Thank you everyone for the very insightful questions. Let me make a couple of general comments before I dig into the specific questions; The answers I am providing make the simplifying assumption that the black hole in question does not have an accretion disk. The accretion disk is something like the rings of Saturn except that it is a region filled with extremely high temperature plasma (ionized atoms and subatomic particles) so that any adventurer who wants to come close to the black hole horizon would be incinerated. The accretion disk is also filled with intense ionizing radiation so if you're offered an opportunity to approach a black hole, please only come near the ones that do not have an accretion disk (and they all do). The following is an artist rendition of a black hole with jets and an accretion disk. I. have also included an actual image of an accretion disk. If you want more info on the image, go to https://eventhorizontelescope.org/

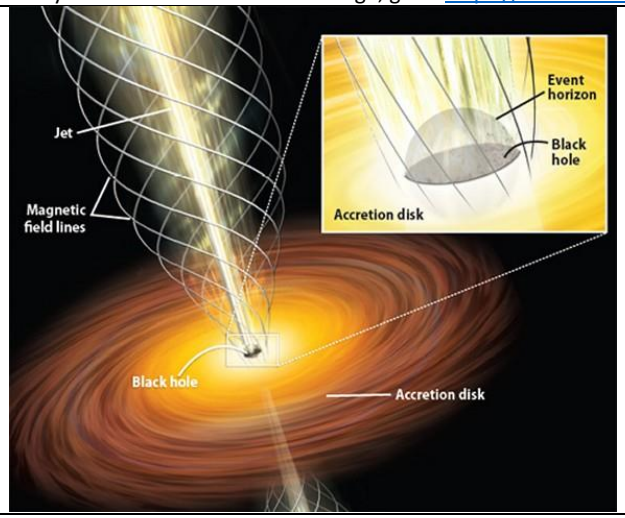


Figure 1 Artist conception of the neighborhood of a black hole.

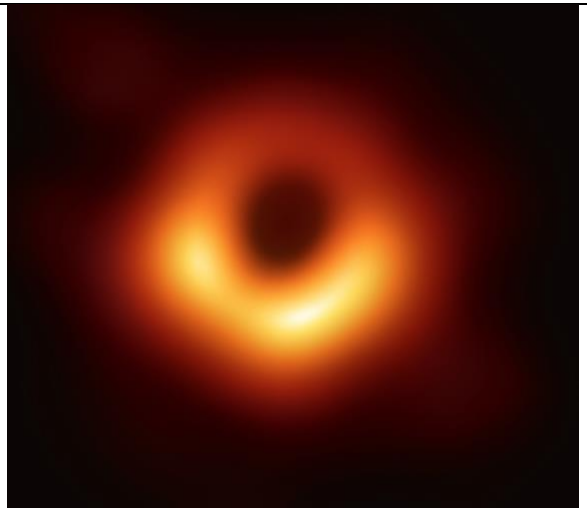

Figure 2 An image of an accretion disk obtained with the EHT network. https://eventhorizontelescope.org/

- I have included web links for those who want to do follow-up reading.
- I use American English spelling.
- If my answers don't resolve your issues, write to me and I'll try another approach.
- edfriedmanis65@gmail.com
- I have posted the full notes for the 2-hour version of this talk for you. It includes a discussion of the prospect for tunneling through spacetime by using entangled black holes and other exotica. Find the lecture notes here; https://drive.google.com/file/d/1TExTYu3mXOyPaGdE8KHHoPcfkuj3c7ci/view?usp=sharing You will also find a version of this lecture in my YouTube channel.

