Introduction to Space (Physics) Instrumentation

SPACE 471

Winter 2024

Revised: 05 Feb 2024 (Changes highlighted**)**

1 Course Fundamentals

Instructor: Prof. Jim M. Raines

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Office Hours: 30 min. after class and by appointment (may be over Zoom)

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Instructional Aide (IA): Tyler Eddy

Office Hours: by appointment, in-person or over Zoom

Email: tjeddy@umich.edu

Lecture Times and Location:

Mondays and Wednesdays, 16:30-18:00

1024 FXB

2 Course Goals and Approach

Goal of Class: ***"To be able to describe the underlying physics behind the instrument/measurement techniques and limitations of instruments used to quantify space regions and processes and to develop your critical thinking abilities with regards uncertainties and errors in Space Science observations."*** Measurements are the key ingredient of science and

engineering and the innovation and creativity of quantifying and observing our world is amazing.

The course will discuss the physical measurement principles, fundamentals of the designs of different instrumentation, and how instrument measurements are converted to physical parameters. Understanding the key assumptions, limitations, errors of different techniques to measure the same plasma, particle and field environments will be emphasized. This class will cover a broad and comprehensive range of observational techniques (including both remote sensing and in situ) used to study the Earth's ionosphere and magnetosphere, the solar corona and solar wind, and the space environments of other planets. The final project of the class will be to develop a science traceability matrix and corresponding instrument definition white paper for potential future investigations.

Please let us know if there is anything we can do to assist you in getting the most out of the class.

Course Style and Format:

The course is fully in person. Lectures will be recorded but not necessarily made available immediately.

The class will consist of lectures interspersed with a variety of activities, including short calculations, pair or small group discussions, problem solving and analysis. Research shows that it is hard to learn if you don't think, so opportunities will be provided for everyone to think aloud and discuss topics with your classmates. Reading the assigned material prior to class makes discussions more impactful.

This class will make extensive use of articles in the scientific literature describing different observational techniques. *Reading is very important in this course.*

Class attendance is an important part of learning and therefore is strongly encouraged and supported by providing ample classroom learning opportunities. Please send an email prior to class for any excused absences.

Canvas will be used extensively. All assignments (quizzes, homework, exams, etc.) will be posted on Canvas and must be turned in via a Canvas submission. Lecture slides will be uploaded prior to class, typically at least 1 hr prior, to enable students to take notes on the slides.

Course philosophy:

We are committed to the principle of universal learning. This means that our classroom, our virtual spaces, and our interactions be as inclusive as possible. Mutual respect, civility, and the ability to listen and observe others carefully are crucial to universal learning. Active, thoughtful, and respectful participation in all aspects of the course will make our time together as productive and engaging as possible. Everyone contributes to classroom climate -- Try to make your contribution a positive one.

Every student should be able to fully participate and do their best work in this course.

Your success in this class is important to us! If there are circumstances that may affect your performance in this class, please let me know as soon as possible so that we can work together to develop strategies for adapting assignments to meet both your needs and the requirements of the course.

I will give you midterm feedback on your participation.

Use this 100% anonymous form to communicate any issues in class, including issues with the way your or others have been treated, areas that need improvement in the lectures, assessments or activities, etc.

Useful Reference Books:

1. Moldwin, Mark, "An Introduction to Space Weather", 2023.

On the UMich campus or VPN, this book can be read for free with the 'read online' option offered at the link below:

https://www.cambridge.org/highereducation/books/an-introduction-to-space-weather/CC822E727D563A79CF959F49E85214C2#contents

Chapters 1-5 provide a short overview of the Solar-Terrestrial Relations discussed in SPACE 370.

2. D. J. Griffiths, "Introduction to Electrodynamics", 4th Ed., 2012.

3. Bevington and Robinson, "Data Reduction and Error Analysis for the Physical Sciences", 3rd Ed., 2003.

Advised Prerequisites:

SPACE 310 - Satellite Mission Design

SPACE 370 - Solar-Terrestrial Relations

Students who have not taken one or both of these courses but are willing to put in some extra time reading background material (e.g. Moldwin, Ch 1-5, above) should not be at much of a disadvantage.

