

Undarkening the darkest: Charting New Horizons with the next generation Event Horizon Telescope (ngEHT)

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EHT Science Board

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and the EHT/ngEHT Collaboration

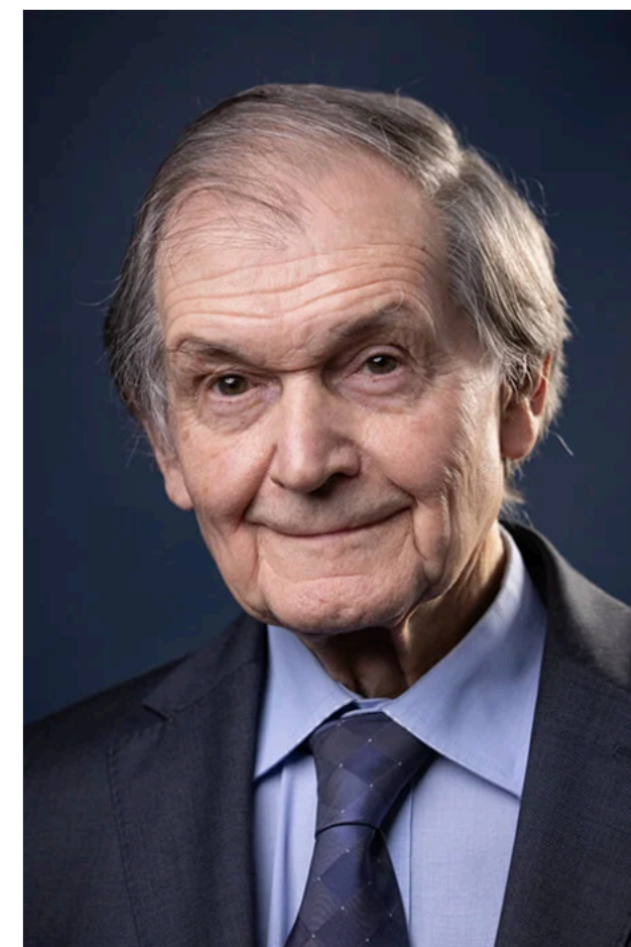


1st Undark meeting, IAC, September 30th, 2025



Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity", the other half jointly to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive **compact object** at the centre of our galaxy"

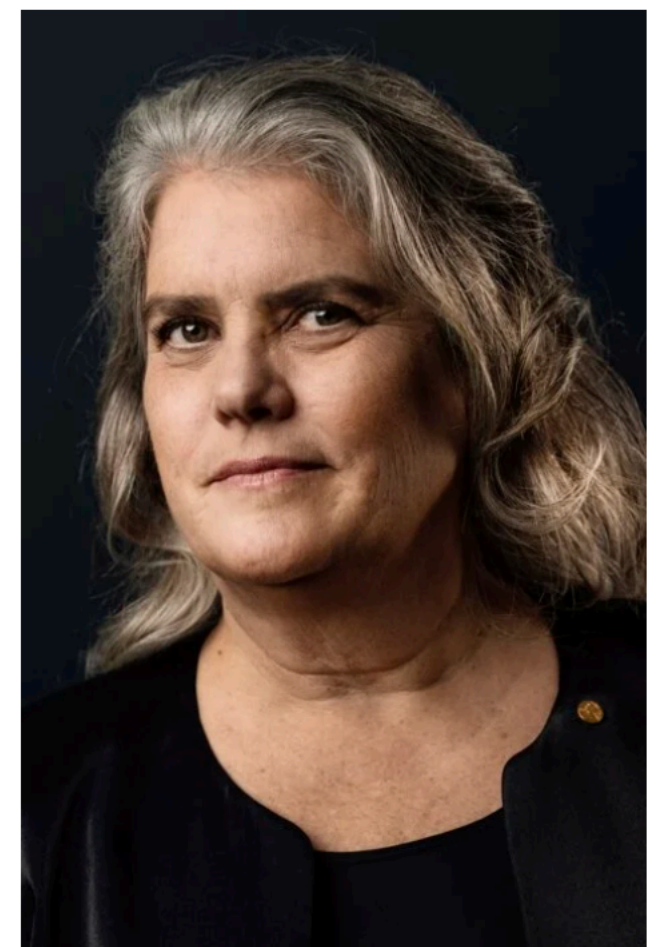
The Nobel Prize in Physics 2020



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Fergus Kennedy
Roger Penrose
Prize share: 1/2

