Phil Morrison's Friday Meetings

A Covid-19 Induced Seminar Series 2020–

My Friday online seminar series evolved naturally out of the informal Friday meetings I have been holding onsite at the University of Texas at Austin for more than 25 years. Because of Covid-19 these Friday meetings went online and then grew organically to include former students, postdocs, collaborators, etc.

As you can see from the eclectic list of abstracts below, a wide range of topics, both theoretical and experimental, have been treated, although there is a clear slant towards plasma and mathematical physics or as I like to say *Theory for Theory's Sake.* In general basic theoretical/mathematical tools of use in many disciplines are germane.

As evidenced by the rapid increase in my mailing list for this series, the style of science here is not unpopular. If you would like to be added to the mailing list for announcements and zoom links, send me an email with a two line self-description and I will add you.

The time of **8:30am CDT** was chosen to accommodate both European and Asian colleagues (with apologies to my West Coast friends).

210618: Prof. Francesco Pegoraro (Enrico Fermi Department of Physics, University of Pisa, Italy)

Title: **Dispersive electromagnetic waves in QED vacuum and higher order derivative Lagrangians**

Abstract:

The radiation intensity generated by ultra high power lasers is presently reaching the range where the nonlinear properties of the vacuum predicted by quantum electrodynamics become significant and will make it possible to probe the vacuum polarization effects induced by these super-strong electromagnetic (e.m.) waves. We consider nonlinear e.m. waves propagating in the QED vacuum within the framework of an e.m. Lagrangian with higher derivative terms implemented so as to account for the QED vacuum dispersive properties. Conceptual limitations inherent to the use of this higher derivative Lagrangian approach are mentioned. An exact solution of the nonlinear wave equation of the Korteveg-de Vries soliton type is obtained.

This talk is based on F. Pegoraro and S.V. Bulanov, Phys. Rev. D 103, 096012 (2021).

210528: Dr. Masayuki Yokoyama (National Institute for Fusion Science, Japan)

Title: **One example for bridging the plasma-fusion and statistical-mathematical community on fusion research: Progress of statistical modelling of thermal transport of fusion plasmas**

Abstract:

Progress of statistical modelling of thermal transport of fusion plasmas based on (2–4 a) a transport analysis database is described. Statistically induced ion and electron thermal diffusivities are checked with an actual discharge which had not been included in the database. Usefulness of this statistical approach is explained in terms of (1) extracting important parameters through the application of information criterion, and (2) making possible for discussing exponents of regression expression and then implying the thermal transport property. The statistical approach reported in this paper could provide a new insight for thermal transport modelling for fusion plasmas, complementing conventional global scalings on the energy confinement time.

This talk is based in part on M. Yokoyama and H. Yamaguchi, Nucl. Fusion **60**, 106024 (2020).

210521: Prof. George Throumoulopoulos (University of Ioannina, Greece)

Title: **Certain advances on conventional and Hamiltonian magnetic confinement theory**

Abstract:

Certain results on magnetic confinement theory will be reviewed. The presentation consists of two parts: In the first one a generalized Grad-Shafranov equation with CGL pressure anisotropy and incompressible flow of arbitrary direction will be presented on the basis of which the impact of flow and pressure anisotropy on the plasma magnetic properties (paramagnetic or diamagnetic) will be examined. In the second part, the extended MHD model, a simplified two-fluid model including the ion Hall-term and electron inertia, will be presented and the energy-Casimir method will be utilized to construct helically symmetric equilibria with isotropic pressure and either compressible or incompressible flow. In addition, an ellipticity sufficient condition for the set of PDEs involved will be derived, implying the possibility of an elliptic-hyperbolic transition due to electron fluid flow.

210423: Prof. Melvin Leok (Department of Mathematics, UCSD)

Title: **The Connections between discrete geometric mechanics, information geometry, accelerated optimization and machine learning**

Abstract:

Geometric mechanics describes Lagrangian and Hamiltonian mechanics geometrically, and information geometry formulates statistical estimation, inference, and machine learning in terms of geometry. A divergence function is an asymmetric distance between two probability densities that induces differential geometric structures and yields efficient machine learning algorithms that minimize the duality gap. The connection between information geometry and geometric mechanics will yield a unified treatment of machine learning and structure-preserving discretizations. In particular, the divergence function of information geometry can be viewed as a discrete Lagrangian, which is a generating function of a symplectic map, that arise in discrete variational mechanics. This identification allows the methods of backward error analysis to be applied, and the symplectic map generated by a divergence function can be associated with the exact time-h flow map of a Hamiltonian system on the space of probability distributions. We will also discuss how time-adaptive Hamiltonian variational integrators can be used to discretize the Bregman Hamiltonian, whose flow generalizes the differential equation that describes the dynamics of the Nesterov accelerated gradient descent method.

210423: Prof. Iberê Caldas (Institute of Physics, University of São Paulo, Brazil)

Title: **Transport barriers in symplectic maps**

Abstract:

Chaotic transport is a subject of paramount importance in a variety of problems in plasma physics, specially those related to anomalous transport and turbulence. On the other hand, a great deal of information on chaotic transport can be obtained from simple dynamical systems like two-dimensional area-preserving (symplectic) maps. In this work we review recent works on transport barriers in area preserving maps, focusing on systems which do not obey the so-called twist property. For such systems novel dynamical features show up as shearless curves and shearless bifurcations. After presenting some general features using a standard nontwist mapping, we consider magnetic field line maps for magnetically confined plasmas in tokamaks.

