Dark Matter and the Dinosaurs Study Guide

Dark Matter and the Dinosaurs by Lisa Randall

Contents

Chapter 1: Development of the Universe

Summary

Dark matter is everywhere. Yet, it is not visible to our eyes or detectable by current instruments. As physicist Lisa Randall points out in her book, Dark Matter and the Dinosaurs, the scientific community believes dark matter is present because of its measurable gravitational effects. Scientific thought is that dark matter comprises a full 85 percent of all matter in the universe. In other words, the great bulk of the universe is invisible to our eyes and instruments. It is entirely possible that dark matter dislodged a comet from its weak orbit 66 million years and sent it crashing into earth, which caused the extinction of the dinosaurs and most forms of life.

A misnomer makes a highly abstract notion about the universe seem impenetrable. Dark matter is not dark, but rather transparent (or invisible), Randall asserts. Dark matter has only feeble interactions with the matter we understand and no interactions with light, although it played a major role in shaping the structure of the universe. However, dark matter and black holes are entirely separate. Dark matter does not interact with light; black holes absorb and retain light. Also, dark matter is not the same as dark energy which suffuses the universe but does not "clump" like regular matter or form objects that make the distribution of dark matter uneven. Moreover, dark energy, unlike dark matter or radiation, remains constant over time.

Randall ends the first chapter on an optimistic note that matter "should" yield its secrets through the application of known principles of particle physics in a number of experimental probes currently underway. A better understanding of dark matter should explain some of the structures of our universe and provide insight into the development of life on earth, as well as help explain elliptical events such as meteoroid impacts on earth.

Analysis

It becomes clear in the first chapter that astrophysics is a field of research that is nurtured by both intuition and number crunching, as well as multiple theories on practically everything. The notion of dark matter and dark energy seems chimerical, almost as fantastic as medieval philosophers who argued about how many angels could dance on the head of a pin. Juxtaposed with this heady atmosphere is the reality that physics has brought us the atomic and hydrogen bombs and many other innovations clearly within the physical world. It seems that Randall can easily slip from the actual and practical into the world of theory and imagination, not unlike the theoretical particles of matter that may exist in other dimensions and are the subject of intense study at the CERN particle accelerator in Switzerland. Randall easily explains these seemingly paradoxical ideas in a non-threatening, scientific manner that invites the reader to keep going as the author takes a pathway toward truth. Randall believes dark matter can and will be explained by known physics principles that can be unraveled by the scientific method. Randall uses rhetorical "teases" to lead the reader deeper into her subject.

Vocabulary

minuscule, imperceptibly, allude, quantum, amenable, infelicitous

Chapter 2 - "The Discovery of Dark Matter"

Summary

German physicist Fritz Zwicky observed in 1933 that the visible mass of a galactic cluster of stars could not be held in balance only by the observable matter which emits light. There would need to be 400 times the amount of visible matter to produce sufficient gravitational pull to hold these clusters. Zwiucky named this unknown force dunkle Materie ("dark matter"). These observations remained scientific oddities until the 1970s when scientists began to probe further into the question of dark matter. Astronomers Vera Rubin and Kent Ford found that the rotational speeds of stars were identical regardless of their distance from the galactic center. They concluded that ordinary, visible matter accounted for only one-sixth of the mass required to hold them in stable orbits. Where did the additional mass come from? According to Ruben and Ford, additional mass came from dark matter. The evidence seemed to demonstrate that the biggest, most powerful force in the universe is dark matter.

The question of how to measure this invisible force, dark matter, remained. Zwicky believed it might be possible to measure this force indirectly, by its influence on other visible objects such as stars. Zwicky believed that "dark matter in galaxy clusters could thereby be detected by the observed change in light rays, which would depend on the total mass that the intervening cluster contained," Randall writes. With physicists hot on the trail of invisible dark matter, it became necessary to measure its extent and power. Zwicky realized that it would be possible to identify dark matter by its effect on other forces such as gravitational fields and the path of light, which is distorted by the presence of dark matter. Referred to as gravitational lensing, this method enables scientists to detect dark matter by its effect on distorting light not unlike the observation that wind is blowing because of the movement of trees.

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The bullet cluster is a good example to contrast dark matter with conventional matter. The bullet cluster was formed by the collision of at least two galaxy clusters. Using gravitational lensing, astronomers and physicists determined that dark matter is located on the periphery of this combined cluster, while conventional, matter in the form of gas clouds, gathers at the center, according to Randall. This clear-cut delineation is taken as proof that dark, non-interactive matter exists side-by-side with interactive conventional matter.

Randall notes that it was not until the ambient radioactivity of the primal universe cooled down millions of years ago that atoms, as we know them today, were formed and conventional as well as dark matter were created. Astronomical observation of light generated millions of years ago enables scientists to study this early recombination of elements as well as acoustic oscillation—a condition created by the opposing forces of gravity and radiation. As a result, scientists know that dark matter contains 85 percent of all matter in the universe.

Two different teams of physicists actually discovered dark energy by measuring supernovae, those brilliant explosions of light and energy that emanate from dying stars. Randall credits one team led by Saul Perlmutter and another by Adam Riess and Bian Schmidt.

Type 1a supernovae, which result from nuclear explosions of giant dwarfs, (or burnt-out stars) all burn at an identical brightness which means they can be used to measure how quickly they are receding, or the expansion rate of the universe. When these light sources reach a frequency rate known as the redshift they can be used to figure that rate of expansion precisely. When this technique was used in 1998, astronomers found the supernovae were farther away than anticipated. The cause of this accelerated expansion was found to be dark energy which proved the existence of dark matter.

The importance of dark matter is its role in providing structure to the universe in the form of galaxies, Randall says.

Analysis

The notion that 85 percent of everything in the universe consists of mysterious dark matter and dark energy may seem like the setting for an episode of "The Twilight Zone," but to physicists like Randall it is a very real fact. At this point in time, we cannot see, touch, or feel dark matter; but, we can infer its existence because of its effects on ordinary matter. Dark matter seems to provide some answer to the question why the universe is expanding at a much faster rate than initially. In other ways, astrophysicists such as Randall now believe dark matter gives shape and form to the universe. Scientists are working hard to understand the true nature of dark matter and prepared to rip open the shroud of unknowing about this important area of physics. The answers they find behind this shroud will likely represent a new era in physics and a quantum leap toward a better understanding of the universe and ourselves.

Vocabulary

nonluminous, vicinity, elliptical, quasar, progenitor, svelte, homogeneity, oscillation, supernova, innocuous, acronym, redshift, photon

Chapter 3 - The Big Questions

Summary

Randall poses five "unanswerable" questions within the realm of physics, and provides a background that suggests possible answers:

Why is there something rather than nothing in the universe? She notes that the question really is, why is there not an equal amount of matter and antimatter? Antimatter is not dark matter but carries the same types of changes as matter. Unlike dark matter, antimatter interacts with light. However, because of an asymmetry there is slightly more matter than antimatter which is why there is something rather than nothing.

What exactly happened during the "big bang?" Although the term has been in circulation for decades, no one knows what happened in the big bang according to Randall. The only possible approach to an answer could most likely be found in a theory of quantum gravity. Quantum mechanics and gravity are important concepts in cosmology, but have not been mapped in the scale of the big bang.

What happened before the big bang? Although no one knows the answer to this question, there are three possibilities: the universe has existed forever; the universe started at a particular time; or, there are multiple universes (multiverses). Randall reflects that the answer to the question would probably satisfy no one. She suggests that the most probable explanation is that there are multiple universes.

Did our universe start with the "big bang" or did it evolve out of one of many multiverses? Could there be numerous multiverses, infinitely large and timeless, although our own universe is limited in both size and in time? Randall says current physical theories imply that multiverses are common. "Nothing about our world is inconsistent with the existence of a multiverse," she says.

Just when the reader is getting comfortable with the notion that most of the universe is powerful and invisible, Randall tells us there are probably many universes, or multiverses. The author draws a clear distinction between science and philosophy: "Science concerns those ideas that, at least in principle we can verify or rule out through experiments and observations. Philosophy, to a scientist at least, concerns questions we expect we will never reliably answer." This impacts science in the sense that we can only know or understand a limited slice of the universe observable with light rays during the life of the universe. It is only from those regions, Randall says, that any kind of signal can reach earth during the lifetime of the universe. Anything farther beyond what scientists call the cosmic horizon cannot be observed.

Randall says her personal belief is that the spatial part of the universe is infinite in scope and probably has no beginning and no end. She says there must be multiverses because without them, other universes would collapse or explode.

Analysis

Lisa Randall wants it understood that she is not a cosmetologist. Tongue in cheek, she explains how sometimes her profession as a cosmologist is misunderstood as someone expert in applying cosmetics. "which I find very funny given how poorly suited I would be for this vocation." Randall explains that both words derive from the Greek 'kosmos' which in its origin referred to the universe. By 1200 AD, the word had come to mean "order, good order or orderly arrangement.

She playfully adds that cosmology and cosmetology share the same root word because "like a face, the universe has both beauty and an underlying order." The author uses a bit of lightness and humor to approach cosmic issues—gifts she uses in other places to gain the confidence of the reader that she is no "mad scientist," rather someone who is intrigued by physics and its potential to help understand some of the "big questions" about the universe that mankind has sought for centuries. She gains the trust of the reader by demonstrating her humility and sense of awe at these questions.

Everybody is intrigued by the concepts of infinity and timelessness although few are the scientists who can actually conceptualize those ideas. In a sense, this fact serves as a marker of how far physicists have come using the limited powers of observation and measurement at hand. When one speaks of infinity or timelessness he or she is standing atop an elevated platform of logic, probability and limited observation that could be swept away at any time by new ideas. To work in this atmosphere takes resilience and open-mindedness that is breath-taking.

In seeking answers, Randall explains how early humans relied more on philosophy than physics, Philosophy might have provided a few answers to questions, but "many others were wrong." Today, cosmology relies almost 100 percent on science with a bit of philosophy. Randall asserts, "Science concerns those ideas that at least in principle we can verify or rule out through experiments and observations." Philosophy, to a scientist, "concerns questions we will never reliably answer." While it is possible that other domains or other universes may operate with an entirely different physics, for now our science cannot reach beyond our domain, or universe,Randall says. This limit is referred to as the "cosmic horizon."

Again extending her hand to the puzzled reader, Randall insists that philosophical speculation about things beyond this horizon "can often be deep and fascinating." There is no reason why anyone should trust scientists' speculations more than those of others.

Vocabulary

cosmology, infinitesimal, antimatter, asymmetry, multiverse, braneworld, anthropic, annihilate

Chapter 4 - Almost the Very Beginning

Summary

Shortly after the big bang 13.8 billion years ago, the universe was a witches' brew of random particles zooming about at the speed of light, in an orgy of interaction and annihilation, where energy became matter and the reverse, according to Einstein 's theory of relativity. The primal cauldron of the universe burned at a "trillion trillion" degrees, Randall says. As the universe slowly cooled, large particles combined with antiparticles to produce new energy. Gradually protons and neutrons combined into nuclei held together by powerful nuclear forces, and helium, lithium and deuterium were created. Scientific observations and measurements agree with, and confirm, both the big bang theory as well as nuclear physics.

These measurements confirm existing theories and limit new theories with the result that the amount of normal matter cannot be significantly greater than what has been observed, because this would create unsustainable imbalances in elements of the universe. About 380,000 years after the big bang, positively charged nuclei combined with negatively charged electrons and created neutral atoms. Since that conversion, the universe has consisted of matter with no electrical charge. This also meant that photons, or light particles, could travel the universe freely. So the background radiation we find in today's universe is composed of photons from 380,000 years ago, just after the big bang explosion.

