

The Black Hole War

Leonard Susskind

Comments will be given first and then questions about the more substantive aspects of the book.

On page 242 Susskind makes a strange statement when discussing mental pictures: "Mental pictures have more to do with limitations imposed by our evolutionary past than with the actual realities that we are trying to understand." He should have given references to the research behind this statement. Perhaps in the future he will write a book for the masses on it. It would be a fascinating read. Some think that evolution is happening here and now where a few common people are evolving into theoretical physicists who live between the real world and the paper that contains their scratchings.

Most modern physics books for the masses are going to pay homage to the great man of physics, Darwin. It is something one just has to expect. Penrose didn't pay proper respect to the man in *Shadows of the Mind*. He must have been reprimanded by his fellow physicists for being so remiss. Susskind goes beyond homage. He embarrassingly prostrates himself to Darwin with the like of: "...Darwin whose masterstroke ejected God from the science of life", "Darwin's idea of natural selection, combined with Watson and Crick's double helix replaced the magic of creation with the laws of probability and chemistry." In today's world it is held that evolution is based on probability and chemistry at the grade school level. Susskind did not even give physics a piece of the pie.

It appears that theoretical physicists are in the same bag as public school teachers and politicians. Darwinism was a first try at explaining evolution. It does not explain what its proponents claim it does - the origin

of life or the creation of new species. Darwinism was glommed onto by atheist of every mental degree because of its theological value. They will not give it up even if a better “idea” comes along. It has become a religion. People like Dawkins preach Darwinism because they are atheists. Susskind appears to be an atheist because of Darwinism. That ranks him in the league for the Darwin award. Susskind in his quote above is claiming that Darwinism is an “idea” that has removed God from creation. Our beliefs in creation in the scientific age are not based on someone’s “idea”, especially one that is 150 years old. Susskind can do his morning and evening prayers to Darwin. The more inquisitive will look for more sophisticated answers.

Just when one thinks Susskind is going to get back to crowing how he beat out Hawking he degrades back to his theology: “How is it possible that human beings have evolved so powerful an impulse to create irrational belief systems and hold on to them with such tenacity?” Will Mr. Susskind, tell us how you do it?

After writing about a talk he had with a Mormon who gave him a brief history of Mormon’s founding, Susskind wrote the following:

“I was fascinated, and still am, by this story. I believe that at the time, it affected my feelings – no doubt completely unfairly – about Stephen and his powerful charismatic influence over many physicists. Obsessed with my own frustration, I imagined him a pied piper leading a false crusade against Quantum Mechanics.”

Looking at the paragraph and the part set off by hyphens one gets a sense of a bully punching someone in the gut and then patting him on the

shoulder apologizing for doing so. A page later the bully comes back and says he did not mean to punch while gloating to himself how good it felt.

The point of the book is that Susskind is the equal of Stephen Hawking. Is that true? Certainly, it is not true in character.

What is all this doing in a book about black holes? This book is not ecologically green. It uses a lot of paper that could still be on a tree. The book could be much smaller and cover the title.

On page 285 of the paperback edition, Susskind tells of his admiration for Stephen putting him alongside Nelson Mandela and Moby Dick. Stephen is one of three of Susskind's set of three heroes. Stephen must be as proud of that as Moby Dick is. Susskind then goes on to bash Stephen. Susskind should have let his psychiatrist review the book, instead of Susskind psychoanalyzing Hawking.

On page 311: "No one knows for certain whether String Theory is the right theory of our world, and we may not be sure for many years." The statement should be stronger: No one knows if math and physics can produce a right theory of our world. An absolute fact is that no one will ever know. I don't know if anyone believes there are actually little strings vibrating. If string theory is consistent and explains physical phenomenon, at best it can be said that it mimics the real world.

Now for the subject of the book.

