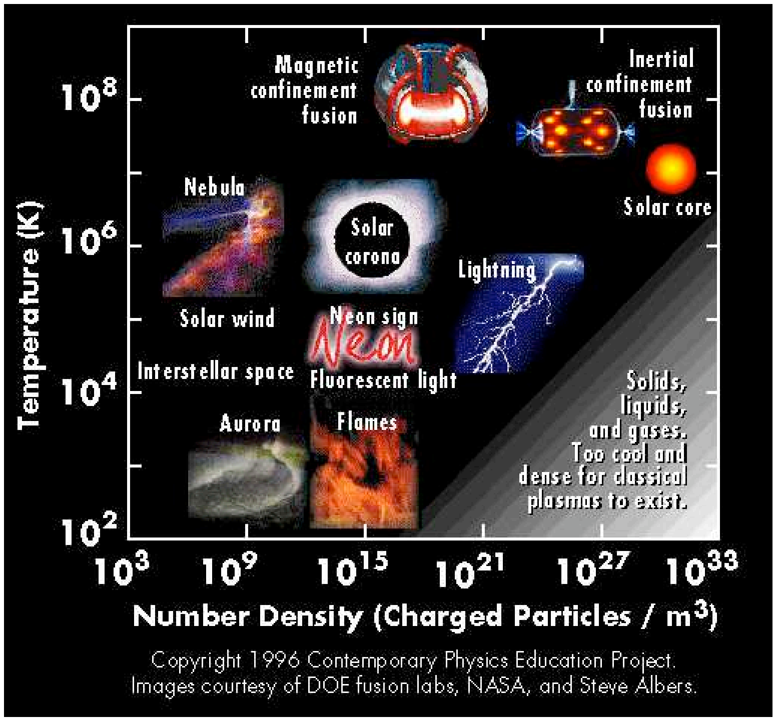
AS727 Cosmic Plasma Physics

Spring 2017

1 Description



The temperature of the sun's surface is 4000K-5000K, but just outside the surface, in a region called the corona, the temperatures exceed 2 million degrees K. The mechanism that heats and sustains these high temperatures remains unexplained. In the auroral regions of the Earth's ionosphere and magnetosphere large numbers of electrons have been measured traveling near the speed of light and the mechanism of acceleration has alluded thirty years of scientific inquiry. Magnetic fields weave through galaxies and the universe, possibly storing two orders of magnitude more potential energy than contained in all the universe's gravitational fields, but astronomers have only recently begun to understand the importance of these fields on galactic formation and evolution. To address these questions we need to understand the behavior of electrically charged fluids called plasmas.

In AS727, we will study the physics and mathematics of fundamental plasma physics as it applies to space and astrophysical situations. We will begin the class by defining the fundamental interactions of charged particles and their motion in an electromagnetic field. Then, we will make a number of simplifying assumptions about the collective behavior of large numbers of particles in order to derive the "kinetic equations" of plasma physics. Under some conditions, these complex equations simplify further, generating a set of fluid equations which we will use to study waves and instabilities in plasma physics. Making still more simplifications will allow us to derive the equations of magnetohydrodynamics (often call "MHD") which describe some of the behavior of plasmas near the sun, in magnetospheres and in man-made controlled fusion devices. We will then return to the kinetic equations and discuss how to solve them.

2 Mechanics: Times, Dates, & Places

- Lecture Time and place: Tuesdays and Thursdays 9:30-10:50am CAS 502
- Problem sets generally due on Tuesdays in class
- Review and problems solving sessions:
  - Monday 2:30-3:20 run by Meers Oppenheim in CAS 502
- Instructor: Meers Oppenheim, Office: CAS 517, Work phone: (617) 353-6139 Home phone: (617) 965-7345 Cell: (617) 821-0952, FAX: (617) 353-5704 email: meerso@bu.edu
- Course WWW page address: http://learn.bu.edu/ (AS727)
- Office hours: Monday 2:30-3:30 in CAS 502 (highly recommended), Tuesdays 1:30-2:30, Fridays 1:30-2:30 or by appointment
- Tentative exam dates: Midterm - Mar. 2 (in class), Final - Tue. 5/9 9:00a.m. - 11:00a.m

