Living in the Middle of Space and on the Edge of Time

Legacy of Einstein, Minkowski, Robertson, and Walker: the EMRW model

Einstein's spherical Universe revived

In his book 'My Theory' of 1917, Einstein described a spherical Universe. He abandoned his model in 1931, after seeing astronomer Hubble's work on the redshift of distant galaxies. Now, we revive Einstein's model by using Minkowski's space-time. This results in a universal model which needs neither dark energy nor dark matter, reviving Einstein's model into a *space-time* model: the Einstein, Minkowski, Robertson, and Walker (EMRW) model. *Our* EMRW model replaces the *current* FLRW model, see the paragraph 'The current FLRW model is out of date'.

Minkowski: Think space-time

Minkowski, Einstein's teacher, said it so eloquently in 1908: 'Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality'. Let us apply this to the Universe, and let us think of the expansion of *space-time*. Let us forget spatial thoughts and think of time as the true fourth dimension. The Universe not just growing in size, but growing in time as well. We then get to a very simple statement: '*The future lies outside of our universal space-time*', see figure 1.

Note that a space-time model is four-dimensional (4D), of which you see a 2D section in figure 1. More about this in the paragraphs: 'Einstein's first model' and 'Minkowski and the entity of space-time.'

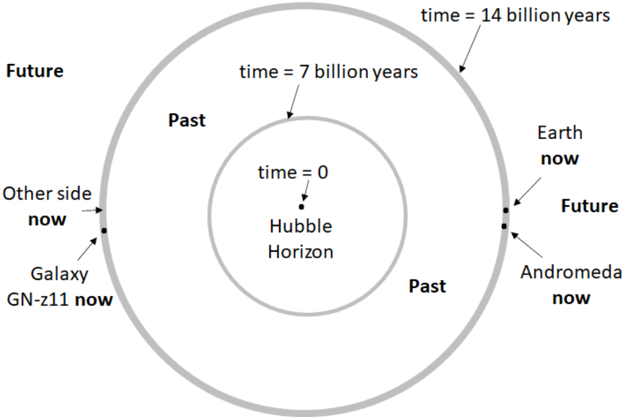

Figure 1: 2D section of our EMRW model of the Universe

The future lies outside of our Universe

The logical consequence being that *the past lies on the inside of our universal space-time*. This ultimately means that we live on the *edge* of space-time. We could call this edge simply 'now'. However, 'now' is hard to define. You cannot measure 'now', not even on a clock. Clocks keep ticking, there is no such thing as 'the' time. We cannot confirm anyone's statement of what the time is, our time measurement is always a little later. The problem for cosmologists is even harder: What we observe from any galaxy now, is how it *was* many millions or even billions of years ago.

In Einstein's original model, the Universe was kept from collapsing by the cosmological constant, now called 'dark energy'. In our new EMRW *space-time* model, the Universe expands over time, slower and slower, but never stops, see the paragraph 'Expansion of the Universe', while there is no need for dark energy. In current thinking (the FLRW model), the expansion would go faster and faster, see the paragraph 'Original Hubble law and Dark Energy'. To understand our EMRW model, we need to get back to the basics of physics and Relativity: variables, constants, units, and coordinates.

Coordinates and measurement units in Relativity

Physics is based on measurements. The art of physics is to find the simplest formulas describing all the observations. A formula like Einstein's $E = m.c^2$ is a beauty of physics. The 14th century monk Ockham (or Occam) said it so eloquently: 'The simplest solution explaining all the observations has the preference'. We now call this principle 'Occam's razor'.

However, what many physicists overlook is that the formula $E = m.c^2$ is worthless without the measurement units. We need those units to be able to get an outcome useful in real life. Those units are standardized by the SI organization (French: Système International d'unités), called SI units. Measurements exist out of *coordinates* like the quantities: mass 'm', speed of light 'c', and energy 'E' and their SI *units* respectively kilogram, meter per second, and Joule. Coordinates can be variables or constants; 'c' is the constant 299,792,458.

Units make the difference between mathematics and physics. Your teacher in physics at high school probably said it: 'do not forget the units'. However, even Einstein sometimes forgot the units. Einstein forgetting the units, is especially poignant since he was the one who made the units *variable*, see below. The variable units in Relativity will be highlighted in this article by writing the units between square brackets '[ ]'. In other words, when you see a formula followed by units between square brackets, you know that the units can vary. For example: The energy of a particle on Earth is given by $E = m.c^2$ [J], *both* the energy 'E' as variable *and* the unit Joule vary at speed and in gravitation.

To understand variable units, let us look at the unit second. This unit is defined as 9,192,631,770 cycles on a cesium clock, according to the SI organization. Einstein argued in 1916 that a clock ticks slower at speed and in gravitation: 'time dilation'. As late as in 1971, this was confirmed by experiments with cesium clocks in planes by Hafele and Keating.

In other words, the length of the unit second depends on both speed and gravitation. *The unit second is not a constant, but a variable*. We cannot work with variable units in measurement physics, we need a standard to relate to. That's why we are going to use Greenwich as standard for the unit second $[s_{2000}]$ in Relativity, see box 1. The EMRW space-time model is based on variable basic units (second, meter, kilogram, and Coulomb), which leads to surprisingly good results. Firstly, we have to get our observations right. We need to look at what we can observe and how that is related to time, the subject of the next two paragraphs.

