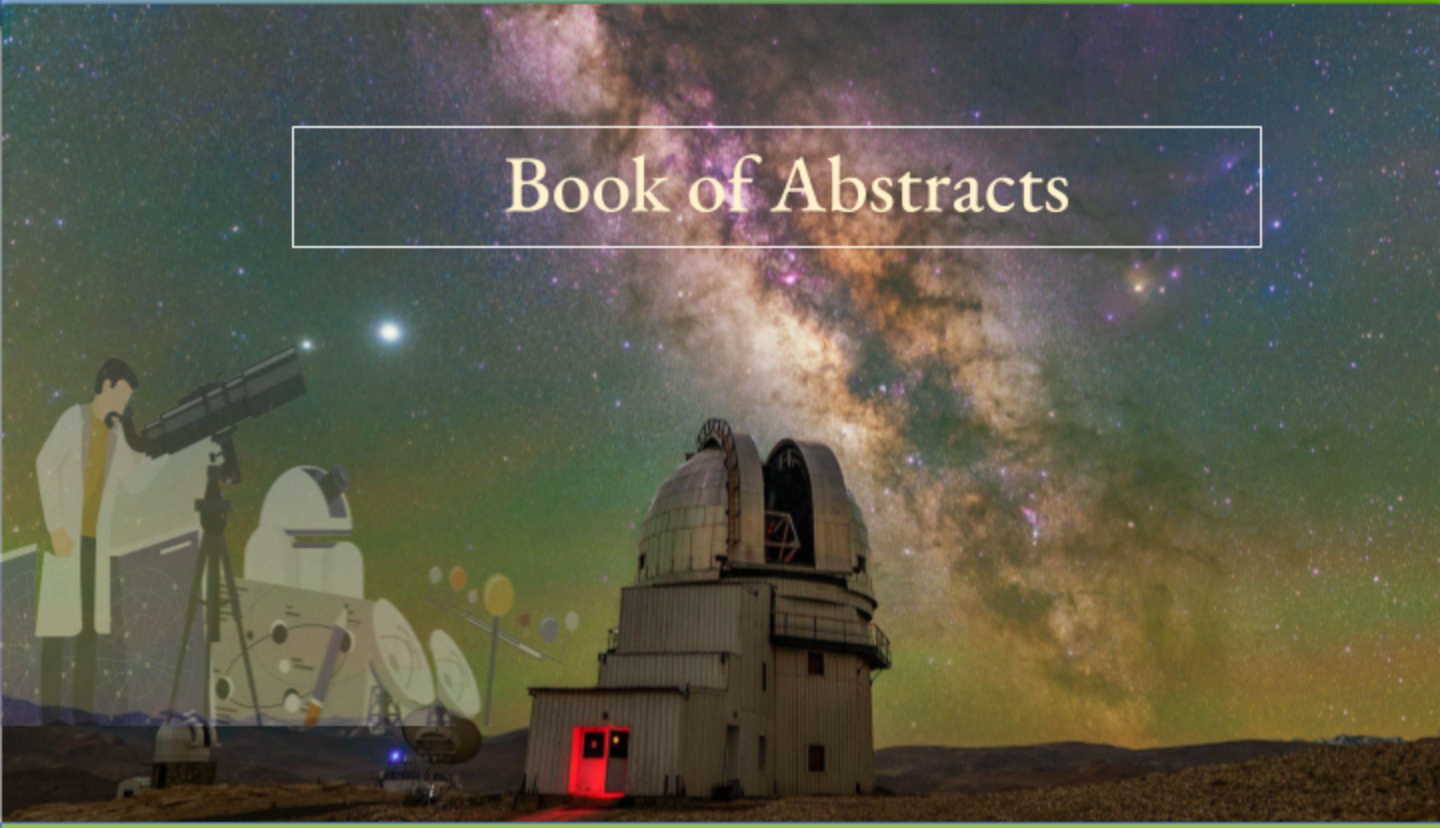
Conference on Plasma Simulation-2022

13-15 July 2023



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Raman Science Center, Indian Institute of Astrophysics, Leh
Institute For Plasma Research, Gandhinagar

CPS -2022

Conference on Plasma Simulation

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Book of Abstracts

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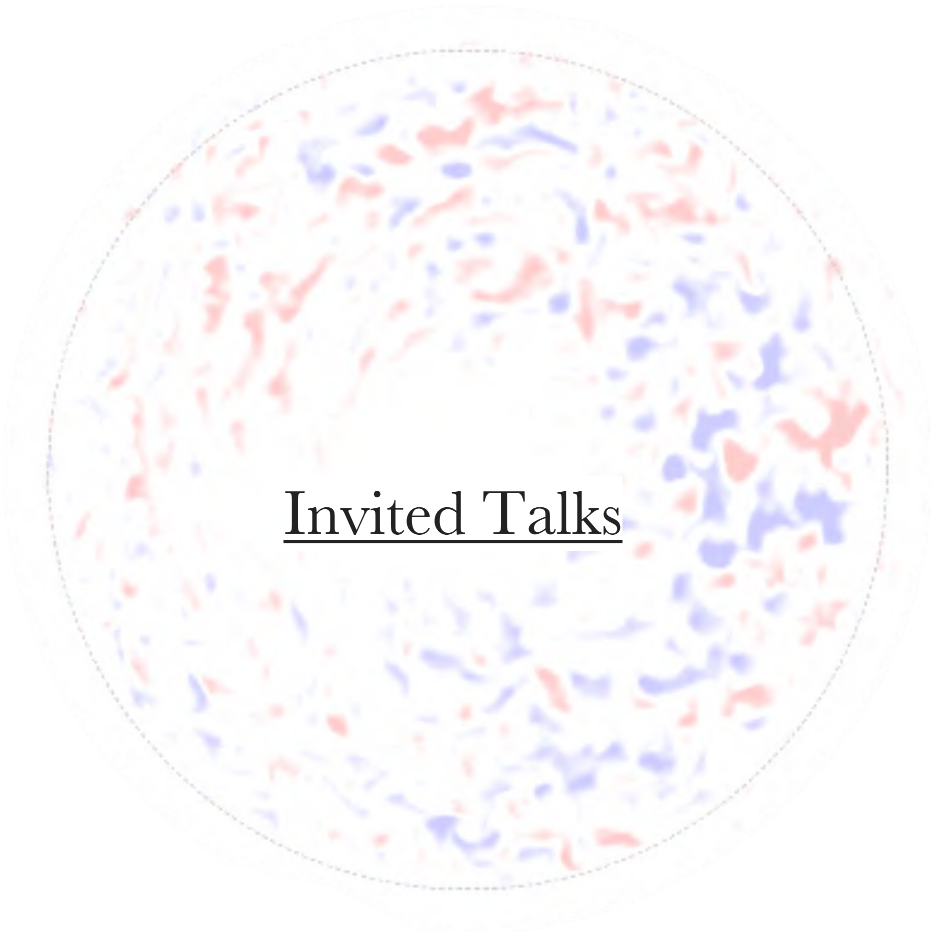

Invited Talks

Electromagnetic wave Transparency in strongly magnetized plasmas

Amita Das
Department of Physics, Indian Institute of Technology Delhi, Delhi

Abstract
Plasma medium modifies the dispersion relation of electromagnetic wave. This happens as the electrons and ions respond to the electromagnetic fields of the wave and are responsible for generating charge and current density in the medium. The presence of charge and current density acts as sources in the Maxwell's equation and modifies the vacuum dispersion of electromagnetic wave. It is demonstrated that there exists a possibility in the presence of strong externally applied magnetic field for the oppositely charged electrons and ions to respond in a manner such that neither a current density nor a charge density gets generated in the plasma medium. The electromagnetic wave then travels in the plasma medium with its usual vacuum dispersion properties.

The Magnetohydrodynamic particle in Cell treatment of heliospheric shocks

Shawnee Sow Mondal, Bhargav Vaidya, Andrea Mignone and Aveek Sarkar

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Abstract

The comprehension of the particle acceleration process in astrophysical shocks has been a longstanding issue. It is believed that similar types of shocks within the heliosphere could also give rise to solar energetic particles (SEP), which are detected by in-situ observatories situated at different locations in the heliosphere. To gain insight into the origins of these energetic particles, we employ the magnetohydrodynamic-particle in cell method to simulate such shocks. In this approach, the background plasma is considered as thermal and treated using the magnetohydrodynamic model, while the energetic particles are handled using the particle in cell method. The outcomes of these simulations provide valuable information regarding the potential physical conditions that may emerge around interplanetary shocks. These findings can be further explored using upcoming in-situ data, such as those from the ASPEX instrument aboard Aditya L1.

Fluid Simulation of Relativistically Intense Wake Waves in a Cold Homogeneous Plasma

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Abstract

We report on a fluid simulation study of spatio-temporal evolution of a relativistically intense wake wave excited by an intense electron beam propagating through a cold homogeneous plasma [1, 2, 3]. The simulation is based on a flux corrected transport scheme [4]. Simulation results reveal that in the limit of infinitely massive ions, the excited wake wave is a longitudinal Akhiezer-Polovin wave [1, 2, 5], whereas in the case of finite ion mass, the excited wake wave is a Khachatryan wave [3, 6]. In both the cases it is observed that, as time progresses, the profile of the excited wave gradually sharpens and eventually breaks exhibiting explosive behaviour. It is found that breaking happens at amplitudes which is far below the analytically derived lim- its [2, 3]. This phenomenon of wave breaking at amplitudes well below the breaking limit, is understood in terms of phase mixing of the excited wake wave due to relativistic effects [7, 8]. Our simulations, supported by approximate analysis, show that the phase mixing time (wave breaking time) scales inversely with the energy density of the wake wave [3, 9].

