**1 Introduction**

Snowmass 1994 brought together for the first time a very disparate, yet interconnected, group of astrophysicists, cosmologists, particle physicists, nuclear physicists, gravitational physicists, and astronomers for an intensive two-week Summer Study to discuss the goals of problems that link them intellectually. The range of topics discussed was vast, but clear connections could be easily discerned. Thus, even though the Summer Study was organized in terms of five topical “supergroups” (Neutrino, Cosmic Rays, Low-Background Experiments, Gravitational Phenomena, and Cosmology), there were clear overlaps. For instance, short-baseline neutrino oscillation experiments probe neutrino masses which are cosmologically significant. Results in this area may well impact other searches for dark matter in low-background experiments. Similarly, searches for gravitational waves produced by violent events in the universe may illuminate other enigmatic phenomena, like intense rapidly varying gamma-ray bursts.

The remarkable high attendance at Snowmass 1994 (nearly 460 participants) signaled a field coming of age. Although it is still difficult to draw a clear boundary around this emerging discipline of Particle and Nuclear Astrophysics and Cosmology, two facts are contributing to its vitality. First, there is a strong synthetic synergy resulting from the joining of disparate disciplines. Thus, for example, the organizational and computational talents of particle physicists have enabled astronomers to scan millions of stars for the Markev model. Conversely, remarkable astrophysical phenomena like super energetic air showers have rejiggered physicists away from their laboratories to construct extensive open-air detectors to better understand these phenomena. Second, the development of new instruments, telescopes, and detectors has been most crucial. Indeed, it is the fact that drives the field. From COBE to Galaxies and Reionization, to the new 8m telescopes and the instruments on CGRO and the Bubble observatory, data in profuse quantities has been flowing. These data is the lifeblood of this new field. What is particularly exciting is that the flow of new information is just beginning, with a number of second generation projects underway and many new initiatives already well advanced.

In this overview, we want to describe briefly some of the accomplishments of this field and the intellectual goals that guide it. At the same time we want to delineate some of the areas where we can expect progress in the future, outlining some of the proposed new initiatives. In keeping with the organization of the Summer Study this overview is structured in a similar fashion, except that we have incorporated the discussion of low-background experiments into that of the other areas.

**2 Neutrinos**

Neutrinos are playing an increasingly crucial role in tests of the standard model of electroweak interactions, in cosmology, and in probing the nuclear and particle astrophysics of stars and supernovae. In particle physics, neutrino properties may provide us with a window on new physics phenomena at energies scales well beyond the direct reach of accelerators. Measurements of neutrino masses and mixing could provide the experimental foundations for building a new and more general standard model. In cosmology, neutrinos are a leading candidate for the “missing mass” that appears to govern the clustering of galaxies on very large scales. Measurements by COBE and other groups of the angular variations of the temperature of cosmic microwave photons suggest that such “hot dark matter” is present. In nuclear and particle astrophysics, neutrinos provide a probe of the interiors...
of our sun and supernovae, higher energy neutrinos could allow us to look into the cores of active galactic nuclei.

There is also no small measure of serendipity in the relationship between these neutrino astrophysics subfields. In the past decade it was discovered that the effects of neutrino mass and flavor mixing are intricately woven into motivations for the search for neutrino oscillations. It is also appears that the two neutrino mass flavors favored by cosmologists could help explain how supernovae explode, and thus how our galaxy may have been seeded with the heavy elements responsible for life. Such connections have greatly stimulated collaboration allowing us to look at neutrino physics from new angles.

It has also meant that we have added to our "toolbox" of laboratory neutrino experiments powerful new tools for neutrino astrophysics and astrophysical probes of neutrino properties.

As we enter the next century, we are finding that neutrino physics at a fundamental level is not the same as we were taught before.

The synchrotron emission of low energy gamma-rays from the Crab nebulae can be related to high energy gamma rays produced in inverse Compton scattering of the high energy electrons responsible for that synchrotron emission. Gamma-rays, unlike the charged cosmic ray particles, are unaffected by magnetic fields and can reveal sources of the charged cosmic ray particles. Thus, the study of all kinds of radiation incident on the earth provides insight into a broad range of astrophysical problems and mysteries.

