Lesson 1

To infinity and beyond

Plotting the orbits of planets in our own and distant solar systems

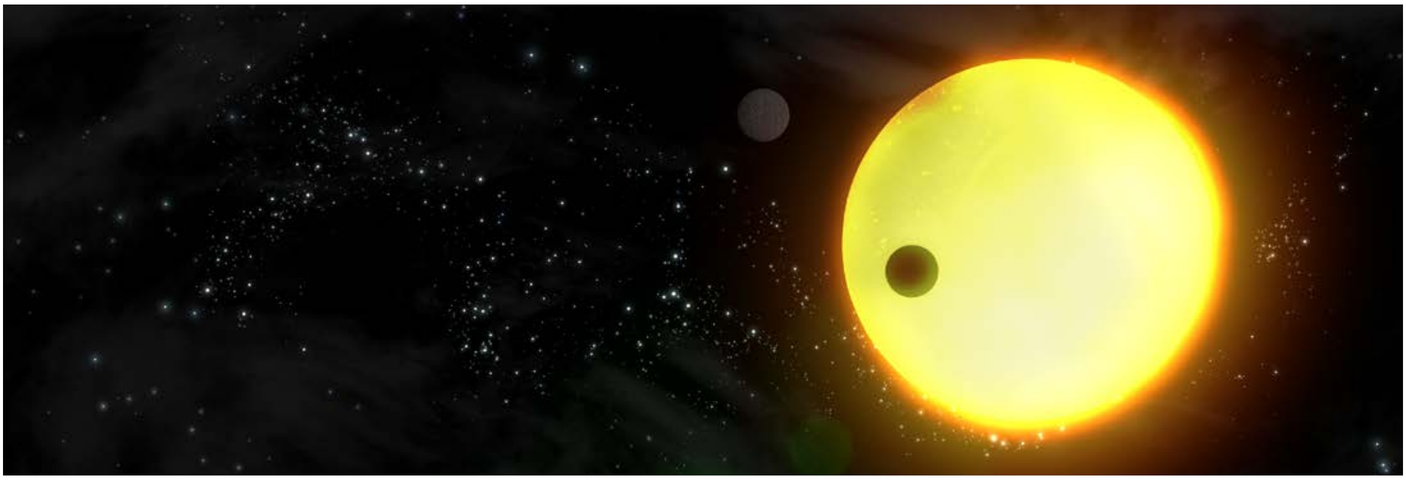
Curriculum links

England Earth and space | Light | States of matter | Living things and environment

Scotland Space

Wales The sustainable earth

Northern Ireland Measures/Number | World Around Us | Place in the Universe



Background

The distances between planets and the stars they orbit are measured in astronomical units or AU. Earth is 1 AU from our star, the Sun. The region around a star that is neither too hot nor too cold and where water could exist in liquid form is known as the Goldilocks or habitable zone. In this activity, the children plot the position and orbits of Earth and other planets in our own solar system; they then calculate the position of the Goldilocks Zone. They learn that there are other solar systems where planets orbit stars other than our Sun; by plotting the positions of these distant exoplanets, they discover which are potentially habitable.

Objectives

To learn:

- our solar system consists of eight planets orbiting our star, the Sun
- Earth orbits the Sun in the habitable or Goldilocks Zone
- other solar systems exist in space
- to interpret information and scales and use decimals to plot orbital distances of planets

Resources per group of four

60cm x 60cm square of black paper x2
60cm square of polystyrene or foam board x 2 (optional)
Plasticine of various colours (optional)
Cocktail sticks (optional)
A4 paper
Metallic pens/coloured chalks/coloured pencils
Calculator
Scissors
Glue stick
Solar system fact cards x 4
Exoplanet fact cards x 4
Solar system Goldilocks Zone calculation cards x 2
Exoplanet Goldilocks Zone calculation cards x 2
Solar system planets order of size template

Advance preparation

All classroom sessions involve the children working in groups of four. A set of role badges for 'galactic astronomer' should be prepared before the lesson if the teacher wishes to use them. (Appendix 1).

Draw the two axes, marked into 1cm divisions on sheets of black paper before attaching to the backing boards. (See the diagram in teacher information).

Two sides of one board may be used instead of two separate boards, by attaching a second sheet of black paper to the reverse of the board. Alternatively, planets cut from paper and coloured in can be stuck onto their orbits on the black paper, without attaching the paper to a board.

Photocopy Activity sheets 1a and 1b onto card, cut into individual cards. Provide solar system fact cards for all groups. In addition, prepare a different set of exoplanet information cards for each group. Goldilocks Zone calculation cards are required for all groups.

