Cosmological Constants: Determinants of our Universe

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Overview

This cosmological unit is a description of the current state of cosmology. The unit focuses on the six cosmological constants presented by Martin Rees, in his book Just Six Numbers. These six constants are the parameters that determine the nature of the universe as we experience it. If these six cosmological numbers were even slightly different than they are life would not be possible. Exploring the consequences of changing any of these numbers even slightly leads to a greater appreciation of the tenuous balance required for the existence of life on earth. This unit is an intensive explanation of the current level of knowledge of cosmology, the implication of these six constants and the nature of current exploration. The unit also explores the consequences of quantum mechanics and the possibility of achieving "a theory of everything." The current state of our universe and its eventual fate is at the heart of the study of cosmology and is the unifying focus of this unit on cosmology.

The unit is intended for high school physics classes ranging from Mainstream to Advance Placement. The unit can be adapted to the different levels by increasing or decreasing the difficulty of the mathematical explanation that is presented. The Advanced Placement course incorporates an intensive mathematical explanation of the derivation of the six numbers, whereas the course for CAS, Scholars and Mainstream would have successively less mathematical explanations and the focus would shift to the implication of the cosmological factors. The conceptual level is made appropriate for all physics classes by adjusting the depth of the explanation. Simplifying the conceptual level makes the material accessible for all physics classes. This unit can also be adapted for General Science by presenting the material as a survey and utilizing the video resources to supplement the conceptual ideas presented.

Rationale

Cosmology is on the cutting edge of physics and the human desire to find physical laws to explain and incorporate physical reality from the scales of the very small to the very large. It is cosmology that attempts to determine the origin and fate of our universe. The fundamental nature of both time and space are within the realm of cosmological study. It is a remarkable endeavor that humans have the capacity to attempt to comprehend the universe that they inhabit and it is within the study of cosmology that this ability attains its broadest reach into the unknown. It is this same discerning ambition that enables man to seek out the possibility of other life forms. The six cosmological constants explored within this unit delve into the nature of the universe and the basic parameters required for the sustenance of life. Understanding the cosmological constants enhances our comprehension of the improbability that life could exist if the constants were altered even slightly. This appreciation leads to a more profound grasp of the nature of the incomprehensibly large universe and is essential for our attempts to explore the universe beyond the earth. Eventually, a greater understanding may lead to our ability to leave the earth and colonize the universe. Our endeavor to explore beyond the limits of the earth is predicated on a broader appreciation of the limits imposed by the six cosmological constants. The Mars Landers are an awesome example of man's ability to reach out into the universe to test our hypothesis that life could potentially exist elsewhere. In the near future it will be possible to travel out into our universe and within the foreseeable future it is conceivable that we could begin to explore our galaxy. Significant technological advancements are required but it is not outside the realm of possibility that humans may soon travel into the galaxy to establish other planets habitable for life. The Mars Landers are a powerful indicator of our current ability to explore the nature of our cosmos. For now we must be content to research the nature of the cosmos from the earth, but our robotic technology has greatly advanced our capacity to reach into the solar system and perform experiments to test the nature of other planets.

We have at our disposal a myriad of telescopes that are capable of reaching billions of years back in time to determine the origin, scale and future our universe. There is a plethora of telescopes searching every band of electromagnetic radiation from infrared to gamma radiation looking into the nature of the cosmos, its age and makeup and the possibility of the transmission of intelligible signals from intelligent life. The Hubble Telescope, COBE, WMAP and other telescopes have enabled man to establish the constituent parts of our universe. The knowledge obtained has led to the discovery that the universe is made up of 4% atoms, 23% dark matter and 73% dark energy. This discovery is based on several different sources including the utilization of standard candles and gravitational motion to determine the gravitational mass in

