A Universe from Nothing

Lawrence Krauss

`summarised by`
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ABSTRACT

This book summaries what we know about the universe, how it began and how we managed to learn this.

This document is a summary of the book, ordered by chapters. Since not everything is explained in *trivial* terms in the book, I'll try my best to provide explanations for a few concepts along the way.

Check out for newer versions: `https://t.karchnu.fr/doc/universe-from-nothing.pdf`
And if you have questions: `karchnu@karchnu.fr`

Lastly compiled the **22/6/2022** (day/month/year, you know, like in any sane civilization).
Status: preface, chapters 1 & 2 are almost done (maybe require some extra info and polishing, but not much). Chapter 3: WIP. Annexes are WIP.

Preface

The preface is about what simplistic ideas we have of the creation of the universe, mostly religious ones. Religion argues for an infinite regression that could only be solved by some magic being that conveniently appears to be *infinite* and *eternal* so our universe doesn't have to. Theologians and religious people are a bit mocked for their many, many dishonest arguments to keep their beliefs. For example, the *Intelligent Design* concept, which not only requires to ignore a lot of what we actually **do** know about life on earth, but also serves as a magic all-in-one concept without any consistency to reject evolution. Invoking a god to explain *how* stuff appears is intellectually lazy and is at best irrelevant.

Science is our best effort to understand our universe, and it follows three key principles[1] :

- follow the evidence wherever it leads;
- theories should be tried to prove wrong as much as we try to prove them right;
- experiment is the only truth, not beliefs nor mathematical elegance of a model.

Science can make people uncomfortable since it changes how we view the world, and this happened quite a few times in history. With recent discoveries, one may even wonder if the *laws of nature* really are fundamentals.

Krauss introduces the concept that maybe the universe could come from nothing. And *nothing* is something rather odd, and we don't actually have experienced it so we can't make much assumptions on it. First we thought that *nothing* could be a simple *quantum vacuum* but now we know that a vacuum (a space without any material entity) isn't really nothing since there are still space and time applied to it. Even then, we know that space and time can spontaneously appear. Since the concept of *nothing* isn't by any mean trivial to understand, the book (Krauss, 2012) will explain it in details later.

1. a cosmic mystery story: beginnings

`Contrary to the book, I describe things chronogically in the summary. Some pieces of information (such as dates, explanations, events), absent from the book, are added for the sake of completeness.`

1514 Nicolaus Copernicus suggests an heliocentric model.

> **Planets move around the sun.**

Between 1609 and 1619 Johannes Kepler publishes his *laws of planetary motions*, which fixes a few problems with the view of Copernicus on the matter:

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[1] The following definition really is simplistic and only covers the general idea behind science. Do not take it for an absolute definition.

- Planets move around the sun in ellipses.
- The Sun is not near the center but at a focal point of the elliptical orbit.
- Neither the linear speed nor the angular speed of the planet in the orbit is constant, but the area speed (closely linked historically with the concept of angular momentum) is constant.

Another way to express the same thing, with a direct citation from the book:

- Planets move around the sun in ellipses.
- A *line* connecting a planet and the Sun sweeps out equal *areas* during equal intervals of time.
- The *square* of the *orbital period* of a planet is directly proportional to the *cube* (3rd power) of the *semi-major axis* of its orbit (or, in other words, of the "semi-major axis" of the ellipse, half of the distance across the widest part of the ellipse).

1665 Isaac Newton uses a prism to see the sunlight disperse into the colors of a rainbow. He manages to obtain this result by only letting the light of the sun enter a room by a small hole in the window shutter. His conclusion: the white light contains all these colors.

> **Sunlight contains a spectrum of colors.**

1784 first observation of Cepheid variable star, which are stars whose brightness varies over some regular period.

(around) 1815 a scientist[2] analyses the dispersed light: some colors aren't there. His conclusion: some materials in the outer atmosphere of the sun are absorbing the light of certain colors or wavelengths. Known materials are tested to see what are the colors they *absorb*, which includes: hydrogen, oxygen, iron, sodium, and calcium.

