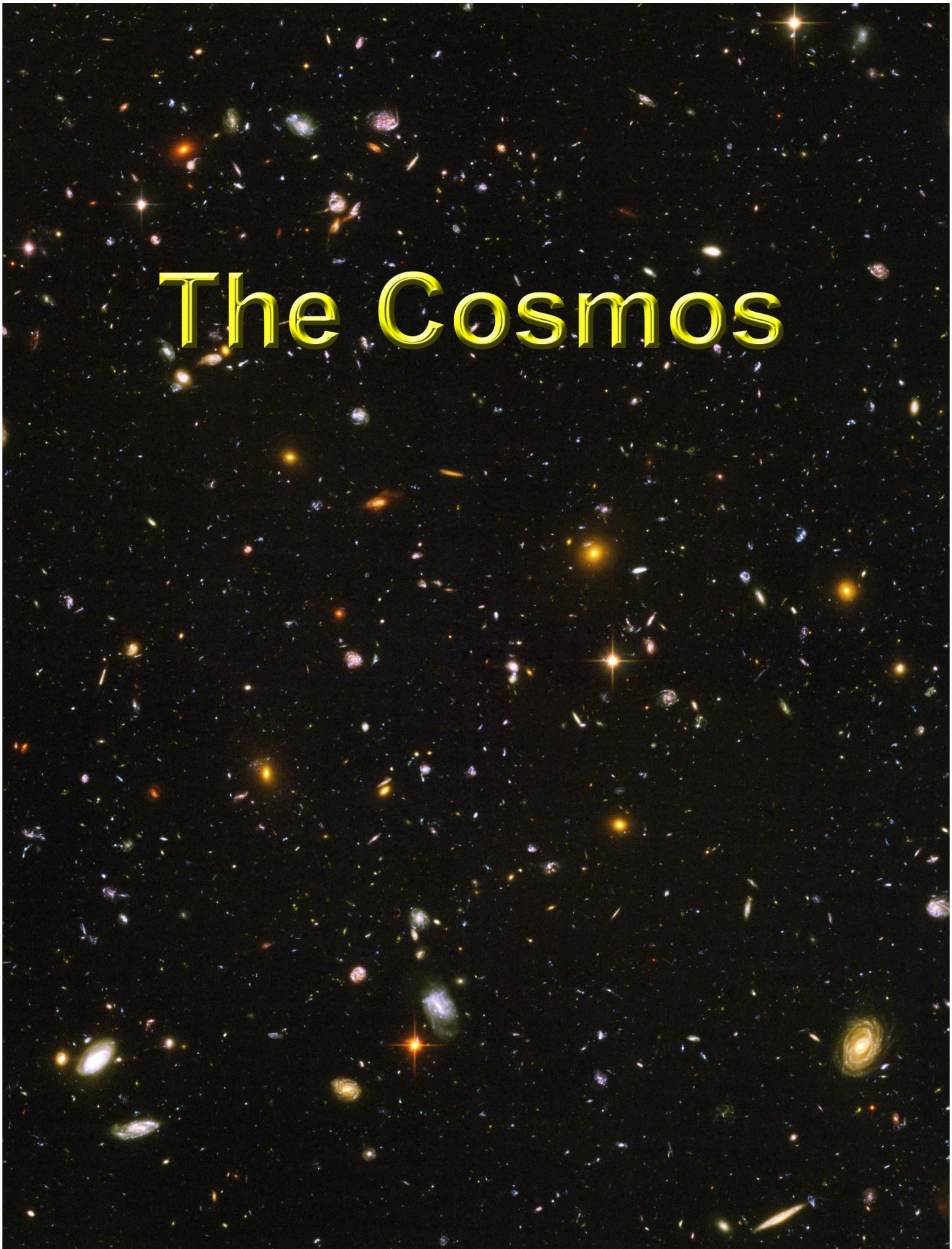

The Cosmos

The Cosmos

*{**Abstract** – In this final segment of our "How far away is it" video book, we cover the structure of the visible Universe as we currently know it.*

We start with some galaxy and galaxy clusters beyond our local superclusters, including: Abell 2029 with its supermassive galaxy IC 1011; Quasar Markarian; a massive cluster gravitationally lensing a more distant cluster; Abell 370; MACS – J0025 with its evidence for 'Dark Matter'; El Gordo; Supernova Remnant 2002dd; and the thousands of galaxies in the famous Hubble Ultra Deep Field.

