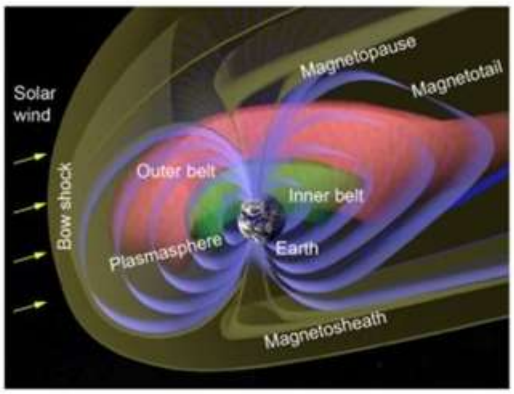
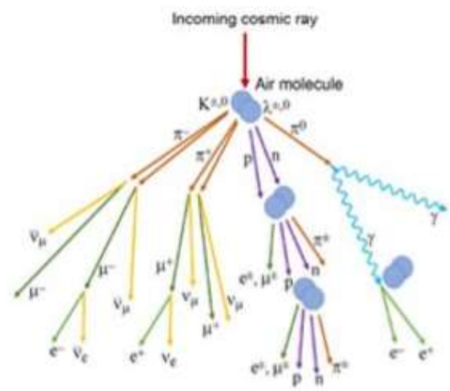
STEM—Teaching Particle Physics in Space Weather Studies



Structure of Earth magnetosphere with magneto-potentials in blue, inner radiation belt in green, and outer radiation belt in red.



Mechanisms of primary components of atmospheric cosmic rays (based in part on Bowersox (2011)

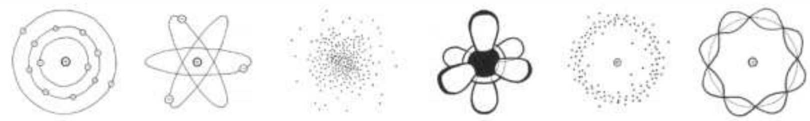
Background

During my US Pathways Summer 2016 Internship with the Office of Science (High Energy Physics) of US Dept. of Energy (Germantown MD), I evaluated the US workforce readiness for future US particle physics projects for further research of the Standard Model of Physics and Beyond. One of the findings showed literacy disparities in physics of American secondary students in comparison to those of other Western countries. This paper expands on an AAPT 2018 presentation I gave on the disparity between global literacy and American literacy regarding Standard Model of Particle Physics. The model described subatomic particles and the interactions with each other. A proactive, coordinated effort from the entire U.S. particle physics community reinforced the view expressed in the 2013 European Strategy Report that outreach and communication in particle physics should be recognized as a central component of the scientific activity. Since 2018, my role has transitioned to Editor-in-Chief, Journal of Space Operations & Communicator and Chair, AAIA's Space Operation & Support Technical Committee. And, the extraterrestrial empirical studies of satellite space weather experiments have compositionally revealed the same subatomic particles described in the Standard Model. 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.

Introduction

In an international study that documented the conceptions of atomic models held by 1062 in-service high school science teachers from 58 countries, teachers' conceptions were investigated by analyzing their drawings of atomic models describing the subatomic architecture of matter. The results showed that the teachers' conceptions of atomic models are almost evenly distributed over six different atomic models: the Bohr model, the Rutherford model, the probability model, the orbital model, the probability orbit model, and the wave model. The majority of teachers preferred using historical atomic models over modern atomic models in the classroom. However, the findings also highlighted that the use of modern atomic models in the classroom was positively correlated with growing teaching experience [1]

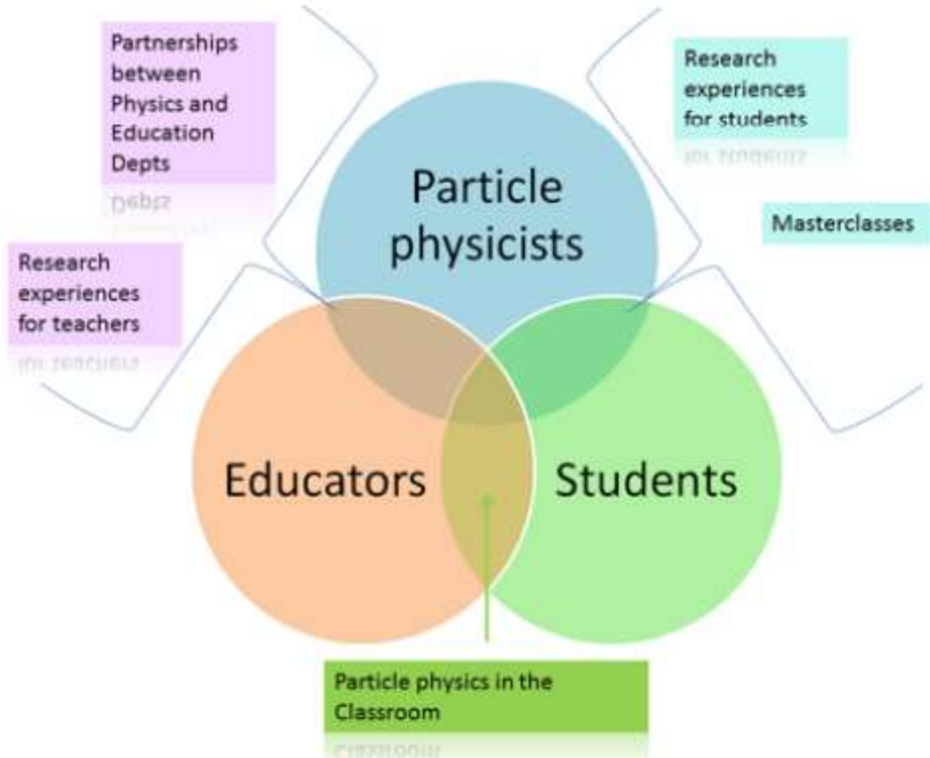
Table 1. Overview of the frequencies of teachers' responses to the three questions of the questionnaire.



