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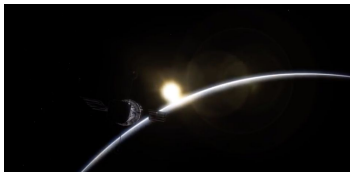
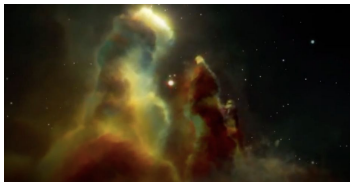
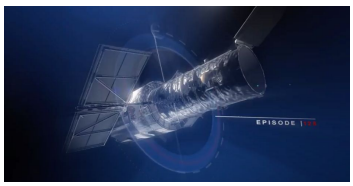
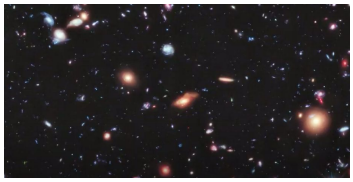
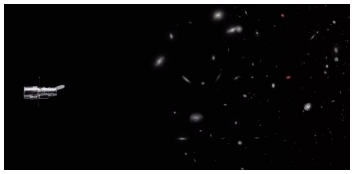
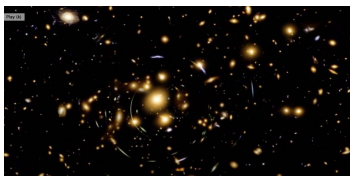
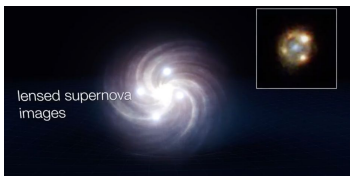
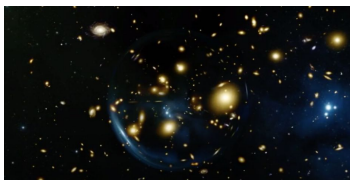
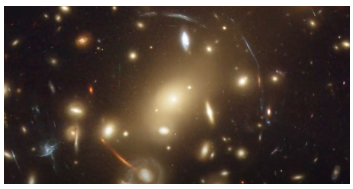
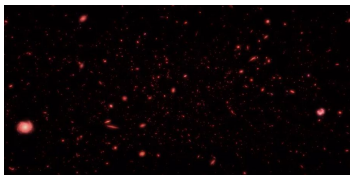
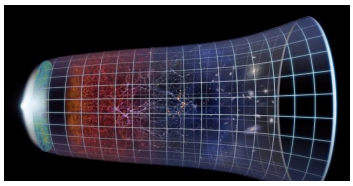
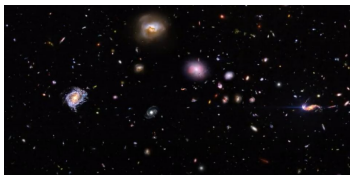
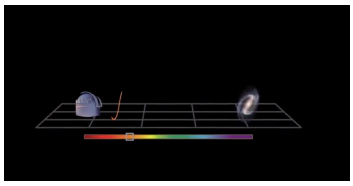
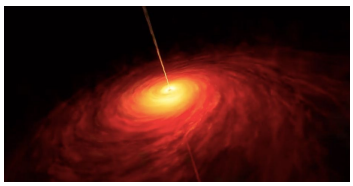
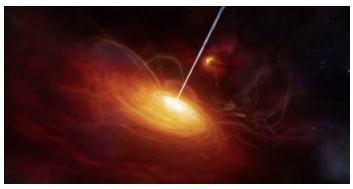
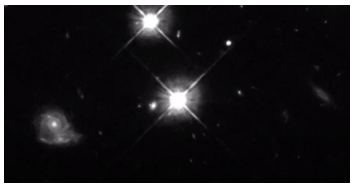
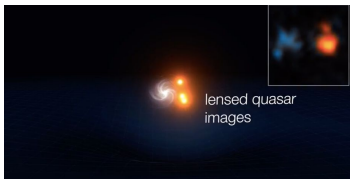
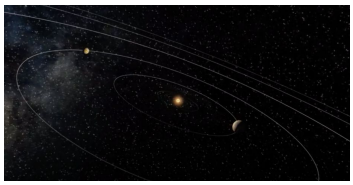
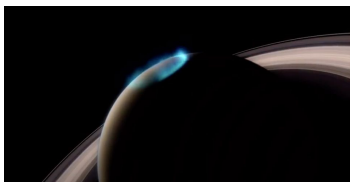
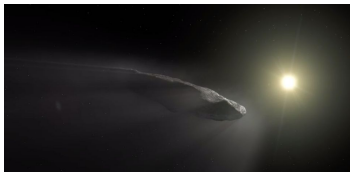
Hubblecast 128: 30 Years of Science with the Hubble Space Telescope	**Visual notes**
00:00-00:32 On 24 April 1990 the NASA/ESA Hubble Space Telescope was sent into orbit aboard the space shuttle *Discovery* — the first space telescope of its kind. It offered a new view of the Universe and has, for 30 years, surpassed all expectations, beaming back data and images that have changed scientists' understanding of the Universe and the public's perception of it.	 
00:33-00:54 Hubble's discoveries have revolutionised nearly all areas of current astronomical research, from planetary science to cosmology, and its pictures are unmistakably out of this world. This video will revisit some of Hubble's biggest science discoveries throughout its three decades of operation.	 

