
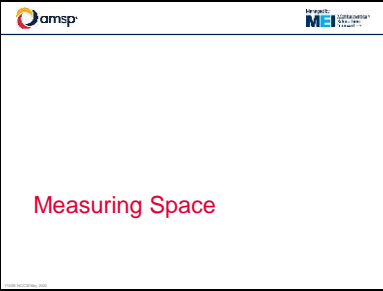
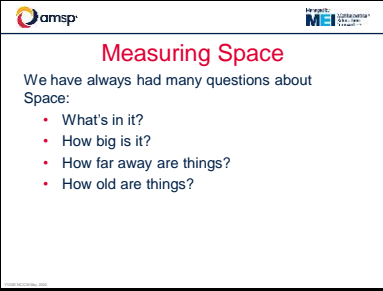
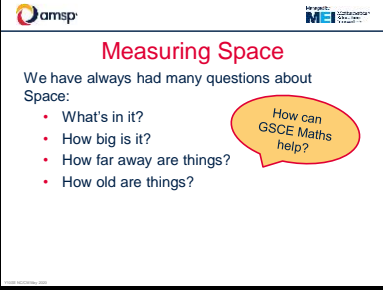
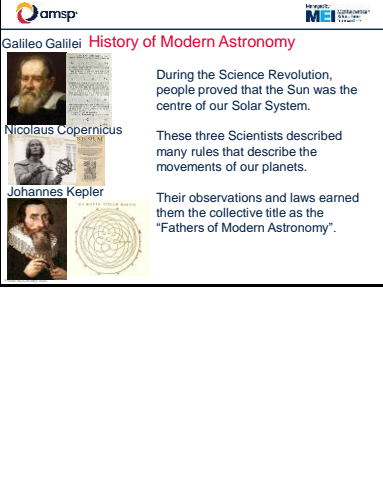
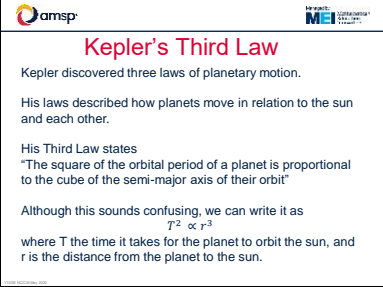






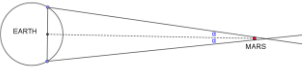



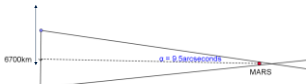



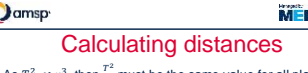

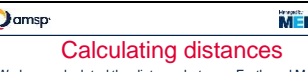
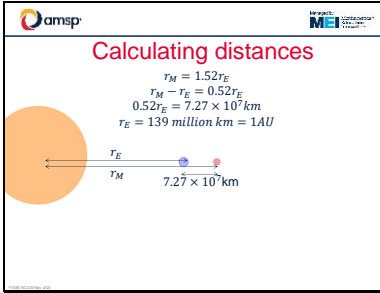
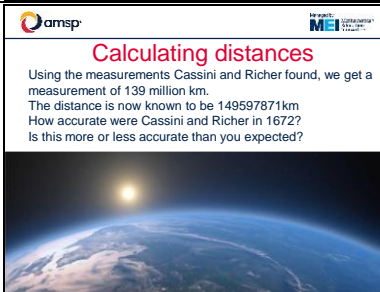
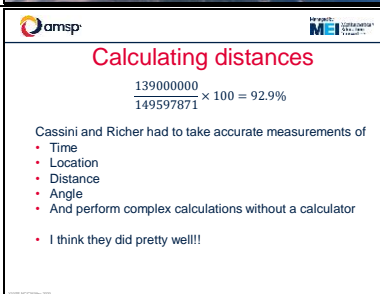
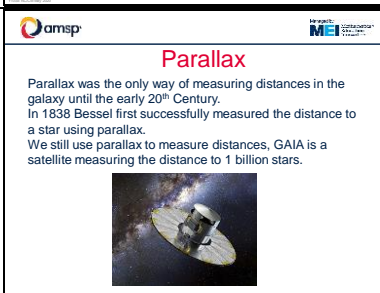
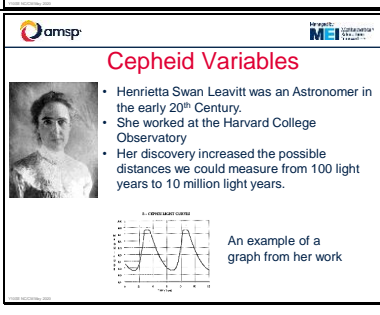
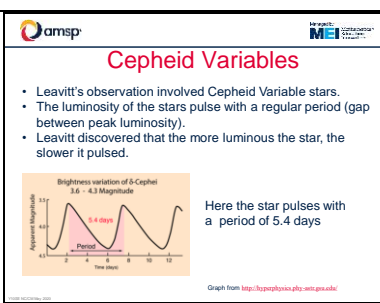














