FUTURE EXPERIMENTS IN ASTROPHYSICS

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The measurement methodologies of astrophysics experiments reflect the enormous variation of the astrophysical radiation itself. The diverse nature of the astrophysical radiation, e.g. cosmic rays, electromagnetic radiation, and neutrinos, is further complicated by the enormous span in energy, from the $1.95K$ relic neutrino background to cosmic rays with energy $> 10^{20}$ eV. The measurement of gravity waves and search for dark matter constituents are also of astrophysical interest. Thus, the experimental techniques employed to determine the energy of the incident particles are strongly dependent upon the specific particles and energy range to be measured. This paper summarizes some of the calorimetric methodologies and measurements planned by future astrophysics experiments. A focus will be placed on the measurement of higher energy astrophysical radiation. Specifically, future cosmic ray, gamma ray, and neutrino experiments will be discussed.

1. Introduction

The measurement of the properties of the astrophysical radiation is one of the key components in understanding the underlying astrophysical phenomena. Unlike experiments at terrestrial accelerators, the specific properties of the astrophysical particle beam are usually not known. This translates into experimentally determining the energy, arrival direction, particle type, and arrival time of the incident radiation and possibly correlating these with measurements in other wavelength bands, e.g. optical or infrared. The exact experimental arrangement needed to perform these measurements is dependent upon nature of the radiation under study and on the energy scale of experimental interest. The situation can be further complicated by sources of background that can overwhelm the signal of interest or by attenuation effects of the atmosphere. For example, gamma ray measurements need to be performed above the atmosphere in orbiting experiments, which forces strict mass and power requirements on the detector systems.

This paper discusses the future experiments that plan on performing cosmic ray, gamma ray, and neutrino measurements with a focus on higher energy.

Nearly all of the these experiments employ calorimetric principles to determine the energy of the incident particles. At high energies, calorimetry is the only technique available to measure the energy of the astrophysical radiation. As the general tendency of the flux of cosmic radiation is to decrease with increasing energy, there is a certain energy scale where it becomes prohibitively expensive in mass, volume, etc. to directly measure the radiation. Thus, astrophysical experimental configurations fall into two classes, those that directly measure the particles, usually from sub-orbital (balloon) or orbital (satellite) platforms, and those that use the atmosphere, Earth, or moon as the detection media. Each has its own unique set of technical challenges to overcome. In particular, the calibration of large-scale detectors at extreme energies requires input from Monte Carlo simulations as the energy is beyond any terrestrial particle accelerator test beam. Furthermore, the properties of the detection medium, e.g. the atmosphere, must be monitored and well-understood to accurately understand the energy resolution. Systematic effects on detector energy resolution can have devastating effects when measuring a steeply falling spectrum as is the case for many astrophysical observations.

2. Cosmic Ray Experiments

The measurement of the cosmic ray spectrum highlights the nuances of measuring the cosmic radiation. The differential flux of cosmic rays is shown in Figure 1 and displays a power law behavior over more than 11 orders of magnitude, from $\sim$ GeV to more than 10^{11} GeV. Several features due to changes in the spectral index are evident in the figure. The first, at $\sim 10^{15}$ eV (knee), is identified by a steepening of the spectrum. The second, $\sim 10^{18}$ eV (ankle), shows a recovery of the spectrum. The question of whether or not there is a feature at $\sim 10^{20}$ eV (big toe), is currently an issue and several future cosmic ray experiments are planned to make decisive measurements at this extreme energy.

Figure 1 also illustrates the variation in cosmic ray integral flux at a particular energy: from ~ 1 particle per m^2-s at 100 GeV to ~ 1 particle per km^2-century at 10^{10} GeV. It turns out that the energy below which direct cosmic ray measurements are feasible with current technology is approximately 10^{15} eV, i.e. the location of the knee. Above this energy, indirect measurements using the Earth's atmosphere as the detector medium are required in order to obtain an appreciable event rate. At the extreme energy of 10^{20} eV, even terrestrial experiments that employ the atmosphere as a vast target become rate limited. The possibility of using space-based experiments to monitor even larger atmospheric volumes offer the opportunity to increase the experimental sensitivity to the highest energy particles known in the universe.

