TEACHER NOTES – ASTRONOMY IN THE NEWS #29

HABITABLE PLANET AROUND A WHITE DWARF

Slide 2 – Background Science: The Goldilocks Zone

The search for habitable exoplanets concentrates on finding conditions that are similar to those found on Earth, as we currently have no other safe assumption that we can make. As a result, the search concentrates on the conditions that allow for liquid water to exist. This Habitable Zone, or Goldilocks Zone, is calculated using the distance of the planet from the star as well as the mass of the star. Both of these quantities impact the temperature at the surface of the planet, with the closer to the star the planet is, the hotter it is, whilst the larger the star, the further away the planet is required to be to be in the Habitable Zone.

The Habitable Zone relies on some level of the greenhouse effect to govern the surface temperature and allow for surface water. The inner edge, where Venus is located, has a runaway greenhouse effect, ensuring water is not sustained in a liquid state. Whereas, the outer edge has CO_2 condensation which prevents the sustaining of liquid water as the greenhouse effect is not sufficient enough.

The Habitable Zone is also dependent on the atmosphere of the planet. Dryer planets can be further inwards, where there is little surface water, where hydrogen-rich atmospheres can be further away from the host star.

There are also other possibilities for life, such as the inside of Titan, where there is thought to be a subterranean ocean. Titan, orbiting Saturn, is clearly outside of the Habitable Zone. However, the protection of the crust, along with the internal heating can potentially produce the conditions for life.

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 star will have expanded. In the Solar System, the Sun may reach the orbital radius of 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 star continues, getting larger and larger. At this point, burning continues in shells of hydrogen and helium alternatively, with further expansion.

This begins the mass loss phase, turning the star into a planetary nebula with a core left at about half a solar mass, but in the range of 0.15 to 1.2 solar. This core will cool, leaving a white dwarf.

IMAGES:

1. (Left) Cartoon depicting the Goldilocks Zone for three stars, one hotter than the Sun, a Sun-like star and one colder, such as a white dwarf. The green area is the Habitable Zone (Goldilocks Zone), which is found further away from the star in hotter stars, and closer in cooler stars. The red zone is where surface water would be lost to due to evaporation and the runaway greenhouse effect, whereas the blue zones are where water would be frozen.
2. (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.

Slide 3: Habitable Planet around a White Dwarf?

Observations of the white dwarf WD 1054-226 with ULTRACAM on the New Technology Telescope in Chile at ultraviolet and visible wavelengths displayed a periodic feature in the light curve of the object This period lasted 25.02 hours. Within that period, there is a series of dimming events that occur at every 23.1 minutes.

If this periodicity is caused by a planet, the existence of features all along the light curve imply constant obscuring by occulting gas and dust. This planet is at a distance from the white dwarf, and with the stellar parameters of the star, that places the planet in the Habitable Zone. Future observations of other close by white dwarfs will determine how common planets around these objects.

The cause of the dimming events every 23 minutes is unclear, with many theories postulated but none of them are able to completely explain the observations, such as an unseen object which orbits 65 times for every one orbit of the potentially detected planet, but this does not convincingly describe the features seen.

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

https://www.bbc.co.uk/news/science-environment-60325010

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

https://arxiv.org/abs/2109.06183

IMAGES:

1. (Top left) Light curve of WD 1054-226 over three nights of observations. The observations from each of the nights are lined up to match features that occur along the 25.02 hour period.

2. (Bottom left) Cartoon of detecting the transit method. The top is an image showing the orientation of the planet and stars, whilst the lower panel is the light curve of the light reaching Earth. As the planet is not in front of the star, the brightness of the star is at 100%, whereas when the planet is in front of the star, a dimming occurs. This will occur periodically, with the period length the same as the orbit period of the planet.
3. (Top right) Combined light curves for two sets of observations, 13 nights in 2019 and 5 nights in 2020. The light curves are as a function of orbital phase, which is the fraction of the completed orbit, or of the 25.02 period observed. These two lines show that although the depth of the features varies, the periods of them are very much coincident across the two observing runs.

Slide 4 – Activity: How far away from the star is the planet?

The activity for this bulletin is a maths based one and requires a couple of calculations. The first is to use the information on the slide (speed and time of an orbit) to calculate the distance travelled. This distance can then be used as the circumference of a circle, and calculating the radius gives a value of 3.70 solar radii. This compares well to the value of 3.69 solar radii found in the paper.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	3.4, 12.4, 12.6, 13.8, 14.9
Pearson Edexcel Physics	2.6, 7.16
Pearson Edexcel Combined Science	2.6
OCR Physics B	4.2.1
OCR Combined Science B	4.2.1
AQA Physics	4.5.6.1.2, 4.8.1.2
AQA Combined Science: Trilogy	4.5.6.1.2

A-Level Physics Specifications:

Specification	Knowledge Point
OCR Physics A	5.5.1(c,d)
AQA Physics	3.9.3.4