the form of matter that exists in the cosmos. The presence of 73% dark energy has been established by the required repulsive affect to overcome gravity that is necessitated by the empirical evidence that the universe is not contracting but is in fact accelerating outward. The transition from deceleration to acceleration has occurred in the recent past within the last billion years. Although physicists still do not know what dark energy is, they improve their understanding all the time and it is this scientific search that leads to discovery. In fact, these percentages of the constituent parts of the universe as well as the nature of the constituent parts may very well change as more understanding is achieved. Cosmology is undergoing and unprecedented period of new discovery and it is impossible to predict what the future understanding of these profound discoveries will be. The essence of the scientific pursuit is to search into the unknown for greater comprehension. Cosmology is establishing the very parameters of the unknown and guiding the search for a unified understanding of the physical world. Martin Rees, in his book Just Six Numbers, establishes the six cosmological constants that determine the nature of our universe, and it is the understanding of the implications of these constants that will lead to further advancements in the future.

Quantum physics and the study of the very small also has a tremendous effect on the development of cosmology. There is currently a search for the "Theory of Everything" that will unify all of our knowledge into one theory. This would include everything from the infinitesimally small to the inconceivably large and would unify all forces including gravity and the electromagnetic strong and weak forces. Superstring theory suggests that everything is reducible to infinitesimally small vibrating strings of energy in one dimension. M Theory is the most likely possibility but it is currently just theoretical and untestable. M theory predicts the possible existence of eleven dimensions although we currently can only account for four. The extra six dimensions could possible be rolled up into very small and undetectable dimensions and there is the possibility of another time dimension. Quantum effects such as the possibility of solid material passing through matter and the uncertainty principle lead to profound unpredictability. In the quantum universe everything exists as a probability wave function and the implications of this are pervasive. Our understanding of matter on a large scale is as incorrect and insufficient on the quantum scale as Newtonian mechanics was for explaining relativity and the effect of speeds approaching the speed of light. For now we must rely on the six cosmological constants and it is these six constants that show the boundaries of our current knowledge. This cosmological unit will be based on the discussion of these six cosmological constants and their implications in our universe.

The state of current cosmology can be summed up by discussing the implications of these six cosmological constants, so let us first consider the

current state of the universe. It is currently established that the universe is 13.7 billion years old and began in the Big Bang. The Big Bang was possibly a singularity that reached 10 billion degrees. In the beginning the universe experienced inflation. At some point in the recent past of a billion years or so, the universe went from a state of deceleration to our current state of expansion. This fact was presented by Hubble because the light from virtually all stars is red shifted, which as a consequence of the Doppler shift, means that the stars are moving away from us. The universe is expanding and is actually expanding at an accelerating rate which means that the universe will continue moving outward and getting ever colder. Additionally, the acceleration will eventually cause distant stars to move away from us faster than the speed of light which will gradually cause all the stars to gradually blink out over the next sixty billion years or so. As for the nature of dark energy, which is the primary constituent of the universe and the cause of the universal acceleration, not much is yet known about it. The future of cosmology is certain to uncover much of the mystery that currently surrounds the six cosmological constants that have even determined and may eventually be able to unify all these factors into a single theory. Currently, string theory, or more specifically, M theory is the best, although untested, possibility.

The methods used by cosmology to discern the nature of the cosmos will be discussed. These subjects will include the explanation of the speed of light and the red shift, the establishment of the use of standard candles and cosmological events such as supernovae, the different types of detectors and methods of "reading" the information contained within the frequencies of EM radiation in the sky, the existence of black holes, brown dwarfs and dark matter and the nature of dark matter. The speed of light is constant, c, at 3 x 10^8m/s and is always detected to be the same regardless of the motion of the source or the receiver. In addition, moving at speeds close to the speed of light causes time to dilate and is calculable based on the theory of relativity. The relative motion of the source and the receiver results in the Doppler shift which is a change in the frequency of the electromagnetic wave. A red shift indicates that the light source and the receiver are moving away from each other, whereas a blue shift would indicate motion towards each other. Much of the knowledge about the relative distances of our cosmos is based on the existence of standard candles. These standard candles are A1 supernovae. A1 supernovae are exploding stars that have a predictable light curve that results in incredible intensity over a determinable amount of time that can be calibrated to determine the distance to the source. These standard candles can be used to look back billions of years into the cosmos. Because the process of these supernovae is predictable and has a distinctive light signature they can be distinguished from other cosmic events and by diligent use of the most powerful telescopes and computers the distances deep into the universe can be accurately determined. The existence of black holes, which only a decade ago were science fiction, have been firmly established by the bending of light in their vicinity and

