Instructional Context for Standard Model of Physics:

Space Weather

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Background

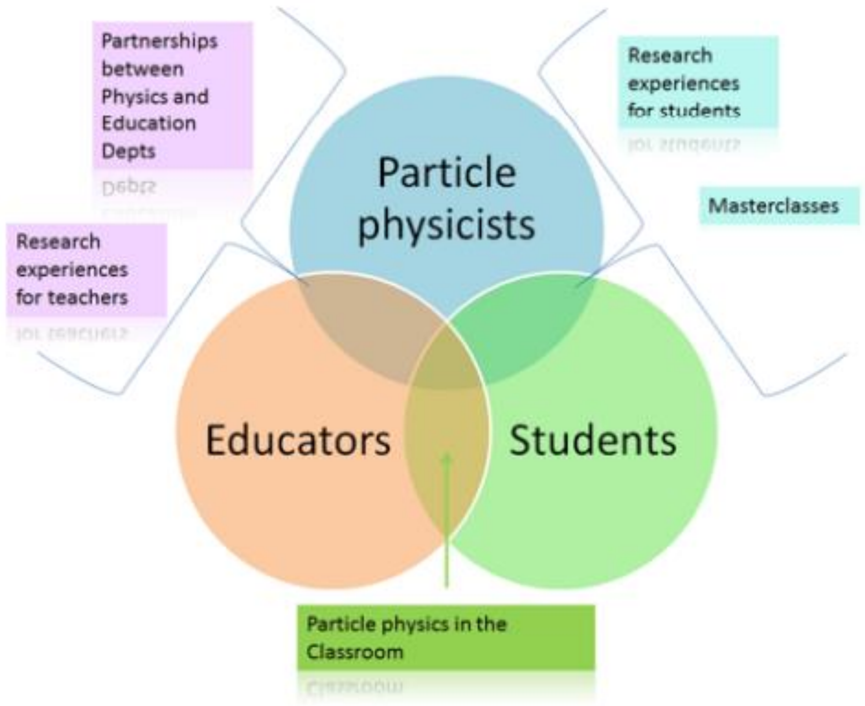
- US Pathways Summer 2016 Internship with the Office of Science (High Energy Physics) of US Dept. of Energy (Germantown MD)
- Literacy disparities in physics of American secondary students in comparison to those of other Western countries.
- AAPT 2018 presentation I gave on the disparity between global literacy and American literacy regarding Standard Model of Particle Physics
- The commonality of particle physics observed from extraterrestrial satellite experiments and terrestrial ATLAS and CMS of Large Hadron Collider experiments contribute to a more comprehensive understanding of LEO operations and of prospective Lunar/ Martian explorations and operations as well as that of matter, including Dark Matter and Dark Energy.
- Presentation Purpose: To provide real-world context of relevancy for curricular instruction of the Standard Model of Physics.

International study documented the conceptions of atomic models held by 1062 in-service high school science teachers from 58 countries. Note 38% teachers vs 90% students perceive atom representation in Bohr or Rutherford models.

	Bohr model	Rutherford model	Probability model	Orbital model	Probability orbit model	Wave model
1) When you think of an atom, what do you see?	**19%**	**19%**	**19%**	**19%**	**14%**	**10%**
2) When your students think of an atom, what do they see?	**52%**	**38%**	3%	3%	3%	1%
3) What is your favourite representation of an atom to use in the classroom?	**52%**	**22%**	6%	7%	7%	6%

From a science education research perspective, the study considered how the particulate nature of matter was introduced in the classroom. Large Hadron Collider (LHC) technology and Higgs boson discovery reached audience levels unprecedented for a particle physics event. The student population should constitute part of the audience.

Question: How can STEM-curricular instruction engage students to better appreciate the societal value of basic research of particle physics?



Space Weather: The most intense forms of space weather - great bursts of electromagnetic energy and particles sometimes stream from the sun. Solar activity currently ramps up toward what is known as solar maximum, something that occurs approximately every 11 years.

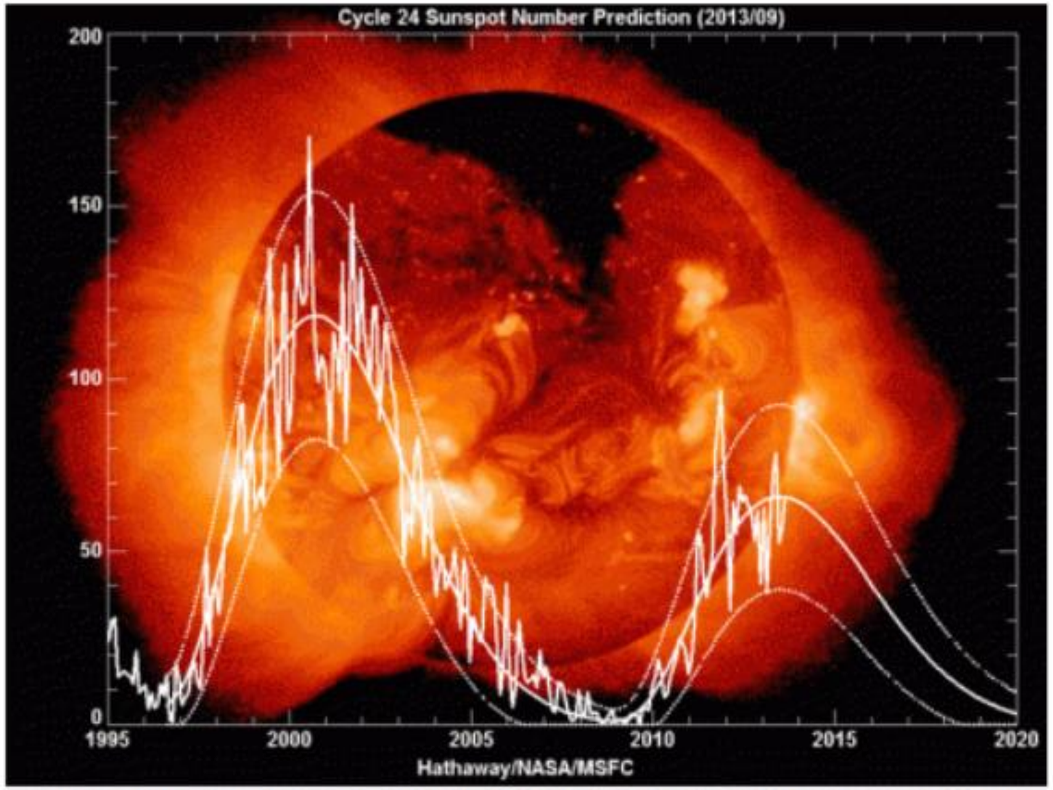


Diagram showing the sunspot number prediction for Sunspot Cycle 24. The peak appears around the summer of 2013.

Naturally occurring space radiation is always with us. It occurs when atoms, ions, or subatomic particles are accelerated to high velocity by processes such as solar particle events (SPEs) and coronal mass ejections (CMEs) from the Sun or stars creating solar energetic particles (SEPs), the solar wind, trapped radiation in magnetic field "belts," and galactic cosmic rays (GCRs) from outside our solar system. Space radiation can take the form of fast-moving atoms, subatomic particles, ions, or high-energy electromagnetic waves.

Solar causes for when space-ground communications are lost.

- The Sun's coronal mass ejections (or CMEs) cause a geomagnetic storm that may disrupt the Earth's magnetosphere to interfere with communications and GPS satellites.
- Highly energetic protons and electrons of solar winds along with CMEs overwhelm protections of spacecraft resiliency and damage their electronics to disrupt communications to and from satellites.

