Term Information

Effective Term	Autumn 2023
Previous Value	*Spring 2014*

Course Change Information

What change is being proposed? (If more than one, what changes are being proposed?)

We propose a re-numbering of Astronomy 1140 to 2140. The revised course, Astronomy 2140, is proposed for inclusion in the Origins and Evolution Theme. It will also continue to satisfy the legacy Foundations course requirement, although it is not eligible for the new Foundations (which require 4 credits and a lab).

What is the rationale for the proposed change(s)?

Astronomy 2140 was one of the 10 initial courses submitted in the approved proposal for the Origins and Evolution Theme. To create Astronomy 2140, we extensively revised the prior Foundations 1140 course, and we view 2140 as a logical replacement for 1140. The proposed changes include a number of elements that require a 2000-level designation rather than a 1000-level designation. These include the requirement that the natural sciences Foundation be satisfied, readings, problem sets, in-class discussions, field trips, a variety of assessment tools, and a greater emphasis on interdisciplinary questions.

What are the programmatic implications of the proposed change(s)?

(e.g. program requirements to be added or removed, changes to be made in available resources, effect on other programs that use the course)?

The new course will satisfy the GE Themes, but not the foundations. The precursor course was not a prerequisite for other courses, and neither is the proposed 2140 course. We therefore expect no net impact on other programs. Neither course requires a laboratory, so there is no change in required laboratory facility needs.

Is approval of the requrest contingent upon the approval of other course or curricular program request? No

Is this a request to withdraw the course? No

General Information

Course Bulletin Listing/Subject Area	Astronomy
Fiscal Unit/Academic Org	Astronomy - D0614
College/Academic Group	Arts and Sciences
Level/Career	Undergraduate
Course Number/Catalog	2140
Previous Value	*1140*
Course Title	Planets and The Solar System
Transcript Abbreviation	Solar System
Course Description	We study the formation, current properties, and evolution of the Sun, planets and minor bodies of the Solar System; how they compare with planetary systems around other stars; and how people, over millennia, inferred that the Earth was not at the center of the Universe.
Previous Value	*Physical nature of the sun and its family of planets, satellites, comets and minor bodies; gravitation, light, and telescopes. Not recommended for students who plan to continue in astronomy or physics.*
Semester Credit Hours/Units	Fixed: 3

Offering Information

Length Of Course	14 Week, 12 Week
Flexibly Scheduled Course	Never
Does any section of this course have a distance education component?	No

Grading Basis	Letter Grade
Repeatable	No
Course Components	Lecture
Grade Roster Component	Lecture
Credit Available by Exam	No
Previous Value	**Yes**
Previous Exam Types	*EM Tests via Office of Testing*
Admission Condition Course	Yes
Admission Condition	Natural Science
Off Campus	Never
Campus of Offering	Columbus, Lima, Mansfield, Marion, Newark, Wooster
Previous Value	*Columbus, Lima, Mansfield*

Prerequisites and Exclusions

Prerequisites/Corequisites	Prereq: Completion of the Natural Science GE Foundation and Math at the level of 1050 or higher, or permission of instructor.
Previous Value	*Prereq: ACT Math Subscore of 22 or higher, or Math Placement Level R or better, or Math 1050 (075) or 102, or permission of instructor.*
Exclusions	Not open to students with credit for 1140, 1161, 1161H, or 2291.
Previous Value	Not open to students with credit for 1161 (161), 1161H (161H), 2291 (291), or 171.
Electronically Enforced	No

Cross-Listings

Cross-Listings

Subject/CIP Code

Subject/CIP Code	40.0201
Subsidy Level	General Studies Course
Intended Rank	Freshman, Sophomore, Junior, Senior

Requirement/Elective Designation

General Education course:

Physical Science; Origins and Evolution

Previous Value

General Education course:

Physical Science

Course Details

Course goals or learning objectives/outcomes

- The course goals and learning objectives are taken from those required for all new GE courses, as well as those specific to the Origins and Evolution Theme. The goals are below, and the learning objectives are given in the attached ELO questionnaire.
- General GE Goal 1: Successful students will analyze an important topic or idea at a more advanced and in-depth level than the foundations. (abridged)
- General GE Goal 2: Successful students will integrate approaches to the theme by making connections to out-of-classroom experiences with academic knowledge or across disciplines and/or to work they have done or will do in other courses. (abridged)
- Origins and Evolution GOAL 1: Analyze the origins and evolution of natural systems, life, humanity, or human culture at a more advanced and in-depth level than in the Foundations component.
- Origins and Evolution GOAL 2: Integrate approaches to the origins and evolution of natural systems, life, humanity, or human culture by making connections to their own experiences and to other course work they have done or will do. (abridged)
- Origins and Evolution GOAL 3: Appreciate the time depth of the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.
- Origins and Evolution GOAL 4: Understand the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.

