Space Environment and Effects: Syllabus

Location and Time: MUEN E0046, MWF 9:00 – 9:50 am

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1 Overview

Space Environment and Effects is a new course this year (Fall 2018) meant to introduce you to the near-Earth space environment and its effects of spacecraft, communications systems, astronauts, and more. Future aerospace engineers working on space-related technology or applications need a broad understanding of the environment in order to design their spacecraft appropriately. But more generally, anyone with a passion for space will be fascinated to learn about the different regions of the space environment, how they couple together and affect each other, and how they affect our daily lives.

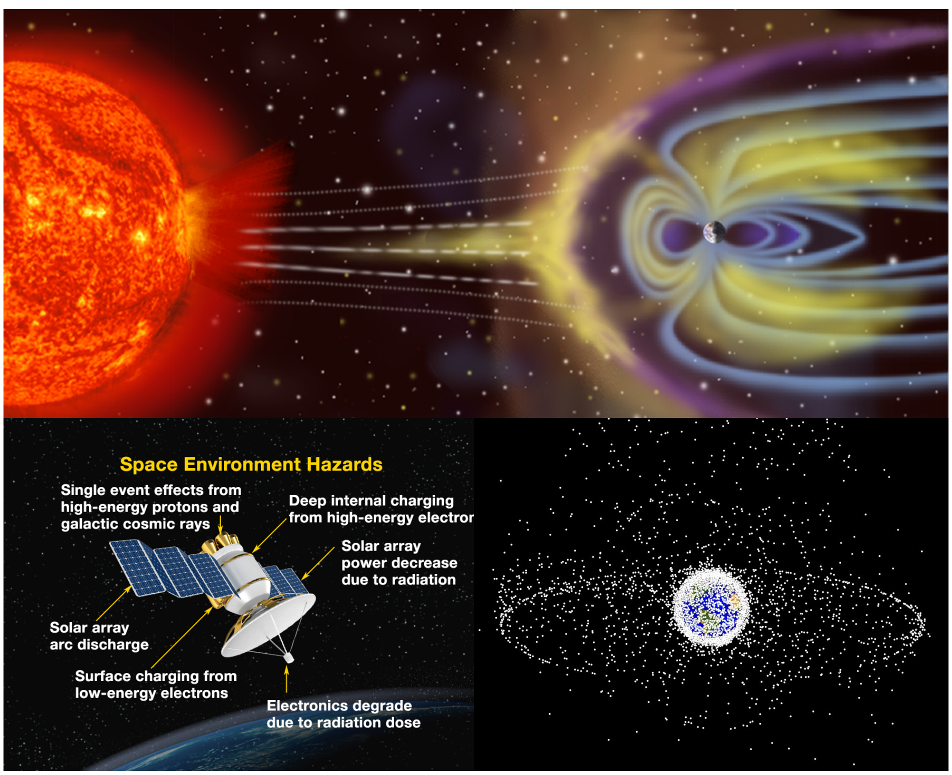

Figure 1: Top: Depiction of the space environment and its response to solar inputs. Bottom left: Hazards to spacecraft due to the space environment. Bottom right: the orbital debris environment around Earth – individual objects not to scale!

We define the "near-Earth" space environment as the region of space surrounding the Earth this as affected by the sun and where most of our satellites operate. As such, this course focuses on the space environment surrounding the Earth – don't expect to learn about the solar system, galaxies, interplanetary space, and so on. However, we will take a look at the environments around other planets for comparison with Earth, for example the "near-Jupiter" space environment.

The near-Earth space environment extends from the surface of the Earth up to an altitude of about 90,000 km, at the bow shock. Within this environment there are different overlapping regions: the atmosphere, made up of neutral molecules and atoms; the ionosphere, where the gas of the atmosphere becomes ionized; the plasmasphere, where the gas is completely ionized and trapped in Earth's magnetic field; and the radiation belts, which contain high-energy electrons and ions. These regions are affected by Earth's magnetic field, and the region where this field is dominant is called the magnetosphere. Within the magnetosphere there are different population of particles, different electric currents, and all sorts of complex plasma and electromagnetic waves. In addition, the environment also contains dust and meteoroids that live in our solar system, as well as the spacecraft and orbital debris that we are directly responsible for.

In this course we will learn about each of these regions, why they exist, and the positive and negative effects they have on spacecraft, astronauts, and different aspects of society. There are electrical and radiation effects on spacecraft and astronauts; effects on the communications signals from GPS and other spacecraft; effects on the ground due to magnetic field perturbations; impacts on spacecraft by dust and meteoroids; and much more.

The course is organized into **Modules** covering each of the regions of the space environment, with each module encompassing 1–2 weeks. In each module, there will be reading from the assigned textbooks and from course notes; movie and mission assignments; and graded homework problems.

