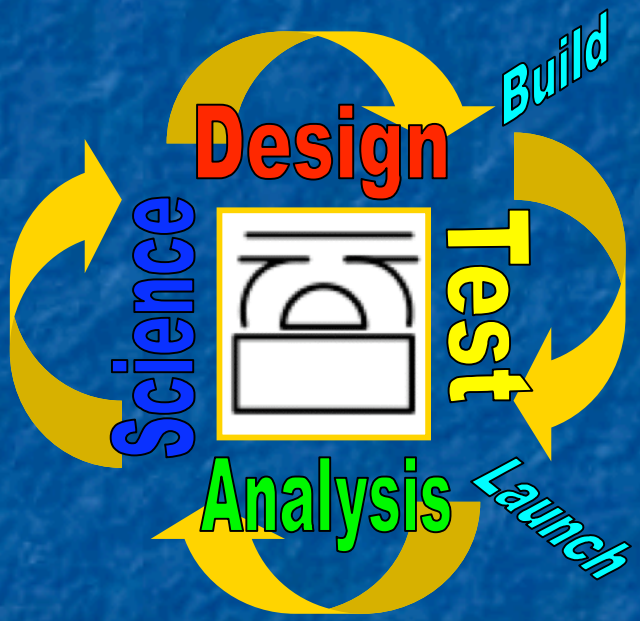
# P-24 Talk - July 11, 2007

## Experimental Space Science

Elizabeth MacDonald,
ISR-1

# Outline

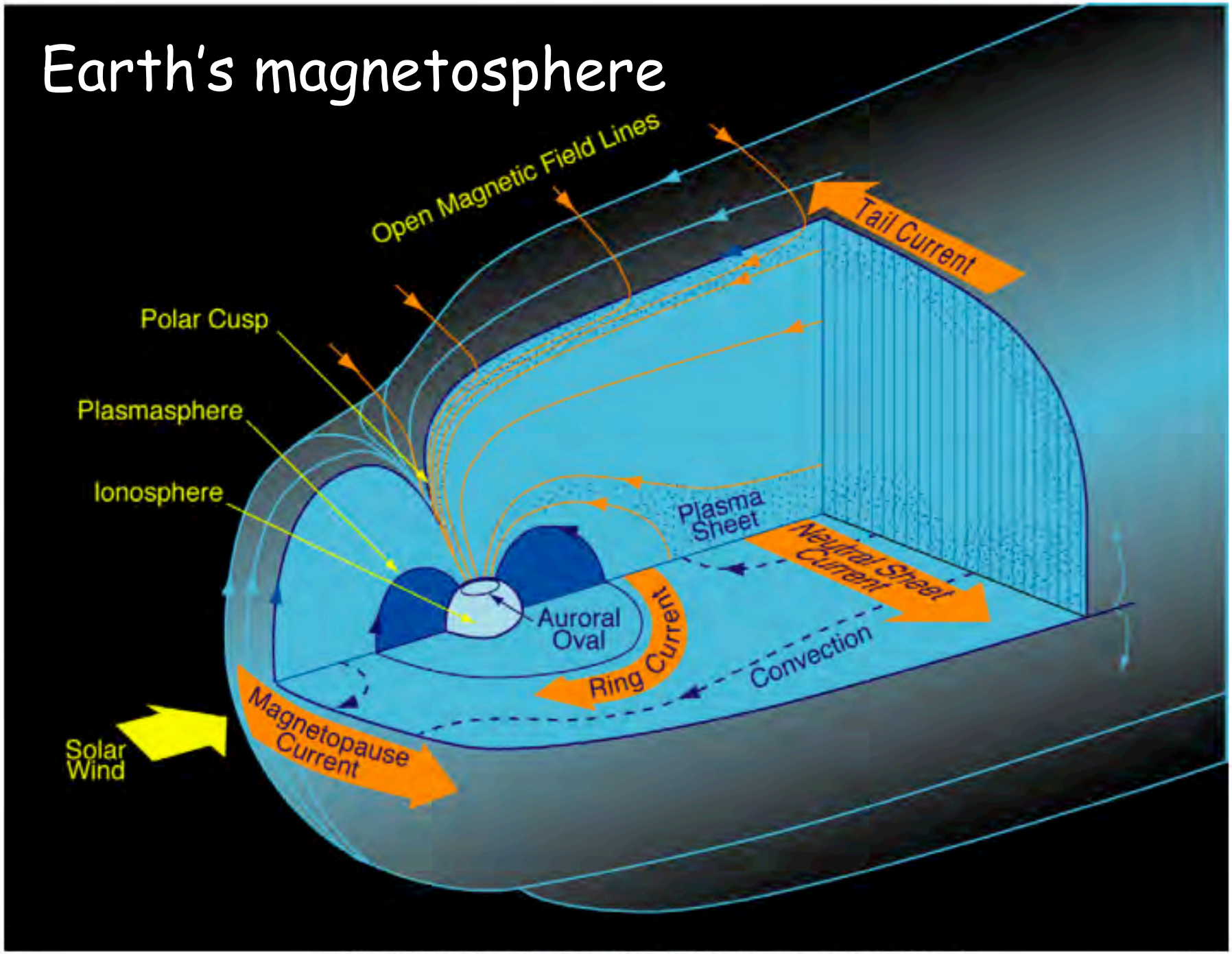
- Intro to space science
- Graduate research
  - Study the aurora with sounding rockets
  - Why do we do it?
  - How do we do it?
    - Research cycle
    - Instruments
    - Typical campaign
- Current LANL research
  - New instruments
  - Magnetospheric physics



# Basics

- Plasma physics, $n_e$, $n_i$, E, B
  - Reconnection, debye length…
- Heliosphere, magnetosphere, ionosphere
- Modern, tangible, practical field
  - Experiments, Observations, Theory, Modeling, Simulations, Laboratory plasmas
  - From the Sun to Earth and in-between
- Multi-scale physics
  - Spatial: 100 A.U. to atoms
  - Temporal: Years to milliseconds
- Complexities and specializations

# Earth's magnetosphere




Source: http://ssdoo.gsfc.nasa.gov/education/lectures/magnetosphere/index.html

# Space weather effects

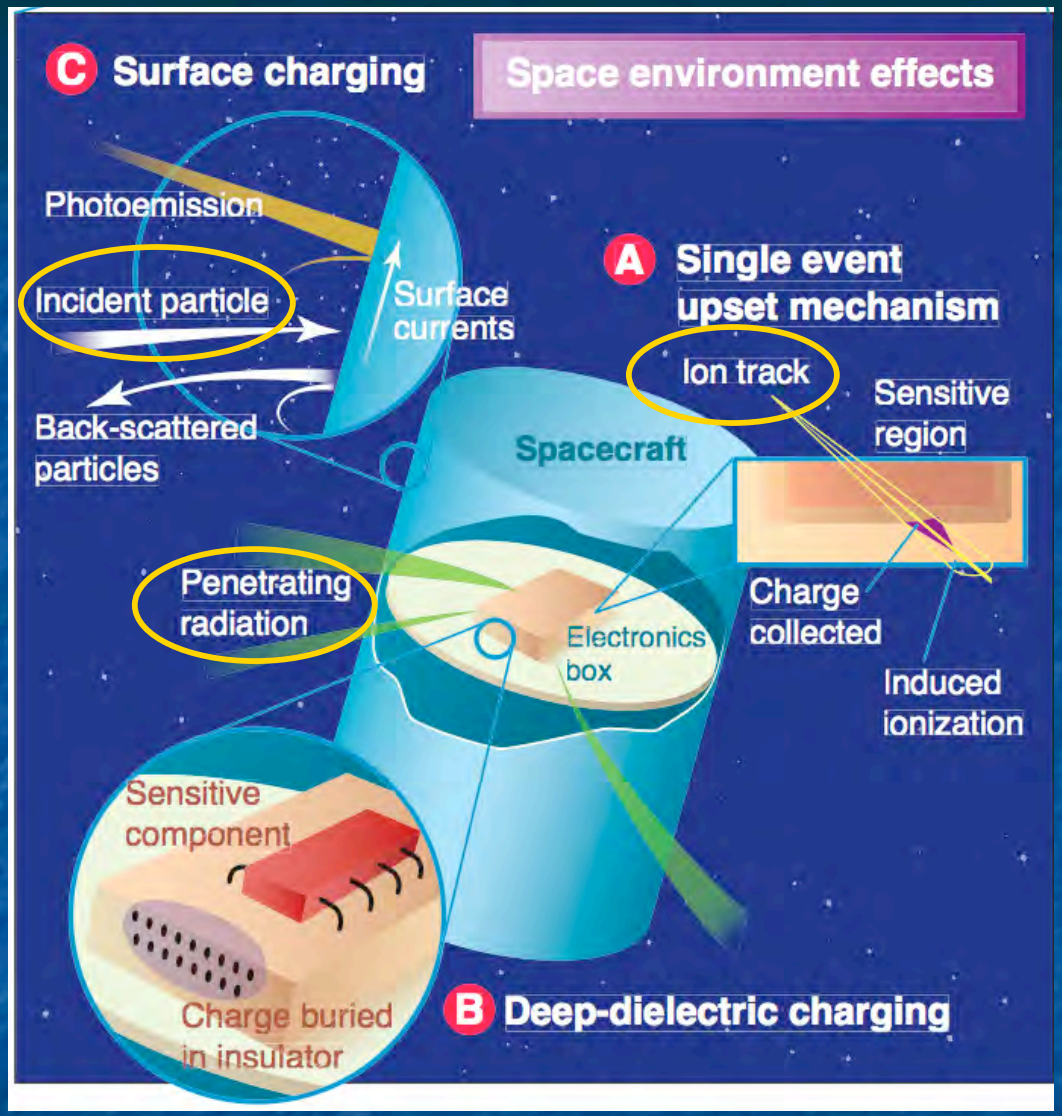
- Satellite failures
  - e.g. Galaxy IV 1998, U.S. pager/comm. sat
- Powergrid failures
  - e.g. Hydro-Quebec 1989, 8 hr. blackout, $2 billion
- Communication (HF disruptions),
  - Airlines priority for new trans-polar flight paths

NASA, USAF, ESA, NOAA, NSF all share in monitoring and enhancing predictive knowledge

- Practical
  - Protection of society's technological assets
- Scientific quest
  - Understanding all parts of this complex coupled system

# Electronics effects

- Monitor fluxes of ions, electrons, UV, & radiation incident to satellites in different locations
- Understand system to know causes of variability in these populations



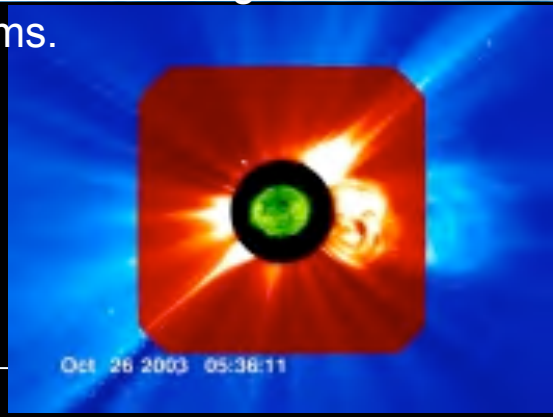
NEW!

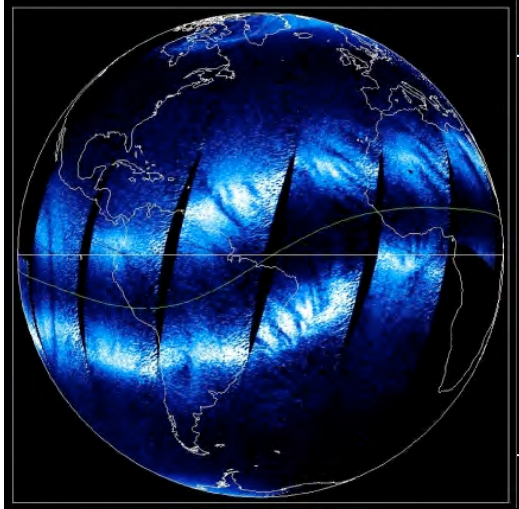
# NASA Heliophysics Division Objectives

Agency Strategic Objective: Explore the Sun-Earth system to understand the Sun and its effects on the Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems.

