2014 04 24

Mike Polioudakis

Time dilation under great mass-energy concentration, especially for waves

If you know some physics, and you want to get to the point of this note, jump to section "F". You can find it by searching for asterisks (**).

A

In the early days of proving Relativity, the behavior of muons entering the Earth's atmosphere was used as evidence of time slowing at high speeds (velocities). I forget if it was really muons or other particles, but that does not matter here. Muons do not live indefinitely like electrons. They have a lifetime. When a muon "dies" it decays into other particles and some energy. When a muon is produced on the surface of the Earth, and does not move very fast relative to us, it has a certain decay time (lifetime). Muons also are produced high in the atmosphere by collision of "cosmic rays" with particles there. When a muon from "on high" enters our atmosphere, it is travelling very fast. It takes much longer for fast moving muons to decay compared to relatively stationary muons. Moving muons have a longer lifetime than comparatively stationary muons. The increase in time is in line with predictions about time slowing down from Relativity. In effect, time slows down for moving muons and for anything else that moves. This effect is well-proven now.

B

In Relativity, time slowing is called "time dilation". In Relativity, time dilation also occurs under gravity. Time goes more slowly on the surface of the Earth where Earth's gravity is strong than it does far away where Earth's gravity is weak. Time goes more slowly where space-time is more curved compared to where space-time is less curved. I think this effect of gravity has been well verified. In the same way, time goes more slowly on the surface of the sun than the surface of the Earth because the sun's gravity is even stronger. I think this effect has been verified by comparing the vibration rate of atoms on the sun with the rate on Earth. Time goes even more slowly on the surface of a neutron star where matter is even denser than the sun. I am not sure if this effect has been verified by observation but I would not be surprised. Theoretically, in a black hole, time stops entirely, but, really, we don't know what happens. Of course, this effect of time stopping cannot be experimentally confirmed or denied because we can't see inside a black hole and we can't get any signals from inside a black hole.

The formulas for changes in space and time due to speed are the "Lorentz Transformations." Similar formulas work for changes in space and time due to gravity, part of the "Einstein Equations". Slowdown in time due to speed or gravity is not linear. There is not a direct one-to-one relation between speed and rate of time or between mass and rate of time. If you increase speed by X kilometers per second to get Y slowing down of time, and then increase speed by X kilometers again, to increase speed by 2X, you do not get exactly twice (2Y) the slowdown in time. If you increase mass by X kilograms to get Y slowing down of time, then increase by X kilograms again, to get mass increase of 2X, to you do not get exactly twice the slowdown in time (2Y). The details of the non-linear relation are not important here, only that it is non-linear.

C

The real issue here for the effect of mass on time is not total mass but what total mass is concentrated into what volume. Time dilation depends on curvature of the nearby space-time field, and that curvature depends on the amount of mass that is concentrated into a particular volume. Our Milky Way galaxy has much more total mass than the sun, but most pieces of the galaxy are far away from each other, and so the mass of the galaxy does not curve space even as much as space is curved around the Earth. An atom floating between the stars but still inside the galaxy vibrates at about the same rate as the atom would in deep space, between galaxies, away from almost everything.

When we think about mass concentration, we think about mass per unit of volume of space. Although our sun might have more total mass than a neutron star, time runs slower on the surface of the neutron star than the surface of our sun because mass is more concentrated in the neutron star. A “mini black hole” is a black hole that did not start out as a huge star. A mini black hole has less mass than a typical black hole that was made from a collapsing big star. But a mini black hole is still a black hole because its mass is concentrated in a very small space. Stephen Hawking made mini black holes famous with his ideas of how matter-energy “leaks” out of them. Time runs slower near a mini black hole than around a neutron star or around our sun because mass is more concentrated around a mini black hole. As with other black holes, it is not clear what time actually does inside the mini black hole (more exactly: inside the “event horizon” of any black hole).

D

Here is a point I do not entirely understand.

Space does not have an absolute volume. The volume of a region of space might depend on how we move relative to it and to the objects in it. If the volume depends on how we move relative to a region, then the concentration of matter also depends on how fast we move relative to that region of space and relative to the objects in that region. If we see that region of space (more likely, the objects in that region) as moving relative to us, then the concentration is higher than if we were not moving relative to each other. The concentration is higher because of shortening of (the objects in) that region in the direction of movement. (This shortening is another Relativistic effect. I do not explain the effect here. The degree of shortening is not linear, but follows the Lorentz rules.)

So the difference in gravity and time dilation also depends somewhat on any differences in movement between that region of space (its objects) and us. This effect is not much of a problem.