Previous Value

- *Understanding the basic principles and central facts of astrophysics, and their relation to other ideas in the physical and biological sciences*
- *Understanding how we discovered the important principles and facts of astrophysics, thus understanding key events in the history of science both as events in human history and as case studies in the methods of science.*
- *Investigating the relationship between science and technology.*
- *Understanding the social and philosophical implications of major scientific discoveries.*

Content Topic List

- Motions in the Sky: What people in the distant past could measure and how they interpreted it. The size & shape of the Earth, motions of the Sun, Moon, and planets; seasons and eclipses.
- Development of the Heliocentric Model; Kepler's and Newton's Laws; the interaction of light and matter.
- Present-day constituents of the Solar System: the Sun, planets, and small bodies. The formation and evolution of our solar system, and the tools that we use to reconstruct them.
- Other worlds. The discovery of planets around other stars, their properties, and how they compare with our solar system.

Previous Value

- *Basic astronomy: the celestial sphere, seasons and calendars, eclipses*
- *Dynamics of the Solar System: Copernicus, Kepler, Galileo, and Newton*
- *Light and atoms*
- *Telescopes and starlight*
- *Constituents of the Solar System: the Sun, planets, and small bodies*

Sought Concurrence

No

Attachments

- Astronomy_2140_OE elo_questionnare_proposed.docx: ELO questionnaire

  (GEC Model Curriculum Compliance Stmt. Owner: Pinsonneault,Marc Howard)

- Astronomy_2140_syllabus_proposed.docx: Proposed New Syllabus

  (Syllabus. Owner: Pinsonneault,Marc Howard)

- Ast1140Sp19Syl.pdf: Sample prior syllabus

  (Syllabus. Owner: Pinsonneault,Marc Howard)

Comments

- This is one of four astronomy courses being transitioned from the 1000 level to the 2000 level. *(by Pinsonneault,Marc Howard on 08/30/2022 01:01 PM)*

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Pinsonneault,Marc Howard	08/30/2022 01:02 PM	Submitted for Approval
Approved	Weinberg,David Hal	08/30/2022 02:16 PM	Unit Approval
Approved	Vankeerbergen,Bernadette Chantal	09/27/2022 01:43 PM	College Approval
Pending Approval	Cody,Emily Kathryn Jenkins,Mary Ellen Bigler Hanlin,Deborah Kay Hilty,Michael Vankeerbergen,Bernadette Chantal Steele,Rachel Lea	09/27/2022 01:43 PM	ASCCAO Approval

Astronomy 2140: Planets and the Solar System
Template Syllabus

3 contact hours per week, lecture format with in-class participation and questions

GE Theme: Origins and Evolution

Course Material

Astronomy is the oldest science. Since prehistoric times, humans have used the sky for both creative and practical purposes. Even without modern technology, ancient people could infer basic properties of the Earth – such as its shape and size – and could develop models explaining what we see in the sky. This enterprise continues into the present day. We study the planets in our solar system with a range of tools and have launched numerous satellites to study them. We are also now firmly in the era of exoplanet studies and can place our Solar System in a broader context.

In this course we begin by studying how, over the course of millennia, humans inferred that the Earth was not the center of the Universe. We then answer fundamental questions about the planets in our own solar system: how did they form, and what were they like in the past? Why are the terrestrial planets so different from one another? Why do we have giant planets with many moons in the outer solar system? How does our system compare with others?

This course covers three primary topics:

The emergence of the heliocentric model of the Solar System

The origins, properties and evolution of our Solar System

Planets around other stars

This course begins with a brief introduction to practical astronomy and ends with a discussion of whether we are alone in the Universe.

