Space Environment and Effects

An undergraduate course for both potential space scientists and casual space enthusiasts

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The LAIR

OVERVIEW

An upper-level undergraduate course entitled "Space Environment and Effects" has been developed in the department of Aerospace Engineering Sciences (AES) at CU Boulder. The course is aimed at all majors, but students must have a technical background in order to understand the basic physics involved.

Prerequisites are Calculus II and Physics II; this allows us to keep the material at a high level, while also including some key equations and basic physics.

This course was developed with the following goals:

- Introduce science and engineering students to space science
- Show how the environment is a critical backdrop for spacecraft design
- Show future spacecraft engineers what they need to know to design for the environment
- Provide the fundamentals to understand the objectives of today's NASA Heliophysics missions
- Have some fun scrutinizing great (and terrible) space movies

This elective course was taught to a class of 27 students in Fall 2018. Most students were from engineering, but one was a physiology major with a passion for space. The class will next be offered in Fall 2020, and every 1-2 years.

ORGANIZATION

The course is organized into **modules** covering each component of the space environment:

1. The SUN: Structure of the sun; solar wind and solar emissions; heliosphere; how the sun drives space weather
   - Effects: Thermal effects on spacecraft; UV degradation
2. The ATMOSPHERE: hydrostatic equilibrium; atmospheric layers and composition; winds and tides
   - Effects: Atmospheric drag; oxygen effects; vacuum effects
3. The IONOSPHERE: Ionosphere origin, structure, and composition; plasmasphere; current systems and other phenomena
   - Effects: spacecraft charging; radio wave propagation
4. The MAGNETOSPHERE: Earth's magnetic field; models; magnetosphere structure; ; plasma sheet and current systems; geomagnetic storms
   - Effects: navigation; aurora; geomagnetically-induced currents
5. The RADIATION ENVIRONMENT: Radiation belts (structure, composition, variability); cosmic rays; solar energetic protons
   - Effects: total dose; single event effects; shielding and mitigation
6. METEOROIDS AND ORBITAL DEBRIS: origin and structure of the meteoroid environment; orbital debris environment
   - Effects: Impacts on spacecraft; Kessler syndrome
7. COMPARATIVE ENVIRONMENTS: Atmospheres, Ionospheres, and Magnetic fields of Mars, Jupiter, and other bodies
   - Effects: Impacts on robotic and human missions to other bodies

MODULE ORGANIZATION:

ENVIRONMENT

Introduces basic physics and phenomenology of the space environment

Qualitative description of what is up there: regions, phenomena, variability

Quantitative description of the basic physics and phenomena, using proper units and just a few equations

EFFECTS

Describes critical effects on spacecraft and societal infrastructure

Shows how the physics of the environment drives design requirements for space missions

Basic design problems to account for space environment (e.g. shielding design)

MISSIONS

Introduces recent (and historical) space missions that are built to measure and characterize the space environment

Places the course material in the context of the current state of knowledge

Aim to get students interested in the science and engineering of these missions

MOVIES

Discusses how old and new movies characterize space, and what they get right and wrong

Provides a reprieve from the heavy science and physics of the course material

Usually covered on Fridays to provide a little relief to the week

EXAMPLE: RADIATION ENVIRONMENT

ENVIRONMENT

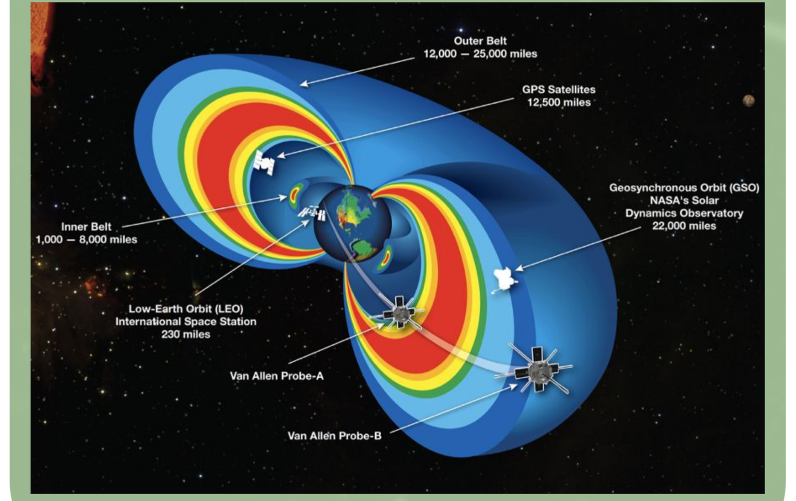
The Radiation Belts: composition, structure, origin, flux and variability

Physics of single-particle motion, adiabatic invariants

South Atlantic Anomaly

Galactic Cosmic Rays: Origin, flux, energy distribution, access into near-Earth space