This so-called "background radiation" was discovered in 1963 by astronomers Arno Penzias and Robert Wilson while they were using a Bell Labs telescope to investigate the use of radio antennae in astronomy. At first, the astronomers didn't realize what they'd discovered. Two physicists at Princeton University—Robert Dicke and Jim Peebles—were designing an experiment to measure background radiation as confirmation of the big bang theory when they realized the Bell Labs scientists had gotten there first. Through MIT astronomer Bernie Burke the two sets of scientists got in contact with shared findings. In 1978 Penzias and WIlson received the Nobel Prize for their discovery.

Because the universe is "large, smooth, flat [and] homogeneous," and denser on its perimeter, it is able to last for an immeasurable time and avoid curvature which would have caused collapse, according to Randall. Studies by the NASA Cosmic Background Explorer, the Wilkinson Microwave Anistropy Probe and the European Space Agency's Planck mission have confirmed theories about the nature of inflation and its relationship to the big bang.

Although their discovery was accidental, it provided new insights into cosmology including cosmological inflation—an early and explosive expansion of the universe.

What if anything, came before the big bang? Randall answers that cosmological expansion, an exponential and "sensational" event, essentially created the universe in a split second. This was then followed by a "large, smooth, flat, homogeneous" universe that evolved according to the big bang theory. This hypothesis helps explain why the big bang was not followed by the "great collapse" but by the comparatively slower evolution of the universe over 13.8 billion years, according to Randall. Part of this slowing is due to the "very nearly flat" distribution of matter in the three spatial dimensions of the universe.

Analysis

This chapter sets the stage for the physical universe as we know it. It is a story of chaos tending toward order, and physicists have been able to stitch this yarn from the random shreds of evidence such as meteor impact craters, dark matter, background radiation and the theoretical multi-dimension universe(s). However, this narrative really doesn't take into account the more recent finding that dark matter constitutes the bulk of our universe and its role in creation and expansion is yet to be quantified. If Randall's theory that dark matter essentially interconnects everything in the universe is correct, then the narrative of creation will need some revision to inculcate both dark and regular matter. Old-school physics focused on observable, physical phenomena very likely will need to make room for the powerful and yet unseen dark matter. While coming to these terms, Randall admits that scientists really do not yet know what dark matter is.

The two themes of this chapter are collaboration between scientists and the sometimes random nature of discovery. Both of these themes—especially collaboration—appear repeatedly throughout the book. Here is Lisa Randall chatting with fellow scientists at a conference; here is Randall having lunch with a fellow physicist from Russia; here is Randall studying old and new ideas about the nature of the universe to familiarize herself with the dynamics of change. The message is that immersion in the scientific process is the best way to know the scientific process; the best way to make advances in science is to constantly have an open mind and not become overly attached to old ideas—one's own as well as the old ideas of the past that may seem to offer some kind of reassurance but that certainly result in a closed mind. It is this process of mental refreshment and openness to new ideas that prepare the scientific mind for new discoveries, Randall suggests.

It is the excitement of cross-pollination of ideas and the dynamic nature of inquiry that Randall wants to communicate with her readers.

Vocabulary

colloquium, extrapolate, kludge, parallax, disentangle, deuterium, Big Bang, ancillary, exponential, paradigm, encapsulate, perturbation

Chapter 5 - A Galaxy is Born

Summary

Although dark matter is nearly ubiquitous in our universe, finding it is extremely difficult because it interacts only through gravity or other forces too small to measure. Despite its appeal as a source of energy, no one has been able to capture or contain it. However, the presence of dark matter was necessary because its gravity helped to shape structure in the early universe. In large, collapsed regions where regular matter is located, dark matter continues to affect the motion of stars and galaxies. Randall gives a lengthy, detailed chronology of the early days of our universe and demonstrates how delicate the cosmic balance can be with radiation pushing outward and gravity pulling inward. Too much of an imbalance of these forces could cause cosmic collapse or a decoupling of the existing galactic structure. This point is referred to as the Jeans mass.

Areas of relatively higher mass attracted more mass, and objects such as stars and planets were formed, leaving fewer free-floating bits of matter as gravity pulled objects together, creating more mass and collecting objects in a "positive feedback process" that swept up small quantum mechanical variations left at the end of cosmological inflation. Dark matter played a crucial role in this process of aggregation because of its inability to react to the forces of radiation, thus providing a compressing force on regular matter to collapse into structure. Randall observes that wherever there is a concentration of regular matter, there is also an abundance of dark matter.

There is a truly dark period in formation of the universe before structure formation that cannot be observed because for a period of a half-billion years there were not yet any stars or galaxies that generated light. After 380,000 years, background radiation registered variations in density as the universe evolved in utter darkness. Randall says new technology is needed to allow direct observation of structure formation in this dark period.

The Milky Way, of which our solar system is a part, is one in a group of galaxies known as the Local Group. The other major galaxy in this system is the Andromeda Galaxy. In fact, these two galaxies are on a collision path which should cause a merger within four billion years.

Galaxies were the first building blocks of the universe and followed the presence of giant stars that either exploded into supernovae or collapsed into black holes. Once they were formed, galaxies merged into galaxy clusters. According to Randall, galaxy formation is hierarchical, meaning that smaller galaxies formed first and were followed by larger structures. Although galaxies may seem individually unique, they are connected to other galaxies that enable them to merge and grow larger

In formation of the universe, less dense regions expand faster than the universe as a whole, while more dense regions expand more slowly. Eventually the higher density regions form sheets at the boundary which, when they intersect, attract more matter that forms into a cosmic web of filaments more dense where they come together. This produces a web-like structure where dense filaments enclose darker areas of relative emptiness. Once again, dark matter determines the density and shape of structure.

Randall notes that the center of the Milky Way is a black hole the size of about four million solar masses. Ordinary matter can collapse into a disk such as the star disk of the Milky Way, whereas dark matter forms a rounded halo. Electromagnetic radiation and its interaction with ordinary matter is what causes this collapse. Ordinary matter can radiate; dark matter cannot. The disk shape of ordinary matter derives from the rotation momentum of the gas clouds from which it evolved.

Analysis

Lisa Randall explains in the language of physics that the earliest days of the evolving universe weren't even days because there was no light. She does this without any reference to the biblical Genesis. What was to become our universe consisted of dark matter and scattered areas of physical matter that were also devoid of light as these elements formed planets, galaxies, stars (suns) in a process that took half a billion years. Although gravity was, and is, a relatively weak force, it tended to pull matter together and was instrumental in forming the structure of the universe, Randall says. This process was balanced by the energy of radiation that pushed systems apart. From the viewpoint of the scientist, this seems like the only way these vast structures could have formed. Physicists can talk of the end of the universe with the same sense of inevitability as its creation. They cannot explain the origins of the universe any more than they can explain its eventual demise. At some point, physics and metaphysics (spirituality and philosophy) tend to merge in subtle ways that are not incompatible, if one follows Randall's arguments and their implications. Her theoretical framework for the evolution of the universe suggests a kind of coexistence between dark and regular matter, in which dark matter could have shaped the regular part of the universe observable to us. The balance between these two types of matter has created a dynamic system, Randall observes.

Vocabulary

filament, perturbation, decouple, predilection, incipient, isotropic, parsec

Chapter 6 - Meteroids, Meteors and Meteroites

Summary

Our sun, which is about 4.5 billion years old, is located near the mid-plane of the Milky Way disk and traverses the galaxy at some 220 kilometers (136 miles) per second. The sun orbits the center of the galaxy approximately every 240 million years. Randall notes that "not only do stars evolve but galaxies do as well." In an interesting aside, Randall discusses the naming of celestial objects including planets, meteors, meteoroids, meteorites and asteroids. Definitions of these terms have changed over time as astronomers learned more about our solar system.

The word "planet" serves as a good example. Originally, the ancient Greeks used the term 'asters planetai' (wandering star) to refer to observable lights in the sky that moved. As astronomy became more precise and a heliocentric (sun- centered) solar system replaced the earlier geocentric (earth-centered) model, planets were understood to be objects, like earth, that orbit the sun. Further study revealed the differing composition, history and orbits of the planets.

The smaller inner planets (Mercury, Venus, Earth and Mars) are made up of "robust" materials such as iron, nickel aluminum and silicates. Outer planets—Saturn, Jupiter, Uranus and Neptune—are referred to as "gas giants" that incredibly make up 99 percent of the solar system mass. A controversy arose over whether Pluto should be called a planet, which led to further refinement of the term. Randall says a planet is now defined as "an object that is round due to its own gravity and has cleared its neighborhood' of smaller objects that would otherwise orbit the sun."

Pluto was officially demoted from planet to dwarf planet by astronomers in 2006, in part because a similar object called Eris although very much like Pluto was considered a dwarf. Measurements revealed Eris to be 27 percent heavier than Pluto, which complicated the picture. So the current definition of dwarf planet requires them to orbit the sun but not rotate like a moon around a planet. Dwarf planets, bigger than asteroids, need to become nearly spherical under heir own gravity. To add more confusion to the interplanetary lexicon, the words "planet" and "asteroid" were used interchangeably.

Perhaps the greatest concentration of dwarf planets is in the Kuiper belt, in the outer reaches of the solar system, Randall says. Many astronomers believe there are between 100 and 200 dwarf planets in this belt.

"Asteroid" is another word in the astronomical lexicon that has a checkered past. At one time, the terms"planet" and "asteroid" meant the same thing. Nowadays the term asteroid describes "an object larger than a meteoroid but smaller than a planet. This includes objects from 10 meters to 1,000 kilometers, according to Randall. Although there are "probably billions," most asteroids fall into one of two categories—stony and made of silicate rocks found near Mars, or carbon-rich rocks found in abundance closer to Jupiter.

Most asteroids are in the asteroid belt that covers the distance between Mars to Jupiter's orbit, about 250 million kilometers from the sun.

Early knowledge of asteroids was spotty and reliant on naked eye or poor telescopic images. In 1801, the Catholic priest Giuseppe Piazzi discovered an object that orbited between Mars and Jupiter. This was the first asteroid ever found, now known as Ceres. Since the object clearly was not a planet, the name asteroid was suggested by the astronomer Sir William Herschel.

A meteoroid is "a solid object moving in interplanetary space considerably smaller than an asteroid and considerably larger than an atom." The study of these objects is called meteoritics, rather than meteorology, to avoid confusion with the study of weather and climate. Meteoroids are a grab-bag of different materials reflecting different origins in the universe. Some are of very low density, while others are chock full of iron, nickel and carbon. Randall uses meteoroid to designate "an extraterrestrial object that enters the atmosphere or that hits the earth."

Analysis

Randall observes that astronomers and physicists wage a perpetual war against misnomers that distort the meaning of language and, thus, obscure the truth they seek. Imprecise language tends to breed imprecise scientific thought. Some of this is the result of use, over-use and abuse of nomenclature. Pluto in our own solar system had been called a planet for many decades but was demoted to "dwarf planet" in 2006. When clear, detailed photos of Pluto were beamed down from a satellite showing evidence of an active past and even possible rivers, scientists renewed their debate to rehabilitate Pluto to planetary status. Although the shift is controversial, at least it serves as a lesson in humility and a sign that astronomers are quite serious about accurate nomenclature. Similar debates have arisen over appropriate use of "asteroid" and "meteoroid."

Randall seems to be making the point that language, to some extent, must evolve with scientific progress. Just as clarity of speech reflects clarity of mind, Randall would like as much precision in language as in the science it must communicate.

Vocabulary

meteoroid, hypothetical, incarnation, spherical, colloquial, egregious, proximity, plutino, resonant, arcane, firmament, colloquial

Chapter 7 - The Short, Glorious Lives of Comets

Summary

Comets—some of the more spectacular celestial objects—have been observed and puzzled over for centuries. Despite what seems like a smoky tail, comets are cold, icebound space travelers with mostly elliptical (oval) orbits. Edmond Halley, a friend of Sir Isaac Newton and amateur astronomer, correctly predicted the reappearance of the comet that bears his name over a 300-year span using Newton's laws and accounting for the gravitational influence of Jupiter and Saturn. Comets carry gasses solidified into ice that return to their gaseous state as the comet draws closer to the heat of the sun. They originate in the far, frozen regions of the solar system and consist of the coma, or aura composed of ice and dust particles, the core or nucleus, and the tail. So-called meteor showers are caused by solid debris that breaks away from the comet and burns upon entry into the earth' s atmosphere.

