**1 -- Our Exploration of the Universe -- A Story**

Script

[1] This series of four presentations will explore the Big Bang Theory and the origin of the universe.

[2] In the first, we will explore the history of our search to understand the universe.

[3] In the second, we will describe what the Big Bang Theory actually claims.

[4] Then we will examine whether the Big Bang Theory is based on observable evidence or just on speculation.

[5] Finally, we will look at some interesting implications of the Big Bang Theory.

[6] Let’s begin by reviewing the scientific process, which is incredibly useful and powerful. However, as we will see throughout this presentation, it never provides more than tentative conclusions.

[7] Science begins with an idea—maybe from an observation, or a question. / The scientist performs experiments to test his or her idea, / and if the results of the experiments are consistent with the idea, a theory is created. / If the results of the experiment *don’t* match the idea, it will be revised or replaced. / Once scientists have created a theory, they will use it to learn more about the world around them.

[8] Scientists use the theory to make predictions, / and then they perform experiments to test their predictions. / Over time, they may amass quite a lot of evidence that supports the theory.

[9] Sometimes, however, the results of the experiments *don’t* support the theory. / And eventually the theory may need to be improved or even replaced.

[10] Then the same process starts all over again. We make predictions and compare them with the results of the experiments.

[11] This presentation tells the story of how we have used this process to learn a lot about our universe.

[12] The information comes from a presentation by Dr. Ken Caviness called “History Highlights the Fundamental Limitations of Science” and is used with his permission.

[13] “Humans have been fascinated by the stars since the dawn of recorded human history.”

[14] “Even in ancient times the patterns of motion of the heavenly bodies were considered significant, / and study of the patterns led to attempted explanations.”

[15] “Since these explanations or models were constructed by humans to explain observations made by humans, / it would have been reasonable to regard them as tentative…

[16] …subject to [change in the future] when new observations and discoveries did not fit with a previously accepted model.” But it wasn’t that simple…

[17] We will learn how scientists from the ancient Greeks to the present made discoveries and constructed theories to understand the “motions of the heavens.”

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[18] In the process, as new observational data called into question well-accepted theories…

[19] …the scientific community reacted in one of three ways: by

1. Denying either the observations or the theory
2. Modifying the theory or
3. Replacing the theory

[20] We will begin with an early scientific model…

[21] The Greek philosopher Aristotle believed that earthly matter falls to the Earth / but heavenly matter remains in the heavens, / traveling in circles, the most perfect of all possible motions (page 4)

[22] The geocentric theory said that the earth was stationary and at the center of the universe.

[23] The original geocentric model could adequately explain much of the data available at the time. / We have repeated experience with dropping things to the ground. No matter how often I pick up a stone, no matter how high I lift it, when released the stone falls back to the ground. Earthly things remain on Earth, or when removed, try to return to Earth. / On the other hand, the sun, moon, and stars do not fall to the ground. It was not really so ridiculous to suppose that they were made of something different from earthly matter. / We see the sun rise, cross the sky, and set every day. / The moon also rises and sets. / We see motion all around us, but feel the Earth under our feet, rock solid and unmoving. Based on these observations, the geocentric model looks quite reasonable: The Earth is the center of all this heavenly and earthly motion.

[24] But there were other observations that could not be explained by the geocentric theory. / Although celestial bodies appeared to orbit the Earth daily, / the waxing and waning of the moon varies on a monthly cycle. / The time of sunrise and sunset, the length of the day, the height the sun reaches overhead, and which constellations are visible in the sky, as well as their rising and setting times all varied according to a yearly cycle. / More mysteriously, the movements of five stars, known to the ancient Greeks as wanderers, could not be explained by this model.

[25] These stars, which usually moved faster than the normal “fixed” stars, would periodically seem to back up temporarily before continuing their orbit. The Babylonians were aware of the complex motion of the five known planets probably as early as the second millennium B.C., but the first scientific model explaining the motion was not developed until the first or second century A.D.

[26] The first scientific model explaining the motion was elaborated by Claudius Ptolemy of Alexandria after about A.D. 150. Rather than orbiting the Earth directly, like the yellow circle in this graphic, each planet’s path was an epicycle, which was still basically a circular path around the Earth, but along the way its orbit includes multiple smaller circles called epicycles—like the red circle in the graphic.

[27] This animation shows how the epicycles could produce the retrograde motion of the “wandering” planets.

[28] Ptolemy modified the existing geocentric model by including epicycles. This made the model more complicated but added to its explanatory power. / Geocentrism plus epicycles could predict planetary positions, where geocentrism alone could not. / This was an extremely successful theory—/ the standard explanation of planetary orbits for more than a millennium

[29] But even this highly successful theory had problems. Because it was too arbitrary and had too many adjustable parameters, it was eventually replaced by a simpler and more elegant model.

[30] …published by a man named Nicolaus Copernicus.

[31] In 1543 Nicolaus Copernicus published his heliocentric model. / This new model did away with the complex epicycles / by simply treating the sun as the center about which the Earth and the other planets circled. / The mysterious retrograde motion was simply and elegantly explained by planets near the sun periodically overtaking the planets further away from the sun. / The Earth’s rotation on its axis and its orbit around the sun explained the motion of the “fixed stars”, the gradual changing of the visible constellations throughout the year, and when coupled with the tilt of its axis, the seasons.

[32] This new model, with its greater predictive power, replaced the previous theory, / which had been widely accepted for over 1,000 years! / In the end, though, Copernicus’s heliocentric model wasn’t true either—only perhaps, more nearly true.

[33] What does this tell us about scientific theories? / Very simply that all theories are tentative. No scientific model can be considered to be the last word. / Even after years of use, something better may come along. Indeed, science is not a means of finding truth. / At best we may eliminate models that make incorrect predictions and hope that the explanations we end up with are approximately true, while keeping in mind that we may find a better approximation in the future. / This does not undermine the value of science, but puts it in proper perspective: it is important to understand the uses and the limitations of any tool in order to use it effectively, and science is arguably the most powerful tool ever invented.

[34] The exploration of our universe continued with two more scientists named Galileo Galilei and Johannes Kepler.

[35] Galileo supported the heliocentric model (perhaps prematurely). His improvements to the telescope enabled him to make several major discoveries: / Lunar craters, / sunspots, / phases of Venus, / and four largest moons of Jupiter. These discoveries added support for the heliocentric model but did not provide direct evidence that the Earth moves. / Lunar craters and sunspots indicate that the heavenly bodies are not as perfect as previously assumed. / The phases of Venus pointed strongly to both Venus and Earth orbiting the sun. / The moons of Jupiter show that Earth is not the center of all motion. Yet for most scholars this was not enough to tip the balance in favor of heliocentrism. There was then, as now, a tendency to cling to the explanation consistent with the current popular worldview, even in the face of mounting evidence against it. The large amount of observational data gathered by Galileo was instrumental in the next leap forward in our knowledge of the universe.

[36] Using the large amounts of recently collected data, Kepler created an astronomical model that provided the needed correction to the heliocentric model / and could explain more about planetary motion than ever before.

[37] Like Copernicus, Kepler thought the sun is in the center. / But unlike previous scientists, Kepler recognized that the shape of the orbit is elliptical not circular.

[38] This became Kepler’s first law, and it required that they abandon the Greek idea that circles were perfect. / His second law states that a planet’s speed does not remain constant, but varies in a predictable way. / You can learn the third one someday too, but for now just remember that, with *just* three general statements…

[39] …Kepler could explain all the data available to him from past observations of the planets. / Not only that, but they also allowed him to predict where the planets would be in the future with better accuracy than the models of either Ptolemy or Copernicus. / As scientists compared the data with Kepler’s 3 laws, his model was recognized as true, and the others false.

[40] Yet, no guarantee of truth could reasonably be given to Kepler’s model of the solar system, any more than to its predecessors. All that could be said is that it fit the data better than the others. Truth cannot be determined by human theories. One must acknowledge that a better model providing even more accurate predictions and better fit to the data might be invented at any time. And sure enough, a better model soon emerged.

[41] The work done by Galileo and Kepler eventually led to Newton’s law of universal gravitation, / which states that the force between any two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them. / Using just this *one* formula, Newton was able to explain all the known observational data of the time either as well as or better than previous paradigms, which was a huge triumph for science! / It explained everything that Kepler’s three laws explained, but did it with simpler and fewer assumptions. As it was used, additional implications became apparent, new predictions were made and confirmed by experiment and observation and the stage was set for a new era of astronomical discovery

[42] With just one theory, scientists could now explain that gravitational attraction keeps the planets, comets, and asteroids orbiting the sun in elliptical paths, / keeps Earth’s moon orbiting Earth / and Jupiter’s moons orbiting Jupiter, / makes the apple fall from the tree to the ground below, / causes the tides, and even pulls the Earth into a spherical shape—a genuinely new and unexpected idea at the time.

[43] An opportunity to test the theory came when Sir William Herschel accidentally discovered the planet Uranus in 1781. / Astronomers tracked the new planet and discovered that it obeyed the same laws proposed for the already known planets, / providing the first new supportive evidence – but not proof – for the new model.

[44] But over the following years, more precise observations showed a discrepancy between theory and experiment, leaving astronomers in a quandary. / They could ignore the conflicting observations (perhaps the default human reaction much of the time), / or in light of this new evidence, they could abandon the theory and seek a new explanation, as Copernicus had done. / The remaining option was to trust the theory and deduce the existence of factors not yet taken into account.

[45] Two men, working independently in the 1840s, decided to trust the theory / and predicted the existence and position of a previously unsuspected planet beyond the orbit of Uranus. Le Verrier presented his final prediction for the location of the unknown planet to the French Academy / and in a private communication to Johann Galle of the Berlin Observatory. The same evening the letter arrived, / Galle discovered Neptune at a point within one degree of the predicted position. / This discovery was acclaimed as “the noblest triumph of theory” / and no serious doubts remained about the truth of Kepler’s laws and Newton’s theory of universal gravitation. Yet it is still worth insisting on the distinction between supporting evidence and proof.

[46] It is interesting how history sometimes repeats itself. / Astronomers tracking the orbits of Uranus and Neptune reported a slight divergence from the theoretical orbits predicted by Newton’s model. / The model was by now so thoroughly established that the most natural thing in the world / was to predict yet another planet in orbit beyond Neptune. / Sure enough—astronomers found what they thought was another planet—Pluto. In this case, however, it turns out that the discovery was a combination of human error and coincidence. / The primary source of the original divergence was an incorrect estimate of Neptune’s mass, which was eventually corrected from data collected by the Voyager flyby mission.

[47] In 2006, Pluto was reclassified by the International Astronomical Union as a dwarf planet—a new category that encompassed many recently discovered objects beyond Neptune. / In this case, the past success of a theory, coupled with erroneous data, / led to an incorrect interpretation and a discovery hailed as further confirmation of the theory, / but which turned out to be only wishful thinking.

[48] This is a real but often unrecognized danger of over-reliance on any given scientific model, / and a weakness of the way humans think—/ too often ignoring any data seeming to disagree with a cherished model, / while considering as confirmation (or even proof) any data that seem to agree.

[49] The Pluto fiasco was a failure of observation and interpretation, / but it did not shake the universal acceptance of Newton’s model as the truth about celestial mechanics. However it eventually WAS shaken by other evidence. / A tiny discrepancy in Mercury’s orbit, which could not be explained by Newton’s theory, made astronomers wonder if there could be another planet between Mercury and the sun. So certain were the searchers that the proposed new planet was even given a name—Vulcan. But Vulcan was never found and its existence was eventually ruled out. Although not realized at the time, / this was the death-knell for a so-called “Universal Law”

[50] Various modifications of the theory were attempted but failed. / Only abandoning Newtonian theory in favor of another could the scientific explanation of planetary motion be saved.

[51] In the same way that each of these models was replaced by theories that could explain more data, / even Newton’s theory of universal gravitation has been superseded.

[52] The model that eventually replaced Newton’s theory is Einstein’s Theory of General Relativity. / This theory delivers more accurate predictions and additional predictive power. / It explains the discrepancy in Mercury’s orbit / as well as smaller orbital precessions of Venus, Earth, and Mars that have been measured since. / And it explains the cause of gravity itself, about which Newton refused to speculate.

[53] According to Einstein, orbits are not caused by a force reaching out from one mass to another across empty space. / Instead, he suggests that the fabric of spacetime itself is warped by the presence of mass—similar to the “dimple” formed on the surface of a trampoline when a large weight is set on it. Just like a marble rolling on the trampoline might be caught in the depression and orbit the central weight, the planets are actually traveling “straight ahead” in the region of curved spacetime caused by the sun and our moon is actually traveling “straight ahead” in the region of curved spacetime caused by the Earth. The central idea of general relativity can be described this way: / Mass warps space / and warped space tells matter (and light) how to move. / Einstein’s equivalence principle states that it is impossible to distinguish locally between acceleration and gravitation, an exciting and productive unification of ideas previously considered distinct.

[54] General relativity also explains phenomena undreamed of in Newton’s day.

[55] Newton’s Law and General Relativity often agree. But when they disagree, / General Relativity gets the right answers. It has all the earmarks of being truth about how the universe operates. / The irony, of course, is that a “natural law”—tested and trusted over hundreds of years—/ was replaced by a “theory”—as we refer to the General Theory of Relativity. But the theory is right where the law was wrong. / Despite the insights that came from using Newton’s explanations, despite the fact that they gave the right answers, / the Newtonian view of the universe was simply not true.

[56] Is this better model, now – finally– true? / In fact, we already know it is not. At the very small scale, at distances comparable to or smaller than the size of molecules and atoms, both Newtonian physics and General Relativity give wrong answers / and Quantum physics must be used. / But it too must be considered only an approximation of the truth

[57] Let’s return to the process which creates scientific theories / and then uses those theories to learn more.

[58] By making predictions / and then performing experiments to test them, scientists often amass quite a lot of evidence over time to support a particular theory.

[59] But eventually, the results of the new experiments may no longer support the theory. / And eventually the theory may need to be improved or even replaced.

[60] Then the same process starts all over again.

[61] We have seen this process at work as scientists through the centuries have tried to understand our universe. This historical sequence of scientific models and paradigm shifts should bring home a fundamental truth about science itself.

[62] Science is tentative, limited, and cannot guarantee truth. The results of science are undoubtedly useful, but may not be true in any real sense. / New theories that explain more than previous models should be thought of as “approaching truth more closely,” but history gives us no reason to believe that all errors of observation or interpretation have now been eliminated. / Although science is an incredibly valuable tool, it is inadequate as a way of learning truth.

[63] This story provides an important backdrop, for a fairly recent theory about the origin of the universe…

[64] …the Big Bang Theory, which we will explore in our next presentation.

[65] Special thanks to Dr. Ken Caviness for permission to use the content of his paper as the basis for this presentation.