Box 1: Relativity of the unit second

To standardize the unit second in Relativity, we are going to standardize on the circumstances at Greenwich in the first second of the first day of the year 2000: $[s_{2000}]$. Examples are:

$[s] = 0.5[s_{2000}]$	7 billion years ago in $[s_{2000}]$
$[s] = 0.1[s_{2000}]$	at dwarf galaxies ($z \approx 9$)
$[s] = 0.001[s_{2000}]$	at Surface of Last Scattering

How far can we look into the past?

The speed of light 'c' is high: 299,792,458 [m/s] to be exact. This is not an approximation, but is 100% exact. That is because the SI organization abandoned the unit meter definition based on the length of a measuring rod in Paris (Sèvres) and replaced it by the distance light travels in 1 / c seconds in vacuum. In spite of the high speed of light, a galaxy like Andromeda is that far away that light takes about 2.54 million years to reach the Earth. Our distance to Andromeda is 2.54 million *light-years*.

The farthest galaxy observed so far, is GN-z11, which is nearly at the other side of our Universe at about 13 billion light-years distance. The speed of light is limited; we are not able to look further back in time than has progressed, about 14 billion years. Consequently, the horizon of observation of the Universe is 14 billion light-years in distance; cosmologists call that the 'Hubble Length', we call that distance *and* time in space-time the 'Hubble Horizon', see the figures 1 and 2.

What do we observe?

Figure 2 shows us what we observe with our telescopes, like the Hubble Space Telescope:

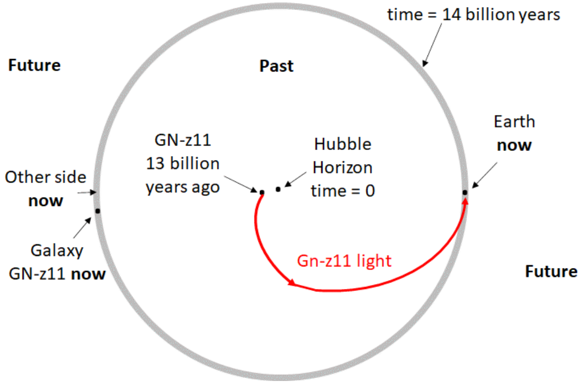

Figure 2: Observing the light from galaxy GN-z11 in a 2D section

Note that the observed light from galaxy GN-z11 (in red) spirals outwards towards us in our space-time model.

Because the light goes around the circle of the cosmic time, while the circles get larger over cosmic time caused by the expansion of the Universe, we get a trajectory of the light in the form of a spiral. The fast expansion at the beginning of the trajectory is called 'cosmic inflation', as we will see later.

A horizon in space-time?

Yes, a horizon in space-time. That horizon will tomorrow be the same horizon, like a horizon at sea. You can sail to a barrel now drifting at your current horizon, but you can never reach the horizon itself. Similarly, if you would be able to travel back in time (you cannot), then the Hubble Horizon would be just as far as it is now at about 14 billion (light)years. In other words, there was no Big Bang, there is just a horizon in space-time: the Hubble Horizon. According to *current* cosmology, the Big Bang would be the beginning of our Universe, born with a tremendous explosion in an infinitely small volume at the beginning of time. Let us have a look at our alternative to current thinking: the Hubble Horizon.

Understanding the Hubble Horizon

The key in understanding the Hubble Horizon lies in the 'comoving coordinates' of Robertson and Walker. In 1931, they were faced with the following problem: When the Universe expands and galaxies move away from us as a consequence, how do we record their position? Most galaxies move farther and farther away from us, making it impossible to measure their distances. Within our solar system we have the same problem. For example, what is the exact distance of Mars to the sun? Astronomers have a simple method now, defining the distance as it was on the first second of the first day of the year 2000. That distance then gets the subscript '2000', as you saw in box 1. Based on its known orbit, we can then accurately compute its position over time.

However, applying this method to the expansion of the Universe creates an extra problem. Because of the vastness of the Universe, we get a timing problem. Is the receding speed the speed as it was in the distant past or the speed as it is now? Additionally, the receding speed is caused by the expansion of the Universe, but also by local gravitation. To circumvent these kind of problems, Robertson and Walker (R&W) introduced 'comoving coordinates', which means that the three coordinates for each galaxy (distance, right ascension, and declination) move along with the expansion. *Comoving coordinates remain the same within an expanding Universe*. The distance from Earth to a galaxy remains the same when it does not have a local speed caused by gravitation. For distant galaxies, the expansion speed is an order of magnitude larger than the local speed. The expansion of the Universe does not change the three comoving coordinates defining the position of a distant galaxy.

