TEACHER NOTES – ASTRONOMY IN THE NEWS #22

A BLACK HOLE IN A YOUNG STELLAR CLUSTER

Slide 2 – Background Science: Globular Clusters and Black Holes

Globular clusters are spherical collections of stars, bound by gravity. They contain hundreds of thousands of stars, which are densely packed, and are often quite old. As a result, the stars in these clusters are often low-mass. These structures were originally thought to be formed all at the same time. However, recent observations have shown that multiple populations (i.e. multiple episodes of star formation) are present. This has thrown formation theories up in the air.

These clusters, as mentioned above, are very densely packed, with stars often much closer than the Sun is to its nearest star. There are, on average, 0.4 stars per cubic parsec (a parsec is 3.26 lightyears) which increases to up to 1000 stars per cubic parsec in the most central regions. Around the Sun, the density of stars is approximately 0.1 stars per cubic parsec. This tightly packed nature is thought to inhibit planet formation and the existence of planetary systems.

Massive stars end their lives in violent core-collapse supernovae. These events impact stars which have an initial mass of greater than 8 solar masses. Stars that are greater in mass than 40 solar masses leave behind a black hole. However, the detection of these black holes is very difficult since they are invisible in optical wavelengths! There are currently three ways of detecting black holes: the detection of gravitational waves from a collision with another compact object; the indirect measure of radio, x-ray or gamma-ray emission that comes from matter accreting onto the black hole; and the detecting the motion of a visible companion in a binary system.

IMAGES:

1. (Left) Hubble Space Telescope image of Hercules, or M13, a globular cluster. This image shows how many stars are present in a globular cluster, as well as displaying the various ages and sizes (through the different colours) that can be present within one of these systems.
2. (Top right) Cartoon demonstrating the different life cycles of stars depending on their initial mass. The top row is for stars less massive than 8 solar masses, whilst the bottom row is for stars with an initial mass of 8 solar masses or greater. A further differentiation is made with the most massive stars at 40 solar masses, where below that the supernova leaves a neutron star, whilst greater than that, a black hole remains. This demonstrates how two binary stars could form a star and a black hole (as shown on the next slide!)
3. (Bottom right) A gif demonstrating the motions of two stars in a binary system. Although not representative of the system that will be described on the next slide, it does illustrate how the orbits of the two objects can impact each other.

Slide 3: Discovery of a Black Hole in a Young Globular Cluster

The Large Magellanic Cloud (LMC) is a galaxy within the Local Group, the group of galaxies the Milky Way is a part of. In the LMC is a young massive globular cluster, NGC 1850, a cluster that is approximately 100 million years old (young in astronomical terms). A cluster that young should contain more massive stars than a typical globular cluster would host. However, by that time, the most massive stars will have already died by supernova, either leaving a neutron star or a black hole.

Within this cluster, binary systems will have formed, a system where two stars orbit each other. However, this allows for the detection of these compact objects by monitoring the motion of stars. In this paper, the motion of a star is monitored, a star that has no optical counterpart. The velocity spectrum of the star, along with the light curve, is a signature of an elliptical orbit. By looking at x-ray data, a counterpart is found, which would confirm the presence of a black hole. This is a significant detection as it will influence globular cluster studies (a starting point for initial masses of black holes in clusters), the studies of binaries, the search for compact sources, and for measuring the masses of black holes.

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:

https://www.ljmu.ac.uk/about-us/news/articles/2021/11/11/stars-odd-behaviour-gives-up-hidden-black-holes

with a further write-up from the European Southern Observatory (ESO), the observatory responsible for the telescope that was used to make this discovery:

https://www.eso.org/public/news/eso2116/

A free, permanent version of the research article can be found here:

https://arxiv.org/abs/2111.06506

IMAGES:

1. (Left) Detection of the orbit period of the star with its companion black hole. The companion black hole is not detectable in the optical wavelengths. The top panel is the velocity over the phase, showing the orbital period. The two lower panels are light curves in different wavelengths. The double peak compared to the velocity period shows that it is an elliptical orbit.
2. (Top right) Two images of the NGC1850 cluster. The left-hand image is the new data presented in this paper and is from the MUSE instrument upon the VLT. It is integrated over all visible wavelengths. In this image, you can pick out a lot of the individual stars. The right-hand image is archival Hubble Space Telescope image, with the observed star marked by the red lines.

3. (Bottom right, left) Optical image from the Gaia satellite of the Large Magellanic Cloud, the second or third closest galaxy to the Milky Way. It has a bar that is off centre, with one spiral arm. This implies it has been gravitationally disrupted by either the Small Magellanic Cloud and/or the Milky Way.
4. (Bottom right, right) Optical 3-colour image of NGC1850, the young massive cluster hosting the black hole. The blue and green colours show those two filters, respectively, whilst the red colours show the H-alpha line.

Slide 4 – Activity: Research Activity

The activity for this bulletin is for the students to research a topic that isn't understood in astronomy, and that is the formation of globular clusters. As described above, multiple populations of stars have been found in these clusters. As a result, basic formation mechanisms from one molecular cloud are not thought to be the method. The students should look into these theories and try to answer the questions on the slide. I don't want to encourage Wikipedia research, however, the section on "Formation" on the Globular Cluster page is a good place to start.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	6.1, 7.6, 13.11, 13.17, 13.33, 14.6, 14.10, 14.11, 15.4, 15.5
Pearson Edexcel Physics	7.18
AQA Physics	4.8.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	5.5.1(e), 5.5.3(b)
OCR Physics B	5.1.3(c)
AQA Physics	3.9.2.6