Department of Physics

Astronomy Course Document

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Department of Physics

Introduction

Welcome to our Level 1 course on astronomy, which forms one component of both PX1511 and PX1512. It is a course intended for everyone, not simply those who have taken Physics before. It is a course intended to inform you, to get you thinking and to some extent get you doing things. We hope you will enjoy it. The lecturer is Dr. Murilo Baptista, based on original material developed by Dr. John S. Reid, FRAS, Cruickshank Lecturer in Astronomy.

As well as this introduction, you must **also obtain the introductory documents relating to the other parts of your course**.

The class meets on Thursdays and Fridays at 10.00 am in Fraser Noble lecture theatre FN1.

Everyone is strongly recommended to get the excellent astronomy textbook called "*In Quest of the Universe*" by Theo Koupelis & Karl F. Kuhn (Jones & Bartlett, London, 5th edition, 2007 ISBN 978-0-7637-4387-1). **This edition can be bought in Blackwell's Bookshop by £10.** The 4th edition was by Kuhn & Koupelis (2004, ISBN 0-7637-08100), 3rd edition (2001) and the 2nd edition by Kuhn alone (1998) are versions used earlier and all are useful if you can pick up a second-hand copy. The 6th edition was announced by £117.95. It is recommended because of its approach and the fact that it doesn't overload you with truckloads of detail.

I like to think that in this course you will meet more up-to-date science than in any other course you're taking. **Koupelis & Kuhn's textbook essentially constitutes the extended background notes for the course, clearly written and colourfully illustrated**. Their book is very well presented with lots of photographs and diagrams, as is appropriate for a very visual science. It also emphasises the principles of scientific advance that you can see at work in astronomy so well and which are applicable to virtually all other sciences. Studying astronomy is not only worthwhile for the astronomical knowledge you'll learn but it is also a very good way to learn what science is about. Perhaps I should add for that if you take our course *Cosmology, Astronomy & Modern Physics* (PX2512) in due course in the second year you'll find Koupelis & Kuhn's textbook useful for that too. The library have a stock of earlier editions that will cater for some borrowers.

Syllabus outline, homework and time spent on astronomy

The syllabus **doesn't** work its way systematically through Koupelis & Kuhn's book but the contents strongly reflect material in chapters 1 - 3, 6 - 12, supplemented by such additional material as seems relevant. Some guidance is given where material is located but use the book's *contents* and *index* pages. Aims and learning outcomes are given in later sections of this document. A more precise summary of course contents than the textbook's 'contents' list is given in the last section of this document, as a guide to library study and as a revision aid.

Homework activities will be given out during the course. These are intended to enrich the experience of the course in areas that are not examinable. The homework is not assessed but one computing exercise for PX1512 is astronomy based.

You are expected to spend on average about 4 hours per week on astronomy, including attending the class, reading, homework and related activities. If you're enjoying the subject matter then this isn't a hardship.

Assessment

Apart from the computing exercise just mentioned, the Astronomy is assessed only in the Degree exam. For any subject at all you should know in advance the type of exam questions that will be asked, the topics on which you will be questioned and the type of answers expected of you. The astronomy questions form one section of the PX1511 and PX1512 exams, as explained in the overall course handouts. The topics on which you will be questioned will be the topics covered in the lectures. There will be 60 multiple-choice questions, with a choice of 5 answers for each question. You have to select the correct answer and fill in your selection on the University's standard multiple-choice answer sheet. You score one mark for each correct answer and zero for a wrong answer, or no answer at all. It's that simple. There is no 'negative marking' for wrong answers. For both courses, the astronomy exam is half the written degree exam.

The multiple-choice format has proved popular with the class and gives you credit for knowledge you have over the whole range of the course material. You can see what the last year's June paper looked like on the library's exam web page at http://www.abdn.ac.uk/library/examdb/. A few years ago the astronomy course had the course code PX1510.

No one would consider wading into deep water without first making sure they had practised swimming. Yet every year otherwise sensible students turn up at exams that can affect their life's career with completely inadequate practice. There is plenty of opportunity to practice multiple-choice astronomy questions. The class will be given some question sessions during the class meetings. There will be a short mock examination just after the Easter break. As well as the on-line questions in the computer class-rooms, Koupelis & Kuhn has multiple choice questions at the end of each chapter. By the time you get to the exam you should have a feeling that 'this-is-old-hat'. Of course, you should have this feeling for every subject you take. I hope you won't need the August resit.

Astronomy learning outcomes

Here are some of the general learning outcomes of the course. By the end you should:

- have cultivated your curiosity and experienced the thrill of discovery of new knowledge
- be able to describe the main features of the planets in our solar system, the sun, comets and other local bodies, different classes of stars and other topics in the syllabus sufficiently to have a well informed view of our surroundings
- be able to describe the main observed motions in the solar system and beyond
- be able to explain current ideas on why our solar system is like it is and behaves as it does
- have thought about what has been discovered in the solar system and beyond and asked yourself questions on these topics
- on occasions be able to make quick, indicative, numerical calculations to support observations and arguments

- be able to apply laws of physics and appropriate physical concepts to the solar system and the stars beyond
- have acquired enough confidence in your knowledge that you can distinguish sense from nonsense
- be able to make sense of frequent news articles on astronomy that appear in the *New Scientist* and elsewhere in the press, and be able to read them in the context of current general knowledge on astronomy
- know and appreciate some connections between science and culture that are made through astronomy
- be able to describe some ways in which science as a discipline refines its knowledge.