To give some contextual reference, and just for fun (not in that order), we will discuss a movie and one or two spacecraft missions in each module. We'll talk about the missions in lecture, but you'll have to do some background reading to learn what these missions are up to. These are meant to highlight the state-of-the-art in our knowledge of the space environment, and to give you an idea of how NASA and other scientists learn about the environment. The movie assignments are used to scrutinize the popular portrayal of the space environment, and to look at what space movies get right and what they get wrong. In recent years, many movies have gotten much better and more accurate with their depictions of space; but they still make plenty of mistakes!

Since we'll discuss these movies and missions in lecture, **participation is very important** in this class. Come to lecture with questions and comments, and be ready for discussion.

This class will also require you have some personal initiative and ability to do some research on your own. We will give you the basics for each mission, for example, and point you to specific websites to learn more; but you will need to dig around to find the answers you need to some questions! We will only guarantee that the answers are there where we point you to look; you'll have to find them on your own.

2 Prerequisites & Eligibility

This course is open to all CU Boulder undergraduate students in their third-year or higher, enrolled in a Bachelor's degree program. It doesn't matter if you are an Aerospace Engineering major, other engineering major, or any other major at CU. But there will be some math and physics in this course, so you need to have completed these prerequisites:

- **Physics II (Electricity and Magnetism)**. The space environment is full of plasma, fluid waves, and electric and magnetic fields. We will also discuss a number of aspects of electronics. We will have a brief review of E&M in the first week, but prior preparation from Physics II is a must.

- **Calculus III (Vector Calculus)**. Electric fields, magnetic fields, and waves in the space environment are all described by vector calculus, and an understanding of this math is critical.

Aerospace Engineering majors can use this course as a 4000-level Professional Area Elective (PAE). This course may be taken as an elective for **Space Minor** students under the *Earth, Space, and the Universe* or open elective category.

3 Reading Materials

Required reading materials for this course are:

- Thomas Tascione, "Introduction to the Space Environment", Krieger Publishing, 2010.
- Alan Tribble, "The Space Environment: Implications for Spacecraft Design", Princeton, 2003.
- Reading and homework assignments distributed on Canvas (see below)

Optional reading material that may be of interest to students include:

- Dolores Knipp, "Understanding Space Weather and the Physics Behind It", McGraw Hill, 2011: a comprehensive book focused on space weather, targeted at graduate students.
- Vincent Pisacane, "The Space Environment and Its Effects on Space Systems", AIAA, 2016: a large reference book with emphasis on effects on specific spacecraft systems.
- various websites and papers that we will disseminate via Canvas

4 Subject Outline

Figure 2 gives an overview of the topics covered in this course each week. Figure 3 provides a more detailed overview of the course material in each lecture period. Note that we may end up going faster or slower, so don't treat this outline as truth for each lecture.

5 Logistics

1. Office Hours: Dr. Marshall will be available in his office (ECNT 315) at the posted times (TBD); feel free to drop by at those times without advance notice. If you can't make those times but wish to meet, please e-mail Dr. Marshall to arrange a time. Meetings will be allocated half-hour time periods unless more time is requested.

2. Assignments: For each module we will post **one** document. This document includes reading material prepared by us for your benefit; movie and mission assignments with key points for you to look out for; and problems/questions that constitute the homework assignment for that module. The due dates for these assignments are posted in the outline above and on the document; **dates on the assignment document take precedence** in case the schedule is updated.

3. Movies: Each module will have a movie assignment. In each movie, there are specific scenes we are interested in discussing, and we will do so in lecture. We then may ask you questions in the homework problems about these scenes, or about other scenes.

	MON	TUES	WED	THU	FRI
Intro: Review of basic physics	08/27		08/29		08/31
Part 1: The Sun and the Solar Wind	Labor Day; no class		09/05		09/07
	09/10		09/12		9/14 HW1 due
Part 2: The Earth's Atmosphere	09/17		09/19		09/15
	09/24		09/26		9/28 HW2 due
Part 3: The Ionosphere and Plasmasphere	10/01		10/03		10/05 Exam 1
	10/08		10/10 Last day to Withdraw		10/12 HW3 due
Part 4: The Magnetosphere	10/15		10/17		10/19
	10/22		10/24		10/26 HW4 due
Part 5: The Radiation Belts	10/29		10/31		11/01 Last day to drop
	11/05		11/07		11/9 HW5 due
Part 6: Micrometeoroids and Orbital Debris (MMOD)	11/12		11/14		11/16 Exam 2
	Thanksgiving Break; no classes				
Comparative Environments: Mars	11/26		11/28		11/30 HW6 due
Comparative Environments: Jupiter	12/03		12/05		12/07
Special Topics: Astronauts	12/10		12/12 Last Lecture; HW7 due		12/14
	12/17		12/19 Final Exam; 1:30-4 pm		

Figure 2: Top-level view of topics covered in this course.