	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%

However, what was lacking in the teaching of the models was how they were predicted and described from elaborate experimentation and theoretical assumptions. The saga of the Large Hadron Collider (LHC) and Higgs boson discovery reached audience levels unprecedented for a particle physics event. From a science education research perspective, the study considered how the particulate nature of matter was introduced in the classroom [2]. From a science teacher education perspective, the fact that teachers' conceptions significantly influence teachers' classroom practice highlighted the need for high-quality teacher education and ongoing professional development of real-world studies of current particle physics experiments. This supports the previously documented notion that focusing on students' domain specific processes of learning and understanding was listed among the key features of effective professional development programs [3]. International Masterclass students interact with particle physicists. In the same way as in the arts, the students not only learn about the underlying physics but also about how to understand the behavior of the experimental instruments and how to get the most out of them. Since 2011, the instruments have become the four main detectors—ALICE, ATLAS, CMS, and LHCb—at CERN's Large Hadron Collider (LHC). From their beginning as a local activity in the United Kingdom in the late 1990s to International Masterclasses today, masterclasses have evolved and grown [4].

An important resource for a healthy particle physics community is a talented and diverse workforce. Whether a student's career path leads them to graduate school and research or into other STEM-related fields, particle physics provides an excellent training ground. This engagement leads to better appreciation of the societal value of basic research, gaining advocates for a physics career. Many individuals, groups and institutions in the U.S. particle physics community reach out to members of the public, decision makers, teachers, and students through a wide variety of activities.



Workshops around the world train science teachers to incorporate particle physics into their classrooms. Particle physics makes an appearance in the curriculum for the International Baccalaureate, a program recognized as a qualification for entry into higher education by many universities around the world. Common conservation-of-momentum problem may be described as the transformation of a top quark and top antiquark into other fundamental particles. To teach conservation of momentum, suggested is to use real data from the discovery of the top quark (https://resources.perimeterinstitute.ca/collections/particle- https://www.symmetrymagazine.org/article/high-school-teachers-meet-particle-physics/. Workshops help other teachers bring particle physics into their classrooms. Each year, about 40 or 50 teachers from Canada and other countries attend a weeklong EinsteinPlus (http://www.perimeterinstitute.ca/outreach/artsand-culture/einsteinplus) workshop, participating in a variety of collaborative activities meant to teach them about modern physics. The canvas for students in International Masterclasses is a set of event displays showing authentic data from actual particle physics experiments. To analyze these events, students interact with particle physicists, the experts in describing substuctural composition of the atom. On the other hand, in the realm of space exploration and discovery, satellite images have discerned both structures and processes inherent within the space extraterrestrial environment.

1. 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. Solar particles of the natural space environment interact with magnetic field near earth to impact radio communications, GPS signals, and utility grids on the ground. Telecommunications of data indicating global views from remote-sensing observations in the Earth-Sun system complement land-based weather radars and surface observing systems to forecast the weather. NASA studies have explored 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 of which many researchers correlate to natural disasters, including earthquakes, forest fires, tropical depressions. Additionally, extreme solar radiation can significantly change the propagation of radio signals emitted by satellites or devices located on the ground (including blackout) with consequences in many remote applications (positioning, 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.

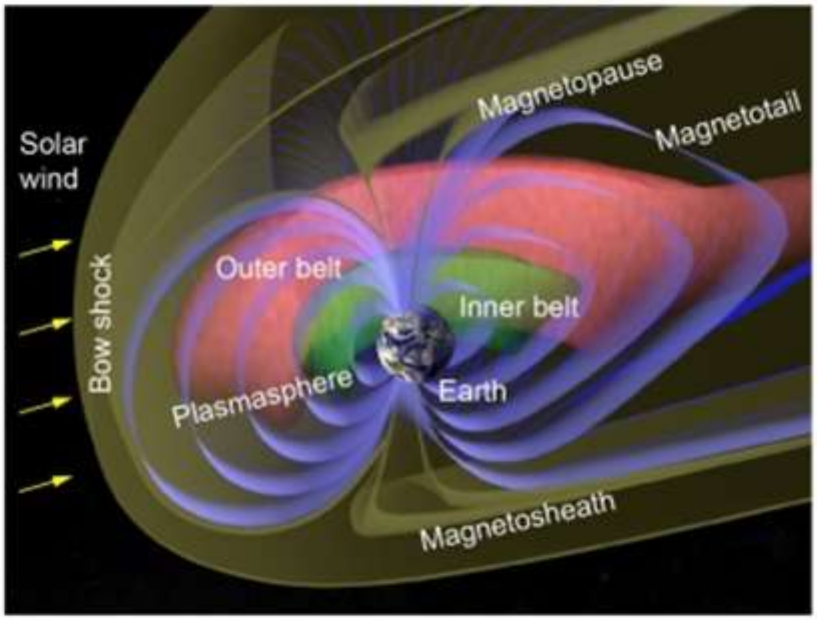


Figure. Structure of Earth magnetosphere with magnetopotentials in blue, inner radiation belt in green, and outer radiation belt in red.

