSP) mission. The first turbulence transport formalism-based model for coronal heating was introduced by Matthaeus et al 1999, in which some fraction of the outwardly propagating Alfven waves is reflected by large-scale density gradients in the corona, resulting in counter-propagating waves that interact non-linearly to produce zero-frequency modes. The turbulence cascading of the fluctuations to higher wave numbers will result in the eventual dissipation of magnetic (and kinetic) energy at small scales, thereby heating the coronal plasma. However, PSP does not observe counter-propagating Alfven waves, finding instead that typically the normalized absolute cross-helicity ~1 in both super-Alfvenic [e.g., Zhao et al., 2020a] and sub-Alfvenic [Zank et al 2022, Zank et al., 2024] flows in the young solar wind. An alternative MHD turbulence model [Zank et al., 2018, 2021] argues that the small plasma beta environment of the low solar atmosphere implies that turbulent fluctuations are primarily quasi-2D non-propagating structures such as magnetic islands, while Alfvenic fluctuations form a minority component [Zank & Matthaeus, 1993, Zank et al., 2017]. The non-propagating 2D turbulent fluctuations undergo a corresponding cascade to small scales at which dissipation associated with multiple small-scale current sheets occurs to heat the plasma. Here we present a series of 3D Particle-in-Cell simulations in the presence of a guide magnetic field with suitable chromospheric conditions that illustrate that the constantly emerging magnetic carpet undergoes extensive turbulent reconnection that produces primarily 2D non-propagating flux ropes that constitute chromospheric and coronal turbulence.

Wednesday, July 16: 9:50:00 AM - 10:15:00 AM
Presenter: Zhang, Ming

A physics-based data-driven model for solar energetic particle radiation forecasting

Ming Zhang, Florida Institute of Technology, USA

A physics-based model for forecasting solar energetic particles requires treatment of many particle acceleration and propagation processes in a realistic coronal and heliospheric environment with a propagating coronal mass ejection shock. Governing the transport of particles is a time-dependent 5-dimensional Fokker-Planck equation containing particle diffusion, pitch angle scattering and focusing, gradient/curvature drift, adiabatic cooling, convection, and particle streaming. We use measurements of the solar photospheric magnetic field to construct the magnetic field and plasma configuration, and coronograph measurements to describe the propagation of the coronal mass ejection through the corona and interplanetary medium. In this talk, I will show how to use stochastic integration to solve the Fokker-Planck equation in high dimensions. Performance of the model calculation is evaluated to assess its potential for space weather forecasting.

SCHEDULE OF TALKS

Thursday, July 17: 9:00:00 AM - 9:25:00 AM
Presenter: Zhdankin, Vladimir

Turbulent Dissipation in Relativistic Collisionless Plasmas

Vladimir Zhdankin, University of Wisconsin-Madison, USA

Kinetic turbulence is a key pathway of energy dissipation in relativistic astrophysical systems such as black-hole accretion flows and jets. I will describe some recent results on this topic from particle-in-cell simulations and theory. I will discuss our latest understanding of how the electron-to-ion heating ratio depends on parameters such as temperature, plasma beta, and the ratio of magnetic fluctuations to background field. I will also discuss the role of compressive fluctuations on dissipation, including exploration of shock heating within transonic kinetic turbulence. These results inform the modeling of particle distributions around supermassive black holes, where the nature of fluctuations is starting to be understood from global magnetohydrodynamic simulations.