Next we cover the Hubble constant and the Big Bang. We show how the constant gives us the age of the Universe at 13.7 billion years. We describe the expansion of the Univers as space itself stretching like a balloon, and what this does to light passing through the stretching space. And we point out that recent redshift measurements from distant Type 1a Supernovas have provided evidence that the expansion is accelerating. We explain how this leads to the concept of 'Dark Energy'.

We then cover some of the recent galaxy surveys that are helping us understand the fabric of the visible Universe. These include the 2dF Galaxy Redshift Survey of 52,000 galaxies out to 3 billion light years, and the Sloan Digital Sky Survey that mapped one million galaxies. We show the 3D supercomputer video that shows the fabric of the Universe is like a web of galaxies with massive voids.

With that, we go into a review of how we constructed our distance ladder over time staring with Copernicus and ending here in 2013. Then we take a look at what we don't know, including the nature of Dark Matter and the nature of Dark Energy. Then, we take a good look at the James Webb Space Telescope. It will help answer some of the questions that still exist about the Cosmos.

We end with Edwin Hubble's own words on the limits of our knowledge.}

Beyond the Local Superclusters

> **[Music:** *Felix Mendelssohn – "Violin Concerto Op.64" – Premiered in 1845, this was Mendelssohn's last large orchestral work. It is also one of the best violin concertos of all time. It's back to back to back fast-slow-fast pace fits our introduction to galaxies beyond our local superclusters.***]**

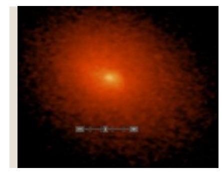
In this final segment, we'll go beyond the 7% covered by Local Superclusters, and examine the Universe as a whole. At the end, we'll quickly review all the territory we've covered since we began our journey exploring the dimensions of the Earth.

So let's start with a look at some of the objects photographed by Hubble that lay beyond our Local Supercluster.

Abell 2029 – 1,000 mly

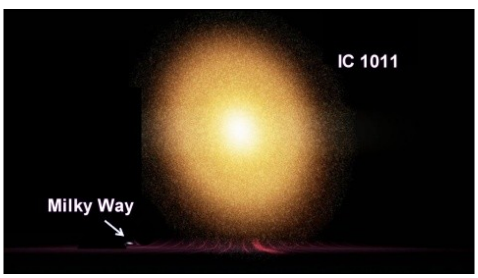
This optical image shows the massive galaxy cluster Abell 2029. The large elliptical galaxy visible in the center of the image is IC 1011. It is surrounded by smaller galaxies. This galaxy cluster has a Redshift that indicates that it is one billion light-years away.

Chandra's X-ray image of this red diffuse emission shows hot intergalactic gas, heated to about 100 million degrees by the enormous gravity in the cluster. This is the optical (blue) and x-ray (red-orange) composite image.



[Additional info: The distances to the clusters in the sample can be derived from the Chandra observations by calculating the relative amounts of hot gas and dark matter. These distances show that the expansion of the Universe began accelerating about six billion years ago.**]**

IC 1011 – 1,000 mly



IC 1011, at the center of Abell 2029 is the largest galaxy ever seen. It is 6 million light-years across – 60 times larger than our Milky Way, and it contains around 100 trillion stars!

Markarian 205 – 1,100 mly

You might recognize NGC 4319. It is a galaxy in the Virgo Supercluster. Of interest now is the small light in the upper right. It's the quasar called Markarian 205. It's 1.1 billion light years away. Markarian 205 is a relatively nearby quasar. Many quasars reside much farther away. **Quasars** are distant galaxies that have extremely bright cores. These powerhouses of light are probably fueled by massive black holes.