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. Anywhere that matter exists, there is a potential to have energetic charged and/or neutral particles. Anywhere changing electromagnetic fields exist, or electromagnetic fields interacting with moving charges, the potential for both particle and electromagnetic-wave radiation exists [5].

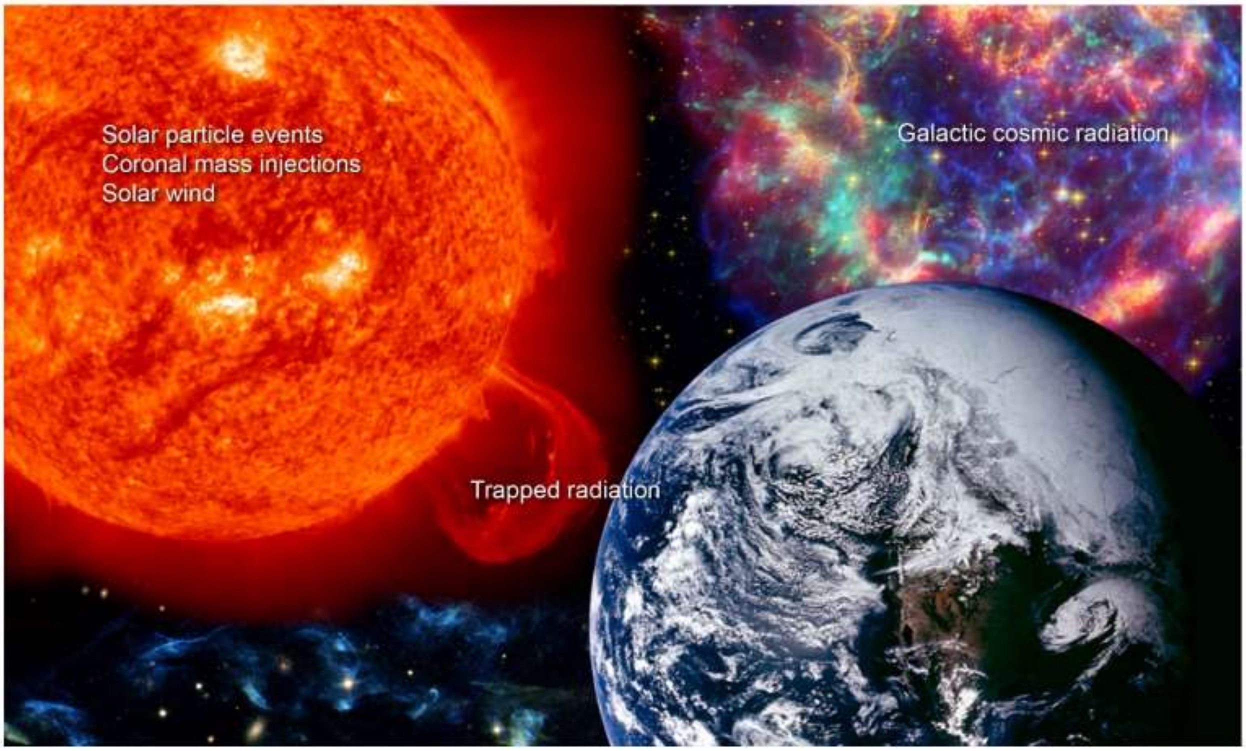


Figure 1. Sources of Space Radiation

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. 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. The following Figure shows the mechanisms of the major components of atmospheric cosmic rays.

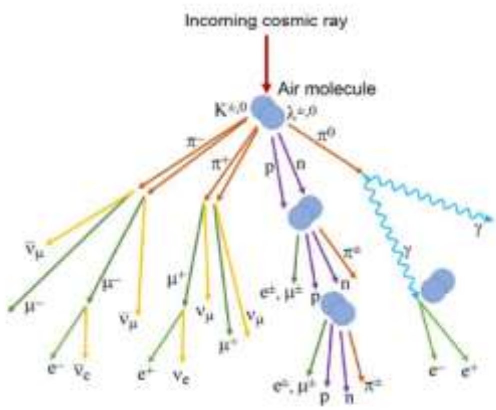
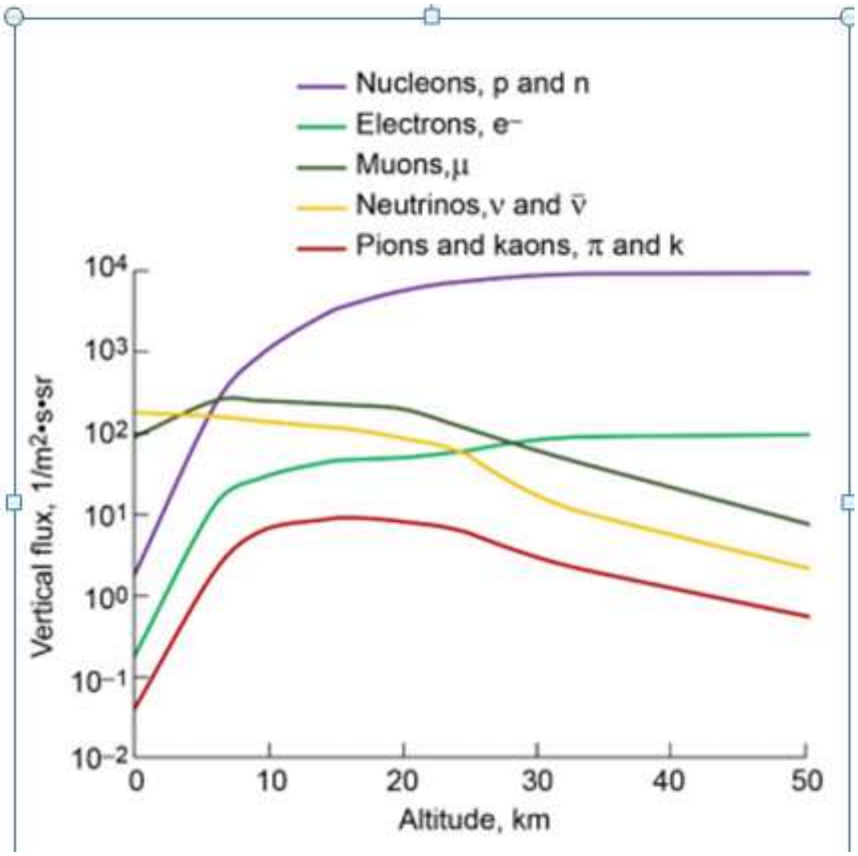


