SYDENHAM AND FOREST HILL SIXTH FORM

Exploring Models of the Universe: Relativity and Geometry

OCR Physics A-Level – PAG 12

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(2017-2018)

The concept of Space-Time:

Space-Time models the universe as a connection of three-dimensional space and one-dimensional time – it is thus four dimensional. Einstein's relativity predicted that mass and energy curve Space-Time, causing it to act as a gravitational field. The apparent straight path of electromagnetic radiation follows the contours in space time caused by a body of mass (the more massive, the greater potential effect), deflecting the path of the photons. There is a possibility that the gravitational distortion can act like a focusing lens to objects behind it - This phenomena is known as gravitational lensing. This is what causes the apparent round face and smile in this image.

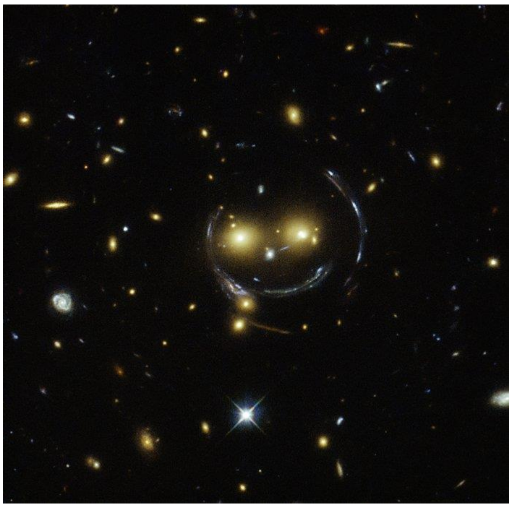


Figure 1 - A Galaxy Cluster Einstein Ring called "Smiley"

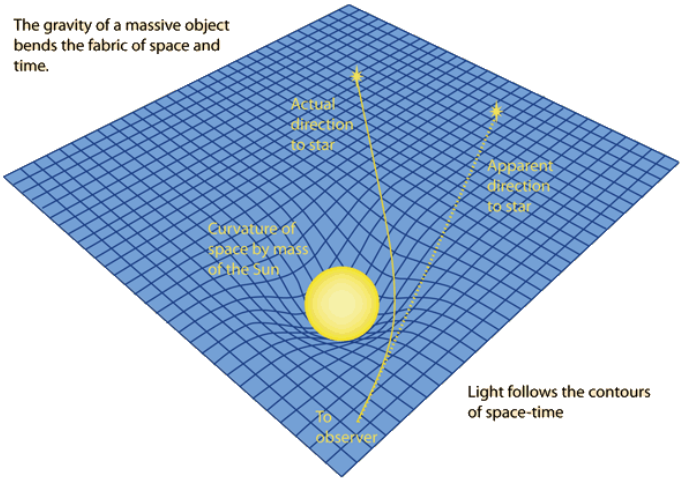


Figure 2 - Space-Time light bending

It turns out that the required mass for such distortion is much greater than the predicted mass of ordinary matter, this may be considered as further evidence for the existence of dark matter.

As Einstein predicted time dilation due to relative motion, he also predicted time dilation due to gravity. This is squarely proportional to the gravitational field strength. The result is that approaching a mass will cause time to progressively slow down.

At extreme events, such as that of a black hole, time will slow down to a complete halt. However, this is not quite how it seems – to an outside observer, in no finite time will a particle reach the horizon, meaning that an entity reaching the horizon and beyond will never be seen doing so. From the object's point of view, time does not slow, and so it will reach the horizon and beyond.