210416: Prof. Manasvi Lingam (Florida Institute of Technology, Melbourne, FL)

Title: **A tale of two noncanonical Hamiltonian models**

Abstract:

Hamiltonian models constitute one of the cornerstones of modern classical physics. In the last few decades, more attention has been devoted to noncanonical Hamiltonian systems, which exhibit several unique properties like being applicable to odd-dimensional dynamical systems (contra canonical Hamiltonian systems). In this talk, I will begin with a brief introduction to the theory of Hamiltonian systems and then focus on two noncanonical models. The first will elucidate the unexpectedly rich mathematical structure of the seminal SIR model in epidemiology, such as its bi-Hamiltonian nature and its connection to the Bianchi classification of Lie algebras. The second part of the talk will delve into a fluid model in plasma physics that represents an extension of ideal magnetohydrodynamics (MHD) and is endowed with a collisionless transport term analogous to viscosity (known as gyroviscosity).

210409: Dr. Thierry Passot (CNRS, Observatoire de la Cote d'Azur, Nice, France)

Title: **Modeling space plasma turbulence with Landau fluids**

Abstract:

Fluid models remain a very useful tool in order to simulate plasma turbulence in the solar wind or in planets' environments. These plasmas are almost collisionless and magnetized, with a ratio between thermal and magnetic pressures ranging from 0.1 to 10, except in regions very close to, or far from the Sun or the planets. Despite a low Mach number, compressibility cannot be totally neglected, leading to a very rich set of coherent structures, often in pressure balance. Due to the absence of collisions, dissipation mechanisms do not take the form of magnetic diffusivity nor viscosity, but are rather dominated by purely kinetic processes. Among them, Landau damping, plays a major role, leading to an effective and selective dissipation, reducing for example the amount of magnetosonic waves. A fluid model, closed at the level of the fourth-rank fluid moments in such a way as to retain the Landau resonance is presented. When also including ion finite Larmor radius effects, it is shown to accurately reproduce the linear kinetic properties of low-frequency waves. Simulations of this model in a turbulent regime illustrate the main role of Landau damping on magnetic spectra and on the global dynamics, with in particular the reduction of the energy transfer rate along the turbulent cascade. The role of Landau damping in the case of a strong imbalance in the propagation of kinetic Alfvn waves is also pointed out.

210402: Dr. William Gilpin (Harvard Quantitative Biology Initiative)

Title: **Learning strange attractors from time series**

Abstract:

Experimental measurements of physical systems often have a limited number of independent channels, causing essential dynamical variables to remain unobserved. However, many popular techniques for inferering latent dynamics from experimental data implicitly assume that measurements have higher intrinsic dimensionality than the underlying system—making coordinate discovery a dimensionality reduction problem. Here, we study the opposite limit, in which hidden governing coordinates must be inferred from only a low-dimensional time series of measurements. Inspired by classical models of partial observations of chaotic attractors, we introduce a general embedding technique for time series, consisting of an autoencoder trained with a loss function that penalizes false neighbors in latent space. We show that our technique reconstructs the strange attractors of synthetic and real-world systems better than existing methods, and that it creates consistent, predictive representations of even stochastic systems. We conclude by

using our technique to discover dynamical attractors in diverse systems such as patient electrocardiograms, neural recordings, fitness trackers, and eruptions of the Old Faithful geyser—demonstrating diverse applications of our technique for exploratory data analysis.

210326: Dr. Ilon Joseph, (Physics Division, Lawrence Livermore National Laboratory)

Title: **Quantum Simulation of Nonlinear Classical Dynamics**

Abstract:

Quantum algorithms can accelerate the solution of a number of important problems relative to classical algorithms. However, quantum computation is limited to the application of linear unitary transformations, and, hence, it is not immediately clear how to accelerate the solution of nonlinear dynamical systems. There are two approaches to quantum simulation of nonlinear classical dynamics: (i) quantize the classical Hamiltonian and (ii) use the Koopman-von Neumann approach to reformulate the conservation of probability, the Liouville equation, as an equivalent Schrodinger equation with a unitary evolution operator. A quantum computer with finite resources can then be used to simulate a finite-dimensional approximation of the unitary evolution operator. Using this approach to quantum simulation is exponentially more efficient than a deterministic Eulerian discretization of the Liouville equation if the Hamiltonian is sparse. Using amplitude estimation for the calculation of observables and quantum walk techniques for state preparation can lead to up to a quadratic improvement over probabilistic Monte Carlo algorithms.

210319: Prof. Cesare Tronci (University of Surrey, UK, and Tulane University)

Title: **Koopman wavefunctions and Clebsch variables in Maxwell-Vlasov kinetic theory**

Abstract:

Over the years, Koopman wavefunctions in classical mechanics have been rediscovered by several prominent scholars including Norbert Wiener, Gerard't Hooft, and Michael Berry, who were apparently unaware of Koopman's seminal work from 1931. The idea consists in constructing a Hilbert-space formalism for a wavefunction $\psi(q,p)$ such that the classical Liouville density is expressed as $\rho = |\psi|^2$.Then, depending on the phase, one is left with possible variants of the formalism. Motivated by recent discussions on the possible role of quantum methods in plasma simulations, this talk will combine Koopman wavefunctions with Hamiltonian and variational methods in the context of the Vlasov-Maxwell system. While in certain cases the canonical structure is intimately related to the celebrated Clebsch variables, it also leads to apparent issues which are overcome by resorting to the noncanonical formalism. Alternatively, a variant of the Clebsch representation is obtained by expressing the Koopman phase in terms of the phase-space Lagrangian, by following Feynman's prescription from path-integral theory.