If the concentration depends on relative speed (velocity), then it seems as if the threshold to become a black hole also depends on relative speed. This is a bit of a problem. It seems, to me, that a piece of matter-energy-space-time either is a black hole or it is not. Suppose we are at rest and see a place as a very high concentration of matter but not as a black hole. A moving (to us) observer might see the place as a black hole while we would not. We might see a moving concentration of mass as a black hole while somebody moving next to the mass, along with the mass, and so stationary relative to the mass, would not. Of course, if the mass concentration was a black hole to somebody not moving relative to the mass (but far enough from it so as not to be sucked into it) then the mass concentration would be a black hole also to anybody else because the mass would be least dense to anybody moving relative to the mass.

Comments welcome.

E

Like a mini black hole, but not exactly like a mini black hole, are there any other concentrations of mass-energy in a small region of space, so concentrated that they might show time dilation effects? Again, I am not sure about this point.

One concentration of energy-mass is waves, another is particles. Is the matter-energy in particles or waves so concentrated that the space around it shows time dilation? Waves are more interesting to me. For that, see below.

One concentration that might show time dilation might be "point" particles or "point like" particles. These particles include all the particles that we now consider basic: leptons (electrons) and quarks. The status of quarks as basic is still not completely decided, but, regardless of that, they do act like point particles. ANY amount of mass, if it is really concentrated into a point, is enough to produce time dilation. In fact, ANY amount of mass, if it is really concentrated into a point, is enough to make a mini black hole. I don't mind thinking of our basic particles as mini black holes, but I don't know what to make of this situation enough to be able to describe it. The biggest problem is how these supposed mini black holes interact with other stuff. Ideally, as mini black holes, there is no interaction in the normal sense. There is no bouncing off of, and no absorption and then re-emitting. As mini black holes, they simply absorb all other stuff that comes close enough, and thereby turn into larger black holes. Cleary that does not happen with electrons and quarks. Also, time should slow down a lot, or even stop, around point-like particles with mass, and that doesn't seem to happen either. There are other problems with thinking of particles as apparently point-like, such as what it means to say they "spin". So it is unlikely they are simple points in the way that we think of geometric points. Thus is born string theory ("M" theory) as a way not to have any points. I don't go into these issues any more here.

It is possible to imagine enough energy concentrated into a particle to produce a mini black hole out of the particle (I have seen the figures but I don't recall them here). It is a lot of energy in a small space. I think the space is hardly bigger than the Planck space. As far as I recall, not only is this result never seen, but it is theoretically highly unlikely as well. So I leave it alone.

Of course, in QM, even point-like particles have a wave function, and the wave is definitely not point-like. As long as the wave is attendant to a particle, it is even hard to make the wave small enough as noted just above. That is another way out. I don't go into this topic more here either other than to let it carry me over into the question of waves and time dilation.

F (****)

A physicist will think the following material is wacky, but I really don't understand, and need guidance.

For this material, it helps to think of these questions:

-Is there a limit on the frequency of a light wave or of the waves of the other forces?

-Is there a limit on how small a wave length can get?

-Is there a limit on how much energy can be packed into a wave?

-Planck's constant helps us to understand the distribution of energy at different wave lengths. It shows how we avoid the "ultraviolet catastrophe" of too much energy in the high end of the spectrum of short wave length and fast frequency. But, as far as I can tell, it does not rule out entirely some very short waves with high period and high energy. Yet I think we don't see waves with ultra high period, short length, and energy. Thus I ask the questions about limits. Why?

At quantum scales, the length of a wave and its frequency depend on the energy in the wave. If we think of a particle as a wave, the associated wave length and frequency depend on the intrinsic mass of a particle (if any) and on the energy of the particle, both kinetic and potential. The same is true in reverse. The shorter the wave length and the higher the frequency, the more energy is in the wave, of both waves and particles-when-they-act-like waves. All this is standard QM stuff.

For what follows, it is important to keep in mind the equivalence of mass and energy, and I do not always distinguish them. It is important to keep in mind that wave length and frequency are absolutely related. QM effects are usually described in terms of frequency, but, for what I am after, it is better to think in terms of wave length. I could do it either way but here I will more often use wave length without pointing out the relation between wave length and frequency. In fact, I think the ideas here point out issues in the absolute correspondence between wave length and frequency, and in our ideas of wave-particle duality, but I postpone those wild speculations.

Think of a wave, and think of the wave getting more and more energy, or, alternatively, of the wave length as getting shorter and shorter, or, more in line with the usual QM equations, as the frequency getting ever faster. As the wave length gets shorter, and the wave gets more energy, then the energy is concentrated into an ever smaller space.

As more mass-energy gets concentrated into an ever smaller space, the wave, and the area around the wave, should experience time dilation and space contraction.

As more mass-energy gets concentrated into an ever small space, and nothing happens to offset the process, eventually the wave will reach a threshold where it becomes like a mini black hole. I don't know how much mass-energy has to be concentrated into what size of space. I don't know what wave length implies a mini black hole. In theory, the calculations should be easy if you know the parameters. I think the equations are not too hard. But I don't know the parameters or the equations, and I don't know where to find them, so I don't do the calculations. If anybody wants to direct me to where to find the parameters and equations, I will be happy to do the calculations.