> **Materials may "absorb" some part of the solar spectrum. Different materials, different parts of the spectrum.**

1842 Christian Doppler discovers the Doppler Effect.

> **Doppler Effect: a wave coming at you will be stretched if the source is moving away from you, or compressed if the source is coming toward you.**

1868 a scientist[3] observes two missing lines in the yellow part of the solar spectrum. This doesn't correspond to the effect of materials we know on Earth. His conclusion: these *absorbed* colors must be the result of an element that doesn't come from Earth. This element is then named *helium*.

A generation after we understood the sun has elements we don't have (as much) on Earth[4], *helium* is isolated on Earth.

> **The spectrum of radiation of stars provides their composition, temperature and evolution.**

1908-1912 Henrietta Swan Leavitt discovers a relation between the brightness of Cepheid variable stars and their pulsation period.

> **The light spreads out uniformly over a sphere whose area increases as the square of the distance (this is called the inverse-square law). Thus since the light is spread out over a bigger sphere, the intensity of the light observed at any point decreases inversely with the area of the sphere.**

— TODO: find out who and when this was discovered

> **Observing the pulsation period of a Cepheid indicates its true luminosity. Also, the observed brightness of stars goes down inversely with the square of the distance to the star. Therefore, comparing its known luminosity to its observed brightness gives us the actual distance to the star.**

Starting in 1912 Slipher observes the spectra of light coming from nearby stars and distant spiral nebulae[5] are almost the same. The difference is a shift of the same wavelength in the *absorbed* lines.

1916 A. Einstein publishes his work on the *general theory of relativity*. This work is about gravity, space and time, and explains not only how objects move in the universe, but also how the universe itself might evolve. Amongst many uses of this theory, the orbit of Mercury can be predicted more accurately than before with Newton's theory of gravity. This fixes a small difference between observation and theoretical results[6].

However, the theories of Newton and Einstein are both, at some point, inconsistent with the observations. Gravitation is thought to be an attractive force: objects should then always collapse into each other. Also, the scientific community still thinks the universe as static, eternal and composed of a single galaxy (our Milky Way) surrounded by a vast, dark, infinite empty space. And without accurate knowledge of the distances with observed stars, nor better images, this idea seems consistent with the observations.

1917 Mount Wilson 100-inch (2.5 m) Hooker telescope, the

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[2] His name is not given in the book.

[3] Again, not named in the book.

[4] Yeah, not even a date, again.

[5] *Nebulae* that we will soon find out they are actually entire galaxies.

[6] The planet doesn't come back to its initial position after an ellipse around the sun. There is a slight precession of the perihelion of Mercury: 43 arc seconds (only of a degree) per century.

world's largest at the time (from 1917 to 1949). It will soon help to discover many things. For example, to prove the Andromeda nebula is external to our galaxy (1923, Edwin Hubble), that the Universe is expanding (1929, Hubble and Milton Humason) and to measure both its expansion rate and the size of the known Universe, to find evidence for dark matter (1930s, Fritz Zwicky), etc[7].

1923-1924 with the period-luminosity relation and the measurement of Cepheid variable stars, Hubble determines that the distance with some Cepheids are too great to be inside our Milky Way[8].

> **The universe contains other galaxies.**

1925 Hubble publishes his study on spiral *nebulae*, where he identified Cepheid variable stars in them (including the *nebulae* we currently know as Andromeda).

1927 Georges Lemaître is the first person to suggest the universe is expanding. This is his conclusion after solving the Einstein's equations for general relativity.

1929 Hubble remarks that galaxies are moving away from each other. More importantly, the more distant, the faster the velocity. The relation is linear: a galaxy twice more distant is moving away twice as fast.

> **The universe is expanding.**

1930 Georges Lemaître proposes that the universe began in a very small point, which he called *Primeval Atom*[9].

Random facts: current state of knowledge

The expansion of the universe started 13.72 billion years ago.

