Space Instrumentation

- Instruments
  - Examples of remote measurements
  - Challenges for in situ measurements
  - Examples of in situ measurements
  - Future missions
  - Obtaining physical results from measurements

- Data Analysis
  - Particle Data Analysis
  - Wave Data Analysis
  - Data Presentation
Space Instrumentation

If you get nothing else out these lectures . . .

- Most data and instrument descriptions are available online:
  - Coordinated Data Analysis Web (CDAWeb)
    http://cdaweb.gsfc.nasa.gov/
  - Instrument and mission web pages
- Instruments and their data can be complex
  - Web pages often have very useful information on using the data
  - Question the data
  - Contact the instrument teams when you have questions
Most ground based observations are remote measurements

We have a long history of some ground based measurements:

- Optical measurements
  - All sky cameras view of the aurora, counting sun spots
- Radar
- Magnetometer chains
- TEC – Uses timing corrections in GPS to determine the Total Electron Content of the ionosphere
- Limitations
  - Remote measurement, must account for atmosphere and ionosphere effects
Charge Coupled Device (CCD) uses photoelectric effect to convert photons into electrons
  • Each pixel accumulates a charge proportional to the number of photons incident
  • The CCD only measures number of photons, not wavelength, so filters must be used
  • Fisheye lens collects light from a full hemisphere and maps it to a plane
Instrumentation - All Sky Camera

For observing aurora in the visible spectrum

Courtesy FMI
Super Dual Auroral Radar Network

- International network of radar stations
- Used to measure the plasma motions of the ionosphere at polar latitudes

How it works --
HF and VHF radars are arranged in a network, capable of sensing backscatter from ionospheric irregularities in the E and F-regions of the high-latitude ionosphere, enable maps of ionospheric motion.

http://superdarn.jhuapl.edu/java/index.html
Instrumentation - SuperDARN

- Measured velocity of the plasma is shown
- Contours show convection flow pattern
- Electric field can be derived from these measurements

http://superdarn.jhuapl.edu/
Space Instrumentation - Space Based

In Situ Measurement Challenges

• It is expensive to launch objects into space
  – Want low mass instruments
• Launch can be rough
  – Need strong instruments
• Unique environment
  – Instrument temperature can range from -30 to +50°C
  – No convective heating or cooling for thermal control
  – High radiation environment
  – Low power
  – High reliability required
• Spacecraft interactions
  – FOV, spacecraft charging, internal B field
• Low telemetry rate available
Space Instrumentation - Geiger Counter

Discovery of the Radiation Belts - First In Situ Instrument

- Geiger counter flown aboard Explorer 1 and 3 in 1958 (first two successful US orbital launches)
- Geiger counter was flown to measure cosmic rays without atmospheric attenuation

It is important to know how your instrument works in space and in all conditions!
Explorer 1 had no data recording, so it did not have a continuous measurement. Data from apogee (furthest distance) showed zero counts.

- Explorer 3 had a tape data recorder. Through apogee, count rate ramped up, then went to zero. The opposite was seen exiting apogee.
- Lab tests showed that counter did not give counts in high radiation environment $\Rightarrow$ discovery of the Radiation Belts
- Important to understand how your instrument responds

Full story: http://www-istp.gsfc.nasa.gov/Education/bh2_2.html
Space Instrumentation - Geiger Counter

How it works --
A sealed tube with electrodes is filled with an inert gas and a halogen gas. An anode wire runs through the center of the tube, and the exterior of the tube acts as a cathode. When ionizing radiation such as cosmic rays enter the tube it creates a charge pair that are accelerated via an electric field to the anode (electron) and cathode (ion), creating a momentary current ‘burst’.

The halogen gas acts to rapidly quench any charge cascade resulting from collisions, enabling a fast ‘recovery’ and the ability to individually detect thousands of cosmic rays/second.

