TEACHER NOTES – ASTRONOMY IN THE NEWS #04

X-RAY MAP OF THE GALACTIC CENTRE

Slide 2 – Background Science: Galactic Centre

The Galactic Centre is the centre of our Galaxy, the Milky Way. It is the most extreme environment within the Galaxy. It contains a supermassive black hole (Sagittarius A*, Sgr A*), which is between 3.6 and 4.3 million times more massive than our Sun. Sgr A* is currently quiescent, and not active. However, the past activity has influenced the Galactic Centre massively. It has an impact with its strong gravitational force, the structure of the Galactic Centre, the kinematics and the ionisation of the interstellar medium (ISM) of the Galaxy.

The Galactic Centre is unlike any other regions of the Milky Way. The conditions of the gas there are orders of magnitude greater than those found near the Sun. The gas densities, gas pressures, cosmic ray ionisation and UV field are more similar to those found at redshifts of 1-3. This is important as most stars in the Universe formed in that range of redshifts, when the Universe was between 6 and 11 billion years old. Therefore, if we can understand the star formation in the Galactic Centre, we may be able to understand the star formation across the Universe.

However, the star formation in the Galactic Centre is currently very low compared to the rest of the Galaxy. Star formation occurs in molecular gas (the most abundant molecules are hydrogen and carbon monoxide) and more specifically in the densest regions of that molecular gas. The Galactic Centre contains 10% of the molecular gas of the Milky Way, but 80% of the dense gas. This would imply that the star formation rate there should be high, but it is orders of magnitude lower than more “normal” regions of the Galaxy.

There are approximately 10 million within a parsec (3.26 light years) of the Galactic Centre, but they appear to be old and of the class of red giant stars. However, there are massive stars which implicates that there was a “recent” star-formation event within the last few million years, probably 2-7 million years ago. These massive stars are a mystery as the tidal forces caused by Sgr A* should have stopped them from forming.

The Galactic Centre has streams of molecular clouds (concentrations of the molecular gas) which are very high in temperature (60-120 K, where typical molecular clouds are approximately 10 K).

IMAGES:

1. (Top left) Image of the Milky Way from the Gaia satellite. This satellite observed stars and mapped their position in the Galaxy. This image shows the Galactic Centre as the brightest point in the central regions.
2. (Top right) Optical image of the Arches cluster, one of the clusters containing massive stars within the Galactic Centre. This image displays the infrared emission

from the cluster, as the optical emission is obscured by the dust and gas present in the Galactic Centre and the 26,000 lightyear distance between the Sun and there.

3. (Bottom) 500-µm map of the Galactic Centre from the Herschel Space Observatory. This zoom-in (compared to the Gaia image) indicates the turbulent nature of the region with lots of substructure apparent. This also shows the orbital pattern of the molecular clouds around SgrA*. There is a figure eight/infinity symbol shape that is apparent and the clouds on this orbit are subject to high amounts of tidal forces from the central blackhole.

Slide 3: X-Ray Map of the Galactic Centre

The majority of x-ray emission in the Universe is from gas at coronal gas temperatures. Coronal gas is made up of a hot plasma or protons and electrons, the gas is ionised. This makes the Galactic Centre a perfect laboratory to study x-ray emission due to the high temperatures that are observed, and radiation fields from SgrA*.

The Chandra X-Ray observatory is a space based telescope that observes the sky at x-ray wavelengths. The observatory needs to be space based as the atmosphere is opaque to x-rays. Chandra has observed the Galactic Centre over 370 times, for a total of 72,000 seconds (20 hours) during the 21 years of observatory operation. The result of this is shown in the slide. The first image (no animation) shows three different versions of this map. The first shows different x-ray wavelengths. Red is the lowest energy, green the intermediate and blue is the highest energy. The middle one is the red map from the first image, showing up the large-scale structure, indicating the plumes that are coming out from the Galactic Centre in the north and south directions. The final panel is a combination of different wavelength regimes. The blue is the Chandra low-energy map (from the middle panel), red is radio wavelengths and green shows the infrared. This map highlights stellar clusters, such as the Arches cluster.

The combination of x-ray with radio wavelengths shows that the Southern plume is an x-ray emitting plume enclosed by a radio lobe. This implies there is hot plasma confined by a strongly magnetised medium.

After the animation, a zoom-in of the Galactic Centre is shown in radio wavelengths. The major features are the large bubbles, which are from structures such as clusters of stars and supernova remnants, and the thin filaments. These thin filaments are non-thermal in nature (i.e. not gas that is heated up) but rather synchrotron emission. Synchrotron emission is where a charged particle (moving at relativistic velocities) is accelerated by a magnetic field that is perpendicular to it. Some of these features are evident in close up maps of the x-ray emission. These features further highlight the ionised gas and the strong magnetic fields both present in the Galactic Centre.

The article that this resource was built from is here:

https://www.theguardian.com/science/2021/may/29/nasa-milky-way-image-downtown

A free version of the research paper it is built upon can be found here:

https://arxiv.org/abs/2010.02932

IMAGES:

1. X-ray maps from the research paper. The first map displays three different wavelength bands of x-ray emission. The middle map is the lowest energy map from the first map. This demonstrates the large-scale structure. The final map is a combination of x-ray, radio and infrared emission. This map demonstrates all the structures that ionise gas in the Galactic Centre, such as supernova remnants and stellar clusters.
2. (Animated image) Zoom in of the Galactic Centre from the MeerKAT survey (a precursor to the Square Kilometre Array) in the radio wavelengths.

Slide 4 – Activity: Drawing magnetic field lines

The suspected synchrotron radiation (the thin filaments) traces the magnetic field lines as if this scenario is correct, they would be fast moving electrons (and positrons). Can the students draw some of the magnetic field lines in the Galactic Centre? These lines are part of the overall field and should run along the lines of these filaments. The overall magnetic field can be found here:

https://apod.nasa.gov/apod/ap150127.html

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	6.1, 6.21, 13.11, 13.22, 13.27, 13.32, 14.9, 14.10, 14.11, 15.9, 15.10
Pearson Edexcel Physics	2.18, 5.10, 5.11, 7.16, 7.19, 12.7, 12.14
Pearson Edexcel Combined Sciences	2.18, 5.10, 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	4.5.1.3, 4.6.1.2, 4.6.2.3, 4.7.1.2, 4.8.1.2
AQA Combined Science: Trilogy	6.5.1.3, 6.6.1.2, 6.6.2.3, 6.7.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	4.4.2, 5.4.2, 5.5.1, 6.3.1
OCR Physics B	5.1.2, 6.1.2
AQA Physics	3.7.2.1, 3.7.5.2, 3.9.1.3, 3.9.2.5