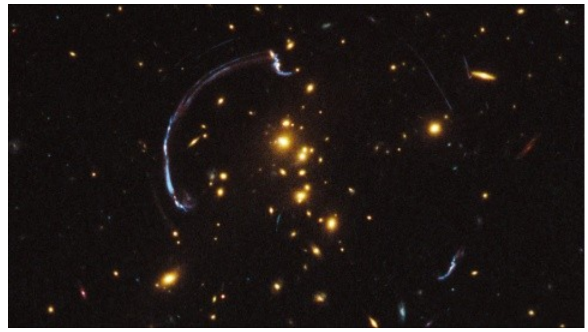
[Additional info: Astronomers used two methods to determine the distances to this quasar. First, they measured the red shift. Then they measured how much the ultraviolet light from Markarian 205 dimmed as it passed through the interstellar gas of NGC 4319.

With powerful telescopes like Hubble, it is often possible to see the quasar's surrounding halo of faint starlight, as is clearly visible around this quasar.

Markarian 205 has a companion, a compact galaxy just below it. The objects appear to be interacting. The compact galaxy may be responsible for the structure in Markarian 205's halo.**]**

RCS2 032727-132623 - 10,000 mly   RCSGA 032727-132609 – 5,000 mly

This is a close-up look at the brightest distant "magnified" galaxy in the universe known to date. It is one of the most striking examples of gravitational lensing, where the gravitational field of a foreground galaxy bends and amplifies the light of a more distant background galaxy. In this image the light from a distant galaxy, nearly 10 billion light-years away, has been warped into a nearly 90-degree arc of light in the galaxy cluster. The galaxy cluster that is bending the light lies 5 billion light-years away.



Abell 370 – 5,000 mly

Abell 370 is one of the very first galaxy clusters where astronomers observed the phenomenon of gravitational lensing.

MACS J0025.4−1222 – 2,000 mly

A powerful collision of galaxy clusters has been captured by Hubble and Chandra. This clash of clusters provides striking evidence for **dark matter** and insight into its properties. The observations of the cluster indicate that a titanic collision has separated the dark from ordinary matter.

MACS J0025 formed after an enormously energetic collision. Using visible-light images from Hubble, the team was able to infer the distribution of the total mass — dark and ordinary matter. Hubble was used to map the dark matter (colored in blue) using gravitational lensing. The Chandra data enabled the astronomers to accurately map the position of the ordinary matter, mostly in the form of hot gas, which glows brightly in X-rays (pink).

As the two clusters that formed J0025 merged at speeds of millions of miles per hour, the hot gas in the two clusters collided and slowed down, but the dark matter passed right through the smashup. The separation between the material shown in pink and blue therefore provides observational evidence for dark matter and supports the view that dark-matter particles interact with each other only very weakly or not at all, apart from the pull of gravity.

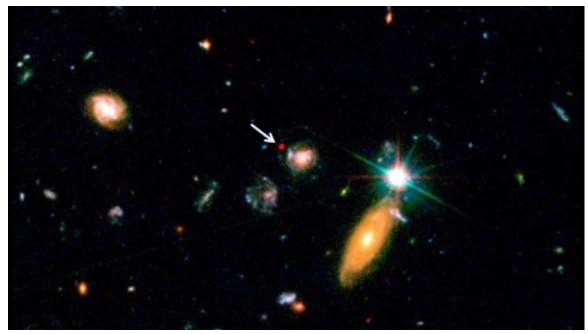
[Music: *Rachmaninoff – "Piano Concerto No 2" – Written in 1901, this is one of Rachmaninoff's most popular pieces. The opening movement begins with a series of bell-like tollings on the piano that eventually climax in the introduction of the main theme - very fitting for our move from evidence for dark matter to Hubble's Ultra Deep Field look back to almost the beginning of the Universe as we know it today.***]**

El Gordo – 7,000 mly

This is a combined ESO Very Large Telescope and Chandra image of the newly discovered galaxy cluster called El Gordo. It consists of two separate galaxy subclusters colliding at several million miles per hour. We are seeing what this cluster looked like when the Universe was only half its current age.