By examining meteorite debris that arrives on earth, scientists have determined that comet nuclei consist of water, ice, small rocky material and frozen gases such as carbon dioxide, carbon monoxide, methane and ammonia. A Harvard astronomer named Fred Whipple described comets in the 1950s as "dirty snowballs." Because comets contain organic compounds such as methanol, formaldehyde and ethanol as well as components of DNA and RNA, they are of special interest. Because of the possibility that comets may have some link to life, they have been the subjects of intense study by NASA as well as the European Space Agency, Randall reports.

Comets are identified as either short-period or long-period based on the relative length of time it takes them to orbit the sun with a 200-year period separating the two types. Short-period comets originate closer in the solar system; long-term comets originate in and most remain in the outer reaches of our solar system. The Kuiper belt's discovery in 1992 caused a shakeup in the astronomical world, one of which was the reclassification of Pluto as a dwarf planet. Neptune's moon Triton and Saturn's moon Phoebe were originally part of the Kuiper belt before they were pulled into orbits around their respective planets. The Kuiper belt is located just beyond Neptune, equal to 30 times the distance between the earth and the sun.

Astronomer Kenneth Edgeworth argued in the early 1940s that the material beyond the realm of Neptune is too diffuse to form planets but would coalesce into a number of smaller objects. Since then, scientific thinking has accepted Edgeworth's theory that the primitive solar disk formed objects smaller than planets, called planetesimals. Gerard Kuiper guessed that Pluto would draw the loose material out of the belt and clear a path. However, Pluto is smaller than Kuiper reckoned in 1951 and did not clear the debris. Sometimes both scientists are honored by reference to the Edgeworth-Kuiper belt.

Scientists now believe the scattered diskbelt is the source for many short-period comets; observations have confirmed there are more than 1,000 objects in this belt, known as Kuiper belt objects (KBOs). In the same neighborhood are plutinos, or objects with eccentric orbits that have fixed ratios with Neptune although that planet's gravitational field sometimes jerks objects out of their oath and sends them hurtling toward the sun where they emit gas and dust and become identifiable as classic comets.

The scattered disk is a comparatively empty area with icy minor planets; it intersects with the Kuiper belt but extends a much greater distance from the sun. Neptune's gravity can destabilize objects in the scattered disk that have a higher rate of eccentricity, range of locations and incline angles than objects in the Kuiper belt. The gravitational force of outer planets "almost certainly" caused the structure of the Kuiper belt and the scattered disk, according to Randall.

If the scattered disk is the source of short-period comets, the Oort cloud is the reservoir of long-period comets. The Dutch astronomer Jan Hendrik Oort had surmised in 1950 there would be a spherical "cloud" of perhaps a trillion icy, minor planets. He observed that long-period comets had huge orbits from much greater distances than the Kuiper belt. Light from the Oort cloud would take nearly a year to reach earth. Because objects at such far distances from the solar system are delicately balanced, even small gravitational disruptions or "nudges" can drive them into the inner solar system where they become true comets.

Here, Randall raises the prospect of objects from the Oort cloud turning into comets when their normal paths are disrupted and colliding with planets, including earth. Due to the Oort cloud's distance from earth, it has been impossible to observe it directly so the Oort cloud's existence is largely hypothetical.

Analysis

While beautiful to observe, comets also served an important role in the evolution of the earth by delivering both DNA and RNA—chemicals necessary for organisms to survive and reproduce, Randall notes. These celestial objects also bring frozen gasses from the far reaches of the solar system, including methanol, carbon monoxide and carbon dioxide. On the question of whether earth was "seeded" by iinterstellar visitors or arose from chemicals and compounds in the earth's mantle, Randall says her best guess is that life probably originated through contributions from both sources. When one looks at all the intricacies of the solar system and its many components, it is easy to see how the French philosopher Renée Descarte declared the universe to be "like a clockwork." Even in its seeming randomness, there are clear patterns indicative of celestial organization.

Vocabulary

parallax, parabolic, volatile, silicate, magnetosphere, luminous, sublimate

Chapter 8 - The Edge of the Solar System

Summary

How big is our solar system? This question became real rather than fanciful when NASA's Voyager I rocket flew into deep space in 2012. News reports that the vehicle had reached the edge of the solar system and was barreling into interstellar space made the question about size of the solar system timely and relevant. By most "reasonable measures," Randall asserts, the Oort cloud alone extends to 50,000 times the distance between the sun and and earth—and possibly twice that distance.

At the time of writing this book, Voyager will not enter the Oort cloud for another 300 years and may not emerge for another 30,000 years. One way of estimating this passage beyond the edge of the solar system is by measuring the increase in high-energy particles that hit the spaceship, as was the case in 2012. Simultaneously, there was a pronounced drop in low-energy particles that would also indicate its passage to the edge of the solar system, Randall says. If the sun's gravitational pull on the Voyager is used to mark its position, then it has not yet left the solar system. Whether the space station has left the solar system depends on which criteria are used to measure its position.

Analysis

In this very short chapter of only fifteen pages, Randall says the best guess of astronomers is that our solar system is about one light year across, or about 50,000 times the distance between the sun and earth..

Vocabulary

obsolescence, exultant, ambiguous, heliosphese, heliopause, addendum, plasma

Chapter 9 - Living Dangerously

Summary

Randall acknowledges that fear is part of the fascination with meteoric objects that suddenly flash into view in the night sky and blaze brightly for seconds before becoming ash. She points out that most of the sizable meteors that have struck earth—often with cataclysmic results—occurred during the Late Heavy Bombardment billions of years ago when the solar system was relatively young. Since then, she writes, the solar system has achieved a kinetic balance that makes the likelihood of earth being struck by a large object almost negligible.

In fact, she even pleads the case for meteoroids as helpful to the earth and to humanity. Meteorites very likely brought fragments of DNA molecules, as well as water, to earth to help with the beginning of life. Randall believes that "most of the minerals we mine here [on earth] come from extraterrestrial impacts." Although the focus of her book is how dark matter may have triggered the asteroid that smashed into our planet 66 million years ago causing the extinction of the dinosaurs, Randall also considers ways that humans can prevent future impacts with such destructive consequences.

Because of the strangeness of the idea that rocks could fall to earth from outer space, it was not until the early 19th Century that scientists accepted the idea after analysis of a meteorite fragment in India revealed a much higher concentration of nickel fused with rocky material than found on earth. Most of the micro-meteoroids that fall to earth are vaporized by heat that results from friction with the atmosphere, often producing the "shooting stars" visible on clear, moonless nights. Every few 1,000 years or so, a huge asteroid can enter the earth's atmosphere and cause a gigantic explosion such as occurred over Tunguska, Russia in 1908. The force of that explosion is estimated at 1,000 times larger than the Hiroshima nuclear bomb, according to Randall. Besides flattening entire forests, killing reindeer and several humans, the blast caused fires, winds, climate change and destruction of about half the ozone in the upper atmosphere.

Science has developed rudimentary means of predicting such catastrophic events. In 2008 scientists predicted that an asteroid they had just found would impact the earth the next morning, which it did. In 2013, a 13,000-ton asteroid traveling about 35,000 miles per hour, slammed into the Ural Mountain region of Russia causing some 1,500 injuries mostly by shattered window panes. Although there are asteroids and other large objects in our solar system capable of smashing into earth, the more frequent encounters are with near-earth objects (NEOs). This category includes some 10,000 near-earth asteroids (NEAs) and several comets. Objects that come close to earth without intersecting its orbit are called near-earth objects (NEOs); near-earth asteroids are known as NEAs. Some of these close objects are called Amors. There is the ever-present possibility that gravitational tugs from Jupiter or Mars could throw any of these Amors into eccentric orbits that would cross the earth's path and present the possibility of a collision.

Randall offers some reassurance to the reader concerned about asteroids or other space debris by noting that although there are more than 10,000 near-earth objects (NEAs) and many that enter our atmosphere or collide with earth, "the great majority of them are harmless." NEAs have become a specialized area of research and they are tracked by advanced telescopes that can pinpoint the exact location of these potentially dangerous objects. The United States and the European Union collaborate under a program called Spaceguard to keep track of these objects. Spaceguard has detected some 100,000 asteroids and about 10,000 NEAs. The only known near-earth object with any probability of hitting earth (0.3 percent) won't come close until 2880. "We are almost certainly very safe, at least for the time being," Randall says.

Long-period comets in the outer reaches of the solar system, however, are a different matter. Should one become destabilized and head toward earth "it would be pretty much impossible to identify long-period comets in time to do anything" even with more advanced technology. According to a 2010 study published by the National Academy of Sciences, the anticipated number of deaths worldwide from asteroids or comets is 91, which is comparable to the annual number of deaths caused by wheelchair accidents, Randall notes. Scientists anticipate that an object the size of the one that hit earth 66 million years ago and caused extinction of the dinosaurs is likely to strike earth only once every 10 to 100 million years.

Although the risks of terrestrial cataclysm from an asteroid or meteor are statistically low, scientists have seriously pondered what kind of defensive strategy could be employed if the earth were in the path of certain celestial annihilation. Those strategies are either destruction or deflection of the risks. Destruction, as in the case of exploding a nuclear weapon close to the object, could actually increase the potential danger by showering the earth with multiple incoming missiles. Deflection therefore is the better alternative, Randall says. However, "none of the suggestions for deflection or destruction would save us from an object bigger than several kilometers in size," she writes. "But really, no one knows for certain how best to proceed."

Analysis

For those of us who are frightened by the thought that earth could be slammed again by an asteroid the magnitude of one that struck 66 million years ago and caused mass extinctions, Randall says that there is no cause for worry. The probability of any kind of interstellar collision is very small. The expected time frame for such an event is once every 10 to 100 million years. The number of deaths worldwide every year is comparable to the incidence of wheelchair accidents. Randall treats the issue of meteor or asteroid strikes as one of the inevitable risks of being alive. She says we should trust science to provide whatever insight we need to minimize such risks.

Is some of the fear about such an apocalyptic event based on the wonder and amazement with which we have always viewed the heavens? Somehow humans have put natural occurrences into boxes labeled safe" and "dangerous." The notion that the universe is neither good nor bad is a hard sell to most humans, stuck as we are with binary brains. The truth is that homo sapiens has evolved in probably the most favorable time since creation, and we have a long time to think about whatever might be the best strategic defense against such an apocalyptic event, Randall assures her readers.

Vocabulary

meteoroid, luminous, mesmerize, trajectory, veracity, fortuitous, equilibrium, bolide, kiloton, perturbations, demonic, diminutive, kinetic, extraterrestrial, fortuitous, hypothesis, asteroid, amors, apollos, atens, atiras, long-period, short-period, logarithmic, deflection, spurious

Chapter 10 - Shock and Awe

Summary

To illustrate the explosive potential and public fascination with meteor craters, Randall uses the kilometer-wide, privately-owned Barringer Crater in Arizona that hit the earth about 50,000 years ago with the force of a hydrogen bomb. That meteoroid was composed mostly of pure iron and nickel. Originally classified as a crater of volcanic origin by the U.S. Geological Survey, it was not until 1905 when it was recognized by the scientific establishment as extraterrestrial in origin. Its final confirmation came in 1960 when scientist Eugene Shoemaker noticed rare types of silica in the crater that could only have been made by either a nuclear explosion or high-impact meteoroid. This finding made plain the earth's link with the solar system and the cosmos, Randall writes.

She notes that high-impact meteoroids create tremendous stress on the earth's mantle and locally intense heating which can produce crystal deformities, shatter cones, tektites, and glassy impact melt spherules, as well as shocked fused glass created by both high temperature and pressure. These and other features of craters were useful in identifying the enormous crater in the Yukatan associated with the extinction of the dinosaurs. Randall notes that most large craters were probably created 4 billion years ago when loose material from the formation of planets collided with larger objects.

