Astronomy 1101 – *From Planets to the Cosmos*

Lecture 39
"This is the Way the World Ends": The Fate of the Universe

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Video Transcript

Part 1

In the previous lecture, we described the physics of the earliest phases of the universe, from just after the Big Bang until the point that stars began to appear in the universe. It's now time to end this unit by looking at what happens at the other end of time.

How does the universe end? What is the ultimate fate of everything? In a matter- dominated universe, the fate of the universe depends upon the matter density within it. Parameterized in terms of the ratio of the total to critical density omega 0. In a high density universe in which Omega0 is greater than 1, the density exceeds the critical density for flatness, there is enough matter to slow, stop, and reverse the expansion.

An Omega0 greater than 1 universe in a matter dominated universe would begin as a Big Bang, expand to a maximum size, and then the universe would stop, reverse, and recollapse again in a big crunch. It was as if the universe was returning to the original, hot, initial, dense state that it emerged from at the beginning of the Big Bang.

A Big Bang followed many billions of years later by a big crunch. In a low density or flat universe with omega 0 less than or equal to 1, the universe expands forever at a steadily decreasing rate. The universe ends in a big chill when everything reaches ultimate, cold, dark, low energy state.

In a matter dominated universe, density is destiny. You could go out, write this on a t-shirt and sell it. This is how the universe will end in a matter dominated universe. High density will recollapse upon itself in a big crunch. Low density, it will expand forever getting colder, thinner, and darker.

A mass energy inventory of the universe, however, finds that the total matter density is about omega matter equals 0.31. Broken down into components, starlight contributes only 1 part in 10 to the 4 of the matter density of the universe. Baryonic matter contributes about 4.8% divided between 4.4% gas and .4% stars.

Dark matter makes up 26% of the matter and energy density of the universe. All of these together, if the universe was matter dominated, omega 0 would equal omega matter would equal 0.31. Such a universe would expand forever, at a steadily decreasing rate getting thinner and colder, and darker.

But we don't live in a matter-dominated universe. We live in a universe with a non-zero cosmological constant, in which we see dark energy. If there is a non- zero cosmological constant it adds to the overall mass energy density of the universe. Omega0 is now equal to omega matter plus omega lambda.

In an omega matter dominated universe it would expand at a pretty much constant rate in round numbers. If Omega0 Lambda is greater than, or equal to 0, matter would act to slow the expansion and the universe would slowly decelerate. If Omega Lambda was large, Omega Lambda would eventually, the dark energy would overwhelm the matter in the universe and the universe's expansion would go faster in the future, slower in the past.

And we would see an accelerating expansion. In the case of a non matter dominated universe in which there is a significant dark energy contribution, quantified as an Omega Lambda term. Density is no longer destiny simply because you are above the critical density does not guarantee that you would necessarily recollapse in a big crunch.

Dark energy could overwhelm even that and prevent the ultimate recollapse of the universe. Observations show that the expansion of the universe is indeed accelerating. Observations of distances for type 1A super novi allow us to probe back into the earlier phases of the universe. And show that the universe was expanding at a slower rate than it is today.

The data are all consistent with an acceleration caused by an Omega Lambda term. When all the measurements from the various techniques are put together, Omega matter, is approximately 0.31. Omega Lambda is about 0.69 and as a consequence, Omega0 is equal to Omega matter plus Omega Lambda comes out to about 1.0.

This is consistent with various observations that the overall curvature of the universe on large scales is indistinguishable from being flat and Euclidian. As a consequence the observation suggest that we live in a spatially flat, accelerating, infinite universe, a universe that will expand forever. Our universe is spatially flat and expanding at an ever increasing accelerating rate in the present epoch.

As the universe expands the rate of expansion will continue to increase. Expanding faster and faster, the space between galaxy clusters will widen at an ever faster pace, and the temperature will drop at an ever increasing rate. What is the ultimate fate of the universe which is spatially flat and expanding at an accelerated rate because of the importance of dark energy?