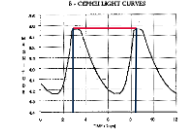
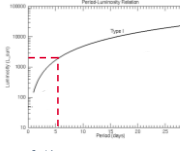
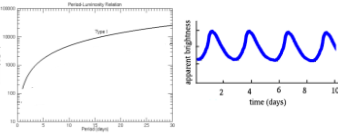
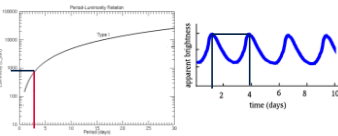

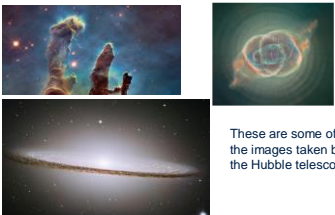
Slide 1	 <p>Advanced Mathematics Support Programme®</p>	
Slide 2	 <p>Measuring Space</p>	Please note that some slides where calculations are done step at a time have been removed from this handout to make printing these notes easier. The numbers have been retained for your reference.
Slide 3	 <p>Measuring Space</p> <p>We have always had many questions about Space:</p> <ul style="list-style-type: none"> <li>• What's in it?</li> <li>• How big is it?</li> <li>• How far away are things?</li> <li>• How old are things?</li> </ul>	
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Slide 5	 <p>Galileo Galilei: History of Modern Astronomy</p> <p>Nicolaus Copernicus</p> <p>Johannes Kepler</p> <p>During the Science Revolution, people proved that the Sun was the centre of our Solar System.</p> <p>These three Scientists described many rules that describe the movements of our planets.</p> <p>Their observations and laws earned them the collective title as the "Fathers of Modern Astronomy".</p>	<p>Discussion points for students – many students are aware that people used to think that the Sun revolved around the Earth. You can ask why people might have thought that – what would the danger be if we suggested that the Earth wasn't the centre of the Universe?</p> <p>Copernicus' model is based on heliotropism, where the Sun is the centre of the Universe. We now know this not to be true either, indeed the Universe doesn't have a centre.</p> <p>The notion that the Sun was the centre of the Universe was first suggested in 3BC</p> <p>How would you model the motion? These astronomers took thousands and thousands of observations from telescopes, and then had to carry out huge calculations by hand.</p>
Slide 6	 <p>Kepler's Third Law</p> <p>Kepler discovered three laws of planetary motion.</p> <p>His laws described how planets move in relation to the sun and each other.</p> <p>His Third Law states "The square of the orbital period of a planet is proportional to the cube of the semi-major axis of their orbit"</p> <p>Although this sounds confusing, we can write it as <math>T^2 \propto r^3</math> where T the time it takes for the planet to orbit the sun, and r is the distance from the planet to the sun.</p>	Kepler's 1st Law states that planets move in ellipses, and his 2nd Law is about the speed that the planets move at different parts of the ellipse.






