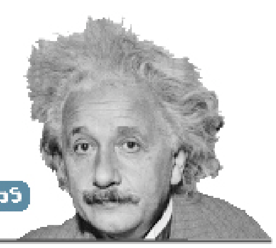
Journey to the Beginning of Time: An Interactive Demonstration

PROLOGUE – Introduction and Overview

Background: Very few people have a comprehensive view of our place in the universe. They think about astronomical objects as disconnected elements, rather than an integrated system. This demonstration takes visitors from our Solar System, the part of the universe with which they are most familiar, outward to our Sun's stellar neighbors, the other stars in our Milky Way galaxy, and into the universe of galaxies beyond. As we journey outward to distant galaxies we discover a surprising fact: the distant galaxies look much different than the galaxies closer to our Milky Way. Why is this? As it turns out, the light from these distant galaxies takes a much longer time to reach us than the light from objects nearby. When the light left distant galaxies many billions of years ago, it "recorded" information about what those galaxies looked like many billions of years ago. Many billions of years ago, the universe had not yet had time to evolve into the galaxies that we observe today. However, billions of years later, we are just now receiving the message contained in the light from these distant galaxies. Therefore, we observe the galaxies as they looked in the distant past, when the light left them. Light from even further away left its source before galaxies even began forming. The message we receive from these ancient photons is a nearly uniform glow, leftover heat from just after the Big Bang. This image, the "cosmic microwave background," has been recorded with the Wilkinson Microwave Anisotropy Probe and represents light from almost 14 billion years ago. Because light takes a finite time to travel through space, we are limited in our view of the universe by the time is takes light to travel from its first moments of existence. We call this limit "the cosmic horizon" and it is the edge of our observable universe.

Suggested Visual: Fly-through Space and Time from the Wilkinson Microwave Anisotropy Probe 9^{th} animation on this page: http://wmap.gsfc.nasa.gov/m_or/mr_media2.html
"Take a trip through space and time…" (under 'Explanations of Cosmology')

This Document: This demonstration is divided into three stages: Exploring Our Galaxy, A Universe of Galaxies, and Light Travel Time. Each section contains a list of materials needed, a core script for presenting the ideas, suggested visuals for illustrating the ideas presented, and supplementary notes with additional content or presentation ideas. Many of the notes (and parts of the core script) presented need not be shared with your audience. We recommend that educators pick and choose the elements they wish to present, based on the level of their audience and time constraints.



To Begin: Welcome your audience and invite them on a journey to the beginning of time. Albert Einstein imagined what it would be like to ride on a beam of light through the universe. Using hands-on activities, and a few images from modern telescopes, we are going to travel through space and time on beams of light and discover what the universe is really like.

Important Idea: One of Einstein's most amazing ideas is that the speed of light is constant. This idea will be very strange to many members of your audience. One suggestion for making them more comfortable with this idea is to ask them how far away something is. For example:

> How far away is the front desk of your museum?
> How far away is the next nearest major city?

Some audience members will answer in terms of distance. ("New York is 250 miles away from Boston"). Others will answer in terms of time. ("It takes 5 hours to get from New York to Boston.")

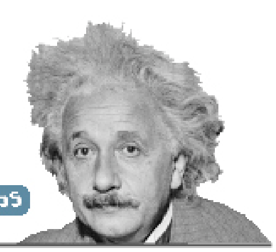
Does one answer have anything to do with the other? Yes! How can that be? Audience members are assuming a speed for their travel, for example 50 miles per hour.

In space we like to think about a cosmic speed limit – nothing can travel faster than the speed of light: 186,000 miles per hour (300,000 km/s). We are going to travel at this speed across the universe and figure out how far away things are.

NOTE: It is entirely possible to present this demonstration without ever using the term "light year." Though used commonly by astronomers, it is often confusing to general audiences. The same idea can be presented by simply asking how long it takes for light to travel across/between a particular object(s).

***Fun fact:** a popular movie involving space travel uses the term 'light year' incorrectly!*

Your audience is now ready to begin exploring…remember to buckle your cosmic seat belt; we're in for an exciting ride!