The Course Evaluation Form handed out near the end of the course will ask you whether the learning outcomes (sometimes called the course 'objectives') and the course aims were clearly stated. The 'aims' come a little later in this document.

What's in the astronomy course?

I'm not talking here about the syllabus. A good university course is not just a couple of intellectual fuel stops a week where you come in to fill up an empty notebook and top up a few grey cells with facts dished out by a university employee at the front of the class. In a good university course you should feel enough enthusiasm for the subject to study it yourself in a variety of ways and the course should provide opportunities for this. The astronomy course tries to be more than just a set of lectures. You can decide at the end whether it succeeds. The intent is that the course consists of:

- lectures
- high resolution slides
- non-lecturing activity in class
- own study of course text
- own reading of library books and information on WWW
- optional use of CAL (i.e. Computer Aided Learning material in a computer class room)
- homework activity
- final examination

Why am I taking a course in astronomy?

It is a dark night, just like every other. The outside lights have gone out and just as you like to do, you've turned out your room lights so you can peer at the total darkness outside through the Perspex dome of your living quarters. There is not a glimpse of the shapes and colours of the day-time clouds. You love to let your imagination wander as you drift off to sleep in the dark. Anyone living on a permanently cloud covered world, such a Venus or Titan, would not in a million years conceive that if those clouds parted they would see points of light in the sky, or moons and planets within their solar system. We are extra-ordinarily lucky to be able to see the stars.

It is easy to imagine a technological civilisation on Earth, even, where we were living in artificial quarters that gave us no view of the stars. The stars may be pin-pricks of light but we would be missing a lot. We now know that we come from the stars. Not just the atoms that make us and all living organisms but the very Earth itself, the moons and planets of the solar system and the Sun itself. Most of the elements we are made of were created in distant space, inside earlier stars long-since exploded and dead. Studying stars is indeed studying other suns but it's also studying what we are part of and how we fit into the Universe as a whole.

Why am I taking an astronomy course? Many of the most worthwhile things we do in life are done because they seem right at the time, though we couldn't write an essay on why. The opportunity is there and it looks to be interesting, and maybe good fun. Astronomy has a special place in science and I have listed below well over a dozen reasons that give the astronomy course its special value. You may think of others. You need only one good reason for doing something to validate it. See if you agree with more than one of these reasons. They are not in any special order.

- The world we live in is stunning in its beauty, its variety and its depth of organisation. Most of us are **eager to learn about the whole world** we live in. Our interest does not stop at our local ecology or the events of our current decade. Astronomy sets all other science (and much of our culture) in a universal context.
- **Modern astronomy is an exhilarating science**. It is truly international, with global collaboration the everyday mode of working; billions of dollars spent on it annually; technology representing the frontiers of modern development; fresh results materialising by the week; a tradition of rapid, world-wide distribution of results; tremendous effort placed on making new findings intelligible to the non specialist. As an advertisement for science, it is hard to beat.
- Astronomy is an **excellent subject to learn how science works**. Data is hard to come by and the skill of deduction has to be honed to the highest. Astronomy is old enough to illustrate how science matures and is self-correcting.
- **The science in Astronomy is truly universal** and not special to a small discipline. The results introduced and the skills required to appreciate the deductions are common to much of physical science. Good, transferable, scientific ideas and methods are learnt in an astronomy course, almost painlessly.
- **Astronomy has shaped mankind's view of the Universe**. If the Earth had been enveloped in permanent cloud, our view of the Universe would have been extremely parochial. From the earliest times, the pageant of the heavens has aroused our curiosity and stimulated our interest, our sense of awe and our desire for discovery. Do you want to study science as if the Earth were enveloped in clouds?
- Many people do not appreciate **the seminal influence of astronomy on society**. Heavenly bodies have directly affected our agricultural life, our tidal shorelines, our time-keeping and calendars, our seafaring and navigation, our current climate and long-term climate change, our scientific and technical life, our religious and philosophical life.
- **All of humanity shares the same sky**; understanding what's in it is a quest we share with everyone on Earth. There is, and has been in times past, a huge range of cultures on Earth, with widely different environmental surroundings, social customs, political systems and religious beliefs yet everyone on Earth who looks up at the starlit sky is looking at the same sky. You can truly say to anyone that my astronomy is your astronomy.
- **Astronomy is the science that has been most intimately connected with civilisation and culture** since records began. It is therefore the science that is accessible to the widest of all audiences.
- The picture of the Universe revealed by modern astronomy should be **an essential ingredient in a modern education.** The colossal size of the Universe, its immense age,

the uniform nature of its constituents and processes all provide a context for the place of mankind in the scheme of things. On a more local scale, our knowledge of the solar system has increased phenomenally in the past 40 years, providing a valid context for environmental science that previous generations have never had.