Image from Wikipedia
Space Instrumentation

- Instruments
  - Examples of remote measurements
  - Challenges for in situ measurements
  - Examples of in situ measurements:
    - Fields, Particles, Waves
  - Obtaining physical results from measurements

- Data Analysis
  - Particle Data Analysis
  - Wave Data Analysis
  - Data Presentation
Space Instrumentation - Magnetometers

Various types of Magnetometers

- Fluxgate
- Quantum mechanical effects
  - Proton precession
    - Measure the proton precession rate caused by external B field
  - Alkali vapor magnetometers
    - Use Zeeman splitting of energy levels
Give absolute B measurements

1890’s horizontal field induction magnetometer -- Courtesy U. Innsbruck
Space Instrumentation - Magnetometers

Fluxgate Magnetometer

- Magnetically susceptible core has property that $B$ saturates at a critical value of $H$
- The primary winding drives the core periodically into alternating saturation using AC current
- This alternating magnetic field drives a current in the secondary coil.
- External field causes a shift in time when the core goes into saturation, and thus a measurable delay in the AC phase.
Space Instrumentation - Magnetometers

Fluxgate Magnetometer

- Can be orientated to obtain 3-component magnetic vector measurements.
- Needs to be isolated or shielded from onboard circuits that could contribute their own magnetic fields to the mix (either by placing on a boom, using magnets or both!)
- Recently, these are often paired with ionized gas magnetometers for calibration and sensitivity purposes.

Voyager 2 -- Courtesy NASA
Proton Precession Magnetometer

• Measures the resonance frequency of protons (hydrogen nuclei) in the magnetic field to be measured, due to Nuclear Magnetic Resonance (NMR).
• A hydrogen rich fluid is placed in a strong magnetic field produced by a current to align the protons.
• The current is then turned off and the protons realign and precess about the background field to be measured a field related frequency (the proton gyroratio = 0.042576 Hz/nT).

Courtesy U. Melbourne
Space Instrumentation - Magnetometers

Ionized Gas Magnetometer

• Very high accuracy, fraction of a nT.
• Uses gas vapor with metastable electron states and ‘optically pumps’ the gas with light at a specific wavelength until all atoms are in the same state (‘polarized’).
• There is a background magnetic field and an applied rotating field perpendicular to the background that cause precession of magnetization due to electron spins.
• During precession the amount of light through the sample will be modulated in synch with the preceding magnetization, a modulation that is detected to extract the strength of the background field.

Cassini MAG Team - Imperial College
Space Instrumentation - Langmuir Probe

Electric Potential Measurements

• Booms
  – Measure voltage difference between ends of two booms (electric potential)
  – Sphere probe has uniform response to photoelectrons, but are more complicated than cylindrical probes
  – Probes need to be further apart than the plasma Debye length to get a valid measurement

\[ \lambda_D = \left( \frac{\varepsilon_0 k_B T_e}{n_e e^2} \right)^{1/2} \]

One of a pair of probes from the Rosetta spacecraft (Courtesy ESA)
Electron Density and Temperature
- Using a constant (or sometimes time-varying) electric potential between the probes, one can measure the $T_e$ and current density flowing to the surface of the probe, i.e.

$$ (V_{pos} - V_{fl}) = \ln 2 \frac{k_B T_e}{e} $$

- The current density is determined by the characteristics of the plasma, hence the electron density, temperature, and (in the case of a collisional plasma) resistivity can be obtained.
Energetic Neutral Atoms

- What are they?
  Generally neutral atoms in space are formed very cold, however, charge exchange with an energetic plasma population can create energetic neutrals which travel in ballistic trajectories rather than being trapped along magnetic fields.
Energetic Neutral Atoms

Are present everywhere in space, but are sourced most readily from regions with high densities of neutrals and ions. Useful for imaging the plasmasphere and ring current at Earth, and the interaction of the atmosphere of the rings of Saturn with Saturn’s magnetospheric plasma.
Energetic Neutral Atom Detectors

There are various types, but how do they work?

