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Time dilation and the Big Bang

If you want to go to the simple point of this note, search down to the sentence marked by stars (*). It is on about page four. The first three pages are for people who don't know much physics.

A

I do not explain "time dilation" and "space shortening" much here. If you don't know what time dilation is, please see note on "Time dilation waves mass" or similar title. If you don't know what "space shortening" is, I have to refer you to a book on Special Relativity. Briefly, the faster an object moves in relation to us, the shorter it appears in the direction that it moves. Its dimensions do not change in other directions at right angles (orthogonal) to the direction that it moves. As a result of its shortening in the direction that it moves, its shape appears distorted to us compared to its shape at rest. That sounds a little weird, but it is true, and well verified by experiment. The technical term for space shortening is "contraction".

"Time dilation" is the slowing down of the time on another object (or in another region of space) compared to our time. If time dilation happened to a clock: when an hour of our time went by, only 40 minutes might go by on the clock; if an hour went by on the clock, an hour-and-twenty minutes might go by for us. "Un-dilation" (my term) is speeding up of time, usually to match our rate of time at rest. Time can never go faster than when an object is at rest (with respect to us). We always reckon as if we are at rest relative to our selves. "Time at rest" is "proper time". "Length at rest" is "proper length". Time dilation happens both when an object is moving fast and when it is in strong gravity (a strong gravity field). The faster the moving, or the stronger the gravity (greater field curvature), the more is the dilation.

(Space effects due to Relativity also happen in a gravity field but are harder to explain. Briefly, objects look shrunk compared to the same objects when they are not in the field. How they shrink depends on how strong the field is in which direction.)

There is a modest difference between space-time effects due to movement from space-time effects due to gravity. (To insist on a difference is heresy in physics, so I don't insist. Still, it is useful to think of the apparent differences.) Movement always occurs in a particular direction. Time dilation due to movement is the same regardless of direction of movement but space changes are not the same in all directions. The object appears to get shorter in the direction of travel but only in that direction. The dimensions of the object stay the same in the other two directions. Both "contraction" in the direction of travel and time "dilation" increase (the object gets shorter and time moves slower) as speed increases. In contrast, in a gravity field, unless the field is unusual, the field extends in all directions. It is not quite equally as strong in all directions but it is almost equally as strong. In a gravity field, shortening varies a little by direction while time dilation is about the same in all directions. Briefly, space shortening and time dilation both get stronger, that is, objects shrink more, and time slows down more, closer to the center.

The important ideas: (1) Time slows down in a gravity field. (2) Time slows down more the stronger the field is. Bigger (more massive) objects make time slow down more than smaller objects. (3) Time slows down pretty much throughout the field, not too much more in any particular direction.

In theory, in a black hole, time stops. Time does not stop at the “event horizon” a certain distance away from the center, the line where light no longer escapes the black hole but instead spirals down toward the center of the black hole. Time stops somewhere closer to the center than the event horizon. I am not sure exactly where time stops, for reasons that I don’t go into here. Time should stop completely at the center. It is doubtful that time does really stop in a black hole except maybe at the center, but nobody knows for sure what happens where in a black hole, so I leave it at the basic ideas that time slows down in the presence of mass, it slows down more when the mass is greater, and the amount of slowing down is not too sensitive to the direction.

B

If we can discount the effects of space shortening in particular directions, then what are the effects of time dilation?

