Space instrumentation

ASEN/ASTR/GEOL 6050

An instrument scientist’s point of view

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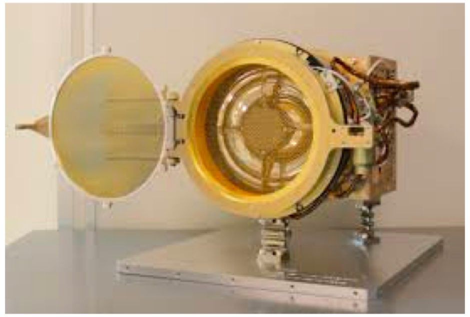
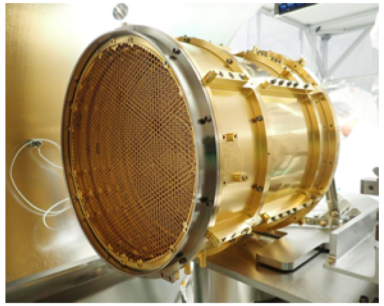
Outline

- My background
- Space physics and planetary sciences at the University of Colorado
- The initial challenges starting a course
- The ASEN/ASTR/PHYS 6050 class
  - Curriculum
  - Sample slides
- Current and future challenges
- Questions? Suggestions?

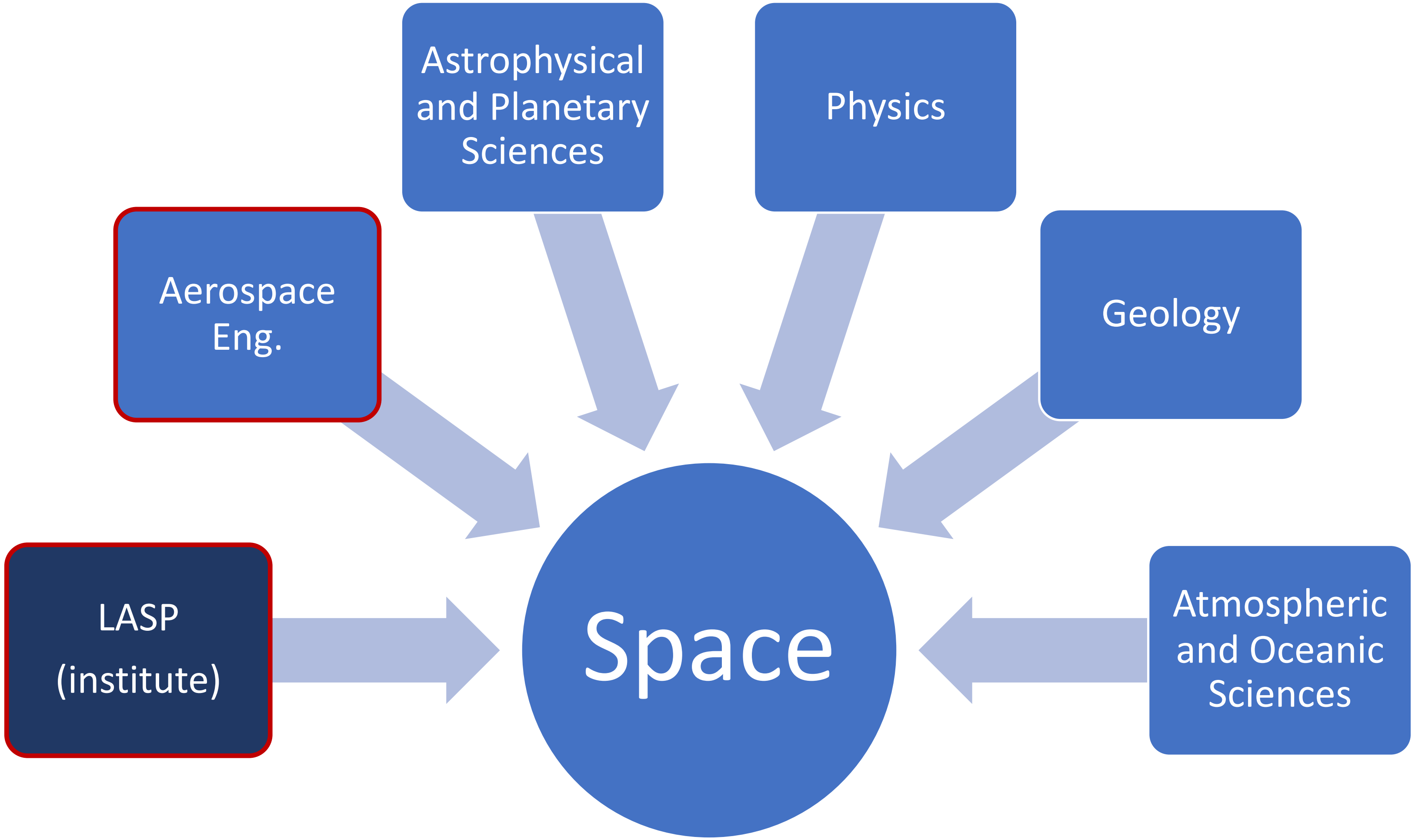
Introduction

- Zoltan Sternovsky, PhD in Physics (2001)
- Professor since 2009
- Early experiences:
  - Starting out as an experimental plasma physicist
  - Two sounding rocket campaign
  - Instrument development through NASA’s PIDD program
- Instrument scientist for flight instruments:
  - LADEE/LDEX (operated 9/2013 – 4/2014)
  - Europa Clipper/SUDA (launch in 2025)
  - IMAP/IDEX (launch in 2024)





The distribution of teaching faculty at CU space physics, heliophysics, and planetary sciences



LASP – Laboratory for Atmospheric and Space Physics

Initial challenges starting a course

- The original attempt in 2009 was establishing a **graduate certificate in lunar and physical sciences (group effort)**
- Motivation:
  - NASA actively supported education activities (~0.5% of total budget)
  - Connected to our NLSI (NASA Lunar Science institute) proposal
  - Young faculty was encouraged to develop their own graduate-level class
  - Need from the space industry hiring graduates with space/lab experience
- 3 new courses were to be developed and offered (by ~4 faculty)
  1. Introduction to dusty plasmas and dust dynamic
  2. **Space instrumentation**