1. Thin carbon foil (3-5 nm, 12-20 atomic layers)
2. ENA stripping followed by ion energy analysis
3. ENA time-of-flight (TOF) detection (background suppression by coincidences)

Courtesy of Astronautics Now
Space Instrumentation - ENA

Energetic Neutral Atom Detectors - INCA on Cassini

Consists of a **collimator** to ensure no charged particles get into the detector, main **foil** to filter out photons, and three **MicroChannel Plates** (MCPs) to determine flux of ENAs, recreate a 2-D image, and determine Time of Flight (ToF).

For more info on ENA detector types:

Courtesy of Astronautics Now
Electrostatic Analyzers

There are three main types of electrostatic analyzers:

- High Pass
- Low Pass
- Band Pass

Operate using DC electric fields and do not use RF or magnetic fields
Electrostatic Analyzers - Retarding Potential Analyzer (RPA)

- Voltage is applied to set up an electric field
  - Apply 1000 Volts the red grid and hold the outer grids at ground
- Charged particles will feel a force as they pass through the grids
- Particles need enough energy to get over the potential wall
- No information is learned about the particles mass
Space Instrumentation - Charged Particles

Electrostatic Analyzers - Retarding Potential Analyzer (RPA)

- An RPA only measures the energy normal to the sensor
- Particles with non-normal Incident angles may still get into the detector

High Pass Filter
Similar to the RPA, the Mirror analyzer detects charged particles with low enough energies to be turned around by a given potential.

Low Pass Filter
Space Instrumentation - Charged Particles

Electrostatic Analyzers - ESA and Tophats

- Energy of particle passed is linearly proportional to the voltage on the analyzer
- The constant of proportionality is the analyzer constant
- This gives an ESA more ‘leverage’ than an RPA or Mirror

\[ \frac{1}{2} mv^2 \frac{q}{q} = k\Delta V = \frac{\text{Particle Energy}}{\text{Charge}} \]
Space Instrumentation - Charged Particles

Electrostatic Analyzers

The RPA and Mirror measure all particles above or below a critical energy. They make an integral measurement. The ESA measures particles in a band of energies. An ESA makes a differential measurement.
Space Instrumentation - Charged Particles

Electrostatic Analyzers

Mass analysis:

- With known energy (per charge), if we can determine the particle velocity, we can determine the mass (per charge) from the kinetic energy.
- Magnets will bend the particle path differently for different velocities.

\[
\frac{\text{Energy}}{\text{charge}} = \frac{1}{2} \frac{mv^2}{q}
\]

\[
r_{\text{gyro}} = \frac{mv_\perp}{qB} = \frac{2E}{v_\perp B}
\]

For a uniform applied magnetic field \( B \), we can determine \( v \), and therefore \( m \). Here \( v \) is necessarily \( v_\perp \) due to the detector geometry.
Space Instrumentation - Waves

- Long antennas listen to radio waves emanating from the magnetosphere plasma
- Fundamental plasma theory generates plasma wave relationships that can be used to extract plasma properties from electric and magnetic frequency spectrograms.

\[ f_c = 28B \text{ Hz} \quad (B \text{ in nT}) \]
\[ f_{UH} = \left( f_p^2 + f_c^2 \right)^{1/2} \]
\[ f_p = 8980\sqrt{N} \quad \text{Hz} \]
\[ N = \frac{f_{UH}^2 - f_c^2}{8980^2} \quad \text{cm}^{-3} \]

\[ f_c \ll f_{UH} \]

Gurnett et al., 1996 — Discovery of Ganymede’s magnetosphere using waves!
Space Instrumentation - Missions

IMAGE Spacecraft - Image the magnetosphere and aurora

• Understand the morphology and variations of the plasmasphere with respect to solar wind variability.
• Study the UV aurora in conjunction with the plasmasphere variability, including the cusp aurora
• Visualize the interaction between the hot plasma sheet plasma and the cooler plasmasphere.

Courtesy SWRI - IMAGE webpage
• Understand the location and size of reconnection regions in the magnetosphere using several spacecraft.
• Examine the important length-scales for magnetic diffusion, including electron and ion skin depths and diffusion regions.
Space Instrumentation - Missions

Magnetospheric Multi-Scale - Magnetospheric Dynamics

Magnetospheric Multiscale
A Solar-Terrestrial Probe

Unlocking the Mysteries of Magnetic Reconnection
STEREO consists of two space-based observatories - one ahead of Earth in its orbit, the other trailing behind. With this new pair of viewpoints, scientists will be able to see the structure and evolution of solar storms as they blast from the Sun and move out through space.

