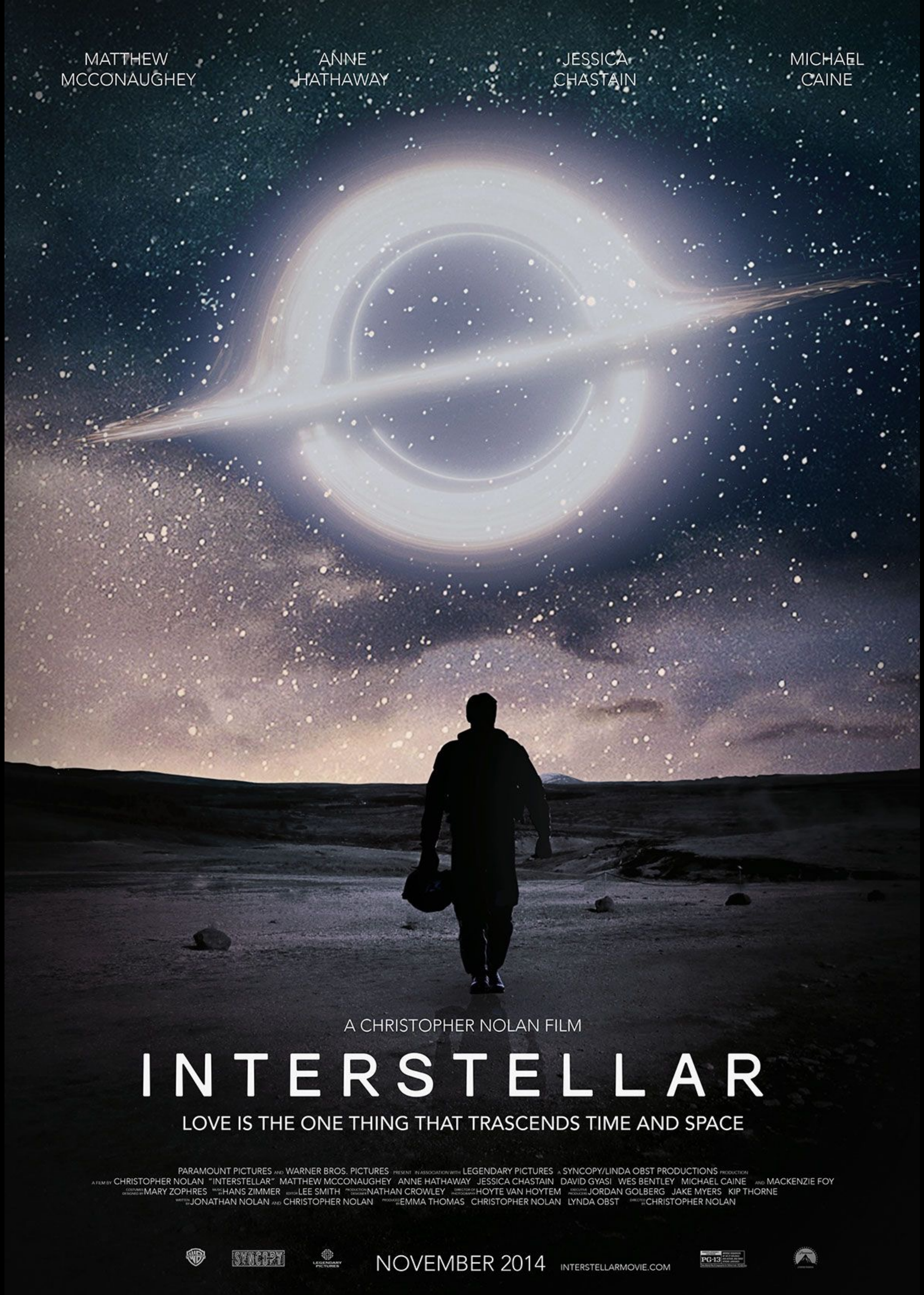
MATTHEW MCCONAUGHEY
ANNE HATHAWAY
JESSICA CHASTAIN
MICHAEL CAINE
A CHRISTOPHER NOLAN FILM
INTERSTELLAR
LOVE IS THE ONE THING THAT TRASCENDS TIME AND SPACE
PARAMOUNT PICTURES AND WARNER BROS. PICTURES PRESENT IN ASSOCIATION WITH LEGENDARY PICTURES A SYNCOPY/LINDA OBST PRODUCTIONS PRODUCTION
A FILM BY CHRISTOPHER NOLAN "INTERSTELLAR" MATTHEW MCCONAUGHEY ANNE HATHAWAY JESSICA CHASTAIN DAVID GYASI WES BENTLEY MICHAEL CAINE AND MACKENZIE FOY