Course Topics

The course will cover the following topics. The week-by-week breakdown is approximate.

Introduction: Motions in the Sky

- What people in the distant past could measure and how they interpreted it. The size & shape of the Earth. Viewing the sky from Earth and constellations.
- Daily, monthly, and annual motions; calendars and navigation.
- The Zodiac and seasons; motions & phases of the Moon. Solar & lunar eclipses.

From Geocentric to Heliocentric: The Birth of Modern Astronomy and Physics

- Motions of the Planets. From Geocentric to Heliocentric; Ptolemy's Model; Copernicus; Galileo, Tycho, & the Copernican Revolution.
- Kepler's Laws and the Scale of the Universe; Newton's Laws of Gravity & Motion.
- The properties of light, blackbody radiation, and the temperature of the Earth.

Understanding the Solar System

- Overview of Solar System formation; the properties, origin, and evolution of the terrestrial planets; the stable, runaway, and failed greenhouse effects and atmospheric evolution; the habitability of Mars.

- Telescopes, spacecraft & spaceflight. The outer solar system. Giant planets and their moons. Tides & tidal locking; resonances; the habitability of Europa, Enceladus, & Titan.
- Minor Bodies in the Solar System: asteroids and comets. The Kuiper Belt and the Oort Cloud.

Other Worlds

- The discovery of exoplanets; their properties and demographics. The exoplanet menagerie: Super-Earths, mini-Neptunes, hot and warm Jupiters.
- New insights into Solar System formation & evolution: migration and scattering. Current frontiers in exoplanet research
- Are we alone? The search for biosignatures and the Fermi Paradox.

Prerequisites

The prerequisites for this course are completion of the Natural Science GE Foundation and math at the level of Math 1050. The math in this course will not go beyond simple algebra, but there will be equations and geometrical or mathematical reasoning in some lectures and assignments. The math itself will not be difficult, but the concepts will be challenging, and *translating concepts into equations and back is one of the major things you will learn during the course*.

Course Materials

The subject matter in the course benefits from a variety of potential sources. *OpenStax Astronomy* by Fraknoi, Morrison, Wolff: https://openstax.org/details/books/astronomy is a useful general resource. *The Planets* by Andrew Cohen and Brian Cox is a readable and comprehensive survey of our solar system, while *The Planet Factory: Exoplanets and the Search for a Second Earth* by Elizabeth Tasker tells the story of exoplanets. *Empires of Time: Calendars, Clocks, and Cultures* by Anthony Aveni covers the interplay between astronomy and timekeeping. *Coming of Age in the Milky Way* by Timothy Ferris is a well-written popular science book related to the history of both the heliocentric hypothesis and the relationship between it and our theories of physics. Selected portions of these texts are the basis for both in-class discussions and the homework assignments below. We emphasize texts that are open-source when possible; failing that, they are available on reserve, or affordable via standard outlets such as Amazon.

Assessments, exams, and grading.

In Class Exercises and Mini-quizzes. To encourage you to engage with the material and to give you an opportunity to earn points for effort and participation, many classes will feature "in-class" exercises. Discussion with your classmates is encouraged (and sometime required). In-class exercises comprise 20% of the total grade.

Homework. Homework will be assigned at regular intervals, with a total of 6 assignments during the semester. The lowest-scoring homework will be dropped. Homework assignments involve answering questions related to text readings and short essays about selected topics and total 20% of the grade.

Quizzes and Final Exam. Depending on the size of the course, and the goals of the instructor, we adopt a mixture of short answer or multiple-choice questions on these tests. Study guides are distributed in advance of the exams, and the questions are drawn from the list of study guide questions. Four in class quizzes, covering the four major sections (Motions in the Sky; Geocentric to Heliocentric; The Solar System; Other Worlds) comprise 10% of the grade each, with a cumulative final exam being 20% of the total.

Students with Disabilities

Students with disabilities that have been certified by Office of Student Life Disability Services (SLDS) will be appropriately accommodated and should inform the instructor as soon as possible of their needs. SLDS is located in 98 Baker Hall, 113 W. 12th Avenue; Phone: 292-3307, VRS: 429-1334; (slds.osu.edu). We will rely on SLDS to verify the need for accommodation and work with them to develop appropriate strategies. Students with disabilities who have not previously contacted SLDS are encouraged to do so by visiting the SLDS website and requesting an appointment. Please take care of this well in advance of the exams, as processing the paperwork takes time.