Equivalence Principle of General Relativity

The equivalence principle is usually presented as an analogy between an accelerating elevator and gravity. In an accelerating elevator the lines of force are parallel. Gravity is from point sources. The lines of force of gravity are rarely parallel, although they are most nearly parallel. Dropping two items, if dropping is the correct word, a foot apart in an accelerating elevator will result in them landing a foot apart on the floor. Dropping the same two items a foot apart in a gravitational field they will be less than a foot apart when they hit the ground. Since gravity is always attractive it is difficult to see how they could ever be further apart or the same distance apart when they hit the ground. Of course, the analogy is not for the behavior of two items being dropped but one item. Only one line of force is being considered in each situation – accelerating elevator or gravity. It would seem that what is not mentioned is that the elevator is one dimensional.

Rolled up dimensions

The visual explanation for rolled up dimensions is by now cliché. Two dimensions are pictured, one a straight line and the other a dimension rolled up around it. In magnified scale it resembles a pipe with the rolled up dimension going around it. The only problem with this is that the picture has to exist in three unrolled up (laid out) dimensional space and cannot be pictured in any kind of two laid out dimensional space. How many laid out dimensional space would three laid out and six rolled up dimensional space be in?

Theoretical physicists are like children with a set of tinker toy equations building universes, as a children with a real set of tinker toys would build a tinker toy house. The main difference is that children would never think that what they built was a real house.

Black Holes

Is it fair to ask if black holes exist? First one must ask where. In the math world they exist, although one who hikes only the lower hills of the math world must accept it on faith. Those who walk the high mountain tops of the math world can shout down to us what they see. What of the physical world? There does seem to be some problems for us who live in it.

One sees the word “singularity”. All the matter of the black hole has collapsed to a point of zero dimensions. Once gravity has overcome the nuclear force, there is nothing to stop the collapse. That is there is nothing in the mathematical models to stop it. There is no stronger force of shorter range than the nuclear force and none pop out of the models. That does not necessarily mean such a force does not exist. It certainly means it does not exist in man’s model of the universe. So a black hole is an extremely large mass in a pixel of space.

Is the black hole the pixel of space or everything within the Schwarzschild radius? The Schwarzschild radius is the distance from the singularity in which nothing can escape. It is derived from general relativity, which is too high up the hills of the math world for us common travelers to encounter. However, there is a classical derivation of the Schwarzschild radius, which gives the correct result. Unfortunately, that derivation does not seem to make sense.

The classical derivation of the Schwarzschild radius as found on the internet follows:

Consider a photon radiated from the singularity at the center of a black hole. The kinetic energy of the photon is given by

$$K = \frac{1}{2}mv^2 ,$$

where m is the equivalent mass of the photon, which has zero rest mass. The potential energy of the photon is related to its distance from the singularity, R , and is given by

$$P = G \frac{Mm}{R}$$

Type equation here.

where G is the gravitational constant, M is the mass of the black hole, and m is the mass equivalent of the photon. The kinetic energy must be great enough to overcome the potential energy for the photon to escape. Equating the two equations gives the demarcation at which escape can happen.

$$\begin{aligned} K &= P \\ \Rightarrow \frac{1}{2}mv^2 &= G \frac{Mm}{R} \\ \Rightarrow R &= \frac{2GM}{v^2} \end{aligned}$$

Since the particle being considered is a photon its velocity is the speed of light, c . So the relation becomes

$$R = \frac{2GM}{c^2}$$

which is the distance from the singularity that no particle can escape. This is the classical derivation for the Schwarzschild radius. That this classical result is the result derived from general relativity is disturbing.

As said above, this appears to not make sense. Writing the equations for the kinetic and potential energy of a photon in terms of mass was not found in physics texts forty years ago. To do so here is very handy because the little “m” cancels out leaving a relation only dependent on the mass of the black hole. Apart from that there are other concerns.

Potential energy has little meaning for physical purposes. The change in potential energy is the physical quantity of interest. A reference point must be taken when considering potential energy. The usual reference point is infinity. Taking the potential energy to be zero at infinity, $P_\infty = 0$,

results in the constant term in $P = G \frac{Mm}{R} + const$ to equal zero. When stating that the potential energy of the photon is $P = G \frac{Mm}{R}$ what is meant is the difference in potential energy between infinity and a distance R from the singularity. It is the energy needed to get from R to infinity, i.e. escape velocity starting at a distance R .