## Open the Frontier to Space Environment Prediction

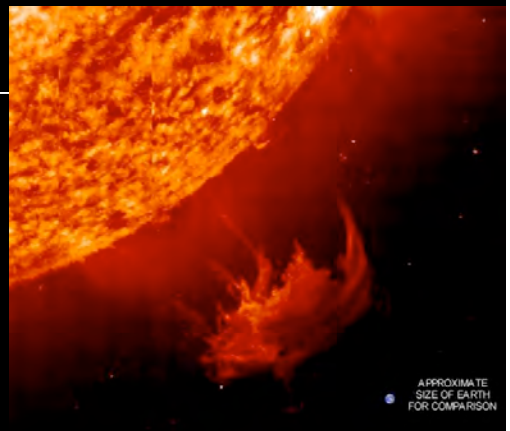
*Understand the fundamental physical processes of the space environment – from the Sun to Earth, to other planets, and beyond to the interstellar medium*



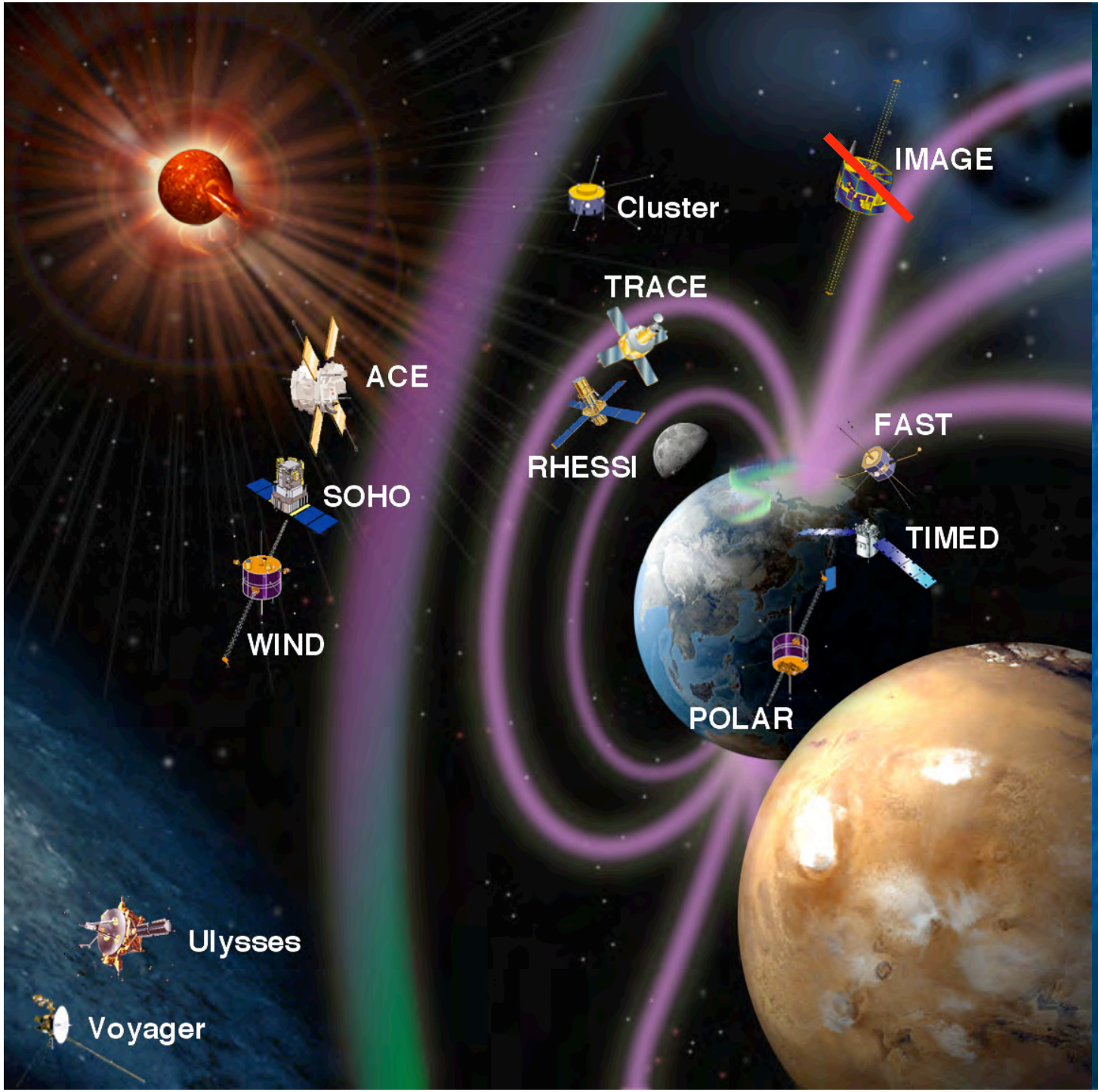
## Understand the Nature of Our Home in Space

*Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields*




## Safeguard Our Outward Journey

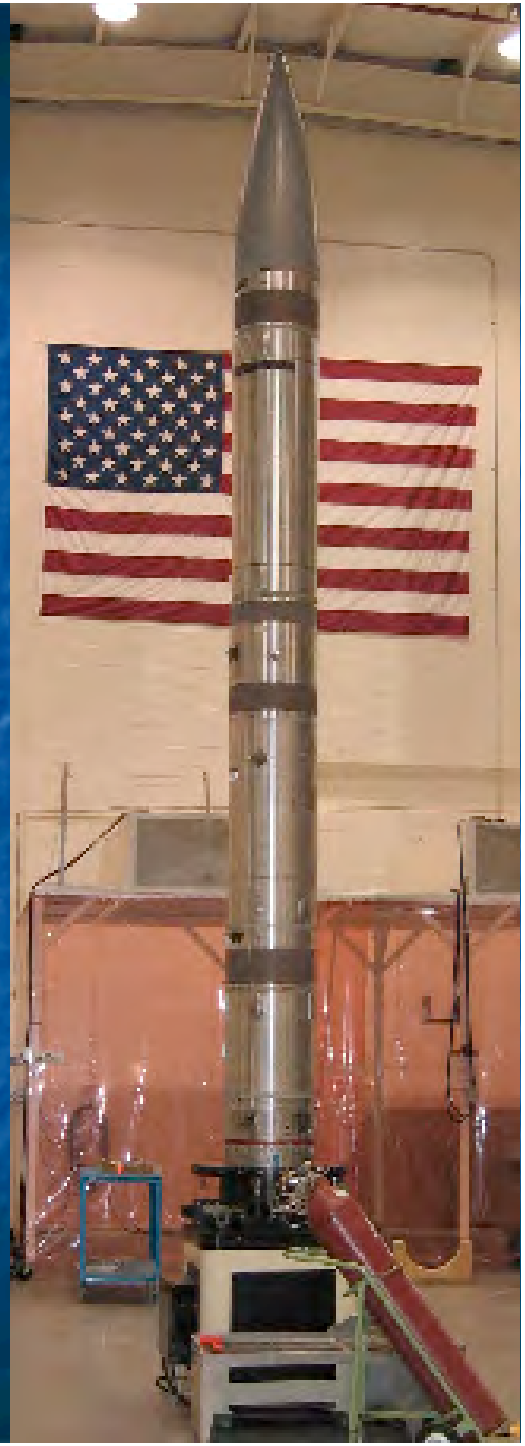
*Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space*




The Fifth Great Observatory (5GO) is a fleet of 13 flight missions operated simultaneously by the NASA Science Mission Directorate (SMD) - Heliophysics Division

# What is a 4 Stage Sounding Rocket?

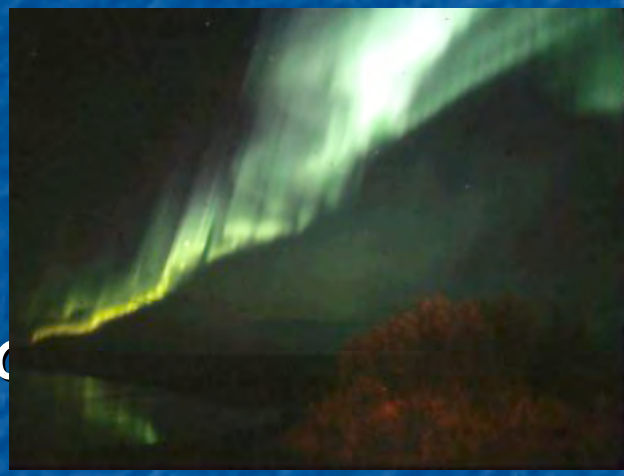
- "Sounding" refers to the nautical term
- Total: 65 ft. tall, 12,000 lbs.
  - Electronics, telemetry, power (batteries), motors, antennae, GPS, Attitude control system
- Expt section: 6 ft, 300 lbs.
- 37 - 870 miles
- 5-20 minutes
- 4 stages of solid fuel
- They launch from Alaska, Norway, Virginia, and even New Mexico!
- 10-20 / year



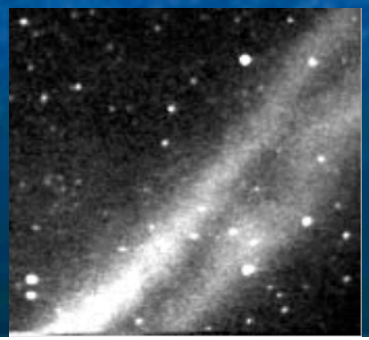
# Rockets can study

- Atmospheric phenomena between 60 - 1480 km
  - High altitude clouds, chemistry, climate, meteors, lightning, other planets, calibrate satellite instruments
  - **Aurora**

Movies!

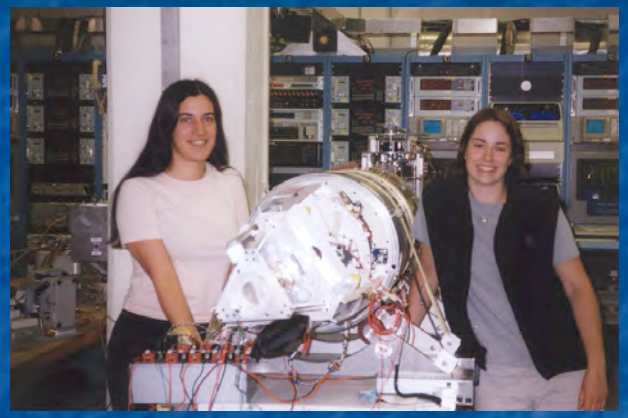


- Input particles which cause aurora
  - Measure energy, mass, direction, & intensity along the trajectory
- Why substorms breakup
- How aurora moves: the dynamics, curling, changes in shape and intensity
  - Microphysics



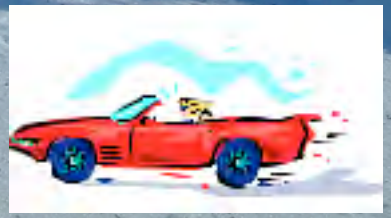
# Why Rockets?

