Physics 443
Astrophysics

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Course Meets: TF 10:00-11:15 am
Office Hours: Frank 234B (x2162), TF 11:30-12:30, T 15:30-17:30, R 14:30-16:30
http://www.guilford.edu/physics/443

Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which are there.
– Richard Feynman, 1965

1 Course Description

In this course, we will explore some of the major, foundational, topics of astrophysics at an advanced undergraduate level. This course will be a twice-weekly seminar, which will use discussion and readings to learn the basics of gravity, cosmology, stellar structure and evolution. We will monitor the current activity in astrophysics research, to see what questions scientists are asking, and which topics are generating the most interest among professionals.

This is a senior-level physics class, and as such will require familiarity with a wide variety of physics concepts. Astrophysics is the study of how the laws of physics as discerned here in labs on the Earth allow us to deduce what is going on out there in the rest of the universe. Since just about everything happens out there in the universe, this course will draw on aspects of mechanics, electricity & magnetism, thermodynamics, quantum mechanics, and more. Mathematics will be dealt with at a level that requires familiarity with multivariable calculus. Physics 320 (Mathematical Physics) is a pre-requisite for this course.

As mentioned above, this course will be conducted as a seminar. Readings will be assigned before class according to the schedule. The tentative schedule is presented in Table 1 and described in Section 2.2. This schedule may be modified as the course progresses by student interest and pacing. Consult the course web page for the most up-to-date version of the schedule. Readings must be completed by the date given in the schedule on the course web page. Students are expected to come to class with questions that the readings raised in their minds, problems they wish to work out with the seminar, and/or derivations they wish to reproduce. Class time will be spent exploring and amplifying the ideas encountered in the readings. See section 2.1 for more details.

Occasionally, as they come up in our exploration of the material, problems and derivations will be encountered that require more time than can be used in class. In these cases, the problems may be assigned as a homework or project. Sometimes these will be completed as individuals and sometimes as groups. Projects involving solving the Lane-Emden Equation for stellar structure and deriving a microlensing light curve are already in the schedule. Others may be assigned as interest demands.

Upon completion of this course, students will have increased familiarity with the topics that are currently of interest to the Astrophysics research community. They will have had exposure to four of the foundational sets of theories on which our understanding of the universe is based: general relativity, Big Bang Cosmology, Stellar Structure, and Stellar Evolution. They will be well-prepared to continue study in graduate school, or simply to understand articles about Astrophysics that appear in the popular press.

The roots of education are bitter, but the fruit is sweet.
– Aristotle (Apothegm, circa 340 B.C.)

2 Course Requirements

2.1 Reading and Participation

The primary requirement for the course will be to complete the readings and participate in the discussions and analysis of them. When problems or experiments are assigned, you will be expected to work together to explore them, and be prepared to share what you have done at the next class session. This is a senior level class; I will be expecting you to not just do the bare minimum required, but to take initiative and think beyond the frame of the assigned reading and ask questions about what might come next.

The bulk of the course will consist of weekly assigned readings and/or problems. You will all be expected to come to class prepared to present your work and/or lead a discussion on the readings. Leading discussions will consist of a brief (15 min) summary of the material, followed by posing the questions that most puzzled you to the class to see if anyone else understood them. You should also solicit questions that puzzle the other students. Understanding the material is not required to lead a discussion, only a willingness to ask questions. Each week, the discussion leader will be chosen at random from those present.

The readings are advanced and ambitious, but I am not expecting you to digest and synthesize all the topics in all the readings. I am expecting you to complete three tasks with respect to the reading: First, you should get an overview of the concepts and relationships within the week's subject. As you read, keep a log of these ideas with short explanations and comments in your own words. This log will be invaluable as we discuss the ideas in class.

Second, you should pick one particular topic that is either the most interesting or the most confusing and delve into it in enough detail that you can explain it to the others in class. When we then meet in class, we can all explain our topics to each other, and thereby be mutually enriched. Keep an eye out for problems or derivations that you would like us to solve together.

Third, you should write down the questions that the reading evokes in you as you go. These may be simply "What the heck does that mean?" types of questions, or they can be philosophical queries about the implications of the observations, or they can be scientific questions that push the concepts beyond what is in the text. Completion of these three tasks should leave you well-prepared to lead or participate in the class discussion.