If you've already seen the movie assigned, no problem. You can save time, then, by jumping straight to the scenes in the movie that are relevant to the homework questions. We won't test you on the plot of the movie.

Unfortunately we cannot cover the cost of each movie. When possible we'll use movies that are available on Netflix / Hulu / Amazon / etc. We may look to organize movie-watching gatherings, in which case we will provide the movie for free (and maybe snacks).

4. Missions: Each module will have one or two spacecraft missions to discuss. We use these missions to highlight the latest in research in the space environment and to show how we investigate the environment. We will also discuss the technical aspects of how these spacecraft are designed to *survive* the space environment. We will point you to specific websites to learn about each mission, but in general a good place to start is the Earth Observation Portal (eoPortal) Directory, which has detailed (but sometimes out-of-date) descriptions of just about every spacecraft imaginable.

5. Deadlines: Each assignment will have a marked deadline. Late assignments will be deducted 20% up to 24 hours past the deadline; 50% up to 72 hours past the deadline; and not accepted after 72 hours. Exceptions will be made with advance notice (at least 24 hours BEFORE the deadline) for acceptable excuses – travel without access to the internet, family emergencies / illnesses, and so forth. The due dates are known well in advance, so you have plenty of opportunity to plan your time around other obligations.

6. Collaboration: We encourage collaboration on homework assignments, discussion about movies and missions, and so forth, but each student must submit her or his own work for each assignment. Do not simply copy each other if you collaborated; collaborate on solutions, but document the work individually. Collaboration on exams is **not permitted.**

Date	Lecture Title	HW	Topics
Mon, Aug 27	Introduction and Overview		Course intro (15 min); Space environment intro (15 min); Syllabus (15 min)
Wed, Aug 29	Review of Basic E&M		Electric fields; Potential; Current and conductivity; magnetic fields
Fri, Aug 31	Maxwell's equations and Plasmas		Maxwell's Equations; introduction to Plasmas
Mon, Sep 3	Labor Day; no class		
Wed, Sep 5	The Sun and Solar Physics		Solar structure; blackbody; UV, IR, and radio emissions
Fri, Sep 7	The Solar Wind, Heliosphere, Solar Activity		Solar cycle; sunspots; flares; solar wind and heliosphere
Mon, Sep 10	Solar Effects		Effects on spacecraft; thermal calculations; others
Wed, Sep 12	Parker Solar Probe; *Sunshine*		Heat near the sun; intensity and eyesight
Fri, Sep 14	The Earth's Atmosphere	HW1 due	Pressure profile; regions of the atmosphere
Mon, Sep 17	Atmospheric dynamics and variability		Solar cycle, winds, tides, gravity waves, etc.
Wed, Sep 19	Spacecraft Drag		Calculations of drag; effect on spacecraft location and lifetime; variability
Fri, Sep 21	Other Atmospheric Effects		Radiation absorption; erosion and sputtering; scintillation and refraction
Mon, Sep 24	Vacuum effects		Outgassing; material degradation; etc.
Wed, Sep 26	DANDE; *Spaceballs*		Measuring atmospheric density; total mass of the atmosphere
Fri, Sep 28	The Earth's Ionosphere	HW2 due	Chapman Layer; ionosphere composition and density by altitude
Mon, Oct 1	Ionospheric regions and variability		Ionosphere by latitudes and variations
Wed, Oct 3	The plasmasphere		Space weather ionospheric effects; currents and such
Fri, Oct 5	EXAM 1		
Mon, Oct 8	Effects of the Ionosphere		Spacecraft charging, radio wave propagation
Wed, Oct 10	ICON, Ampere, *Hidden Figures*		What happens when a spacecraft re-enters the atmosphere? radio blackout
Fri, Oct 12	Earth's Magnetic Field	HW3 due	Basic dipole magnetic field and origin; spherical harmonic approximation; SAA
Mon, Oct 15	Magnetic field complexities		Bow shock and magnetopause; variability; geomagnetic storms
Wed, Oct 17	Particle motions		Adiabatic invariants and particle motions in magnetosphere
Fri, Oct 19	Current systems		Current sheet; ring current; closure in ionosphere
Mon, Oct 22	Magnetosphere effects		Telluric currents; aurora; navigation
Wed, Oct 24	MMS; *The Core*		Magnetic reconnection; Protection from solar wind
Fri, Oct 26	Radiation Belts	HW4 due	Ionizing radiation; structure of two belts; energies, particles, etc.
Mon, Oct 29	Dynamics of radiation belts		variation in fluxes with storm activity; discussion on origin and evolution
Wed, Oct 31	Other radiation sources		Solar energetic particles; cosmic rays
Fri, Nov 2	Effects on spacecraft		Total dose; displacement; single event effects
Mon, Nov 5	Coupling		Revisit coupling of atmosphere, ionosphere, magnetosphere, and radiation belts
Wed, Nov 7	Van Allen Probes; *Apollo 13*		Measuring radiation belts; origin of these particles; flight trajectory
Fri, Nov 9	Meteors	HW5 due	Meteor distributions; origin; mass from radar and optical
Mon, Nov 12	Orbital debris		Discussion of orbital debris distributions and density; Kessler syndrome
Wed, Nov 14	LDEF; *Gravity*		Micrometeoroid impacts; Kessler syndrome
Fri, Nov 16	EXAM 2		
Mon, Nov 19	Thanksgiving; no class		
Wed, Nov 21	Thanksgiving; no class		
Fri, Nov 23	Thanksgiving; no class		
Mon, Nov 26	Mars atmosphere & ionosphere		Atmosphere composition; density; loss due to solar wind. Ionosphere.
Wed, Nov 28	Mars magnetosphere & radiation belts		Crustal fields leading to complex magnetic field; trapped radiation?
Fri, Nov 30	MAVEN; *The Martian*	HW6 due	Loss of the atmosphere; radiation exposure due to thin atmosphere; wind!
Mon, Dec 3	Jupiter atmosphere & ionosphere		Composition; circulation; electrodynamics!
Wed, Dec 5	Jupiter magnetosphere & radiation belts		Massive powerful magnetic field; effects of moons within it; Io torus; radiation intensity
Fri, Dec 7	Juno and Clipper; *Europa Report*		Europa
Mon, Dec 10	Space effects on humans		Radiation and UV hazards; microgravity effects; more
Wed, Dec 12	Review lecture	HW7 due	Review of topics covered; tips for final exam
Wed, Dec 19	FINAL EXAM, 1:30 - 4:00 PM		