When looking at the reasonableness of a presentation, it is best to start at the assumptions. Unfortunately, in writings of science for the masses assumptions are not well explained when given and are for the most part not given at all. The assumptions in our case are that a photon can have a maximum kinetic energy and that the kinetic energy of a photon can be given by the classical kinetic energy equation for a particle with finite rest mass. Given the assumptions, is the classical derivation for the Schwarzschild radius reasonable?

The derivation equates an initial kinetic energy of a photon emitted from the singularity, center of a black hole, to the potential energy difference between some distance, R , and infinity. The unknown term, R , is solved for and declared to be the distance from the center of a black hole at which nothing can escape. A problem of this nature given to a first year physics student would be more like: for a particle with a given kinetic energy within what distance from the center of a mass would the particle be unable to escape the mass. The particle could reach any distance from the mass depending on where within the critical radius it started, but it would return to the mass, i.e. not escape. There would not be a radius at which nothing could go beyond no matter how much energy it had.

Susskind pointed out early on in his book that John Michell and Pierre-Simon de Laplace mused about an object so massive that light could not escape. The foundation of their thinking was that the velocity of light is finite and that light was a particle, i.e. had rest mass. With this thinking, since the velocity of light is constant, its kinetic energy is related only to its mass, and is linearly proportional. The potential energy is also related to the mass and linearly proportional. This results in the classical derivation.

As said above, the fact that the classical derivation gives the same answer as general relativity is disquieting.

The Schwarzschild radius is confusing as presented. Is it the radius at which nothing radiating from the singularity, the center of the black hole, can get further than? Or is it the radius at which nothing can get past once inside? Or is it the radius at which anything radiated from within cannot totally escape? That is an object can go beyond the radius but will eventually return to the black hole. Early on in his book Susskind states "Light that starts inside the horizon will inevitably get pulled back to the black hole...". That makes it sound like the third description of the radius is correct. However, most elsewhere in the book the second description sounds correct. That is, nothing can escape past the Schwarzschild radius once inside the Schwarzschild radius. What questions does that bring up for the novice who has some understanding of classical physics?

A problem is created when the results of general relativity are presented within a context of classical physics (Newtonian) without any explanation of how these things differ from a simpler understanding. This is a failure of those who write physics for the masses. They do not anticipate questions or confusions those lower on the hills of knowledge would have. Confusions such as the following:

A particle below the horizon cannot escape past the horizon no matter how much kinetic energy it has. Say a particle starts out a foot above the horizon (Schwarzschild radius). It falls toward the singularity and is now say a foot below the horizon. The particle is inside the horizon and cannot escape no matter how great a kinetic energy it has. So the potential energy lost from a foot out to a foot in is infinite. Is it the same infinite potential energy from an inch out to an inch in? If the particle had an infinite potential energy to give up from a foot out it had an infinite mass-energy. How did the gravity of the black hole overcome the inertia of the particle? Actually, everything outside the horizon has an infinite mass-energy. How are these infinities taken care of by nature? Or, how are these infinities taken care of by mathematicians?

Everything out there rotates. As matter collapses into a black hole, to conserve angular momentum it must rotate faster. If all the matter collapses into a singularity of zero radius, the rotation rate must go to infinity. The angular momentum is conserved because the angular velocity goes to infinity and the radius goes to zero. It is well known that infinity times zero equals whatever is needed. This is not to say anything is wrong. Again there is a problem explaining results of general relativity to a Newtonian mindset without explaining the differences. Isaac Asimov stated to the effect that if a person understands his subject he should be able to explain it to someone of average mentality who does not have an understanding of it. That is the Asimov principle.