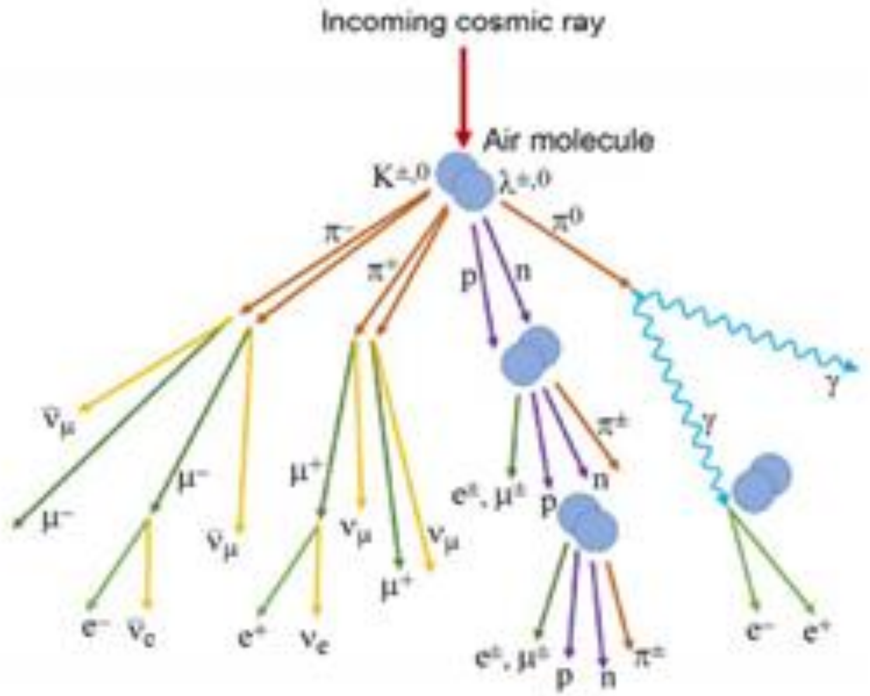
Unpredictable processes and events in the Earth are the consequences of extreme solar radiation.

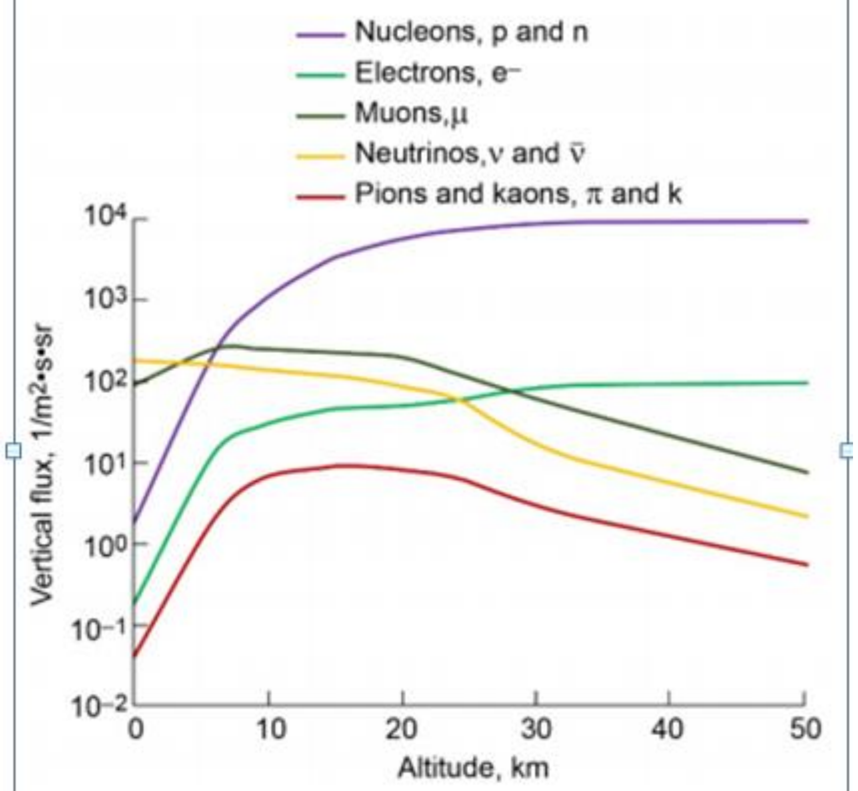
- Natural disasters:

  --earthquakes, forest fires.
- Disrupted propagation of radio signals emitted by satellites:

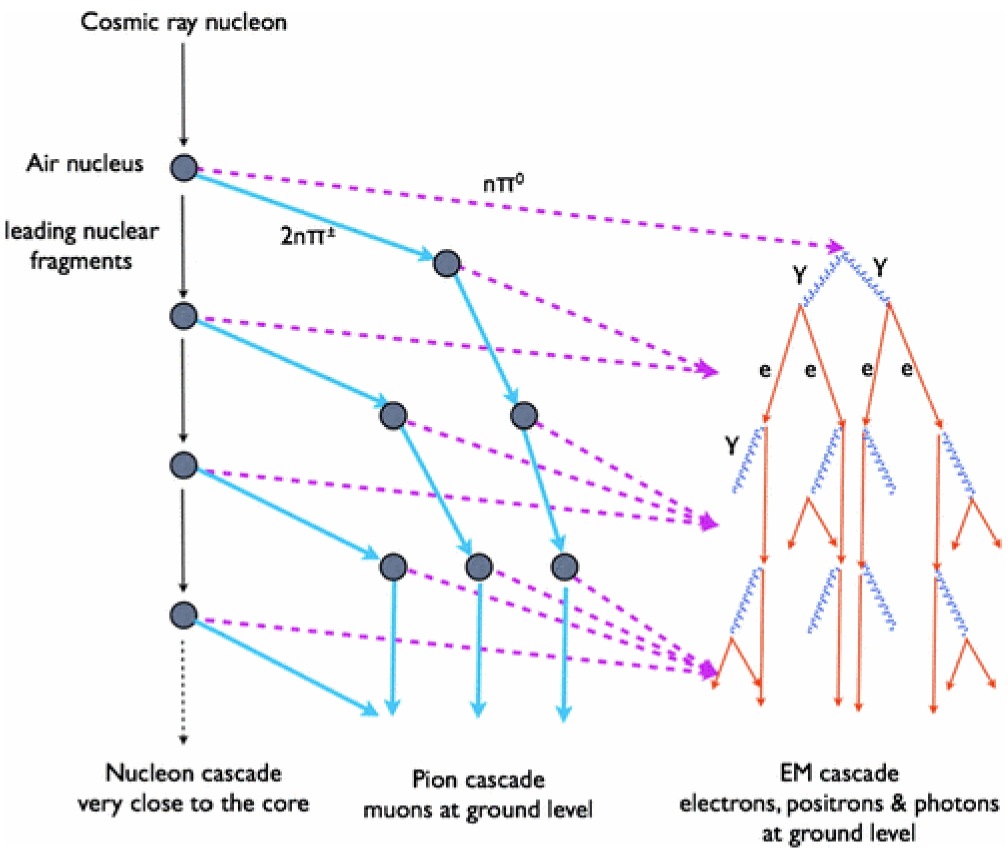
  -- GPS position, telecommunications
- Analyses of historical blackout events in the United States indicate that even short blackouts, which occur several times during a year in the United States, sum up to an annual economic loss between $104B and $164 B.

The form of space radiation with the broadest impact as seen on Earth are the generic "cosmic" rays detected from the ground up to the lower troposphere at elevations less than 5.5 km (18,000 ft). These "rays" are mostly subatomic particles, primarily muons and neutrinos produced by interactions of incoming protons in the air.





Outside a protective atmosphere and magnetic field, there are few obstacles to the passage through space of energetic subatomic particles known as cosmic rays. These particles have energies ranging from about 10^6 eV up to an extreme 10^{20} eV of ultra-high-energy cosmic rays. The peak flux of cosmic rays occurs at energies of about 10^9 eV, with approximately 87% protons, 12% helium nuclei and 1% heavier nuclei. In the high energy range, the flux of electrons is only about 1% of that of protons.Cosmic rays can damage electronic components and pose a health threat to space travelers.



In the 1960s, NASA embarked on empirical studies of solar-sourced structures observed in space: galactic cosmic rays. Peak activity increases approximately every 11 years, and the sun is currently moving towards another solar maximum, likely in 2024.

- Extraterrestrial rays of subatomic particles impair geospace satellite functions of telecommunications, GPS positioning, et c.

  --- NASA history of solar-pointing satellites and geospace satellites

- Satellite imaging and sensor monitoring instruments detection and characterize the particles. National labs of high energy physics experiments artificially produce and also detect and characterize the particles.