Figure. Mechanisms of primary components of atmospheric cosmic rays (based in part on Bowersox (2011) [6]

The next prevalent flux is that of protons and neutrons (nucleons p and n, respectively), remnants of the incoming protons and neutrons from the outer atmosphere. Also seen are electrons, positrons, and photons (gamma rays (γ) and x-rays) that are generally products of cascades from the decay of muons, pions, kaons (K), and lambda baryons (λ) produced by the interaction of cosmic-ray nucleons with air. In the upper troposphere and stratosphere, the nucleon flux is the more dominant source of observed cosmic radiation. The incoming flux comprises primarily relativistic protons with approximately 10 percent neutrons from the outer atmospheric regions. At about an altitude of 15 km (50,000 ft), the incoming protons have traversed the density-normalized attenuation length of 121 g/cm2 in air from outer space, resulting in a peak intensity of secondary radiation. As the nucleon flux drops exponentially through the atmosphere, so does the secondary flux—with the exception of muons, which are longer lived than other secondary particles. The variation of vertical flux of major atmospheric cosmic ray components with atmosphere and altitude is shown in next Figure.



Figure, Vertical fluxes of cosmic rays in atmosphere, derived from measurements of cosmic ray particle energies > 1GeV (based on Olive et al, 2015)

In the 1960s, NASA embarked on empirical studies of solar-sourced structures observed in space: solar winds, solar flares, galactic cosmic rays, and interplanetary magnetic fields. Solar flares are giant explosions on the sun that send energy, light and high speed particles into space. These flares are often associated with solar magnetic storms known as coronal mass ejections (CMEs). The number of solar flares increases approximately every 11 years, and the sun is currently moving towards another solar maximum, likely in 2024. That means more flares will be coming, some small and some big enough to send their radiation all the way to Earth [7]. Solar electron events are common phenomena observed in interplanetary space. They are often observed in the energy range of 300 keV, with an occurrence rate near the earth of ∼190 events per year during solar maximum and ∼10 per year during solar minimum (Wang et al. 2012). Energetic electrons are accelerated either in solar flares or in the vicinity of shocks driven by CMEs. The accelerated electrons escaping at energies of 2 to 10 keV, excite type III radio bursts when propagating through the plasma of the solar corona and interplanetary space. 98.75% of the observed solar electron events in solar cycle 23 were reported by Wang et al. (2012) to be accompanied by type III radio bursts. [8].

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.

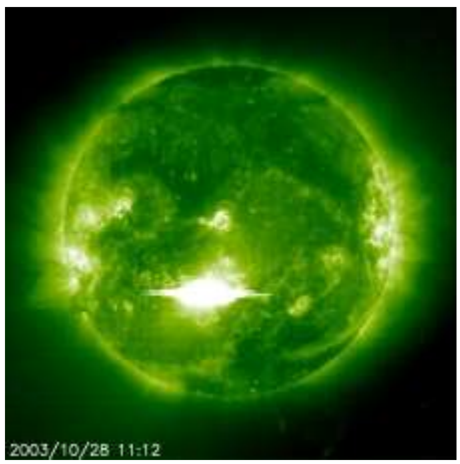


Figure. The Solar and Heliospheric Observatory (SOHO) spacecraft captured this image of a solar flare as it erupted from the sun early on Tuesday, October 28, 2003. *Image Credit: ESA & NASA/SOHO*

Galactic cosmic rays consist primarily of protons with an average flux of about 4 protons/cm^2/s and a wide distribution of energies extending to many giga-electronvolts (GeV). The flux and energy distribution of galactic protons reaching a planetary surface is modulated by the solar cycle. Sunspot counts are a measure of solar activity. Higher fluxes of galactic protons are observed during periods of low solar activity. A larger portion of protons penetrate the heliosphere during solar minimum, resulting in a shift in the population toward lower energies. The flux and energy distribution of the cosmic rays are controlling factors in the production rate, energy distribution, and depth of production of neutrons and gamma rays. [9]**.**

The STEREO solar probe mission consisting of two nearly identical spacecraft in heliocentric orbits aimed 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:

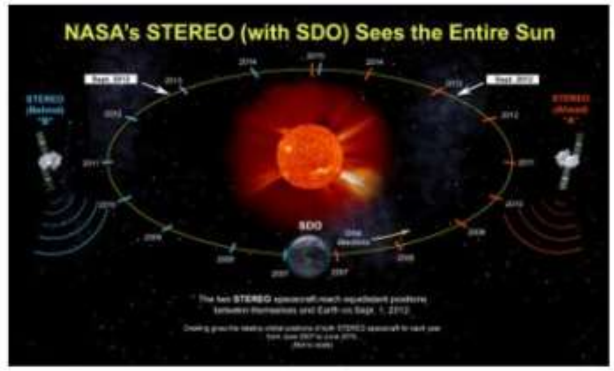
- Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI) - imaging
- In situ Measurements of Particles and CME Transients (IMPACT) – particle detectors
- Plasma and Suprathermal Ion Composition (PLASTIC) – particle detectors
- STEREO WAVES (SWAVES) – electric fields [10].

