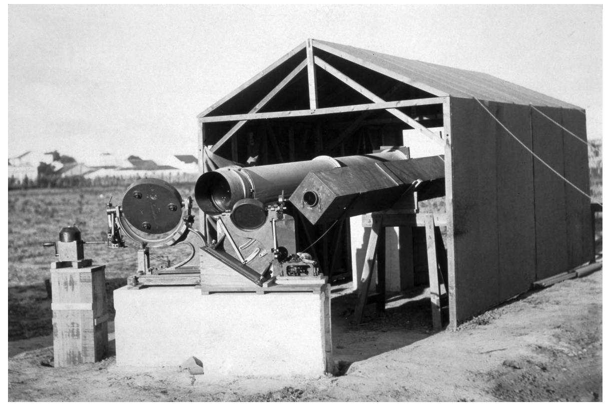
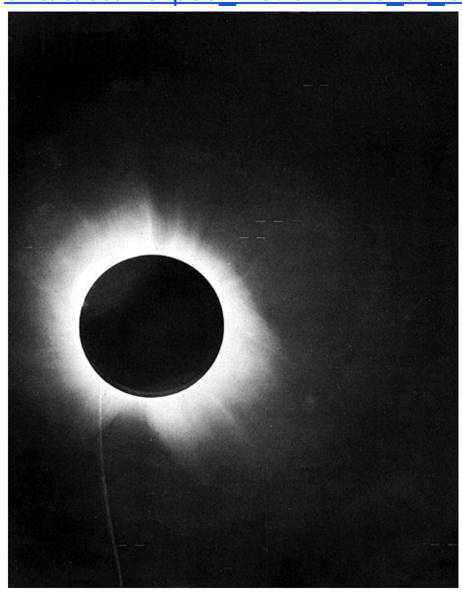
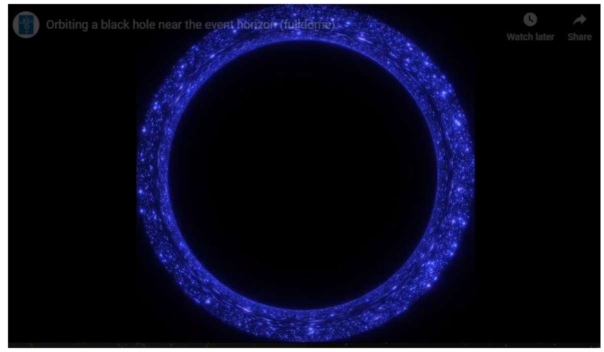
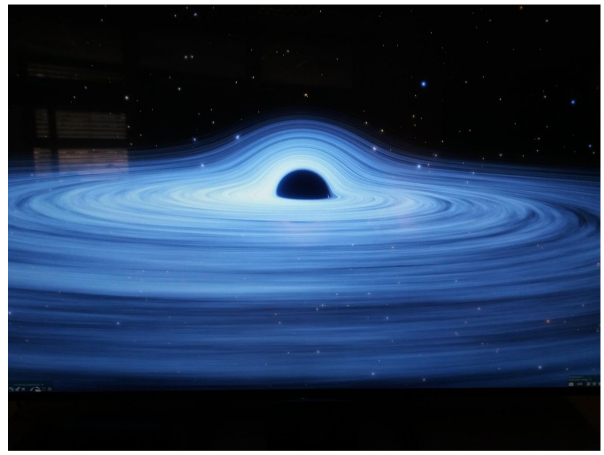
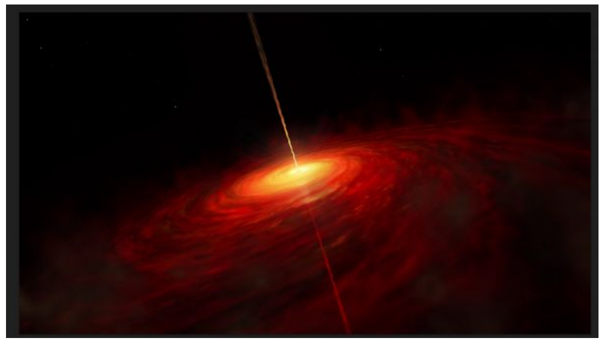
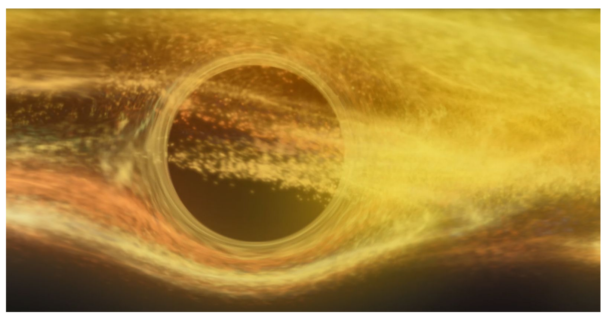
ESO EHT Feature Film: **In the Shadow of the Black Hole**	

