https://www.youtube.com/watch?v=JqKa6qyVYgg

The Science of Extreme Time Dilation in Interstellar

8 453 393 zhlédnutí 9. 7. 2021 #interstellar

For an uninterrupted viewing experience, we recommend watching our full-length Interstellar documentary video instead: • The Untold Story of Interstellar's Ex... PS: Due to copyright restrictions, some of the original music tracks in this video have been replaced with alternate audio after upload. Additionally, certain segments have been removed, which result in moments of silence. If you'd like to see more of this kind of video, consider supporting our work by becoming a member today!

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Pro ničím nerušený zážitek ze sledování doporučujeme místo toho zhlédnout naše celovečerní dokumentární video Interstellar: • Nevyřčený příběh Interstellar's Ex... PS: Z důvodu omezení autorských práv byly některé původní hudební stopy v tomto videu po nahrání nahrazeny alternativním zvukem. Navíc byly odstraněny určité segmenty, což má za následek chvíle ticha. Pokud byste chtěli vidět více takových videí, zvažte podporu naší práce tím, že se staňte členem ještě dnes!

0:00

(01)- This is the Miller's planet. It's the closest planet to the fictional black hole Gargantua. So what's so special about this scene? Well, just in the span of this 5-second clip from this planet, a lot has happened on Earth. I mean A LOT. In this video, we're going to explain time dilation while bringing the context of what happens in Interstellar. We touched upon the fundamentals of this topic from our previous video, about Einstein's relativity. You can check out the video here. But just to give you a brief summary, we can say the following.

Recap of Einstein's relativity

Under the influence of a strong gravitational field, time slows down. So if you're just hanging out a near massive object, you will experience the effect of time going slower. But gravity isn't the only thing that can warp time. According to another one of Einstein's theories, special relativity, time slows down for an object when it moves. Combining these two concepts together, we could consider this scenario. Suppose that we walked up a flight of stairs. Our body is slowly moved away from Earth, meaning that we will experience time going faster. But at the same time, since we are not stationary while going up we should experience time going slower. So being farther from the pull of gravity, causes our clock to tick faster. But moving counteracts this effect. Of course this is all oversimplified and the devil's in the details. But let's not forget why we're here, talking about time dilation. Let's consider two comparable cases. We have person A, floating nearby a massive object with a lot of gravity.

Gravitational redshift

And person B just casually floating in an empty void of space. Person A shines a green laser beam towards person B. Because light is a form of vibration, the laser beam has a colour that corresponds to 600 trillion vibrations each second. Now, light is also a form of energy. And as that beam of light comes out of that gravity of the massive object it loses a lot of energy. This loss means that there is a decrease in frequency. So by the time that beam of light reaches person B, its frequency will have decreased by some factor. That means, instead of the green light at 600 trillion vibrations a second person B gets only -let's say 10 billion vibrations per second which is a microwave radio beam. This phenomenon is called gravitational redshift. But not so fast. Individual wiggles don't just go anywhere and disappear. Since person A creates 600 trillion wiggles every second, while person B only gets 10 billion every second. The only way this can happen is if one second on one astronaut's clock is not the same as one second on the other astronaut. In other words, it only takes one second for person A to create those 600 trillion wiggles. But it will take 60,000 seconds, or nearly a day for person B to receive them. So this is what happens. Our clocks run at widely different rates. And by clocks I don't mean just mechanical or electronic devices but also biological clocks like your heart, lungs, your brains, etc. Person A takes a breath, and takes another breath and measures a few seconds between the two. For him, everything feels normal. Clocks tick the way they are supposed to. On the other hand person B, watching person A through a telescope sees everything in slow motion. With several days passing between the two breaths. So now revisiting this scene again from Interstellar, you should get a better But don't worry, we're not done yet. Stick around if you want to learn more about time dilation in the next part of the video. According to Einstein's special relativity, the greater the acceleration of an object the slower that it will move through time. On Earth, where time is slowed by only a few microseconds per day, gravity's pull is modest. On the surface of a neutron star, where time is slowed by a few hours per day, gravity's pull is enormous.

Time dilation in Interstellar

And at the surface of a black hole, time is slowed to a halt. Where the gravity is so humongous that nothing can escape. Not even light. So if we apply Einstein's relativity here, we would know that Miller's planet would experience time at a very slow rate. But here on Earth, the gravity is at a modest rate. And the gravitational force of the sun is also a billion times weaker than Gargantua. So people on Earth experience time faster than that of the three astronauts on Miller's planet. And of course all of this information is brought to you from the book "The Science of Interstellar" written by the scientific consultant of the film. In real life, this process is happening everywhere in space. One interesting example is our International Space Station. At the ISS, time runs slower as compared to time here on Earth. Technically speaking, it is a different time reference than we are. So by calculating the