Figure 3: Overview of topics covered in each lecture period.

6 Grading

Grading will be based on the following course components:

Element	Fraction
Homework Assignments	40%
Exam #1	12%
Exam #2	12%
Exam #3	26%
Active class participation	10%

Homework Assignments: As described above, homework assignments are integrated into the single document for each module. Each assignment will be graded out of 100 points, and the total of all assignments is worth 30% of the final grade.

Exams: There will be three exams spread out through the semester. Each exam (including the final) will cover material since the previous exam, but may require knowledge from earlier modules. The format of the exams is still to be determined. The first two exams will be in class (50 minutes), and each worth 15% of the final grade. The final exam will be two hours and worth 30% of the final grade.

Participation: Attendance and participation in class discussion is a must! Lectures are designed to have lots of questions from students and engaging discussion. The participation grade will be based on attendance and engagement with the class. Feel free to e-mail Dr. Marshall if you expect to have excused absences from lecture, and these advance notices will be taken into account.

Final Letter Grades: Grades for the overall course will be set based on the standard numerical criteria, tied to qualitative measures of understanding:

Letter grade	Numerical	Qualitative
A	93%	
A-	90%	Superior understanding of the material beyond the course requirements
B+	87%	
B	83%	Comprehensive understanding of the material
B-	80%	
C+	77%	Adequate understanding of the material
C	73%	
C-	70%	Very limited understanding of the material
D	67%	
F	<67%	Unsatisfactory performance

Final letter grades will follow the numerical cutoff scores; however grades made be adjusted (curved) based on student performance and exam difficulty.

7 University Policies

7.1 Cheating

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

7.2 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 and discuss your needs with your professor.

7.3 Religious Observances

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, notify the instructor PRIOR to any potential conflicts to properly accommodate your schedule.

See the campus policy regarding religious observances for full details.

7.4 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.

7.5 Discrimination/Harassment

The University of Colorado Boulder (CU Boulder) is committed to maintaining a positive learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct, discrimination, harassment or related retaliation against or by any employee or student. CUs Sexual Misconduct Policy prohibits sexual assault, sexual exploitation, sexual harassment, intimate partner abuse (dating or domestic violence), stalking or related retaliation. CU Boulders Discrimination and Harassment Policy prohibits discrimination, harassment or related retaliation based on race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Individuals who believe they have been subject to misconduct under either policy should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127. Information about the OIEC, the above referenced policies, and the campus resources available to assist individuals regarding sexual misconduct, discrimination, harassment or related retaliation can be found at the OIEC website.

7.6 Honor Code Violations

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the academic integrity policy. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, resubmission, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code Council as well as academic sanctions from the faculty member. Additional information regarding the academic integrity policy can be found at the Honor Code Office website.