  ---ATLAS (A Torridal Large [hadron collider] Apparatus S) at CERN and

  at SLAC (Stanford Linear Accelerator Center)

Geospace is populated by electrically charged particles at very low densities, the motions of which are controlled by the Earth's magnetic field. These plasmas form a medium from which storm-like disturbances powered by the solar wind can drive electrical currents into the Earth's upper atmosphere.

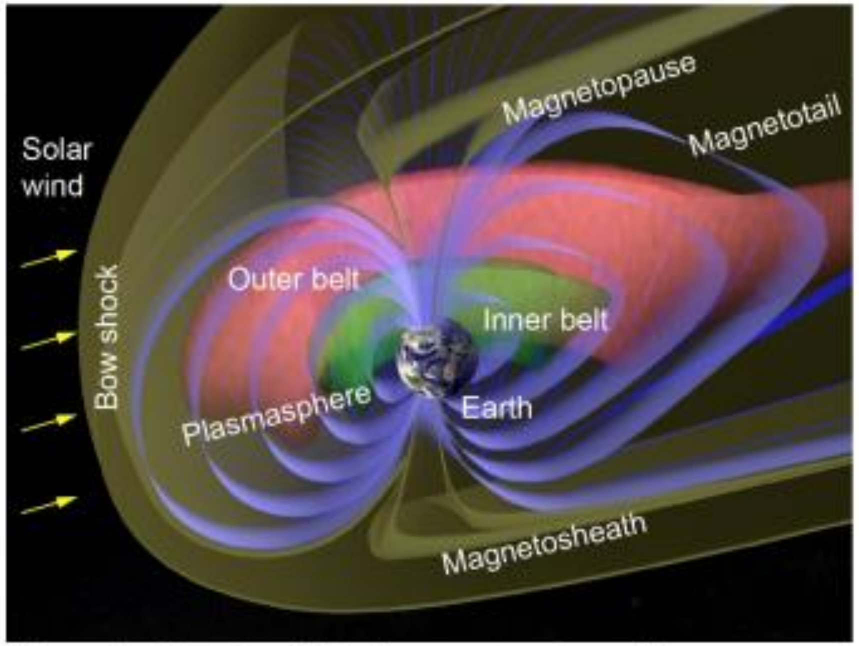


Figure 4.—Structure of Earth magnetosphere with magnetopotentials in blue, inner radiation belt in green, and outer radiation belt in red.

- Geospace is the region of outer space near Earth, including the upper atmosphere and magnetosphere.
- The outer boundary of geospace is the magnetopause, which forms an interface between the Earth's magnetosphere and the solar wind.
- The inner boundary is the ionosphere.
- The variable space-weather conditions of geospace are affected by the behavior of the Sun and the solar wind.

Earth’s magnetic field protects us against the sun’s firehose of energy, but sometimes the sun overpowers the planet’s defenses. When that happens, solar radiation heats the upper atmosphere and charges it with electricity, which is what causes auroras at the northern and southern poles. When coronal mass ejections arrive a day or so later, Earth’s magnetic field changes . CMEs reach Earth in as little as 15 hours and have the potential to damage electrical equipment — from orbiting satellites to ground-based energy grids. Solar storm forecasts are currently based on observations of coronal mass ejections as soon as they leave the Sun's surface, meaning they come with a large degree of uncertainty.

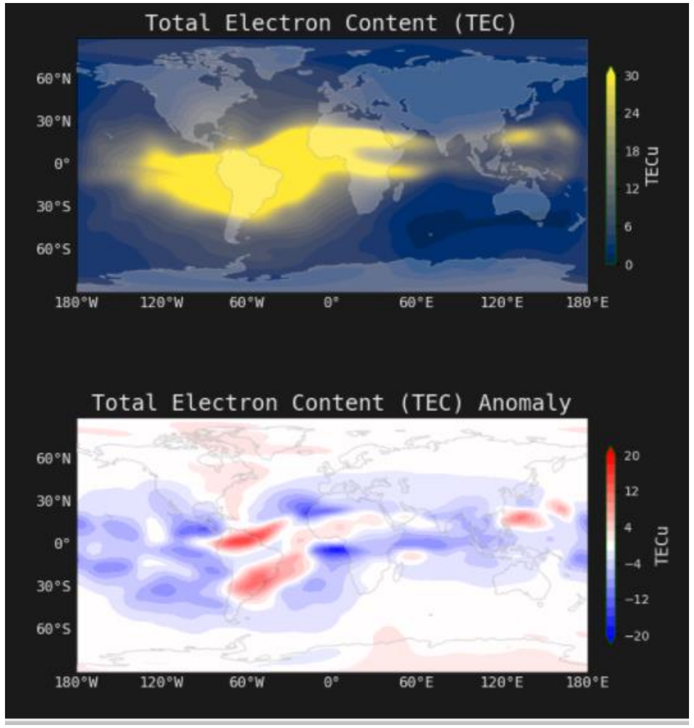
Table 1. Time Sequence of Solar Storm Events[1]

Solar Flares		
	Arrival Time:	Instantaneous[†]
	Effect Duration:	1-2 hours
Solar Proton Event		
	Arrival Time:	15 minute to a few hours
	Effect Duration:	Days
Coronal Mass Ejection		
	Arrival time:	2 or 4 days
	Effect Duration:	Days

Constellations of satellite-containing radio beacons called Coherent Electromagnetic Radio Tomography (CERTO)measure ionospheric total electron content and radio scintillations.

NOAA. The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere. The propagation of radio waves is affected by the ionosphere.

Global Ionosphere: The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. Radio waves are affected by the presence of electrons.



The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere.

- The first of its kind coupled Whole Atmosphere Model and Ionosphere Plasmasphere Electrodynamics Model (WAM-IPE Model) is now part of the Space Weather Prediction Center's (SWPC) suite of forecast tools and has expanded space weather forecasts

- The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver. Radio waves are affected by the presence of electrons. The more electrons in the path of the radio wave, the more the radio signal will be affected. For ground to satellite communication and satellite navigation, TEC is a good parameter to monitor for possible space weather impacts.

Space Weather
Space studies of imaging and measurement have been managed by NASA and other government space agencies since the 1960s. Space weather is a real phenomenon having not only implications for the satellites travelling but also the satellite applications that benefit terrestrial operations and commerce.