Learning Objectives : After completing this course students will be able to describe the fundamental physics concepts used for measuring space physics parameters, calculate errors and uncertainties of different detectors, and design a mission concept that answers fundamental questions about space environments.

3 Course Contents

Outline of Class (DRAFT Subject to Change)

Part I: Background Principals of Observational Techniques

1. Heliophysics overview: Sun, solar wind, magnetosphere, ionosphere. Space weather and its monitoring.
2. Tools of the trade: Dimensional analysis, Error analysis. Electric and magnetic fields and their effect on charged particle motion.

Part II: In Situ Techniques, Sensors and Detectors

1. Plasma sensors (Faraday Cups, Electrostatic Analyzers, Mass spectrometers)
2. Energetic particle sensors (SSD, Scintillators)
3. Magnetometers (Fluxgate, Helium, GMR/AMR, inductive)
4. Electric Field sensors (Langmuir and E-Field Probes, e-beams)

Part III: Remote Sensing

1. Active Radio Techniques (ISR, HF radar)
2. Passive Radio Techniques (plasma wave receivers)

Part IV: Science traceability and missions

1. Science traceability matrix
2. Space physics missions
3. Final project

Course Schedule

Course Schedule (subject to change)

Week	Day	Date	Topic
1	W	10 Jan	Course Intro; Heliophysics and Space Plasma Domains
2	M	15 Jan	Martin Luther King Day -- No Class.

	W	17 Jan	Background: Dimensional analysis, counting statistics, errors
3	M	22 Jan	Plasma sensor -- Overview
	W	24 Jan	Plasma sensor -- Electrostatic Analyzers (ESAs) [T. J. Eddy]
4	M	29 Jan	Plasma sensor -- Faraday Cups [C.M. Bert] and Langmuir Probes [O. Leon]
	W	31 Jan	Detectors in detail -- Channeltrons, MCPs [T. J. Eddy]
5	M	05 Feb	Detectors in detail -- SSDs, APDs [T. J. Eddy] Uncertainty and distributions
	W	07 Feb	Plasma sensor -- Plasma Mass Spectrometers
6	M	12 Feb	Plasma sensor -- Plasma Mass Spectrometers Energetic particle sensors
	W	14 Feb	Energetic particle sensors
7	M	19 Feb	Energetic particle sensors
	W	21 Feb	Exam 1
SPRING BREAK --- 24 Feb - 03 Mar -- No Class			
8	M	04 Mar	Magnetic field instruments
	W	06 Mar	Magnetic field instruments
9	M	11 Mar	Magnetic field instruments Electric field instruments
	W	13 Mar	Electric field instruments
10	M	18 Mar	Active Radio Techniques (HF, ISR, ionosonde)
	W	20 Mar	Passive Radio Techniques (plasma waves)
11	M	25 Mar	GPS TEC observations; Ground-based arrays and observatories
	W	27 Mar	Exam 2
12	M	01 Apr	Science Traceability Matrix
	W	03 Apr	Space Physics Mission Examples
13	M	08 Apr	No Class -- Total solar eclipse
	W	10 Apr	Space Physics Mission Examples Concept Map of Observations
14	M	15 Apr	Final Project Discussion
	W	17 Apr	Review and Q&A for Final Project

15	M	22 Apr	(Last Class) Final Project Discussion
	W	24 Apr	No Class -- Study Day

4 Assessments and Grades

In-class participation:

In-class participation is fundamental to maximizing your learning in this course. Participate by asking questions, answering questions, actively participating in activities, etc. *Regular class attendance is strongly* encouraged.