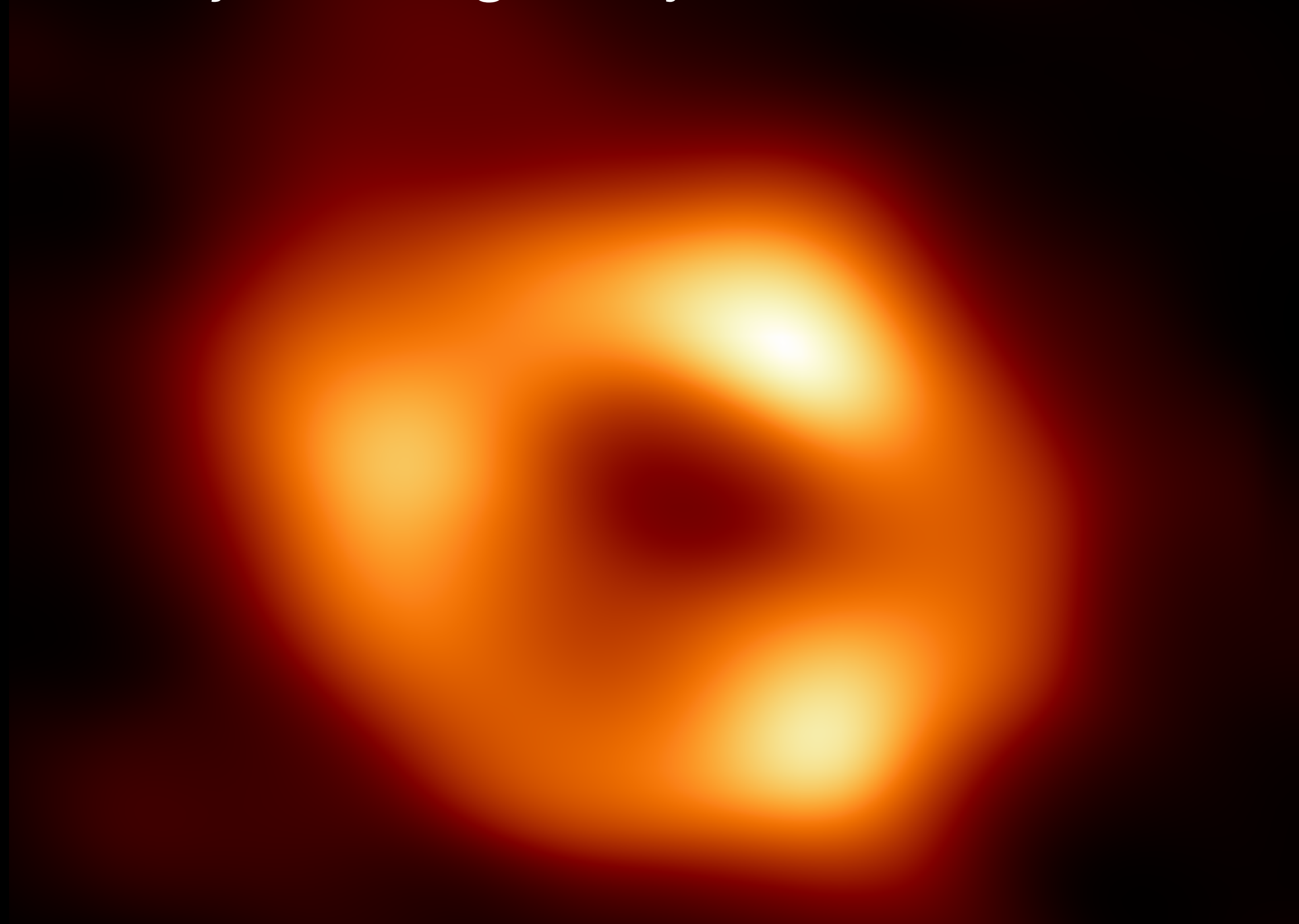


© Nobel Prize Outreach. Photo:
Bernhard Ludewig
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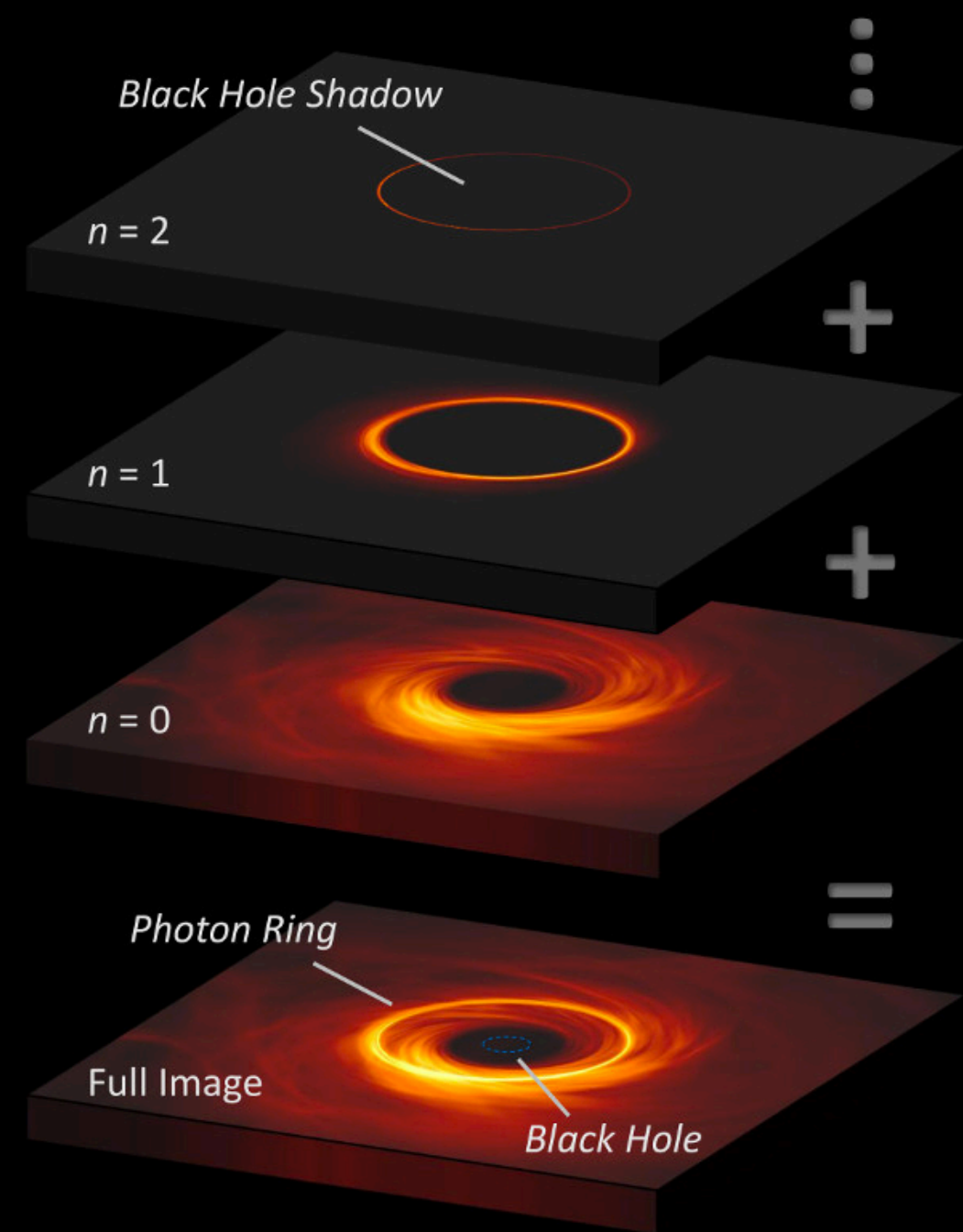
SgrA* *compact object* imaged by the EHT looks like a *black hole*



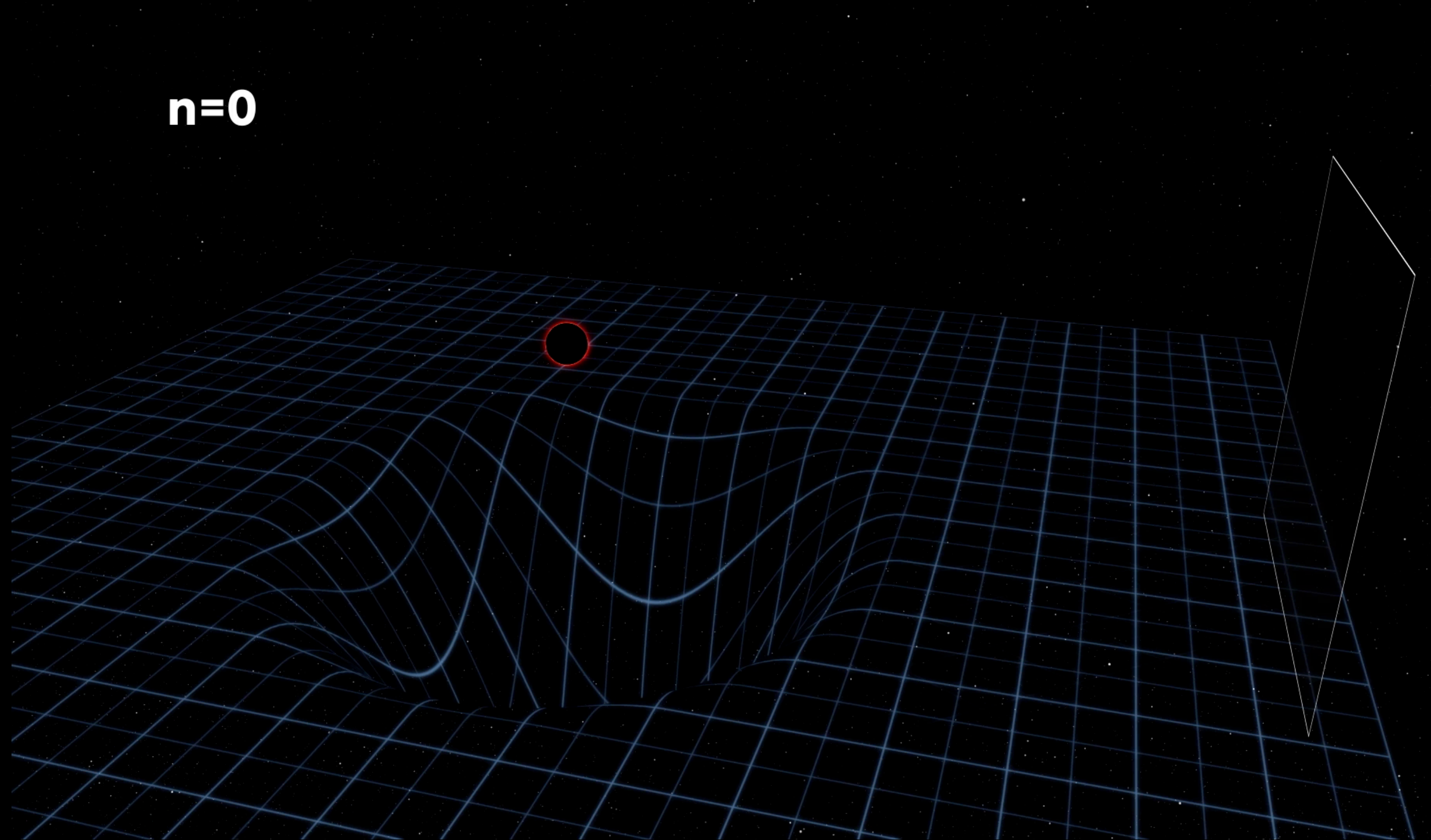
EHT “undarkening” of the compact object at the
center of our galaxy



