TEACHER NOTES – ASTRONOMY IN THE NEWS #10

HIGH-RESOLUTION GALAXY IMAGES

This bulletin takes a different form to the usual format of Astronomy in the News. The news story that this is built upon is the production of a series of high-resolution images of galaxies using the LOFAR radio interferometer. The article can be found here:

https://www.bbc.co.uk/news/science-environment-57998940

A further press release from the LOFAR team can be found here:

https://www.astron.nl/most-detailed-ever-images-of-galaxies-revealed-using-lofar/

This bulletin will in the first slide describe the technique of producing these images, and then the second slide will introduce some of the results from these new spectacular images of galactic systems.

All of the results are described in a series of papers, all of which are free to access and can be found at this link:

https://www.astron.nl/wp-content/uploads/2021/08/papers1782021.pdf

Slide 2: High-resolution galaxy images

LOFAR, the LOw-Frequency ARray, is an array of 54 radio telescopes spread across Europe. They observe the sky at frequencies between 10 and 240 MHz, or between wavelengths of 1.25 and 30m. They are used as interferometers. Interferometry is where smaller, individual telescopes are combined to produce an image that is as it was produced using a much larger telescope. The size of this "virtual" telescope is the same as the largest distance between two telescopes. This has the effect of increasing the resolution of the resulting image due to the Rayleigh criterion:

$$sin\theta = 1.22\frac{\lambda}{D}$$

where ϑ is the angular resolution of the telescope, λ is the wavelength you are observing at and D is the diameter of your aperture (or telescope).

Although there are 54 telescopes across Europe, the most commonly used arrangement is to use the 38 receivers located in the Netherlands. These are arranged as 24 in the "core" arrangement, and a baseline (or virtual telescope size) of 4km, with the remaining 14 spread throughout the Netherlands. This wider arrangement gives a baseline of 120km. These receptors are regularly used, and allow a resolution of 6" (6 arcseconds) to be achieved at 150 MHz.

However, by using all 54 telescopes, the 38 in the Netherlands, 6 in Germany, 3 in Poland and one in the UK, Republic of Ireland, France, Latvia and Sweden, a baseline of 1989km is obtained. This gives a resolution of 0.27" at 150 MHz. The team who developed this have now made this high-resolution science possible, and some of the results are presented on the next slide.

IMAGES:

1. (Top left) An example of some of the LOFAR receivers. This shows a cluster located in the central core in the Netherlands. These don't look like usual telescopes!
2. (Bottom left) The location of the telescopes across Europe. The site in Italy is currently under construction. This displays the largest possible baseline, spreading from Birr in the Republic of Ireland to Łazy in Poland.
3. (Right) A GIF of the comparable telescope setups from the usual resolution of 6 arcseconds to the new method which allows for 0.27 arcsecond resolution. This reveals the extra detail that we can now analyse, such as the structure in the lobes of the Active Galactic Nuclei in the image in the far left.

Slide 3: New structures revealed

The first result (left-hand image) is attempting to determine the cause of the sub-structure within the lobes of the AGN from the Hercules A galaxy. AGN, or active galactic nuclei, are the emission caused by the ejecta from the central black hole found in galaxies. These lobes are massive (at least ten times larger than the Milky Way) with the galaxy barely visible in the centre of the left-hand image. The sub-structure can be seen as the rings that look like shock fronts within the emission, especially in the right-hand side lobe.

These sub-structures have two potential causes. The first is that they ware caused by shocks as the ejecta (plasma) from the AGN hits the ambient gas that is found between galaxies, called the intergalactic medium. The second is that the emission from the AGN is intermittent and the newer ejected material inflates the existing material in the inner lobes and causes this to present as ring-like structures. To determine between the two, you can take images at different wavelengths and produce a spectrum and compare these spectra to models of synchrotron emission. Synchrotron emission is where a charged particle (moving at relativistic velocities) is accelerated by a magnetic field that is perpendicular to it. If these lobes are caused by intermittent emission, there should be evidence of the synchrotron emission slowing down, (or aging) and this is what is found in this study.

The second result (right-hand image) is observations of a galaxy merger, Apr-229. The two brightest features are the two nuclei of the individual galaxies. The improved resolution has revealed the clumpy nature about the outflow from the nucleus in the left-hand galaxy. However, when comparing the spectrum (as discussed above) with models, it is more likely to be driven by star formation rather than AGN. This is in contrast to the right-hand galaxy. The improved resolution has revealed a tentative detection of a outflow, which is likely to be AGN driven.

IMAGES:

1. (Left) 150 MHz image of Hercules A at 0.27” resolution. The galaxy is barely visible in the centre, with the two lobes of the AGN dominate the image. The right-hand lobe displays sub-structure of inner rings inside the main lobe.
2. (Right) 150 MHz image of Arp-229 at 0.27” resolution. Two merging galaxies, with the brightest points the two nuclei of the respective galaxies. The outflow is evident from the left-hand galaxy, with tentative evidence from the right-hand galaxy.

Slide 4 – Activity: How long are the outflows from Hercules A?

The distance to the Hercules A galaxy is known to be 575 Mpc. Using the fact that the lobes are measured to be 190 arcseconds, can the students calculate the length in units of kpc using trigonometry.

The correct answer is ~530 kpc. The correct function to use is tangent (although advanced students may use the small angle approximation), with the adjacent side taken as the distance and the opposite is the outflow length to be calculated.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	11.20, 11.21, 11.22, 13.10, 13.11, 13.25, 13.26, 13.27, 15.10
Pearson Edexcel Physics	1.2, 5.11, 12.7, 12.14
Pearson Edexcel Combined Sciences	1.2, 5.11, 12.7
OCR Physics B	1.1.7, 3.5.2
OCR Combined Science B	P1.1.7, P3.5.2
AQA Physics	4.6.1.2, 4.6.2.3, 4.7.1.2, 4.8.1.2
AQA Combined Science: Trilogy	6.6.1.2, 6.6.2.3, 6.7.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
Pearson Edexcel Physics	1, 60, 122
OCR Physics A	1.1.3(b), 2.1.2(e), 4.4.1(d), 5.5.3(a), 6.3.2
OCR Physics B	1.1.3(b), 2(b), 3.1.1(b)
AQA Physics	3.1.1, 3.3.1.1, 3.9.1.4,