If you must be absent because of an emergency or illness, please make every effort to speak with Prof. Raines about it beforehand. If that is not possible, contact Prof. Raines as soon as you are able. Please notify me of absences due to religious observance or University sporting events as soon as you can, or by the *third week of the semester*. Be aware that more than two unexcused absences can affect your grade.

Quizzes: We will have short, ~5 minute quizzes nearly every class period. They will typically cover key points from the previous lecture or preparatory reading. The goal of these quizzes is to help you keep up in with the course as well provide additional motivation to come to class.

Homework Assignments: There will be homework assignments most weeks, typically consisting of a reading assignment, questions about the reading and a number of quantitative problems, often requiring some calculations. Homework is due Sunday before midnight and must be submitted to Canvas electronically as a PDF, unless otherwise specified otherwise.

It is absolutely *not* permitted to consult problems previously worked by others from past semesters of this course or any other related course. (You are always free to consult your own past work!)

Some *collaboration* on homework is encouraged, but each student must work out the answers on their own and the solutions they hand in must be individually prepared. When in doubt, write an honest note at the top of your assignment saying who you worked with and how much. Rule of thumb: If you sit down and work together (in person or virtually), please list them as a collaborator. People with whom you've had short conversations about the assignment do not need to be listed. The submitted homework write-up must be entirely your own.

The use of generative AI is prohibited. Its use degrades the educational value of completing assignments in this course.

At the end of each homework assignment, test and examination, the students must write the Honor Pledge: "I have neither given nor received unauthorized aid on this homework, test or examination, nor have I concealed any violations of the Honor Code." and type their name under it. More information about the CoE Honor code is further down in this document.

Exams: Exams will consist of problems along the same lines as the homework, with the main difference being that they must be completed entirely on your own with no outside input other than what is specifically allowed in the exam instructions. Exams may be take home or in-class, to be decided at least 1 week in advance. For closed book in-class exams, an opportunity will often be given to recover some of the missed points by submitting a corrected version of your exam.

There will be 2-3 exams this semester.

Research Project: A short research project consisting of developing a traceability matrix and writing a short instrument white paper that describes the scientific objectives, measurement requirements and instrument to be included in a future mission. The goal of this project is to have you practice formulating scientific questions, experiment design, and understanding how requirements are derived for instrumentation as well as the fundamentals of the observational technique.

Late Policy:

The baseline late policy is that grades will be reduced by 10% per day late. Contact Prof. Raines *in advance* if you anticipate having trouble meeting the due date. After the solutions are posted, usually one week after the due date, at least 50% of the grade will be deducted from a late homework unless extenuating circumstances have been discussed with the instructors.

Final Grades:

The final score will be computed from a weighted average of a student's grades in the following four categories:

Weighting of each graded course component in final grade.

Course component	Weight
In-class participation and quizzes	10%
Homework	40%
Exams	30%

Research Project	20%

The final grade will be based on the grading displayed scale below:

Grading Scale

Score	**Grade**	**Score**	**Grade**
100	A+	77-79	C+
92-99	A	72-76	C
90-91	A-	70-71	C-
87-89	B+	67-69	D+
82-86	B	62-66	D
80-81	B-	60-61	D-

Final grades of <60 are failing and will not count for course credit. The grading scale may be adjust slightly to align better with overall class performance.

Issues with Grades:

We went you to receive all the credit that you have earned on everry assignment. If you think a mistake was made in grading or that some earned credit was not given on an assignment, please submit a written description of your specific concerns. Blanket requests, e.g. "I think I deserved

more points on this assignment. Can you please regrade it." are not acceptable. Please note: It is possible for the to affect the grade negatively, as well as positively.

5 Additional Course Policies

Illness

If you are sick, please do not come to class. Please inform Prof. Raines as soon as possible to have your absence(s) excused.

Accessibility and Accommodations

If you think you need an accommodation for a disability, please let us know at your earliest convenience. Some aspects of this course, such as the assignments, in-class activities, or the way we teach may be modified to facilitate your participation and progress. As soon as you make us aware of your needs, we can work with you, the Office of Services for Students with Disabilities, or the Adaptive Technologies Computing Site to help determine appropriate accommodations. We will treat any information about your disability with the utmost discretion.

