Numerical Simulations of Relativistic Outflows in Astrophysical Sources

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Duration: 20 hours (theory and practice)

Evaluation: written examination at the end of the course

Requirements: basic mechanics, hydrodynamics, thermodynamics, electromagnetism

Description

The lectures will cover the basic physics and numerical modelling of relativistic outflows from active galactic nuclei and binary systems (microquasars) in our Galaxy. These outflows are generated in the environment of compact objects and transport matter and energy through long distances and may have a strong impact on the environment. They represent not only interesting laboratories of high-energy plasmas and relativistic flows, but also because of their effect on galactic evolution and as probes of compact objects such as black holes. In the first part of the course I will introduce the observational facts of these objects and discuss the basic physical theories that we use to model them. The second part of the course will be devoted to the numerical techniques that allow us to solve the equations of relativistic hydrodynamics and to the main results provided by our numerical simulations.

Contents

1. Relativistic jets: observational facts.

Relativistic jets emit radiation throughout the whole electromagnetic spectrum. At radio-to-optical wavelengths they emit non-thermal synchrotron radiation and at gamma rays their emission is caused by inverse Compton scattering of lower frequency photons. Multi-wavelength studies of jets have allowed us to study their properties in detail, mainly through interferometric radio observations in short (e.g., VLA, MERLIN) and long (e.g., EVN, VLBA) baselines, but also their high-energy emission using space observatories like *Chandra* (X-rays) and *Fermi* (gamma rays).

2. Basic Physics I: jet formation, acceleration and beyond.

Relativistic jets are possibly launched via magnetohydrodynamical processes in the surroundings of compact, accreting objects, like supermassive black holes (SMBH) at the centre of active galactic nuclei (AGN). Farther from the formation region, they are collimated by the toroidal magnetic field and the ambient medium and accelerated by the conversion of internal or magnetic energy into kinetic energy. I will discuss these processes in detail, along with the physics (including both radiation physics and mechanics) that allow us to model the initial stages of jet evolution, at parsec scales in AGN jets and astronomical unit scales in microquasar jets.

3. Basic Physics II: jet propagation and impact on the environment.

Relativistic jets show remarkable collimation at long distances, although in some cases, jets are decelerated and disrupted at some distance from the formation region. In this lecture I will discuss the evolution of radio sources, the stability properties of relativistic flows and the processes that explain jet deceleration. Furthermore, the impact of jets on the interstellar and/or intergalactic medium can have a relevant effect on the evolution of the host galaxy in the case of AGN as it shocks and heats the gas, possibly quenching further star-formation. I will discuss the mechanisms in which this process could occur and their effect on the galaxy.

4. Numerical relativistic hydrodynamics.

The impossibility to study astrophysical processes in the lab has made of numerical simulations the laboratory in which those scenarios are studied. In this lecture, I will give a short introduction to the numerical techniques that are used to solve the equations of relativistic hydrodynamics and magneto-hydrodynamics. I will also discuss the advantages and limitations of these techniques.

5. Numerical simulations of relativistic jets.

The last lecture will be aimed to a detailed discussion on how to understand the results provided by numerical simulations of relativistic jets. I will also review of the main results that numerical simulations have provided in this field. Finally I will discuss the ways in which our current numerical codes should be improved.

6. Practical work.

The students will have to solve problems, develop simple codes or run numerical calculations with pre-existing codes to tackle problems related to the selected topics.

Bibliography

Compact objects and jets:

- Introduction to Black-Hole Astrophysics, G. E. Romero, G. S. Vila, Lecture Notes in Physics 876, Springer, 2014.

Jets:

- Relativistic Jets from Active Galactic Nuclei, eds. M. Boettcher, D. E. Harris, H. Krawczynski, Wyley-VCH Verlag, Weinheim, 2012.

- The Formation and Disruption of Black-Hole Jets, eds. I. Contopoulos, D. Gabuzda, N. Kylafis, Astrophysics and Space Science Library, vol. 414, Springer, 2015.

Radiative processes:

- Introducción a la astrofísica relativista, Gustavo E. Romero, Josep M. Paredes, Universitat de

Barcelona, ISBN: 978-84-475-3529-3, 2011.
- High-Energy Astrophysics, M. Longair, Cambridge University Press, Cambridge, 2011.

-Radiative Processes in Astrophysics, G. B. Rybicki, A. P. Lightman, Wiley-VCH Verlag, Weinheim, 2004.

Numerical special relativity:

- Numerical Hydrodynamics in Special Relativity, J. M. Martí, E. Müller, Living Reviews in Relativity, 2003.

Jet propagation:

- Jet stability, dynamics and energy transport, M. Perucho, International Journal of Modern Physics: Conference Series, 8, 241, 2012.

- Jet propagation and deceleration, M. Perucho, International Journal of Modern Physics: Conference Series, 28, id. 1460165, 2014.

- Radio-source evolution, M. Perucho, Astronomische Nachrichten (in press), arXiv:1507.03355, 2015.