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.

Because the two spacecraft were in slightly different orbits, the "ahead" (A) spacecraft was ejected to a heliocentric orbit inside Earth's orbit, while the "behind" (B) spacecraft remained temporarily in a high Earth orbit. The B spacecraft encountered the Moon again on the same orbital revolution on January 21, 2007, being ejected from Earth orbit in the opposite direction from spacecraft A.

STEREO Observatory spacecraft during solar panel deploy.

STEREO A and B



A solar flare is a sudden flash of increased brightness on the Sun, usually observed near its surface and in close proximity to a sunspot group. Powerful flares are often, but not always, accompanied by CMEs. Even the most powerful flares are barely detectable in the total solar irradiance (the "solar constant"). Solar flares occur in a power-law spectrum of magnitudes; an energy release of typically 10^{20} joules of energy suffices to produce a clearly observable event, while a major event can emit up to 10^{25} joules. Although originally observed in the visible electromagnetic spectrum, especially in one of the hydrogen emission lines, they can now be detected from radio waves to gamma-rays. Flares are closely associated with the ejection of plasmas and particles through the Sun's corona into outer space; flares also copiously emit radio waves. If the ejection is in the direction of the Earth, particles associated with this disturbance can penetrate into the upper atmosphere (the ionosphere) and cause bright auroras, and may even disrupt long range radio communication. It usually takes days for the solar plasma ejecta to reach Earth. There are typically three stages to a solar flare. First is the *precursor* stage, where the release of magnetic energy is triggered. Soft x-ray emission is detected in this stage. In the second or *impulsive* stage, protons and electrons are accelerated to energies exceeding 1 MeV. During the impulsive stage, radio waves, hard x-rays, and gamma rays are emitted. The gradual build up and decay of soft x-rays can be detected in the third, *decay* stage. The duration of these stages can be as short as a few seconds or as long as an hour [11].

Galactic cosmic rays (GCRs) mainly consist of charged particles. The nuclear component consists of 87% protons, 12% α-particles, and 1% heavier nuclei. In the heliosphere, they 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 radionucleolides [12]. Higher fluxes of galactic protons are observed during periods of low solar activity. A larger portion of protons penetrate the heliosphere during solar minimum, resulting in a shift in the population toward lower energies. The flux and energy distribution of the cosmic rays are controlling factors in the production rate, energy distribution, and depth of production of neutrons and gamma rays [13]. Such research areas focus on the attempt to gain an understanding of how solar activity is anticorrelated with GCR flux in the heliosphere. There are fewer GCR ions observed in the solar system when there appears to be more solar activity. Another topic area of research is the study of observed magnetic field variations in the interplanetary medium down to the sub-millihertz scale. These variations result from transient structures in the heliospheric plasma [14].

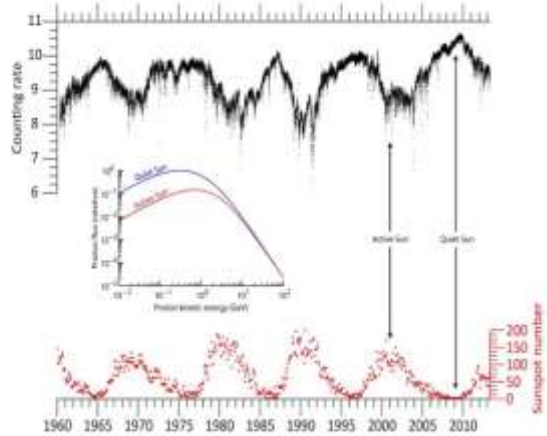


Figure. The variation of neutron counting rates (with units of 10^5 counts per hour) measured at McMurdo Station in Antarctica as a function of time (neutron monitors of the Bartol Research Institute are supported by NSF grant ATM-0000315). Monthly sunspot counts are shown for comparison *(courtesy of SIDC, RWC Belgium, World Data Center for the Sunspot Index, Royal Observatory of Belgium, 1960–2013).* During periods of low solar activity (low sunspot counts), low-energy galactic cosmic rays penetrate the heliosphere, which results in relatively high neutron production rates. During periods of high solar activity (high sunspot counts), the low-energy galactic cosmic rays are cut off, resulting in lower neutron counting rates. The variation in neutron counting rates is about 20% over the solar cycle. Theoretical galactic proton energy spectra within the heliosphere, representative of quiet and active solar years

2. Interplanetary Magnetic Field

The solar magnetic field is stretched out and transported by the solar wind in the heliosphere to form the interplanetary magnetic field (IMF). Since it originates from the solar magnetic field and because the Sun rotates, the IMF twists into the shape of a Parker spiral, it has been confirmed by observations made with satellites. The solar magnetic field is thought to be mostly directed along this spiral, either away from or toward the Sun. According to the polarity of the original solar magnetic field, the positive and negative polarities of the IMF intermittently form two or more sectors (the so-called sector structure) in the equatorial plane. The IMF was first measured by magnetometers on board satellites in 1962, and space-based measurements have continued for more than 50 years. The satellite measurements near Earth and the reconstructed time series show that the IMF varies on timescales of seconds to decades (even longer than several solar cycles), i.e., it varies from solar minimum to maximum, and from one cycle to the next. [15].