Student Mental Health and Well-being

University of Michigan is committed to advancing the mental health and wellbeing of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, contact **Counseling and Psychological Services (CAPS)** at (734) 764-8312 and https://caps.umich.edu/Links to an external site. during and after hours, on weekends and holidays, or through its counselors physically located in schools on both North and Central Campus. You may also consult **University Health Service (UHS)** at (734) 764-8320 and https://www.uhs.umich.edu/mentalhealthsvcsLinks to an external site., or for alcohol or drug concerns, see www.uhs.umich.edu/aodresourcesLinks to an external site.. For a listing of other mental health resources available on and off campus, visit: http://umich.edu/~mhealth/Links to an external site..

Title IX Statement

Title IX makes it clear that violence and harassment based on sex and gender is a Civil Rights offense subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin, etc. If you or someone you know has been harassed or assaulted, you can find the appropriate resources here:

- UM Sexual Assault and Prevention Center (SAPAC) 24-hour confidential crisis line (734) 936-3333 * http://sapac.umich.edu/Links to an external site.
- UM Counseling and Psychological Services (CAPS) (734) 764-8312 * http://caps.umich.edu/Links to an external site.

- University of Michigan Police (DPSS) (734) 763-1131 (or 911 for emergency) * http://www.dpss.umich.edu/

- UM Office of Student Conflict Resolution (724) 936-6308 * http://oscr.umich.eduLinks to an external site.

- UM Newnan Academic Advising Center (734) 764-0332 * https://lsa.umich.edu/advisingLinks to an external site.

Because of my role as a supervisor of student employees, I am obligated by the Cleary Act to report incidents. This report goes to the University and does not need to include names or be forwarded to the police. See above for confidential resources.

Plagiarism

The LSA Office of Academic Affairs defines plagiarism as "representing someone else's ideas, words, statements or other work as one's own without proper acknowledgment or citation" (see http://www.lsa.umich.edu/academicintegrity/examples.htmlLinks to an external site.). New writing challenges can tax your writing fluency, and entering new academic discourses can test your abilities to synthesize and take ownership over source texts and concepts. My job as instructor in this course is to help you through these obstacles so that you can find your footing as a writer in new domains. Your job as a student is to keep the faith, so to speak, and work through these new domains until you regain confidence. This work requires patience, planning, and focus.

Much plagiarism occurs as a result of a lack of care in regard to reading, note taking, and citation practices, or from procrastination, and/or panic. Care, timeliness, and communication will eliminate most of the risk. If you have questions about whether or not you should give credit to a source in your work, you may clarify it with me. In general, though, I recommend always the citing sources you have consulted as well as those you borrow from directly. *If you are having difficulty with a journal entry or final white paper, please contact me right away!*

Honor Code and Classroom Rules

Please conduct yourself ethically and responsibly. Please read the UM Honor Code. Copying of assignments, submitting work of others as your own, violating exam rules, and turning in assignments late will not be tolerated. See http://www.crlt.umich.edu/faculty/honor.phpLinks to an external site. for the code appropriate for your discipline/college/school.

Technology use in class

Please put away cell-phones and keep laptops/tablets closed unless we are using them for a classroom activity. These are a distraction to both the student with the laptop and to those around them. ***If you use laptops/tablets to take notes***, please sit in front.

Communication and Office Visits

We will regularly send you course announcements, reading assignments, and articles of interest through the Canvas Site. Please feel free to email any course material questions you may have directly to Prof Raines. HOWEVER use the discussion board on the CANVAS site for course logistics, quiz, exams, project, and reading type questions.

Office hours are times set aside to meet with your instructor to have questions answered and to receive extra help with course material. They can be scheduled via the Google link at the top of the syllabus. Please feel free to visit office hours even if you just want to discuss some point of interest in more detail.