- "Better, faster, cheaper" (than satellites)
  - Lower altitude, more data, higher resolution
  - 5x slower speed than satellites
  - ~1-2.5% cost of satellites
  - Cool stuff, test new methods and instruments
  - Train next generation students to build hardware



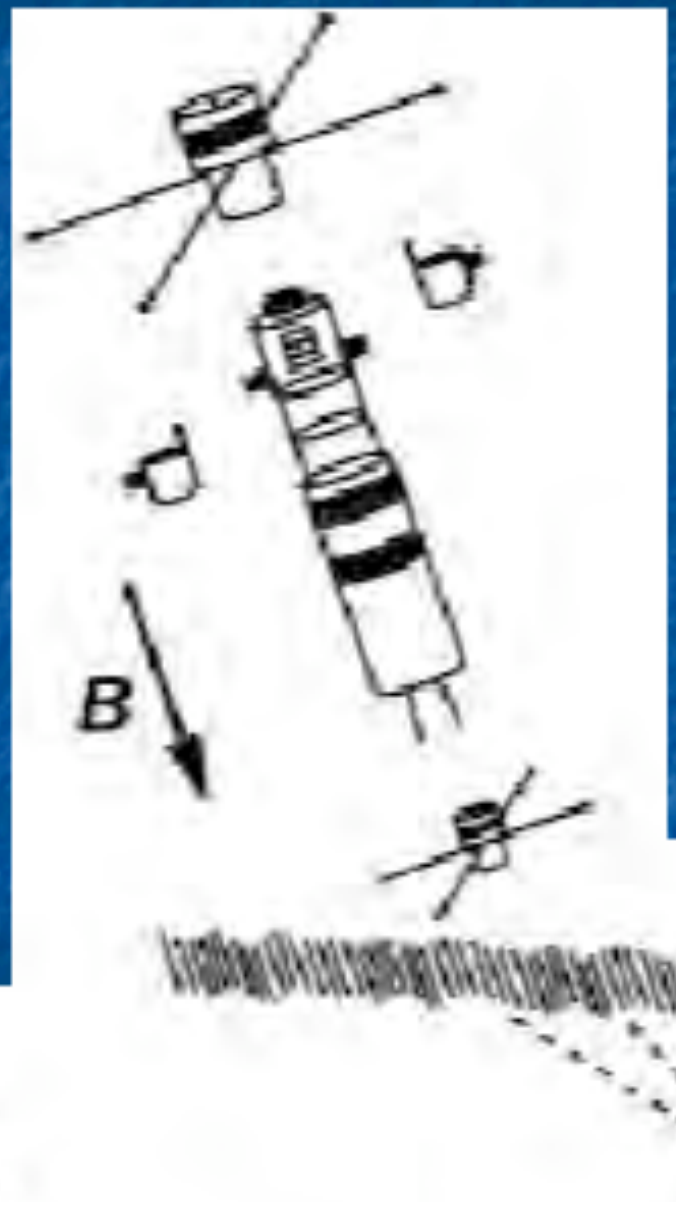
# Difficulties

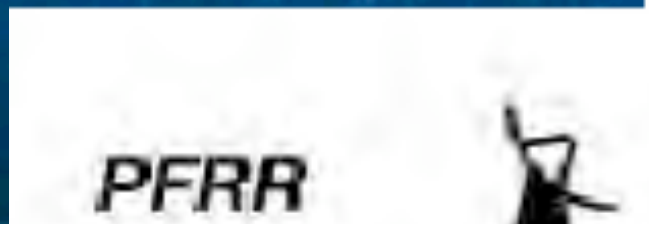
- Accept risk--don't know what you'll get or even if you'll get it
- Rocket moves through arcs, 1 pt measurement of 1 specific unique event
- Can't separate spatial boundary from change in time
  - Rain analogy
  - Unless you have multiple payloads



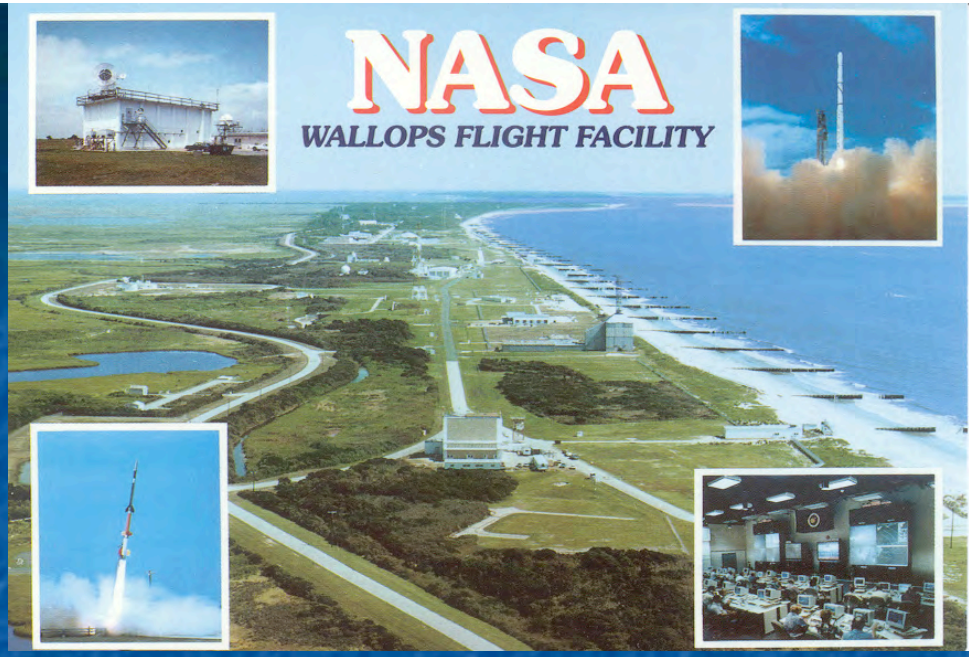
# Cycle of a Sounding Rocket

- Propose to NASA (1 mo.)
  - Specific instruments to solve a specific problem
  - Team of scientists: P.I. is head of project
    - Co-I's from other schools provide additional instruments
  - Catchy Acronym, Budget
  - Wait (6 mo.) for review



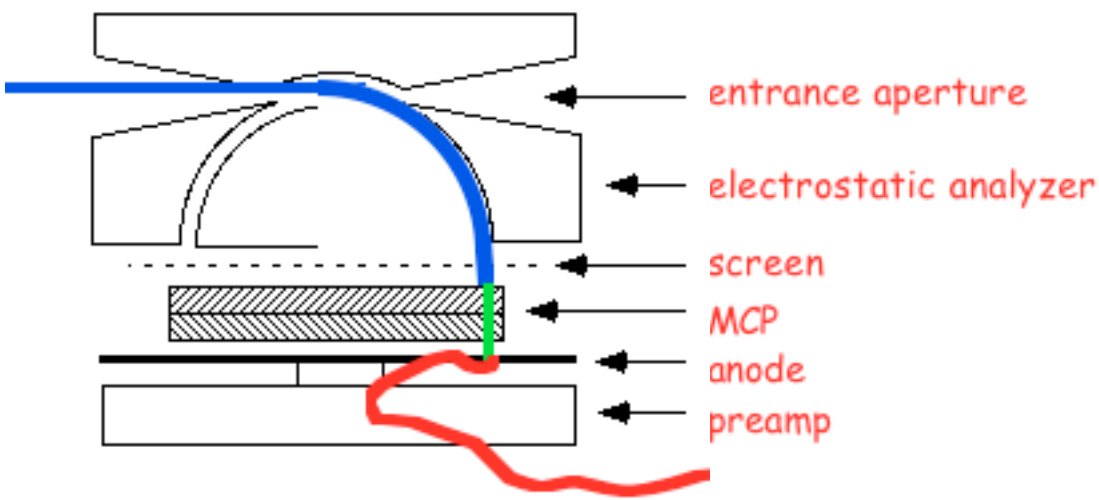



- Design (1 year), build, calibrate (1 year)
- Integrate (with NASA) (2 months)
  - Put experiments together with everything needed to make it fly
  - Test, shake, bake, deploy, balance
- Ready to fly!



# What experiments do we fly?

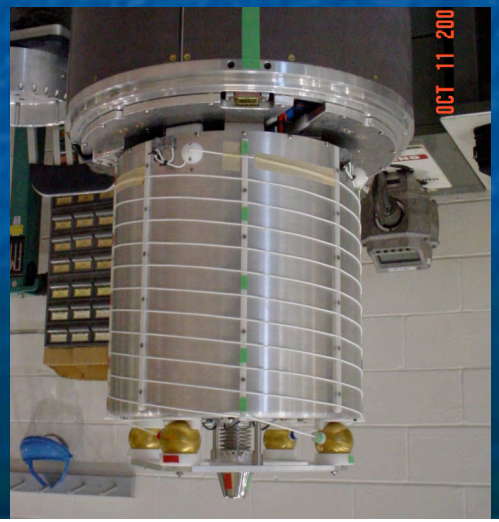
- Charged Particle Detectors
  - Electrons, ions ($H^+$, $O^+$)
  - By applying an electric field across spherical plates, particles of a certain energy and charge are allowed into the detector
    - Spherical plate voltage swept to cover the energy range of interest
  - Incoming particles must be amplified




Must use "night-vision" sensors to get $10^6$ particles out per incoming one ---> enough charge to make detectable current

# Other Experiments

- Magnetometers, sensitive compasses to measure B field
- Electric field probes, voltmeter
- Cameras
- Chemical Releases, glow traces neutrals
- Inventive new instruments and combinations
- Multipoint measurements via subpayloads, free-flyers, hockey pucks



