Stargazing Through the Centuries: Astronomy in a Historical Context

SPU XX

T/Th 10:30 AM

Location TBA

Harvard University

Summary and Course Objectives

Welcome to Stargazing Through the Centuries! Since the dawn of civilizations, mankind has tried to make sense of the Universe we live in. This course follows how our understanding of space and the Universe has evolved over this extensive history. We will look briefly at ancient views of astronomy and then delve into the invention of the telescope and Galileo's first look at the moons of Jupiter. Then, we will trace the progress of astronomical knowledge through to the modern day and conclude by discussing our first glimpse of planets around stars other than our Sun. Over the course of the semester, we will delve into some of the most significant and astonishing discoveries in astronomy and see what those discoveries can tell us about the world we live in. But, perhaps most importantly, this course is about connections. By following this story from the beginning through to today, we will be able to view the process of science and how discoveries build upon one another. Scientific knowledge does not exist in a stasis, but is instead constantly changing, evolving, and building on itself. How did we develop the understanding of the Universe we have today? What role did technology play in getting us here? And, where might we be going in the coming years and decades? After taking this course, you should be able to answer a few of these important questions for yourself!

Course Details

Course website: https://www.cfa.harvard.edu/~mmacgreg/

Required Readings:

Marc L. Kutner, *Astronomy: A Physical Perspective* (Cambridge University Press 2003), ISBN: 978-0521529273

Marcia Bartusiak, *Archives of the Universe* (Random House 2010), ISBN: 978-0375713682

. . . and, excerpts from various other sources!

Course Goals

This course aims to achieve two purposes: (1) to increase your awareness of the scientific process and its role in our world and (2) to give you academic and professional skills that will benefit you in your ultimate careers. As such, the course goals can be divided along similar lines.

By the end of this course, you will . . .

Professional and Personal Goals:

- Be able to read technical articles efficiently for key concepts
- Have experience working and discussing in a group setting
- Be able to use analytical and mathematical skills to solve problems
- Acquire critical thinking skills by learning to evaluate the evidence behind a scientific theory
- Learn how to formulate, test, and evaluate hypotheses through relevant hands-on experiments

Scientific Goals:

- Learn fundamental concepts in astrophysics that will equip you to better understand new scientific discoveries made in the coming years and decades
- Have an understanding of the roles science and technology play in our everyday lives and culture
- Understand astrophysics as a way to describe our real physical world
- Come to view science as a constantly evolving process instead of a static set of rules and equations
- Be able to synthesize and integrate new information and ideas into their personal scientific framework
- Have an understanding of the techniques and methods used to gain new knowledge in physics and astronomy

Beyond these learning goals, this course aims to develop specific skills in line with the goals of the General Education program for Science of the Physical Universe.

Your Instructor

Meredith MacGregor mmacgreg@cfa.harvard.edu
Office phone: (617) 495-4484
Harvard-Smithsonian Center for Astrophysics
60 Garden St.
A-104

Office Hours: M/W 10-11 AM

I am eager to meet with you outside of class to discuss the course or astronomy in general. If these times don't work for you, please email me to set up an appointment!

Course Requirements and Grading

*Problem Sets and Lab Reports **(20%)***

There will be a total of 7 problem sets and 3 short lab reports assigned over the course of the semester. These will be handed out one week prior to the due date. Labs will be carried out in lieu of section on the relevant weeks. Lab reports are expected to be of comparable length to standard assignments, but will give you an opportunity to see what it is like to do real astronomical research. All assignments will be due at the beginning of lecture and since we will hand out solutions at that time, no late assignments will be accepted. However, we will drop the lowest score from the set of 10 total assignments.

*Class and Lab Participation **(5%)***

I expect that you will attend all lectures and sections. I do understand that sometimes things come up that are beyond your control (illness, etc.). However, please make every effort to attend and engage in the course material.

*Reading Assignments **(5%)***

Readings will be assigned once a week and are your first encounter with the material to be covered in lecture on a given week. A brief online questionnaire on the assigned readings will be due each Monday at midnight. The purpose of this questionnaire is twofold: (1) it allows me to verify that you have completed the readings and (2) it gives me a chance to tailor my lectures for the week to your areas of interest or confusion. These questionnaires will be evaluated on a 2-point scale, where 2 indicates that you have completed the readings, 1 indicates room for improvement, and 0 is incomplete or unsatisfactory.