(Nave, 2017)

An attempt for a Unified Field theory:

Attempts have been made for a unified field theory, combining the electromagnetic and gravitational fields. It may not be a coincidence that electromagnetic and gravitational forces rely on the same function of distance. The shared function of distance means that, the ratio of gravitational attraction to electrostatic repulsion is independent of distance and thus can be calculating using constant properties of particles. For two electrons, the ratio is $^{1}/_{4.17 \cdot 10^{42}}$, a very small *natural* constant.[1] It has been proposed that this value could relate to the age of the universe, which is of the same magnitude when given as a relationship of *natural* units as seen below...[2]

$$^{time\ for\ light\ to\ travel\ across\ a\ proton\ (seconds)}/_{age\ of\ the\ universe\ (seconds)}$$

[1] A *natural* constant is a fundamental constant of nature, since it is calculated from *natural* units.

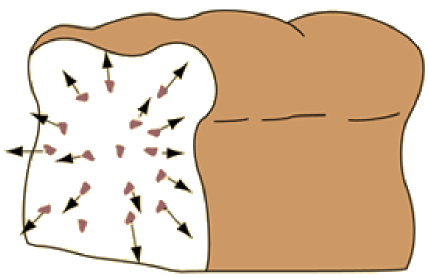
[2] A natural unit is a fundamental unit of nature, since it is derived from natural constants rather than human-devised measurements.

$$\approx {10^{-24}}/{6.3 \cdot 10^{17}}$$
$$\approx 1.6 \cdot 10^{-42}$$

If this relationship was true, then the ratio of these forces would vary with the current age of the universe. The relationship is no longer believed to be true, since the earliest life on earth would have been unable to form under Earth's conditions at the time – all water would be vapour in the air due to greatly increased temperatures from a hotter sun (a greater gravitational force would cause for a much hotter sun).

Models of the universe:

In the majority of scenarios (with the exception of some compact galaxy clusters), all galaxies see every other galaxy drifting away relatively. This is evidenced by red-shift, coupled with the modest assumption that our galaxy is not the centre of the universe. This is due to the universe's current state of expansion, analogous to the expansion of a loaf of bread being baked.



Every raisin in a rising loaf of raisin bread will see every other raisin expanding away from it.

Figure 1 - Model for the expansion of the Universe

With knowledge of the expanding universe and prior to the discovery of Cosmic Microwave Background Radiation, the Steady State Theory was the most widely accepted model of the universe. Steady State Theory proposes that the universe is always expanding whilst maintaining a constant average density through the continuous creation of matter, with no beginning or end in time. This creation of matter violates the fundamental conservation of energy, although it is argued that the creation of matter across the entire universe over time would be so negligible as to be undetectable – and thus the conservation of energy could have been accepted on experimentally flawed grounds. Cosmic Microwave Background Radiation acted as the final blow to this theory, as the absurdly large number of proposed undetected unique radio sources in the observable universe lacked sufficient evidence.

The now widely accepted alternative, the Big Bang Theory, suggests a period of rapid expansion near the beginning of time (a short time later, electromagnetic radiation was emitted, now detected as CMBR) followed by a decelerating rate of expansion. What happens to the rate of expansion will determine the future of the universe. The rate of expansion depends on the density of the universe.

Geometry of the universe:

We can compare the density of the universe to a critical density at which gravitational forces would be enough to overcome the forces causing the expansion of the universe (Dark Energy). If the density is greater than the critical density, then the expansion will stop and the universe will re-collapse. If the density is equal to the critical density, then the expansion will just stop. If the density is less than the critical density, then the expansion will gradually decrease but never stop.

These three outcomes respectively relate to three geometrical interpretations of the curvature of space (**not Space-Time**). The high-density spherical space is finite – Space curves back on itself and time has a beginning and an end. The critical-density flat space and the low-density hyperbolic space is infinite (since we do not believe the universe has boundaries/edges) – Space **doesn't** curve back on itself and time has a beginning and an end. Since all these models have no boundaries, they likewise have no centre, and thus there is no centre to space.