  3. **Hands-on laboratory experiments** (vacuum technology, plasma diagnostics, electronics, detector readout, data acquisition, etc.)
- Insufficient support from the relevant departments for a new certificate
- Insufficient support for establishing the hands-on lab class

ASEN 6050 – Space instrumentation

- First taught in S’2014 as a special topics course
  - 12 students (half from engineering, half from science)
- Constructed from scratch

- Paperwork filed for establishing a regular course later in 2014
- Cross-listed between several departments
  - ASEN/ASTR/GEOL 6050

- Taught the second time in F’2018
  - 12 students (all engineering)

- There is an agreement to offer the class every second year from here on (next in F’2020)

- Established at a 6000 level
  - Aerospace eng. curriculum short on 6000 level courses
  - Must have a 5000 level prerequisite (usually waived)

ASEN 6050 – what is this class about

- Instrument scientists' perspective (linking science and engineering)
  - Teaching faculty expertise
  - University requirements is >= 10 student in a class (need both types of students)
- Space hardware is optimized for maximum science return within a complex frame of constraints (mass, power, data rate, cost, schedule)
  - Requirements & Science Traceability Matrix

- **<u>Three key elements to the class</u>**

1. Understanding the **space environment** and how it affects the design, performance and testing of the instruments
2. **Detector basics** - the continual advancement of detector technology enable new measurements. Capabilities and limitation.
3. Familiarity with the **science and the operation principle of state-of-the-art of instruments,** and their capabilities.

