TEACHER NOTES – ASTRONOMY IN THE NEWS #02
DARK MATTER MAP

Slide 2 – Background Science: Dark Matter

The Universe is made up of billions of galaxies, which contain billions of stars, which may house billions of planets. However, the matter that we can see (of which we are included), only makes up 4.9% of the Universe's mass-energy reserve. The rest is made up of dark matter (26.8%) and dark energy (68.3%). Dark energy is the name given to a force that is speeding up the expansion of the Universe, whereas dark matter is a form of matter we don't understand and cannot see due to its lack of electromagnetic radiation. The only interactions we have witnessed are gravitational.

The existence of dark matter is proposed as a solution to the "missing mass" problem, seen in galaxies. When an orbital system rotates (such as planets around stars or moons around planets) the rotation velocity should decrease the further from the centre you go. The mass is concentrated in the centre of these systems, and therefore follow Kepler's 3rd law:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

Where T is the orbital time, r is the radius, G is the gravitational constant and M is the mass at the centre of the system.

However, galaxies do not follow this rule. By measuring the velocity of gas and stars, we find that the velocity stays flat the further out from the centre they are found (if not increasing). This implies there is a missing mass.

IMAGES:

1. Pie chart showing the make-up of mass-energy density in the Universe. This highlights how little of the Universe is made-up of ordinary matter.
2. This is the Bullet Cluster, a famous example displaying the evidence for dark matter. It is a pair of colliding clusters. The galaxies in the image are an optical image, the pink emission is from x-rays and displays the ordinary matter (in this gas the hot gas of the colliding clusters) and the blue is the inferred dark matter distribution from gravitational lensing (See below). The Bullet Cluster provides evidence for dark matter as it matches predictions and models very well. The centre of mass matches the inferred dark matter distribution, rather than the baryonic mass and also doesn't match predictions produced by modified gravitational theories.
3. This is a set of galaxy rotation curves of 5 galaxies and the Milky Way. They display that the velocity stays flat instead of reducing as you go further from the centre. The expected shape is shown in the green line and represents the Keplerian motion.

Slide 3: Gravitational Lensing and the Dark Energy Survey

The Dark Energy Survey (DES) is a survey designed to map millions of galaxies to help determine the nature of dark energy. The theory of General Relativity has a term called the "Cosmological Constant", and before the accelerated expansion was discovered, it was thought to be equal to zero. However, since discovering the expanded acceleration astronomers are left with two possibilities, dark energy or General Relativity is wrong and we require a new theory for how gravity acts on cosmic scales.

The current results from DES allow scientists to trace the distribution of dark matter in the Universe using a method called Gravitational Lensing. Gravitational lensing is where a foreground body of mass bends the light from a background object around it, distorting the appearance of the background object(s). When we observe the night sky, the amount of gravitational lensing we see in most directions is very small, and not detectable in single sources, this is known as Weak Gravitational Lensing, and requires us to look at huge numbers of galaxies to search for any pattern in the way that background sources appear aligned. This way, using large statistical datasets such as that from DES, scientists can reconstruct the distribution of the invisible dark matter which forms a "cosmic web" throughout the Universe.

These results from DES demonstrate that the models of cosmology are broadly correct. However, the galaxies (and in turn the voids where gravity might be different) are too smooth which could either be due to a measurement error, our need to better understand the physics of galaxies or a change in General Relativity is required.

The original articles that this resource is built off can be found here:

https://www.bbc.co.uk/news/science-environment-57244708

https://www.theguardian.com/science/2021/may/27/astronomers-create-largest-map-universe-dark-matter-einstein

And the research article which explains the science is here:

https://www.darkenergysurvey.org/wp-content/uploads/2021/05/desy3_mass_mapping.pdf

IMAGES:

1. (Top left) This is the map of the dark matter from the DES study. This map is overlaid on top of the Gaia map of our Galaxy, which mapped the position of stars within the Milky Way.
2. (Bottom left) A zoom in on part of the dark matter map. This shows the brighter regions (where there's more dark matter and therefore more galaxies form) and the voids, where there is very little dark matter. These voids may show different physics and different gravity.

3. (Top right) A simulation of dark matter which shows the expected distribution of dark matter in the Universe. You will see that it forms the same web shape as the observed distribution.
4. (Bottom right) The Einstein cross, a gravitationally lensed quasar (a very bright galactic nucleus) with four mirrors of the same object around a foreground galaxy.

Slide 4 – Activity: Spot the Gravitational Lens

The activity is to spot a gravitationally lensed galaxy. There is an animation to this slide, which when used, indicates the position. The spiral galaxy is lensed with an obvious ring, along with a mirror image in the bottom right, and a further ring in the top right.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	8.6, 8.7, 15.3, 16.8, 16.10, 16.11
Pearson Edexcel Physics	7.6
OCR Physics B	4.3, 6.5
OCR Combined Physics	P4.3, P4.5
AQA Physics	4.8.2