Introduction

In ASTR 1210, we have spent the semester exploring how stars and star systems form. While the time it took a protoplanetary disk 4.5 billion years to form into the solar system, when we compare such a timeframe to the bigger picture of the universe it is unimaginably small, even less than a blink of an eye compared to a day. To study the life of the universe, we logically first look to its beginning.

Birth of the Universe

When the topic of the birth of the universe comes to mind, the average person will think of the Big Bang. Many think that the Big Bang was some sort of huge explosion, but contrary to what the name suggests, this is not quite the case.

We first begin with the Doppler Effect. When a fire truck zooms by you while honking its horn, the pitch of the horn appears to get higher as it approaches you, and then lower after it passes you and moves away. This is because the firetruck is a moving source of soundwaves, and as it moves towards you, it emits soundwaves that are effectively compressed and thus have a higher frequency, causing the sound to be perceived as higher pitched, and inversely for when it moves away. Since light behaves as a wave, the same effect happens for fast moving objects. Objects moving away quickly from the observer emit light waves that appear to be stretched out; this is known as redshifting, as red is the longest wavelength of visible light. By observing the redshift of something observed in space, we can determine how fast something is moving away from us (“What is the doppler effect”, n.d.).

In the 1920s, astronomer Edwin Hubble discovered that there is a linear relationship between the distance a celestial body is from Earth and the redshift it experiences and thus the speed at which it recedes from us. The slope of this line is known as Hubble’s constant. It was found that not only was receding from the Earth at an increasing rate, but that everything was also receding from each other at the same rate. This had two big implications: everything in the universe is moving apart not as a result of some sort of net acceleration, rather because the space between them is stretching; and that if everything is moving apart from each other, there had to be a point in time that everything was together at one point (Warren, 2022).

Through kinematic analysis, it was found that everything was together at one point in space about 14 billion years ago. In the beginning, the universe was a hot, dense soup of energy. Only a second later, protons, neutrons, and electrons formed. As the protons and neutrons began to come together to form hydrogen and eventually helium nuclei, there was still a sea of free-floating electrons, where photons were imprisoned, unable to freely travel. After 380,000 years, the electrons joined the nuclei to create atoms, allowing photons to escape, creating the first light of the universe. We know this first light as the cosmic background radiation, where its variations corresponded to variations in density in the early universe.
From there, the hydrogen and helium gas gravitated together to form stars, which created heavier elements through fusion, and even heavier elements in supernovae. Gas and stars gravitated together to form galaxies, where a process of recycling gas allowed for stars to die and form new stars until heavier elements became more plentiful. Gas and surrounding material were able to accrete into stars and planets, which we know as Nebular Theory, bringing us to the present day (“Origin of the Solar Systems”, 2021).

Inflation: An Economist’s Nightmare, An Astronomer’s Riddle

Obviously, if the universe began at one point, then it must’ve expanded to encompass the vastness of space as we know it. When the universe first began, it was inhospitably hot, in the trillions of Kelvin. For the universe to allow for the formation of matter and eventually life, it had to spread out all of its energy over a much more vast space. This period of expansion of the universe is known as the Inflationary Epoch.

What we did not know was how the expansion of the universe would play out in the end of its life. Astrophysicists devised three prevailing models: 1) a collapsing universe, where gravity would eventually win out against expansion, eventually pulling everything back together to create a sort of “big crunch”, possibly birthing a new universe; 2) a costing universe, where gravity balances out expansion, slowing it down until the universe reached some sort of critical size; 3) a runaway universe, where expansion is totally unbothered and the universe expands at an ever-increasing rate.

As we know now, thanks to Edwin Hubble’s observations, the universe’s expansion is not slowing, in fact it’s speeding up. The process that’s driving this expansion is a phenomenon that has yet to be observed, and it does not seem to interact with light like regular forms of matter and energy. We call it dark energy. Dark energy appears to be the dominant form of mass in the universe, accounting for approximately 70% of the universe’s composition, followed by dark matter which accounts for 25%, and then finally “normal” baryonic matter which is only 5% of the universe. Dark energy does not appear to dilute with the expansion of the universe like baryonic matter. Because this field of astronomy is an unsolved mystery, we can’t exactly know the origins or fate of the universe until we know exactly what this stuff is. All we can do is speculate based on our current observations of how dark energy behaves. Current attempts to detect dark energy are ongoing (“Dark Energy”, n.d.).