We're going to now follow the proposed evolution of the universe, spatially flat, and accelerating rate of expansion, starting in the present epoch, and moving forward as far as our physics can take it. We live in the present day in the Stelliferous Epoch, the star bearing epoch. That began about 500, 600,000 years after the beginning of the Big Bang.

Today, the universe is about 13.8 billion years old. We are about 13 billion years, therefore, into the Stelliferous period. Most of the stars, especially the new stars that we see around us, are metal rich. Each of these are in the process of making more and more metals through nucleosynthesis in their cores.

And eventually the most massive of the nearby stars will go supernova and spread even more metals out into the surrounding interstellar medium. The next generation of stars to be born after the ones we see around us today will start out with less hydrogen and a lot more metals.

Each generation of stars, more and more matter gets locked up in stellar remnants. Not all of the matter that passes through stars makes it back into the interstellar medium to form into new stars again. Low mass stars to intermediate mass stars will lock up some fraction of their mass up to a maximum of about 1.4 times the mass of the sun, as a white dwarf.

Even of our own sun will leave behind 45% of its mass as a white dwarf after it shuffles off most of the rest of its envelope at the end of its life. More massive stars will leave behind neutron stars and black holes even though they blast off their envelopes as supernova remnants.

There's always a net loss in the cycle of star formation. Every generation of stars that forms starts out with a little less hydrogen, a few more metals. But starts out with net less gas than before because some fraction of the gas every time around the cycle of star birth life and death leaves behind degenerate stellar remnants, in which the mass is locked up, at least on cosmical timescales as we understand them today.

Remember this, as we move along into the deep history of the universe. We're going to see that locked up may not, in fact, be forever. If what you have to work with is a very, very long scale of time allowed by an infinite expanding universe. What is the fate of the universe?

In many ways what we really want to know, what's the fate of us, what's the fate of the Earth and the Sun. Let's move history forward now from the present day where we are today and move forward in time. The Sun is presently about 4.55 billion years old, and is getting steadily brighter, larger in radius, and hotter as it ages.

This plot shown over here on the right shows the luminosity in blue, the radius in red, and the temperature in black of the Sun as it ages over time. Right now, the dash line shows us where we are today at about 4.55 billion years old. We have not surprisingly one solar radius and one solar luminosity, that's our reference.

In the distant past the Sun was fainter and slightly smaller and a little bit cooler then it was in the present day. The reason for these changes is the slow change in the chemical composition of the core of the sun as hydrogen is converted into helium for fusion as we learned back in unit two.

What's going to happen in the future? Well, as the helium begins to build up more and more inside the core, the sun will rearrange its structure to accommodate the new composition in the very center and the sun will continue to get brighter. It will continue to get a little bit larger in size and its temperature will get a little bit hotter.

All of them moving together in lockstep. About 1.1 billion years from today the sun will be approximately 10% brighter. If we make the sun 10% brighter in overall luminosity then here on the Earth, a Moist Greenhouse Effect will kick into play. This will cause the surface temperature of the Earth to rise dramatically beginning the slow process of beginning to evaporate away the oceans.

It will become so hot on the surface of the Earth that it will effectively end all surface life. 3.2 billion years into the future from today the Sun will be 36% brighter. This will trigger a runaway Greenhouse Effect that will boil away the last of the oceans, evaporate away most of what is left of the atmosphere, except the heaviest parts, and end all life on this planet.

Even that deep in the oceans and perhaps, even except for maybe a few bacterial survivals deep underground. Even this won't last for very long, because after a while the Sun will run out of hydrogen and helium. After it's 10 billion years old, some 5 and a half billion years in the future, at which point the Sun will swell into a red giant and will begin the process of melting the outer crust of the Earth.

And whatever crust was hiding in between the interstices of the crust will long since have vanished from the Earth. At the same time that the Sun is swelling up into a red giant and baking the Earth, the Milky Way and Andromeda will continue their inexorable path closer and closer together.

