Astronomy 206
Introduction to Astrophysics II - Galaxies and Cosmology

Prerequisite: Astronomy 205 or my consent

Instructor: Andrea Lommen, alommen@haverford.edu, KINSC Link 108, office hours TBD
Textbook: *Foundations of Astrophysics* by Ryden and Peterson, the same text used in the first semester of this course. We will cover Chapters 5.4, 16, 19-24 and also use supplementary readings.

What can I get out of this course?
Astronomy is not a practical subject. When people hear my research is supported by the National Science Foundation and NASA, and therefore by the taxes of U.S. Citizens, they usually ask about the "spinoffs." "There must be something useful that comes out of your work," they say. And I say, "Actually, no. There aren't really direct spinoffs." I can stretch a little bit and say things like "without General Relativity the GPS system on your phone won't work." Or "Pulsar Timing is the only thing pushing on terrestrial time standards (atomic clocks)." Both these things are true, and we will talk about both of them. But that's not the reason I do what I do. I think if we stop trying to understand the universe we live in, something fundamental about human nature dies. **So first of all, you can connect to one of the deepest parts of being human: your desire to connect with our origins as human beings.**

In addition to the textbook, this class contains a lot of stuff that's not in a textbook anywhere, but rather is in recently published scientific articles. If you haven't had a lot of experience reading such things (and even if you have) they can be intimidating. You will develop strategies for dealing with these manuscripts. Reading them is a craft. If you notice at the beginning of the course that you're terrible at it, that's right where you should be. **In addition to learning how to read these edge-of-knowledge articles, you will also expand your understanding to the edge of human knowledge in these fields because these peer-reviewed articles represent the edge of human understanding.**

**In one particular area you will become the class expert as you complete your own project.** We will explore a lot of different subjects in this class, and perhaps not all of them to the extent you would want to. If, as we are leaving a subject, you notice you want to explore it further consider forming it into your project. As you explore this area you will get a feel for what it's like to be surpassing the expertise of your advisor (me, in this case), which can be both thrilling and frightening at the same time. To whom will you turn when you don't know the answer? You'll rely on skills you have been acquiring throughout your
scientific career to build a case from available evidence. You'll rely on a peer network (all of the rest of us in this class) to tell you when your case needs bolstering, or to help unstick you when you've gotten stuck. Even though you may know more about it than us at that point, we still may be able to ask you questions and make suggestions that help you. We also may know people outside of our immediate community (the class) who can help - either at this institution or elsewhere. **The completion of this project will build problem solving skills that you will use for the rest of your life, not just as a professional scientist, but in any career.** As you advance in any career, there will be fewer and fewer basic skills, credentials, and training to acquire, and more and more innovations, new ideas, and frontiers to go beyond, for which no one can give you a recipe or road map. At that point you have to gather the relevant evidence, make a plan, position yourself for success as best you can using calculation, estimation, your peer network, and your intuition, and forge ahead. This course will allow you explore this liminal space, and hopefully allow you to start to feel some sense of home there - on the edge where no one really has the answers yet.

Astronomy is in the media a lot, which is a great thing. It means that the public appreciates what we do, albeit somewhat superficially, and with a journalist's slant. ("Life could be possible elsewhere in the universe!" They love to say that when all we've done is discover a planet that could be at a temperature that could have liquid water.) **For the rest of your life, you'll be able to read popular science articles with a critical eye, know where to get more information for yourself from scientific sources, and make up your own mind about the discovery.** Also, if you see articles involving gravitational waves please bring them to my attention. I'm pretty good at catching them, but I'm not perfect.

**Problem Solving Promises**

(The following are promises I put on all my syllabi. These are the promises of every physics/astrophysics course whether or not they are explicitly listed on the syllabus.)

