TEACHER NOTES – ASTRONOMY IN THE NEWS #26

JWST IS LAUNCHED, AND FULLY DEPLOYED

Slide 2 – Background Science: The James Webb Space Telescope

The James Webb Space Telescope, the JWST, launched on Christmas Day and promises to begin a new era of space-based astronomy. The JWST, the successor to the Hubble Space Telescope, will observe the Universe in wavelengths from the visible to the mid-infrared (0.6 – 28 μm) which will make it an ideal facility to look at the earliest stars and galaxies in the Universe, star and planet formation and exoplanets. Some of these objectives will be discussed on the next slide!

JWST is a massive structure, with a 6.5-m mirror and a 14 m x 21 m sunshield. This structure was so large, that to launch it, it had to be folded and placed in the nose of a rocket to be launched into space. However, by folding this structure, this added a great deal of risk to the telescope. This structure would have to be unfolded, including the following stages:

- Unfolding a solar panel
- Unfolding, and providing tension to the sunshields. These sunshields are incredibly delicate, at the thickness of a human hair (but the size of a tennis court), with 5 layers at these dimensions.
- Unfold and deploy the secondary mirror (that's the mirror that sticks out of the front of the telescope)
- Unfolding and deploying of the primary mirror (the segmented structure)

Still to go are the small movements of the individual segments of the mirror (18 in total) and commissioning of the instruments.

A large part of the risk with the JWST is the location where it will be placed. When the Hubble Space Telescope was first launched, there was a flaw with the mirror which had to be fixed. As Hubble orbits Earth, astronauts could visit it and replace instruments which corrected this issue. However, the JWST is going to be in a stable orbit point called L2 (Lagrangian 2) which is located on the other side of the Moon from Earth, or about 1.5 million km away. Obviously at these distances, there will be no chance to make any repairs!

IMAGES:

1. (Left) A cartoon of the fully deployed JWST, and as it will look as it makes observations. The segmented primary mirror is visible, with the fully extended sunshield.
2. (Top right) Illustration of the Lagrangian points, the stable orbits that occur in three-body problems, where one body is substantially smaller and lower mass than the other two (such as a satellite and the Sun and the Earth). L1 occurs between the

Earth and the Sun, L2 is beyond the Moon away from the Sun, L3 is directly opposite the Earth at the same radius, and L4 and L5 follow and trail the orbiting Earth.

3. (Bottom right) The last image of the JWST before it headed to the L2 point, taken from the rocket that launched it.

Slide 3: Potential JWST Science

One potential area of science for the JWST is to observe the earliest stars (and therefore galaxies) in the Universe. After the Big Bang, the first stars did not form for millions of years. The first detection of light after the Big Bang is the cosmic microwave background radiation, which occurred at approximately 379,000 years after the Big Bang. This occurred when the hot plasma and radiation from the Big Bang cooled sufficiently that protons and electrons could combine to form hydrogen.

However, the first stars did not form until a much later time into the Universe. The time at which this occurred is referred to as the 'cosmic dawn' and is thought to have occurred a few hundred million years after the Big Bang. There are hints at when this would have occurred from both simulations and observations. Simulations of dark matter halos show that accumulations large enough to form galaxies that could spark star formation could occur at 150-250 Myr (million years) after the Big Bang, or at a redshift of z = 15-20.

Observations are also consistent with this age range. The ultraviolet emission of stars should alter the emission of the neutral hydrogen. The gas formed after the Big Bang will be cooling, and concentrations of it will absorb the light emitted from the Big Bang. However, once stars form, they will begin to heat the gas. Then stars die, especially the first stars which were massive, leaving neutron stars and blackholes. The x-ray radiation from these objects will further heat the gas. Eventually, the gas will become hotter than the background and a spectrum of neutral hydrogen gas across redshift should show emission prior to the formation of stars, absorption at the redshifts associated with the first generation of stars, and then emission once it becomes warmer than the background. The range for the accumulation of gas, then the heating of the gas because of stars is in the redshift range z = 16-19.