Introduction

Ask the children if they know what a planet is. Can they name any planets in our solar system? How many are there? Do they know which planet we live on and the name of our star?

Show an animation of a solar system eg Paxi and the Solar System: https://www.stem.org.uk/rx34sc

In groups, the children act out the orbits of Earth and the moon around the Sun. They can also demonstrate the orbits of other planets in our solar system. If available, 3D models of the planets can be shown. An activity from the Royal Observatory, Greenwich, has a useful activity using fruits to show the relative masses of the planets, placed in order of distance from the Sun. www.stem.org.uk/elibrary/resource/31649/fruit-solar-system

Explain that we need water to exist and life exists on our watery planet but there may be plenty of watery planets with conditions favourable for life without things living on them. How many of these potentially habitable planets that actually have life is a big (and exciting!) open question. At the moment we have the ability to make observations, which tell us which planets might host life, but that alone won't tell us if alien life exists.

Planets too close to the Sun are far too hot for water to exist as a liquid; it would be turned to steam and evaporate; too far away from the Sun and water would freeze. Earth's orbit is just right; neither too hot nor too cold. We call this the Goldilocks or habitable zone. In this activity, the children will become galactic astronomers, using mathematical skills and key facts to plot the orbits of Earth and planets in our solar system before plotting the orbits of exoplanets around their stars.

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Activity

Activity sheet 1a provides an information card giving the distance of Earth and the planets in Astronomical Units, or AU, from the Sun. Each group is given a set of fact cards relating to our solar system and a pre-prepared sheet of black paper with two axes intersecting in the middle and divided into centimetre divisions, attached to a backing board. Teachers may prefer to provide just the paper without using the backing board. Scales can be pre-marked in detail on the axes or left to the children to extrapolate, depending upon their abilities. The activity provides opportunities for working with numerals to two decimal places.

Initially, the children work as a class as the teacher demonstrates. The position of the Sun is marked at the intersection of the axes. Explain that the distances between planets and the stars they orbit are measured in astronomical units or AU. Earth is 1 AU from our star, the Sun. Using a metallic pen or coloured pencil, they mark the distance of the Earth from the Sun on the appropriate points of the axes, North, South, East and West from the intersection. They can then join up the four points, forming a circle to represent the orbit. If using the board, a cocktail stick, with a small ball of plasticine attached to represent the Earth, may be pushed into a suitable position on the orbit. Alternatively, a sticker or small circle of paper, coloured to represent Earth, may be stuck directly onto the black paper at a point in the orbit. The children independently plot the distances and orbits of the remaining planets. Finally, they calculate and plot the habitable zone by using the information on the Goldilocks zone calculation card (Activity sheet 1b). Remind the children that this region is called the Goldilocks zone where it is neither too hot nor too cold.

If boards are available, they make models in plasticine of each planet, in order of mass, choosing colours appropriate to their knowledge of the features of each planet. Emphasise that they have some information about their planets – their mass and the length of their orbit – which can help them decide how to represent the planets.

Are they likely to be more like the Earth (rocky) or more like Jupiter (gaseous)? Which are more likely to be habitable? (Rocky). They attach each plasticine planet to a cocktail stick and push the cocktail sticks into position on the orbital rings. Paper circles, or stickers representing the planets, can be substituted for plasticine models, and stuck to the paper.

Next, the groups will need a second sheet of black paper, the axes and scales pre-marked and attached to a board. Alternatively, teachers may choose to attach the papers to the reverse of the boards used for the last activity, after removing the plasticine planets, or simply use paper alone.

Do the children have any idea how many stars with orbiting planets there may be just in our own galaxy, the Milky Way? Explain that scientists have discovered hundreds of multi-planet systems and thousands of stars with at least one planet, in our own galaxy, and estimate that there may be tens of billions more. Each group is given fact cards, Activity sheet 1a, for an exoplanet star system and using the information, they plot the position of the planets from the star. The extrasolar data provided are for 55 Cancri, HR 8799, Gliese 581, Gliese 876, Kepler 62, Kepler 186 and Upsilon Andromedae.

Finally, distribute cards showing how to calculate the inner and outer regions of the Goldilocks zone for each of the stars. Each group uses these measurements to mark the zone for their star system on the paper, revealing which, if any, of their planets lies within the zone and could be habitable.

Examples of Y5 pupil's work

Plenary

The groups share their results with the class. The results may be displayed on the whiteboard.

Which groups discovered a planet orbiting within the Goldilocks zone of their star system?

Why would some not be habitable? Remind the children through discussion that they have many types of information about the planets at their disposal relevant to this point.

