SYLLABUS – PTYS 423/523 – MOONS

Professor: Erik Asphaug, asphaug@arizona.edu
Location: Kuiper 330, Mon and Wed 12:30-1:45
423 Prerequisites: Math 223 + PHYS 140/141 or equivalent (vector calculus + calculus-based mechanics)
523 Prerequisites: In good standing in PTYS, ASTR, GEO, AME or related UA graduate program
Office hours: via zoom, or my faculty office Drake 114H, by appointment

Course Description. We study the natural satellites (moons) of planets, starting with a survey of our own solar system, and introduce the principles and theories of their formation and evolution. How do Galilean satellites form? What causes Triton's plumes? Is the Saturn system young? How old is the Moon? Why are binary asteroids and KBOs so common? Is Phobos falling apart? Then we will consider the science questions motivating current and planned missions of exploration, and the discovery of exomoons. The class will emphasize quantitative approaches and will therefore rely upon a common understanding of mechanics and calculus. Familiarity with geology is helpful but is not required.

The first 8 weeks will be mostly lectures: an overview of the geography of the major satellites, a quantitative introduction (and for some, a review) of fundamental concepts such as tides and collisions and resonances, and principles of satellite formation, dynamics, and surface and interior evolution (geology). Lectures will go over the homework assignments and readings. This will conclude with the mid-term exam, and the opportunity to re-write the exam after the answers are explained.

The week after the midterm, students will pitch their project idea to the class, as described in detail below, and receive feedback. The rest of the course will consist mostly of interactive discussions based on readings related to student final projects, supplemented by focused lectures by the professor.

Course Objectives: The overall objective is for introductory planetary scientists to develop a working understanding of natural satellite formation, evolution and geology, and to gain experience working with the major research literature and critically discussing it. The course will teach the following:
- the 'lay of the land' of the major satellite systems
- physical and dynamical concepts related to natural satellite formation and evolution
- relationship between satellite formation and planet formation and evolution
- observations and discoveries, old and new, behind our current understanding
- major knowledge gaps motivating current and future missions and next-generation telescopes

Expected Learning Outcomes: Upon successful completion of the course, all students will
- be familiar with the names, orbits, and basic geology of the major moons of the solar system
- have a quantitative understanding of principal concepts in moon formation, dynamics, and geology
- have a descriptive knowledge of several major science questions regarding moons
- know the timescales and sequences of events involved in planet and moon formation
- know the past, current and planned science and exploration missions of moons, and their astronomy
- know how to set up and lead productive research discussions, in person and on zoom
- develop detailed quantitative knowledge of one research question, and a familiarity with major quantitative concepts such as tides, collisions, and resonances.

Graduate Student Learning Outcomes: In addition to the above, graduate students will

- gain experience preparing class lectures for a mixed group of students, working with hypotheses during question and answer sessions, and productively directing a research discussion
- gain experience in a research topic that could be outside their area, turning curiosity into a *question.*

400/500 Co-convened Course Information

This is a combined class for graduate students and for upper-division undergraduates. The graduate students will be evaluated according to higher expectations and assignments. Student comments are commonly that the course is taught at too high of a level for the undergraduates, and too low of a level for graduate students. There is no easy solution, but the more questions students ask the better. Also, this format has the advantage of exposing undergraduates to the abilities and thought processes of graduate students, which is helpful if they are considering graduate education for themselves.

Grading:

The grading scale for all students is 90%-100% = A; 80%-89% = B; 70%-79% = C; 60%-69% = D; 59% and below = E. The course grade for all students will be based on the following weighted categories: Final project = 30%; midterm = 30%; homework = 10%; course participation = 15%; seminar leadership 15% (presenting your ideas to the class).