The fundamental forces of natural are: electricity and magnetism, combined into (1) electromagnetism, (2) weak nuclear force, (3) strong nuclear force, and (4) gravity. There are four or five forces depending on how you count. Most physicists count four forces, taking electromagnetism as one force. The forces differ in strength. Gravity is much weaker than the others. Their strength varies a bit under conditions, but the only conditions that I worry about here are those I specify. Electromagnetism and gravity, in theory, have no limit on their scope, the range over which they exert their force. Over enough time, the Earth’s gravity and magnetic field would attract pieces of iron across the universe. The weak force and strong force usually are much more limited to about the size of an atomic nucleus. In theory, the electromagnetic force and weak force combine at high energy levels into one electroweak force. The evidence for this effect is good. In theory, the electroweak and strong forces combine at even higher energy levels to one electronuclear force. Evidence suggests this effect is true but the evidence is not conclusive. Physicists describe the first three forces in terms of messenger particle-waves that move between recipient and donor particles-waves. For example, electromagnetic waves (light) move between electrons and protons, to produce electric and magnetic effects. Nobody yet knows how to describe gravity in the same terms as the other forces, or how to combine gravity with the other forces. Gravity is described in terms of a field going through space with difference strength and direction at different points. Although quite weak, on the whole, over the universe, gravity is the most influential force.

When particles move quickly, time slows down for them, and they seem to live longer (to an observer who is at rest compared to the particles). In particular, messenger particles from the three non-gravity basic forces live longer. Because the scope of a force depends on the lifetime of its messenger particles, the scope of a force increases under time dilation. Under a strong gravity field, particles change in other ways too that can confound what I say here about the effects of time dilation under gravity, but I ignore the complications. In general, I think the effects of longer life for particles and greater scope for the forces win out overall. In a strong gravity field with time dilation, the three non-gravity forces all come closer to equal strength and scope. In a strong enough field, they might unite. That still does not say what is the relation between the three forces (electromagnetic, weak, strong) and gravity.

Light is sometimes a wave and sometimes a particle. It always has the characteristics of both. In fact, all small particles are both waves and particles, and have the characteristics of both. Electrons and protons are both particles and waves. To fully understand light or small particles, we always have to consider both aspects. Waves have energy, some mass, frequency, and wavelength.

Under gravity, as time slows, wavelength increases and frequency decreases. Physicists say light is "red-shifted" because red light has the longest wavelength and slowest frequency of visible light; objects look redder in strong gravity than when they are away from gravity. Under strong gravity, light, the messenger wave-particle for electromagnetism, increases its wavelength and decreases its frequency. As waves, other messenger wave-particles for the other forces, are "red-shifted" as well. The stronger the gravity field, the stronger is the slowing down of time, and so the stronger is the increase in wavelength and the decrease in frequency, or the stronger is the red shift.

In general, waves and wave-particles that have more energy also have shorter wave length and higher frequency. Waves and particles that have less energy have a longer wave length and lower frequency. The exact relation is important in quantum mechanics but the details don't matter here.

The "red-shifting" of light and particles under great gravity implies that they have less energy, longer wave length, and lower frequency. Yet strong gravity also implies that a lot of energy-mass is concentrated in a small area. That, in turn, implies that wave-particles there might have high energy, and so would have shorter wavelengths and higher frequencies. They are "blue-shifted". I am not sure how these apparently opposing tendencies work out. It seems that light and particles that leave a strong gravity field are more red-shifted than blue-shifted. I am not sure about waves and particles that stay resident.

The following point does not follow standard physics: As I said in another note, eventually additional "doses" of energy don't have as much effect on wave length and frequency. After enough energy, wave length does not shorten as fast under more energy as it did at lower energy levels. This effect is like "diminishing returns" in economics. There might be a limit as too how short a wave might get and how fast it might get. When a wave is short enough, additional energy can't be added to the wave directly, but additional energy could be added by making similar other waves (quanta). I have not worked out this effect. It might be important for other effects that I discuss below.

C

Before going on, I have to make sure of three points.

(1) First, in another note about time dilation, I described how fast-moving objects experience time slowly and age slowly compared to stationary observers. In particular, I used the case of muons that are produced when "cosmic rays" strike the upper atmosphere and then muons come speeding down to the surface of the Earth. Here on the surface, we see muons as feeling time slower because we are not moving along with them. Yet if we moved along with some muons, we would experience time as they do, and we would not think time was moving slowly. Time would go normally. When a muon moves relative to us, it seems to have a long life compared to when it does not move relative to us. When comparatively at rest along with us near the face of the Earth, a muon decays quickly into other stuff. When moving

quickly, the muon takes a longer time to decay into other particles-and-energy. If somehow we moved along with the muon, it would appear to have the same life as if we were both at rest.