- Astronomy more than almost any other discipline **opens one's mind** to think the unthinkable and experience the limits of nature. It was the great biologist Thomas Huxley who said that astronomy is the science "*which of all sciences has filled mans' minds with general ideas of a character most foreign to their daily experience*", and that was when astronomical knowledge covered a fraction of its present range.
- Life has established itself on Earth in virtually every accessible place, in an enormous range of environments. Modern science indicates that life began on Earth comparatively soon after the Earth was formed. Life is composed almost entirely of the four most common chemically active atomic species in the universe, H, C, N and O, along with phosphorus, P and sulphur, S. CHNOPS are the 6 atomic species associated with life. Yet biological science still seems to be taught as if it is concerned only with what happens on Earth. Modern astronomy is slowly strengthening the view that biology is likely to be a common phenomenon in the Universe. **It is time for the next generation of biologists to have some knowledge of astronomy**.
- If the previous paragraph sounds like a ‘head in the clouds’ biology, then I’d go further and say that it’s time the biologists put their heads above the clouds and looked at the rest of the solar system, at the very least. **Can life that is radically different from life on Earth develop in alien environments**, not fantasies dreamt up by science fiction writers but environments that really exist? Think of the cold, oxygen free, atmosphere of Saturn’s moon Titan, or the sulphuric acid laden clouds of Venus. No use looking for the biology we know about in these places but what about something radically different? What can the subject of astrobiology tell us? In truth, not a huge amount at the moment because people are just beginning to realise that there are serious questions here needing serious, complex and fascinating answers.
- To re-enforce the previous conclusion, it is worth realising that life began on Earth when the Earth was quite unlike its present state. In fact life on Earth as we now recognise most of it could not have existed on the early Earth. Hence, **it is already completely established that life can exist in environments that are quite unlike those found over most of the Earth today**.
- It is not just biologists of the future who should be taking an interest in astronomy. The days are long past when astronomy was the preserve of those who liked to pass solitary nights wrapped in a warm cloak observing the Universe through a telescope. Planetary astronomy is now a cutting edge subject occupied by academic geologists, meteorologists, technologists and biologists. Space science is an international multi-billion commercial industry. **Astronomy is everyman's science in the 21st century**.
- The Earth was formed about four-and-a-half billion years ago, as astronomy and geology tell us, but it was not simply formed and left on its own to evolve. It is becoming increasingly clear that **the dynamics of the solar system**, from orbital sizes and shapes to meteorite impacts, **has shaped life on Earth**. Educated people should know the basic dynamics involved.
- The Earth has provided an environment that has been ‘just right’ for the evolution of life for a few billion years. Is the stability of this environment guaranteed whatever we do, or can it go horribly wrong? **The study of other planets is essential knowledge** for answering this question.

- As mankind exploits the Earth, there is perhaps a tendency to think that six billion people on this globe can't be wrong. The perspective that our solar system is but a speck of dust in the cathedral of the Universe, to quote another astronomer, tends to make those with this knowledge **better world citizens**. We have to take responsibility for our own actions, and far from being the end of the Universe if we don't, it is worth realising that it won't make a jot of difference to the Universe.
- *Heaven/ Is as the book of God before thee set/ Wherein to read his wond'rous works*, as the poet Milton said a long time ago. You or I mightn't use the same religious imagery these days but the sentiment is still the same.
- Finally, to return to the excitement that is modern astronomy, a good case can be made that **this is a golden age for astronomy**. This golden age has been achieved by the huge advances made by space probes visiting much of the solar system, by opening up the whole of the electromagnetic spectrum to observation now that measurements can be made outside the atmosphere, and by the application of modern technology to produce a generation of Earth-based telescopes with performances that are factors of ten better than their predecessors. As a result, we are witnessing a blossoming of knowledge, understanding and insight that is profoundly changing our perceptions of the Universe.

Enough? You could debate some of these points but my personal view is that for someone who has the skills and good fortune to have a healthy life, integrated into society, there is no knowledge more valuable than an appreciation of the Universe in which we find ourselves. If you go to your deathbed without such knowledge, then you have missed out on part of the human experience. It will be a life less fulfilled than it should be. In my list of '100 things to do before you die' then learning something about modern astronomy is right up there close to the top. It's a personal view but it's no bad thing that your lecturer on Astronomy feels strongly about the worth of the subject.

The underlying theme of Aberdeen University's science degree programmes should be that we are trying to create scientists with both special skills and with vision. I think that the student who takes the astronomy course will be a better scientist because of it, whatever their Honours Degree.