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Understanding magnetic field line and particle diffusion in plasma turbulence by means of adaptive step size methods

Kirit Makwana
Department of Physics, Indian Institute of Technology Hyderabad, Kandi, Sangareddy, Telangana 502284, India

Abstract

Plasmas are often in a turbulent state displaying features having a vast range of spatio-temporal scales. The nature of this turbulence often determines the transport of energy and particles in a plasma. For example, in a turbulent reconnection scenario, spreading of magnetic field lines is proposed to speed up the reconnection rate. We also observe that there are sudden changes in the field line and particle trajectories due to the chaotic nature of turbulence. In order to efficiently track these trajectories, we require adaptive step size integration techniques. I will describe the adaptive step-size Runge-Kutta and the Bulirsch-Stoer methods. Using these we study diffusion of magnetic field lines in magnetohydrodynamic (MHD) turbulence. We find that field line wandering does affect the reconnection process. In 2D, it is able to produce explosive reconnection. Particles are observed to diffuse following the Richardson diffusion law in MHD turbulence. We also find the scaling of various diffusion coefficients via these methods. We find that the fast magnetosonic modes are most efficient in scattering of cosmic ray particles.

Neural network assisted electrostatic global gyrokinetic toroidal code using cylindrical coordinates

Jaya Kumar[1], Joydeep Das[1], Sarveshwar Sharma[2], Animesh Kuley[1]

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Abstract
In the last three decades, several gyrokinetic simulation codes were developed, such as GTC[1], GYRO[2], ORB5[3], GENE[4], etc., to understand the microturbulence in the linear and nonlinear regime of tokamak core. These codes use flux coordinates, which encounter the mathematical singularity of the metric on the magnetic separatrix surface. To avoid such constraints, we have developed a new simulation code called global toroidal code using the X point (GTC-X)[5] using cylindrical coordinates, similar to XGC-1[6] and TRIMEG[7]. This coordinate system allows GTC-X, XGC-1, and TRIMEG to calculate the particle dynamics in arbitrarily shaped flux surfaces, including separatrix and X point in the tokamak. GTC-X has fully kinetic (FK) and guiding center (GC) particle dynamics, but XGC-1 and TRIMEG only have guiding center particle dynamics. GTC- X uses field-aligned gather-scatter operation based on a neural network prediction scheme to achieve field-aligned mesh efficiency. We train a multi-layered neural network with field line geometry estimates obtained by numerical integration to predict and locate the particles within the simulation grid. The main focus for developing GTC-X is to couple the core and SOL regions to understand the electromagnetic turbulence using the guiding center and fully kinetic particle dynamics.

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Numerical simulation and forward modelling of transverse waves in the solar corona

Vaibhav Pant
Aryabhatta Research Institute of Observational Sciences, Nanital-263001

Abstract:

Magnetohydrodynamic (MHD) waves are ubiquitous in the solar corona. They are believed to be one of the candidates for the coronal heating. In this talk, I will present state-of-art 3D numerical simulations of MHD waves in the transversely inhomogeneous plasma similar to those found in the coronal holes of the Sun. Propagation of waves lead to the development of the turbulence leading to the formation of the fine-scale structures. I will also present the forward modelling of the numerical simulations that generate synthetic images and spectra to explain the observed spectroscopic and imaging characteristics of these waves in the solar corona. Finally, I will compare our model with the observations taken from different space and ground-based instruments.

Resonance Line Polarization as a Diagnostic Tool for Stellar Atmospheres

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Abstract

Stellar atmosphere is known to be a heterogeneous mixture of neutral and ionized matter immersed in a diffuse radiation field. Interaction between the matter and radiation in such an atmosphere clearly involves several physical phenomena that directly affects both the constituents. More specifically the scattering of radiation by matter leads to a non-local coupling of the two and the atmosphere is said to be in a state of non-local thermodynamic equilibrium (NLTE). Furthermore, scattering of limb-darkened radiation field by atoms and electrons produces polarized light via resonance (in the case of atoms) and Thomson (in the case of electrons) scatterings. This resonance line polarization provides an important diagnostic tool for the stellar atmosphere. In this talk, I will present our recent work (see Sampoorna et al. 2022) on the impact of Thomson scattering redistribution on resonance line polarization formed in a spherically symmetric extended and expanding atmosphere.

References:

[1] Sampoorna, M., Megha, A., Supriya, H.D., 2022, ApJ, 937, 25.

Study of self-induced transparency in laser-driven radiation pressure acceleration

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Abstract:
One of the critical issues for the successful realization of laser driven radiation pressure acceleration (RPA) [1,2] is the poor quality of the accelerated proton beam due to excessive electron heating. This heating is caused during the self-induced transparency of the laser [3] when initially over-critical thin target becomes transparent due to laser-plasma interaction. In particular, interaction of laser with the transverse density modulations, induced by Rayleigh-Taylor-like instability, is responsible for such heating. In this talk, through Particle-In-Cell (PIC) simulations, we will demonstrate the suppression of laser transparency using a novel target design where a thick near-critical density (NCD) target is placed behind a thin RPA target [4]. The suppression is achieved by restricting the depletion of electron density in the RPA target by the return current of electrons from the NCD target. This leads to a significant improvement in the energy spread of the accelerated protons. We also observe further improvement in the proton beam quality when a thick metallic foil is placed behind the NCD target to produce the sheath fields by the escaping fast electrons from the RPA target. The potential well formed by these sheath fields filters the lower energy spectrum of the accelerated protons while giving an extra-energy boost to the high energy protons crossing the well. Such hybrid RPA-TNSA (Target Normal Sheath Acceleration) acceleration leads to the generation of a quasi-monoenergetic beam even with a linearly polarized laser. Our PIC simulations, performed with in-house developed code AGASTHII-py, demonstrate the acceleration of a proton beam up to 300 MeV with around 10% energy spread with a linearly polarized laser of wavelength 800 nm and intensity 8×10^{20} W/cm^2. Detailed results of PIC simulations along with associated physics will be discussed in the presentation.

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Radiative magnetohydrodynamic simulations of the solar atmosphere

LS Anusha
Indian Institute of Astrophysics, Koramangala, Bangalore 560034 India

Abstract:

To understand the structuring and dynamics of the atmosphere of the Sun, we need to improve and extend the existing numerical radiation magnetohydrodynamical (MHD) simulations. In the solar chromosphere, radiative energy transport is dominated by only the strongest spectral lines. For these lines, the approximation of local thermo-dynamic equilibrium (LTE) is known to be very inaccurate, and a state of equilibrium cannot be assumed in general. To calculate the radiative energy transport under these conditions, we have developed a non- LTE non-equilibrium radiative transfer module to the well-known MHD code MURaM. In this module we have developed a numerical method to solve the evolution equation for the atomic level populations in a time-implicit way, keeping all time dependent terms to first order. Our main non-equilibrium treatment is of the Hydrogen bound and free states. For the equation of state, to determine kinetic temperature, we treat the Hydrogen molecular evolution also in non- equilibrium. The other elements comprising the gas are treated with only the collision rates. Finally, the pressure and the radiative flux divergence from the RT module are provided to the MHD equations, to evolve the MHD and the radiative quantities self-consistently and iteratively. In this talk, I will describe the method, discuss some results of the dynamic evolution.

MHD wave coupling of solar atmosphere

Nitin Yadav
Indian Institute of Science and Research Thiruvananthapuram, Kerala-695551

Abstract:
The solar atmosphere is a complex and dynamic region that consists of several layers, including the photosphere, chromosphere, transition region, and corona. These layers are interconnected and exhibit a wide range of physical processes, including wave coupling and dynamics. MHD wave coupling refers to the transfer of energy between different layers of the solar atmosphere through MHD waves. The different types of MHD waves that are observed in the solar atmosphere include fast/slow magnetoacoustic waves and Alfvén waves. These waves are often excited by the turbulent convective motion of the plasma in the photosphere consisting of disordered plasma motions across a wide variety of lengthscales and/or timescales. These plasma motions can be rotating, such as intergranular vortices, vertical, such as global p-modes, or they can be random. Influenced by the topology of omnipresent magnetic fields throughout the solar atmosphere, these motions excite various MHD waves that travel to higher solar atmospheric layers. MHD waves have been considered a potential candidate for maintaining high-temperature plasma since their theoretical prediction decades ago. MHD waves and oscillations are now known to exist throughout the solar atmosphere, spanning a wide range of spatial scales and wave periods, thanks to recent solar observations.

The dynamics of the solar atmosphere are also strongly influenced by these waves. For example, magnetoacoustic waves are important in transporting energy and mass from the lower layers of the solar atmosphere into the corona, where they can contribute to the heating of the corona. Alfvén waves are believed to play a key role in the acceleration of the solar wind, which is a stream of charged particles that flows out from the Sun and fills the entire solar system. Overall, MHD wave coupling is an important process in the solar atmosphere that can lead to energy transfer and heating of the plasma and can have important consequences for the dynamics and evolution of the solar atmosphere.

Understanding Fast Electron Generation in Laser Plasma Interaction through PIC Simulations

Ajit Upadhyay[1,2]

[1]*Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai 400 094, India*
[2]*Raja Ramanna Centre for Advanced Technology, Indore 452 013, India*

Abstract:
Study of dense matter in extreme condition similar to astrophysical objects has always been a matter of interest for theoretically study[1]. The invention of high-power pulsed laser paved the way to experimentally study the plasma in extreme condition [1,2]. When such laser pulse is focussed to a size of few μm using suitable focusing optic, it yields an enormous intensity (I) in the range of ~10^{18}-10^{22} W/cm^2, leading to creation of ionized matter under extreme conditions at the laser focus. Further, a number of particles viz. fast electrons, protons, ions and x-rays are accelerated to very high energy (~keV to tens of MeV) from the interaction region. The study of energetic fast electrons in dense solid is a subject of research investigation for various potential applications including laser driven fast ignition[4], proton and ion acceleration[5], creation of ultrashort x-ray sources[6] and creation of warm dense matter.