Physicists say, to see time dilation, we have to be outside the system that is moving. If we are part of the system that is moving, then we do not feel time dilation. What it means to be part of a system or not part raises interesting philosophical questions about subject and object, but those are not important here.

Point one is like the idea we get sometime as children: If everything in the universe doubled in size, or got half as small, including the distances between everything, and including all the rulers, then how would we know? We wouldn't know. We would need something that didn't double or get half the size. We would need an absolute standard outside of everything else. In physics, we don't have that. If all time goes half as fast for everybody and everything, then it would seem to everybody that time was going at exactly the same rate as it ever did.

(2) Second, going on from point one, we can always change frames of reference, and make calculations from a different frame of reference. If two people glide toward each other, both moving at rate X, person A can say he (person A) is standing still while person B is moving toward him (A) at rate 2X, or person B can say he (person B) is standing still while person A is moving toward him (B) at rate 2X, or either one can say they are both moving toward each other at rate X. Most fast-moving muons are created by "cosmic rays" when the rays first hit the Earth's atmosphere, fairly high up. A muon coming to Earth from the sky can insist it is standing still, and, really, the Earth moves up toward it at a fast rate. In both cases – the Earth is still while the muon moves, or the muon is still while the Earth moves - the end results are the same. In that case, for the muon, time on Earth would move more slowly but time for the muon would move normally. This conclusion is counter-intuitive, and I don't explain it thoroughly here.

Try this: From the point of view of the muon, the whole Earth is going in slow motion. It takes a long time for a bird to fly from tree to tree or for a person to walk out to check the mail. Therefore the muon can move a long distance before its life is over, before it decays into other particles and energy. The muon sees time on Earth as dilated while Earthlings see muon time as dilated. But the end result is the same: the muon gets a lot done (travels far) during the time that Earthlings get little done. The muon sees this as time dilation for Earth while Earthlings see this as time dilation for the muon.

(3) Third, time dilation (and space shortening) is not "linear". Time dilation can occur when an object moves quickly or under strong gravity. Time dilation is not directly proportional to speed or to strength of gravity. It is NOT the case that, the faster you go, or the stronger the gravity, the more time slows down, in direct one-to-one proportion to speed or gravity. Instead, time dilation is like what mathematicians call "hyperbolic". It is like what happens when people drink alcohol. At first, when you drink, you don't get very drunk. Then as you drink more, it all "catches up to you", and you get really drunk really fast. Then, if you continue to drink, you don't get too much drunker but you do get really sick. This point is hard to show without equations but is important, so bear with me. The equations that describe time dilation due to speed are called the "Lorentz Transformations".

Suppose we increase the speed of an object by 1000 kilometers per second. As a result, time slows for the object by Y amount. Then we increase speed by 1000 kilometers per second again. Time does not slow down by another Y amount, in direct proportion to the increase in speed. How much more time slows down depends on details that I don't have to go into here. Suppose we take an object at rest and increase the mass by 1000 kilograms. Time slows down by Y amount due to the 1000 kilograms mass increase. Then we increase the mass by 1000 kilograms again. Time does not slow down by another Y amount in direct proportion to the increase in mass. How much more time slows down depends on details that I don't have to go into here.

In the same way as when a person drinks booze, (1) at first, at slow speeds or in weak gravity, there is almost no time dilation. Time goes as fast as ever. (2) As speed increases, or as gravity gets stronger, time does slows down more but not much more. (3) Then, as speed gets fast, or as gravity gets strong, time slows down a lot. It slows down at least in direct proportion to the increase in gravity. It "catches up" to the fast speed or the strong gravity. (4) Then, as gravity gets even stronger, time does slow down more but not nearly as much more. Increases in gravity or speed show only "diminishing returns" in their effect on the rate of time. (5) Eventually time goes steadily at a crawl in a very strong gravity field or at high speeds. If gravity gets even stronger, and gets tremendously strong, time does slow down a little bit more but not very much more.