# Fly! (1 month)

## launch campaign

Feb 27-Mar 14 this winter

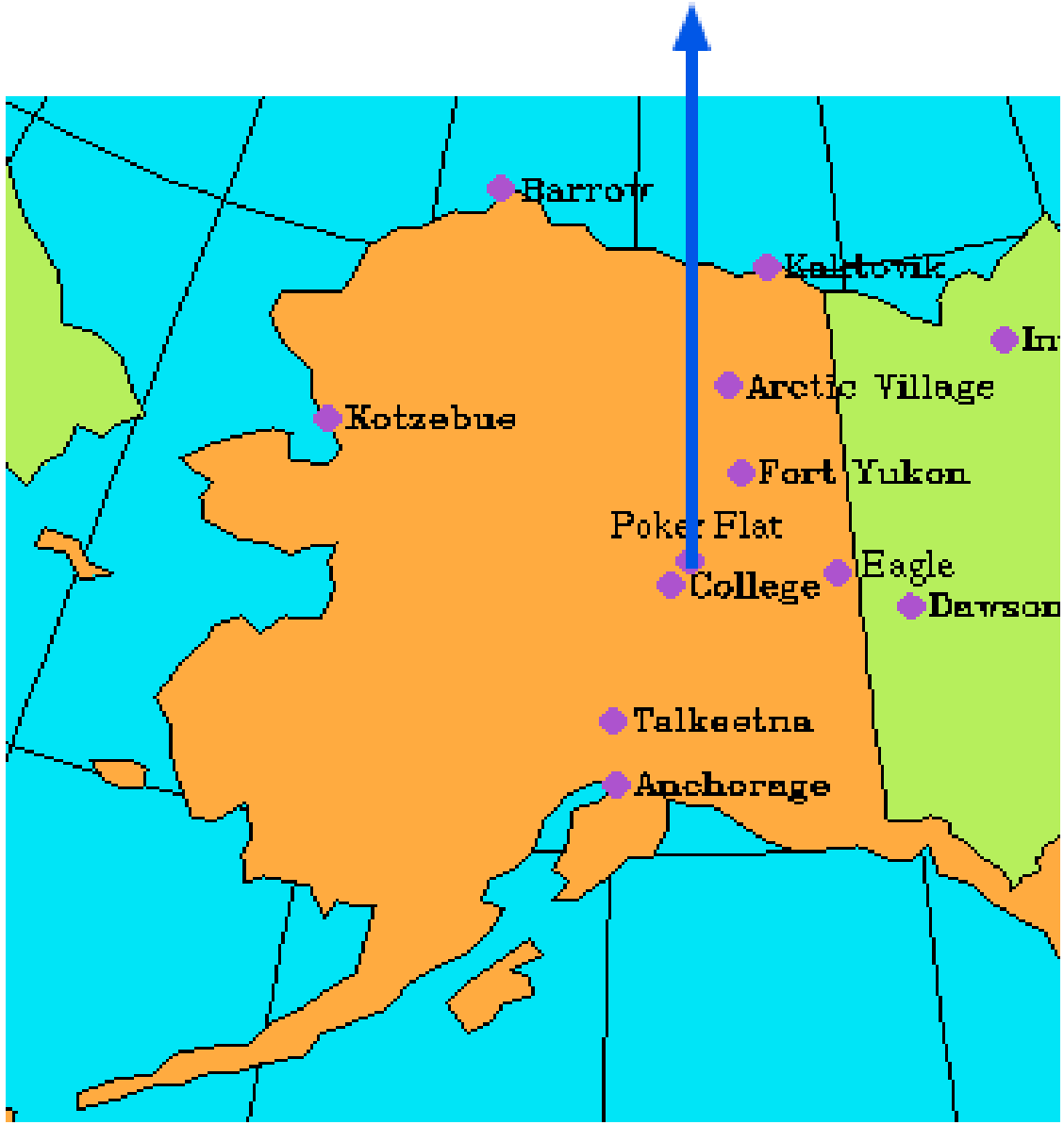
2-week moon-down window

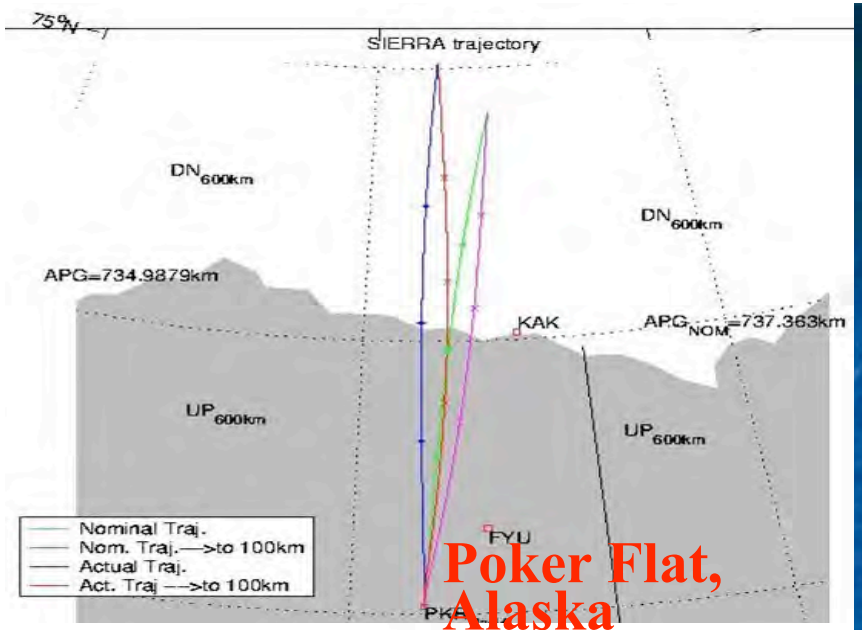
clear skies

steady winds

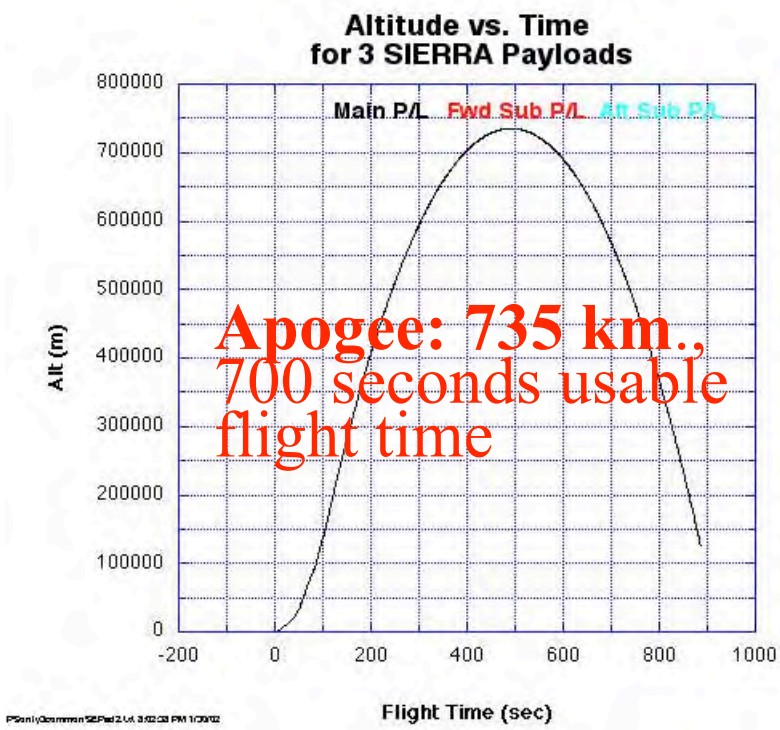
good aurora

good rocket






**Poker Flat, Alaska**
**65°N, 147°W**




**Apogee: 735 km., 700 seconds usable flight time**

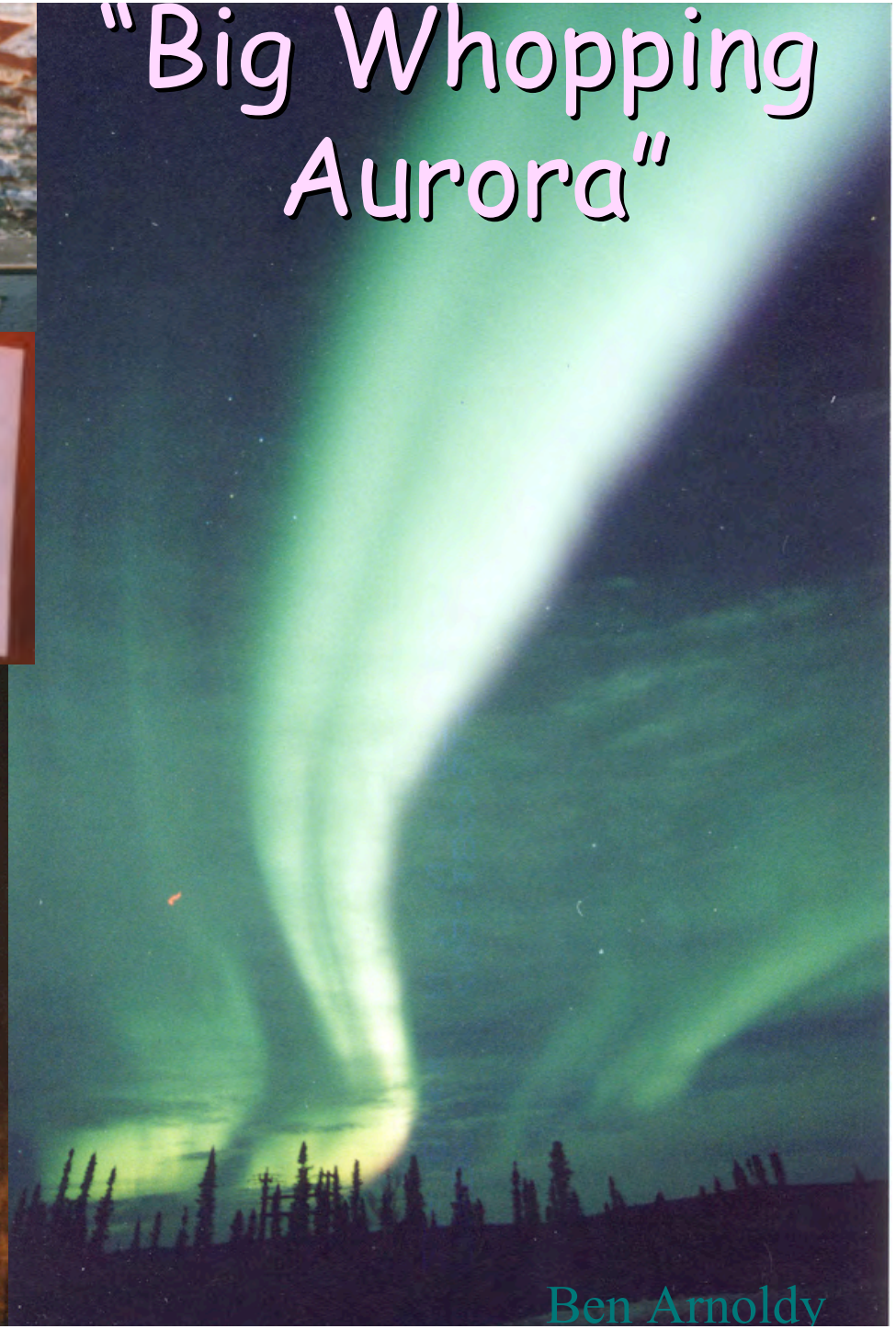
# SIERRA launch

- **08:23:05 UT**, Jan. 14, '02
  - Whole flight in **darkness**
- **Auroral Conditions:**
  - BWA
  - Substorm breakup & expansion phase
  - Small but "classic" substorm, ~150 nT bay, low Kp
- **Fully instrumented**
- **3 payloads; <1 km separation**

# "Big Whopping Aurora"

Chatanika Lodge

**Date:** January 3, 2002
**Publication:** Fairbanks Daily News-Miner (AK)
Cornell University professor Paul Kintner Jr. is crossing his fingers for some "big whopping aurora." "We need lots of current. We need a bright active auroral display, lots of things waving around in the sky with the red borders on the bottom," he said, "the kind of aurora that people would see and their mouths would drop open and say aaahhh!"