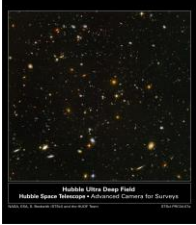











<p>Slide 7</p>	 <table border="1" data-bbox="220 138 523 264"> <thead> <tr> <th>Planet</th> <th>Distance to the sun (AU) - this is r</th> <th>Period (days) - this is T</th> </tr> </thead> <tbody> <tr> <td>Mercury</td> <td>0.39</td> <td>87.8</td> </tr> <tr> <td>Venus</td> <td>0.72</td> <td>225</td> </tr> <tr> <td>Earth</td> <td>1</td> <td>365.25</td> </tr> <tr> <td>Mars</td> <td>1.52</td> <td>687</td> </tr> <tr> <td>Jupiter</td> <td>5.2</td> <td>4332</td> </tr> <tr> <td>Saturn</td> <td>9.5</td> <td>10759</td> </tr> </tbody> </table> <p>Using Kepler's data</p> <ol style="list-style-type: none"> <li>For each planet, calculate <math>\frac{T^2}{r^3}</math></li> <li>What do you notice?</li> <li>How far away is Jupiter from The Sun?</li> <li>What is the unknown in these units of measurements?</li> </ol> <p><small>AU = Astronomical Unit</small></p>	Planet	Distance to the sun (AU) - this is r	Period (days) - this is T	Mercury	0.39	87.8	Venus	0.72	225	Earth	1	365.25	Mars	1.52	687	Jupiter	5.2	4332	Saturn	9.5	10759	<p>All the planets are as a fraction of 1AU, which is the distance from the Earth to the Sun.</p> <p>Without knowing what 1AU is, we have no value for any other distance either.</p>
Planet	Distance to the sun (AU) - this is r	Period (days) - this is T																					
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<p>Slide 8</p>	 <p><b>How far away is the sun??</b></p>  <p>This was something that baffled astronomers for centuries, until they realised they could use something called parallax.</p> <ol style="list-style-type: none"> <li>Close one eye, stretch your arm in front of you and line it up against Nelson's Column.</li> <li>Open your eye and close the other one, keeping your finger where it is.</li> <li>What do you notice?</li> </ol>																						
<p>Slide 9</p>	 <p><b>How far away is the sun??</b></p>  <p>You should notice that when you switch from one eye to the other, Nelson's Column appears to move.</p> <p>This is called Parallax.</p>																						
<p>Slide 10</p>	 <p><b>Parallax</b></p> <p>Astronomers used their knowledge of Mars in 'opposition'.</p> <p>By measuring the angle to Mars from two known places on Earth, they were able to estimate the distance.</p> 	<p>This is a very simplified diagram of parallax, most likely the object we are looking at will not be equidistant between the two observation points on the Earth which makes the trigonometry more tricky.</p>																					
<p>Slide 11</p>	 <p><b>Cassini and Richer</b></p> <ul style="list-style-type: none"> <li>Cassini and Richer used this to calculate the distance to Mars.</li> <li>Richer went to Cayenne, in French Guiana, Cassini stayed in Paris</li> <li>On the same day, they measured the angle to Mars</li> <li>They waited until Mars was really close to the Earth, so the angle was as large as possible.</li> <li>They could then calculate the distance.</li> </ul> 	<p>Cassini set Richer out a year in advance so he could accurately measure his position as calculating position on Earth was challenging! He measured position by taking measurements of the stars.</p> <p>They waited for Mars to be 'in opposition'. More information is available here <a href="https://archive.briankoberlein.com/2015/01/08/martian-chronicles/index.html">https://archive.briankoberlein.com/2015/01/08/martian-chronicles/index.html</a></p>																					
<p>Slide 12</p>	 <p><b>Calculating distances</b></p>  <p>6700km</p> <p>9.5 arc seconds <math>\Rightarrow 9.5 \div 60 = 0.1583</math> arc minutes</p> <p>0.1583 arc minutes <math>\Rightarrow 0.1583 \div 60 = 0.00264^\circ</math></p>																						