*Timeline of Astronomy **(10%)***

Over the course of the semester you will be asked to complete a personal 'Timeline of Astronomy' synthesizing the material from lecture into a cohesive format (more instructions to be handed out soon!). Each month, you will turn your 'in progress' timeline into your TF for evaluation. The TF will score you on a 2-point scale and provide feedback on how to improve your timeline. At the end of the semester, you will turn in your completed timeline for a final grade.

*Final Project **(15%)***

The final project of the course allows you to explore a topic discussed in lecture in much greater detail and then to present your results in a creative way. All of your final projects will be incorporated into our class 'Timeline of Astronomy.' More details to follow!

*Midterm Exam **(15%)***

We will hold one midterm exam in class on Thursday, XX/XX/XX. All students are expected to take the exam at this time. If you have a conflict, please let me know immediately. Under exceptional circumstances, we can make alternate arrangements for a make-up, but these accommodations will need to be arranged will in advance.

*Final Exam **(30%)***

The date of the final 3-hour exam will be set by the Office of the Registrar and announced roughly halfway through the semester. Please note that the Administrative Board of Harvard College has sole jurisdiction over granting make-up final exams.

Grading

The course will graded on an absolute scale with the following letter grade assignments:

90-100%	75-89%	60-74%	50-60%	<50%
A, A-	B+, B, B-	C+, C, C-	D	E

Astronomy Laboratories

For three weeks during the semester, laboratories will replace regular section meetings. This is meant to mix up the routine of typical problem sets, by giving you a chance to work with real data and to see what real astronomical research is like. The order of these three labs is as follows:

Week 3: Galileo and Jupiter's Moons

> We will recreate Galileo's historical observations, by observing Jupiter's Galilean moons ourselves. To do this, we will use the Clay Telescope on the roof of the Science Center.

Week 6: Spectroscopy

> We will learn the basics of spectroscopy. We will begin by looking at the spectra of several common elements and then compare these to the observed spectrum of the Sun.

Week 8: Galaxies Other Than Our Own

> We will use data from a millimeter wave telescope located at the CfA to calculate the rotation curve of our own Milky Way galaxy.

On weeks that there are labs, the usual homework assignment will be replaced by a brief lab report. These lab reports will be of a comparable length to a typical homework assignment and will consist of several questions that you should investigate and provide answers to after performing some basic data analysis. They are certainly not meant to be a considerable undertaking and count for the same percentage of the final grade as any other homework assignment.

Policy on Collaboration

We encourage you to collaborate in class, in section, and on the homework assignments. This course is graded on an absolute scale, which is intended in part to eliminate any worries the you might lower your own grade by helping others. Your fellow classmates are a very important resource to help you understand the course material. The best strategy is to attempt all of the problems on the assignment on your own, before consulting others. That way you will benefit the most from your discussions afterwards. If you collaborate on a homework assignment or lab report, you must (1) state the names of the students with whom you collaborated, and (2) submit your own individual, original solutions or write-up, which you write without consulting someone else's solutions. Work that matches closely with that of another student, or for which you do not state the names of your collaborators, is unacceptable.

Week	Lecture	Topics	Readings	Assignments
1	Tues.	**Introduction and Early Astronomy** *What did the ancient Greeks really know about astronomy?*		
	Thurs.	**The New Heliocentric View** *What prompted Copernicus to propose his new theory?*	*Archives of the Universe*, p. 53-68	Pset #1 assigned
2	Tues.	**The Invention of the Telescope** *How did this new instrument change astronomy forever?*	Kutner, Ch. 4, p. 41-52	
	Thurs.	**The Discoveries of Galileo** *How did Galileo's work set the stage for the astronomers that came after him?*	*Starry Messenger* selections *Archives*, p. 76-96	**Pset #1 due** Pset #2 assigned
3	Tues.	**Kepler's Laws of Planetary Motion** *What important predictions did these fundamental laws make?*	NASA's page on Kepler	
	Thurs.	**Newton and Gravitation** *What other course topics have this fundamental theory as their foundation?*	*Archives*, p. 97-106	**Pset #2 due** Lab #1 in section
4	Tues.	**New Solar System Objects** *How did we miss these objects and how did we finally find them?*	*Archives*, p. 107-115, 128-133 ,and p. 149-189	
	Thurs.	**The Beginning of Spectroscopy** *What is a spectrum and why is it a useful tool in astronomy?*	Kutner, Ch. 4, p. 60-62 *Archives*, p. 203-210	**Lab #1 due** Pset #3 assigned **Timeline Check #1**
5	Tues.	**Measuring Distance in Space** *How do we measure distances in astronomy?*	*Archives*, p. 226-231	
	Thurs.	**The Sun** *What do we know about the closest star to us?*	Kutner, Ch. 6 *Archives*, p. 211-217	**Pset #3 due**
6	Tues.	**Everything Stars!** *What can we learn about other stars and how do we learn it?*	Kutner, Ch. 9	
	Thurs.		*Archives*, p. 233-249	**In class midterm** Lab #2 in section
7	Tues.	**Star Formation and Stellar Evolution** *How do stars form and evolve?*	Kutner, Ch. 15	
	Thurs.		Kutner, Ch. 10 *Archives*, p. 377-397	**Lab #2 due** Pset #4 assigned