ACT I – Exploring Our Galaxy

When Albert Einstein was first proposing his revolutionary ideas, our view of the cosmos was limited. We had no idea how big the universe was, or even what it was really made of. In this part of our journey, we are going to explore the Milky Way Galaxy. In 1905, our galaxy was thought to be the full extent of our universe. Before we can begin traveling through the universe, we must build a scale model of where we are going.

You Will Need:

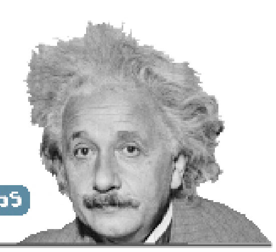
- Round cookies between 1 and 2 inches in diameter
- Round cake-decorating sprinkles (sometimes called nonpareils)
- Two hungry volunteers
- Supplemental slides (if desired)
- A container into which the sprinkles can be poured.

Step 1 – Our Solar System
Suggested Visual: A diagram of our Solar System and a picture of a cookie

Ask your audience to imagine shrinking the entire solar system, from the Sun all the way out to Pluto, down to the size of a round sandwich cookie. Remind your audience that even on this scale, the Sun itself is a microscopic speck of sugar in the center of the cookie. Pluto, then, is an even tinier speck rolling around the outside edge of the cookie. If you like, you can call up a volunteer to "be" the solar system, holding the cookie at one end of the room.

> NOTE: Some presenters may wish to provide all the members of their audience with solar systems. This will allow you to make comments as the demonstration goes on about people eating their solar systems, as audience members are wont to do.

Let's take a moment to think about how big this is. Consider that light takes 8 minutes to travel from the Sun to the Earth. The Earth is approximately 1/40 of the way out from the center of the cookie. This means that it takes eight minutes, traveling at the cosmic speed limit, to travel 1/40 of the way across a single cookie.



***Fun Fact:** The Voyager spacecraft has been traveling for over 30 years and has made it twice as far as Pluto. That is only one cookie diameter!*

Step 2 – The Next Nearest Star
Suggested Visual: Another cookie and a football field

Now ask your audience the following question: on this scale (solar system = one cookie, approximately two inches) how far away is the next nearest star? If you like, you can invite another volunteer to become our Solar System's nearest neighbor by holding a second cookie and standing the correct distance away. Let your audience guess how far away the second cookie should be.

NOTE: Scientists have not actually found planets orbiting the nearest star to our Sun. Using a cookie for Alpha or Proxima Centauri requires a bit of artistic license.

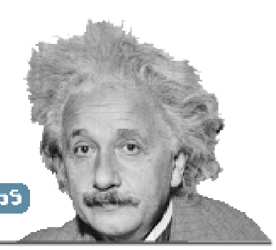
As it turns out, the next closest star to our Sun is approximately two football fields away! Your second volunteer may not be able to model this distance in your demonstration. As consolation, though, you do have a cookie to spare.

NOTE: If you prefer, objects such as poker chips, large coins, or any round disk between 1 and 2 inches, will work in place of cookies. Just remember not to feed your quarters to your volunteers!

It takes light 4 years to travel from our solar system to the nearest star. Does anyone in your audience know someone who was not alive when the light from our nearest neighbor began its journey to our eyes?

This is the rough separation of stars in our area of the galaxy. Can you imagine traveling for four years to visit your nearest neighbor?

Step 3 – All the Stars in our Galaxy
Suggested Visual: A view of stars toward the center of our galaxy



It is now time to imagine the even bigger picture…our Sun (and the neighboring stars outside our Solar System) is just one part of the entire Milky Way galaxy. In order to imagine the entire Milky Way galaxy, we need to think in terms of stars. We will pretend that the microscopic speck at the center of the cookies are actually a tiny grains of sugar – cake-decorating sprinkles.

NOTE: You may wish to do this part of the demonstration with birdseed. Be sure to remind your audience that this is much too large for stars on this scale. In fact, even the sprinkles are too large!

How many cake-decorating sprinkles are in our entire galaxy? Astronomers have determined that there are anywhere from 200 billion to 400 billion stars in our galaxy. They estimate that 7% (about 14 billion) of those stars are like our Sun.

