Astrophysical Fluid Dynamics
Mini-Courses 1, 2 & 3

Winter 2019

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TIME & PLACE:
TBD

DESCRIPTION:
Introductory Mini-Courses for Astronomy Graduate Students

Whether one is interested in planets, stars, disks, galaxies or clusters of galaxies, fluid dynamics plays an important role. In fact, our understanding of the formation, structure and evolution of nearly all the objects of astronomy relies on it. These minicourses are an introduction to the fundamental concepts of fluid dynamics. Once the basics are covered, the class will focus on standard applications of the theory to a variety of important astrophysical situations and objects. In addition, since much of the astrophysical research involving fluid dynamics is done through numerical simulations, a brief introduction to several key numerical concepts will be given in mini-course 2. The course series will conclude with a brief description of the complications that arise when a fluid is magnetized, a rather common situation in astrophysics. The students will be asked to carry out a modest fluid numerical project during each of the mini-courses.

Note that students can opt to take only one (#1) or two (#1 and #2) out of the three mini-courses being offered. Each mini-course builds on the knowledge developed during the previous mini-course (s).

MAIN TOPICS:

- Fluid approximation: validity and derivation
- Ideal and non-ideal fluids
- Supersonic flows and shocks
- Introduction to numerical techniques
- Waves, instabilities and turbulence
- Magnetized fluids: MHD approximation
- Astrophysical applications: stellar structure, astrophysical disks, winds and jets, gravitational collapse, blast waves...

TEXTBOOKS:

Primary: "Physics of Fluids and Plasmas" by Choudhuri.

Secondary: "The Physics of Astrophysics II. Gas Dynamics" by Shu.

Extras: "Fluid Mechanics" by Landau & Lifshitz; "Elementary Fluid Dynamics" by Acheson.

SHORT NUMERICAL PROJECTS:

Thestudents will have a choice in the nature of their numerical project. All students will use the research-grade, general purpose PLUTO code and will be given easy access to computing ressources to run their projects. As an example, a student could opt to use PLUTO to simulate a non-trivial extension of one the test problems packaged with the code. The instructor will also offer a list of potential numerical projects inspired by the various astrophysical applications discussed in class.
The emphasis of these projects will not be on numerics, but rather on being creative within bounds set by both physics and numerics. Adequately posing the problem so that it can be simulated, as well as interpreting the simulation outcomes using the knowledge developed in class, will be key to this exercize.

GRADING (applies to each mini-course):

One Assignment (concept questions + problems): 20%
Numerical Project: 10% for design, 15% for execution, 15% for final presentation (total 40%)
Final Exam (one-to-one oral exam on understanding a research article of relevance): 40%

TENTATIVE SCHEDULE:

MINI-COURSE 1: Fluid approximation - Ideal and non-ideal fluids - Astrophysical Applications

- Lecture 1: overview, classes of theories and approximations (C 1)
- Lecture 2: from kinetic theory to hydrodynamics (C2 and C3)
- Lecture 3: ideal fluids - continuum description - vorticity - Bernoulli's principle - Kelvin's theorem (C4)
- Lecture 4: ideal fluid applications - hydrostatic atmospheres - Bondi accretion solution - Parker wind solution (C4.4, C6.8)
- Lecture 5: viscous flows - Navier-Stokes equation (C 5)
- Lecture 6: viscous flows - boundary layers - Reynolds number (C5)
- Lecture 7: viscous flow applications - accretion disks (C5.7)
- Lecture 8: viscous flow applications - accretion flows - stellar interiors

MINI-COURSE 2: Supersonic Flows and Shocks - Numerical Fluid Solvers - Astrophysical Applications

- Lecture 9: supersonic flows and shocks (C 6)
- Lecture 10: supersonic flows and shocks (C 6); application: de Laval nozzle and extragalactic jets (C6.7)
- Lecture 11: shock applications: blast waves, supernova explosions (C6.6), GRB jets
- Lecture 12: numerical techniques - mathematical considerations (Eulerian/Lagrangian, uniqueness, stability) - SPH
- Lecture 13: numerical techniques - grid-based methods - Godunov-type schemes
- Lecture 14: linear waves and stability (C7.1) - sound waves (C6.2) - helioseismology (C7.6)
- Lecture 15: linear instabilities - convection - Rayleigh-Taylor - Kelvin-Helmholtz - Jeans - Toomre (C7)
- Lecture 16: linear theory and beyond - shear instability - w/ stratification - finite amplitude waves and instabilities (C5/C7)
- Lecture 17: turbulence - wave interactions - Kolmogorov theory - turbulent transport and mixing (C8)

MINI-COURSE 3: Magnetized fluids - MHD - Collisionless limit - Astrophysical Applications

- Lecture 18: plasmas - from kinetic theory to magnetohydrodynamics (C10, C11)
- Lecture 19: MHD approximation (C13)
- Lecture 20: basic MHD - flux freezing - MHD waves (C14)
- Lecture 21: strong field MHD applications - Weber-Davis wind - magnetic truncation of accretion disks - Parker instability
- Lecture 22: weak field MHD applications - magnetorotational instability
- Lecture 23: a sample of complications - relativistic MHD - radiation dominance - reconnection
- Lecture 24: a sample of complications - weakly-ionized fluids - dynamos - collisionless processes