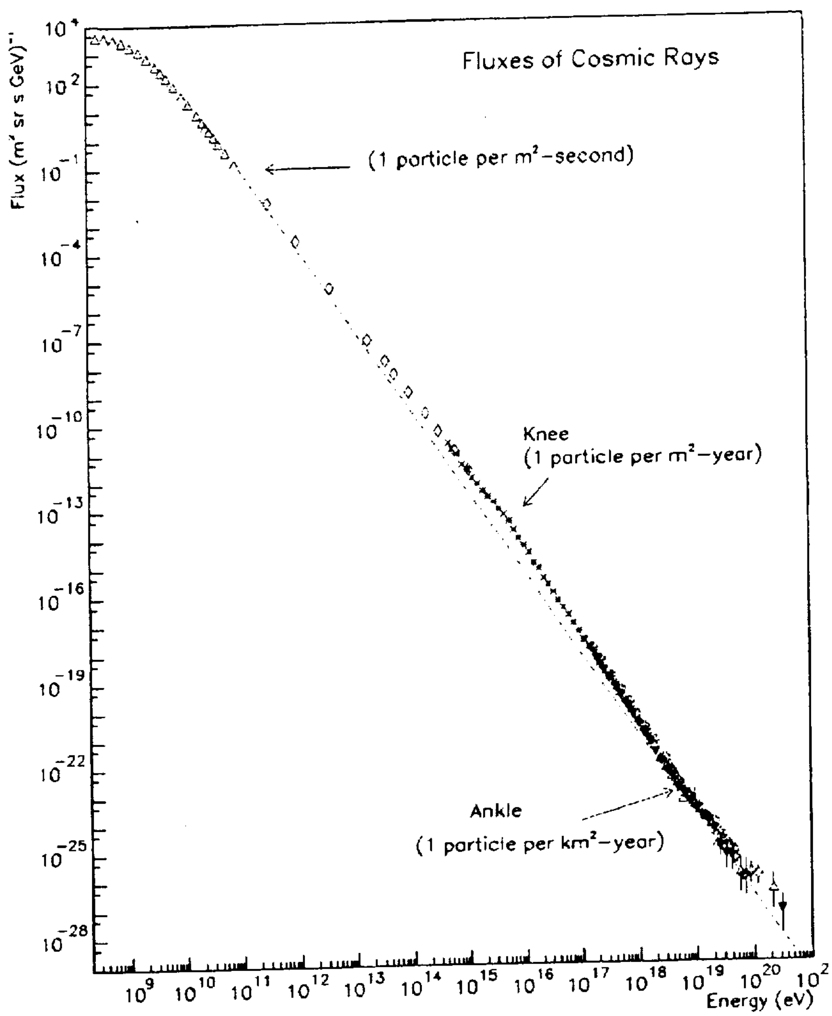

Figure 1. The differential flux of cosmic rays as a function of incident energy (Source: Simon Swordy).

Astro-particle physics experiments that measure the lower end of the cosmic ray spectrum require only a fraction of a m^2-sr geometry factor to achieve a substantial event sample in several hours operation. This experimental size fits well into a balloon-borne payload. As an example, the CAPRICE instrument[1] has had two successful flights performing measurements on the proton and helium spectra ($0.4 - 200$ GV), antiproton measurements ($0.62 - 49$ GV), electrons and positrons (0.85 – 14 GeV), and atmospheric muons. The experimental configuration employs a detector suite using a superconducting magnetic spectrometer, RICH detector, time-of-flight (TOF) system, and a segmented calorimeter. The 48×48 cm^2 imaging calorimeter is 7 X_0 and is constructed of interlaced planes of tungsten absorbers and silicon strip detectors. This configuration achieves an energy resolution of approximately $15\%/\sqrt{E}$. The CAPRICE instrument is to have a dedicated flight to perform atmospheric muon measurements, as an aid in determined the atmospheric neutrino flux, in the 2003.

