Lectures on Turbulence Theory and Application to Space and Astrophysical Plasmas

Prof. W. H. Matthaeus

Características del curso

Tiene una duración total de 40 hs, organizadas de la siguiente manera: 18 hs en clases teóricas, 12 hs en trabajos numéricos en la Sala de Computadoras, y 10 hs en actividades de discusión. Los trabajos prácticos se aprueban mediante la entrega de una carpeta de ejercicios, y el exámen final consiste en la entrega de un trabajo especial en un tema a convenir con el profesor.

Programa del curso

<u>Theoretical subjects (18 hs)</u>

1. Introduction. Turbulence examples. Incompressible NS equations. Other hydro/gas models. Derivation of equations for MHD/plasmas.

2. Elementary properties of random processes and fluid turbulence. Ergodic theorems; line stretching, averages, a simple stochastic process with memory; correlation function; simple dynamical model. Normal/Gaussian distribution, higher order statistics, fourth order geometrical interpretation; skewness, multivariate Gaussian, lognormal distribution.

3. Properties of the Navier Stokes equations. Fourier transform. Pressure. Viscosity. Conservation laws. Vorticity theorems. Singularities. Global and point-wise invariants. Energy conservation revisited. Energy decay. Helicity. Properties of incompressible MHD equations. Alfven invariants. Decay and exchange of energy. Alfven waves. Linear and nonlinear couplings. Examples from simulations.

4. Homogenous turbulence I: Weak homogeneity. Correlation functions. General structure of 2nd order correlations. Hydro and MHD. Homogenous turbulence II: Fourier/periodic representation and limits. Loitsiansky and k-expansion. Rugged and non-rugged invariants. Spatial scales: correlation scale, Taylor scale, Kolmogorov scale. Time scales: large scale turnover time scale dependent eddy time, dissipation time. MHD: more scales. Space-time structure. Double Fourier transform. Scale dependent correlation function Gamma(k,t). Observational issues, Taylor hypothesis. Examples from ocean, atmosphere. wind tunnel, solar wind.

5. MHD. Mean field and anisotropy. Spectral/correlation anisotropy vs variance/polarization anisotropy.

6. Dynamics, Similarity and Decay: Von Karman-Howarth self preservation and decay laws. MHD case. Nonuniversality? Cascade and self-similarity: self-similarity, inertial range, dimensional analysis and Kolmogorov 1941. MHD case and its ambiguity.

7. More complex cascades: Rugged invariants and cascades in various models: 2D/3D HD/MHD. Examples from simulations.

8. Statistical mechanics approach: Liouville and basis of statistical mechanics. Absolute equilibrium Gibbs ensemble. Condensation, modified thermodynamic limit, inference of direction of cascade. Conectino with nonlocality and 1/f noise.

9. Third order law: Hydro, MHD, solar wind, effects of shear and expansion. Higher order statistics and intermittency. Kolmogorov 63. Nonuniformity of dissipation. Examples.

<u>Numerical analysis and Methods (12 hs)</u>

1. Spectral Methods I: Galerkin and PS methods, General characteristics and Fourier, 2D examples.

2. Spectral Methods II: Theory, convergence, comparison to FD and examples.

3. 2D hydro in some detail. Selective decay. K^-3 spectra coherent structures. vortex merger

4. Max entropy theories. Coherent structures. Point vortex model. Self organization, sinh-Poisson equation.

<u>Discussion and applications (10 hs)</u>

1. Solar wind primer: Large scale wind and MHD turbulence, kinematics, dynamical processes and observations. Heliophysics observations and connections with theory.

2. Relation of MHD to Vlasov/kinetic models and dissipation. Solar wind studies

3. Solar wind: Large scale evolution and turbulence effects. Heating. Pickup Ions. Solar modulation of Galactic Crs

4. Coronal heating: RMHD. Open and closed field line regions. What controls turbulence. Timescale inequalities.

5. Transport of charged energetic particles. Diffusion and transport. General formulation of "nonlinear" diffusion (beyond QLT) Field lines. Shredding. Nonlinear diffusion. Trapping and supressed diffusive escape. Summary and other applications (ISM etc). Directions for future studies.