Week	Lecture	Topics	Readings	Assignments
8	Tues.	**The Cosmic Distance Ladder** *How do we determine distances when are usual methods fail?*	Kutner, Ch. 10, p. 179-183	
	Thurs.	**Hubble and Galaxies** *How did we come to realize that there are galaxies other than our own?*	Kutner, Ch. 18, p. 339-345 *Archives*, p. 413-414	**Pset #4 due** Lab #3 in section **Timeline Check #2**
9	Tues.	**New Wavelengths of Observation** *What can we learn about the Universe using other wavelengths of light?*	Kutner, Ch. 4, p. 62-77 *Archives*, p. 449-464, p. 495-502, and 522-528	
	Thurs.	**The Discovery of the CMB** *How did this discovery change our notion of the formation of the Universe?*	*Archives*, p. 363-376	**Lab #3 due** Pset #5 assigned
10	Tues.	**Mapping the Universe** *How did we start to map and unravel the structure of the Universe?*	Kutner, Ch. 18, p. 345-351 *Archives*, p. 583-590	Start thinking about the topic for your final project
	Thurs.	**The Space Age** *How did the invention of rockets and the space program impact astronomy?*	Kerbal Space Program resources	**Pset #5 due** Pset #6 assigned
11	Tues.	**New Telescopes, New Discoveries** *How did sending telescopes into space expand our astronomical horizons?*	*Archives*, p. 591-599	
	Thurs.	**Introduction to Modern Observations and Cosmology** *What are our modern views?*	Kutner, Ch. 20-21 selections	**Pset #6 due** Pset #7 assigned **Project topic due**
12	Tues.	**Modern Cosmology** *How do we think the Universe formed and how do we know that?*	Kirshner, *Extravagant Universe* selections *Archives*, p. 415-424	
	Thurs.		*Archives*, p. 576-582	**Pset #7 due** **Timeline Check #3**
13	Tues.	**Worlds Other Than Our Own** *How do we learn about planets around other stars?*	*Archives*, p 600-623	
	Thurs.		Seager, "Introduction to Exoplanets"	**Final project due** **Final timeline due**

Astronomical Timelines

Science is all about connections, both historical and physical. Each new discovery builds off of previous knowledge and provides a stepping-stone for future science. In astronomy, this is particularly true. Since the invention of the telescope we have continually been improving our technology and, as a result, exploring further and further into the depths of our Universe. For Galileo, it was heresy to suggest that the Earth was not the center of the Universe. Today, we are learning about planets around other stars and even about the initial formation of our Universe (you'll learn more about the recent BICEP-2 discovery in a future assignment!). We have certainly come a long way in our understanding of astronomy. But, to better appreciate that, we have to keep in mind how we got to where we are today and where we might be going in the years after you leave Harvard.

This assignment serves two purposes. The first is to give you a better understanding of connections in astronomy. By creating a 'Timeline of Astronomy,' you will begin to see the process of scientific discovery and the 'baton pass' from student to teacher that pushes science forward. The second part of the assignment allows you to take your new understanding of how astronomical discoveries fit together and turn it into something creative that synthesizes the information in a way accessible to the general public.