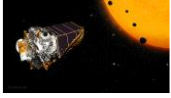





<p>Slide 17</p>	 <p><b>Calculating distances</b></p> <p>6700km</p> <p>9.5 arc seconds <math>\Rightarrow 9.5 \div 60 = 0.1583</math> arc minutes  <math>0.1583</math> arc minutes <math>\Rightarrow 0.1583 \div 60 = 0.00264^\circ</math>  <math>6700 \div 2 = 3350</math>km</p> <p>3350km</p> <p><math>\alpha = 0.00264^\circ</math></p> <p><math>\tan(\alpha) = \frac{3350}{L} \Rightarrow L = \frac{3350}{\tan(0.00264)} \Rightarrow L = 7.27 \times 10^7</math></p>	
<p>Slide 18</p>	 <p><b>Calculating distances</b></p> <p>We can combine our distance with Kepler's third law to calculate 1AU (the distance from the Sun to the Earth).</p>	
<p>Slide 19</p>	 <p><b>Calculating distances</b></p> <p>We can combine our distance with Kepler's third law to calculate 1AU (the distance from the Sun to the Earth).</p> <p>As <math>T^2 \propto r^3</math>, then for all planets, <math>\frac{T^2}{r^3}</math> must be the same value</p> <p>1) Can you show that <math>\frac{T_M^2}{r_E^3} = \frac{T_E^2}{r_M^3}</math>?</p> <p>2) Using the data <math>T_M = 687</math> days, <math>T_E = 365</math> days can you find the ratio <math>\frac{T_M}{T_E}</math>?</p>	
<p>Slide 22</p>	 <p><b>Calculating distances</b></p> <p>As <math>T^2 \propto r^3</math>, then <math>\frac{T^2}{r^3}</math> must be the same value for all planets</p> <p>1) Can you show that <math>\frac{T_M^2}{r_E^3} = \frac{T_E^2}{r_M^3}</math>?</p> $\frac{T_M^2}{r_E^3} = \frac{T_E^2}{r_M^3}$ $\frac{T_M^2}{T_E^2} = \frac{r_E^3}{r_M^3}$ $T_M^2 T_E^{-2} = r_E^3 r_M^{-3}$ $\frac{T_M}{T_E} = \frac{r_E}{r_M}$	
<p>Slide 26</p>	 <p><b>Calculating distances</b></p> <p>2) Using the data <math>T_M = 687</math> days, <math>T_E = 365</math> days can you find the ratio <math>\frac{T_M}{T_E}</math>?</p> $\frac{687^2}{365^2} = \frac{r_M^3}{r_E^3}$ $\frac{r_M^3}{r_E^3} = 3.54$ $\frac{r_M}{r_E} = \sqrt[3]{3.54}$ $\frac{r_M}{r_E} = 1.52 \text{ (3sf)}$	
<p>Slide 27</p>	 <p><b>Calculating distances</b></p> <p>We have calculated the distance between Earth and Mars  We know that <math>\frac{r_M}{r_E} = 1.52</math>  Can you calculate the estimate for the distance between Earth and the Sun?</p> <p>7.27 <math>\times 10^7</math>km</p> <p><math>r_E</math></p> <p><math>r_M</math></p>	

<p>Slide 28</p>		
<p>Slide 29</p>		<p>You may wish to discuss whether you want to put in a more accurate number for Cassini and Richer, or a less accurate measurement for the Sun, as these measurements are not to the same number of significant figures.</p>
<p>Slide 30</p>		
<p>Slide 31</p>		<p>GAIA is an ESA satellite that maps the stars. More information here <a href="https://sci.esa.int/web/gaia">https://sci.esa.int/web/gaia</a> You might want to see if students think that 1 billion stars is all the stars in the Milky Way? Or the Universe? It's around 1% of the stars in our 'galactic group' (Milky Way plus a few extras).</p>
<p>Slide 32</p>		<p>Henrietta Leavitt was one of the 'Harvard Calculators'. She originally took up an unpaid role at Harvard University as she was a woman, but ended up leading a team of astronomers. She died when she was very young, otherwise Hubble was sure she was worthy of a Nobel prize, but they're not awarded posthumously. She became deaf after graduating. More information can be found here <a href="https://www.khanacademy.org/partner-content/big-history-project/big-bang/other-materials2/a/henrietta-Leavitt">https://www.khanacademy.org/partner-content/big-history-project/big-bang/other-materials2/a/henrietta-Leavitt</a>.</p>
<p>Slide 33</p>		<p>Our sun's luminosity varies by 0.1%. This is what makes Cepheid Variables so useful.</p>