Academic Misconduct

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term academic misconduct includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct (studentconduct.osu.edu).

Learning Objectives

General Education Learning Goals & Outcomes

The Curriculum Committee of the College of Arts & Sciences requests that syllabi of all GE courses list the goals and learning objectives for the relevant category of the GEC.

Goals: Successful students will:

1. Analyze the origins and evolution of natural systems, life, humanity, or human culture at a more advanced and in-depth level than in the Foundations component.

2. Integrate approaches to the origins and evolution of natural systems, life, humanity, or human culture by making connections to their own experiences and by making connections to work they have done in previous classes and/or anticipate doing in the future.

3. Appreciate the time depth of the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.

4. Understand the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.

Expected Learning Outcomes, Origins & Evolution Theme

Successful students will be able to:

1.1 Apply their understanding of scientific methods to quantitative calculations.

1.2 Engage in critical and logical thinking about the origins and evolution of the universe, physical systems, life on earth, humanity or human culture.

2.1 Identify, describe, and synthesize approaches to or experiences of origins and evolution questions in different academic and non-academic contexts.

2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.

3.1 Illustrate their knowledge of the time depth of the universe, physical systems, life on earth, humanity or human culture by providing examples or models.

3.2 Explain scientific methods used to reconstruct the history of the universe, physical systems, life on earth, humanity or human culture and specify their domains of validity.

3.3 Engage with current controversies and problems related to origins and evolution questions.

4.1 Describe their knowledge of how the universe, physical systems, life on Earth, humanity or human culture have evolved over time.

4.2 Summarize current theories of the origins and evolution of the universe, physical systems, life on earth, humanity or human culture

Astronomy 1140, Spring Semester, 2019

TuTh 11:10-12:30 PM
Room: Hitchcock Hall 324

Professor: Marc Pinsonneault
Office: 4043 McPherson Lab
Office Hours: W 2:30-3:30 PM;
Tu 1:30-2:30 PM or by appointment
Email pinsonneault.1@osu.edu

TA: Lyra Cao
Office: 4020 McPherson Lab
Office Hours: W 11AM-noon
M 1-2 PM or by appointment
Email cao.861@osu.edu

Grading, Exam and Textbook Summary:

- *6 in-class mini-quizzes*. These exercises, given roughly every other Thursday, will be based on questions discussed in class and will represent 10% of the grade (15 POINTS). Lowest dropped.
- *3 in-class exams*. These will be 60% of the total grade (90 POINTS) and are in multiple choice format. Makeup exams require a medical excuse and will be in short answer format.
- *Final Exam.* The final exam is 30% of the total grade (45 POINTS). ***The Cumulative Final Exam is Monday, April 29 from 10:00-11:45.***
- The (recommended) text is Chaisson & McMillan "Astronomy Today" (9^{th} ed.)

Syllabus

I. MOTIONS: EARTH, MOON, SUN, STARS. GEOCENTRIC & HELIOCENTRIC MODELS. GRAVITY AND MECHANICS

Week 1 1/8 – 1/10: Introduction; size and shape of the Earth. Moon and Sun: Phases and Seasons.
Week 2 1/15-1/17: Eclipses; motions of the stars and planets; the geocentric model of the Solar System. **Miniquiz.**
Week 3 1/22-1/24: Copernicus, Tycho and Kepler. Kepler's Laws.
Week 4 1/29 - 1/31: Galileo and his trial. Newtonian mechanics and gravity. **Miniquiz.**
Week 5 2/5 - 2/7: Newton and Kepler's Laws Explained; proofs of the motion of the Earth; Modern Physics. **QUIZ 1 2/5**

2. THE INNER SOLAR SYSTEM

Week 6 2/12 - 2/14: Properties of Light. The Sun. **Miniquiz.**
Week 7 2/19 - 2/21: Comparative Planetology. Geology of the Earth**.**
Week 8 2/26 - 2/28: Geology of the Terrestrial Planets and the Moon. Atmospheres of the Terrestrial planets. The greenhouse effect and retention of atmospheres. **Miniquiz.**
Week 9 3/5 – 3/7: Climate Change. Asteroids and Resonances. **QUIZ 2 3/7**
SPRING BREAK 3/11 – 3/15 NO CLASS