Assignment Overview:

This assignment has two parts:

1. Develop a 'Timeline of Astronomy' over the course of the semester
2. Pick one of the significant astronomical discoveries we discussed in the course, do additional research to understand it more deeply, and then develop a creative project that presents your new knowledge to the rest of the class

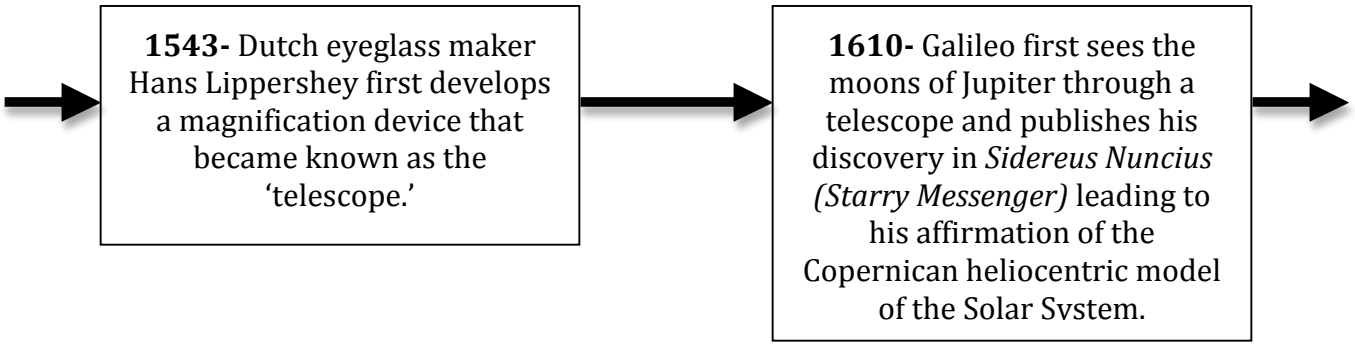
Don't worry if this seems overwhelming! This assignment is intended to stretch over the whole semester, with several smaller due dates along the way to help keep you on track.

Part 1: Individual Timeline

The purpose of this assignment is to synthesize the material from lecture into a 'Timeline of Astronomy.' Let's be a bit more specific. Your timeline might start with the following entry:

> **1543-** Nicolaus Copernicus' renowned book discussing a heliocentric worldview, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), is first published.

You should then link that entry to subsequent important events or discoveries in astronomy. For example, your timeline might continue as follows:



Over the course of the semester, you will build up a complete trajectory of scientific discovery. Here are a few things to keep in mind:

1. Your timeline entries should include enough information that another reader of your timeline would clearly understand the importance of each event. For example, instead of writing "Galileo discovers the moons of Jupiter," you might instead write "Galileo discovers the moons of Jupiter, which led to his affirmation of the Copernican heliocentric model of the Solar System." The second sentence conveys both the discovery *and* the ultimate significance of it.
2. Try to emphasize connections! If Galileo was only able to see the moons of Jupiter because of the invention of the telescope, make sure that is clear in your timeline.

We have obtained a course account for the online interactive timeline tool Tiki-Toki (*http://www.tiki-toki.com*). Instructions for setting up your own Tiki-Toki account will follow in a subsequent document. This website provides you with a simple tool to create your timeline for this course. Then, each month, you will simply provide a link to your online timeline to your TF for checking and grading purposes.

Our 'official' course timeline . . .

At the end of each month, the TFs will be posting the 'official course timeline' to the website using the same interactive timeline tool, Tiki-Toki. You can use this 'official' timeline to compare your own work to what your TFs think is most important to keep in mind. Combining this with the comments you receive on your own timeline each month should help you develop your understanding of the course material further. And, of course, you can check what important discoveries and connections you might be missing, so that you can make your final graded product that much better!

Important due dates:

- Last section of each month: Turn in your timeline as it stands to your TF. Timelines will be returned the following week with comments. This will help keep you up to date with the course material, so you don't have to rush to finish at the end of the semester.
- Final class: Turn in your finalized timeline to your TF to be included in your final grade for the course.

Over the course of the semester, your TFs and myself will be available during office hours to discuss the timeline and any questions you might have.

Part 2: Creative Further Exploration

This second assignment is designed as an add-on to the first timeline assignment. It will give you a chance to explore a significant astronomical discovery, the events leading up to it, and its impact on future science. And, it will let you consider all of this *creatively*! Each person in the course will select a significant milestone in the history of astronomy, say, Galileo's discovery of the moons of Jupiter. Next, you will do additional research to learn more about the science of that discovery and its historical context. Finally, you will condense this research into a final project that presents your new understanding in a fun and creative way at a level that is accessible to the general public. We are leaving it up to you what kind of format your final project will take. Let's consider our example topic further. If you chose to do Galileo and Jupiter's moons, your final project might discuss Copernicus and the heliocentric model of the Solar System, the invention of the telescope, Galileo's actual observations, our current understanding of the structure of the Solar System, . . . The list can go on and on! For obvious reasons, we don't expect your video to discuss *every* possible connection and nuance of this discovery. The trick will be distilling all of this information down to what best represents the science and the connections you want to emphasize.

