Messier 87

&

Most detailed image of a Black Hole ever obtained with

Event Horizon Telescope (EHT)

Some useful links:

EU Research press conference (Brussels): https://www.youtube.com/watch?v=Dr20f19czeE

Press conference at National Science Foundation: https://www.youtube.com/watch?v=lnJi0Jy692w

Detailed explanation of the observed phenomenon: https://www.youtube.com/watch?v=vlgs2_C-EtM

Short description of Event Horizon Telescope: https://www.youtube.com/watch?v=gK-R6U5KCjE

Live press conference in Italy: https://www.youtube.com/watch?v=uEhpjDjifGM

ESO science release: https://www.eso.org/public/news/eso1907/

The cluster of galaxies closest to the Milky Way

The Virgo Cluster
Distance: $d = 20$ Mpc
Binding mass: $M \sim 1.2 \times 10^{15}\ M_\odot$
Size: ~ 3 Mpc
About 1500 galaxies (mix of elliptical, S0 & spiral galaxies)

Radio galaxy *M87* with jet
Apparent magnitude: $m_V = 9.59$
Distance: 16.40 ± 0.50 Mpc
Total mass: $M_{tot} = 6 \times 10^{12}\ M_\odot$
Mass central black hole: $M_{BH} = 7 \times 10^{9}\ M_\odot$

Messier 87: one of the most massive galaxies in the *Local Universe*

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(one of the highest mass known for a black hole)