Those with atmospheres, like earth, show craters that accumulated over long period of time while those without atmospheres, such as the moon, show evidence of early and ongoing bombardment in their cratered faces. The Earth Impact Data base records only 34 large, destructive impact craters within the last 500 million years, according to Randall.

Analysis

Randall is fascinated with impact craters and loves to climb rocks to explore large craters such as the kilometer-wide Barringer Crater in Arizona. Not only do such craters provide fascinating geological data but in some cases they can also offer clues about the status of the earth and solar system at the time of impact. Because of the speed of extraterrestrial objects, they usually make shocked glass which can sometimes be retrieved from inside the crater, formed by the intense heat of passage through the atmosphere followed by violent impact.

Most impact craters on earth were formed some 3.9 billion years ago as planets were formed by the accretion of rocky chunks pulled together by gravity, at a time when a plethora of random material, Randall says. Much of the debris that circles the earth and sometimes smashed into it, is essentially left-over material that did not get swept into the formation of orbiting planets.

Against this benign background, though, there is geologic evidence of neutrinos from the sun that hitched a ride to earth aboard asteroids that show our planet's direct connection with dark matter, such as the Sudbury mine in Canada. At that location mining has resumed while an underground scientific laboratory nearby searches for dark matter. The lab is located some two meters below the surface, which provides a screen that deflects cosmic rays that could interfere with the search for dark matter. In this sense, Randall sees great opportunities to advance science because of the geologic composition of the impact zone.

Vocabulary

eponymous, tectonic, morphology, caldera, cogent, conical, stratigraphy, propagate, igneous, astrobleme, paucity, subduction, hydrothermal

Chapter 11 - Extinctions

Summary

Although Darwinian concepts of evolution and adaptation explain many aspects of life and its dynamism, they do not explain the origin of life itself. The same holds true for the origins of the universe. While evolutionary changes are gradual and slow, changes caused by extraterrestrial intervention in the form of a colliding asteroid or meteoroid are sudden and unpredictable. The dinosaurs, for example, had evolved over time into many subspecies and types when they were largely wiped off the face of the earth by the cataclysmic event of 66 million years ago.

"It is easy to forget how dependent our existence is on the many contingencies that allow life to form and to die out," Randall says. "Extinctions connect our planet to meteorological events in both senses—weather and outer space." Life itself started on earth about 3.5 billion years ago. Photosynthesis emerged about a billion years after that and opened the door to the emergence of multi-cellular algae. About 540 million years ago life exploded with great diversity during the Cambrian period. The extant fossil record from that point shows evidence of numerous extinctions along with the appearance of new life forms.

The nature of fossils, as they appear in sedimentary layers on both land and sea, makes visualization of complete animals from just their skeleton extremely difficult; uneven sedimentary deposits also make determination of exact age difficult. Two tools used by paleontologists to answer these questions include isotopic analysis, in which the amount of a given isotope—or molecular structure—can be used to determine how quickly decay has changed its composition. The other tool is carbon dating, which is very accurate for material less than 50,000 years old. Randall presents a list of possible explanations for the extinction of species.

These include temperature or precipitation changes that occur too suddenly for creatures to adjust, parasites or diseases that spread rapidly and widely because of temperature increases, decline or extinction of food sources, an increase in ocean acidity levels and oxygen depletion, proliferation of invasive species that compete for an organism's food supply, sudden cataclysmic events such as the collision of a large meteor or comet with earth terrestrial upheavals such as gigantic volcanic eruptions, shifts in the earth's axis or orbit that trigger climate change, destruction of the protective ozone layer by use of sulfate aerosols or cosmic rays that affect earth's cloud cover and thus its weather.

Paleontologists have identified five primary extinction events events, according to Randall. These are the Ordovician-Silurian extinction that occurred about 450 million years ago and lasted about 3.5 million years. This event was characterized by drastically lowered temperatures and massive glaciation; the Devonian-Carboniferous transition, which began 380 million years ago and lasted for 20 million years. This period was marked by three to seven pulsed extinctions, each lasting several million years; the Permian-Triassic cataclysm of about 250 million years ago wiped 90 percent of life forms away from the seas and land. Important species such as surface plankton and bottom species such as coral, shellfish and trilobites went extinct. This was the only known mass extinction of insects. Although the exact cause is disputed, the extinction coincided with massive climate change as well as major alterations in the chemistry of both atmosphere and oceans. An eight-degree Celsius rise in temperature was undoubtedly linked to massive vulcanism in Siberia.

A fourth mass extinction that followed the third by 40 or 50 million years destroyed about 75 percent of all life forms, at a time when life was gaining a new foothold. The cause of this extinction also is not known, though lower sea levels and the beginning of tectonic changes that formed he Atlantic Ocean were most likely factors, Randall writes. The fifth mass extinction, formerly known as the Cretaceous-Tertiary event, took place 66 million years ago on the heels of the collision of earth with a gigantic meteoroid.

However, Randall argues, humankind is flirting with a sixth extinction potentially worse than any before. Many scientists believe earth may already be in the beginning of a largely man-made catastrophic extinction caused by man-made climate change. Admittedly, it would be impossible to predict without a thorough and complete inventory of every species and its rate of decline but existing figures and trends "indicate disturbing trends of a higher extinction rate than usual" by a factor of 100 per year, according to Randall. Within the last 500 years, for example, 80 mammal species have gone extinct of a total of less than 6,000.

Some possible scenarios for dealing with this looming extinction include creation or resurrection of species through DNA manipulation that can adapt to the new and changing environment. Even if this were practical, Randall says, we could not keep pace with the rate at which species are disappearing. Ironically, she is optimistic that even if a sixth extinction is in our future, it would provide new opportunities for organisms to emerge that would benefit the earth globally. Because humans now have the tools and skills to predict an extinction, they have a responsibility to do so, Randall writes.

Analysis

Earth's history is a record of serial extinctions. For the first time, man now has the tools and scientific sophistication to make a difference in further extinctions, Randall observes. The multiple possible explanations include everything from cosmic rays to an increase of invasive species that consumed most or all of an organism's food supply. Many scientists think the earth has already entered a sixth—and perhaps the final—extinction. If that's truly the case, Randall says, there is really nothing we can do to avert another extinction, short of abandoning all fossil fuels at once. Naturally, this will never work politically.

The notion of resurrecting ancient DNA from animals, including humans, to bring back old species or create new ones is far-fetched, Randall says. There would most likely be an emergence of new species that would represent a turning away from what we now consider to be natural evolution. Here, Randall wrestles with one of the thorniest ethical questions facing modern medicine. There will certainly be big changes in flora and fauna whichever path is taken. Extinction begs the question: did cosmic collisions actually accelerate the normal rate of evolution?

Vocabulary

amenable, nascent, gradualism, incursion, adaptation, notwithstanding, extinction, hypothesis, genera, gradation, conflate, foraminifera, overhomogenizing, troposphere, phanerozoic, crinoid, archosaur, mesosaurus, megafauna

Chapter 12 - The End of the Dinosaurs

Summary

Extinction of the dinosaurs ("those magnificent animals") was caused by a meteoroid impact 66 million years ago "through no fault of their own," which makes clear the connection between terrestrial and extraterrestrial occurrences, according to Randall. "A disk of dark matter in the plane of the Milky Way was theoretically responsible for triggering the meteoroid's fatal trajectory." Randall traces the gradual human understanding of how the collision of off-earth objects affected evolution of species as well as the geologic composition of limestone layers that mark different epochs in earth's history.

In 1980, father-son scientists Luis and Walter Alvarez led a team from the University of California, Berkeley who determined that dramatic variations in limestone layers included high levels of iridium—an element relatively rare on earth but scattered throughout the solar system. In various locations around the earth, the scientists found corresponding spikes in iridium deposits, which strongly suggested a sudden explosion caused by the impact of a huge object of extraterrestrial origin that smashed into the earth some 66 million years ago. Mounting evidence for an extraterrestrial explanation split the scientific community into two camps

"Geologists tended toward the gradualist viewpoint whereas physicists went for the catastrophic," Randall observes. A careful examination of lunar craters indicates the moon's surface was marked by plate tectonics—the rearrangement of huge land masses because of gravity and friction—as well as by catastrophic changes caused by meteoroid and comet impacts. Further investigation has shown that dinosaurs did not immediately go extinct because of the impact of the huge comet that hit near the Yucatan Peninsula 66 million years ago. That space object, according to Randall, was three times the size of Manhattan and released the energy equivalent of 100 trillion tons of TNT. The result: extreme winds and tidal waves on the opposite of the planet, "perhaps the most massive earthquake the earth has ever experienced" as well as clouds of super-heated dust, ash and steam that ignited fires everywhere.

"The earth"s surface would have literally been cooked," Randall says. "More than half the world's biomass was incinerated within months of the impact."

Surviving species were reduced to but a few individuals. The devastation to the world's oceans lasted from hundreds of thousands of years to perhaps a million years. The origin and influence of the meteoroid that smashed into the Yucatan "deftly illustrate the earth's abiding connections to the universe," Randall argues.

Analysis

The devastating destructive power of the asteroid that struck earth 66 million years ago took millions of years to restore our planet to a vibrant home for life, and hundreds of thousands years to replace the oceans. This was a global catastrophe that caused worldwide extinctions. Most of the creatures and plants that survived the destruction bore little resemblance to their ancestors. Whole species of animals disappeared completely. Darwin believed that extinction is a part of evolution. The reflective reader may wonder whether such a violent and destructive cataclysm is necessary to advance evolution.

In the case of the K-Pg asteroid impact, its discovery in Spain enticed University of California, Berkeley geologist Walter Alvarez to study the crater as part of a huge continental shelf that was then hundreds of meters below the surface of the sea. At first, scientists did not figure into their theories the millions of years of continental drift that rearranged huge land masses after the impact. Once biologists, physicists, geologists, paleontologists, astronomers, geochemists and others began to compare notes an hypothesis began to emerge that challenged prior scientific consensus on the origin of the crater.

By comparing iridium levels inside and outside the crater, scientists found iridium deposits inside the impact crater more than 30 times higher than in surrounding limestone deposits, which suggested a sudden and profound change caused by the impact. This discovery flew in the face of existing theories of a gradual change in surface geology. Randall concludes that only an extraterrestrial event that deposited 500,000 tons of iridium throughout the globe could account for its sudden spike. Similar geological anomalies have been studied in more than 40 different locations worldwide.

This interpretation of the evidence comports with, and supports, Randall's faith in the value of scientific collaboration although in this instance it also provides the basis for a challenge to gradualist notions about origins of the iridium deposits. Her narrative serves to illustrate the benefits of collaboration, as well as the pitfalls of professional and personal competition that serve to impede, rather than advance, scientific understanding.

Vocabulary

superfluous, mesozoic, colloquial, triassic, theropods, iridium, prescient, foraminifera, geomagnetic, supernova, gradualist, palladium, spherules, spinel, incandescent, vindication, proximity

Chapter 13 - Life in the Habitable Zone

Summary

Randall acknowledges the important role that ordinary matter played in the formation of stars, planets, solar systems and galaxies. She also acknowledges the difficulties of finding the origins of life for the simple reason that no one can really define what life is. Nevertheless, she reviews some of the ideas that have been put forth to explain how life started on earth.

One is the notion of panspermia that comets or asteroids in effect seeded earth with the necessary elements and some of the basic structure of life.

Another hypothesis rests on the idea that earth has the conditions needed for the emergence of life—without the the need for extraterrestrial intervention.

There is no way to avoid the obvious fact that heavy elements such as carbon, nitrogen, phosphorus and sulfur originated in deep space, Randall says. Hydrogen, a major component of our sun and other stars, existed in the earliest days of the universe. Chemicals on earth formed stable organic compounds that evolved into self-reproducing RNA and DNA that led to multi-cellular organisms. The implication is that formation of organic elements "is relatively straightforward on earth as well as anywhere else in the galaxy and solar system," Randall writes.