A few critical details . . .

We are leaving it up to each of you to decide what form your final project will take. You can choose to do a video, podcast, website, blog post, etc. The majority of your final grade will be based on the content of your project. However, we encourage you to be as creative as you want! The goal of the project is to deepen your understanding of a significant astronomical discovery, while also emphasizing that science can be learned and presented in ways that are more creative than the typical research paper. If you need some inspiration to get started, check out this wonderful YouTube video created for the 400th anniversary of Galileo's discoveries:

https://www.youtube.com/watch?v=l8WBMlmWJLo

This should give you a good idea of how your project might demonstrate the connections and process of scientific discovery. Keep in mind you should include a bit more content than this example. And, of course, we don't expect a polished music video or original composition. A simple and clear presentation is perfectly adequate. But, don't hesitate to be as creative as you want to be!

On a final note, we will be incorporating all of your final projects into our completed 'official course timeline.' When you turn in your project, we will add it as an insert to the online interactive timeline (we will demonstrate how this will work in class). After everyone has completed their project, you will be able to click on each event in the timeline and see the work your classmates have done over the semester. In the end, this comprehensive timeline should prove to be an excellent study tool for the final exam!

Important due dates:

Week 10: Select a topic

Week 11: Meet with your TF to discuss your plans for the final project
* Turn in a two-page description of topic and connections you might focus on. Make sure to include 3-5 sources you plan on using.

Week 12: Continue working on your project

Week 13: Finalize your project
*Turn in the finalized project on the last day of class!

Motivation for this assignment:

This course emphasizes connections, both historical and physical, within astronomy. Sometimes it is easier to see those connections when they are presented visually. The first part of this assignment aims to solidify those connections for the students by asking them to create a 'Timeline of Astronomy' over the course of the semester, which they will eventually be able to use on the final exam. The second part of this assignment aims to show students that science can be creative, not simply memorizing facts and equations out of a textbook. Students will use their imagination and creativity to turn a piece of their timeline into a creative project that not only explains the relevant connections at a deeper level, but also presents the material at a level appropriate for the general public.

**This will not be shared with the students, but provides a bit more context as to how this assignment was created and formatted.*

Name: _____

Feedback on Timeline Check #_____

0	1	2
Timeline is incomplete or not turned in at all. No connections between discoveries are evident.	Timeline is missing some significant pieces from lecture, but is mostly complete and connections between events are clear.	Timeline includes all significant pieces from lecture. Connections between entries are clear.

Score: _____

Comments and Suggestions:

Stargazing Through the Centuries: Astronomy in a Historical Context

Course Rationale

Course Description

Since the dawn of civilizations, mankind has tried to make sense of the Universe we live in. This course follows how our understanding of space and the Universe has evolved over this extensive history. We will look briefly at ancient views of astronomy and then delve into the invention of the telescope and Galileo's first look at the moons of Jupiter. Then, we will trace the progress of astronomical knowledge through to the modern day and conclude by discussing our first glimpse of planets around stars other than our Sun. Over the course of the semester, we will delve into some of the most significant and astonishing discoveries in astronomy and see what those discoveries can tell us about the world we live in. But, perhaps most importantly, this course is about connections. By following this story from the beginning through to today, we will be able to view the process of science and how discoveries build upon one another. Scientific knowledge does not exist in a stasis, but is instead constantly changing, evolving, and building on itself. How did we develop the understanding of the Universe we have today? What role did technology play in getting us here? And, where might we be going in the coming years and decades? After taking this course, students should be able to answer a few of these important questions for themselves!

Target Audience

This course is designed as a general education level course in astronomy that aims to introduce students to our current understanding of the field as well as to the process of science and its role in our world. Thus, the course will be open to all students who have an interest in learning more about the field of astronomy and our Universe. No prior background in physical sciences will be required.

Why this course?