Our galaxy is one of the about 100 to 400 billion other galaxies in the observable universe.

Over 200 million stars already exploded within our galaxy, providing us the material resources necessary for life on Earth.

Big Bang created light elements in massive quantities, such as hydrogen. No nuclei heavier than lithium were produced during the initial universe expansion (too hot). Heavier elements require the stars to be created (by their massive gravity), and their explosion to be dispersed across the galaxy. The universe expansion explains the abundance of light elements.

> **Life on Earth is, literally, made of stars.**

A supernova (the explosion of a star) occurs once every hundred years or so per galaxy. The last one in our galaxy was in 1604.

Rare events, such as supernova, happen constantly at the scale of the universe. Therefore, each night with a good enough telescope, you can expect to see a supernova.

Type 1a supernova (a certain type of exploding star) accurate luminosity can be infered by the duration they shine. Their *observed* brightness provides their distance (with the inverse-square law), which also determines the distance with their galaxy. Then, the redshift of the light from the stars in the galaxy indicates its velocity. Finally, comparing the velocity of the galaxy and its distance allows us to infer the *expansion rate of the universe*.

Galaxies are more and more distant from each other, this is the general trend. In some cases, two galaxies may collide, but that is rare (again, rare events happen all the time).

Independent estimates of the age of the oldest stars in our galaxy are consistent with the rate of the universe's expansion. The Big Bang is consistent with all the different ways we observed our universe, with independent methods.

2. a cosmic mystery story: weighing the universe

`This chapter presents the thoughts of the scientific community while unravelling some mysteries about our universe. This includes how galaxies and clusters of galaxies are working, dark matter, gravity, nature of matter in our universe, etc. This chapter also is about the excitment felt by L. Krauss as a young scientist, and his perspectives in the 1980s. Finally, the chapter describes how a picture of a 5 billion light-years away galaxy tells us about the distribution of mass within a cluster of galaxies (and` **how our universe will end**`, probably).`

How will the Universe end? Since the Universe isn't static, there are three main possibilities. The first one is the *Big Crunch*: the Universe will collapse, creating a reverse Big Bang. In the second case the Universe will **almost** stop expanding. Last possibility, the Universe will continue to expand at a finite rate. To answer this question, we use the theory of general relativity and we need to know the total mass of the universe.

First, the nature of the universe

Gravity shapes solar systems as well as galaxies and *clusters* of galaxies. But the apparent gravity force cannot be explained only by visible objects, such as stars and planets.

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[7] We now make ten times bigger telescopes and hundred times bigger in area.

[8] Hubble identifies a first galaxy (NGC 6822) in 1925, then the Triangulum galaxy (M33) in 1926, and Andromeda (M31) in 1929.

[9] This isn't accepted by the scientific community right away: actual observations were provided by Edwin Hubble beforehand.

For example, the movement speed of stars (and hot gas) within our galaxy isn't explained only by the sum of gravitational forces of other stars, gas and planets.

Also, the mathematical formulas leading to the explanation of the abundance of light elements (hydrogen, helium and lithium) in the universe[10] give an approximation of the total number of protons and neutrons must exist in the universe. Problem: there should be twice the amount of material we can see in stars and hot gas[11]. Second problem: even then, this isn't even remotely near enough material to explain the mass of galaxies. Invisible matter should represent ten times the mass of visible matter. So, this*dark matter* cannot be only made of neutrons and protons.

> **The Universe is mostly made of matter we don't understand.**

Identifying this dark matter

Maybe this dark matter is made of a particle that can be identified through calculations or educated guess for example. This way, new experiments could be proposed to detect this dark matter, and learn more on what appears to be the main component of the universe. Later, to that end, we built machines on Earth to recreate an environment where these particles could be created (see the *Large Hadron Collider*). We also created dectectors, deep in mines to avoid perturbations from all sorts of cosmic rays.

