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PHYS 405

Term Paper Outline

The Consequences of Einstein’s Theory of General Relativity

1. Introduction
2. Discuss Bending Light from Solar Eclipse 1919 and Mercury Orbit

* “The first prediction put to test was the apparent bending of light as it passes near a massive body. This effect was conclusively observed during the solar eclipse of 1919, when the Sun was silhouetted against the Hyades star cluster, for which the positions were well known” (Putting Relativity to the Test).
* “Since almost two centuries earlier astronomers had been aware of a small flaw in Mercury's orbit around the Sun, as predicted by Newton's laws. As the closest planet to the Sun, Mercury orbits a region in the solar system where spacetime is disturbed by the Sun's mass. Mercury's elliptical path around the Sun shifts slightly with each orbit such that its closest point to the Sun (or "perihelion") shifts forward with each pass. Newton's theory had predicted an advance only half as large as the one actually observed. Einstein's predictions exactly matched the observation” (Putting Relativity to the Test).

1. When astronomers began to accept general relativity as a possible solution to many current issues with Newtonian Physics, major consequences arose.
2. Talk about the basic principal rules that general relativity is founded i.e. speed of light.

* “As a result of these principals, Einstein deduced that there is no fixed frame of reference in the universe. Everything is moving relative to everything else, hence Einstein’s Theory of Relativity” (Nola).

1. **Consequences of GR**
2. Gravitational Time Dilation and Frequency Shift

* Light sent down into a gravity well is blueshifted, whereas light sent in the opposite direction (i.e., climbing out of the gravity well) is redshifted; collectively, these two effects are known as the gravitational frequency shift” (General Relativity).
* More generally, processes close to a massive body run more slowly when compared with processes taking place farther away; this effect is known as gravitational time dilation” (General Relativity).
* Known as the Doppler Effect, the same phenomena occurs with waves of light at all frequencies. In 1959, two physicists, Robert Pound and Glen Rebka, shot gamma-rays of radioactive iron up the side of a tower at Harvard University and found them to be minutely less than their natural frequency due to distortions caused by gravity” (Nola).
* Time does not pass at the same rate for everyone. A fast-moving observer measures time passing more slowly than a (relatively) stationary observer would. This phenomenon is called time dilation” (Nola).

1. Light Deflection and Gravitational Time Delay

* General relativity predicts that the path of light will follow the curvature of spacetime as it passes near a star. This effect was initially confirmed by observing the light of stars or distant quasars being deflected as it passes the Sun” (General Relativity).
* Closely related to light deflection is the gravitational time delay (or Shapiro delay), the phenomenon that light signals take longer to move through a gravitational field than they would in the absence of that field” (General Relativity).
* Since the "higher" observer measures the same light wave to have a lower frequency than the "lower" observer, time must be passing faster for the higher observer. Thus, time runs more slowly for observers who are lower in a gravitational field” (Introduction to General Relativity).
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1. Gravitational Waves

* Just as sound waves disturb the air to make noise, gravitational waves disturb the fabric of spacetime to push and pull matter as if it existed in a funhouse mirror. If a gravitational wave passed through you, you’d see one of your arms grow longer than the other. If you were wearing a watch on each wrist, you'd see them tick out of sync” (Resnick).
* Two black holes colliding unleash a loud thunderclap of gravity. If you were near the black holes when they collided, you’d see the universe expand and contract like you were living inside a funhouse mirror. But by the time they reach the Earth — like ripples nearing the edge of a pond — they grew faint” (Resnick).
* Almost nothing is opaque to gravity. With LIGO, we could potentially listen in on the gravitational waves emanating from the early universe, or even the Big Bang, and gain a better understand of how it formed” (Resnick).

1. Black Holes- Karl Schwarzschild

* If enough mass is concentrated in a given location, the perfect geometrical prison should form - a region called a black hole” (Golm).
* Because the gravitational field around a black hole is so strong, we must use general relativity to understand the properties of black holes; indeed, most of what we know about black holes comes from theoretical studies based on general relativity” (Heckert).
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1. Primordial Quantum Black Holes – Stephen Hawking

* U.S. physicist Stephen Hawking (1942–) has combined general relativity with quantum mechanics to predict the existence of primordial quantum black holes” (Heckert).
* Hawking predicts that over sufficiently long time these small, quantum black holes—and larger black holes, too—can evaporate, that is, lose their mass to surrounding space despite their intense gravity, like drops of water evaporating into dry air. This view has replaced the earlier, too-simple belief that nothing can escape from a black hole” (Heckert).

1. Applications and Conclusion
2. Discuss the applications with GR

* One can solve Einstein's equations of general relativity for an isotropic, homogeneous universe (which ours is at large scales) and get solutions for an expanding universe that depend on the density of matter and of dark energy (the cosmological constant)” (Perrenod).
* This was confirmed by the Eddington eclipse expedition in 1919, only a few years after the 1915 date when Einstein first put forth the theory of general relativity. Which has survived every test thrown at it for 100 years now” (Perrenod).
* Kurt Gödel showed that solutions to Einstein's equations exist that contain closed timelike curves (CTCs), which allow for loops in time. The solutions require extreme physical conditions unlikely ever to occur in practice, and it remains an open question whether further laws of physics will eliminate them completely” (General Relativity).
* As a result of Energy being proportional to its mass, as an object gains kinetic energy, it gains mass. This makes an object harder and harder to accelerate as it approaches the speed of light (Nola).
* More than ninety years after the theory was first published, research is more active than ever (Introduction to General Relativity).

1. Conclude with a quick summary to wrap all the information given in the essay. Widen from the small to the biggest concepts and objects to let the reader zoom out.

Work Cited

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