Extreme Exploration: Journey to Earth’s Van Allen Radiation Belts

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Sun Earth Connections

The Sun is a dynamic star

We live in the atmosphere of the Sun
Sun Earth Connections

Earth responds to the changing Sun, and this response is known as Space Weather.

The Aurora is a visible, physical sign of this Space Weather.
Solar Flares

Sun-Earth System --
Driven by 11 Year Solar Cycle

Solar Maximum:
- Increased flares, solar mass ejections, radiation belt enhancements.
- 100 Times Brighter X-ray Emissions 0.1% Brighter in Visible
- Increased heating of Earth’s upper atmosphere; solar event induced ionospheric effects.

Declining Phase, Solar Minimum:
- High speed solar wind streams, solar mass ejections cause geomagnetic storms.
The Violent Sun

Solar flares are violent explosions that occur at the Sun’s surface.

But the Sun is not Vegas; what happens on the Sun does not stay on the Sun!
These solar flares can accelerate huge amounts of very energetic solar protons.
These protons can reach Earth in about 30 minutes.

Less than 1 hour after the initial arrival of the protons, the imager becomes saturated & remains so for almost a day.
Sun Earth Connections - from there to here

Billions of tons of solar material are hurled from the Sun at millions of miles an hour

When the material reaches the Earth it interacts with our protective magnetic field
Dangerous electrons and protons are not able to penetrate down to Earth’s surface but are forced to move around it by the magnetic field.
What is Radiation?

Energy moving from one place to another carried by particles or waves

Particle Radiation - A mixture of ions and electrons that have enough energy to knock electrons off of atoms. At times these particles can move close to the speed of light.

Electromagnetic Wave Radiation - Examples include: radio waves, microwaves, infrared (heat), visible light, ultraviolet (UV), x-rays, and gamma rays.

The Van Allen Probes will investigate the first type of radiation, high energy particle radiation.
During violent solar events, the Sun can accelerate electrons and protons to almost the speed of light, which gives them huge amounts of energy. Protons and electrons at these high energies can be very dangerous to living cells.
Between Apollo 16 and 17, one of the largest solar proton events ever recorded arrived at Earth. The radiation levels that an astronaut inside a capsule would experience during this event were simulated. Even inside the spacecraft, astronauts would have absorbed lethal doses of radiation within 10 hours after the start of the event (4000 mSv).
The first discovery of the space age

The radiation belts were discovered by James Van Allen in 1958 using data taken on Explorer 1.
The radiation belts

High energy particles get trapped by the Earth’s magnetic field and forced to circle around the Earth within two large donut-shaped regions.

The belts are different from each other.

- The inner is stable and made of protons,
- The outer changes a lot and is made of electrons and ions.
Where are the radiation belts?

**Inner Belt:** About 60-6,200 miles up

**Outer Belt:** About 12,500-39,000 miles up

To help you imagine it:

- **60 miles:** About the distance it takes to drive 1 hour on the highway
- **6,200 miles:** About the distance to drive from the equator to the north or south pole
- **12,500 miles:** About the distance to drive from the north pole to south pole
- **39,000 miles:** About 1/6 as far as the moon

Image Courtesy of Windows to the Universe, http://www.windows.ucar.edu
Radiation Belt Variability

Instruments aboard spacecraft have monitored the radiation belt activity and have discovered that the belts are highly variable both in intensity and size.
The radiation belts – danger, danger!!

- Most spacecraft either avoid these regions of high radiation or turn off sensitive instrumentation while in transit through them
  - Large space weather events can adversely effect spacecraft and operations

- The radiation belts are now part of our technology infrastructure.
  - If we can understand the belts, we can improve our mission planning, and spacecraft operation and system design.