> *The job of physics is not to invent things we cannot see to explain things we can see, but to figure out how to see what we cannot see.*

— Lawrence Krauss

Knowing the abundance (and the nature) of dark matter is important to know how the Universe will end. Two possibilities are given in the book to make this calculation. First, in case this "dark matter" was created during the Big Bang, then its abundance could be estimated by ideas from the forces that govern the interactions of elementary particles. Second, by reusing some ideas from particle physics[12].

More about general relativity

Einstein general relativity predicted that space is curved in the presence of matter or energy. This leads to our universe having different possible geometries depending on the total density of mass in the universe[13].

The first possible geometry of our universe could be *closed*. It can be described as a *three-dimensional sphere*. A way to picture it is to imagine looking far enough in any direction and see the back of your head. In this case, the general relativity tells us the energy density of the universe is dominated by matter like stars, galaxies and this *dark matter*, and will end in a Big Crunch. The second is the *open* universe. The universe will continue to expand at a finite rate. Finally, the *flat* universe, which expands but slows down with time without ever stopping. This requires the "dark matter" to be 100 times more massive than visible matter[14].

Back to the main track: weighting the universe

How to get the density of mass in the universe? The largest gravitationally bound objects are *superclusters of galaxies* that can contain thousands of galaxies (or more). These are so massive, most of galaxies are within a supercluster. Measuring the weight of a supercluster (which also includes its dark matter) and then estimating the density of superclusters in the universe leads to *weighting the universe*.

How to get the density of mass of a supercluster? In one word: gravity. Gravity bends space, so bright objects behind something massive (such as a galaxy, or a cluster of galaxies) can be seen. So, gravitational lensing is a thing. Also, Fritz Zwicky analyzed as early as 1933 that galaxies in the Coma cluster were moving so fast they would have quit the cluster unless the cluster was 100 times more massive than the sum of the masses of the stars. Therefore, the speed of galaxies in a cluster can be some sort of metric to estimate the density of a cluster, too.

`Note: at the time, little was known of black holes, red dwarves, neutron stars, etc. A good chunk of the missing mass actually comes from these objects, with little to no light emissions. And some emissions are infrared, which isn't easily visible on Earth, so we waited orbital telescopes to observe them.`

In 1998, the physicist Tony Tyson shows that the mass of a cluster mostly comes from between the galaxies. He used magnified images of a distant galaxy from the Hubble Space Telescope to calculate its mass. The mass was computed with a mathematical model of the cluster of the galaxy, using laws of general relativity, and calculating a lot of paths[15]. Finally, once the model produced an image matching the observation, the model was used to determine the mass of the cluster. The result was, as stated before, that the mass of the cluster mostly comes from between the galaxies, not from stars or hot gases. More precisely: there is 40 times more mass between the

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[10] TODO: explain these formulas.

[11] Some of the non observed matter is contained in planets, since it is hard to see something that doesn't produce light.

[12] In both cases: the chapter doesn't include an explanation of what these *ideas* could be. That's kind of a bummer.

[13] This isn't explained further in the chapter how the general relativity actually indicates that. Second bummer.

[14] TODO: the difference between Big Crunch, flat and open isn't clear **at all**. This probably needs some polishing.

[15] From what is actually written in the book, this seems almost like an exhaustive computation. An evolutionary algorithm maybe? Too bad there isn't much details: Krauss said the model was based on general relativity but the actual algorithm (to some extent) could have been interesting to learn.

galaxies than within, which is 300 times more mass than within stars alone with the rest of visible matter in hot gas around them.