How do you solve problems you've never seen before based on problems you have seen before? Let's say you're a medical doctor instead of a physicist. A patient comes to you with 4 symptoms you have a lot of experience with and 3 more that you don't. How do you determine which details are nuisances that will take you down rabbit holes and which details give you clues to the solution you seek? **In this course you have the opportunity to develop your ability to tackle problems you have never seen before.**

Furthermore, in solving problems, everyone (doctors, musicians, biologists, computer scientists...) goes down paths that ultimately prove wrong. How can you use those (wrong) paths to gain important insights into the ultimate solution? In
this course you have the opportunity to develop these skills. **In this course you have the opportunity to develop your ability to make profitable "wrong turns" in problem solving.**

How do you break down a really complex problem into solvable parts? Some parts you can separate and some you cannot. **In this course you have the opportunity to develop your ability to tackle really complex problems by breaking them down, wisely, into parts.**

What do you do with problems that are presented to you in a misleading way? This happens unintentionally all the time. One of your collaborators or a team member comes to you with problem that he/she is sure is caused by another person. Or a patient comes in with a set of symptoms and is sure she/he has strep throat and is prepared to convince you of this. You need to be the person who has enough perspective to consider that "Do you have strep throat?" is the wrong question. What's the right question? **In this course you have the opportunity to develop your ability to deal wisely with the different pieces of information provided to you.**

Finally, after you've come up with a solution to a problem, how do you determine if it is the right one? What checks can you do to confirm that your solution is the best one? **In this course you have the opportunity to develop your skill at checking your answer, determining if its reasonable, and relating it to other things you know (without having a "back of the book" to check!)**

Whew that was a lot. Here are the promises distilled down to a list of 9 things.

**Promises of the Course. You will:**
1. Connect to the thrill of investigating our origins.
2. Learn how to read scientific articles.
3. Expand your knowledge to the edge of human understanding in a variety of astronomical fields.
4. Become an expert in an area (of your choosing.)
5. Develop problem solving skills, specifically in solving problems you've never seen before.
6. Evaluate and criticize the media's representation of science.
7. Develop your ability to make profitable wrong turns in solving problems. In other words, learn from your mistakes.
8. Develop your ability to break down complex problems into doable parts.
9. Develop your ability to determine if your answer is reasonable.

**Overview**
This is the second half of a year-long introduction to astrophysical topics. This course will provide a physically motivated, contemporary overview of the beginning to end of the universe and everything in-between. The framework we will develop is also a pre-requisite to the study of more advanced astronomical topics. When appropriate, we will enrich our study with material outside of our text, including research articles. By the end of this year-long course, you will have experience in both basic observational and computational astronomical techniques and the ability to read basic papers in the research literature.

Labs
During the Fall semester, observational astronomy projects acquainted you with basic observational techniques and analysis. To complement this observational experience, we will conduct two labs that will require you to learn a little programming. These labs will teach you about numerical simulations as a technique to study the universe.

How to fulfill on the Promises of the Course

In order for me to deliver on the promises I just made, we need to engage in much more than me talking and you listening and you writing some stuff down and you handing it in. We need to be a team. Each of you has something to contribute to the operation of this team. Thank goodness not all of you has the same thing to contribute to the operation of the team. That would be boring and it wouldn't work very well. So first, please when you notice someone has something to contribute that isn't currently in your skill/knowledge set please practice saying something like, "This team is great! I'm glad we all have different skills."

Research shows that the more different ways you engage you with concepts, the more likely you are to be able to use that concept in the future. I am providing many different ways for you to engage the material.

Prepare for class by doing what I recommended you do after the previous class. (The grid associated with the syllabus has a column for this.) I will try to advise you in advance about which parts to pay special attention to, but knowing me I will forget sometimes, and in those cases please give some parts a try and come to class with questions. Class discussions will then clarify and strengthen your understanding of the material.

Homework. There are a variety of activities I will assign as homework, most of them will be traditional homework problems, some of them will be coding (computer programming) assignments, some will be essays, some will be collaborative, and some will be presentations.
The goal of having a variety of exercises is to get you to think about the material in as many different ways as possible so as to deliver on the promises of the course. The more you work through things on your own, your retention of the information is significantly better. Ultimately to learn new things you have to build scaffolding in your own brain. Each member of our team will do this differently and we need to respect all of them.

I remember in college (Carleton) that when I would talk over a problem with my peer sometimes I would actually start to get mad, because I could tell they were thinking about it in a different way, and I wasn't ready to stop thinking about it my way yet. I knew I almost had a solution, and if I thought about it their way, I was going to have to take down my own scaffolding. At the time I doubt I could've articulated the idea of scaffolding. In any case, I hope I was pretty good at not actually getting mad at my friend, and saying "Thank you, I need to go work on this by myself a little bit now," and working by myself. Then when I had my scaffolding up - my way of understanding it, I could usually go back to that person and say, "could you tell me again how you solved it?" And then comparing my solution to theirs was really helpful and deepened my understanding of the problem.

