Week 1 Review

Cherenkov Radiation:
It is named after Soviet scientist Pavel Alekseyevich Cherenkov, the 1958 Nobel Prize winner who was the first to detect it experimentally. It is electromagnetic radiation emitted when a charged particle (proton) passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. Cherenkov radiation had been theoretically predicted by the English polymath Oliver Heaviside in papers published in 1888–1889. A common analogy is the sonic boom of a supersonic aircraft or bullet. Most Cherenkov radiation is in the ultra violet spectrum. The theoretical interpretation was published in 1937, and Cherenkov's experiments were carried out between 1934 and 1937. However, the phenomenon was not well understood until 20 years later, in 1958. There is a threshold velocity below which no Cherenkov radiation will be emitted.

Cherenkov radiation in the atmosphere:
Imaging Air Cherenkov Telescopes (IACT) measure this. Cosmic rays traveling through space emit Cherenkov radiation when they hit the Earth's atmosphere (dielectric medium, different indices of refraction)

Photo-Multiplier Tubes (PMT's):
Very sensitive to ultra violet light. They multiply the current produced by the detected light by up to 100 times. This allows individual photons to be measured when the flux is very low.

Cosmic Rays:
Protons, alpha particles, or heavier nuclei. 89% are protons (CERN reference), 10% are alpha particles (helium nuclei), and 1% are heavier nuclei up to Uranium.

Milagro:
Spanish for miracle. Standard astronomical telescopes view the universe in visible light, where Milagro saw the universe at very high energies. The light that Milagro saw was about 1 trillion times more energetic than visible light. The Milagro Experiment stopped taking data in April 2008 after seven years of operation. They probably shut it down to change location, which is why they shipped and moved all the photo-multiplier tubes and equipment to Mexico, where the sky is dark and cloudless.

H.A.W.C.:
High Altitude Water Cherenkov

Oh-My-God particle:
An ultra high energy cosmic ray. Probably the inspiration for this experiment, and probably instigated the merging of particle physics with astrophysics. A particle, presumably a proton, came screaming into the atmosphere and landed on the University of Utah's Fly's Eye detector on October 15, 1991. The event was recorded another 15 times, so it was not a mistake. These particles are extremely rare, however. This particle had 40 million times more energy than the most energetic protons produced at accelerators, and 50 million times more energy than any event ever observed. The Utah researchers measured the energy of the unusual cosmic ray event in 1991 to be 3.2 × 10^20 electronvolts (eV).

Radiation Length:
Radiation length is a characteristic of the material. This is a measure of the amount of energy lost, but not due to ionization. High energy photons predominantly lose energy by the production of an

electron/positron pair. High energy electrons predominately lose energy by Bremsstrahlung (a result of collision with atoms in the medium, not acceleration by the Lorentz force).

Gamma ray bursts (GRB's):

Gamma rays produced by a mechanism other than radioactive decay. They are the most powerful events recorded so far in the cosmos. They are perhaps generated by the collapse of a hyper-novae star. The term hyper-novae has sometimes been used to describe the merging of super-massive black holes. A gamma ray burst from a nearby hyper-novae could destroy life on earth.

Fermi Telescope:

In June 2008, NASA launched the Fermi space telescope, which will search for the terminal gamma-ray flashes expected from evaporating primordial black holes. Developed by SLAC (a Dept of Energy facility), at a cost of $196 million.

Ultra High Energy Cosmic Rays:

The most energetic type of radiation known so far, either from the laboratory or from the cosmos, are the ultra-high energy cosmic rays, and a major question is their possible relation to black holes, either massive or stellar. Ultra-high energy cosmic rays, neutrinos and gravitational waves, whether associated with these black holes, or perhaps other more exotic phenomena, will certainly provide unique probes to extend our current reach into the depths of the Universe.

Fly's Eye Detector

University of Utah ultra high energy cosmic ray detector that operated only on clear, moonless nights (paper reference). Could detect these high energy cosmic rays at a distance of 20km away or more. 80-90% of the Earth's atmosphere is located within the troposphere region, which measures a height of 12 km from the Earth's surface. The stratosphere reaches upwards to a height of 53 km. Therefore, Fly's Eye detected cosmic rays that had already entered the Earth's stratosphere but had not yet reached the troposphere. There were 120 individual "eyes", made from corrugated steel cylinders. Also used PMTs. But used mirrors instead of water, however.