The coupling of laser energy to electrons is fundamental to almost all topics in intense laser–plasma interactions, including laser-driven particle and radiation generation, relativistic optics, inertial confinement fusion and laboratory astrophysics. In the case of laser irradiation of bulk solid targets, laser absorption takes place through electrons gaining energy (sub-MeV to tens of MeV) via various mechanisms governed by laser and plasma parameters. In addition to the well understood and studied mechanism of resonance absorption, there are mechanisms specific to the ultra-short laser pulse regime, viz., vacuum heating, JxB heating, etc. Energetic electrons, also termed as fast or hot electrons, dump energy in the over-dense plasma and solid density cold target, and even can escape from the target. Angular distribution of fast electrons is a direct manifestation of the applicable acceleration/absorption mechanisms and, therefore, has been widely investigated during last the two decades.

In this talk, I will discuss fast electron generation through JxB heating verified by particle-in-cell (PIC) simulations and their experimental manifestation in ultra-short intense laser plasma interactions.

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Simulation and Analytical Models of Low Temperature Magnetized Plasmas created for Laboratory experiments

S. K. Karkari, Y. Patil, S. Das, Swati, P. Singh, S. Binwal, J.K. Joshi, A. K. Pandey and M.P. Bhuva

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Abstract:

Magnetised plasma sources are employed in a variety of technical processes, such as the machining of material substrates, the production of neutral beams for plasma heating in fusion, the development of Hall thrusters used in space propulsion, and basic plasma physics studies carried out in linear devices. One of the key areas of fundamental research is plasma transport across magnetic fields, which has applications for fusion devices, space and low temperature plasmas produced in laboratories. Instabilities caused by density and potential gradients inside a magnetised plasma medium have a significant impact on the migration of charged particles across magnetic field lines [1,2]. In addition to the axial and radial boundary conditions, it is critical to take the method used to generate the plasma into account in order to ascertain what type of plasma equilibrium exists within the magnetized plasma [3,4].

In this work, we present some examples of the use of analytical models to investigate the behaviour of magnetised plasmas in linear devices, as well as the application of commercial simulation tool to explain the structure of the plasma density and electron temperature distribution within the plasma column produced by a hollow cathode device. It will be demonstrated through simulation that the axial magnetic field acts as a guide for the electron trajectories coming from the cold hollow cathode surface, producing an ionizing area that extends further than 3.0 m from the source. Simulation reveals the experimentally performed electron temperature and plasma density profile at various axial distances. On the other side, a theoretical analysis of a magnetised plasma caused by a conducting axial end-plate will be presented, which explains how the potential profile in a partially magnetised plasma is controlled.

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Role of turbulent diamagnetism in formation of magnetic flux concentrations

Nishant Singh
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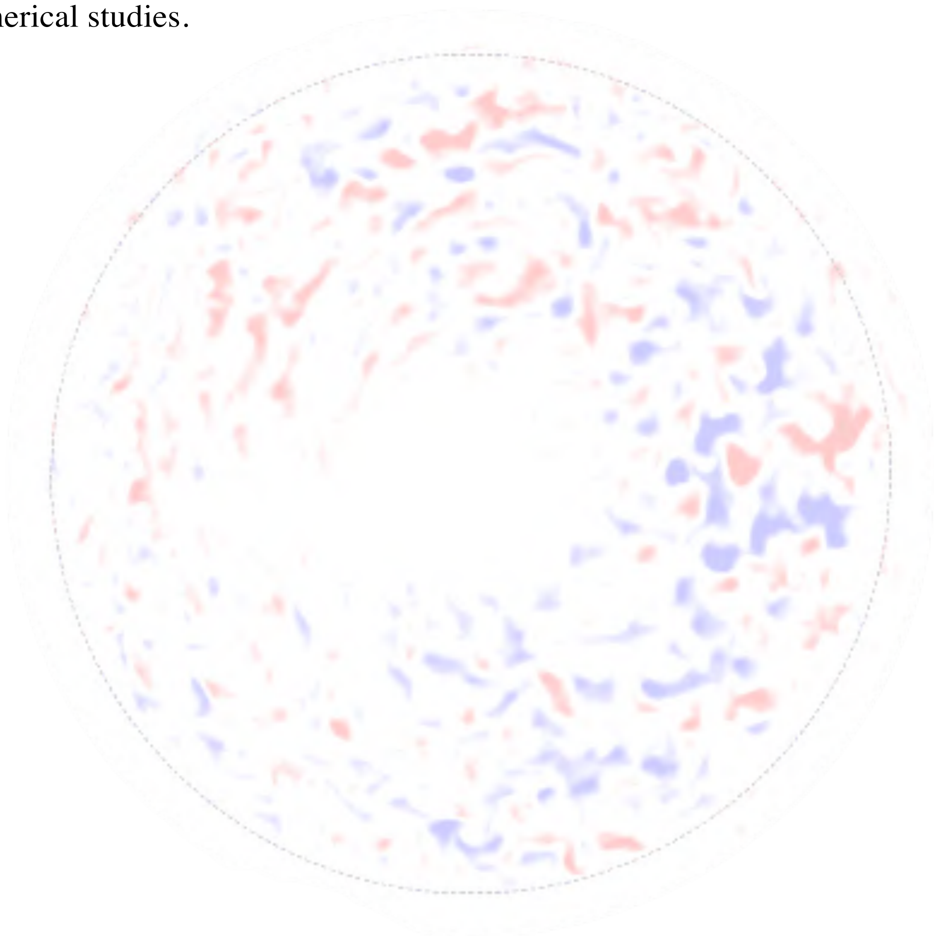
Abstract:

Spontaneous formation of localized magnetic structures, resembling active regions (ARs) or sunspots, has proved to be challenging in more realistic simulations of turbulent magneto-convection. We will discuss some latest developments on these topics based on recent numerical studies.



Simulation Study of Altitudinal Reach of Earth's Radiation Belt Particles

Amar Kakad

Indian Institute of Geomagnetism, New Panvel, Navi Mumbai, India

Abstract:

The Van Allen radiation belt is a region of energetic charged particles in the Earth's inner magnetosphere. Most of these particles originate from the solar wind and are captured and held around the Earth by its magnetic field. The magnetic field that surrounds Earth acts as an impenetrable barrier to prevent the entry of high-speed solar wind in near-Earth space. Solar wind conditions and interplanetary magnetic field configuration affects various magnetospheric processes including the dynamics of energetic charged particles in the radiation belts. This aspect has been investigated over the past few decades, however, the possible role of the geomagnetic field on the dynamics of the charged particles is not explored. Various studies have reported a continuous decline in the geomagnetic field strength over the past few centuries. The role of such a declining magnetic field on the lower altitudinal reach of the radiation belt particle is thoroughly investigated. This talk will briefly discuss the computer simulation experiments on the quantitative estimation of the lower altitudinal reach of the Van Allen radiation belt and its implications to our satellite technology.

Two avatars of MHD turbulence in astrophysics : freely decaying and instability driven.

Pallavi Bhat
International Centre for Theoretical Sciences, Bengaluru

Abstract

Regarding the first avatar, recently, it was found that decaying nonhelical MHD turbulence shows inverse transfer in energy. We show that this is potentially due to magnetic reconnections and thus can help in understanding the origin of primordial magnetic fields in cosmic voids. We discuss the associated temporal and spectral scaling laws. In the case of the second avatar, using direct statistical simulations, we have studied the problem of large-scale dynamo and angular momentum transport in magneto-rotational instability (MRI) driven turbulence. In particular, we identify two key mechanisms the rotation-shear-current effect and the rotation-shear-vorticity effect that are responsible for generating the radial and vertical magnetic fields, respectively. Notably, both of these mechanisms rely on the intrinsic presence of large-scale vorticity dynamo within MRI turbulence.

Hall Magnetohydrodynamics (HMHD) Turbulence: Direct Numerical Simulation (DNS)

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Abstract:

Decaying three-dimension (3D) Hall magnetohydrodynamics (HMHD) plasma turbulence is characterised by computing various statistical quantities [1] to understand the velocity and magnetic field fluctuations in inertial and sub-inertial regions [2]. Hall MHD is a simplified fluid model [3, 4], that is employed to understand solar-wind plasma turbulence. In this work, we developed a pseudospectra code for direct numerical simulations of the 3D HMHD equations to explore the dependence of 3D HMHD turbulence on the Reynolds number (Re), the magnetic Prandtl number (Pr_M), and the ion-inertial scale (d_I). We observe $k^{-7/3}$ and $k^{-11/3}$ magnetic energy spectra at scales close to the ion-inertial scale (d_i) depending upon simulation conditions. These two different scaling behaviours are related to right (R) and left (L) circularly polarized waves in Hall MHD [5].

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Global gyrokinetic simulations of electrostatic microturbulent transport in LHD stellarator with boron impurity

Animesh Kuley[1], Tajinder Singh[1], Javier H. Nicolau[2], Federico Nespoli[3], Gen Motojima[4], Zhihong Lin[2], Sarveshawar Sharma[5], Abhijit Sen[5]

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Abstract
Global gyrokinetic simulations of electrostatic microturbulent transport for discharge # 166256 of the LHD stellarator are carried out in the presence of boron impurity using the gyrokinetic toroidal code (GTC). The simulations show the co-existence of the ion temperature gradient (ITG) turbulence and trapped electron mode (TEM) turbulence before and during boron pow- der injection. ITG turbulence dominates in the core, whereas TEM dominates near the edge, consistent with the experimental observations. Linear TEM frequency increases from ~80 kHz to ~100 kHz during boron injection, and the ITG linear frequency decreases from ~20 kHz to ~13 kHz, consistent with the experiments. The poloidal wave number spectrum is broad for both ITG: 0 – 0.5 mm^{-1} and TEM: 0 – 0.25 mm^{-1}. The nonlinear simulations with boron impurity show a reduction in the turbulent transport compared to the case without boron. The comparison of the nonlinear transport shows that the ion heat transport is substantially reduced in the region where the TEM is dominant. However, the average electron heat transport through- out the radial domain and the average ion heat transport in the region where the ITG is dominant are similar. The simulations with boron show the effective heat conductivity values qualitatively agree with the estimate obtained from the experiment.

