**ESA/Hubble**
ESA Office - Space Telescope Science Institute
3700 San Martin Dr, Baltimore, MD 21218, United States
info@esahubble.org

ESAHubble.org

| Space Sparks Episode 5 | Visual Notes |
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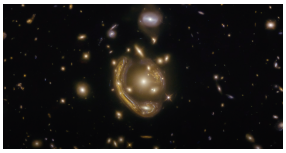
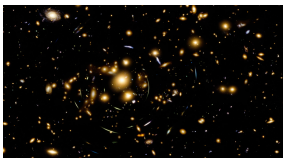
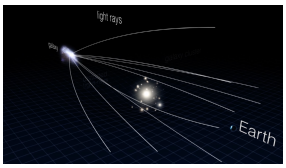
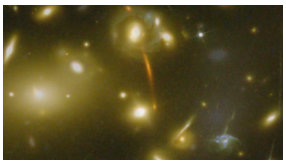
| 00:00 - 00:22<br><br>Light does not always travel in straight lines. Einstein predicted in his General Theory of Relativity that massive objects will deform the fabric of space itself. When light passes by a really massive object, such as a cluster of galaxies, its path is bent slightly. |  |
| 00:23 - 00:38<br><br>This effect, called gravitational lensing, is only visible in rare cases and only the best telescopes — including the NASA/ESA Hubble Space Telescope — can observe the results of gravitational lensing. |  |
| 00:39 - 00:47<br><br>***Intro*** |  |
| 00:48 - 01:41<br><br>The strong gravity of a massive object, such as a cluster of galaxies, warps the surrounding space, and light from distant objects travelling through that warped space is curved away from its straight-line path.<br><br>When light from a distant galaxy is bent around a cluster of galaxies between it and us we see multiple images of the galaxy, each with a characteristically distorted shape. These shapes can appear as lines, banana-shaped arcs, and even rings.<br><br>Hubble's sensitivity and high resolution allow it to see details in these faint, distorted images of distant galaxies that cannot be detected with such clarity by ground-based telescopes, whose images are blurred by the Earth's atmosphere. |  <br>  <br>  |

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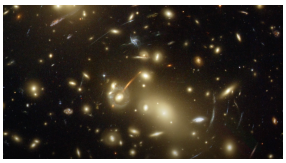
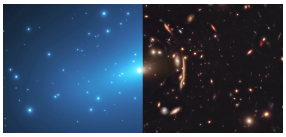
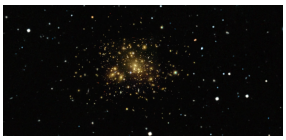
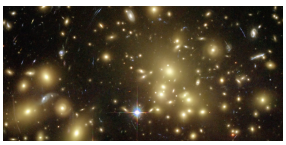
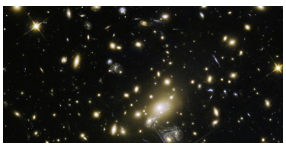
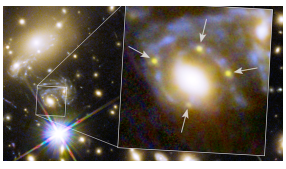
| 01:42 - 02:16<br><br>An important consequence of gravitational lensing is that the distorted image of the distant galaxy is actually magnified , allowing us to observe details of the objects that would otherwise be too faint to be seen. Hubble makes use of this magnification effect to study objects that ought to be beyond the sensitivity of its 2.4-metre-diameter primary mirror,  showing us the most distant galaxies humanity has ever encountered! |  <br>  |
| 02:17 - 02:37<br><br>Depending on the total mass of the intervening cluster, gravitational lensing can be used to ‘weigh’ clusters. This has considerably enhanced our understanding of the distribution of the ‘hidden’ dark matter in galaxy clusters and hence in the Universe as a whole. |  |
| 02:38 - 02:58<br><br>If the galaxy cluster contained only the matter that we can see directly, its gravity would not be sufficient to distort the light in the way that we observe it. So there must be additional, invisible matter present, and gravitational lensing tells us how this so-called dark matter is distributed within the cluster. |  <br>  |
| 02:59 - 03:48<br><br>The Hubble Frontier Fields observing campaign drew on the influence of massive clusters of galaxies to unleash the full potential of the Hubble Space Telescope.<br><br>The programme used 630 hours of Hubble observing time, over 560 orbits of the Earth, from 2013 to 2017.<br><br>This campaign used six galaxy clusters to peer into the farthest reaches of the Universe. The gravitational lensing observations allowed astronomers to study objects behind the clusters in the very distant Universe that would normally be too faint to see, even for Hubble. |  <br>  <br>  |
| 03:48 - 04:32<br><br>One of the most distant clusters studied in this campaign is MACS J1149.5+2223 — so distant that it takes light from it five billion years to reach us. For the first time, astronomers spotted four images of a distant exploding star - a supernova. The images were arranged in a cross-shaped pattern by the powerful gravity of a foreground galaxy embedded in a massive cluster of galaxies. As the supernova was perfectly aligned with one of the galaxies in the cluster, its light has been split into four images |  <br>  |

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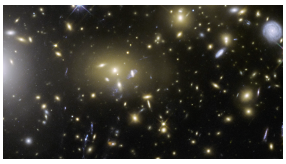
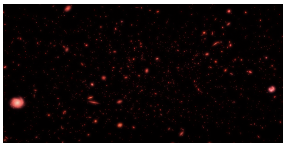
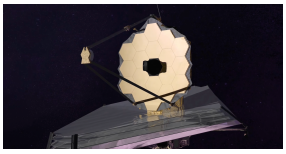
| 04:33 - 05:05<br><br>The Frontier Fields programme produced the deepest observations ever made of galaxy clusters and the magnified galaxies behind them. These observations are helping astronomers understand how galaxies emerged from the dark ages of the Universe, when space was dark, opaque, and filled with hydrogen atoms.<br>Thanks to Hubble's vast observations of gravitational lenses, astronomers have studied the most distant galaxies humanity has ever encountered. |  <br>  |
| 05:06 - 05:20<br><br>They have also given us a glimpse of the cosmos that will be unveiled by the upcoming NASA/ESA/CSA James Webb Space Telescope. |  |
| 05:21 - 05:31<br><br>***Outro*** |  |

Total Time: 05:31