Expansion of the Universe expressed in comoving coordinates

There is a unique characteristic of comoving coordinates that is often overlooked: The Universe does not expand. By definition, the Universe stays exactly the same size in comoving coordinates. Expressed in comoving coordinates, the Universe was, is, and will always be the same size. This size is the Hubble Horizon of about 14 billion (light)years. Does that mean that the Universe does not expand? No, the Universe expands in *measurement terms*, but not in comoving coordinate terms.
In measurement terms, you need an invariant unit of measurement. To express any length or distance, you need a constant unit of measurement (meter, light-year, parsec..). *Comoving coordinates is another way of saying that your measurement units expand over time along with the expansion*. In effect, the unit meter is tomorrow larger than today's unit meter. The expansion of the Universe is thus an expansion of the unit meter. In the cosmic past the unit meter was a lot smaller, and in the future the unit meter will be a lot larger relative to the unit meter of today. Table 1 shows how the distance to galaxy GN-z11 and to the Hubble Horizon remain the same in comoving coordinates:

Table 1: Distance to GN-z11 and the Hubble Horizon in comoving coordinates

In constant units $[s_{2000}]$:	7 billion years ago	The year 2000	14 billion years from now
In comoving coordinates			
Distance to GN-z11:	13 billion light-years	13 billion light-years	13 billion light-years
Hubble Horizon:	14 billion light-years	14 billion light-years	14 billion light-years
Expanding units			
Unit meter:	$[m] = 0.5[m_{2000}]$	$[m] = [m_{2000}]$	$[m] = 2.0[m_{2000}]$
Unit second:	$[s] = 0.5[s_{2000}]$	$[s] = [s_{2000}]$	$[s] = 2.0[s_{2000}]$

In other words, the evolution of the Universe can be seen in two ways: 1) The expansion as a *growing measurement values* in constant units meter $[m_{2000}]$ and second $[s_{2000}]$, or 2) *No expansion at all in comoving coordinates*. In the figures 1 and 2 you see a *measurement* expansion of the Universe based on the constant unit meter of the year 2000, symbolized by $[m_{2000}]$. *This is where Noether's theorems become important to determine whether we need to apply physics in constant units or in comoving coordinates*. Emmy Noether was a brilliant mathematician working for David Hilbert at the university of Göttingen in Einstein's time. She laid the ground rules for guaranteeing energy and momentum conservation. Being a woman in science, her theorems were largely ignored, also by Albert Einstein.

Noether's theorems of energy and momentum conservation

Noether's theorems describe the properties of a reference frame in order to guarantee energy and momentum conservation: 1) To guarantee momentum conservation within the chosen reference frame, all locations must be the same everywhere (homogenous) and the same in all directions (isotropic), and 2) To guarantee energy conservation, all the laws of physics and its constants must remain the same over time. The reference frame (t,x,y,z) in space-time as Einstein used, comprises of time 't' and the three coordinate axes of space 'x', 'y', and 'z'. In other words, a space-time reference frame (t,x,y,z) must be homogenous and isotropic in both space and time in order to guarantee energy and momentum conservation. Cosmologists call Noether's theorems the 'perfect cosmological principle'. Consequently, in order to guarantee energy and momentum conservation of a space-time reference frame (t,x,y,z), all constants of nature must be the same everywhere, the same in all directions, and the same over time.

For example, the speed of light of 299,792,458 [m/s] must be everywhere the same, the same in all directions, and the same over the entire cosmic past. However, the unit meter is growing over cosmic time in comoving coordinates. Because the speed of light is expressed in meters per second, *the unit second must grow along with the unit meter* in order to guarantee energy conservation of the Universe, see table 1. That is, if you accept that the Universe conserves its energy; after all, the Universe is all there is.

Does the Universe conserve its energy?

Not all cosmologists believe that the energy of the Universe is conserved. The following statements come from a highly acclaimed book about cosmology in the paragraph 'where has the energy gone'[1]: 'The principle of conservation of energy that is familiar to physicists is a local statement, known to hold only for finite regions'. Further down: 'we need not be concerned with the lost energy of the redshifted photons'. We reject both statements. Of course, you may argue that the Universe does not conserve its energy. However, that would also mean that the laws of physics could change over time, that constants of nature could change over time, and that no conclusions may be drawn from any astronomical observation. You cannot draw conclusions based on physics and at the same time reject the basics of physics. Cosmologists cannot have it both ways. For example, in the spectrum of light of stars you find absorption lines, color frequencies which measure less power than slightly higher and lower color frequencies.

Light and other electromagnetic radiation have two frequencies, which are often confused with each other: the intensity frequency 'f_{int}' (measured number of photons per second), and the color frequency 'f_{col}' (determining the energy of a single photon). The color frequency is not a directly measurable property of a photon. What is measurable is its energy, the color frequency is then found by dividing this energy in Joules by the Planck constant 'h' (0. followed by 33 zeroes and then 663), see box 2. According to Einstein, the proper time of light is zero. In other words, photons do not move and consequently cannot have a frequency; color frequencies are no frequencies, but a measure of energy! Let us get back to the absorption lines.

Box 2: Frequencies of radiation

$h = 6.63 \times 10^{-34}$ [J.s] Planck constant
$E_{pht} = h.f_{col}$ [J] energy of one photon
$P = f_{int}.E_{pht}$ [W] Power of laser beam

For example, the power of a green (577 TeraHz) laser beam with an intensity of 2.0 [PetaHz] equals:

$E_{pht} = 3.82 \times 10^{-19}$ [J] Energy of green photon
$P = 0.76$ [mW] Power of green laser

The absorption lines in the spectrum of stars are very similar to the absorption lines of the elements hydrogen and helium on Earth, see the paragraph 'Redshift of the light of a galaxy'. If you do not take physics seriously, you may not conclude that stars like the sun contain hydrogen and helium. Or, if you do take physics seriously, you must adhere to the basics of physics: Noether's theorems of energy and momentum conservation.

