# Space Radiation

Dr. Nickolas Solomey

Professor of Physics and Director Space Science Studies

# I am formally trained as a Nuclear and Elementary Particle Physicist, but there are many types of Physicists.

## What is a Physicist?

- Nuclear Physicists
- Elementary Particle Physicists
- Atomic, Molecular and Optics Physicists
- Solid State physicists
- Quantum Physicists
- Gravitational Physicists
- Astro Physicists
- Bio-Physicists (also Medical Physics)

## Where do they work in NASA

- Studying the Sun and its core fusion
- Cosmic Gamma ray observations
- Spectroscopy of planets, stars …
- Sensors for Observations
- Quantum communications
- Black Holes, Neutron stars and AGN
- The big pictures cosmology, stars …
- Life on other planets and origin

# NASA does Space Science in the Davison called Space Science Mission Directorate (SSMD)

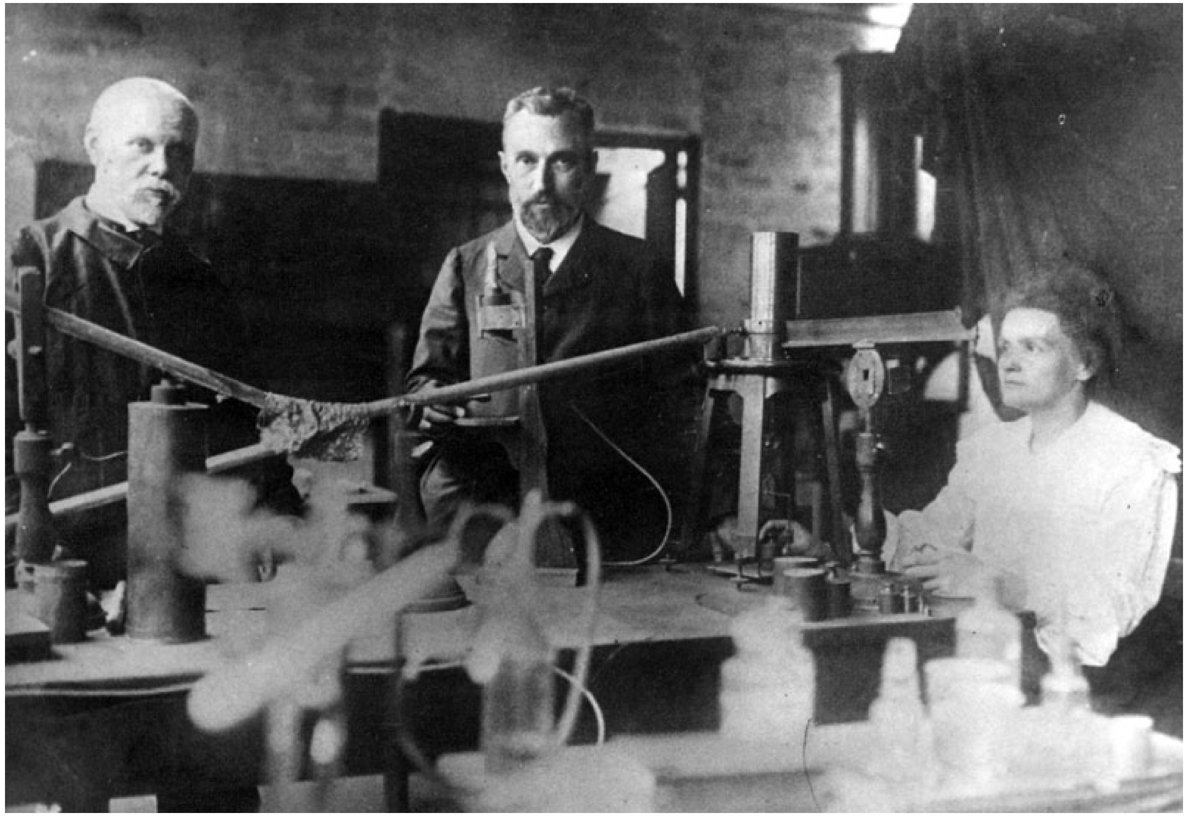
- Heliophysics Division:  Sun and Space Weather
- Astrophysics Division: Stars, Galaxy, Universe, Dark Matter and Cosmology
- AstroBiology Division: Life origin and elsewhere in Universe
- Earth Science Division: Studies the Earth from Space
- Planetary Science Division: studies the planets and exoplanets

It is far to broad a topic to cover all so I will discuss what I know best and work with in how a Physicists works with all these NASA Science Divisions to understand Space Science Radiation effects on equipment and humans.

# Radiation and Space

**Discovery of Radiation**

In 1895 Curies and Becquerel discovered radiation

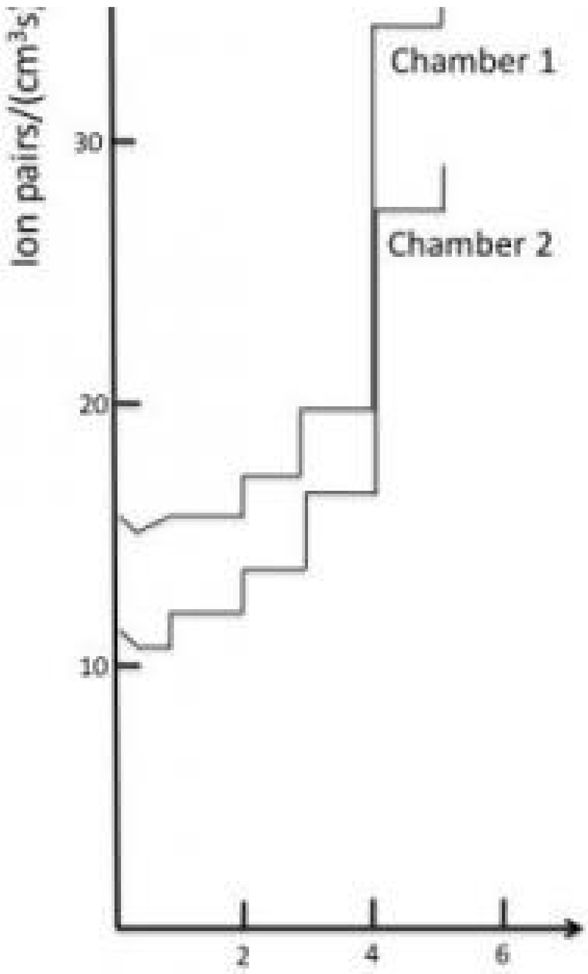


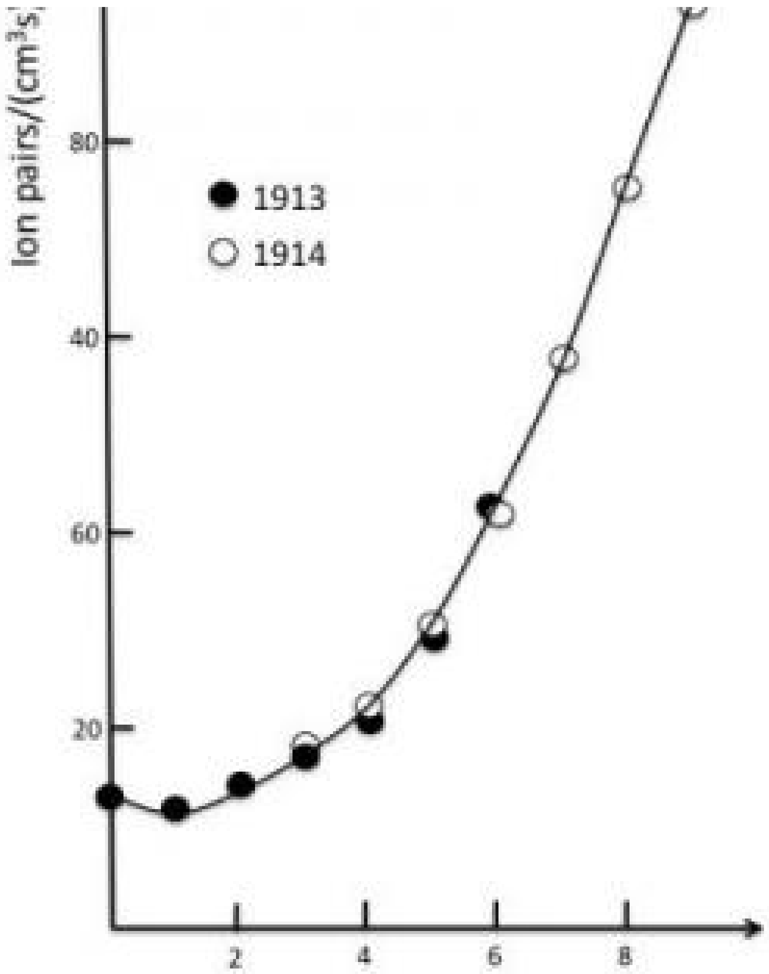
**Protection from Radiation**

1. Limit the time exposed to radiation, close to a source for 1 minutes is 10x less radiation than 10 minutes.
2. Increase your distance from radiation, it is $1/d^2$ law, so doubling your distance means the radiation is ¼ the strength.
3. Shield yourself by putting material between you and the radiation: concrete, water, atmosphere.
4. Magnetic fields sweep charged particle radiation away from you.

# Cosmic Radiation

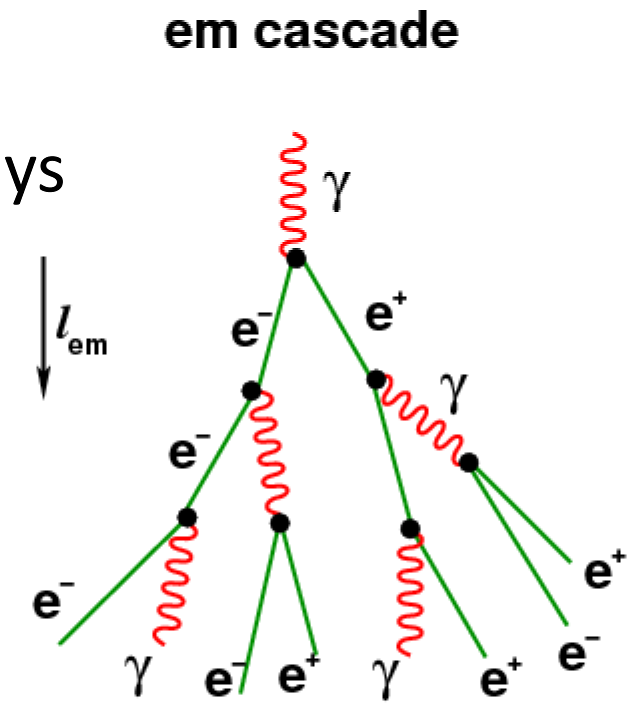
Victor Hess discovered cosmic radiation in 1913 when he studied radiation levels in a balloon flight.