This work is supported by National Supercomputing Mission (NSM) (Ref No: DST/NSM/R&D_HPC_Applications/2021/4), Board of Research in Nuclear Sciences (BRNS Sanctioned no. 57/14/04/2022-BRNS), Science and Engineering Research Board EMEQ program (SERB sanc- tioned no. EEQ/2022/000144).

Particle-in-cell simulation study of capacitively coupled plasma discharges excited by tailored waveform

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Abstract:

Capacitively coupled plasma (*CCP*) discharges are widely used in materials processing applications for the fabrication of semiconductor devices. The surface processing such as deposition and etching using CCP discharges are dominantly driven by a synergy between discharge plasma chemistry and ion flux/ion bombardment energy onto the substrate. It has been discovered that generating CCP discharges with a waveform other than sinusoidal waveform, often known as “Tailored waveforms”, can drastically affect discharge parameters that are beneficial for processing applications. This is attributed to a change in the electron heating mechanism via radio-frequency oscillating sheaths, which results in electric field non-linearity and higher harmonics generations in the discharge. In the present work, using particle-in-cell simulation technique, we investigate the low-pressure CCP discharges driven by a sawtooth-like waveform. Our simulation results include plasma and ionization asymmetry, *DC* self-bias generation, higher harmonics, and electron heating mechanism. Both phase-averaged and spatio-temporal results are presented to elucidate electron kinetics in the discharge. The effect of driving frequency on the bulk parameters including electron energy distribution functions (EEDF) will be discussed.

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A PIC/MCC CODE FOR THE SIMULATION OF A 2.45 GHz MICROWAVE ION SOURCE

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Abstract:

A 2.45 GHz microwave ion source is designed, developed and commissioned at VECC. A proton beam current of 12mA at 75 keV was extracted and transported from the ion source [1]. An experimental study of parametric variations on the performance of ion source was performed. In order to establish a theoretical correlation with the experimental results a Particle-in-cell / Monte-Carlo collision code is developed. In the code the PIC/MCC method is used to implement the interaction of charged particles with the electromagnetic fields and collision between the particles. The validity of the PIC/MCC code is confirmed by the simulation of beam plasma instability. The simulation results show that microwaves are absorbed efficiently at ECR resonance condition. The absorption of microwaves under different magnetic field profiles are calculated from the code and compared with the experimental results. The code is implemented using open-source software Octave.

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Propagation and damping of ion-acoustic waves in two-electron temperature plasma

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Abstract

Ion-acoustic waves (IAWs) are low-frequency oscillations of ion density that perturb and propagates through the plasma. Such waves prove to be an excellent diagnostic tool for identifying additional plasma components such as negative ions, high energetic electrons and so on [1]. Here, a hydrodynamic model is considered to study the damping behaviour of an IAW in a collisional two-electron temperature plasma. The dispersion relation obtained from the model is found to depend on the hot and cold electron densities, temperatures and ion-neutral collision frequency. From this relation, the collisional damping rate has been estimated. Further, IAWs are also excited in a two-electron temperature plasma and its damping characteristics are investigated experimentally. The experimental results obtained are found to be in good agreement with the theoretical predictions [2]. Moreover, the study establishes that traces of high energy electrons in the system can be effectively identified from the damping of IAWs [3].

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Particle-In-Cell Simulation of Electrostatic Waves in the Ionosphere

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Abstract

It is usual to observe plasma with two electron components in the Earth's upper atmosphere (ionosphere). The cold electrons ($Te{\sim}1eV$) usually originate in the ionosphere, while the hot electrons ($Te{\sim}100\ eV$) come from the magnetosphere. Along with these two electron species, a beam of electrons might also stream along the magnetic field lines. These beam electrons excite various electrostatic wave modes such as the Langmuir mode, electron acoustic mode and beam mode. Based on the drift velocity of the beam electrons, the ensuing instability can be divided into two distinct categories, such as weak beam and bump on tail. The evolution of the linear, non-linear and saturation phase of the instability has been explored for various parameters.

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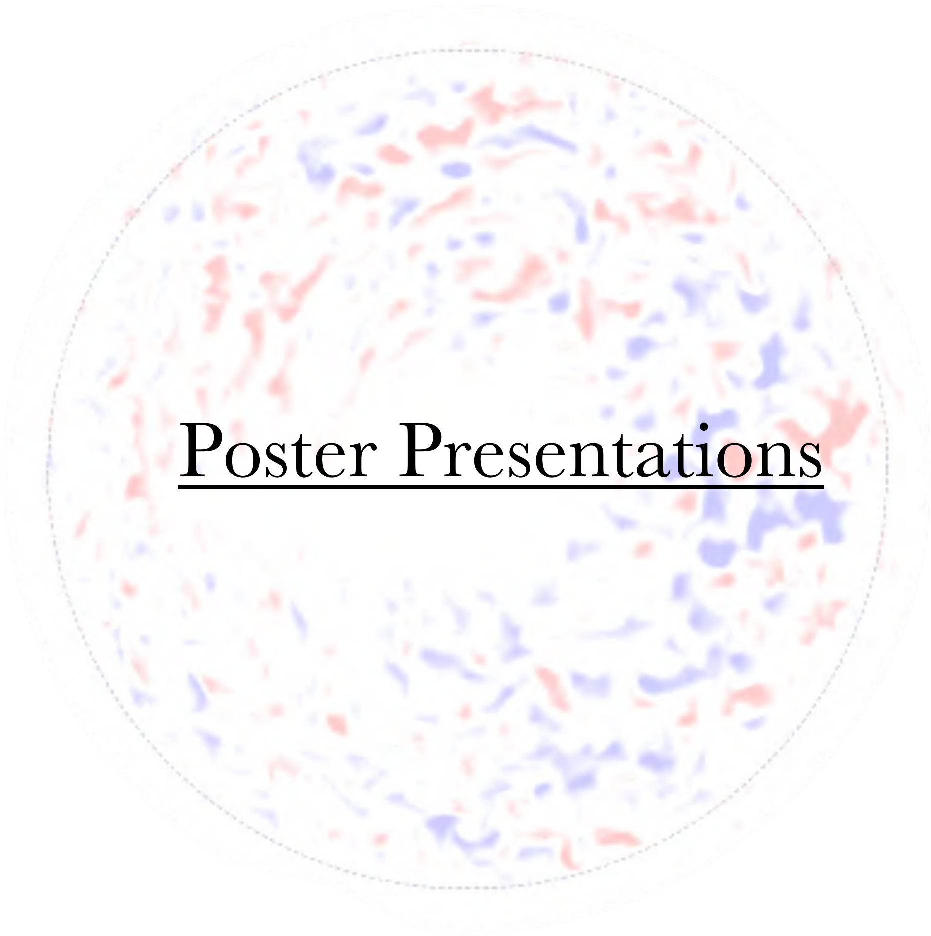

Poster Presentations

Poisson solver for complex geometries using ideas from transformation optics

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Abstract

Numerical solution of Poisson's equation is essential for wide range of problems in computational plasma physics and fluid dynamics. In particular, many of the real-world problems require development of Poisson solvers which can handle complex geometries typically involving non- uniform and/or non-orthogonal numerical grids. Typically for such applications, a weak solution to Poisson's equation is obtained by solvers which are based on finite element methods whereas finite difference methods are considered to be not-so-suitable. In this work, we present the development of a finite difference Poisson solver for complex geometries which is inspired by ideas from transformation optics [1]. In transformation optics, the flow of electromagnetic fields through distorted space is effectively modelled by transformed properties of the medium viz. permittivity and permeability. This is essentially possible due to the fact that Maxwell's equations are form invariant [2]. Therefore, the space distortions through co-ordinate transforms can be absorbed into the modified permittivity and permeability tensors which can be anisotropic. We use this concept to develop an efficient Poisson solver for arbitrary shapes/geometries where numerical solution is obtained on regular orthogonal cartesian grid involving modified permittivity tensor representing complex transformed space of the problem. The robustness of the method will be demonstrated through various applications involving non-uniform mesh, curved geometries and numerically generated grids. The details of computational algorithm, numerical implementation and error analysis will be presented along with demonstration of various applications described above.

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Generation of high harmonics in Magnetized over dense plasma upon interaction with high-power Microwaves

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Abstract

Plasma nonlinearity is known to generate higher harmonics while interacting with electromagnetic waves. The mechanism helps in the generation high power, coherent, high frequency radiations with the help of a low- frequency electromagnetic wave[1]. In recent studies [2,3] it was shown that by applying an appropriate magnetic field transverse to the wave propagation direction (O and X modes) one can increase the efficiency of harmonic generation. The optimum value of the magnetic field strength for the efficient generation magnetic field was also identified in the study[3]. The present work discusses the possibility of harmonic generation in the context of RL mode geometry for which the applied magnetic field is along the propagation direction. Both one and two dimensional configuration were chosen. For 2D studies inhomogeneous magnetic field profile was also chosen. These studies have been carried out by particle-in-cell simulation using EPOCH 4.17.16 framework. In contrast to previous studies carried out for X and O modes where both even and odd harmonics were observed, here only odd harmonics get excited [4]. The analytical understanding for this has also been provided.

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Thrust Measurement of An Electron Cyclotron Resonance Thruster Experiment Using A Two-Fluid Approach

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Abstract

The concept of magnetized plasma expansion is utilized in advanced research within the field of electric propulsion. One specific technology in this domain is the Electrode-less Plasma Thruster (EPT), which represents a futuristic approach to electric propulsion. The EPT incorporates a Magnetic Nozzle (MN) [1], which facilitates the acceleration of plasma through its converging-diverging magnetic field. The primary function of the magnetic nozzle is to convert the internal thermal energy of electrons into directed kinetic energy for ions, resulting in their acceleration.