Step 4 – 200 Billion Stars
Suggested Visual: Sprinkles and a school bus

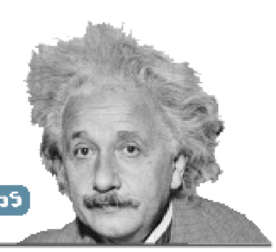
Invite volunteers from your audience up to the stage to pour sprinkles into a clear container. (We suggest a large bottle, such as that found at a water cooler. You will not need to fill it all the way, just enough to realize how long it takes to create a substantial pile.) Ask them how close they think they are to 200 billion. A large water bottle or two will seem to many like a reasonable approximation for that many sprinkles.

Now reveal that it would take 15 standard-size school buses filled with sprinkles to represent 200 billion stars.

Alternate Demonstration:

Suggested Visual: a football field and birdseed

If you are using a larger object, such as birdseed, to represent stars, you can ask your audience to picture a football field. Now have them build a wall around the field that is four feet high. If you have any audience members who are four feet tall, they may want to help you with this next step. You are going to build a wall (metaphorical, of course) four feet tall around that football field and fill it with birdseed.



Building the Wall, Version 1
Using a thin four-foot high clear container, invite some volunteers to pour the birdseed into the container. They will pour for a very long time, but the container will not fill up very quickly…can you imagine how long it would take to fill the entire football field?

Building the Wall, Version 2
An alternative to the clear container is to take a large four-foot long roll of paper and use adhesive to secure a layer of birdseed on it. Then ask your volunteers to unroll the paper and imagine how many seeds it would take to fill the football field.

These activities are meant to give your audience a hands-on sense of how large 200 billion is. It is very difficult for the human mind to comprehend numbers this large!

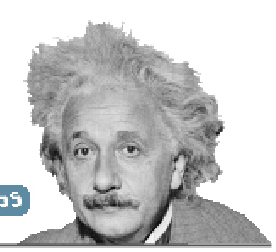
Step 5 – The Milky Way Galaxy
Suggested Visual: A picture of a spiral galaxy superimposed over a picture of North America

We now have fifteen school buses stuffed with sprinkles. What do we do with them? Where do we put all the sprinkles? If each star is the size of a sprinkle…and each solar system the size of a cookie, the entire Milky Way galaxy will be the size of North America, a very flat disc 2500 miles across and 25 miles deep!

About one third of the sprinkles need to go into the middle of the galaxy. Take five of your school buses and drive them off to Kansas for unloading. The rest of the stars need to spread out all across the continent. Remember that stars in the disc are approximately two football fields apart. This means that as you are driving around the continent, you need to drop off one star every tenth of a mile you drive. Get ready for a long trip!

Our own sprinkle (and its surrounding cookie) would be about 10 miles off the ground, floating above Buffalo, New York (or similar location).

NOTE: Other locations can be used for the location of our Solar System. Our Solar System is approximately two thirds of the way out from the center of our Galaxy, roughly halfway between the top and the bottom of the disc.



Our solar system is to our Milky Way Galaxy as a cookie is to North America!

> ***Fun Fact:*** *Commercial jets fly at approximately 5 miles above the surface of the Earth.*

It takes light one hundred thousand years to travel from one side of our Galaxy to the other. On the scale of our model, that's 100,000 years just to get from one side of North America to the other!

> ***Using Birdseed:***
> We now have a football field filled with stars, but is our entire galaxy the size of a football field? Ask your audience to remember how far apart individual stars are apart…two football fields. In order to visualize the true scale of our galaxy, we need to take these 200 billion sprinkles and spread them out over the entire continent of North America. That's right, our entire galaxy is the size of an entire continent!

Now we have built our Milky Way Galaxy. Remember that in 1905, our Milky Way was all there was to our known universe. Even Einstein believed this. One of the greatest discoveries over the last century is that our galaxy is one of many. In fact, galaxies are the building block of our universe.

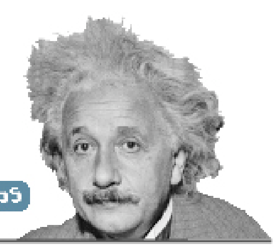
Optional Perspectives

Recommended for presenters who do not plan to journey beyond the Milky Way, due to time constraints or the conceptual leap of changing from the scale of stars to the scale of galaxies.