| | | | The Strange Neighborhood of Black Holes 32 |
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| # | Question | Asker Name | Answer |
| 1 | How accurate on a scale of 1-10 (10 being very accurate) would you say the film Interstellar is in depicting blackholes? | jack | Let me quote from Thorne, Kip. *The Science of Interstellar* (p. 4). W. W. Norton & Company. Kindle Edition. Thorne and his collaborators agreed that:<br><br>1. Nothing in the film will violate firmly established laws of physics, or our firmly established knowledge of the universe.<br>2. Speculations (often wild) about ill-understood physical laws and the universe will spring from real science, from ideas that at least some "respectable" scientists regard as possible.<br><br>In summary, *Interstellar* is not really a science fiction movie. It is a 'science fact' movie with various extrapolations from current science and technology to propel the drama. |
| 2 | If Alice & Bob communicated by quantum entanglement rather than by light, would that make any difference? (I'm not sure whether quantum entanglement communication is at the speed of light, or faster - if that were possible!) | John Purdy | Quantum entanglement is an instant (no time delay) realization of the connection between entangled states BUT it is not a scheme for communication. To know that the state of entangled quantum particles, the results of measurements made by Alice and Bob must be compared and that requires conventional communication. Any measurement Bob makes tells him what Alice will measure but she does not know what he has seen so Alice and Bob cannot communicate any faster than the speed of light. |
| 3 | If you were inside the event horizon, but looking "outwards" from the singularity, what would you actually see? | Angus | You would see starlight and, if you had a companion sending you signals, you would see those signals as well. Any light or radio signals you would be receiving would be blue shifted because of the warpage of spacetime in the vicinity of the intense gravity of the black hole so you had better plan to bring a radio receiver able to accommodate that shift. Its more complicated because as you descend toward the singularity, the geometry around you is dramatically altered. Just before your journey ends, a star directly above you would appear as a ring at the extreme of your peripheral vision, 90˚. |
| 4 | How can you know if a black hole is spinning if no information can exit the hole? | David W | We see the evidence in the properties of the accretion disk; it rotates under the influence of the rotation of the black hole, and we can see how this affects its light. Check out the following article. black-hole-spin-rate. |
| 5 | Why are the light cones upright (same orientation) in both Kruskal and normal space? | Patrick O'Donohoe | The upright cone in normal space is a feature of a flat spacetime. Its properties derive from the decision to pick dimensions so that a 45˚ angle represents the speed of light. When using coordinate transforms to consider issues like black holes, we want those same attributes. That's one of the features that Kruskal built into the coordinate transformation that he invented. The Kruskal diagram also insists that light rays move at 45˚ angles. |

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| 6 | According to Einstein's general relativity theory, gravity will curve space and time. Does this imply that the Earth gravity have any significant effect on the atomic clocks on the GPS satellites? Does this effect vary from different orbiting objects, for example, between the ISS and the newly launched James Webb telescope? | Sami Nofal | YES to your first question. Clock correction must be built into the GPS system to accommodate the fact that the satellites experience a different gravitational force than the clock in your GPS receiver or telephone. The difference in gravity leads to a change in the rate at which time advances. An additional correction must be made for the velocity difference between the satellites and the surface of Earth.<br><br>The difference amounts to a daily shift of 38,637 nanoseconds. Those who are interested can write to me to get a copy of my lecture notes on this topic. They derive from the book described below.<br><br>Those who have a technical background can learn more about these corrections by getting a free copy of a fantastic book on Einstein's theory that only requires calculus. Go to this website https://www.eftaylor.com/general.html. Chapter 4 addresses the GPS problem.<br><br>Also, yes to the second part of your question; the pace at which time advances on a satellite depends on the orbit height and velocity. In general, the clock rate is not an issue except for satellites that are involved in precise navigation. |
| 7 | Our understanding of what happens near a black hole is based on Einstein's theory of general relativity. But if we manage to develop a unified field theory might this not potentially and radically change our understanding of gravity and what black holes are. | Ed L | The expectation is that any modification of Einstein's theory to include quantum gravity as a part of a unified theory would not undo the theory he introduced in 1917. Rather there would be an extension of the theory to deal with quantum mechanical effects. Enormous amounts of money have been made to check Einstein theory in many ways and no defects have been found. Perhaps someday there will be a completely new theory that handles both gravity and quantum mechanics and that would be the radical change you mention but **it must be able to duplicate the success of the current theory of gravity.** |
| 8 | Is the James Webb telescope going to be able to track Black holes - since it is tracking a wide electromagnetic spectrum? | Phil Wrenn | Webb has the potential to see deep into galaxies because it operates at wavelengths that reduce the adverse effects of dust in the outskirts of those galaxies. As a result, it will come closer than any telescopes we currently use to investigate the neighborhood of black holes. There is already a formal study planned for using Webb to look at the black hole in the center of the Milky Way; https://www.inverse.com/science/jwst-milky-way-black-hole |
| 9 | If we assume that Bob flashes a green light every second in his time, what will Alice see as she gets closer and closer to the event horizon? Will she see the time between flashes go to zero? | Jonathan | I have added Jonathan's larger version of the is question at the end of this document. |