3. THE OUTER SOLAR SYSTEM AND EXTRASOLAR PLANETS

Week 10 3/19 – 3/21: Gas and Ice Giants. Tides, Rings and the Galilean Moons.
Week 11 3/26 – 3/28: Moons of the giant planets, comets & KBOs. The Kuiper Belt & Oort Cloud. **Miniquiz.**
Week 12 4/2 – 4/4: Formation of the Solar System: Static and dynamic models.
Week 13 4/9 – 4/11: Extrasolar Planet (ESP) detection and properties. **Miniquiz.**
Week 14 4/16 – 4/18: Migration and scattering in exoplanets. Life in the Universe. **QUIZ 3 4/16**

Astronomy 1140 is a General Education Curriculum (GEC) Physical Science course in the Natural Science category. The goals for this course include:

- Understanding the theories and methods of modern astrophysics
- Investigating the relationship between science and technology
- Exploring the effects of science and technology on the environment.

Learning Objectives:

- To investigate the basic facts, principles, theories and methods of modern science as practiced in astrophysics.
- To learn important events in the history of astrophysics, particularly the discovery of the size and age of the Universe and our place within it.
- To explain the role of modern technology in the investigation of astrophysical phenomena.
- To consider human impacts on planet Earth, including topics such as energy balance and effects of human activity.

New Theme Course Submission Form

Astronomy 2140: Planets and the Solar System

Submitted for approval for the new theme "Origins and Evolution"

Background Statement

Astronomy 1140, Planets and the Solar System, has been taught as a Natural Sciences GE course since 2009. Traditionally, Astronomy has numbered all of its GE classes at 1000-level and used 2000-level and above for calculus-based courses designed for astronomy & astrophysics majors. Under the revised GE, we are numbering Foundation courses at 1000-level and renumbering the Theme courses to 2000-level. These courses, including Life in the Universe, have always required the application of algebra and geometry to understanding the physical universe and solving astrophysics problems. Our renumbering partly acknowledges that students have always regarded these courses as challenging, and it also recognizes the higher level of presentation, discussion, and assignments that are feasible now that students will have completed the Natural Sciences Foundation requirement before taking them. We have added required readings, homework, and more heavily weighted in-class discussions as well.

This course covers four main themes. First, we study the human view of the sky from Earth and how it affects our everyday life, from timekeeping to calendars to navigation, as well as its role in story-telling and divination. We use planetarium shows and, when available, night sky observations as learning components. Second, we learn about how humans learned about the nature of the Earth and the solar system although they were tied to a moving body much bigger than they were. Through creativity, logic and geometry, humans inferred that the Earth is round, it goes around the Sun, and the scale of the solar system and of the stars. The Copernican revolution put Earth and humans in their proper perspective. These ideas developed over millennia, and therefore fit the deep history of human culture aspect of the theme. The emphasis in the first and second themes is on physical reasoning: what do we observe in phenomena like the phases of the Moon, eclipses, or seasons, and how could we explain them? How do planets move in the sky, and why is that pattern difficult to explain on a stationary Earth? The complete replacement of the geocentric model by the heliocentric one is an ideal framework for addressing the role of paradigms and paradigm shifts in science, as well as the role of culture and technology in such changes.

In our third theme, we will look in-depth into the origins, current properties, and evolution of our solar system. We base this heavily on physical principles, such as the inverse square law for the propagation of light and the properties of blackbody radiation. Students will learn about how we established the chronology of the Earth and solar system, including quantitative calculations, and they will engage in comparative planetology to understand how Mercury, Venus, the Earth, and Mars ended up very different despite starting out very similar. A comparison of the inner and outer planets then leads us to the formation of the Solar System, and the study of minor bodies has led to the recognition that our Solar System evolved in dramatic ways after it formed, with the current planets in very different locations than they are today. Finally, we extend this to other worlds, going through how we find exoplanets, the very different system architectures that we observe, and theories that reconcile our system with them. The third and fourth components speak directly to the origins and evolution theme.

