Formation & Evolution of Galaxies

Prof. Trevor Ponman

NOTICES

- Problem Sheet 2 is now complete below. I will run through this and last year's paper in our Revision Lecture on April 23rd.
- I will hold a weekly office hour for this and the *Evolution of Cosmic Structure* course in my room (236 Physics West) at 3pm each Friday. If you plan to come but cannot make it by 3.15pm then it is best to warn me, or I may move on to other things.

1. Introduction to the course

Galaxies are the building blocks of the Universe. In this module we aim to understand the structure of galaxies, and how they form and evolve in the Universe. The course is open to all Year 3/4 Physics students. There are no formal pre-requisites, but Year 2 Structure in the Universe is recommended.

We will start by examining the structure and dynamics of galaxies of different types, before looking at how they form due to gravitational instability of the early large-scale structures. The growth of supermassive black holes within galaxies is an area of great activity in astrophysics, and we will consider how this relates to the growth and evolution of the host galaxy. Star formation and its cessation play a central role in establishing galaxy properties, and their dependence upon environment. Finally we will develop models for the chemical and dynamical evolution of galaxies, and examine the role of galaxy mergers.

2. Mechanics of the course

You are expected to make your own notes during the lectures, but electronic notes covering much of the material will be available below. You are advised to print these out in advance and annotate them in class. The primary text for the course is Sparke and Gallagher, and references to the relevant sections are given in the table below.

This module is available to Year 3 and Year 4 students. Year 4 students will be required to undertake some independent study on a topic to be announced during the lectures. This will be examined through a dedicated Year 4 question in the final exam.

3. Syllabus and notes

The following may evolve a little as we progress, so regard the later parts only as an initial guide at this stage. Numbers of lectures associated with each section are approximate. Notes for each part of the course can be downloaded as pdf files as they become available by clicking on the corresponding Part number in the first column. The S&G column gives references to Sparke & Gallagher.

Part	Topic	Lect	Contents	S&G
I	Introduction to Galaxies	2	components of galaxies stars: lifetimes, evolution, IMF dynamical timescales galaxy types	1.3, 1.1, 3.2
II	Gravity & Dynamics	2	gravitational potentials density distributions virial theorem	3.1
III	Stellar Orbits	2	integrals of motion central force problems	3.3, 3.4

			radial and azimuthal motion	
IV	Spiral Galaxies	2	components Tully-Fisher relation winding dilemma differential rotation spiral structure	5
V	Elliptical Galaxies	1	structure Faber-Jackson, fundamental plane velocity dispersion and rotation	6
VI	Milky Way and Local Group	1	Milky Way galaxy MW companion galaxies the Local Group mass and future of the Milky Way	1.2, 4
VII	Galaxy Formation	2	Jeans mass and its evolution spherical infall model baryon cooling	1.5, 4.3, 8.3, 8.4, 9.4
VIII	Active Galaxies	4	introduction to AGN evidence for supermassive b.h. estimating b.h. masses relationship between SMBH and host galaxy classification of AGN energetics growth of b.h. and AGN evolution feedback from AGN	9.1, 9.2
IX	Star Formation in Galaxies	3	the ISM and star formation where do stars form? measuring the rate of star formation quenching star formation	2.4, 9.4
X	Galaxy Evolution	2	chemical evolution models dynamical friction galaxy mergers	4.3.2, 7.3

4. Exam papers and problems

This course was new in 2011/12, so there is only one past exam paper, which you can find here for Year 3 and Year 4.

Course problems can be found below, and some of these will be worked through in the supervision classes, and in revision lectures.

Problem sheet 1
Problem sheet 2

Fourth year students are required to do some independent study, which will be assessed via a special compulsory question in section 3 of the examination paper. The topic is the observed properties and underlying astrophysics of AGN. You should prepare yourself to provide intelligent comment on any of the following questions. (Note that these are not simple well-resolved issues!) You should be aware of both theoretical arguments and the relevant observations.

- Since all galaxies above a certain mass are believed to have a supermassive black hole at the centre, why do some manifest themselves as radio AGN, some as optical AGN and some X-ray AGN, and others appear completely inactive?
- Is the primary determinant of the nature and vigour of any AGN activity (a) internal (type of galaxy, source of fuel, trigger, region of emission) or (b) external (environment)?
- How is AGN activity related to galaxy evolution?

Your primary reference for this study is the review paper by Alexander and Hickox (2012), plus any references within this review which you need to follow up.

5. Reading

Clicking on the title of most of the following books will take you to dedicated websites, which have follow-up links and supplementary material.

- **Linda Sparke and J S Gallagher III: Galaxies in the Universe, an Introduction (Cambridge University Press, 2nd Ed, 2007**
  Sparke and Gallagher covers all the material in this module, and will be the primary textbook to follow. The book's website (click above) has useful links, and a list of errors in the printed version.

- **B A Carroll and D A Ostlie: An introduction to Modern Astrophysics (Benjamin Cummings, 2nd ed, 2006)**
  (The first edition (1995) is also useful.)
  This is a massive book and covers a much wider swathe of astrophysics than is required for this course. However it useful due to its accessible but physics-based approach, and you may find it useful for other astrophysics courses. There are several copies in both long and short loan stacks in the library. The exercises given at the end of the relevant chapters are very useful. The book's website (click above) has very useful online resources.

- **H. Mo, F. van den Bosch and S.D.M. White, Galaxy Formation and Evolution (Cambridge University Press, 2010)**
  This book is for postgraduate students, and the general level is more advanced than that of this course. However, you may find it useful to browse through.

Send comments or suggestions on these pages to Trevor Ponman.
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