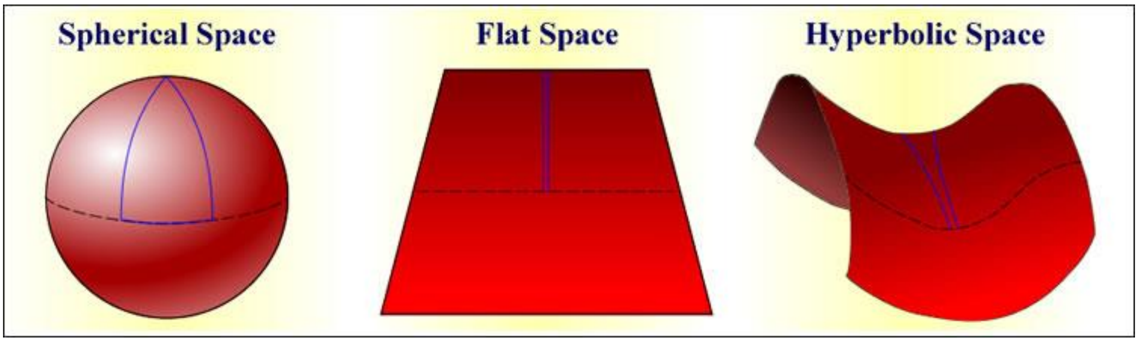


Figure 2 - Geometries for the Universe

The measured cosmic microwave background radiation has been used to calculate the mass density of the universe by calculating the amount of normal matter and using the known abundance relationships of normal matter to dark matter and dark energy. The finding is remarkably close to the critical density, with the critical density fitting within the margin of error. This suggests that space-time is in fact a flat space.

(Schombert, n.d.)

Gravitons and Gravitational waves:

The standard model has not yet succeeded at incorporating gravity amongst the other well established fundamental forces. The anticipated graviton – the force carrier of gravity, is yet to be detected. Assuming its existence, this is because it is virtually impossible to currently detect, although we know what we're looking for (a calculated particle with no mass and a spin of two). This is due to it carrying insignificant amounts of energy and undergoing very weak interactions, similar to how weak the gravitational force is in comparison to the other forces. We can however detect Einstein's proposed gravitational waves, and have recently done so.

The problem of detecting gravitons is not the end-all however, as quantum electrodynamics was confirmed by its predictions, not by the detection of photons. Similarly, a quantum theory of gravity (once completed) can be confirmed by its predictions, rather than the detection of gravitons.

The recent detections of gravitational waves originate from the merging of two black holes. As their masses combine, a fair portion of the mass is converted into energy as gravitational waves. Electromagnetic observatories are being alerted of possible detections, allowing for potential electromagnetic detection of the merge. Nothing is yet to be seen. This is unsurprising however since no light would be emitted - only the effects on photons travelling through the nearby disturbed Space-Time would be detected. Since only two detectors have previously been in operation, the position of the black holes has not been triangulated – meaning the exact vicinity of sky to look at is unknown. With the recent installation of a third detector, the position can now be triangulated, giving a much better chance of seeing the effects.

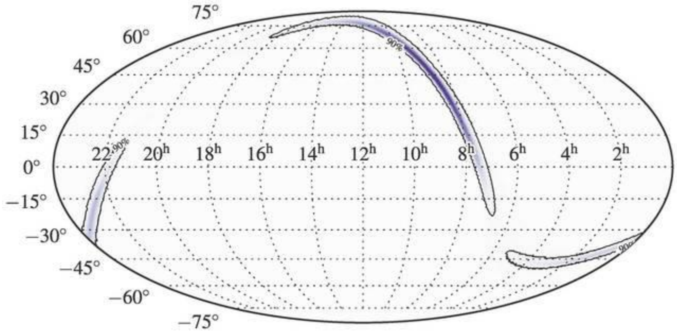


Figure 3 - The un-triangulated, potential positions of the Black Hole merger

The current detectors have measured the speed of gravitational waves to be of the same order as the speed of light, with a fairly large margin of error. Future equipment are expected to confirm the speed as being the speed of light to a greater degree of precision.

(Boughn, 2006)
(Clavin, 2017)
(Abbott, 2016)

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