Balloon-borne payloads offer the opportunity to develop technologies for incorporation in satellite-based experiments and the W-Si calorimeter used by CAPRICE is a prime example. This calorimeter has been further developed and is an integral part of the PAMELA experiment[2,3] that is scheduled to be launched in 2003. The experiment's scientific goals are the determination of the proton spectrum to 700 GeV, the electron spectrum to 400 GeV, positron spectrum to 270 GeV, the antiproton spectrum to 190 GeV, and perform searches for anti-nuclei. The experiment will be attached to a Russian Resurs-DK1 satellite and will be launched in an elliptical, quasi-polar orbit. The PAMELA detector suite includes a magnetic spectrometer with silicon strip detector tracker, a transition radiation detector, TOF detector, anti-coincidence detector, and a W-Si imaging calorimeter. The 24×24 cm^2 calorimeter, which provides electron-hadron separation, is 16.3 X_0 and 0.6 λ_{Int} with an energy resolution of $\lesssim 6\%$ for electrons ($E_e \gtrsim 25$ GeV).

Several other cosmic ray experiments using large area calorimeters are planned to be flown (and re-flown) in the future include the AMS-02 experiment[4] which will be placed on the International Space Station and experiments that will be flown on long and ultra-long duration balloons, ATIC[5] and CREAM[6]. The AMS-02 experiment is to be launched in 2005 and will include a superconducting magnetic spectrometer, transition radiation detector, RICH detector, time-of-flight system, and a $\sim$ 16 X_0 lead-scintillating fiber calorimeter in its detector suite. The AMS-02 experiment will perform charged-particle spectroscopy and anti-matter searches, extending these measurements to higher energies and sensitivities. The ATIC experiment, which uses a $\sim$ 18 X_0 segmented BGO calorimeter, a silicon charge detector, and scintillator detectors, has had a successful long-duration balloon flight (15 day) and plans another this year. The CREAM experiment plans an ultra-long duration (100+ day) balloon flight in 2003 and employs a 20 X_0 sampling tungsten-scintillating fiber calorimeter along with a timing-based scintillation charge detector and transition radiation detector. The science goals of ATIC and CREAM are to perform composition measurements of the cosmic ray spectrum to greater than 10^{14} eV.

There has been recent development on realizing the goal of placing an instrument with a large calorimeter in orbit with the science goal of measuring the cosmic ray composition at the knee, 10^{15} eV. Two versions of an instrument known as ACCESS[7] have been proposed and each includes a deep, segmented, large-area calorimeter in their design. Under the ACCESS development program, prototype TRDs, charge detectors, and calorimeters have been tested in a variety of CERN test beam experiments along with detector modules from the PAMELA, ATIC, and CREAM experiments.

Above the energy of approximately 10^{15} eV, it becomes extremely difficult to construct a direct measurement experiment that can have an appreciable cosmic ray event rate. However, the atmosphere can be used as a target and detection medium for cosmic ray induced airshowers. Two different methodologies are employed[8]. The first uses a sparse array of ground detectors to measure the charged particle content of the traversing airshower. The energy of the airshower can be extracted from the measured signal at some distance from the shower core by comparing the results to airshower simulations. The incident direction of the airshower can be obtained via detector timing. The second method, pioneered by the Flys Eye experiment[9], uses the atmosphere as a calorimeter by measuring the near-UV nitrogen fluorescence excited by the traversing charged particles in the propagating airshower. A detector with sufficient spatial, angular, and temporal segmentation can image a large portion of the profile of the airshower, which facilitates energy, angular, and incident particle identification measurements. Air fluorescence detectors can only operate on dark, moonless nights and thus have $\sim 10\%$ duty cycle as compared to the 100% of ground arrays. Furthermore, the transmission properties of the atmosphere must be well understood in order to accurately reconstruct the airshower energy.