COSTUMES DESIGNED BY MARY ZOPHRES MUSIC BY HANS ZIMMER EDITOR LEE SMITH PRODUCTION DESIGNER NATHAN CROWLEY DIRECTOR OF PHOTOGRAPHY HOYTE VAN HOYTEM EXECUTIVE PRODUCERS JORDAN GOLBERG JAKE MYERS KIP THORNE
WRITTEN BY JONATHAN NOLAN AND CHRISTOPHER NOLAN PRODUCED BY EMMA THOMAS CHRISTOPHER NOLAN LYNDA OBST DIRECTED BY CHRISTOPHER NOLAN
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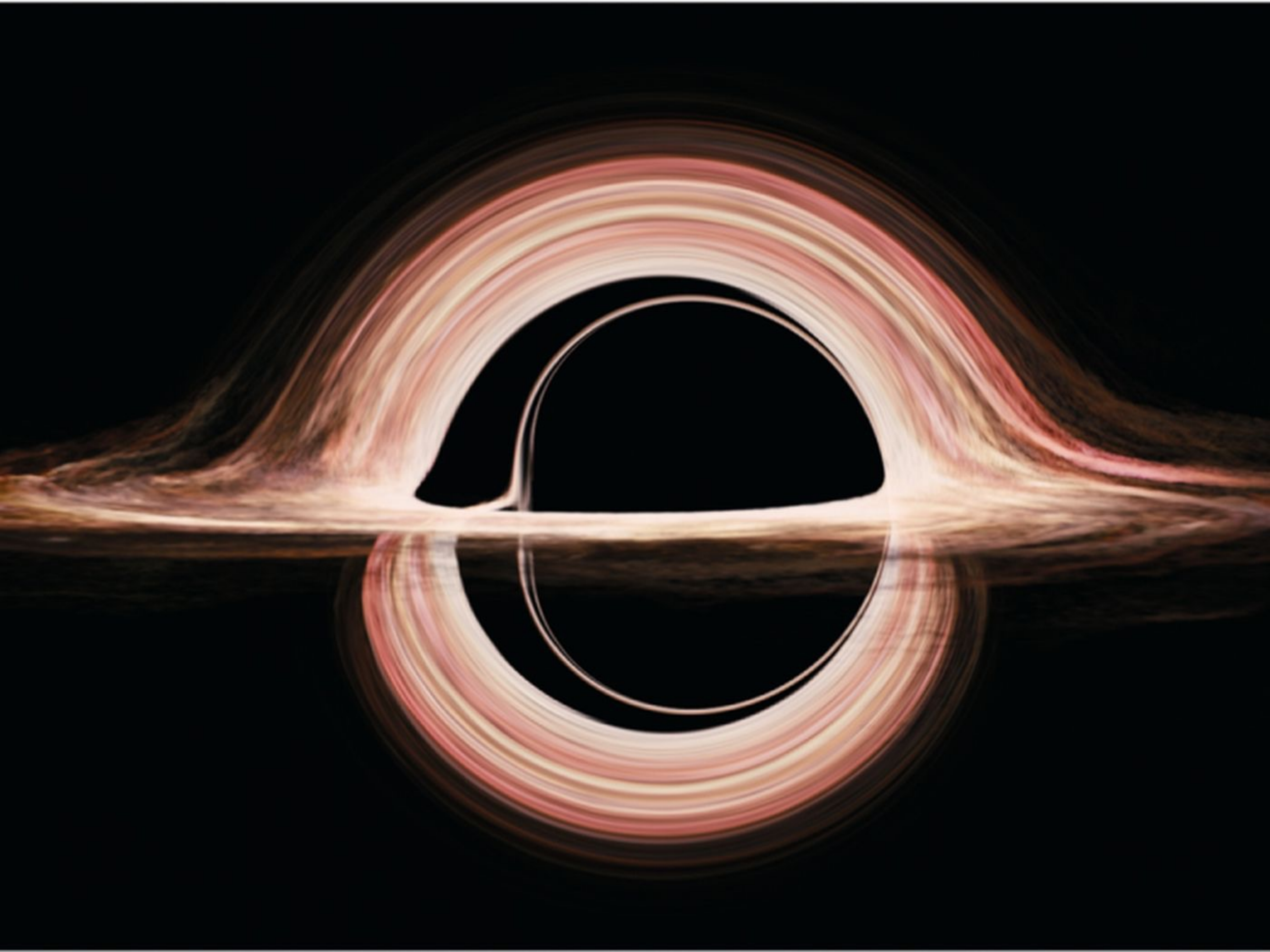