3 Requirements and Grading

- Prerequisites:
  1. Junior level electrodynamics, mechanics, statistical mechanics, vector calculus, partial differential equations and complex analysis (or consent of the instructor).
  2. All students have completed AS703 and should be familiar with the basics of charged particle motions in electromagnetic fields, adiabatic invariants, the fluid description of a plasma and the MHD description of a plasma.
- Problem Sets (25% of grade)
  - Weekly problem set assignments
  - Solutions will be handed out at the time of an assignment's due date in order to provide immediate feedback. Hence, no extensions or late problem sets will be accepted.
  - Students may work in groups but should write up solutions individually.
  - Recommendation: students should initially attempt problems individually.
  - To receive full credit on a problem, it must include:
    - a reasonably clear explanation of the method used to obtain a solution,
    - legible and,
    - single sided pages
  - Not every problem will be graded.
- Midterm test in class (30% of grade)
  1. Exams cover material from lectures, text, and, predominantly, problem sets.
  2. Exams will include problem set problems
- Final exam (45% of grade)

4 Academic Conduct

The Dean of CAS/GRS has asked faculty to remind students of the academic conduct code. The objective of the GRS academic conduct code is: "In order to ensure that the academic competence of students be judged fairly, and to promote the integrity of graduate education, the Graduate School embraces two broad principles: (1) No honest student should be put to a disadvantage because of the dishonesty of another student; (2) Penalties should be commensurate with the misdemeanors." Details of this policy can be found at http://www.bu.edu/grs/academics/resources/adp.html.

5 Bibliography

- Assigned text: *Introduction to Plasma Physics and Controlled Fusion* by F. Chen
- Secondary text (more modern, advanced and terse): *Fundamentals of Plasma Physics* by Paul M. Bellan
- Also Assigned 4 years ago: *Introduction to Plasma Physics* by D. Gurnett and A. Bhattacharjee.
- Space Physics oriented book: *Basic Space Plasma Physics* by W. Baumjohann and R. Treumann
- More advanced space oriented plasma physics book: *Plasma Physics* by Sturrock (also, costs less than $30)
- More advanced book: *Introduction to Plasma Physics* by R. Goldston and P. Rutherford.

6 Proposed Lecture List

1. Introduction
   (a) Introductions
   (b) Logistics
   (c) What is plasma physics?
2. Intro to plasmas I
   (a) Numerical approach to plasmas (PIC)
   (b) Fundamentals of plasma physics - density and temperatures
   (c) Fundamentals of plasma physics - length and time scales, plasma parameter
3. Drifts I
   (a) Single particle motion - gyromotion, $\mathbf{F}\times\mathbf{B}$ drifts
   (b) $\nabla\mathbf{B}$ and curvature drifts.
   (c) Linearization
4. Drifts II
   (a) Flux and magnetic moment conservation
   (b) Polarization drifts

(c) Pondermotive force

5. Introduction to kinetic theory
6. Kinetic theory, phase-space and derivation of the Vlasov equation
7. Kinetic theory - Derivation of fluid equations.
8. Linear (perturbation) theory, plasma oscillations and dispersion relations.
9. Fluid drifts, quasineutrality and ion acoustic waves.
10. A zoo of electrostatic waves
11. A zoo of electromagnetic waves
12. Generalized approach to waves
13. More on waves - resonances and cutoffs and whistlers
14. Radiation in a plasma X and O modes, R and L modes
15. More on Waves: R, L waves and Alfven waves
16. Alfven Waves: Interpretations and Magnetosonic waves
17. Review of waves and start on Collisions, Diffusion and Resistivity
18. Diffusion, Ambipolar Diffusion, Cross-field Diffusion, and Coulomb collisions
19. Resistivity, conductivity, creation and annihilation
20. Fluid Stability and Instability - Example Ionospheric instabilities
21. Kinetic Stability and Instability - Landau damping and growth
22. Kinetic Stability and Instability II - Landau damping and growth
23. Kinetic Stability and Instability III - Landau damping and growth
24. Kinetic Theory - Other waves, BGK modes
25. Nonlinear Plasma Physics: Quasilinear theory.
26. Nonlinear Kinetic Plasmas - A research talk on Electron Phase Space Holes.