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(01)- This is Miller's Planet. It's the closest planet to the fictional black hole Gargantua. So what's so special about this scene? Well, a lot happened on Earth during this 5-second clip from this planet. I mean A LOT. In this video, we'll explain time dilation while also providing context for what's happening in Interstellar. We covered the basics of this topic in our previous video on Einstein's Relativity. You can watch the video here. But just for a quick summary, here's a **recap of Einstein's Relativity** Under the influence of a strong gravitational field, time (not time, but the rate of time changes, so intervals stretch relative to the chosen interval) slows down. Sure, it slows down, but only in the projection of the Observer's observation device. So if you happen to be hanging around with a nearly massive object, you'll experience the effect of time dilation. Gravity isn't the only thing that can warp time. *Deform* is an inappropriate word for physical reality, i.e. changing the pace of time, i.e. changing the size of observed intervals (time). Why does the interval change? Because an

object moving in a gravitational field rotates its own frame relative to the frame of the observer, who thus perceives the change in the size of the interval in the time dimension. According to another of Einstein's theories, the special theory of relativity, time slows down for the object, the pace of time slows down in the observer's observatory, but not on the observed object. A serial watch runs the same everywhere, at the same pace when it moves. Combining these two concepts together, we could consider this scenario. Suppose we were walking up the stairs. Our body is slowly moving away from the Earth, which means that we experience that time is running faster. We-the Observer are moving through gravitational potential levels, (OTR), which are curved, or show changes in values in the radial direction from the Earth. This results in a change in the rate of time even in a projectively moving Observer, the rate accelerates. But at the same time, because when climbing we are not standing still, we should experience that time passes more slowly. No. We do not experience this in our own system. We are an Observer who is moving, and therefore according to STR we rotate (for a standing Observer), therefore we do not observe changes in the rate of time passing on ourselves. Only an Observer who is standing on the seashore can (according to STR) observe a change in the rate of time on an object that is moving, but nothing is observed on the object itself, dilation is not observed, precisely because the object is in motion, it rotates its own system. Because we are further from strong gravity, our clocks tick faster.No, the clocks tick the same everywhere, it is an iron machine with a set tick size = interval,… but time ticks = passes faster, not the watch.
But motion prevents this effect. Of course, all of this is oversimplified, and the devil is in the details. But let's not forget why we're here, talking about time dilation. Consider two comparable cases. We have person A floating near a massive object with high gravity. **Gravitational redshift** A and person B just floating around in the empty void of space. Person A shines a green laser beam toward person B. Since light is a form of vibration, the laser beam has a color that corresponds to 600 trillion vibrations ???, or a frequency of $6 .10^{14}$??? every second. ?? Now light is also a form of energy. And as that beam of light emerges from that gravity of the massive object, it loses a lot of energy. This loss means that there is a decrease in frequency. $c = f . \lambda = 1/6 .10^{-14}$ sec. x 18.10^{+22} meters.
So by the time the beam of light reaches person B, its frequency has dropped by a factor of some. That means that instead of green light at 600 trillion vibrations, person B only gets - let's say 10 billion vibrations per second, 10^{-9}, which is a microwave radio beam. This phenomenon is called gravitational redshift. But not that fast. The individual wobbles don't just go away and disappear. Because person A creates 600 trillion wobbles every second, while person B only gets 10 billion every second. The only way this can happen is that one second on one astronaut's clock is not the same as one second on the watches of the other astronauts. And that's not true. It doesn't change on the watch, but it does change in "spacetime with curved time dimensions". In other words, it only takes person A one second to create those 600 trillion wobbles. But it will take person B 60,000 seconds, or almost a day, to receive them. So this is what happens. **?** Our clocks run at very different speeds. That is, they run in different curvatures of space-time dimensions. And by clocks I don't just mean mechanical or electronic devices, but also biological clocks like your heart, lungs, your brain, etc. Person A takes a breath, takes another breath, and measures a few seconds between them. Everything is normal for him. The clock is ticking as it should. On the other hand, person B, who is watching person A through a telescope, **sees** everything in slow motion. Person B has turned around with respect to A, so the word "sees" means that he is reading the data rotated,

longer for time, contracted for length. Several days have passed between two breaths. So now, if we go back to this scene from Interstellar again, you should improve. But don't worry, we're not done yet. Stay tuned if you want to learn more about time dilation in the next part of the video. According to Einstein's special theory of relativity, the greater the **acceleration** "a" of an object, !! (which acceleration "a" is the one or the other mover that rotates the object's frame. The surrounding environment is the same as for a stationary Observer. Whereas with gravity for a very massive body, it is the case that A and B are both stationary, but the environment around them is curved differently for each.), the slower it will move through time. On Earth, where time slows down by only a few microseconds per day, gravity is modest. On the surface of a neutron star, where time slows down by a few hours per day, the pull of gravity is enormous. Time dilation in Interstellar A On the surface of a black hole, time slows down until it stops. Where gravity is so enormous that nothing can escape. There, the space-time system is so twisted that even light "escapes" tangentially to the object, which immediately "pulls it back in". Not even light. So if we apply Einstein's relativity here, we would know that Miller's planet would experience time very slowly. But here on Earth, gravity is mild. And the gravitational force of the sun is also a billion times weaker than Gargantua. So people on Earth experience time faster than the three astronauts on Miller's planet. And all this information is of course brought to you by the book "The Science of Interstellar", written by the scientific consultant of the film. In real life, this process happens everywhere in space. One interesting example is our International Space Station. On the ISS, time runs slower compared to time here on Earth. O.K. The clock runs the same, but time does not. Technically speaking, it is a different time value than ours. So by calculation …………………………………………………………………………………………..