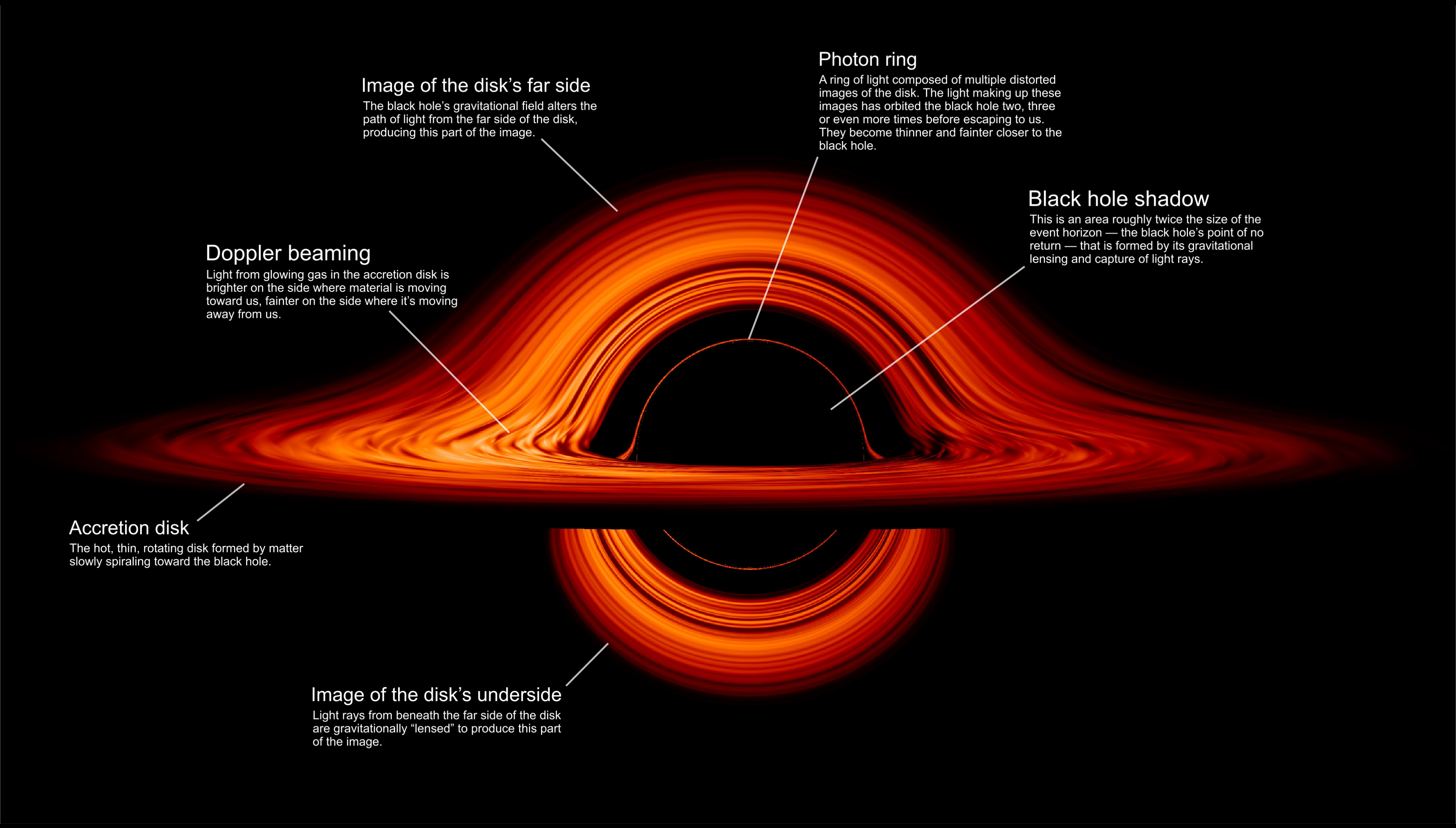
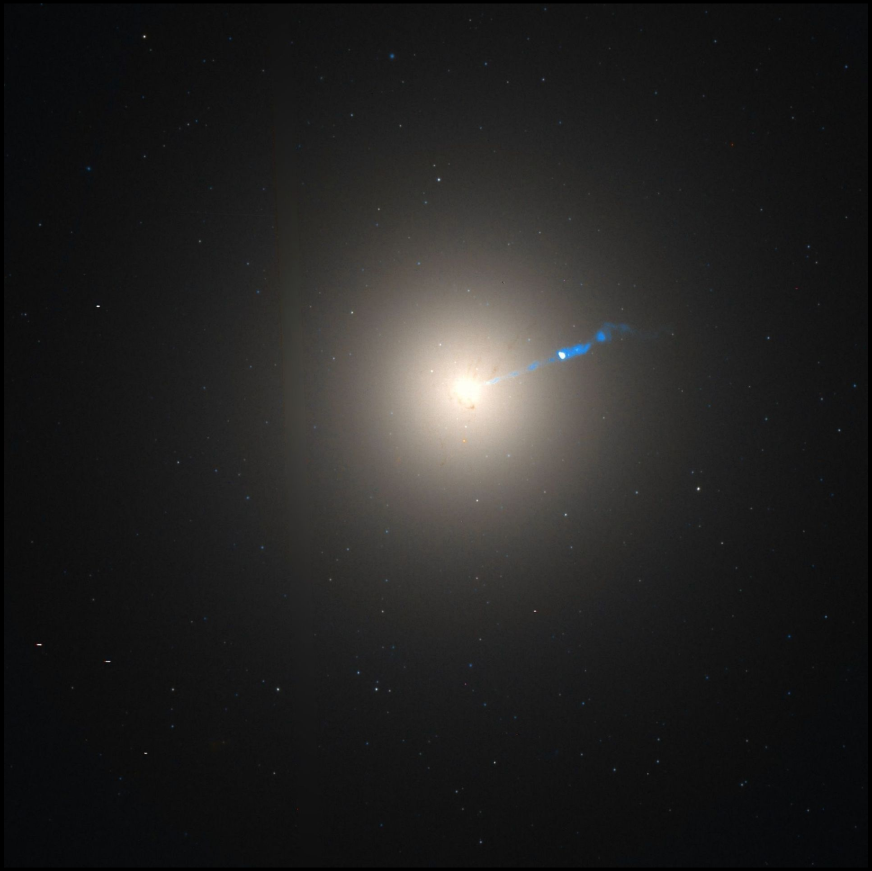