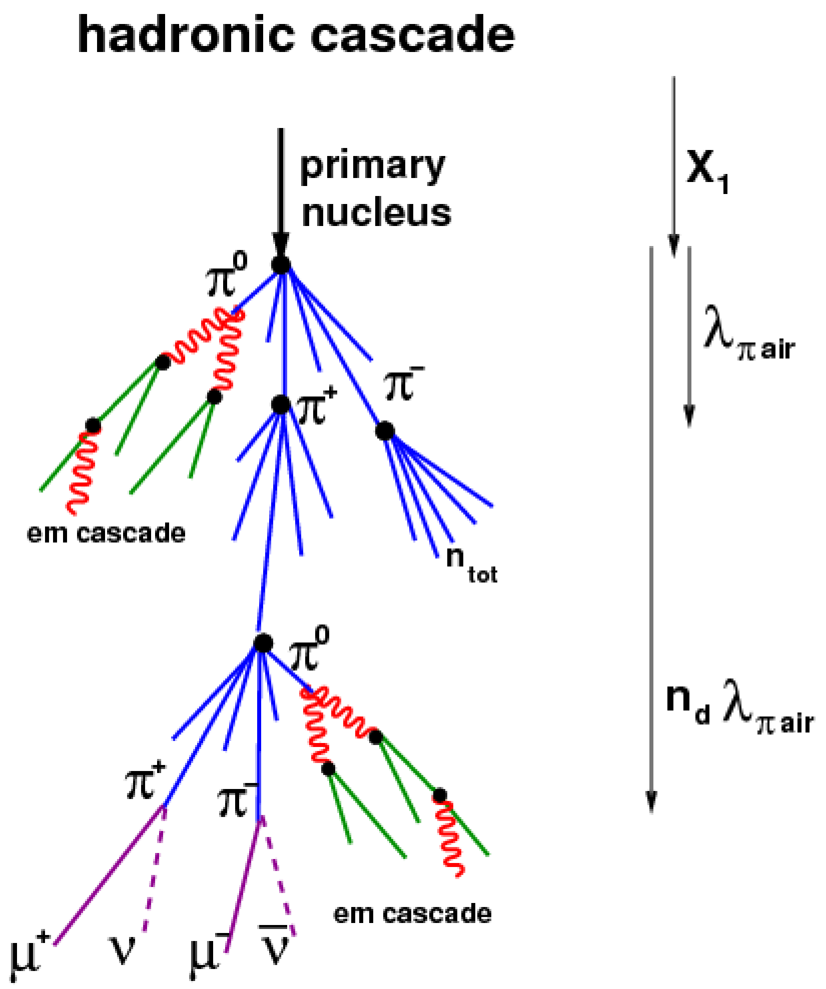


# What is Cosmic Radiation?

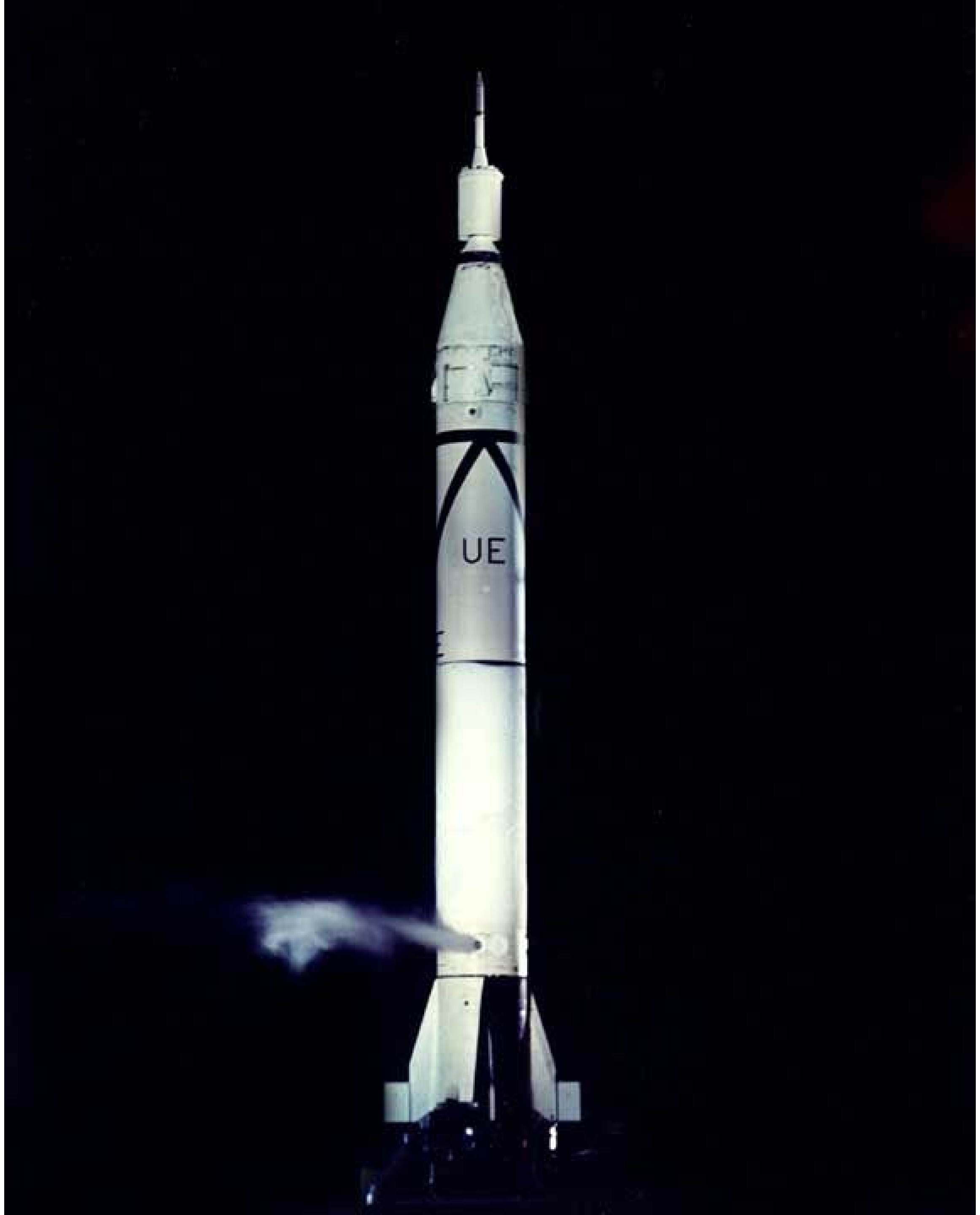
- Mostly High Energy Protons or Gamma Rays
- <1% Helium or Iron nuclei accelerated to high energy
- When these hit the upper atmosphere they make a shower of energetic particles.



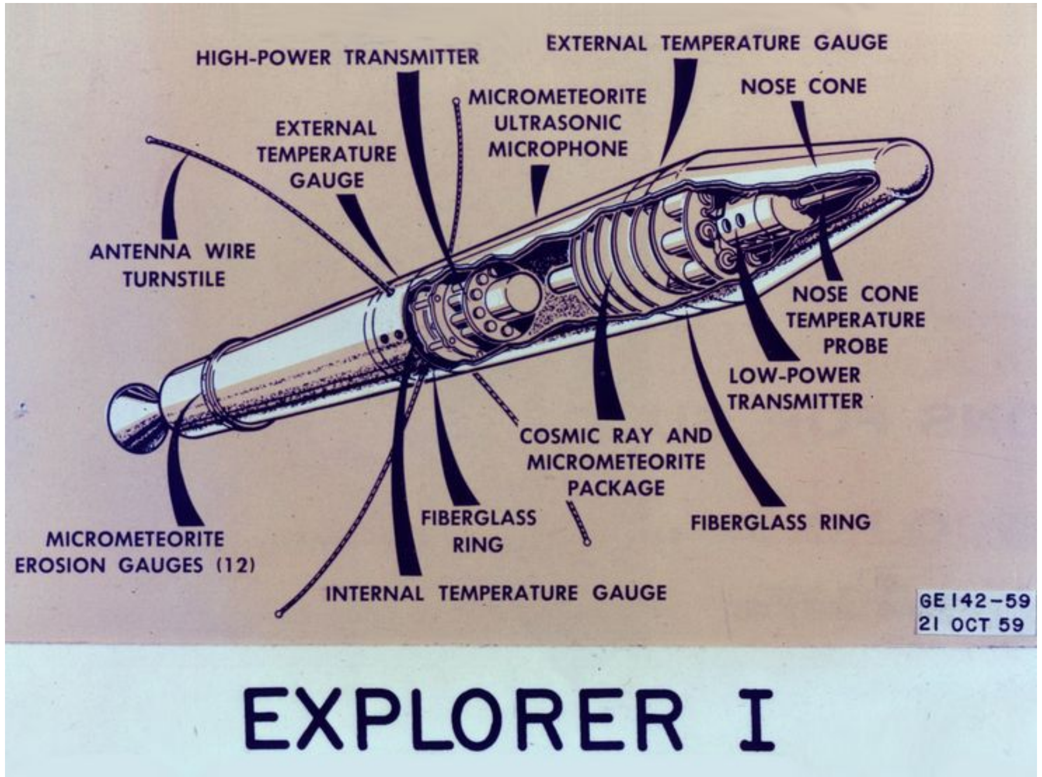
# Space Science

In 1958 with one of the first successful space craft launch into orbit, called Exporer-1, a major unexpected new discovery was made by Physicists Van Allen working with NASA through the Univ. of Iowa. Launched with the Juno-1 rocket.

