Glen Cowan
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PH3930: Particle Astrophysics

Welcome to PH3930! The lectures will be given by

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In addition, there will be weekly discussion sessions led by

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Lectures are on Thursdays from 3 to 5 pm in T125. The discussion sessions are Mondays at 1 pm also in T125. All of this information, as well as updates, problem sheets, links to course resources, papers, etc. can be found on the PH3930 web site:

`www.pp.rhul.ac.uk/~cowan/astrophy.html`

The purpose of the discussion sessions will be to go over the problem sheets, to provide additional examples of the material presented in the lecture, and to give you the chance to ask questions and discuss. To first approximation there should be no fundamentally new material presented in the discussion sessions, but exceptions to this rule may occur.

Aims and objectives

The aim of PH3930 is to give an overview of a number of related aspects – experimental and theoretical – of astrophysics, cosmology and particle physics. One connection between the fields is straightforward: the early universe was very dense and the temperature extremely high. To figure out how the universe evolved through this period, we need to understand the high energy interactions of particles. Conversely, astrophysical observations can provide new discoveries about elementary particles. The early universe provides the ultimate particle accelerator, giving us experimental access to energies that will never be attained with man-made devices.

The course will also provide an overview of astrophysical particle sources such as cosmic rays, solar neutrinos, and neutrinos from supernovae. We'll take a look at a number of current and planned experiments, including facilities on the South Pole, off the Mediterranean coast of France, in an Ohio salt mine and on the International Space Station. (If you plan on doing research in the field, the choices you make could have major consequences for your lifestyle!)

Often these studies exploit the known properties of particles to learn about the nature of the particle source; this is typically the case in gamma-ray astronomy and cosmic-ray physics. In other experiments, such as the case of recent studies with neutrinos created in cosmic ray showers, the measurements lead to new knowledge about the nature of the fundamental particles, namely, that neutrinos have a non-zero mass. Other questions lead to a more complex connections between astrophysics and particle physics, such as the study of dark matter. We'll look at a number of such examples involving interplay between theory and experiment and between different branches of physics.

Books and lecture notes

Some lecture notes will be distributed in class. These will cover at least the first 2/3 of the course. For the final third on cosmic rays, gamma ray astronomy and neutrino astrophysics, we will rely more on papers that will be distributed in the lectures. These have the advantage of being very up to date and the disadvantage of being often fairly technical. Textbooks are of course more pedagogical in their approach, but there does not exist a good single text for the course. Essentially all of the lecture material will be contained in the following texts, which are (or will be) available in the library:

> Lars Bergström and Ariel Goobar, *Cosmology and Particle Astrophysics*, Wiley, 1999. The best single reference for the course, although it contains more detail than we need.
>
> S. Weinberg, *The First Three Minutes*, BasicBooks, 1993. This is a qualitative 'almost popular' text but nevertheless gives a surprisingly complete description of the early universe. Highly recommended reading.
>
> Alan Guth, *The Inflationary Universe*, Vintage, 1998. A personal/historical account of the development of theory of inflation with a nice description of the physics involved.
>
> G. Bothun, *Modern Cosmological Observations and Problems*, Taylor & Francis, 1998. Readable and up-to-date description of structure, cosmic background radiation, dark matter. Updates and supplementary material available at `http://zebu.uoregon.edu/tandf.html`.
>
> M.S. Longair, High Energy Astrophysics, CUP, 1994. Good source of information for the more phenomenological parts of the course, especially on cosmic ray physics.
>
> John N. Bahcall, *Neutrino Astrophysics*, CUP, 1989. A very readable text with much information relevant to the course, but it does not contain the important results of the last decade, and in many ways goes into more detail than necessary for PH3930. Recommended for further reading.

Also useful but more advanced:

> Edward W. Kolb and Michael S. Turner, *The Early Universe*, Addison-Wesley, Reading, Mass., 1990. This is the classic text on our subject but is now 13 years old and quite theoretical.
>
> H.V. Klapdor-Kleingrothaus and K. Zuber, *Particle Astrophysics*, IOP, 1997. This book gives a very nice overview of essentially all of the course material, but at a fairly advanced level. Recommended for further reading.
>
> G.Börner, *The Early Universe: Facts and Fiction*, Springer, 1988; very relevant to the course but at a quite theoretical level. Can be looked at for further reading.

Problem sheets

Problem sheets are a vital part of this course and will form 10% of the mark. They should be handed in by the announced due date and time and can be turned in either in my pigeon hole or in my office, W262. Late submissions will be corrected, but no marks will normally be credited unless the delay is agreed with me before the deadline. If you are away ill, you should see me on your return.

Discussion of the problems with fellow students is encouraged, copying is not. Papers bearing a resemblance that cannot be accounted for other than by copying will not be credited.

PH3930 Course Outline (approximate by week)

1. Particle physics beyond the Standard Model: GUTs and SUSY.
2. Review of cosmology, redshift, Friedman equation, fluid and acceleration equations.
3. Thermal history of the early universe from the Planck scale to 1 ms. Baryogenesis.
4. Big Bang Nucleosynthesis, abundances of the light elements.
5. Cosmic microwave background radiation, inflation.
6. Dark matter: astrophysical evidence, MACHOs, WIMPs.
7. Experimental searches for dark matter.
8. Cosmic rays: composition, energy spectrum, sources, experiments.
9. Gamma-ray astronomy: sources, experiments.
10. Neutrino astronomy: high-energy neutrino experiments, neutrinos from supernovae.
11. More neutrino astronomy: neutrino oscillations, solar neutrinos, atmospheric neutrinos.