D

Matter and energy are not completely distinct. During the first moments of the Big Bang, it does not make as much sense to speak of distinctions between matter and energy as it does now. It makes more sense to speak of matter-energy, and, mostly, I will do that.

We live about 14 plus billion years after the Big Bang. Matter now is, on average, far apart; and gravity field(s) between matter are, on average, weak. So we experience almost no time dilatation due to gravity fields.

Now play the Big Bang in reverse. Matter gets closer together, gravity field(s) between matter get stronger, and gravity field(s) between matter get more uniform in all directions around all matter. When matter-energy gets close enough together, dense enough, then gravity gets strong enough so that time dilation matters. The time dilation will be everywhere, and it will be about the same in all directions. The closer and denser matter-energy gets, the more important time dilation gets too. At some point, much before we get back to the Big Bang, time dilation is really extreme.

This situation is like the conditions that prevail in a black hole. Other than that simple statement, I do not compare the Big Bang to a black hole much because I don't know enough to make comparisons. There are many black holes in the universe. There is much more than enough matter-energy in the universe to make a black hole or many black holes. Therefore the density of matter-energy at the Big Bang was not like any currently known single black hole. So conditions during the Big Bang are unlikely to be exactly like any currently known black hole, although conditions during the Big Bang likely are more similar to those in a black hole than conditions that prevail in such "ordinary" space as our solar system.

If time stands still at the center of a black hole, then it seems as if time also would have stood still during the Big Bang. Either time and the Big Bang originated together, and-or we don't know enough about how time works under conditions of extreme matter-energy density.

Probably some kind of time dilation is necessary to unify the four major forces of the universe. Likely, the four major forces were unified right after the Big Bang. So, likely, time was considerably dilated right after the Big Bang, and for a while after.

***Here is the major point of this note:

If time dilated a lot during the early moments of the Big Bang, then how are we to understand time during the early moments of the Big Bang? When a physicist says that a billionth of a second elapsed soon after the Big Bang, and such-and-such events occurred during that billionth of a second, are we to think about that billionth of a second and its events in terms of un-dilated time that we experience now or in terms of dilated time we would expect to see under extreme matter-energy density? What differences does it make if we think about one way or the other?

The easy answer is that we can think about time as dilated time moving much more slowly than time now. That billionth of a second might well have been like a million years now.

That easy answer might or might not hold up. It would more likely hold up if we were not part of the Big Bang too. We can't look at the Big Bang from outside in, as a physicist does when she measures the life spans of a resting muon versus a moving muon. The physicist is a muon too, either resting or moving. We are part of the Big Bang too. Even if time did slow down according to an observer outside the Big Bang, it would not slow down for all of us inside the Big Bang. Because everything slowed down, we would still see (measure) time as going just as fast or as slow as it ever did. It is not clear to me what this means for our guessing back to conditions of extreme matter-energy density when we would expect time dilation.

On the other hand, there really was extreme matter-energy density and so there likely was time dilation by some standards. I am not sure whose standards. At least we can think hypothetically as if we were outside the Big Bang looking in. Thinking about it in this way makes sense of the high energy then and of the unification of the four forces then. Not thinking about it in this way makes also it a lot harder to think in terms of high energy and the unification of the four forces.

Suppose we think of the billionth of a second as really taking one million years. (What follows is not accurate in detail but is useful for illustrating ideas.) Suppose we start the Big Bang with a million muons. In a billionth of a second with no time dilation, we might expect one-tenth of the muons to decay. In a million years, we would expect all of them to decay. So which is it? Likely for us, living inside the Big Bang, one-tenth of the muons would decay, but I am not sure. Suppose we start the Big Bang with one kilogram of radium. Radium is strongly radioactive, which means that radium tends to fall apart (decay) into other elements a bit at a time over steady periods of time. In a billionth of a second, without time dilation, we might expect one percent of the radium to decay away. In a million years, we might expect 90 percent of it to decay. So which is it? Likely, for us, inside the Big Bang, one percent of the radium decays. I honestly don't know. I would like opinions either way.