the gravitational behavior of other celestial bodies. Tremendous black holes have been found at the center of many galaxies. Other celestial luminescent bodies such as red and brown dwarfs which are stars in various stages of their evolution have also been plotted. Gradually cosmologists are using celestial events to discern more about the make-up and age of the cosmos.

The unit will consist of lessons on the significance of each of the six cosmological constants and how they establish our current understanding of the cosmos. The six cosmological constants are N, the ratio of the electromagnetic force to gravity, ε nuclear efficiency, Ω critical density, λ the inflation constant, Q cosmic smoothness, and D the number of dimensions. Explaining these six numbers and their implications will form the structure of the unit. In addition, the likely direction of cosmological advances in the near future will be explored. Of the six constants, two relate to basic forces, two fix the size and overall texture of the universe and determine whether it will continue forever, and two constants determine the properties of space itself.

The two constants that relate to basic forces are N and ε. N, the ratio of the electromagnetic force to gravity is 10^{39}. This huge number allows for us to evolve in the universe because there is enough time for the evolution of life and gravity is weak enough that it does not crush us. ε, nuclear efficiency of stars equals 0.007. This determines how firmly nuclei bond together and determines how stars transmute hydrogen into all other elements. A constant of 0.006 or 0.008 would mean we could not exist. The two constants that determine the size and overall texture of the universe and determine whether it will continue forever are Ω and λ. Ω, critical density measures the amount of matter in the universe. This includes galaxies, diffuse gas and dark matter. Ω tells us the relative importance of gravity and expansion in the universe. If Ω were too high the universe would already have contracted and if Ω were too low no galaxies would have formed so life would not have existed. λ, the inflation constant, determines the expansion or contraction of the universe. In fact the universe is expanding. This anti-gravity has no discernible effect on scales less than one billion light years. However, λ is responsible for the expanding universe. If λ were larger it would have prevented galaxies from forming. The two constants that determine the properties of space are Q and D. Q cosmic smoothness results from primordial ripples. The universe is uniform to a constant of one part per 100,000 and is the seed for cosmic structures. If Q were even smaller the universe would be inert and structureless. If Q were larger the universal environment would be violent and no stars or systems would survive and the universe would be dominated by massive black holes. D the number of special dimensions is three. Life could not exist with 2 or 4 dimensions. Time is the fourth dimension but it is distinct because it appears to only travel in one direction. Time and space are

related by relativity and both warp in high gravity of black holes, at speeds close to the speed of light and near the extreme environment of the Big Bang. String theory predicts the possibility of the existence of ten special dimensions. The extra seven dimensions might be curled up in very small dimensions. M Theory also predicts the possibility of our 4 dimensional membrane (known as branes) colliding with another brane with catastrophic consequences.

The pursuit of M theory may result in a theory of everything but for now these six cosmological constants are distinct and can not be determined by using the other numbers and therefore, they are as simplified and fundamental of an explanation as can currently be expressed. Each of these six constants "plays a crucial and distinctive role in our universe, and together they determine how the universe evolves and what its internal potentialities are: moreover, three of them (those that pertain to the large-scale universe) are only now being measured with any precision." (Rees, p.4) The six numbers are essential and if any of them were changed, the existence of stars and life would not be possible. The calibration of these constants is extremely exacting and our existence can be understood as a consequence of these numbers being what they are. Therefore, "this realization offers a radically new perspective on our universe, on our place in it, and on the nature of physical laws." (Rees, p.4) The six constants are all that is needed to project our universe from these initial features. "It is astonishing that an expanding universe, whose starting point is so 'simple' that it can be specified by just a few numbers, can evolve (if these numbers are suitably 'tuned') into our intricately structured cosmos." (Rees, p.4)

