NPAC course on Astroparticles

0 - INTRODUCTION

The course and the exam

First part of the course: **Astroparticles** (7 classes, 3h each)
Second part: **Cosmology** (14 classes, 3h each)

Written exam -> final mark is 1/3 x Astro + 2/3 x Cosmo
If final mark <10 and Astro < 10 -> oral exam in Astro

Introduction

Probably, the most complete textbook on **High Energy Astrophysics** is Malcolm Longair's "High Energy Astrophysics" (Cambridge University Press).

According to Longair, High Energy Astrophysics is "the astrophysics of high energy processes and their application in astrophysical and cosmological contexts. For example, we need to explain:

- ✓ how the massive black holes present in the nuclei of active galaxies can be studied,
- ✓ how charged particles are accelerated to extremely high energies in astronomical environments,
- ✓ the origins of enormous fluxes of high energy particles and magnetic fields in active galaxies,
- ✓ the physical processes in the interiors and environments of neutron stars,
- ✓ the nature of the dark matter,
- ✓ the expected fluxes of gravitational waves in extreme astronomical environments, and so on… "

Introduction

Probably, the most complete textbook on **High Energy Astrophysics** is Malcolm Longair's "High Energy Astrophysics" (Cambridge University Press).

According to Longair, High Energy Astrophysics is "the astrophysics of high energy processes and their application in astrophysical and cosmological contexts. For example, we need to explain:

- ✓ how the massive black holes present in the nuclei of active galaxies can be studied,
- ✓ how charged particles are accelerated to extremely high energies in astronomical environments,
- ✓ the origins of enormous fluxes of [Cosmic Rays] and magnetic fields in active galaxies,
- ✓ the physical processes in the interiors and environments of neutron stars,
- ✓ the nature of the dark matter,
- ✓ the expected fluxes of gravitational waves in extreme astronomical environments, and so on… "

Galactic cosmic rays

Victor Hess got the Noble Prize for the discovery of cosmic rays (1912)

Cosmic rays are a flux of energetic particles (mainly protons) that hits the Earth's atmosphere from above

- Cosmic ray particles are accelerated to extreme energies (up to 10^{20} eV!)
- The Galaxy is filled of cosmic rays
- Most of them are accelerated within the Galaxy
- Where are they from?

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos

-> p-p interactions

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique

-> p-p interactions

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique

-> p-p interactions

-> Bremsstrahlung

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamics
    - Class 3 [0.5h] — **Exercises** on Lecture II

-> p-p interactions

-> Bremsstrahlung

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamic
    - Class 3 [0.5h] — **Exercises** on Lecture II

-> p-p interactions

-> Bremsstrahlung

-> Synchrotron

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamic
    - Class 3 [0.5h] — **Exercises** on Lecture II
      - Class 4 [1.5h] — V - **Particle transport** in turbulent magnetic fields
      - Class 4 [1.5h] — **Exercises** on Lectures II, III, and IV

-> p-p interactions

-> Bremsstrahlung

-> Synchrotron

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamic
    - Class 3 [0.5h] — **Exercises** on Lecture II
      - Class 4 [1.5h] — V - **Particle transport** in turbulent magnetic fields
      - Class 4 [1.5h] — **Exercises** on Lectures II, III, and IV
  - Class 5 [0.5h] — II ter - Inverse Compton scattering
  - Class 5 [1.5h] — VI - **Particle acceleration**: diffusive shock acceleration
  - Class 5 [1h] — **Exercises** on all classes

-> p-p interactions

-> Bremsstrahlung

-> Synchrotron

-> inverse Compton

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamic
    - Class 3 [0.5h] — **Exercises** on Lecture II
      - Class 4 [1.5h] — V - **Particle transport** in turbulent magnetic fields
      - Class 4 [1.5h] — **Exercises** on Lectures II, III, and IV
    - Class 5 [0.5h] — II ter - Inverse Compton scattering
    - Class 5 [1.5h] — VI - **Particle acceleration**: diffusive shock acceleration
    - Class 5 [1h] — **Exercises** on all classes
- Class 6 [3h] — **Exam simulation**