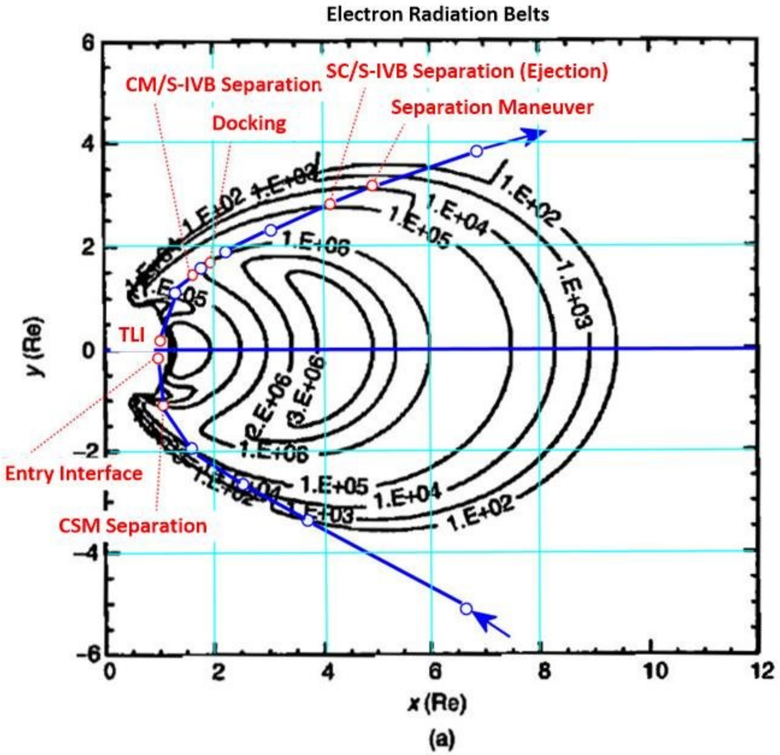


# First observation of Earth's Radiation belt

**Space craft instrumentation**



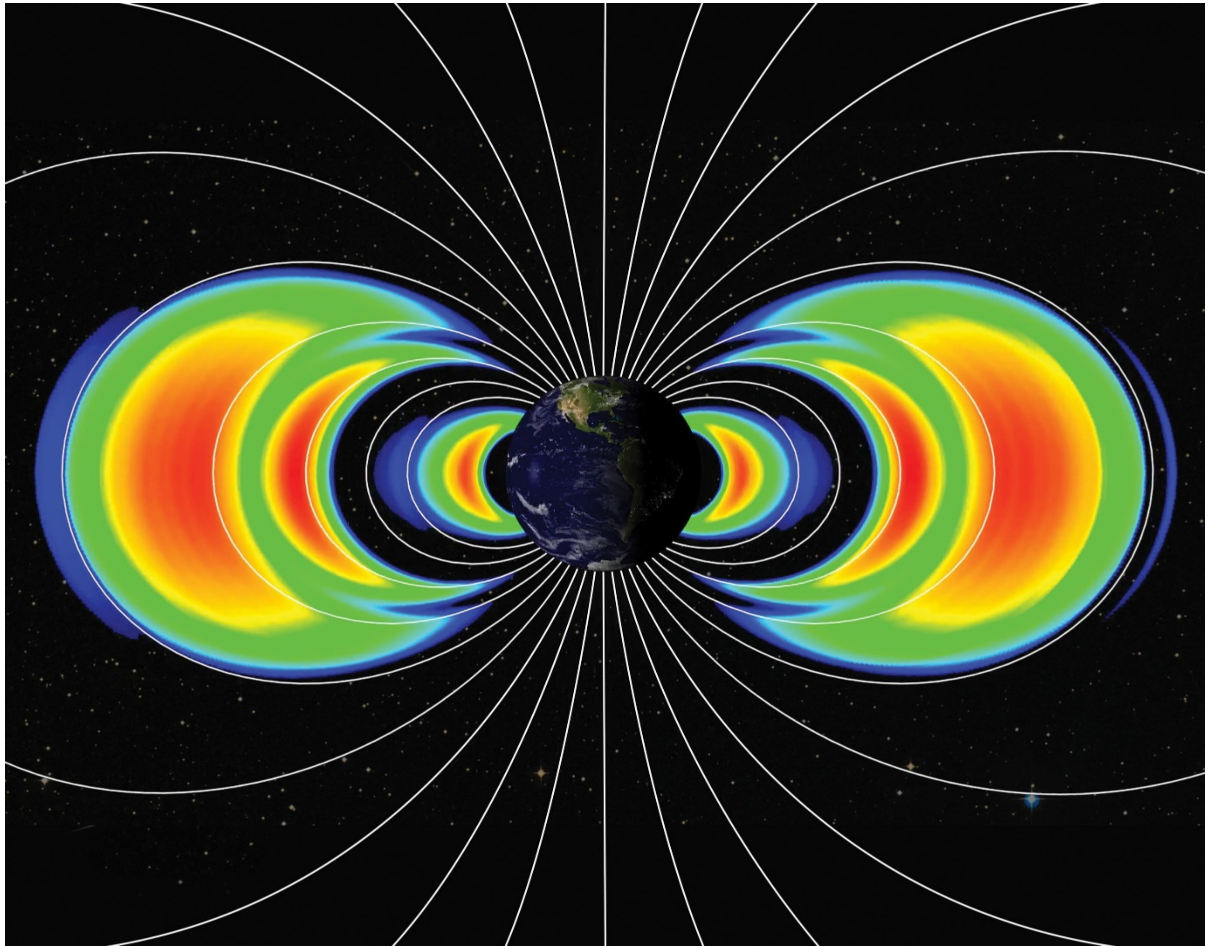

**Flight path in blue of space craft, and first map of radiation belt around Earth**



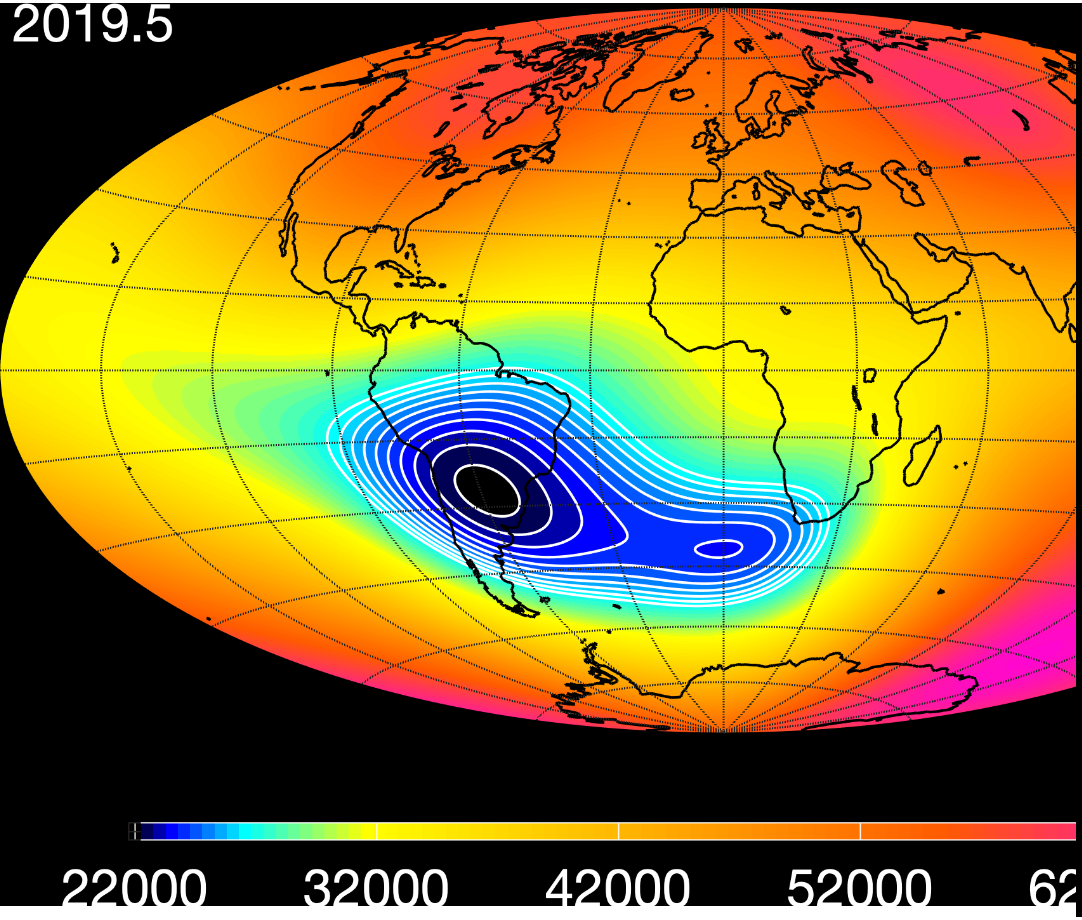
# Van Allen Radiation Belts

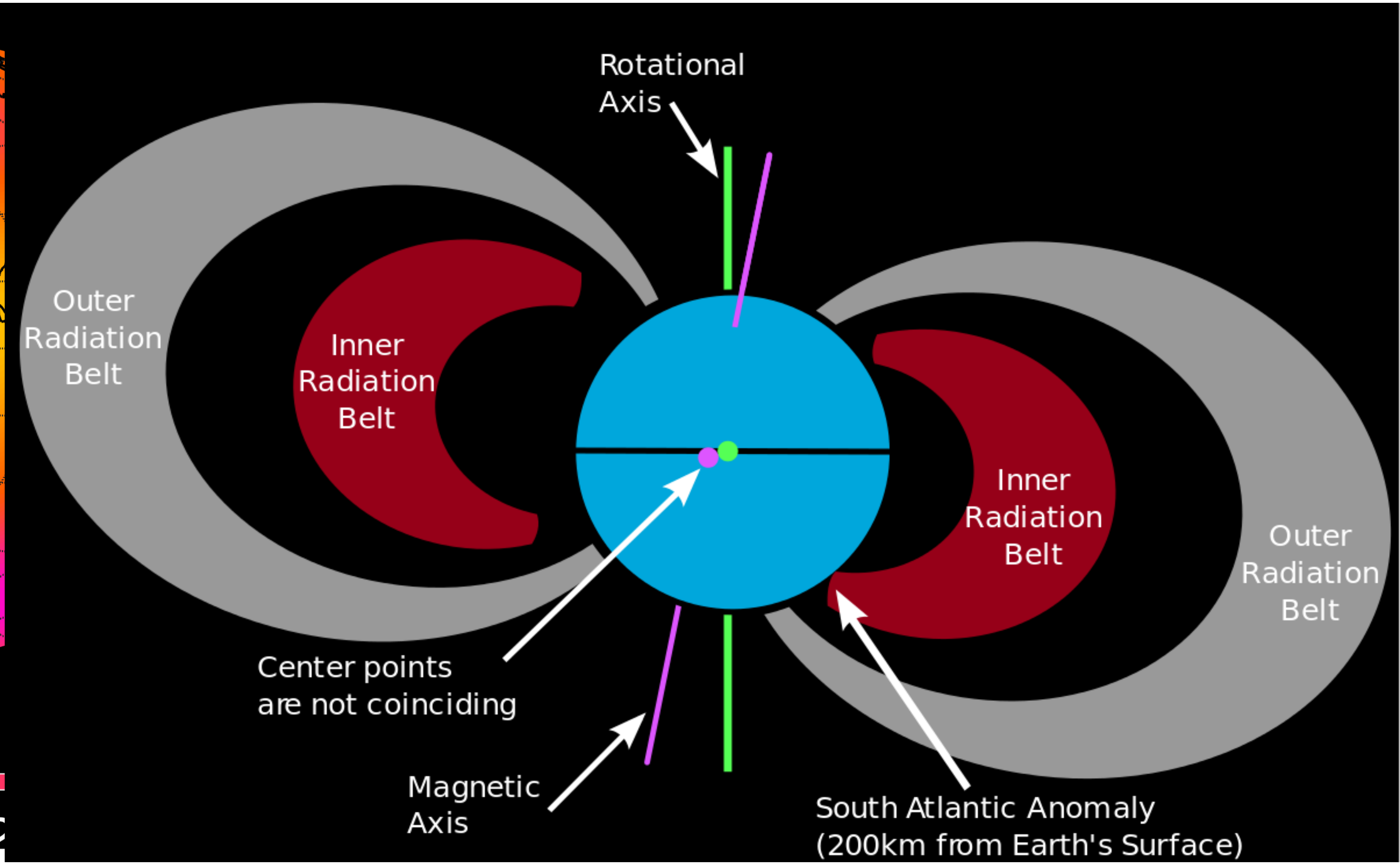
Two layers of belts with intense radiation that protect the Earth from cosmic radiation, and are a major problem for space craft instrumentation.

Space craft in Low Earth Orbit do not have to worry about this except when passing through the South Atlantic Annomly.



# South Atlantic Anomaly

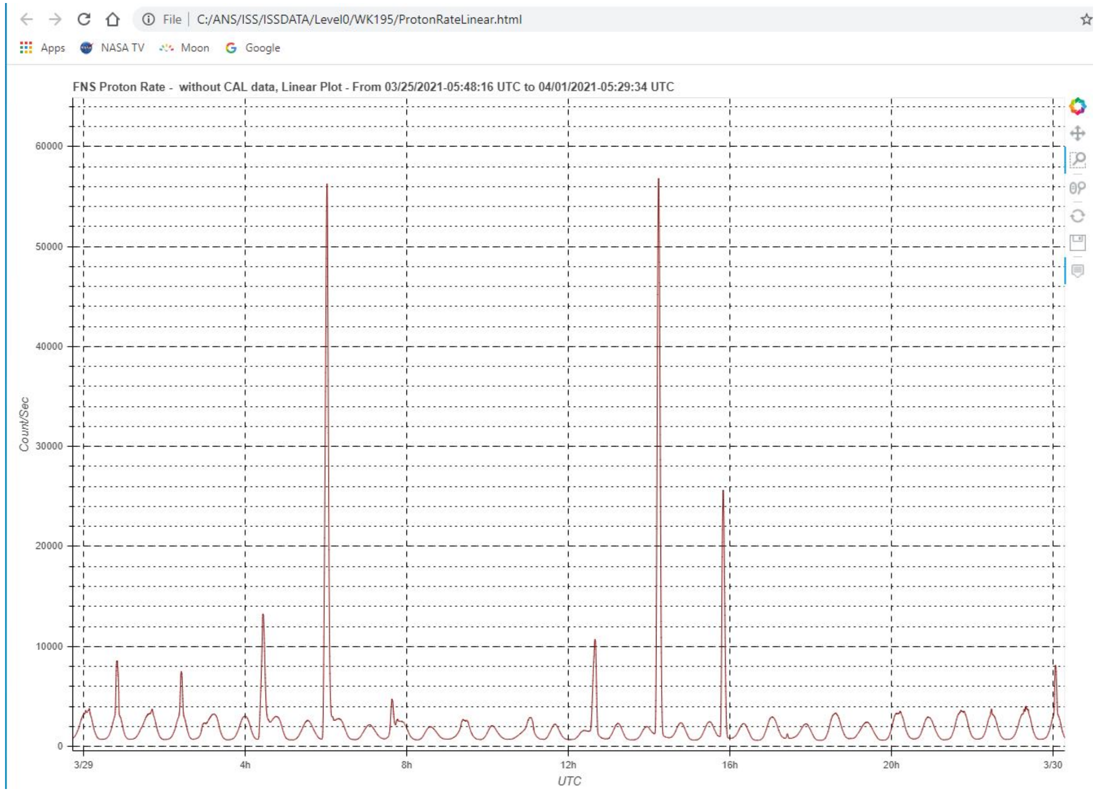



This is all due to the Earth's magnetic core shifted from rotational center, and it is a major problem for doing Space Science.

# South Atlantic Anomaly

- All Low Earth Orbits like that of the International Space Station must pass through the Intense Radiation of the South Atlantic Anomaly.
- Here from a neutron detector on the ISS show the radiation spike
- It is a danger to equipment, people and impedes Space Science if not handled correctly.

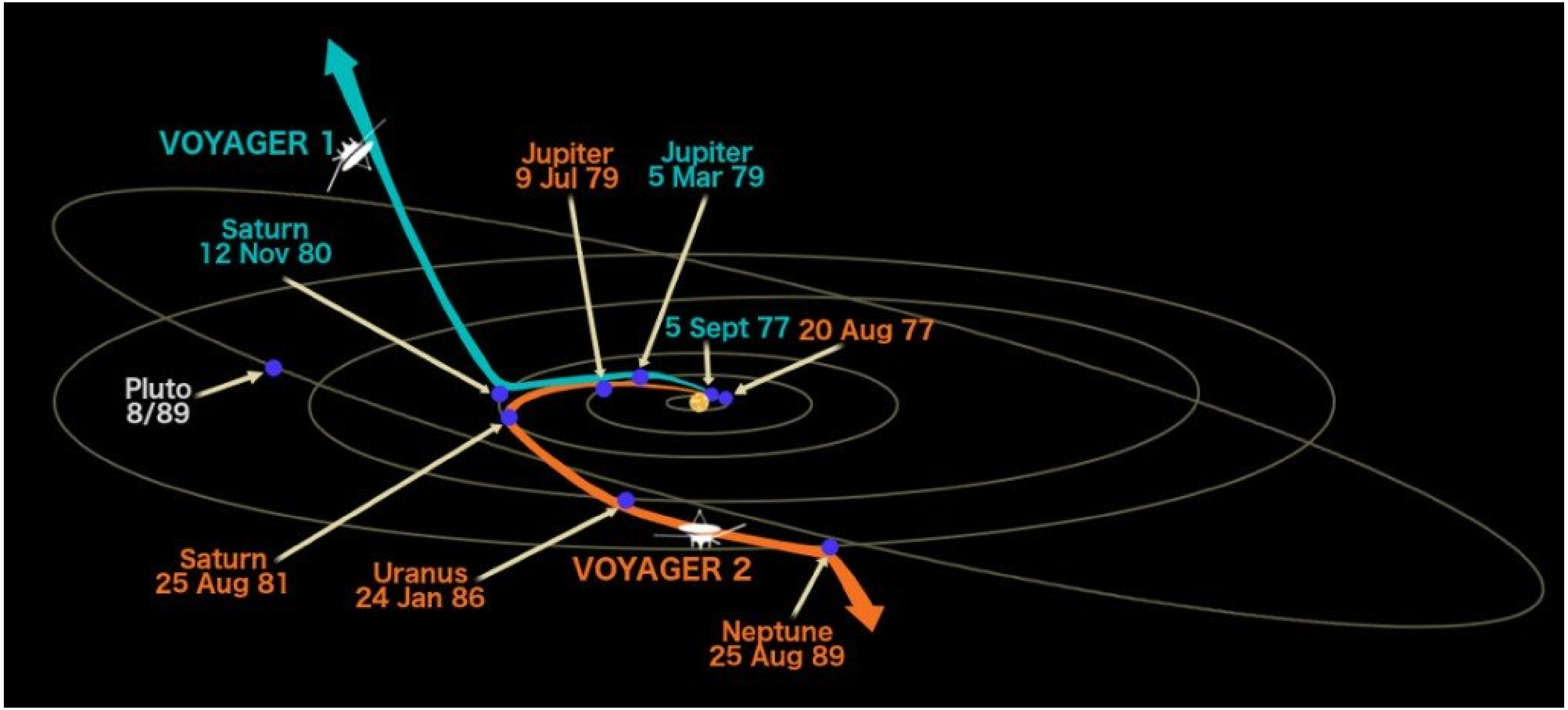


# Deep Space

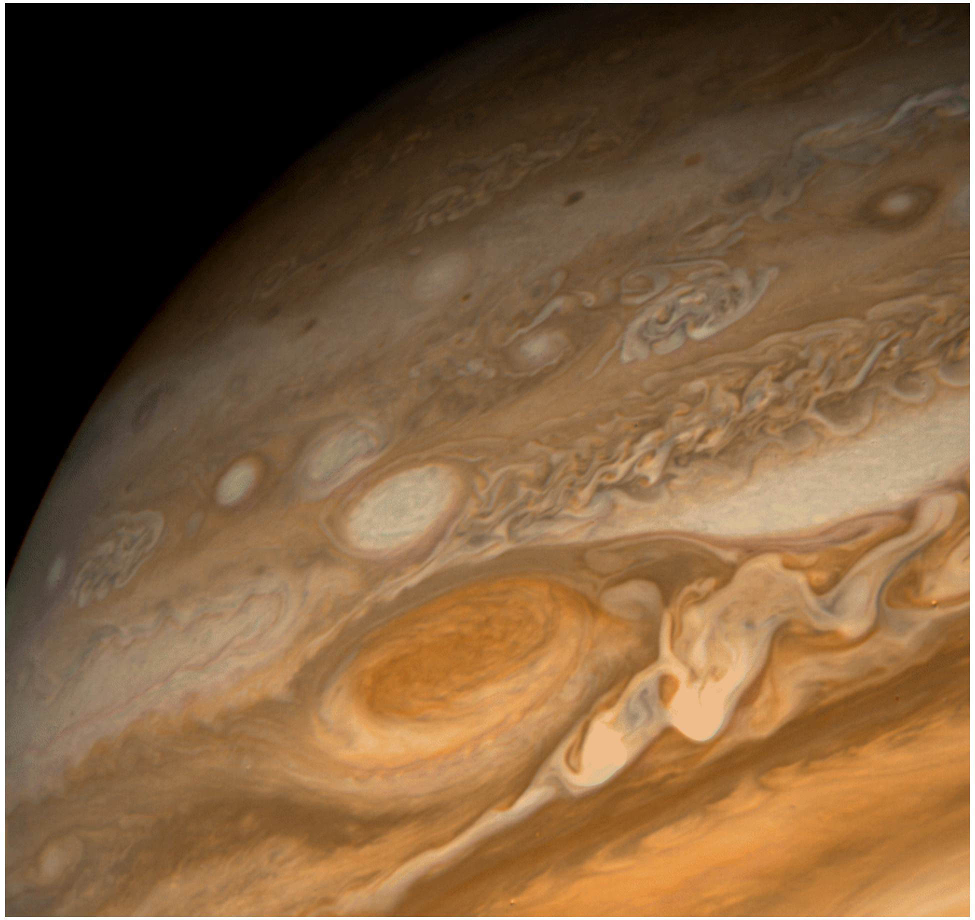
- So we saw that from Low Earth Orbit out to higher Earth Orbits Space is a harsh environment.
- However harsh Earth orbit is we managed to design equipment that can work in these conditions and do so for a very long time, Geostationary satellites can operate 20 to 30 years if engineers properly.
- Lets turn our attention next to Deep Space, beyond Earth which includes the Moon, missions to Mars and travels to all the distant outer planets.