2.2 Tentative Schedule

This seminar is designed to give you experience with two major topics of modern Astrophysics at the advanced undergraduate level. These topics are Cosmology and Stars. We begin with a review of Einstein's Theory of General Relativity, as this theory is the foundation for the Big Bang model. You may wish to read Ford, Chapter 21 (from your Physics 121 course pack) over the summer as a preparation for this topic. We will use readings from Gerosh and Bradt to lay the groundwork for an understanding of the basics of GR, and then we will use Maoz and Paczinski as an example of the application of GR to physical systems.

Then we will tackle cosmology directly by exploring the evidence that has led Astronomers to accept the Big Bang as the standard model for Universal origin and evolution. Chapters from Maoz and Bradt will guide us through this topic, and then we will examine parts of seminal papers by Tonry et al. and Spergel et al. that revolutionized the field in recent times. Students will choose which of these papers to read, and explain the main points of the papers to the other half of the class.

After Fall Break, we will commence our study of stellar structure. We will examine the physics that dominates in stellar interiors and the standard models that are used to understand these objects. We will then spend two weeks exploring how stars change as their sources of fuel become exhausted. Finally, we will close the semester by examining how stars die: the violent explosions of supernovae as well as the more stately beauty of Planetary Nebulae. We will also look at the compact remnants left behind by these processes: white dwarfs, neutron stars, and black holes.

Note that there are four days with no assigned readings. These days are meant to give us a chance to catch up if we are falling behind. They fall at the end of each block of material, and therefore also give us a chance to go over any remaining questions or concerns. Exactly how we will spend these days will be decided during the previous class session.

In addition to the readings, a weekly assignment will be to monitor the astro-ph postings. Each student will pick one day of the week when s/he will read through the astro-ph abstracts published that day. You will jot down your sense of the distribution of topics, and pick *one* abstract to read in detail. At the start of each Friday class session, we will quickly report on what we learned. At the end of the semester, we will have a strong sense of what cutting-edge work is going on right now, and which topics are the most popular among astrophysicists.

Performance on assignments and engagement in class are the primary source of the grading assessment in this seminar. See section 4 for more details.

Table 1: Tentative Schedule of Readings

Date	Topic	Assignment
Aug 25	Introduction	
Aug 28	Relativity	Geroch Ch. 5
Sep 01	Gravity	Geroch Ch. 6
Sep 04	Curved Space	Bradt III-14:1-11
Sep 08	Lensing	Maoz 6.1.3, Paczinski 1986
Sep 11	Lensing	
Sep 14		Lensing Project Due
Sep 15	Cosmological Observations	Maoz 7
Sep 18	Big Bang GR	Maoz 8.1-2, Bradt III-14:12-20
Sep 22	Expansion	Maoz 8.3-5
Sep 25	Hubble Diagram	Bradt III-15:1-13
Sep 29	Cooling Universe	Bradt III-16
Oct 02	Cosmology	
Oct 06	Inflation	Bradt III-17.4
Oct 09	CMBR	Maoz 9
Oct 13	Modern Data	Tonry et al. (0305008)
Oct 16	Modern Data	Spergel et al. (0302209)
Oct 18	Fall Break	astro-ph/0704.2291 (optional)
Oct 27	Stellar Structure	Maoz 3.1-6
Oct 30	Polytropes	Prialnik 5
Nov 03	Energy	Bradt II-3, Prialnik 4.1-6
Nov 06		
Nov 09		Lane-Emden Project Due
Nov 10	Evolution Overview	Bradt II-5
Nov 13	Main Sequence	Prialnik 7.3-5
Nov 17	Stellar Evolution	Prialnik 8 (not 8.8)
Nov 20	Supernovae	Prialnik 9.1-3, Burrows (1987)
Nov 24	Supernovae	
Nov 27	Thanksgiving	
Dec 01	Degeneracy	Bradt II-8
Dec 04	Compact Objects	Prialnik 8.8 & 9.4-6, Maoz 4
Dec 08	Compact Objects	

2.3 Presentation

It is expected that each student in the Astrophysics seminar will make a 15-minute presentation to the Department Seminar on wednesday afternoon. This presentation may be on any topic touched upon during our Astrophysics seminar: a paper you read about on astro-ph, a derivation from one of our readings, or one of the projects/problems you solved. I recommend you use one of the undersubscribed time slots earlier in the semester, before everything gets crowded at the end. This presentation should use PowerPoint or Keynote as a visual aid, and should explain the material at a level that second year physics majors can follow.