The existence of the earth's atmosphere dictates the choice of detection techniques to observe astrophysical objects in various ranges of the electromagnetic spectrum. From the ultra-violet to gamma-rays, energy − 20 GeV, the atmosphere is opaque. Thus, observations must be made from satellites or on high altitude balloons. In the infrared, telescopes at high altitude must be used. In the radio and X-ray bands, rocket borne observatories are commonly used. It is only in the gamma-ray domain that the atmosphere is reasonably matched to the earth's magnetic field. Observations of high energy gamma rays produced in the atmosphere are limited to 100 MeV. Even above this energy, the gamma rays produced by the interaction of cosmic gamma rays and atmospheric nucleons are anisotropically distributed in the sky and do not correlate with bursts in other parts of the electromagnetic spectrum. The EGRET detector
The cosmic rays which strike the earth isotropically comprise nuclei with abundances which are very similar to solar system abundances, except that elements with high ionization potential are systematically suppressed. It is as if the particles are injected at low energy into an accelerator. It is believed that this scenario is correct with supernova shock waves serving as the accelerator. Shock acceleration naturally produces a power law spectrum as observed. Detailed examination of this acceleration mechanism suggests that the upper limit of this process occurs at about 10^15 eV. Certainly the cosmic ray spectrum steepens at about 3 x 10^18 eV which may be related to the upper limit of acceleration.

The cosmic rays are contained in the galaxy by its magnetic field. As the cosmic rays pass through the dust and gas, their energy is reduced by collisions with the interstellar matter. Above about 10^13 eV, the cosmic rays are absorbed, produced by spallation reactions and detected by the average of the amount of galactic material traversed by the cosmic rays and hence their lifetime. The spallation products show that the mean life of the cosmic ray nuclei in the galaxy is about 10^6 years and that the particles with higher magnetic rigidity escape from the galaxy more easily. These facts imply that the mean atomic weight of the cosmic rays should increase with their total energy in the regime of the knee. Since the flux of cosmic rays falls rapidly with energy, it has been difficult to directly measure the abundances above 10^15 eV. New techniques and new instruments will permit the direct measurement of the relative abundances up to 10^20 eV. Indirect measurements of the mean atomic number will be possible by means of the simultaneous measurement of a number of shower parameters. This technique will be effective above 10^19 eV, so that an order of the two techniques is possible.

Beyond the knee little is known about the cosmic rays other than they are accelerated in the Local Group of galaxies. The acceleration mechanism, the source (galactic or extragalactic), and the mean atomic number. In the next decade technical means will be developed to answer these questions. Cosmic rays do not exist independently of other powerful astrophysical phenomena; the effort to understand the origin of cosmic rays on a much broader scale is underway.

Among the charged cosmic rays there are also electrons, positrons, and antiprotons which are much less abundant. Their presence in the cosmic rays is expected at a pre-valence of 10^-6. Their detection will provide tests of theories. Lower energy cosmic rays with galactic material. Excesses of the antiparticle nuclei may be related to the collapse of the universe when the density of matter and antimatter are in cosmic strings, the early universe. These examination new concept for a space-based instrument for probing black holes, neutron stars, white dwarfs, cosmic string, and the early universe. These experimentally accessible phenomena have much intellectual contact with Particle and Nuclear Astrophysics and Cosmology, and thus were included in the Snowmass Study. Also included were two quantum gravity phenomena (quantum cosmology and black-hole evaporation) which, though not directly experimentally accessible today, nevertheless may have long-term import for Particle and Nuclear Astrophysics and Cosmology.

4.1 Quantum Aspects of Gravity

General relativity theory states that the Universe begins in a big bang singularity where the density of matter and the curvature of space-time were both infinite. Relativity theory also states that no mass-energy of infinite density and curvature reside inside black hole. Simple quantum mechanical considerations predict that, when the density and curvature exceed a Planckian value constructed from Planck's constant, the quantum nature of gravity will be affected. Thus, the very fabric of the universe should be the domain of quantum gravity.

There is hope, from cosmological observations, that once matter exits the Planckian regime, quantum gravity will be significant. One can come to two different directions. The first is that of quantum cosmologists who use candidate, partial formulations of the laws of quantum gravity to try to understand the big bang. The second is that of the Universe in the early universe. These two directions have much intellectual contact with Particle and Nuclear Astrophysics and Cosmology (quantum strings, and the early universe). These examinations new concept that the universe made its transition from an initially quantum state of zero density, to the world in which we live now. This direction taken by participants in the Snowmass G. working group. The second direction is that of astrophysicists and physical cosmologists who begin with observations of the universe today and try to extrapolate back toward the Planck era. This direction, which was taken by Snowmass subgroup E, is concerned with understanding the details of the universe, such as the early universe and its evolution. The details of such a direction might be conceived in the context of quantum gravity, but it is not clear what new concept that the universe made its transition from a Planckian era.
A successful partial step toward quantizing gravity was achieved in the 1970s, when several theorems, coming from different directions, converged on a seemingly unique way to treat quantum fields that avoids the classical, curved spacetime of general relativity. Much to everyone's amusement, the resulting quantum field theory in curved spacetime predicted that a black hole must emit radiation ("Hawking radiation") and thereby must evaporate, if one waits long enough (for the longer than the Universe's age for stellar mass black holes, but much less for black holes much more massive).