Black-Hole Shadow Decomposition

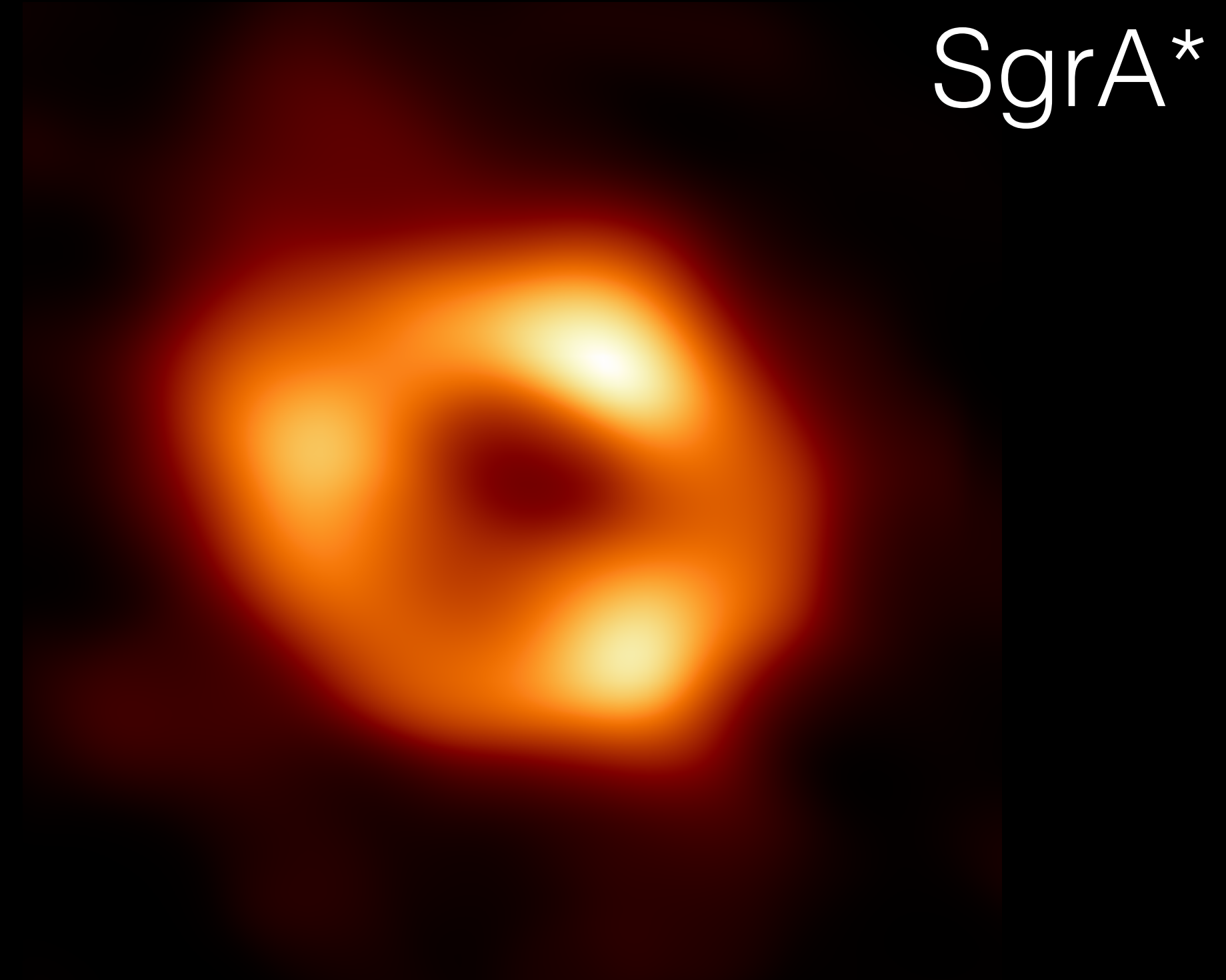
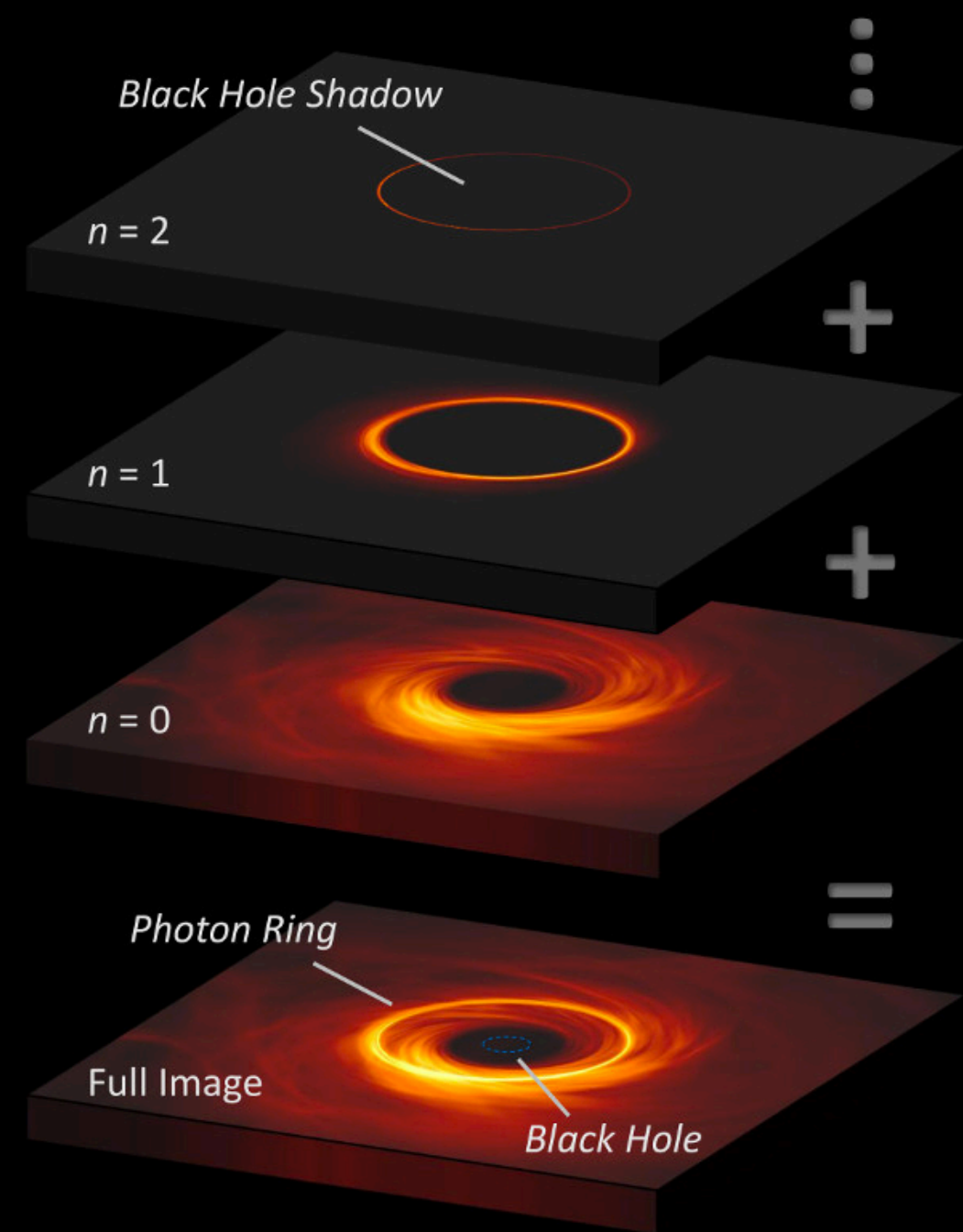