2.4 Projects

There are currently two projects in the schedule. These are meant to give you some hands-on experience with implementing the mathematics we talked about in class. The first one applies the equations derived in one paper to confirm a result claimed in another paper. The second one uses your Runge-Kutta skills developed in MathPhys to derive the sizes of a Neutron Star and a White Dwarf star. More projects could be added in class, if there is interest.

These projects may be done in groups (up to and including the entire class). Those students who contributed to the writeup should be listed as authors. I expect to receive a writeup that presents your results in a clear, easy-to-read, scientific fashion. The writeup can be printed out on paper or emailed to me in PDF format. I will not accept other electronic formats. They must be either in my mailbox or emailed to me by 5 pm on the date indicated. Projects may be re-written a single time for a better grade that replaces the initial grade. This rewrite is optional, but if carried out, it must be turned in to me by 5 pm of the day one week after the day the graded project is returned.

The projects are described in PDF files posted to the course web page, and the objectives for each project are listed in those files as well. Any questions about the clarity of these objectives will be thoroughly discussed in class. A single grade will be assigned to each project based on how well the writeup completes the objectives of the project. Each author of a single writeup will receive the same grade. The grade for each project will contribute 5% of the total grade for the course. If additional projects are added, they will also count 5%, and the weighting of the participation score will be reduced to compensate.

2.5 Final Exam

To assess your understanding of the material we covered in the semester, each of you will schedule a 90-minute block of time to meet with me during finals week to complete an oral examination. I will ask you questions and pose problems raised during the course, and we will discuss together possible answers to them. Please don't panic – this is meant to be a conversation, not an interrogation.

Grades will be assigned according to the following rubric: A - comfortable with all the ideas in the course and can discuss them confidently. B - Adequate understanding, requires a lot of prompting to make connections. C - Has some familiarity with the concepts in the course, had to give up on some of the questions without much exploration. D - Poor understanding, flailed around in search of answers, stumped more often than not. F - Could not answer most questions, or did not complete exam.

In the beginning the Universe was created. This has made a lot of people very angry and been widely regarded as a bad move.
– Douglas Adams

3 Reading List

I have reserved three books that will be available at the college bookstore for purchase:

1. **Required**: Dan Maoz, "Astrophysics in a Nutshell", Princeton University Press, 2007, ISBN 0691125848

2. **Required**: Dina Prialnik, "An Introduction to the Theory of Stellar Structure and Evolution", Cambridge University Press, 2000, ISBN 052165937X

3. **Required**: Robert Geroch, "General Relativity from A to B", University of Chicago Press, 1978, ISBN 0226288641

I will also distribute photocopies of draft chapters from Hale Bradt's "Introduction to Astrophysics" as we go, and there will also be selections from other sources (see list of optional books, below), as well as the occasional refereed journal article (which may be downloaded from astro-ph). The exact sequence of readings will be posted on the course web page, but I anticipate a calendar that looks something like the schedule posted in Table 1.

There are other texts you may wish to look at (but probably not buy). I mention these because they are excellent treatments of the subjects we will be covering, and they may serve as useful supplemental materials. In no way are you expected to purchase or read any of these books. This list is merely provided for your interest.