-> p-p interactions

-> Bremsstrahlung

-> Synchrotron

-> inverse Compton

- Class 1 [0.2h] — 0 - **Introduction**
- Class 1 [1.4h] — I - **Astronomy**: the Milky Way
- Class 1 [1.4h] — II - **Particle interactions**: cosmic rays, γ-rays, neutrinos
  - Class 2 [1h] — **Exercises** on Lecture II
  - Class 2 [1.5h] — III - **Astrophysics**: SuperNova Remnants
  - Class 2 [0.5h] — II bis - Gamma-ray astronomy: Cherenkov technique
    - Class 3 [1h] — **Exercises** on Lecture III
    - Class 3 [1.5h] — IV - **Plasma physics**: MagnetoHydroDynamic
    - Class 3 [0.5h] — **Exercises** on Lecture II
      - Class 4 [1.5h] — V - **Particle transport** in turbulent magnetic fields
      - Class 4 [1.5h] — **Exercises** on Lectures II, III, and IV
    - Class 5 [0.5h] — II ter - Inverse Compton scattering
    - Class 5 [1.5h] — VI - **Particle acceleration**: diffusive shock acceleration
    - Class 5 [1h] — **Exercises** on all classes
  - Class 6 [3h] — **Exam simulation**
- Class 7 [0.5h] — **Conclusions**: what did we learn?
- Class 7 [2.5h] — **Exercises** on all classes

-> p-p interactions

-> Bremsstrahlung

-> Synchrotron

-> inverse Compton

- Class 1 [0.2h] — 0 - Introduction
- Class 1 [1.4h] — I - Astronomy: the Milky Way
- Class 1 [1.4h] — II - Particle interactions: cosmic rays, γ-rays, neutrinos
- Class 2 [0.3h] — II bis - Gamma-ray observations: Cherenkov technique
- Class 2 [0.7h] — Exercises on Lecture II
- Class 2 [1h] — III - Astrophysics: SuperNova Remnants
- Class 2 [1h] — Exercises on lecture III
- Class 4 [1.5h] — Plasma physics: MagnetoHydroDynamics
- Class 5 [1.5h] — Particle propagation in turbulent magnetic fields
- Class 6 [1.5h] — Particle acceleration: diffusive shock acceleration at SNRs
- Conclusions [0.5h] — What did we learn?

- Class 1 [0.2h] — 0 - Introduction
- Class 1 [1.4h] — I - Astronomy: the Milky Way
- Class 1 [1.4h] — II - Particle interactions: cosmic rays, γ-rays, neutrinos
- Class 2 [0.3h] — II bis - Gamma-ray observations: Cherenkov technique
- Class 2 [0.7h] — Exercises on Lecture II
- Class 2 [1h] — III - Astrophysics: SuperNova Remnants
- Class 2 [1h] — Exercises on lecture III
- Class 4 [1.5h] — Plasma physics: MagnetoHydroDynamics
- Class 5 [1.5h] — Particle propagation in turbulent magnetic fields
- Class 6 [1.5h] — Particle acceleration: diffusive shock acceleration at SNRs
- Conclusions [0.5h] — What did we learn?

Total = ~10h of theoretical classes

- Class 1 [0.2h] — 0 - Introduction
- Class 1 [1.4h] — I - Astronomy: the Milky Way
- Class 1 [1.4h] — II - Particle interactions: cosmic rays, γ-rays, neutrinos
- Class 2 [0.3h] — II bis - Gamma-ray observations: Cherenkov technique
- Class 2 [0.7h] — Exercises on Lecture II
- Class 2 [1h] — III - Astrophysics: SuperNova Remnants
- Class 2 [1h] — Exercises on lecture III
- Class 4 [1.5h] — Plasma physics: MagnetoHydroDynamics
- Class 5 [1.5h] — Particle propagation in turbulent magnetic fields
- Class 6 [1.5h] — Particle acceleration: diffusive shock acceleration at SNRs
- Conclusions [0.5h] — What did we learn?

Total = ~10h of theoretical classes

- Exam simulation [3h]
- Exercises [8h]

Total = ~11h of practical classes

Bibliography

General reference

- Longair, High Energy Astrophysics

Radiative processes

- Rybiki & Lightman, Radiative processes in astrophysics
- Ghisellini, Radiative processes in high energy astrophysics
- Aharonian, Very high energy cosmic gamma radiation
- Gaisser, Cosmic rays and particle physics

Bibliography

Plasma physics

- Shu, Gas dynamics
- Kulsrud, Plasma physics for astrophysics
- Vietri, Foundations of high energy astrophysics

Particle acceleration/ propagation

- Gaisser, Vietri, Kulsrud (see above)
- Berezinskii et al., Astrophysics of cosmic rays