- Ring $n=0$ dominated by astrophysics
- Rings $n=1$ and $n=2$ allow us to test General Relativity and determine the spin of the black hole



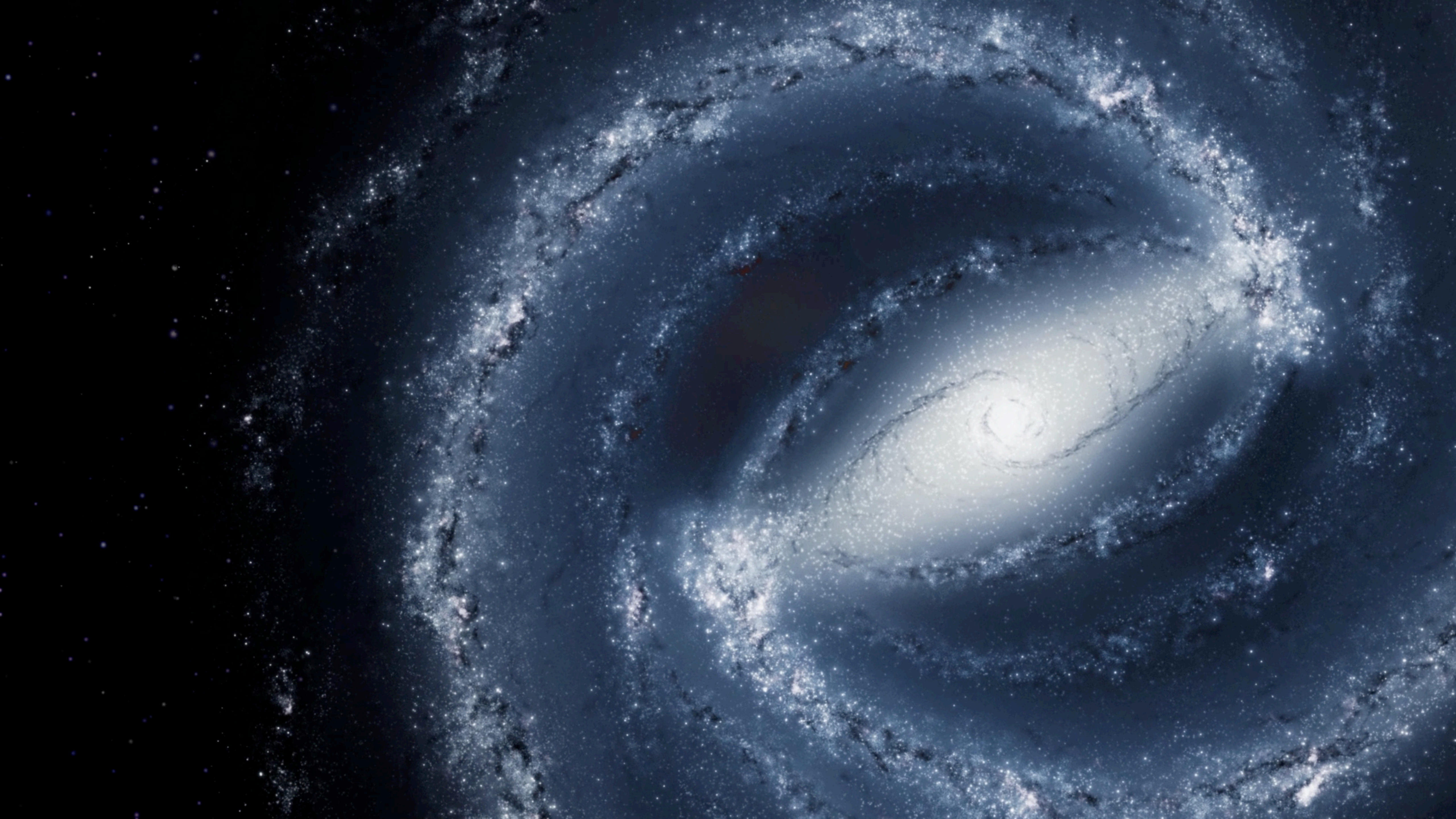
$$\theta_{\text{Shadow}} \sim 42 \mu\text{as} \text{ (M87*)} \sim 52 \mu\text{as} \text{ (SgrA*)}$$

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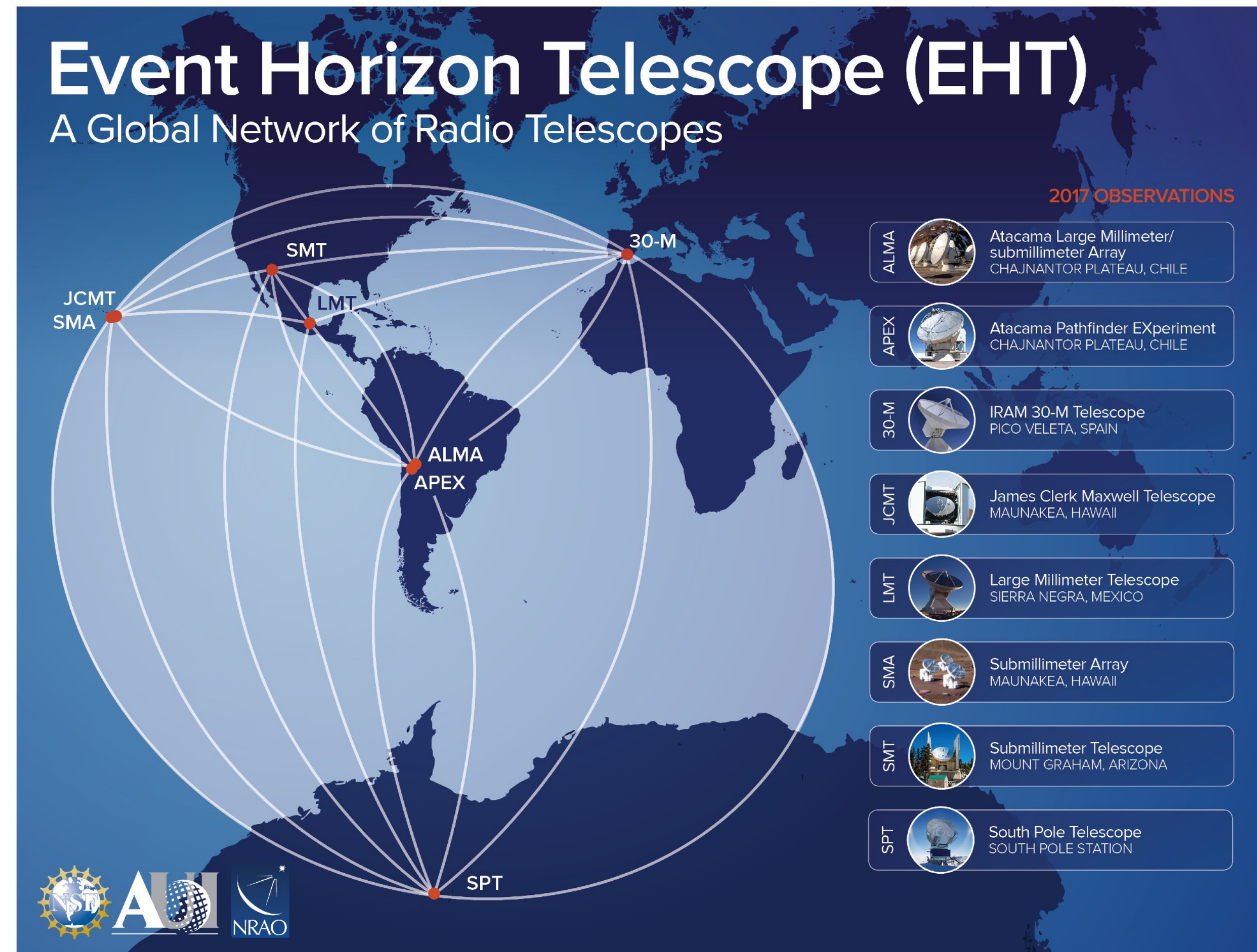
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2017 Event Horizon Telescope