00:01.5 **[Narrator]** In 1919 the now famous Eddington expedition ventured out to see whether gravity can bend light — a major test of Einstein's general theory of relativity. By viewing a total solar eclipse, they showed that the Sun *did* change the path of starlight just as predicted — making Einstein and his theory world-famous.	 https://upload.wikimedia.org/wikipedia/commons/b/ba/Eclipse_instruments_at_Sobral.jpg  https://commons.wikimedia.org/wiki/File:1919_eclipse_positive.jpg
Now, a whole century later, scientists have set out again, to even more remote locations scattered across four continents. They will once more push the limits of astronomical knowledge, testing the same theory in a way Einstein could never have imagined. Their goal: to take a picture of a black hole,	Upbeat, exciting music Scientists at work in different environments, incl. ALMA and APEX

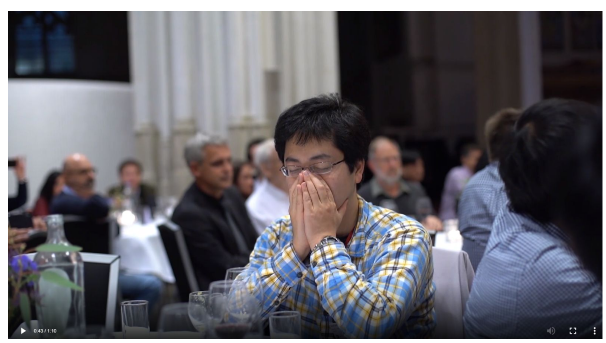
something so ambitious that it seemed impossible...until now!	
In the Shadow of the Black Hole	TITLE SEQUENCE Title music 
01:08.8 **[Narrator]** The story of black holes begins as a puzzle. In 1915 Karl Schwarzschild noticed that Einstein's then-new general theory of relativity predicted the existence of strange objects known as "singularities". They were places where his new equations describing gravity seemed to go haywire. Inside them was a bizarre place where time stopped and space became infinite... At the time, many scientists, including Einstein, considered them too strange to be	**00:00**  https://commons.wikimedia.org/wiki/File:Karl_Schwarzschild_in_his_working_place.png Photo of Einstein.

worth seriously researching. Over the hundred years since then, however, evidence has piled up indicating that singularities do exist in our Universe… ...as *black holes*.	Black holes https://www.spacetelescope.org/videos/hubblecast43d/ https://www.spacetelescope.org/videos/hubblecast43b/ BH  BH  BH
02:06.6 **[Speaker]** *A black hole is the most mysterious object in the Universe. It's where matter gets to be in such a small space and is so dense that the force of gravity prevents even light from escaping. Now that's a one-way door from our Universe.*	Sheperd S. Doeleman Harvard-Smithsonian Center for Astrophysics, USA Jordy simulation

02:22.3 **[Speaker]** *We know they sit at the hearts of galaxies and they drive how those galaxies grow and how those galaxies die, they swallow gas and stars up. They're also these incredibly enigmatic and mysterious objects that live at the boundary between our two great theories of physics: general relativity, which describes gravity, and quantum mechanics, which describes the smallest things in the world.*	Geoffrey Bower ASIAA, Taiwan R.O.C. Source: Geoffrey Bower Interview 00:23-00:48 Cut to Black hole animation  Rendering
02:49.0 **[Speaker]** *If you want to make a test of the fundamental theories of the Universe you want to go to the most extreme laboratories in the Universe, and a black hole is that.*	Sheperd S. Doeleman video 00:35-00:44
02:59.5 **[Narrator]** But observing this most extreme laboratory requires an extreme instrument. The immense gravity of black holes is an obstacle to viewing them directly. No light can escape from them and they are tiny — crushing huge amounts of matter into small points of darkness.	
03:22.9 **[Narrator]** Even as the existence of these strangest of objects became more widely accepted, seeing them directly remained an impossible dream.	Flight through the Universe https://www.eso.org/public/videos/eso1813f/