Observations of individual galaxies (i.e. the output of the stars in the galaxy) can be converted to redshifts by observing two sets of hydrogen lines, the Lyman series and the Balmer series. These lines are prevalent in stellar objects due to the high abundance of hydrogen in the Universe. They are caused by the transition of an electron from a higher energy level to either the first (Lyman) or second (Balmer). There is a break in the spectrum which is caused once an electron completely leaves the hydrogen atom, thus causing a hydrogen ion and these breaks occur at the wavelengths quoted below. The observed wavelengths can be converted to redshifts using the standard redshift formula:

$$z = \frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}}$$

Where z is the measured redshift, λ_{obs} is the observed wavelength and λ_{emit} is the emitted wavelength (i.e. the theoretical wavelength). The further back in the Universe a galaxy was formed (higher redshifts), the longer the wavelengths that the Lyman and Balmer breaks occur at, potentially into the infrared regime.

A small number of these early galaxies have been found, and by looking at the sensitivities of instruments on the James Webb Space Telescope, we should be able to observe many more of these and constrain the exact age that star formation started in the Universe.

The articles that this resource were built on can be found here:

https://www.bbc.co.uk/news/science-environment-59782057

https://www.theguardian.com/science/2021/dec/24/astronomers-on-tenterhooks-as-10bn-james-webb-telescope-set-for-lift-off

https://www.bbc.co.uk/news/science-environment-59873738

https://www.bbc.co.uk/news/science-environment-59914936

Further information about the JWST can be found here:

https://webb.nasa.gov/index.html

IMAGES:

1. (Left) Example of a galaxy spectrum in the optical and near-infrared. This example spectrum shows a galaxy at z=7, where the Hubble Space Telescope can observe the Lyman break, whilst Spitzer can observed the Balmer break. The Lyman break usually occurs at 912 Å (912 Angstroms, or 91.2nm at ultraviolet wavelengths), whilst the Balmer break occurs at 3646 Å, which is also ultraviolet. However, as you'll see in this spectrum, these features are redshifted to 1 and 3 μm.
2. (Top right) Spitzer image at 4.5 μm of one candidate high-redshift star-forming galaxies. This image is to show how hard it is to currently detect these galaxies as even using space telescopes, they are very pixelated and only a handful of pixels across.
3. (Bottom right) Model spectral energy distribution fits with predictions of the flux that should be observed in a particular line at different redshifts, in this case the 1500 Å line, which is a predictor of star-formation rate. The star-formation rate is the mass of stars per year that a system forms. By looking at these predicted line strengths, and comparing them to the different instruments and filters on the James Webb Space Telescope, we may be able to observe a large sample of galaxies which are forming stars at redshifts of z = 12-14, even to z = 16 for some galaxies.

Slide 4 – Activity: What JWST science are you most looking forward to?

This week's activity is a discussion and research activity for the students. They should use the JWST science website (https://jwst.nasa.gov/content/science/index.html) to research the science goals (such as galaxy evolution, star formation and exoplanet atmospheres). They can then discuss and decide which results they are looking forward to the most.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	11.19, 11.22, 11.25, 11.26, 11.27, 13.21, 16.1, 16.2
Pearson Edexcel Physics	5.3, 6.7, 6.8, 7.9, 7.12, 7.19
Pearson Edexcel Combined Science	6.7, 6.8
OCR Physics B	1.1.6, 1.1.7, 6.5.7
OCR Combined Science B	1.1.6, 1.1.7
AQA Physics	4.4.1.1, 4.6.2.1, 4.6.2.6, 4.8.2
AQA Combined Physics	4.4.1.1, 6.6.2.1, 6.6.2.6

A-Level Physics Specifications:

Specification	Knowledge Point
Pearson Edexcel	96
OCR Physics A	5.5.2 (a,c,e), 5.5.3 (f,h,n)
OCR Physics B	3.1.1 (a), 5.1.3 (a), 6.2.1 (a)
AQA Physics	3.2.2.3, 3.9.3.1