Another problem as seen from a layperson perspective is the horizon of a black hole. As an object approaches the horizon what does one see or measure, seeing also being a measurement. Say the object emits a light. As it gets closer to the horizon the wavelength of the light sifts toward the red end of the spectrum. It gets longer until it can no longer be measured. The object fades from vision or any measurement. Any clock on the object will be seen to slow down until it stops. It will not be seen to stop because the object cannot be seen. What if a light is shined on the object? Does the reflected light red shift until it is no longer detected? As the light approaches the object, or falls toward it, it gains kinetic energy and is blue shifted. The reflected light loses the kinetic energy it gained and is red shifted. It would seem that the only difference in the light would be the Doppler shift caused by the object receding from the observer. The object would be seen but would appear to approach the horizon slower and slower until it appeared to stop. Or would it? (In all physics books for the masses the authors confuse measuring with seeing. To a physicist by seeing they mean measuring. To the rest of us by seeing we mean seeing.)

Susskind tells us that a string theory string would spread out over the horizon as the string approaches the horizon. If objects are made of strings does that mean all objects would spread out as they approach the horizon? It was not made clear. What seems clear is that nothing can be seen to enter a black hole by any observer outside the Schwarzschild radius. So how can a black hole grow? This is all conjecture, of course, from a low

land hiker. The object would spread out over the horizon and owing to the increased mass the horizon would increase, the Schwarzschild radius would get larger, and encompass the object. What would be observed is the increase in the horizon.

How fast does a black hole form and when does the horizon come into existence and at what radius? A given mass will have a certain Schwarzschild radius. If all that mass collapses within that radius a black hole is formed. Is the black hole formed instantaneously as the last particle gets within the radius? The collapsing mass would be denser near the middle than further out. It would seem that a smaller black hole than the total mass would be formed with some radius within the collapsing matter with the horizon increasing with time. What would be the scenario? Or one may ask at what point the singularity exists in the collapse of a large amount of matter. It would seem that at the instant of the big bang all energy-matter would be a black hole. If so, how did everything get beyond the Schwarzschild radius? There is much confusion regarding black holes for us commoners. Hawking radiation is not explained at our level. It can be assumed that virtual particles appear and disappear at some rate. Looking from outside the black hole, time is greatly slowed at the horizon. Does this slow or stop the rate at which virtual particles appear? If so how does that effect Hawking radiation? If a string spreads out over the horizon owing to time dilation in general relativity, would it spread out owing to time dilation in special relativity? If a string moves near the speed of light is it spread out? Light moves at the speed of light. If photons are made of strings, are they spread out over the universe? If so, how do things work? These questions may be naïve but a good writer on the subject would anticipate them and give them a few paragraphs if not a page.

Physics in this area is depressing. Is it the world of substance being explained or the world of math? Is this a math game the inquisitive public is made a dupe of? Supposition is of interest and entertaining, but if called real those things that are implied between supposition and reality should be stated. There should never be a slippery slope between what is supposed and what is known to be real.

Closing

Many modern writers of physics for the masses are in your face with their religion and politics. Susskind is the worst. Susskind should have started with an introductory chapter with a core dump of his religion and politics and kept to the subject for the rest of the book. Even at that much of the rest of the book would be Susskind tooting his own horn with the tones being off key. A writer of science for the mass should not put too much of his own personality into his writing. One should not be able to make personal conclusions about the writer. After reading the book I feel that Susskind is not a person I would want to have dinner with. If the subject of conversation came to politics, one can imagine it would be like having dinner with Joe Biden. One would hear the most outlandish comments supported with statistics that sprout from the walls. It would be like the presidents analyst talking to a gun totting liberal. His personality added nothing to the book as his treatment of Hawking also added nothing to the book.

Stephen Hawking carries a weight few of us have been burdened with. He has climbed a mountain few of us could have made an effort at. And he did it carrying that weight. Hawking is not a fiction hero or a political hero of the masses. He is a hero in the sense of courage worth emulating.

A little fun with low level math

Planck dimensions are quite prominent throughout the book. They are defined by three physical constants of nature G, c and \hbar . The constant G is the gravitational constant ($G = 6.67 \times 10^{-11} \frac{nt-m^2}{kg^2}$), c is the speed of light in a vacuum ($c = 3.00 \times 10^8 \frac{m}{sec}$), and \hbar is the reduced Planck's constant ($\hbar = 1.054 \times 10^{-34} \text{ Joule} - \text{sec}$).