A passing reference

I've recommended the following book of essays to the meteorologists and have decided to repeat my recommendation to those taking the astronomy section of the course. The tile is *It must be beautiful: great equations of modern science*, ed Graham Farmelo (Granta Books, London, 2003, ISBN 1-86207-555-7, pbk £9.99). I bought my copy in Gatwick airport. It has rave reviews from non-scientists and scientists alike. "This book can open your eyes to new worlds….". "This superb collection of essays reveals the profound mathematical beauty at the heart of science". "Reads like poetry….", etc. Each chapter is about an equation that gets mentioned once. The ideas behind it are explained clearly, set in their historical context and consequences for us all are drawn. Equations run from the Molina-Rowland catalytic destruction of ozone to Drake's equation predicting the likelihood of there being intelligent civilizations, through such favourites as $E = mc^2$ and Schrödinger's equation. Don't wait until you next go to Gatwick to get hold of a copy. The library has two copies.

On-line numerical assistant

The more confident you are with numbers, the better the scientist you will be. To help you practice without the pressure of staff leaning over your shoulder as you work or asking you in front of a tutorial class whether you can do it, we have developed an on-line numerical assistant, in co-operation with the University's Learning Technology Unit. This assistant is a web-based resource with numerical questions relevant to particular courses, including astronomy, and feedback in the form of answers and hints. The questions give you practice using the sort of mathematical skills you are expected to have as a science graduate (in almost any subject) but which many people are rusty in. They also help you understand the concepts in the course (astronomy here) by seeing how they work in different circumstances. Questions on the same topic will come up with different numbers in them when you try them again. Hence if you make a mistake, you can try again without knowing the correct answer in advance.

This assistant has been developed to improve your 'I-can-do-it' confidence when using numbers, in the privacy of your own working at a computer terminal. **You can access it from the astronomy web page**. Please use it. Instructions are included when you reach the numerical assistant web page. It doesn't matter if you make mistakes in your answers. In fact I'm a believer in the old adage that your experience is based on the number of times you get things wrong. Hidden software doesn't record your performance. There will be some numerical problems in the multiple-choice Degree exam, so it makes sense to make sure you are up to speed in this area. Please e-mail me with any positive suggestions for improving the assistant.

With respect to numeracy, students who have taken the course *Tools for Science* will find that our astronomy and meteorology courses are good courses to take as a follow on. The emphasis in these courses is on science, though, not technique.

Planetarium session

In past years we have been able to visit the Aberdeen Planetarium at a small cost per person. The Aberdeen Planetarium was one of the best in the Scotland. Unfortunately, this planetarium has been closed, probably for good. However, for the last three or four years a voluntary day bus trip to the Glasgow Science Centre has been organized. There, they have perhaps the best planetarium in Britain, and much else to see beside. Everyone who has been on the trip has really enjoyed it and if there is enough interest in the class this year I'll organise a repeat trip. The trip will be subsidised and further details will be given out in the class. In the planetarium you will be able to experience the sight of the heavens, the motion of the stars and planets, and learn where objects of interest are in the sky, without freezing on a winter's night outside.

Our observatory

The Cromwell Tower Observatory (CTO) at King's College was set up for astronomy in the first half of the nineteenth century. For most of its life, and certainly for much of the twentieth century, it has been used as a meteorological observatory. We are now reviving it for astronomical use.

The original refracting telescope has long since ceased to function and we have invested in a modern 250 mm aperture, 2.5 m focal length, Schmidt-Cassegrain reflecting telescope. We are still putting in place facilities to use the telescope, including guidelines, modifications to the observing platform, operating instructions and so on. We have entered into a co-operative agreement with the Aberdeen Astronomical Society (AAS) who have monthly meetings in the Cromwell Tower. If you want to see through a telescope yourself, the best way is to come to the AAS meetings and join them. Their schedule of meetings is available on their web-site at http://www.aberdeenastro.org.uk/, with a link from our class 'astronomical links' web page. The CTO is small and can take only a maximum of 10 people at once, and that’s a bit of a crowd. Do come along if you are interested. I should add that there are two problems. This winter we are still having troubles with water leaking through the roof and hence the observatory is not as fully operational as it will be in the future. Secondly, the flood-lighting at King’s has degraded the view. If you want to see really well through a telescope, then join the AAS and visit their ‘dark-site’ when it is in use, though its location within a forest 20 miles W. of Aberdeen makes this easier said than done.

World Wide Web (WWW) and computer-based resources

The lecturer’s overheads are on-line and indeed his notes that are used in conjunction with what he says. You can use both of these as a revision aid later in the course or as a means of looking ahead and reading in advance the topics about to be covered. Some material has already been updated since last year; other updates are added near the time of the lectures so the ‘final version’ of the overheads and notes only appears after a given course section has been delivered. However, having the material up-front lets you listen to a lecture in the context of your wider knowledge. Looking at the overheads on the **web is not a proper substitute** for attending the lectures because you will miss a lot of explanation, context, personal comments and illustrative slides. I would like to thank Karl Kuhn and his publishers for permission to use textbook diagrams on the web pages that accompany this course.