Maybe our intellect allows us to think of the Big Bang and conditions right after the Big Bang as if we were outside looking in, as if we were not part of it, and that is enough for what we need.

E

What differences does it make if there was time dilation or no time dilation?

I have already mentioned the unification of the four forces and the high energy needed to unify the four forces.

Recall that time dilation is not linear. Here we have to think about the non-linearity in reverse because we start with high concentrations of matter-energy (high gravity uniformly everywhere) and then go to much lower concentrations of matter-energy (low average gravity).

Right after the Big Bang, the universe would be in a situation where time was highly dilated (time would be going very slowly). As the universe expanded at first, the universe would not expand too much too quickly (remember, time is running slowly), and matter-energy would still be highly concentrated. With some modest expansion, time might un-dilate (speed up) a little bit, but not much. Then, as the universe expanded more and matter-energy got less concentrated, time would un-dilate (speed up) much faster. As time sped up, everything would speed up too, including the expansion of the universe. The speeding up of time and the expansion of the universe would somewhat "feed on each other". For a short while, we would have a big burst of expansion and of time un-dilating (speeding up). Then, after the universe had expanded a lot and time had sped up a lot (un-dilated a lot), the universe would slow down its expansion a lot and time would slow down its speeding up a lot. Time would continue to un-dilate (speed up) but not nearly as quickly as before. Time would settle in to the consistent rate that we find throughout most of the universe except for some local pockets of high gravity or fast speed.

In fact, something like this is likely exactly what did happen in the history of the universe. Right after the Big Bang, for a few seconds, the universe went along modestly expanding for a while, then expanded very quickly for a short burst of a few seconds, and then settled in to slower steadier expansion for billions of years. The quick brief expansion is called the "Inflation" or "the Inflationary Universe". The man who got the idea, Alan Guth, wrote a good fun accessible book about it. The non-linearity of time dilation might not be needed to explain rapid inflation of the universe at one brief stage in its early history but the non-linearity of time dilation does go along with that sequence of events.

Since about 1995, evidence has mounted that the universe did this: For a while, after the "Inflation", the universe slowed down its expansion. But then the universe did not continue in a slow steady expansion as we might expect. Instead, after the slowing down of expansion after the Inflation, expansion seems to have gone ever faster. The universe is expanding faster now than it did right after the Inflation. The increase in expansion has not led to anything like another Inflation but still has led to faster expansion than cosmologists had anticipated. The universe is expanding faster now than it was expanding, say, about 10 billion years ago. So we have something like this: (A) slow expansion for a few seconds after the Big Bang; (B) huge inflation for a brief period of a few split seconds; (C) continued expansion but at a much slower rate than during the Inflation; and (D) continued increase in the speed of expansion from about 14 billion years ago right through now. It is not clear what will happen in the future.

I can't go into the evidence here for the increase in the rate of expansion in the last 10 or so billion years, but I am not sure I agree. It might be a good idea to evaluate the evidence considering the possibility that time was going slower 14 billion years ago than it is going now and that the rate of time has not been steady over the history of the universe. Instead the rate of time consistently changed with conditions until the rate of time settled into the rate we have now a few billion years ago. We need to consider the effects of matter-energy concentration at different phases in the expansion of the universe on the overall rate of time during those phases. The increase in the rate of expansion in the last 10 billion years or so might be an illusion or an artifact of changes in the rate of time. Of course, likely I am wrong.

Other than this, I am not sure what difference time dilation under high general gravity makes, what changes in time rate with changes in matter-energy concentration makes, or what difference reaching time “normalcy” (speeding up to a general consistent rate) makes. I have a few other odd speculations about time and energy-matter but there is no point going into it here until I know more. I would be happy to get some remarks but please be kind.