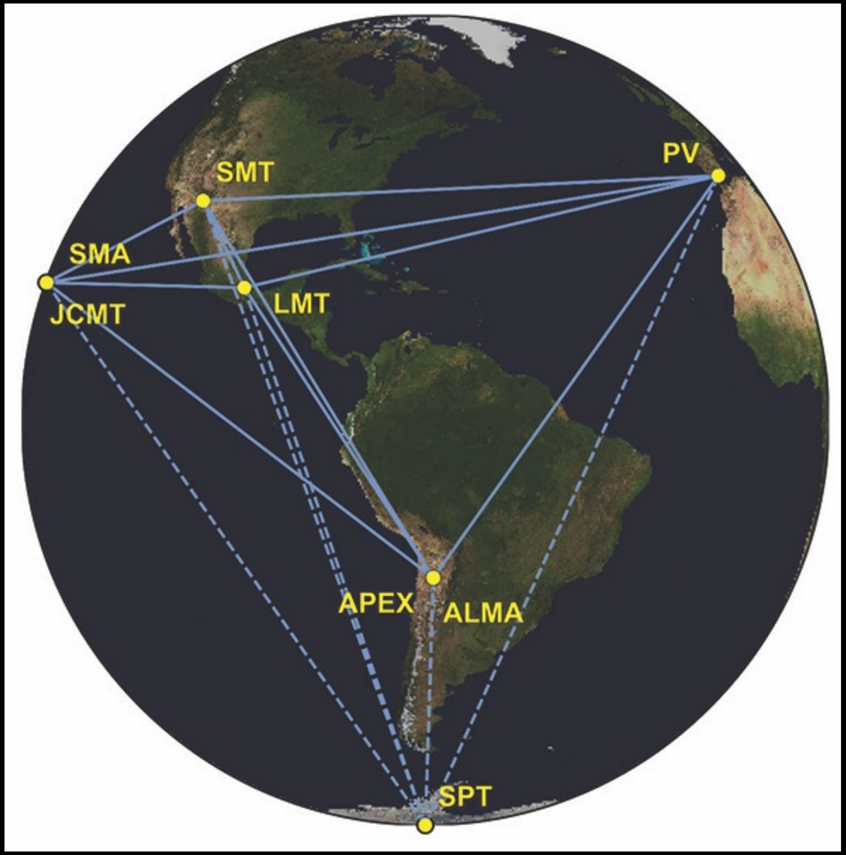


