KTH Fysik

# SH2201 - Astroparticle Physics - 6 credits (h.p.)

# Course Plan - 'kurs-PM'

Version 2009-1.0

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## *Introduction*

In recent years, the fields of particle (subatomic) physics, astrophysics and cosmology have become woven together and the new field of astroparticle physics (or particle astrophysics, as it is sometimes known) has grown from their interdependence. This symbiosis has led to tremendous advances in our understanding of the universe at the very largest and the very smallest scales of both time and distance. During this course, particular emphasis is placed on the experimental aspects of astroparticle physics. Key results will be surveyed and the methods used to obtain them will be discussed.

Some of the teaching methods used in this course are quite different from those you usually meet. The methods used may seem foreign and even uncomfortable to you at first. However, these methods have been adopted to promote deep understanding and to avoid superficial learning. This is reflected in both the course activities and examination methods.

## *Course goals*

After completing this course, you should be able to:

- Classify the fundamental subatomic particles by their possible interactions.
- Explain how 'particle probes' can open a new window on the universe compared to historical observations using electromagnetic radiation.
- Explain how particles can be detected and their properties determined, and appreciate the limitations of different detection techniques.
- Identify the astrophysical observations which motivate the key features of the current 'Standard Cosmological Model'.
- Use a Newtonian-inspired model to describe the expansion of the universe. Account for the dynamics of the expansion of the universe during the radiation- and, subsequently, matter-dominated epochs. Defend the basic properties of your model with observational data.
- Defend the hypothesis that the vast majority of the universe consists of forms of ('dark') matter and energy which are completely unknown today. Explain the

independent observations which lead to this startling fact. Hypothesise over the possible particle candidates for the 'dark matter' of the universe.

- Perform dimensional analysis to define relationships between physical variables in astrophysical systems.

- Interpret data from figures published in the scientific literature and use this to perform calculations and develop conclusions.

- Reflect on the current 'open questions' in astroparticle physics and the experiments planned to address these issues.

## *Course level and prerequisites*

There are no mandatory prerequisites for this course. The course is primarily designed for:

- students in the final year of physics studies and, in particular, those following the 'subatomic physics' specialisation within 'F4'.
- students following the Modern Physics Master's Programme

It is therefore assumed that you have followed introductory courses in quantum mechanics, particle physics and nuclear physics (to a level corresponding to the 'subatomic physics' course given in 'F3'). This course builds on the course SH2201 Experimental Particle Physics which was given in the autumn term (October – December) of the previous year and remedial work may be required if this course has not been followed. Other students should note that while the course is predominantly non-mathematical, you should feel comfortable manipulating equations and performing elementary calculus.

## *Course literature*

Due to the dynamic nature of the subject, there is not a single textbook which covers the entire course. The basic concepts and theoretical ideas of the course are covered in the recommended textbook:

- D. Perkins, 'Particle Astrophysics', Oxford University Press, ISBN 0-19-850952.

An additional textbook which covers similar material, but with a more rigorous treatment of the theoretical side of the subject is:

- L. Bergström and A. Goobar, 'Cosmology and Particle Astrophysics', J. Wiley & Sons, ISBN 0-471-970542.

Students are recommended to have continuous access to the Perkins book during the course. At several instances during the course, it will be very useful to also consult the Bergström and Goobar book.

In additional to these 'traditional' academic texts, there are a large number of more popularised texts (books, articles and web pages) which describe our understanding of the origins and evolution of the universe and the key scientific breakthroughs in the subject area. As the course progresses, there will be frequent references to such sources of further reading.

## *Lecture structure*

The course is based around 7 lecture topics, which are detailed in the following section. Each topic is the focus of 2 consecutive lecture sessions, where each lecture session consists of a standard 2 x 45 minute timetabled period.

## *Lecture topics*

The following 7 lecture topics form the basis of the course. The relevant parts of the course textbooks are indicated in brackets (P = Perkins and B = Bergström and Goobar (1st Edition); P 1 means Perkins: chapter 1, for example). Additional material will be provided in the form of hand-outs during the course.