**Notice how you learn best.** I suspect you each have different experiences solving problems and working with peers, so my point is that you should notice what ways of working deliver the largest gains in the promises of the course. I am asking nothing less than consciousness about the way you learn new things and you will write a paper about what you notice. I invite you to jot down some thoughts (starting with today’s paper, but also throughout the course) about what you noticed about your learning process at the end of each assignment and/or bring them up in class or office hours.

**Peer Assistance:** Overall I encourage you to work together with other students in the class on homework problems and get advice from each other about projects.

**Talking with other students about the problems is yet another way to engage with the material.** It uses a different part of your brain and in particular will help you think about the different ways to do the problems. It can actually be disconcerting in a truly wonderful way to hear how classmates think about these problems. It makes you think critically at a really deep level. For example, your classmate may have arrived at the wrong answer using means that appear on the surface to be acceptable, or the right answer via a completely different method than what you used. You may get to discover together what is wrong or right! And if you don't, you should bring it to me and we can figure it out. **The ability to notice that something is wrong is enormously important.** When you notice that
something has gone wrong please congratulate yourself that you know something has gone wrong instead of beating yourself up that you did something wrong. Honestly being able to smell a wrong answer is 75% of the way toward getting the right answer.

Working Together, Plagiarism, and the Honor Code. Working together means getting together to discuss problems, asking for help from other students on a step you are stuck on, or comparing solutions. I really encourage you to work together, and I know you will want to be mindful not crossing the line into plagiarism. Plagiarism is passing off someone else's work as your own. Let’s talk about this on the first day of class, and be sure to keep talking with me if you become concerned as you work with other students. We may come up with other solutions, but to start I’d like to start with the following suggestion: for the first couple of assignments I suggest you include very brief descriptions of where your ideas came from, e.g. “I got the idea to start the problem this way from Devon.”

How will my progress in accomplishing the promises of the course be adjudicated?

This is an interesting question, because the promises are enormous and some of them are impossible to test (like connecting you with the thrill of investigating our origins). However, it’s important to get feedback throughout the semester regarding what adjustments you need to make in order to fulfill on the promises. So how can I adjudicate whether or not you are making good progress toward what I promised you? I think of it like project management rather than grading. If I were Haverford’s President and wanted a new building built by December 1st 2018, I wouldn’t just say “Hey everybody, let’s build this building by December 1 2018,” and then check in with my team again a year later on December 1, 2018 and make sure it’s done. I would have a lot of checkpoints along the way... we should have bids by October, we should have a contract by November, the foundation should be dug by December, etc. You get the idea. Back to you. Getting feedback on your progress toward the promises is a multi-faceted task, just like your participation in the course in multi-faceted. In other words, I am looking at the whole constellation of your participation in this course, not just your performance on a few things.

Assignments and Grading
The grading breakdown will roughly be: homework (40%), labs (10%), exams (40%), participation (10%). You will have an opportunity to rewrite and/or respond to my comments on homework and lab write-ups. The first time you hand it in counts for 60% of your grade on that assignment. The next time you hand it in counts for 40% of your grade on that assignment. If you choose not to do a rewrite/response your first grade counts for 100% of the assignment. Homework assignments will be due
at the beginning of class, roughly every other week for a total of 5 over the course of the semester. There will be a midterm and a final exam. There will also be articles to read, and discussions and debates to prepare for.

I consider us a team who is trying to learn this material together, rather than me some omniscient being who shall impart all her knowledge to you. So our meetings tend to be largely strategy sessions: How can we help each other, how can I help you, where are the sticking points, etc. The content will come more from you working on your own or with each other outside of class. There’s some mix of both content and strategy and logistics in most classes.

Honor Code
You may not consult any resource from any previously taught astronomy class when completing your coursework - in particular homework and exam solutions. You also may not distribute any materials you obtain when taking this class to any entity or person who is not currently enrolled in this class. If a student is interested to see example materials, then I would be happy to provide them myself.

Collaboration is an important part of doing science. I encourage you to collaborate on your homework and lab assignments. I would be happy to facilitate such collaboration if you need help setting up a study group. All assignments must still be completed by each student on her/his own, and work handed in may not have been copied off of work written down by another student or off of any other resource.

Please ask me to clarify any aspect of your coursework for which you have an honor code or plagiarism question (May I use source X for assignment Y? How should I properly credit source Y for having number Z that I used in a calculation?). I would be very happy to discuss.