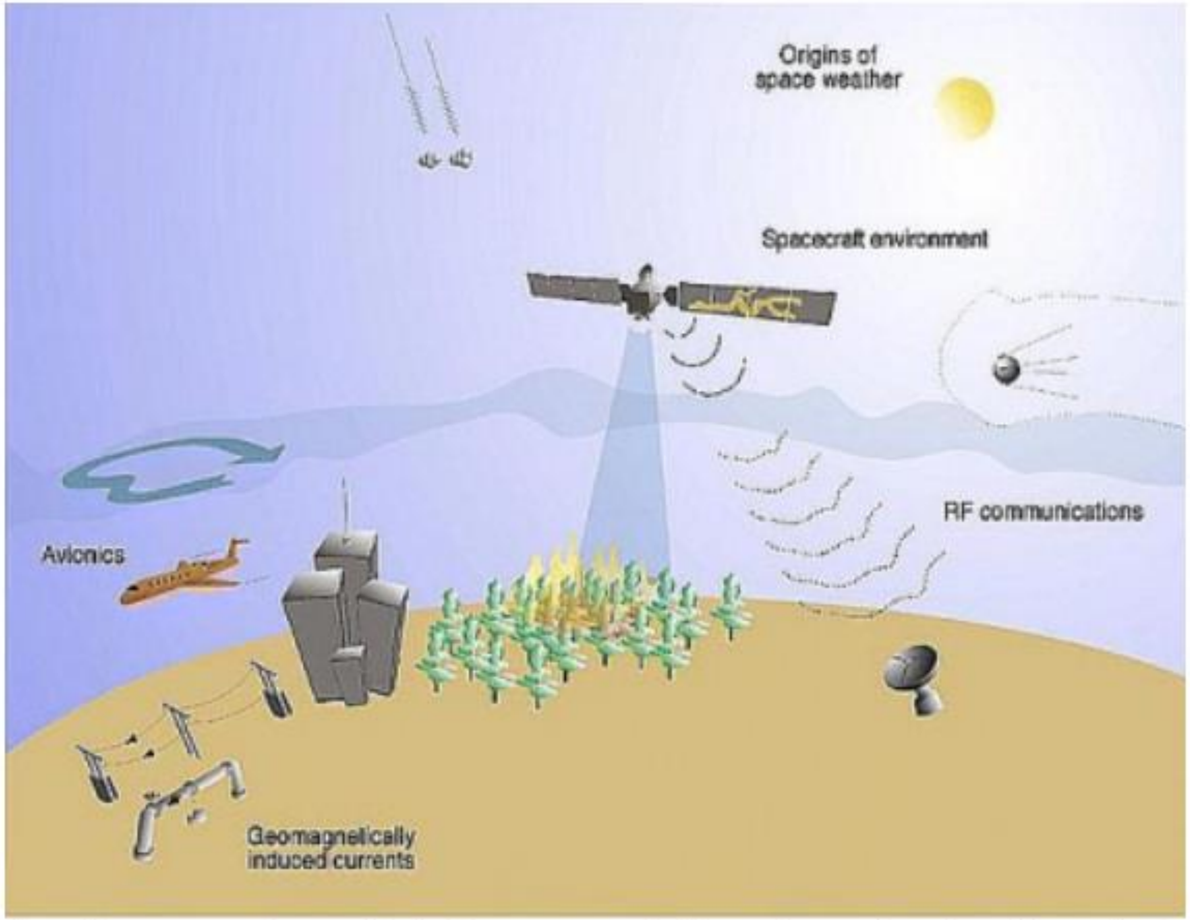


Figure: How space weather may disturb risk management, in this case the operation of a satellite monitoring a forest fire [*Pirjola et al.*, 2003a]

Naturally occurring space radiation is always with us. It occurs when atoms, ions, or subatomic particles are accelerated to high velocity by processes such as solar particle events (SPEs) and coronal mass ejections (CMEs) from the Sun or stars creating solar energetic particles (SEPs), the solar wind, trapped radiation in magnetic field "belts," and galactic cosmic rays (GCRs) from outside our solar system (SEPs), the solar wind, trapped radiation in magnetic field "belts," and galactic cosmic rays (GCRs) from outside our solar system.

Pioneer 5	**Pioneer 6**	**Pioneer 7 (solar-cell and battery-powered satellite)**	**Pioneer 8 (solar-cell and battery-powered satellite)**	**Pioneer 9 (solar-cell and battery-powered satellite)**
4/1960-6/1960	12/1965-2000	08/1966-1995	12/1967-2001	11/1968-05/1983
Measured magnetic field phenomena, solar flare particles, and ionization in the interplanetary region.	Experiments to study positive ions and electrons in the solar wind, the interplanetary electron density (radio propagation experiment), solar and galactic cosmic rays, and the interplanetary magnetic field.	Experiments to study positive ions and electrons in the solar wind, the interplanetary electron density (radio propagation experiment), solar and galactic cosmic rays, and the interplanetary magnetic field.	Experiments to study the positive ions and electrons in the solar wind, the interplanetary electron density (radio propagation experiment), solar and galactic cosmic rays, the interplanetary magnetic field, cosmic dust, and electric fields.	Experiments to study the positive ions and electrons in the solar wind, the interplanetary electron density (radio propagation experiment), solar and galactic cosmic rays, the interplanetary magnetic field, cosmic dust, and electric fields.

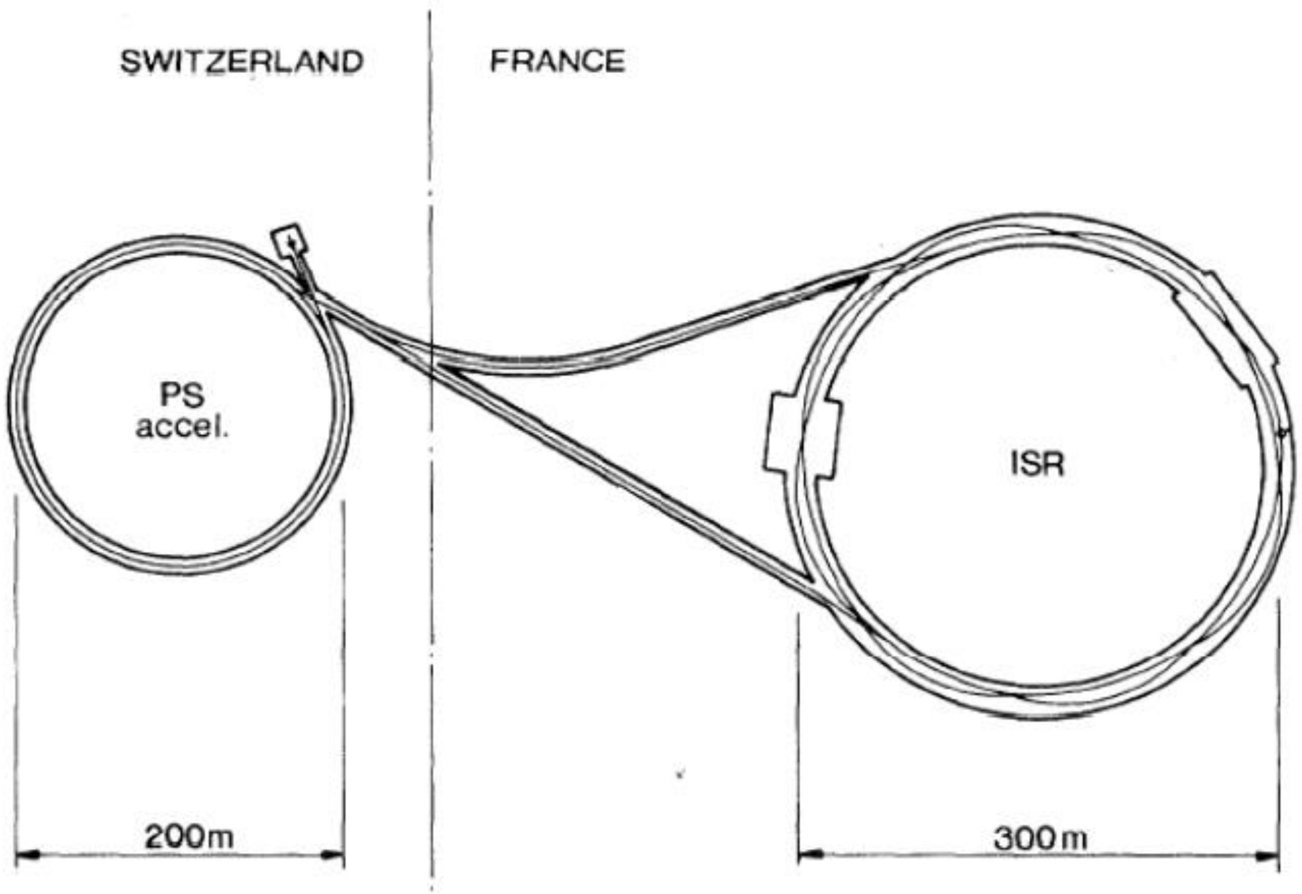
The STEREO solar probe mission consists of two nearly identical spacecraft in heliocentric orbits designed to investigate the three-dimensional structure of the Sun's corona, the origin of coronal mass ejections (CME's), and the dynamic coupling between CME's and the Earth's environment.