Optical image

Messier 87: radio galaxy with jet

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Radio image

Messier 87: radio galaxy with jet

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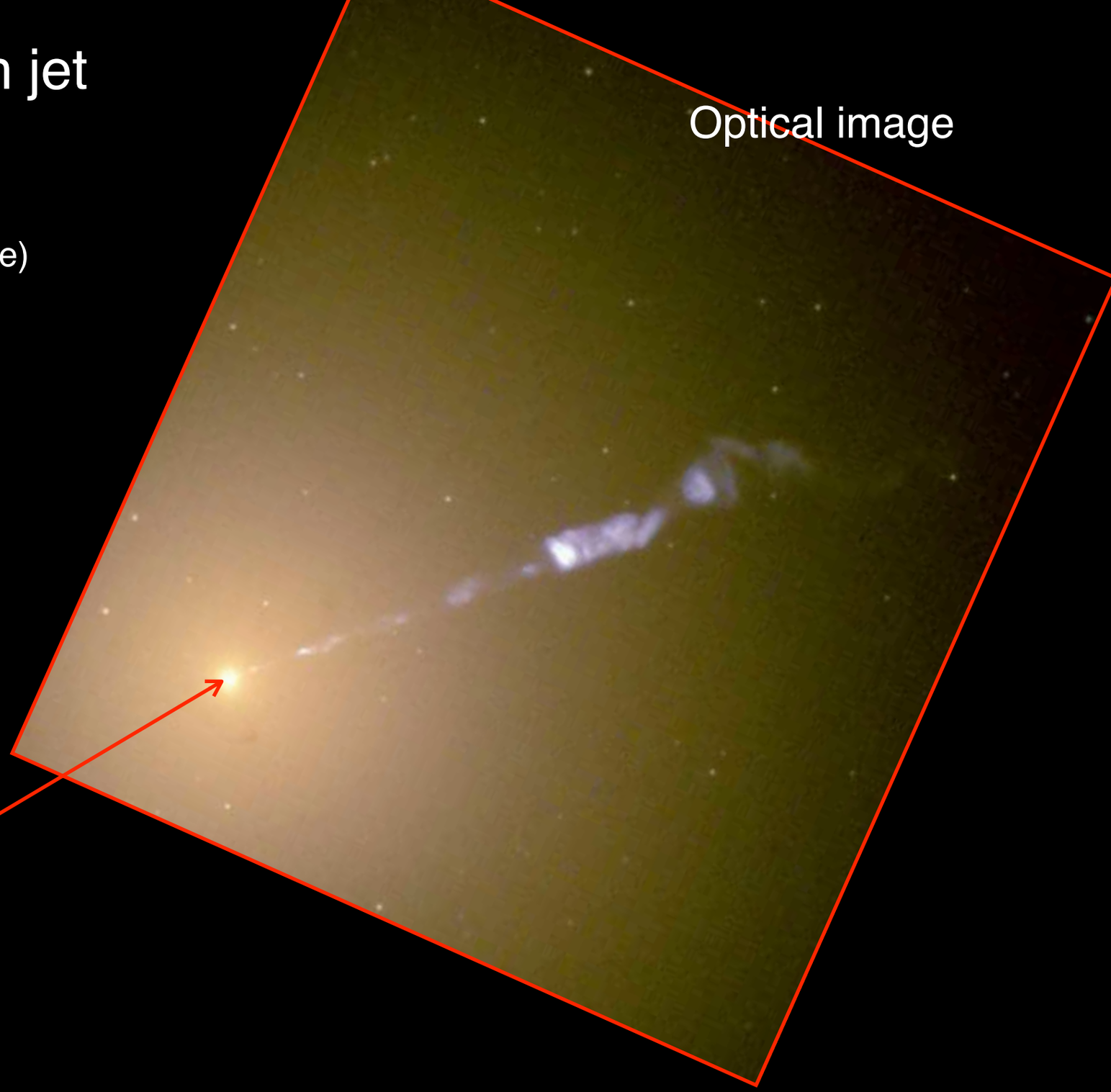
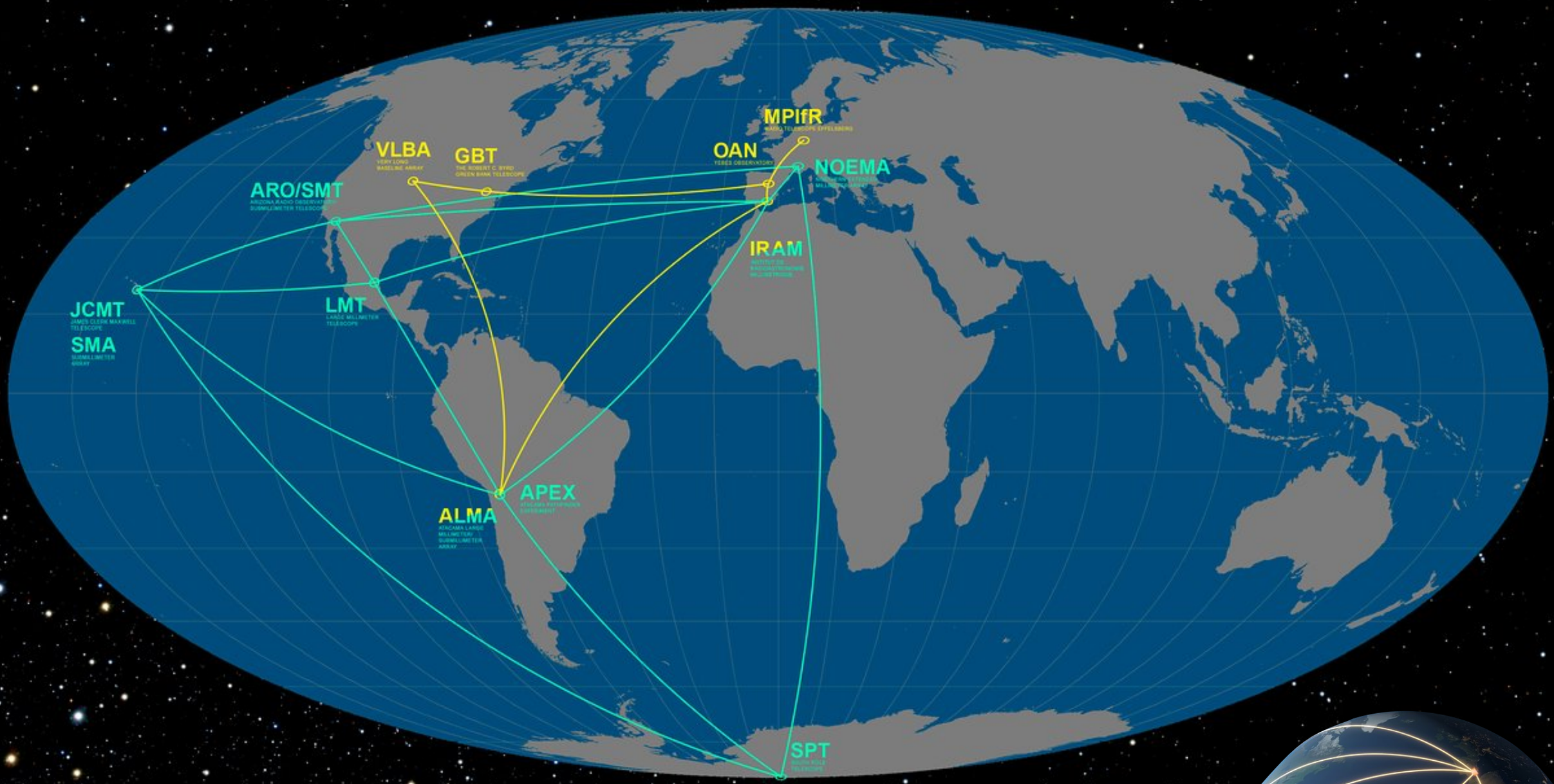


Black hole at center

Event Horizon Telescope (EHT) to “observe” a black hole



EHT uses technique called *very-long-baseline interferometry* (VLBI)

8 radio observatories used on the entire Earth

Total data volume collected in 2017: 5 petabytes (350 terabytes/day)