The prediction of black-hole evaporation has led to a theoretical conundrum, the resolution of which may teach us much about the full laws of quantum gravity. Our current understanding of black holes suggests that a black hole should be fully determined by its mass and spin, and hence as many years of analysis by many gravitational theo­reticians, we now fully understand these predictions, with one major exception. We do not yet understand in detail the behavior of highly, degenerate black holes (e.g., colliding and colliding black holes). That dynamical understanding may come within the next decade, as a result of combined numerical solutions of Einstein's equations in a thermodynamic vanishingly small state, the hole's form and subsequent evap­oration seems to transform in a strange manner.

In other words, information about quantum mechanical conditions is lost not just in practice, but even in principle. Such an information loss and pure-to-mixed transitions are forbidden by the standard Hamiltonian formulation of quantum mechanics, but is permitted by certain general­izations of quantum theory based on Feynman's path integral methods.

Since the endpoint of the evaporation is governed by the (ill-understood) full laws of quantum gravity, it may be that this notion is too narrow to tell us that quantum gravity cannot be formulated in a Hamiltonian way. However, this is just one of several possible implications of the apparent information loss—indeed, the one that most theoreticians find least plausible. While there is great disagreement about the role of chance, there is general agreement that theorems are likely to learn much about the inter­face between general relativity, quantum theory, and astronomy. The latter, in turn, is (apart from the null horizon) the principal focus of the General Covariant Group Q.

4.2 Black Hole Astrophysics

Black holes are predicted to exist by general relativity, and there is compelling circumstantial evidence that they do exist in rela­tively small numbers. The 1970s saw the discovery of a new class of objects, stellar-mass black holes (M = 3 to 30 M⊙) that are recog­nized by their emission of massive neutron stars, and supermassive black holes (M = 107 to 109 M⊙) that rel­ate to the masses of galaxies. These objects were first observed primordial black holes formed in the very early universe with a temperature of 10^22 K or higher.

4.3 Gravitational Wave Astrophysics

Gravitational waves are ripples of space-time curvature that travel through the universe. They are produced by the gravitational field of a massive object as it accelerates. Gravitational waves are expected to be produced by a wide range of astrophysical phenomena, including the coalescence of neutron stars and black holes, and supernovae. The detection of gravitational waves is a major goal in astrophysics.

In the late 1960s, the first tentative evidence for gravitational waves was reported. This evidence was based on observations of the pulse timing of pulsars, which are highly magnetized, rotating neutron stars. Since then, many more observations have been made, and the evidence has grown stronger.

4.4 Interferometric Gravitational Wave Astronomy

Interferometric gravitational wave astronomy is a rapidly developing field that uses advanced interferometer techniques to detect and measure gravitational waves. The most advanced interferometers are the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo interferometer. These instruments use laser light to measure the tiny distances traveled by gravitational waves. The first gravitational wave detection was announced in 2015, marking a major milestone in the field.

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operate at the upper end of this band, where the interstellar medium is transparent to most astronomical frequencies. The network of interferometers is designed to work in the frequency domain, over frequency bands of several orders of magnitude, and they can determine the direction to sources outside the gravitational-wave field. The two waveform models of a gravitational wave, as measured with LIGO/VIRGO, are expected to be of comparable accuracy, and they would allow us to measure the ephemeris, observed gamma-ray sources are coming from the remnant of binary neutron stars at near cosmological distances, since these cores should produce observable gravitational waves. Moreover, we have only to look to the stars about our millimeter, the time at which the final remnant... point) determining how long after the collision the gamma-ray burst is expected to occur. Just as in the gravitational case, the magnitude determines the age of the universe, is verified out to several hundred megaparsecs (Mpc=3.08×10^24 cm), using galactic markers that trace back to the first billion years or so after the big. In the past few years, the COBE Far Infrared Absolute Spectrophotometer (FIRAS) experiment and the first experiments of the University of British Columbia detector group have verified the Planckian spectrum of the cosmic microwave background is in exquisite detail. This result is an extraordinarily compelling verification that the universe was once hot and has been expanding and cooling past its infancy. The gravitational waves’ sources, the highly relativistic photons produced during the first seconds after the big bang, are likely to be wholly unexpected discoveries. The grand ambitions of cosmology is to explain the evolution of the universe in terms of a simple, predictive paradigm in hand: the hot big bang model. According to this model, the universe began as an infinitesimal patch of space filled with hot, dense gas which suddenly began to expand and cool. The universe we see today is the result of this process. The age of the universe has been traditionally estimated by developing all of these techniques and seeking confirmation. Future Tests The new millennium approaches, cosmology is entering an epoch of unprecedented opportunities that enhance the big bang picture. As the new millennium approaches, cosmology is entering an epoch of unprecedented opportunities that enhance the big bang picture.
subject to evolutionary assumptions. Continued improvements in dynamical codes to model stellar atmospheres and supernova nucleosynthesis, such as late-decaying particles.