Energy conservation of photons of the Cosmic Background Radiation

The Surface of Last Scattering (SLS) was an era in the evolution of the Universe in which light was scattered for the last time. Before the SLS the Universe looks 'misty', since then, the Universe is translucent, we can observe every galaxy since then. The scattering was caused by the electromagnetic field of the nuclei and electrons, which come loose from each other at a certain high temperature. That last scattering is observed on Earth as the Cosmic Background Radiation (CBR) coming from all

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[1] Hawley J. and Holcomb K. 'Foundations of Modern Cosmology' Oxford Press, 2005, chapter 14

directions. In the *current* FLRW model, the wavelength of the photons (light particles) of the SLS, received as the CBR on Earth, would be 'stretched' by the expansion of the Universe.

To make a mixture of hydrogen and helium 'misty', we need a temperature of 2978 Kelvin. The CBR spectrum that we observe on Earth now has a temperature of just 2.725 Kelvin according to Planck's law. All photons of the CBR spectrum have a wavelength that has become 2978 / 2.725 = 1093 times longer. A longer wavelength means a lower color frequency (Planck's law) and thus less energy per photon, see box 2. In other words, these photons would have lost more than 99.9% of their energy on their way from the source, the SLS, to their destination, the CBR observed on Earth, according to *current* cosmology. Where has the energy gone?

Do you believe the statement 'we need not be concerned with the lost energy of the redshifted photons' in the aforementioned book? Do you accept that energy just disappears? There is a simple alternative explanation: the unit of energy Joule at the SLS was 1093 times smaller than our current unit Joule is. In that way, the *measured* energy remains the same at all times. The much smaller Joule of the past matches up with the much smaller unit meter in the comoving coordinates of R&W and the logically following smaller unit second of the past. In other words, energy conservation forces us to think in terms of expanding units Joule, meter, and second, instead of larger coordinates: *The energy of the Universe is conserved in comoving coordinates, while the basic units expand: That is our interpretation of the expansion of the Universe over time.*

Building a model of the Universe based on energy conservation

A model of the Universe based on Noether's energy conservation has constants that are what their names say: constant. *All* constants of nature, like the speed of light 'c', the Newton constant 'G' (Gravitation law of Newton), and the Hubble constant 'H', are then by definition invariant to circumstances (constant). This has far-reaching consequences. The unit meter is the distance travelled by light in vacuum in 1 / c seconds, according to the SI organization. When the unit meter changes over cosmic time, then so must the unit second in order to ensure an invariant speed of light over cosmic time. In this way, the speed of light is always exactly 299,792,458 [m/s], even though the units meter and second change over time.

The Newton constant 'G' is measured in [$m^3/s^2/kg$]. When the units meter and second change over cosmic time, then so must the unit kilogram. Since $E = m.c^2$, in which 'E' is the energy in Joules and 'm' the mass in kilograms, then so must the unit Joule change in the same way as the unit second, meter, and kilogram. See how all the pieces of the puzzle fit together? Now, *the demands of Noether's theorems and of the perfect cosmological principle do match up with the observations of the CBR*.

In table 2 you see the total amount of energy in the Universe in Joules (16 followed by 69 zeroes), see the Appendix for the formula. The energy can be translated back into mass in kilograms; Einstein talked about *mass-energy*, expressed in either Joules or kilograms.

Table 2: Total energy and mass of the Universe

In constant units [s_{2000}]:	7 billion years ago	The year 2000	14 billion years from now
In comoving coordinates			
Universal energy:	1.60×10^{70} [J]	1.60×10^{70} [J]	1.60×10^{70} [J]
Universal mass:	1.78×10^{53} [kg]	1.78×10^{53} [kg]	1.78×10^{53} [kg]
Expanding units			
Unit Joule:	[J] = 0.5[J_{2000}]	[J] = [J_{2000}]	[J] = 2.0[J_{2000}]
Unit kilogram:	[kg] = 0.5[kg_{2000}]	[kg] = [kg_{2000}]	[kg] = 2.0[kg_{2000}]

The changing unit second over cosmic time

In the EMRW model of the Universe in which energy is conserved, both the unit meter and second were a lot smaller in the past. This is a change from the *current* Robertson and Walker (R&W) Solution to Einstein's theory of General Relativity. Einstein's theory provides the basic formulas (field equations) to solve the strength of the gravitational field under specific circumstances. R&W have solved these formulas for the Universe. In the current R&W Solution, only space (not time) *as coordinate* is scaled with the scale-factor a(t). A scale-factor a(t) means that everything is smaller by a factor that depends on time 't'. For example, at the SLS a(t) is about 0.001, or 1 / 1093 to be exact, see also box 1. Do not confuse the scale-factor a(t) with the normal symbol for acceleration 'a'.

In contrast to the *current* R&W solution, in *our* R&W solution, repaired for Noether's theorems, *both the units meter and second are scaled* by the scale-factor a(t) in order to ensure an invariant speed of light, while the coordinates remain the same: 'comoving coordinates'. We thus have to understand that a measurement by telescopes in today's meter and second does not represent the physics at that cosmic time. To understand the physics at that cosmic time (Einstein called that proper physics, physics based on measurements locally and immediately), we need to correct our observations on Earth by the scale-factor a(t). This scale-factor of the basic SI units (second, meter, kilogram, and Coulomb) depends on the 'redshift' of the light of the galaxy under observation. Let us first look at the measurement of redshift.