<p>Slide 34</p>	<p> <b>Cepheid Variables</b> </p> <ul style="list-style-type: none"> <li>Leavitt's observation involved Cepheid Variable stars.</li> <li>Normal stars have constant luminosity</li> <li>Cepheid variables pulse.</li> <li>Leavitt discovered that the more luminous the star, the slower it pulsed.</li> <li>How do we measure luminosity? <ul style="list-style-type: none"> <li>If you shine a torch near to you, it looks bright, but if you shine it far away it is much less bright.</li> <li>Luminosity is an inverse square law</li> </ul> </li> <li><math>L \propto \frac{1}{x^2}</math></li> </ul>													
<p>Slide 35</p>	<p> <b>Cepheid Variables</b> </p> <p>Example: A star has luminosity 400 Watts when it is 5 light years away, what luminosity would we see if the same star was 100 light years away?</p> <table border="1" data-bbox="274 504 533 645"> <tr> <td colspan="2" style="text-align: center;"><b>STEP 1:</b></td> </tr> <tr> <td style="width: 50%;">Find k</td> <td style="width: 50%;"></td> </tr> <tr> <td><math>L = \frac{k}{x^2}</math></td> <td></td> </tr> <tr> <td><math>400 = \frac{k}{5^2}</math></td> <td></td> </tr> <tr> <td><math>k = 400 \times 5^2</math></td> <td></td> </tr> <tr> <td><math>k = 10,000</math></td> <td></td> </tr> </table>	<b>STEP 1:</b>		Find k		$L = \frac{k}{x^2}$		$400 = \frac{k}{5^2}$		$k = 400 \times 5^2$		$k = 10,000$		
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<p>Slide 37</p>	<p> <b>Cepheid Variables</b> </p> <p>Your turn:</p> <ul style="list-style-type: none"> <li>The sun gives 1368 Watts/m<sup>2</sup> to the Earth</li> <li>The sun is approximately 150 million km from the Earth</li> <li>If the sun was at Alpha Centauri, which is 41 trillion km away, how luminous would it be to Earth?</li> </ul> <table border="1" data-bbox="247 1093 533 1256"> <tr> <td style="width: 50%;"><b>STEP 1:</b></td> <td style="width: 50%;"><b>STEP 2:</b></td> </tr> <tr> <td>Find k</td> <td></td> </tr> <tr> <td><math>L = \frac{k}{x^2}</math></td> <td></td> </tr> <tr> <td><math>1368 = \frac{k}{150,000,000^2}</math></td> <td></td> </tr> <tr> <td><math>k = 1368 \times 150,000,000^2</math></td> <td></td> </tr> <tr> <td><math>k = 3.08 \times 10^{19}</math></td> <td></td> </tr> </table>	<b>STEP 1:</b>	<b>STEP 2:</b>	Find k		$L = \frac{k}{x^2}$		$1368 = \frac{k}{150,000,000^2}$		$k = 1368 \times 150,000,000^2$		$k = 3.08 \times 10^{19}$		
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<p>Slide 39</p>	<p> <b>Cepheid Variables</b> </p> <p>Your turn:</p> <ul style="list-style-type: none"> <li>The sun gives 1368 Watts/m<sup>2</sup> to the Earth</li> <li>The sun is approximately 150 million km from the Earth</li> <li>If the sun was at Alpha Centauri, which is 41 trillion km away, how luminous would it be to Earth?</li> </ul> <table border="1" data-bbox="247 1680 533 1821"> <tr> <td style="width: 50%;"><b>STEP 1:</b></td> <td style="width: 50%;"><b>STEP 2:</b></td> </tr> <tr> <td>Find k</td> <td>Find L</td> </tr> <tr> <td><math>L = \frac{k}{x^2}</math></td> <td><math>x = 41 \times 10^{12}</math></td> </tr> <tr> <td><math>1368 = \frac{k}{150,000,000^2}</math></td> <td><math>k = 2.05 \times 10^{11}</math></td> </tr> <tr> <td><math>k = 1368 \times 150,000,000^2</math></td> <td><math>L = \frac{2.05 \times 10^{11}}{(41 \times 10^{12})^2}</math></td> </tr> <tr> <td><math>k = 3.08 \times 10^{19}</math></td> <td><math>L = 1.83 \times 10^{-8}</math></td> </tr> </table> <p>Alpha Centauri is the nearest star system to our Solar System)</p>	<b>STEP 1:</b>	<b>STEP 2:</b>	Find k	Find L	$L = \frac{k}{x^2}$	$x = 41 \times 10^{12}$	$1368 = \frac{k}{150,000,000^2}$	$k = 2.05 \times 10^{11}$	$k = 1368 \times 150,000,000^2$	$L = \frac{2.05 \times 10^{11}}{(41 \times 10^{12})^2}$	$k = 3.08 \times 10^{19}$	$L = 1.83 \times 10^{-8}$	
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<p>Slide 40</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>Cepheid Variables</h3> <ul style="list-style-type: none"> <li>How does luminosity help?</li> <li>We can use graphs like the one below that measure the light from a Cepheid Variable.</li> <li>We need to measure the <i>period</i> (the time it takes for the cycle to repeat)</li> </ul>  <p>Period = <math>8.4 - 3 = 5.4</math></p>	
<p>Slide 41</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>Cepheid Variables</h3> <p>Once we know the period, we can use this to find the luminosity using this graph.</p> <p>1) What is different about the y axis?</p>  <p>We can read off the graph to find the luminosity of the star from the previous page with a period of 5.4 days.</p> <p>The luminosity is 1100 (units are <math>L_{Sun}</math>, which compares the luminosity to that of the sun).</p>	<p>Students might want to see other examples of logarithmic graphs, and even compare what they would look like on a linear scale. The most recent example is the graph of Covid-19 cases comparing countries <a href="https://ourworldindata.org/coronavirus#coronavirus-country-profiles">https://ourworldindata.org/coronavirus#coronavirus-country-profiles</a></p>
<p>Slide 42</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>Cepheid Variables</h3> <p>The y axis has a <i>logarithmic scale</i>, where the scale uses a multiply by 10 rule rather than add 10. We can compare values with a huge range. Log scales are used in exponential models.</p> <p>2) Can you use these graphs to estimate the luminosity of the star?</p> 	
<p>Slide 43</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>Cepheid Variables</h3> <p>2) Can you use these graphs to estimate the luminosity of the star?</p> <p>The period is approximately <math>3.9 - 1 = 2.9</math> days  <math>2.9</math> days = 900 Luminosity</p> 	
<p>Slide 44</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>What's in the Universe?</h3> <ul style="list-style-type: none"> <li>As well as measuring distances in the Universe, we also want to know how what is in it.</li> <li>To do this, we use telescopes to look at the Universe, such as the famous Hubble Space telescope.</li> </ul> 	
<p>Slide 45</p>	<p><b>amsp</b> <b>MEI</b></p> <h3>What's in the Universe?</h3>  <p>These are some of the images taken by the Hubble telescope</p>	