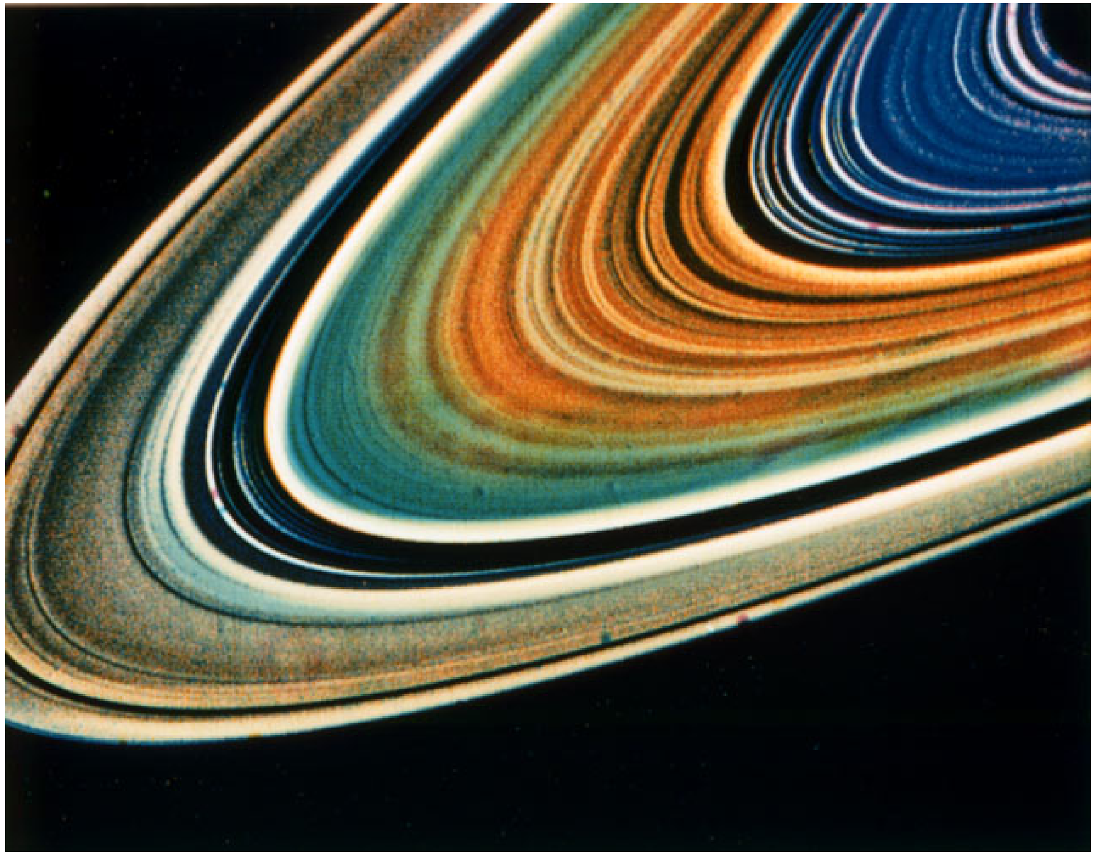
# Voyager 1 and 2

Just 20 years after the first Satellite launch, mankind launch two probes to the outer planets, Voyager 1 and 2 would visit up-close Jupiter and Saturn and Voyager 2 go on to explore Uranus and Neptune the only spacecraft to visit these Ice-Giants



# Voyage images of discovery

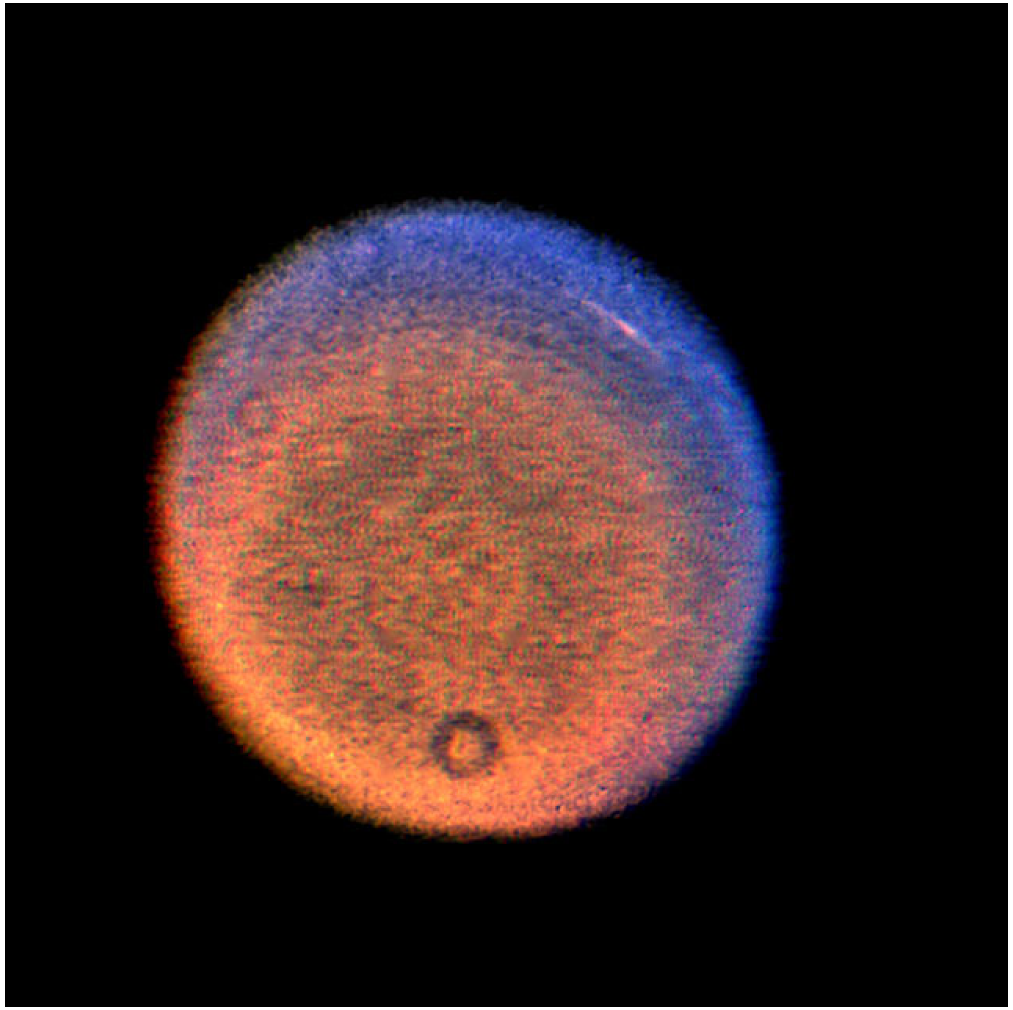




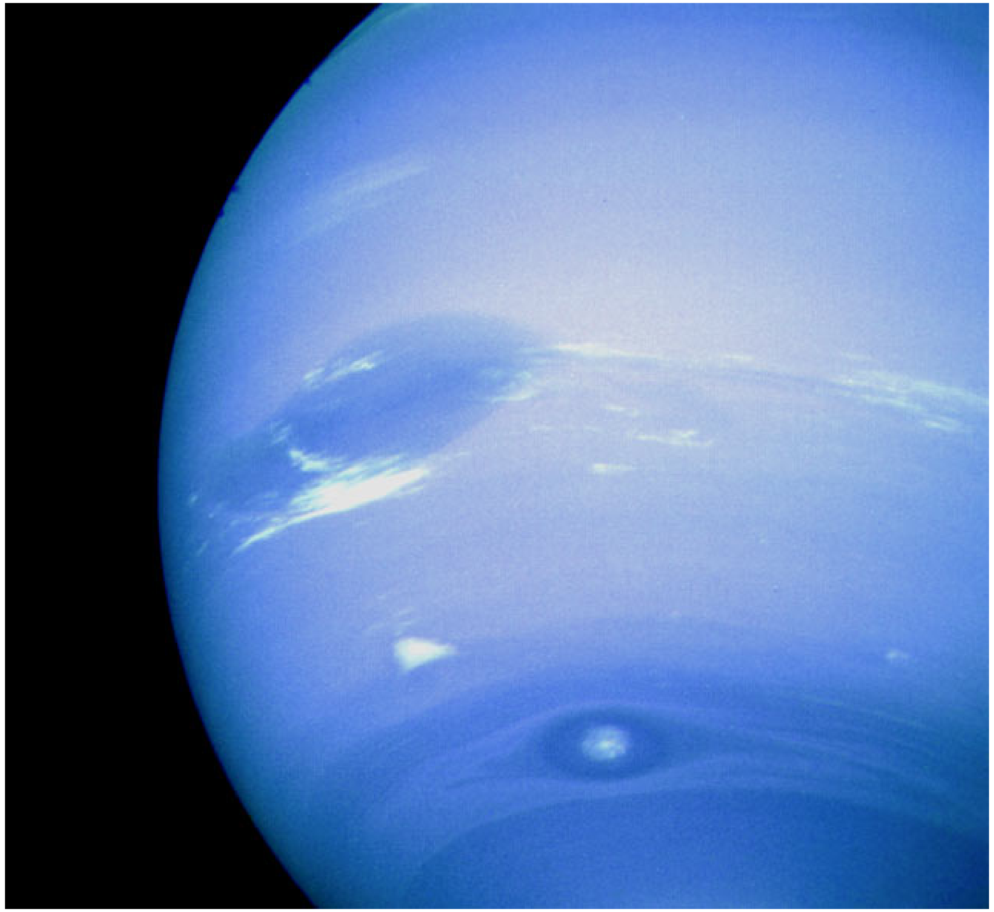
Jupiter's giant red spot, a hurricane on the planet that never ends.

Saturn’s rings when viewed up close has a lot of sub structure due individual particle material size and motion.

# Voyage images of discovery

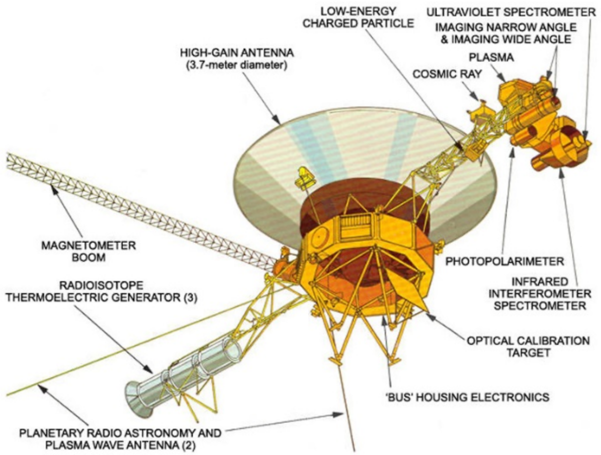


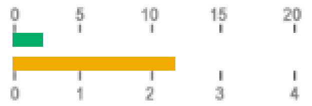
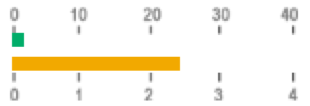
Uranus's clouds and weather viewed here from the polar cap we can see the planets clouds rotation.



Neptune and Ice-Giant with similar structure as Jupiter but much colder; it still has hurricane type storms that persist for 100s of years.

# Voyage spacecraft has two charged particle monitors, low and high energy




| | Voyager 1 | Voyager 2 |
|---|---|---|
| Launch Date | Mon, 05 Sept 1977 12:56:00 UTC | Sat, 20 Aug 1977 14:29:00 UTC |
| Mission Elapsed Time | 43 : 08 : 17 : 11 : 40 : 49<br>YRS MOS DAYS HRS MINS SECS | 43 : 09 : 02 : 10 : 07 : 49<br>YRS MOS DAYS HRS MINS SECS |
| Distance from Earth | 14,138,389,701 mi | 11,765,421,622 mi |
| | 152.09801830 AU | 126.57009398 AU |
| Distance from Sun | 14,212,651,252 mi | 11,814,130,128 mi |
| | 152.89690948 AU | 127.09409051 AU |
| Velocity with respect to the Sun (estimated) | 38,026.77 mph | 34,390.98 mph |
| One-Way Light Time | 21:04:57 (hh:mm:ss) | 17:32:39 (hh:mm:ss) |
| Cosmic Ray Data |  |  |

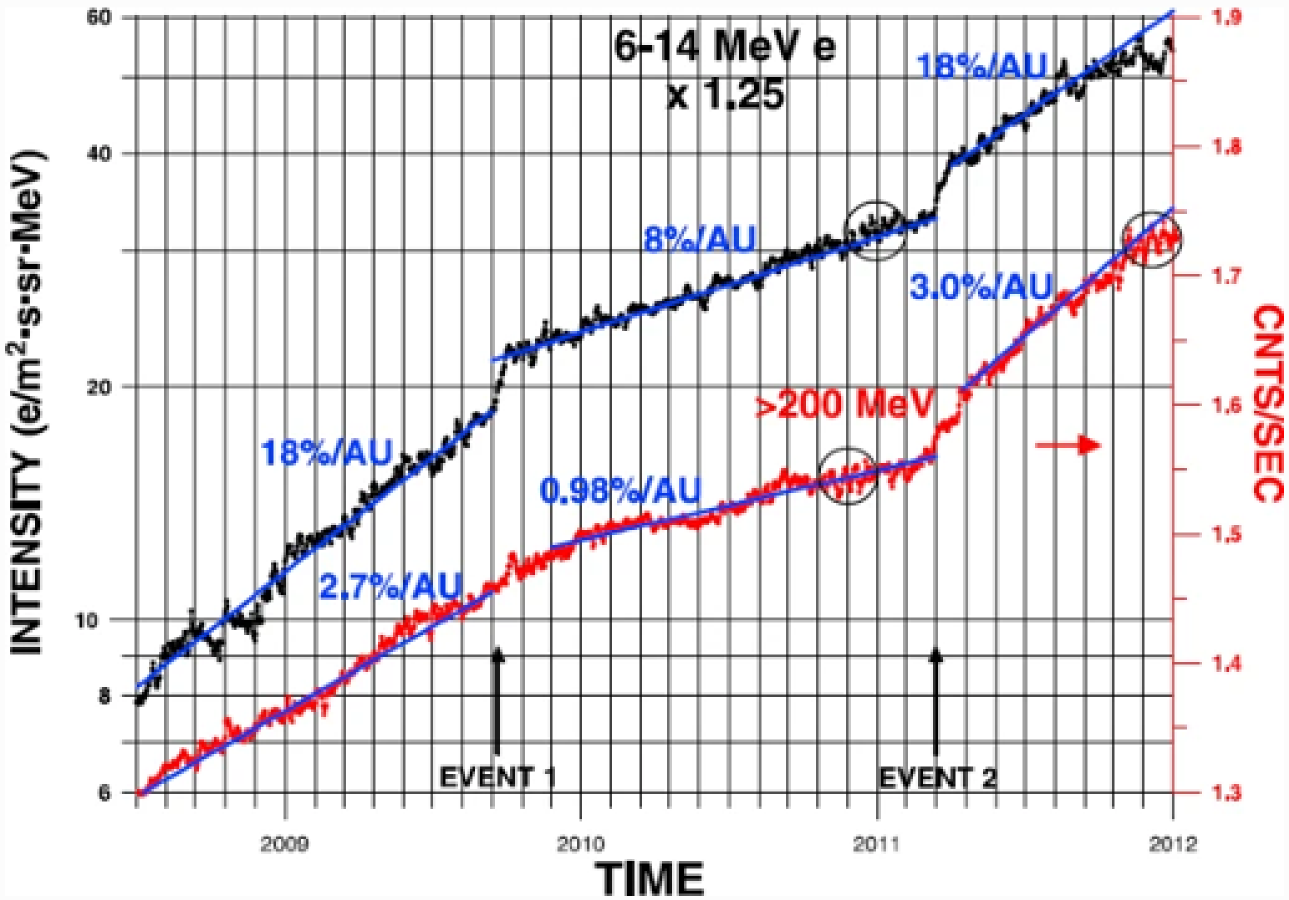
Low Energy from Sun

High Energy from Deep Space

# Voyage low and high radiation levels

- As we travel away from Earth the radiation levels increase
- Several unusual effects where seen:
  - Event 1: Sharp increase in low energy which we feel is due to shock wave boundary
  - Event 2: Sharp increase in high energy particles that the Sun's protective layer cannot stop from entering from Galactic core.
- Deep Space is far harsher than the space around the Earth.