1. **Introduction**
    a. Practical information
    b. Overview of course content
    c. Information sources
    d. Teaching methods
2. **Review of the concepts of particle physics**
**(P 1, P 3.5 – P 3.12 / B 6)**
    a. The matter particles: leptons and quarks
    b. The force carriers
    c. The interactions (electromagnetic, weak and strong)
    d. Problems with current theories
3. **The contents and dynamics of the universe**
**(P 2.1 – P 2.6 / B 4)**
    a. Basis principles of cosmology
    b. The distribution of matter and radiation in the universe
    c. Dynamics of matter: redshift and Hubble's Law
    d. Deductions from a Newtonian cosmological model – the critical density and geometry of the universe
4. **Big Bang nucleosynthesis and thermal relics**
**(P 2.10 – P 2.11, P 3.13 – P 3.15 / B 8)**
    a. The Planck era
    b. The chronology of the Big Bang
    c. Radiation, matter and the expansion of the universe
    d. Temperature – time relationship
    e. Nucleosynthesis
    f. Antimatter in the universe
    g. Thermal relics
5. **The Cosmic Microwave Background and cosmological parameters**
**(P 2.7, P 5.1 – P 5.2, P 5.9 / B 11, B 12)**
    a. The discovery and origins of the cosmic microwave background
    b. Anisotropies in the cosmic microwave background
    c. Measuring the anisotropies and extracting cosmological parameters
    d. Future experiments
6. **Dark Matter - the missing mass of the universe (P 4)**
    a. The dark matter problem
    b. Dark matter candidates and experiments trying to find them
    c. Present results and future prospects
7. **The role of neutrinos in the universe**
**(P 7 / B 15)**
    a. Interactions and cross-sections
    b. Stellar and solar neutrinos
    c. Neutrinos as probes of supernovae
    d. Atmospheric neutrinos
    e. High energy neutrinos
    f. Neutrino detectors
    g. Neutrino masses and oscillations
8. **Cosmic rays: Galactic (P 6 / B 13) and at / near the earth (P 6 / B13, B14)**
    a. The discovery of cosmic rays on earth
    b. Production and acceleration
    **c.** Ultra-high energy cosmic rays and their detection
    d. Sources of cosmic rays in the solar system

e. Solar and terrestrial effects on cosmic rays
f. Studying cosmic rays with balloon- and satellite-borne experiments
g. Cosmic gamma-rays

## *Lecture notes*

At the start of each lecture topic, copies of the slides to be shown will be distributed. These are available free of charge and are provided in order to minimise the amount of time you spend taking verbatim notes. Use the time to absorb the material presented and formulate questions instead!

## *Examination method*

Successful completion of the course will lead to grades A – Fx, F being awarded. There are three components to the examination, as detailed below:

1. Three home assignments, each containing 2 extended questions
2. Student seminar day
3. Oral examination

Each component is described in more detail below, along with the grading scheme. To achieve grade B - Fx, only the first two components need be completely satisfactorily. To be considered for grade A, the oral examination is also mandatory.

### Home assignments

The 7 lecture topics are covered by three home assignments, each containing 2 extended questions. The home assignments will be handed out periodically during the course and must be completed within one week. The distribution and collection scheme will be provided during the first lecture. Note that while you are welcome (encouraged!) to discuss the problems with others, the answer script you submit must represent your own work. Identical scripts will be treated as plagiarism (‘plagiat’). During grading (see section below), attention will be paid to the explanation and presentation of solutions – and this should represent your own work.

### Student seminar day

You will be asked to identify a topic covered during the lectures which you found particularly interesting, or select a topic from a list which will be posted on the course homepage. You will search for additional scientific information (i.e.: not simply repeat what has already been discussed in class) about this topic and deliver a ~20 minute long (TBD) presentation to the rest of the class during the student seminar day. You will grade each others presentations according to the scheme detailed in the next section. These grades will be averaged to form each student’s final grade for the seminar day. The course responsible will independently grade the presentations and will randomly sample a selection to ensure marking standards are upheld. Each presentation will be followed by a time for questions, and active participation is expected.