Although it is difficult for scientists to ascertain exactly where all the necessary components of living organisms originated, Randall says many scientists believe some of the materials probably came from outer space and some from earth itself. Laboratory experiments have shown that amino acids—the building blocks of protein—can survive the impacts of comets or even be created when extraterrestrial objects strike the earth.

Despite the fact that about 60 percent of earth's surface is covered by water no one knows absolutely where it originated. Some water may have arrived in rocks and comets from outer space but a more likely explanation may lie in the mixture of gasses, rising and falling atmospheric temperature and the effects of sunlight, according to Randall. Although there is much legitimate concern today about rising levels of greenhouse gasses, a certain level of planetary warming was necessary for liquid water instead of ice.

The habitable (or "Goldilocks") zone is that which is just the right distance from the sun to create conditions of heat and water conducive to life. Randall says. Earth's habitable zone will only last another 4 billion years until the sun becomes a red giant, completely burning out in a few billion more years.

Analysis

From a scientist's viewpoint, the formation of amino acids (proteins) from basic elements is natural and predictable. Theirs is a purely scientific attitude that says the emergence of multi-cellular organisms is a straightforward chemical process. Evidence suggests there is an interconnected system linking asteroid impacts and extinction of species. It also suggests that humans have co-evolved in an environment that changes slowly, not catastrophically, according to Randall.

Dark matter, about which much remains to be discovered, has been given short shrift in the narrative about creation and the origin of life. A "dense disk of ordinary matter" that was created by the condensation of dark matter served as a a scaffolding for the creation of stars and heavy nuclei which helped attract into galaxies and galactic clusters the heavy elements for construction of an environment conducive to the emergence of life but defining this process is problematic, Randall says, because no one has been able to define what life is. Chemicals on earth formed complex stable organic compounds that created both self-reproducing RNA and DNA that formed cells, and eventually multi-cellular organisms.

This kind of scientific reasoning that posits a purely chemical process for the creation of life obviously runs counter to the creationist belief that a higher power created each species and creature individually. This controversy, amazingly, persists today as self-described creationists quote from the Bible about the appearance of Adam and Eve, while Darwinists rely on strictly scientific processes and explanations. This "controversy " has raged in American public schools, churches and even the political process. Randall deftly sidesteps this argument and presents an objective view of both camps.

Vocabulary

interstitial, hypothesis,isotope, luminosity, equilibrium, subduction, heliosphere, igneous, astrobleme, prebiotic, micrometeoroid, trilobite, anomaly, micro-tektites, wavelength

BOOKRAGS

Chapter 14 - What Goes Around Comes Around

Summary

Earlier scientists have investigated whether there is any connection between the periodicity of extraterrestrial objects that strike the earth and the periodicity of climate patterns. In the former case, periodic impacts of objects occur separated by 30 to 35 million years. In the latter, scientists have observed both a 20,000-year and a 100,000-year periodic cycle in the earth's climate, Randall notes. Although there are many suggestions for the cause of periodic bombardment of earth with extraterrestrial objects, none of them match with the crater records on earth. Serbian astronomer Milutin Milankovic posited the existence of both a 20,000-year and 1000,000-year periodicity in temperature patterns that reflects global ice ages. These do not serve as evidence of meteoroid strikes on earth, because the search for crater periodicity must take into account much longer time frames spanning millions of years, Randall explains.

Randall and her research associate, Matt Reece, began their investigation of periodicity by reading as much of previous literature as they could uncover. In a parenthetical note, Randall discusses the difficulty of finding and understanding the existing pile of data on the subject that has been mired in scientific controversy for decades. One of the periodicity skeptics—Coryn Bailer-Jones at the Max Planck Institute for Astronomy in Germany—believes previous research is tainted by "confirmation bias," or the tendency for researchers to find the facts that support their beliefs and convictions. In 1988, for example, geologist Richard Grieve pointed out that imprecise dating could eradicate any signs of periodicity.

The following year, researchers Julia Heisler and Scott Tremaine proposed that an uncertainty factor of 13 percent makes it impossible to have more than only 90 percent confidence that there is periodicity in the data. Two geologists, David Raup and Jack Sepkoski of the University of Chicago, found a 26-million year periodicity in density and diversity of life forms, possibly reflecting periodicity of bombardment craters. However, none of these investigators can explain why extinctions on earth seem to have a periodicity of their own, Randall says.

"Random meteoroid strikes don't call for any particular explanation," according to Randall. "Periodic meteoroid strikes very likely do. If meteoroid impacts truly occur on a regular basis, the time dependence could signify an underlying cosmic cause."

Analysis

What is the significance of periodicity? In the case of comets, meteors and asteroids, periodicity points to a cyclical pattern in the cosmos and possibly on earth. So the quest among astronomers and physicists for periodicity is really an attempt to wrest order from the seeming randomness of these events. Cyclical bombardments of planet earth could signify its passage though the asteroid belt or through the gravitational influence of another orbiting object, such as a planet. Scientists devote time and study to this question because the answer may help to explain many unknowns.

Randall points out that previous attempts to understand periodicity may have failed because of sloppy record-keeping and preexisting beliefs, or biases, on the part of investigators. If there is any connection between earth bombardments and dark matter , this may offer a better understanding of the ubiquitous but elusive dark matter and how it influences "normal" matter that is visible and tangible. This could lead to a better understanding of the structure and function of the universe. As Randall points out, periodicity could well be the link between the invisible effects of subatomic particles and the seemingly limitless energy of dark matter. Could there be a symmetry, a web, that goes from the subatomic to the galactic scale?

Is periodicity evidence of "the astounding interconectedness of the universe?"

Vocabulary

periodicity, precession, randomness, cautionary, calibrate, superimposition, ambiguous, optimal, bombardment, surmountable, caveat, discrepancy, precipitate

Chapter 15 - Flinging Comets from the Oort Cloud

Summary

Astronomers now generally agree that asteroids are probably the cause of smaller impact craters on earth consisting of space junk "flung" out of the Oort cloud, while comets are truly visitors from deep space. Comets are probably responsible for large impact craters on earth, while the smaller craters most likely were formed by asteroids, Randall says. Comets also carry a disproportional amount of energy because of their speed, which is twice the speed of asteroids according to astronomer Gene Shoemaker. Randall says the Oort cloud ("a somewhat spherical collection of minor bodies") may extend to 50,000 times the distance between the sun and the earth and probably is a major source of comets like the one that smashed into the earth 66 million years ago.

In that region, the power of gravity between the sun and these proto-comets is 100 million times weaker than the gravitational bond between the sun and earth, according to Randall. These objects travel in a very weak field of gravity, which means they can be perturbed quite easily——and sometime veer toward earth. Somewhat like the moon's effect on ocean tides, "the galactic tide caused by the Milky Way bends the orbits of outer solar system objects," Randall writes. "Some are in precarious positions so that just a minor nudge will send the comet into the inner solar system."

Randall and her research associate, Matt Reece, spent a lot of time reading old research papers on perturbation of matter in the outer solar system. They concluded that a perceived periodicity of comets is not "a real effect" or that the structure of the Milky Way galaxy is different than conventional wisdom believed and the tidal effects could be much larger and more dramatic than previously known.

Analysis

In their search for evidence of periodicity related to earth impacts, Randall and her research partner Matt Reece found that conventional notions of periodicity were incorrect. They also concluded that the galactic tide caused by the Milky Way bends the orbits of objects in the far regions of the Milky Way enough to cause perturbations that could direct one of these objects towards earth.

Randall likens the situation to a group of dancers who perform an exotic choreographed routine that depends on dancers suspending other dancers in an elaborate, web-like structure that seems to defy gravity. Although there is the appearance of solidity in this structure, the reality is that even the slightest wrong move could bring down the entire edifice with a spectacular crash and probably injured dancers. The audience, like the performers, are caught somewhere between fear and excitement.

So it is with objects in the far reaches of the Oort Cloud; where comets and asteroids are delicately balanced in their orbits, according to Randall. The Oort Cloud is the only source of long-period comets that enter the solar system and probably the source also of many comets. Some of the objects in the Oort Cloud are so delicately balanced that the gravitational pull of planets as they pass can sometimes dislodge these fellow travelers from their orbits—with the unlikely and unfortunate outcome of heading directing toward earth.

Vocabulary

errant, chondritic, Jovian, perihelion, elliptical, oscillate, requisite, simulation, reminiscent

Chapter 16 - The Matter of the Invisible World

Summary

Admittedly, dark matter is called "dark" because it does not interact with light and therefore "we don't yet know precisely what dark matter actually is," Randall reports. However, it is known that dark matter does not carry an electric charge; moves at only a fraction of the speed of light and interacts very weakly with ordinary matter and with itself.

Scientists do not know the mass of dark matter, even if it is made of an elementary particle; neither do they know whether dark matter has any non-gravitational interactions; nor do they know how it was created in the early universe. Although " most physicists would bet that dark matter is composed of a new elementary particle devoid of the usual interactions of standard model particles, according to Randall.

Randall digresses for a moment to consider the nature of "seeing," either through natural vision or through the imagination—and she observes how context often provides a trigger for what we "see." Very often our perceptions are shaped by our expectations. Randall examines five potential candidates to elucidate the nature of dark matter. These include WIMPS, or weakly interacting massive particles; asymmetric dark matter axions, neutrinos and nachos

Randall puts forth the brain-teasing idea that, through the eons of heating and cooling in the universe, "stable particles with roughly the (recently-discovered) Higgs boson's mass happen to be left with about the right abundance to be the dark matter." Other WIMP searches have yielded further evidence that may in fact not be evidence at all but rather statistical anomalies.

"The absence of experimental support for WIMPS is making even those who were formerly in the WIMP camp question that they are on the right track," according to Randall.

Asymmetric dark matter refers to the seeming coincidence that the amounts of dark and ordinary matter are "surprisingly comparable." Through a process called baryogenesis, more matter than anti-matter was created and perhaps a similar process involving dark matter and dark anti-matter also occurred.

Axion particles are "extremely light (with) extremely weak interactions. However, they must be reckoned with for their role in the overall balance between dark and regular matter. In fact, Randall says, "dark matter could be composed of axions that carry precisely the measured dark matter energy density." Randall confides that she is skeptical that axions constitute dark matter.

Neutrinos, on the other hand, are a million times lighter than electrons and although at one time they seemed good candidates for dark matter it is now known that they cannot be dark matter because they are too light.

MACHOS (massive compact halo objects) give off very little light and thus were once also considered as potential dark matter. Examples of MACHOS include black holes, brown dwarfs and neutron stars. Somewhere between one-third the mass of the moon to 100 times the mass of the sun, MACHOS are composed of ordinary matter and have been ruled out as dark matter, according to Randall.

Black holes created by ordinary matter are "extremely unlikely" to be dark matter, she says.

Analysis

Exotic names, acronyms, wrong identification, and chimera seem to be hallmarks in the quest to know dark matter better. Weakly interacting massive particles (WIMPS) asymmetric dark matter, axions and neutrinos have been suggested as dark matter. Searches for WIMPS have largely been unsuccessful. As Randall points out, "the evidence (for WIMPs) is certainly not overwhelming." Likewise, there is no consensus on whether axions and neutrinos could be part of dark matter; Randall does not see either of these as explanations, or components of, dark matter. As the physicists peel back more layers of the puzzle of dark matter, it seems as if their esoteric naming of these possible candidates is of little avail.

One of the limitations to "seeing" the makeup of dark matter is the all-too-human characteristic of "sheer obliviousness or lack of attention," Randall writes. Model building is a technique for testing theories about what the makeup of dark matter might be and for surmounting the tendency toward obliviousness by focusing on relatively simple notions. "Model builders like me try to imagine what might be out there that experimenters have not yet looked for or realized could be within their grasp," she explains.

The consensus among physicists is that dark matter is made up of a new elementary particle that interacts with other particles in a manner not explained by the Standard Model. Randall says that she and her collaborators prefer models that are "as economical and predictive as possible" and that are consistent with experimental and observational findings, in the spirit of the previously-mentioned Occam's Razor.