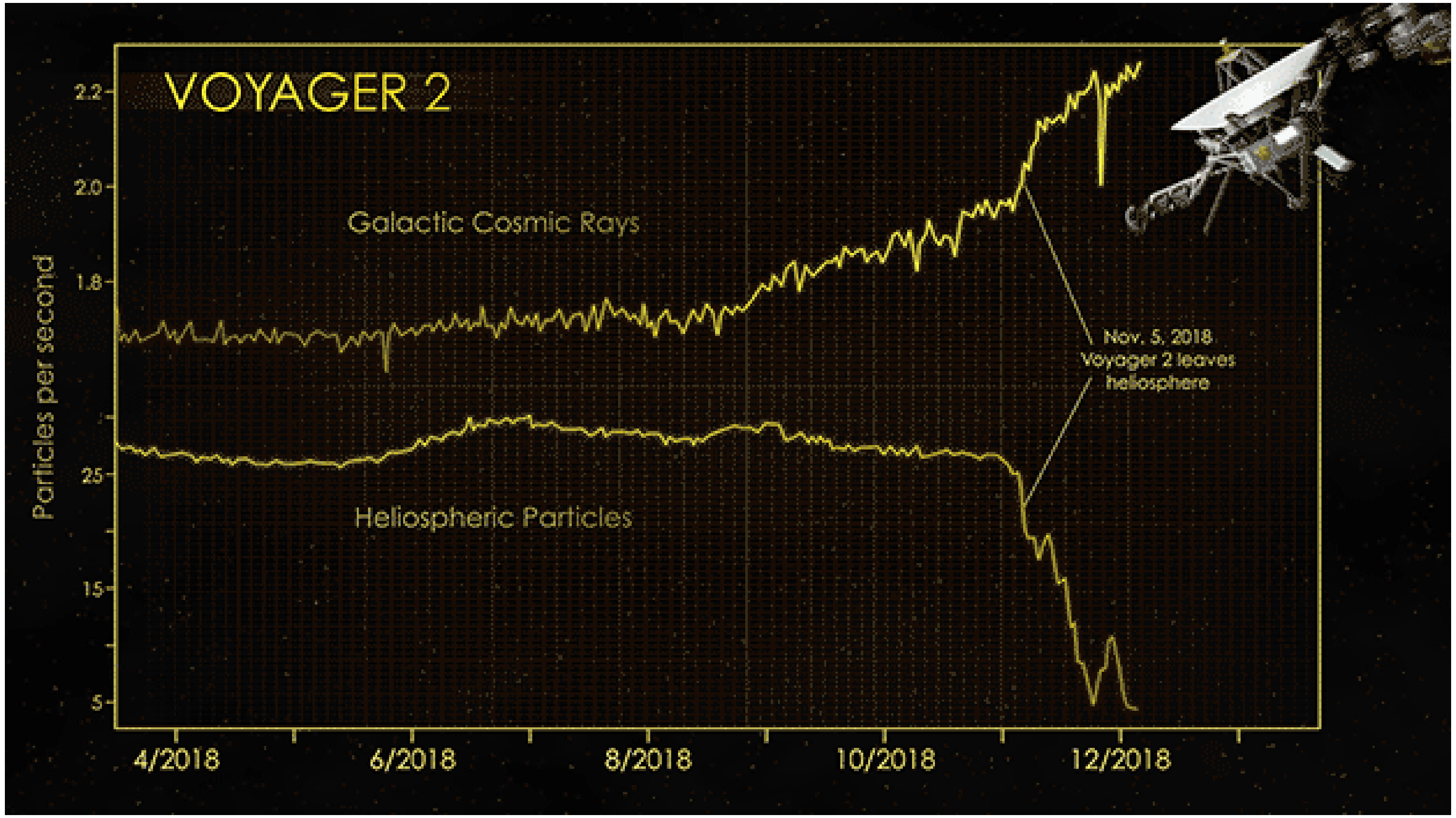
**Figure 27:**




The 5-day running average of the 6–14 MeV electrons and $E$ > 200 MeV protons intensities measured at Voyager 1 from 2008.5 to 2012. Note the first sudden intensity increase of electrons at 2009.70 (111.2 AU) and the change in radial gradients of both electrons and protons before and after this increase. Similar behaviour followed n the second sudden intensity increases of both electrons and protons at 2011.2 (116 AU). The continuing increase of electron and proton intensities after 2011.3 is a notable feature. Image reproduced by permission from Webber *et al.* (2012), copyright by AGU.

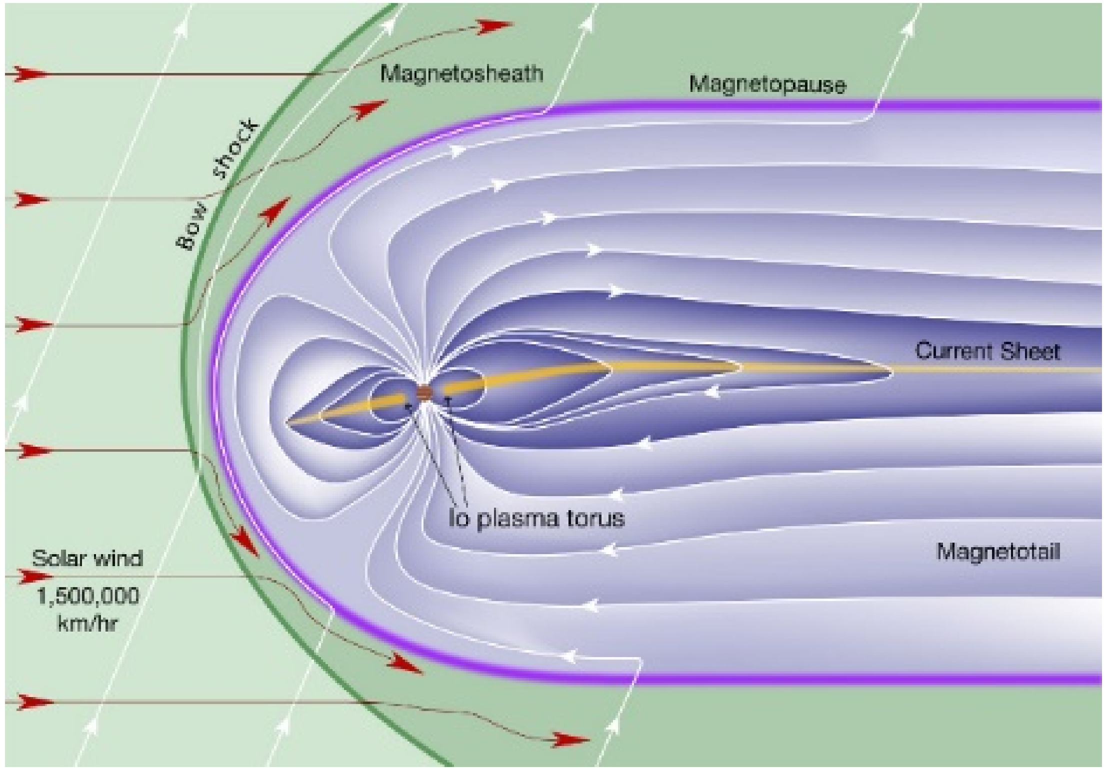
# Voyage evidence it left the Solar System

- Two particle rates monitored
  - Low energy from the Sun's solar wind emission, ~0.5 MeV.
  - High Energy from outside our solar system that the Sun protects us from, >70 MeV.
- When the solar wind particle stop and the high energy particle increase we have left the Heliopause.

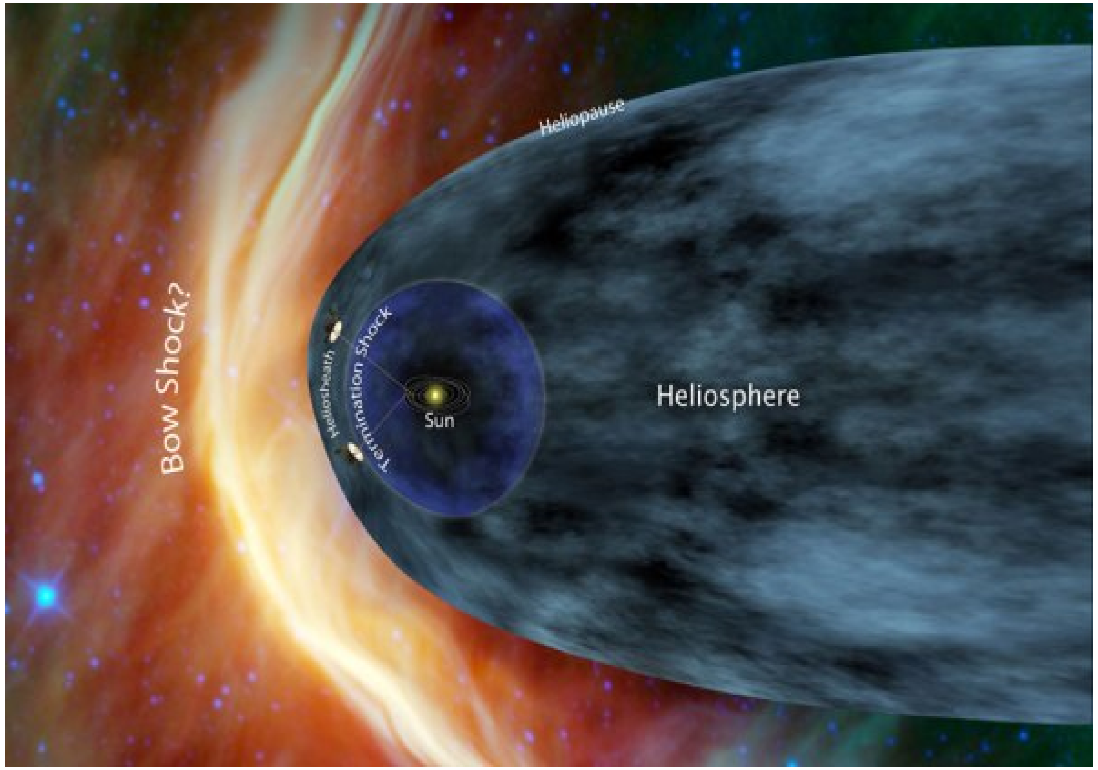


# Magnetic field of Earth guards us from solar radiation and the Sun protects us from Galactic core radiation

**Earth's protective bubble**



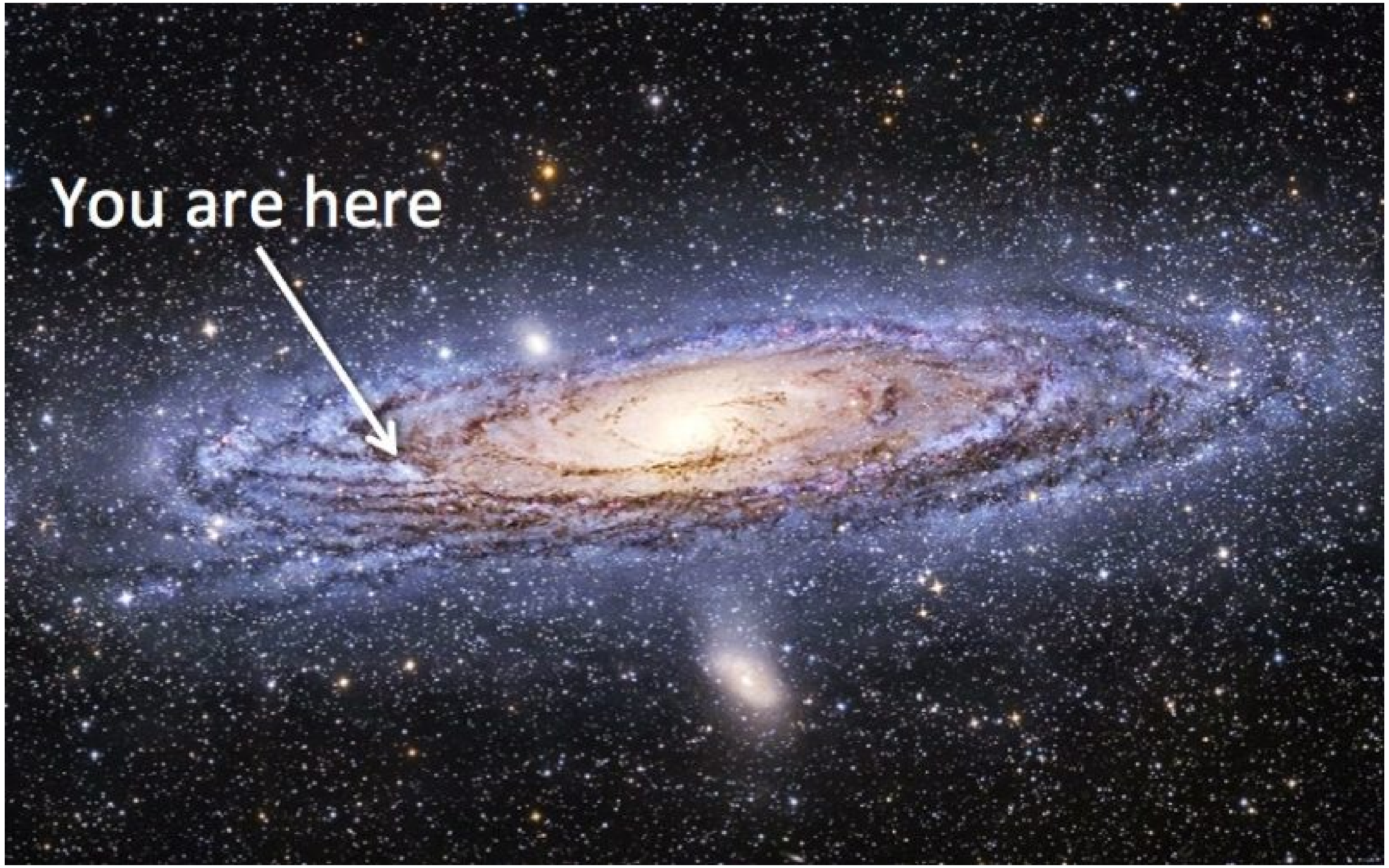

**Sun's protective bubble**



# Our Sun is 25,000 light years from the galactic core, inside the protective bubble of the galaxy

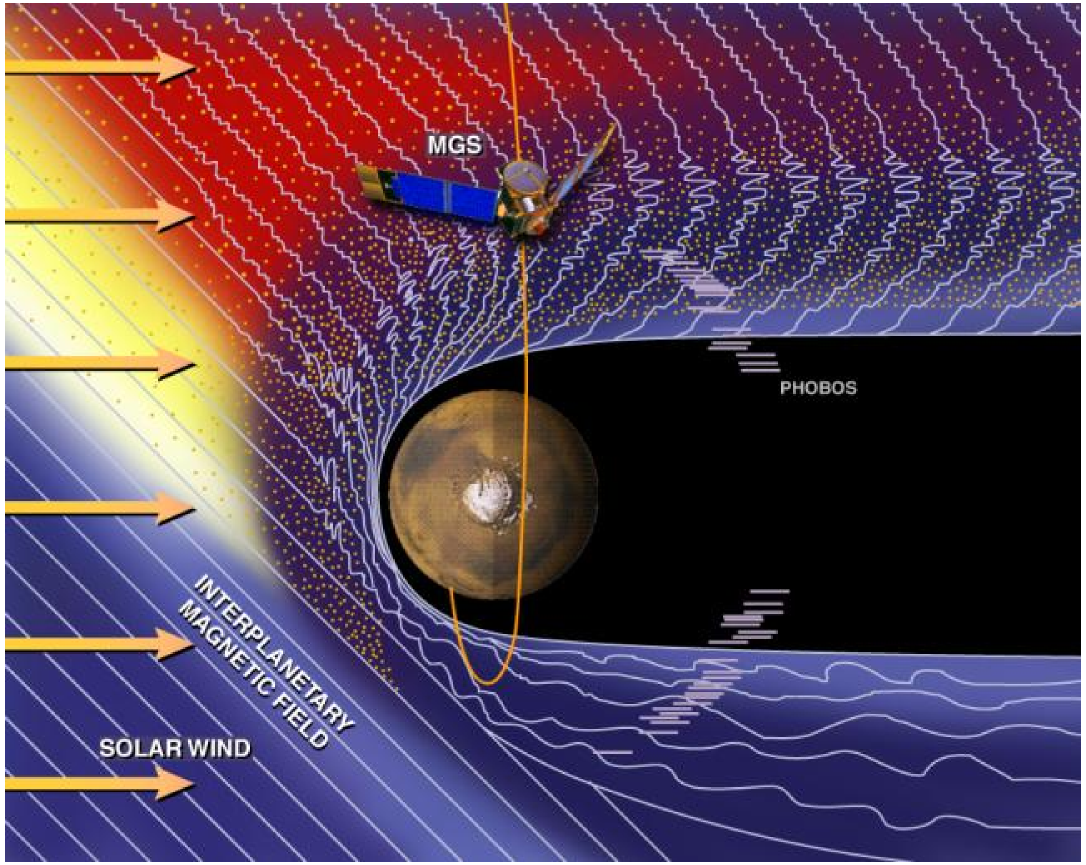
Radiation from the galactic core is immense 700x higher energy than compared to our Sun yet still we have protection from intergalactic space radiation which is even worse.

