

# ICOPS-2016 – Plasma Simulation Mini-course

## Information on Lectures

### **1. Carl Sovenic (University of Wisconsin)**

*Title:* “Magnetohydrodynamics(MHD) and Extended-MHD”

*Topics Covered:*

- I. Introduction - Provide a brief overview of plasma confinement, MHD equilibrium, stability, and the role of numerical computation.
- II. Background
  - a. Parallel current density and magnetic curvature are the primary sources of free energy.
  - b. Resonances are weak spots in the configuration's ability to restore perturbations, and they lead to separation of spatial scales for macroscopic dynamics.
  - c. Consider collisions and the separation of timescales.
- III. Representative computational results from magnetically-confined plasmas (eg. Tokamak, Reversed-Field Pinch, etc)
- IV. Models of macroscopic dynamics
  - a. Primitive-equations systems describe the evolution of physical fields without order reduction.
  - b. Reduced models separate temporal and spatial scales, and eliminate some to yield equations for potentials.
  - c. Results on ideal-MHD spectra help illustrate distinct behavior.
- V. Numerical approximations
  - a. Time-stepping at various degrees of implicitness is used to address the separation of temporal scales.
    - i. Differential approximation shows where explicit time-step limitations arise from waves.
    - ii. Implicit methods for fusion MHD need to avoid large dissipative errors.
    - iii. Crank-Nicolson has been the basis for a number of computations.
    - iv. Semi-implicit methods represent an alternative line of development.
    - v. The two-fluid version of the semi-implicit method is an implicit leapfrog.
  - b. Spatial representation of macroscopic dynamics requires appropriate function spaces.
    - i. Spectral pollution results from numerical coupling of physically distinct dynamics.
    - ii. Requirements for second-order (eigenvalue) and first-order (time-dependent) models differ.
    - iii. High-order and spectral methods help model anisotropy with evolving magnetic topology.

- VI. Parallel computation - (?) Parallel computing is challenged by the need to solve large, sparse, ill-conditioned matrices.
- VII. Conclusions - Summary of progress and open challenges

## 2. Thomas Mussenbrock (Ruhr-Universität Bochum, Germany)

Title (Tentative): “Modeling of nonequilibrium plasmas at high pressure”

Topics Covered (tentative):

- How to get from single particle to fluid description of plasmas?
- Which is the appropriate model for the situation under inspection?
- When are kinetic models needed?
- Which simulation strategies are appropriate in order to meet the goals of scientific accuracy and computational efficiency?

## 3. Richard Marchand (University of Alberta, Canada)

Title: Simulation of space environment interaction with satellites

Topics Covered:

- Space environment: thermal plasma, solar radiation, energetic particle fluxes, micrometeoroids and space debris.
- Material interaction with space environment
  - Surface charging by
    - plasma particle collection,
    - photo-electron emission
    - secondary electron emission from electron and ion impact
    - reflection of incident particles
  - Deep dielectric charging from energetic penetrating particles.
  - Aging
- Kinetic Particle in Cell simulations
  - Different approaches: geometrical representations and simulation meshes.
  - Unstructured tetrahedral grids.
- Post-processing: Test-particle calculations
- Technical details
  - Material properties and data.
  - Validation with laboratory and in situ measurements.

#### **4. Frederico Fiuza (Stanford (SLAC))**

Title: “Kinetic simulations of intense laser-plasma interactions”

Topics Covered:

- Kinetic description of plasmas
- The particle-in-cell methodology
- High-performance computing
- Plasma-based accelerators
- Laboratory astrophysics
- Laser-solid interactions and ICF
- Hybrid approaches for multi-scale modeling
- Future prospects and challenges

#### **5. Götz Lehmann (University of Duesseldorf, Germany)**

Title: Vlasov Plasma Simulations and Applications

Topics Covered:

- From the N-body plasma model to the Vlasov equation
- The (relativistic) Vlasov-Maxwell system
- Application scenarios for Vlasov codes: From 2D to 5D phase-space
- Numerical methods for the Vlasov equation
  - Operator splitting
  - Interpolation
  - Semi-Lagrangian methods
- Parallelization strategies
- Examples for Vlasov Simulations in Laser-Plasma interactions
  - Comparing PIC to Vlasov simulations: Relativistic high harmonic radiation from overdense plasma targets
  - Kinetic effects in backscattering instabilities