Let P_L be the Planck length, P_T be the Planck time, and P_M be the Planck mass. The definition of each is

$$P_L = \sqrt{\frac{\hbar G}{c^2}} = 1.616 \times 10^{-35} \text{ meters}$$

$$P_T = \sqrt{\frac{\hbar G}{c^5}} = 5.391 \times 10^{-44} \text{ sec}$$

$$P_M = \sqrt{\frac{\hbar c}{G}} = 2.176 \times 10^{-8} \text{ kg}$$

From these equations one can find the physical constants used to derive the Planck units in terms of those Planck units. The results are

$$c = \frac{P_L}{P_T}$$

$$G = \frac{P_L^2}{P_M P_T}$$

$$\hbar = \frac{P_L^2 P_M}{P_T}$$

In determining the increase in the surface area of the horizon of a black hole Susskind uses three equations and one assumption. The three equations are

$$E = mc^2 \quad \text{Einstine's mass – energy equation}$$

$$R_S = \frac{2MG}{c^2} \quad \text{Schwarzschild radius}$$

$$E = \frac{2\pi\hbar c}{\lambda} \quad \text{Energy of a photon}$$

One oddity is that while G, c and \hbar are call constants, P_T, P_L and P_M are called units. Why not call G, c and \hbar units. The speed of light, c is sometimes call a unit of velocity. G and \hbar as units would not fit into an intuitive feel as to what a unit should look like. Take P_T, P_L and P_M to be units and rewrite the above three equations in these units. The following equations result.

$$E = M \left(\frac{P_L^2}{P_T^2} \right) \quad \text{Einstine's mass – energy equation}$$

$$R_S = 2M \left(\frac{P_L}{P_M} \right) \quad \text{Schwarzschild radius}$$

$$E = \frac{2\pi}{\lambda} \left(\frac{P_L^3 P_M}{P_T^2} \right) \quad \text{Energy of a photon}$$

The units are in parentheses. All units are Planck units. Energy is in Planck energy, derived below. One information bit is the lowest energy that can be added to the black hole and is taken to be a photon with a wavelength equal to the Schwarzschild radius, R_S . What is wanted is the change in surface area of the horizon, S_Δ , owing to the increase of one bit of information to the black hole. Let M_Δ be the change in mass of the black hole and R_Δ the change of the Schwarzschild radius. From the equations above with units in parentheses

$$\begin{aligned}
R_{\Delta} &= 2M_{\Delta} \left(\frac{P_L}{P_M} \right) \\
&= 2E_{\Delta} \left(\frac{P_T^2}{P_L^2} \right) \left(\frac{P_L}{P_M} \right) \\
&= 2 \frac{2\pi}{\lambda} \left(\frac{P_L^3 P_M}{P_T^2} \right) \left(\frac{P_T^2}{P_L^2} \right) \left(\frac{P_L}{P_M} \right) \\
R_{\Delta} &= \frac{4\pi}{\lambda} (P_L^2)
\end{aligned}$$

The change in surface area is

$$\begin{aligned}
S_{\Delta} &= 4\pi(R_S + R_{\Delta})^2 - 4\pi(R_S)^2 \\
&= 4\pi(2R_S R_{\Delta} + R_{\Delta}^2) \\
&= 4\pi \left(2 \frac{4\pi}{\lambda} (P_L^2) R_S + \frac{(4\pi)^2}{R_S^2} (P_L^4) \right) \\
S_{\Delta} &= 32\pi^2 \frac{R_S}{\lambda} (P_L^2) + \frac{(4\pi)^3}{R_S^2} (P_L^4)
\end{aligned}$$

Susskind says that this shows that putting one bit of information into a black hole increases the horizontal surface area by one Planck area. That is not what comes out of the math he gave us. Rewrite the last equation above as

$$S_{\Delta} = 8\pi \frac{R_S}{\lambda} (4\pi P_L^2) + \frac{4\pi}{R_S^2} (4\pi P_L^2)^2$$

In both equations the second term is negligible for any black hole larger than Planck size. One could deduce from the rewritten equation that adding one bit of information increased the horizon area one Planck spherical surface area, except for the 8π factor, having taken $R_S = \lambda$.