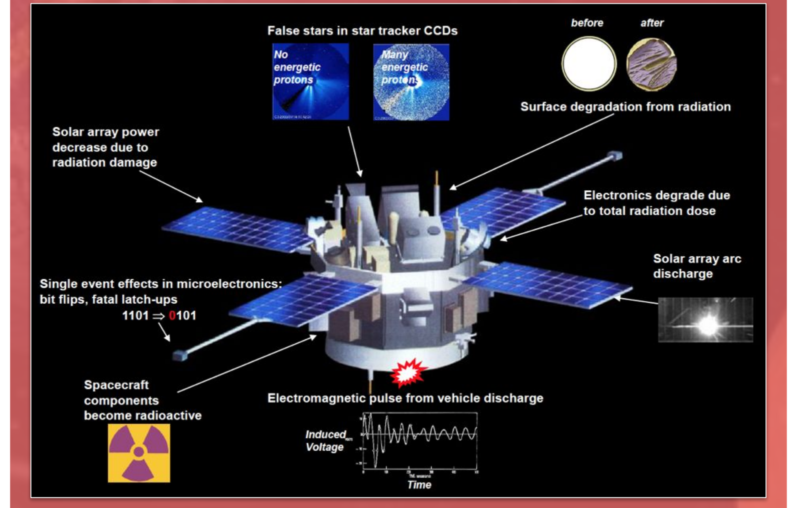
Solar Energetic Protons: Origin, flux, energy distribution, access into the magnetosphere



EFFECTS

Total dose: conversion from flux to dose units

Introduction to the many units for radiation and their proper use



When and where different sources of radiation are problematic

Single event effects, deep dielectric discharge

Shielding design and other radiation mitigation methods

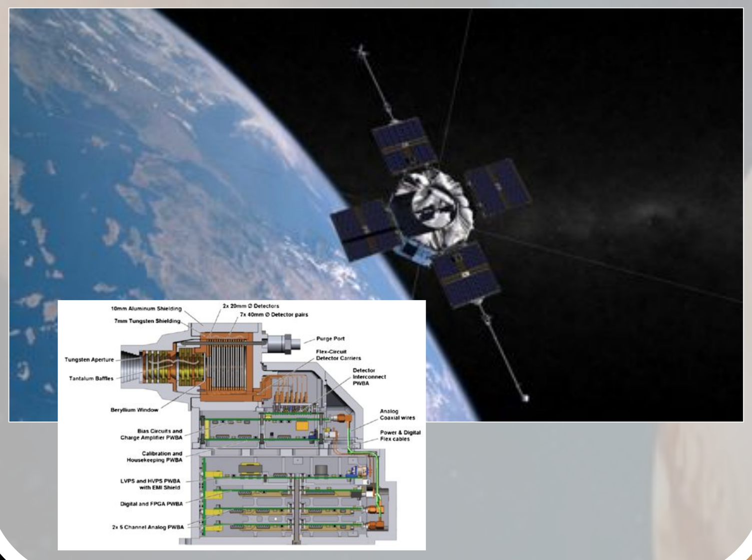
MISSIONS

Brief descriptions of historical missions: Explorer I, SAMPEX

Description of particle measurements on operational missions: POES, GOES, GPS

Introduction to Van Allen Probes mission: science goals and methodology

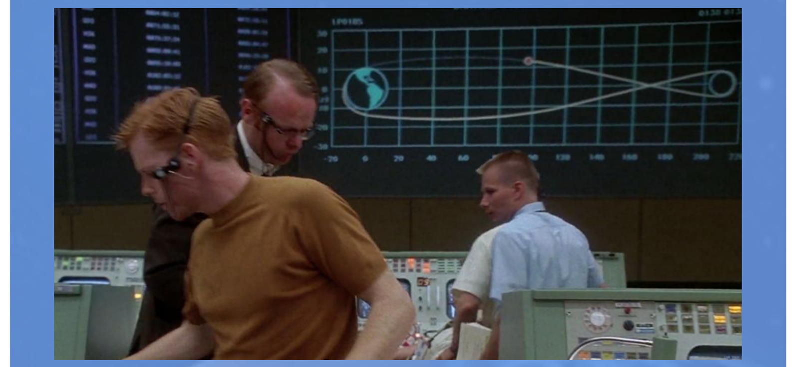
Description of instruments, with focus on energetic particles instruments (MagEIS and REPT) and how they work



MOVIES

Apollo 13:

Trajectory of Apollo missions from Earth to moon appear a number of times in the movie. Why did Apollo take this particular trajectory?



It was hard to find movies with relevance to the radiation belts! This one was a bit of a stretch. Other areas are easier:

The Sun: *Sunshine* (2007)
Atmosphere: *Spaceballs* (1987)
Ionosphere: *Hidden Figures* (2016)
Magnetosphere: *The Core* (2003)
Mars: *The Martian* (2015)
Jupiter: *Europa Report* (2013)
Titan: *The Titan* (2018)

FEATURES

- Movie / Mission content provide "real-world" examples to augment the physics
- Lectures combine traditional lecturing (slides, equations, derivations, etc) and interactive discussion
- Material adapted from *Tribble* (2003), *Tascione* (2010), *Knipp* (2011), *Pisacane* (2016)
- Developed ~200 pages of course notes in Latex, ~60 homework problems
- NASA mission videos and movie clips incorporated directly into lectures

FEEDBACK

- First course offering to 27 students had expected hiccups, but was well received by the students (course rating 5.1 / 6)
  - "I loved this class. By far the best elective I have taken. Very interesting while still being intellectually stimulating."
  - "I really love all the science - the topics covered are awesome!"
  - "Slow down or maybe cut back on the amount of material we need to cover."
  - "I would really enjoy writing essays on topics within the course."
  - "The movies give me a reason to care about the things we study."

CHALLENGES

- Space physics involves a lot of math that is not commonly used in majors outside of the physical sciences. How to teach critical concepts (e.g. particle drifts) without hard math (e.g. vector calculus)?
- Dozens of movies provide plenty to talk about when it comes to orbits and microgravity; but very few directly address space environment issues
- So much great material to cover: what to leave out and what to keep?