Telescopes used in the 2017 EHT Observations

- Atacama Large Millimeter Array (ALMA), Chile
- ALMA Pathfinder Experiment (APEX), Chile
- James Clerk Maxwell Telescope (JCMT), Hawaii
- Large Millimeter Telescope (LMT), Mexico
- IRAM 30-meter Telescope (PV), Spain
- South Pole Telescope (SPT), South Pole
- Submillimeter Array (SMA), Hawaii
- Submillimeter Telescope (SMT), Arizona



M87* 2017 April 11



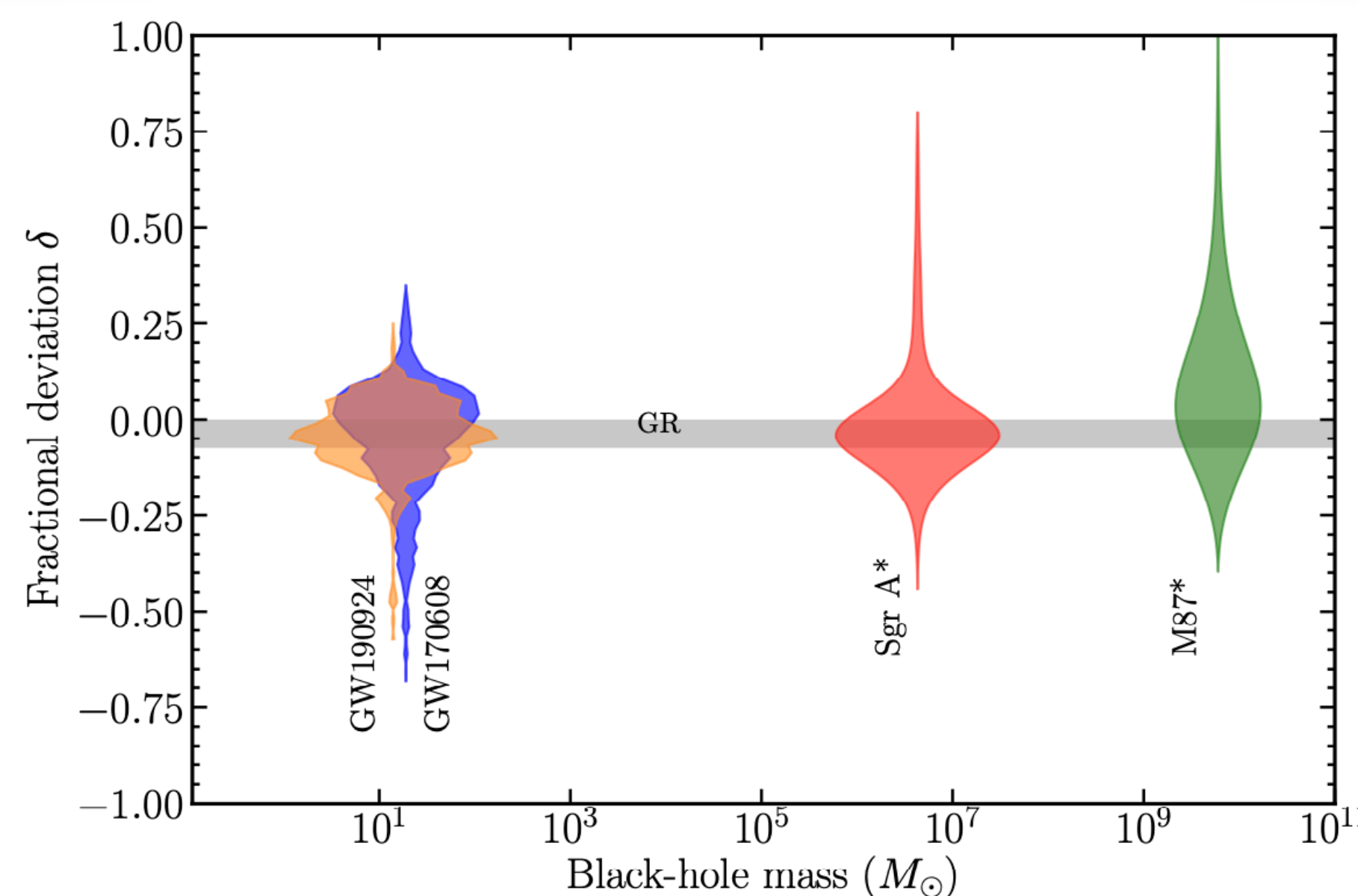
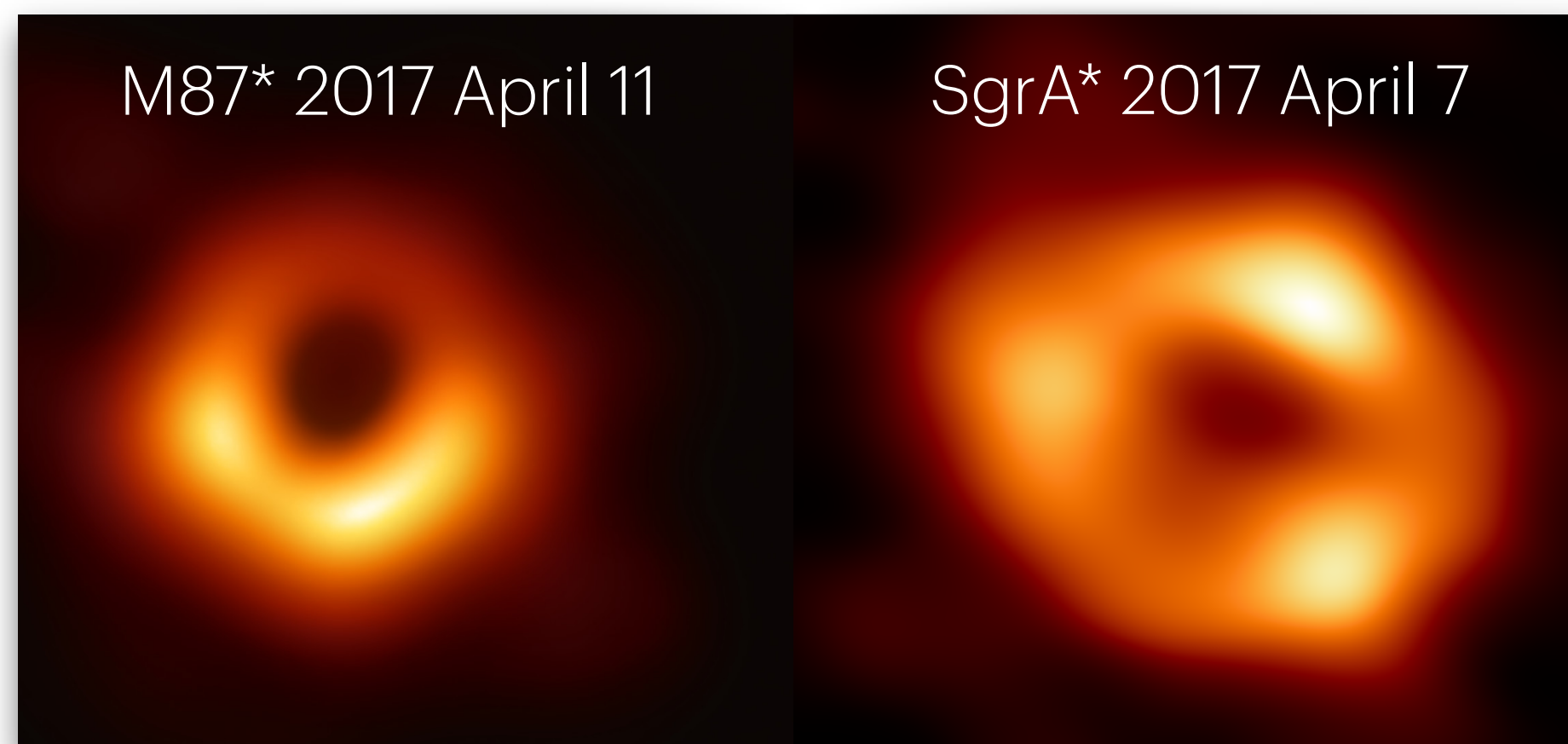
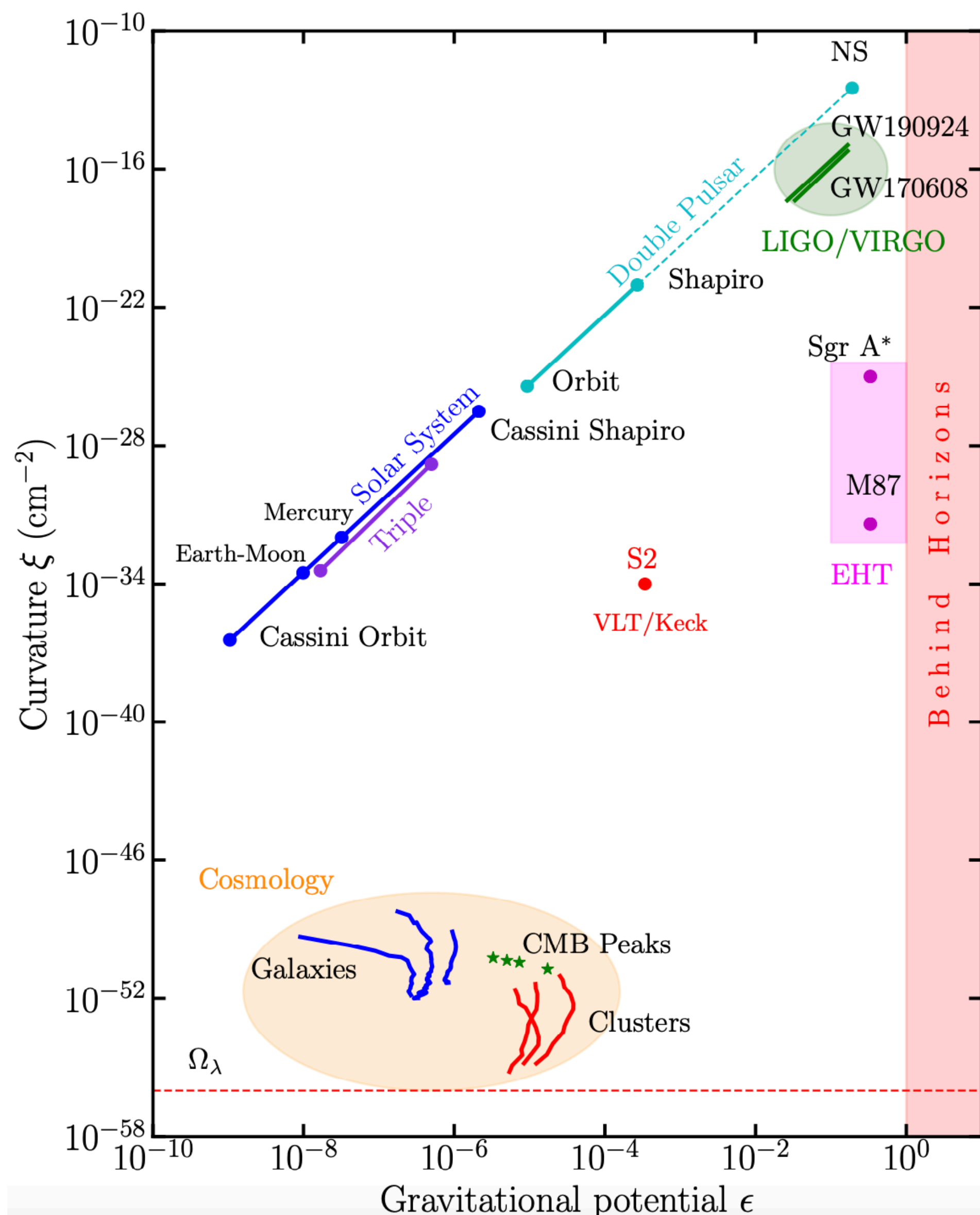
EHTC+ 2019