Course subject & number

The 3-credit hour course is comprised of class meetings involving lecture and small-group discussions, in-class questions based on those discussions. Readings form a key part of the course. The readings are from four books, written for the general public, but rigorous. *The Planets* by Andrew Cohen and Brian Cox is a readable and comprehensive survey of our solar system, while *The Planet Factory: Exoplanets and the Search for a Second Earth* by Elizabeth Tasker tells the story of exoplanets. *Empires of Time: Calendars, Clocks, and Cultures* by Anthony Aveni covers the interplay between astronomy and timekeeping. *Coming of Age in the Milky Way* by Timothy Ferris is a well-written popular science book related to the history of both the heliocentric hypothesis and the relationship between it and our theories of physics.

In the remainder of this form, instructions and examples have been set in blue type while the new responses are set in black type.

Overview

Each category of the General Education (GE) has specific learning goals and Expected Learning outcomes that connect to the big picture goals of the program. Expected Learning Outcomes (ELOs) describe the knowledge or skills students should have by the end of the course. Courses in the GE Themes must meet the ELOs common for **all** GE Themes and those specific to the Theme, in addition to any ELOs the instructor has developed specific to that course.

The prompts below provide the goals of the GE Themes and seek information about which activities (discussions, readings, lectures, assignments) provide opportunities for students to achieve the ELO's associated with that goal. The answer should be concise and use language accessible to colleagues outside of the submitting department or discipline. The specifics of the activities matter—listing "readings" without a reference to the topic of those readings will not allow the reviewers to understand how the ELO will be met. However, the panel evaluating the fit of the course to the Theme will review this form in conjunction with the syllabus, so if readings, lecture/discussion topics, or other specifics are provided on the syllabus, it is not necessary to reiterate them within this form.

Goals and ELOs shared by *all* Themes

Goal 1: Successful students will analyze an important topic or idea at a more advanced and in-depth level than the foundations. In this context, "advanced" refers to courses that are e.g., synthetic, rely on research or cutting-edge findings, or deeply engage with the subject matter, among other possibilities.

Goal 2: Successful students will integrate approaches to the theme by making connections to out-of-classroom experiences with academic knowledge or across disciplines and/or to work they have done in previous classes and that they anticipate doing in future.

For each of the ELOs below, please identify and explain course assignments, readings, or other activities within this course that provide opportunity for students to attain the ELO. If the specific information is listed on the syllabus, it is appropriate to point to that document. The ELOs are expected to vary in their

Course subject & number

“coverage” in terms of number of activities or emphasis within the course. Examples from successful courses are shared on the next page.

ELO 1.1 Engage in critical and logical thinking.	This course requires students to engage in critical and logical thinking to understand how we learn about the nature of planets and solar systems and to evaluate current controversies. Two clear examples are related to the retention of atmospheres and geological activity in the third theme. For the third theme, we give students some general principles about retention of atmospheres: that they are easiest to retain with high gravity, cold temperatures, or for heavy molecules. We then ask students, for homework, exams, and in-class discussions, to reason through how the atmospheres that we see would change if we moved planets or moons to different locations in the solar system or if we changed their size. We then look at comparative planetology of the terrestrial planets and infer from that a general pattern that small bodies lack geological activity while large ones are active. This is then generalized in a simple explanation, with small bodies having a larger surface area to volume ratio. Later, we encounter small moons like Io, which are active and small; this allows us to introduce another idea, that there must be a different heat source (in that case, tides). We also use meteorites to establish that some bodies are differentiated. We then walk through the proof that the Earth and other large planets are differentiated, and in discussions and readings use this to infer that they must have formed hot.
ELO 2.1 Identify, describe, and synthesize approaches or experiences.	Students will learn about planets and the solar system using a variety of approaches, including lectures, in-class demonstrations, planetarium shows, and in-class exercises and discussions. For example, in the first theme, we ask students to observe the night sky and noting changes on different time frames: how stars move during the night, and how this compares with the motions of the Sun and Moon. Students observe and record the position of the setting sun on the horizon and the position and phase of the Moon over the course of the semester to see changes over longer time scales. We then use planetarium shows to synthesize this into models. Students can then test with an in-class exercise where they are asked to determine what phases (e.g., full, crescent) the planets in the solar system will have to an Earth observer in a heliocentric and geocentric solar system and compare with observations. This is then enriched with readings from *Empires of Time* and *Coming of Age in the Milky Way* that develop the historical context of the discovery of these models.