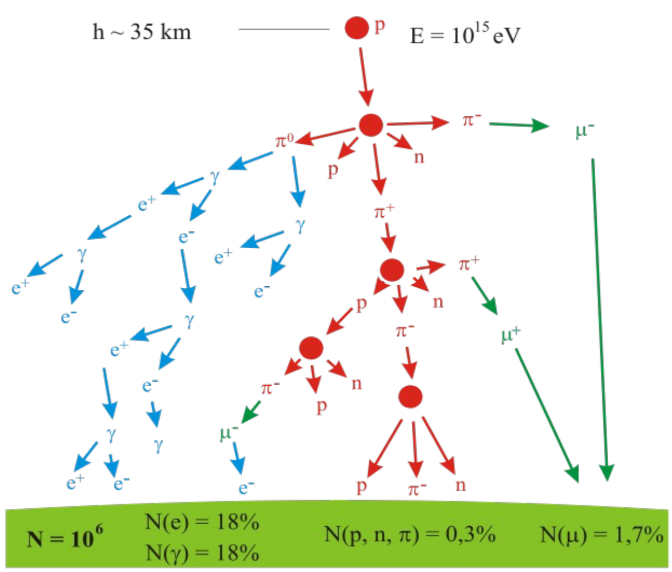

Illustration 1: Cosmic ray air shower with near-isotropic decay pattern

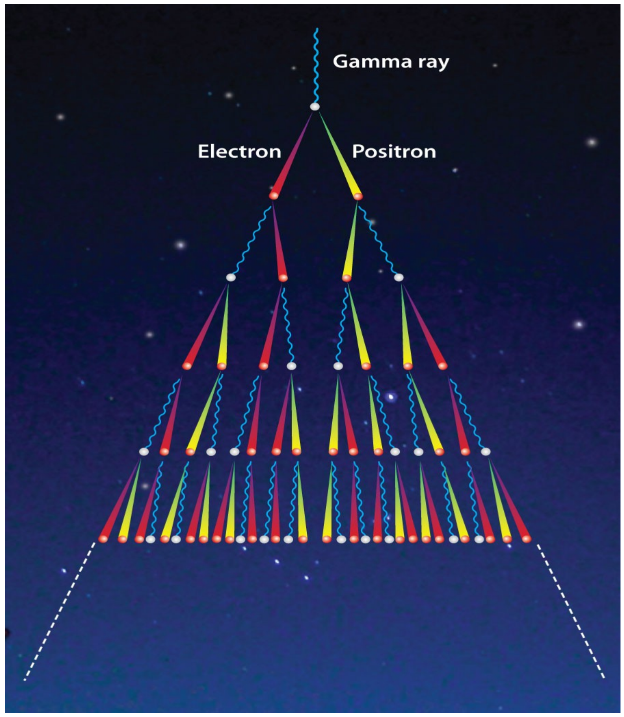

Illustration 2: Gamma ray air shower with less isotropic decay pattern

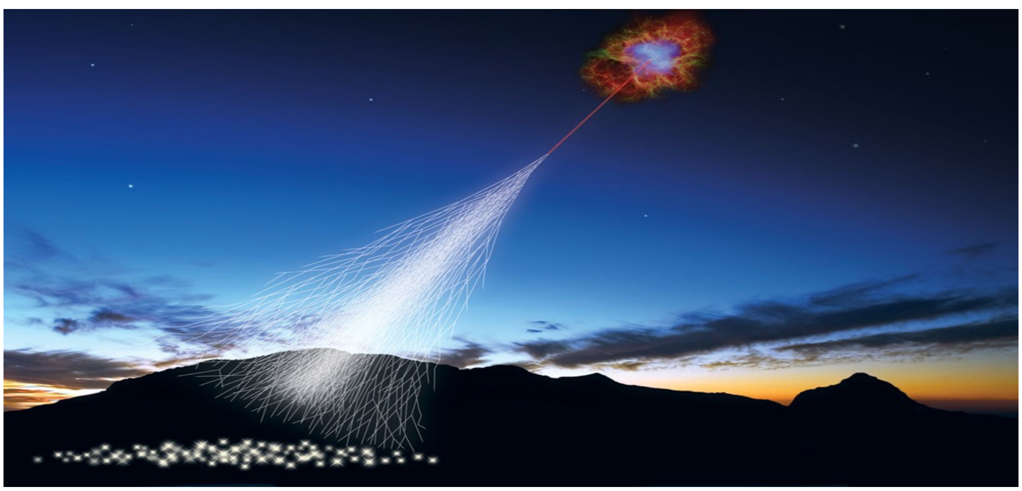

Illustration 3: Goal of HAWC project to determine location and source of high-energy gamma rays, here shown to potentially arise from Crab Nebulae, but other potential sources could be Primordial Black Holes (PBH) and dark matter.

Hawking Radiation:

In 1975 Hawking published a shocking result: if one takes quantum theory into account, it seems that black holes are not quite black! Instead, they should glow slightly with "Hawking radiation", consisting of photons, neutrinos, and to a lesser extent all sorts of massive particles. Only for very small black holes would this radiation be significant. Still, the effect is theoretically very interesting, and folks working on understanding how quantum theory and gravity fit together have spent a lot of energy trying to understand it and its consequences. The most drastic consequence is that a black hole, left alone and unfed, should radiate away its mass, slowly at first but then faster and faster as it shrinks, finally dying in a blaze of glory like a hydrogen bomb. Hawking radiation reduces the mass and the energy of the black hole and is therefore also known as black hole evaporation. Hawking's work followed his visit to Moscow in 1973 where the Soviet scientists Yakov Zeldovich and Alexei Starobinsky showed him that according to the quantum mechanical uncertainty principle, rotating black holes should create and emit particles. Because of this, black holes that lose more mass than they gain (through other means) are expected to shrink and ultimately vanish.