Joint work with Ilon Joseph, (Physics Division, Lawrence Livermore National Laboratory)

210312: Dr. John M. Finn (LANL and Tibbar Plasma Technologies, NM)

Title: **Machine Learning methods for forecasting error-field locking in tokamak plasmas**

Abstract:

A rotating tokamak plasma can interact resonantly with an external helical magnetic perturbation, also known as an error field. This can lead to locking, which can lead to disruptions. The aim here is to leverage machine learning (ML) methods to train them to predict locking events, leading to the possibility of the avoidance of locking in real time operations. We use a simple coupled third order ODE model to represent the interaction of the magnetic perturbation with the error field, in order to explore using a large sample for training the various ML algorithms. This model is sufficient to describe the locking and unlocking bifurcations, and we describe an analogy with the van der Waals equation of state. The independent variables of the ODE are the magnitude of the reconnected (perturbed) magnetic flux, its phase relative to the error field, and the plasma rotation, all at the mode rational surface. We consider a pair of control parameters: the magnitude of the error field and the rotation frequency associated with the momentum source that maintains the plasma rotation. For measuring outcomes, we consider the independent variables to be order parameters, i.e. parameters that completely characterize the time-asymptotic state, whether locked or unlocked. We use ML methods to classify locked and unlocked states, and note the importance of using a certain normalization of the order parameters. We estimate the probability of locking in the region of control parameter space with hysteresis, i.e. the set of control parameters for which both locked and unlocked states can exist.

This talk is based on joint work with Cihan Akçay (Tibbar), Dylan Brennan (Princeton), Doğa M. Kürkçüoğlu (Fermilab) and Thomas Burr (LANL)

210226: Dr. Martin Campos Pinto (Max Planck Institute, Garching Numerical Plasma Physics)

Title: **A general framework for structure-preserving particle approximations to Vlasov-Maxwell equations**

Abstract:

Variational discretizations are known for preserving key physical invariants in a natural way, leading to long-time stability properties. In this talk I will present

a discrete action principle for the Vlasov-Maxwell equations that applies in a general structure-preserving discrete framework.

In this framework the finite-dimensional electromagnetic potentials and fields are represented in a discrete de Rham sequence involving general Finite Element spaces, and the particle-field coupling is represented by a set of projection operators that commute with the differential operators.

One application of this approach is a new variational spectral PIC method that has a discrete Hamiltonian structure and relies on particle-field coupling techniques very similar to those encountered in standard PIC schemes.

This talk is based on the following papers, and the new part is a joint work with Jakob Ameres, Katharina Kormann and Eric Sonnendrcker from the Max Planck IPP in Garching, Germany

https://arxiv.org/abs/2101.09247

https://arxiv.org/abs/2102.02106

https://arxiv.org/abs/1609.03053

210212: Prof. Zensho Yoshida (University of Tokyo → NIFS, Japan)

Title: **How strong can zonal flow be?**

Abstract:

The partition of enstrophy between zonal (ordered) and wavy (turbulent) components of vorticity has been studied for the beta-plane model of two-dimensional barotropic flow. An analytic estimate of the minimum value for the zonal component has been derived. The energy, angular momentum, circulation, as well as the total enstrophy are invoked as constraints for the minimization of the zonal enstrophy. The corresponding variational principle has an unusual mathematical structure (primarily because the target functional is not a coercive form), by which the constraints work out in an interesting way. A discrete set of zonal enstrophy levels is generated by the energy constraint; each level is specified by an eigenvalue that represents the lamination period of zonal flow. However, the value itself of the zonal enstrophy level is a function of only angular momentum and circulation, being independent of the energy (and total enstrophy). Instead, the energy works in selecting the "level" (eigenvalue) of the relaxed state. The relaxation occurs by emitting small-scale wavy enstrophy, and continues as far as the nonlinear effect, scaled by the energy, can create wavy enstrophy. Comparison with numerical simulations shows that the theory gives a proper estimate of the zonal enstrophy in the relaxed state.

Talk based on arXived paper by H. Aibara and Z. Yoshida here.

210205: Dr. Daniela Grasso (Politecnico di Torino, Torino, Italy)

Asymmetry effects driving secondary instabilities in two-dimensional collisionless magnetic reconnection

Abstract:

In the framework of the studies on magnetic reconnection, much interest has been recently devoted to asymmetric magnetic configurations, which can naturally be found in solar and astrophysical environments and in laboratory plasmas. Several aspects of this problem have been investigated, mainly in a two-dimensional geometry and by means of particle-in-cell (PIC) simulations. Still, there are open questions concerning the onset and the effects of secondary instabilities in the nonlinear phase of an asymmetric reconnection process. In this work, we focus on the conditions that lead to the appearance of the Kelvin-Helmholtz instability following an asymmetric reconnection event in a collisionless plasma. This investigation is carried out by means of two-dimensional numerical simulations based on a reduced fluid model assuming a strong guide field. We show that, unlike the symmetric case, in the presence of asymmetry, a Kelvin-Helmholtz-like instability can develop also for a finite equilibrium electron temperature. In particular, simulations indicate the formation of steep velocity gradients, which drive the instability, when the resonant surface of the equilibrium magnetic field is located sufficiently far from the peak of the equilibrium current density. Moreover, a qualitative analysis of the vorticity dynamics shows that the turbulent behavior induced by the secondary instability not only is confined inside the island but can also affect the plasma outside the separatrices. The comparison between simulations carried out with an adiabatic closure and a Landau-fluid closure for the electron fluid indicates that the latter inhibits the secondary instability by smoothing velocity gradients.

Based on D. Grasso, et al. Phys. Plasmas **27**, 012302 (2020).

210129: Prof. Sunghwan (Sunny) Jung, (Cornell University)

Physics in drinking and diving

Abstract:

Fluids are vital to all life forms, and organisms have presumably adapted their behaviors or features in response to mechanical forces to achieve better performance. In this talk, I will discuss two biological problems in which animals exploit mechanics principles. First, we investigated how animals transport water into the mouth using an inertia-driven (lapping) mechanism. Dogs accelerate the tongue upward (up to 4 g) to create a larger water column while drinking, whereas cats use a tongue motion with relatively small acceleration. We found that, in order to maximize the water intake per lap, both cats and dogs close the jaw at the column beak-up time governed by unsteady inertia. Second, we studied how birds with long slender necks plunge-dive and survive from the impact. Physical

experiments using an elastic beam as a model for the neck attached to a skull-like cone revealed the limits for the stability of the neck during plunge-dive. We found that the small angle of the birds beak and the strong muscles in the neck predominantly reduce the likelihood of injury during high-speed plunge-dive. In addition, I will talk about various diving postures in human diving in terms of the force acting on the body.