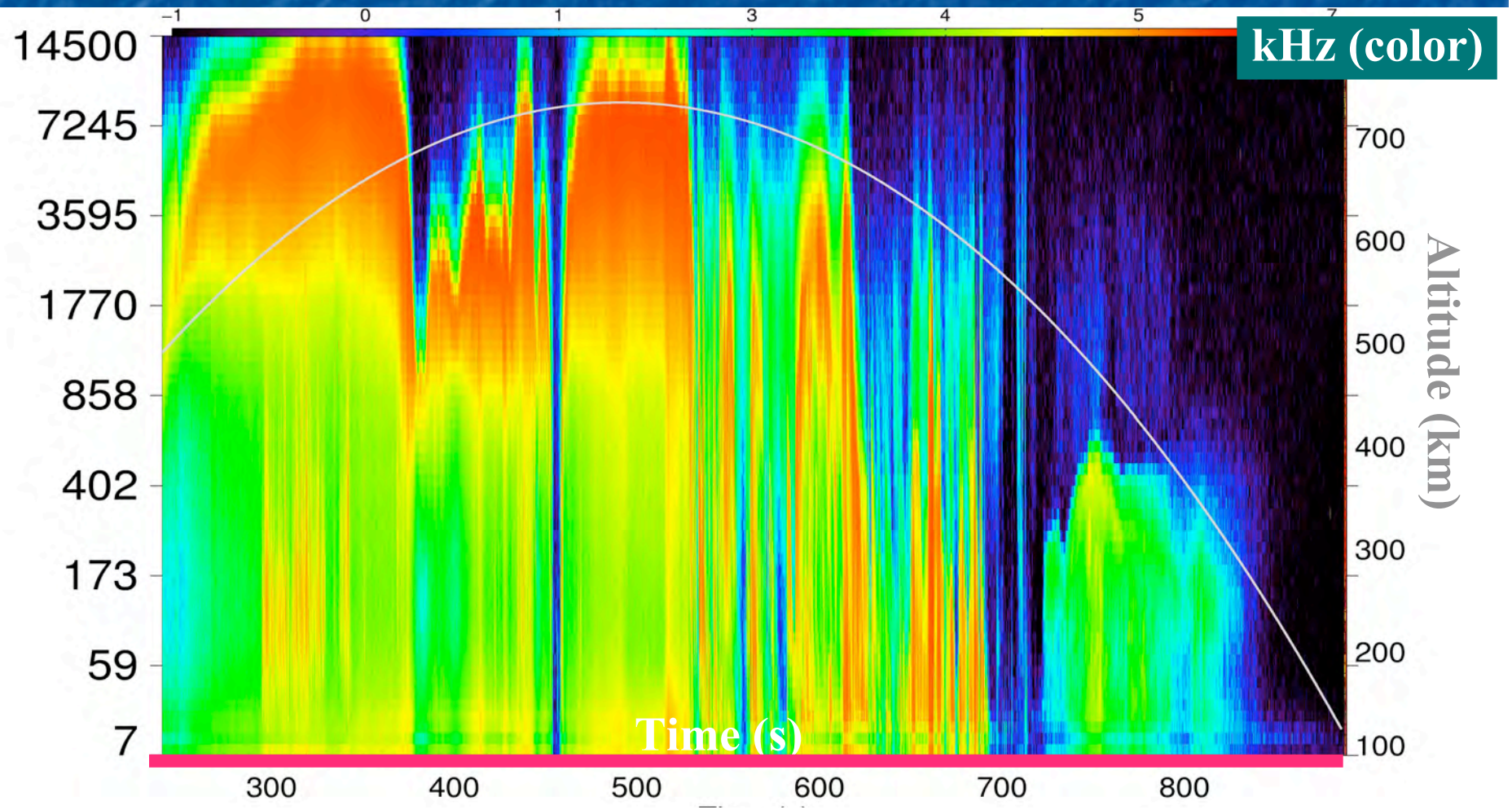


Ben Arnoldy

# SIERRA mission goal:

*study microphysics of active upward and downward current systems*

- Inverted V arcs & Alfvenic region



## analysis (1-2 years)

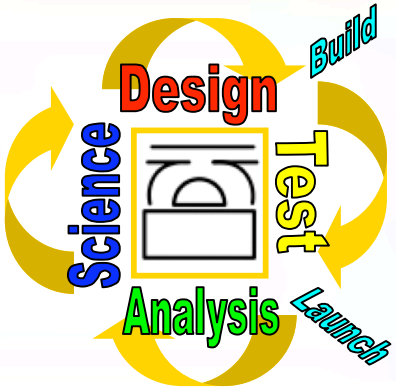
characterize event

look for interesting structures

analyze spatial vs temporal changes

quantify interpretations

use to test models of auroral dynamics




Then repeat cycle…

# Why is LANL in space?

NUDET Detection
- Verification
- Defense support

Nonproliferation
- Remote sensing

Space Weather Monitoring

Basic Research
- High-energy astrophysics
- RF physics (esp. lightning)
- Solar wind physics
- Magnetospheric physics
- Planetary physics
- Ionospheric/atmospheric physics

# History of LANL space environment programs

DOE/Defense

- Vela
- Past geosynch
- GPS/DSP
- Current geosynch
- SABRS/SAVE

Basic Research

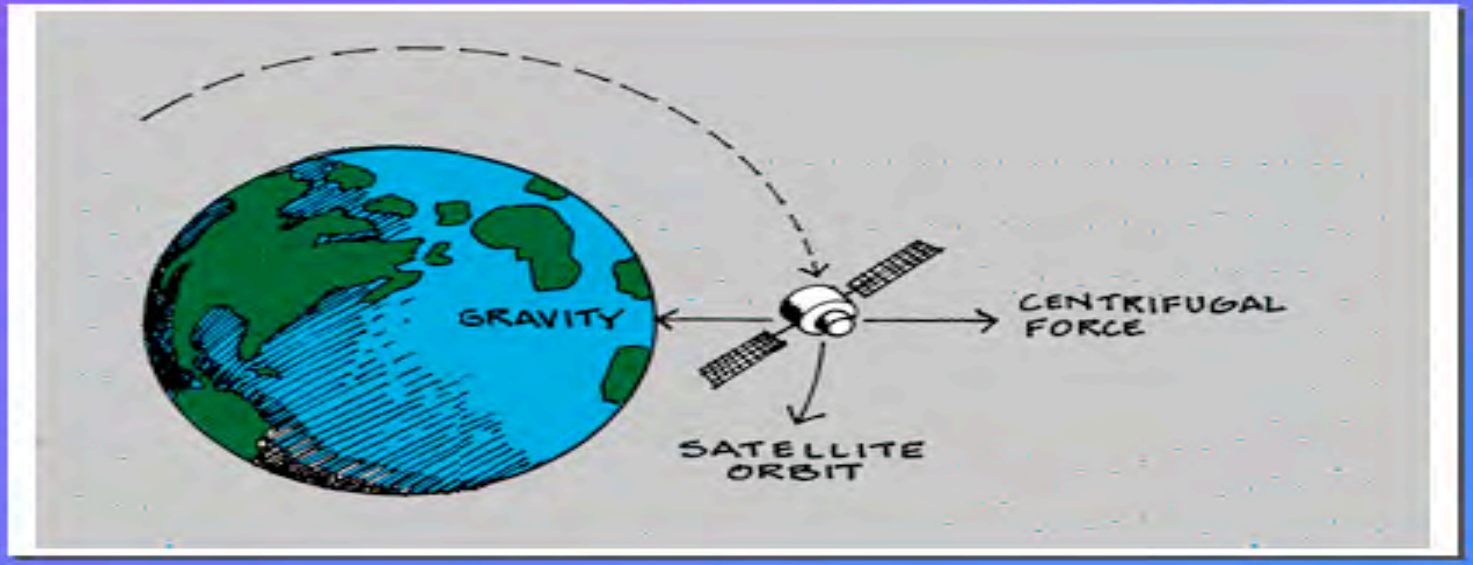
- IMP
- ISEE
- Ulysses
- Polar
- FAST
- Cassini
- ACE
- Deep Space-1
- Lunar Prospector
- Cluster
- Genesis
- LENA-P
- IMAGE

Competencies

- Space-borne instrumentation
- Sensor science
- Data handling
- Solar wind science
- Magnetospheric science
- Planetary science
- RF physics

# Definition of Geosynchronous Orbit

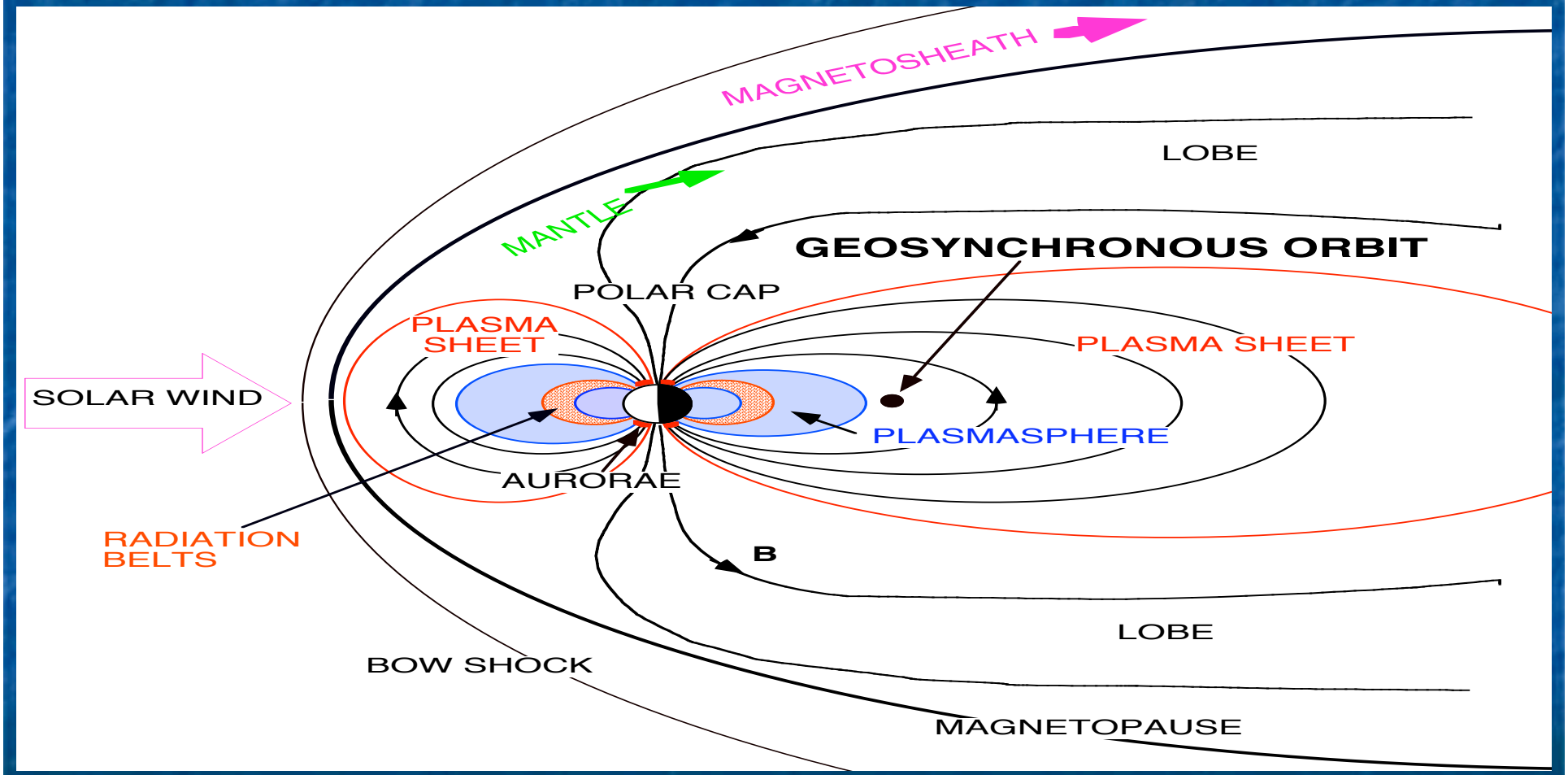
- **Orbit period**: 1 siderial day ~ 23h 56 m 4s.
- **Average orbit radius** is fixed by gravitational and centrifugal force equality:




$T = (4\pi^2/GM)^{1/2}\, r^{3/2}$

$T = 24$ hours for $r = 6.6\ R_E$

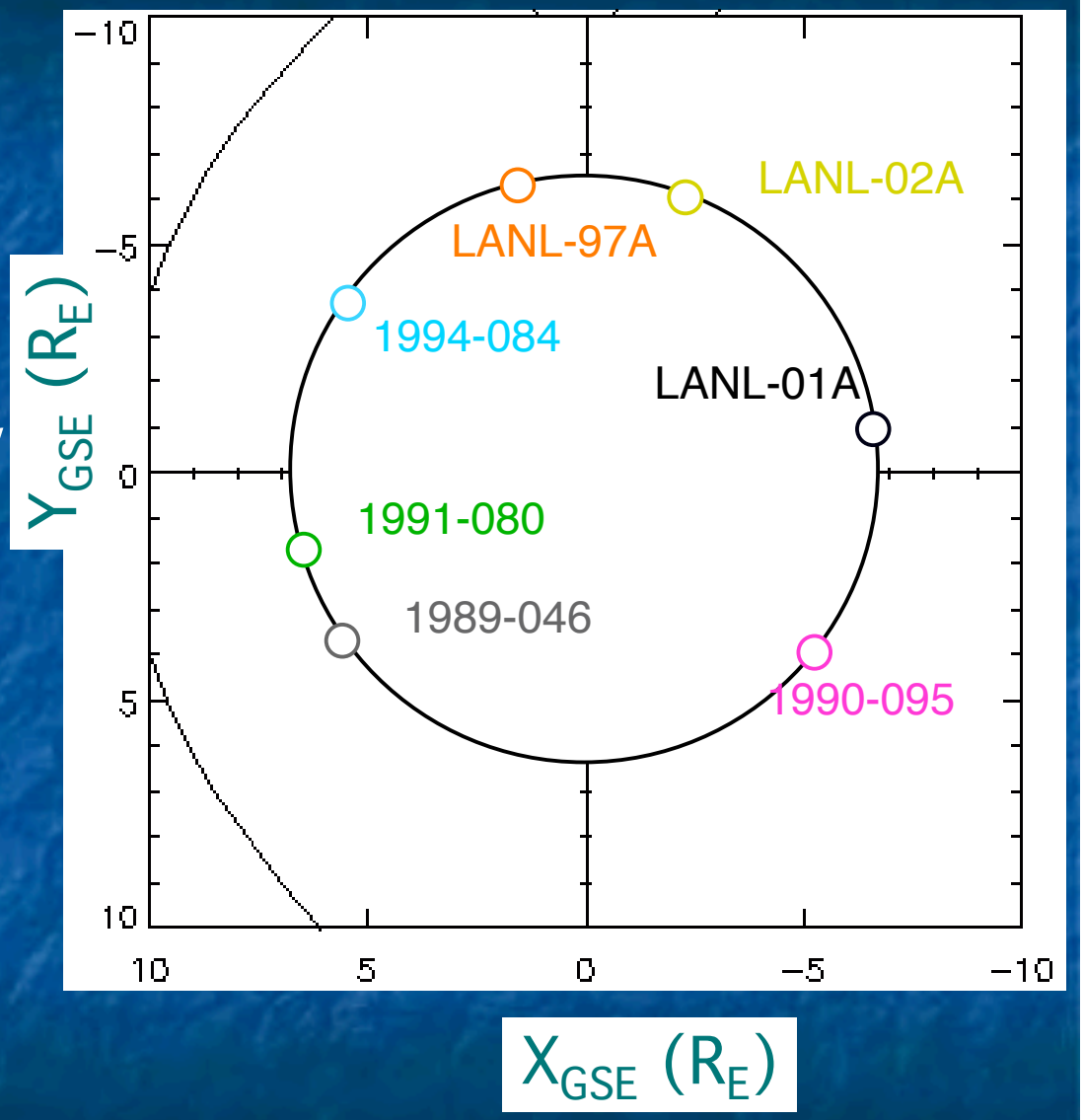
# Geosynchronous Orbit: The Crossroads of the Magnetosphere

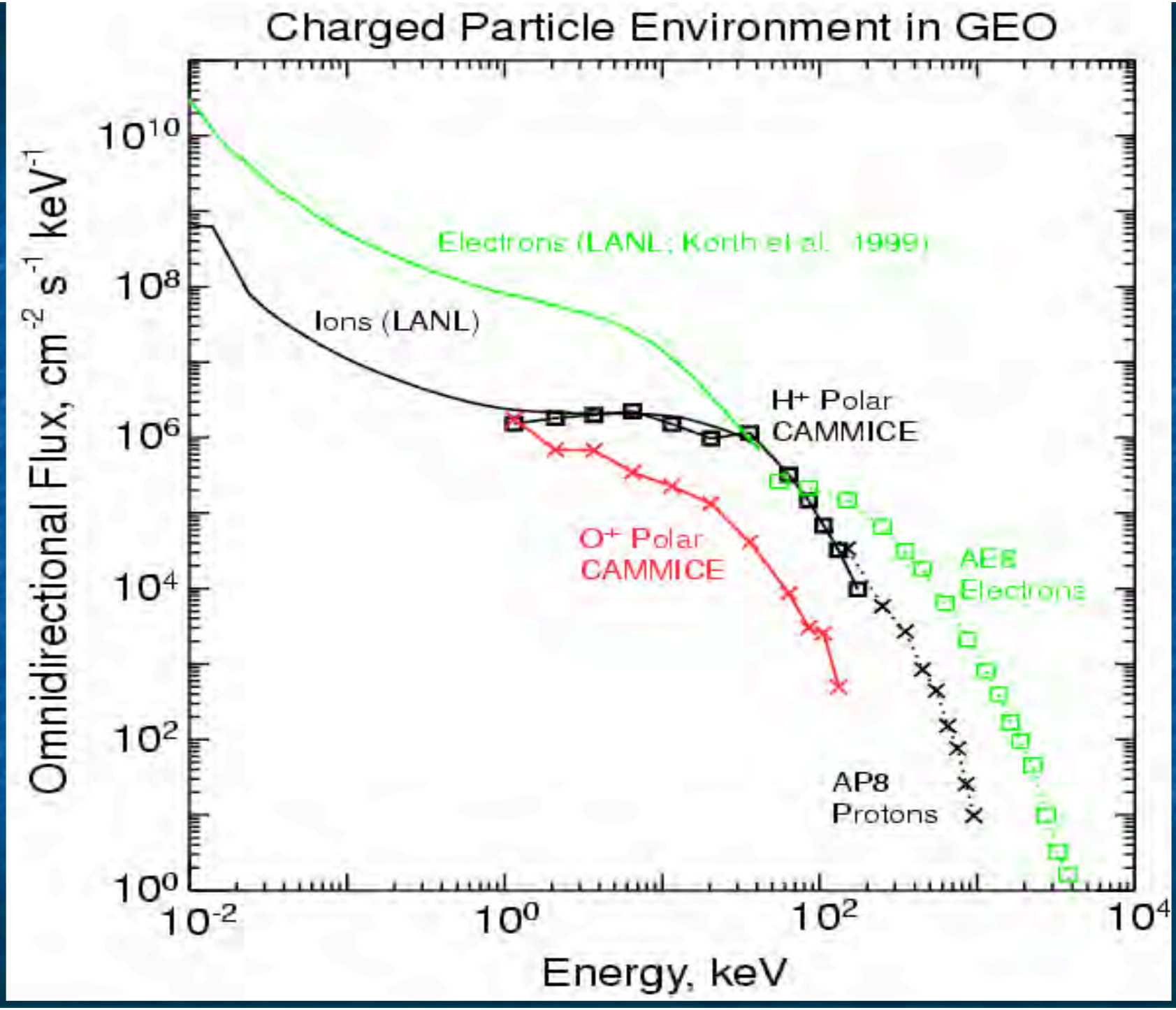


# MPA plasma instrument

- Full 3-D distribution functions up to 40 keV/q for **ions and electrons**
- Measures plasma sheet = Ring current source
- Background characterization / discrimination
- Spacecraft anomaly support
- Near-real-time delivery to Air Force, NOAA, and NASA
- Long-term environment specification and surface-charging and ”killer electron" studies
- Basic understanding of space weather phenomena

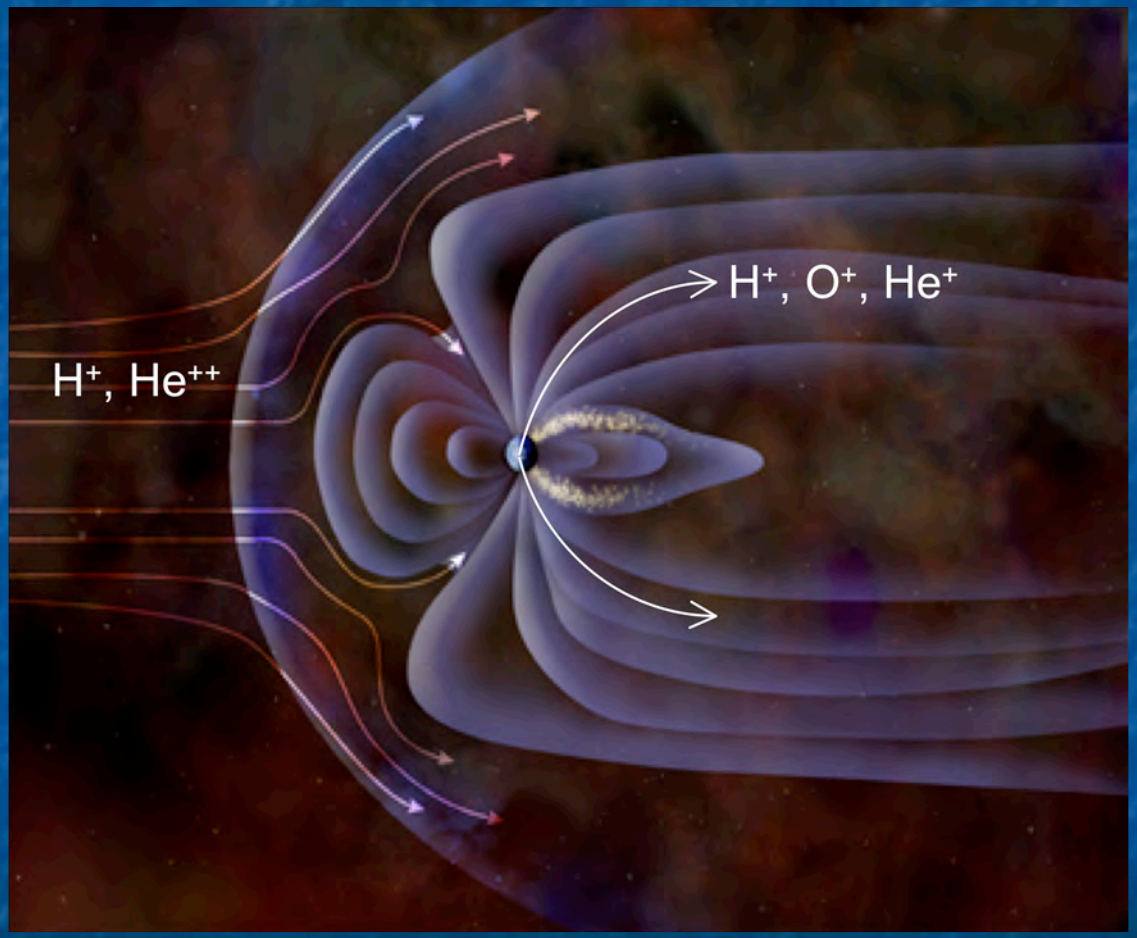
Geosynchronous Satellite Locations at 0 UT on 18 September 2002




Charged Particle Environment in GEO
Omnidirectional Flux, cm$^{-2}$ s$^{-1}$ keV$^{-1}$
Energy, keV
$10^{10}$
$10^{8}$
$10^{6}$
$10^{4}$
$10^{2}$
$10^{0}$
$10^{-2}$
$10^{0}$
$10^{2}$
$10^{4}$
Electrons (LANL; Korth et al. 1999)
Ions (LANL)
H+ Polar
CAMMICE
O+ Polar
CAMMICE
AE8
Electrons
AP8
Protons

# Why measure ion composition in the magnetosphere?

- Variable sources
  - Solar wind
  - Ionosphere
- Dynamics
  - Storms
  - Substorms
  - Solar cycle
- Ions affect
  - Ring current
  - Storm strength
- Practical
  - Modeling
  - Spacecraft lifetimes and material properties




- **Not currently monitored at GEO**
- New opportunities to monitor

# Advanced Miniaturized Plasma Spectrometer

- To be launched in geosynchronous orbit, 2007
- Electrostatic analyzer measures E/q
  - 2 eV/q - 40 keV/q (16 steps)
- 1 Solid State Detector (SSD) for ions
  - $H^+$, $He^{+2}$ (solar wind), $O^+$ (ionosphere)
- Low mass, low power