Our View from Within

Suggested Visuals: city from within, city from above, galaxy from within, (another) galaxy from above

Imagine looking out from our vantage point across North America. Like living within a city our view is limited. We cannot the whole city or, in the case of the Milky Way, the whole galaxy. Our view of the other side of the continent is blocked by the large number of sprinkles in Kansas. This matches our view of the night sky—when we look toward the center of the galaxy, we see a large number of stars, gas, and dust concentrated in a band across the sky. When we look out in other directions—toward our nearest coast, or "up" or "down," we see many fewer stars.



We would need to leave the Milky Way to get a picture of the whole galaxy. Remember that the average travel time between stars in our part of the galaxy is 4 years. Light, traveling at the cosmic speed limit, takes four years to get from one sprinkle to another, traveling across two football fields. What are the chances that we could send a space ship to other stars in our Galaxy? What are the chances that we could leave our galaxy to photograph it from the outside? For this reason, astronomers have never taken a picture of our Milky Way from the outside. Instead, any pictures your audience may have seen of our Milky Way "as seen from outside" are artists' renditions, computer simulations, or pictures of other galaxies.

Other objects in the Galaxy

Suggested Visuals: the objects about which you are talking

- Stars in the handle of the Big Dipper, about 2 miles away. (Note: other stars within the Big Dipper are at different distances)
- The Orion Nebula (star-forming region), 40 miles away from our solar system, 3/4 mile across…roughly the size of a shopping mall.
- Pleiades Star Cluster (young stars), 10 miles away from our solar system, 1/3 mile diameter
- Crab Nebula (exploded star), 160 miles away from our solar system, 1/4 mile in diameter

ACT II – A Universe of Galaxies

The next step of our demonstration requires a dramatic shifting of scale. This will be particularly difficult for younger audiences, so presenters may wish to remain in the realm of the stars and explore the galaxy in more depth. However, for those intrepid explorers…

You Will Need:

- CDs
- Enthusiastic volunteers
- An open mind
- Accompanying slides (if desired)

NOTE: If you have given members of your audience solar systems of their very own (i.e. cookies) this would be a good time for them to destroy the evidence of their previous model (i.e. eat their solar systems), so as not to confuse the two scaling systems.

Step 6 – The Milky Way Galaxy
Suggested Visual: A spiral galaxy and a CD

Remind your audience about the cosmic speed limit. It takes 100 thousand years for light to travel across a single spiral galaxy. In our previous model, one spiral galaxy was the size of a continent. If we are going to build a universe filled with galaxies, we are going to have to shrink this continent down into something much smaller. Put on your shrinking caps and let's go!

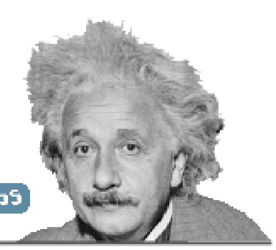
A galaxy is about one hundred times wider than it is thick. A good approximation of this ratio is a compact disc. So let's take the entire continent of North America and shrink it down to the size of a CD. Coincidentally enough, you just happen to have a CD with you. (Feel free to add a bit of cotton candy to the hole in the middle to represent the bulge.) This CD is now our Milky Way Galaxy! Is there a volunteer who would like to be the Milky Way galaxy?

Remember that light takes one hundred thousand years to travel across the entire galaxy. A CD may seem small, but even on Einstein's hypothetical beam of light, it takes a long time to cross it.

Cosmic Interlude – Inside Einstein's Universe
When Einstein was first proposing his revolutionary ideas, it was commonly known that our Milky Way Galaxy was the full extent of the universe. That is not to say that people did not observe other galaxies; they just thought those other galaxies were "spiral nebulae" within our own galaxy. It was in 1923 that Edwin Hubble's observations proved that there were many galaxies in the universe outside our own. We now know that our own Milky Way is one of billions of spiral galaxies throughout the observable universe. In fact, galaxies are the building blocks of our universe.

Step 7 – The Andromeda Galaxy
Suggested Visual: The Andromeda Galaxy (and a CD)

A second volunteer can be the nearest spiral galaxy to the Milky Way, the Andromeda Galaxy. How far away does the audience think the Andromeda Galaxy is from the Milky Way? After their experience with stars within the galaxy, many audience members will try to send your second volunteer to another city!