Eventually colliding and merging into a giant elliptical galaxy. A process that will end as the settling down as a giant elliptical. In the center of the local group, some 8 billion years from today. As we go further in time, the interactions among galaxies in the local group will move on, so by the time the universe is between a 100 and a 1,000 billion years old, the remaining local group galaxies will all have merged into one giant elliptical galaxy.

Where in the present day, we see a relatively small and modest group of galaxies. Three big spirals, a couple of irregulars, and about 50 or 60 small dwarf galaxies. A trillion of years into the history of the universe, the local group will be gone replaced by a single, enormous elliptical galaxy.

This may be the end of our history and the history of the Milky Way, but it's not the end of our story. We'll continue in the next part.

Part 2

In the first part of our lecture on The Fate of the Universe we followed the evolution of our accelerating expanding universe from the first stars to the end of the local group into a giant elliptical galaxy. In the same time, the Sun will have long since faded into a white dwarf into the long night.

The Universe is now 1 trillion tears old. How far can we carry this evolution forward into the future? And what is the ultimate fate of our expanding universe? The Universe is about 2 trillion years old the accelerating expansion for the Universe will carry all of the galaxies outside of our local Supercluster beyond our observable horizon.

These galaxies will now be moving away too far, for us to be able to see them anymore. The galaxies are beyond our horizon and are too redshifted to be able to see. After a while, even those small handful of galaxies that are just outside what remains of the Local Group will be out of causal contact with the rest of the Universe.

Our universe will suddenly be left with only the galaxies around us. The Degenerate Epoch will begin when the universe is at 10 to the 14 years old, 100 trillion years old. This is the time when all star formation will end, and the last stars will make the last of the degenerate remnants, white dwarves, neutron stars, and black holes.

The free gas reserves of the Universe will have finally been exhausted. The cycle of star birth and death that has been going on since the universe was a half a billion years old has finally been broken. Nuclear fusion will cease and red dwarf stars will burn out as low mass helium white dwarfs.

All of the remaining matter is locked up in black dwarfs, cold neutron stars, and black holes, except for those small, tiny, thin bits of matter that were never formed into stars and still remain as an ever thinning, ever colder gas. After the Universe is about 10 to the 15 years old, all the planets around all the stars either have fallen into the remnants of their parents stars, or have been ejected into interstellar space by gravitational encounters with other stellar systems.

Some planets will spiral in and merge with the remnants of their parents stars over a long period of time as gravitational radiation slowly, but surely, bleeds away angular momentum, and the planets will eventually merge with their white dwarves, or neutron stars, or black holes at the center of their systems.

Others will be disrupted by gravitational encounters, and scattered into space, where they will wander until they run into a black hole or find themselves deep and empty and alone in the darkness of space. By the time the Universe is 1000 trillion years old all of the planetary systems that have formed since the first star of systems formed at half a billion years into the big bang have dissolved and gone away.

Now we're getting into time scales of 10 to the 19 to 10 to the 20 years. By this time, the galaxies will have all dissolved as stellar remnants escape or fall in to the super massive black holes. Star-star encounters, and later on stellar remnant-remnant encounters, will eventually change the gravitational configuration of a galaxy.

This is an exceedingly slow process and while it is important in part of how galaxies get their shapes today, if allowed to run for a very long time. How long? About 10 to the 19 or 10 to the 20 years. Eventually the galaxies will. Contents will begin to interact in a way that causes the galaxies to slowly, but surely, dissolve.

About 90% of the remnants of the galaxies will gain enough energy from their interactions to be able to exceed the escape speed, and so escape from their galaxies. And go out into the cold of intergalactic space. The remaining 10% will lose energy and fall into the central super mass of black hole where they will be consumed, briefly shining as their matter falls into the black hole and causing the central black hole to grow larger.