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| 10 | How can gravity exit from the mass in a black hole if no information can do so? Does gravity (the influence of a mass) travel faster than light? | Tim Denvir | First, gravity propagates at the speed of light. If the sun were to disappear now, our orbit would not change for about 9 minutes. The confirmation of this fact was not demonstrated until gravitational wave sensors and gamma ray telescopes first observed the merger of neutron stars. The difference in arrival of the gamma rays and gravitational waves from the event confirmed that gravitational waves travel at the speed of light. The arrival times differing by about 1.7 seconds due to the physics involved in the two processes.<br>https://physics.aps.org/articles/v10/114<br><br>The presence of the black hole distorts the local space time; no *exiting* occurs. Nothing is leaving the black hole to project its gravitational force. Another issue (dealt with in the following paper) has to do with the quantum mechanical interpretation of gravity.<br>http://curious.astro.cornell.edu/most-popular/89-the-universe/black-holes-and-quasars/theoretical-questions/451-how-do-gravitons-escape-black-holes-to-tell-the-universe-about-their-gravity-advanced |
| 11 | Suppose bob stays in a fixed place a long way from the black hole and observes matter (eg Alice and her friends) falling into the black hole. Bob never sees Alice actually cross the horizon, so in Bob's space time, the mass of the black hole never increases. So how do black holes ever grow in size (eg the super massive black hole at the centre of each galaxy)? | Dave Sinclair | There is no incompatibility in the issues your you raise. Some scientists describe this process as follows; the approaching mass about to enter the horizon causes its own distortion of the spacetime outside the horizon. The small distortion of the entering matter causes the horizon to bulge out a bit until it encompasses the entering mass. Once the mass is inside the horizon, the horizon resumes its former spherical shape but with a bit larger size.<br><br>In reality, of course, Alice doesn't notice anything odd at the horizon. She sails through just as if she were traveling from one county to another in England. |
| 12 | Excellent explanation of Kruskal diagrams. Thank you. | Jonathan | Thanks |
| 13 | If the Singularity shrinks to zero (nothing), can it be explored ? | John M | A zero-mass singularity will not sustain a horizon; no black hole will exist. It will just be an empty place in space. |
| 14 | What is the name of Ed's YouTube channel? On the slide it was just a hotlink. | John Purdy | It doesn't have a name; just follow the link<br>https://www.youtube.com/channel/UC7cYzISD4v9Udjycr45BzNw |
| 15 | Can Alice send a message from the inner side of the event horizon towards the past,to Bob in the past? | las | NO. The upward opening cone is the only region anything can move within or send signals into. The downward opening light cone only represents the region of spacetime from which our present state evolved. See Q and A 26 for more details. |
| 16 | If a huge amount of matter makes up a black hole, is it possible for dark matter too produce something similar? | scott | NO. The reason is that atomic matter interacts with itself through a variety of mechanisms while dark matter appears to only interact through gravity. The mechanisms used by normal matter to create friction, for example, aren't a factor with dark matter so they have no way to exchange energy. A cloud of normal matter can form a black hole by producing heat when the particles collide; the heat radiates away, thereby reducing the energy of the particles so that a cloud can gradually condense. In the accretion disk that forms around a black hole, atoms get ionized and interact through electromagnetic forces which is another mechanism for energy loss. On the other hand, dark matter has no such mechanisms so it cannot create black holes. Some people think that dark matter black holes might have been created in the early universe, but I know of no observations that support this idea.<br>https://bigthink.com/starts-with-a-bang/black-holes-dark-matter/ |

