High-Energy Processes in Sources with Relativistic Outflows

Professor: Dr. Valentí Bosch-Ramon (Universitat de Barcelona)

Duration: 20 hours (theory and practice)

Evaluation: Written examination at the end of the course

Requirements: Basic mechanics, thermodynamics, electromagnetism

Description: This course will provide a general overview of the dynamical and radiative processes occurring in astrophysical outflows (jets and winds). These processes can lead to the generation of relativistic particles and associated radiation. The course will aim at providing the basic elements that should allow the students to get a general view of the main physical processes involved, together with the tools to estimate the relevant scales of the phenomena depending on the source conditions. Applications to astrophysical systems such as microquasars and active galactic nuclei will be discussed.

CONTENTS:

1. Outflows: jets and winds

In this first part of the course, I will provide a basic description of the astrophysical sources in which relativistic outflows play a dominant role in the production of high-energy radiation, as well as non-thermal radio emission. I will consider first galactic and extragalactic collimated outflows (jets), in particular those found in microquasars and active galactic nuclei. These outflows are moderately relativistic. I will also briefly describe the jets of young stellar objects and gamma-ray bursts, as non-relativistic and ultra-relativistic jet examples, respectively. Afterwards, I will describe the wider ultra-relativistic outflows, or winds, produced in pulsar magnetospheres, finishing with a brief mention to non-relativistic powerful winds, like those originated in massive stars.

2. Flow dynamics

I will present the basics of flow dynamics, focusing mainly on the case of a fluid with a weak magnetic field (hydrodynamics), although some attention will also be given to the case with a strong magnetic field (magnetohydrodynamics). I will briefly explain the basics of the production of relativistic outflows as well as their propagation and interaction with the environment, all these issues strongly linked to the flow content of matter and electromagnetic fields, and with the production of high-energy emission.

3. Non-thermal processes in relativistic outflows: particle acceleration

In this part of the course, I will first discuss the different regions in relativistic outflows where energy can be dissipated generating relativistic particles. After that, I will overview different acceleration processes that can take place in relativistic outflows. These processes mostly take place at shocks or other forms of strong velocity gradients, in turbulent flows, and also in regions of intense magnetic field reconnection (in a similar fashion to the solar coronal events).

4. Non-thermal processes in relativistic outflows: radiation processes

In this part, I will enumerate and briefly discuss the main radiation processes relevant for the production of high-energy emission in sources that host relativistic jets and winds. These radiation processes can be synchrotron, inverse Compton and relativistic Bremsstrahlung when electron-positron pairs are the dominant emitting particles, and proton-proton, proton-synchrotron, photomeson production and photodisintegration for protons and nuclei. Although the basic physics of the mechanisms will be sketched, I will mostly focus on the typical conditions, energies and time-scales relevant to each of them. Emission at lower energies due to synchrotron radiation will also be considered.

5. Non-thermal processes in relativistic outflows: radiation reprocessing

The course will finish with a general overview of the processes that may affect non-thermal emission once it is generated in relativistic outflows. Radio, X-rays, and (most importantly) gamma rays can be absorbed and sometimes reprocessed in the form of lower energy photons, inside the source or in their way to the observer. We will consider three processes of absorption, pair creation in the context of gamma rays, free-free absorption, and photo-electric absorption. The stress will be put on gamma-ray absorption though, together with the radiative consequences of the subsequent production of relativistic electron-positron pairs inside the source.

Bibliography

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