More on dark matter

> *[...] more recent observations from other areas of astronomy have confirmed that the total amount of dark matter in galaxies and clusters is far in excess of that allowed by the calculations of Big Bang nucleosynthesis. Dark matter must be made of something that isn't normally on Earth nor in stars.*

— Lawrence Krauss

Dark matter should be all around us, including basically everywhere on Earth. It should be comprised of an elementary particle (or several particles) and experiments are done to detect it. As already said: deep in mines and with the LHC. Since it doesn't interact electromagnetically (therefore, it doesn't absorb, reflect or emit light), we assume that its interactions with normal material are extremely weak. Dark matter could, for example, traverse anything. Therefore, it will be difficult to detect. Removing most of the cosmic rays of the equation is necessary and this is why the dark matter detection is expected to be made deep in mines. The LXC also has a great chance to detect dark matter, by recreating what is thought to be an environment near the conditions of the early universe. This is done by smashing protons together with an incredible energy. Direct observation is not necessary, an imbalance between the energy used to smash protons and the result could be an indicator that something emerged from the experiment.

The book is from 2009, since then the LXC actually produced results. However, at the time of this writting (october 2021), still no direct confirmation that dark matter actually exists.

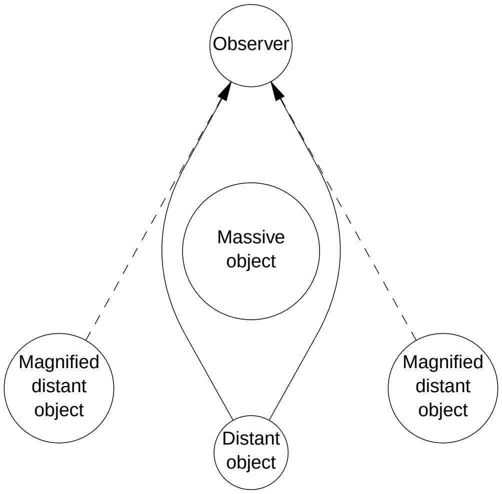
Conclusion

Even if dark matter isn't observed, gravitational lensing still provided the clusters' mass. This is confirmed by independant estimates of the clusters' mass. For example, the X-rays emissions of a cluster are related to the temperature of its gas, which itself is related to the cluster's mass. And the final result is: the total mass in and around galaxies and clusters only is 30 percent of the total amount of mass needed for our universe to be flat. Even if the invisible matter is 40 times more massive than visible matter, this is still way less than required for our universe to be flat.

So we are living in an open universe, expanding forever... or maybe not!

Yes, there is a cliffhanger at the end of the chapter. Stay tuned, kids!

Random facts



Gravitational lensing

According to Zwicky, gravitational lensing can be useful for:

- testing the general relativity;
- using galaxies to magnify distant objects;
- determine the mass of a galaxy or a cluster.

Anecdotes

Einstein became famous mostly because he predicted sunlight curving around the Sun during an eclipse in 1919. It wasn't because of its famous mathematical equation in 1904:

$$E = mc^2$$

Einstein predicted that gravity could help see objects beyond other objects, through lensing. Gravity bends space, so bright objects behind a massive object can still be seen. This is practical: objects can be seen by gravitational lensing via galaxies or cluster of galaxies. However, Einstein thought at the time that his prediction was useless since he only thought of star by star lensing.

3. Light from the beginning of time

This chapter introduces a more reliable way to determine the geometry of the universe, thanks to the cosmic microwave background radiations.

Trying to measure the universe weight by gravitational lensing galaxies and clusters is fundamentally flawed. This could only provide a rough approximation in case the weight actually came from somewhere within clusters. In case the weight of the universe comes from between clusters, then our method doesn't work.

Another involves observing cosmic microwave background radiations (CRBR) and actually measure see the curvature of the universe.

Measuring the geometry of the universe

Before trying to explain how to measure the curvature of the universe, let’s try to answer a simpler question.

How to measure the curvature of a world in two dimensions?
To be defined or to finish.