Each spacecraft was equipped with four instrument suites: In-situ instruments, measuring data from the solar wind that passed by the spacecraft, included:

- Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI) - imaging
- In situ Measurements of Particles and CME Transients (IMPACT) – particle detectors
- Plasma and Suprathermal Ion Composition (PLASTIC) – particle detectors
- STEREO WAVES (SWAVES) – electric fields

Helios-A, Helios-B (a pair of deep space probes byGermany/USA)	Wind (together with Geotail, Polar, SOHO, and Cluster projects, constitute the International Solar Terrestrial Physics (ISTP) program)	SOHO	ACE	STEREO A The Solar-Terrestrial Relations Observatory (STEREO) mission includes two spacecraft in heliocentric orbit around the Sun	STEREO B
11/1974 -82	11/1994-present	05/1996-present		12/2006-present(A)	12/2006-12/2018 (B)
Mission was to make pioneering measurements of the interplanetary medium from the vicinity of the earth's orbit to 0.3 AU with electric and magnetic wave experiments, which covered various bands in the frequency range 6 Hz to 3 MHz; charged-particle experiments, which covered various energy ranges starting with solar wind thermal energies and extending to 1 GeV; a zodiacal-light experiment; and a micrometeoroid experiment.	Wind spacecraft is to measure the incoming solar wind, magnetic fields and particles, although early on it will also observe the Earth's foreshock region. Wind measures the incoming solar wind, magnetic fields and particles continuously and provides an approximately one-hour warning to the other ISTP spacecraft of changes in the solar wind.	Solar and Heliospheric Observatory mission (SOHO) to investigate: (1) the physical processes that form and heat the Sun's corona, maintain it and give rise to the expanding solar wind; and, (2) the interior structure of the Sun. Discovered of more than 50 sun-grazing comets;	Advanced Composition Explorer (ACE) is to collect observations of particles of solar, interplanetary, interstellar, and galactic origins, spanning the energy range from that of KeV solar wind ions to galactic cosmic ray nuclei up to 600 MeV/nucleon.	Heliocentric orbit around the Sun for remote 3-D imaging and radio observations of coronal mass ejections (CMEs). These events are responsible for large solar energetic particle events in interplanetary space and are the primary cause of major geomagnetic storms at Earth. Investigation for in-situ sampling the 3-D distribution and 4. plasma (characteristics of solar energetic particles and the interplanetary magnetic field, and the PLAsma and SupraThermal Ion and Composition (PLASTIC) experiment to measure elemental and charge composition of ambient and CME plasma ions	The two spacecraft are launched to drift slowly away from the Earth in opposite directions at about 10 degrees per year for the lagging spacecraft and 20 degrees per year for the leading one.

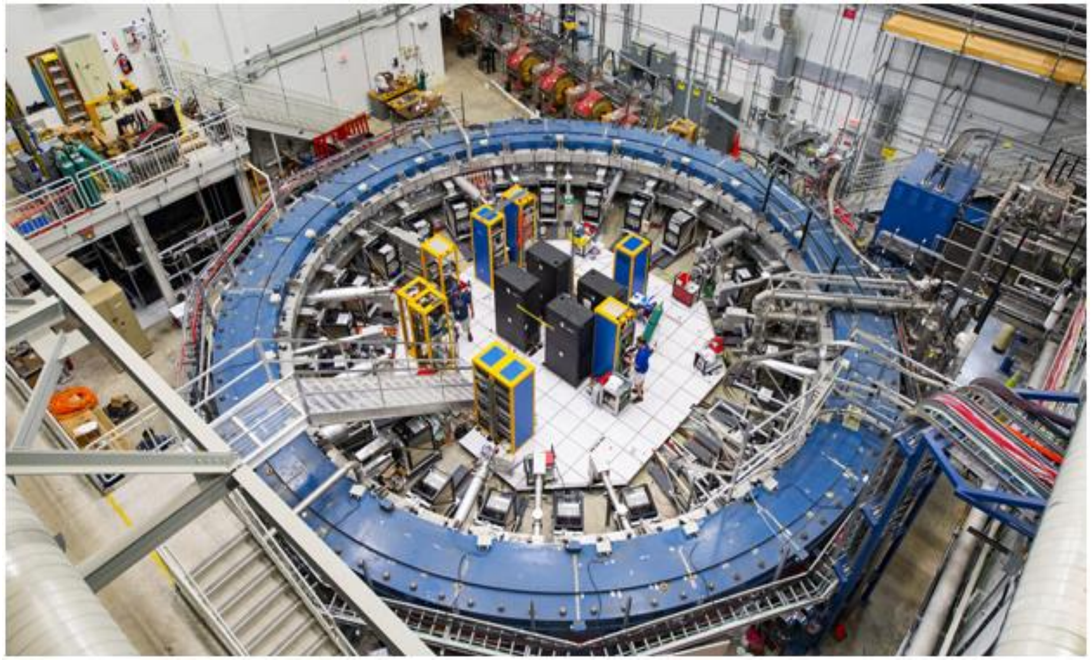
Proton-Proton Beam Collision: In 1969, physicists at CERN studied the idea of building two intersecting storage rings that could be fed by the existing 28 GeV proton synchrotron (CERN-PS). Construction took place on the new Intersecting Storage Rings (ISR) between 1966 and 1971.



LHC experiments have relocated to CERN and the thrust of Intensity Frontier at Fermi National Lab (FNAL) and other labs may now focus on neutrino science. Neutrinos are important as the starting material for discovery in both SM and BSM of particle physics. Although notably produced in nuclear reactions, particle accelerators whereby the collision of protons with a fixed target produce neutrino beams.

The Tevatron, a synchrotron collider type particle accelerator at Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois, USA.

The LHC can create almost a billion proton-proton collisions per second. In March 2010, it collided protons at a center-of-mass energy of 7 trillion electron volts, 3.5 TeV per beam. It is eventually expected to reach a center-of-mass energy of 14 TeV, seven times higher than Fermilab's Tevatron.

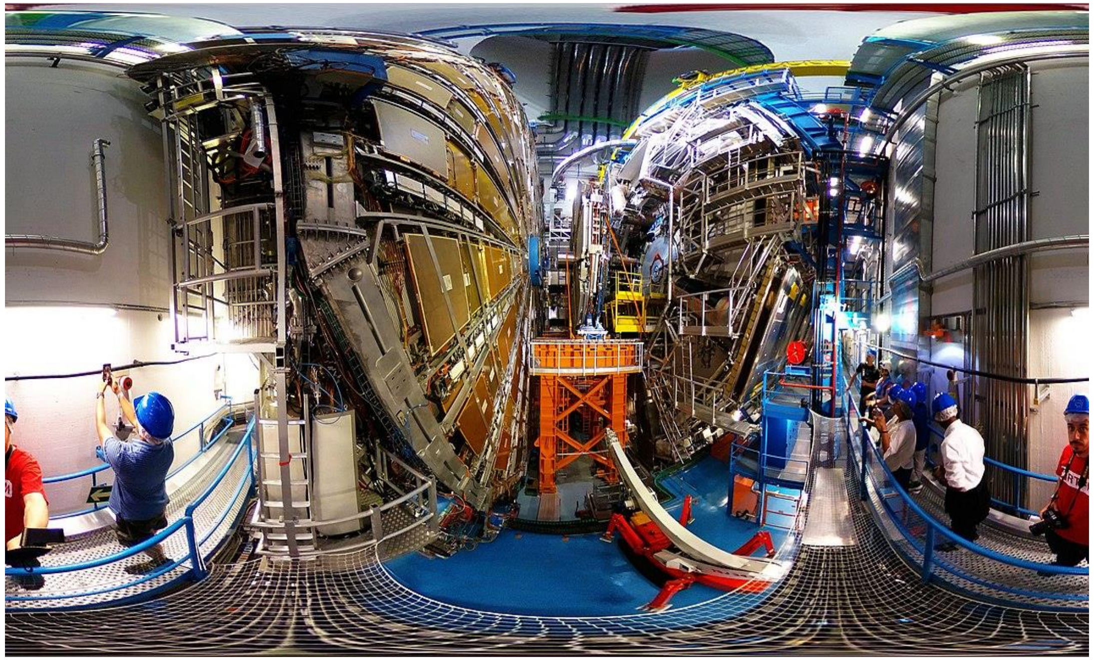


ATLAS (A Toroidal LHC ApparatuS) Experiment: A collaboration involving roughly 3,000 physicists from 183 institutions in 38 countries to produce the first proton–proton collisions occurred at the LHC and were recorded by ATLAS, at a relatively low injection energy of 450 GeV per beam in 2009 but 6,500 GeV per beam in 2014.