These categories are defined as follows:

•*Midterm exam* will cover material from lectures, readings and assignments in Weeks 1-8. A missed midterm exam can be made up within 2 weeks of the exam date, but only for the following reasons: (1) University approved activity (advanced notice and Dean's approval required); (2) religious holiday (advanced notice required); (3) medical emergency, for which you must provide a doctor's note; and (4) jury duty (advanced notice and documentation required).
Midterm re-write: Once all the exams are graded and returned, a student may re-write their exam, clearly showing all their work, to receive up to half-credit for whatever they missed. Thus, a student who gets a 70% on the midterm, can end up with 85% with a perfect rewrite. Unlike the homework, *you may not work together on the midterm rewrites*; these must be entirely your own work.
Graduate questions: The midterm will feature one or two questions for graduate students only; undergraduates are welcome to try it for extra credit (although not in the exam rewrite).

•*Final project:* Students will assemble a body of research ideas for their final project, where they hone an existing expertise or try out a new one. Students will each assign one reading assignment (a paper or pages of a textbook) and lead a class discussion about the reading, and turn in a write-up and prepare simple handouts (e.g. geologic map, or table of cosmic abundances, or a figure or link to a tool).
For graduate students the project is a brief but original quantitative research study or proposal (5 pages, plus figures and bibliography) plus a 30-minute summary lecture with handouts.
For undergraduate students it is a research proposal, literature analysis, or original research effort of 5 pages (plus figures and bibliography), plus a 10-minute lecture with one handout.
The writeup is 1/2 the project grade, lecture is 1/3, and relevance & impact is 1/6.

•*Homework* will be assigned occasionally in weeks 1-8 (often a problem from de Pater & Lissauer) and will be announced in class and posted on D2L. You are to solve problems on scratch paper, and before submitting, clean up your steps, and write them down clearly (e.g. on white/ruled papers, compiled pdf, computer workbook). Homework is graded on a 10-point scale, where 10 means answers are correct and methodology is clear. You are encouraged to work together but the work that you submit must be your own. Answers written down without steps or justification (methodology) will receive zero credit. Late homework will be deducted 2 points for 1 day late, 5 points for 2, and thereafter not accepted. *Graduate homework:* There will sometimes be one additional question for graduate students, and undergraduates are welcome to try it for extra credit.

•*Course participation:* Participating in the course is vital to the learning process. Attendance is required at all scheduled lectures and discussions. Class participation also includes *allocating adequate time to read the assignments* so you come to class prepared. This, in turn, raises the intellectual level of the class. If students are not prepared to participate, there will be a pop quiz counting towards the participation grade. Graduate and undergraduate students will be graded the same for participation.

•*Seminar leadership:* Students will be graded on how well they lead the discussion seminar related to their own research topic. Graduate students will be evaluated additionally based on how substantially they contribute to seminar discussions overall.

•*Final exam:* There will be no final exam, but reserve the exam date for final presentations.

Required Textbook: "Planetary Sciences" by I. de Pater and J. Lissauer (Cambridge University Press, 2nd Edition, 2015). This book is available in PDF format for free download through the University library.

Academic Integrity: All students are expected to know and to abide by the University's Academic Integrity policy, https://deanofstudents.arizona.edu/policies/code-academic-integrity.

Attendance: If you anticipate being absent, are unexpectedly absent, or are unable to participate in class activities, contact the professor as soon as possible, preferably one week in advance. If you will be missing a course meeting or an assignment deadline, notify me right away by email. Non-attendance for any reason does not guarantee an automatic extension of due date or rescheduling of examinations/assessments. If you must miss more than one week of class, you should also contact the Dean of Students Office DOS-deanofstudents@email.arizona.edu to share documentation about the challenges you are facing. A request for reasonable religious accommodations will be granted, please see policy.arizona.edu/human-resources/religious-accommodation-policy for details.

Compliance with COVID-19 mitigation guidelines: To protect the health of everyone in this class, students are required to follow the university guidelines on COVID-19 mitigation. Please visit the UArizona COVID-19 page covid19.arizona.edu for regular updates. If you feel sick, or may have been in contact with someone who is infectious, *stay home from class* and notify me as soon as possible. Except for seeking medical care, avoid contact with others and do not travel. Note that voluntary, free, and convenient COVID-19 testing is available for students on Main Campus. COVID-19 vaccine is available for all students at Campus Health.