Surprisingly enough, the answer is eight feet, or approximately 20 CD diameters away. Galaxies are much closer together than stars, relative to their size. Do not be fooled, however; it is still very difficult to travel between them. You can ask another volunteer to be a photon of light traveling between the two galaxies, but it will take him or her 2 million years to travel that distance. At this scale (1 galaxy = 12 cm) light takes 1 million years to travel 4 feet.

Fun Fact: The Andromeda is the furthest object we can see in the night sky without the aid of a telescope. Assuming, of course, we have access to a very dark sky…

What was happening on Earth 2 million years ago, when the light from the Andromeda Galaxy began its journey to our eyes?

Optional Extension: An interesting comparison is the relative distance between galaxies as compared to distances between stars. Recall that the next closest star to our sugar-sized Sun is two football fields away, while the next closest galaxy to our CD-sized Milky Way is only 8 feet away. Considering these two facts, which type of object is more likely to interact with similar objects, stars or galaxies? [Answer: galaxies, being much closer together relative to their sizes, have much more gravitational interaction than stars.] The relative separation between galaxies is much smaller than the relative separation of stars within a galaxy. This is why galaxy collisions are common, yet one galaxy can pass through another galaxy with very few of the actual stars within them colliding. (The dramatic pictures in the news of galaxies colliding show interaction of interstellar gas and dust.)

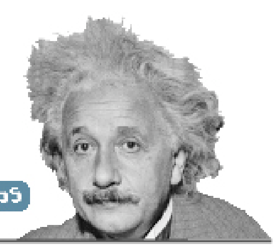
Galaxies are the building blocks of our universe. The farther out we look, the more galaxies we see.

Optional Conclusion

Recommended for presenters who do not wish to present the concept of light travel time (next stage of the demonstration). For younger audiences in particular, the ideas of size and scale are challenging enough. Building a scale model of the universe is a worthwhile exercise in and of itself and if an audience leaves with the big idea that galaxies are the building blocks of the universe, the demonstration has made its point.

A Universe of Galaxies

Suggested Visual: slide show of galaxies, or a fly-through of galaxies in the universe



All the galaxies that we can see in the universe can be modeled using CDs. The furthest galaxies that we can see would be located about 10 miles away, in all directions. Presenters with younger audiences or time constraints may wish to stop at this step. The next section of the demonstration deals with light travel time and requires an even greater conceptual leap than switching scales. It is still a testament to Einstein that we have been able to build up such an amazing picture of our cosmos. Remember that in 1905 the fuzzy blobs we now know to be other galaxies were then thought to be 'spiral nebulae' within the Milky Way.

ACT III – Light Travel Time

In this demonstration, volunteers model the travel time of light by carrying messages from different distances in the universe. You may wish to prep your volunteers before embarking on this journey. Two volunteers have the task of forming galaxies and two have the task of carrying a message from those galaxies to you, the telescope/observer. Each galaxy is at a different distance from you and has one messenger assigned to it.

You Will Need:
- 2 sets of 6 building blocks, each one printed with a letter on one side and a number on the other: 1 = Y, 2 = X, 3 = A, 4 = L, 5 = A, 6 = G
- Printed images of the building blocks at each stage of their "creation" (Y, XY, AXY, etc.)
- (Optional) Digital images of the printed images to project on the screen
- 4 volunteers (2 to build galaxies, 2 to be photons)

Step 9 – Distant Galaxies
Suggested Visual: Image of a spiral galaxy with a more distant galaxy in the same field
A good example is: http://hubblesite.org/newscenter/newsdesk/archive/releases/2003/24/

The large spiral galaxy in this image is about 50 times farther than the Andromeda Galaxy. On the scale of our CD-filled universe, this is about 400 feet from our own Milky Way CD. Your volunteer would have to stand in the parking lot to model this to scale.

What about the smaller galaxy in the lower right part of the image? Is this a smaller galaxy at the same distance or a further away galaxy that simply looks smaller? Astronomers assume that most, if not all, spiral galaxies look pretty much the same. Therefore, this smaller-looking galaxy is probably a more distant galaxy. It is about five times as small as the larger-looking galaxy, so it is probably about five times farther…about two third of a mile away, on the scale of CDs! Light traveling from these galaxies takes millions of years to get to our telescopes.