Image Credit: L. J. Lanzerotti, Bell Laboratories, Lecent Technologies, Inc.
NASA’s Van Allen Probes Mission

- On August 30, 2012 NASA launched two identical probes into the radiation belts to provide unprecedented insight into the physical dynamics of near-Earth space.
The Van Allen Probes’ Mission Objective is important and its Impacts are broad

- **Objective:**
  Provide understanding, ideally to the point of predictability, of how populations of relativistic electrons and penetrating ions in space form or change in response to variable inputs of energy from the Sun.

- **Impacts:**
  1. Understand fundamental radiation processes operating throughout the universe.
  2. Understand Earth’s radiation belts and related regions that pose hazards to human and robotic explorers.
Van Allen Probes: A Mission to Benefit Life and Society

- Data collected by the probes will help researchers develop and improve various radiation belt models that can be used to:
  - design radiation-hardened spacecraft and prevent costly spacecraft over design
  - predict space weather phenomena and alert astronauts and spacecraft operators to potential hazards
  - resolve anomalies
  - improve radiation belt models
Van Allen Probes: A Fundamental Physics Mission

Planetary Radiation Belts are a Universal Phenomenon: ISEE and Voyager results show clear evidence that radiation belts exist at all strongly magnetized planets throughout our solar system.

Particle acceleration to high energies is observed in other space plasma systems.
Van Allen Probes Observatories

ECT REPT

EMFISIS MAG Boom

ECT MagEIS (Low and Medium 75)

ECT HOPE

ECT MagEIS (High and Medium 35)

RPS

ECT REPT

Van Allen ProbesICE

EFW Axial Boom (fwd and aft)

EFW Spin Plane Wire Boom (4x)

EMFISIS Search Coil Boom

Van Allen Probes ICE
Magnetometer Booms
• Extend 10 feet from spacecraft body

Spin Plane Booms
• 2 at 130 feet long
• 2 at 165 feet long

Axial Booms
• 40 feet tip-to-tip (extend to 45 feet)
The twin Van Allen Probes observatories . . .

- stay stable by spinning (5 times per minute)
- get an ‘attitude adjustment’ every 3 weeks
- are designed to operate for 2 years
Spacecraft Development

Integration and Test
Acoustic and Vibration Testing
Van Allen Probes launched on August 30, 2012 at 4:05 AM EDT

http://youtu.be/9mlaQothGWA
First month into the mission...
Third Belt Discovery
A few months into the mission...

We can now map out spatial distributions of the inner (and outer) belts with high fidelity.

We have now measured damaging protons in the heart of Earth’s inner belt to one billion electron volt energies; it is not possible in practical systems to shield against such high energy particles.
A few months into the mission...

- Electron responses to Interplanetary Shock-driven Ultra Low Frequency (ULF) waves were captured by the Van Allen Probes ECT instruments. Fast oscillations extend from 22 to 520 keV energies.

- >145 keV electrons show “electron drift echoes” where electrons are “phase-bunched” as they drift all the way around the Earth, with drift structures that persist for hours.

- ECT measures these echoes with unprecedented energy resolution (inset) providing new insights that have not before been available.
A year into the mission...
The Sounds of Space

The EMFISIS/Waves tri-axial search coil magnetometer and receiver captured several notable peak radio wave events in Earth’s magnetosphere. The radio waves, which are at frequencies that are audible to the human ear, are emitted by the energetic particles in the magnetosphere.

People have known about chorus for decades. Radio receivers are used to pick it up, and it sounds a lot like birds chirping. It was often more easily picked up in the mornings, which along with the chirping sound is why it’s sometimes referred to as ‘dawn chorus.'
Van Allen Probes: Exploring Earth’s Radiation Belts and the Extremes of Space Weather

Find out more:
http://VanAllenProbes.jhuapl.edu/
Acknowledgements

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The Van Allen Probes team is vast and is comprised of talented people from many fine institutions. See the following websites for information on the project and instrument teams:

http://vanallenprobes.jhuapl.edu/mission/team.php
http://rbsp-ect.sr.unh.edu/team.shtml
http://emfisis.physics.uiowa.edu/about/team
http://rbspice.ftecs.com/Team.html
http://rbsp.space.umn.edu/team.html