* Understand the causes and mechanisms of coronal mass ejection (CME) initiation.
* Characterize the propagation of CMEs through the heliosphere.
* Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
* Improve the determination of the structure of the ambient solar wind.

http://stereo.gsfc.nasa.gov/
Space Instrumentation - Missions

STEREO - Solar TErrestrial RELations Observatory

STEREO Ahead EUVI 304

2008-09-29 08:26:15
Space Instrumentation - Missions

STEREO - Solar TErrestrial RElations Observatory
Kepler Launched!!!!

Kepler will be in an orbit around the Sun, trailing the Earth, surveying more than 100,000 stars for three years.

**Small Cousin**
Considerably smaller than the Hubble Space Telescope, Kepler is the largest telescope ever to be sent beyond Earth's orbit.
Space Instrumentation - Missions

Solar panels
Provide up to 1,100 watts of electrical power and shield the telescope from the Sun's direct heat.

Thermal control
Blankets of teflon and other materials (not shown) help maintain operating temperatures.

Reaction wheels
Allow minor changes in orientation, without burning fuel.

Star trackers
Help orient the telescope in space.

Primary mirror
Made of ultra-low expansion glass coated with silver, it measures 55 inches in diameter.

Corrector plate
A 37-inch glass plate compensates for aberrations in the primary mirror.

Radiator
Cools the focal plane to minus 121 degrees.

Onboard thrusters

Control thruster

HOW IT WORKS
Kepler will hunt for planets by measuring tiny drops in a star's brightness as a planet passes in front of it, or transits. Three or more transits will be required to rule out other causes, like sunspots.

Sources: NASA; Ball Aerospace

Frank O'Connell / The New York Times
Kepler - A very sensitive telescope and camera.

Focal plane
Kepler's 95-megapixel camera holds 42 light-sensitive modules. It is the largest camera NASA has flown in space.

Field of view
The camera will focus on one region of space, monitoring more than 100,000 stars every half-hour for three years. A region of the northern sky was chosen because it is rich in stars similar to our Sun and continuously viewable during the mission.

http://www.nytimes.com/2009/03/03/science/03kepl.html?pagewanted=all#
Space Instrumentation - Missions

NASA Flagship Missions: Thoroughly study all aspects of the intended target(s)

Voyagers 1 & 2 - Solar System Tour and the Heliopause

Galileo - Jupiter system (atmosphere, moons, rings, magnetosphere, aurora, plasma torus, etc…)

Cassini - Saturn system (moons, rings, magnetosphere, aurora, Titan -- Huygens lander)
Space Instrumentation - Missions

NASA Flagship Missions: Prioritized
First Jupiter moons, next Saturn moons

http://opfm.jpl.nasa.gov/community/opfmselectiontext2/
Europa Clipper Mission Concept

Objectives:

- **Ocean**: Existence, extent, salinity
- **Ice Shell**: Water within or beneath; nature of surface-ice-ocean exchange
- **Composition**: Key compounds; links to ocean composition
- **Geology**: Surface feature formation; sites of recent or current activity
- **Reconnaissance**: Surface characteristics at lander scales

Operations Concept:

- 32 low-altitude flybys from Jupiter orbit
- Investigation of globally distributed regions
- Simple repetitive science operations
- Minimal time in high radiation environment

Validated Cost Estimate:

- Aerospace validated cost: $2B ($FY15, w/o LV)

Model Payload:

- Ice-Penetrating Radar
- Stereo Camera
- Infrared Spectrometer
- Neutral Mass Spectrometer
- Gravity Science Antenna
- Magnetometer & Langmuir Probes
- Reconnaissance Camera
- Thermal Imager

http://europa.seti.org/one-small-step-for-a-mission/