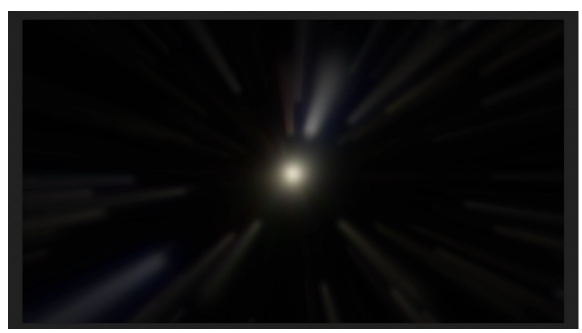
In fact, to achieve the necessary resolution to see black holes directly, a single telescope would need to be the size of planet Earth — clearly too large to be feasible. Instead, astronomers spent decades studying the effects that black holes have on the matter around them. But the dream of getting more concrete evidence of these exotic objects was too tempting to be simply forgotten.	Earth: https://www.eso.org/public/videos/earth_2015_4k/ Cosmology: https://www.eso.org/public/videos/distant-galaxies/
04:11.0 **[Speaker]** *We all understand from a mathematical point of view that black holes exist, but to actually see something is a very visceral experience and I think important for science and also for us to believe in it.*	2:06-2:18 Sera Markoff University of Amsterdam, The Netherlands
04:24.9 **[Narrator]** In the late 1960s, a new technique changed astronomy. Called very long baseline interferometry, it enabled several telescopes to observe as a team — creating a larger, “virtual” telescope that could overcome constraints on telescope size.	Interferometry illustration. Preferably radio telescopes linked up. Cartoon schematic showing lines linking telescopes (not necessarily EHT ones as that might be needed later) - CAN BE IMPROVED LATER.
04:47.0 **[Narrator]** As this method spread, it became clear that direct imaging of a black hole was a real possibility. In 2009, the Event Horizon Telescope project, the EHT, was born — to pursue this exciting goal.	Idea for visual: scientists discussing at conferences etc. ALMA compilations: https://www.eso.org/public/videos/alma2010comp/ (starting around)24:13 min https://www.eso.org/public/videos/alma2012compilation/ Starting around 11:40 min https://www.eso.org/public/videos/eso1137c/ Around 14:00 min
05:07.7 **[Speaker]**	1:22-1:40

The Event Horizon Telescope collaboration is a collaboration of scientists around the world from many different countries, continents and institutions to make a telescope the size of the Earth, giving us the highest resolution there is that currently is achievable with telescopes of any kind.	Heino Falcke Radboud University, The Netherlands
05:27.2 **[Narrator]** It was clear from the outset that the EHT would face unique hurdles. But “seeing is believing”, and the team was dedicated to revealing a black hole for the first time.	B-roll footage from external partners or telescopes
05:41.9 **[Narrator]** To create it, eight telescopes across the world were linked together. ESO plays a key role in two of these telescopes, both located on the Chajnantor Plateau in Chile: the Atacama Large Millimeter/Submillimeter Array — ALMA — and the Atacama Pathfinder Experiment, known as APEX. The other telescopes that make up the EHT are the IRAM 30-metre telescope in Spain, the Large Millimeter Telescope in Mexico, the Submillimeter Telescope in Arizona, the James Clerk Maxwell Telescope and the Submillimeter Array, both in Hawai’i, and finally the South Pole Telescope in Antarctica. Together, they can achieve a resolution equivalent to reading a newspaper in Paris while sitting in New York.	Map of the EHT locations of the telescopes around the world Footage of the 8 telescopes Paris + New York photos

06:58.4 **[Narrator]** The immense challenges of the project soon became clear. The telescopes, all highly-advanced instruments in their own right, were not built to work together. Making them work together as one interconnected interferometer required a huge team.	**Dramatic** music sequence starts ALMA timelapse Night time or drone footage https://www.eso.org/public/videos/alma-droneaerial2015a/
07:17.8 **[Speaker]** *These are engineers, observers, theoreticians, and they all work together, not only to image the event horizon of a black hole, but also to understand what we are seeing.*	0:47-0:58 Monika Mościbrodzka Radboud University, The Netherlands
07:30.7 **[Narrator]** The project brought together more than 200 scientists from over 100 institutions, all of whom had to play things by ear as they built this brand-new organisation. Coordinating such a large team spread across the globe was just one of many significant challenges. With a project that sets new benchmarks for human ingenuity, there is plenty of scope for things to go wrong. And, one after another, they did... Equipment failures... Power failures… Not enough hard drives to store data ... Believe it or not, at one point, some of the scientists were even held at gunpoint during their observations... Soon the project was in dire straits...	Footage showing scientists 
08:21.9 **[Narrator]** The locations of the telescope also presented huge practical challenges.	Telescope footage (any)