The Planck length is somewhat arbitrary. It could be defined as

$$P_L' = \sqrt{\frac{hG}{c^2}} \quad \text{where } \hbar = \frac{h}{2\pi}$$

$$\Rightarrow P_L = \frac{P_L'}{\sqrt{2\pi}}$$

Using the second definition for Planck length the equation for the change in horizon surface area becomes

$$S_\Delta = 4 \frac{R_S}{\lambda} (4\pi P_L'^2) + \frac{4}{4\pi R_S^2} (4\pi P_L'^2)^2$$

$$= 4 \left(\frac{R_S}{\lambda} + \frac{16\pi P_L'^2}{4\pi R_S^2} \right) (4\pi P_L'^2)$$

Taking $\lambda = R_S$, the change in horizon surface area is 4 Planck surface areas and a tiny bit more. The second term in the far right parentheses is 1 Planck surface area divided by the horizon surface area, a very small term but interesting. The above equation shows that taking the photon wavelength equal to the Schwarzschild radius is why the increase in horizon surface area is in the Planck range although not as small as Susskind told us it was.

An assumption was made that one bit of information had a mass-energy equal to a photon of wavelength of the Schwarzschild radius of the black hole. Various Planck units have been derived. Add to those the unit of Planck energy.

$$P_E = \sqrt{\frac{\hbar c^5}{G}} = \sqrt{\frac{(6.63 \times 10^{-34})(3.00 \times 10^8)^5}{6.67 \times 10^{-11}}} = 1.95 \times 10^9 \text{ joules}$$

Planck length and Planck time are tiny by any standard, which gives them a supposed special status. Claims, without verification, can be made about them being the fundamental length and time of the universe. What of Planck mass and Planck energy. In terms of the atomic realm they are huge. They certainly cannot be fundamental in the sense of being the smallest mass and least energy. So are any Planck units really that special or are some special and not others.

Adding one bit of information to a black hole was taken to be the smallest amount of energy that could be added, which was taken to be a photon with a wavelength equal to the Schwarzschild radius. Could a wavelength a little larger be absorbed by the black hole? It was said that larger wavelengths would be reflected. There may be a subtlety and the smallest wavelength is 50% larger than the Schwarzschild radius.

From the equation for increase in horizon surface area, S_Δ , above one sees that taking λ equal to the Schwarzschild radius results in the increase in surface area being independent of the mass of the black hole. The mass is hidden in the R_S term and is divided out by taking $\lambda = R_S$. There is an oddity in all this that was not addressed. As the mass of the black hole gets greater the photon wavelength necessary to add one bit of information gets longer. That is the energy needed to add one bit of information gets less as the mass of the black hole gets greater.

Using Susskind's equations, which somewhat hide what is taking place, and his numbers to see how much a bit of information adds to the horizon surface area of a black hole of 1 Solar mass, one gets

$$\begin{aligned}
 S_\Delta &= 4\pi((R_S - R_\Delta)^2 - R_S^2) \\
 &= 4\pi(2R_S R_\Delta - R_\Delta^2) \\
 &= 8\pi R_S \frac{2hG}{R_S c^3} \quad R_S \gg R_\Delta \\
 &= 16\pi \frac{(6.63 \times 10^{-34})(6.67 \times 10^{-11})}{(3.00 \times 10^8)^3} m^2 \\
 &= 8.23 \times 10^{-68} m^2 \\
 &= 315 P_L^2
 \end{aligned}$$

One sees the R_S canceling out of the derivation. One sees why the increase in horizon surface area from adding one bit of information is independent of the black hole mass. One bit of information takes less energy as the mass of the black hole gets larger as was determined above.

Using the derivation for S_Δ in Planck units one gets

$$\begin{aligned} S_\Delta &= 32\pi^2 P_L^2 \\ &= 316 P_L^2 \end{aligned}$$

The answers are the same. Neither is $1 P_L^2$ as we were told. But Susskind assures us that it comes out right in string theory, or is it that string theory makes it come out right. It gets confusing.