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Presenter: ,

Poster Presentations

Bhattacharjee, Chinmoy	***Gravitomagnetic Vorticity and Enstrophy Generation in Accretion Disk: Implications for Plasma Flow Stability*** Chinmoy Bhattacharjee New York Institute of Technology, OW, USA We explore a novel vorticity generation mechanism in accretion disks around slowly rotating black holes, focusing on its subsequent role in seeding turbulence through enstrophy, which contains flow vorticity and magnetic field contributions. Employing a multispecies plasma model in the linearized gravity limit of General Relativity, we analytically derive the generalized vorticity generation rate driven by frame-dragging in barotropic fluids. Our results show that generalized vorticity and its enstrophy density—a critical measure of turbulence intensity—are negligible at the disc mid-plane but increase significantly with vertical height, peaking near the innermost stable circular orbit (ISCO). Numerical estimations reveal that generalized enstrophy would cause vigorous turbulence in the disk's upper layers, particularly in tenuous discs around low-mass, fast-rotating black holes. By comparing enstrophy-driven turbulent energy to plasma energy, we identify critical disc heights where gravitomagnetic effects may destabilize flow, providing spatial constraints for accretion disc models. These findings will enhance computational plasma modeling by offering a framework to incorporate gravitomagnetic effects in accretion disks near Black holes and rotating stars.
Crawford, Chris	***Transition from Vortical to Alfvénic-like Fermi Electron Acceleration in Magnetic Reconnection with Increasing Guide Field*** Chris Crawford, Center for Space Plasma and Aeronomic Research (CSPAR), Department of Space Science, University of Alabama in Huntsville, United States Haihong Che, Center for Space Plasma and Aeronomic Research (CSPAR), Department of Space Science, University of Alabama in Huntsville, United States Gary Zank, Center for Space Plasma and Aeronomic Research (CSPAR), Department of Space Science, University of Alabama in Huntsville, United States Arnold O. Benz University of Applied Sciences and Arts Northwestern Switzerland, CH-5210 Windisch, Switzerland Using particle-in-cell simulations of magnetic reconnection (MR), we investigated how the changing magnetic guide field strength impacts the evolution of the electron Kelvin-Helmholtz instability (EKHI), and the associated Fermi-electron acceleration proposed by Che and Zank in 2020. Through this investigation, an Alfvén-like Fermi-electron acceleration mechanism is discovered for strong guide field MR B_g/B_0 > 2.5, B_g is the magnetic guide field. The electrons are accelerated by the intensive electric potential produced through delta U_i X B where the ion velocity fluctuations delta U_i propagate parallel to the direction of the Alfvén-like waves. Differing from the two-stage second-order Fermi-acceleration produced by the stochastic electric field of EKHI, the Alfvén-like wave mechanism is a much more efficient one-stage process that produces a much harder power-law electron energy spectrum with an index ~2 than that of the EKHI with an index ~ 4.

Poster Presentations

Roley, Karin	***Modeling Particle Acceleration in Magnetic Reconnection with Machine Learning-Driven Sub-grid Physics*** Karin Roley, Matt Golden, Dimitrios Psaltis Magnetic reconnection is a ubiquitous mechanism for particle acceleration in astrophysical environments, from solar flares to the turbulent accretion flows around black holes. While particle-in-cell (PIC) simulations have provided detailed insights into the microphysics of reconnection and associated acceleration processes, the extreme disparity between kinetic and global scales makes it infeasible to resolve reconnection-driven acceleration in global simulations. In this work, we leverage modern machine learning algorithms applied to extensive suites of PIC simulations to discover dynamical models for the evolution of particle energy distributions during reconnection events. These data-driven models are designed as sub-grid prescriptions for global simulations, enabling the study of nonthermal particle populations in complex astrophysical systems.
Wang, Bingbing	***One dimensional analytical solutions of the transport equations for incompressible magnetohydrodynamic (MHD) turbulence*** Bingbing Wang, Center for Space Plasma and Aeronomic Research (CSPAR), University of Alabama in Huntsville, USA Gary P. Zank, Department of Space Science, University of Alabama in Huntsville, USA Laxman Adhikari, Department of Space Science, University of Alabama in Huntsville, USA Swati Sharma, Center for Space Plasma and Aeronomic Research (CSPAR), University of Alabama in Huntsville, USA We derive one dimensional (1D) analytical solutions for the transport equations of incompressible magnetohydrodynamic (MHD) turbulence developed by Zank et al. (2012), Adhikari et al. (2024), including the Elsässer energies and the correlation lengths. The solutions are suitable for an arbitrary given background convection speed and Alfvén speed profiles but require near equipartition of turbulent kinetic energy and magnetic field energy. These analytical solutions provide a simple tool to investigate the evolution of turbulence and resulting energetic particle diffusion coefficients in various space and astrophysical environments that possess simple geometry.
Wang, Xiangyu	***Acceleration of ultrahigh-energy cosmic rays in the early afterglows of gamma-ray bursts: Concurrence of jet dynamics and wave-particle interactions*** Xiang-Yu Wang; Nanjing University, China Ruo-Yu Liu; Nanjing University, China Ze-Lin Zhang, Nanjing University, China The origin of ultrahigh-energy cosmic rays (UHECRs) remains a mystery. It has been suggested that UHECRs can be produced by the stochastic acceleration in relativistic jets of gamma-ray bursts (GRBs) at the early afterglow phase. We develop a time-dependent model for proton energization by cascading compressible waves in GRB jets while considering the concurrent effect of the jet's dynamics and the mutual interactions between turbulent waves and particles. Considering the fast mode of a magnetosonic wave as the dominant particle scatterer and assuming the interstellar medium for the circumburst environment, our numerical results suggest that protons can be accelerated up to 10^19 eV during the early afterglow. The spectral slope can be as hard as d N /d E ∝E^0, which is consistent with the requirement for the interpretation of the intermediate-mass composition of the UHECRs as measured by the Pierre Auger Observatory.

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