Unfortunately, we don't have the time or the space to show this. Instead we will need to shrink this scale down to use our auditorium, and tag along on the journey through space using our trusty volunteers. Einstein imagined what it would be like to ride on a beam of light; what if we actually become beams of light? What will we learn about the galaxies in our universe?

Step 10 – Setting Up

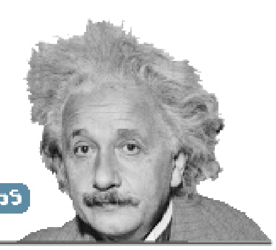
Position your first volunteer at the back/far side of the room with a set of building blocks and photographs. (S)he is the Distant Galaxy.

Position your second volunteer (along with the second set of blocks and photographs) about halfway between you (the telescope/observer) and Distant Galaxy. (S)he is Not-So-Distant Galaxy. Make sure there is a straight path between you and both galaxies for your photons to travel.

Explain to your audience that we are going to take pictures of galaxies in the universe. As we just demonstrated, sending a spacecraft to these distant objects would take too long. Luckily, these objects are sending information to us in the form of photons (beams/packets) of light.

Now call up your third and fourth volunteers. These are your 'light messengers' – photons or beams of light traveling across the vast distances of space. They will each carry a message from their source galaxy. When these photons reach our telescopes here on Earth, or just above the Earth in space, we collect the light (their message) and focus it to record an image of what that object looks like. Your volunteer photons are going to carry messages of what their galaxies look like to you.

Assign one photon to each galaxy. Remind your audience that there are many photons (or beams) of light coming from each galaxy, but we are interested in these two. These photons need to reach you (the telescope) at the same time. Because Einstein tells us that the speed of light is the same for ALL photons, which photon needs to leave first? [Answer: the Distant Photon]



Step 11 – Forming Galaxies

Cosmic time begins! Your galaxies begin building up their blocks, starting with the block labeled "Y" forming galaxies…Y! Now another block…XY!

Step 12 – Distant Photon Leaves

Volunteer 3 (Distant Photon) begins its journey, traveling at the speed of light – baby steps please! Remember that light from this galaxy has been shining this whole time, but this particular photon is the one leaving now, taking with it the picture (photograph) of what the galaxy looks like at that moment (XY).
The galaxies continue to form…AXY! LAXY!

Step 13 – The Distant Photon Arrives at the Distance of the Not-So-Distant Galaxy

This galaxy has also been forming and shining since cosmic time began, but we are interested in the photon that is leaving now. Not-So-Distant photon (Volunteer 4), please begin your journey! Don't forget your message of what the galaxy looks like now (LAXY).

Remember photons, you are traveling at the cosmic speed limit. It is taking you millions and millions of years to travel through space. All the while, galaxies are continuing to form…ALAXY…GALAXY.

Step 14 – The Photons Arrive at our Telescopes

Finally, after millions of years the photons are here! Photons, deliver your messages! Tell us what your galaxy looked like when you left:

- Distant Galaxy is only two blocks big (XY).
- Not-So-Distant Galaxy is four blocks big (LAXY)

(If you are using digital versions of the images, you should take this moment to project the two images on your screen. Taking the messages from the photons and "inputting them into your computer" can be a representation of the telescope gathering light and focusing it into an image.)

Now ask your audience, what the galaxies look like today. What would they see if they could travel instantaneously through space? Of course, Einstein tells us that we cannot travel instantaneously, but luckily you have people stationed near each galaxy to tell us what each galaxies looks like today.

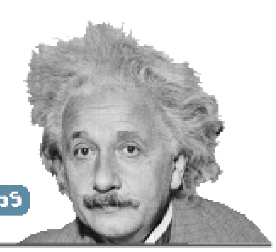
They are fully formed! (GALAXY) If we could travel instantly through space to get to distant spiral galaxies, they would probably look like our own Milky Way looks today.