ASEN 6050 - Content

- **Space environment (~4 weeks)**
  - Vacuum (very low pressure)
  - Thermal environment and thermal design
  - Solar spectrum and its effects
  - Other sources of radiation
    - Galactic background
  - Radiation environment
  - Plasma and charged particle environment
  - Meteoroid environment
  - Review of relevant processes:
    - SEE, Ion surface interactions, Photoemission, Ionization, Particle and photon scattering
- **Materials (1 week)**
  - CTE, outgassing, mass loss, radiation damage, surface properties
- **Detectors (2 weeks)**
  - Photon/light detectors
  - Particle detectors
- **Electronics basics (1 week)**
  - Front end electronics
  - Voltage/current/charge measurements
  - Practical limitations
- **Instruments (8 weeks)**
  - Dust detectors and analyzers
  - Magnetometers
  - UV spectrometers
  - IR instruments (thermal imaging)
  - IR instruments (spectrometers)
  - Imaging/cameras
  - Neutral/ion mass spectrometers
  - Plasma instruments
    - FC
    - Solar wind analyzers
    - Energetic particles
  - Neutral particle detectors (high and low energy)

ASEN 6050 - Instruments covered

- Subjective list
- Optical instruments covered only at the very basics (there are classes in the astrophysics program that teach optics design)
- **2014:** List inspired by the instruments on *Cassini*
- **2018:** List inspired by the instruments on *Europa Clipper* and *IMAP*

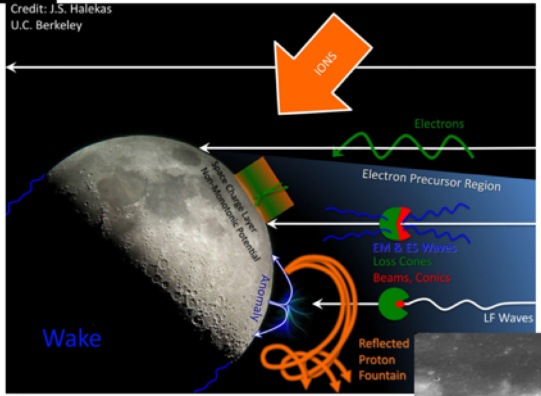
- **Instruments (8 weeks)**
  - Dust detectors and analyzers
  - Magnetometers
  - UV spectrometers
  - IR instruments (thermal imaging)
  - IR instruments (spectrometers)
  - Imaging/cameras
  - Neutral/ion mass spectrometers
  - Plasma instruments
    - FC
    - Solar wind analyzers
    - Energetic particles
  - Neutral particle detectors (high and low energy)

ASEN 6050 – the typical outline of material for each instrument

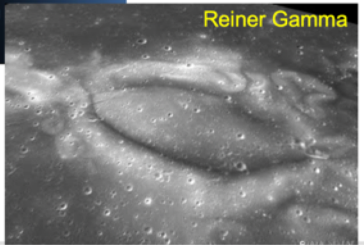
- Review of the relevant science and open questions
- Physical principle of the measurement
- Basic/typical parameters of instruments and their relation to requirements
- Overview of past and current instruments (design, parameters, capabilities, etc.)

Snapshots from the lecture on magnetometers (4 out of about a total of 50 slides)

Lunar crustal magnetic fields

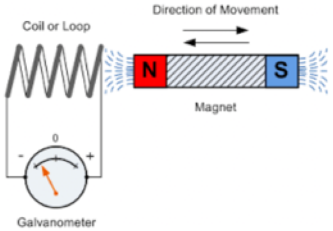


- The Moon has no global field, only localized crustal magnetic fields
- Generation of mini-magnetospheres with SW interactions
- Related to impact craters
- Helps to understand the early history and thermal development



Lunar "Swirls" – optical features on the lunar surface – related to magnetic anomalies