SN2002dd – 8,000 mly

Hubble is a 'supernova machine' for probing the early universe. Here's a type 1a it found that's approximately 8 billion light-years from Earth. It exploded so long ago, that the universe may have been decelerating under its own gravity instead of accelerating as it seems to be today. Eight billion light years is about as far as we can go with supernova standard candles. Beyond this, we only have Redshift.



[Astronomers are trying to fill in a blank region where the universe's rate of expansion switched from deceleration due to gravity to acceleration due to the repulsive force of dark energy.**]**

Ultra Deep Field

In 1996, Hubble trained its eye on a small part of the sky where nothing had ever been seen: no planets, no stars, and no galaxies. The Hubble Space Telescope's time was very valuable, and some thought that this was a poor use of its resources. The exercise could have turned up nothing at all. But pure human curiosity won out.

In the direction of the Big Dipper, the patch of sky was no bigger than of a grain of sand held out at arm's length. Hubble kept its aperture open for 10 full days. When the aperture closed, and the image developed, they found over 3 thousand galaxies. Every spot, smear and dot in the image was an entire galaxy, with each one containing hundreds of billions of stars. Spectral analysis of the light showed a red shift that indicated some of these galaxies were 13 billion light-years away. This made them the youngest galaxies ever seen.

In 2004, they repeated the experiment. This time, they looked in the direction of the Orion Nebula, took 11 days, and used upgraded, improved sensitivity instruments. This is the resulting picture. It's called the Ultra Deep Field and contains over 10 thousand galaxies. This is the furthest we have ever seen into the Universe.

[Additional info: Using the distances to each galaxy in the Ultra Deep Field, a 3D model was put together. Here we are zooming through galaxies that were formed only 700 thousand years after the Big Bang. Nearer, newer galaxies have form. These early versions of galaxies are more disheveled. What we're seeing are clumps of stars beginning to form galaxies. Remember that that means we are seeing these galaxies as they looked 12 to 13 billion years ago. The furthest is actually 13.1 billion years away. That's very early in this epoch of our Universe, just 600 million years after our Universe began.

Another way to look at this is to consider that the handful of photons from that galaxy that landed on Hubble's plate, left its home star before there was an Earth, a Solar System or even a Milky Way galaxy. They were two thirds of the way here when the Earth formed. They were almost here when the first forms of complex life arose on the Earth, and just about all the way here when the Human species that built the Hubble telescope began.

This is just one small sliver of the Universe observed by Hubble. There are over 100 billion galaxies in the Universe. We pointed the most powerful telescope ever built at absolutely nothing for no other reason than we were curious and discovered that we occupy a very tiny place in the heavens.**]**

Hubble Parameter and the Big Bang

> **[Music:** *Mozart - Piano Concerto No.21 'Elvira Madigan' – Written in 1785, this concerto gets its name from the 1967 movie "Elvira Madigan" where it was featured. It has a wonderful pace suited nicely for explaining the Big Bang theory.***]**

We've talked about the big bang and how long ago it happened. The age comes from Hubble's constant. Remember that the Hubble constant is the ratio of how fast galaxies are receding away from us to their distance from us. This astronomical value is used to determine distances, sizes, and the intrinsic luminosities for many objects in our universe, and the age of the universe itself. As simple as Force = mass times acceleration, we have a galaxy's Velocity = the Hubble constant time its distance.

This gives us the velocity if we know the distance. It also gives us the distance if we know the velocity. It also tells us that as time goes on, the distances to galaxies will increase, and if we look backwards in time, the distances will decrease. In fact, Hubble's constant gives us the time it would take for the distance to reach zero.