Image of the disk's far side
The black hole's gravitational field alters the path of light from the far side of the disk, producing this part of the image.
Photon ring
A ring of light composed of multiple distorted images of the disk. The light making up these images has orbited the black hole two, three or even more times before escaping to us. They become thinner and fainter closer to the black hole.
Black hole shadow
This is an area roughly twice the size of the event horizon — the black hole's point of no return — that is formed by its gravitational lensing and capture of light rays.
Doppler beaming
Light from glowing gas in the accretion disk is brighter on the side where material is moving toward us, fainter on the side where it's moving away from us.
Accretion disk
The hot, thin, rotating disk formed by matter slowly spiraling toward the black hole.
Image of the disk's underside
Light rays from beneath the far side of the disk are gravitationally "lensed" to produce this part of the image.





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First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole

The Event Horizon Telescope Collaboration
(See the end matter for the full list of authors.)
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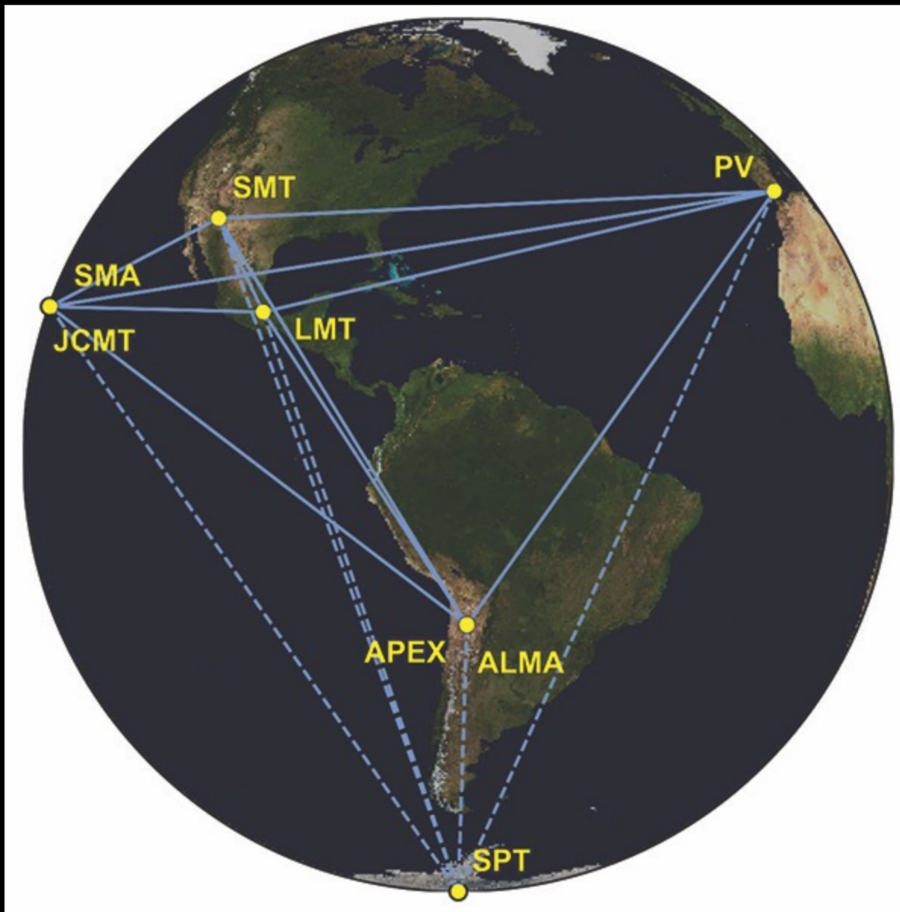
Abstract