Redshift of the light of a galaxy

Light as observed on Earth coming from all the stars within any galaxy outside of our local group of galaxies, is redshifted. The visible white light coming from stars is seen as red or even as infrared on Earth. The whole spectrum is shifted from what we know that the stars emit to what we measure on Earth. When the light received has the same spectrum as the spectrum of the sun, the redshift is zero, noted down as z = 0. Redshift in relation to the sun is called the 'heliocentric' redshift. This is what satellites like the Hubble Space Telescope (HST) can accurately measure. This redshift is the measurement of the shift in the absorption lines of hydrogen, helium, and some other elements.

In figure 3 you see the visible spectrum of the sun in the middle, with strongly exaggerated absorption lines to get the picture. You see the absorption lines of the top spectrum have shifted substantially, about 15% or z = 0.15. All color frequencies are reduced by a factor of 1.15.

Why the factor z + 1 (1.15) and not just 'z' (0.15)? That is the difference between a shift and a factor of multiplication. This is just like a percentage increase of your salary and the factor you must use on a calculator to compute your new salary. For example, a 6% increase results in a factor of 1.06. Similarly, a redshift of 0.15 (= 15%) results in a factor of 1.15. Redshift is a percentage, cosmic inflation is a factor, see the paragraph 'Causes of redshift'. Redshift or blueshift (negative redshift) is a dimensionless (unitless would be a better description) property of a galaxy. Often, redshift is expressed as a speed, but that is only true in case speed is the *only* cause of redshift, it is not. Other cause of redshift are gravitation and cosmic inflation, see the paragraph 'Causes of redshift'. Let us first have a look at the redshift of a real galaxy: GN-z11.

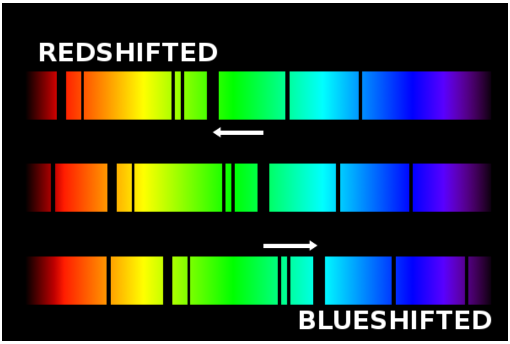

Figure 3: Redshift and blueshift of the light of galaxies

Redshift of the light of galaxy GN-z11

The spectrum of radiation from a star is not just the visible light, but the whole spectrum from radio waves to gamma rays, according to Planck's law. In other words, even invisible ultraviolet light can become white light as observed on Earth, Figure 4 shows the galaxy GN-z11 as observed by the Wide Field Camera number 3 (WFC3) of the HST measuring infrared light (the redshift of GN-z11 is 11.1, hence its name). You cannot see infrared light, therefore the *infrared* (IR) camera *displays* the low infrared light as red light, while the high IR is *displayed* as white light, which was ultraviolet closer to GN-z11. The factor at which the *observed* photons of the light have *seemingly* diminished in energy, is the factor redshift plus one (z + 1), for GN-z11 by 12.1. The previously mentioned scale-factor a(t) equals 1 / (z + 1), for GN-z11 that amounts to 0.0826.
In other words, we observe events on GN-z11 that *seem* to proceed 12.1 times faster than these events really happened at that time at that place according to *our* R&W Solution, repaired for Noether's theorems. This is what we call 'cosmic inflation': events like rotation and star formation *seemingly* proceeding faster than these really happened if you would be measuring time there and then (proper measurements in proper physics), see next paragraphs.

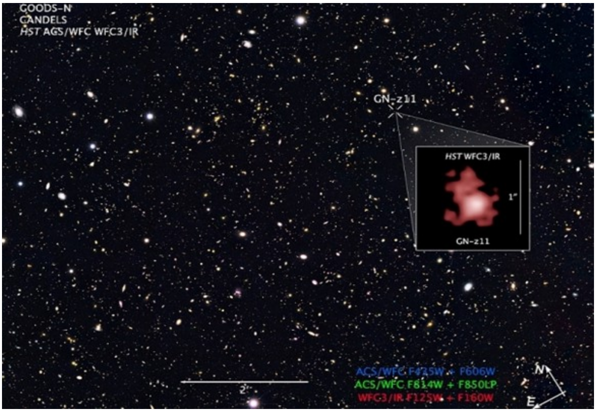

Figure 4: Observing the light from Galaxy GN-z11

Causes of redshift

There are so far three causes of redshift known in physics: speed (Doppler Effect), gravitation (general relativity), and cosmic inflation. Cosmic inflation is a relatively unknown cause of redshift. This was not known at the time when Hubble presented his law, more about that later. Cosmologists recognize an era called the (cosmic) 'inflation era' in which physics proceeded extremely fast. That era was very long ago and invisible to observers, since this era was even before the 'Surface of Last Scattering' (SLS), when the Universe became translucent. The redshift of the SLS is about 1092, thus we may assume that the inflation era had a much higher redshift, since Hubble discovered the relation between distance (and thus time) and redshift. The (cosmic) inflation era must have had an extremely high redshift if it would be visible, according to Hubble. The point is that physics proceeded extremely fast, and thus that the unit second must have been an extreme amount smaller than our current unit second 10^{50} (1 with 50 zeroes) times as small.
When building a model based on energy conservation, we have seen that the unit second was then the scale-factor smaller than the unit second is now. In our EMRW model, the cosmic inflation is not just limited to a specific era, but is *a property of the entire cosmic past* and amounts to redshift plus one. In this model, we observe events at galaxies outside of our local group to proceed redshift plus one faster than at galaxies within our local group. What we can observe is the speed of formation of stars. Consequently, since cosmic inflation is not just a specific era, we observe star formation to proceed redshift plus one faster at galaxies outside of our local group.