Which of their planets would be too hot/cold for life to exist?

Extension

The groups might research other exoplanets and stars discovered in our galaxy and prepare a poster or presentation about their findings.

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Teacher information

An **astronomical unit (AU)** is the distance of the Earth from the Sun; this distance varies as Earth orbits the Sun, equivalent to 149,597,870,700 metres.

A **planet** is defined as a body that orbits the Sun, which is sufficiently massive for its own gravity to make it spherical and has 'cleared its neighbourhood' of smaller objects around its orbit.

A **light year** or **ly** is the distance light can travel in one year, or 300,000 kilometres/second.
Luminosity is a measure of brightness or power of a star, the amount of energy that a star emits from its surface. It is usually expressed in watts and measured in terms of the luminosity of the Sun.

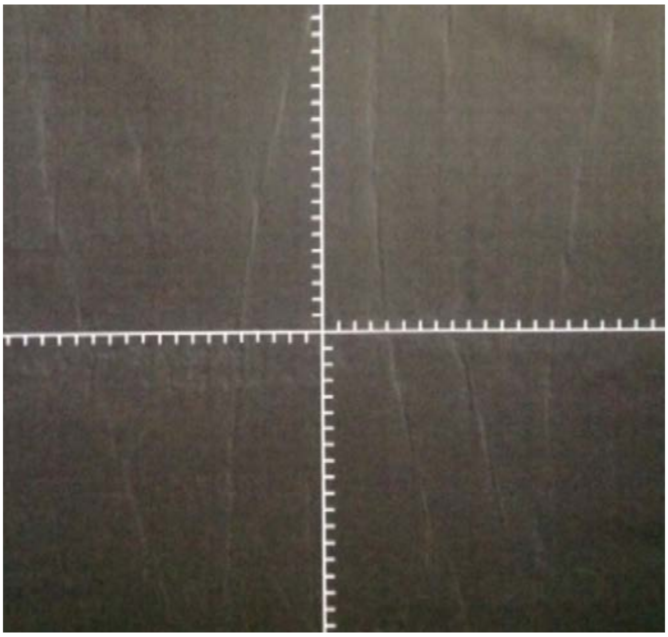

Image of exoplanet plotting sheet with two intersecting axes

Exoplanets in the habitable zone

The habitable zone or Goldilocks zone is the area around a star where the temperature is neither too hot nor too cold for water to exist in liquid form. The closest and furthest distances from the star where liquid water can be found depend on the size and temperature of the star, among other things. The stars Upsilon Andromedae, Gliese 581, Cancri 55, Kepler 62 and Kepler 186 are thought to have planets orbiting within the Goldilocks or habitable zone of their stars. However, data for extra solar systems are liable to change as new information is gathered. The data shown is correct at the time of writing but may be revised as new discoveries are made and more accurate measurements are taken by the latest telescopes. Such is the nature of science.

More able pupils may enjoy calculating the distance in AU of the habitable or Goldilocks zone for the stars featured on their activity sheets using the formula √luminosity of the star x 0.7 for the inner edge of the habitable zone and √luminosity x 1.5 for the outer edge of the zone. Note that luminosity is in solar units or 'Suns' ie, luminosity is compared with our Sun.

For an introduction to exoplanets, see:
http://www.esa.int/esaKIDSen/SEM3NFXPXPF_LifeinSpace_0.html
https://exoplanets.nasa.gov/
http://eyes.jpl.nasa.gov/eyes-on-exoplanets.html
https://www.stem.org.uk/elibrary/resource/31030/exoplanets

The James Webb Space Telescope is the successor to the Hubble Space Telescope and represents an international collaboration of the European Space Agency, Canadian Space Agency and NASA. It will carry a UK-led instrument that will allow spectroscopic measurements that are expected to revolutionise the study of exoplanet atmospheres. This telescope will be able to observe the first galaxies ever to form in the Universe and will study distant events and objects in the Universe which are currently beyond the reach of current ground-based instruments. Another goal is to understand the formation of stars and planets, including direct imaging of exoplanets. For further information, see:
http://jwst-miri.roe.ac.uk
https://www.jwst.nasa.gov/

Red dwarf A small, old, relatively cool star.

Brown dwarf A celestial object intermediate in mass between a gas giant planet and a small star, believed to emit infrared radiation. They are of different colours despite the name.

Orange dwarf Also known as a K-type main-sequence (hydrogen burning) or K dwarf. Intermediate in size between a red M-type main-sequence star and yellow G-type main-sequence star.

Yellow dwarf Our Sun is a yellow dwarf. These stars have a mass similar to the Sun. As they cool, they are known as yellow white dwarf stars.