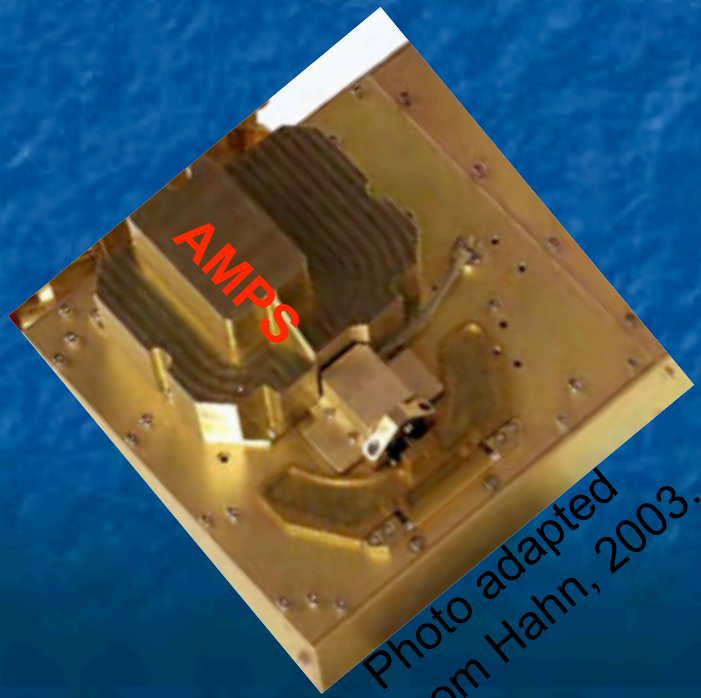
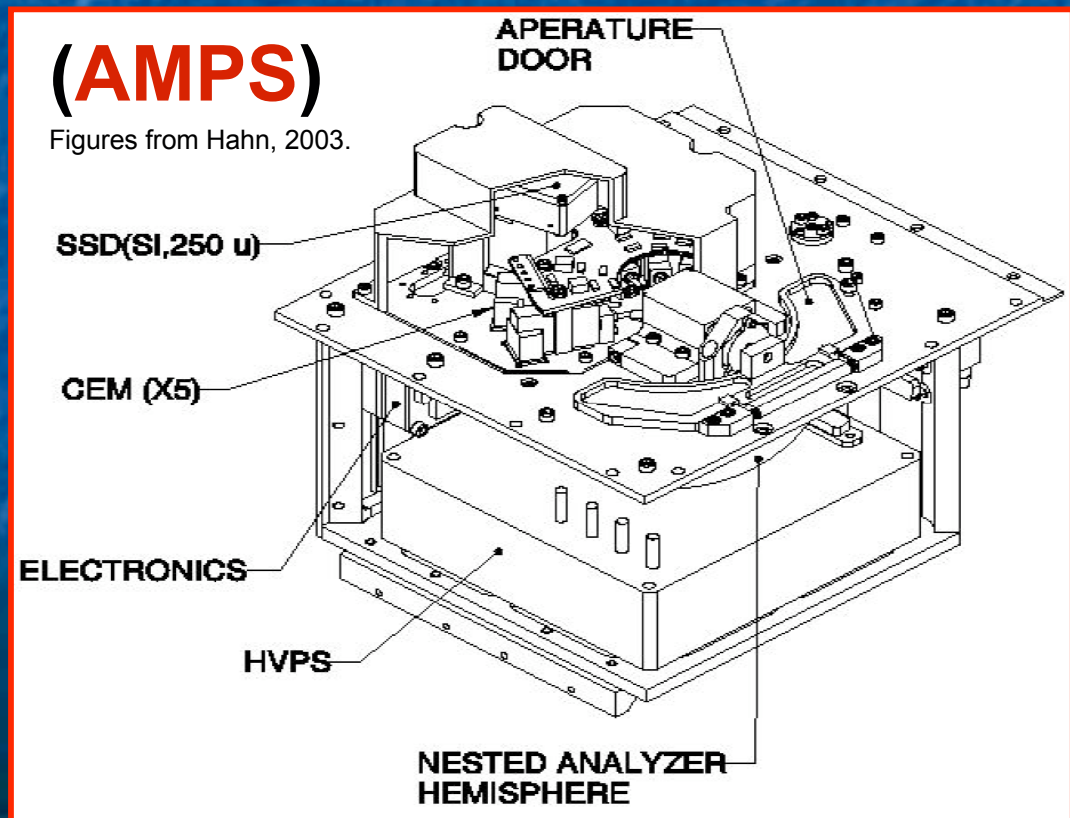
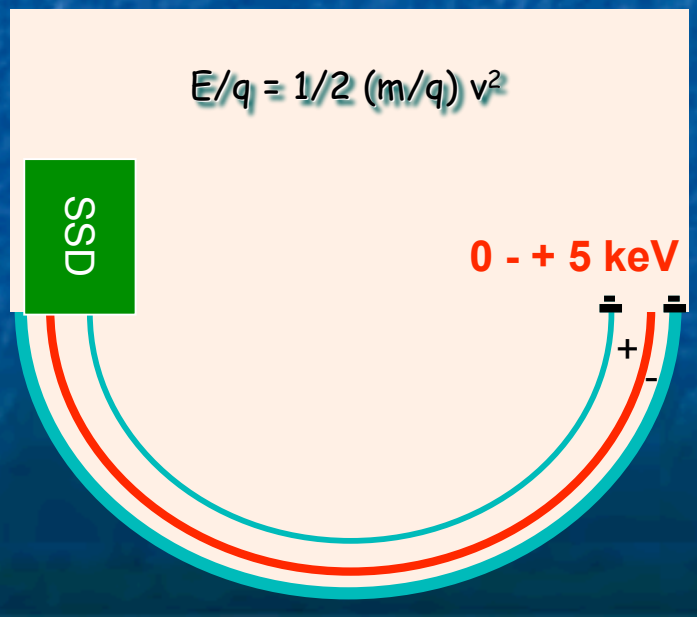
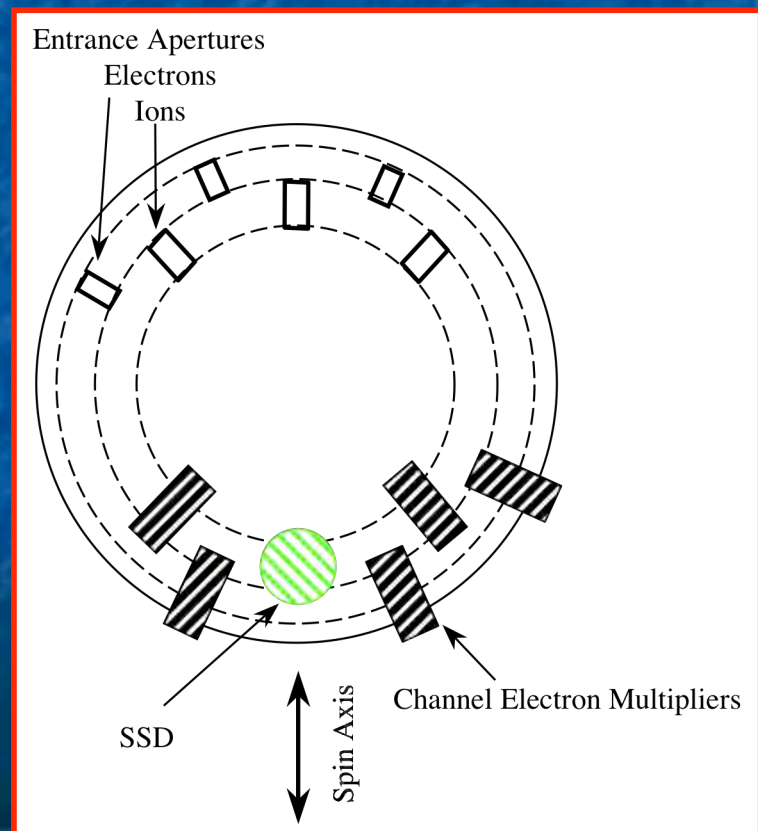



Photo adapted from Hahn, 2003.

