Relativistic kinetic theory
and its applications in astrophysics and cosmology

Lecture course for International Relativistic Astrophysics PhD
Erasmus Mundus Joint Doctorate Program from the European Commission

by Gregory Vereshchagin

The course consists of five lectures (90 minutes each), three of which describe theoretical foundations and main branches of kinetic theory, the remaining two lectures are devoted to applications of kinetic theory in astrophysics and cosmology.

Recommended textbooks:

1. S.R. de Groot, W.A. van Leeuven and Ch.G. van Weert, *Relativistic kinetic theory* (North-Holland, Amsterdam, 1980);

2. A.V. Zakharov, *Macroscopic gravity* (Yanus, Moscow, 2000), in russian;

3. V. P. Silin, *Introduction to Kinetic Theory of Gases* (Lebedev inst. press, Moscow, 1998), in russian;

4. Yu. L. Klimontovich, *Statistical physics* (Harwood, New York, 1986);

5. E.M. Lifshitz, L.P. Pitaevskii, *Physical Kinetics* (Elsevier, Amsterdam, 1981);

6. A.I. Akhiezer, *Plasma Electrodynamics* (Elsevier, Amsterdam, 1975);

7. J.L. Synge, *The relativistic gas* (North-Holland, Amsterdam, 1957).

8. C.M. Van Vliet, *Equilibrium and non-equilibrium statistical mechanics* (World Scientific, Singapore, 2008);

9. R.L. Liboff, *Kinetic theory* (Springer, New York, 2003).

Part I. THEORY

Lecture 1. Basic concepts of kinetic theory

Phase space. Density of particles in the phase space. Statistical averaging, macroscopic quantities. Ergodic theorem. Equilibrium. Invariance of the one particle distribution function. Moments of DF, entropy flux and hydrodynamic velocity. Kinetic equation. Boltzmann equation with binary collisions. General relativistic kinetic equations. Quantum corrections. Cross-section.

References:
de Groot et al., 1980, chapter 1
Zakharov, 2000, chapter 1
Uehling and Uhlenbeck, Phys. Rev. 43 (1933) 552

Lecture 2. Conservation laws and equilibrium

Conservation laws. H-theorem. Local and global equilibrium. Number density, energy density and pressure in equilibrium. Relativistic Maxwell distribution. Rate equation in pair hydrodynamics. Klimontovich DF for many-body systems. Liouville theorem and relativistic BBGKY hierarchy.

References:
de Groot et al., 1980, chapter 2
De Jagher, Sluijter, Contrib. Plasma Phys. 28 (1988) 2, 169

Lecture 3. Gases and plasmas

Physical scales and approximations. Basic plasma parameters. Correlation functions. Binary collisions and equilibrium in gases. Landau damping. Landau collision integral for plasmas. Belyaev-Budker collision integral. Vlasov-Maxwell system. Eistein-Vlasov system. Macroscopic gravity.

References:
Silin, 1998, chapters 4 and 5
Zakharov, 2000, chapter 2
Klimontovich, Phys. Uspekhi 40 (1997) 21
Lifshitz and Pitaevskii, 1981, chapters 3 and 4

Part II. APPLICATIONS

Lecture 4. Pair plasma and Gamma Ray Bursts sources

Pair plasma in GRBs. Interactions in hot dense plasma. Collision integrals for two- and three-particle interactions. Kinetic and thermal equilibria. Examples. Relaxation timescales evaluation. Relaxation timescales for the pair plasma with proton admixture.

References:
Aksenov, Ruffini and Vereshchagin, Phys. Rev. Lett. 99 (2007) 125003
Aksenov, Ruffini and Vereshchagin, Phys. Rev.D 79 (2009) 043008
Aksenov, Ruffini and Vereshchagin, Phys. Rev. E 81 (2010) 046401

Lecture 5. Collisionless and selfgravitating systems

Plasma instabilities. Weibel and two-stream instabilities. Collisionless shocks. Jeans instability in collisionless system. Phase mixing. Lynden-Bell violent relaxation. Hierarchical clustering and dark matter halos.

References:
Akhiezer, 1975, chapter 6
Lifshitz and Pitaevskii, 1981, chapter 6
Weibel, Phys. Rev. Lett. 2 (1959) 83
Spitkovsky, ApJ 682 (2008) L5
Bisnovatyi-Kogran and Zeldovich, Soviet Astronomy 14 (1971) 758
Lynden-Bell, MNRAS 136 (1967) 101
Navarro, Frenk and While, ApJ 462 (1996) 563