<p>Slide 46</p>	  <p><b>What's in the Universe?</b></p> <p>The most significant Hubble Image?</p> <p>Draw a 1mm by 1mm square on your thumbnail and hold your arm at full stretch. Look at the size of the square.....</p> 	
<p>Slide 47</p>	  <p><b>What's in the Universe?</b></p> <p>Imagine squashing this picture in to a 1mm<sup>2</sup> square on your thumb.</p> <p>It is the Hubble Ultra Deep Field, taken by the Hubble telescope focussed on the same section of sky for 5 months.</p> <p>Each dot is a galaxy.</p> 	
<p>Slide 48</p>	  <p><b>What's in the Universe?</b></p> <ul style="list-style-type: none"> <li>• Rotate your arm around your body. What shape do you trace out?</li> <li>• We can model the Universe using this shape.</li> </ul> 	
<p>Slide 49</p>	  <p><b>What's in the Universe?</b></p> <p><u>Building our model</u></p> <ul style="list-style-type: none"> <li>• Your arm is approximately 1m long.</li> <li>• The Universe is the size of the sphere you trace out.</li> <li>• How many 1mm squares would fit on the surface area of the sphere?</li> </ul> <p>(The formula for the surface area of a sphere is <math>4\pi r^2</math> To simplify our model we can use <math>\pi \approx 3</math>)</p>	
<p>Slide 50</p>	  <p><b>What's in the Universe?</b></p>  <p>Each square has <b>10,000</b> galaxies</p> <p>Surface area of sphere = _____ m<sup>2</sup> Surface area of sphere = _____ mm<sup>2</sup> Number of galaxies =</p>	
<p>Slide 51</p>	  <p><b>What's in the Universe?</b></p>  <p>Surface area of sphere = <math>4 \times 3 \times 1^2 = 12 \text{ m}^2</math> Surface area of sphere = <math>12 \times 1000 \times 1000 = 12,000,000 \text{ mm}^2</math> Number of galaxies = <math>12,000,000 \times 10,000 = 120,000,000,000</math></p>	