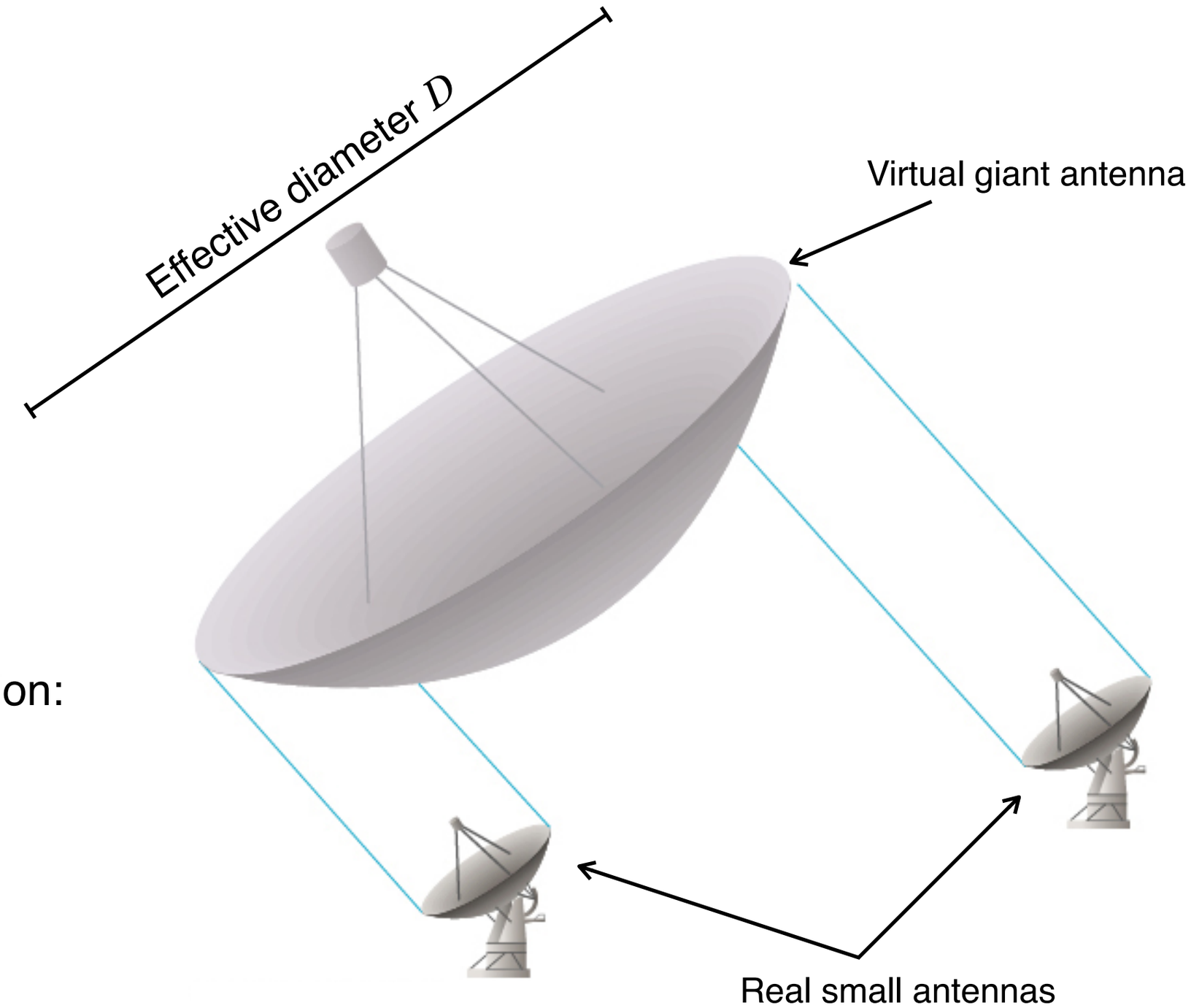
Resolution achieved: 20 micro-arcseconds (20 μas)

Wavelength observed: $\lambda = 1.3$ mm

Interferometry with relatively small radio antennas
to get resolution of giant telescope

ALMA - Atacama Large Millimeter Array
66 12/7-meter diameter antennas
Movable antennas covering area from 150 metres to 16 kilometres

Interferometry with relatively small radio antennas
to get resolution of giant telescope



Effective angolar resolution:

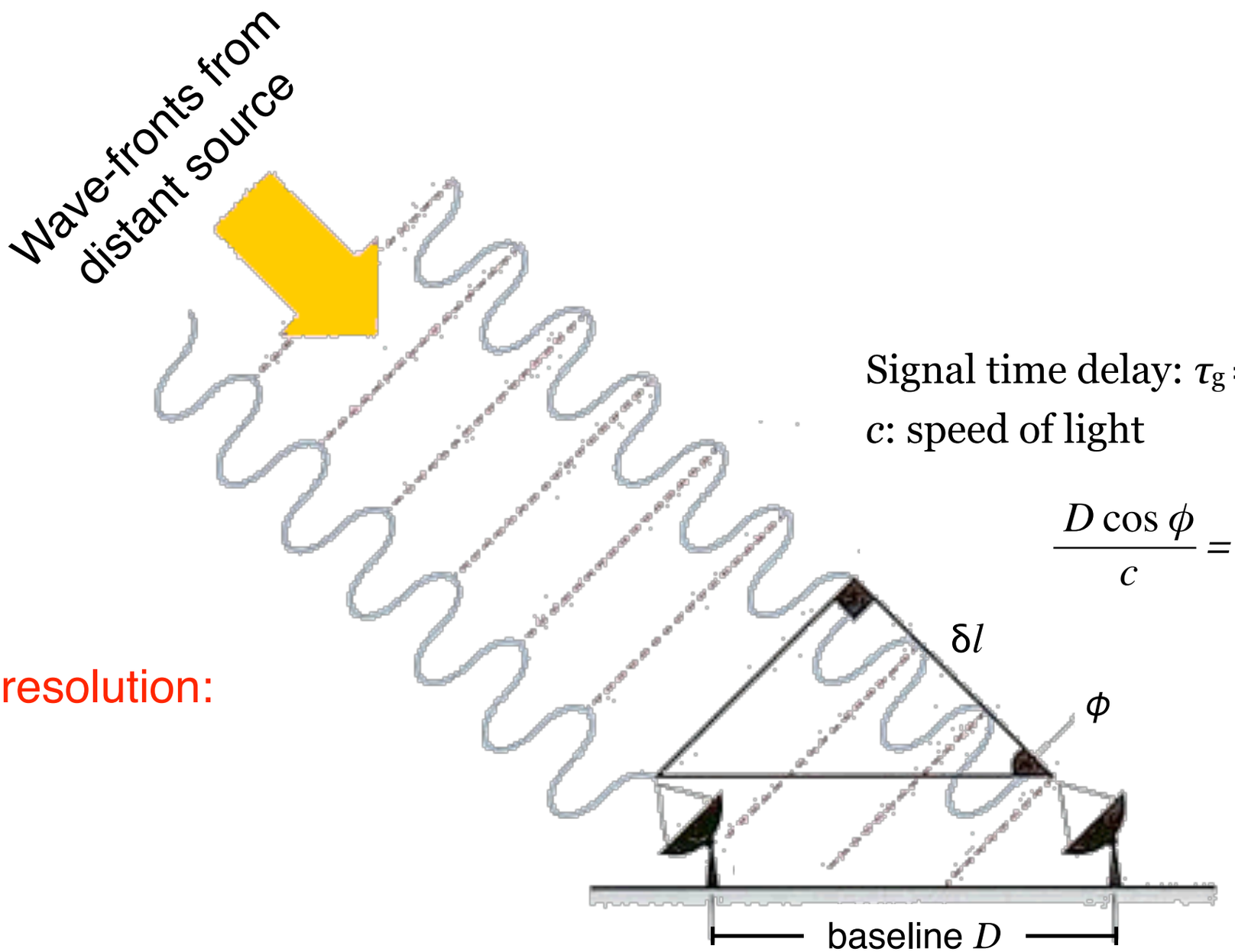
$$\theta = 1.220\frac{\lambda}{D}$$

Fringe pattern is created if separation between two antennas is $> 10 \times \lambda$

Interferometry for radio telescopes

Interferometer: signal is combined from two or more telescopes to produce a sharper image

to obtain **higher angular resolution**



Signal time delay: $\tau_g = \delta l/c$

c: speed of light

$$\frac{D\cos\phi}{c} = \tau_g$$

Effective angolar resolution:

$$\theta = 1.220\frac{\lambda}{D}$$

Effective diameter

Same source $\Longmapsto$ signal perfectly in phase & same frequency

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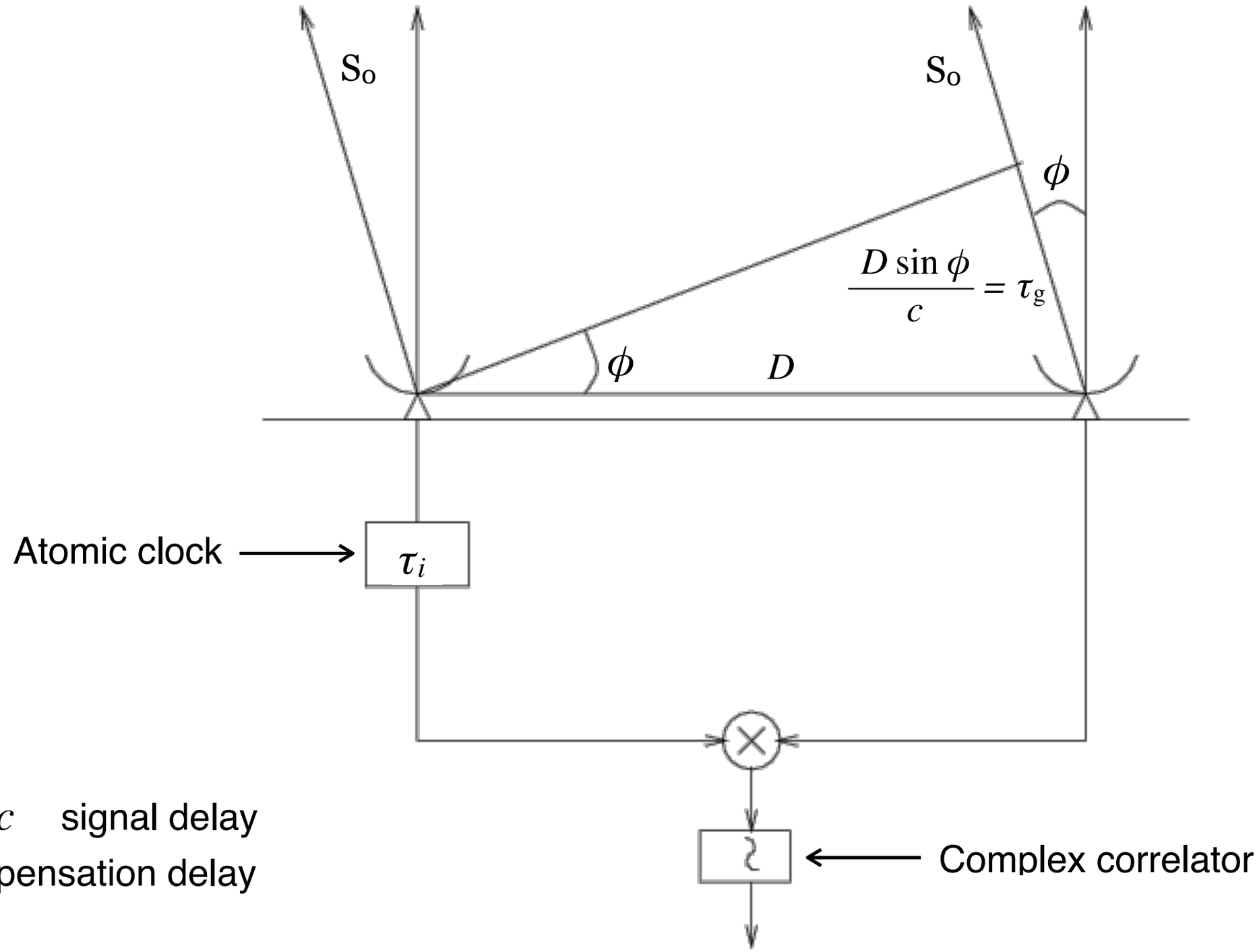
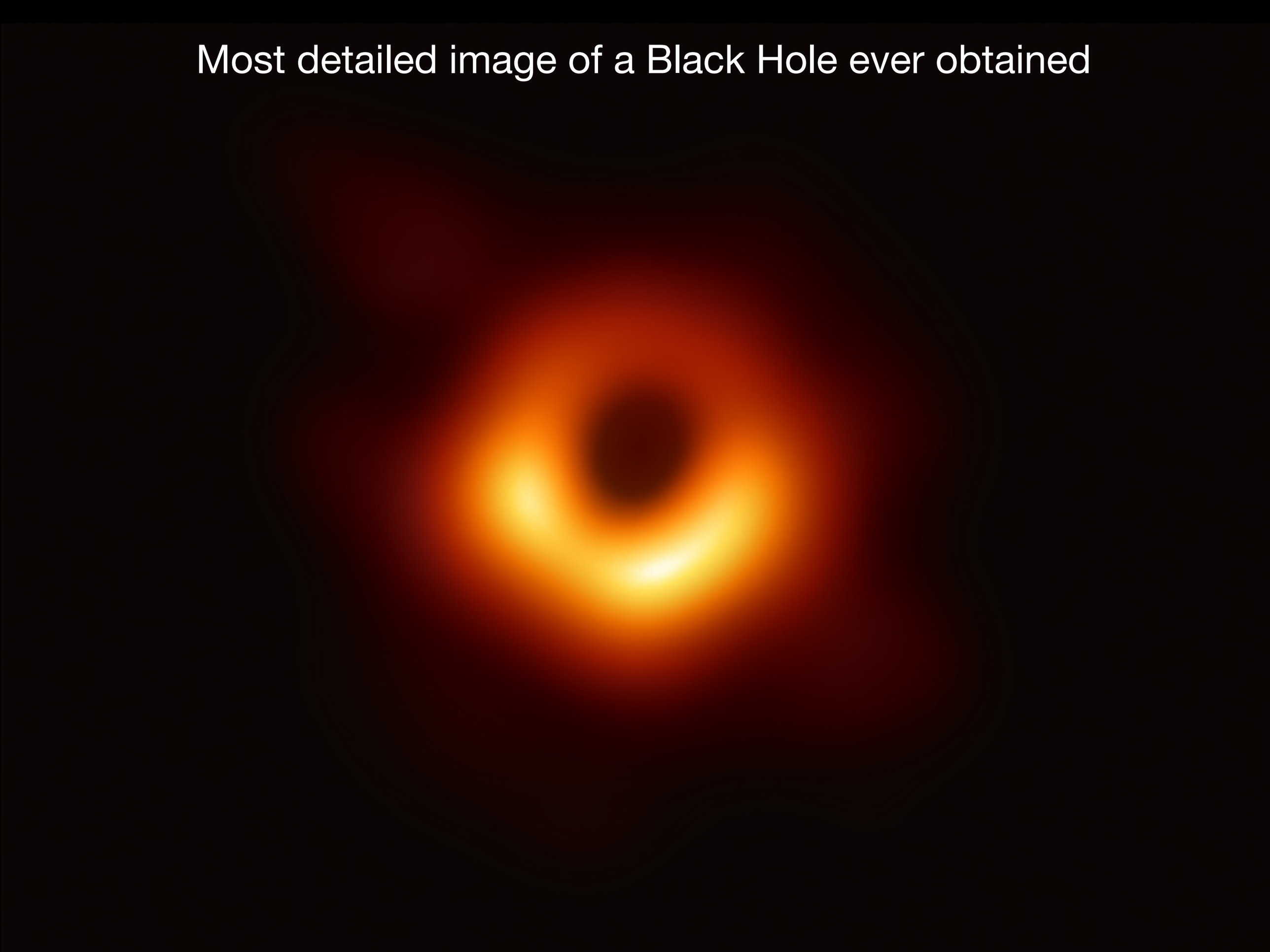