Search coil (or induction coil) magnetometers



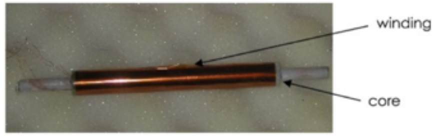


Fig. 1 Picture of a THEMIS search coil before potting

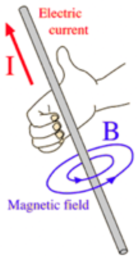
- As the name implies – this is a coil
- Operation based on electromagnetic induction (Faraday's law):
  - Electromotive force:
  - $emf(t) = -\frac{d\Phi}{dt} = -\mu_0\mu_r nA\frac{dH(t)}{dt}$
- Number of turns ***n***, cross sectional area ***A***
- Helps to make the measurement with a coil wound over a soft ferromagnetic material
  - Explain why
- This is a vector magnetometer with a principal axis aligned with the cylinder

Magnetic field basics

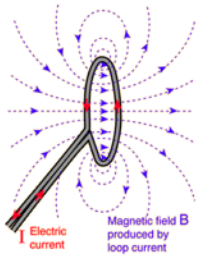
- There are no magnetic charges:
  - $\nabla \cdot \vec{B} = 0$ which is equivalent to: $\oint_S \vec{B} \cdot d\vec{S} = 0$
- The magnetic field is defined through the effect is has on the environment (i.e. charged particles)
  - Lorentz force: $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
  - Or as a torque on magnetic dipoles (e.g., compass)
- There are three relevant quantities:
  - **H – magnetic field** – the most basic quantity – unit is [A/m]
  - **B – magnetic field intensity** – [T] = Tesla
  - ***Φ*** **– magnetic flux** – [Wb] = Weber
  - $\Phi = \vec{B} \cdot \vec{S}$
- Moving charges generate a magnetic field
  - Biot-Savart law:
  - **Permeability of vacuum** $\mu_0 = 4\pi * 10^{-7}$ m kg s^{-2}A^{-2}

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int_C \frac{I d\boldsymbol{\ell} \times \mathbf{r}'}{|\mathbf{r}'|^3}$$

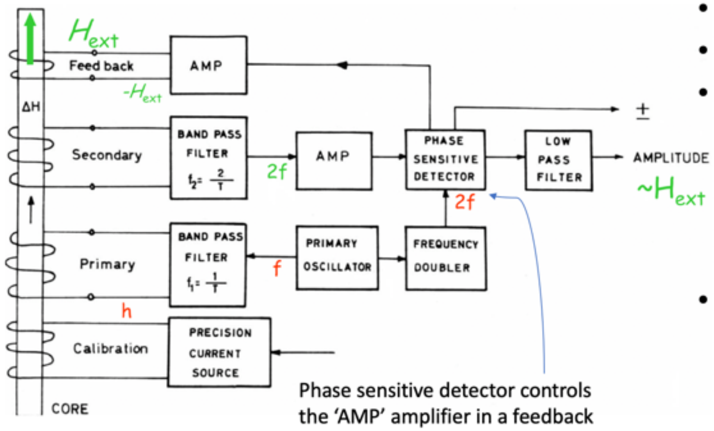
Wire



Loop



FM – measurement concept – null detector



Phase sensitive detector controls the 'AMP' amplifier in a feedback look and automatically zeroes out the second harmonic signel

Components:

- Primary driving signal and coil
- Secondary sensing coil
- The useful part of the sensed signal is that at $2f_0$ frequency
  - This signal could be directly measured using a lock-in amplifier (mixing the signal with a $2f_0$ sinusoid and measuring the amplitude)
- But there is a better method:
  - Apply a DC field to the core using the feedback coil, until there is second harmonic is zeroed out
  - The current needed is proportional to the external field
  - This is called the null detector

ASEN 6050 – Current and future challenges

- Class currently to a single teaching faculty
  - Non-standard curriculum with no textbooks
  - Not eligible as a topic for a comprehensive examination
  - There may be volunteers to help teaching it (and expend upon)
- Demanding to teach!
  - Developed from scratch
  - Requires substantial updating each time (instruments evolve)
- Lack of resources (books, review articles, websites)
- Finding good homework/exam problems is non-trivial
- May be cancelled if enrollment falls under 10 students

Summary

- There is a new graduate-level space instrumentation class offered at the University of Colorado

- Questions?
- Suggestions?