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

Location / Time:

AERO 232
T/Th 10am – 11:20am

Instructors

Kevin France, APS
Kevin.france@colorado.edu
303-492-1429
SPSC N214 / Duane D219
Office Hours: Th 12pm (SPSC), or by appointment.

Robert Marshall, AES
Robert.Marshall@colorado.edu
303-492-4075
AERO 419
Office Hours: T/Th 1-2 pm, or by appointment.

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 multi-disciplinary skills required to design the science and instrument concepts for a NASA-funded small space mission in astrophysics, heliophysics, planetary science, or earth sicence, and to create a successful proposal for this mission.

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 current state of scientific knowledge; the most timely problems to tackle next; and 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, or the flux of electrons in the radiation belts. 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 an feasible mission proposal under each of these aspects.

These goals will be supported and augmented by the participation of NASA's Jet Propulsion Laboratory (JPL) in the course design and implementation. JPL will provide hands-on engagement during the proposal development and will take part in the design review at the end of the semester. Further guest lectures will be provided by experienced scientists and engineers from LASP, SwRI, and other research centers. 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 2019)**. 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 2019**. 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 (2010-2020)**. 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 (2014).** 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 (2014)**. 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 (2015-2019)**. 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 Handout #2 for lecture / assignment schedule.

Logistics

Office Hours – We have them, you should attend them. See page 1 for office hour listings.

Assignments – The end product in this course is a **complete mission proposal** that could be submitted to NASA. These proposals will be developed in teams of 4-6 students. To get to the final proposal, students will build pieces through a series of assignments.

- First, either as individuals or with partners, students will submit a two-page **concept proposal**, outlining their idea for a mission concept. These concept papers constitute the first graded assignment. Students are expected to conduct literature research to demonstrate the scientific need, timeliness, and feasibility of their mission concept. The instructors will then downselect 4 to 6 of these concepts to go forward to the proposal stage, based on science quality, feasibility, and novelty.
- A series of **homework assignments** throughout the semester will be used to build pieces of the final proposal. First is the science traceability matrix (STM), followed by assignments on the instrument design, spacecraft design, mission design, and so forth. These will be graded, and feedback will be given to allow students to improve them for the final proposal. Although students are working on the final proposal as a team, homework assignments shall be complete either individually or in pairs (maximum two people). If students choose to work in pairs, **you may work with the same partner on a maximum of two (2) homework assignments**.
- Roughly half-way through the semester, students will give a short ~20 minute **in-class presentation** 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, their peers, and external reviewers on issues with the current mission design.
- The final proposal will also involve a **presentation**, constructed as a "red-team review", where reviewers pick apart the proposal concept for major issues. These reviews will be conducted both in class time and outside class time to give each team more time. Teams will then have a few weeks to finalize their **proposals** before submission.

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 phone, email, or carrier pigeon. If you know in advance that you will not be on campus for a due date, you may submit your assignment to the instructors any time prior to the due date or through e-mail.

Grading

Grades on individual assignments and for the overall course are set based on the following criteria:

A, A-	Superior understanding of the material beyond the course requirements; excellent technical work
B+, B	Comprehensive understanding of the material; strong technical work
B-	Adequate understanding of the material; complete technical work
C	Barely adequate understanding of the material and minimally sufficient technical work
D	Poor technical work
F	Unsatisfactory performance

Activities	%
Homework	**35%**
Concept Paper	**10%**
Proposal/Presentations	**45%**
mid-semester slides	5%
mid-semester oral	5%
final proposal slides	5%
final proposal oral	10%
final proposal document	20%
Active class participation	**10%**

The final proposal document will be graded in five sections: i) Science Motivation and Background; ii) STM and Instrument Design; iii) Spacecraft Design; iv) Mission Design; and v) Project Management. Each student on the team should lead one of these sections. The final grade for the document will then be split: **50% from the overall document grade, and 50% from the individual's section**. This split ensures that all team members are motivated to complete their section, while also contributing to the rest of the document.

University Policies

Cheating

Cheating will not be tolerated and the CU Honor Code will be upheld.

Special Accommodations

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed.

Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Classroom Expectations

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail 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. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

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 policy may include: plagiarism, 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 the Honor Code (honor@colorado.edu); 303-492-5550). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

Discrimination and Harassment

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct intimate partner abuse (including dating or domestic violence), stalking, protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

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, please notify the instructors PRIOR to any potential conflicts to properly accommodate your schedule. See full details at http://www.colorado.edu/policies/fac_relig.html and http://www.interfaithcalendar.org/