Course subject & number

ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.	The in-class questions and assignments provide regular opportunities for self-assessment, as students can determine how well they understood the material. The in-class exercises become more complex during the semester, as concepts are repeated in novel situations. For example, in the planetarium, students are presented with a view of the sky and initially asked to determine what time it is. We then progress to asking them to also determine where they are. This is more difficult than the last time because they are not always on Earth or even in our solar system. Another key example requires them to confront our elegant theory for the formation of our own solar system with the very unusual exoplanetary systems that we have discovered. They begin by learning the classical picture, with small rocky planets close to the Sun and giant planets far away. This is reinforced as a major pillar of the third theme of the class. We then discover that there are numerous gas giants close to other stars, which requires serious revision for our formation theory; with the help of lectures, readings and discussions they will then reason through to the realization that orbits can be drastically modified by migration and scattering. The exams and homework questions also provide an opportunity for self-assessment about their success in understanding arguments presented in the readings and their synthesis of the material to answer the exam questions.

Goals and ELOs of the GE Theme: Origins and Evolution

GOAL 1: Analyze the origins and evolution of natural systems, life, humanity, or human culture at a more advanced and in-depth level than in the Foundations component.

GOAL 2: Integrate approaches to the origins and evolution of natural systems, life, humanity, or human culture by making connections to their own experiences and by making connections to work they have done in previous classes and/or anticipate doing in the future.

GOAL 3: Appreciate the time depth of the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.

GOAL 4: Understand the origins and evolution of natural systems, life, humanity, or human culture, and the factors that have shaped them over time.

Enter your ELOs in the Table below, editing and removing rows as needed. There should be at least one ELO for each goal, and they should be numbered to correspond to the goal (e.g., ELO1.1 is the first ELO for Goal 1, ELO 2.2 would be the second ELO for the second goal).

Course subject & number

For each ELOs, please identify and explain course assignments, readings, or other activities within this course that provide opportunity for students to attain the ELO. If the specific information is listed on the syllabus, it is appropriate to point to that document. The number of activities or emphasis within the course are expected to vary among ELOs. Examples from successful courses are shared below.

ELO 1.1 Apply their understanding of scientific methods to quantitative calculations.	Quantitative calculations are key learning tools for us in homework assignments and in-class exercises. Some in-class examples are more straightforward – for example, calculating the relative distances between planets using Copernicus' method, or the relative sizes of exoplanets and their host stars from eclipses. Others are more involved – for example, computing the temperature of a planet requires students to be able to compute the degree of solar heating, employing the inverse square law for the propagation of light. They must also be able to compute the heat emitted by a blackbody, and then be able to compute the equilibrium temperature. They can use this to compute the temperature of the Earth, as well as the location in the solar system where ices could have survived during the formation epoch.
ELO 1.2 Engage in critical and logical thinking about the origins and evolution of the universe, physical systems, life on earth, humanity or human culture	We work with fleeting glimpses of the history of our Solar System and must rely on logical reasoning to fill in the blanks. A central topic of the course is asking students to learn how to connect the information that we have into a theory of how and a reconstruction of what must have occurred. The problem of water on Mars is a good example. We start with lectures and readings about Mars, which show a desert planet. We then build a phase diagram to show that liquid water can't exist on Mars today. After this, we start with clues about substantial residual ice on Mars, evidence for past liquid water on Mars, and evidence for substantial past (but not current) geological activity. We then reason through, with the assistance of homework, lectures, and readings, that Mars must have had a thicker atmosphere in the past, and more geological activity, and use this to infer the past history of the planet.
ELO 2.1 Identify, describe, and synthesize approaches to or experiences of origins and evolution questions in different academic and non-academic contexts.	Students will learn about planets and the solar system using a variety of approaches, including lectures, in-class demonstrations, planetarium shows, and in-class exercises and discussions. For example, in the first theme, we ask students to observe the night sky and noting changes on different time frames: how stars move during the night, and how this compares with the motions of the Sun and Moon. Students observe and record the position of the setting sun on the horizon and the position and phase of the Moon over the course of the semester to see changes over longer time scales. We then use