The ground array method has been employed by the KASCADE experiment[10] (and others) to measure the cosmic ray spectrum from around 10^{15} eV. In addition, the ground array and air fluorescence methods allow the construction of detector systems with detection apertures large enough to measure the cosmic ray spectrum to energies $> 10^{20}$ eV. The results of the HiRes air fluorescence experiment[11] and the AGASA ground array experiment[12] have indicated cosmic rays in excess of 10^{20} eV albeit without full agreement on the absolute flux. These events have fueled the mystery of their source as their energy places them above the Greisen-Zatsepin-Kuzmin (GZK) cutoff, caused by the interaction of ultra-high energy protons and the cosmic microwave background, and they do not point back to any obvious local (< 100 Mpc) sources.

In order to resolve the mystery of Ultra High Energy Cosmic Rays

(UHECR), several experiments are under construction or being developed. The first is the Pierre Auger Observatory[13], currently under construction in Argentina, will employ a large ground array of detectors along with air fluorescence detectors. This hybrid measurement technique allows for the cross-calibration of a sample of airshower events using the two measurement techniques. The Auger ground array will contain 1600 water Cherenkov tanks spaced 1.5 km apart along with 4 air fluorescence telescopes. This arrangements leads to full efficiency at 10^{19} eV with an aperture of $\sim$ 7000 km^2-sr, which is nearly an order of magnitude larger than currently running experiments. The aperture of the Auger array which uses the hybrid technique is $\sim$ 700 km^2-sr. Simulation studies indicate that the angular resolution should be $\sim$ 1 deg with an energy resolution (at 10^{20} eV) of $\sim$ 25% for the ground array and $\sim$ 10% for the hybrid mode. The array is expected to be complete in 2005, and an engineering array, comprised of 40 water tanks and an air fluorescence detector, is currently in operation. Plans also exist for constructing an Auger site in the Northern Hemisphere that will have a similar aperture as the Southern site. There is also another ground-based experiment, the Telescope Array[14], that is developing an array of air fluorescence detectors to yield a large aperture UHECR instrument.

Ground-based experiments such as Auger push the limits on the size of a UHECR experiment. However, space-based experiments using the air fluorescence technique can substantially increase the detection aperture of UHECR[15]. The Extreme Universe Space Observatory (EUSO)[16], currently under European Space Agency (ESA) Phase A study, entails placing a large air fluorescence detector on the International Space Station. The experiment is comprised of a telescope with wide-angle optics that will collect and focus the near-UV air fluorescence signal on a segmented focal plane array. The baseline instrument design in an orbit of 400 km with a 10% duty cycle leads to an effective detection aperture of 50,000 km^2-sr and an energy threshold of slightly more 10^{19} eV. Simulation studies indicate an energy resolution of better than 20% at 10^{20} eV and good angular resolution. EUSO is planned to be deployed $\sim$ 2009.

The Orbiting Wide-angle Light-collectors (OWL) experiment[17], currently under study by NASA, will employ two air fluorescence telescopes in quasi-equatorial, 1000 km orbits. Each telescope will use large, wide-angle optics to image the air fluorescence signal onto a segmented focal plane array. The two telescopes will orbit with a nominal 500 km separation leading to stereo viewing of UHECR induced airshower events. Stereo reconstruction, as proved by the Fly's Eye and HiRes experiments, offers a powerful methodology in both reconstructing the events and understanding the properties of the atmosphere.

Simulation studies indicate an energy resolution $\sim$ 15% at 10^{20} eV and an angular resolution $\sim$ 1 deg. The event detection aperture, assuming a 10% duty cycle, is more than 200,000 km^2-sr with an energy threshold slightly less than 10^{20} eV. Thus, the OWL mission offers the opportunity to obtain a substantial sample of trans-GZK events and unravel the mystery of the source(s) of the highest energy particles known in the Universe.