SgrA* 2017 April 7

EHTC+ 2022



Testing Gravity



- Horizon-scale images of M87 and SgrA* probe a previously unexplored region of the parameter space of gravitational physics tests.
- Tests with gravitational waves and black-hole images span black-hole masses that are different by 8 orders of magnitude.
- All consistent with the GR predictions that all black holes are described by the same metric, independent of their mass

* deviation parameter δ : quantifies the fractional difference between the inferred shadow diameter and its expected value for a non-spinning (Schwarzschild) black hole

M87* 2017 April 11



EHTC+ 2021

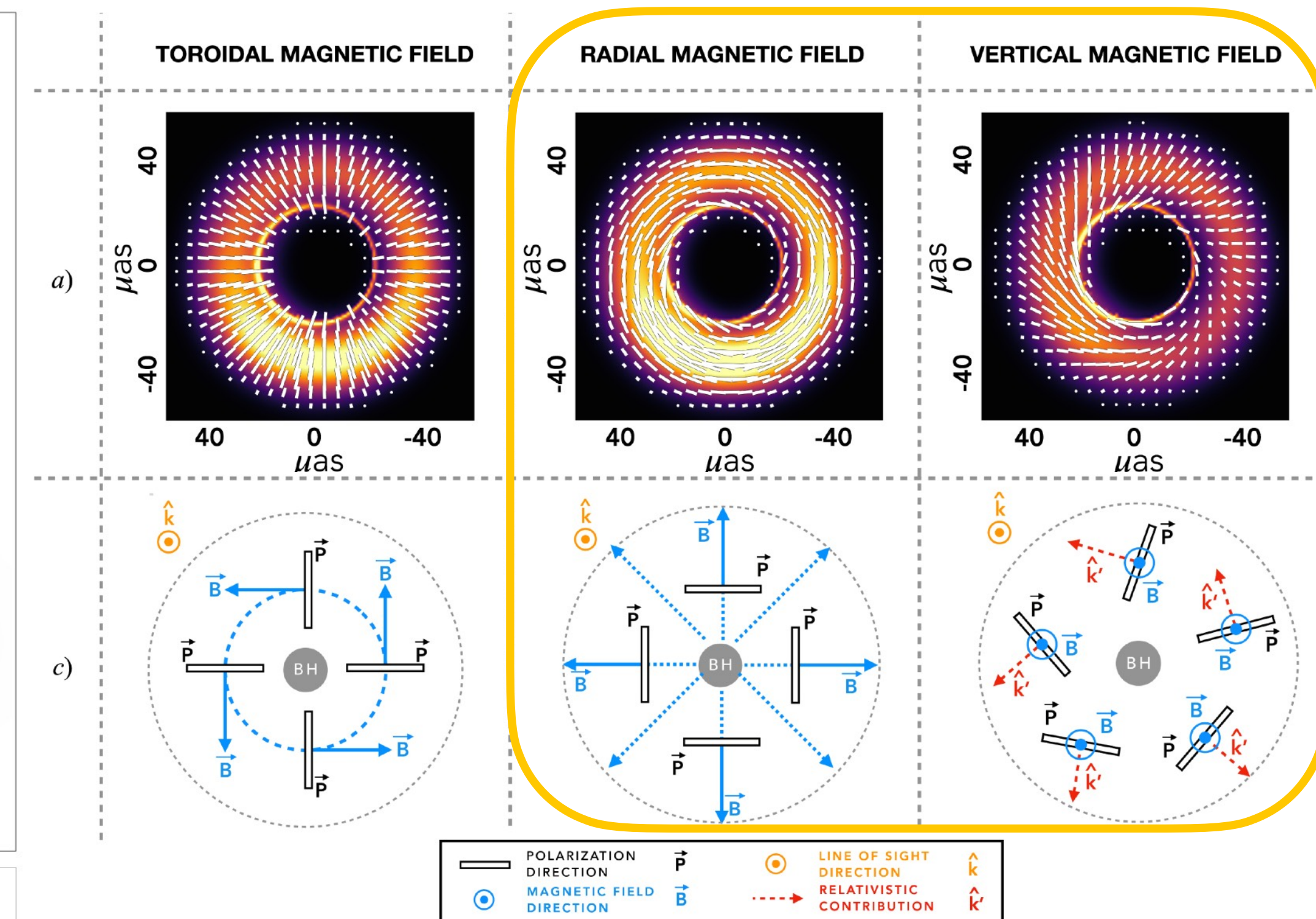
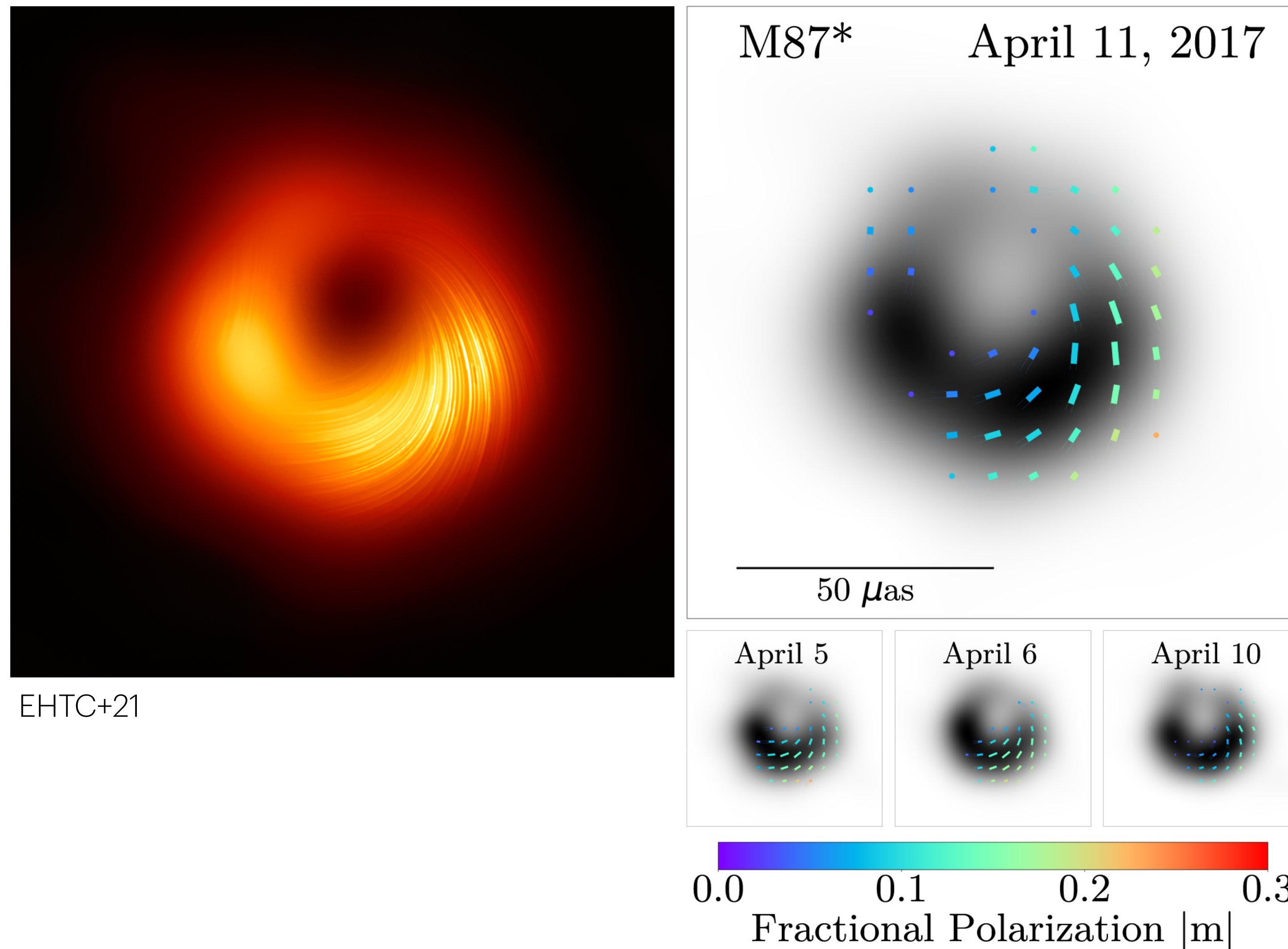
SgrA* 2017 April 7



EHTC+ 2024

2017 M87* Polarization

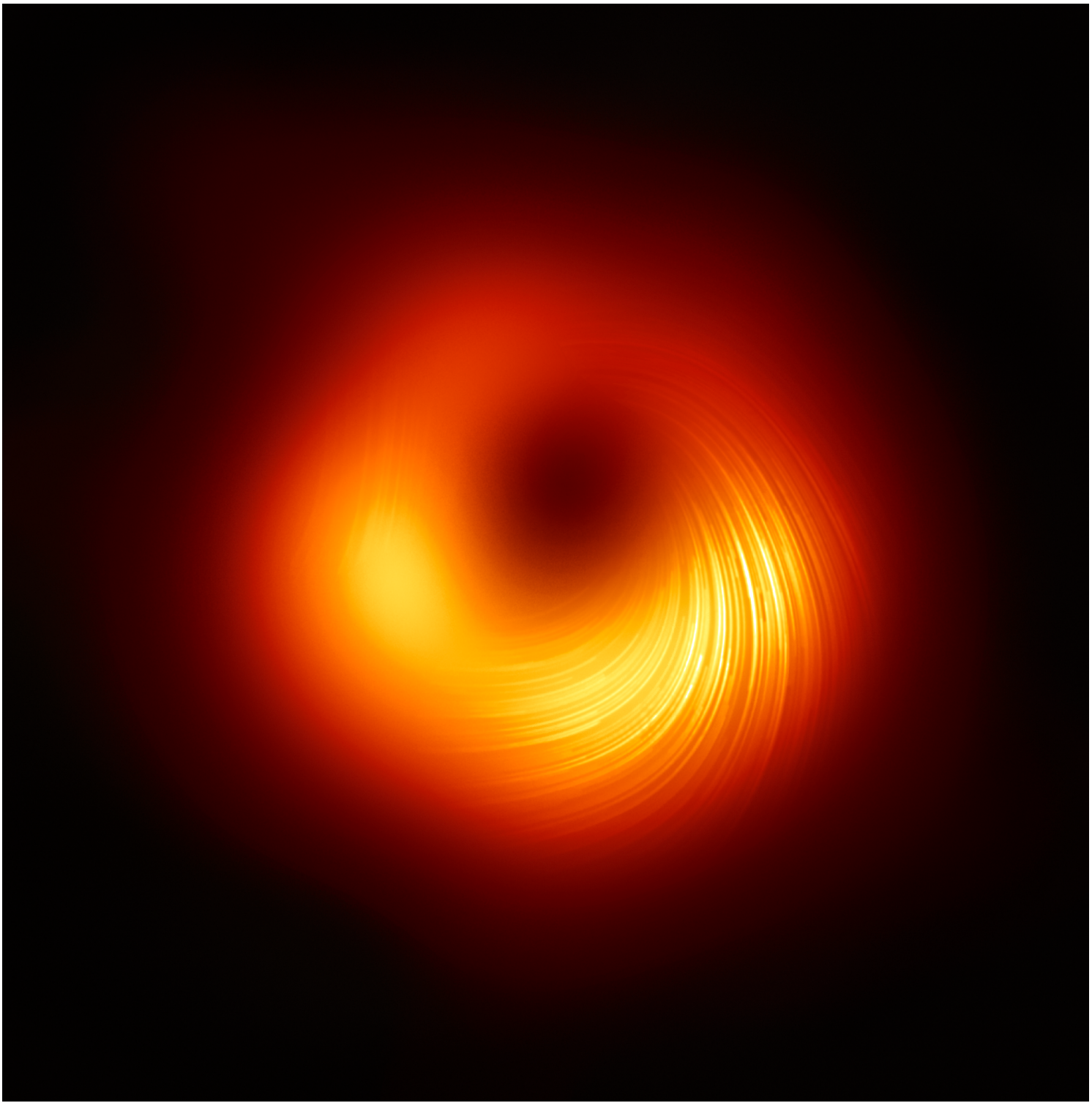
Linear Polarization (< 15%)