This is what NASA/ESA observed from ‘dwarf galaxies’ around redshift nine ($z \approx 9$): ‘The findings also show that these dwarf galaxies were producing stars at a furious rate, ***about ten times faster*** than is happening now in nearby galaxies’[2]. This is clear proof that cosmic inflation of $z + 1$ is not just an era, but spans the *entire* cosmic past. There are the two other causes of redshift: speed (Doppler Effect) and gravitation. The effect of gravitation on redshift of galaxies is so small, that we can ignore this effect. The effect of speed due to the Doppler Effect is mainly noticed within our local group of galaxies and is presented in the next paragraphs.

Original Hubble law and Dark Energy

In 1931, Hubble and Humason published the relation between speed and redshift *assuming* that speed was the *only* cause of redshift. That means that the original Hubble law *requires* dark energy. Let us explain. If a galaxy like GN-z11 would indeed speed away from us at 92% of the speed of light as the relativistic Doppler Effect predicts, it would be even farther away tomorrow, causing an even higher speed. The speed of GN-z11 would accelerate. Acceleration requires a force. That force is called ‘dark energy’ or the ‘cosmological constant’ as Einstein called his self-proclaimed ‘greatest blunder’. The *assumption* that redshift is only caused by speed has led to the theory of dark energy. We now know that due to cosmic inflation, distance is another cause of redshift. In other words, we do not need dark energy.

The current Hubble law is out of date

The final nail in the coffin of the original Hubble law is the observation of star formation at distant ‘dwarf galaxies’, see above paragraph ‘Causes of redshift’. If those galaxies would be speeding away from us, then star formation would be observed to proceed ten times *slower*. That is similar to a fast train passing you at a station. Suppose a high-speed train passes you at a station at 600 [km/h], which is half the speed of sound of 1200 [km/h]. To warn people at the station, the train driver uses the train horn of 6,000 [Hz] every second for 1/10th of a second. You hear that signal at the station as 12,000 [Hz] every half a second for 1/20th of a second as long as the train is approaching. When the train has gone by, you hear that same signal as just 3,000 [Hz] every two seconds for 1/5th of a second. *Receding objects are observed as being in slow-motion according to the (relativistic) Doppler Effect*.

The Hubble law based on the Doppler Effect, would result in the observation of star formation in *slow-motion of a factor ten*, while cosmic inflation predicts the opposite, *faster by a factor of ten*. This difference is substantial, a difference of a factor 100. So, cosmic inflation as cause of the redshift of distant galaxies is clearly better fitting the observations than the Hubble law, which outdates the current FLRW model, see next paragraph. Finally, the Yonsei university in South Korea concluded recently that dark energy is erroneous (5-1-2020) based on the observations of supernovae.

The current FLRW model is out of date

Note that the Hubble law is part of the current cosmological model, the FLRW model (Friedmann, Lemaître, Robertson, and Walker), also called the Lambda-CDM model (Lambda is dark energy and CDM is Cold Dark Matter). *Lemaître put the Hubble law in this model*. That takes Lemaître out of any model of the Universe. Friedmann computed the density of the Universe in the shape of a *normal* sphere. A normal sphere has a midpoint and an edge and thus does not abide by the cosmological principle and not by Noether’s theorems. That takes Friedmann out of the model of the Universe. Those two will be replaced by Einstein and Minkowski, while we hang on to Robertson and Walker. Finally, the current model is not supported by the observations of the number of galaxies over redshift (see paragraphs to come). The FLRW model is out of date. FLRW becomes EMRW.

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[2] www.nasa.gov/mission_pages/hubble/hst_young_galaxies_200604_prt.htm

Our Advanced Hubble law

Hubble and Humason could not possibly know in 1931 that their data of galaxy redshifts were influenced by *both* speed *and* distance. Our advanced Hubble law corrects their original data for the other cause of redshift: cosmic inflation. The exact formula is given in box 3.

The amazing fact arises that Hubble and Humason were (unwittingly) the first to see the effect of cosmic inflation on redshift ‘z’, see the second formula based on their data ($z \approx \dots$).

There are two terms in our advanced Hubble law, one for the non-relativistic Doppler Effect of local speed ‘v_0’ on redshift ‘z’: $z = v_0 / c$, and one for the cosmic inflation effect of distance ‘D’ on redshift ‘z’: $z = H.D / (c - H.D)$.