Most introductory astronomy courses are taught straight from a textbook. A set number of 'crucial' concepts are presented in a fairly arbitrary order without any attempt to build connections between concepts. This method of teaching gives students the false perspective that science consists simply of a collection of known theorems that describe unconnected phenomena. Students in such courses get no perspective on how science is actually undertaken and how it describes a real physical world where each part is intimately connected to every other part. This course was designed to change this view. Over the course of the semester, students will not only learn the fundamental concepts of modern astronomy and astrophysics, but will also be asked to explore how scientific discoveries build off of each other. In addition, students will be exposed to how topics discussed in lecture apply to real world scenarios and applications. By structuring the course in this way, the hope is that the students will come away with a new understanding

of science as a process that is continuously evolving over time and that makes predictions about our real physical world.

Course Goals

This course aims to achieve two purposes: (1) to increase students' awareness of the scientific process and its role in our world and (2) to give students academic and professional skills that will benefit them in their ultimate careers. As such, the course goals can be divided along similar lines.

By the end of this course, students will . . .

Professional and Personal Goals:

- Be able to read technical articles efficiently for key concepts
- Have experience working and discussing in a group setting
- Be able to use analytical and mathematical skills to solve problems
- Acquire critical thinking skills by learning to evaluate the evidence behind a scientific theory
- Learn how to formulate, test, and evaluate hypotheses through relevant hands-on experiments

Scientific Goals:

- Learn fundamental concepts in astrophysics that will equip them to better understand new scientific discoveries made in the coming years and decades
- Have an understanding of the roles science and technology play in our everyday lives and culture
- Understand astronomy as a way to describe our real physical world
- Come to view science as a constantly evolving process instead of a static set of rules and equations
- Be able to synthesize and integrate new information and ideas into their personal scientific framework
- Have an understanding of the techniques and methods used to gain new knowledge in physics and astronomy

Beyond these learning goals, this course aims to develop specific skills in line with the goals of the General Education program for Science of the Physical Universe.

Course Format

This course is designed to have biweekly lectures (tentatively, Tuesday and Thursday mornings). In addition to these lectures, weekly sections will be essential. Students will be assigned to sections after enrolling in the course. Starting the second week of classes, sections will meet regularly each week for the remainder of the semester. These sections will serve several purposes, including:

1. An opportunity for teaching fellows (TFs) to clarify and review concepts discussed in lecture that remain unclear to the students

2. A chance for the students to ask questions concerning course assignments
3. Provide hands-on learning experiences through laboratories for students to interact with the real process of doing science

There will be three laboratories over the course of the semester. Each laboratory will be carried out within section and the write-up following will replace the problem set for that particularly week. Currently, laboratories are scheduled to take place in section during weeks 3, 6, and 8 with reports due during weeks 4, 7, and 9. During the other weeks of the semester, section will be reserved for review, questions, discussions, and time to work on assignments.

Relevant Pedagogy

The main pedagogical principle used in designing this course is 'backward design,' meaning that the entire course is structured around a few critical learning goals. Once these learning goals are chosen, the lectures, course calendar, and assignments are all designed to emphasize these goals and to evaluate that they are being met. The first learning goal for this course is that students should leave at the end of the semester with an understanding of science as a process, not simply as a static set of theorems. In order to achieve this goal, the course calendar was designed to emphasize the evolution of astronomy throughout history. The first lectures discuss the invention of the telescope and the first discoveries that depended on this new instrument. Then, the lectures move forward through time, farther out in the Universe, and onwards to better and better technology. In order to assess this goal, students will complete a two-part 'Timeline of Astronomy' project over the course of the semester that will provide a visual tool to illustrate connections between scientific discoveries. The second learning goal for the course is that students will become aware of how concepts discussed in class are relevant to the real world and modern events. To this end, each lecture will end with an introduction to a current topic, event, or discovery that relates to the subject discussed in that lecture. This routine will give students a chance to begin thinking about how the equations and concepts covered in class can be applied in the real physical world. The course problem sets will follow-up on the lectures and assess whether or not students have actually learned how to apply concepts from lecture to real problems. Instead of using 'canned' book problems, the homework assignments for each week will include problems that expand on the applications discussed in class. This format will hopefully give students an opportunity to explore these applied scenarios more fully and begin to see how astronomy really does describe a physical world. The use of 'backward design' in this course means that each week of lectures and assignments connects back to the overarching learning goals. This practice should ensure that these goals are not forgotten over the course of the semester and that the students in the course achieve these goals by the end of the semester.