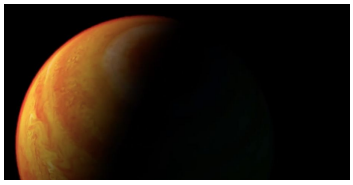
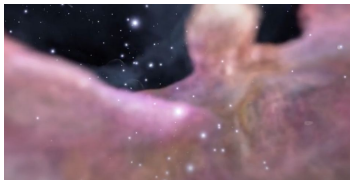
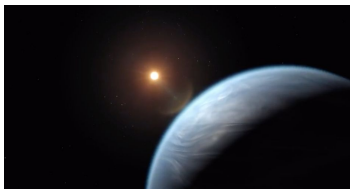
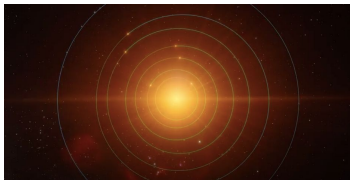
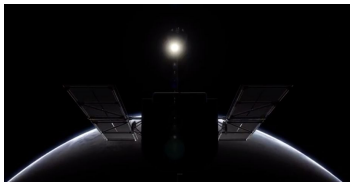
00:55-01:04 [Intro Screen]	
01:05-03:13 An early and memorable result is the Hubble Deep Fields. These are extended observations of a particular region of the sky intended to reveal faint objects by collecting the light from them for an appropriately long time. These images fascinated scientists and the general public alike, as the thousands of galaxies captured in single images spawned widespread fascination and amazement. The original and now famous Hubble Deep Field image released in 1996 consisted of an area of sky with a width equal to just one-twelfth that of the full Moon. In it Hubble found almost 3000 distant galaxies. The Hubble Ultra Deep Field from 2004 was the deepest portrait of the visible universe ever achieved by humankind. The 2012 Hubble eXtreme Deep Field was an impressive combination of many existing exposures — over 2000 of them — into one image. The results were astonishing for astronomers. By studying the thousands of galaxies captured in these Deep Field observations, including some of the most distant primeval galaxies, they were learning more about the very early Universe. The bulk of the early and remote galaxies had not yet had time to form stars and were also characterized by an atypical shape, as they seemed to be smaller and more irregular than those nearer to us. This was taken as a clear indication that galaxies form by merging together smaller objects.	    
03:14-05:14 The Hubble Frontier Fields observing campaign drew upon the power of massive clusters of galaxies to unleash the full potential of the Hubble Space Telescope.	

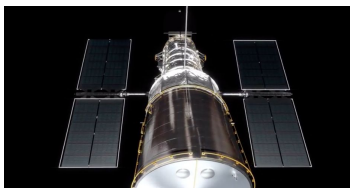
Hubble's sensitivity and high resolution allow it to see faint and distant gravitational lenses that are harder to detect with ground-based telescopes. Gravitational lensing is a phenomenon created by extremely concentrated masses like the cores of galaxies or galaxy clusters. Their strong gravity warps the surrounding space, and light from distant objects travelling through that warped space is curved away from its straight-line path, as if passing through a lens. Hubble can resolve details within the multiple banana-shaped arcs that are one of the main results of gravitational lensing, as the images of background sources are distorted. An important consequence of lensing distortion is magnification, allowing us to observe objects that would otherwise be too far away and too faint to be seen. Hubble makes use of this magnification effect to study beyond the sensitivity of its 2.4-metre-diameter primary mirror by showing us the most distant galaxies humanity has ever encountered. Hubble's observations of lensing effects have also given us a glimpse of the cosmos that will be unveiled by the upcoming NASA/ESA/CSA James Webb Space Telescope.	    
05:15-06:11 One of Hubble's initial core purposes was to determine the rate of expansion of the Universe, known to astronomers as the "Hubble Constant". This value is an essential ingredient needed to determine the age, size and fate of the cosmos. Before Hubble was launched, the value of the Hubble constant was not known precisely, and calculations of the Universe's age ranged from 10 billion to 20 billion years. Now, astronomers using the Hubble Space Telescope's data and observations have refined their estimates of the Universe's present expansion rate and are working to make it more accurate. Hubble's refined distance values have helped to put the age of the Universe at 13.8 billion years.	 
06:12-07:54 While improving the measurements of the Hubble Constant, the Hubble Space Telescope's data have also supported the development and use of the cosmic distance ladder, which is an important scientific tool that is used to measure accurate	