The last few quasars. The last few accreting super massive black holes, will continue to shine through this period, as long as there is still matter, in some form, to accrete. It might be degenerate white dwarf matter. It might even be degenerate neutron matter. As long as there's something to eat, the gravitational energy will be released.

And we will see tiny bright flashes of the last emission of light. By the time the Universe it between 10 to the 34 and 10 to the 40 years old, matter itself as we understand it will begin to dissolve as protons steadily decay into positrons and photons. Particle models of physics predict that protons are in fact unstable and will eventually decay into positrons and photons.

It's basically a two-step process. A proton, decays into a positron plus a neutral pion, a heavy particle, and the pion itself is unstable, and eventually decays into two gamma ray photons. The end state is that protons turn into positrons, plus a pair of gamma ray photons. Experiments have shown that the proton half-life must be extremely long.

Because we do not observe yet, any protons to have decayed in the Universe. The half-life currently has a limit of at least 10 to the 36 years, perhaps longer. The actual limit is not well understood, because we have not yet seen any evidence of even one proton to have decayed anywhere inside of our giant particle detectors.

The Super Kamiokande detector, which we saw in previous lectures, is being used to detect solar neutrinos. And neutrinos from nearby supernovae is also being used to try and search for evidence of proton decay. Some models say it's long, some models say it's short. Those with relatively short decay times have already been ruled out.

But long decay times are still in play. But we have an infinite universe. We have literally all the time in the Universe to wait and 10 to the 36 years. If that's the proton half life, eventually, matter will begin to dissolve. All of the matter that is not locked up inside of black holes.

We will begin and complete the process of dissolution when the Universe is approximately 10 to the 40 years old. If the half life is 10 to the 36 years, the first significant protons decays will occur around 10 to the 34 and by 10 to the 40 nearly all the protons in the Universe, that have not fallen into black holes will have decayed into positrons and photons.

At 10 to the 40 years, with the last dissolution of organized matter, Black Hole Epoch will begin. At 10 to the 40 years, all the matter that is not locked up in black holes has dissolved into leptons and photons. After 10 to the 67 years, the remaining stellar-mass black holes with have evaporated by emitting Hawking Radiation.

We met Hawking Radiation at the end of our lecture on black holes, back in Unit Two, however Hawking Radiation in the present epoch is extremely slow and extremely inefficient. The lifetime of a stellar-mass black hole is approximately ten to the sixteenth or more years. We don't have, the Universe hasn't been around long enough for black holes to begin to evaporate, certainly not of stellar mass black hole size.

But when the Universes could be infinitely old, it has all the time it needs and when the Universe gets to be 10 to the 67 years old. Nearly all of the stellar mass black holes will vanish into subatomic particles and photons. After 10 to the 100 years, the very largest supermassive black holes that were once at the centers of their galaxies will begin to evaporate one by one as Hawking radiation erodes them away.

And eventually, the last black hole in the Universe will vanish in a weak flash of gamma rays and sub-atomic particles. This will mark the end of the epoch of all forms of organized matter in the Universe. All that will remain are leptons, electrons and positrons, handfuls of neutrinos and photons filling an increasingly dark and disorganized universe.

At long last, 10 to the 100 years after the Big Bang, we've reached the end. The final Dark Epoch will begin when the last black holes will have evaporated. The universe continues to expand, continuing to cool off as the radiation temperature approaches absolute zero. It never gets there, cuz it would take an infinite amount of time.

But an infinite amount of time is what an infinitely expanding acceleration universe has to work with. The last matter in the Universe is a thin, formless gas of electrons, positrons, and neutrinos. The last light is a few, increasingly redshifted photons fading and stretching into longer and longer wave lengths.

The final state in the end is a cold, dark, and disordered low-energy state. What began in the brilliant flash of the Big Bang and the creation of all the matter and radiation that we see around us will end in a cold, long, dark night of dissolved matter and increasingly right shifted photons.