08:28.7 **[Narrator]** The environments that are best for viewing the night sky are often the most difficult places to build observatories. The telescopes of the EHT are no exception. Their remote sites are scattered across four continents, including observatories in the barren Chilean Atacama Desert, on a freezing plateau in Antarctica and on top of a dormant volcano in Hawai'i.	Aerial views of challenging locations… desert … south pole … IRAM… Hawai'i…
08:57.7 **[Narrator]** All these telescopes are located far from civilisation, where city lights don't pollute the night skies. But, for the astronomers who ventured to the telescopes to take the data, isolation was the least of their troubles. Very dry places at high altitudes are ideal for observations, since they avoid water vapour in the atmosphere interfering with the light from astronomical objects.	Chajnantor:https://www.eso.org/public/videos/uhd_alma2_2014/ ALMA https://www.eso.org/public/videos/almatimelapse12i/ https://www.eso.org/public/videos/uhd_comp_alma_2014/
09:30.7 **[Narrator]** ALMA and APEX are located on the Chajnantor Plateau, at an altitude of 5000 metres in the barren Chilean Atacama Desert, a place so inhospitable that it serves as testing ground for Mars rovers. People working here had to use oxygen tanks as the air is too thin to breathe.	People with oxygen canisters at ALMA https://www.eso.org/public/videos/uhd_photogr7_2014_1/
09:58.1 **[Narrator]** The dangers of altitude sickness were also shared by observers at the James Clerk Maxwell Telescope and the Submillimeter Array located near the summit of the dormant volcano Mauna Kea. In this exposed location high above sea level, astronomers ran the	Mauna Kea volcano SMA stills and JCMT timelapses

risk of serious dehydration and sunstroke.	
10:23.8 **[Narrator]** At the opposite extreme of the temperature scale, observers at the South Pole Telescope in Antarctica had to endure sub-zero temperatures for long stretches of time. Here, there were unique challenges; in winter the Sun never rises above the horizon, creating a single night that lasts for months. Wonderful for the telescopes, but it takes a psychological toll on humans.	SPT videos
10:56.1 **[Narrator]** Sleepless nights were spent working in these hostile regions.	**Dramatic music sequence end**

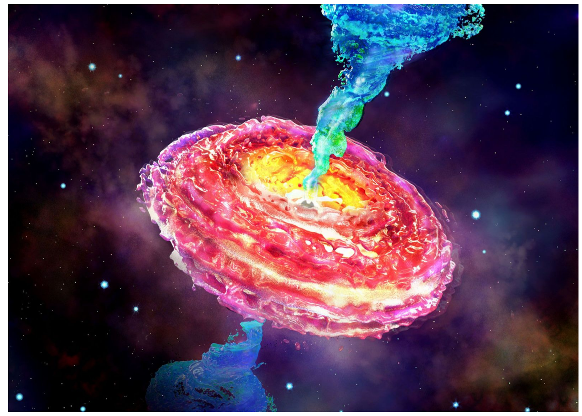
11:02.9 **[Narrator]** After almost a decade of preparation, the EHT was finally ready to use all eight telescopes as one instrument. On 5 April 2017 the EHT was for the first time aimed at the chosen target, M87*, the black hole in the centre of the enormous galaxy Messier 87, about 55 million light years from Earth. Attempting to peer into the dark heart of a galaxy tens of millions of light years away might seem like a strange choice. There are many black holes closer to home. But M87* was carefully selected. It had two big advantages: It’s one of the biggest black holes known, giving the astronomers a better chance of seeing it than smaller black holes in our neighbourhood; and isn’t too far north or south in the sky — crucial if telescopes all over the world have to observe it at the same time.	Music builds up to a crescendo! Visual: Zooming animation from ALMA to M87 