Cosmic Microwave Background Radiations

Somewhere around 300 000 years after the Big Bang, the universe became cold enough to emit radiations. **To be defined or to finish.**

> **Gravity is propagated at the speed of light.**

I. events

- 1665, Isaac Newton
- 1784, first observation of Cepheid variable star.
- 1908-1912, Henrietta Swan Leavitt discovers a relation between Cepheid variable stars' brightness and period of their variation. And this leads to knowing the distance between these stars: we now can make wild approximations on astonomic distances between us and stars.
- 1916, general theory of relativity, a decade-long struggle to create a new theory of gravity by Albert Einstein.
  This work is also about space and time, and explains not only how objects move in the universe, but also how the universe itself might evolve.
- 1925, Hubble publishes his study on spiral *nebulae*, where he identified Cepheid variable stars in them (including the *nebulae* we currently know as Andromeda).
- 1925, Mount Wilson 100-inch Hooker telescope, the world's largest at the time.
- 1927: Lemaître shows that the Einstein's equations suggest an expanding universe.
- 1930: Lemaître proposes an universe beginning in a small point he called *Primeval Atom*.
- 1933: Zwicky concludes that the Coma cluster is about 100 times more massive than the sum of the masses of its stars.

II. vocabulary

- perihelion: point of an orbit where the object (e.g.: a planet) is the closest from another object (e.g.: a star).
- aphelion: opposite of perihelion, point of an orbit where the object is the farthest from another object.
- precession: change in an angle over time. This can be the angle of the ellipse formed by the orbital journey of a planet (apsidal precession). Or this can be the movement of the rotational axis of an astronomical body, whereby the axis slowly traces out a cone (axial precession). Finally, the precession can be a change in the *plane* of the orbital course (nodal precession), which can be caused by a third gravitational object.
- nebulae: *fuzzy thing* (or cloud) in latin. Galaxies were named this way before we understood what we saw.
- Cepheid variable: star whose brightness varies over some regular period, indicating a change in diameter and temperature.
- Doppler Effect: a wave coming at you will be stretched if the source is moving away from you, or compressed if the source is coming toward you.
- Nuclei:

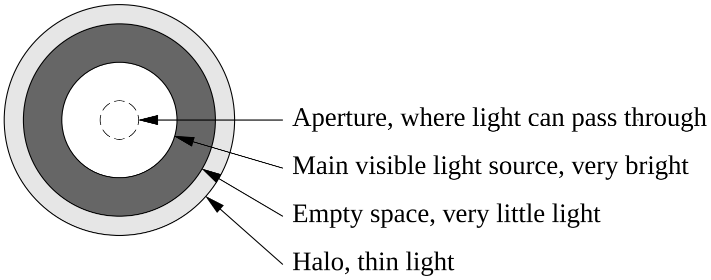
III. people involved

- Johannes Kepler: known for the first heliocentric model.
- Isaac Newton:
- Christian Doppler: australian physicist, known for the "Doppler Effect".
- Albert Einstein:
- Georges Lemaître: physicist and preist, first to suggest that the universe was expanding in 1927.
  He started as an engineer, then was a decorated artilleryman in WW1, switched to mathematics, and priesthood in early 1920s. Then moved to cosmology and first studied with Sir Arthur Stanley Eddington before moving on to Harvard and receiving a second PhD in physics from MIT.
- Arthur Stanley Eddington: astronomer.
- Henrietta Swan Leavitt: Harvard College Observatory "computer". Discovered the relation between Cepheid variable stars' brightness and period of variation.
- Edwin Hubble: former lawyer, became astronomer. Made the first observation of the expansion of the universe.
- Harlow Shapley: discovered the Sun wasn't at the center of the Milky Way, and that our galaxy was much larger than we previously thought.
- Vesto Slipher: astronomer, he measured the spectra of light coming from several galaxies.
- Fritz Zwicky: astronomer, analyzed in 1933 that galaxies in the Coma cluster were moving so fast they would have quit the cluster unless the cluster was 100 times more massive than the sum of the masses of the stars.
- Tony Tyson: physicist. Discovered the mass between galaxies through images from the Hubble Space Telescope.

IV. Random explanations

TODO: explain how we measure stuff with telescopes (resolution, focal, arcsecond unit, etc.).

Diffraction: behavior of waves when reaching an aperture.



Circular diffraction

References

Lawrence Krauss, *a Universe from Nothing*, Simon & Schuster (2012).