A two-fluid model has been examined to study the expanding magnetized plasma, discharged from the Compact Electron Cyclotron Resonance (ECR) Plasma Source (CEPS) [2] developed by the Plasma Physics Laboratory (PPL) of IIT Delhi. This modelling approach aims to analyse the mechanisms behind thrust generation and evaluate the potential for performance enhancement, ultimately facilitating a comprehensive understanding of the experimental observations [3].

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Energy Absorption by Ions in Laser interacting with plasma immersed in a strong magnetic field

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Abstract

One of the important research areas of study for laser-plasma interactions is ion heating. In the context of laser interactions with magnetized plasma, this study explores the mechanisms of energy absorption by ions. It is shown that the laser energy can be channelized to the heavier ion species by restricting the dynamics of electrons with an externally imposed magnetic field. The external magnetic field offers passband frequency ranges for the laser pulse to propagate even inside an overdense plasma. Furthermore, one can arrest the motion of the lighter electron species by choosing the magnetic field such that the laser frequency lies between electron and ion gyrofrequencies [1]. This choice arrests the motion of electrons transverse to the magnetic field. The ions move freely in the laser field to absorb the laser energy. We have carried out PIC studies for two orientations of the magnetic field with respect to the incident EM wave propagation vector and shown that in both cases, the optimum absorption occurs when the laser frequency is close to but slightly off-resonance. The competing mechanisms operative on both sides of the optimum absorption have been identified. The role of laser intensity, polarization, etc., has also been studied.

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Development of 1D/2D PIC-MCC Code for simulations of Hall Thruster instabilities

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Abstract

Hall Thrusters are ion propulsion devices in which the necessary thrust is provided by the high exhaust velocity of ions, accelerated using strong axial electric field. The ions inside the thruster are produced through electron-neutral collision process. Although Hall thrusters are quite simple in design and concept, its physics is still not well understood in many aspects. In particular, the issue of anomalous transport of electrons or increased mobility across the channel, caused by interplay of various plasma instabilities, has recently gained attention of researchers. These studies indicate that Electron cyclotron drift instability (ECDI) and Modified two stream instability (MTSI) are the major reasons behind this phenomena. In this work a 2D Particle in cell- Monte Carlo Collision code has been developed which has been validated with numerous plasma test cases. This code has been used to simulate ECDI/MTSI instabilities with varying dimensional parameters. Further analysis has been done to observe the changes in the effective mobility of electrons and the anomalous transport.

A weakly relativistic electron beam from laser-cluster interaction in an ambient magnetic field

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Abstract

For the last few decades, table-top laser-plasma accelerators have brought significant progress to replace traditional high-energy accelerators. The production of a relativistic electron beam (REB) from laser-plasma interaction has become a recent topic of interest in the laser plasma community. REB has wide applications in the fast ignition technique of inertial confinement fusion and many medical applications. In this work, we report the generation of weakly REB in the collision-less regime of laser cluster interaction (laser intensity $I_0 > 10^{16}$ W/cm^2 and wavelength $\lambda > 600$nm) with an ambient magnetic field B_{ext}, which may not be possible only with the laser field. In reference to our recent work [1], using a rigid sphere model (RSM) and a 3D particle-in-cell (PIC) simulation [2], we address average electron energy $E_A \approx 30 - 70U_p$, (where U_p is the ponderomotive energy). Note that, only with the laser field, typically $E_A \approx 2 - 3U_p$. We show that enhancement of E_A with B_{ext} happens in two stages, an harmonic resonance (AHR) and electron-cyclotron resonance (ECR) absorption or relativistic ECR (RECR), by satisfying phase matching and frequency matching conditions. Further, these energetic electrons form narrow angular distributions in the position as well as in the momentum space within an angular spread of $\Delta\theta < 5°$ like a monoenergetic weak REB [3]. For this particular work, we upgrade the existing PIC code to a hybrid PIC code to handle the particle-particle interaction outside the simulation box, similar to molecular dynamics (MD) simulation. With the increasing cluster size from 2.2nm to 3.3nm – 4.4nm though energy absorption per cluster electron remains almost the same, the absolute energy absorption increases with more energy carriers. Hence, one can obtain an energetically intense REB. We show that, the PIC results closely resembles with RSM findings.

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FEM based Field Solver and Neural Network based Particle Locator for PIC simulation in Tokamaks

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Abstract

We generated field-aligned grids using D-III Data (Shot Number 158103) and created a mesh on the poloidal plane of the Tokamak using The Triangle Code [1]. Next, we employed a neural network to determine the triangle in which a given particle resides. The neural network aims to establish a smooth function that maps particle coordinates to corresponding flux surface and triangle numbers. We used a feed-forward regression network in which the values between zero and one were generated. However, due to inherent inaccuracies in the neural network, an additional iterative procedure was required to correct triangle labelling. Utilizing a neural network provides several advantages, including lower memory usage compared to brute-force methods for determining triangle locations, as well as faster performance with numerous cells. Following mesh generation, we use the Finite Element Method to solve Poisson's Equation.

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Effect of static magnetic island on drift wave of ADITYA-U tokamak

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Abstract

Magnetic islands are coherent structures which are characterized by localized magnetic field perturbations. These are explored to limit their impact on plasma confinement and improve overall plasma performance. Recently, it has been observed in the ADITYA-U tokamak that the presence of MHD activity in the intermediate region significantly influences the heat transport from plasma core to the edge region [1]. In the first step, we perform the simulation which shows the formation of the static magnetic island using the ADITYA-U equilibrium data and we have also implemented static magnetic islands in gyrokinetic code to study their effect on microturbulence and drift wave instability. As the magnetic field of the islands have a radial component, which can affect the neoclassical transport, microturbulence, and macroscopic MHD instabilities. Finally, we review the ongoing research efforts aimed at controlling and mitigating the adverse effects of magnetic islands.

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Simulating Charged Particle Dynamics in Ultra-Relativistic Electromagnetic Fields with Radiation-Reaction Effects

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Abstract

Over the last few decades, laser technology has advanced enormously. The chirped pulse amplification (CPA) technique, which achieves peak laser intensities $\sim 10^{23}$W/cm^2 (corresponding electric field 10^{13}V /cm) [1] is now capable of accelerating the electron up to ultra-relativistic energies ($\sim$ GeV) in a fraction of the time compared to the period of the laser. In these scenarios, the back reaction due to emitted radiation becomes comparable to the Lorentz force and thus inclusion of radiation-reaction effects on charged particle dynamics is significantly important. In this study, a MATHEMATICA-based 3D test particle code was developed to numerically solve Modified- Hartmann-Luhmann, Landau-Lifshitz and Ford-O'Connell equations in covariant form. The code allows for the numerical calculation of particle dynamics in arbitrary electromagnetic fields. Furthermore, the code has been enhanced to incorporate quantum corrections into the charged particle dynamics.

The code has been tested with known analytical solution of Modified-Hartmann-Luhmann and Landau-Lifshitz equation of motions for the charged particle dynamics in intense electromagnetic wave [2, 3]. Subsequently, the numerical study is extended for a focused electromagnetic wave train/ pulse. The inclusion of focusing effects show that irrespective of the choice of the initial conditions, particles go through the focal point, provided the radiation reaction force dominates over the ponderomotive force, thus gaining forward energy [4]; this is in sharp contrast from the reflection scenario observed in previous works [5]. These results are found to be independent of model equation used (Modified-Hartmann-Luhmann, Landau-Lifshitz and Ford-O'Connell).

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Investigation of electron plasma waves in the presence of inhomogeneous immobile ions: A fluid and kinetic simulation study

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Abstract

Excitation and evolution of electron plasma waves (EPW) has been a topic of extensive research for more than a century [1, 2, 3, 4]. In one of the work, using warm plasma fluid model in 1D with periodic boundaries, energy transfer mechanism which led to “fluid" damping of high phase velocity EPW mode via mode coupling phenomenon with inhomogeneous stationary background of ions is illustrated [5].

In the following, using high resolution kinetic (VPPM-OMP 1.0) and fluid (BOUT++) solvers, we present the investigation on the effect of finite system sizes on the temporal evolution of long-wavelength electron plasma wave (EPW) in the presence of stationary periodic ion background non-uniformity [6]. For a particular case i.e k min = 0.1 (where k min=2π/L max), despite choosing the exact parameter sets for the comparative studies, interesting differences between solutions obtained from kinetic and fluid solvers are discovered. Details of the work will be presented.

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Exploring Spectral Line Asymmetries due to the Propagating MHD Waves in the Solar Atmospheres

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Abstract:
MagnetoHydro Dynamic (MHD) waves are considered to be one of the candidates for coronal heating and solar wind acceleration. Decades-long studies on solar coronal and transition region emission lines have found broadening and asymmetries, which points towards mass and energy transport from lower layers of the solar atmosphere to the corona. Previous studies have suggested slow magnetoacoustic waves and chromospheric upflows to be the possible cause behind these asymmetric spectral lines. However, due to insufficient multi- wavelength observations and low spectral and spatial resolution of the current instruments, spectral line asymmetries caused by transverse MHD waves have not been observed yet. But they could be studied by using current state-of- art MHD simulations. For this study, we have used the forward modelled LOS integrated data for the Fe XIII emission line obtained from a 3D MHD simulations using MPI-AMPVAC, for propagating kink waves in an inhomogeneous plasma, depicting a coronal hole region. We then applied the ”Blue-Red (BR) Asymmetry” technique to obtain BR asymmetry profiles. Our analysis shows the presence of spectral line asymmetries due to the turbulence generated by these propagating transverse MHD waves in inhomogeneous plasma. We found that these asymmetries are different from the previously studied asymmetries caused by the up flows and follow a bimodal distribution. We expect to observe these asymmetries using modern and upcoming facilities like DKIST and VELC \ADITYA-L1.