Neutrino Oscillations:

Neutrino interactions, both at these terrestrially non-achievable energies and at lower energies, are especially interesting, because neutrinos provide to date the only clear experimental evidence for physics beyond the Standard Model, through the phenomenon known as neutrino oscillations. "I don't know what you imagine being 'oscillating masses'. Neutrino oscillations is nothing else but saying that the neutrinos which are "multiplet eigenstates" and are not pure energy (or mass) eigenstates, but are linear combinations of it." So exactly, the neutrino oscillation phenomenon is in fact describing the eigenstate of the neutrino in that it is not a pure eigenstate. A pure eigenstate does not exist. How can that be? The identity of the neutrino changes. Why? The probability of measuring a particular flavor for a neutrino varies periodically as it propagates. Neutrino oscillation is of theoretical and experimental interest since observation of the phenomenon implies that the neutrino has a non-zero mass, which is not part of the original Standard Model of particle physics. On July 19, 2013, at the European Physical Society meeting in Stockholm, the international T2K collaboration announced a definitive observation of muon neutrino to electron neutrino transformation, confirming this phenomenon. It has been scientifically observed.

Synchrotron Radiation:

Phenomenon unique to electrons. The synchrotron radiation, the emission of very relativistic and ultra-relativistic electrons gyrating in a magnetic field, is the process which dominates much of high energy astrophysics. Synchrotron radiation is generated by the acceleration of ultra-relativistic charged particles through magnetic fields. Synchrotron radiation may be achieved artificially, or naturally by fast electrons moving through magnetic fields. When high-energy particles are in rapid motion, including electrons forced to travel in a curved path by a magnetic field, Synchrotron radiation is produced. Only occurs for electrons traveling at relativistic speeds.

Black Holes:

May have played a role in the evolution of the Universe. "Astronomers have found convincing evidence for a super massive black hole in the center of our own Milky Way galaxy, the galaxy NGC 4258, the giant elliptical galaxy M87, and several others." (Hubble website) There are 4 classifications of a black hole: super-massive, intermediate-mass (this could be the speculated primordial black hole class), stellar and micro (from largest to smallest).

Stellar Black Hole:

Forms as the result of the gravitational collapse of a massive star. This process could be observed as a gamma ray burst.

Intermediate-Mass Black Holes:

One of the three most popular theories says IMBH could be primordial black holes. First evidence found 2012 bu Australian team CSIRO after confirmation of data from 3 years prior.

Super-massive Black Hole:

Most and possibly all galaxies contain a super-massive black hole. In the Milky Way galaxy, the super-massive Black Hole is theorized to be located at Sagittarius A.

Primordial Black Holes:

Formed as a result of pressure during the first moments after the Big Bang. These types of black holes are hypothesized to emit Hawking radiation. Hawking theorized that these specific types of black holes could emit energy at at a greater rate than they absorb it, and therefore could experience a runaway "evaporation". In the final phase of this process, the PBH would emit a massive burst of radiation, an explosion of astronomical proportion. Furthermore, it has also been hypothesized that PBH could be candidate for dark matter.

Cherenkov radiation in the HAWC tanks:

The HAWC project specifically measures local Cherenkov radiation, which is how it differs from the Fly's Eye detector, which measured non-local Cherenkov radiation (the Cherenkov radiation emitted during passageway through the Earth's atmosphere). The bladders limit the amount of particles entering the tanks, primarily for the purpose of blocking visible light (white light from the sun). This is what allows HAWC to run all day everyday. But the bladders do not block all particles, otherwise there would be no signal for the PMTs to detect. The incoming particles are cosmic rays that have traveled all the way through the Earth's atmosphere. (Most of the cosmic ray particles experience attenuation, or decay into other particles... Dr. Tollefson compared this to the shower of particles that results from smashing two protons together). Cosmic rays can decay into gamma rays when they enter the atmosphere, otherwise, when traveling through a vacuum, they do not include gamma rays. Gamma rays exist independently from cosmic rays in space. Therefore, both cosmic rays and gamma rays enter the atmosphere. Gamma rays decay into electron/positron pairs which then produce Cherenkov radiation that the HAWC tanks detect. Cosmic rays decay into lots of different particles that also produce Cherenkov radiation the HAWC tanks detect. So, we see that HAWC tanks detect Cherenkov radiation from cosmic ray showers as well as from gamma ray showers, but the HAWC project is only interested in the gamma ray shower Cherenkov radiation. To determine what portion of the Cherenkov signal is from gamma ray showers, the parameter Compactness is used to classify the radius/spread of the shower. The gamma ray showers have smaller spread when they hit the ground, since the decay chain is less isotropic than the decay chain of the cosmic ray showers. The goal is to locate the direction of the gamma ray shower, in hopes of determining what the source of the gamma ray shower might be (Primordial Black Hole (PBH) is strongly anticipated).

Gamma Ray Decay energy scale:

There is no lower limit on gamma decay energy since it is only defined by mechanism, not energy scale. Typical values are in the range of a few hundred KeV to usually no greater than 10MeV.

High-Energy Gamma Ray energy scale:

H.E.S.S. (an IACT) looks for high-energy gamma rays in the range of between 30GeV to 100TeV.