TEACHER NOTES – ASTRONOMY IN THE NEWS #11

HYCEAN PLANETS

Slide 2 – Background Science: Planet Habitability

The search for life on other astronomical bodies spans from looking at other Solar System planets (such as Venus; bulletin #08) and moons (Titan; bulletin #01) to looking at exoplanet systems.

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 Goldilock's 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.

IMAGES:

1. (Left) The Habitable Zone illustrated for a series of stellar masses, from 0.2 to 2 solar masses. The square and triangular symbols represent detected exoplanets, with the shape and colour of the symbol indicating the method by which the planet was discovered. Earth, along with the Solar System planets, are plotted on the axes. Mercury is not in the Habitable Zone, whilst Venus, Earth and Mars are located in one of the interpretations of this Zone. The green region represents dry planets, where there is very little humidity and low levels of surface water. The light blue represents Earth-like planets with N_2-H_2-CO_2 atmospheres whilst darker blue shows the region where the atmosphere is hydrogen-rich.
2. (Right) Depiction of the properties of water as a function of pressure and temperature. The blue regions show where water is in ice form, whilst green is

liquid, and yellow is vapour. Venus, Earth and Mars are labelled, where Mars is at the triple-point, Earth is solidly in the liquid zone and Venus is in the vapour region.

Slide 3: Hycean Planets

The vast majority of exoplanets detected are between 1 and 4 Earth radii. These planets are either named super-Earths or mini-Neptunes, with no solid consensus on a name. The fact that there is no Solar System analogue of these planets adds to the confusion over the names with predictions made on their composition, either rocky terrestrial or ice giants. To demonstrate this. All terrestrial planets have radii smaller than Earth, whilst the gas giants have Radii ratios, compared to Earth of 11.21, 9.45, 4.01, and 3.88 for Jupiter, Saturn, Uranus, and Neptune, respectively.

This paper identifies a potentially new population of planets called hyceans. These planets have hydrogen-rich atmospheres with a surface ocean underneath this atmosphere. They are too large to have rocky interiors, as they would have radii above 1.6-2 Earth radii and less than 4, i.e. Neptune.

These planets could have the correct conditions to sustain life, and they would have water mass fractions as high as 90%, with an equilibrium temperature of 500K, and an atmospheric pressure of 1000 bar. The habitable conditions would be found at the surface and would be similar to those found on Earth at 395K and 1000 bar.

There are obvious molecules that are indicators of life, such as O_2, O_3, and CH_4 (methane). However, the complication with these species are that life originated on Earth before O_2 and O_3 and methane is produced on Mars without life by a process called serpentinization. There are molecules which are definitely produced by metabolism, such as dimethysulfide (DMS), dimethyldisulfide (DMDS), methanehiol (CH_3SH) and carbonysulfide (OCS). H_2-rich atmospheres, such as hyceans, could show these molecules at a stronger rate than the rocky, interior planets like Earth. As a result, to detect life on exoplanets, it may be easier to detect these biomarkers with new telescopes, such as the James Webb Space Telescope or the Extremely Large Telescope in a much less-expensive way than the Earth-like planets. This both due to the abundances in the atmosphere and the larger planetary radii.

If these findings are proven to be true, we may be in a position to detect life in other planetary systems within the next 2-3 years.

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

https://www.theguardian.com/science/2021/aug/26/mini-neptune-beyond-solar-system-may-soon-yield-sign-life-hycean-exoplanet-cambridge-astronomer

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

https://arxiv.org/abs/2108.10888

IMAGES:

1. (Top left) Mass-radius plot of planets, with the hycean region indicated. The grey, green and brown dotted lines represent 100% Iron, 100% Silicate and Earth-like planets. An entire planet made out of water is the blue dashed line, whilst the cyan shaded region and red regions are the hycean planets and dark hycean planets. The dark hycean planets are those planets which are tidally locked, i.e. don't rotate, so the dayside is too hot for life, but the nightside would have suitable conditions for life. A sample of observed planets are plotted in this plane.
2. (Bottom left) Synthetic spectrum from a potential Hycean planet, K2-18b. The data points on the spectrum are synthesised observations using the James Webb Space Telescope. On this spectrum are the wavelengths of lines which are linked to biological and metabolic activity.
3. (Top right) Artist's impression of the James Webb Space Telescope which is expected to be launched in November 2021.
4. (Bottom right) The Habitable Zone for Hycean planets. This plot demonstrates that potentially habitable planets which are much larger than Earth can be found at similar orbits to that of Earth. The dark hycean region is indicated, whilst cold hyceans are also there. Cold hyceans are planets which have no irradiation from the host star, i.e. too far away from the star.

Slide 4 – Activity: What can protect larger planets from stellar activity?

Stars, especially those which we have found planets around, tend to be more active than our Sun. This stellar activity includes coronal mass ejections, stellar winds and high UV flux, all of which erode the atmospheres of the nearby planets. This erosion would impact the planet's ability to sustain the conditions for life.

However, larger planets (i.e. larger than Earth) are slightly more protected from this effects. What reasons can the students think of for this? Three possible reasons are higher gravitational pull of the planet which stops the atmosphere escaping the planet, higher magnetic fields, which deflect the stellar winds as these winds are ionised, and thicker atmospheres, which protect from the UV flux of the stars.

GCSE Specifications:

Specification	Knowledge Point
Pearson Edexcel Astronomy	12.4, 12.5, 12.6
Pearson Edexcel Physics	5.13, 7.3
Pearson Edexcel Chemistry	2.1, 8.19, 8.26
Pearson Edexcel Combined Science	2.1C, 8.19C, 8.26C, 5.13P
OCR Physics B	1.1.5, 6.5.1
OCR Chemistry B	1.1.1, 1.1.4, 1.1.5, 1.1.8
OCR Combined Science B	C1.1.1, C1.1.4, C1.1.5, C1.1.8, P1.1.5

AQA Physics	4.6.2.2, 4.8.1.1
AQA Chemistry	4.2.2.1, 4.9.1.2, 4.9.1.3
AQA Combined Science: Trilogy	5.2.2.1, 5.9.1.2, 5.9.1.3, 6.6.2.2, 6.8.1.1