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| 17 | if most galaxies contain a black hole why do they not all dissapear (or is that the eventual future) | paul | I take it that your question gets to whether a black hole would eventually absorb an entire Galaxy. This will not happen. Consider the black hole in the center of the Milky Way. It has a mass of about four million Suns while the total mass of the Galaxy amounts to about 100 billion Suns. Any star or cloud of gas that comes within the realm of the black hole at the center of the Milky Way could get absorbed but stars at other locations in the Galaxy (which is about 200,000 light years in diameter) barely notice that the black hole even exists. The black hole and its environment are just not massive enough to make much difference. |
| 18 | If Alice and Bob 'could' travel faster than light, but the communication didn't, what would that mean to the cone diagrams detailed? i.e. could they still communicate inside of a black hole? | Anonymous Attendee | Let's set aside the first sentence since they cannot travel faster than light. But, if both are inside the horizon, they can communicate for as long as they are not killed by tidal forces. |
| 19 | Your diagram indicates a 'waterfall' effect as you enter the horizon, does that mean things get faster, so does light travel faster or is space also compressed so it does not ? | Mike Wilsher | Light travels at the speed of light **through the space in which it is traveling.** But if the space is being dragged into the singularity at a rate higher than the speed of light a combination of the speeds occurs. Explore the fantastic world of black holes by visiting the site created by Andrew Hamilton of the University of Colorado. The answer must be in there somewhere. https://jila.colorado.edu/~ajsh/insidebh/intro.html |
| 20 | Amazing topic thanks Ed your discriptions were brilliant.Many thanks to you and the IET East Coast team. | Michael | Many thanks |
| 21 | How is it know if anything gets further than the event horizon if an observer outside this area only sees anything apparently freeze/stop at this point? | Tim | We know nothing of the actual dynamics inside the black hole; we rely on Einstein, and we have found no defects in his theory. For example, observations of mergers of black holes can be treated as if one of the holes consumed the other. Einstein's theory perfectly predicts the signals we get from such mergers including the mass of the resulting object. |
| 22 | Is the singularity of zero size, and if not how big is it ? How could we tell how big it is ? | Steve Cheal | We have no way of knowing the actual size, but it is generally assumed that it is a geometric point with zero size. On the other hand, there is something called the Planck length which is thought to be the smallest physical dimension allowed by physics. It is $1.616\times10^{-35}$ m. Perhaps that is the right number. |
| 23 | How can the messages between Bob and Alice travel in straight lines? Shouldn't these also be curved? | Bernard Arambepola | The coordinate system invented by Kruskal manages to preserve the highly desirable property that light rays travel in straight lines at 45˚. |
| 24 | You detailed Alice and Bob orbiting a black hole within a spaceship. Could it be possible for a planet or other mass to orbit a black hole without being pulled towards it? | Kat Sullivan | YES. A sufficiently large velocity for an object can ensure that it won't fall into the hole. However, this assumes that there is no accretion disk. An accretion disk will complicate things enormously and result in our spaceship losing energy and falling into the hole.<br><br>In an idealized situation with no accretion disk, even light will orbit a black hole. |