The Parker Solar Probe	Solar Orbiter	Genesis	Ulysses	DSCOVR
11/2018-12/2025	10/01/20	2001-2004	2000-2001	02/2015-present
The detailed science objectives are: 1) trace the flow of energy that heats and accelerates the solar corona; 2) determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind; and 3) explore mechanisms that accelerate and transport energetic particles.	Solar Orbiter 1. to study the drivers of the solar wind and the origin of the coronal magnetic field; 2. to determine how solar transients drive heliospheric variability; 3. to learn how solar eruptions produce the energetic particles that fill the heliosphere; and 4. to study	To collect samples of solar wind particles and return them to Earth for detailed analysis. The science objectives are to obtain precise measurements of solar isotopic and elemental abundances and provide a reservoir of solar matter for future scientific analysis. Specifically, the	To investigate, as a function of solar latitude, the properties of the solar wind and the interplanetary magnetic field, of galactic cosmic rays and neutral interstellar gas, and to study energetic particle composition and acceleration	The Deep Space Climate Observatory, or DSCOVR, is a spacecraft which will orbit between Earth and the sun, observing and providing advanced warning of particles and magnetic fields emitted by the sun (known as the solar wind) which can affect power grids, communications

	how the solar dynamo works and drives connections between the Sun and the heliosphere.	primary scientific objectives were to obtain precise measurements of isotope ratios of oxygen, nitrogen, and solar wind isotopic fractionation.		systems, and satellites close to Earth.

The conditions of the interplanetary environment are dominated by solar activity. During the maximum solar activity period some structures are more predominant, such as flares and coronal mass ejections. CMEs consist of huge numbers of energetic particles and magnetic energy release processes in the Sun, resulting in considerable effects in the Earth's ionosphere–thermosphere domain, eventually affecting satellite-borne instrumentation and ground electric power transmission networks. Once the CMEs with southward component of the interplanetary magnetic field north-south direction (IMF Bz) reach the Earth, magnetic storms occur suddenly, generating large disturbances in the magnetosphere–ionosphere– thermosphere system. It is well known when the IMF Bz has a sudden southward turning can cause an eastward prompt penetration electric field during daytime and westward at nighttime. Such an electric field is associated with an under-shielding condition [16]. A sudden northward turning causes the opposite effect which is associated with an over-shielding condition. High-intensity, long-duration continuous auroral electrojet (AE) activity (HILDCAA) events may occur during a long-lasting recovery phase of a geomagnetic storm. They are a special kind of geomagnetic activity, different from magnetic storms or substorms. Wei et al. [17] announced that multiple electric field penetration to equatorial ionosphere is associated with HILDCAAs. This means that short pulses of dawn–dusk electric field bear the shielding effect [18].

3. Large Hadron Collider

The LHC at CERN, the European Organization for Nuclear Research, is the largest, most complex and most powerful particle accelerator ever built. It operates in a circular tunnel almost 17 miles in circumference about 330 feet underground. 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. Physicists conduct experiments in the Energy Frontier Program with two general purpose detectors, ATLAS and CMS, and two specialized detectors, ALICE and LHCb. Physicists predict that its very-high-energy proton collisions will yield extraordinary discoveries about the nature of the physical universe. Beyond revealing a new world of unknown particles, the LHC experiments could explain why those particles exist and behave as they do. Collisions create showers of new particles. Regarding interesting events for the types of particles they produce, about 100 of which occur each second, CMS and ATLAS record each particle's flight path, energy, momentum and electric charge. Physicists use this information to identify the types of particles created by the collisions and to determine if they have discovered something new.

By the 1950s, it was known that the protons and neutrons of the atomic nucleus had many cousins: other "hadrons" with names like pions, kaons, Deltas, rho mesons, etc. In the early 1970s a picture of these particles, complicated objects built from quarks, antiquarks and gluons, were themselves held together by strong nuclear forces.

Starting in the 1960s, it was gradually understood that the properties of the world required a non-zero field, known as the Higgs field which altered properties of many of these particles in nature. Without a Higgs field, the architecture observed in nature would collapse. Understanding what this field is and how it works is one of the central projects of particle physicists today, and the main justification for building the Large Hadron Collider [19].