Box 3: Advanced Hubble law:

$z = v_0 / c + H.D / (c - H.D)$
$z \approx v_0 / c + H.D / c$ $\qquad D \ll c / H$

$c = 299{,}792$ [km/s] speed of light
$H \approx 70$ [km/s/Mpc] Hubble constant

For example: Andromeda is at a distance ‘D’ of 0.778 [Mpc] and is redshifted ‘z’ by –0,001. We can thus compute the approaching speed as:

$v_0 = -0{,}001 \times 299{,}792 - 70 \times 0.778$
$v_0 = -355$ [km/s]

In box 2 we also compute the speed at which galaxy Andromeda is approaching us (negative redshift, also called ‘blueshift’). This speed is higher than current estimates based on the assumption of speed as the *only* cause of redshift (current estimate: $v_0 = -301$ km/s). *Our advanced Hubble law offers an entirely new vision on the Universe*. For example, galaxy GN-z11 is not speeding away from us at nearly the speed of light, but is standing still or nearly standing still. This means that the search for dark energy is not ever going to be successful. Our EMRW model based on the *advanced* Hubble law does not require dark energy. Einstein’s contribution is the spherical Universe, a model of beauty!

Einstein’s first model

Einstein introduced the spherical model of the Universe in 1917. This model is called a 3-sphere, mathematically the *curved* three-dimensional (3D) ‘surface’ of a four-dimensional (4D) sphere. The beauty of this model is that it is the same at all locations and the same in all directions. In other words, it fulfills the ‘cosmological principle’ in space. The cosmological principle is a short version of the ‘perfect cosmological principle’, but applies to space only, not to time. A 3-sphere is in this respect better than a normal sphere; a normal sphere has a unique midpoint and an edge. Do not bother to imagine a 3-sphere, we as humans cannot imagine 4D. The best way of thinking of a 3-sphere is thinking of possible trajectories. In whatever direction you go, you end up back at the same place, moving in grand circles or ‘geodesics’ of many billions of light-years. It is like a normal (x,y,z) reference frame in which the positive x-axis ends up at the negative x-axis in a very large circle. The same applies to the y-axis and z-axis.

The key question here is: is the Universe infinitely large or not. If the Universe would be infinitely large, then we would see more and more galaxies the farther we look. (for the experts: a quadratic function of distance). If the Universe is a limited 3-sphere like Einstein argued, then we see more and more galaxies up to a certain distance, but see less and less galaxies beyond that point (for the experts: a sinus squared function). A galaxy count over distance can thus determine whether the Universe is a 3-sphere or whether the Universe is infinitely large. That is based on the assumption that within a homogenous model of the Universe the same amount of galaxies is found in the same volume. In other words, if we see more and more galaxies the farther we look (the higher the redshift ‘z’ and the further back in time), then the Universe is Euclidean (straight or flat) and infinite. If a peak in the number of galaxies is reached at a certain redshift, then the Universe is indeed a 3-sphere as Einstein first proposed.

Figure 5 shows a galaxy count of galaxies per square arcminute per 0.2 redshift 'z' as produced by the University of Amsterdam (UvA) in 2007. It clearly shows a peak in the number of galaxies (75 on average) around a redshift between 0.8 and 1.0.

The formula supplied by the UvA (N = …) peaks exactly at a redshift of one. This is a clear indication that *the Universe is more likely to be a 3-sphere than a Euclidean (straight or flat) and infinite space*.

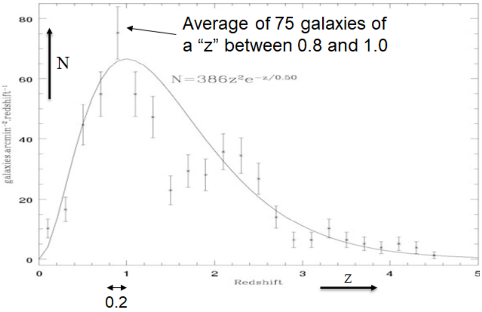

Figure 5: Distribution of galaxies over redshift

These counts are influenced by the fact that galaxies merge. If the Universe would be infinite, the count would even increase much more above a redshift of one. You can recognize four peaks in this picture; massive and about simultaneous mergers of galaxies over time would be a reasonable explanation of those peaks. Recently, evidence of a spherical Universe was presented in 'Nature Astronomy' volume 4 (2020).

Einstein was right, the Universe is spherical

Remains the question why Einstein abandoned his beautiful model. He abandoned his model because he suddenly realized that speed by itself could take the role of his cosmological constant (now called dark energy). This is like shooting a bullet into the air. If that bullet has enough speed when shot, then it will never come back. That speed at which it escapes the gravitation of the Earth is called the 'escape speed'. That speed amounts to 11,190 [m/s]. Over distance and time, the speed of that bullet gets lower and lower, with decreasing deceleration caused by gravitation, but never gets down to zero. Similarly, the expansion speed of the Universe of the EMRW model in constant units of the year 2000, decreases with decreasing deceleration over time as well, but also never stops. To understand that, we firstly have to take a look at *space-time*, as Minkowski urged us to do.

Hermann Minkowski was Einstein's teacher in mathematics, who called Einstein a lazy student, but was also one of the first professors to support Einstein's Relativity. In fact, his version of Einstein's theory of Special Relativity became the basis for Einstein's theory of General Relativity.

Minkowski and the entity of space-time

What is space-time? Can we define time such that it is mathematically perpendicular to the three axes of space? When we succeed in that, we have fulfilled Minkowski's dream. To make that happen we equated the 4D radius of the 3-sphere to the speed of light 'c' times time 't' and divided the outcome by pi, see the Appendix. Then we have reshaped Einstein's 3-sphere into a true space-time model because *local time is then perpendicular to the three local axes of space*, making local space-time a Euclidean 4D subsection (t,x,y,z) of a spherical Universe. In our book 'Repairing Robertson-Walker's Solution', the mathematical proof is given. Now you may understand the figures 1 and 2 at the beginning, these figures are based on the constant units meter and second of the year 2000.