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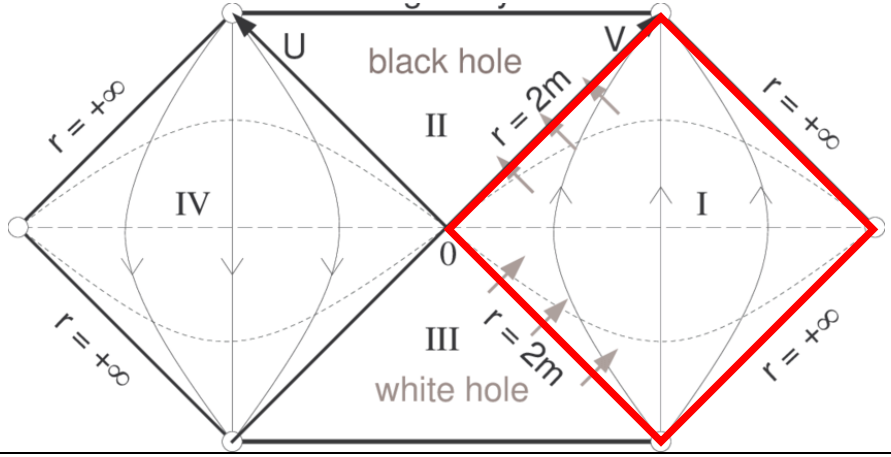
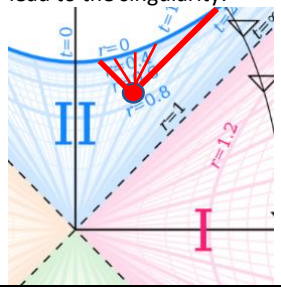
| 25 | I'm looking at a Penrose diagram and it mentions a white hole as the opposite of a black hole ..... help! | Andrew Rylah | For those who haven't seen a Penrose diagram, here is an example. It has many similarities to the Kruskal diagram; 45˚ lines represent the speed of light, etc. The difference is that Penrose has a scheme such that the region in the red square encompasses all of space and time of our universe. As with Kruskal the upper triangle (II) represents the black hole. Penrose includes a lower triangle (III) that represents (perhaps) the source for all the energy and matter that created our universe. It is important to know that Penrose (a recent winner of the Nobel prize for his work on black holes), is an advocate for an idea that our universe is the result of a previous one that collapsed. His diagram can be claimed as evidence for his idea, Conformal cyclic cosmology, but is a topic of debate among current researchers. debate_conformal_cyclic_cosmology.<br>  |
| 26 | Escape velocity from earth is 25,000mph but I think that is unpowered, but with enough fuel a rocket could theoretically go to the moon from earth at say a constant 1000mph - so in the same way, could a rocket not escape through an event horizon if it was not too far in? | Caroline Monkman | NO. There is no escape for any object (or light) that is inside the event horizon. The escape velocity at the horizon is the speed of light. No amount of energy can avoid being sucked into the singularity because nothing can go faster than light. Look at this segment of a Kruskal diagram. An object (the red dot) is confined to move within the space defined by the thick red lines. All trajectories (thin red lines) lead to the singularity.<br>  |

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| 27 | If time come to a halt for Alice as she goes through the horizon from the point of view of Bob, then how can anything pass through the horizon. Won't everything just pile up at the horizon? | Mark | Time does not halt for Alice. She proceeds without hesitation right through the horizon. An external observer sees her stop, but a clock traveling with her just keeps on ticking. |
| 28 | If Bob never sees Alice actually go across the horizon, then from Bob's perspective the black hole can never increase in mass - is this true? | Dave Sinclair | See answers to questions 11, 21, 27. |
| | Bob is flashing a green light at one flash per second in his time frame. What will Alice see looking back at Bob? Will she see Bob's light shifted into gamma radiation and beyond? More importantly will the interval between flashes decrease to zero as she approaches the event horizon? In other words will an infinite amount of time have passed in Bob's time frame by the time Alice reaches the event horizon? | jonathan | **What will Alice see looking back at Bob?**<br>She will see his signals as well as star light.<br>**Will she see Bob's light shifted into gamma radiation and beyond?**<br>She will his signals blue shifted but likely not as far as gamma rays, at least not until she is nearly at the singularity.<br>**More importantly, will the interval between flashes decrease to zero as she approaches the event horizon?**<br>The interval between the flashes will decrease but the decrease is a gradual effect with nothing dramatic occurring at the horizon. She will continue to see the blue shift and shortening of the interval between pulses until she is killed by tidal forces.<br>**In other words, will an infinite amount of time have passed in Bob's time frame by the time Alice reaches the event horizon?**<br>Yes, Bob will have to wait an infinite time before he sees her stop on the horizon UNLESS he also agrees to cross the horizon. Then he will see her cross the horizon just as he does. This is shown in one of the figures of my lecture notes. |