Bibliografía del curso

Monin, A. S. and Yaglom, A. M., Statistical Fluid Mechanics, Vols.1 and 2, MIT Press, Cambridge, Mass. (1971)

Batchelor, G. K., The Theory of Homogeneous Turbulence, Cambridge U. Press (1970 and earlier editions)

Batchelor, G. K., An Introduction to Fluid Dynamics, Cambridge U. Press (1967)

Orszag, S. A., Lectures on the Statistical Theory of Turbulence. In "Fluid Dynamics" ed by Balian, R. and **Peube**, J-L., Page 235, Gordon and Breach, New York, 1977 [Les Houches Summer School, 1973]

Gottlieb, D. and S. **Orszag**, Numerical analysis of spectral methods: theory and applications, SIAM, Philadelphia (1977)

Orszag, S. A., Analytical theories of turbulence, J. Fluid Mech, 41, 363 (1970)

Kraichnan, R. H. and Montgomery, D. C., 2D Turbulence, Rep. Prog. Phys., 43, 547, (1980)

U. Frisch, Turbulence, Cambridge U. Press (1995)

D. Biskamp. "Magnetohydrodynamic Turbulence", "Nonlinear Magnetohydrodynamics", "Magnetic Reconnection in Plasmas" (3 books) Cambridge U. Press

Y. Zhou , W. Matthaeus and P. Dmitruk, Magnetohydrodynamic turbulence and time scales in astrophysical; and space plasmas. Rev. Mod. Phys., 76, 1015 (2004)

Universidad de Buenos Aires
Facultad de Ciencias Exactas y Naturales

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Buenos Aires, 07 OCT 2013

VISTO:

la nota 29/07/2013 presentada por el Dr. Pablo Mininni, Director del Departamento de Física en la que se eleva información y programa del curso de posgrado: **Lectures on turbulence theory and application to space and astrophysical plasmas**, que dictarán los Dres. W.H. Matthaeus y Daniel Gómez en el 2do. Cuatrimestre de 2013

el CV de William H. Matthaeus

CONSIDERANDO:

lo actuado en la Comisión de Doctorado de la FCEN el 30/09/2013,
lo actuado en la Comisión de Enseñanza, Programas, Planes de Estudio y Posgrado,
lo actuado por este cuerpo en Sesión Ordinaria realizada en el día de la fecha,
en uso de las atribuciones que le confiere el Artículo Nº 113 del Estatuto Universitario,

EL CONSEJO DIRECTIVO DE LA FACULTAD DE
CIENCIAS EXACTAS Y NATURALES
RESUELVE

Artículo 1°: Autorizar el dictado del curso de posgrado **Lectures on turbulence theory and application to space and astrophysical plasmas** de 40 hs de duración.

Artículo 2°: Aprobar el programa del curso de posgrado **Lectures on turbulence theory and application to space and astrophysical plasmas** obrante a fs 4 y 5 del expediente de la referencia.

Artículo 3°: Aprobar un puntaje máximo de DOS (2) puntos para la Carrera del Doctorado.

Artículo 4°: Aprobar un arancel de 20 módulos. Disponer que los montos recaudados serán utilizados conforme a lo dispuesto por Resolución CD Nº 072/03.

Artículo 5°: Comuníquese a la Dirección del Departamento de Física, a la Biblioteca de la FCEN y a la Subsecretaría de Postgrado (con fotocopia del programa incluida fs 4y 5). Comuníquese a la Direccion de alumnos sin fotocopia del Programa. Cumplido archívese.

RESOLUCION CD Nº 2444
SP'med 30/09/2013

Dr. JAVIER LÓPEZ DE CASENAVE
SECRETARIO ACADEMICO

JORGE ALIAGA
DECANO