There is also our own collection of active links to other web sites of astronomical interest and relevance to the course. Though I say it myself, this is well worth spending some time with and will give you a good flavour of what is happening NOW in astronomy. In addition, the publishers of the latest edition of the course text have an extensive set of pages with active links directly tied in to the text. You are reminded throughout the book of the URL http://www.jbpub.com/starlinks, where you can find good summaries of each chapter, multiple-choice questions and other helpful information.

If you look at the blue panel on the left of the astronomy web page then you’ll see that there is a range of supplementary material to access, including the lecturer’s views on topics such as astrology, life elsewhere in the universe and so on.

Also on the course web page (http://www.abdn.ac.uk/~wpe001/astro/index.html- bookmark it!) are links to Java applets on astronomy. These are simulations that illustrate some of the science in the course. They show graphic examples of particular situations where you can alter the defining numbers and see the effects produced. I think they are really helpful and I hope you agree.

Not quite the web but also available in the computer class-rooms through the *Physics* icon are multiple-choice astronomy questions, astronomy simulation exercises through the CLEA project and a computer generated sky map that shows what is visible in the cloudless sky at any time of the day or night.

Supplementary reading

Supplementary reading should be part of every university course you take. Selective use of the WWW is excellent for introducing you to up-to-the-minute material in easily read form and for giving access to research level papers. However, there is another layer of resource that plays a vital role in providing fuller explanations of subjects dealt with in the lectures, and providing well considered opinion and a huge amount of fact. This is the resource of textbooks, encyclopaedias, journals and magazines kept by the library. A very good rule-of-thumb for almost any context is *never read only one source of information* and this applies to courses and a course textbook as much as any other situation. Other books may make better sense to you, give you background material that sets the lecture material in a wider context, and provide extra visual illustrations and results of recent work in the field.

The library has a good selection of up-to-date astronomy texts, though it has few multiple copies. It also has many shelves of astronomy books under Dewey number 52 that provide good background reading. In addition, don't forget the 'History of Science' section under Dewey number Sc 52 for more books of general interest.

The textbooks in the following short list are recommended for supplementary reading to give alternative accounts of the topics covered in the course. There are many more astronomy books in the library.

Supplementary textbooks, in alphabetical order of author

Jeffrey Bennett, Megan Donahue Nicolas Schneider & Mark Voit *The Cosmic Perspective* (Pearson Education Inc, San Francisco, 4th ed'n 2007) Library: 523.1 Ben. An up-to-date textbook with CD ROMs from a different stable to the course text. Send any comparative comments to me by e-mail.

Eric Chaisson & Steve McMillan *Astronomy Today* (Pearson, New Jersey, 5th edition 2005) Library: 520 Cha. Well chosen pictures and plenty of good coloured diagrams supplement a text that often contains more information than our course text.

Neil F. Comins & William J. Kaufmann III *Discovering the Universe* (Freeman, New York, 5th ed'n 1999) Library: 520 Com. A colourful, popular textbook, similar in general style to the course text. The 7th edition is the current version.

James B. Kaler *Astronomy!* (Harper Collins, NY, 1994) Library: 520 Kal. I like this book even though it doesn't include the most modern results. It is well written, with numerous coloured pictures and diagrams a little bit different from those in 'Koupelis & Kuhn'. A few of these will be shown in the class. The level is about that of our course but many subjects are dealt with in a little more detail. This is a good supplementary book for anyone wishing to extend their knowledge from that given in the course.

Jay M. Pasachoff *Astronomy: from the Earth to the Universe* (Brooks/Cole-Thomson, 6th edition, London, 2002) Library 520 Pas. A very good text from the (more expensive) competition to our course textbook. Jay Pasachoff is also co-author of a good first year portfolio textbook *Physics with Modern Physics*. Astronomy is his speciality.

Jeff Hester et al. *21st Century Astronomy* (W. W. Norton & Co., London, 2nd ed'n 2007) Library: on order. Not much by way of historical background but a good source of up-to-date information presented in modern textbook style, with lots of blocked sections, summaries etc.

Otto Struve, Beverly Lynds & Helen Phillans *Elementary Astronomy* (OUP, 1959) Library: 520.2 Str. OK, why am I recommending an ancient book with no colour pictures? Because it is very good, particularly for anyone with Higher Physics, in showing how simple physical principles are applied to deduce hard numerical facts about the solar system, the Sun, stars, stellar evolution and other astronomical matters. Not all physics in modern textbooks is modern and Otto Struve, who at least has the same name as a famous astronomer, deals with the basic physics very well.

Single Subject Books: there are plenty in the library. Browse the shelves or catalogue.

Reference works:

Encyclopaedia of the Solar System, ed. Paul R. Weissman, Lucy-Ann, McFadden & Torrence V. Johnson (Academic Press, London , 1999) Library: Ref 523.2 Wei. Almost a portfolio of specialist chapters on all the substantial topics you can think of in relation to the solar system.

Encyclopaedia of Planetary Sciences ed. James H. Shirley & Rhodes W. Fairbridge (Chapman & Hall, London, 1997) Library: Ref 523.4 Shi. Almost a portfolio of review articles, providing a wealth of further information, well-referenced though in rather small type.