3. Gamma Ray Experiments

The flux of astrophysical gamma rays exhibits an effect similar to that observed in the cosmic ray spectrum: the flux decreases with increased energy. Aside from effects caused by the astrophysical generation mechanisms, the gamma ray flux is further depleted at higher energies, with a strong dependence on the redshift of the source, due to the interaction with the bath of IR photons in the Universe[18]. Thus, there is an energy where it becomes difficult to obtain an appreciable gamma ray event rate with direct detection. However, since high energy photons induce airshowers, the atmosphere can be used as a target and detection medium. For example, this phenomena is used to measure high energy gamma rays by imaging the Cherenkov radiation induced by electromagnetic cascades in the atmosphere.

The Swift mission[19], scheduled for launch in 2004, is designed to make sensitive measurements of the Gamma Ray Burst (GRB) phenomena with arcsecond precision. The instrument includes a UV and optical telescope, an X-ray telescope ($0.2 \leq E_\gamma \leq 10$ keV), and a Burst Alert Telescope (BAT, $15 \leq E_\gamma \leq 150$ keV). The BAT is comprised of 256 modules each with 128, $4 \times 4 \times 2$ mm^3 cadmium-zinc-telluride (CZT) detectors. The > 0.5 m^2 CZT detector array images gamma rays that pass through a coded aperture mask with a 2 sr field of view. Laboratory measurements have demonstrated an energy resolution $\sim$ 5% at 60 keV.

At higher energies, two missions are planned to improve upon the pioneering measurements provided by the EGRET instrument[20] that was part of the Compton Gamma Ray Observatory. In particular, these missions will extend the energy range of gamma ray measurements. The first is the AGILE experiment[21] which is to be launched in 2003. This instrument is comprised of a pair-conversion telescope employing silicon strip detectors and tungsten absorbers followed by a shallow, 1.5 X_0 CsI calorimeter formed in two, segmented layers. The AGILE instrument will have a large, $\sim$ 3 sr field-of-view imaging gamma rays in energy range $\sim$ 30 MeV $-$ 50 GeV.

The GLAST mission[22], to be launched in 2006, is to perform gamma ray astronomy with high sensitivity in the energy range $\sim$ 5 MeV $-$ $\sim$ 300 GeV.

The large field-of-view ($\sim 75\%$ sky coverage every orbit) instrument consists of silicon microstrip detectors with lead absorbers to form a pair-conversion telescope with an on-axis area of over 2 m^2, a gamma ray burst monitor, a segmented anti-coincidence system, and a CsI segmented calorimeter. The 9.5 X_0 calorimeter[23] will be constructed in a modular arrangement mimicking that used for the silicon, pair-conversion telescope with each of the 16 modules containing 8 layers of CsI logs. Test beam and simulation results indicate energy resolutions of $< 20\%$ ($5 - 100$ MeV), $< 10\%$ (100 MeV -10 GeV), and $< 6\%$ ($10- \sim 300$ GeV).

A novel approach to perform gamma ray astronomy in the 100 keV $-$ 1 MeV range is offered by the Fresnel Lens Gamma Ray Telescope[24]. This visionary mission is based upon the principle that a several meter diameter phased-Fresnel lens constructed of aluminum can be employed to concentrate gamma rays on a segmented detector array leading to orders of magnitude improvement in gamma ray sensitivity. Furthermore, angular resolutions of a micro-arcsecond can be achieved enabling the imaging of gamma rays emitted from the horizons of extragalactic black holes. This imaging capability in gamma rays will complement that in X-rays that will be provided by the MAXIM mission[25]. As the focusing of the lens is weak, the focal length of the telescope is of the order of 10^6 km and requires the formation flying of two spacecraft, one with the lens and another with an array of gamma ray detectors. The detectors must have very good energy resolution, $\sim 1\%$, in order to exploit the full angular resolution potential of the lens which has energy dependent focusing.