Website
The class Moodle page will be your primary resource for information about this class. This site will contain the syllabus and an up-to-date list of and links to reading and written assignments. It will also provide links to resources necessary for your labs.

In particular the Moodle page will have a link to a Google document called “What you’re working on.” Please get used to look there to help you keep track of what we’re doing. You’ll find this class has a lot of moving parts. You’ll be preparing a homework set while rewriting the last one, while being asked to prepare for class. You’ll have at least two weeks notice before a problem set is due (most of them, in fact, are available right now). I’m going to try to return your first draft of your homework to you on the Tuesday after you hand it in (on Thursday). You’ll have a week to turn back in a rewrite/response (on Tuesday). Then usually 2 days later
you’ll have another homework set due. I think you’ll find it doable, but we need to help each other keep track of it all. Please do let me know as logistical issues arise. For example last semester I really appreciated when my class let me know that they all had an exam on a certain day, and if I could move my due date a little it would help them a lot.

An example of the two week cycle:
Week3: Tuesday
Week3: Thursday: Homework 1 due
Week4: Tuesday: Andrea returns HW1 with comments
Week4: Thursday:
Week5: Tuesday: Rewrite/response of HW1 due
Week5: Thursday: Homework 2 due

Here is a tentative schedule for the semester. Supplementary reading will be assigned along the way:

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<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Text</th>
<th>Written work</th>
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<tbody>
<tr>
<td>Jan. 23, 25</td>
<td>Interstellar medium (ISM)</td>
<td>Chapter 16</td>
<td>Syllabus&lt;br&gt;Response paper and Learning Styles paper due Friday! (Described below)</td>
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<tr>
<td>Jan. 30, Feb 1</td>
<td>ISM (Th. in Stokes 004)</td>
<td>Chapter 16</td>
<td></td>
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<tr>
<td>Feb 6,8</td>
<td>ISM and the Milky Way</td>
<td>Chapter 19</td>
<td>HW #1 (due Th)</td>
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<tr>
<td>Feb 13, 15</td>
<td>Milky Way</td>
<td>Chapter 19</td>
<td></td>
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<tr>
<td>Feb 20, 22</td>
<td>Milky Way and Galaxies</td>
<td>Chapter 20</td>
<td>HW #2 (Th)</td>
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<tr>
<td>Feb 25, 27</td>
<td>Galaxies</td>
<td>Chapter 20</td>
<td></td>
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<tr>
<td>March 6, 8</td>
<td>Galaxies</td>
<td>Chapter 21</td>
<td>Midterm (Fr)</td>
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<td>March 20, 22</td>
<td>Galaxies - Guest lecture on 17th</td>
<td>Chapter 21</td>
<td>HW #3 (Th)</td>
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<tr>
<td>March 27, 29</td>
<td>Large Scale Structure (both in Stokes 004)</td>
<td>Chapter 21</td>
<td></td>
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Week | Topic | Text | Written work
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April 3, 5 | Active Galaxies | Chapter 22 | Lab #1 (Th)
April 10, 12 | Cosmology | Chapter 23 | HW #4 (Th)
April 17, 19 | Cosmology - BP guest lectures for both | Chapter 24 | 
April 24, 26 | Cosmology | Chapter 24 | Lab #2 (Tue)
May 1, 3 | Cosmology and exam review | | HW #5 (Th)

Syllabus Reaction Paper: A one-page (maximum) reaction to the syllabus. Ungraded. What parts are you most excited about, what parts seems overwhelming? What are you most worried about? What doesn't make sense? This needs to be submitted electronically on Moodle by 5:00pm Friday. But I would just do it this afternoon!

Learning Style Paper: No sources, no citations. Ungraded. Write one page about how you learn best. Describe what you’ve noticed from other classes, including specific adjustments you’ve made when you noticed something wasn’t going well. Also include challenges for which you haven’t yet found solutions. Include how you tend to navigate group work situations, and where you envision yourself growing in your ability to navigate groups in this class. Include what you can do to help yourself succeed in achieving the promises of the course, and what I can do to help you succeed in achieving the promises of the course. (Remember the promises and the ways we will work to achieve the promises are on the syllabus.) This needs to be submitted electronically on Moodle by 5:00pm Friday as well. (But it’s only one page and it’s ungraded, so I bet you could knock this out in the next day or so as well! Please don’t agonize over it!)