Video specials on cosmology as they relate to the current state of knowledge will be utilized to supplement the lectures and lessons on the current state of cosmology. The Elegant Universe by Brian Greene delves into the consequences of superstring theory and the possibility of a unifying theory of everything. Quantum physics is explored in relation to our experience on a large scale of matter relative to the bizarre implications of quantum mechanics on the scale of the very small. Strings are vibrating energy on the scale of billions and billions of time smaller than anything we can currently detect. The Astronomers series expounds on the nature of stars, planets, constellations, stardust, black holes, the Big Bang theory, gravity waves, and new technologies. These videos will be utilized to supplement the study of celestial bodies and phenomenon as well as the most current theories of the universe and its future. Steven Hawkings' Universe series will address the theoretical nature of cosmological exploration by one of the greatest living theoretical physicists. Runaway Universe explains that the universe is currently in a state of acceleration. Within the last billion years the universe has switched from a state of deceleration to one of acceleration. The implication of this is that the universe will continue to accelerate until all the stars are moving away with a speed greater than the speed of light. Consequently, light

will no longer be able to reach the earth and one by one all of the stars will blink out until no light at all reaches the cold earth. Understanding Uncertainty delves into the cutting edge knowledge of cosmology and tackles quantum theory and relativity. All of these video resources are supplemental resources that present the current understanding of cosmological advances as they exist today.

This cosmological unit is designed to be used primarily in high school physics courses. The difficulty of the level of math used will make it appropriate for mainstream physics, scholars physics, honors physics or Advanced Placement physics. Primarily this unit is a survey of the concepts of cosmology and can therefore be adapted to any level. By simplifying the concepts this unit will also be applicable for the freshman General Science course. For the mainstream, scholars and honors physics courses the cosmological unit will be a capstone for many of the concepts covered throughout the year, including universal gravitation, Light, Electromagnetism, and the Atom. For Advance Placement Physics this unit will be a supplemental unit presented after the AP test are administered. The General Science curriculum has a unit on the Universe and this cosmological unit will be incorporated into it.

Objectives

Creating a comprehension of and enthusiasm for cosmology is the primary goal of this unit. This unit is intended to instill enthusiasm in students about the current and relevant issues of cosmology. Nearly daily the newspapers report advances in cosmology and students will be encouraged to apply their knowledge of cosmology to these developments. Students require a base of understanding to be able to understand the current advances in scientific knowledge and to build a framework to grasp the new improvements of technology. Making cosmology pertinent to students will be accomplished by having the students construct a vision of the universe as it currently exists. The students will compare their view of the solar system and the cosmos with the predominant view that recent experiments have established in cosmology. This new paradigm will motivate students to modify their view of the universe. The knowledge that the universe is more than thirteen billion years old will encourage students to embrace new theories about the construction of time and space. The students will formulate concepts about the formation of our solar system and the incredible fact that life exists. The imagination will be sparked by the revelation that if the six cosmological constants were altered even slightly life would not be possible. In addition, if life exists here on earth and there are billions and billions of other stars in each galaxy, each of which has the possibility of having habitable planets then the likelihood that other life forms could exist elsewhere will have to be entertained. So on a fundamental level the study of cosmology requires the