Optional Extension: What would our Milky Way look like to an observer in Distant Galaxy? Answer: the same as Distant Galaxy looks to us today! Because the light from our Milky Way would need to travel across such a vast distance, the observer in the Distant Galaxy would see the Milky Way as it was when the light left it, much less evolved. Are museum goers in a distant galaxy looking at an ancient picture of our Milky Way?

Step 15 – A Big Round of Applause for our Time Travelers

It must be exhausting to travel for millions of years, so we should probably thank our volunteers and let them return to their seats.

NOTE: Some educators have suggested that disposable or digital cameras be used to record the images of the distant galaxies when the photons leave. While this does a good job of showing exactly what the galaxies look like when the photons leave, it can be confusing to audiences. Research has shown that a very common misconception about astronomy is how telescopes record pictures. Many people, students and adults alike, believe that space telescopes like the Hubble Space Telescope travel to distant objects in order to photograph them. In reality, the Hubble Space Telescope is only a few hundred miles above the surface of the Earth. The reason it has such a clear view of objects in space is because it is above the atmosphere of the Earth, not because it is significantly closer to the objects it is photographing. Having the photons carry a camera can perpetuate misconceptions about we photograph the universe. If you do choose to use a camera, be sure to remind your audience how big the universe is and how long it takes light, let along telescopes, to travel through it.



NOTE: Another option for presenting these ideas it to use photographs of people in various stages of their lives (i.e. infant, toddler, teenager, etc.) to represent different stages of galaxies formation. This level of abstraction is appropriate for some adults, but is often too far removed for younger audiences to grasp. The creators of this demonstration chose building blocks to represent galaxies because they are far enough removed from the actual process of galaxy formation to illustrate the concept clearly without promoting misconceptions about how galaxies actually form, a process that is not yet fully understood by astronomers.

Step 16 – Telescopes are Time Machines
Suggested Visual: The Hubble Ultra Deep Field, image or fly-through
Image: http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/07/
Animation: http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/28/video/b

The further out in space we look, the more distant galaxies we see. Our volunteers have just shown us, however, that the more distant the galaxy, the longer ago light left it to travel to our telescope. Therefore, as we look out in space, we are also looking back in time.

The Hubble Ultra Deep Field is a very important image. With a few exceptions, every fuzzy point of light in this image is a galaxy. The larger-looking ones are the closest and the smallest-looking ones are the most distant. Light from these farthest galaxies has been traveling for 12 billion years. We see these galaxies as they looked 12 billion years ago, when stars were first beginning to shine.

Fun Fact: *The Hubble Ultra Deep Field covers a patch of sky one-tenth the diameter of the full moon. The area of the sky covered by this field is the same as a pin's head held at arm's length. Astronomers compare this image to looking through a very long drinking straw—it is very narrow, but very deep.*

Step 17 – The Earliest Galaxies
Suggested Visual: ancient red galaxies in the Hubble Ultra Deep Field

Zooming in on a small section of the Hubble Ultra Deep Field, we see tiny red blobs. (You may have to increase the contrast in order for your audience to see them.) At the time this script was produced, these galaxies were the earliest galaxies astronomers have been able to observe. They look they way we think all galaxies look very early in their lives.

NOTE: The red color appears because the light from these galaxies has been stretched into the red part of the electromagnetic spectrum.

Step 18 – Before the Age of Galaxies
Suggested Visual: The Cosmic Microwave Background, against a skyline – first with a uniform background, and then again with increased contrast.

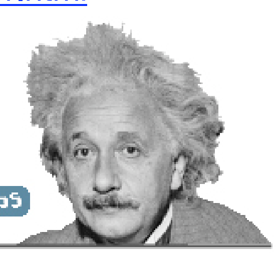
What is really amazing is that we can use our telescopes to see back to a time when there were no galaxies! Before stars or galaxies existed, the whole universe was a sea of hot gas. Living in this early universe would have been like living inside the Sun – a hot, dense plasma soup.

Using special detectors we can detect this sea of gas, all around us. In fact, when we look at the night sky with these detectors we see light that has been traveling for almost 14 billion years to reach us. Everywhere we look we see this light. It is left over heat from the Big Bang!

NOTE: Since this light began its journey, it has cooled down and been stretched. We now see it using radio telescopes, specifically those sensitive to microwave frequencies. The microwave band of light is a subset of radio light. For this reason, astronomers call this view "the cosmic microwave background."