These limits, more quantitative measurements of primordial abundances of light nuclear elements using nuclear physics, atomic, and astrophysics, new ideas that go beyond the big bang picture, only true in the universe when the temperature throughout the cosmos was sufficient to excite interactions among elementary particles ($\sim 10^{10}$ GeV). Hence, the answers to the problems of cosmology may be directly linked to our understanding of the universe. Theory and observation in cosmology in the near future is an extraordinary, superluminal expansion, "inflation," during the first instants after the big bang. The remarkable stretching smooths the distribution of matter and energy, explaining why the universe is so homogeneous and isotropic. The stretching feature may special covariant, explaining why space appears to be Euclidean. According to Einstein's theory of general relativity, a spatially flat universe must have energy density equal to the critical density that divides open from a closed universe. Hence, the flattening induced by inflation also explains why the observed energy density, $\rho$, is close to the critical density today. A key, insurmountable problem is that the ratio of the energy density to the critical value, $\Omega = \rho / \rho_c$, is today.

The Planck satellite mission has been established as a primary tool of the big bang picture and as one of the best means of measuring the abundances of heavy elements, the universe, lie between 0.1 and 1. To improve upon these limits, more quantitative measurements of primordial abundances are needed along with improved understanding of chemical evolution, stellar processing, stellar atmospheres, and supernova nucleosynthesis. The development of multi-dimensional hydrodynamics, stellar structure, and astrophysical models will be important developments. Also, recent attempts to measure the abundances of light nuclear elements, the $\gamma$-ray hydrogen cloud ($\gamma$-ray cloud) appears to be a very promising, independently of gas formation, assuming sufficient fractions of helium. What is the dark matter that comprises the baryons of galaxies and perhaps missing matter of the universe?

Most likely, the answer to this question comes from the analysis of the cosmic microwave background, which is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model of the universe is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture. The inflationary model is the leading candidate for an explanation and predictive theory that extends beyond the standard big bang picture.
The observed baryon excess is in fact due to two distinct processes. The first is the baryogenesis related to the early universe, which occurred during the phase transition of the Higgs field. The second is the baryon production following the decay of long-lived relics, which could be neutralinos, gravitinos, or other dark matter candidates. These two processes are not necessarily exclusive and can occur simultaneously in some models.

The baryogenesis in the early universe was driven by the Higgs field, which underwent a phase transition. This transition led to a non-uniform distribution of baryons and antimatter, with more baryons than antimatter. The reason for this asymmetry is not yet fully understood, but it is thought to be related to the early universe's behavior during the phase transition.

The baryon production following the decay of long-lived relics is a more recent idea. This process is driven by the decay of particles that were produced in the early universe but have not yet decayed. These particles could be neutralinos, gravitinos, or other dark matter candidates.