reinvention of our place in the cosmos. Throughout history humans have struggled to come to terms with the nature of reality and now the vastness of cosmology forces us to embrace the sheer magnitude of a universe that is billions of light years across and that was formed in the potential singularity that was the Big-Bang. However, physicists are undaunted by this vastness and instead strive to comprehend the nature of the universe and its beginning. The judgment about our place in the cosmos is theoretical by the nature of the question but science attempts to illuminate some of the parameters of that discussion. Students must evaluate the magnitude of knowledge presented by cosmology and decide what our position in the universe is and what our future must hold. Concurrently, though, it is also essential to keep in mind that cosmology is still in its infancy and advances are made every day. Therefore the scientific search for truth is unfolding and dynamic. The truths that we find are temporal and the search is ongoing so students come face to face with the malleability of our knowledge and the requisite desire to comprehend. Cosmology demonstrates the need to assess information, to formulate conclusions and to constantly reanalyze the conclusions. Studying cosmology instills the confidence that as sentient beings we have the awesome capacity to explore our environment and to decipher the origin of ourselves and of the entire cosmos that we live in. This enables us to utilize this information in the formulation of a strategy to most profitably engage our environment and control our environment.

Students will be able to explain how scientific principles of chemical, physical, and biological phenomenon have developed and relate them to real-world situations. (S1) Students will understand how the universe developed into galaxies and stars and how stars fused matter together to form all the matter in the universe. Eventually matter resulted in life on earth. Students will demonstrate knowledge of basic concepts and principles of physical, chemical, biological and earth sciences (S2). The students will construct and evaluate scientific and technological systems using models to explain or predict results (S5). The various models of the Big Bang and the resulting creation of the universe, including expansion, will be investigated. The anthropomorphic ideas that have often led man to place himself at the center of the universe will be addressed and all students evaluate advantages, disadvantages and ethical implications associated with the impact of science and technology on current and future life (S7). The students will utilize the immense resources on the internet and demonstrate basic computer literacy, including word processing, software applications, and the ability to access the global information infrastructure, using current technology (S9). In addition to the scientific emphasis, the cosmological unit will address the mathematical methods and tools used in the study of cosmology. All students use numbers, number systems, and equivalent forms (including numbers, words, objects and graphics) to represent theoretical and practical situations (M1). Math is the language of physics and cosmology and

must be utilized to comprehend the current advances being made. All students compute, measure, and estimate to solve theoretical and practical problems, using appropriate tools, including modern technology such as calculators and computers (M2). Explaining the status of cosmology all students will formulate and solve problems and communicate the mathematical processes used and the reasons for using them (M3). All students understand and apply basic concepts of algebra, geometry, probability and statistics to solve theoretical and practical problems (M5). Much of cosmology is based on the mathematical application of statistics to interpret the information that is gathered from a vast array of sources. Math enables this data to be correlated into meaningful sources of knowledge. All students evaluate, infer, and draw appropriate conclusions from charts, tables and graphs, showing the relationships between data and real-world situation (M6).

Strategies

Multiple educational strategies will be instituted to achieve the learning objectives. The cosmological evidence will be provided in presentations that focus on the historical information and the six cosmological numbers. Interspersed with the information will be opportunities to graphically represent the information. Charts and visual information will be plentiful since much of the information is visual in nature. Students will have many opportunities to diagram the information presented. The theoretical and speculative nature of cosmology lends itself to discussions regarding the nature of cosmological information, the uncertainty of the information and the potential implications of cosmology. Discussing how the six cosmological constants are determined allows for active rational exploration by students that exists because cosmology is experiencing constant revision and creation. It is invaluable for students to experience the scientific method in action. Simply explaining the advances in this science over the past decade and the respectability cosmology has achieved in the last fifty years, powerfully illustrates the dynamic quality of the study of cosmology. In addition, the immense resources of the internet will be incorporated by having the students prepare presentations on the current issues of cosmology. This will undoubtedly impress the students with the pervasiveness of cosmological study. Video resources will also be utilized in the classroom to bring the leaders in cosmology into the classroom in thoughtful and enervating presentations that can not be reproduced otherwise. All of these methods will be used to hook students into the enthralling advances cosmology is currently experiencing and potentially encouraging some of the students to continue their study of cosmology on the collegiate level.

