Astronomy 581: Astrophysical and Computational Fluid Dynamics

Spring 2015 (3 credits) TuTh 9:10-10:25 Webster B12

Prerequisites: Phys 320 and Phys 330, or graduate student status

Instructor: Dr. Matthew Duez

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Office hours:	4pm Monday

Textbooks

Required: *The Physics of Fluids and Plasmas: An introduction for astrophysicists* by Arnab Choudhuri

Student Learning Outcomes

The first goal of the class is to give students a solid understanding of the hydrodynamic and magnetohydodynamic equations in the context (compressible, inviscid, highly conducting) most important for astrophysics. Students will become familiar with important equilibrium solutions–polytropes, Bondi accretion, etc–and also with the most astrophysically relevant instabilities–convective, Reyleigh-Taylor, magnetorotational, etc. They will also (although more briefly) be exposed to radiation transfer and its more interesting limits.

The second major goal is to introduce students to the techniques most commonly used to evolve fluid dynamical (or other hyperbolic) systems numerically. Particular attention will be given to high-order shock-capturing finite difference/ finite volume methods, but finite element and particle methods will also be discussed.

Third, students will gain a working knowledge of the two main types of astrophysical systems: stars and accretion disks.

Grade Breakdown

100% of the grade will come from homework assignments due roughly every other week except for the month before prel

Grade Distribution

A	93-100%
A-	89-92
B+	85-88
B	81-84
B-	78-80
C+	75-77
C	71-74
C-	68-70
D+	65-67
D	60-64
F	<60

Academic Integrity

Students may discuss and work together on homework assignments, but all submitted work must be original and individual. Academic dishonesty, including all forms of cheating, plagiarism, and fabrication, is prohibited as stated in the WSU Handbook. (See http://conduct.wsu.edu/default.asp?PageID=343.)

WSU Disability Statement

Reasonable accomodations are available for students with a documented disability. Please notify Dr. Due the first week of class of any accomodations needed. Late notifications may cause requested accomodations to be unavailable. All accomodations must be approved through Disability Resource Center (DRC), Administration Annex 205, 335-1566.

WSU Safety

For WSU's general safety statements, see http://safetyplan.wsu.edu.
For current safety alerts, see http://alert.wsu.edu.
For advice on dealing with emergencies, see http://oem.wsu.edu/emergencies.

Instructional methods

Classroom time will follow the traditional lecture format. Students will gain mastery of the material through homework. Homework problems will be of two types. First, there will be self-contained analytic problems. Second, there will will be computer problems, in which students will be asked to write short programs to solve problems numerically. To complete these assignments, students should both email their completed code to Dr. Duez and turn in a write-up with plots of the data output.

Computing resources

Students may use whatever computing enviromnent they are most comfortable with: C++, fortran, Python, Matlab, or other. They will also need to have some way of plotting results. Matlab, Mathematica, and Python have internal plotting capabilities (the latter through the matplotlib library). For C or fortran code, one can output data to files and plot it using graphing software such as Grace.

Compilers and plotting software can be acquired in several ways.

1) If the student has a laptop running Ubuntu or Mac OS X, all the needed software is freely available online. (For the Mac, you do this by downloading XCode. Lots of additional free software can be easily downloaded and installed via MacPorts or Homebrew.) (On Ubuntu, one can use the Software Center, apt-get, or synaptic to get lots of free software.) (Pip is the recommended tool for installing python packages.)

2) The machines "student-desktop", "time1", and "time2" in Webster 926 have been set up with all the needed software.

Course synopsis

Unit 1: Fluid dynamics

We derive the ideal fluid equations from kinetic theory and from them entropy and vorticity conservation. We then generalize to include transport processes, and consider when they would be important. The theory of incompressible turbulence is reviewed. We obtain formulae for transport of energy by radiative diffusion. The fluid equations are put in covariant form and considered in a rotating coordinate system, allowing a discussion of the effect of Coriolis forces on fluids.

Unit 2: Stars and disks: Equilibria

After enumerating the relevant processes and timescales, the equilibrium properties of main sequence stars and thin accretion disks are studied.

Unit 3: Magnetohydrodynamics

We describe the evolution of magnetic fields in perfectly conducting fluids. Non-ideal effects at current sheets are described. Then we look at applications of MHD to magnetic breaking and coronal heating in stars, jet formation in accretion disks, and pulsar magnetospheres. The idea of a dynamo is introduced.

Unit 4: Mathematical structure

We review some general properties of hyperbolic conservation laws, including techniques like characteristic variables and Riemann invariants used to study them. We study shock, rarefaction, and contact waves, allowing us to solve the Riemann problem for the Euler system.

Unit 5: Numerical methods

We look at the convergence and stability properties of simple but representative finite difference techniques. We introduce Godunov's method for finite volume techniques, including the approximate Riemann solvers and reconstructors used in modern research codes. Finite element methods (nodal discontinuous Galerkin methods in particular) and smoothed particle hydrodynamics are then outlined.

Unit 6: Stars and disks: Oscillations and instabilities

We review perturbation theory methods–Eulerian and Lagrangian. These are applied to the oscillation modes and stability of stratisfied atmospheres and nonrotating stars. Next, we study the stability of rotating, shearing flows, with applications to rotating stars and accretion disks.

Course outline

Week	Topic
1	advection; fluid equations
2	ideal fluid properties; star and photon gases
3	transport processes; turbulence
4	relativity; Coriolis forces; polytropes
5	main sequence stars
6	thin accretion disks (alpha model)
7	MHD equations; effects of magnetic tension
8	hyperbolic equations; characteristic fields
9	shocks and rarefactions; Riemann problem
10	finite difference methods; finite volume methods
11	Godunov's method; finite element methods; SPH
12	perturbation theory; Schwarzschild criterion
13	stellar oscillations and helioseismology
14	rotating flow instabilities; spiral density waves
15	thick-disk accretion and corotation instabilities