distances to galaxies near to and far from Earth. To do this, astronomers use Hubble to measure the distances to a class of pulsating stars called Cepheid variables, which are used as milepost markers. Once the Cepheids are calibrated, astronomers move beyond our Milky Way to nearby galaxies for other reliable yardsticks: supernovae, exploding stars that flare with the same amount of brightness. Astronomers use the Cepheids to calibrate the relationship between absolute luminosity and apparent brightness relation for supernovae, which is a function of the distance from us of their host galaxy. We detect supernovae in galaxies hundreds of millions of light years from us, giving us a powerful tool for calibrating redshifts at larger distances than Cepheids can. However, scientists discovered that supernovae at higher redshifts were fainter than one would expect when assuming a constant expansion of the Universe, meaning they were further away. These observations helped astronomers to then determine how fast the Universe is expanding over time.	   
07:55-08:27 To their surprise, the data implied that the universe has not been expanding at a constant rate, but instead is accelerating. Many scientists believe this acceleration is caused by something called dark energy that must make up about 70 percent of the entire Universe. By observing how dark energy behaves over time, astronomers hope to gain a better understanding of what it is and how it might affect the future of the cosmos.	 
08:28-09:02 The telescope also carried out surveys and developed new methods to look for clues about the equally mysterious dark matter, which makes up about 27% of the Universe. Astronomers used Hubble to create a map of everyday, visible matter, from which they could trace the large-scale distribution of dark matter by studying how its gravitational presence distorted light in the images.	 

09:03-09:50 Hubble has also lifted the veil surrounding the cosmic monsters that lurk at the centre of most galaxies: supermassive black holes. Using its spectroscopic observing capabilities, Hubble peered into the galaxy cores and found that the stars there moved in tight orbits at enormous velocities. This strange behaviour indicated the presence of a truly colossal gravitational field — that could only be produced by a supermassive black hole. Hubble provided the first solid proof of their existence. Today it is known that there is a black hole in the centre of almost every galaxy.	  
09:51-10:35 Another phenomenon that Hubble's instruments have observed throughout the years is quasars. These are powerful jets of energy that come from extremely luminous galactic centres. The power from a quasar is enormous and they typically have luminosities thousands of times brighter than the Milky Way. In 1996, Hubble's 100 000th exposure was a quasar located 9 billion light-years from Earth. More recently, Hubble discovered the brightest quasar ever seen in the early Universe.	  
10:36-12:08 Hubble has revolutionised planetary science in a number of ways through its precise observations of our own Solar System. Hubble has charted the dynamic activity on Jupiter and its moon Io. In 1994, it also witnessed a comet crash into the planet's surface. Hubble has also observed the auroras on several of our Solar System's planets, including Saturn and Uranus.	 

The telescope's data were also used to study the origin of the smallest known moon orbiting the planet Neptune, known as Hippocamp. In 2013, Hubble provided the first observational evidence of water vapour erupting from the frigid surface of Jupiter's moon Europa near its south pole.	  
12:09-13:03 The telescope has also captured observations of some special interstellar visitors. In 2018, Hubble studied `Oumuamua, the first interstellar object discovered in the Solar System. In cooperation with other ground-based telescopes, it was determined that the object was likely a comet and was moving away from the Sun faster than previously expected. In 2019, Hubble provided astronomers with their sharpest and best observation to date of the interstellar visitor Comet 2I/Borisov, which is believed to have arrived here from another planetary system elsewhere in our galaxy.	  
13:04-14:15 Hubble's high resolving power has also been crucial in the investigation of regions of star formation, both in the Milky Way and in other galaxies; and its infrared capabilities have allowed it to peer through the thick clouds of dust and gas present in those regions. The death of a star can be as beautiful and interesting as its birth. Hubble has observed both Sun-like stars as they come to the end of their lives in the form of planetary nebulae, and massive stars experiencing explosive deaths as supernovae.	 

By studying them at different times in their lives, Hubble has allowed us to paint a more complete picture of stars, the building blocks of galaxies.	
14:16-16:27 While not one of its original science goals, Hubble has also made a name for itself as an exoplanet explorer — in particular by studying exoplanet atmospheres. The chemical makeup of a planet's atmosphere leaves a unique fingerprint on the starlight that passes through it. By studying the Orion Nebula, Hubble made the stunning discovery that at least half of the stars in the region were surrounded by rotating discs of gas and dust — the raw materials necessary for the formation of planets. In 2016, Hubble analysed for the first time the dry atmosphere of a super-Earth, 40 light-years away. In 2019, in an exciting discovery, the telescope's data were used to detect water vapour in the atmosphere of a super-Earth within the habitable zone. K2-18b is eight times the mass of Earth and at its discovery was the only planet orbiting a star outside the Solar System, or exoplanet, known to have both water and temperatures that could support life. Prior to Hubble's work, just one planetary system had ever been confirmed. Hubble's observations have shown us that planets are being formed around many more stars than previously thought, increasing the possibility that life could exist somewhere out there. And in the future, Hubble could possibly find hints of life in one of these fingerprints.	     
16:28-17:22 An outstanding successful project of international cooperation between NASA and ESA, the Hubble Space Telescope will continue to work for as long as its components operate and it provides a good service to the scientific community.	

Its unprecedented capabilities have made it one of the most powerful science instruments ever conceived by humans, and certainly the one most embraced by the public. On its 30th birthday, we look back at its unparalleled scientific contributions and its spectacular imagery, while anxiously awaiting what discoveries are yet to come!	 

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