1. Optional: Bahcall & Ostriker, "Unsolved Problems in Astrophysics", Princeton University Press, 1997, ISBN 0691016062

2. Optional: Shapiro & Teukolsky, "Black Holes, White Dwarfs, and Neutron Stars", Wiley, 1983, ISBN 04718731603

3. Optional: Rybicki & Lightman, "Radiative Processes in Astrophysics", Wiley, 1979, ISBN 0471827592

4. Optional: P. J. E. Peebles, "Principles of Physical Cosmology", Princeton University Press, 1993, ISBN 0691019339

5. Optional: Hale Bradt, “Astronomy Methods”, Cambridge University Press, 2004, ISBN 0521535514

6. Optional: Hale Bradt, “Astrophysics Processes”, Cambridge University Press, 2008, ISBN 0521846560

7. Optional: Alan Guth, “The Inflationary Universe”, Basic Books, 1998, ISBN 0201328402

8. Optional: George Gamow, “The Birth and Death of the Sun”, Dover, 2005, ISBN 0486442314

9. Optional: Robert Kirshner, “The Extravagant Universe”, Princeton University Press, 2004, ISBN 069111742X

10. Optional: Fred Adams, “The Five Ages of the Universe”, Free Press, 1997, ISBN 0684865769

Of course, there are many, many other books on these kinds of topics. See me if you’d like more recommendations.

4 Grading

This is a senior-level course. Your work is expected to be motivated, thorough, and creative. A-level work will show mastery of the topic at hand and clarity in its expression. Work will exceed the minimum satisfactory level and show thought beyond the explicit frame of the assignment, such as addressing an unforeseen implication or making a connection to another class of problem. Mistakes, if any, will be minor. B-level work will have the main idea and answer the assigned question at a functional level, but will lack the initiative and creativity to go beyond the letter of the specific assignment. Mistakes may be more serious, but still not impeding the overall sense of understanding. C-level work will contain the bare minimum amount to indicate some understanding of the assigned topic. It may contain several serious mistakes. D-level work will be rife with error and misunderstanding, or it will be so poorly written that the level of understanding cannot be accurately assessed. An F will be given to missing work or work that completely fails to show any understanding of the course material.

The grade for this course will be based on four contributions:

1. Class participation (60% of grade)

2. Final Exam (20%)

3. Seminar presentation (10%)

4. Projects (10%)

I see grades purely as an assessment tool. They are not motivations nor are they punishments. I want the grades to be completely transparent. I do not *give* you grades. You *earn* them. If you are confused as to how your work on a particular assignment corresponds to the grade you were given, please come talk to me.

5 Course Policies

5.1 Credit Hours

This course is worth two credits, although we will only spend two hours in official class contact per week. For a two-credit course, it is expected that you spend on average six hours a week on the course. This expectation is based on the faculty approved standard that students are awarded one credit for every three hours they spend on course work. I will expect you to spend about an hour each week day (on average) on your reading assignments and presentation projects. If you spend less time than this preparing for the course, the in-class time will be less fruitful and useful for you.

5.2 Attendance Policy

This class is heavily based in the participation in group discussions, and therefore chronic absence will interfere with your ability to learn what the class has to offer. Guilfords policy for classes that meet twice a week is that after six absences, you may be forcibly withdrawn from the course. If you know of an impending situation that will require your absence from class, you must contact me in advance. Tardiness is rude to your classmates and detrimental to the learning environment, and I do not allow it. If you are chronically tardy, you may find the door locked when you arrive, and you will be counted as absent that day.

5.3 Honor Code

I am a firm believer in acting with integrity and performing at least to the standard of the Guilford Honor code. The work you submit is understood to be claimed by you to be your work. If others helped you, or if you got ideas from other sources, you must credit them appropriately. I have a zero-tolerance policy for plagiarism. If I am convinced you have violated the Guilford Honor Code, you will fail this course, and the case will be referred to the Dean's office for the possibility of other consequences. According to the college catalog, the statement, "I have been honest and have not observed any dishonesty," gives testament to the honor system and should be pledged in writing on all academic work. Compliance is assumed even if the statement does not appear on college work. The word "pledged" may substitute for the longer statement.

5.4 Accommodations

Guilford complies with the Americans with Disabilities Act by providing a process for disclosing disabilities and arranging for reasonable accommodations. The policy may be found online[1]. Students who require accommodations must complete a disabilities disclosure form and submit it to the Disability Services Coordinator, located in the Learning Commons (x2253), along with the appropriate documentation. It is the students choice to disclose difference/disability

[1] http://www.guilford.edu/about guilford/values/handbook/ada.html

information to individual instructors. However, only students who provide their instructors with a 504 Accommodations Agreement may receive accommodations. All disability information is treated confidentially and is not a part of your academic record.

The usual approach of science of constructing a mathematical model cannot answer the questions of why there should be a universe for the model to describe. Why does the universe go to all the bother of existing?
– Stephen Hawking