Spontaneous generation and annihilation of three-dimensional magnetic nulls in solar atmosphere

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Abstract

Three dimensional (3D) magnetic nulls are the location where magnetic field is zero. They are preferential sites for magnetic reconnections1-3 and triggering various solar coronal transients [4-7]. Although these nulls are abundant in the solar atmosphere[4,8-10], but their generation is yet to be thoroughly explored. This work explores the mechanism of generation as well as annihilation of 3D nulls in solar corona in detail using numerical simulations. It is believed that Photosphere is non force free, the simulation is initiated with non-force free extrapolated magnetic field of active region NOAA 11977. The simulation starts from a motionless or with zero external flow and initially, only the non-zero Lorentz force pushes the plasma to generate the dynamics. During the course of evolution it is observed that the 3D magnetic nulls are spontaneously generated in pair having complementary topological degree and therefore, preserves the net topological degree. The simulation also shows 3D null pair annihilation. Magnetic reconnections are identified to be responsible for the generation and annihilation of the nulls opening up the possibility for the nulls to be self-organized structures. Furthermore, the reconnection being ubiquitous in the corona, it can explain the coronal abundance of magnetic nulls.

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Investigation of Accretion Disk Dynamics around a Stellar Mass Black Hole

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Abstract
Accretion disks around compact objects have been a source of rich physics for several years. They can also act like probes for studying the properties of the central compact object itself. Jet formation is one of the most remarkable phenomena associated with accretion disks. Jets are formed within the system in the presence of strong magnetic fields coupled with the matter in the disk. The matter moves along a field line under the influence of magneto-centrifugal forces and the flow is collimated by the magnetic tension force. This is the Blandford-Payne mechanism [1]. We have used the open- source Pencil-Code* to simulate an axisymmetric 2.5-dimensional system of a sub-Keplerian accretion disk around a non-rotating 20 $M_\odot$ black hole [2]. The general relativistic effects of the black hole were incorporated by using a pseudo-Newtonian potential [3]. The system was initialized both without and with magnetic fields.

The simulation for the non-magnetic system was run for 170,000 time-steps and several propagating waves were observed as initially the system is not in numerical equilibrium. There was no self- gravity and radiation pressure in the model. The sub-Keplerian disk moved closer to the black hole and it became thicker. Several propagating waves were also seen during the time evolution of the system owing to the system not being in numerical equilibrium. These may be shocks due to the large density stratification present and the disk and corona system trying to adjust to the pressure on each other in the absence of any magnetic fields. It is possible to calculate their speed by using time- distance techniques which can then be used to calculate their Mach number.

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* https://github.com/pencil-code

Effect of Stream-wise Vortices in the Spot Formation Mechanism at Large Aspect Ratios

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Abstract

Turbulence in a plane-Couette flow (PCF) is known to be subcritical in hydrodynamics. Upon applying an infinitesimal perturbation to the system in equilibrium, the system continues to remain stable or laminar. However, when a finite-amplitude perturbation is applied to the flow system, the system abruptly becomes turbulent. One of the main characteristics of subcritical turbulence is that both laminar and turbulent regions co-exists in the system (in a certain range of Reynolds number). When a PCF is perturbed with a finite amplitude perturbation, the system becomes turbulent subcritically. As a result of turbulence present in the system, stream-wise (flow direction) velocity streaks surrounded by large-scale flow is observed in hydrodynamics [1,2]. At the same time the stream-wise vortices are also generated [1, 2]. There is a deep connection between stream-wise streaks and stream-wise vorticity in a turbulent PCF [1].

In the past we have studied turbulent PCF in a 3D Yukawa liquid using “first principles” classical 3D Molecular Dynamics (MD) simulation [2]. In this study, we have discovered that the behavior of PCF is more fluid like, when the interaction range among the grains in the system is large [2]. In addition to the range of interaction, we have recently found that the turbulent dynamics of the system depends upon the system size (or aspect ratio). The system size increases with the increase in the number of particles. The increasing system size effects the generation of stream-wise velocity streaks and stream-wise vorticity [3]. The stream-wise velocity streaks and stream-wise vortices mutually effects the generation process of each other [1]. In our present work, we have performed our 3D MD simulation starting from 1.3 million particles to up-to 76 million particles and studied the effect of increasing system size in the dynamics of turbulent PCF. We present various diagnostics, such as stream-wise velocity contours, stream-wise vorticity contours, spatio-temporal analysis, Fourier-space analysis, etc., to discuss the effects of large system sizes or large degrees of freedom in the turbulent dynamics of a PCF in a 3D Yukawa liquid.

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Reconnection driven particle acceleration to explain the non-thermal emission in galaxy clusters

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Abstract

From observation [1], we see non-thermal emission, mainly in radio and x-ray extended over a large region (~megaparsec) in galaxy clusters. To explain this, the electrons should be energized or accelerated. One explanation is that the energy released during the merger event could be channelled to accelerate electrons through turbulence [2] or shock [3]. However, the efficiency of these mechanisms are every low.

Recently, magnetic reconnection in collisionless plasmas has been observed to produce plasmoids in Particle-in-cell (PIC) simulations [4], which can lead to efficient particle acceleration. The PIC simulations are, nevertheless, for relativistic plasma. On the contrary, the plasma in the intergalactic medium (IGM) is non-relativistic. Our aim, therefore, is to explore PIC simulation in case of non- relativistic fluid. It is less-explored, particularly, in the context of galaxy clusters. To get the particle acceleration therein, we study plasmoid driven magnetic reconnection in non-relativistic, collisionless plasma using WARPX, which is a publicly available PIC code and its applicability to particle energization in systems like galaxy clusters as mentioned above. The Attached figure shows the variation of number distribution of particles (f(γ)) as a function of kinetic energy (γ-1) per unit rest mass energy. It shows that the initial Maxwellian distribution (the black curve) becomes a power law (the red curve) after final code-time unit. The curves in between indicates particle distribution for different times in code-time unit, as also indicated in the color legends. We, therefore, get enough particle energization in the non-relativistic case.

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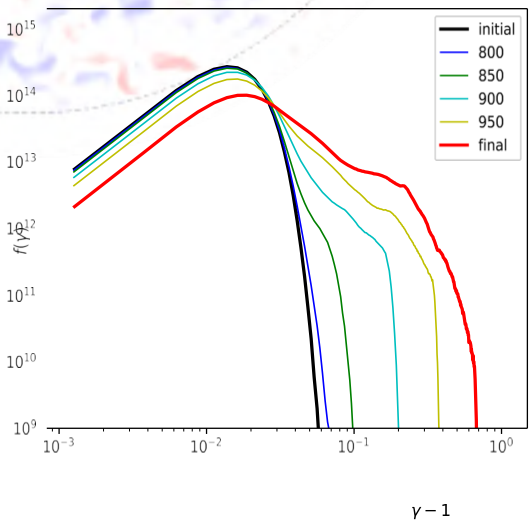

Insights into the genesis and dynamics of the solar spicule forest: aided by MHD simulations and laboratory experiments

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Abstract

Solar spicules are plasma jets that are observed in the dynamic interface region between the visible solar surface and the million-kelvin hot solar corona [1]. It is estimated that about three million spicule jets are present at any given time over the entire solar disk. Due to their ubiquitous nature, they are believed to be a crucial candidate for conduiting mass and momentum flux to the solar wind, the primary driver of space weather [2]. Despite the paramount importance, several physical processes, such as the formation mechanism, the highly dynamic nature, heating contribution of spicules at the corona, are not completely understood.

In the first part, I will present an intriguing parallel between the simulated spicular forest in a solar- like atmosphere and the numerous jets of viscoelastic (polymeric) fluids in laboratory experiments when both are subjected to harmonic forcing. In a radiative Magnetohydrodynamics (rMHD) framework, solar global surface oscillations are excited similarly with sub-surface convection. This process can solely assemble a forest of spicules that matches very well with the observed quantitative features of the Sun. Fascinated by the visual similarity between these highly non-linear astrophysical and laboratory systems, we further explore the mathematical and phenomenological similarities and present four sufficient conditions to form a forest of jets on the Sun as well as in polymeric fluids [3].

In the second part, we shed new light on the morphology of spicular jets: drapery of plasma against the cylindrical plasma column structure by utilizing three-dimensional rMHD simulation data sets [4]. I will further describe various complex motions of spicules (spinning, swaying, splitting), which are reported by several high-resolution observation facilities [5], e.g., Hinode and IRIS spacecraft. We detect multiple episodes of rotation amongst clusters of synthetic spicules, similar to their observed counterparts, due to interaction with hot swirling plasma columns. Interestingly, some of these swirling columns are triggered by the spicular jets. Finally, I will conclude by providing the mass and energy flux contribution of spicules and swirls to the solar wind, supporting their role as a significant mass and energy reservoir.

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Surface Flux Transport Modelling Using AI

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Abstract

Studying the solar surface and its dynamic behaviour plays a crucial role in understanding the space weather of the inner heliosphere and its effect on Earth. Surface flux transport (SFT) modelling has emerged as a powerful tool for investigating the intricate processes governing the evolution of the solar magnetic field. These magnetic features govern the underlying plasma dynamics and contribute to the overall behaviour of the solar magnetic field. SFT modelling allows us to simulate and analyse the transport and evolution of magnetic flux on the solar surface, providing valuable insights into the mechanisms responsible for solar activity. SFT modelling aids in restricting the solar dynamo models as well as serving as an initial condition for space weather to extrapolate the solar magnetic field to the heliosphere [1]. By simulating the surface dynamics and magnetic field evolution, we gain insights into the formation and decay of sunspots, the emergence and dispersal of magnetic flux, and the generation of solar flares and coronal mass ejections. We integrate numerical techniques and machine learning to develop models capturing plasma dynamics and magnetic field interaction. These models incorporate advection, diffusion, and magnetic flux emergence, using empirical relations to mimic the solar magnetic field's evolution. In this regard, we have solved the 1D SFT equation using Physics Informed Neural Networks (PINNs) [2] and the Finite Volume method with operator splitting. PINNs produce mesh-independent solutions with comparable accuracy to second-order numerical techniques and is computationally less intensive. In this presentation, I shall showcase a comparison between the results obtained from the numerical approach and those from PINNs. We intend to employ the SFT module to forecast the solar wind plasma parameters at the L1 point.