<p>Slide 52</p>	 <p><b>What's in the Universe?</b></p>  <p>Surface area of sphere = <math>4 \times 3 \times 1^2 = 12 \text{ m}^2</math>  Surface area of sphere = <math>12 \times 1000 \times 1000 = 12,000,000\text{mm}^2</math>  Number of galaxies = <math>12,000,000 \times 10,000 = 120,000,000,000</math></p> <p>On average, a galaxy contains 100,000,000,000 stars  Can you estimate how many stars are in the Universe?</p>	
<p>Slide 53</p>	 <p><b>How big?</b></p> <ul style="list-style-type: none"> <li>Using our model, we can estimate that there are <math>1.2 \times 10^{22}</math> stars in the Universe.</li> <li>How many of those stars have planets? How many of those planets have life? How many aliens are there?</li> <li>These questions are much harder to answer, but the better Astronomers are getting at looking for planets, the more we are finding!</li> <li>From the first exoplanet discovery in 1995, we have definitely found more than 4,000 more. We have thousands more 'candidates', which need confirming by looking at the data.</li> </ul>  	
<p>Slide 54</p>	 <p><b>Where are the aliens?</b></p> <ul style="list-style-type: none"> <li>The Fermi paradox explores our question of 'where are the aliens', as we have found many exoplanets yet found no life.</li> <li>The Drake Equation explores how many planets with aliens might be in our galaxy.</li> <li>To explore why it might be so difficult, we can think of a few things: <ul style="list-style-type: none"> <li>An Earth-like planet is Proxima Centauri b. This is <math>1.2 \times 10^{13}</math> km away. It takes 4.2 years for light to reach us.</li> <li>The most Earth like planet found so far is Trappist-1b which is 39.5 light years away.</li> </ul> </li> <li>To find more, there is some good reading <a href="#">here</a> and <a href="#">here</a> and an interesting video <a href="#">here</a>.</li> </ul>  	<p>More information on the drake equation can be found here <a href="https://exoplanets.nasa.gov/news/1350/are-we-alone-in-the-universe-revisiting-the-drake-equation/">https://exoplanets.nasa.gov/news/1350/are-we-alone-in-the-universe-revisiting-the-drake-equation/</a> and on SETI, which was the institute founded by the work of Drake, can be found here <a href="https://www.seti.org/">https://www.seti.org/</a></p>
<p>Slide 55</p>	 <p><b>Contact the AMSP</b></p> <p> 01225 716 492   <a href="mailto:admin@amsp.org.uk">admin@amsp.org.uk</a>   <a href="http://amsp.org.uk">amsp.org.uk</a>   <a href="#">Advanced_Maths</a></p>	<p>Stay informed about the AMSP and receive updates:  <a href="https://amsp.org.uk/subscribe">https://amsp.org.uk/subscribe</a></p>