Energetic Particles in Nature and the Lab

Basic information

- **Time and Place:** 2135 Chamberlin, TR 1:00 - 2:15
- **Instructor:** Professor Ellen Zweibel
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- **Course web page:** http://courses.library.wisc.edu/mini/Old!s
- **Reading:** I recommend buying *Plasma Physics for Astrophysics* , by Russell Kulsrud (Princeton, 2005), although Chapter 12 is the only one we will be following closely in this course. Many of the relevant radiative processes are covered in *Radiative Processes in Astrophysics*, by George Rybicki & Alan Lightman (Wiley-Interscience 1979) and in *Cosmic Gamma Rays*, by Floyd Stecker (1971). There is also *Cosmic Ray Astrophysics*, by Reinhard Schlickeiser (Springer 2002), which is very comprehensive on many of our topics. The Kulsrud & Schlickeiser books will be on reserve in the Physics Library. Most of what we do will come from journal articles, some of which are already linked to the web page. For quick reference, the *NRL Plasma Formulary*, which is available on the web at `wwwppd.nrl.navy.mil/nrlformulary/`, is a useful compendium of plasma physics constants and formulae.

Why does this course exist?

Approximately once every 5 seconds an atomic nucleus with energy 10^{20} eV or more (equivalent to a cubic centimeter of water traveling at 650 km/hr) reaches the Earth. Such particles represent the high energy tail of the cosmic ray distribution: relativistic ions which constitute less than one in 10^9 of interstellar particles by number, but have energy density comparable to the thermal energy. Approximately once every 5 minutes, the MST experiment in the basement of Chamberlin triggers magnetic reconnection events which heat ions fourfold in less than 10^{-4}s, up to $\sim 10^7$ K ($\sim$ keV). These are just two examples of anomalous heating and acceleration processes, which seem to be ubiquitous. Ion heating is one of the 5 basic plasma physics areas studied in the Center for Magnetic Self-Organization based here at UW.

The study of energetic particles has wide significance. At least two particle species, positrons and muons, were first identified is cosmic rays, and the known cosmic ray energy spectrum still extends well beyond the limits of terrestrial accelerators (e.g. 7 TeV per beam in the LHC). Astrophysical systems such as active galactic nuclei and their jets, and strongly magnetized neutron stars, are probed primarily through their high energy particle populations.

Energetic particle research is in a particularly intense period. An extensive suite of laboratory diagnostics and astronomical observatories is gathering detailed information on the particles themselves, their sources, propagation, and associated physical phenomena (see the web page for links). Advances in theory and simulation are making it possible to develop and test theories of how particles are energized and how they interact with their environment. We are seeing rapid progress in this field.

Topics to be Covered

- Radiative processes, *in situ* detection, extensive air showers
- Ion heating in MST (S. Prager)
- Solar energetic particles
- Galactic cosmic rays
- Gamma ray bursts (S. Heinz)
- Ultra high energy cosmic rays (S. Westerhoff)
- Neutrino astrophysics (T. Montaruli)
- Energy loss mechanisms
- Wave-particle scattering
- Stochastic Fermi acceleration and applications
- Shock acceleration and applications
- Acceleration during reconnection and applications

- Instabilities driven by energetic particles
- Feedback of energetic particles on their environment

Coursework

For students taking the course for 3 credits, there will be 4 homework assignments and a final project. Students taking the class for 1 credit will be graded on participation.