Above the energy of a few hundred GeV, it is difficult to construct an instrument to directly measure gamma rays with an appreciable event rate. However, on dark, quasi-moonless nights, the atmosphere can be used as a target and calorimeter by imaging the Cherenkov radiation generated by the induced electromagnetic cascade. The Cherenkov light fills in a cone with a characteristic angle of ~ 1 deg and illuminates an area $\sim 50,000$ m^2. At ground level, the Cherenkov signal arrives in several nanoseconds with a strength of approximately 100 photons/m^2 at 1 TeV. Pioneered by the Whipple experiment[26], Imaging Airshower Cherenkov Telescopes (IACTs) use large mirrors to collect this Cherenkov light and focus the photons onto a segmented detector. The incident shower direction is obtained from the orientation of the image in the detector while the shape of the image allows for rejection of hadronic showers. The intensity of the signal in the detector yields a measurement of the energy of the primary photon.

One of the goals of the next generation IACTs is to lower the gamma ray detection threshold to the level of 10's of GeV and thus provide an overlap with the GLAST measurements. The Magic telescope[27] will have a collecting area of ~ 240 m^2 and thus will able to lower the energy threshold to < 15 GeV. The energy resolution is expected to be 10% at 1 TeV, and the angular resolution is anticipated to be $0.2 - 0.5$ deg. Other experiments plan on constructing arrays of IACTs and employ stereoscopic imaging to improve on the angular resolution to < 0.1 deg. Included in this group are HESS[28], Cangaroo-III[29], and Veritas[30]. The energy threshold for these arrays is given as ~ 50 GeV with an expected energy resolution of $\sim 10\%$ at 1 TeV.

Another methodology to measure high energy photons is to employ Solar collector farms (during dark nights) to harvest the Cherenkov light onto a segmented array of detectors. As the individual heliostats have collecting areas of 10's of m^2, the incorporation of a large number of the available heliostats in the measurement leads to a large effective collecting area and thus a lower energy threshold. Experiments currently using this technique include STACEE[31], CELESTE[32], GRAAL[33], and the Solar Two Observatory[34]. The performance goals of these instruments are an energy threshold in the 10's of GeV, angular resolution in the range $0.1 - 0.25$ deg, and energy resolution of $\sim 25\%$ at an energy ~ 50 GeV.

Gamma ray astronomy can also be performed by measuring the charged particles in the photon induced electromagnetic cascades. The benefit of this type of measurement is that a large area can be instrumented with 100% duty cycle detectors that can achieve large solid angle acceptance. Experiments such as Milagro[35] and ARGO-YBJ[36] are located at high altitude where the charged particle density in the airshower is relatively large. Milagro is a large pond of water instrumented with two layers of photomultiplier tubes that detect the Cherenkov radiation from the charged particles in the shower. The area coverage is enhanced to $40,000$ m^2 with the incorporation of 170 "outrigger" Cherenkov water tanks. An energy threshold of ~ 200 GeV is eventually anticipated with an energy resolution of $30 - 50\%$ for $E_\gamma > 1$ TeV and an angular resolution < 1 deg. The ARGO-YBJ detector, with an energy threshold ~ 100 GeV, will employ a single layer of RPC's covering an area of ~ 6500 m^2.

4. Neutrino Experiments

The ability to measure the flux of extraterrestrial neutrinos offers a unique window to the astrophysical processes of the universe. Neutrinos are unaffected by magnetic fields and propagate virtually unattenuated. Thus, astronomy using neutrinos promises to expand the study of astrophysical phenomena, particularly in energy ranges where photon astronomy is limited due to absorptive effects, e.g. at energies $\gtrsim 1$ TeV. Neutrinos are difficult to measure because of their small interaction cross sections and the existence of large backgrounds due to sources such as the much more numerous products of cosmic ray interactions. These lead to the need for large detector volumes to obtain an appreciable event rate and requirements to reduce the backgrounds such as locating the neutrino detector deep underground.

The energies of astrophysical neutrinos range from $\sim 10^{-4}$ eV ($1.95K$ relic neutrinos) to $> 10^{20}$ eV for neutrinos from the interaction of UHECR with the cosmic microwave background. Between these energy extremes are neutrinos from the Sun ($E_\nu \lesssim 15$ MeV), neutrinos from supernovae ($< E_\nu > \approx$ 10's of MeV), atmospheric neutrinos which follow the spectrum of the inducing cosmic rays, and high energy neutrinos with ($E_\nu \gtrsim 100$ GeV).