The Encyclopaedia of Astronomy and Astrophysics ed. Paul Murdin (IoP, Bristol, 2001) Library: Ref 520 Mur. This is a comprehensive, highly rated 4-volume encyclopaedia.

Periodicals: If you're going to look at just one, go for *Astronomy & Geophysics* Per 520 Ast. Short, colourful, written for the non-specialist, bang up-to-date. Published bi-monthly by the Royal Astronomical Society.

Don't forget to look at *The New Scientist*, which comes out weekly and is very good for news items on astronomy and *The Scientific American*, which comes out monthly and can have authoritative articles on recent developments in Astronomy.

Course aims

At the top-level, the course aims to:

- Give you a working knowledge of concepts that are helpful in observing the stars and planets
- Show how Western civilisation's ideas on the universe have evolved over the centuries to the modern view
- Show how physical laws discovered on Earth have been applied to deducing how the universe at large works
- Give a detailed account of the modern view of our solar system, covering the Sun, planets, asteroids, meteorites and comets
- Introduce quantitative knowledge of the stars.

Course content

The course is divided into a dozen unequal sections. The titles were derived from early editions of "*In Quest of the Universe*" but the most recent editions by Theo Koupelis & Karl F. Kuhn have been re-arranged in places so the correspondence between sections of the course and the book is not quite as close as it used to be. However, the course content has also diverged in places from that of the textbook so following the textbook to the page doesn't seem so relevant now. The course is planned to cover the following contents, which are closely related to the material on the lecture overheads, but remember that his summary has been written before the course has been delivered and there will be minor changes of content and emphasis in keeping with breaking news and matters of interest in astronomy. Any significant deviations will be announced. **Keep these notes to help with revision**.

Prologue

Introduction and course objectives; on vision: only angular size of objects observed; small angles measure *width/distance*, angles measured in degrees, minutes and seconds of arc; example of converting degrees to arc seconds; the further away objects are, the larger they have to be to be seen, limit of human eye's ability to distinguish detail; slides of solar system and beyond; dual purpose of telescopes: collecting more light and giving magnification, nature of image of stars in a telescope; units of distance: *astronomical unit* (AU) and *light year* (LY); our galaxy and the scale of the Universe, *exponential notation* for (large) numbers and number of stars in our galaxy; the Hubble deep field picture and conclusions.

Earth-Centred Universe

The *fixed stars*, *celestial sphere*, *sidereal day*, solar day, Sun's motion in sky, variation in length of solar day; constellations, rotation of celestial sphere, *celestial poles*, celestial equator; height of pole star above horizon; the *ecliptic*, the zodiac; motion of heavenly bodies in the sky, locating heavenly bodies: *declination* and *right ascension*; *vernal equinox* or 'first point of Aries' (♈); Claudius Ptolemy: *Almagest* and the Greek view of the heavens, *epicycles*, incorporation into Christian theology; models of the heavens: epicycles illustrated for Mercury and Venus, Mars' retrograde motion with epicyclic explanation; order of days in the week.

Sun-Centred Universe

Elements of Copernicus' theory in *De Revolutionibus Orbium Coelestium*; relation to accepted theology and view of the times; Tycho Brahe, master observer; Uraniborg; achievements of Tycho; Johannes Kepler, his motivation, Rudolphine tables; Kepler's first law: properties of an *ellipse*, major and minor axes, *eccentricity*, foci and their distance from the centre; Kepler's second law: changing speed of a planet in its orbit, relation to concept of angular momentum; Kepler's third law: relative periods of different planets; universality of Kepler's laws; empirical nature of his laws.

Gravity & the Rise of Modern Astronomy

Galileo: telescopic achievements, dawn of new view of the heavens; evidence to support his championing of heliocentric theory; conflict with Church; Galileo's mechanics; Newton's achievements: reflecting telescope, mechanical models of the heavens given mathematical backing; Newton's first law of motion: behaviour of body in absence of a force; Newton's second law of motion (F=ma): acceleration produced by a force, mks unit of force is the Newton; Newton's third law of motion: bodies exert equal and opposite forces on each other; Newton's law of gravitation ($F=Gm_1m_2/d^2$): resultant for a spherical moon or planet; on the strength of gravity; nature of *weight* (W=mg); gravity elsewhere; concept of *centre of mass*; centre of mass of Earth - Moon system; tides a universal phenomenon; underlying cause of tides; variation of attraction of Moon across Earth; nature of horizontal tidal forces; other influences; rotation of Earth's tidal bulge; influence of Sun: spring tides and neap tides; future evolution of Earth - Moon system; precession of Earth's rotation axis; precession of the ecliptic; possible impact on climate; Lagrangian points, their nature and uses; Einstein's development of the general theory of relativity: importance to cosmology, predictions tested; on human understanding.