### Oral examination

Students wishing to be considered for grade A must take an oral examination. This examination will be administered in small groups. During the oral examination, the group will be asked to develop ideas and concepts developed during the lectures. Each student will be asked to contribute in turn to the discussion and will be graded individually. Each oral examination will last for approximately 45 minutes. It is not possible to repeat the oral examination.

## *Grading scheme*

Successful completion of this course will lead to grades A-Fx being awarded. Each element of the examination is weighted as specified in the following table:

<table>
<tr><th>Examination type</th><th>Points</th><th>Point breakdown</th></tr>
<tr><td>Home assignment 1</td><td>2 x 10</td><td rowspan="3">The following criteria will used when assigning points:<br>• Identification of correct physical principles (~40% of points)<br>• Creation of the correct mathematical framework to solve the problem (~40% of points)<br>• Numerically correct answer (~20% of points)</td></tr>
<tr><td>Home assignment 2</td><td>2 x 10</td></tr>
<tr><td>Home assignment 3</td><td>2 x 10</td></tr>
<tr><td>Student seminar day</td><td>40</td><td>• Organisation and coherence of presentation material (10 points)<br>• Quality of presentation materials (10 points)<br>• Identification and explanation of the key physical principles (10 points)<br>• Keeping time, tempo (10 points)</td></tr>
<tr><td>Oral examination</td><td>Pass or fail</td><td>You will be judged according to the following criteria:<br><br>1. Being able to coherently describe concepts introduced during the course.<br>2. Being able to interpret information (a figure, perhaps) based on concepts introduced during the course.<br>3. Being able to combine concepts developed during the course to hypothesise and defend new material.<br><br>Note that the criteria are ranked from 1 (superficial understanding) to 3 (deep understanding). A pass will only be awarded to students judged to surpass level 1.</td></tr>
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The final grade is assigned as follows:

| Grade | Overall percentage |
|---|---|
| A | 90% + oral pass |
| B | 80% |
| C | 70% |
| D | 60% |
| E | 50% |
| Fx | 40-49% |
| F | < 40% |

A grade Fx can be 'upgraded' to grade E. The course responsible will define the extra work which must be completed for the upgrade. This work must be successfully completed within 6 weeks of the issue of the course results. After this time the grade will be automatically, and irreversibly, converted to 'F'.

## *Use of web materials*

There is a large amount of very useful material related to particle physics on the web (you should also be aware that some sites promote material that is not widely accepted!). Useful pages can be easily located with your favourite search engine. For example, searching for "Hubble Constant" with *Google* yields over 79 000 hits! You are encouraged to make use of this information to increase your understanding of the topics covered in the course. Verbatim copying from web sources is strictly forbidden when completing home assignment, and preparing for the seminar day. This will be considered as plagiarism ('plagiat') and appropriate disciplinary measures taken. Web sources used in the preparation of talks for the student seminar day should be clearly stated.

## *Appeals*

Appeals against grades awarded must be communicated to the course responsible in writing.

## *Course language*

This course is given in English.

## *Timetable and location*

This course runs in the Spring term (January - March). The exact course timetable is available from 'KTH schema' (http://www.kth.se/student/schema). The schedule for student seminar day will be fixed during the course.

## *Course evaluation*

You are strongly encouraged to complete a web-based course evaluation at the end of the course. Further instructions will be given nearer the time. The evaluation is anonymous and consists of approximately 15 'multiple choice' questions with space for written comments. The feedback received will be used to continuously monitor and improve the course. Your opinions are very valuable!

## *Course homepage*

The course homepage can be found at: http://www.particle.kth.se/SH2200

## *Course updates*

Any important information, changes of lecture times, latest news etc. will be sent to course participants primarily by e-mail and also registered on the course homepage. It is therefore very important that you provide a valid and **legible** e-mail address when registering for the course.

## *Course responsible*

The course responsible / examiner is Professor Mark Pearce, pearce@particle.kth.se, 08-55378183.

He can be found in AlbaNova University Centre on the 5$^{th}$ floor (A5:1009). Enter the main AlbaNova building on the Ruddammen side through the main entrance and ask the receptionist to direct you to his office. It's always safest to book a time in advance by e-mail or phone, but you are also very welcome to simply drop by with questions.