Results of calculations for habitable zones

Star	Goldilocks Zone range	Planets within zone
Sun	0.7–1.5	Earth, Mars, Venus
Gliese 581	*0.077 –0.165 or 0.08–0.165	c, g or just g
HR8799	1.54–3.31	none
55 Cancri	0.5–1.125	f
Kepler 62	0.31–0.67	e
Kepler 186	0.04–0.33	b, c, d, e
Gliese 876	0.07–0.15	c
Upsilon Andromedae	1.32–2.83	d

*If the actual value of 0.077 is used, planets c and g are found in the Goldilocks Zone; if the number is rounded up to 0.08, then only planet g is found. This could lead to a discussion on when it is appropriate to round a number to two decimal places. In this case it makes a big difference!

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Activity Sheet 1a
Plot the exoplanet units

The Star Gliese 581 Red dwarf

Distance 20.3 ly
Mass 0.3 Suns
Luminosity 0.013 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
e	0.03	1.7	3.15
b	0.04	15.8	5.37
c	0.07	5.5	12.91
g	0.13	2.2	32
d	0.22	6.98	66.8

The Star HR 8799 Yellow dwarf

Distance 129 ly
Mass 1.49 Suns
Luminosity 4.9 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
e	14.5	2224	50
d	24	2224	100
c	38	2224	190
b	68	1589	460

The Star 55 Cancri Yellow dwarf

Distance from Earth 40 ly
Mass 0.95 Suns
Luminosity 0.57 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
e	0.02	8.63	18 hours
b	0.115	262.21	14.65 days
c	0.24	54.35	44.34 days
f	0.78	45.7	260 days
d	5.74	1,214.11	14 years

The Star The Sun Yellow dwarf

Distance from Earth 8 light minutes
Mass 332946 Earths
Luminosity 1

Name	Distance(AU)	Mass (Earths)	Orbit (days)
Mercury	0.4	0.05	88
Venus	0.7	0.8	225
Earth	1	1	365
Mars	1.5	0.1	687
Jupiter	5.2	317	11.9
Saturn	9.5	92	29.5
Uranus	19.2	14	84
Neptune	30	17	164.8

Appendix

Lesson 1
Activity Sheet 1a
Plot the exploplanet units

The Star Kepler-62 Orange dwarf

Distance from Earth	1200 ly
Mass	0.69 Suns
Luminosity	0.21 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
b	0.05	2.1	5.71
c	0.09	0.1	12.44
d	0.12	5.5	18.16
e	0.43	4.5	122.38
f	0.71	2.8	267.29

The Star Kepler 186 Red dwarf

Distance from Earth	15.20 ly
Mass	0.37 Suns
Luminosity	0.01 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
b	0.04	N/A*	3.88
c	0.06	N/A*	7.26
d	0.09	N/A*	13.34
e	0.12	N/A*	22.40
f	0.40	1.4	129.94

The Star Gliese 876
Red dwarf

Distance from Earth	40 ly
Mass	0.95 Suns
Luminosity	0.57 Suns

Name	Distance(AU)	Mass (Earths)	Orbit (days)
d	0.02	6.83	1.94
f	N/A*	9.53	10.01
g	N/A*	38.13	15.04
c	0.13	225.65	30.01
b	0.21	724.65	61.12
e	0.33	14.60	124.26

The Star Upsilon Andromedae
Yellow white dwarf

Distance from Earth	44 ly
Mass	1.27 Suns
Luminosity	3.6 Suns

Name	Distance(AU)	Mass (Earths)	Orbit
b	0.06	197	4.62 days
c	0.83	4443	241 days
d	2.54	3257	3.5 years
e	5.25	305	10.5 years

* Data not available

Appendix

Lesson 1
Activity Sheet 1b
Calculating the Goldilocks Zone in Astronomical Units

Upsilon Andromedae

To work out the Goldilocks Zone (AU)

Inner zone	1.90 x 0.7=
Outer zone	1.90 x 1.5=

Gliese 581

To work out the Goldilocks Zone (AU)