Some current models for dark matter that have gained favor with physicists include the WIMP, or weakly interacting massive particle. WIMP particles have a mass consistent with the recently-identified Higgs Boson. Another model is based on asymmetric dark matter, or the idea that the amount of dark matter and ordinary matter in the universe are "surprisingly comparable." Models based on axion particles help to explain how there is a more or less equal parity between dark and ordinary matter. Neutrinos are elementary, extremely light particles that interact weakly and whose energy density rules them out as dark matter.

Massive compact halo objects (MACHO) are particles that give off little or no light and may be abundant in black holes but have been ruled out as an explanation for dark matter, Randall says. An open and inquiring mind is requisite for sorting through these and other explanations of black holes, according to Randall. Once again, she favors the simplest theory based on known principles. By this standard, none of the existing models fully explain or measure dark matter, according to Randall who has proven herself to be a careful and conservative astrophysicist.

Vocabulary

asymmetric, baryogenesis, obdurate, antiparticles, supersymmetry, baryon, axion, neutrino

Chapter 17 - How to See in the Dark

Summary

If dark matter only interacts through gravity—or through some yet-undiscovered force—with other matter it may be too weak to be detected by devices made from ordinary matter, according to Randall. So far, scientists have had to content themselves with only "tantalizing results" of their search for dark matter. Broadly speaking, there are two approaches to this search—direct and indirect detection.

An example of the first method is the cryogenic detector—a super-cold device outfitted with sensitive crystals that respond to even the slightest amount of heat that causes a disruption in the device's superconductivity. Other direct detectors employ "noble liquids," or gasses that have a small range of temperature between their gaseous and liquid state including helium, neon, argon, kryptonite and xenon. Both cryogenic and noble liquid detectors are designed to detect and record the minuscule energy of a dark matter particle.

Some of these detectors are located deep in the earth inside abandoned gold mines and other man-made tunnels from 1,400 to 1,500 meters deep to help shield the detectors from radiation interference.

Indirect measuring devices seek the signal that would be produced if dark matter particles annihilate with dark matter particles and produce other types of matter more visible in light. A Nobel laureate, Sam Ting from MIT designed a particle detector to search for positron and anti-proton particles aboard the International Space Station. Sadly, this effort seems to have been a dead-end.

Under the standard model of the universe, it's also possible that dark matter could self-annihilate into quarks and antiquarks or into gluons—**particles that interact with the strong nuclear force. Randall notes that a balloon-based experiment to be launched from Antarctica by 2019 will test this theory. Experimenters must deal with the fact that dark matter can't be directly observed, only other particles produced with it, according to Randall.

Although scientists have confirmed some basic ideas about the structure of the universe, that work is not yet complete. Possible discrepancies in this theory can conceivably explain how dark matter interacting with itself could shed light on density fluctuations in the early universe. In the denser regions, with stronger gravity, galaxies formed clusters along "sheets and filaments" that provided the template for other, larger structures. Science allows accurate predictions about the features of these larger structures but is not so useful for quantifying smaller structures, Randall says.

Observational and computational advances in the next decade will permit new discoveries about "the underlying physical properties of matter and energy in the universe," she predicts.

Analysis

Scientists' search for some hard evidence of dark matter resembles nothing so much as shadow boxing. A number of indirect methods of confirmation have been tried to no avail. Randall says technological advances over the next decade may make it possible to measure dark matter—whether directly or indirectly.

The theoretical framework for dark matter is sound, but can not be verified by observational approaches. The next step appears to be an attempt to determine by a balloon-based device if there are any particles in space that would be indicative of dark matter. Scientists at this level must have patience in research into the basic laws of physics that would be advanced by detection of dark matter, according to Randall.

Because telescopes and detectors may have some usefulness in finding dark matter, they are limited in this regard because they were designed to find light and particles emanating from astronomical sources in the sky. Theoretically, these same telescopes and other devices could be useful in the search for dark matter. If astrophysicists understand the astronomical sources of particles that may resemble dark matter they can distinguish them from an excess caused by actual dark matter. Another means of accounting for dark matter is by using neutrinos for indirect detection. according to Randall.

Although some of the re-purposed uses for conventional astrophysical tools and strategies may sound odd to the general reader, Randall presents them as logical and useful approaches to understanding dark matter. Her confidence in the basic science behind these ideas is reassurance for the reader to keep going deeper into this journey.

Vocabulary

supersede, antiparticle, scintillation, shielding, cryogenic, colloquium, tantalizing, superconductivity, acronym, fiducial, polyethylene, putative, antiproton, antineutron, thermal

Chapter 18 - Socialy Connected Dark Matter

Summary

Tools that scientists currently use to confirm and quantify dark matter are few and rather imprecise, according to Randall. For example, astronomers have been able to predict with some accuracy statistical properties of galaxies and galaxy clusters. Predictions for the nature of small-scale structures such as dwarf galaxies have been more theoretical than actual. For example, predicted peak densities of matter at the centers of galaxies are smaller than expected and density along the edges of such galaxies is greater. In short, the mathematical models of the larger-scale galaxies simply do not fit smaller galaxies. This, in turn, has scientists rethinking and reworking their models to encompass all the known variations in density in their quest to learn more about dark matter.

Randall surmises that these discrepancies between large and small scale structure "will be resolved only with a new discovery about the underlying physical properties of matter and energy in the universe (depending on) observational and computations in the next decade." There also remains the challenge to physicists and astronomers of determining the role of ordinary matter in the growth of structure in the universe; i.e.,how big is the role of ordinary matter in small-scale structure? Scientists also want to know if dark matter interactions—apart from gravity—influence structural issues. This answer may be connected with self-interacting dark matter, according to Randall.

"Perhaps dark matter has a non-interacting component and a self-interacting one too, and both of them contribute to the universe's structure and behavior," she speculates.

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Analysis

Because dark matter does not follow the predictions of scientists for structural design it may be that dark matter is not what scientists have thought, Randall writes. This helps explain some of the drama associated with dark matter. "Perhaps dark matter is not so weakly interacting after all," Randall suggests. Even though dark matter has been assumed to work only on large scale structure, the finding that it also works on a smaller scale indicates that science does not yet have all the answers to questions about the role and influence of dark matter throughout the universe, according to Randall.

Randall places her hopes in technology for advancement in understanding dark matter. For example, the structure of ordinary matter on a galactic scale may not apply to smaller structures. If that's the case, then what is the role of ordinary matter in the actual structure of the universe? At this point, any pronouncements on these issues are premature and scientists must await the advent of more powerful, more sophisticated electronic gear for the answers. It's entirely possible, for instance, that dark matter may have non-interacting and self-interacting properties. Again, these are speculations about what is possible in the nature of our universe that have yet to be proven or discarded.

Vocabulary

self-interacting, fluctuations, scaffolding, cuspy, simulation, paucity, conciliatory, cliquish, bulbous, repulsive, amorphous, diffusion

Chapter 19 - The Speed of Dark

Summary

Randal explains in depth the difference between dark matter and "ordinary" matter by noting that we humans are usually much more concerned with the latter (because that's the here-and-now everyday world) than the former. Nevertheless, it's possible that dark matter is just as important as physical matter in terms of interaction with other forces and components of the universe.

"If we were creatures made of dark matter, we would be very wrong to assume that the particles in our ordinary matter sector were all of the same type," Randall writes. "Perhaps we ordinary matter people are making a similar mistake." It's possible, according to Randall, that one type of dark matter (say, 5 percent) interacts through gravity with particles in the sphere of ordinary matter

that contribute greatly to the structure of the universe. If there is a dark electromagnetic force, it's probably a new type of particle, or dark photon, that can interact with itself similarly to the patterns of ordinary material.

In this scenario, Randall says, ordinary and dark matter could interact on the level of a unique form of light and "ordinary matter and dark matter could even physically overlap without any kind of interaction. Using observations and measurements from the Fermi earth satellite, Randall and her team wanted to know why some dark matter is denser than they predicted. One explanation would be a disk with much greater density than scientists predicted, according to Randall. This would posit two disks pancaked together —one disk of dark matter thinner than the narrow disk of the Milky Way, the other of ordinary matter.

The challenge for astrophysicists is to determine whether an interacting component of dark matter and dark matter disks exists, Randall says.

Analysis

After laying down some basic principles of how dark and ordinary matter could coexist in close proximity and experience limited interactions through dark photons, Randall proposes nothing short of a revolutionary idea in physics: a disk of interacting dark matter within the disk of regular matter. Because of the fact that dark matter accounts for about 85 percent of the universe's composition and ordinary matter only about 15 percent, the enhanced density of the interacting portion of dark matter could make it easier to find and identify than the usually diffuse dark matter. This kind of structure would make interacting dark matter and non-interacting dark matter like first cousins—very similar but distinct in their differences.

Randall suggests that "ordinary matter and dark matter could even physically overlap without ever interacting." In the dark universe, light as we understand it does nott exist. However, there is a kind of dark light unknown in our universe, Randall says. She calls this force "dark electromagnetism." Randall looks forward to the time when we can know and measure the extent of self-interactions within dark matter. 'Partially interacting dark matter remains a viable and promising possibility," Randall muses. "Dark matter might have different particles with different behaviors that might influence the universe's structure in a measurable fashion."

Vocabulary

cumbersome, elegance, phenomena, cosmologist, ubiquity, analogous, self-interaction, spherical, wavelength, shoehorn

Chapter 20 - Searching for the Dark Disk

Summary

Although it is tempting for science fiction writers and those with active imaginations to envision a scenario where creatures from the "dark dimension" prey upon, manipulate, and exploit humans in some kind of cosmic showdown, there is little to no possibility that would ever happen, according to Randall. The first problem is that dark matter is invisible to us because it does not interact with light. Therefore, searching for the DDDM presents a huge challenge Some particle physicists and astronomers find it difficult to accept the idea of a double disk structure to our galaxy.

Where does one search for the double disk dark matter (DDDM)? Randall identifies herself as a conservative physicist, or one not prone to leap from a few facts to an overarching Theory of Everything. One reason is that the scientific establishment, quite appropriately, is skeptical of new ideas until they are tested and proven. Another is that Randall tries to follow the "Occam's Razor" principle: that any new ideas in science should first be tested to see if they can be proven with existing knowledge. This principle acts as a brake on excess exuberance and saves time on researching something that can be easily explained, so that truly new ideas can be investigated for what they are.

She explains how her team consisting of herself, Audrey Katz, Jiji Fan and Matt Reece went about investigating dark matter. Direct detection of dark matter relies on a weak interaction between dark and ordinary matter that can be affected by mass of dark matter, velocity, microwave background radiation and the relative temperatures of dark matter and cosmic background radiation, according to Randall. If those temperatures are close, only about 5 percent of interacting dark matter would be needed to trigger meteoroid strikes, Randall asserts.

As Randall and her team of scientists begin to contemplate ways to measure the gravitational power of the dark matter disk at the center of our Milky Way galaxy, they are pleasantly surprised to learn that the soon-to-be-launched GAIA satellite would do exactly that. "t will conduct precisely the dark disk measurement we might have requested had we been asked during its preparation," she writes.

The GAIA satellite includes a space observatory to measure the positions and velocities of one billion Milky Way stars that oscillate in and out of the Milky Way plane. This will enable astronomers to confirm or question the existence of the dark matter disk. "We wanted to know if a dark disk is allowed or even possibly favored by the data—not just whether or not one can fit the measured stars' properties without one," Randall explains.

Analysis

Dark matter may be invisible to us humans, but it only takes 5 percent of interacting dark matter (dark matter that interacts with ordinary matter or itself) to trigger meteoroid strikes on our planet, according to Lisa Randall. This may be the closest science can come to absolute proof dark matter and ordinary matter generate enough energy to set off cosmic catastrophes. Although sensible enough, this idea remains a theory until it can be verified, perhaps by new instruments yet to be built.

Oddly enough, some scientists believe if there is merit to the idea that the core of our Milky Way galaxy is populated with a disk of dark matter plus another disk of ordinary matter, it could explain many questions about interactivity. Indeed, Randall predicts that this question will surely be focus of many research papers and graduate degrees in physics.

"With a thin dark disk embedded in a thicker ordinary matter one, dark matter's concentrated pull would combine with the more diffuse tug of ordinary matter to yield a distinctive measurable influence on stars that would vary with the distance from the midplane of the Milky Way," Randall writes. So there are forces other than gravity that help explain the content and movement of our solar system.

Although the idea of a dark universe with dark creatures is thrilling to contemplate because "enticing as it is, dark life is hard to test for," Randall says. "It is hard for the universe to create."

Vocabulary

analogous, hubris, extrasolar, photon, recoil, fortuitous, cavalier, gamma ray

Chapter 21 - Dark Matter and Comet Strikes

Summary

As Randall and her associate Matthew Reece focus on the effect of dark matter on ordinary matter, their work becomes intensified. Randall defines the exact purpose of their mission:

"The idea was that dark matter could effectively sling comets out of the Oort Cloud so that they periodically catapulted into earth, possibly even precipitating a mass extinction."

At first blush, that notion seemed far-fetched but they decided to proceed because Randall had inadvertently asked Reece about meteoroid impacts on the same day that the Chelyabinsk meteoroid crashed into earth. They wondered why dark matter affected earth in the form of meteoroids in a 30 to 35 million year cycle. Their work would test the idea whether a 15-kilometer-wide asteroid smashed into the earth 66 million years ago, triggered by the gravitational force of a dark matter disk near the center of the Milky Way.

Randall says the Milky Way was formed about thirteen billion years when ordinary matter and dark matter collapsed into a gravitationally bound structure referred to as a disk. About four and a half billion years ago, our sun and solar system were created. Some planets shed matter as they began their orbits around the sun; this matter drifted into the Oort Cloud where small, icy objects circling around the solar system were bound up in their orbits by only weak gravitational forces.

Our solar system, according to Randall, traveled from one end of the galaxy to the other every 32 million years. As it drew closer to the galactic plane, the solar system was strongly affected by the gravitational effects of the dark disk. When it was near the dark disk, the solar system was most affected by the gravitational pull of the dark disk.

"The tidal influence of a thin dense disk of dark matter might have disrupted the tranquility of some of the weakly bound objects in the Oort Cloud. Once in range of the dark disk, Oort Cloud's icy material were unlikely to stay all in place," Randall writes. Some of these objects were drawn to the inner solar system where one could have become comet aimed directly at earth. I this theory, that comet zoomed into earth at a point above the Yucatan where it would "pulverize irs target and end a journey that would culminate in massive global destruction."

Randall reasons that the dark disk at the center of the Milky Way galaxy causes perturbations each time the solar system crosses the galactic plane and triggers comet showers on a regular basis of about one to two million years. Randall and Reece concluded that meteoroid hits on should occur every 30 to 35 million years and "we could be on the tail end of an enhanced comet flux and have the potential to see heightened impacts today."

Analysis

In the concluding chapter, physicist Randall weaves various aspects—dark matter and dark disks, elliptical orbits, vast time periods, gravity, and the abundant geological evidence of a major earth collision some 66 million years ago—into a coherent whole, while also giving the reader a peek inside the world of pure science. She does this by discussing her relationships with other scientists, most notably her research partner, Matt Reece. She shares her own reasoning about following different research directions. Randall reveals that, even in a highly mathematical discipline, there is room for creativity in following intuitive hunches and room to explore very unconventional ideas. Above all, she demonstrates the absolute necessity of rigorous mining of ideas, possibilities, and facts "outside the box" of conventional wisdom. She demonstrates that original scientific research, like a new direction in the arts, always challenges the status quo and sometimes disturbs the orbits of minds caught in an endlessly repeating universe of old ideas.

Vocabulary

perturbation, strenuous, fallacy, periodicity, oscillation, galactic, fortuitous, resilient, snafu, parsec, trajectory, proxy, surreptitiously, ubiquitous, instigate, onslaught, endemic, decimate

Important People

Alan Guth

Alan Guth is the physicist who in 1980 outlined the theory of cosmological inflation to answer several questions unaddressed in the big bang theory. Some of these include why the universe has endured for such a long time. Using just the theory of gravity, a reasonable expectation would be that a dense universe would either expand into infinity or collapse. During its almost 14 billion years of existence, our universe has evolved relatively slowly and maintains a state of equilibrium.

Lisa Randall

Dr. Randall is important to this story because she is the narrator/author who pulled together history, research, observation and her own training as a physicist at Harvard University to synthesize her unique theory of how dark matter affects physical objects in the solar system. She presents scientific theory with clarity and simplicity so even the non-scientist can understand her work. She comes across as dedicated, collaborative and genuinely curious.

Richard Gaitskell

Gaitskell is a physics professor at Brown University who heads LUX, a major experiment to find dark matter. He is notable for leading the team of researchers that quickly overtook previous efforts because it could create an almost-perfect environment in which to conduct its studies. Randall is assured the LUX project will generate major advances cosmology, particle physics and astronomy in its search for dark matter.

Matthew Reece

Reece is another astrophysicist who has worked extensively with Lisa Randall on a number of projects, serving as a sounding board to new ideas, theories and notions.

Anthony Barnosky

Barnosky is a biologist at the University of California, Berkeley and one of the scientists who has raised red warning signals about the accelerating pace of extinctions, most caused by homo sapiens. Barnosky traces the rise in human population fostered and nurtured by the industrial revolution that enables humans to consume proportionally more energy. "Changes to the environment are occurring now which have a disturbing resemblance to those at the time of ([the last major) P-Tr extinction," acccording to Randall.

Luis Alvarez

Alvarez is a geologist who led a team of scientists from the University of California, Berkeley that discovered much higher levels of iridium (a rare metal) around the impact crater K-Pg than in surrounding soil samples. The crater is known by its place name—Scaglia Rossa in Italy. The scientists could measure the approximate size of the meteoroid by comparing its iridium content compared with the average iridium in colliding objects. They estimated that the size of the object that hit earth 66 million years ago was between 10 to 15 kilometers in diameter.

Milutin Milankovic

Milankovic was a Serbian geophysicist and astronomer who developed a theory that both a 20,000-year cycle and a 1000,000-year climate cycle exist. The cycles affect the earth's existence of eccentricity, axial tilt, and precession. This is reflected in temperature patterns and global ice ages, which are known as Milankovic cycles.

Richard Grieve

Richard Grieve is a geologist and head of the astrophysics group at Princeton's Institute for Advanced Study. He published a paper in 1989 that sets some boundaries for identifying periodicity. Grieve said that an uncertainty of 13 percent makes it impossible to get a better than a 90 percent confidence level that there is periodicity in the data. If the uncertainty is 23 percent, the probability of detecting a periodic signal is no more than 55 percent.

Howard Georgi

Howard Georgi is a physicist at Harvard College who suggested the name "double disk dark matter (DDDM)" to describe two disks embedded within each other in the Milky Way Galaxy. The dark matter and normal matter disks interact through gravity and align themselves with each other. Hence, the double disk moniker.

Richard Bambach

Richard Bamback is a paleobiologist with the Smithsonian National Museum of Natural History. He discovered that most extinctions occur within 3 million years of a 27-million year time period, usually during periods of decreasing diversity in species within a 62-million year span. This is evidence, however weak, of periodicity in the universe.

Objects/Places

Hadron Super-Collider

The Hadron Super-Collider is a huge circular particle accelerator built in Switzerland and financed by a number of European countries. One of its purposes is to smash particles into other particles at the speed of light to see what results. Some scientists have theorized that elusive subatomic particles created by these collisions could be evidence of multi-dimensional effects that could only result from particles zooming in and out of those multiple dimensions.

There is also the possibility that the Hadron Super-Collider could answer questions about the nature of dark matter and its role in the universe. The Collider established the existence of the so-called Higgs Boson, another theoretical subatomic particle that helps to fill in the picture of overlapping periodicity.

Milky Way galaxy

The Milky Way galaxy ("our" galaxy) is a disk-shaped aggregation of stars (suns), some with orbiting planets. As far as galaxies go, it is rather unexceptional although immense —many light years in size—and one of billions of galaxies in the known universe. At the center of the Milky Way galaxy is a disk-shaped area of dark matter. Its method of interacting with ordinary matter is the subject of intense and ongoing research.

K-Pg boundary at Itzurun Beach, Spain

The K-Pg boundary is a coastal feature of Itzurun Beach in Spain where a dramatic limestone outcrop displays 60 million years of geological history, including impact craters formed by meteoroids. These missiles usually struck the earth at about 88 km/sec, many times the speed of sound. Because of the force of impacts, the collision site is often a laboratory for scientists. If an object hits the earth at a high speed, it can have the same devastating impact as a nuclear explosion and create shocked crystal.

The Oort Cloud

The Oort cloud is a ring of miscellaneous matter precariously balanced between the weak gravitational pull at a great distance from our solar system and dark matter. The thesis of this book is that these forces of equilibrium were disturbed some 66 million years ago, with the result that a huge asteroid or comet came hurtling toward earth. Its impact was so huge as to cause the extinction of the dinosaurs and most all living things.

Barringer Meteor Crater

The Barringer Meteor Crater near Flagstaff, Arizona, is an impact crater about 1,200 meters across and 1,200 meters deep. It is named for Daniel Barringer, a mining engineer and businessman and a friend of Theodore Roosevelt. Barringer staked a claim to the crater with mathematician and physicist Benjamin Chew Tilghman. At the time (1905), the scientific consensus was that the crater was caused by an ancient volcano. However, Barringer and Tilgham published scientific papers claiming correctly that the crater was caused by an extraterrestrial impact.

Murchison Meteorite

The Murchison meteorite struck the earth in 1969 near Murchison, in Melbourne, Austrralia. It was a chunk of an asteroid that came originally from the area between Mars and Jupiter. The meteorite carried both DNA and RNA. Research into the meteorite demonstrated that amino acids can survive impacts or be created when extraterrestrial matter strikes earth.

Dr. Lisa Randall's Office at Harvard

Lisa Randall's office in the physics department at Harvard is, by her own admission, an unruly mass of papers, books, and other tools of the trade. It is also the spot where she and her colleague, Matt Reece, explored ideas about dark matter and planted the seeds of this book.

Bullet Cluster

The Bullet Cluster is a formation caused by merging clusters of dark matter as well as other galactic structures that take a similar form. This was observed with gravitational lenses as one cluster passed through dark matter from another. Unimpeded, two bulbous formations took shape in the outside areas with gas trapped in the center.

Standard Model

The Standard Model is the best guess by physicists as to the structure and functioning of the universe. This model is altered when new discoveries are made and proven true. The current Standard Model includes six kinds of quarks, three kinds of neutrons, three sorts of charged leptons (including the electron), all of the particles responsible for forces, and the Higgs boson.

Dark matter disk

Physicists believe that a concentrated disk of dark matter resides on the same plane as the Milky Way, oriented in the same position. The current theory is that the disk of dark matter caused the deviant path of the meteoroid that smashed into earth 66 million years ago, causing a mass extinction of life.

Themes

Value of Sharing Information

Frequently, Lisa Randall mentions her friendships, professional connections, and collaborator, as well as conferences and seminars with other physicists, astronomers, and geologists. The reader often finds her burning the midnight oil with graduate student Matthew Reece as they discuss the nature of dark matter and possible avenues for research. Randall frequently refers to the work of other scientists that is presented in professional journals and through personal contact. Physicists are not shy about expressing their opinions of current theories. Usually, the scientists welcome the different views because they realize the value of sharing their work.

Challenging Old Ideas

Sometimes, even scientists who are supposed to maintain "broad and open minds," as Lisa Randall describes it, have favorite ideas and notions to which they are attached. The history of science is nothing if not a testament to the meaningful exchange of ideas made possible through a friendly and collaborative spirit. New ideas are often resisted, or even fought. Some of these include the notion that earth is flat, or that the sun revolves around the earth, or that humans evolved from ape-like ancestors. In modern times, scientists have come to use the standard of whether a new idea or theory is "elegant" to determine its value in an intuitive fashion.

Exploring the Unknown

Physics, by ts very nature, can often seem chimerical, elusive, and strange for the simple reason that it is not always possible to design experiments to test new ideas. In many instances, theories and intuitions precede scientific proof. Occam's Razor and the notion of elegance have proven to be useful guidelines for intellectual exercises in physics and other sciences. Lisa Randall shows that the Hadron Super-Collider in Switzerland, space satellites, and even balloon excursions into the upper atmosphere have proven to be very useful tools for astrophysicists to push ahead their ideas and theories. It is finding answers for the many unknowns that drives scientists. Curiously, it is also imaginative curiosity that drives the works of many science fiction writers.

Working with Half-baked Ideas

In order to find the truth, sometimes a scientist must follow an idea that turns out to be wrong in the face of accumulating scientific evidence. As Randall's book demonstrates, scientists often learn more from their mistakes than from their triumphs. For this reason, she says, it is important to pursue interesting theories, even if they do not fly in the face of reality. Oftentimes there is a core of truth hidden beneath layers of misguided thinking that will emerge when the gem of original thought is cleaned and buffed.

Maintaining an Open Mind

Lisa Randall's book underscores the necessity of maintaining an open mind in theoretical physics—as in many other areas of intellectual pursuit. Surely there was more than the king's gold that drove Christoper Columbus toward the Americas. If Columbus had a completely closed mind, he probably would never have taken his journey because of the danger of falling off the edge of the earth. If the Wright Brothers had truly believed that powered human flight was impossible, why would they have toiled to build their airplane? If the dark matter deniers hold onto their belief, they will undoubtedly be left behind in the forward march of astrophysics, as Randall's book makes clear.

Styles

Structure

As a nonfiction book about physics, there is no plot and there is no problem for the lead character to work out. The problem, or challenge, is not just for Lisa Randal but for many other physicists. All would like to know more about dark matter, and Randall partners with a number of brilliant scientists as she explores the subject. The structure of the book is episodic, as it moves from one aspect of the topic to another. Randall does a good job of fleshing out her story with living people who play an active part in her research. The reader gets a glimpse of Randall's personality through little anecdotes—such as nursing an ankle injury from a skiing accident. The biggest message of the book—that dark matter is capable of throwing comets and asteroids at earth— is merely hinted at early in the book. Later, it is explored and explained.

Perspective

The perspective is that of the story teller—in this case an astrophysicist —who is also a participant in the story. By making herself both narrator and participant, Randall succeeds in drawing her readers into the story so much more effectively than would a dry recital of facts devoid of a human dimension. It is obvious that Randall and the scientists with whom she collaborates love their scientific life and the discipline of theoretical physics. These physicists get excited about promising pathways and become dejected when they reach a dead-end. They support each other in many ways and share in the hard work. A victory for one in the small population of theoretical physicists is a victory for them all.

Tone

The tone of the book is rational and restrained, but it is leavened with occasional moments of humor. Randall relates an incident at a conference when someone referred to her as a "cosmetologist." She confesses she would have no idea of how to be a cosmetologist, although she can converse for hours with other scientists.

Quotes

Given the dominance of dark energy and dark matter, and even the mystery of why so much ordinary matter has survived to today, physicists joke that we live in the dark ages. But these mysteries are precisely what make this an exciting time for anyone investigating the cosmos." (Chapter 1, p. 9)
-- narrator (1 - The Clandestine Dark Matter Society paragraph 4-5)

Importance: Lisa Randall strives throughout the book to connect even the most sophisticated scientific concepts to the general reader in a way that's easily understood. She also tries to present her findings in a way that indicates their relative importance. Here she indicates that the study of dark matter and energy is nothing less than the future of physics.

Errant comets or asteroids can both be a source of meteoroids. The trajectories of distant comets are difficult to predict, but sufficiently large asteroids can be detected well before they arrive. In October 2008 scientists announced they had found an asteroid that would hit Sudan the next day—and indeed it did.
-- Narrator (chapter 9 paragraph 1)

Importance: This quotation demonstrates that humans aren't completely powerless in facing the threat of asteroids hitting our planet. The likelihood is that early detection protocols now being developed should help reduce the threat of such collisions and possibly enable humans to divert or destroy any threatening asteroids. The implication is that a huge asteroid impact such as the one that destroyed the dinosaurs may become entirely preventable.

Most of the energy of ordinary matter is carried by atoms, which is why the cosmic pie chart uses 'atoms' and 'ordinary matter' interchangeably. In other words, dark matter caries five times the energy of ordinary matter, meaning it carries 85 percent of the energy of matter in the universe.
-- narrator (2 - The Discovery of Dark Matter paragraph 2)

These [extinction] numbers are consistent with an extinction event. Changes to the environment that are occurring now have a disturbing resemblance to those at the time of the P-Tr extinction. Carbon dioxide levels rose at that time—as did the temperature—oceans became more acidic and dead zones where oxygen is absent arose in marine environments. The rate of temperature and changes in pH seem to have been comparable at that time to what they are today.
-- narrator/author (chapter 11 paragraph 1-5)

Importance: This a key passage that shows how the rate of current environmental degradation because of human activity is rising an in arc that mirrors the earlier P-Tr extinction. Randall relies on Berkeley biologist Anthon Barnosky for both the facts and comparative trends that also show how "the staggering human population growth" correlates with human energy consumption.

Universes might exist that are closer than the horizon but separated from us across another dimension of space—a dimension beyond the three that we observe—left-right, up-don, forward-backward. Although no one has yet seen such a dimension, it might exist and in principle a universe separated from us along this dimension might as well. This type of universe is known as a braneworld.
-- narrator (3 - The Big Questions paragraph 3)

Importance: This quote is referring to the possibility that other universes may well exist in close proximity to our own. Those universes are unknown to us because they exist in another dimension which has not been discovered.

Sulfur would have been released into the atmosphere, creating sulfuric acid that could have remained there and blocked sunlight, creating global cooling that followed the global heating immediately after the catastrophe occurred and lasting perhaps for years. The loss of photosynthesis would have reverberated throughout the food chain. Global arming and dust particles blanketing the earth could have played some role, too—extending the deviant heating and cooling for many more years,
-- narrator (chapter 12 paragraph 2)

Importance: The author presents a vivid picture of the comet's effect on earth that sounds like an environmental hell far worse than anything predicted in the present day scenario of global warming. The time period for these changes and for earth's slow progress toward a new equilibrium is hundreds of thousands of years.

Astrophysicists have a lot to learn about astrophysical sources such as pulsars. As long as conventional sources stand a chance of explaining (such) signals, no convincing argument for dark matter can be made.
-- narrator/author (chapter 17 paragraph 2)

Importance: Randall cautions against allowing the enthusiasm for an idea, such as dark matter, to overwhelm both empirical evidence and the scientific method. This refers to signals from deep space that astrophysicists thought might be related to dark matter but later had to retract. It is reminiscent of Sigmund Freud's comment on symbols in psychoanalysis: "Sometimes my cigar is just a cigar."

Ordinary matter's many component hve different interactions and contribute to thr world in different ways. So too might dark matter have different particles with different behaviors that might influence the universe's structure in a measurable fashion.
-- narrator (Chapter 18 - The Speed of Dark paragraph 4)

Importance: The author is challenging the reader to "think outside the box" of the physical world of ordinary matter in which we live by imagining the possibility that we are unable to directly experience 85 percent of the universe made up of dark matter. The path of science is to investigate—not dismiss—the unknown, Randall asserts

Dark objects or dark life could be very close—but if the dark stuff's net mass isn't very big, we wouldn't have any way to know. Even with the most current technology only

some very specialized possibilities might be possible. "Shadow life," exciting as that would be, won't necessarily have any visible consequences that we would notice, making it a tantalizing possibility but one immune to observations.
-- narrator (20 - Searching for the dark disk paragraph 4)

Importance: Randall clearly wants to discourage any fantastic or magical thinking about the possibilities for dark matter. Perhaps because of such lurid imaginings of a century ago that included living creatures on the moon and other planets, Randall the conscientious physics scholar is careful to restrain her statements on "dark life" to actual facts and report that such an occurrence is very unlikely.

We do know that at least some organic material is delivered to earth through the impacts of objects within the solar system. The amount of organic matter inside the asteroid belt seems to be markedly smaller than that outside, which is one reason to suspect that some reasonable fraction of the earth's organic material was delivered from outer space.
-- narrator (chapter 13 paragraph 1)

Importance: To address questions uppermost in readers' minds about the origin and nature of life, Randall admits there is some possibility that life on earth originated from organic materials delivered via meteoroids, comets and asteroids. By stating scientific facts and avoiding speculation, Randall does not infringe on the religious/nonreligious beliefs of the reader. She promotes an open-minded approach without taking sides in the creationist vs. scientific debate.

Not surprisingly, a number of people have thought about the problem and many proposals—though no actual devices—for dealing with dangerous objects from space are under consideration. The two basic strategies are destruction or deflection. Deflection is probably the more sensible approach.
-- narrator (chapter 9 paragraph 3)

Importance: The author demonstrates that astrophysics is concerned with the minuscule as well as the cosmic, and it addresses a contemporary concern about objects from space. In most science fiction movies where earth is facing an imminent collision with an object from outer space, scientists build a rocket to carry select members of the human race to another world where human life is possible. While this scenario is unlikely in the real world, Randall lays out the two basic strategies for such an unhappy occurrence and says deflection is probably the best course.

Density perturbations subsequently grew and transformed the initially homogeneous universe into what would be amplified into differentiated regions in the sky. Two competing forces contributed as collapse into structure began. Gravity pulled matter in while radiation—though not the dominant type of energy—pushed it out.
-- narrator. (chapter 5 paragraph 1-2)

Importance: One of the miracles of creation is explained in scientific terms—the exquisite balance of elemental forces that made possible our world and our lives.

Randall points out several balancing mechanisms at work in our universe. One is the apparent balance between regular and dark matter. Another is the precarious balance of physical objects in the Oort cloud that can be perturbed and send meteors towards earth. The third is the balance between expansionary and deflationary forces described in this chapter.

Topics for Discussion

How and where did the scientific method replace fantasies and suppositions about the universe?

The scientific method probably replaced fantasies and suppositions about the universe during the Age of Enlightenment that preceded the Renaissance. Leonardo Da Vinci is perhaps the best example of the rational application of the scientific method in the Renaissance.

Is the idea that the universe is infinite and never-ending a religious idea or a physics equation?

The idea that the universe is infinite and never-ending is both a religious idea and a physics equation.

Whtat is Occam's Razor and how is it used in physics?

Occam's Razor is the principle that only observable facts should be used to find the simplest possible explanation for scientific theories.This could be paraphrased that simpler is always better and it is more likely to contain the truth.

If the universe is 85 percent dark matter, why was it only recently discovered?

Dark Matter is invisible, since it does not interact with light.

Does it seem more likely that amino acids rode to earth on a comet or asteroid? Or, were they a part of the early earth's creation?

Either is a plausible explanation. This is one unanswered question that may be resolved through physics in the near future.

What accounts for the seemingly stable condition of our universe?

There is a balance between expansionary forces driven by radiation and inward pressure from gravity.

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What substance is commonly found in impact craters?

Shocked quartz is often found in impact craters.

Why does ordinary matter in the Milky Way not form a spherical mass?

The rotation of the galaxy sends ordinary matter—heavier than dark matter— towards its edges

What is at the center of the Milky Way galaxy?

A black hole of about 4 million solar masses is at the center of the Milky Way galaxy.

What causes ordinary matter to collapse in the Milky Way?

Ordinary matter collapses into a disk because of electromagnetic radiation.