In the arena of Solar neutrino measurements, the Super-Kamiokande experiment[37] (water Cherenkov detector) is to be rebuilt, the Sudbury Neutrino Observatory[38] (heavy water Cherenkov detector) will continue to take data, and the ICARUS experiment[39] (liquid argon TPC) is to be constructed. The next generation of solar neutrino experiments have a focus of reducing the neutrino energy threshold to well below 1 MeV in order to measure the monoenergetic neutrinos from the ^7Be solar process and obtain better determination of the neutrino oscillation parameters[40]. The reduced energy threshold also allows for measurement of neutrinos from the *pp* process which is more insensitive to solar modeling. The BOREXINO experiment[41] will use 300 tons of liquid scintillator as the neutrino target and detector to achieve an energy threshold of ~ 250 keV and an energy resolution of $\sim 5\%$ at 1 MeV. KAMLAND[42] employs 1000 tons of liquid scintillator and plans to extend its primary science of a reactor neutrino oscillation search to solar neutrinos. Other experiments include the LENS experiment[43] which will use Yb loaded liquid scintillator, HERON[44] using superfluid helium, and HELLAZ[45] which will employ a helium gas TPC.

Galactic supernovae occur with a frequency of one every 10−30 years. Thus, experiments sensitive to the observation of neutrinos from supernovae need to be designed for long, many-year operation in order to guarantee an observation. Currently operating experiments such as Super-Kamiokande and SNO are sensitive to neutrinos from supernovae. In addition to the future Solar neutrino experiments that will have supernovae-neutrino sensitivity, multi-ton experiments have been proposed to use high-Z neutrino targets and detect the products, particularly neutrons, from the neutrino-nucleus interactions. The OMNIS experiment[46] will use iron and lead as the target materials. The different energy thresholds for the various interaction channels leads to a methodology to distinguish between ν_e charged-current and neutral current interactions as well as ν_X neutral current interactions[47]. The event rate dependence of the different interaction channels leads to a sensitivity to neutrino oscillations. OMNIS and another experiment of this type known as LAND could be located at a dedicated, underground neutrino laboratory.

At energies $\gtrsim 1$ TeV, astrophysical objects such as Active Galactic Nuclei (AGNs)[48] and Gamma Ray Bursts[49] could be a source of neutrinos via the decay of mesons produced from an accelerated hadronic component. However, detectors with ~ 1 km^3 of water-equivalent volume are required in order to obtain an appreciable event rate[50]. At these energies, the neutrinos can be detected by measuring the Cherenkov radiation of the interaction products using the technique pioneered by the DUMAND[51] and BAIKAL[52] experiments. The ICECUBE experiment[53] will expand upon the successful AMANDA array[54] by deploying 80 strings totalling 4800 PMTs to instrument ~ 1 km^3 of Antarctic ice. The energy resolution from measurements of the muon from ν_μ interactions is expected to be $\sim 0.3\log(E_\mu)$ with an angular resolution of ~ 1 deg. For shower-type events, e.g. ν_e interactions, the energy resolution is expected to improve while the angular resolution will be degraded. Several experiments are planned to construct large, underwater neutrino telescopes with an eventual volume ~ 1 km^3. These include ANTARES[55], NESTER[56], and NEMO[57]. These experiments have a nominal energy threshold of ~ 1 TeV and a planned upgrade to the BAIKAL experiment would provide neutrino measurements at lower energies. As the Cherenkov light-scattering length is much longer in water than ice, the underwater experiments expect an angular resolution ~ 0.5 deg for muons from ν_μ interactions. These experiments will also have a sensitivity to bursts of lower energy neutrinos such as ν_e from supernovae.