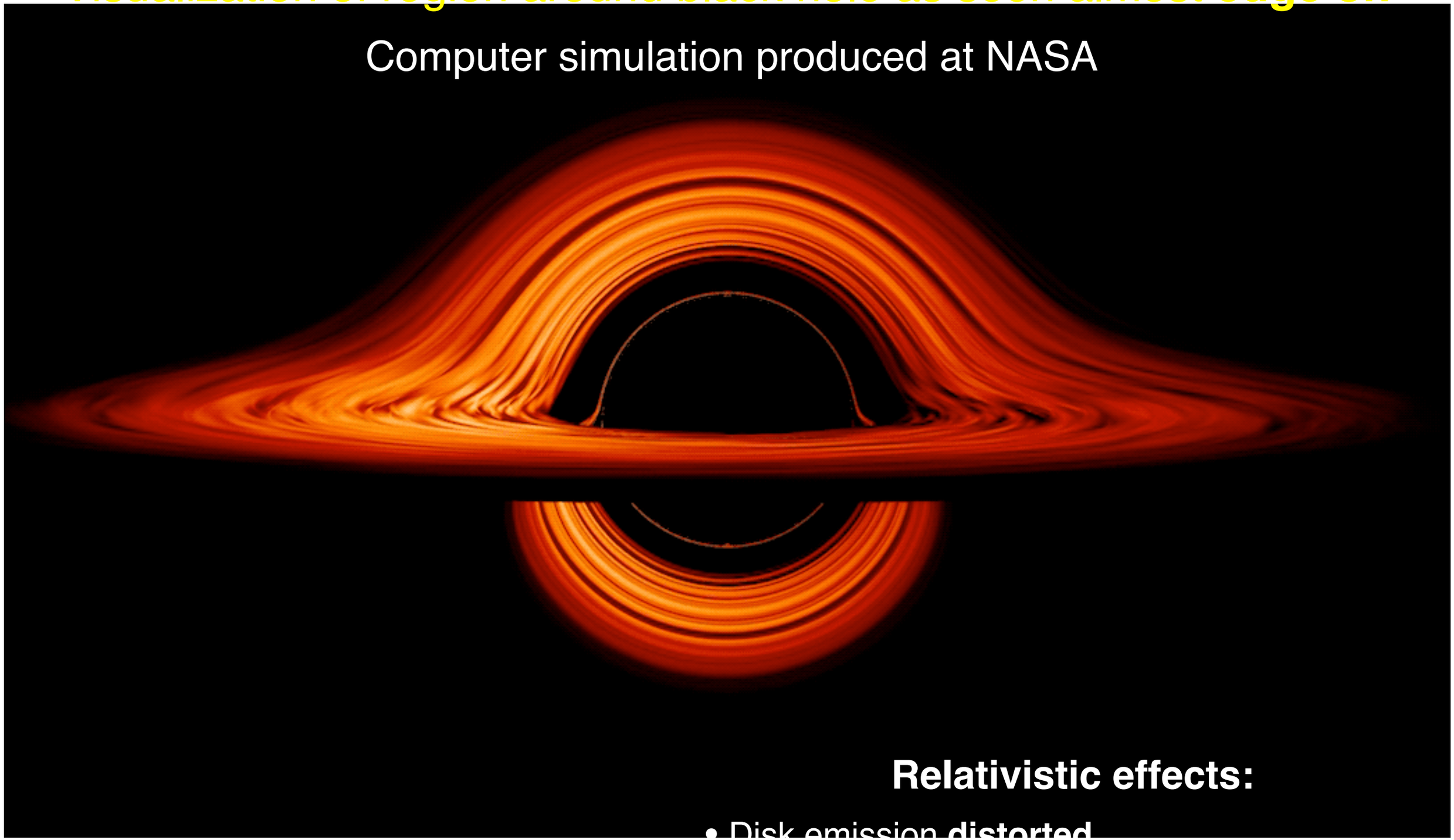
$\tau_g = \delta l / c$ signal delay

τ_i : compensation delay

Most detailed image of a Black Hole ever obtained

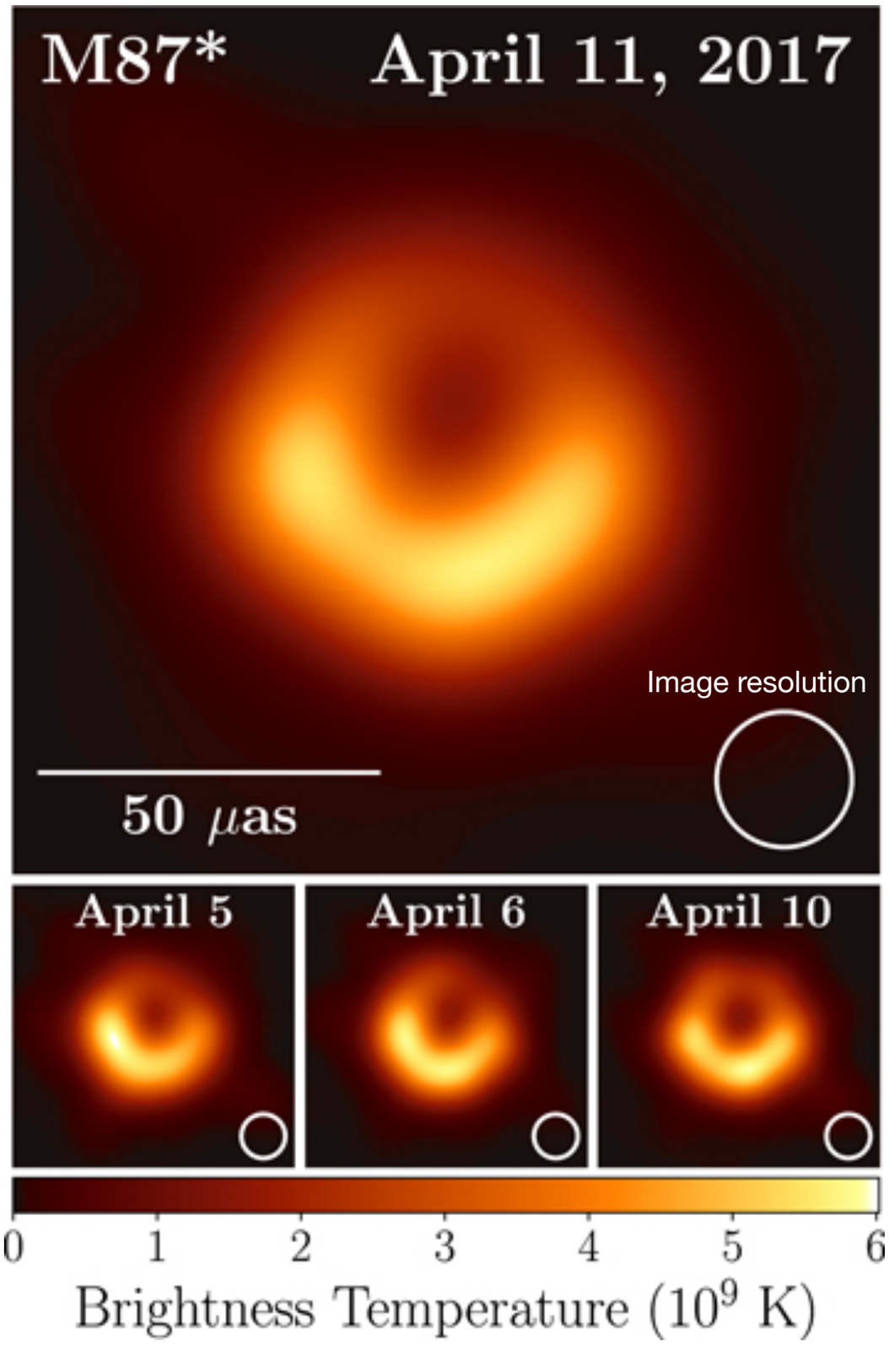


Visualization of region around black hole as seen almost **edge on**



Most detailed image of a Black Hole ever obtained

Direct studies of event horizon now possible via astronomical observations

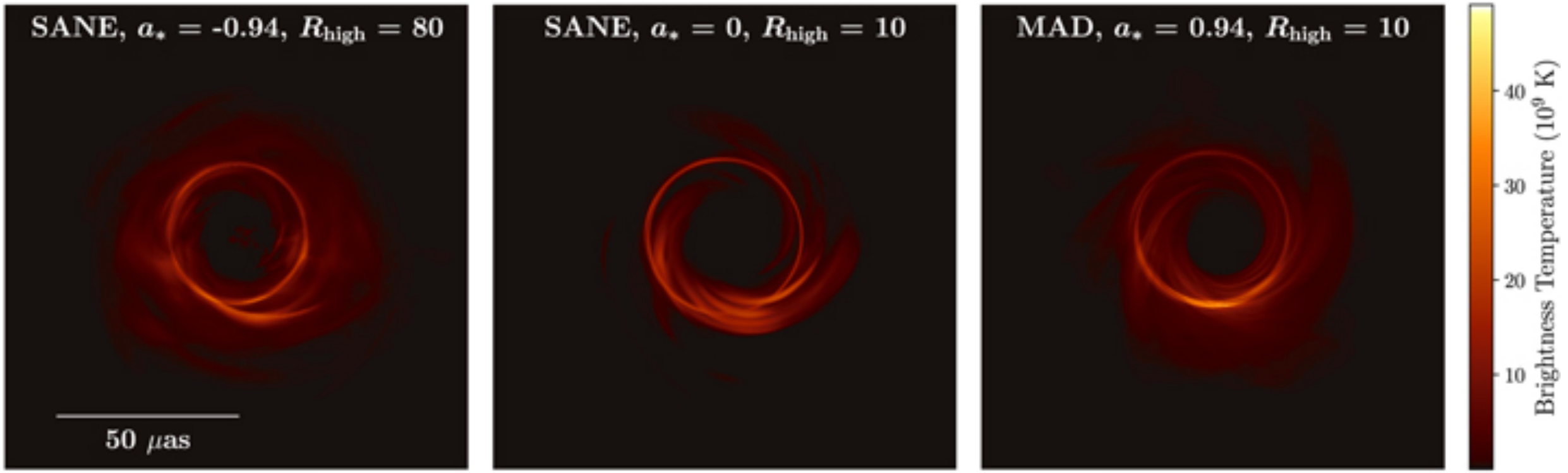


- Image resolution: 20 micro arc-seconds (μas)
- Equivalent to a **2 cents coin seen from Earth on the Moon**
