ASTR 5780 / ASEN 5440:
Mission Design and Development for Space Sciences

Location / Time:

AERO N240
T/Th 1:00pm – 2:15pm

Instructors

Prof. David Malaspina, APS
David.Malaspina@lasp.colorado.edu
303-492-9501
SPSC N278 / Duane D315
Office Hours:
Tuesdays: 9:00 to 10:00 in LASP/SPSC N278
Thursdays 2:30 to 3:30 in LASP/SPSC N278

Prof. Zoltan Sternovsky, AES
Zoltan.Sternovsky@colorado.edu
303-819-2783
NPL 242 / AERO 347
Office Hours:
Wednesdays: 9:00 - 10:00 in AERO 253A
Thursdays: 5:00 - 6:00 over zoom

Teaching Assistant

Kathryn Van Artsdalen, AES
Kathryn.VanArtsdalen@colorado.edu

Overview

The goal of ASTR5780 / ASEN5440 is to expose both science and engineering students to the process by which space missions are conceived, developed, designed, and proposed. The course will bring science and engineering students into the same classroom environment to develop the multidisciplinary skills required to derive the science and instrument concepts for a NASA-funded small space mission in astrophysics, heliophysics, or planetary science. The students will create a successful proposal for a mission of their choice and will learn the proposal evaluation process.

The students enrolled in this course will have three primary goals:

1. Develop the **proposal science objectives** based on scientific community priorities, inherent interest, and practical considerations imposed by the NASA Announcement of Opportunity;
2. Learn how the **mission science requirements** lead to the design of the proposed instrumentation package; and
3. Develop an understanding of practical considerations when **designing a scientific instrument**, **spacecraft, and mission** that can accomplish these science goals.

The process begins with a science question – what is it we wish to learn, and why do we care? It is far from trivial to formulate and craft the right science questions. It requires an understanding of the (a) current state of scientific knowledge; (b) the most timely problems to tackle next; and

(c) the specific goals of NASA and the scientific community, as spelled out in a variety of relevant documents. Early in the semester, we will discuss these documents and how they drive our choice of science problems to investigate.

From the science questions posed for the mission, the design process flows through a number of critical design steps:

1. **Measurement**: determine the necessary measurement that will address the science questions. This could be the brightness of a star in some wavelength band, the flux of electrons in the radiation belts, or the detection of particles in the vicinity of a celestial object. The measurement will have specific fidelity requirements: wavelength, flux, dynamic range, time resolution, and so forth, which directly tie to the science questions. Finally, do the measurements alone close the science question? If not, what supporting modeling and analysis/interpretation required?
2. **Instrument**: determine the instrument(s) necessary to make the measurements above. Quantitatively demonstrate that the selected instruments can make the measurements with the required fidelity. The instrument performance is tied back to the science questions, through the measurement requirements, in an important table known as the Science Traceability Matrix.
3. **Spacecraft**: The spacecraft is designed to ensure the required measurements, made with the instrument(s), can be taken from an appropriate time and place in space. The spacecraft must accommodate the instruments; ensure the appropriate orbit and spacecraft attitude (i.e. pointing) requirements; provide power to the instrument(s) and to itself; and relay the required data to the ground for analysis. The spacecraft is therefore comprised of many subsystems, the design of each of which is critical to mission success.
4. **Mission**: The selection of the appropriate orbit, mission duration, and operations plan are critical to success. The mission design is deeply coupled to the spacecraft design.
5. **Management**: When proposing a mission to a federal sponsor (e.g., NASA), we have to show that we have the expertise to carry out the proposed science investigation, that we can build the instrument(s) and spacecraft in a reasonable amount of time; that we have a plan to build, test, calibrate, and verify the spacecraft before launch; we have a plan to operate the spacecraft and carry out the required analysis to meet the mission science goals; and that we can do it in a reasonable (and limited) budget.

This course focuses on the design of a specific instrument to make a specific measurement, as well as critical aspects of spacecraft and mission design, and the art of crafting a competitive proposal. All of the aspects listed above are coupled to each other, and we will discuss how to make tradeoffs that ensure a feasible mission proposal under each of these aspects.

This course establishes a working relationship between scientists and engineers that is essential for development of a comprehensive and successful mission proposal. The course will focus on science and engineering applications for a small space mission, driven by recent NASA proposal opportunities in astronomy, heliophysics, earth science, and planetary science. By design, this course is a cross-disciplinary effort and is therefore being cross-listed and co-taught by the Aerospace Engineering and Astrophysics and Planetary Sciences departments.