Classroom Activities

HISTORY OF COSMOLOGY – (two class periods)
The initial focus of the cosmology unit will be to provide the students with the historical background of cosmology. Historically, cosmology had little respectability and was largely perceived as a "quack" science. In the beginning, cosmology was known as astronomy and could merely plot the position of stars. The limited power of telescopes and technology severely limited astronomers' ability to determine the basic characteristics of the universe. Initially it was believed that the earth was at the center of the universe. In time, using the motions of the stars and planets it was realized that the sun was at the center of our solar system and it was realized that there were many solar systems in our galaxy. It was long believed, though, that our galaxy encompassed the entire universe. Gradually it was discovered that our galaxy was only a small portion of the celestial bodies. With the development of technological tools and a more systematic approach, scientists like Hubble brought respectability to cosmology. Hubble established the fact that certain light sources were not merely stars but were actually entire galaxies that were very far away. By analyzing the light from these galaxies he discovered that the light from these galaxies was what is called "red shifted." This means that the frequency of the light from these galaxies was shifted in frequency to the longer end of the light spectrum and appeared more red. This is known as the Doppler shift. This remarkable discovery led Hubble to the proper interpretation that these galaxies must be moving away from us. By calculating the amount of the red shift, Hubble was able to significantly validate the study of cosmology as a empirical science. Continued measurements have demonstrated that Hubble was correct in postulating that all the galaxies in the universe (with only a few local exceptions) are in fact accelerating away from us. This was established because galaxies that were further away were more red shifted than those that were closer. Hubble could have postulated that we were consequently at the center of the universe, but given the history of the failure of the anthropomorphic viewpoint it was hypothesized that the entire universe was expanding away from everything else because space itself was expanding. Today many of the brightest physicists and mathematicians are involved in the study of cosmology. The theoretical implication of the study of cosmology on the scale from the very large to the very small has placed cosmology on the cutting edge of scientific exploration.

Group Discussion- (1 period)
Introductory Set- How old do you think the universe is, did it have a beginning, how big is the universe and what do you think the fate of the universe will be? This discussion will address the scientific, cultural and religious preconceptions of the students.

Supplemental Video- Astronomer Series (two class periods)
Two videos from The Astronomer Series will be shown to illustrate the history of astronomy and the early advances in the science.

THE HISTORY OF OUR UNIVERSE- THE BIG BANG THEORY (1 class period)
Once Hubble discovered that the universe was accelerating outward the existing theory that the universe was static was debunked. The universe was in a state of flux so what was the universe like in the past. Since all matter and space was expanding outward there must have been a time when the matter was contracted. This led to the theory of the Big Bang. Extrapolating backward in time, all matter had a trajectory back to the beginning of time and that trajectory led to the proposition that the universe began in a fantastic explosion. All of the math indicates that a singularity would have occurred at that time so our equations can not take us all the way back to the beginning but they do indicate back within the initial moments of our current universe. All matter was condensed into an infinitesimally small space at millions of degrees. A rapid expansion occurred that propelled all matter out from a single point. We are still experiencing the consequence of that initial expansion. Science cannot say whether time existed before that time but it is possible that if this expansion was eventually overcome by gravity that the universe could collapse back on itself and the process could be repeated.

Group Work- Class Debate (1 period)
The students will research the Big Bang Theory and as many alternative theories as they can find and will determine the relative merits of each theory. The students will compile the information. Each group will prepare the pros and cons of one theory and defend that theory in a class debate.

Supplemental Video- Stephen Hawkings' Universe (2 class periods)
Stephen Hawkings' Universe discusses the current state of the universe and the theoretical conceptualization of the universe based on the current scientific knowledge and the scientist's brilliant capacity for envisioning future developments in cosmology.