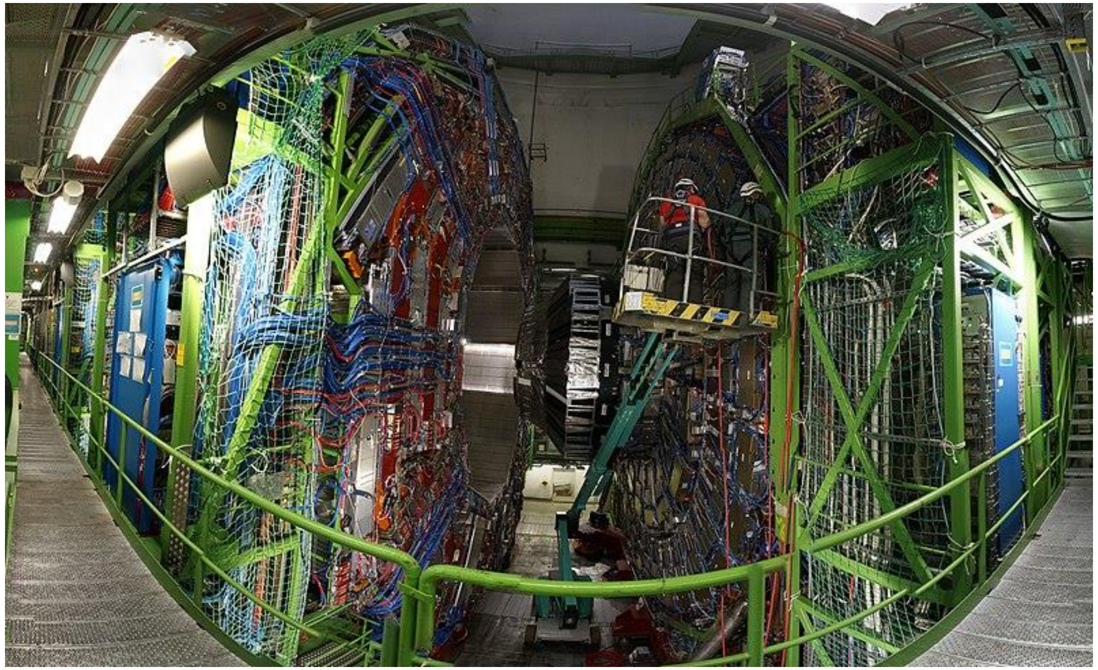
- While the Standard Model predicts that quarks, electrons, and neutrinos should exist, it does not explain why the masses of these particles differ by orders of magnitude.
- On July 4, 2012, ATLAS — together with CMS, its sister experiment at the LHC — reported evidence for the existence of a particle consistent with the Higgs boson with a mass around 133 times the proton mass. This new "Higgs-like" particle was detected by its decay into two photons and its decay to four leptons.
- The Standard Model of particle physics describes all known particles and their interactions. It includes three flavors of leptons: the familiar electron and two heavier cousins known as muons and tau particles.
- Some muons come directly from the decay of W bosons; and some come from a tau lepton (with a different lifetime) itself decaying into a muon plus two invisible particles called neutrinos.
- The new result gives the ratio of a W boson decaying to a tau or muon to be very close to 1. Such a measurement signifies that the decay to each lepton occurs with equal frequency implying that Ws couple with each lepton with equal strength—just as the Standard Model predicts.

Large Hadron Collider: Scientists analyze data per LHC collisions of protons measured in ATLAS/CMS detectors. Heavy ion collisions have the ability to create quark gluon plasma.

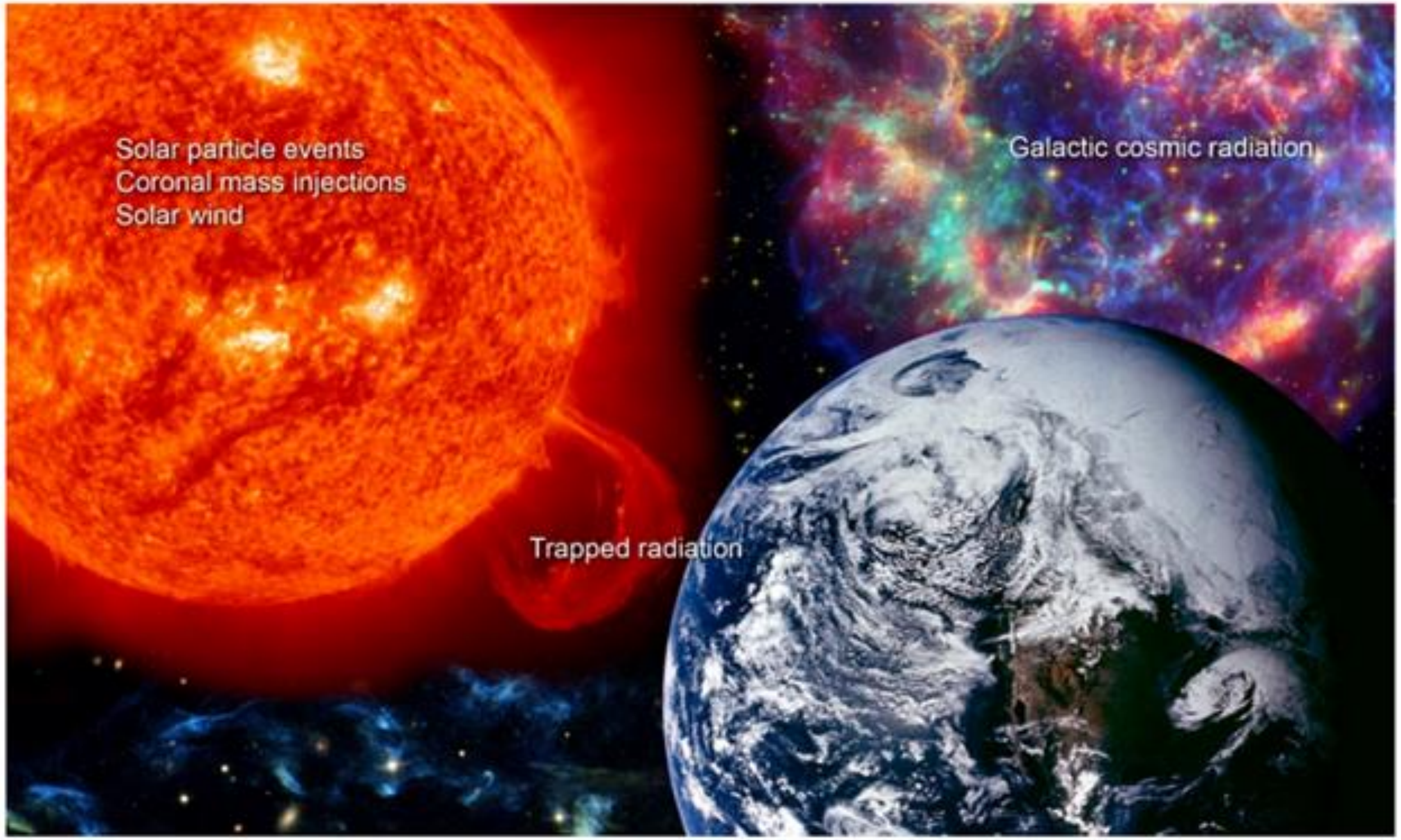
ATLAS: Six different detecting subsystems arranged in layers around the collision point record the paths, momentum, and energy of the particles, allowing them to be individually identified. A huge magnet system bends the paths of charged particles so that their momenta can be measured.



The **Compact Muon Solenoid** (**CMS**) **experiment:** The goal of CMS experiment is to investigate a wide range of physics, including the search for the Higgs boson, extra dimensions, and particles that could make up dark matter.