When surrounded by a transparent emission region, black holes are expected to reveal a dark shadow caused by gravitational light bending and photon capture at the event horizon. To image and study this phenomenon, we have assembled the Event Horizon Telescope, a global very long baseline interferometry array observing at a wavelength of 1.3 mm. This allows us to reconstruct event-horizon-scale images of the supermassive black hole candidate in the center of the giant elliptical galaxy M87. We have resolved the central compact radio source as an asymmetric bright emission ring with a diameter of $42 \pm 3\,\mu$as, which is circular and encompasses a central depression in brightness with a flux ratio $\gtrsim$10:1. The emission ring is recovered using different calibration and imaging schemes, with its diameter and width remaining stable over four different observations carried out in different days. Overall, the observed image is consistent with expectations for the shadow of a Kerr black hole as predicted by general relativity. The asymmetry in brightness in the ring can be explained in terms of relativistic beaming of the emission from a plasma rotating close to the speed of light around a black hole. We compare our images to an extensive library of ray-traced general-relativistic magnetohydrodynamic simulations of black holes and derive a central mass of $M = (6.5 \pm 0.7) \times 10^9 M_\odot$. Our radio-wave observations thus provide powerful evidence for the presence of supermassive black holes in centers of galaxies and as the central engines of active galactic nuclei. They also present a new tool to explore gravity in its most extreme limit and on a mass scale that was so far not accessible.

Key words: accretion, accretion disks – black hole physics – galaxies: active – galaxies: individual (M87) – galaxies: jets – gravitation