Expansion of the Universe

Remains the question as to how exactly the Universe as 3-sphere space-time expands. As stated before, in comoving coordinates the Universe does not expand. Since the units second and meter get larger over time, the expansion speed from *measurement* point of view, in constant units [m_{2000}] and [s_{2000}] gets slower and slower. Therefore, by deduction in the very distant cosmic past (before the SLS), the expansion of the Universe *seems* to have been very high at very high deduced redshifts.

Cosmologists call this the 'inflation era', but in the EMRW model it is a deduced (and observed at redshift nine) accelerating redshift into the past. *Cosmic inflation is not a deduced era in the unobservable cosmic past, but a partially observed property of the entire past.*
You could also say that the clock ticks slower and slower over time, but never stops. Since everything is relative to the clock, this slowing down is not noticed by anyone. We cannot see in the future; it is only noticed when we observe events from the past, cosmic inflation.

Dark matter is replaced by universal curvature and cosmic inflation

There is no need for dark matter in the EMRW model either. Dark matter is often quoted as an explanation of fast orbits of the outer stars around a large galaxy, like our Milky Way. Compare it with high speed cyclists needing a curved stadium to stay on track. The three-dimensional curvature of our Universe *requires* the outer stars to orbit faster. The outer stars of galaxies are the ones that undergo the universal curvature. There is no need to explain these orbits by dark matter.
The fast development of the Universe before the SLS as observed on Earth as the CBR, is also given as a proof of dark matter. How could the Universe have developed that fast shortly before the SLS? We know the answer now: cosmic inflation. Cosmic inflation went from infinity at the Hubble Horizon to 1093 at the SLS. There is no place for dark matter in cosmology.

Properties of the EMRW model

Our EMRW model is beautiful in its mathematics and physics. It adheres to Noether's theorems and to the perfect cosmological principle. It has invariant constants of nature. It has a clearly defined energy, volume, and density, see the Appendix. It is based on our advanced Hubble law, which fits the original dataset of Hubble and Humason. It explains very many of the astronomical and cosmological observations (galaxy distribution, fast star formation, fast orbits of outer stars in galaxies, the Pioneer 10&11 anomaly, and more). The only thing we still need is a better estimate of the Hubble constant. In this document we have used the value of 70, resulting in a Hubble Horizon of 14 billion (light)years. There are also many articles on this topic on www.loop-doctor.nl.

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Appendix: formulas in SI units

Constants and variables used

c	speed of light	$= 299{,}792{,}458$	[m/s]	defined and exact value in vacuum
G	Newton constant	$= 6.67384 \times 10^{-11}$	$[m^3/s^2/kg]$	also called 'Gravitational constant'
H	Hubble constant	$= 2.27 \times 10^{-18}$	[Hz]	$H = 70$ [km/s/Mpc]
v_0	local speed		[m/s]	peculiar (local) speed
z	redshift		[ ]	heliocentric, has no units
D	distance		[m]	Distance to galaxies
t	time		[s]	universal time without speed or gravitation
ω	fourth coordinate		[m]	(x,y,z,ω) is a location on a 3-sphere

Advanced Hubble law

$z = v_0 / c + H.D / (c - H.D)$	[ ]	*Advanced* Hubble law
$D\% = z / (z + 1)$	[%]	Distance% of Hubble Horizon ($v_0 = 0$)

Einstein's 3-sphere model

$x^2 + y^2 + z^2 + \omega^2 = R_4^2$	$[m^2]$	Einstein's 3-sphere model of the Universe

EMRW model in constant units of the year 2000 (figure 1 and 2)

$x^2 + y^2 + z^2 + \omega^2 = r_4^2$	$[m_{2000}^2]$	EMRW 3-sphere space-time model
$r_4 = c.t / \pi$	$[m_{2000}]$	radius in $[m_{2000}]$ and time 't' in $[s_{2000}]$

Values in comoving coordinates

$D_H = c / H$	$= 1.32 \times 10^{26}$	[m]	comoving Hubble Horizon
$t_H = 1 / H$	$= 4.41 \times 10^{17}$	[s]	comoving Hubble Horizon
$R_4 = c / \pi.H$	$= 4.21 \times 10^{25}$	[m]	comoving radius of the Universe
$E = c^5 / G.H$	$= 1.60 \times 10^{70}$	[J]	comoving total energy of the Universe
$M = c^3 / G.H$	$= 1.78 \times 10^{53}$	[kg]	comoving total mass of the Universe
$V = 2c^3 / \pi.H^3$	$= 1.47 \times 10^{78}$	$[m^3]$	comoving total volume of the Universe
$\rho = \pi.H^2 / 2G$	$= 1.21 \times 10^{-25}$	$[kg/m^3]$	comoving average density of the Universe

Repaired R&W Solution

$a(t) = 1 / (z + 1)$	[ ]	scale-factor applied to basic units (s, m, kg, C)
$[s] = a(t).[s_{2000}]$		cosmic inflation for the unit second
$z + 1$		cosmic inflation of the EMRW model