Magnetohydrodynamics and Turbulence (M16)

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It is sometimes said that turbulence is the last great unsolved problem of classical physics. MHD turbulence, or turbulence of a magnetised conducting fluid, exists in many physical systems: liquid-metal experiments, fusion devices, the Earth's interior and virtually all astrophysical plasmas from stars to galaxies and galaxy clusters. Many observed properties of astrophysical bodies (and, in some cases, their very existence) cannot be explained without recourse to some model of turbulence and turbulent transport in the constituent plasma: thus, one could view theory of MHD turbulence as a theory of the fundamental properties of luminous matter that makes up large-scale astrophysical objects. MHD turbulence is an area of very active current research, motivated by rapid and simultaneous progress in astrophysical observations (especially of the solar photosphere, interstellar and intracluster medium) and high-resolution numerical simulations.

The aim of this course is first to provide a basic introduction both to the laws of fluid motion in conducting media (magnetohydrodynamics) and to the fundamental theory of turbulence, and then to bring together these two subjects in presenting the modern state of the MHD turbulence theory. The approximate list of topics to be covered is as follows

- What is turbulence?
- Kolmogorov's 1941 dimensional theory of turbulence.
- Passive advection (mixing) of a scalar field.
- Measures of turbulence: correlation functions and spectra.
- MHD equations.
- Lagrangian MHD, flux freezing, conservation laws.
- MHD waves.
- Dimensional theories of MHD turbulence in the presence of a mean magnetic field (Alfvén-wave phenomenologies).
- Generation of small-scale magnetic fluctuations by turbulence (small-scale dynamo).
- Introduction to turbulence in the solar wind, interstellar medium and glaxy clusters.
- Introduction to kinetic theory of plasma turbulence.

Desirable Previous Knowledge

This course is suitable both for astrophysicists and fluid dynamicists. It will not require any previous knowledge of either astrophysics or MHD. Basic familiarity with the equations of fluid dynamics and of electricity and magnetism will be helpful.

Reading

1. L. D. Landau and E. M. Lifschitz, *Course of Theoretical Physics,* vol. 6: *Fluid Mechanics* (Butterworth-Heinemann, 1995), §§33–34.

2. P. A. Davidson, *Turbulence — An Introduction for Scientists and Engineers* (OUP, 2004).

3. P. A. Davidson, *An Introduction to Magnetohydrodynamics* (CUP, 2001).

4. P. A. Sturrock, *Plasma Physics* (CUP, 1994), §§12–17.

5. R. M. Kulsrud, *Plasma Physics for Astrophysics* (Princeton University Press, 2005).

6. A. A. Schekochihin and S. C. Cowley, *Turbulence and Magnetic Fields in Astrophysical Plasmas*, a chapter in the book *Magnetohydrodynamics: Historical Evolution and Trends*, S. Molokov, R. Moreau, and H. K. Moffatt, Eds. (Springer, 2006) — available on the web from http://www.damtp.cam.ac.uk/user/as629/mhdbook.pdf