Prerequisites & Eligibility

ASTR5780 / ASEN5440 is open to senior undergraduate and graduate students in Astronomy, Engineering, Physics, Atmospheric Sciences, Applied Math, and related fields. Students are expected to have strong problem solving and organizational skills, a strong background in mathematics and classical physics, as well as good oral and written communications skills. A background in basic modern physics is strongly encouraged.

Specific APS undergraduate student prerequisites include: Permission of instructor.

Specific AES undergraduate student prerequisites include: Permission of instructor. Recommended background: senior undergraduate level orbital mechanics, electronics, and/or mission design.

Reading

All suggested reading for the course is available on the Canvas course website. While none of this reading is strictly required, we strongly recommend you familiarize yourself with these documents and highlight important sections (which we will help identify). The important documents include:

- **NASA, Research Opportunities in Space and Earth Sciences (ROSES 2023)**. ROSES is not a funding opportunity on its own, but rather a compendium of opportunities. The ROSES documentation is released once per year, usually in February, to outline what opportunities will be available to proposers in the next year.
- **Astrophysics Small Explorer Announcement of Opportunity 2022**. The Small Explorer class, or SMEX mission, is the entry level into NASA missions. These are $145 million missions involving multiple institutions. The AO will give students an idea of what goes into one of these larger proposals.
- **Decadal Surveys (2013-2022)**. Every 10 years, each of the four science areas (Astrophysics, Heliophysics, Planetary Science, and Earth Science) releases a “Decadal Survey” of the state of the science community, the critical science that needs to be addressed in the coming decade, and the missions that are recommended. The astrophysics decadal survey will be running concurrently with this class and we will use real-time examples of the decadal survey process to reinforce classroom discussions.
- **NASA Science Plan (20TBD).** The Decadal Surveys are commissioned by the National Academies of Science (NAS); they are not strictly NASA-related. In the Science Plan document, NASA pulls directly from the Decadal Survey to outline the goals for the administration.

- **NASA Strategic Plan (2024)**. While the Science Plan relates to science goals for the Science Mission Directorate (SMD) of NASA, the Strategic Plan is a higher-level document for all of NASA, including technology development, human space flight, and education.
- **NASA Technology Roadmaps (2014-2033)**. The Technology Roadmaps come from the Space Technology Mission Directorate (STMD), which focuses on the development of new technologies for NASA. The Roadmaps outline priorities for the coming decade; small satellite missions can often target these priorities to enhance their relevance to NASA.
- **NASA Systems Engineering Handbook Rev 2 (2016).** The NASA SE Handbook describes NASA's process for conducting space missions. Missions conducted outside of NASA, but funded by NASA, need to show NASA that they have a reasonable Systems Engineering Management Plan that emulates NASA's established processes.
- **Scientific and Instrumentation Journal Articles** will be assigned based on science and instrument development concepts developed in class.

Subject Outline

1. Introduction to space missions and NASA proposal opportunities
2. Community science priorities, introductory and detailed science investigations
3. Introduction to science topics in Heliophysics, Astrophysics, and Planetary Science
4. Proposal science topic definition for semester mission/proposal projects
5. Science Traceability Matrix
6. Requirements definition, measurements and instrumentation
7. Science instrument selection and design
8. Spacecraft design and subsystems
9. Space environment considerations
10. Spacecraft data reduction and analysis
11. Mission schedule and budget development
12. Team roles; proposal layout, responsibilities, and writing
13. Proposal review

Schedule: See the class on canvas.

Logistics

Assignments – The end product in this course is a **complete mission proposal** that is written to the standards of NASA. These proposals will be developed in teams of ~6 students. To get to the final proposal, students will build pieces through a series of assignments, to be completed individually.