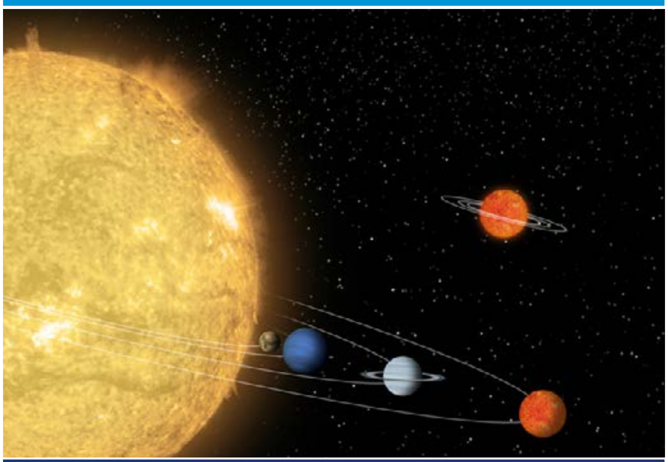
Inner zone	0.11 x 0.7=
Outer zone	0.11 x 1.5=

HR 8799

To work out the Goldilocks Zone (AU)

Inner zone	2.21 x 0.7=
Outer zone	2.21 x 1.5=

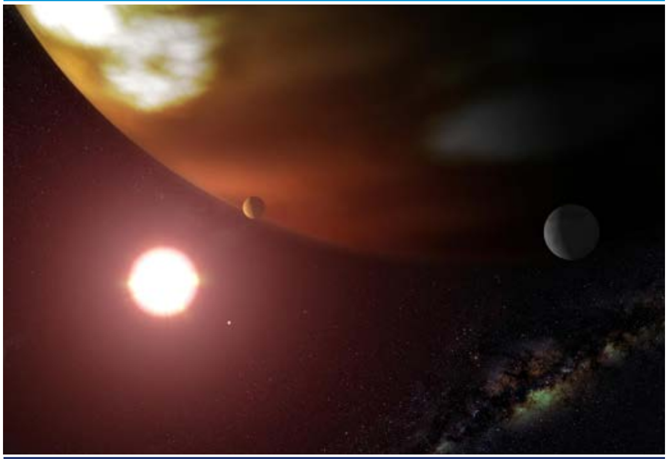
55 Cancri



To work out the Goldilocks Zone (AU)

Inner zone	0.75 x 0.7=
Outer zone	0.75 x 1.5=

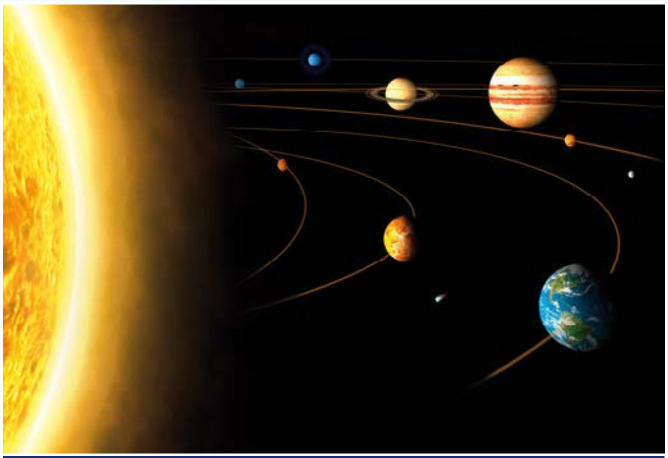
Gliese 876



To work out the Goldilocks Zone (AU)

Inner zone	0.1 x 0.7=	
Outer zone	0.1 x 1.5=	

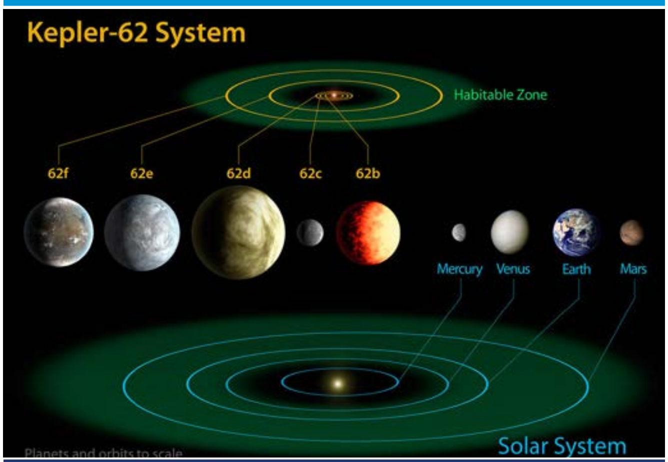
The Sun



To work out the Goldilocks Zone (AU)

Inner zone	1 x 0.7=	
Outer zone	1 x 1.5=	

Kepler-62



To work out the Goldilocks Zone (AU)

Inner zone	0.46 x 0.7=	
Outer zone	0.46 x 1.5=	

Kepler 186

To work out the Goldilocks Zone (AU)

Inner zone	0.22 x 0.7=	
Outer zone	0.22 x 1.5=	