Academic advising: If you have questions about your academic progress this semester, please reach out to your academic advisor (advising.arizona.edu/advisors/major). Contact the Advising Resource Center

(https://advising.arizona.edu/) for all general advising questions and referral assistance. Call 520-626-8667 or email to advising@arizona.edu

Life challenges: If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at (520) 621-2057 or DOS-deanofstudents@email.arizona.edu.

Additional resources: basicneeds.arizona.edu/index.html

Resources specific to graduate students: gradcenter.arizona.edu/resources

Physical and mental-health challenges: If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520) 621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.

Students with disabilities: University of Arizona strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, you are welcome to let me know so that we can discuss options. You are also encouraged to contact Disability Resources (520-621-3268) to explore reasonable accommodation. The accessible table and chairs in Room 312 will be available for students who find that standard classroom seating is not usable.

Safety on Campus and in the Classroom

For a list of emergency procedures for all types of incidents, please visit the website of the Critical Incident Response Team (CIRT): https://cirt.arizona.edu/case-emergency/overview

Also watch the video available at https://arizona.sabacloud.com/Saba/Web_spf/NA7P1PRD161/common/learningeventdetail/crtfy000000000003560

Nondiscrimination and anti-harassment policy: The University of Arizona is committed to creating and maintaining an environment free of discrimination. In support of this commitment, the University prohibits discrimination, including harassment and retaliation, based on a protected classification, including race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, or genetic information. For more information, including how to report a concern, please see: policy.arizona.edu/human-resources/nondiscrimination-and- anti-harassment-policy

University policies: For other university policies, including academic integrity, please see: academicaffairs.arizona.edu/syllabus-policies.

Class recording: This class is in-person so we do not expect to use class recordings. For lecture recordings, which are used at the discretion of the instructor, students must access content in D2L only. Students may not modify content or re-use content for any purpose other than personal educational reasons. All recordings are subject to government and university regulations. Therefore, students accessing unauthorized recordings or using them in a manner inconsistent with UArizona values and

educational policies (Code of Academic Integrity and the Student Code of Conduct) are also subject to civil action.

Subject to change notice: Information contained in the course syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor of this course. Course content, reading materials, and homework assignments are subject to change, with reasonable advanced notice, as deemed appropriate by the instructor.

Course Schedule

Specific schedule will depend on number enrolled, ratio of graduate to undergraduate students, and will accommodate conferences and special events like mission launches, new discoveries, and occasional experts in town. It is an active research field, so several of the readings are likely to be updated when we get to that point, and homework assignments may change, so pay attention to the in-class and D2L announcements and check in with a fellow student or the instructor if you miss a class. The numbers 1-13 refer to specific lecture subjects that will be posted on D2L as slide sets at the end of the subject.

Week 1 Introductions (around the room, and about the subject)
Walk through the syllabus in detail
Go over schedule (below) and grades and expectations and D2L
Start of lectures…

1, Survey of natural satellites
Socratic discussions to establish the base level
Optional: students can set up discussion group / homework meeting times outside of class

Week 2 **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

3. Dynamics of satellite evolution
Will be referring to de Pater and Lissauer (2015) so make sure to have downloaded

Week 3 **4. 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 3 **5. Satellites of Mars and Venus**

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

6. Satellites of asteroids, comets and KBOs
Lucy mission binary targets; Dinkanesh and other oddities
Guest lecture: binary KBOs

Week 4 **7. 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 **8. Titan, Enceladus and the gang**
Cassini mission results

Dragonfly mission science goals
Reading: Planetary Sciences 2023-2032 Decadal Survey, Saturn System

9. Saturn system: old or new?
A network of resonances

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

Week 6 **10. Pluto and other binary KBOs**
Reading: Moore and McKinnon (2020): *New Horizons at Pluto*

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

Week 7 **12. Exploring ocean moons**
Ocean worlds: Europa, Enceladus, Titan, Pluto?
JUICE and Clipper missions to Europa

Reading: Rhoden et al. (2020)

Week 8 **13. 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
Midterm rewrites due for half-credit

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
Movie: *2001: A Space Odyssey* (in Drake auditorium)

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