Not In Fire, But In Ice

As the universe ages, so will everything inside of it. Stars will die, some will burst into brilliant supernovas, some will collapse into black holes, others will leave behind neutron stars and white dwarves. In two billion years, our sun will increase in luminosity after it runs out of hydrogen to burn, puffing up like a balloon, causing Earth’s oceans to boil away and life to die out, assuming it didn’t already die from a massive asteroid or gamma ray burst before then. The sun will swallow up the planets and then leave behind a white dwarf.

The cycle of galactic recycling will take place, although as each star fuses atoms into heavier elements, each generation of stars will leave behind a little less hydrogen and helium for the next. Eventually, there will be not enough gas for new stars to form, and the night sky will go dark as the stars disappear like a city turning off its lights before bedtime.

Some neutron stars by pure chance will collide to form black holes. Some brown dwarves by pure chance will collide to form new stars. Eventually these stars will also die and join the rest of the universe in the cold, dark fate that awaits them (“Life Cycle of Stars”, n.d.).

Remaining bodies will eventually be sucked up by supermassive black holes at the center of the galaxies they belong to, which have been slowly getting more massive over the billions of years. Matter that doesn’t get sucked in will be ejected into intergalactic space, possibly never to be seen again.

The universe is now a graveyard. All that remains are white dwarfs, neutron stars, and black holes. Nothing but the corpses of what was once a brilliant universe. Despite the universe seemingly being on its last legs, it's still barely been alive. If the universe had the same lifespan as a human, it would still be considered a newborn baby.

Intelligent life, if it still exists, may find itself living in close proximity to a white dwarf, neutron star, or even a black hole that's sucked in accreted material so hard that the material has begun to glow - a quasar. Over the years, the already cold white dwarfs will cool down, becoming black dwarfs. The process of becoming a black dwarf is theorized to take so long, that it is likely that no black dwarf exists in the universe right now.

Dust to Dust

As the universe is dragged unwillingly into the dark age of black holes, some baryonic material may remain in intergalactic space, where space expands too fast for it to find something to orbit. Although highly speculative, it's believed that eventually this material will break down due to proton decay. A big problem in modern physics is the relationship between the existence of matter and the state of equilibrium in the universe. Applying the laws of physics as we know them today, it's believed that in the beginning of the universe, matter and antimatter came into existence and annihilated each other, and those quantities should have been equal, and that the overall quantity of baryonic matter should be zero. Obviously, since matter does exist, there was an asymmetry in the quantity of matter and antimatter, leading to some matter not being annihilated, forming the universe as we know it.

If the assumption that all matter eventually must cease to exist, then it is the case that protons, what we believe to be the building blocks of the universe, what we previously expected to be eternal, will eventually break down. Since proton decay is yet another unsolved mystery, this chapter of the universe may look wildly different, should we make any new discoveries concerning the matter ("The Enduring Quest", 2021).

Death of the Immortal Black Holes

As all baryonic matter begins to disappear due to proton decay, all that remains in the universe are black holes, which are seemingly immortal bodies. In the story of equilibrium and entropy, however, it must be that the blacks holes must also die eventually.

English theoretical physicist Stephen Hawking details the death of black holes through the interaction of the Casimir Effect and the immense bending of spacetime by the gravitational influences of black holes. The Casimir Effect posits that, in the vacuum of space, there is a continuous and spontaneous generation of virtual pairs of particles and antiparticles, which quickly separate and recombine to annihilate each other, ceasing to exist as quickly as they came into existence. Laboratory experiments involving placing two metal plates incredibly close to each other found that the Casimir Effect exerts a measurable force due a difference in quantum wavelengths, and that by adding energy to the system by accelerating the plates away from each other, these virtual particle-antiparticle pairs are pulled apart, and the forsaken virtual particles suddenly become real particles thanks to the energy introduced to the system.