THE FATE OF OUR UNIVERSE- (1 class period)
Once it was determined that the universe was moving outward the next question regarded the state of the universe- Is the universe going to collapse back into itself or will it escape the gravitational pull of the mass of the universe and continue expanding outward forever? Initial calculations were not conclusive as to the future of the universe but gradually it was determined that the universe did, in fact, have terminal velocity and will continue expanding outwardly forever. The

gravitational contraction of the universe was not enough to stop the expansion so the universe will continue outward. It has been determined recently that the universe is actually accelerating as a result of the cosmological expansion constant. Within the last billion years the universal expansion constant has become dominant and has resulted in the transition from deceleration to acceleration.

Supplemental Video- Runaway Universe (1 class period)
Runaway Universe discusses the implications of the calculations that the universe is actually expanding and explains how this conclusion is derived. Einstein was the first to propose the cosmological constant which is a repulsive force also known as antigravity, but he introduced it in his equation because he believed the universe should be static. Now it has been established using standard candles that the universe is accelerating. Dark matter holds our galaxy together and dark energy is responsible for the expansion of the universe.

THE SPECIFICS ABOUT OUR UNIVERSE – THE SIX COSMOLOGICAL CONSTANTS (4 class periods)
The six cosmological constants are the parameters that establish the universe as we know it and allow our universe to be hospitable to life. The six cosmological constants are N, the ratio of the electromagnetic force to gravity, ε nuclear efficiency, Ω critical density, λ the inflation constant, Q cosmic smoothness, and D the number of dimensions.

Of the six constants, two relate to basic forces, two fix the size and overall texture of the universe and determine whether it will continue forever and two constants determine the properties of space itself.

The constants that establish the relative strength of the forces that exist in the universe are N, which is the strength of the EM force compared to gravity and ε, the nuclear efficiency. N, the ratio of the electromagnetic force to gravity is 10^{39}. This huge number allows for us to evolve in the universe because there is enough time for the evolution of life and gravity is weak enough that it does not crush us. If N were larger matter would form more rapidly and there would not be enough time for life, which take billions of years, to evolve. If gravity were stronger then we would not be able to survive as we are in the stronger gravitational field.
ε nuclear efficiency of stars equals 0.007. This determines how firmly nuclei bond together and determines how stars transmute hydrogen into all other elements. If nuclear efficiency varied even slightly matter would not be stable enough to create heavier elements. A constant of 0.006 or 0.008 would mean we could not exist.

The two constants that determine the size and overall texture of the universe and determine whether it will continue forever are Ω, which measures the amount of matter in the universe, and λ, the cosmological expansion constant. Ω critical density measures the amount of matter in the universe. This includes galaxies, diffuse gas and dark matter. Ω tells us the relative importance of gravity and expansion in the universe. If Ω were too high the universe would already have contracted and if Ω were too low no galaxies would have formed so life would not have existed. λ, the inflation constant is determines the expansion or contraction of the universe. In fact the universe is expanding. This anti-gravity has no discernible affect on scales less than one billion light years. However, λ is responsible for the expanding universe. If λ were larger it would have prevented galaxies from forming.

The two constants that determine the properties of space are Q, the smoothness factor and D, the number of dimensions. Q cosmic smoothness results from primordial ripples. The universe is uniform to a constant of one part per 100,000 and is the seed for cosmic structures. If Q sere even smaller the universe would be inert and structureless. If Q were larger the universal environment would be violent and no stars or systems would survive and the universe would be dominated by massive black holes. D the number of special dimensions is three. Life could not exist with 2 or 4 dimensions. Time is the fourth dimension but it is distinct because it appears to only travel in one direction. Time and space are related by relativity and both warp in high gravity of black holes, at speeds close to the speed of light and near the extreme environment of the Big Bang. String theory predicts the possibility of the existence of ten special dimensions. The extra seven dimension might be curled up in very small dimensions. M Theory also predicts the possibility of our 4 dimensional membrane (known as branes) colliding with another brane with catastrophic consequences.

