PTYS/ASTR 423/523 — MOONS

Spring 2026 • University of Arizona

In-person course with occasional zoom guest lectures
Co-convened graduate and undergraduate enrollment

Instructor: Prof. Erik Asphaug
Email: asphaug@arizona.edu

Class Meetings: Tu Th 12:30–1:45, Kuiper 330
Office Hours: Kuiper 426 (Planet Formation Lab) by appointment

Course Description

We investigate the natural satellites (moons) of planets—how they formed, how they evolve, and what we learn from their geology, dynamics, and exploration. The course begins with a broad overview of satellite systems in our solar system, and then develops physical principles including tides, resonances, collisions, thermal evolution, and interior and surface processes. Applying these, we explore science questions such as: How was the Moon created? What makes binary asteroids, and binary objects beyond Neptune? Is the Saturn system young? Is Jupiter a canonical giant planet system? Does tiny Mimas really have an ocean? What can we learn from sampling the plumes of Enceladus? We conclude with current and upcoming missions and the nascent field of exomoons.

Prerequisites

The course assumes working knowledge of Newtonian mechanics and basic familiarity with vector calculus; familiarity with geology is helpful but not required.
423: Math 223 + PHYS 140/141 (or equivalents)
523: Graduate standing in PTYS, ASTR, GEO, AME, or related field

Course Objectives

During this course students will:
- develop working knowledge of the major satellite systems in our Solar System
- analyze physical and dynamical processes controlling satellite formation and evolution
- examine relationships between planetary formation and satellite systems
- work with current research literature and data
- explore science questions motivating mission concepts and exploration
- prepare and lead discussions on scientific papers

Expected Learning Outcomes

Upon completion of this course students will be able to:
- identify and name the major natural satellites and describe their orbits and basic geology and surface features
- apply quantitative concepts including tidal evolution, geodynamics, and impact physics
- interpret geological and dynamical evidence for satellite origins and histories
- summarize several major open research questions in satellite formation and evolution
- compare past, current and upcoming missions and exploration strategies
- prepare for and lead an informed research discussion
- develop and communicate a focused quantitative research topic

Graduate students will additionally be able to:
- design and deliver a seminar-style research presentation
- evaluate and lead scientific discussions at an advanced level
- prepare a short original research or research-proposal document

Fully In-Person Modality
This course meets fully in person. Attendance, participation, and preparation are essential. If unavoidable circumstances arise, contact me as soon as possible so we can determine a reasonable plan. We may occasionally meet on zoom during normal class hours when there is a guest lecturer from off campus or overseas.

Communication & Course Tech
We use D2L (d2l.arizona.edu) for materials, announcements, assignment submission, and for relevant science news. Students should check announcements daily. Email queries to the professor will normally be replied within 48 hours.

Required Text
I. de Pater & J. Lissauer, *Planetary Sciences* (Cambridge, 2nd ed., 2015). PDF available for free to registered students through the UA library: https://www-cambridge-org.ezproxy1.library.arizona.edu/core/books/planetary-sciences/6EB428DDC505B163480E9C63FE74ACDD

Assignments & Evaluation

Final project – 30%
Midterm exam – 30%
Homework – 10%
Course participation – 15%
Seminar leadership – 15%

Grading Scale:

90–100	A
80–89	B
70–79	C
60–69	D
<60	E

Homework:
Answers will be presented in class when homework is due, so homework must be turned in on time. Answers written down without steps or methodology will receive zero credit.

Late work:
Valid excuse must be provided before due date by email to professor. Rewrites are permissible within 1 week of original due date for potentially half-credit.

Midterm exam and rewrite:
There will only be the one exam, and it will be challenging. But after the graded midterms are returned, students may rewrite in one week, to earn back up to half the missed credit. Rewrites must be individual work and all steps/derivations must be clearly shown.

Graduate-specific questions:
Occasionally these more advanced questions will be included on homework and exams; these will be graded as optional extra credit for undergraduates.

Class discussions and presentations:
Students will give two presentations about their final project. The first presentation will be brief (10-min) and provide a handout and a reading assignment for the class; second presentation will be longer (20-min) and kick off a class discussion that the student leads, in a supportive and well-informed environment.

Final project:
Students will submit a short research paper on their topic.
Undergraduates: 5-page research summary, plus a page of references, including an informed analysis of what came up in the class discussion.
Graduate students: 5-page quantitative research study or draft of a research proposal.
The final project grade evaluates all components: the presentations, the discussion preparation, and the write-up.

Course Participation
Effective participation means doing the readings, contributing to discussions, and supporting a collaborative learning environment. Participation includes *allocating adequate time to read the assignments* so you come to class prepared. Occasional pop quizzes may be used to encourage preparation and detailed reading of the assignments.