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	planetarium shows to synthesize this into models. Students can then test with an in-class exercise where they are asked to determine what phases (e.g., full, crescent) the planets in the solar system will have to an Earth observer in a heliocentric and geocentric solar system and compare with observations. This is then enriched with readings from *Empires of Time* and *Coming of Age in the Milky Way* that develop the historical context of the discovery of these models.
ELO 2.2 Demonstrate a developing sense of self as a learner through reflection, self-assessment, and creative work, building on prior experiences to respond to new and challenging contexts.	The in-class questions and assignments provide regular opportunities for self-assessment, as students can determine how well they understood the material. The in-class exercises become more complex during the semester, as concepts are repeated in novel situations. For example, in the planetarium, students are presented with a view of the sky and initially asked to determine what time it is. We then progress to asking them to also determine where they are. This is more difficult than the last time because they are not always on Earth or even in our solar system. Another key example requires them to confront our elegant theory for the formation of our own solar system with the very unusual exoplanetary systems that we have discovered. They begin by learning the classical picture, with small rocky planets close to the Sun and giant planets far away. This is reinforced as a major pillar of the third theme of the class. We then discover that there are numerous gas giants close to other stars, which requires serious revision for our formation theory; with the help of lectures, readings and discussions they will then reason through to the realization that orbits can be drastically modified by migration and scattering. The exams and homework questions also provide an opportunity for self-assessment about their success in understanding arguments presented in the readings and their synthesis of the material to answer the exam questions.
ELO 3.1 Illustrate their knowledge of the time depth of the universe, physical systems, life on earth, humanity or human culture by providing examples or models.	Ages are one of the most crucial pieces of information in astronomy, and also one of the most difficult to measure. An example is teaching students how we can infer the age of the Sun and the solar system. We introduce radioactive age dating through readings, lectures, and in-class exercises. When applied to meteorites this yields an ancient age for the Solar System. Independently, we can build theoretical models of the Sun and use the data from solar oscillations to infer a similar age with very different methods. Finally, when applied to the Earth we see a wide range of ages, indicating the central role of

	terrestrial processes that erase our history from most of the surface. Students encounter these different methods at different times during the course, allowing them to build a sense of time depth.
ELO 3.2 Explain scientific methods used to reconstruct the history of the universe, physical systems, life on earth, humanity or human culture and specify their domains of validity.	Studying the origin and evolution of the solar system requires synthesizing a number of techniques and approaches. For example, during the evolution of solar systems, the orbits of planets can change substantially, with potentially large consequences for the entire system. However, the evidence for migration is indirect, requiring a number of independent pieces of evidence. Through lectures, readings, and exams, students will learn and explain how we know that this migration happens. In readings and homework assignments we present the evidence that the migration of Jupiter and Saturn is necessary to explain our solar system, such as the small size of Mars and the existence of the asteroid belt. We complement this with data on the Kuiper belt and Oort cloud, which require comets to have migrated and been scattered respectively. The atmospheres of rocky worlds also evolve substantially. Through lectures, readings, and exams, students will learn and explain how we know this happened.
ELO 3.3 Engage with current controversies and problems related to origins and evolution questions.	The striking differences between exoplanetary systems and our own Solar System are a major current research area in astronomy, and one that the students confront in the fourth theme. *The Planet Factory* discusses the many currently unsolved problems in the formation of solar systems and planets, such as the origin of Super Earths. It also shows the ways that planets that lie in the temperate zone around their stars might not be habitable while other planets could have special niches where life might arise. This naturally leads to the question of whether we are alone in the Universe or not – one that students engage with during in-class discussions and from readings. We compare and contrast exoplanets with our Solar System using in-class discussions and lectures and assess their knowledge through quizzes and the final exam.
ELO 4.1 Describe their knowledge of how the universe, physical systems, life on Earth, humanity or human culture have evolved over time.	We rely on quantitative assessment, in the form of our quizzes and final exam, to test their knowledge of the evolution of stars, planets and life over time.
ELO 4.2 Summarize current theories of the origins and evolution of the universe, physical systems, life on earth, humanity or human culture.	We rely on quantitative assessment, in the form of our quizzes and final exam, to test their knowledge of theoretical explanations for the formation of stars, planets and life and their evolution over time.