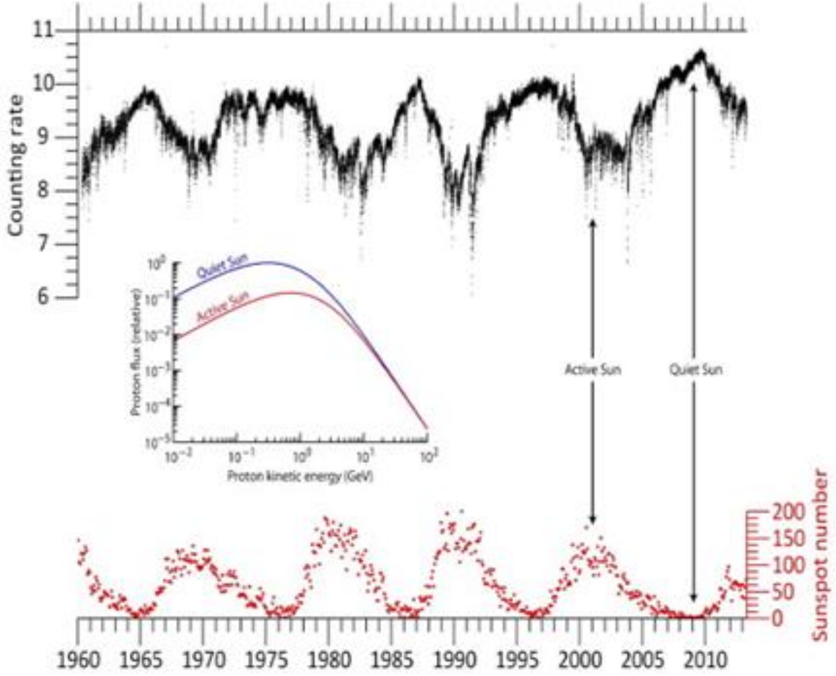


Anywhere that matter exists, there is a potential to have energetic charged and/or neutral particles. Anywhere changing electromagnetic fields exist, or electromagnetic field exist, or electromagnetic fields interacting with moving charges, the potential for both particle and electromagnetic-wave radiation exists.



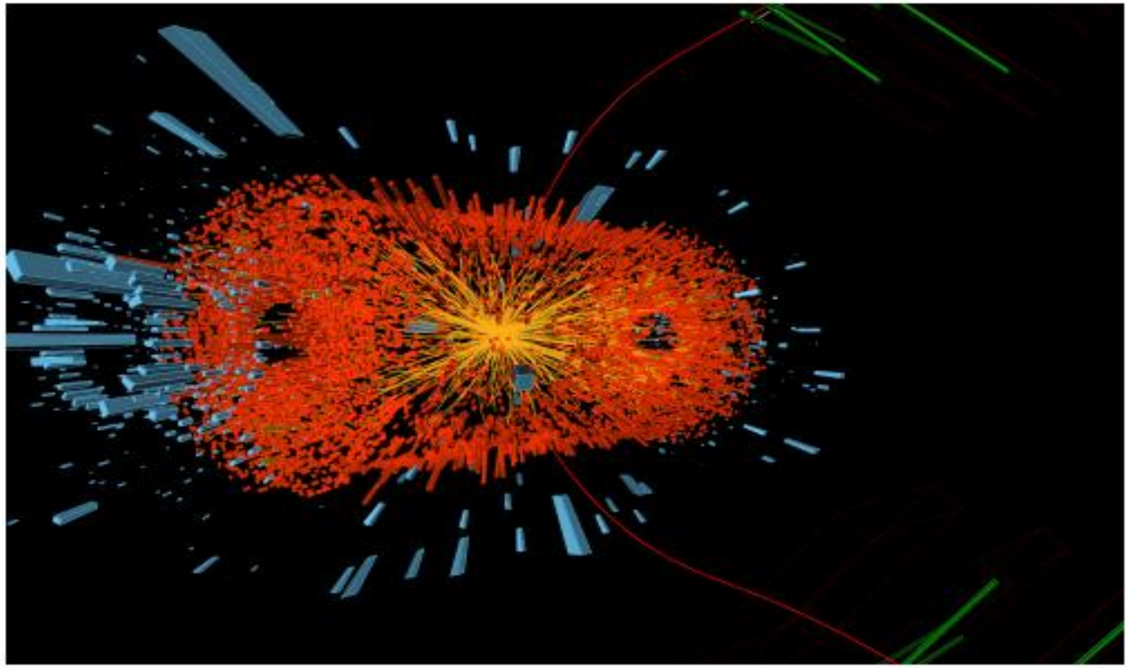
Galactic cosmic rays (GCRs) mainly consist of charged particles. The nuclear component consists of 87% protons, 12% α-particles, and 1% heavier nuclei.

GCRs interact with the solar magnetic field that is carried by the solar wind. The amount of GCRs reaching the Earth's atmosphere depends on the strength of the magnetic field and the energy of the GCR particles. Lower energy GCR particles get preferentially deflected with higher solar shielding. Low solar activity implies less solar magnetic shielding, more cosmic rays reaching the Earth, and higher production rates of cosmogenic radionuclides.



In 2011, CMS presented early evidence that Upsilon (Y) particles produced in lead-lead collisions "melt"

A quark-gluon plasma (QGP) can be defined as a phase of quantum chromodynamics (QCD) which exists at extremely high temperature and/or density. This phase consists of (almost) free quarks and gluons, which are several of the basic building blocks of matter. The universe is composed of the fundamental particles of the standard model of physics (i.e. quarks, gluons, electrons, photons, neutrinos, W and Z particles, and Higgs bosons with their respective quantum fields) as well as gravitational fields and waves, which are not included in the standard model.

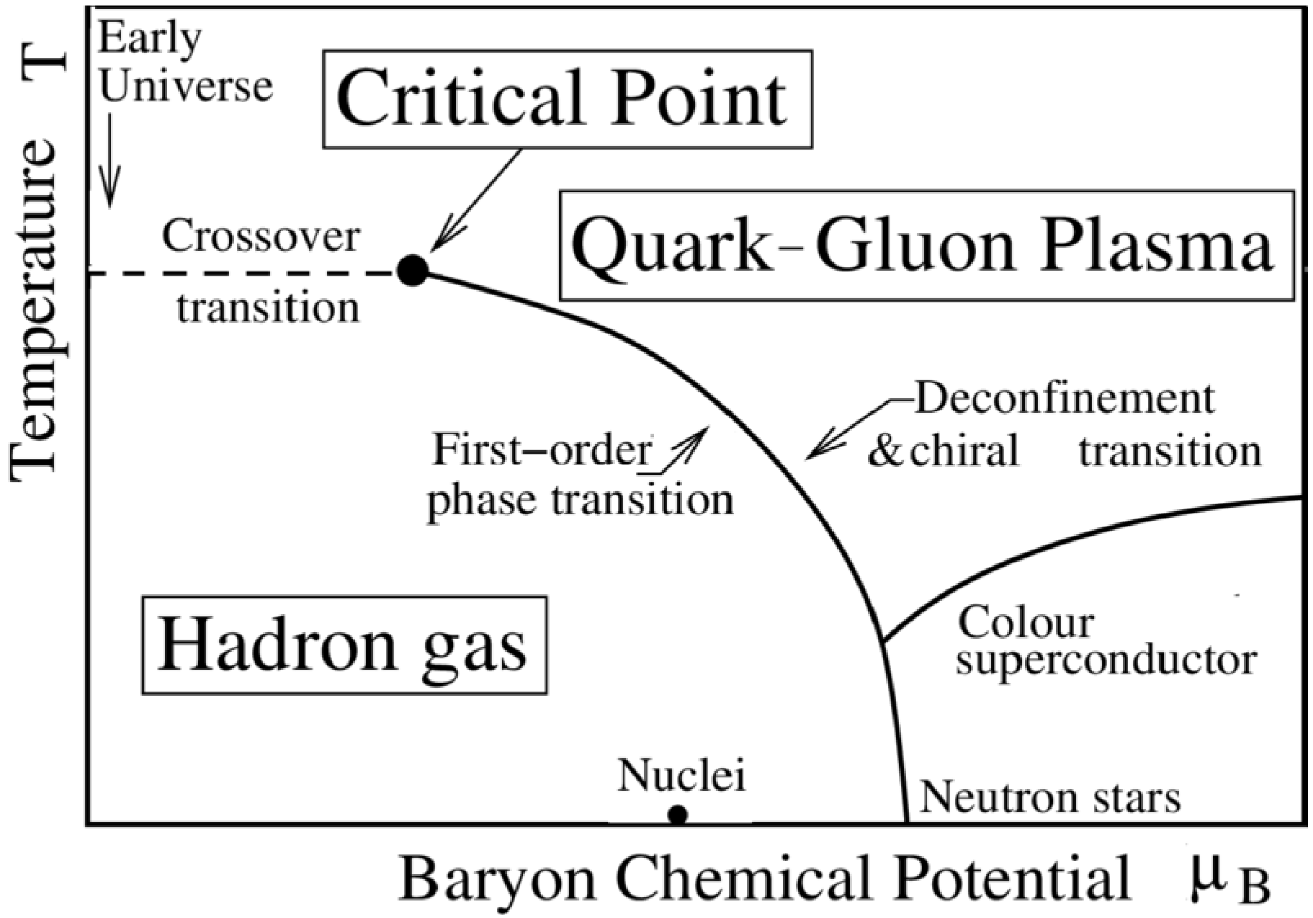


Candidate Y decay to two muons observed in a lead-lead collision at the LHC.