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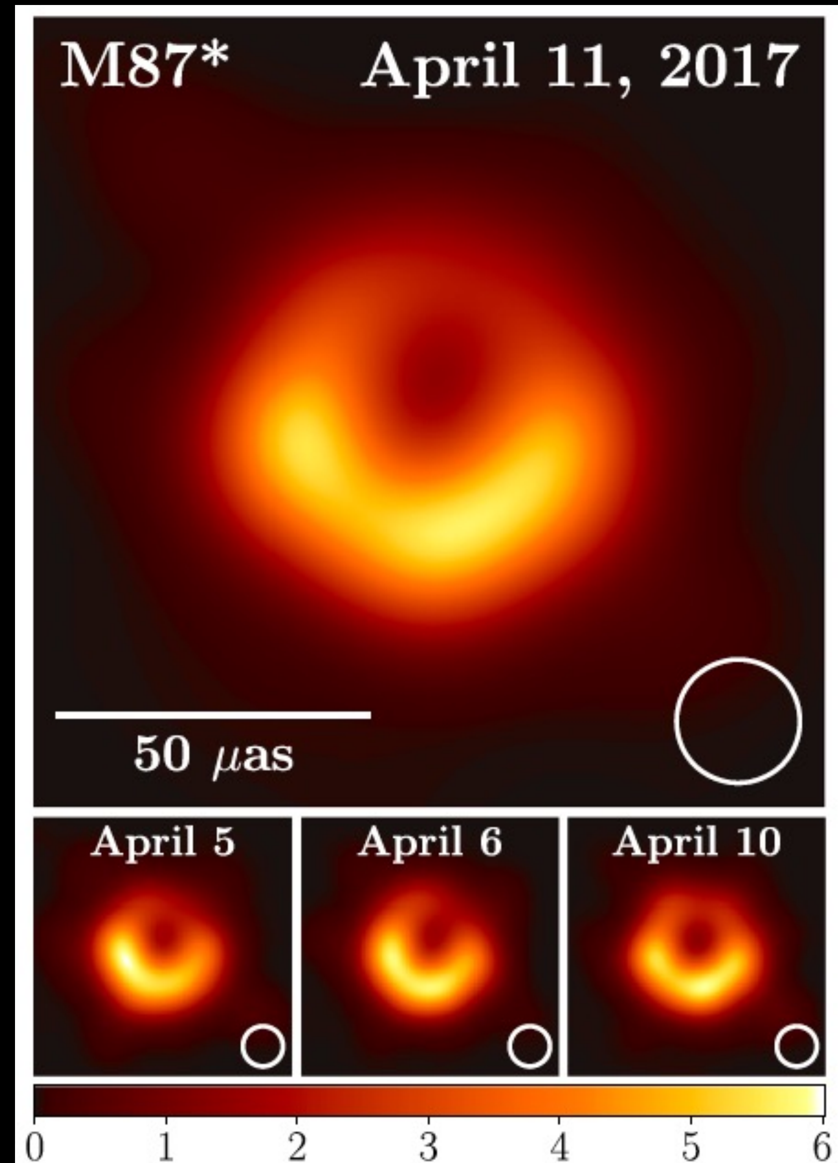
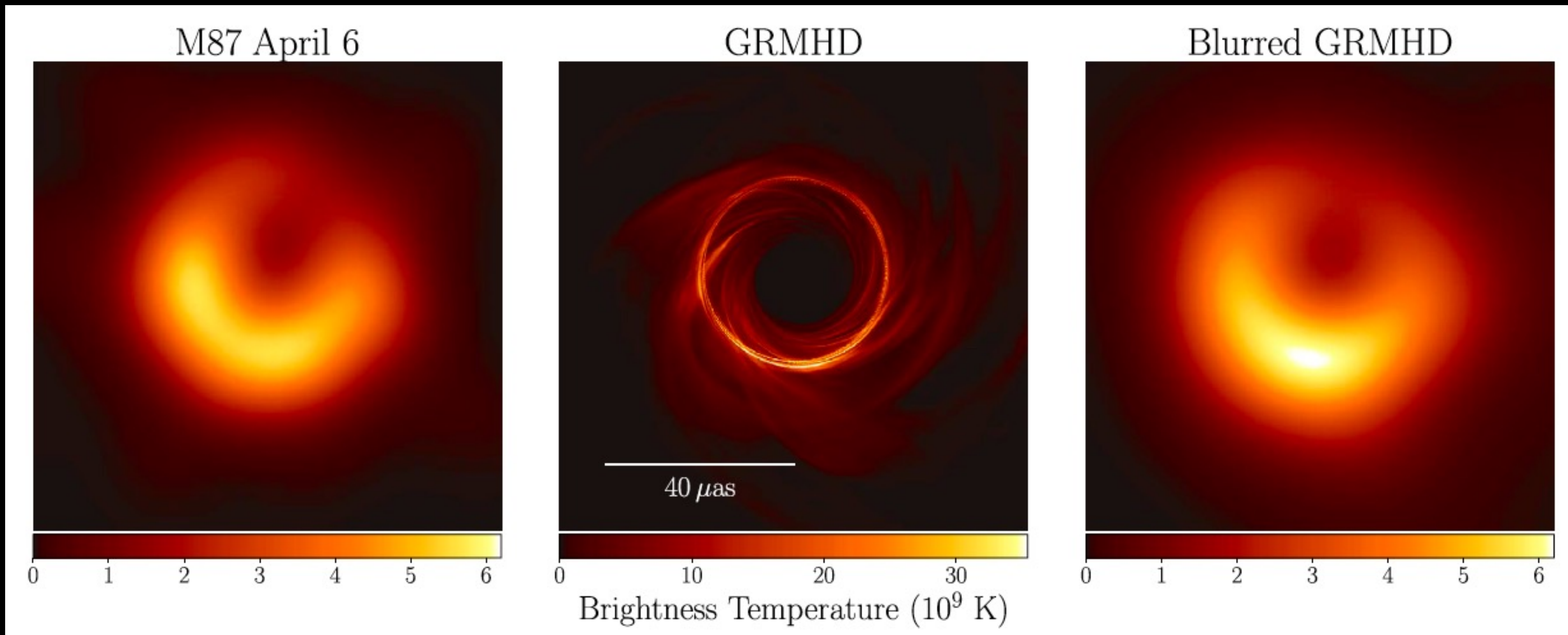