(02)- difference through Einstein's equations we could correct the time at the ISS. Because we use a lot of references to the movie Interstellar here we might as well just take one case study of how filmmakers do this time dilation feel in the movie. In the opening scene when Cooper and his team stepped on Miller's planet an intense music with clock-ticking elements starts. The tempo changes over the course of the song.

One second on Miller's equals one day on Earth

where time dilation takes effect because of the proximity to a singularity. Roughly we'll get about 221 million seconds in seven years. This gives us a conversion factor of about 61,400 seconds which pass on earth for every second spent on Miller's planet. Multiply this by the interval between each tick, and you'll get 77,000 Earth second. Or about 21 hours. So each tick you hear is almost a whole day passing on Earth. And this is side by side of what happens on Miller's planet versus earth in real-time. After grasping all of this piece of information, of course we want to ask the question. Is this extreme time dilation possible on such a planet? Could we even walk on the surface of it? At one point, we are told that the gravity on this planet is 130% of the Earth's gravity. We see the actors panting. A little bit under duress because of the extra gravity. But is this enough for this kind of time dilation? Well, actually not even close. If you've visited the surface of our sun which is not a supermassive body

The problem with this extreme time dilation

but still much more massive than Earth, you would gain about 66 seconds per year. To get to an extreme dilation where one hour corresponds to seven years, you would need such a strong gravitational field. Essentially the event horizon of a black hole. There is simply no planet that can have this kind of gravity and if you try to land on the surface, it'll be so strong that it would crush you. The weight of the astronauts would be several million tons, and that's even

without doing the math. But anyhow, if they wanted to get all the science right, we wouldn't be able to enjoy the movie. After all, it's science fiction. And to make a great film, a superb filmmaker often pushes things to the extreme. But in our case today, it's sufficient enough to turn the concept of time dilation into a beautiful film.
9:25
"We'll find a way professor. We always have".
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(02)- by the difference using Einstein's equations we were able to correct the time on the ISS. Because. Because both 3+3D systems are slightly rotated relative to each other… we use a lot of references to the movie Interstellar here, we can also take one case study of how the filmmakers feel this time dilation in the movie. In the opening scene, when Cooper and his team enter Miller's planet, intense music with elements of a ticking clock starts. The tempo changes throughout the song. **One second on Miller is equal to one day on Earth**, where time dilation occurs due to the proximity of the singularity. We get roughly about 221 million seconds in seven years. This gives us a conversion factor of about 61,400 seconds passing on Earth for every second spent on Miller's planet. Multiply that by the interval between each tick and you get 77,000 Earth seconds. Or about 21 hours. So each tick you hear is almost a full day passing on Earth. And this is in addition to what is happening on Miller's planet versus Earth in real time. After grasping all this information of course we want to ask ourselves the question. Is this extreme time dilation possible on such a planet? "There is no dilation on the planet/rocket, but we observe it, !! that "it is there", because we observe a rotated system of dimensions and by that "observation" we launch ***on our observatory*** changed intervals. When I look at a panel house that is rotated towards me, I see=observe its length of 20 meters shortened on my meter in projection. Ditto with time, but in reverse. The rocket rotates its system when accelerating, and when we use our second to determine "its second", the rocket second lengthens - Yeah, yeah, it's hard to explain to the listener who "doesn't" want to understand. Could we even walk on its surface? At one point, we're told that the gravity on this planet is 130% of Earth's. We see the actors gasping for breath. A little under the strain of the extra gravity. But is that enough to cause that much time dilation? Not even close. If you visited the surface of our sun, which is not a supermassive body. **The problem with this extreme time dilation** but still much more massive than Earth, you would gain about 66 seconds per year. To get to the extreme dilation where one hour is equal to seven years, you would need such a strong gravitational field. Essentially the event horizon of a black hole. There is simply no planet that could have that kind of gravity, and if you tried to land on the surface, it would be so strong that it would crush you. The astronauts would weigh several million tons, not counting. But anyway, If they wanted to get all the science straight, we wouldn't be able to enjoy the movie. After all, it's science fiction. And to make a great movie, a great filmmaker often pushes things to the extreme. But in our case today, that's enough to >make a beautiful movie out of the concept of time dilation.
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