In the past few decades the number of identified subatomic particles has risen to more than 100. as powerful machines were developed for smashing bits of matter together and studying the scattered by-products. At first physicists believed these particles could not be broken down into smaller entities. Then they found that only the four leptons (the electron. the muon and two kinds of neutrino) seemed to be truly elementary in the sense of having no measurable size and no constituent parts. Since 1964, the quark hypothesis has been a cornerstone of particle physics, stating that hadrons were all ensembles of only three elementary entities named quarks. An additional quark was soon postulated for both theoretical and experimental reasons. Fermi National Accelerator Laboratory (Fermilab) discovered a new particle with a mass whose energy equivalent is 9.4 GeV (billion electron volts), a mass more than three times greater than that of any subatomic entity previously identified. Designated upsilon (Y), the new particle points to the existence of a fifth quark. Scientists analyzed data per LHC collisions of protons measured in ATLAS/CMS detectors. Additionally, heavy ion collisions have the ability to create quark-gluon plasma. Scientists on the CMS experiment at the LHC compared the production of the three states of upsilons in both types of collisions. Heavy-ion collisions seemed to produce a smaller fraction of lightly bound upsilons than proton-proton collisions. This could be because the less tightly bound upsilons break up in the heat of the quark gluon plasma, but not the most tightly bound ones. The fact that only some types of upsilons melt apart in the QGP gives scientists a great tool for divining the temperature of the plasma. They calculated the energies at which the different states would break apart. They knew from experiment that the QGP was hotter than the breaking points of the weakest two states but cooler than that of the strongest one. Scientists on the ALICE, ATLAS, and CMS experiments studied the interactions of other particles with the QGP. Other J/psi particles also seemed to break up in the quark-gluon plasma, but they only come in one easily measurable bound state. Photons and Z bosons do not interact strongly and so seem unaffected by the quark-gluon plasma. Another phenomenon scientists are using to reveal the secrets of the quark-gluon plasma is jet quenching. Particle collisions often produce sprays of particles that fly away from the interaction point in opposite directions. Scientists looked that these back-to-back jets created in the quark gluon-plasma and found that many of them were imbalanced. The jets on the side with a greater density of the plasma shrank significantly before shooting out the other side, sapped of their energy by the QGP (Symmetry (05/11), "LHC experiments dive into the quark gluon plasma").

4. QGP

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 solids, liquids, gases, plasmas and Bose-Einstein condensates. Experiments at the Large Hadron Collider have begun to study the quark-gluon plasma, a hot soup of unbound particles theorists say made up the universe having evolved just after the Big Bang.

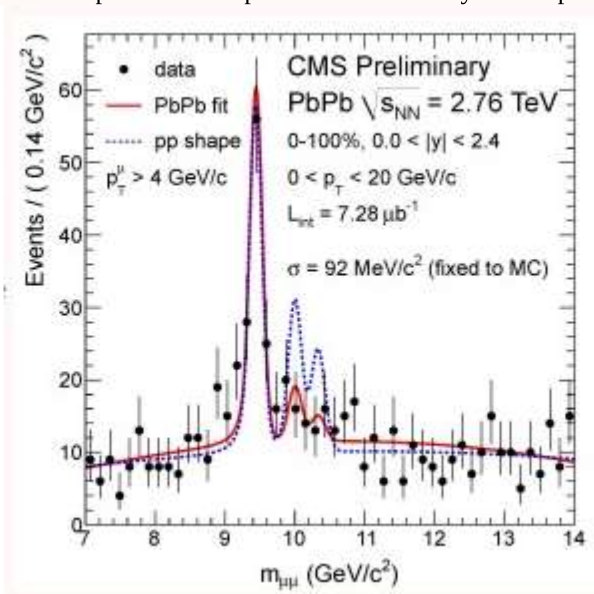


Figure. The highest peak on the graph shows the production of tightly bound upsilons in both proton-proton and heavy-ion collisions. The bumps outlined in dotted blue show the production of the two other upsilon states in proton-proton collisions, while the red line shows the same production in heavy-ion collisions.

It is estimated that the Hadron Epoch covers the time from 10^{-6} seconds to 1 second after the Big Bang [20]. A new physical interpretation of the state of matter of the quark-gluon is the most fundamental building blocks in nature. Such a model is based on the assumption that dark matter and dark energy behave as a perfect ideal fluid at extremely high temperature by the virtue of Boltzmann constant of the ideal gas law and NASA's Cosmic Microwave Background Explorer (CMB) which estimated that Space has an average temperature close to 2.7251 Kelvin, the equivalent mass- energy of the fundamental particle of the dark matter/dark energy.

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 [21]. This temperature, based upon measurements by the PHENIX collaboration at RHIC, is higher than the temperature needed to melt protons and neutrons into plasma of quarks and gluons. 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. RHIC has created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. When nuclear matter is heated beyond 2 trillion degrees, it becomes a strongly coupled plasma of quarks and gluons. Experiments using highly energetic collisions between heavy nuclei have revealed that this new state of matter is a nearly ideal, highly opaque fluid.

Discussion

A little over a decade from the discovery of naturally occurring background radiation in 1900, indications were seen that a significant portion of this ionizing background was coming from extraterrestrial sources. In the late 1940s and early 1950s, these "cosmic rays" were the source of high-energy particle physics research before the advent of large particle accelerators. The discovery of the more common subatomic particles—muons, pions, kaons, and lambda baryons—as well as discovery of important particle properties (such as quark flavors, charge conjugation parity symmetry (CP) violation, and neutrino mass) owe their discovery to cosmic ray experiments [22]. At present, the study of space radiation is still very important for astrophysics and particle physics.

Whereas the Standard Model has typically been developed through experimentation within an artificially-produced electromagnetic environment, similar particles have been detected within space weather regions with solar probing imagers and detectors onboard satellites. To better understand coronal mass ejections, solar winds, galactic cosmic rays as they constitute space weather and penetrate the Earth's atmosphere to infrequently impact terrestrial as well as space telecommunications, the natural space environment has been observed to contain the same subatomic particles as those observed and analyzed from detectors housed in particle accelerators and colliders of US Department of Energy national labs and CERN.