- Completely dark region is where light cannot escape
- Luminous ring diameter: **42 ± 3 μas**, brighter in the south
- Inclination angle of the orbiting disk with respect to Earth: 17°
- **Event horizon** around **2.5 times smaller than dark region**
- Size of event horizon is just under **40 billion km**
- Equivalent to the **orbit of Pluto around the Sun**
- Measured mass of black hole: $M_{BH} = (6.5 \pm 0.7) \times 10^9\ M_\odot$

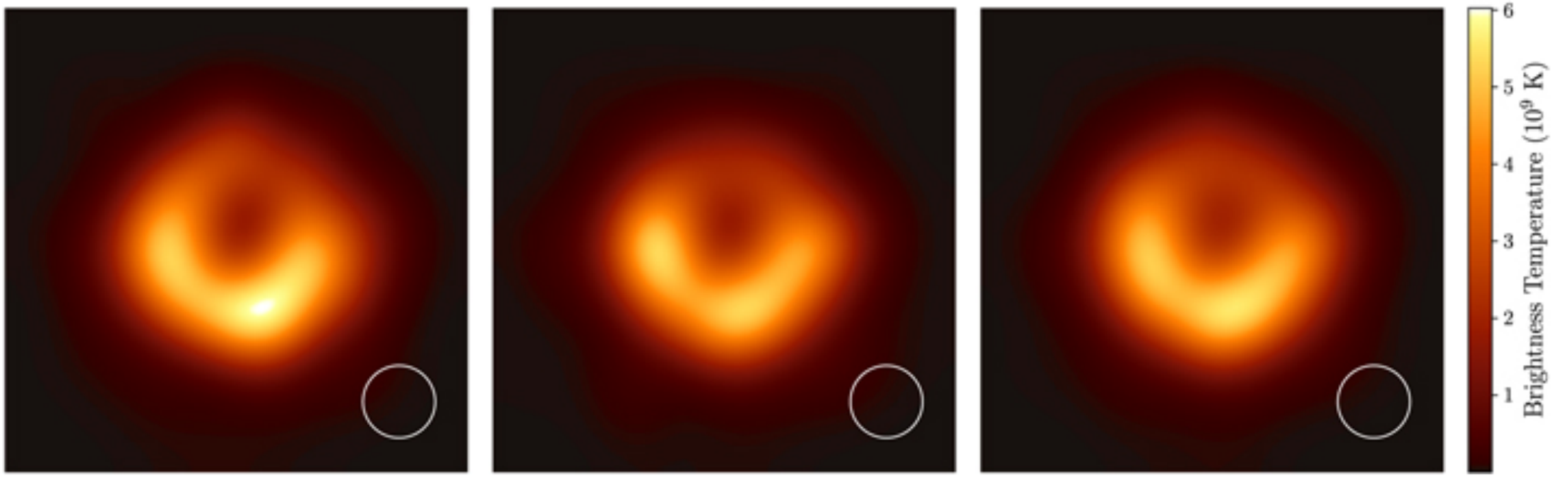
Theoretical expectations & computer simulations

40-50 thousand simulations, a few reproducing observations

Theoretical models of accretion flows



Computer simulation of expected observations



Future: **Space** Very Large Baseline Interferometry

Bibliography: 6 papers published in *Astrophysical Journal Letters*

- Paper I: The Shadow of the Supermassive Black Hole
- Paper II: Array and Instrumentation
- Paper III: Data processing and Calibration
- Paper IV: Imaging the Central Supermassive Black Hole
- Paper V: Physical Origin of the Asymmetric Ring
- Paper VI: The Shadow and Mass of the Central Black Hole