NOTE: The Big Bang is a rather misnamed event. The moment of the so-called Big Bang is used to describe the moment when some pre-existing form of energy transformed into a sea of matter – mostly hydrogen, but some helium and even less lithium. The Big Bang model for the origin and evolution of the universe describes how the universe changed from a sea of hot gas into the stars and galaxies we observe today.

Step 19 – The Baby Picture of the Universe
Suggested Visual: WMAP image of the Cosmic Microwave Background + baby + WMAP space craft
The WMAP image can be downloaded here: http://wmap.gsfc.nasa.gov/m_or.html



This light has been detected and carefully mapped across the entire sky by the Wilkinson Microwave Anisotropy Probe. Looking at this map is like looking at the baby picture of the universe. This is not a picture of the universe as it appears now, but rather, how it appeared when it was very young. You may wish to use a baby picture of your grandparent to illustrate this idea…a young picture of a very mature object.

Step 20, Option 1 – Looking Back in Time
Visual: sixth animation down on http://wmap.gsfc.nasa.gov/m_or/mr_media2.html
"See how the structure of the Universe evolved from WMAP's 'baby picture' of the Big Bang through the clumping and ignition of matter (which caused reionization) up to the present."

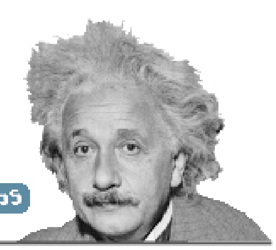
Closing Visual: "Looking back in time" from http://wmap.gsfc.nasa.gov/m_or/m_or3.html

Step 20, Option 2 – Journey to the Beginning of Time
Visual: ninth animation down on http://wmap.gsfc.nasa.gov/m_or/mr_media2.html
"Take a trip through space and time to put 'earliest light' in perspective."

NOTE: When audiences see this visualization, they sometimes think that physically traveling out in space would allow us to travel back in time. In fact, the opposite is true. If we were really to travel out to those distant galaxies (even if we could) it would take many millions of years to get there (even more if we were not traveling at the speed of light) and so we would see the distant galaxies as they appear millions of years after we first began our journey!

The Cosmic Microwave Background is a key piece of evidence in the Big Bang model for the origin and evolution of the universe. This model has its roots in Einstein's equations about the nature of space and time. The Big Bang model predicts that our entire observable universe was much smaller in the past than it is now. At this time, the universe would have been very dense—like living inside the Sun. The cosmic microwave background is evidence for this once-hot gas. Thought the Big Bang model is well supported by scientific evidence, astronomers do not yet know what happened before the Big Bang or what powered it. These questions are at the forefront of today's research.

You can find out what NASA is doing to explore "Beyond Einstein" here: http://universe.nasa.gov/



Optional Perspective

Recommended for questions about the shape of the WMAP image. It is often confusing for audiences, but can be compared to the oval shape of the flat maps of the Earth's surface.

Mapping the CMB

Suggested Visual: Temperature map of the Earth

We can map the glow of the early universe across the entire sky, much in the way that we map temperatures here on Earth. Picture the oval on the bottom as an inside-out sphere, or the inside of a beach ball. It is like looking at the continents on the Earth from the inside. The oval shape is what occurs when we project this 3-d globe onto a 2-d surface. (This method of projection is known as an Aitoff Projection.)

The Universe Forum would like to thank:

NASA's Night Sky Network – http://nightsky.jpl.nasa.gov/

The Astronomical Society of the Pacific – http://www.astrosociety.org/

NASA's WMAP mission – http://wmap.gsfc.nasa.gov/

The scientists and educators who contributed to making this demonstration possible. To learn more about the Big Bang and the ideas presented in this demonstration, please visit the Universe Forum's web site: http://www.universeforum.org/.

Additional materials from the "Inside Einstein's Universe" program are available on the "Inside Einstein's Universe" web site: http://www.universeforum.org/einstein/. We are very interested in hearing how educators use the materials in this demonstration. If you find new ways to present this information or alternate hands-on demonstrations for illustrating these ideas, please drop us a line at einstein2005@cfa.harvard.edu.