The Sun takes about 150,000 years to orbit around the galactic core.



# Earth is protected but Mars or the Moon is exposed to the ravages of the Sun's Solar winds

**Mars has NO Magnetic field so no protective bubble**




**Goldilocks zone**

- The Moon and Mars are both in the Goldilocks zone from the Sun, but without a magnetic field there is no way life can exist there.
- The atmosphere of Mars and if the Moon ever had one were ripped away by the Sun's solar winds.

# Going close to the Sun

**The Sun is a source of low energy particles**

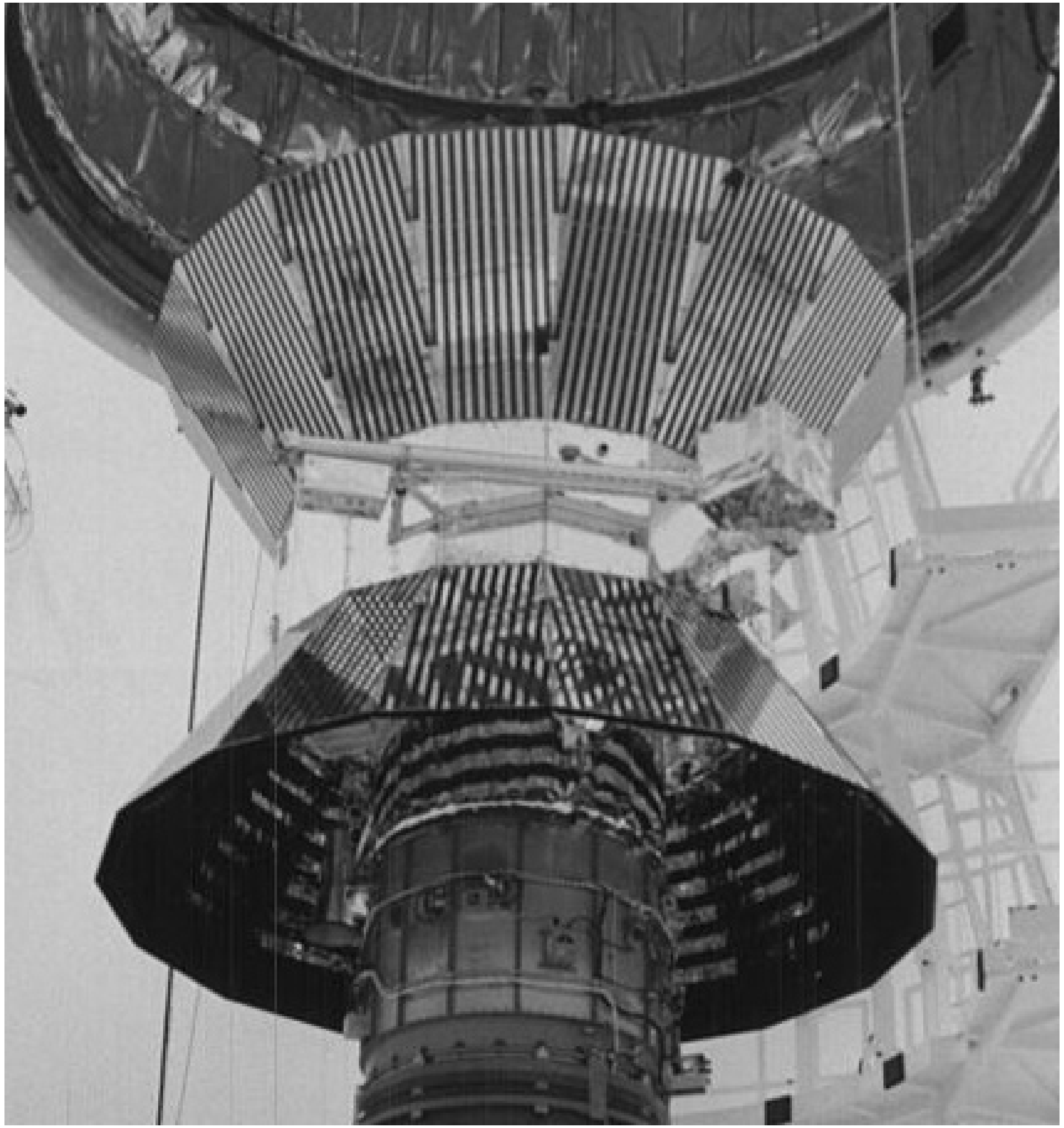
- Low energy Electrons, Positrons and Protons from the Surface of Sun
- As we go close to the Sun this increased by $r^2$
- Easy to shield due to low Energy

**The Sun is an even bigger magnetic than the Earth**

- Charged Particles sweep away by Magnetic field
- Only high energy particles can make it close to the Sun

# Touching the Sun

- NASA and Germany in 1974 launch Helios-1 and Helios-2 spacecraft to go close to the Sun.
- It would go within 35 Solar Radii to study
  - Magnetic field of Sun
  - Charged Particles from Sun
  - Electric Field of Sun



# Taking the Temperature of the Sun

- Charged particles measured for first and only time from the Sun
- Protons out to 100 MeV
- Electrons and Positrons out to <10 MeV

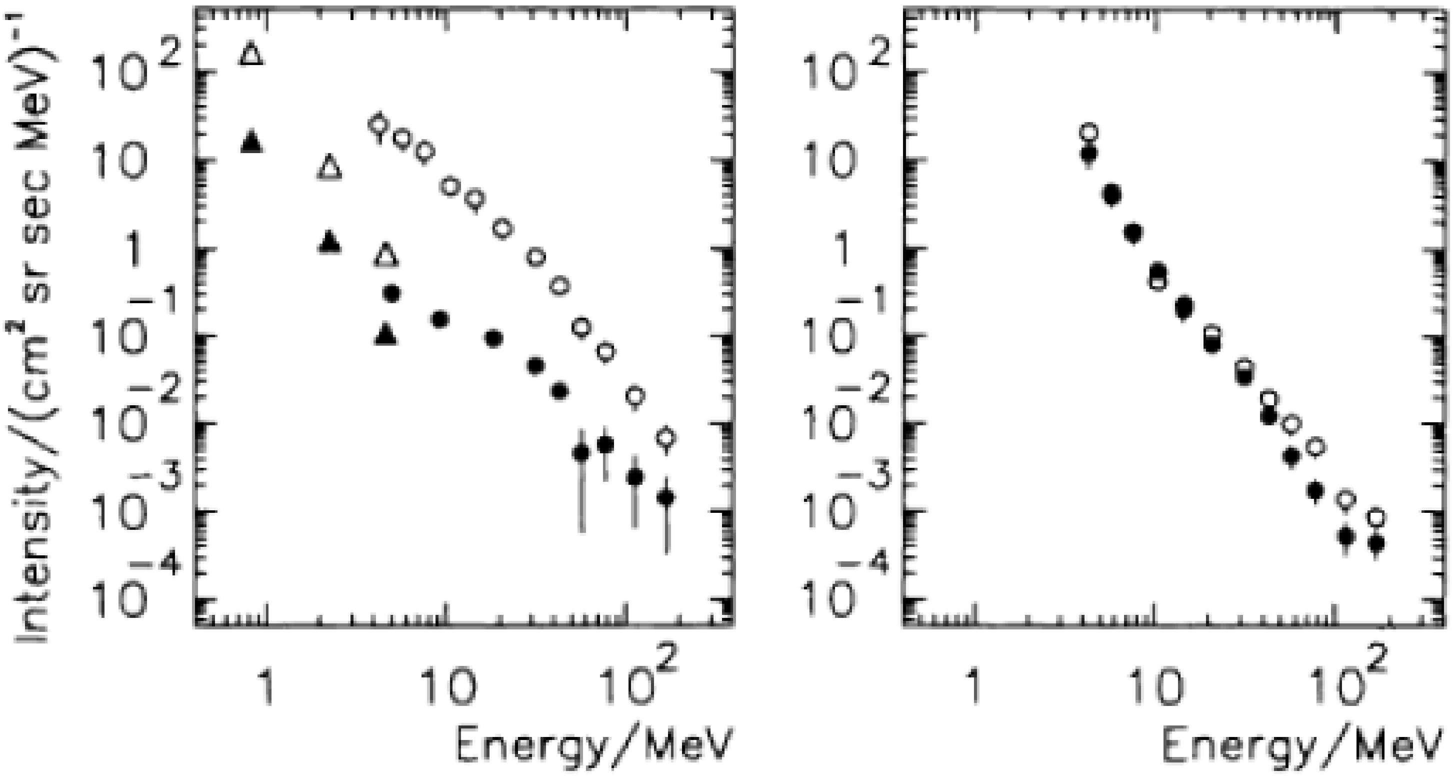
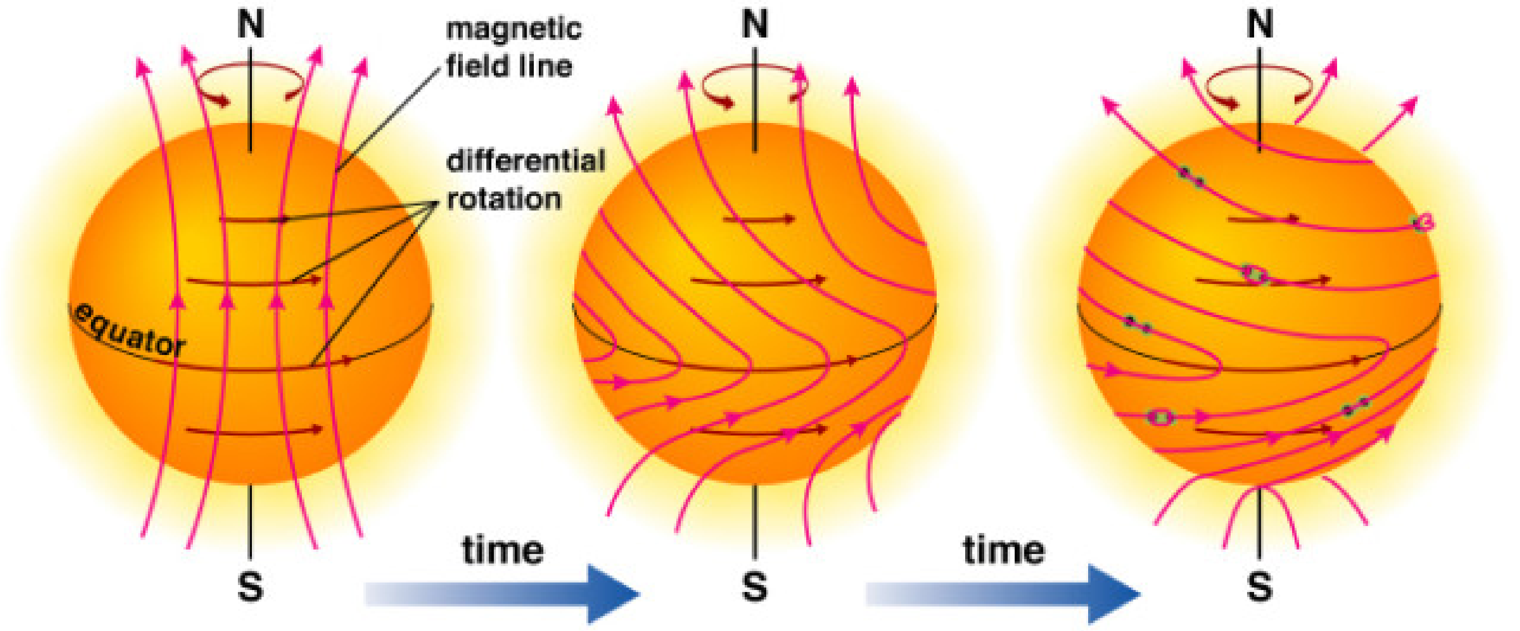



Figure 3: left: prompt spectra; right: shock spectra – Open circles (triangles): protons (electrons) HELIOS 1; full circles (triangles): protons (electrons) HELIOS 2