Academic Integrity
All students must follow the University of Arizona Code of Academic Integrity. Collaboration is permitted where indicated, and is encouraged when preparing for seminars and presentations. Otherwise your submitted work must be your own. Unauthorized assistance on evaluations or rewriting graded material is a violation. University policies: https://academicaffairs.arizona.edu/syllabus-policies

Use of AI Tools in a Research Context
Generative AI tools (e.g., ChatGPT, Gemini, Copilot) may be used for background exploration such as identifying research directions, clarifying terminology, or locating literature. They may not be used to generate written assignments, solve problems, produce text for seminar slides, or complete any graded activity. Students consulting AI tools are responsible for evaluating accuracy against peer-reviewed sources and must cite any ideas derived from AI. Submitting AI-generated material as original work constitutes unauthorized assistance under University policy.

Nondiscrimination
The University of Arizona is committed to creating an inclusive and respectful environment. For policies and reporting information, see University policy links in https://academicaffairs.arizona.edu/syllabus-policies

Accessibility & Support
If you anticipate or experience academic or physical barriers due to disability or pregnancy, please contact me and Disability Resources (https://drc.arizona.edu) to discuss options and

accommodations. If unexpected circumstances affect your engagement, please reach out early; we can discuss reasonable adjustments.

Land Acknowledgment
We respectfully acknowledge the University of Arizona is on the homelands of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes. Consistent with the University's commitment to diversity and inclusion, it is important that we recognize the peoples upon whose lands we reside, learn, and work.

Subject to Change
The schedule, readings, and assignments may be updated with reasonable advance notice.

University Policies
Please see https://catalog.arizona.edu/syllabus-policies for additional policies that apply to all University of Arizona courses.

Course Schedule
Specific schedule will depend on number enrolled, ratio of graduate to undergraduate students, and will accommodate special events like mission launches, new discoveries, and occasional experts presenting to the class.

The study of moons is an active field, so several of the readings below may be switched out with newer papers when we get to that point, and homework assignments may change. Students must be aware of in-class and D2L announcements; check in with a fellow student or the instructor if you miss a class.

Week 1 Introductions (around the room, and about the subject)

Walk through the syllabus; survey the required text
Go over schedule and grades and expectations and D2L
Start of lectures…

Survey of natural satellites
Socratic discussions to establish the base level

Week 2 Theories of planet formation

Known history of ideas: Ancients to modern knowledge
What do we really know about planet formation?
-from Kepler's numerology, to modern theories
Dynamics of satellite evolution

Week 3a Geologic record of the Moon

Reading: Shoemaker et al. (1963): *Interplanetary Correlation of Geologic Time*
Reading: Cameron and Ward (1976): *The Origin of the Moon*
Listening: 13 Minutes to the Moon (podcast)

Impacts; KREEP; magma oceans
Dynamics of tidal evolution

Overview of the satellites of outer Solar System (Jupiter to Pluto)

Reading: Wilhelms (1987): *The Geologic History of the Moon (Chapter 1)*
Reading: One chapter from *New Views of the Moon II* (TBD)

Week 3b Satellites of Mars and Venus

Reading: Nakamura et al. (2021), Science operation plan for MMX mission

Satellites of asteroids, comets and KBOs
Lucy mission binary targets; Dinkanesh and other oddities

Guest lecture: binary KBOs

Week 4 Galilean satellites of Jupiter
Laplace chains and origins
Tidal evolution around Jupiter and Saturn

Reading: Planetary Sciences 2023-2032 Decadal Survey, Jupiter System

Week 5 Titan, Enceladus and the middle-sized moons
Cassini mission results
Dragonfly mission science goals
Reading: Planetary Sciences 2023-2032 Decadal Survey, Saturn System

Saturn system: old or new?
A network of resonances

Reading: Asphaug & Reufer (2013): *Late Origin of the Saturn System*

Week 6 Pluto and other binary KBOs
Reading: Moore and McKinnon (2020): *New Horizons at Pluto*

Triton, Io and other oddballs
Guest Lecture: Io mission concepts

Week 7 Exploring ocean moons
Ocean worlds: Europa, Enceladus, Titan, Pluto?
JUICE and Clipper missions to Europa

Reading: Rhoden et al. (2020)

Week 8 Moons of exoplanets
Any discoveries yet?
Reading: Heller et al. (2014): exomoons review

Midterm Exam

Graded exams returned
Outline of final projects due

Week 9 Student seminars
Student presentations
Reading: as assigned

Week 10 Student seminars
Student presentations
Reading: as assigned

Week 11 Student seminars
Student presentations
Reading: as assigned

Week 12 Student seminars
Student presentations
Reading: as assigned

Week 13 First drafts of final projects due
Round-table project status updates (10 min each)

Week 14 Graduate student lectures

Final Exam Day:
No final exam – but *reserve the exam date and time* in case it is necessary for students to complete their final project presentations to the class