210115: Santhosh Ganapa, (ICTS TIFR, Bengaluru, India)

Thermalization and chaos in the α-FPUT system

Abstract:

This study revisits the thermalization problem of the Fermi-Pasta-Ulam-Tsingou (FPUT) system. Most studies on this problem have focused on equipartition of energy being attained amongst the normal modes of the corresponding harmonic system. In the present work, we instead discuss the equilibration problem in terms of local variables, and consider initial conditions corresponding to spatially localized energy. Measuring thermalization in classical systems necessarily requires some averaging. Here we consider averaging over initial conditions chosen from a narrow distribution in phase space. We examine in detail the effect of the width of the initial phase space distribution, and of integrability and chaos, on the time scales for thermalization. We show how thermalization properties of the system, quantified by its equilibration time, defined in this work, can be related to chaos, given by the maximal Lyapunov exponent. Somewhat surprisingly we also find that the ensemble averaging can lead to thermalization of the integrable Toda chain, though on much longer time scales.

See https://arxiv.org/pdf/1911.03673.pdf for preprint.

210108: Chris Smiet (Princeton Plasma Physics Lab)

Topological bifurcations of the magnetic axis and the alternating-hyperbolic sawtooth

Abstract:

The sawtooth phenomenon is ubiquitous in tokamak fusion devices, and consists of a crash and flattening of the core temperature and pressure. The most prevalent model, put forth by Kadomtsev, explains the crash as a rigid (1/1) displacement of the core by an ideally unstable mode, and fits well with the observations of most crashes. There is however a subset of observations in which the safety factor (an inverse measure of the 'twist' in the field lines in the center) is 2/3, significantly different from the Kadomtsev model prediction. We identify the structure of the magnetic field in the center of the tokamak with elements of the Lie group $SL_2(\mathbb{R})$, where the subsets (conjugacy classes) correspond with topologically distinct magnetic structures. When the safety factor reaches 2/3, there is a transition to an alternating-hyperbolic configuration (corresponding to

a period-doubling bifurcation). MHD stability calculations show that in equilibria where this is the case, there is an ideal (2/3) mode which drives this transition. At high amplitude this mode causes stochastisation of the magnetic field in the core, which magnetically connects the plasma in the core region, and can explain the observed crash.

201218: Baptiste Coquinot (ENS Paris, France)

A general metriplectic framework with application to dissipative extended magnetohydrodynamics

Abstract:

General equations for conservative yet dissipative (entropy producing) extended magnetohydrodynamics are derived from two-fluid theory. Keeping all terms generates unusual cross-effects, such as thermophoresis and a current viscosity that mixes with the usual velocity viscosity. While the Poisson bracket of the ideal version of this model has already been discovered, we determine its metriplectic counterpart that describes the dissipation. This is done using a new and general thermodynamic point of view to derive dissipative brackets, a means of derivation that is natural for understanding and creating dissipative dynamics without appealing to underlying kinetic theory orderings. Finally, the formalism is used to study dissipation in the Lagrangian variable picture where, in the context of extended magnetohydrodynamics, non-local dissipative brackets naturally emerge.

Talk based on B. Coquinot and P. J. Morrison, “A General Metriplectic Framework with Application to Dissipative Extended Magnetohydrodynamicss,” J. Plasma Phys. **86**, 835860302 (32pp) (2020).

201211: Dr. David Ciro Taborda (REMA - UFSC, Brazil)

Invariant manifolds and chaotic magnetic fields

Abstract:

Magnetohydrodynamic equilibrium in tokamak plasmas assumes an axially symmetric magnetic field under regular operation conditions. The control of particle exhaust relies on the formation of a magnetic saddle, which is a closed field line at the plasma edge that delimits the magnetic separatrix between open and closed magnetic surfaces. In the presence of small asymmetric components of the field some closed field lines continue to exist and the separatrix splits in a couple of intersecting surfaces immersed in a chaotic layer. In this talk we discuss the numerical aspects of the determination of arbitrary closed field lines and their associated three-dimensional invariant surfaces in tokamak plasmas and other three-dimensional non-integrable fields. The numerical methods are illustrated with the determination of the magnetic footprint and the corresponding heat deposition pattern of a DIII-D tokamak discharge.

201204: Dr. Diego del-Castillo-Negrete (ORNL)

A Feynman-Kac based numerical method for the exit time probability of a class of transport problems

Abstract:

The exit time probability, which gives the likelihood that an initial condition leaves a prescribed region of the phase space of a dynamical system at, or before, a given time, is arguably one of the most natural and important transport problems. Here we present an accurate and efficient numerical method for computing this probability for systems described by non- autonomous (time-dependent) stochastic differential equations (SDEs) or their equivalent Fokker-Planck partial differential equations. The method is based on the direct approximation of the Feynman-Kac formula that establishes a link between the adjoint Fokker-Planck equation and the forward SDE. The Feynman-Kac formula is approximated using the Gauss-Hermite quadrature rules and piecewise cubic Hermite interpolating polynomials, and a GPU accelerated matrix representation is used to compute the entire time evolution of the exit time probability using a single pass of the algorithm. The method is unconditionally stable, exhibits second order convergence in space, first order convergence in time, and it is straightforward to parallelize. Applications are presented to the advection diffusion of a passive tracer in a fluid flow exhibiting chaotic advection, and to the runaway acceleration of electrons in a plasma in the presence of an electric field, collisions, and radiation damping. Benchmarks against analytical solutions as well as comparisons with explicit and implicit finite difference standard methods for the adjoint Fokker-Planck equation are presented.