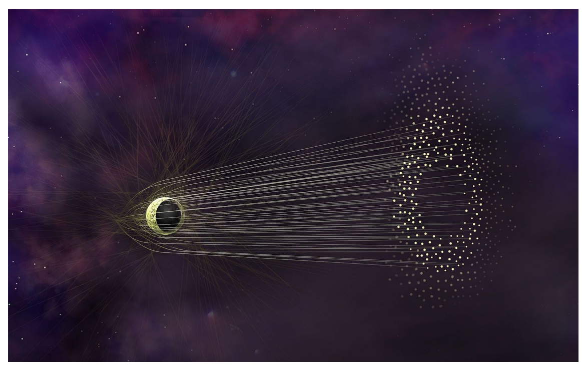
12:07.3 **[Narrator]** When those sleepless nights of observation ended, a new phase of work began. In order to find out what they'd seen the scientists had to painstakingly combine and analyse the data. Two computation centres, one in Europe and one in the US, combined a staggering quantity of data — about 350 terabytes per day from each telescope. The data had to be synchronized by atomic clocks so precise that they lose only 1 second every 10 million years and then transported on specialised helium-filled hard drives. Hand-carrying this precious cargo might seem like a low-tech solution, but the drives contained so much data that moving them by hand was, at times, the fastest data transmission in history.	Visual: Either some images of the data collection (eg. these ones from the campaign if we can get high enough quality) or whatever b-roll/images of astronomers at work/transporting data/etc
13:07.2 **[Narrator]** After countless hours of work on the data, an image began to take shape.	Visual: scientists processing data OR JORDY simulation

13:12.9 **[Narrator]** This image would tell hundreds of scientists whether decades of work had attained the unattainable, or had been in vain.	
13:23.5 **[Narrator]** Although black holes themselves are completely dark, they influence the path of photons travelling in their vicinity and leave an unmistakable signature on the light from the accretion disc surrounding the black hole — a large disc of matter gradually spiralling in towards its host. The infalling matter becomes very concentrated, causing friction to heat it to form a glowing plasma. The path of the light emitted by this glowing gas is determined by	NSF CLIP (in progress)

the black hole: the light passing close by it is bent by the enormous gravity, skirting the edges, but light passing too close is captured, never to escape.

Seen from Earth with radio telescopes, these effects manifest themselves as the shadow of a black hole — a dark central region silhouetted against the luminous plasma.





How the light is bent around the BH (NSF)

	 Luciano’s simulation Music starts to climax
14:28.1 **[Narrator]** After 2 years of painstaking calculations, the image was finally ready….	Music reaches its dramatic high Last stages of the zoom
14:58.0 **[Narrator]** Although taken from the staggering distance of 55 million light-years, the image revealed a ring-like structure with a dark central region. *For the first time in history:* the shadow of a black hole!	Image revealed
15:12.6 **[Speaker]** *And then we look at our first source and we see that ring. We see the event horizon and we see that shadow, that dark region and you know immediately we are looking at an event horizon at a black hole from all sides at once in this thing. We see at a region where time stops. This is a very different part of the Universe we are seeing for the very first time.*	Heino Falcke: 4:04-4:26
15:35.9 **[Speaker]** *I mean this is exactly what we have been looking for but after eight years and all that long process, a few weeks of imaging and they showed us exactly what we wanted. I couldn’t believe it.*	Short interview part 2: 3:30-3:45 Neil Nagar University of Concepción, Chile

15:47.6 **[Speaker]** *Well, I have to say it's taken on a new importance now, as we actually have images that look like the simulations. There's extraordinary confluence between theory and experiment and it promises tremendous breakthroughs on the horizon.*	Avery Broderick: 1:50-2:06 Perimeter Institute, Canada

16:06.0 **[Narrator]** This historic achievement is a major milestone in our evolving understanding of the Universe, and also sets a new precedent for global collaboration in scientific research.	
16:19.8 **[Speaker]** *One of the most uplifting things for me is the team that we've built, and the fact that we're doing something that people have told us was impossible, and when you at the end of the day do something that people tell you can't do it's an incredible feeling, and I think the whole team is very very proud that we've accomplished something like this. It's not just for us, it's for everyone.*	Sheperd S. Doeleman: 2:02-2:25 Smiling scientists [people working]

16:46.9 **[Narrator]** As the EHT is expanded it will allow us to probe the deep questions that attract researchers to black holes: how well do our laws of physics hold up under the most extreme conditions we know of? How do the mechanics of gas, radiation, and particles around a black hole work? Which theories are correct, and which will break down with more precise observations?	Dramatic music

Only time will tell which mysteries the EHT will unravel next.	END
	EHT logos *Produced by ESO, the European Southern Observatory.* *Reaching new heights in Astronomy.*