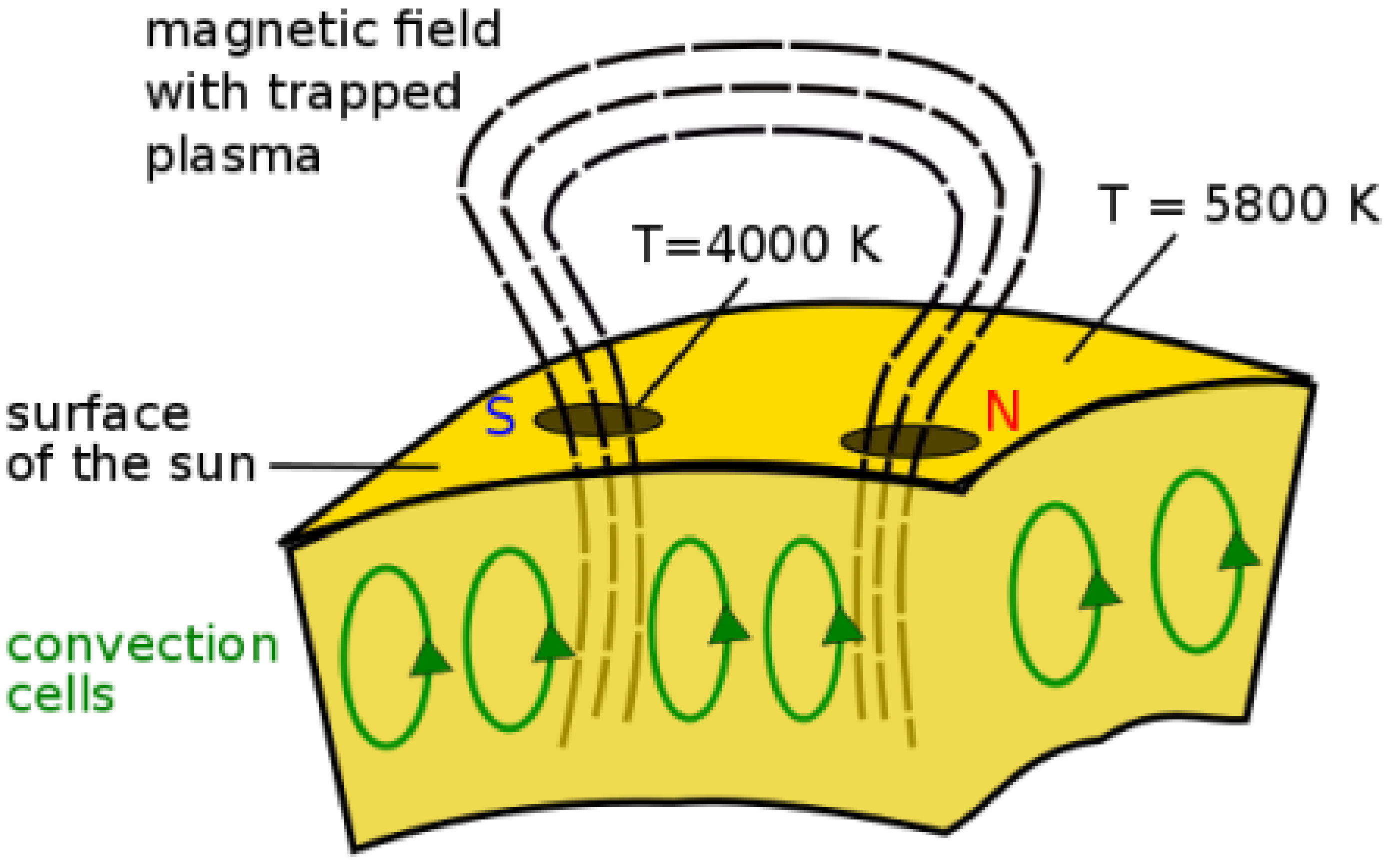
# Sun's Magnetic Field Measured

- Sun magnetic field thousands time stronger than Earth
- The Sun rotates at different speed with latitude, with the equator being the fastest
- The Sun flips magnetic field every 11 years and repeats every 22 years.
- The Sun provides the inner planets with lots of extra protection from charged cosmic rays.



# Sun Spots are colder regions that are source of Current

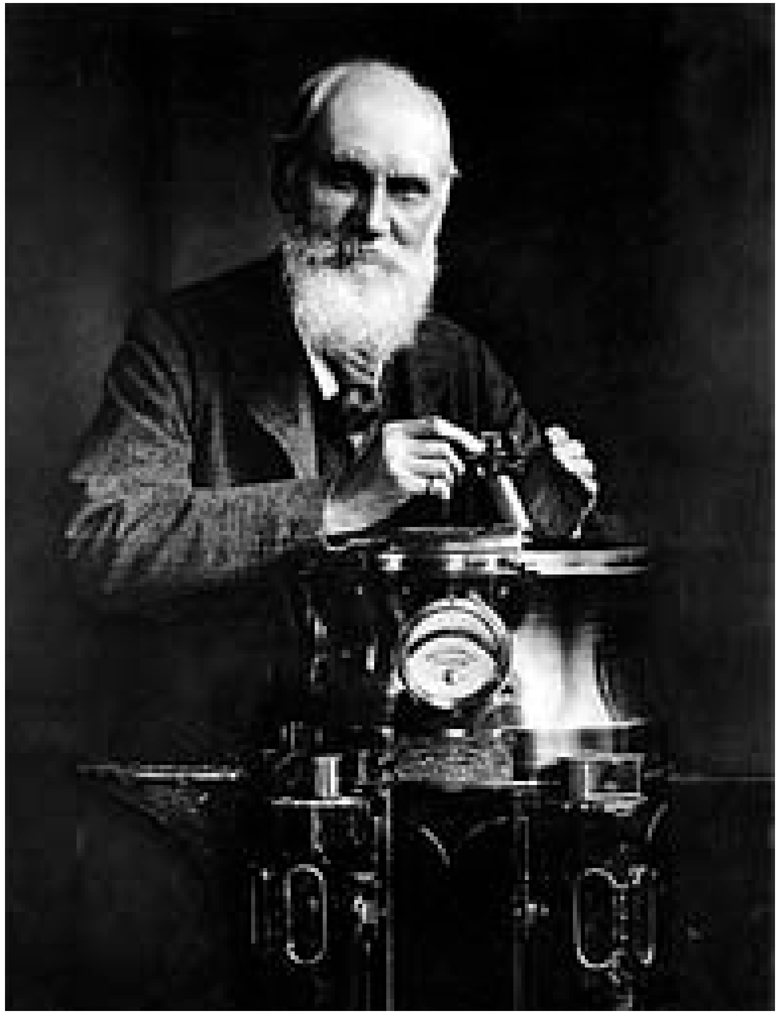
- The current generate magnetic fields that loop back to other sun spots due to convection zone below Sun Surface
- These field lines break creating solar flares and prominences that fly off into space, and could impact the planets.

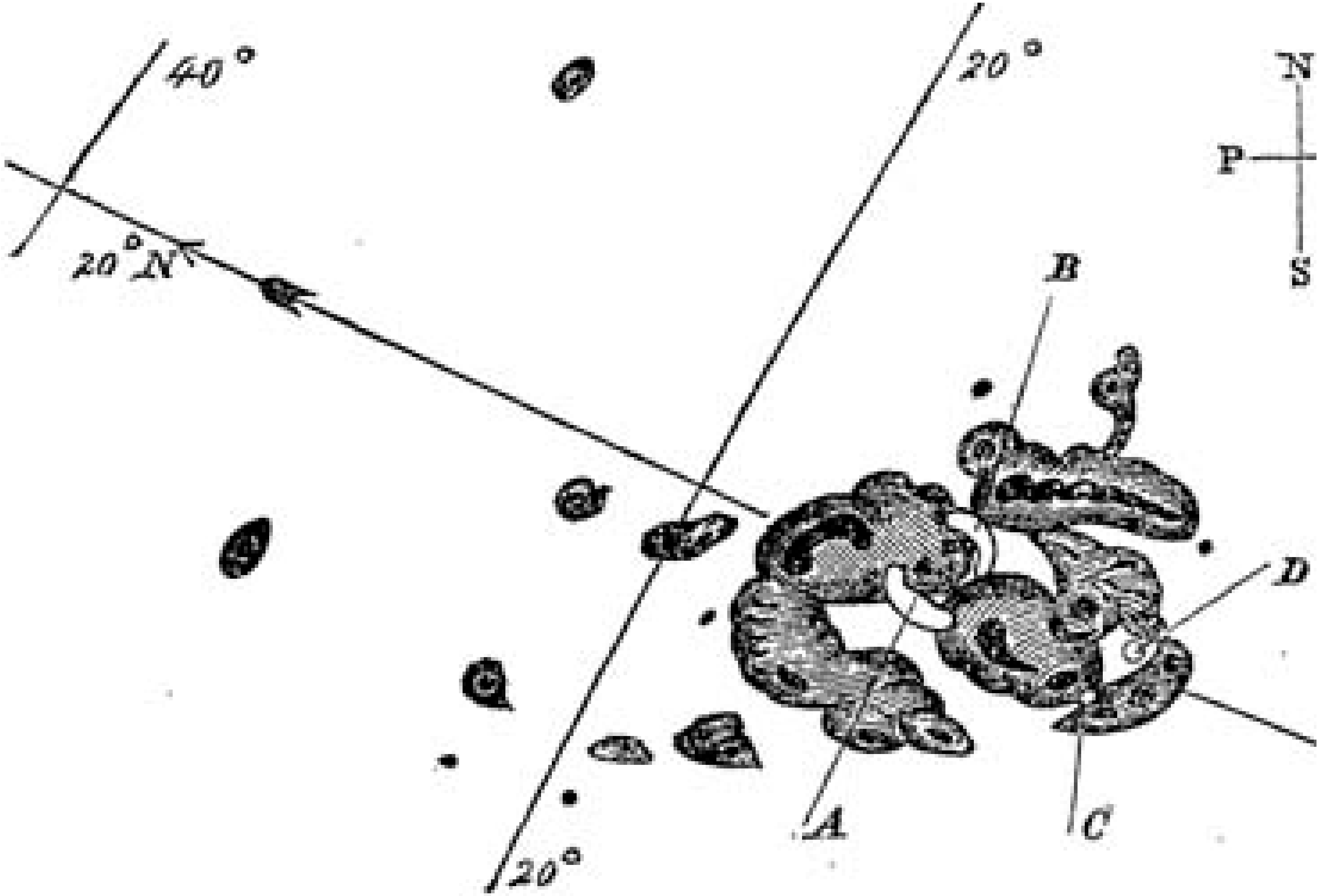


# First Solar Flare Observed

In 1859 while studying Sunspots on the Sun the First Solar Flare was observed by Richard Carrington, Carrington Event as called today.

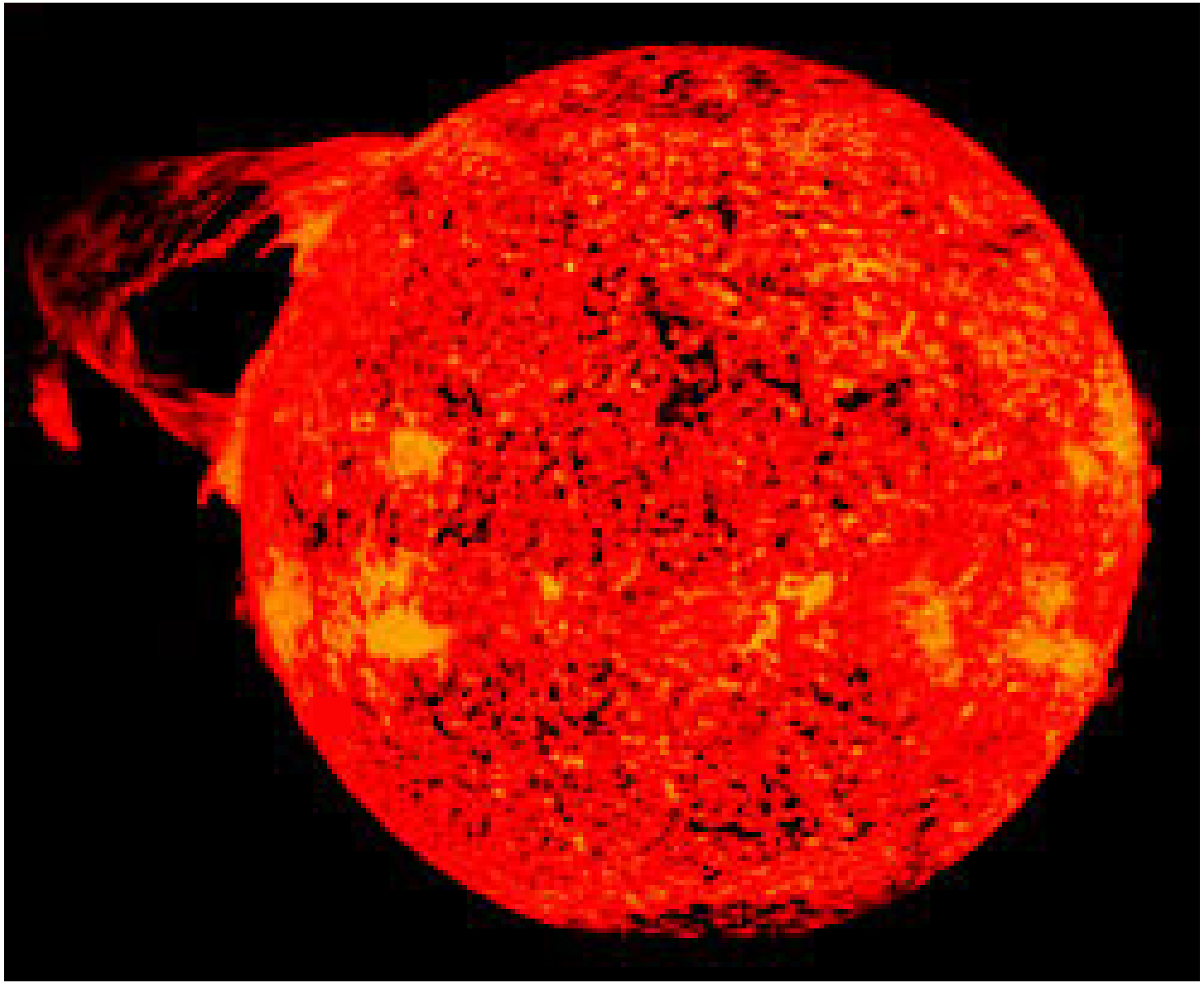
He saw a white light flare move across a sunspot taking about 5 minutes, 18 hours later the largest solar storm ever hit Earth.





# Flares and Prominences from Sun

- They can produce Coronal Mass Ejection (CME) events where intense charged particles reach Earth and make the northern lights as charged particles come down through the magnetic field lines of the poles.
- They can destroy electronics equipment: transformers, integrated circuit chips, computer chips and generators/motors.
- Deadly to humans in space, or on planets without magnetic fields.
- Both the Moon and Mars have no magnetic field which are deadly to all life on those planets.