201030: Prof. Alain Brizard (Saint Michaels College, VT)

Hamiltonian formulations for perturbed dissipationless plasma equations

Abstract:

The Hamiltonian formulations for the perturbed Vlasov-Maxwell equations and the perturbed ideal magnetohydrodynamics (MHD) equations are expressed in terms of the perturbation derivative $\delta F/\delta\epsilon = [F, S]$ of an arbitrary functional $F[\psi^a]$ of the Vlasov-Maxwell fields $\psi^a = (f, E, B)$ or the ideal MHD fields $\psi^a = (\rho, u, s, B)$, which are assumed to depend continuously on the (dimensionless) perturbation parameter ϵ. Here, $[,]$ denotes the functional Poisson bracket for each set of plasma equations and the perturbation action functional S is said to generate dynamically accessible perturbations of the plasma fields. The new Hamiltonian perturbation formulation introduces the framework for the application of functional Lie-transform perturbation methods in plasma physics and highlights the crucial roles played by polarization and magnetization in Vlasov-Maxwell and ideal MHD perturbation theories.

201023: Prof. Masaru Furukawa (Tottori University, Japan)

Title: **Simulated annealing for MHD equilibrium calculation and some discussion on the stability**

Abstract:

Simulated annealing (SA) is a kind of relaxation method for obtaining equilibria of ideal fluids including magnetohydrodynamics (MHD). These are Hamiltonian systems, and the SA method is constructed on the basis of the Hamiltonian nature. We solve an initial-value problem of the SA that is devised to monotonically change the energy of the system to reach an equilibrium or an energy extremum on a Casimir leaf. In the talk, I will show some examples of reduced MHD equilibria obtained by the SA. Also I will discuss stability of cylindrically symmetric equilibria by using the SA. The perturbation for the SA is taken to be on the same Casimir leaf as the equilibrium. The SA leads to another equilibrium from the original equilibrium even though the original equilibrium is linearly stable against ideal MHD modes.

201016: Prof. Cristel Chandre (CNRS, Institut de Mathématiques de Marseille, France)

Title: **Hamiltonian reductions from kinetic to fluid models**

Abstract:

We consider the Vlasov-Maxwell equations with one spatial direction and two momenta (referred to as the 1.5D Vlasov-Maxwell equations), one in the longitudinal direction and one in the transverse direction. By solving the Jacobi identity, we derive a reduced Hamiltonian fluid model for the density, the fluid momenta and the second order moments. We also discuss the link between this reduction and the existence of Casimir invariants of the reduced Poisson bracket. Joint work with Brad Shadwick (U. Lincoln).

201009: Vitor M. de Oliveira (University of So Paulo, Institute of Physics, Brazil)

Title: **Order-chaos-order and invariant manifolds in the bounded planar Earth-Moon system**

Abstract:

In this talk, I am going to present the results of our current research where we investigate the connection between dynamics and geometry in the Earth-Moon system, as modeled by the planar Circular Restricted Three-Body Problem (CRTBP). Specifically, we are interested in the relationship between the phase space configuration and the invariant manifolds associated with a family of periodic orbits called Lyapunov orbits. We also describe the different dynamical scenarios that emerge in the system, and we illustrate how such higher-dimensional geometrical structures can influence the systems transport properties. See https://arxiv.org/pdf/2006.13111.pdf for publication.

201002: Dr. Florian Holdereid (Max Planck Institute, Garching Numerical Plasma Physics)

Title: **MHD-kinetic hybrid code based on structure-preserving finite elements with particles-in-cell**

Abstract:

We present a STRUcture-Preserving HYbrid code - STRUPHY - for the simulation of magneto-hydrodynamic (MHD) waves interacting with a small population of energetic particles far from thermal equilibrium (kinetic species). Such configurations appear for instance in deuterium-tritium fusion reactors, where hot α-particles or fast ions coming from external heating devices can resonantly interact with MHD waves and thus compromise confinement time. The implemented model features linear, ideal MHD equations in curved, three-dimensional space, coupled nonlinearly to the full-orbit Vlasov equations via a current coupling scheme. The algorithm is based on finite element exterior calculus (FEEC) for MHD and particle-in-cell (PIC) methods for the kinetic part; it provably conserves mass, energy, and the divergence-free constraint for the magnetic field, irrespective of metric (= space curvature), mesh parameters and chosen order of the scheme. These properties enable reliable long-time simulations of energetic particle physics in complex geometries, covering the whole range of MHD waves. In STRUPHY, the finite element spaces are built from tensor products of univariate B-splines on the logical cuboid and can be made high-order by increasing the polynomial degree. Time-stepping is based on splitting of a skew-symmetric matrix with implicit sub-steps, mitigating CFL conditions from fast magneto-acoustic waves. High-order time splitting schemes can be used in this regard.

200918: Dr. Yohei Kawazura (Tohoku Univ, Sendai, Japan)

Title: **Partition of Alfvnic and compressive fluctuations in turbulence driven by nearly toroidal magnetorotational instability**

Abstract:

Is accretion disk turbulence Alfvénic or compressive? This is a simple yet unanswered question in astro plasma physics. Our recent gyrokinetic study on collisionless turbulence [Kawazura et al., arXiv:2004.04922 (2020)] shows that the ratio between Alfvénic and compressive fluctuations is crucial for interpreting the observation of the accretion disk by the Event Horizon Telescope. In order to compute the partition between Alfvénic and compressive fluctuations, one must dig deep into the inertial range until the reduced MHD (RMHD) ordering is satisfied. When the RMHD ordering is satisfied, the Alfvénic and compressive fluctuation are decoupled, and the partition will be maintained until the cascade reaches the kinetic scales. However, when the magnetic field of the disk is nearly toroidal (which is often the case), the fastest-growing mode of the magnetorotational instability (MRI) resides in $k_\perp \to \infty$ infinity [Balbus & Hawley (1991)]. This is problematic because the significant numerical resolution is required to reach the scale at which the RMHD ordering is satisfied when one solves the standard MHD.