Group Work- (1 class period)
Each group will be assigned one of the cosmological constants and will create a skit for the class about how that variation of that constant would make the universe inhospitable to life.

IMPLICATIONS OF STRING THEORY AND QUANTUM MECHANICS – (1 class period)
The study of the universe from the large scale to the small has led to the development of string theory and the possibility of achieving the "theory of everything."

Supplemental Video- The Elegant Universe (2 class periods)

The Elegant Universe discusses the development and implications of superstring theory and quantum mechanics. This phenomenal video comprehensively explains the development of string theory.

The pursuit of M theory may result in a theory of everything but for now these six cosmological constants are distinct and cannot be determined by using the other numbers and therefore, they are as simplified and fundamental of an explanation as can currently be expressed. Each of these six constants "plays a crucial and distinctive role in our universe, and together they determine how the universe evolves and what its internal potentialities are: moreover, three of them (those that pertain to the large-scale universe) are only now being measured with any precision." (Rees, p.4) The six numbers are essential and if any of them were changed, the existence of stars and life would not be possible. The calibration of these constants is extremely exacting and our existence can be understood as a consequence of these numbers being what they are. Therefore, "this realization offers a radically new perspective on our universe, on our place in it, and on the nature of physical laws." (Rees, p.4) The six constants are all that is needed to project our universe from these initial features. "It is astonishing that an expanding universe, whose starting point is so 'simple' that it can be specified by just a few numbers, can evolve (if these numbers are suitably 'tuned') into our intricately structured cosmos." (Rees, p.4)

Group Discussion (1 class period)
How does the universe of the very small (quantum physics vary and string theory) differ from the reality we experience on a daily basis? What are the implications that these two realities differ so greatly and will there come a time when we are able to unify these two realities?

Supplementary Video- Understanding Uncertainty (1 class period)
Understanding Uncertainty explains the baffling implications of quantum mechanics.

CULMINATING RESEARCH PROJECT (3 class periods)
The students will be responsible for research on the internet of one of the current cosmological issues and will make a presentation to the class. These can include but are not limited to finding and establishing standard candles, micro-wave background radiation and its implications, the current status of mapping the universe, the current knowledge of black holes and their relevance to cosmology, the capabilities of our current telescopes and technological tools for studying deep space, the make-up of our galaxy, the prevalence of dark matter in the universe, the predominance of the existence of dark energy and what we know about it, the acceleration of the universe based on the red shift and when the universe went from deceleration to our current acceleration, the history of our universe and what

we know back to the Big Bang, the description of string theory and the possibility that M theory may be the "theory of everything." The students will be given time to research their topics and to prepare their PowerPoint presentations.

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Appendix-Content Standards

Appendix: The following standards will be incorporated into the cosmological unit.

SCIENCE STANDARDS
S1. All students explain how scientific principles of chemical, physical, and biological phenomenon have developed and relate them to real-world situations.
S2. All students demonstrate knowledge of basic concepts and principles of physical, chemical, biological and earth sciences.
S5. All students construct and evaluate scientific and technological systems using models to explain or predict results.
S7. All students evaluate advantages, disadvantages and ethical implications associated with the impact of science and technology on current and future life.
S9. All students demonstrate basic computer literacy, including word processing, software applications, and the ability to access the global information infrastructure, using current technology.

MATH STANDARDS
M1. All students use numbers, number systems, and equivalent forms (including numbers, words, objects and graphics) to represent theoretical and practical situations.
M2. All students compute, measure, and estimate to solve theoretical and practical problems, using appropriate tools, including modern technology such as calculators and computers.
M4. All students formulate and solve problems and communicate the mathematical processes used and the reasons for using them.
M5. All students understand and apply basic concepts of algebra, geometry, probability and statistics to solve theoretical and practical problems.
M6. All students evaluate, infer, and draw appropriate conclusions from charts, tables and graphs, showing the relationships between data and real-world situation.