Let: v = a galaxy's receding velocity
r = distance to the galaxy
H_0 = the Hubble constant
T = time

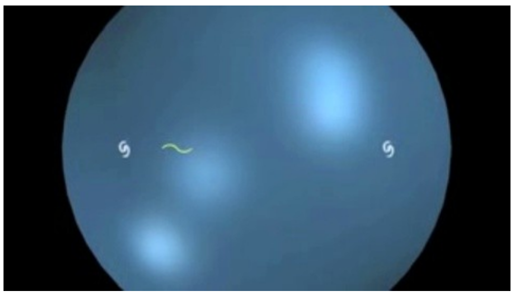
We have: $v = H_0 r$ and $r = v/H_0$

And: $1/H_0 = r/v = T$

1 million light years/(13.6 miles/sec) = 13.7 b yrs

You can see that the age of the Universe as we see it today depends completely on the exact value of the Hubble constant. With the current best value for the Hubble Constant at 13.6 miles/sec per million-light-years, we get a time of 13.7 billion years for the most distant galaxies to get as far away as we see them. You can see why astronomers and astrophysicists are using all the tools in our distance ladder and dozens of more sophisticated techniques, to continue refining the value of the Hubble constant. This work is ongoing.

The Stretching of Space

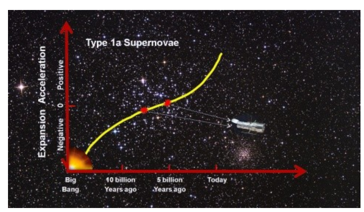


We have been going forwards and backwards in time with this blue balloon because it helps illustrate the nature of the expanding Universe. Simply put, space itself is being stretched. New space is being created all the time. It's stretching everywhere and in all directions. It has been from the beginning when there wasn't any space at all.

If you watch the light wave on the balloon as it passes through the expanding space between the two galaxies, you'll see that its wavelength grows longer. It gets stretched along with the space it is passing through. This is what creates the red-shift. The further away the source of the light, the more time the light has had to stretch. This gives us Hubble's law.

Dark Energy

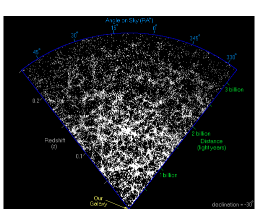
Information from studies of Type 1a supernovae confronted astronomers about five years ago with the stunning, unexpected revelation that galaxies appeared to be moving away from each other at an ever-increasing speed.



In other words, the expansion of the Universe seems to be accelerating. Not having any idea how this can be happening, physicists speculate that there is a thing called 'dark energy' that is doing it. The nature of this dark energy is not understood.

[Additional info: Looking farther away into the universe (and, because of the distances involved, further into the past), they've seen evidence that gravity was at that time slowing the expansion of the universe. Astronomers have very little data, though, on the period of transition between these two phases, when the repulsion produced by dark energy began to surpass the tug of gravity. As you can imagine, research in this area is very hot.**]**

Fabric of the Universe



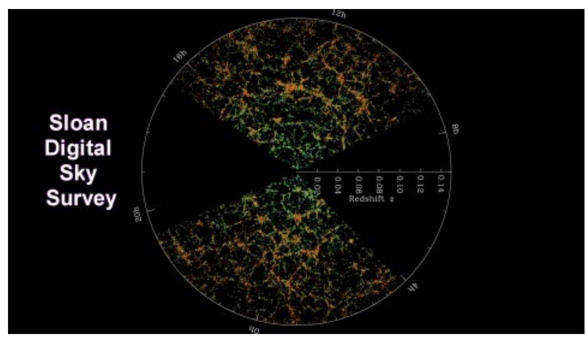
You'll remember from our segment on local Superclusters that galaxies form larger structures called "filaments", or "walls" that may span between several hundred million light-years to one billion light-years. By collecting distances to thousands of galaxies in a narrow strip of the sky, it is possible to produce a slice of the universe, like this one from the 2dF Galaxy Redshift Survey.

In 2003, this survey looked out into the universe to 3.5 billion light years. These types of plots show how clustered the galaxies in the universe really are, even on the largest scales. There are about 52,000 galaxies in this plot.