M87*
April 11, 2017
50 μas
April 5
April 6
April 10
0
1
2
3
4
5
6

Observed image | Theoretically predicted image, perfect resolution | Theoretical image blurred to EHT resolution



Bright ring is the "photon ring" arising because light rays go many times around the black hole.

Asymmetry arises from "Doppler boosting" which makes emission from material moving towards us appear brighter. Requires gas moving close to the speed of light; approaching gas on the bottom of the ring.

Central black region is the shadow cast by the event horizon.

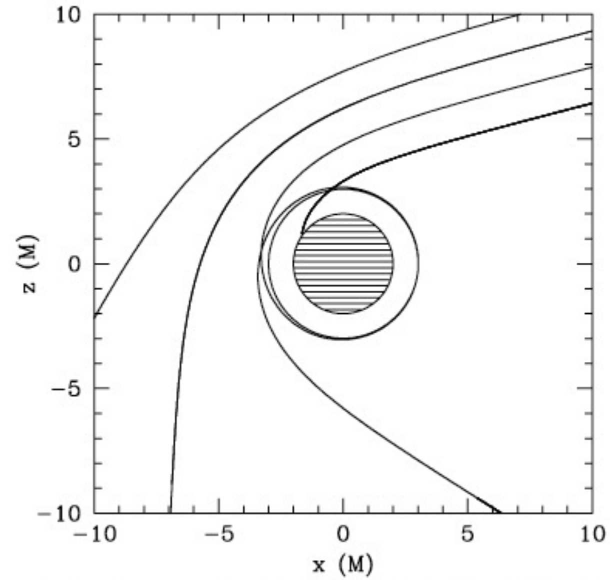


Figure 4. Light rays around a Schwarzschild black hole illustrating the emergence of the bright emission ring. Several light rays approach the black hole from the top right corner. If a ray reaches the photon ring with a 3-momentum that is nearly tangential to the photon orbit, it orbits around the black hole several times, while all other rays are either immediately scattered or captured by the black hole. The footpoints of the orbiting light rays on the image plane will be brighter than those of the nearby rays. The shaded region marks the event horizon.

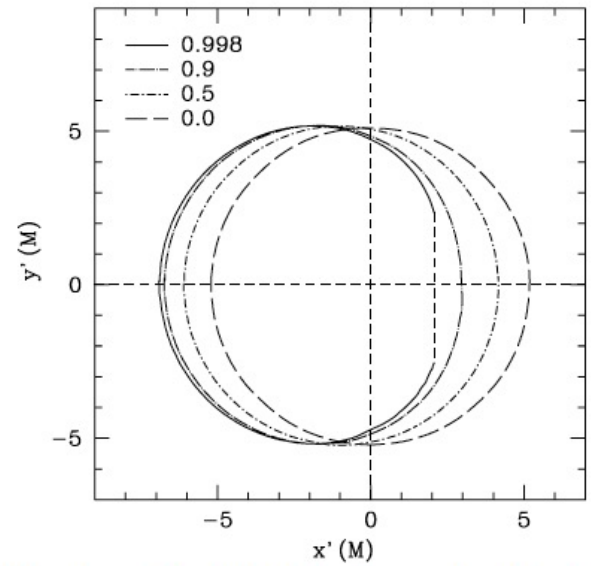


Figure 5. Dependence of the bright photon ring seen by a distant observer on the spin of a Kerr black hole. Increasing the spin leads to a displacement of the photon ring with minimal deformation of its shape. In all cases, the inclination of the observer corresponds to $\cos i = 0.25$.

Johannsen & Psaltis 2010