In the presence of a black hole, according to Stephen Hawking, the formation of these virtual pairs in space near the event horizon of a black hole result in some pairs being separated as one particles is sucked in, leaving the forsaken particle to wander off into space, its destiny of annihilation so rudely interrupted. To repay the theoretical energy debt, the energy created from the interruption of the Casimir Effect is paid off by the black hole losing mass. Over time trillions and trillions of years, this gradual loss of mass over time will result in the black hole losing all of its mass. This process is named after its discoverer and is known as Hawking Radiation. Despite how intuitive Hawking's explanation is, it's not actually correct. If black holes were to die in such a way as described by Hawking, then we would see black holes radiate all sorts of particles, not just photons. The death of black holes can be more accurately explained through the concept of zero-point energy. Zero-point energy is the observation that there is energy associated with seemingly empty space. This is observed through the Casimir Effect, as previously explained, as well as the fact that space is expanding due to dark energy. When spacetime is curved due to gravitational forces, zero-point energy at that point is greater than zero-point energy in empty space. Hawking Radiation can then be explained, as the radiation of energy (mostly photons) from areas of higher zero-point energy due to the bending of spacetime by mass, to lower points of zero-point energy, thus all objects, not only black holes, have Hawking Radiation and lose mass due to it, it is just the case that most other objects such as stars and planets have other ways that will end their existence before they can lose of their mass via Hawking Radiation ("The beginning of the end", 2021).

In the end, the last remaining black hole will die after 10^{100} years. Its mass will be so small that it no longer has a strong enough gravitational pull to trap everything inside of its event horizon, resulting in the black hole to explode into one last brilliant burst of photons through space. With the death of the last black holes, there will be nothing in space left but freely wandering photons. All matter ceases to exist, and all energy is equally distributed. Entropy ceases to increase as the universe has finally reached its carrying capacity of disorder, and, for the first time in cosmological history, time becomes meaningless. From the birth of the universe 14 billion years ago, to the evaporation of the last black hole, the universe has finally run its course, having lived a lifespan so great that even writing its age down in numbers becomes incomprehensible. Through intense observation and calculation, we humans have an idea of where we came from and where we will go. This life story of the universe is so unimaginably long, that English astronomer Brian Cox puts things into perspective: "as a fraction of the lifespan of the universe [...], life as we know it is only possible for one-thousandth of a billion billion billionth, billion billion billionth, billion billion billionth, of a percent (10^-84)"(Cox, 2013).

Works Cited

Cox. (2013, February 17). *Professor Brian Cox - Wonders of the Universe - Destiny.* Althinking. http://www.althinking.com/2011/03/13/professor-brian-cox-wonders-of-the-universe-destiny/

Dark Energy | COSMOS. (n.d.). https://astronomy.swin.edu.au/cosmos/d/Dark+Energy

Libretexts. (2021, July 26). *8.2: Origin of the Solar System—The Nebular Hypothesis*. Geosciences LibreTexts. https://geo.libretexts.org/Bookshelves/Geology/Book:_An_Introduction_to_Geology_(Johnson_Affolter_Inkenbrandt_and_Mosher)/08:_Earth_History/8.02:_Origin_of_the_Solar_SystemThe_Nebular_Hypothesis

Life Cycle of a Star | National Schools' Observatory. (n.d.). https://www.schoolsobservatory.org/learn/astro/stars/cycle

The Beginning to the End of the Universe: How black holes die. (2021, February 3). Astronomy.com. https://astronomy.com/magazine/news/2021/02/the-beginning-to-the-end-of-the-universe-how-black-holes-die

The Kavli Foundation. (2021, April 16). *The Enduring Quest for Proton Decay*. Kavli Foundation. https://kavlifoundation.org/news/the-enduring-quest-for-proton-decay

Warren. (2022). *The Hubble constant, explained*. https://news.uchicago.edu/explainer/hubble-constant-explained

What is the Doppler effect? (n.d.). https://www.qrg.northwestern.edu/projects/vss/docs/communications/3-what-is-the-doppler-effect.html

Honor Pledge

On our honor as students, we have neither given nor received unauthorized aid on this assignment.

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