Properties of stars discussed before the Planetarium visit

Properties of stars; *Luminosity* in Watts; *apparent magnitude*, dependence on three quantities; Hipparchus originator of division of stars into magnitude classes; modern measurement of apparent magnitude; basic step involves increase in light of 2.512; zero and negative magnitudes; range of apparent magnitudes; quantitative magnitude comparisons - 2 examples; measuring stellar temperature by *colour index*; stellar parallax, the *parsec* (pc); stellar distances, measuring using parallax, Hipparcos, *absolute magnitude* a measure of luminosity, measured at 10 pc; diagrammatic examples; numerical example of finding absolute magnitude; luminosity and absolute magnitude example; finding stellar diameters; example; *binary stars*, visual, spectroscopic, *red shift* and blue shift, rotation about fixed centre of mass, value of binaries to astronomy, *eclipsing binaries*; Stellar spectra; *spectral classes* of stars, O B A F G K M;

Earth - Moon System

Generality of issues encountered in Earth - Moon system; size of the Earth: Eratosthenes measurement of Earth's radius and principle behind it, reasons for approximate value found; distance to Moon: concept of *parallax*; geometry of small-angle triangle; variation in Moon's distance; phases of Moon; appearance of Moon during waxing and waning; Features on the Moon's surface; Moon's apparent and actual motion; synchronous lunar rotation and orbital period; lunar librations; difference between synodic and sidereal periods; Moon's orbit, whereabouts of the Moon in the sky; comparison of the apparent orbits of the Sun and Moon; behaviour of nodes of Moon's orbit; precession of the Moon's orbit; lunar eclipses: Earth's *umbra* and *penumbra*, basic cause of eclipses, total and partial eclipses; recent examples of eclipses; appearance of moon during total eclipse; when do eclipse occur? importance of inclination of Moon's orbit to ecliptic; influence of precession of nodes of Moon's orbit; eclipse year of 346.62 days; eclipse season of 24 days; Saros of 18 years 11.33 days; average number of eclipses per Saros; eclipses of the Sun: visibility on Earth, difference between *total*, *annular* and *partial* eclipses, total eclipse atlas; typical elapsed time, appearance of chromosphere and corona of Sun during totality; Moon's surface: reasons we expect no atmosphere, craters and maria, *kinetic energy* ($½mv^2$) of impacting meteor in megatons, difference between volcanic and meteoric craters; formation of craters; Man on the Moon; space tourism; the Moon's surface deduced from Earth observations; Moon rocks: high melting point anorthositic rocks and KREEP norite; history of Moon as learnt from Moon's rocks: basalt, 6 stages in evolution of Moon; Moon's mantle and core; theories of origin of Moon, discussion of impact theory.

The Sun

Sun's parallax; measuring scale of solar system by radar, distance to Sun, diameter of Sun; mass through Newton's modification of Kepler's third law: $(M+m)P^2=a^3$; [use of this relationship to find mass of nearby binary stars]; other properties of Sun; Sun as a typical star; *luminosity*: finding it from solar radiation received at Earth; assessment of energy production mechanisms: age of Sun; chemical, gravitational, nuclear energy sources; relevance of $E=mc^2$; description of basic nuclear concepts, isotopes, positrons (anti-matter), *neutrinos* (history of discovery), historical Nobel Prize winners; Fred Hoyle; physics of *the proton-proton chain*, need for high energies and pressures resulting in energy production in Sun's core, net result of reaction; need for other reactions to build up heavier elements, mention of carbon cycle also effecting transformation of H to He; concept of pressure; hydrostatic stability of Sun from balance of pressures; '*standard solar model*' for interior of Sun; *heat transfer* outwards from core by absorption and re-radiation resulting in immensely long energy *diffusion* times; statistical nature of diffusion; role of *convection* in last 150,000 km; granulated appearance of *photosphere*; Sun's composition and relation to material produced by the Big Bang; the great neutrino problem: general observational results of solar neutrino fluxes, resolution of the problem; description of solar *chromosphere* and *corona*; nature of *solar wind*; effects of solar wind on Earth; appearance of aurora; the auroral oval; space weather; monitoring the Sun; *sunspots*: their nature, relation to Sun's magnetic field; 22 year cycle; butterfly diagram; relevance to Earth's climate; sunspot activity in times past deduced from carbon 14 production rates; hairy ball model of solar magnetic field.

Solar System Overview

Inventory of solar system; relative sizes of planets and Sun; relative distances of planets: Bode's law, discovery of Uranus and Ceres; diameters, masses and densities of planets (density = mass/volume): volumes from diameters, masses from Newton's version of Kepler's third law; Jovian and terrestrial planets; rotation in the solar system: lengths of planetary 'days'; orbits and satellites; planetary atmospheres: average energy ($\frac{1}{2}mv^2$) of molecules proportional to temperature; *Maxwell's distribution law* of molecular velocities in a gas; variation of *escape velocity* from planets and moons; where atmospheres are expected; formation of the solar system: features to be explained, relevance of conservation of angular momentum to evolutionary theories; behaviour of a collapsing rotating dust cloud; failure of catastrophe theories; von Weizäcker's resuscitation of evolutionary theories; ingredients of the modern view. Extrasolar system planet search; extrasolar planet properties; a shift of expectations; planetary eclipses; looking for Earth-like planets.