The purpose of this paper was to contextualize the study of particle physics, hence make the study relevant for learning, reframed within the environment of space weather. Subatomic and/or ionized particle absorption in Earth atmosphere infrequently impacts global commerce. The relevance of astrophysics has implications not only for disruptions to radio and other telecommunications, power of electrical grids, GPS localizations and navigations but to the less frequently mentioned global warming.

How relevant STEM students value these potential impacts on their lives correlate to the degree of personal engagement they see themselves in a career that addresses environmental challenges. In other words, STEM students envision their roles in the outcome expectations/contributions of their chosen vocations. And, their visions signify self-identification with their choices. By illustrating the progression timeline in developing astrophysics according to real-world events and knowledge-building milestones, student self-reflection becomes the instructional process for further STEM-based education and vocational planning.

Conclusion

Although the timeline for developing the Standard Model of Physics and its counterpart "Beyond" has traditionally developed from theoretical and experimental studies, space weather provides an alternate dimension for which to study particle physics. The natural space environment extends contiguously from that of Earth. And proximally constitutes the medium through which satellites operate and travel toward destinations and missions for greater understanding of the Universe. The unified extaterrestrial and terrestrial domains establish the real-world context for which students organically learn and comprehend particulate material realm of human existence and interactions. In other words, the learning experience of space weather provides not only a contextualized but interdisciplinary curriculum for particle physics. The fact that space weather potentially disrupts satellite operations and satellite-based human commerce provides possibilities of student expectation toward their societal role albeit related to modern physics.

.

References and Notes

[1] Kiray, S. (2016). The pre-service science teachers' mental models for concept of atoms and learning difficulties. *International Journal of Education in Mathematics, Science and Technology, 4*(2), 147-162.

[2] McKagan, B., Perkins, K., & Wieman, C. E. (2008). Why we should teach the Bohr model and how to teach it effectively. *Physical Review Special Topics - Physics Education Research*, *4*(1)

[3] Lipowsky, F. & Rzejak, D. (2015). *Key features of effective professional development programs for teachers. Ricercazione, 7*(2), 27–51).

[4] Ceciirei, K., Melo, I., & Tomasik, B. (2018). Bringing particle physics into classrooms. *Physics Teaching in Engineering Education PTEE 2017* . University of Zilina, Slovakia, May 18-19, 2017).

[5] Wrbanek, J. & Wrbanek, S. (2020). *Space Radiation and Impact on Instrumentation Technologies*.

[6] Bowersox, P. (2011). *Up, Up, and Away*; *Victor Hess discovers the cosmic rays* (2012). CERN

[7] Fox, K. (2011). *: What Does It Take to Be X-Class Solar Flares?* NASA's Goddard Space Flight Center, Greenbelt, MD.

[8] Zhao, L., Li, G., Zhang, M., Wang, L., Moradi, A., & Effenberger, F. (2019). Statistical analysis of interplanetary magnetic field path lengths from solar energetic electron events observed by WIND. *The Astrophysical Journal*, *878*(2), 107.

[9] Prettyman, T. (2014). Remote sensing of chemical elements using nuclear spectroscopy. In Encyclopedia of the Solar System (Third Edition),

[10] Cox, M. & Ossing, D. (2018). The Fall and Rise of STEREO Behind. In *2018 SpaceOps Conference* (p. 2565)

[11]. Zell, H. (2017).*What is a Solar Flare?*. NASA.

[12] Muscheler, R. (2013**).** Ice core methods. 10Be and cosmogenic radionuclides. In *Ice Cores*.

[13] Prettyman, T. (2014) Remote sensing of chemical elements using nuclear spectroscopy. In *Encyclopedia of the Solar System* (Third Edition),

[14] Wrbanek, J. & Susan Wrbanek (2020). Space radiation and impact on instrumentation technologies (NTRS Document ID 20200001895).

[15] Wang, M., Lu, J., Kabin, K.., Yuan, H.., Zhou, Y., & Guan, H. (2020). Influence of the interplanetary magnetic field cone angle on the geometry of bow shocks. *The Astronomical Journal*, *159*(5), 227.

[16] Santos, A., Abdu, M., Souza, J., Sobral, J., Batista, I., & Denardini, C. (2016). Stormtime equatorial plasma

bubble zonal drift reversal due to disturbance hall electric field over the Brazilian region: Disturbed zonal plasma drift. *Journal of Geophysical Research: Space Physics, 121*(6), 5594–5612.

.[17] Wei, Y., Hong, M., Wan, W., Du, A., Lei, J., Zhao, B., Wang, W., Ren, Z., & Yue, X. (2008).: Unusually long lasting multiple penetration of interplanetary electric field to equatorial ionosphere under oscillating IMF Bz, *Geophys. Res. Lett., 35*, L02102

[18] Silva, R., Sobral, J., Koga, D., & Souza, J. (2017, October). Evidence of prompt penetration electric fields during HILDCAA events. In *Annales Geophysicae* 35(5), 1165-1176).

[19] Of particular significance. Conversations about science with theoretical physicist Matt Strassler *Particle Physics: Why do it? And why do it *that* way?* http://atlas.physics.arizona.edu/

[20] Hawking, S. (1998). *A brief history of time: From the Big Bang to Black Holes*. New York: Bantam Books,

[21] Walsh, K. & Genzer, P. (2010). New findings on hot Quark Soup produced at RHIC. US Department of Energy's (DOE) Brookhaven National Laboratory.

[22] De Angelis, A. (2013). Cosmic Rays: studies and measurements before 1912. *Nuclear Physics B-Proceedings Supplements, 239*, 3-10.