In this study, we formulate shearing RMHD (SHRMHD) which includes MRI and shear flow effect in RMHD. This model captures the fastest growing mode of nearly toroidal MRI while neglecting the slower modes. The linear analysis and nonlinear simulation of SHRMHD show that the Alfvénic and compressive fluctuations are almost equipartitioned in turbulence driven by nearly toroidal MRI. This indicates that the accretion disk turbulence is qualitatively different from the solar wind turbulence, which is predominantly Alfvénic.

200911: Dr. Jason Derr (Rice University)

Title: **Stability Analysis of geomagnetic (auroral) substorm onset**

Abstract:

A geometric wedge model of the near-earth nightside plasma sheet is used to derive a wave equation for low frequency shear flow-interchange waves which transmit $\vec{E} \times \vec{B}$ sheared zonal flows along magnetic flux tubes towards the ionosphere. Discrepancies with the wave equation result used in Kalmoni et al. (2015) for shear flow-ballooning instability are discussed. The shear flow-interchange instability appears to be responsible for substorm onset. The wedge wave equation is used to compute rough expressions for dispersion relations and local growth rates in the midnight region of the nightside magnetotail where the instability develops, forming the auroral beads characteristic of geomagnetic substorm onset. Stability analysis for the shear flow-interchange modes demonstrates that nonlinear analysis is necessary for quantitatively accurate results and determines the spatial scale on which the instability varies.

200904: Santiago Benavides (MIT grad student)

Title: **MHD turbulence subject to global rotation and a misaligned background magnetic field**

Abstract:

Astrophysical plasmas are often subject to both rotation and large-scale background magnetic fields. Individually, each is known to two-dimensionalize the flow perpendicular to the direction of interest. In realistic flows, both of these effects are simultaneously present and, importantly, need not be aligned. In this work, we numerically investigate forced MHD turbulence subject to the competing effects of global rotation and a background magnetic field, when the global rotation vector and the magnetic field are perpendicular. We find rich behavior in the parameter space of rotation rate and field strength. In the case of a strong background field, increasing the rotation rate from zero produces significant changes in the structure of the turbulent flow. Starting from a two-dimensional inverse cascade scenario at zero rotation, the flow transitions to a forward cascade of kinetic energy, then a shear-layer dominated regime, and finally a second shear-layer regime where the kinetic energy flux is strongly suppressed and the energy transfer is purely mediated by the induced magnetic field.

200828: Dr. Jim Thomas (UNC, Chapel Hill)

Title: **Geophysical turbulence at oceanic mesoscales**

Abstract:

Oceanic mesoscales, ranging from 10-100 km horizontal scales, are constrained by the effects of rapid rotation and strong density stratification. Conventional wisdom in the past decades used to be that the turbulence phenomenology at these scales is set primarily by nonlinear interaction of mesoscale eddies, which are approximately in geostrophic and hydrostatic balance. However, satellite altimeter datasets, in situ measurements, and realistically forced global scale oceanic model outputs in recent times point out that oceanic mesoscales are rich with high energy internal gravity waves; consisting of wind generated high baroclinic near-inertial waves and gravitationally generated low baroclinic tides. Not only do these waves have spatial scales comparable to balanced mesoscale eddy field, in multiple parts of the world's oceans the wave energy levels are seen to significantly exceed balanced energy.

In this talk I will explain how interactions between waves and balanced flow shapes geophysical turbulence phenomenology at oceanic mesoscales. The talk will clearly distinguish and elaborate on how wind generated near-inertial waves, gravitationally generated low baroclinic tides, and the internal gravity wave continuum or the Garret-Munk spectrum of waves interact with geostrophically and hydrostatically balanced flow. The focus and goal of this research direction is to develop a comprehensive understanding of oceanic mesoscale wave-balance energetic interactions and the resulting turbulence phenomenology. An improved understanding of the flow at these scales will assist in developing better parameterization schemes for large scale general circulation models that are still far from capturing intricate fast and small scale oceanic flow dynamics.

Talk based on papers below:

[1] J. Thomas and R. Yamada, J. Fluid. Mech. **875** 71 (2019).

[2] J. Thomas and S. Arnun, Phys. Rev. F **5** 014801 (2020).

[3] J. Thomas and D. Daniel, *Turbulent exchanges between near-inertial waves and balanced flows.* Draft (2020).

200821: Dr. George Hagstrom (Ecology and Evolutionary Biology and GFDL, Princeton)

Title: **A trait-based approach to describe the elemental stoichiometry of marine phytoplankton and the regulation of the biological pump**

Abstract:

The regulation of the biological pump plays a central role in the global carbon cycle. Recent laboratory studies and field observations demonstrate considerable

variation in the ratio of Carbon:Nitrogen:Phosphorus (C:N:P) of both phytoplankton growing under different environmental conditions and in particulate organic matter across regions. Multiple distinct environmental drivers, including both temperature and inorganic nutrient concentrations, have been hypothesized as mechanisms responsible for these variations, each implying different feedbacks in the Carbon cycle. To reconcile the biological and geochemical measurements of C:N:P and to determine the extent to which temperature and nutrients control C:N:P, we here developed a trait-based model (ATOM, Adaptive Trait Optimization Model) designed to capture known metabolic regulation of different cellular biochemical components and estimated variation in C:N:P along environmental gradients. Bayesian optimization of this model against a newly compiled dataset of both C:N:P measurements and high-resolution measurements of inorganic N and P revealed that nutrient supply rates followed by nutrient levels were the strongest regulators of C:N:P. Integrating ATOM with a global-scale model of Nitrogen and Phosphate cycling led to an improved fit of carbon export to nutrient traps compared to both a static Redfield model and a model based on nutrient concentrations only. Thus, the biological regulation of C:N:P captured a global rearrangement in carbon export with important implications for the carbon cycle.

200814: Dr. George Miloshevich (CNRS, Observatoire de la Cote dAzur, Nice, France)

Title: **Inverse cascade and magnetic vortices in kinetic Alfvén-wave turbulence**

Abstract:

A Hamiltonian two-field gyrofluid model for kinetic Alfvén waves (KAWs) in a magnetized electron-proton plasma, retaining ion finite-Larmor-radius corrections and parallel magnetic field fluctuations, is used to study the inverse cascades that develop when turbulence is randomly driven at sub-ion scales. In the directions perpendicular to the ambient field, the dynamics of the cascade turns out to be nonlocal and sensitive to the ratio χ_f of the wave period to the characteristic nonlinear time at the driving scale. When χ_f is not too large, decay instability can develop, enhancing for a while inverse transfers. The balanced state, obtained at early time when the two counter-propagating waves are equally driven, also becomes unstable for small χ_f, leading to an inverse cascade restricted to a limited spectral range. For β_e smaller than a few units, the cascade slows down when reaching the low-dispersion spectral range. For higher β_e, the ratio of the KAW to the Alfvén frequencies displays a local minimum. At this transverse wavenumber, a condensate is formed, associated with the development of ion-scale magnetic vortices. The cascade towards larger scales is then inhibited. In the parallel direction, depending on the parameters, a local inverse cascade can develop, leading to elongated vortices.

Talk based on paper arXived here.

200807: Dr. Francois Mauger (Lousiana State University, Baton Rouge, LA)

Title: **Nonlinear dynamics of charge migration in model carbon chains**

Abstract:

When forced out of equilibrium, electrons and holes in molecules can react on exceedingly fast time scales, as short as a few femtoseconds (10^-15 s) or less. These ultrafast coherent electronic dynamics are typically called charge migration, and are raising increasing interest for their potential role in down-stream processes such as chemical reactions, photovoltaic or photosynthesis. In this presentation I will discuss recent applications of nonlinear dynamics to charge migration motions in reduced models of carbon chains [1]. Using a quantum mean-field Hamiltonian framework and frequency-map analyses, I will show how the apparent synchronization of electronic degrees of freedom can lead to quasiperiodic migration modes in those systems. I will also discuss the implication of those dynamical modes for our physical and chemical understanding of charge migration. This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Award No. DE-SC0012462..

[1] F. Mauger et al., Nonlinear dynamics of attosecond charge migration in model carbon chains (2020). Live link below.

Talk based on paper arXived here.

200731: Dr. Carlos Gonzalez (UT, Austin)

Title: **Hybrid simulations of parallel propagating large-amplitude Alfvnic fluctuations**

Abstract:

Large amplitude Alfvénic fluctuations tend to be unstable to parametric instabilities which result in a decay process of the initial wave into different daughter waves depending upon the amplitude of the fluctuations and the plasma beta. The propagation angle with respect to the mean magnetic field of the daughter waves plays an important role in determining the type of decay. We have revisited this problem by means of hybrid simulations. Starting from either monochromatic or non-monochromatic circularly polarized fluctuations, we have investigated the stability of Alfvénic fluctuations, the saturation mechanisms of the decay process and the final nonlinear state reached at different pump wave amplitudes and plasma beta values. As opposed to one-dimensional simulations where the instability is suppressed for increasing plasma beta values, we find that the decay process in multi-dimensions persists at large values of the plasma beta via the filamentation/magnetosonic decay instabilities. In general, the decay process acts as a trigger both to develop a perpendicular turbulent cascade and to enhance field-aligned wave-particle interactions. We find indeed that the saturated state is characterized by a turbulent plasma displaying a field-aligned beam at the Alfvn speed and increased temperatures that we ascribe to $n = 0$ resonances and pitch angle scattering in phase space. By addressing the stability of large

amplitude Alfvénic fluctuations, and by providing a mechanism that may contribute to turbulence development as well as to collisionless plasma heating and particle acceleration, these results are relevant to the solar wind and to space and astrophysical plasmas in general.

This talk will be based on the paper: here.

200724: Dr. Josh Burby (LANL)

Title: **Fast neural Poincaré maps for toroidal magnetic fields**

Abstract:

Abstract: Poincaré maps for toroidal magnetic fields are routinely employed to study gross confinement properties in devices built to contain hot plasmas. In most practical applications, evaluating a Poincaré map requires numerical integration of a magnetic field line, a process that can be slow and that cannot be easily accelerated using parallel computations. We show that a novel neural network architecture, the HénonNet, is capable of accurately learning realistic Poincaré maps from observations of a conventional field-line-following algorithm. After training, such learned Poincaré maps evaluate much faster than the field-line integration method. Moreover, the HénonNet architecture exactly reproduces the primary physics constraint imposed on field-line Poincaré maps: flux preservation. This structure-preserving property is the consequence of each layer in a HénonNet being a symplectic map. We demonstrate empirically that a HénonNet can learn to mock the confinement properties of a large magnetic island by using coiled hyperbolic invariant manifolds to produce a sticky chaotic region at the desired island location. This suggests a novel approach to designing magnetic fields with good confinement properties that may be more flexible than ensuring confinement using KAM tori.

200717: Prof. Jean-Luc Thiffeault (Univ of Wisconsin, Madison)

Title: **Modeling microswimmers and active particles with PDEs**

Abstract:

Stochastic modeling of particle transport is an important problem. For instance, how do particles disperse in the presence of flow, and how do they interact with permeable boundaries, such as filters? If a filter has a certain density of defects, wouldn't you like to know the rate of particle transport across the filter? This kind of problem has recently gained new prominence, owing to the ongoing apocalypse. I will give an introductory lecture on this topic, and discuss key equations such as the mean exit time equation.

200710: Dr. Achilleas Evangelias (University of Ioannina, Greece)

Title: **On equilibrium and stability of helically symmetric magnetized plasmas with flow and pressure anisotropy**

Abstract:

Results of a recent PhD thesis on the equilibrium and stability properties of a helically symmetric magnetized plasma with pressure anisotropy and incompressible flow will be presented. A main novel contribution is the derivation of a generalized Grad-Shafranov equation governing pertinent equilibria with flow of arbitrary direction, in connection with the steady states of two-dimensional straight stellarator configurations as well as of helically symmetric astrophysical jets. In addition, a new class of analytical solutions of the aforementioned equation is obtained and specific equilibria are con- structed for a plasma surrounded by a fixed boundary, and the impact of both pressure anisotropy and mass flow on their physical properties is examined. Furthermore, the symmetry transformations for magnetohydrodynamic equilibria with isotropic pres- sure and incompressible flow with collinear velocity and magnetic fields introduced by Bogoyavlenskij are generalized in the case of the respective Chew-Goldberger-Low equilibria with anisotropic pressure. Regarding stability, a sufficient condition for the linear stability of plasma equilibria with incompressible flow parallel to the magnetic field, constant mass density and anisotropic pressure such that the ratio of the difference between the scalar pressures in the directions parallel and perpendicular to the magnetic field over the magnetic pressure remains constant, is derived. This condition is applicable to any steady state without geometrical restriction and involves physically interpretable terms related to the magnetic shear, the flow shear and the variation of total pressure perpendicular to the magnetic surfaces. On the basis of this condition the impact of pressure anisotropy, flow, and torsion of a helical magnetic axis on the stability properties of a specific class of analytic equilibria is examined.

200626: Dr. Emanule Tassi (CNRS, Laboratoire Lagrange, Observatoire de la Côte d'Azur, Nice, France)

Title: **A Hamiltonian gyrofluid model based on a quasi-static closure**

Abstract:

Gyrofluid models provide a valuable tool for the investigation of low frequency plasma dynamics, and can be used as a complement to the more complete, but also computationally more demanding, gyrokinetic models. In this seminar, I will discuss a new gyrofluid model, based on a closure which is referred to as quasi-static. This closure is obtained from linearized gyrokinetic equations in the limit of field fluctuations propagating along the direction of a magnetic guide field at a speed much smaller than the corresponding particle thermal speed. Such closure leads to a gyrofluid model where gyroaverage operators are determined exactly and all nonlinear terms have the canonical bracket structure, which is ubiquitous in reduced fluid models for plasmas in the presence of a strong guide field. In particular, this simplifies the identification of a Hamiltonian structure for the model. This gyrofluid model accounts for parallel magnetic perturbations, equilibrium temperature anisotropy and electron inertia, which could make it a

valuable tool in particular for the investigation of basic phenomena of interest to space plasmas. This is joint work with Thierry Passot and Pierre-Louis Sulem.

200619: Prof. Eric Sonnendruecker (Director NMPP, Garching)

Title: **GEMPIC: the geometric electromagnetic particle-in-cell code**

You can read about it in J. Plasma Physics 83, 905830401 (2017).

200612: Tobias Blickhan (PhD candidate NMPP, Garching)

Title: **Projection-based, structure-preserving model reduction for particle methods**

Abstract:

After a short overview of projection-based reduced-order models, we review recent results for the 1d1v Vlasov equation. We discuss challenges that arise when treating fields self-consistently (Vlasov-Poisson). Lastly, we present alternative methods from the field of model reduction that could be explored for this and similar problems and outline potential future research directions.

200605: Dr. Dimitris Kaltsas (University of Ioannina, Greece)

Title: **Using Dirac constraints to enforce quasineutrality**

200529: Dr. Jeffrey Heninger (UT, Austin)

Title: **Hamiltoniain magnetic monopoles**

200522: Dr. Tommaso Andreussi (ITAEL S.p.A., Pisa, 56121, Italy)

Title: **Research activities on plasma propulsion for space applications**

Abstract:

Electric Propulsion (EP) relies on an electric power source to accelerate a propellant and generate thrust. In particular, plasma-based EP technologies proved capable of significant performance improvements over traditional chemical systems and, consequently, made great technological and commercial progress over the past decades [1]. The development of plasma-based EP technologies relies on the study of basic, low temperature plasma (LTP) dynamics. Understanding the physics behind the operation of these devices can help improving their performance to make them an even more promising choice for a wide variety of space missions. However, despite several experimental, theoretical, and numerical investigations, questions directly related to the plasma state still remain unanswered [2]. In this talk, I will present some of the most active research areas on EP, focusing in particular on the development and testing challenges, as well as on plasma diagnostics, modelling and simulations.

[1] D. Lev, et al., “The Technological and Commercial Expansion of Electric

Propulsion in the Past 24 Years", Proc. 35th International Electric Propulsion Conference, Paper No. IEPC-2017-242 (2017).
[2] B. Jorns, et al.,"Plasma Propulsion Research in Academia", Decadal Assessment of Plasma Science-2020 (2019).

200515: Dr. Omar Maj (Max Planck Institute, Garching Numerical Plasma Physics)

Title: **On the Hamiltonian theory of cold-plasma waves and its structure-preserving discretization**

200508: Prof. Francesco Pegoraro (Dipartimento di Fisica Universita' di Pisa, Italy)

Title: **Nonlinear electrodynamics at cylindrical "cumulation" fronts**

200501: Prof. Jose Alvarado (UT, Austin)

Title: **Fluid flow over a boundary with hair**

200424: Benedikt Perse (PhD candidate NMPP, Garching)

Title: **Using GEMPIC for Jeans instability in stellar dynamics**

200417: Prof. Anna Tenerani (UT, Austin)

Title: **Reconnection and the solar wind**

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