> **[Music:** *Mozart - Clarinet Concerto – Written in 1791, this clarinet concerto was his final purely instrumental work. It is noted for its delicate interplay between solo clarinet and the orchestra. We use it here as the background music for the interplay of our most modern discoveries with the history of our distance ladder development.***]**

Between 2000 and 2008, the Sloan Digital Sky Survey (SDSS) conducted one of the most ambitious and influential surveys in the history of cosmology. Over eight years of operations it obtained deep, multi-color images covering more than a quarter of the sky and created a 3-dimensional map containing more than 1 million galaxies. **[**The second survey is in operation as we speak and will publish results periodically over the next decade.**]**

These are the color enhanced slices through the SDSS 3-dimensional map of the distribution of galaxies. Earth is at the center, and each point represents a galaxy. Galaxies are colored according to the ages of their stars, with the redder, more strongly clustered points showing galaxies that are made of older stars. The outer circle is at a distance of two billion light years. The region between the wedges was not mapped by the SDSS because dust in our own Galaxy obscures the view of the distant universe in these directions.

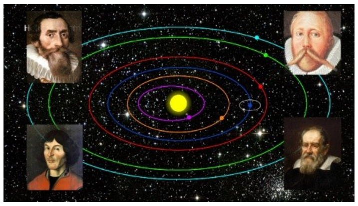


Working with the Virgo Consortium of scientists and the Max-Planck Institute in Germany, SDSS put every data point into a supercomputer and created the largest 3D image ever created. Here we are zooming into and panning across that image. Here you cannot see individual galaxies or even galaxy clusters. What we can see are superclusters linked together in filaments or walls in a gigantic cosmic web. **[**We see the same number of galaxies and voids in every direction. Some think it looks like a sponge.**]**

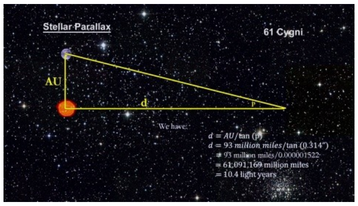
In this view to the cosmos, the great Virgo Supercluster is just a dot. There are more stars in the universe than there are grains of sand on all the beaches of Earth. This is the big picture of our universe as we understand it today.

Review

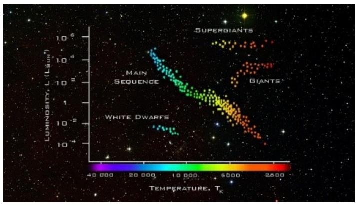
We've come a long way from our start triangulating the size of the Earth.



Our story really began in the 1500s, when Copernicus proposed that the Sun was actually at the center of our Solar System, and we were in orbit around it. A hundred years later, in the 1600s, Tyco Brahe used Parallax to measure distance to planets. Around the same time, the likes of Johannes Kepler and Galileo demonstrated that the sun was indeed at the center and we orbited it. This was the beginning of our cosmic distance ladder.

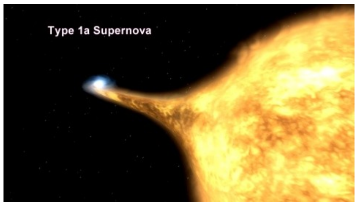


By the 1830s, telescopes had improved and parallax was used to measure distances to nearby Stars. For the first time, we knew that stars were trillions of miles away and must shine by their own light. This extended our distance ladder reach to nearby stars.

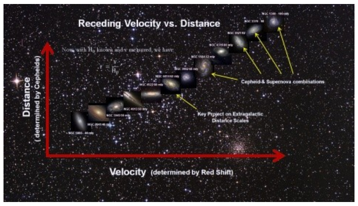


The 20th century was non-stop advancements in the field of astronomy. It started early in 1913 with Hertzsprung and Russell developing the H-R Diagram that could be used to calculate distance from a stars spectroscopy. Around that same time, Henrietta Leavitt gave us Cepheid Variables as a standard candle. RR Lyrae stars followed shortly after that.

These tools were used to discover the size of the Milky Way and our place in it.



In 1923, Hubble, using Cepheid variables, discovered that stars and galaxies existed well outside of the Milky Way. In 1930, the famous Indian astrophysicist, Subrahmanyan Chandrasekhar solved Einstein's equation for a black hole and Type 1a Supernova was added to our distance ladder. In the same timeframe, broad based research on the brightest HII regions and the brightest globular clusters demonstrated that they are good standard candles, giving us an expanded distance ladder, capable of full Milky Way galaxy coverage.



