Syllabus – PHYS 629 – Spring 2017

Course Information:

PHYS 673:	Methods Numerical Simulation in Fluids and Plasmas, 3 credits, Spring 2017
Meeting Times:	Tuesday, Thursday, 9:45-11:15
Meeting Location:	Reichardt 202

Instructor Information:

Instructor:	Peter Delamere, Professor of Space Physics
Office:	708E Elvey (Geophysical Institute)
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Office Hours:	Tues: 1:00 to 4:00 (Reichardt) or By appointment (Elvey)

Prerequisites: Undergraduate E&M, undergraduate differential and partial differential equations, Plasma Physics (PHYS 626), experience in programming, or permission of the instructor.

Scope: The course will introduce, analyze, and apply methods for the numerical solution of partial differential equations (PDEs) which determine the dynamics of fluids and multi particle systems. The elements of this course include (a) classification and applications of partial differential equations, (b) methods for discrete representation of PDEs, (c) stability and accuracy of the numerical solution, (d) boundary and initial conditions. The discrete representation of PDEs includes finite differences, finite elements, finite volume, and spectral methods. The course address efficiency of various methods, and considers aspects of vector and parallel computer architectures. Applications address the dynamics of fluids, plasmas, and multi particle systems; and consider steady state configurations, convection problems, linear and nonlinear instabilities. Some specific applications can be chosen according to the interest of students enrolled in the course.

Approach: The course is intended to provide a general overview of numerical simulation methods of fluids that are common in atmospheric, ocean, space plasma applications. However, special emphasis will be given to plasma applications, though no prior expertise in plasma physics is necessary. Both plasma fluid and particle simulation methods will be addressed.

Topics:

- Elementary numerical methods for ordinary differential equations
- Introduction to partial differential equations
- Preliminary computational techniques/Finite difference methods
- Theory: consistency, stability, and convergence
- Elliptic equations and steady state problems
- Diffusion equation
- Convection equations
- Fluid and plasma equations
- Fluid and plasma simulation
- Kinetic (particle) simulations
- Weighted residual methods
- Applications and projects

Student learning outcomes: Upon completion of this course, students should be able to:

- Classify partial differential equations.

- Discretize PDEs and understand the merits of each method.
- Apply discrete representations of PDEs to specific fluid and plasma applications.
- Analyze the stability and accuracy of numerical solutions.
- Understand the basic numerial methods of kinetic (particle) simulations (vs. fluid PDEs).
- Understand the various weighted residual methods.
- Debug and analyze the output of numerical simulations
- Write code (MPI) for parallel implementation of numerical simulations.

Textbook: There is no textbook requirement for this course. But the following textbooks are highly recommended:

Fletcher, Computational Techniques for Fluid Dynamics, I and II, Springer (1988): A very good two volume text with very detailed coverage of basic and advanced fluid simulation techniques including finite differences, finite element, spectral and other methods. Many programming examples for illustration and as tutorials. The text addresses dynamic and steady state problems, explicit and implicit treatment, flux corrected transport, boundary conditions, and grid generation. It lacks all aspects of plasma simulation.

Potter, Computational Physics, John Wiley (1973): Out of print but available in the GI library. A good text book which covers most of the basics of fluid simulation including theoretical aspects. It also addresses plasma simulation, however because of its age it is slightly outdated, lacks some of the more recent developments and the overall coverage is significantly smaller than in Fletchers text.

Tajima, Computational Plasma Physics: With Applications to Fusion and Astrophysics, Addison Wesley (1889): The text focuses on plasma simulation by particle simulation with coverage of explicit, implicit, full electromagnetic, and hybrid models. It also addresses the most important fluid aspects of plasma simulation including finite differences, spectral methods and flux corrected transport.

Birdsall and Langdon, Plasma Physics via Computer Simulation, IOP (1995, based on 1985 original): Good textbook on plasma simulation but entirely focused on particle simulation techniques. Very detailed presentation with many applications. Good coverage of electrostatic and electromagnetic simulation including theory and physics.

Hockney and Eastwood, Computer Simulation using Particles, IOP (1994, revised from 1980 edition): Good textbook covering the same range of topics as Birdsall and Langdon. Less detailed regarding the plasma physics applications, however, with additional coverage of simulations of semiconductors and of astrophysical problems.

Stephan Jardin, Computational Methods in Plasma Physics, Chapman & Hall/CRC Computational Science Series: Nice introduction to MHD equations and numerical methods for solving the MHD equations.

Programming languages: Students are welcome to submit programming solutions in the language of their choice. Recommended languages for this course are Matlab, IDL, and Python.

Grading:

Homework	50%
Final Exam	20%
Term Project	30%

Term project: The course is intended to culminate in a significant computational project of interest to the student. Proposals for the term project are due by **March 7**. Projects are due during the last week of class (April 25, 27) and should be demonstrated as an in-class presentation.

Course Policies:

(a) Attendance and participation in class is expected of all students.
(b) Assignments are due at the beginning of class on the due date.

(c) Students are encouraged to work together on homework problems, but the final written solutions must be individual work.

(d) Students must acknowledge all sources of information – included fellow students – used in homework solutions and final projects. The UAF catalog states: "The university may initiate disciplinary action and impose disciplinary sanctions against any student or student organization found responsible for committing, attempting to commit or intentionally assisting in the commission of . . . cheating, plagiarism, or other forms of academic dishonesty. . . "

(e) All UA student academics and regulations are adhered to in this course. You may find these in the UAF catalog (section "Academics and Regulations").

Students with Disabilities Notice: The University of Alaska Fairbanks is committed to equal opportunity for students with disabilities. Students with disabilities are encouraged to contact the coordinator of Disability Services (Mary Matthews) at the Center for health & Counseling (x7043). See section on Disability Services of the UAF Class Schedule (http://www.uaf.edu/schedule/).

Schedule:

Topic	Week	Dates
Numerical solutions to ODEs	1	Jan 17, 19
Classification of PDEs/Intro to fluid equations	2	Jan 24, 26
Introduction to Finite Difference Methods	3	Jan 31, Feb 2
Theory: Consistency, Stability, Convergence	4	Feb 7-9
Diffusion Equation	5	Feb 14, 16
Diffusion Equation	6	Feb 21, 23
Convection Equation	7	Feb 28, March 2
Convection Equation, Intro to plasmas	8	March 7, 9
Project topics due	8	March 7
Spring Break–no class	9	March 13-17
MHD (Magnetohydrodynamics) simulations	10	March 21, 23
Kinetic plasma simulations	11	March 28, 30
Weighted Residual Methods	12	April 4, 6
Weighted Residual Methods	13	April 11, 13
Steady Problems, High Performance Computing	14	April 18, 20
In-class presentations	15	April 25, 27
Final exam	16	Thursday, May 4, 8:00 -10:00