As far as I can tell, waves do not often become mini black holes even at high energies. That observation pushes the following ideas.

Well before the wave reaches the threshold to become a mini black hole, it should begin showing time dilation and space shortening around itself and in itself. A lot of energy-mass is concentrated into a small space, and that means time dilation and space shortening. What does that mean? I am not clear, largely because the effects of time dilation and space shortening might undo each other.

Although not clear, I focus on the effects of time dilation and ignore the effects of space shortening.

Time dilation means that the wave moves more slowly, which means that it decreases in frequency, and increases in wave length. The apparent decrease in frequency and increase in wave length might be just compensated by space shortening, but I am not sure. If they are, then it is possible that a wave could get enough concentrated energy-mass to turn into a mini black hole, and I don't like that alternative. In that case, we need a theory of mini black holes with wave lengths and frequencies that make physical sense, and I don't know of any such theory.

Back to wave length. As the wave length gets shorter and shorter, and energy-mass get more and more concentrated, the wave "bothers" itself (in plain English, the wave "interferes" with itself, but "interferes" is a reserved word with special meaning when talking about waves). The wave slows down, and the wave length does not get shorter and shorter. The wave length does not get shorter as much as we would expect from the simple input of energy according to the standard QM equations. At first, this effect would not be noticeable. As energy levels get high, the effect gets disproportionately stronger. The wave does get shorter but not as much shorter as we would expect. At high enough energies, the wave does not get any shorter despite the input of energy.

But the fact that the wave length does not get shorter, and the period (frequency) does not decrease, mean that the wave does not have the energy, or at least does not show the energy. Paradoxically, as the wave gets more energetic and massive it does not get more energetic and massive. The loss of apparent energy due to time dilation does not equal the gain in energy from more energy input until a lot of energy is input. The gain in energy input overcomes the apparent loss in energy from time dilation for a long range. I am not sure how the trade off works because I don't know the parameters and I have not put them into the correct equations, but it should not be too hard.

(What I am describing here might be the Relativistic modification of the Schrodinger wave equation by Paul A.M. Dirac, but I am not sure. I have seen the Dirac equations but I don't know enough to relate them to what I am saying here.

What I am describing here might be an alternative way to see quantification of action (energy), another way to get at Planck's constant (h). I am not sure, so I don't want to go into any details here.

What I am describing here might be another way to get at the distinction between a wave and wave packet. I am focusing on the wave inside the wave packet.)

Eventually as the wave gets more energetic, the effects of time dilation overcome the effects of more energy. This does not mean the wave length increases. It means the wave length stops getting smaller (or observably smaller) regardless of how much energy we put into the wave. There is a lower limit on the size of any wave, and the concentration of mass-energy of any wave. I don't know what this lower limit might be, but it should not be hard to calculate for somebody who knows the parameters and has the equations.

At this limit where more energy input does not result in a smaller wave length and increased frequency, do we have something like a mini black hole with a wave length (but, of course, not a real black hole)? I don't know but I doubt it. The idea is intriguing but I don't know what to make of it.

Suppose we are at something like this limit, and have put a lot of energy into the wave. Then something happens to the wave, and it "decides" to have a longer wave length and slower frequency. When it does that, it should release a lot of energy at once. I don't know what form this stored energy might take, but, I would guess, another wave. I don't know if this effect has been seen.

Even if space shortening somewhat counteracts the effects of time dilation, something is still going on here that I would like to have explained. Comments really are welcome.

In any case, there might be a limit on how short a wave can get, and how fast a wave can get. I am not sure what happens to the ability to put more energy into a wave as we reach this limit. I suspect this limit is reached when the wave length approaches the "Planck length". I am not sure what the associated energy would be. I am not sure what a wave is like as we approach, or get to, this limit. It is as if the wave turns into something more particle-like. The wave becomes "frozen energy". Then more energy has to be added to the "wave" in other ways, such as by accelerating the whole wave packet without changing the waves within the packet.

G

I mentioned in another note that I have always been bothered by the idea of an electromagnetic wave as long as we think of an EM wave as like a water wave or even like any other transverse wave. My unease focuses around the fact that an EM wave has no typical amplitude.

Suppose we don't think of an EM wave as too much like a wave from ordinary life but instead think of it as more like a "pulse" from ordinary life. A pulse has a quantity of energy but it doesn't necessarily have any amplitude. It has a time between pulsed but it does not necessarily have a wave length. Thinking of an EM wave in this way might help me deal with the questions raised above. I don't know of any systematic treatment of EM "waves" as pulses in this way.

H

For more on mass-energy concentration and time dilation, see other notes.