TEACHER NOTES – ASTRONOMY IN THE NEWS #15

INVISIBLE GALAXIES IN THE EARLY UNIVERSE

Slide 2 – Background Science: Dust Extinction & Redshifts

The material that is found between stars is called the interstellar medium, or the ISM. The ISM is made up of gas and dust, the material that will go on to form stars. The dust, however, has an impact on what we can observe. Dust in the foreground absorbs and scatters light from background objects. This absorption is extinction, and makes objects dimmer, and the scattering makes objects appear redder. However, in infrared wavelengths, more light is able to pass through the dust and allows astronomers to see what is behind the dust.

As well as existing between stars, dust is also found around starburst galaxies. Starburst galaxies are galaxies which are forming stars at a much higher rate than more normal galaxies, such as the Milky Way. Our Galaxy forms about 3 solar masses of stars per year, whereas starburst galaxies can have star-formation rates up to 100 solar masses of stars per year. Due to the starburst nature, these galaxies must have a large reservoir of gas and dust from which they can form stars with. As a result, the chance for dust to obscure our view is high.

Redshift is the shifting of an observed wavelength to a longer (or redder) wavelength which occurs as a galaxy that is far away travels away from us. However, when a redshift is calculated, it is referring to the distance a galaxy is away from, or more specifically, an age for these objects. The higher a redshift, the older an object is, and, as a result, the earlier in the lifetime of the Universe you are probing by looking at that object.

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).

IMAGES:

1. (Left) An illustration of a cloud of dust in the foreground extinguishing the light coming from the background stars. This cloud, Barnard 66, is observed in various wavelengths. In increasing wavelengths you start in the top left and then the next row starts in the bottom right, going from visible to infrared.
2. (Top right) Image of the starburst galaxy Henize 2-10. Optical wavelengths from the Hubble Space Telescope are in red, green and blue, X-rays from Chandra in purple and radio wavelengths observed with the Very Large Array are represented by yellow. This displays the level of dust and gas around this system.
3. (Bottom right) 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.

Slide 3: "Invisible" Galaxies

The REBELS (Reionisation Era Bright Emission-Line Survey) survey is a survey designed to observe 40 UV-bright high-redshift galaxies with ALMA in [CII] lines. [CII] is the single ionised state of carbon. By doing this, a large sample of these galaxies can determine how stellar mass increased at these redshifts, giving an insight to how the star-formation rate density has changed over time.

Two of these observations are featured in this paper, with one shown on this slide. The bright galaxies were observed with very solid detections and confirmed to be high redshift with values of z = 6.6847 and z = 7.347 (the one shown here). However, within the observed fields, two separate but significant features are also detected. By looking at the detections, the width of the spectral feature is too wide for it to be simply noise. There was no counterpart in optical or near infrared. The non-detection in the ultraviolet and optical indicate that these objects must be heavily-obscured high-redshift galaxies. The fact these galaxies exist is important for our understanding of the early Universe. If there is a sizeable population of these galaxies, they could contribute between 10-25% of the star-formation rate density at the redshifts probed. The range in the contribution comes from whether they are only found around other bright galaxies (as with the two observed) or if they also exist in the field.

This bulletin is slightly different to the usual bulletins in that it is not built upon a news article that was in the national media. Instead, it is built upon a press release from my host department at Liverpool John Moores University and I wanted to highlight some of the work done here. The article that this resource is built on can be found here:

www.ljmu.ac.uk/about-us/news/articles/2021/9/23/discovery-of-invisible-galaxies-deep-in-space

A free version of the research paper can be found here:

https://arxiv.org/abs/2109.10378

IMAGES:

1. (Top) Observations of one of the two "invisible galaxies". The cut outs are observations at various wavelengths from UV through to infrared through to the millimetre from the ALMA observations. The non-detection is evident at the UV, visible and infrared wavelengths, but it appears in the millimetre and [CII] observations.
2. (Bottom) The left panel is the infrared image from the VISTA telescope, with the main target galaxy the obvious bright object in the middle of the field. The white circle indicates the ALMA field, with the two cut outs showing the main target and the obscured galaxy with contours of [CII] overlaid. The right shows the spectra of these detections and the width of the feature for the obscured galaxy shows that it is a real detection.

Slide 4 – Activity: Why is red light scattered?

The activity this week is to get the students to work out why red (or infrared) light is scattered less than bluer, more energetic light. I have given the students a simplified version of the Rayleigh scattering equation as:

$$I_{scattered} \propto \frac{1}{\lambda^4}$$

Where $I_{scattered}$ is the intensity of scattered light and λ is the emitted wavelength. For completeness the full equation is:

$$I_{scattered} = I_{emitted} \frac{1 + \cos^2\theta}{2R^2} \left(\frac{2\pi}{\lambda}\right)^4 \left(\frac{n^2 - 1}{n^2 + 2}\right)^2 \left(\frac{d}{2}\right)^6$$

Where $I_{emitted}$ is the intensity of emitted light, θ is the scattering angle, R is the distance to the particle that is doing the scattering, n is the refractive index, and d is the diameter of the scattering particle.

What this equation means is that the intensity of scattered light varies as a function of λ^{-4}, indicating that blue light is more intense after scattering. The bonus question relates to the colour of the sky, where the shorter wavelengths are scattered more strongly which means blue light appears to us from all directions.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	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