Terrestrial Planets

Diversity of the terrestrial planets; new knowledge of Mercury & Venus; Mercury is like the Earth inside and the Moon outside; restricted visibility from the Earth; lack of atmosphere; Mercury close up: Mariner 10 exploration; cratered lava plains and scarps; Caloris basin; Mercury's rotation period $^2/_3$ of its orbital period (spin-orbit coupling); the day on Mercury; Mercury's core; Mercury's magnetic field; Venus, the sister from hell; general features, nature of the land revealed by Magellan radar probe: drier than dust, burning hot lava plains; examples of radar revealed topography; the atmosphere: composition (96% CO_2, H_2SO_4 clouds, etc.), very high upper atmospheric winds, very high surface temperature and pressure; nature of the greenhouse effect; Venus' overheated greenhouse; Mars from Earth: next planet out, eccentric orbit, best seen in opposition, white polar dry-ice caps shrink in summer, approximately half diameter of Earth, similar length of day and ecliptic tilt, length of Martian year; Mars from space: dry, dusty planet, weathering, past water, large dead volcanoes, no tectonic movement, rust surface, dust storms; Moons of Mars; examples of Martian topography from space and from the Mars rovers; Martian atmosphere, very thin, 95% CO_2, typical temperature variation, lack of ozone layer, solid CO_2 clouds and dusty haze; Mars' atmospheric pressure; the latest view of Mars now and in times past; Martian water, now and in the past; life on Mars? What it would look like to stand on Mars – 3D pictures; purpose of first Mars rover mission; recent 3D rover pictures.

Jovian Planets, Pluto & the TNOs

The Galilean moons: names, sizes and orbits; further Moons of Jupiter; Jupiter from Earth: deduction of average solar distance from Kepler's 3rd law, diameter deduced, mass deduced; Jupiter the hoover of the solar system; out-of-round, differential rotation, bands, great red spot; Jupiter from space: Voyager 1 & 2 and Galileo probes, red spot a storm system, very strong magnetic field; Jupiter's banded atmosphere: cause, composition, structure; Jupiter's internal structure; internal energy source; Io, dry, volcanic, sulphurous, tidally heated; Europa, covered by a frozen ocean, cracking and flexing; Ganymede, largest moon in solar system, cracked ice darkened by meteoric debris, residual magnetic field; Callisto, least dense of Galilean moons, Valhalla impact crater; Saturn, a blander version of Jupiter, banded cloud system, giant storm spot, magnetic field, internal heat, internal structure; Saturn's rings, appearance, James Clerk Maxwell's insight, scope of ring system, Cassini-Huygens mission; Cassini pictures, Cassini division caused by orbital resonance with Mimas; nature of the Roche limit; Saturn's moons, Cassini images; Titan, 99% N_2 atmosphere with methane and presence of other organic compounds. Huygens probe results images and detail; Saturn's irregular moons; Uranus, cold blue world discovered by Wm Herschel in 1781, CH_4 atmosphere; odd rotation axis, odd magnetic field, rings and moons, notably Miranda; Neptune, another cold, blue world, storm system, internal heat drives high level clouds very rapidly, views of Triton. Pluto, the new dwarf planet – what's visible; what's likely to be there; moons Charon, Nix and Hydra; Varuna, Quaoar, Sedna, Orca and other Trans Neptunian Objects (TNOs).

Asteroids, Comets and Meteors

Asteroids: what is an asteroid? Ceres (now classified as a dwarf planet), discovery and size; variation of asteroids in size, reflectivity and composition; pictures of asteroids; orbits of asteroids: about 5000 have computed orbits (note Aberdonia); location of orbits mainly in belt between Mars and Jupiter; Kirkwood gaps due to orbital resonance with Jupiter; Aberdonia; current positions of asteroids; Apollo asteroids; Trojans and Lagrangian points; origin of asteroids, total mass of asteroids, mutual separation, Centaurs; outer solar system TNOs; residue of primordial material; nature of *comets*, *nucleus*, dirty snowball model, jets of ejected material, *coma* and tail; Hale-Bopp; comet tails: *dust tail* caused by radiation pressure, reason for curved tail, changing direction of tail in orbit, the *ion tail*; *Kuiper belt*; *Oort cloud*, size and location, relevance of Kepler's 3rd law; Stardust and Rosetta missions; *meteors*, *meteor showers* and *meteoroids*, origin of material, appearance of meteor showers, better observation pre-dawn than evening; *meteorites* and craters; stony, iron and stony/iron meteors, example of 'Meteor Crater' in Arizona; meteoric extinction of dinosaurs? Astrochemistry.

More on Measuring the Stars

Motion of stars; example of the Great Bear; *proper motion; Hertzsprung - Russell diagram*, *main sequence* stars, *supergiants*, *giants* and *white dwarfs*; *spectroscopic parallax*; use of H-R diagram; spectroscopic parallax; example; luminosity classes; mass-luminosity relationship ($L=M^{3.5}$) finding the scale of the universe, *Cepheid variables*, concluding remarks.

The end

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