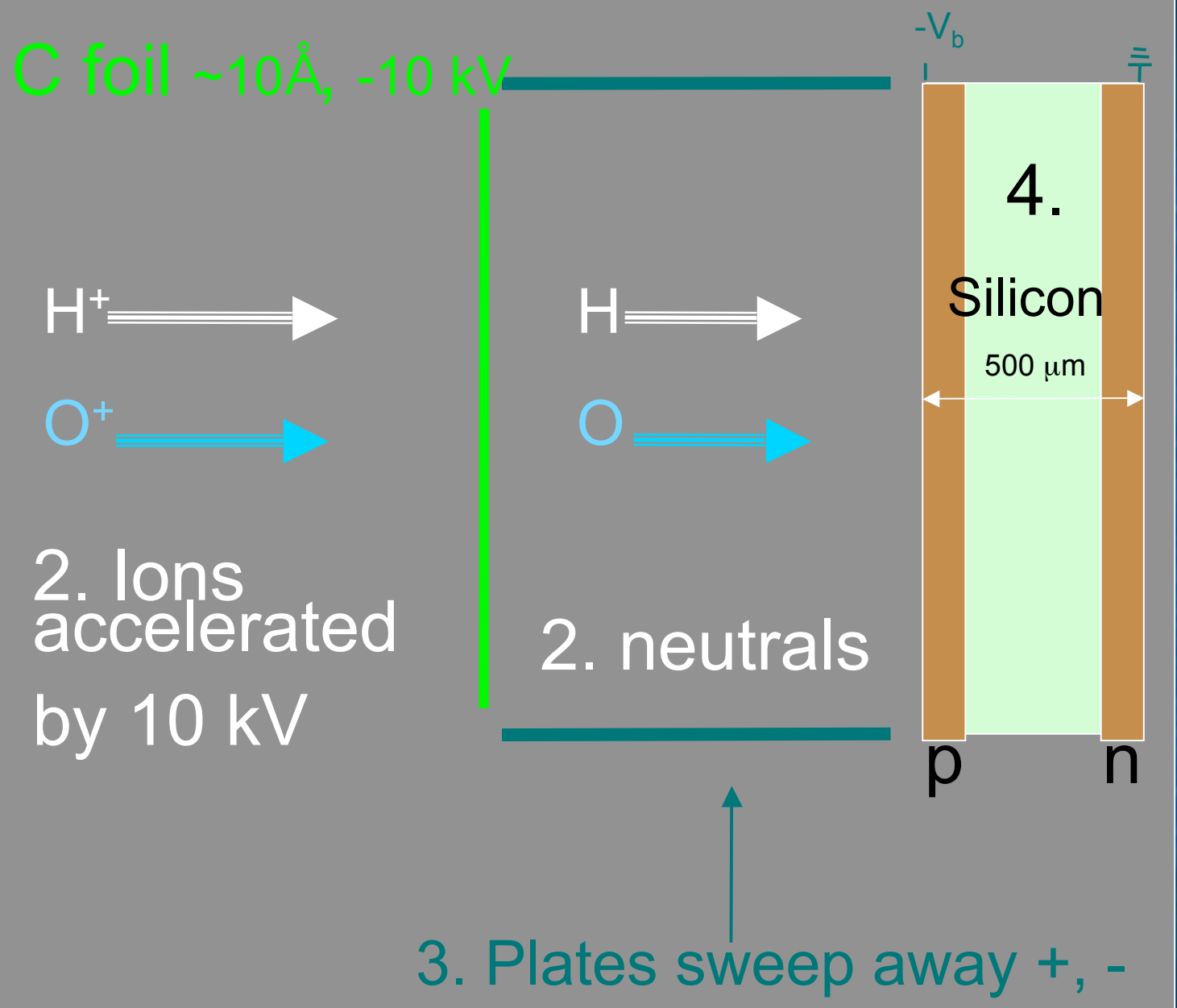


# Electrostatic analyzer



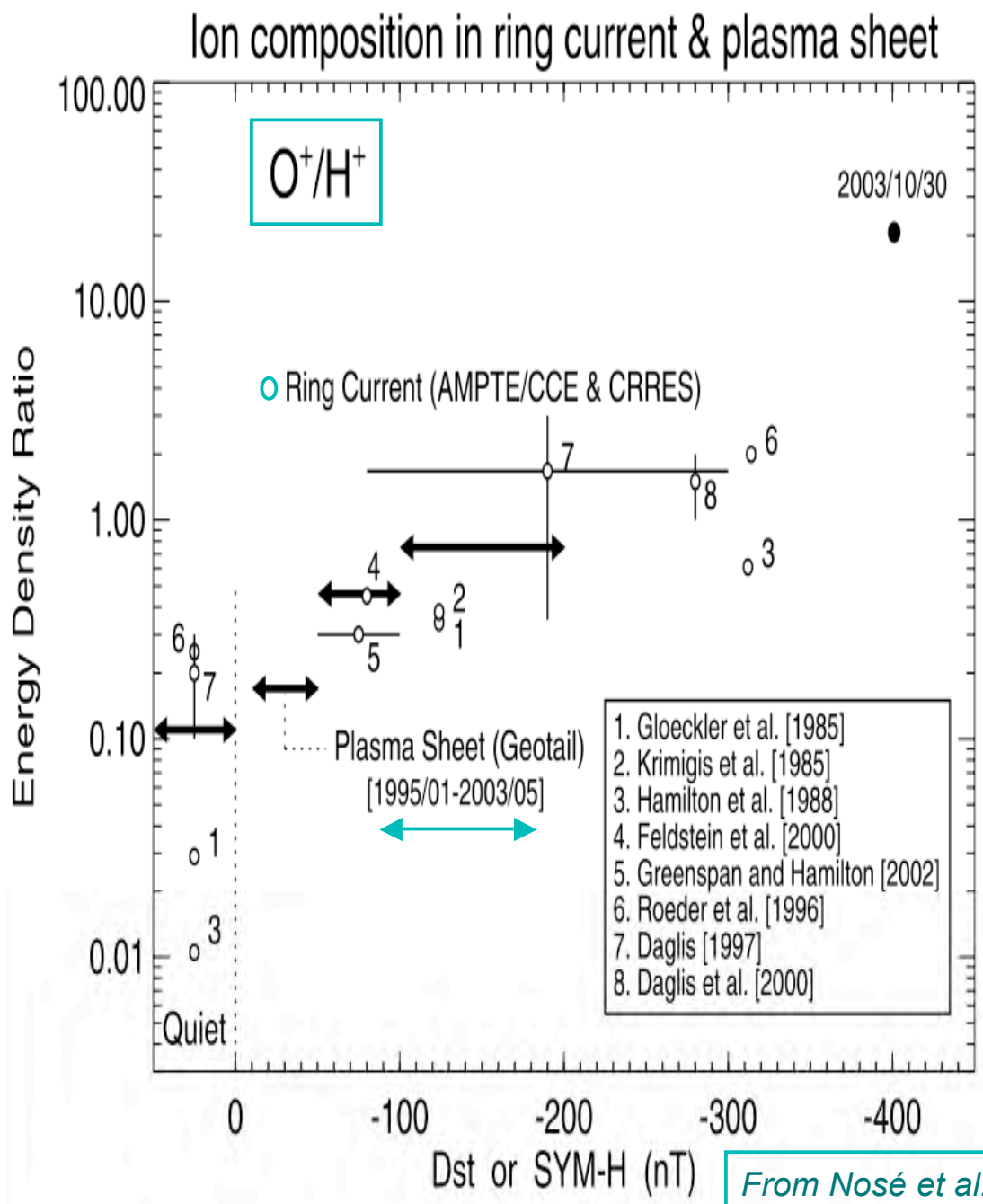
# Solid state detector schematic



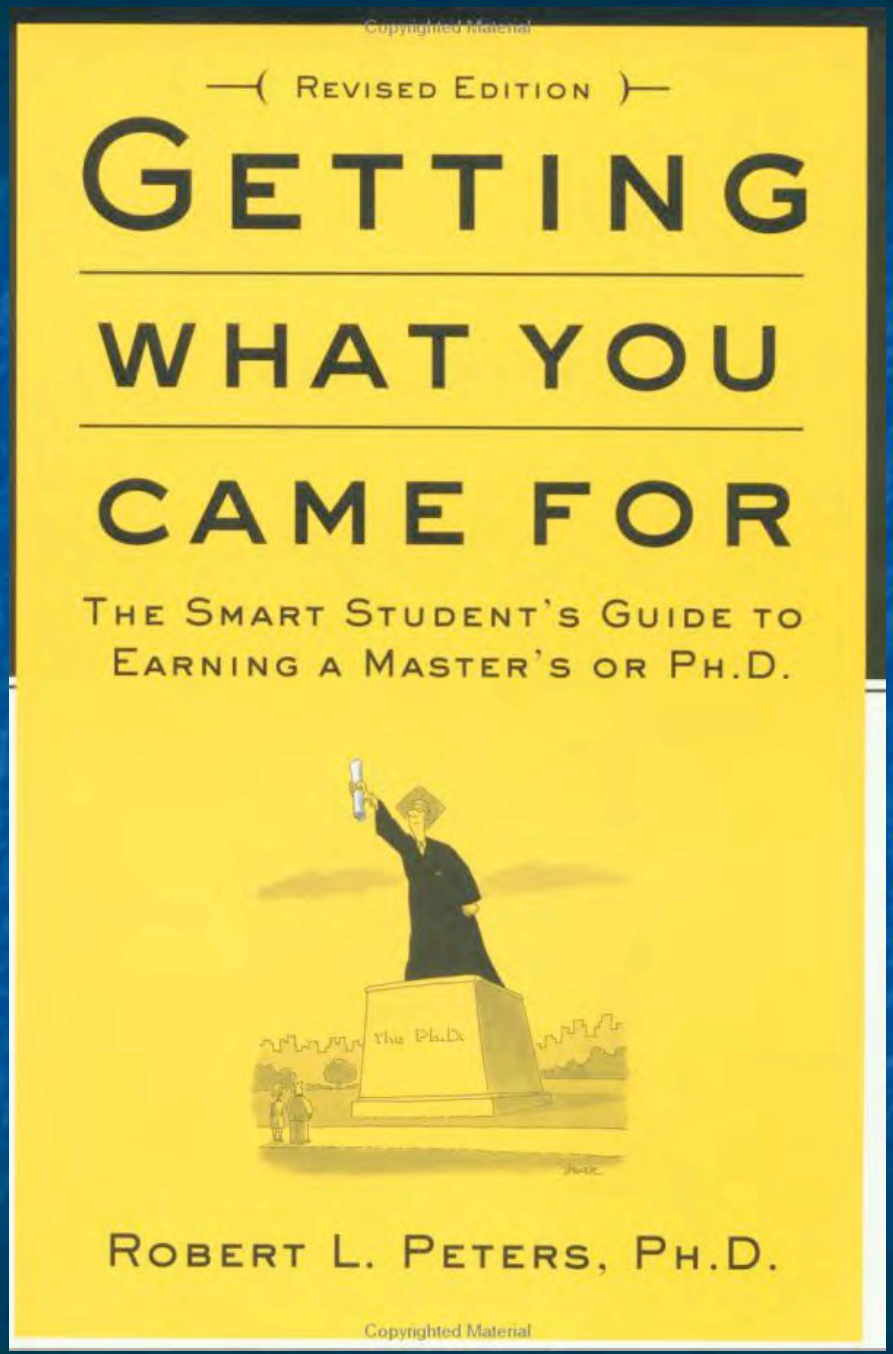

1. Ion enters and travels through hemisphere, E/q selected
2. Ion accelerated, measurable SSD pulse & transits thin C foil, neutralizes
3. Plates sweep away charged particles, only neutral enters SSD, SSD near ground
4. Reverse biased solid state detector measures charge deposited, proportional to input energy

# Oxygen can dominate in biggest storms

- Plasma sheet is a source for the ring current
- Exponential increase of $O^+$
- Composition varies greatly
  - Limited # of measurements
- New capability for LANL instruments
  - AMPS, SABRS, RBSP




*From Nosé et al., 2006, 2005*




# Thank you!

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# Resources

- **HAO aurora multimedia module http://www.meted.ucar.edu/hao/aurora/**
- **Cool NASA movies: http://svs.gsfc.nasa.gov/Gallery/NASAsSun-EarthGallery.html**
- News: www.spaceweather.com
- Images:
  - RocketCam http://www.eclipticenterprises.com/gallery_rocketcam.shtml
  - Nordly's, http://www.northern-lights.no/english/what/index.shtml
  - Live Aurora Cam, http://www.aurorawebcam.com/
- Rocket Ranges and Websites:
  - Poker Flat www.pfrr.alaska.edu
  - Lynch Rocket Lab www.dartmouth.edu/~aurora
  - Andoya www.rocketrange.no
  - White Sands http://www.wstf.nasa.gov/, www.wsmr.army.mil, http://lcps.k12.nm.us/departments/SCIAD/index.shtml
  - Wallops Flight Facility www.wff.nasa.gov
  - Rocket Article, National Geographic
    - http://news.nationalgeographic.com/news/2003/02/0213_030213_northernlights.html
  - X Prize, Las Cruces Spaceport, www.xprize.com, http://www.starchaser.co.uk/

RTw 01/25 1218

# Norwegian scientific rocket causes global scare By Rolf Soderlind

OSLO, Jan 25 (Reuter) - Norwegian scientists were appalled on Wednesday that the peaceful firing of a scientific rocket had apparently triggered an air defence alert in Russia and an international scare. A Russian report said a missile had been launched from Norway but failed to reach Russia, instead crashing in Norway's Spitzbergen arctic territory.

Norway's defence ministry said the missile was part of a scientific research programme at a civilian rocket range on an island in the Lofoten region off northern Norway. The rocket splashed into the sea off Spitzbergen as planned after a 24-minute successful flight 1,564 km north of Andoya island, where the rocket range lies, the ministry said.

"I was terrified when I heard about the attention our routine firing got," Kolbjoern Adolfsen, a Norwegian scientist at the range, told Reuters in a telephone interview. "I was in a meeting when the telephones started ringing."

"For 32 years we have done this," he said. "We study the Northern Lights over Spitzbergen in daytime. It is pitch dark up there at this time of the year. We have fired 607 rockets since we started." The Northern Lights (Aurora Borealis) are colourful light phenomena in the arctic skies during the winter. Adolfsen suggested the Russians might have reacted because the 6.24 a.m. (0524gmt) launch was the first time a northern light rocket had gone up in such a high ballistic trajectory, reaching an altitude of 1,453 kms.

"But it should not have come as a surprise to anyone," the 57-year-old said. "A message was sent through the foreign ministry on December 14 to all nations concerned that we would be doing the firing. Air traffic had been diverted because the rocket would be flying so high." A foreign ministry official said, without having knowledge of this particular case, that such messages were routinely forwarded to other nations. Interfax quoted a high-ranking Russian air defence official as saying the missile had landed in the archipelago, Norway's northernmost arctic outpost, about 1,500 km (930 miles) north of Oslo. The Interfax report contradicted an earlier despatch by the news agency, citing a different source, which said a missile fired from an unspecified north European country had been shot down by Russian air defences over Russian territory. Adolfsen said Wednesday's firing was part of a Norwegian-American project financed by Oslo University and NASA, the U.S. space agency.

Andoya, a craggy island whose main sources of income are fishing and whale safaris, has a population of 6,500 and the town is six kms from the rocket range, which has 26 employees and currently about 30 guest researchers. "The firing was completely successul," Adolfsen said. "It was a very good test."

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