- A series of **homework assignments** throughout the semester will be used to build pieces of the final proposal. The concept proposal and the draft science traceability matrix (STM) will be developed and submitted individually. These will be followed by assignments on instrument design, spacecraft design, mission design, and so forth. These will be graded, and feedback will be given to the groups with the expectation of further improvements for the **final proposal**.
- First, students will each submit a two-page **concept proposal**, outlining their idea for a science-driven mission concept. Students are expected to conduct literature research to demonstrate the scientific need, timeliness, and feasibility of their mission concept. The instructors will then downselect the adequate number of these concepts to go forward to the proposal stage, based on science quality, feasibility, and novelty.
- Students will participate in the **peer review** of the concept papers (homework) and provide anonymous feedback to each other, in the form of identified Strengths and Weaknesses. Peer review is an important part of the proposal process – it allows students to learn directly from each other as well as develop critical analysis skills.
- Roughly half-way through the semester, student teams will give short ~20 minute **in-class presentations** on their mission proposal, outlining the science concept; the STM; instrument and spacecraft design. This will be an opportunity to get feedback from the instructors and their peers on issues with the current mission design.
- The submitted final proposals will be evaluated in the form of a **review panel**. Eech student will provide a written review on the strengths and weaknesses of 2-3 proposals, participate in panel discussions, and provide a comprehensive evaluation as a group.
- There will be **weekly quizzes** on the provided reading material.
- Part of the grade will be based on anonymous peer review within each group.
- **Active class participation** is an expectation. Students are encouraged to engage in discussion in the classroom, office hours, and within their groups. Asynchronous students are expected to participate in discussions on canvas following each lecture.

Grading – The final grade will be calculated from the assignments as shown below:

Activities		
	Individual	**Group**
Homework assignments	10%	20%
Weekly quizzes	5%	
Mid-term presentations		
Slides	5%	
Oral presentations	5%	5%
Proposal reviews and review panel	5%	10%
Final proposal document		25%

Peer reviews	5%	
Active class participation*	5%	
TOTAL	40%	60%

* Asynchronous students are expected to engage in discussions on canvas

Deadlines – Each assignment will have a marked deadline. Late assignments are not accepted except under extenuating circumstances; 24-hour notice is required for work to be considered after the due date. If such an event occurs, you are expected to contact the instructors immediately by e-mail or carrier pigeon.

University Policies

Classroom Behavior

Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote, or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation, or political philosophy.
For more information, see the classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

Requirements for Infectious Diseases

Members of the CU Boulder community and visitors to campus must follow university, department, and building health and safety requirements and all public health orders to reduce the risk of spreading infectious diseases.

The CU Boulder campus is currently mask optional. However, if masks are again required in classrooms, students who fail to adhere to masking requirements will be asked to leave class. Students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct & Conflict Resolution. Students who require accommodation because a disability prevents them from fulfilling safety measures related to infectious disease will be asked to follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

For those who feel ill and think you might have COVID-19 or if you have tested positive for COVID-19, please stay home and follow the further guidance of the Public Health Office. For those who have been in close contact with someone who has COVID-19 but do not have any symptoms and have not tested positive for COVID-19, you do not need to stay home.

Accommodation for Disabilities, Temporary Medical Conditions, and Medical Isolation

Disability Services determines accommodations based on documented disabilities in the academic environment. If you qualify for accommodations because of a disability, submit your accommodation letter from Disability Services to your faculty member in a timely manner so your needs can be addressed. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance.

If you have a temporary medical condition or required medical isolation for which you require accommodation, please alert the instructors about absence due to illness, injury, or medical isolation. Students are not required to state the nature of their illness or provide "doctor's notes" for classes missed due to illness. Also see Temporary Medical Conditions on the Disability Services website.

Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

Honor Code

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology [such as essay bots]), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty.

All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: honor@colorado.edu, 303-492-5550. Students found responsible for violating the Honor Code will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to academic sanctions from the faculty member. Visit Honor Code for more information on the academic integrity policy.

Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation

CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. These behaviors harm individuals and our community. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who believe they have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureport@colorado.edu. Information about university policies, reporting options, and support resources can be found on the OIEC website.

Please know that faculty and graduate instructors have a responsibility to inform OIEC when they are made aware of incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive an outreach from OIEC about their options for addressing a concern and the support resources available. To learn more about reporting and support resources for a variety of issues, visit Don't Ignore It.

Religious Holidays

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, the students are asked to alert the instructors at least two weeks in advance in case of a recognized conflict.

See the campus policy regarding religious observances for full details.

Mental Health and Wellness

The University of Colorado Boulder is committed to the well-being of all students. If you are struggling with personal stressors, mental health or substance use concerns that are impacting academic or daily life, please contact Counseling and Psychiatric Services (CAPS) located in C4C or call (303) 492-2277, 24/7.

Free and unlimited telehealth is also available through Academic Live Care. The Academic Live Care site also provides information about additional wellness services on campus that are available to students.