TEACHER NOTES – ASTRONOMY IN THE NEWS #19

THE SOLAR SYSTEM AFTER THE SUN DIES

Slide 2 – Background Science: Evolution of the Sun

The Sun is a G-type main sequence star. It is classified as a G star due to two prominent ionised calcium lines. Stars with this spectral type are low in mass, with a range of 0.9 – 1.1 solar masses. Low mass stars end their lives with a whimper, unlike their higher-mass counterparts which explode with violent supernovae. These low-mass stars exhaust their hydrogen fuel, and this causes the core to contract. This contraction leads to an expansion of the star. However, the gravitational collapse in the core allows for the remaining hydrogen to begin burning in a shell around the core. In this time, the Sun has expanded and engulfed Mercury and Venus, and maybe Earth.

Once this hydrogen is exhausted, the contraction of the core and expansion of the star restarts. The core collapse eventually causes helium burning to begin. Once the helium burning is completed, the expansion of the Sun continues, with the Sun getting larger and larger. At this point, burning continues in shells of hydrogen and helium alternatively, with Earth almost certainly engulfed.

This begins the mass loss phase, turning the Sun into a planetary nebula with a core left at about half the mass of the current Sun. This core will cool, leaving a white dwarf.

IMAGES:

1. (Top left) 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.
2. (Bottom left) Cartoon depicting the evolution of the Sun every billion years. It is formed from a molecular cloud and then spends until 5-6 billion years in a very steady state on the main sequence. At which point, it remains on the main sequence but starts to get warmer and larger. At approximately 10 billion years, it has expanded to a red giant star, and by 11 billion years will have lost the outer shells as a planetary nebula, leaving a white dwarf.
3. (Top right) Illustration of the new size of the Sun after it becomes a red giant in the context of the planets. The Earth is possibly on the edge of the star, but would not be habitable, whilst Mercury and Venus will be engulfed by the expansion. At this point Jupiter and Saturn would be in the habitable zone.
4. (Bottom right) Size comparison between the Sun now and as a red giant star. The Sun would be approximately one hundred times larger.

Slide 3: Planet orbiting a White Dwarf

A microlensing event was observed. A microlensing event is a form of gravitational lensing, caused by a smaller body. Gravitational lensing is when the background light is bent by the gravitational field of a foreground object, causing either multiple images or distorted images. However, small objects (like planets) don't cause distortions large enough to be detected by current telescope technology. As a result, the way to detect these events is to observe an object over time, and see the change in brightness as the two objects move relative to each other. The light curve, and shape of it, can then be compared to models to give the masses of the bodies involved.

Predictions of the mass of the star and planet were made, giving estimates of 0.15 – 0.93 solar masses for the star and 0.5 – 2.1 Jupiter masses for the planet. Observations of the expected main sequence star predicted the motions the star would make over time. However, these predictions did not match the observations.

Therefore, the observations were looked at again to try to find what was causing the lens. However, when the identified regions were observed, no star was found. As the mass limit of these objects is so low (thus ruling out a black hole or neutron star), and no main sequence star was observed, it was determined it must be a white dwarf that is causing the lensing. As a result, this is confirmation that a Jupiter sized planet can survive the death of a star with a similar mass to the Sun.

The article that this resource is built off can be found here:

https://www.theguardian.com/science/2021/oct/14/what-will-happen-after-the-sun-dies-serendipitous-discovery-gives-clues

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

https://arxiv.org/abs/2110.07934

IMAGES:

1. (Top left) Follow-up observations of the microlensing event with the Keck observatory. Panel a) shows the wide angle of the region, whilst b) is a zoomed in version. c) is the same image but with contours showing where the lens should be after 3 years (panel b was taken in 2015, whilst c was in 2018). There is no object visible here, with the only other object an unrelated main sequence star in the upper left.
2. (Bottom left) Light curve of the microlensing event. The different colours are observations from different telescopes. The lines drawn on the graph are different models of the microlensing event. The grey dashed line is if one object was causing the lens (i.e. just a star with no planet) whilst the black line implicates more than one object, i.e. a planet orbiting a star.
3. (Right) Parameter space of the microlensing star. On the x-axis is the distance to the star, whilst the y-axis is the magnitude (brightness) of the star. The detection limit of

Keck is shown as the horizontal white line, with everything above that detectable. The curved white lines are lines of constant mass in the range of stellar masses causing the lens. The white band is further constrained range for the star, with the entire band observable with Keck. The fact that there is no detection indicates that it must be a white dwarf.

Slide 4 – Activity: Relative distance of planets

The best way to visualise how differently sized the Sun will be is to visualise it in the context of the Solar System. If we take the unit of the "astronomical unit" (the distance between the Earth and the Sun) to be 1m, then the current Sun is 1cm across. We can then model where the planets are. By cutting out circles and placing them where the planets are (distance to scale, not the planet sizes), we can see the gap between the planets. Then if we imagine that the Earth will be engulfed by the red giant Sun, we can see how differently the size will change after it has reached this phase.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	6.1, 7.6, 11.1, 11.9, 13.1, 13.5, 13.6, 14.4, 14.9
Pearson Edexcel Physics	7.2, 7.3, 7.16, 7.17
OCR Physics B	6.5.1
AQA Physics	4.8.1.1, 4.8.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	5.5.1(c)
AQA Physics	3.9.2.4