By 1936, Hubble had discovered that the universe was expanding. This gave us Hubble's Law and Red-Shift as our final distance ladder rung. These foundations, developed in the 1st half of the 20th century, made the discoveries of the 2nd half possible. By the 1990s, the Hubble Space telescope was opening new horizons that stretched to the very beginnings of time as we know it.

We entered the 1900s thinking that all the stars in the Universe were in the Milky Way, and that we were at the center of the galaxy. We left the 20th century with great space telescopes probing billions and billions of light years into the cosmos across the full electromagnetic spectrum.

A little on what we don't know

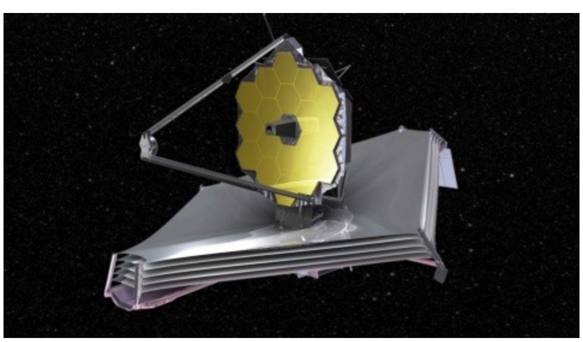
Indeed, we have come a long way. But…

- We see some of the effects of dark matter, but we don't know anything about what it really is – even as it appears to be what the universe is mostly made of.
- We see that the Universe appears to be expanding at an ever increasing rate, but we don't know why. Is it being pulled by masses much further out, or pushed by dark energy within. If it's dark energy, then we have to admit, once again, that we don't know what it is.
- And even the stretching of space calls for a continuous reduction in the energy of each and every traveling photon. This is at odds with long standing conservation of energy principles.

To help find solutions to problems like these, the next generation space telescope is in development.

James Webb Space Telescope

> **[Music:** *Delibes – "Flower Duet" – First performed in1883, this duet was written for Delibes' opera Lakmé. It is actually about flowers. Here we have the beautiful soprano aria begin as the next generation space observatory starts to open its wings.***]**



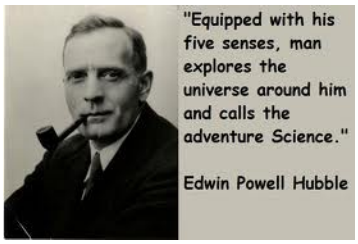
To help find solutions to problems like these, the next generation space telescope is in development. Scheduled for launch in 2018, the James Webb Space Telescope is optimized for observations in the infrared, and a scientific successor to the Hubble Space Telescope and the Spitzer Space Telescope. It will be almost three times the size of Hubble, and orbit far from Earth in the Earth–Sun L_2 Lagrange point.

It will be studying the birth and evolution of galaxies, and the formation of stars and planets. One particular goal involves observing some of the most distant objects in the Universe, beyond the reach of current ground and space based instruments. These include the very first stars, and the formation of the first galaxies.

[Additional info: Another goal is understanding the formation of stars and planets. This will include imaging molecular clouds and star-forming clusters, studying the debris disks around stars, direct imaging of planets, and spectroscopic examination of planetary transits across their suns. The telescope's tennis court size sunshield is in the early stages of testing. If all goes well, we could have as big a beginning to the 21st century as we had for the 20th.**]**

Conclusion

All this reminds me of Edwin Hubble's own words in 1936. They are still appropriate today:



"Thus the explorations of space end on a note of uncertainty - and necessarily so. We are, by definition, in the very center of the observable region. We know our immediate neighborhood rather intimately. With increasing distance, our knowledge fades, and fades rapidly. Eventually, we reach the dim boundary – the utmost limits of our telescopes. There we measure shadows, and we search among ghostly errors of measurement for landmarks that are scarcely more substantial. The search will continue. Not until the empirical resources are exhausted, need we pass on to the dreamy realms of speculation."