Both processes are important in understanding the current baryon asymmetry of the universe. The baryogenesis process occurred in the early universe, while the baryon production following the decay of long-lived relics occurred later in the universe's history.
mass is such a way that if it does exist, it must be cosmologically significant, accounting for a large fraction of the critical density. These "invisible" objects at the halo of our galaxy could in fact be detected through their collisions with protons in the walls of ionized gas. For the past five years, two pilot efforts have explored the technology, but lacked about three orders of magnitude in sensitivity to reach a cosmologically interesting limit. A second generation experiment is currently being prepared at Livermore, which will not only improve the sensitivity but will bring into operation a new transit experiment that will be a factor of five lower in cost. They hope to see the first announcement in a few years. The advent of large-area redshift surveys is radically extending our view of the universe. The survey's ability to detect large-scale structures as they were amplified through the action of gravity on long-wavelength scales before gravity had a chance to amplify them. The next generation of surveys, such as large high energy experiments measuring the magnitude of the initial inhomogeneities before gravity had a chance to amplify them. The most important question determined is the expansion parameter, the Hubble constant and the cosmological constant. COBE DMR, more than a dozen experiments measuring the magnitude of the initial inhomogeneities before gravity had a chance to amplify them. The most important question determined is the expansion parameter, the Hubble constant and the cosmological constant.
long-duration balloons which circumnavigate Antarctica, and, for example, for weeks or months. The balloon projects will evolve quickly, obtain good results soon, and be critical in developing advanced technologies. The most precise results, however, are likely to come from future satellite missions which avoid atmospheric and side-loop problems of earth and balloon-borne missions and is able to measure the full sky in a controlled, redundant fashion. Such a mission would be a monumental and historic contribution to our understanding of cosmology.

Explored at small-angle scales (less than half-degree) are important because features observed in the angular distribution are not scaled to the large-angle means and the small-angle means of cosmological parameters, such as the cosmological density. They can also be used to distinguish the nature of dark matter, e.g., the proportion of hot or cold dark matter. These three arrays will also be optimal for detecting the polarization of the microwave background, non-thermal contributions to power-law fluctuations, the Sunyaev-Zeldovich effect, and secondary anisotropies associated with reionization of the microwave background. Land-based and balloon-borne experiments will be the dominant contributors to our understanding of this regime, since larger instruments are needed to obtain the fine resolution and there is less demand for full-sky coverage.

In sum, a program of high-resolution measurements of the cosmic microwave background anisotropy is the highest priority for microwave background studies and probably for cosmology in general. Each of the three angular-scale regimes reveals different, fundamental facets of the universe. Improving large-angle spatial special arrangements, e.g., a small satellite mission, is a second priority.

A balanced program of land, air and space missions is needed to extract the extraneous wealth of information which the cosmic microwave background has to offer. Combined with measurements of large-scale structure and peculiar velocity, the cosmic microwave background will provide a new understanding of the origin and evolution of the universe, a trigger for advancements in the first few billion years and be one of the historic achievements of the new millennium.

56 Structure of the Field

By its very nature science is a continuously evolving enterprise, with existing new fields arising at the interface between well established disciplines. In fact, the appearance of new fields, three important issues of science policy are

1. In a severely constrained budget climate, how can one support a developing field without an established "budget line?"

2. How can cross-disciplinary priorities be established so that new endeavors may be judged relative to well established activities?

3. As new fields develop and their financial needs grow, how can the community organize to set long-term strategies that can serve as a basis by which new proposals can be evaluated?

Particle and early astrophysics and cosmology is a case in point. Most agree that a fascinating field is emerging at the intersection between particle and nuclear physics, cosmology, stellar astrophysics, high-energy astronomy, and the like. However, these fields have by now been deeply involved in the field. More importantly, there is a widening recognition that DOE and particle astrophysics is another of the dominant science missions for the future. However, it is clear that we do not yet have in place the machinery necessary to address in a coherent fashion large international projects on the drawing boards. There is no shortage of proposed projects with price tags between $15M and $100M proposes for second-generation cosmic microwave background satellites, dedicated cosmological telescopes, a new generation of solar neutrino detectors, astronomical PAMs to explore the highest energy cosmic rays, cubic-kilometer neutrino detectors to look for high-energy cosmic neutrinos, a space-based gravitational wave interferometer, and so on.

While NASA may have in place the necessary machinery to continue satellite proposals, the other funding agencies (DOE and NSF) lack the reviewing and prioritization tools necessary to address the benefits of a proud scientific tradition. The 1994 Swamson Summer Study was welcome in the face that we do not lack the intellectual boldness or technical imagination to address questions once thought to be beyond the realm of human comprehension. For two weeks in the summer of 1994, 4511 physicists in the mountains of Colorado united in the conviction that we must enter the 21st century with a new commitment to the dreams of science and technology. As stated by the American Physical Society in the conclusion of the Swamson Summer Study, the "Becca have a new beginning in the framework of a new millennium."

There is much we could do to decrease the potential barrier examined by excellent proposals, to welcome young investigators into a more nurturing environment, to optimize the scientific output in the framework of a very limited budget, and to pursue and develop the necessary international partnerships in large projects. An innovative mix of some of the above suggestions may go a long way towards habitat the framework needed to realize the potential of the emerging scientific areas.

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