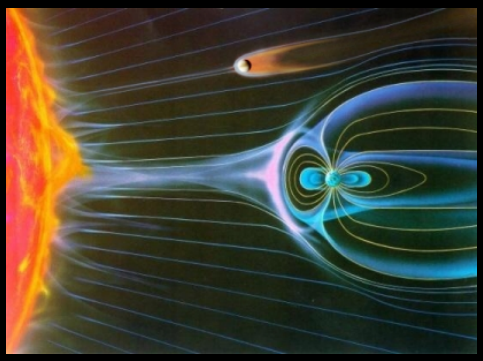
Stellar and Galactic Physics

Shocks in Astrophysical Plasmas



SUMMARY.
Plasma is the fourth fundamental state of matter. It consists of a very hot gas in which atoms or molecules are ionized. The resulting free charged ions and electrons interact self-consistetly with the electromagnetic fields, making the plasma dynamics sensitive to these fields. Plasma is the most abundant form of ordinary matter in the universe. Plasma is mostly associated with stars, extending to the rarefied intracluster medium and possibly the intergalactic regions.

OBJECTIVES

- Provide an introductory lecture to plasma physics with applications to astrophysics;
- Acquire theoretical and practical knowledge about the physics of the different kinds of shocks found in astrophysical plasmas: hydrodynamics shocks, radiative shocks and collisionless shocks;
- Be able to identify the main dominant physical processes from the ordering of the characteristic length/time scales (dimensionless parameters) and consequently select the appropriate model(s).

PREREQUISITES

Fluid mechanics; Statistical physics; General Astrophysics; Numerical methods; Stellar Physics.

THEORY

by C. Michaut & P. Henri

1. Introductory plasma physics lecture, including (i) the modelling of fluid and plasma physics: Boltzmann equation, Vlasov (collisionless Boltzmann) equation, fluid equations (Navier-Stokes, Euler, MHD); (ii) the fundamental scales of interest and/or dimensionless parameters for shocks physics (e.g. Debye length, mean free paths, inertial length, Larmor radius, Mach number, etc).

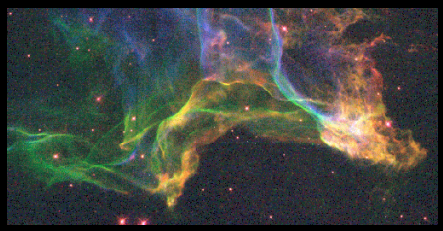
2. Theory of shocks, including radiative and collisionless shocks, as well as their occurrence in various astrophysical objects.

APPLICATIONS

Two specific applications for astrophysics purposes will be considered.

by Claire Michaut

1) Supernovae are an archetype of radiative shocks in astrophysics, from an analytical perspective. The Rankine-Hugoniot equations will be derived analytically, together with shock classification.



by Pierre Henri

2) The Earth bow shock is an archetype of collisionless shocks in the solar system. In situ space data from the ESA CLUSTER mission will be used to explore shock properties and verify the Rankine-Hugoniot equations.

MAIN PROGRESSION STEPS

Lectures on plasma physics and associated applications to astrophysical plasmas together with bibliographic study (ends by a 2-hour exam) - first 3 weeks.
Two practical applications - 2 weeks
Report and talk preparation - last week

EVALUATION

Theoretical exam based on bibliography study and courses (50%) during the 4th week; Project final report and presentation (50%) at the end of the 6th week.

BIBLIOGRAPHY & RESSOURCES

- Chen F.F., *Introduction to Plasma Physics and Controlled Fusion*. Springer Int. Publishing Switzerland (2016)
- Balogh A. & Treumann R.A., *Physics of Collisionless Shocks: Space Plasma Shock Waves*, ISSI Sci. Rep. Ser. Vol. 12, Springer Sci. & Busi. Media New York (2013)
- Zeldovich Y. & Raizer Y., *Physics of shock waves and high-temperature hydrodynamic phenomena*, Dover ed. Vol. 1, (Academic Press, New York, 1966) (2002)

Stellar Physics, Fluid Turbulence and Plasma teams

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