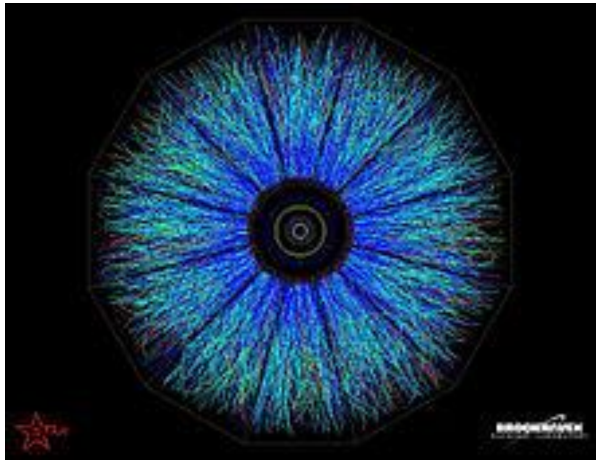
Quark Gluon Plasma:

- The universe is composed of the fundamental particles of the standard model of physics (i.e. quarks, gluons, electrons, photons, neutrinos, W and Z particles, and Higgs bosons with their respective quantum fields) as well as gravitational fields and waves, which are not included in the standard model. All are moving through space-time, some of which combine to form atoms and molecules and states of matter such as gases, liquids, plasmas and Bose-Einstein condensates.
- A quark-gluon plasma (QGP) can be defined as a phase of quantum chromodynamics (QCD) which exists at extremely high temperature and/or density. This phase consists of (almost) free quarks and gluons, which are several of the basic building blocks of matter. Recent analyses from the Relativistic Heavy Ion Collider (RHIC), a 2.4-mile-circumference (atom smasher) at the U.S. Department of Energy’s (DOE) Brookhaven National Laboratory, establish that collisions of gold ions traveling at nearly the speed of light have created matter at a temperature of about 4 trillion degrees Celsius—the hottest temperature ever reached in a laboratory, about 250,000 times hotter than the center of the Sun.
- These new temperature measurements, combined with other observations analyzed over nine years of operations by RHIC’s four experimental collaborations—BRAHMS, PHENIX, PHOBOS, and STAR—indicate that RHIC’s gold-gold collisions produce a freely flowing liquid composed of quarks and gluons. Such a substance, often referred to as quark-gluon plasma, or QGP, filled the universe a few microseconds after it came into existence 13.7 billion years ago.
- In black holes, baryonic matter is converted into quark-gluon plasma. A black hole consists of a small core (“drop” from QGP) and a large gravitational radius. In small black holes, the radius of the core of the quark-gluon plasma will be equal to the gravitational radius. In large black holes, the radius of the QGP core will be much less than the gravitational radius.

Large Hadron Collider: Scientists analyze data per LHC collisions of protons measured in ATLAS/CMS detectors. Heavy ion collisions have the ability to create quark gluon plasma.



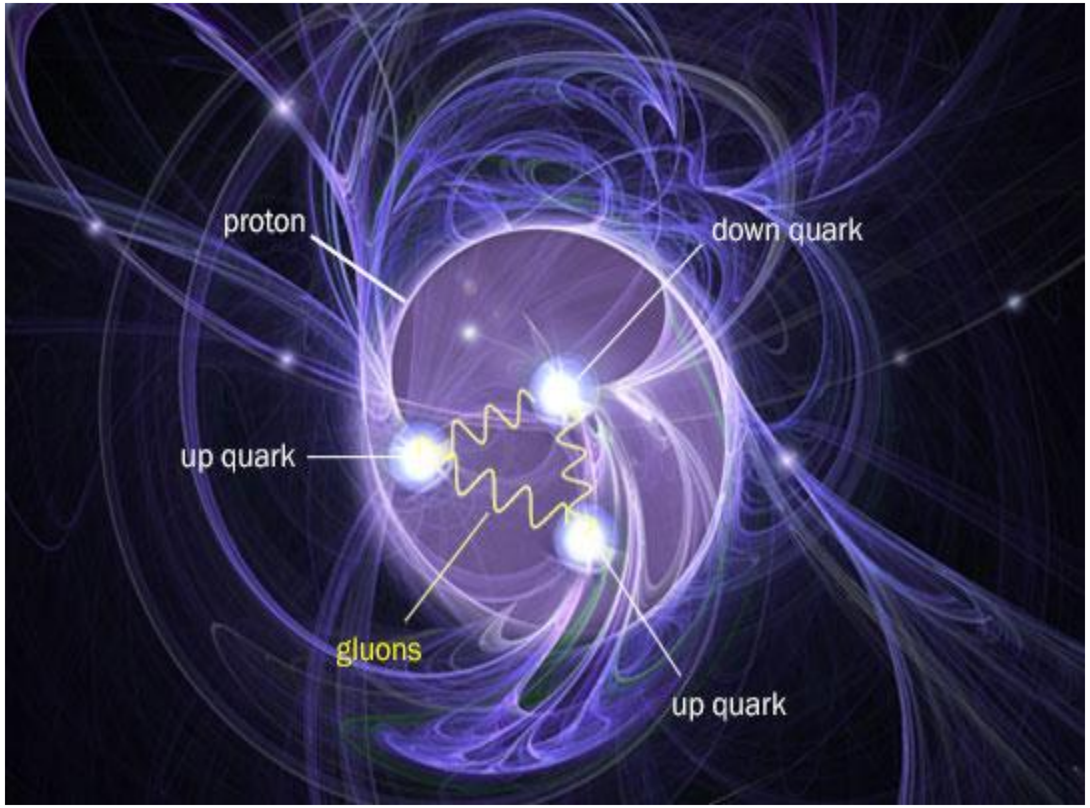
Relativistic Heavy Ion Collider:
The discovery of a new extreme state of matter a “perfect” quark-gluon liquid



- In 2010, RHIC physicists published results of temperature measurements from earlier experiments which concluded that temperatures in excess of 345 MeV (4 terakelvins or 7 trillion degrees Fahrenheit) had been achieved in gold ion collisions, and that these collision temperatures resulted in the breakdown of "normal matter" and the creation of a liquid-like quark–gluon plasma.

- For the experimental objective of creating and studying the quark–gluon plasma, RHIC has the unique ability to provide baseline measurements for itself. This consists of the both lower energy and also lower mass number projectile combinations that do not result in the density of 200 GeV Au + Au collisions, like the p + p and d + Au collisions of the earlier runs.

On the Characterization of Quark-Gluon:
Call for Collaboration Proposals for Detectors at the Electron-Ion Collider



- Deep within the protons and neutrons of an atomic nucleus, powerful and poorly understood gluons flit in and out of existence. These fundamental particles carry the strong nuclear force, which acts as a kind of subatomic "glue," binding quarks together.
- Quarks are nearly massless, and gluons are massless, but their interactions are sufficiently strong to generate the energy that gives mass to matter through Einstein's iconic equation: $E=mc^{2}$. . Quarks and gluons, unlike electrons or photons of light, can never be observed directly. But they do carry a form of charge.
- The nature of the quantum vacuum is inextricably tied up with the strong force generated by quark and gluon charges. But exactly how color-charged quarks and gluons form colorless protons and neutrons—and how tiny residuals of color forces bind those protons and neutrons together to form nuclei—remain among the most profound mysteries in science. The unique and powerful tools of the Electron-Ion Collider will cast fresh light on these questions.

Conclusions

- Space Weather: Incorporation of real-world contextualization of theory and experiment operations in developing the Standard Model of Physics and Beyond.
- Space Weather: Space radiation, solar flares, CMEs, space electromagnetic fields, quark-gluon plasma, trapped subatomic particles therein.
- Space Weather: Solar-based causes of natural disasters and satellite applications (ie GPS, telecommunications, electric [power grids)
- Particle Physics Research: Large Hadron Collider/ATLAS and CMS Detectors (CERN)
- Particle Physics Research: Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC)