THE BIOLOGOS FOUNDATION

How are the ages of the Earth and universe calculated? How accurate are those figures?

Introduction

There is strong evidence that the Earth is roughly 4.5 billion years old and the universe is roughly 14 billion years old. Here, we will look at the evidence supporting those claims.[1]

Determining the Age of the Universe

Much reliable evidence from a surprising number of very different sources supports the age of the universe. Consider the distance from the Earth to other objects in the universe. For example, 93 million miles of space separates the Earth and its sun, and because light travels at 186,000 miles per second, it takes light 8.3 minutes to travel that distance. When we look at the sun, we see it as it was just more than 8 minutes prior. Other stars and galaxies have been observed from which light takes — millions and even billions — of years to reach the Earth. If the light has been traveling billions of years to reach us, then the universe must be at least that old.[2] For these distant objects to be observed in a universe just a few thousand years old, either the speed of light must have once been much greater, which would have drastic impacts on other factors of the universe, or photons must have been originally created mid-journey.[3] This second option is often promoted by those who argue God made the universe with the appearance of age. To do this, however, God would have had to do much more than simply create photons en route: God would have had to set numerous aspects of matter and energy very precisely so that multiple lines of evidence would converge in a way that would mislead us about the universe's true age. Such deception seems inconsistent with a God who is the author of truth. The clearest and most natural explanation is that the universe is billions of years old, just as it appears.[4]

The universe began in an event called the Big Bang, and it has been expanding ever since. The distant galaxies have been spreading ever farther apart because the space between them is expanding. Edwin Hubble discovered this expansion in 1928 and realized that this implied that the universe had a finite age.[5] This age can be easily calculated by running the equation backward.[6] Imagine that while driving a car, the cruise control is set to 60 miles per hour. After going 150 miles, a simple calculation tells us that the car has been traveling for 2.5 hours.[7] This same logic applies to stars and galaxies: by knowing the universe's rate of expansion and the average distance between galaxies, a similar calculation can reveal how long ago the universe has been expanding from its original, vanishingly small size.

The expansion rate can be measured using the Doppler effect*,* which is often illustrated by the following example: When a train passes an observer and blows its whistle, the pitch of the whistle sounds higher as it approaches and lower after it passes. The same effect can be heard when a vehicle passes blaring a siren. This effect is created because sound waves are pressed closer together when their source — the train – moves toward someone who can hear it. This produces a higher pitch for the observer. As the source leaves, its sound waves spread farther apart, generating a lower pitch. This is called the Doppler effect, and it can be detected quite easily. Police officers use the Doppler effect to determine the speed of cars.

To determine the age of the universe, the Doppler effect can be applied to light waves from distant galaxies. Like the pitch of a sound, the color of light is determined by the frequency of a wave. Therefore, when a galaxy is moving away its light waves are spread further apart, making it appear redder. The change in the galaxy's color is called the red shift, and it can be used to calculate the rate of expansion just as the police officer determines the speed of a car.

Next, the distance to the galaxy can be computed by comparing the actual brightness of the star or galaxy with the amount of light that reaches Earth: stars that are further away will appear more faint.[8] The actual brightness of a galaxy — as opposed to the apparent brightness, which declines with distance — can be determined by identifying some aspect of the galaxy that has a wellestablished brightness. This would be like estimating the distance to a car based on the fact that car headlights are all very similar in brightness. With this information, the tools are now in place. Using accurate measurements of the universe's expansion rate from the Hubble telescope, astronomers have determined the universe to be 13-14 billion years old.[9] Distant galaxies must have been moving away from each other for this amount of time to be where they are. This conclusion has also been confirmed by several other techniques.[10]

The Age of the Earth: Non-radiometric Methods

Several methods use various different cycles in nature to measure the passage of time. For instance, trees form yearly rings on their trunks, so we can determine a tree's age by counting its rings. The oldest living trees on earth are bristlecone pines found in the Sierra Nevadas and are about 6,000 years old. However, the dead trees lying beside them are as old as 11,800 years.[11] Similarly, lakebeds accumulate different types of sediment depending on the season like more minerals in spring, more pollen and plant material in summer and fall. This causes the formation of distinguishable annual layers that can be counted on the bottom of lakes, just like counting tree rings. Scientists have found lakebeds with layers as old as 35,000 years.[12] The seasonal ice rings in glaciers provide another similar example. The ice forms through the accumulation of years of falling snow, and we can distinguish seasonal differences — such as increased dust and larger ice crystals in summer — that allow the age to be determined. Scientists have drilled ice cores deep into the glaciers and found ice that is 123,000 years old in Greenland,[13] and as old as 740,000 years in Antarctica.[14]

Other methods take us even farther. Variations in the Earth's orbit generate Milankovitch cycles, long-term cyclic changes in climate. In recent geological time — the last few hundred thousand years — these cycles produced the ice ages. Analysis of the effects of Milankovitch cycles takes us back 30 million years.[15] Also, the Earth has a magnetic field that reverses direction about two to three times every million years. Evidence of these reverses are left behind in rocks that were molten and had their magnet fields frozen at the time of the reversals. By counting these, we can trace back to 170 million years ago.[16]

The above methods give a lower limit for the Earth's age, but not an upper limit. They simply cannot point further back because of limitations in measurement. In the case of tree rings, approximately 11,800 years ago, or the end of the last ice age, the climate changed abruptly, and the locations of old trees underwent a major shift.[17] For sediment in lakebeds, the layers become too compressed after 35,000 years and can no longer be distinguished. Therefore, in order to go back to the formation of the Earth, we need methods that take us back much further. Fortunately, radiometric methods do just that.

The Age of the Earth: Radiometric Methods

Radiometric dating measures how the proportions of different elements in rocks differ from their initial ratios. Darrel Falk offers a simplified explanation.[18] Imagine being taken captive and kept in solitary confinement with nothing but the duffel bag you had when you were seized. You want to find some way to keep track of the date, and you happen to find two boxes of tissues in the bag. Having counted the tissues – 300 total – you decide that every day you will use one tissue to wipe your hands and face. Keeping track of the number of used tissues will allow you to determine how long you have been held captive. This basic principle can also be applied to measure the age of rocks.

First we need a brief chemistry review.[19] All matter is made of elements such as carbon, oxygen, hydrogen and nitrogen. These elements can come in different forms known as isotopes such as the three forms of carbon: ^{12}C, ^{13}C, ^{14}C. All three forms have nearly identical chemical properties, but they each have a slightly different mass. This difference is revealed on the nuclear level: each atom for a given isotope has a certain number of protons and neutrons in its nucleus. ^{12}C has six protons and six neutrons, and ^{14}C has six protons and eight neutrons. The extra neutrons make the ^{14}C nucleus unstable, and sometimes it will transition or decay into a more stable form. This occurs when one of the eight neutrons splits into a proton and an electron. What remains is an atom with a new proton and a new electron, for a total of seven, and one less neutron, also seven. This is now a nitrogen atom. Although most isotopes of all elements are stable, many are not. These unstable isotopes allow us to determine the age of the rocks. The energy released during the radioactive decay, when a neutron converts into a proton and an electron, is called radioactivity. It can be detected with an instrument called a Geiger counter that allows us to determine the age of rocks.

Uranium contains useful radioactive material. Just as ^{14}C is unstable and decays into a more stable form, Uranium-235 (^{235}U) decays into Lead-207 (^{207}Pb), through a sequence of radioactive events. Uranium-235 is like the collection of clean tissues in the example above, and lead-207 plays the role of the dirty tissues. As time passes, there will be more lead and less uranium, so we can use the relative amounts of lead and uranium — their ratio — to determine the age of the rock. If the Earth were infinitely old, there would be no uranium-235 because it all would have been converted to lead-207. If it were very young, hardly any would have been converted. Neither of these is the case; rocks are found with a combination of uranium and lead.

In the captivity example, we used up one tissue every 24 hours. Similarly, to date a rock we need to know the rate at which the uranium is being converted into lead. For radioactive decay, we speak of a half-life, or how long it takes for half of the material to decay from its unstable starting point to its more stable final form. If the half-life of element X was one hour, and we started with 40 atoms of *X*, then after one hour we would have 20 atoms of *X*, after two hours we would have 10 atoms and after three hours we would have five atoms left. In a day or so element X would be completely gone, and only its more stable end product would remain. Obviously element X would be useful only for measuring rocks that were a few hours old. To measure the age of the Earth, we need something with a much longer half-life. Fortunately, there are several such elements: the half-life of uranium-235, for example, is 713 million years. This is determined with a Geiger counter that detects an emission whenever a uranium atom decays.[20]

To use this process to date a rock, we need to know how much uranium and lead the rock had to begin with. If we assume the rock started out as pure uranium, then dating would be easy. If it now was half-uranium, it would be 713 million years old. If it now was only one quarter uranium, then it would be twice that old, or 1.426 billion years. This cannot be assumed so easily, however, for it is not known that all such rocks began as pure uranium. Instead, we must determine the initial composition of the rock. Fortunately, this is also fairly easy. There are two isotopes of lead: Lead-207 and Lead-204. The two isotopes are chemically identical, with nothing to distinguish them but the number of neutrons buried deep in the nucleus. So when the rock is forming and lead is being incorporated into its composition, no preference will be shown for either isotope. The two types will be incorporated in the same relative amounts as are found in the Earth's crust. However, when Uranium-235 decays, it only creates Lead-207, so one can use the excess Lead-207 to determine the initial amount of lead in the rock.[21]

We now have the information needed to date the rocks. The dates we get with this particular radioactive decay measurements can be further confirmed and refined by comparing this result to other radioactive systems. There are about 40 different radiometric techniques available for dating rocks, each with different half-lives.[22] Using the uranium/lead system, the age of the Earth has been determined to be 4.566 billion years, with a margin of error at ±2 million years.[23] Although this error may seem large compared to human history, it is actually just a fraction of a percent — considerably smaller than the error that results from laying out a baseball field by pacing off the distances between the bases.

Two common objections are raised to radiometric dating primarily by those who believe that the Earth is young. First, there is a concern about inconsistencies in the dates determined by different systems. But although there is error in the measurement, it is not significant. Even a huge error resulting in a number 10 percent too low would make the Earth 4 billion years old instead of 4.6

billion.[24] This is still a long way from claims that the Earth is only thousands of years old, as thought by those who date the Earth with an ultraliteral reading of Genesis. Second, some suggest that radioactive decay rates were much faster in the past, making things look older than they really are. There is simply no evidence of any sort for this claim. In fact, there is counterevidence that the rates have never changed. Radioactive decay is a nuclear event and very resistant to change. Even at temperatures and pressures capable of ripping the electrons off the atom, absolutely no change in the nuclear decay rates has been observed. Additionally, all decay rates would have to undergo gigantic and tightly coordinated changes in order for a relatively young Earth to appear several billion years old.[25]

Conclusion

Many different and complementary scientific measurements have established with near certainty that the universe and the Earth are billions of years old. Using the red shift, cosmic background radiation and other methods, astronomers have determined the universe is 13.7 billion years old. As for the Earth, radiometric dating reveals its age to be 4.566 billion years.

Consulted Experts:
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Notes

1. Several of the examples in this response come from Darrel Falk's book, Coming to Peace with Science: Bridging the Worlds between Faith and Biology (Downers Grove, IL: InterVarsity Press, 2004).
2. Darrel R. Falk, Coming to Peace with Science: Bridging the Worlds between Faith and Biology (Downers Grove, IL: InterVarsity Press, 2004), 79-80.
3. Darrel Falk gives one example: "The speed of light is a property of the fundamental laws of electromagnetism (Maxwell's equations). If the fundamental laws had changed, those alterations would have impacted the lines of light spectra (that is, patterns of emitted light) that emanated from the atoms of individual elements. Since the spectral lines are identical in the ancient light compared to light generated today, the laws operating at the time of the emission of the ancient light must have, in effect, been the same as those in operation today. No change in the laws, no change in the speed of light" Darrel R. Falk, Coming to Peace with Science: Bridging the Worlds between Faith and Biology (Downers Grove, IL: InterVarsity

Press, 2004), 80.

4. A common response is that God could have created a Universe with the appearance of age. This takes the question from science to theology. While God is certainly capable of creating the appearance of age, many note that this does not align with his character or a clear reading of Genesis.
5. HubbleSite, “Hubble Uncovers Oldest ‘Clocks’ in Space to Read Age of Universe,” HubbleSite, http://hubblesite.org/newscenter/archive/releases/2002/10/ (Accessed February 19, 2008).
6. HubbleSite, “Hubble Uncovers.”.
7. Based on example in Falk, Coming to Peace, 76.
8. Based on example in Falk, Coming to Peace, 77-78. For discussion on determining the “actual brightness” of stars, see W. L. Freedman, “The Expansion Rate of the Universe,” Scientific American 267, no. 5 (1992): 54.
9. HubbleSite, “Hubble Uncovers.” Scientists are also taking into account a newly discovered phenomenon called dark energy. At this point, dark energy is understood very little.
10. Two further methods confirm the result of an ancient Universe. In 2002, the Hubble telescope discovered white dwarf stars that also pointed to an ancient Universe. These dying stars grow increasingly faint with time, allowing them to be used as “clocks” by measuring their brightness. These discovered white dwarfs were found to be 12-13 billion years old, which, combined with an earlier finding that they formed ~1 billion years after the Big Bang, also pointed to a Universe 13-14 billion years old. In 2003, astronomers were able to map cosmic background radiation, leftover heat from the Big Bang which the field of space a faint glow at 2.725 K (-270°C), as noted in Paul Davies, Cosmic Jackpot: Why Our Universe is Just Right for Life (Great Britain: Penguin Press,2006). Studying its distribution, they were able to calculate the more precise age of 13.7 billion years, as explained in Bob White, “The Age of the Earth,” Faraday Papers, no. 8 (2007), http://www.st-edmunds.cam.ac.uk/faraday/Papers.php.
11. Falk, Coming to Peace, 73. The ages of the dead trees were calibrated by comparing rings from the end of their lives to the early rings of trees still living. For example, a tree from 11,800 years ago lived 6000 years and then died. Its last 200 rings could be calibrated with the first 200 rings of a living tree that is currently 6000 years old.
12. Falk, Coming to Peace, 74. There are actually even older sediment layers, but beyond 35,000 years, layers become so compressed that they cannot be distinguished for accurate dating.
13. Roger C. Wiens, “Radiometric Dating: A Christian Perspective,” American Scientific Affiliationhttp://www.asa3.org/aSA/resources/Wiens.html (Accessed February 18, 2008)See also, North Greenland Ice Core Project Members, “High-resolution Record of Northern Hemisphere Climate Extending into the Last Interglacial Period,” Nature 431 (2004): 147–151,

which reports ages back to 123,000 years.

14. EPICA Community Members, "Eight Glacial Cycles from an Antarctic Ice Core," Nature 429 (2004): 623–628.
15. Bob White, "The Age of the Earth," The Faraday Papers, no. 8 (2007), http://www.st-edmunds.cam.ac.uk/faraday/Papers.php (accessed February 18, 2008). Here is a more detailed description from Bob White's paper, page 2: "Perhaps more surprisingly, changes in the Earth's orbit cause long-term cyclicity in climate patterns, known as Milankovitch cycles. Eccentricity of the Earth's orbit round the sun produces 100,000 and 413,000 year cycles, tilt of the Earth's axis generates 40,000 year cyclicity, and precession of the Earth's axis of rotation creates cycles at approximately 19,000 and 23,000 years. Identification of these cycles by their rhythmic climatic effect on ancient sediments allows precision dating back to 30 million years."
16. Bob White, "The Age of the Earth." Here is a more detailed description from Bob White's paper, page 2: "A final example of irregular cyclic changes that can be used to date rocks is their magnetic polarity. Fluid motions in the Earth's liquid outer core create a dynamo which generates a global dipole magnetic field roughly aligned with the Earth's axis of rotation. The magnetic field reverses its polarity on average 2–3 times per million years. Since rocks bearing magnetized minerals record the direction of the magnetic field at the time they were deposited, the polarity reversals can be recognized and used to date the volcanic basement of the seafloor back 170 million years. This technique was the basis of recognizing seafloor spreading, leading quickly to the plate tectonics theory which in the 1960s revolutionized geological interpretation of the Earth's history."
17. Weins, "Radiometric Dating," 13.
18. Falk, Coming to Peace, 65-66.
19. Review based on Falk, Coming to Peace, 62-63.
20. Falk, Coming to Peace, 63-64.
21. Falk, Coming to Peace, 64-65.
22. For a sampling of thirteen, see table in Weins, "Radiometric Dating,"
23. White, "The Age of the Earth."
24. Falk, Coming to Peace, 69-70.
25. Falk, Coming to Peace, 70-72.

Further Reading

Articles

- White, Bob. "The Age of the Earth." *Faraday Papers*, no. 8 (2007).

- Wiens, Roger C. "Radiometric Dating: A Christian Perspective." *American Science Affiliation* (2002).

Books

- Falk, Darrel R. "Putting Creation into a Time Frame." Chap. 3 in *Coming to Peace with Science: Bridging the Worlds between Faith and Biology*. Downers Grove, IL: InterVarsity Press, 2004.
- Young, Davis A. *The Bible, Rocks, and Time: Geological Evidence for the Age of the Earth*. Downers Grove, IL: InterVarsity Press, 2008.