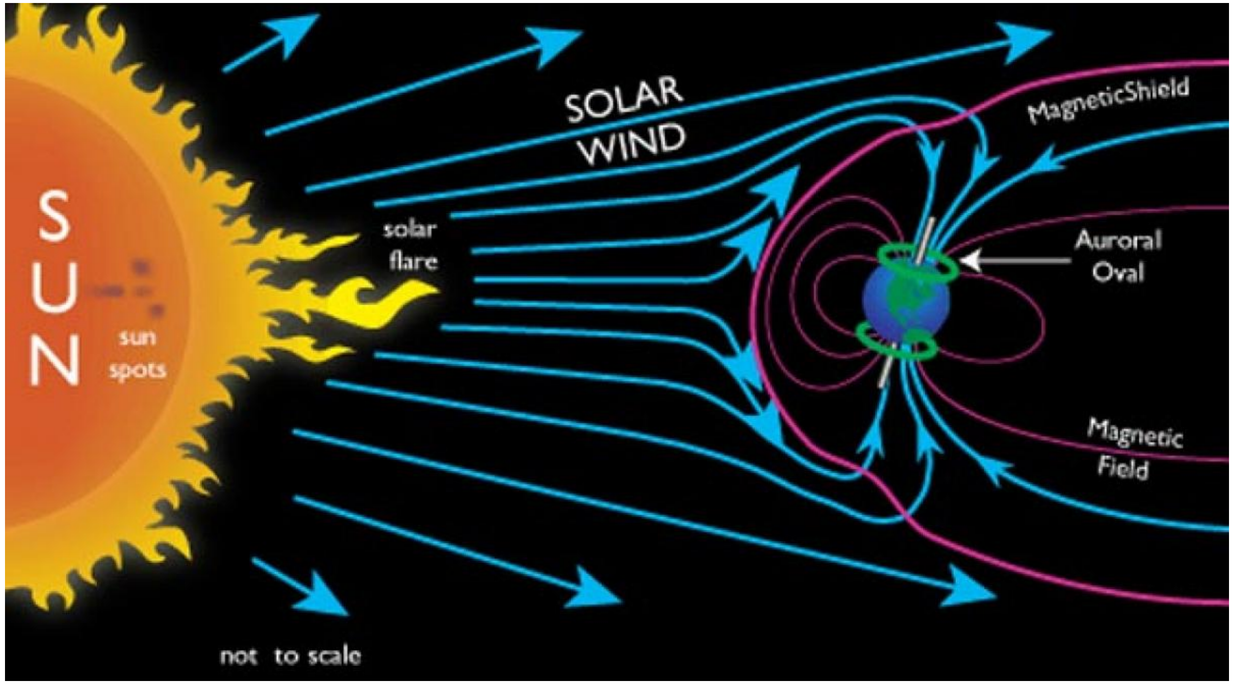


# Damage from Coronal Mass Ejection

- Studying the 1859 CME event where you could read a newspaper from the light of the CME’s Northern Light at midnight in Cuba; Lloyd's of London Insurance Co., Forbes Magazine and US Solar Observatory working together estimated if such an even occurred in 2018 it would have done 2.6 Trillion Dollars damage, about 15% of economy.
- The next biggest event was the 1921 CME that would have caused 0.4 T$ damage
- Two weeks after the Apollo 12 landing on the moon a small CME hit the Earth and Moon and the Moon without a magnetic field it would have had a major lethal radiation event to the Astronauts if they had been there at the time.

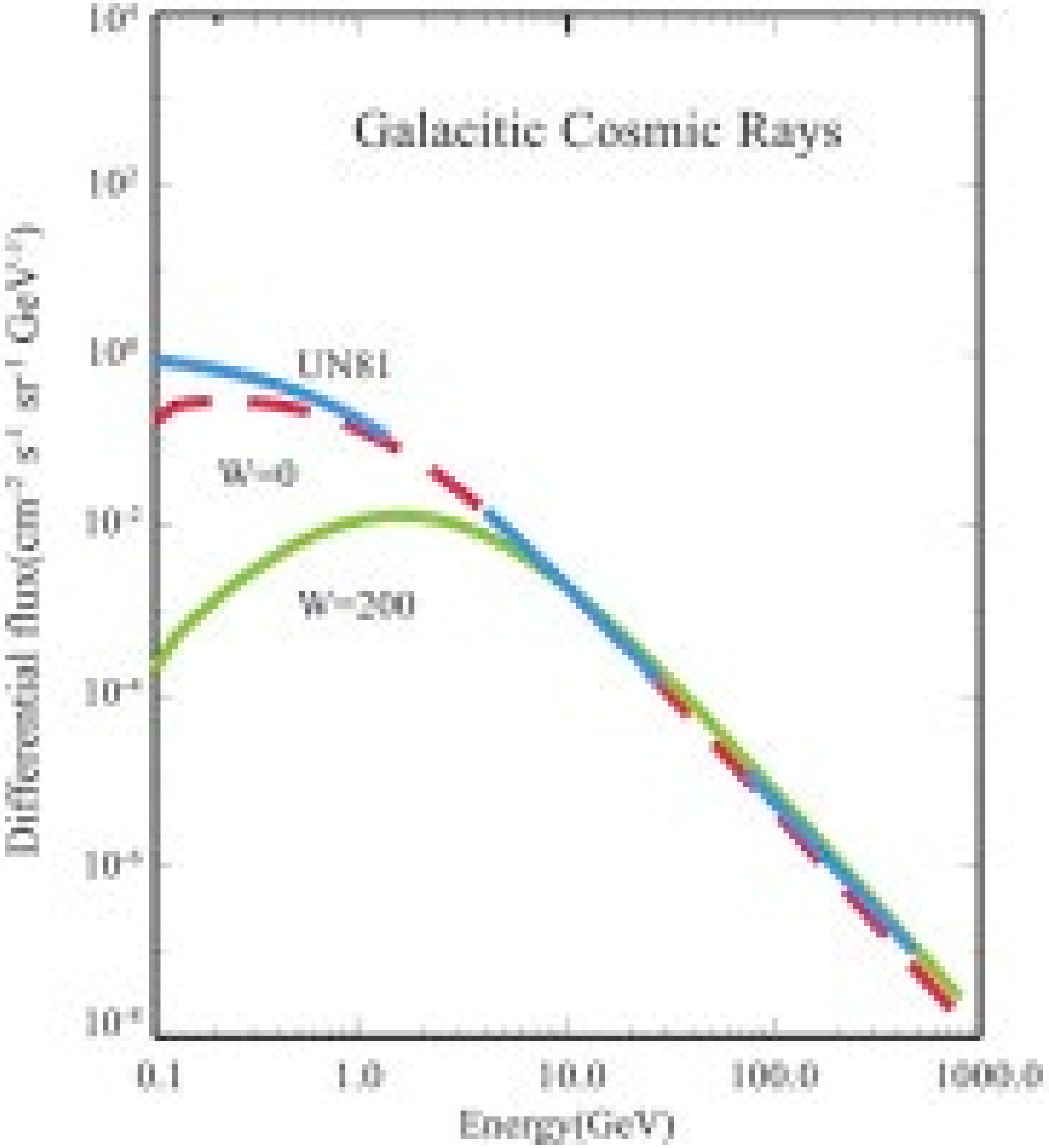
# Solar Wind

Apollo missions set up a solar wind experiment to measure its intensity, with the moon having no magnetic field it was a perfect spot to study the Sun emission. It was also sensitive to CME particles.

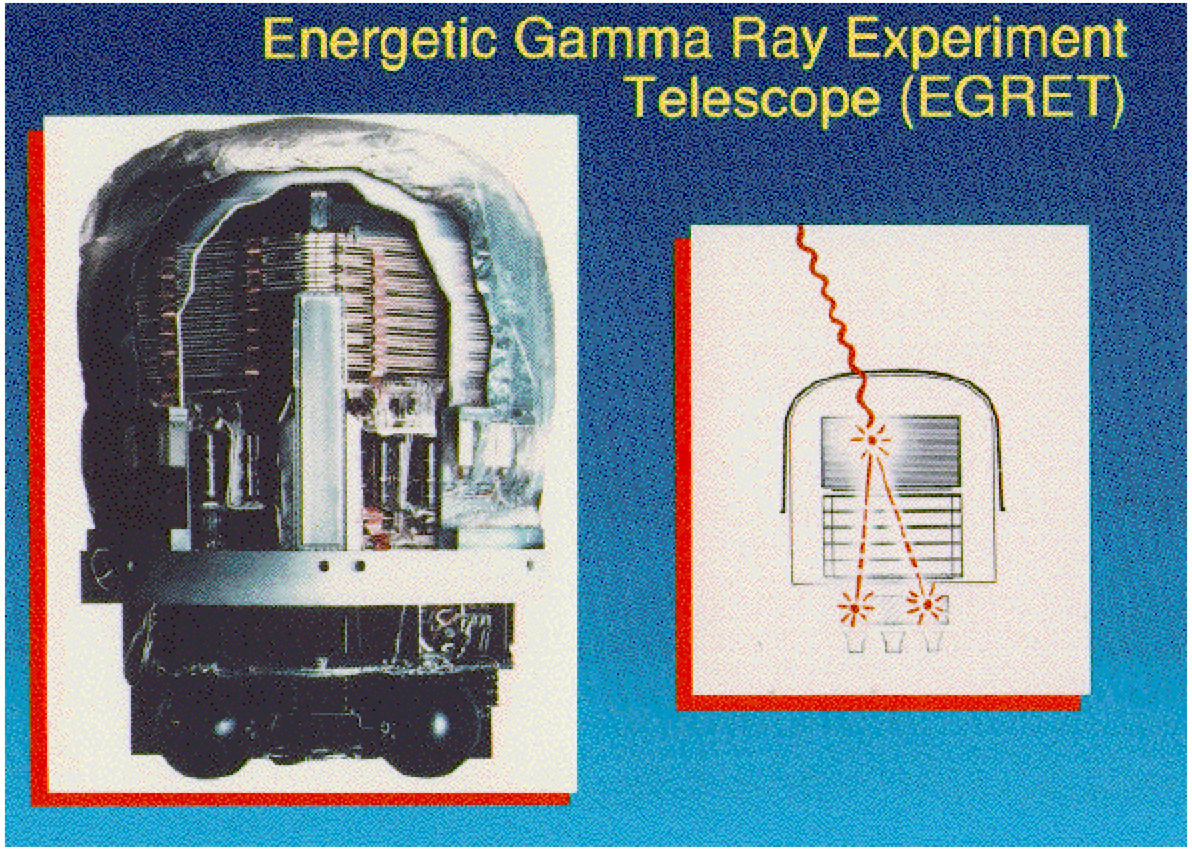



# Galactic Cosmic Rays

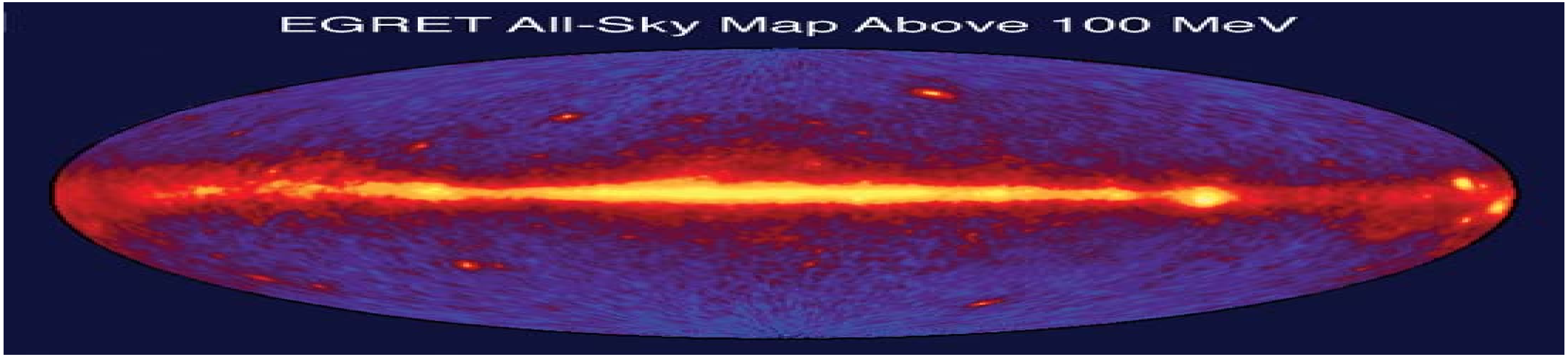
- Eugen Parker predicted Solar Modulation of the Galactic Cosmic Rays as you get closer to the Sun
- Low energy galactic cosmic rays are swept away and do not make it to the orbit of Mercury
- They are also far less at Venus than at Earth
- Conversely out at Jupiter galactic cosmic rays are much more intense in the outer solar system due to a lower solar magnetic field there.



# Scientists can study the Universe using cosmic rays

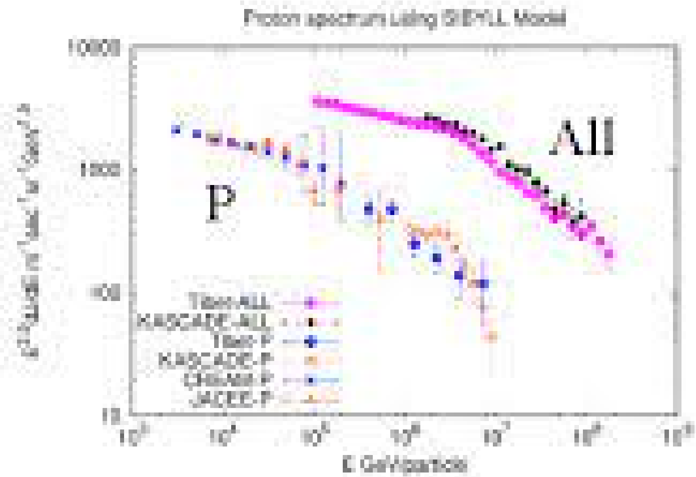


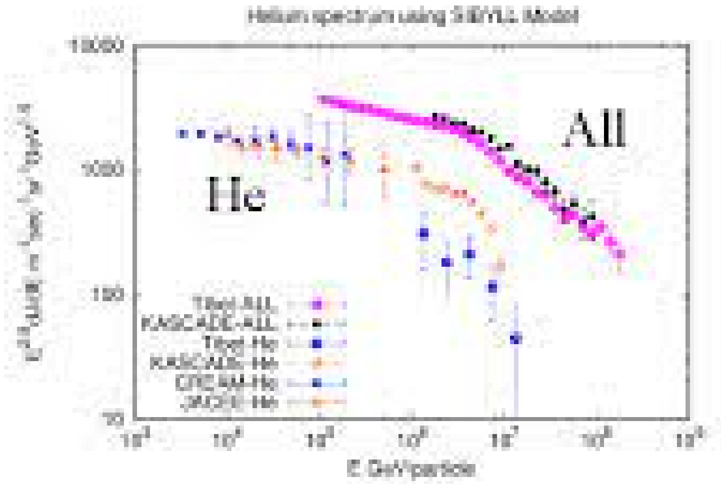

Gamma Ray Astronomy can only be done above the Earth's atmosphere but inside the magnetic field of the Earth is not a problem because gamma rays have no charge. In 1992 NASA launched EGRET observatory



# Cosmic Rays looking at air showers can study the Universe

Charged particles like Protons or Iron nuclei are bent by magnetic fields but very high energy particles can be studied with large air showers on the ground.

# Conclusion

- Space Radiation is very dangerous to living things.
- It can be used to study the Universe.
- We on Earth are well protected by:
  - Earth’s Magnetic Field
  - Earth’s Atmosphere
  - Sun’s Magnetic Field
- Human’s traveling in space have to be protected from Space Radiation
- Going to Mars or the Moon give no or very little protections since Mar’s atmosphere is 1/1000 that of Earth and like our moon has no magnetic field.
- Equipment is easily destroyed by Space Radiation.