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Investigation of Toroidal Electron Plasmas: A 3D3V Particle-in-Cell Study Using OpenACC Parallelized PEC3PIC Code

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Abstract

Pure electron plasmas, confined in straight cylindrical trap (Penning-Malmberg [1] trap), with uniform external magnetic field, are studied theoretically/computationally and experimentally, to explore the fundamental ideas (as for example: isomorphism between 2D inviscid Euler fluids [2], ion resonance instability [3]). In such linear trap, particles achieve thermal equilibrium [4] easily and extensively used in several experimental applications e.g. anti-matter investigations [5], experiments with pair plasmas found in astrophysical environment [6].

Recently, a quiescent quasi-steady (QQS) [7] state of pure electron plasma confined using a toroidal magnetic field, in a tight aspect ratio, axisymmetric toroidal device, has been numerically discovered using a 3D3V particle-in-cell code PEC3PIC [7, 8], which provides a novel test bed to explore the fundamental properties of electron plasmas under inhomogeneous magnetic field. The effect of ions on this quasi-steady equilibrium state has been also reported [9]. PEC3PIC code [7, 8] is a 3D3V electrostatic Particle-in-Cell code written in Cartesian coordinates which resolves three dimensions X, Y and Z and the electron dynamics via v_x, v_y and v_z velocities. The grid size in three directions is $192 \times 192 \times 192$. Because of a large number of PIC particles (10^{14}) and an adequate grid size, reduction of the computational cost is a priority. In the previous studies [7, 8, 9], the OpenMP (Open Multi-Processing) version of the code has been used. In a recent study, the PEC3PIC code has been upgraded with an OpenACC (Open Accelerators) [10] version, using a single GPU card. Benchmark analysis has been performed along with a 5X speed up (than the OpenMP version) of the code [11]. These results will be presented. Several new studies of electron plasma confined in similar toroidal device but with a non-axisymmetric configuration [12], has been investigated with the OpenACC version of the code. Relevant results will be presented also.

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Simulating magnetised super-Chandrasekhar white dwarf using STARS

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Abstract

We have explored evolutionary path of a (highly) magnetised star leading to a magnetised white dwarf. We have explored this based on the Cambridge stellar evolution code, STARS. In order to do so, we have appropriately modified the code by introducing magnetic effect and cooling. We show that, depending on field strength and geometry, the final magnetised white dwarf could be highly super-Chandrasekhar with mass well exceeding 2 solar mass. Indeed, for the past two decades or so, from the observations of peculiar type Ia supernovae, super-Chandrasekhar white dwarf progenitors of even 2.8 solar mass have been inferred. Our simulation confirms that such a massive white dwarf is possible in the presence of magnetic field satisfying underlying stability.

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Massively Parallel PIC Simulations for E × B Low Temperature Plasmas: Implementation, Benchmarking and Performance Analysis

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Abstract

Accurate simulations of plasma transport in E × B based low temperature plasma devices using Particle-In-Cell (PIC) simulations have gained significant attention in recent times due to its wide range of applications [3,2]. With the increasing availability of powerful supercomputers and upcoming exascale computing facilities, we can expect more realistic device-scale 2D/3D simulation studies aimed at more detailed investigations for potential applications. E × B Low-temperature plasma (LTPs) based devices find diverse applications in different areas such as Hall effect thrusters (HET), negative ion sources, ion-mass separators etc. The externally applied magnetic field in such systems is oriented perpendicular to the plasma flow which leads to several instabilities such as E × B drift. The kinetic instabilities due to strong electron drift, often called Electron Cyclotron Drift Instability (ECDI) has attracted much attention as a possible source of the anomalous electron transport. These instabilities may also lead to formation of double layers in such systems [4]. Thus, understanding the origin of these instabilities and its effect on plasma transport is of paramount interest which can be accurately modeled using kinetic PIC-MCC simulations. Challenges to such simulations lie in the problem size as it requires actual density which translates to large number of simulation particles $\approx 10^7$. In order to simulate device-scale phenomena on the order of a few centimeters in LTP with relatively high plasma density $n \approx 10^{18} m^{-3}$, cell size $\Delta x \approx \mu m$ and time steps $\Delta t \approx$ ps are necessary. In the past few decades, several PIC-MCC codes have been developed by different research groups across the world to study such plasmas, however, there are issues related to the accuracy and acceptability of the simulation results as well as its comparison with experimental observations. Recently, a concerted global effort to create a benchmark code has been initiated by multiple LTP research groups for validation of PIC codes [1]. For the benchmark case, a time step of $\Delta t = 5 \times 10^{-12}$ s and a grid spacing of $\Delta x = 50$ µm with a grid of 500 × 256 cells are used. 4×10^6 time steps are simulated, which corresponds to 20 µs. On an average, this benchmark simulation requires 60,000 CPU hours. This necessitates advanced parallelization techniques at multiple levels to take advantage of modern HPC systems. We use several techniques such as self aware sorting, and a new strategy of charge deposition which helped to reduce the run-time significantly compared to international average for the benchmark simulation. Our code has been executed on Param-Sanganak supercomputer. In this paper, we will present the implementation and optimization strategies of our in-house parallel 2D PIC code (developed using OpenMP and MPI to take advantage of multiple threads and nodes). A comprehensive analysis of the performance obtained from this representative simulation and important results from the benchmark simulation are also presented.

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Particle-in-Cell Simulations with a Deep Learning-Based Solver

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Abstract
An integration of Deep-learning (DL) based methods with traditional Particle-in-Cell (PIC) simulation has been implemented in present work. A DL-based solver using Deep Neural Network (DNN) or Physics-informed Neural Network (PINN) [1] has been trained on density data obtained from 1-D electrostatic PIC simulation to solve poisson's equation.

Phenomenon of Landau damping and two-stream instability are taken to test and evaluate the DL-based solvers. Conservation properties of the system such as energy and momentum are explored for the DL-based solvers. A general (qualitative & quantitative) comparison between the traditional & DL-based PIC simulations is carried out and the results for the same are presented. DL based methods viability, at present, for developing next-gen PIC algorithms is analysed given their strength and limitations.

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Parametric study on EM field simulations of MPCVD cavity

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Abstract

In recent years, concentrated efforts have been made to study the use of microwave plasmas for diamond growth applications in controlled lab environment. Diamond exhibits interesting properties such as high thermal conductivity, extreme hardness, wideband optical transparency etc[1]. Due to these properties lab grown diamond (LGD) finds extensive use in tools and machineries, semiconductor industry, laser industry, fiber optics and telecommunications, biomedical industry, wearables and fashion industry.

Microwave plasma chemical vapor deposition (MPCVD) is a well-established technique for fabrication of LGDs[1]-[4]. However, the design of MPCVD reactors remains a major challenge due to the complex nature of physics and gas phase chemistry involved in diamond growth process[4]. In the present work, parametric simulation of clamshell MPCVD reactor geometry has been attempted using COMSOL RF and plasma modules. Clamshell reactor configurations are widely employed in many commercial MPCVD reactors due to easy accessibility to sample mounting stage[1],[3]. Reactor geometry has been optimized using eigen mode analysis for maximum power coupling at 2.45 GHz. Variation of electromagnetic field distribution with puck height and diameter has been studied and an optimum puck dimension has been suggested based on the simulation results.

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Development of Finite Difference Time Domain (FDTD) Code for Plasma Antenna

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Abstract

A plasma antenna is a radio-frequency (RF) antenna partially composed of plasma instead of metals. In most of the designs, the antenna is constructed by filling a dielectric (glass) tube with low- pressure gases, and plasma is generated by feeding RF power at the end of the tube which travels along the plasma column as the surface wave [1]. The FDTD code has been developed for the plasma antenna with a given density and conductivity profile in the radial and axial directions. The FDTD code is used to calculate important parameters, like the input impedance of the monopole plasma antenna. The input impedance is an important parameter of all the antenna design which is used to calculate the radiation and Ohmic losses in the antenna. The FDTD code will help the experimentalist choose the plasma antenna geometrical configuration, plasma density, and conductivity profiles to maximize the radiative power and minimize the loss for a given frequency bandwidth [2].

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Modelling of plasma start-up and burn-through in Tokamaks

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Abstract

In future fusion devices, it is crucial to establish a start-up process that is reliable, reproducible, and low-risk. This necessitates a comprehensive understanding of all aspects of plasma initiation. The start-up process comprises three stages: breakdown, burn-through, and ramp-up [1]. In conventional tokamaks, breakdown occurs as the initial step of start-up, where the neutral gas is ionized to create plasma. Typically, inductive start-up is employed, where the toroidal electric field/loop voltage induced by the central solenoid serves as the energy source. This voltage drives a toroidal current, which enhances the plasma temperature through ohmic heating. The objective is to rapidly distribute this energy throughout the system to minimize energy loss and maximize ionization. Several factors contribute to potential losses, including heat and particle loss during plasma transport, Bremsstrahlung and impurity radiations, ionization, recombination, and equilibration. Therefore, maintaining energy balance is crucial for achieving successful start-up, allowing for the overcoming of radiation and ionization barriers during the burn-through phase with minimal energy consumption. Failures during start-up often occur due to plasma contamination from impurities originating from the first wall, In only carbon (C) first wall machines and oxygen (O) being the primary impurity constituents. The complete ionization of these impurities during the burn-through phase consumes a significant portion of the input energy. Therefore, to comprehend the evolution of impurities, it is necessary to develop a dynamic plasma-wall interaction model that accounts for the dominant impurity fraction, as well as a wall recycling model that efficiently handles neutral density.