At energies $\gtrsim 1$ PeV, the neutrino and antineutrino cross sections become virtually equivalent[58]. Furthermore, the average energy of the lepton in a neutrino interaction is more than 70% of the initial neutrino energy, increasing to $\sim 80\%$ at $E_\nu = 10^{20}$ eV with the remaining energy given to a hadronic shower at the neutrino interaction point. These kinematics lead to an unique, "double-bang" signature for high energy, charged-current ν_τ interactions where the produced τ-lepton has a sufficient Lorentz boost to lead to a separated shower induced by the τ decay[59]. Thus experiments, such as ICECUBE, have a methodology to detect ν_τ events that could arise from the oscillations of astrophysical ν_μ neutrinos. The importance of ν_τ sensitivity is enhanced when considering the fact that the Earth attenuates neutrinos with energies $\gtrsim 40$ TeV, but ν_τ can effectively propagate through the Earth, albeit with degraded energy, due to regeneration[60].

Neutrinos at ultra-high energies, $\sim 10^{20}$ eV, are expected from the decay of pions produced from the interaction of UHECR with the microwave background[61], i.e the GZK effect. Furthermore, the speculative, "top-down" processes, such as topological defects[62] or Z-bursts[63], that are proposed to be the source of the trans-GZK cosmic rays also predict hard neutrino spectra at ultra-high energies. The next generation UHECR experiments, Auger, Telescope Array, EUSO, and OWL, monitor a large atmospheric volume and thus have a sensitivity to ultra-high energy, neutrino induced airshowers. These events can be separated from the more numerous UHECR events by using the fact that neutrino-event interactions can occur much deeper in the atmosphere. Thus deep, horizontal airshowers offer a signature for ultra-high energy neutrino interactions.

An ingenious method for detecting high energy ν_e interactions in the Earth (or moon) uses the radio Cherenkov signal generated by the subsequent electromagnetic shower[64]. Proposed by Askaryan, the intense coherent, Cherenkov radio pulse is caused by a $\sim 20\%$ charge asymmetry in developing electromagnetic showers and the coherence leads to an energy dependent power enhancement. The Askaryan effect has been verified in a SLAC test beam[65] and has been employed by the RICE array[66] in Antarctica to search for high energy ν_e interactions in the ice and the GLUE experiment[67] which uses radio telescopes to search for ultra-high energy neutrino interactions in the moon. The strength of the radio Cherenkov technique is that for materials with good radio transmission properties, extremely large neutrino detectors can be instrumented. The use of ~ 25 km^3 salt domes is being investigated as well as flying a radio Cherenkov experiment on a long duration balloon over Antarctica. The latter experiment, ANITA[?], would have $\sim 10^6$ km^3 of ice as the neutrino fiducial volume and be sensitive to neutrinos above $\sim 10^{17}$ eV. The experiment is expected to have an energy resolution of ~ 1 at 10^{18} eV and an angular resolution of ~ 10 deg. The potential performance combination of the relatively low energy threshold and large neutrino-detection aperture of these experiments surpasses the neutrino detection capabilities of other techniques for ultra-high energy neutrinos.

5. Summary

Future experiments in the area of cosmic rays will extend charged-particle spectroscopy measurements and provide a sensitive search for antimatter in the cosmic radiation (PAMELA, AMS), provide elemental composition measurements to 10^{15} eV (ATIC, CREAM, and possibly ACCESS), and try to unravel the mystery of the source of ultra-high cosmic rays (AUGER, Telescope Array, EUSO, OWL). Future gamma ray missions promise to study the phenomena of gamma ray bursts with superb angular resolution and sensitivity (SWIFT) and close the energy window that exists between ~ 20 GeV and 1

TeV (GLAST, Air Cherenkov Telescopes, MILAGRO) while making dramatic improvements in angular resolution and sensitivity. The potential to perform high energy neutrino astronomy will be realized with the construction of km^3 neutrino detectors (ANTARES, NESTER, ICECUBE). These combined with the neutrino measurement potentials of the UHECR experiments and experiments that employ the radio Cherenkov technique (ANITA) promise to open a new window to the astrophysical processes of the universe.

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