However, in the absence of sophisticated models for plasma wall interaction or impurity concentration evolution, the plasma evolution during the burn-through and ramp-up stages has been simulated using the OOPS (0D Optimization of Plasma Start-up) code developed at IPR for SST-1 [2]. The simulated results closely align with experimental findings, indicating a good level of agreement. The OOPS code has now been updated to include a comprehensive impurity evolution model, making the impurity content of the plasma dynamic and influenced by changes in density (ne), temperature (Te), and the evolving influx of impurities from plasma-facing components. Additionally, the OOPS code incorporates an electron cyclotron heating (ECH) module based on a theoretical model of ECH power absorption [3]. To validate its performance, the updated OOPS code has been bench-marked against other existing start-up codes such as DYON, SCENPLINT, and BKD0, for a plasma shot of JET [4]. Moreover, simulation results have been compared for ohmic burn-through of a pure hydrogen plasma using constant parameters relevant to ITER [4]. Encouragingly, there is significant agreement among all the codes used in the JET and ITER start-up studies. These benchmark studies instill confidence in applying burn-through simulations to investigate critical aspects of plasma physics and to conduct start-up simulations for our in-house Tokamaks, ADITYA-U and SST-1.

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Uniformity Analysis of Asymmetric waveguide of Large Area Cold Plasma for Radioactive Decontamination

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Abstract

Different types of atmospheric pressure plasma sources have been reported especially dielectric barrier discharges, RF discharge and pulsed DC discharge. Spatiotemporal intermittent discharges have rendered low and non-uniform plasma density due to these sources. Microwave based atmospheric pressure plasma has high density plasma compared to RF as power absorption efficiency is better due to frequencies being near to collusion frequency. Drawback of microwave plasma is that it has short wavelength in the few centimetres range which generates standing waves resulting in spatially non uniform discrete plasma which is not suitable for large area. For sustaining Plasma in rare gas and molecular gas discharges, it requires high power, instead of increasing power which has its own drawbacks, low impedance slotted waveguide is used which increases the surface currents without increasing power. Here it has symmetrical distribution of electromagnetic field and half of current does not aid in Plasma generation. If the cross section of waveguide is reduced, the current density will increase which will result in resistance losses in the waveguide.

As an alternative technique, asymmetric cross section waveguide will enhance the surface currents effectively and concentrate the current in the slot by improving the coupling between the power in the waveguide and the slot suppressing standing waves. In this technique of atmospheric pressure large area plasma generation, the ratio of two surface currents flowing in the waveguide wall is changed by modifying the cross sectional structure properly. Thus, the asymmetric waveguide structure is effective to localize the surface currents resulting in large current density than the conventional waveguide. Accordingly, the area of waveguide can be increased without increasing the power as magnetic field is strongly localized inside the gap. So modifying the waveguide the possibility of high electric field is realized resulting in large area plasma generation and subsequently sustainment.

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Formation of Structures in Strongly Coupled Medium Driven by Electrostatic Interactions

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Abstract

The formation of classical bound structures in electron-ion ultracold neutral plasma (UCP) [1] is studied in two and three dimensional simulations using an open-source classical Molecular Dynamics simulation software LAMMPS [2]. The charged particles interact through long-range pair Coulomb potential. At short scales Lennard-Jones (LJ) repulsive potential is also added to avoid blowing up of attractive Coulomb interaction between unlike charges at short distances. The chosen LJ parameters provide a minima in the interaction potential of electrons and ions. This minima leads to the formation of a variety of classical bound state, specially when the system is strongly coupled. The details of the formation, their distinct varieties, and the associated binding energy for the configurations will be presented in detail [3]. Other issues that are extensively studied and will be presented involve applying external disturbance in the system to study the screening profile, its role on the formation of structures etc.

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Novel Instabilities in Non-Abelian Plasma

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Abstract

The quark-gluon plasma is produced in high-energy heavy ion collisions. It is also believed that the universe went through this phase soon after the big bang [1]. The behavior of this state of matter can be understood by the Yang-Mills theory, a generalization of Maxwell's theory of electrodynamics. The Yang-Mills theory is inherently non-linear due to the non-abelian nature of the gauge transformations, giving rise to new solutions [2][3]. In this poster, we study the instabilities arising in the non-abelian plasmas due to counter-streaming beams and bring out the novel unstable modes which are due to the non-abelian effect.

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Detection possibility of continuous gravitational waves from rotating magnetized neutron stars

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Abstract

In the past decades, several neutron stars (NSs), particularly pulsars, with mass $M > 2M_{\odot}$ have been observed. Hence, there is a generic question of the origin of massive compact objects. Here we explore the existence of massive, magnetized, rotating NSs with various equation of states (EoSs) using *XNS* code, which solves axisymmetric stationary stellar equilibria in general relativistic magnetohydrodynamics (GRMHD). We visualise the deformation of NS due to magnetic field (Toroidal and/or Poloidal) and rotation (Uniform or Differential), by solving the Einstein equation (describes space-time metric) and Magneto-Hydrostatic Equilibrium (provides distribution of matter/energy) simultaneously. Such rotating NSs with magnetic field and rotation axes misaligned, hence (triaxial system) having non-zero obliquity angle, can emit continuous gravitational waves (GW), which can be detected by upcoming detectors, e.g., Einstein Telescope, etc. We discuss the decays of magnetic field, angular velocity and obliquity angle with time, due to angular momentum extraction by GW and dipole radiation, which determine the timescales related to the GW emission. Further, in the Alfvén timescale, a differentially rotating, massive proto-NS rapidly loses angular momentum to settle into a uniformly rotating, less massive NS due to magnetic braking and viscous drag. These explorations suggest that detecting massive NSs is challenging and sets a timescale for detection. We calculate the signal-to-noise ratio of GW emission, which confirms that any detector cannot detect them immediately, but detectable by Einstein Telescope, Cosmic Explorer over months of integration time, leading to direct detection of NSs.

Microwave Scattering Diagnostics of Laser Induced Microplasma

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Abstract

Multiphoton ionization (MPI) is a fundamental process in high-energy laser-matter interactions and first step in generating laser induced plasmas.[1], [2] Laser induced plasma's were discovered in mid 1960's and over the decades have found several applications such as studying of fundamental plasma processes, soft ionization source, compact particle accelerators and XUV deep UV radiation source.[3]–[5] However the diagnostics of such microplasma, using traditional approached such as laser interferometer and time of flight mass spectrometry, is since they require large number density(>10^{18} 1/cm^3) and volume [6]. Determination of MPI parameters such as photo ionization rates and mpi cross- sections typically rely on either semi empirical relations or theoretical models. There also exists great variability in the reported rates(two order of magnitude difference in ionization rate for O_2 and N_2 or unrealistic close despite having). [7], [8] this study presents a novel approach for directly measuring absolute plasma electron numbers generated during MPI using microwave scattering, allowing for precise determination of ionization rates and cross-sections.

Microwave scattering was developed for diagnostic of small plasma object and has been shown to work with atmospheric plasma jet and nana second repetitive pulsed discharges.[9]–[12] The method involves radiating the microplasma with microwaves and measuring the scattered signal using homodyne detection. The size of the plasma volume is significantly smaller than the wavelength of the microwaves, while the skin depth is greater than the plasma. As a result, all the electrons within the volume behave coherently and collectively act as a single dipole scatterer. The strength of this scattered signal is proportional to the number of electrons present in the volume. The system was calibrated using dielectric scatter (Teflon) of known physical parameters (length=1cm, diameter=3mm, = 2.1). Figure 1. a) Presents the schematic of scattering of microwaves by laser produced plasma.

The laser induced microplasma were generated in air, O_2, Xe, Ar, N_2, Kr, and CO at atmospheric pressure and room temperature using 800nm, 100fs pulse focused using 1m Plano convex lens. Laser pulse energies ranging from 100 to 700 µJ resulted in electron populations spanning from 3×10^8 to 3×10^{12}.[13] Figure 1.b) Presents the temporal evolution of electrons produced by fs pulse in air primarily due to ionization of O_2 since is ionization energy is lower than N_2. The extremely fast decay (~2ns) is due to electron attachment.[14] In Figure 1c, it can be seem that the measured total number of electrons follow power 8 law and correspoing eight-photon ionization cross section of the oxygen molecule by 800 nm photons was found to be $\sigma_8 = (3.3 \pm 0.3) \times 10^{-130}\ W^{-8}m^{16}s^{-1}$.

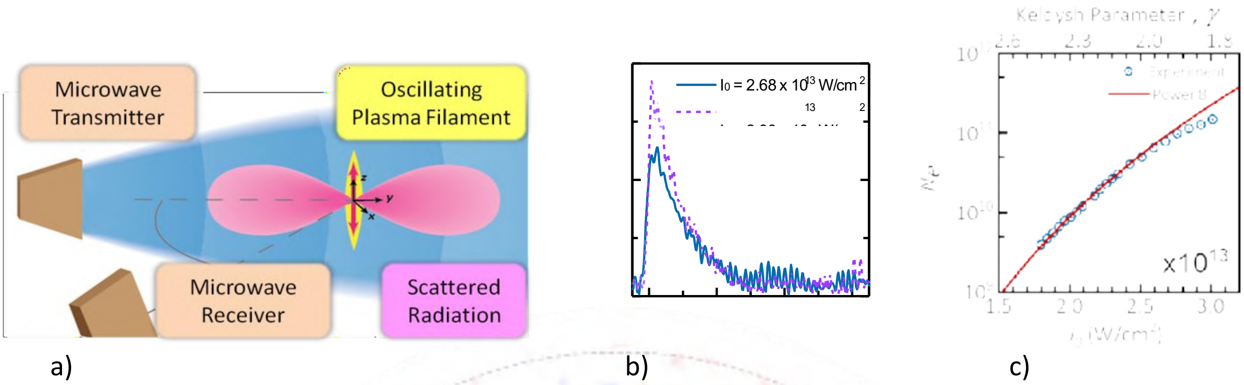

Figure 1. a) Detailed schematic of the Microwave Scattering (MS) technique b) Temporal evolution of total number of electrons produced in air at two laser intensities c) Total number of electrons generated at different laser intensities. Blue region denotes the pure 8 photon MPI regime for O_2

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