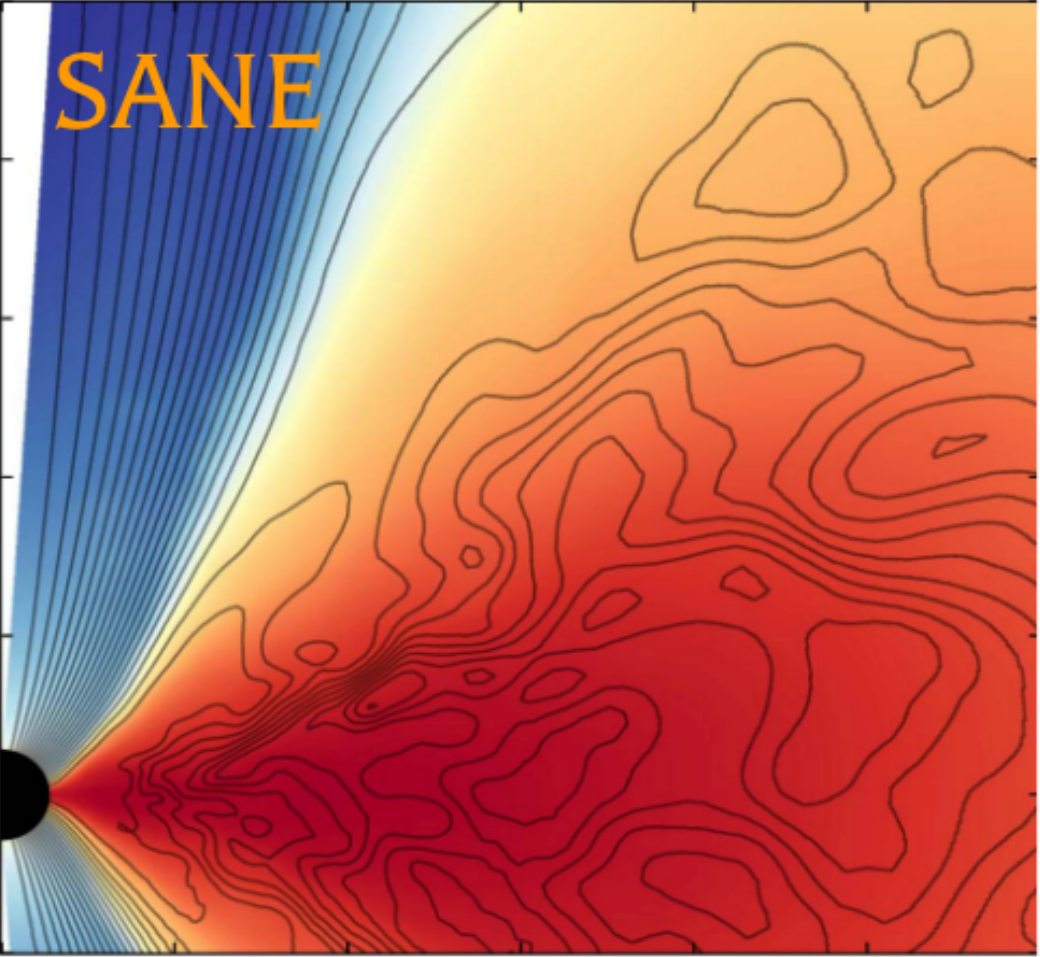
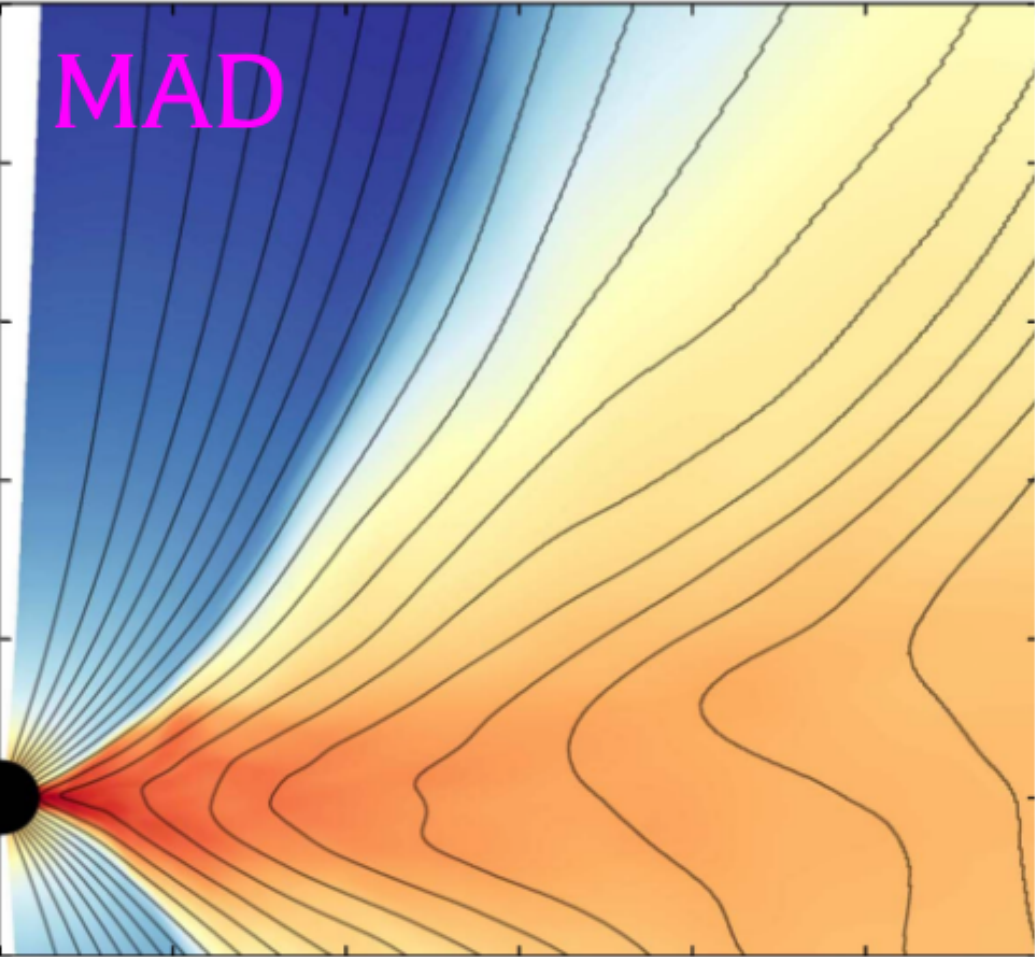
- First magnetic field structure at event horizon scale of M87*
- Supporting the poloidal magnetic field structure with a strength of 1-30 G

2017 M87* Polarization

Linear Polarization (< 15%)

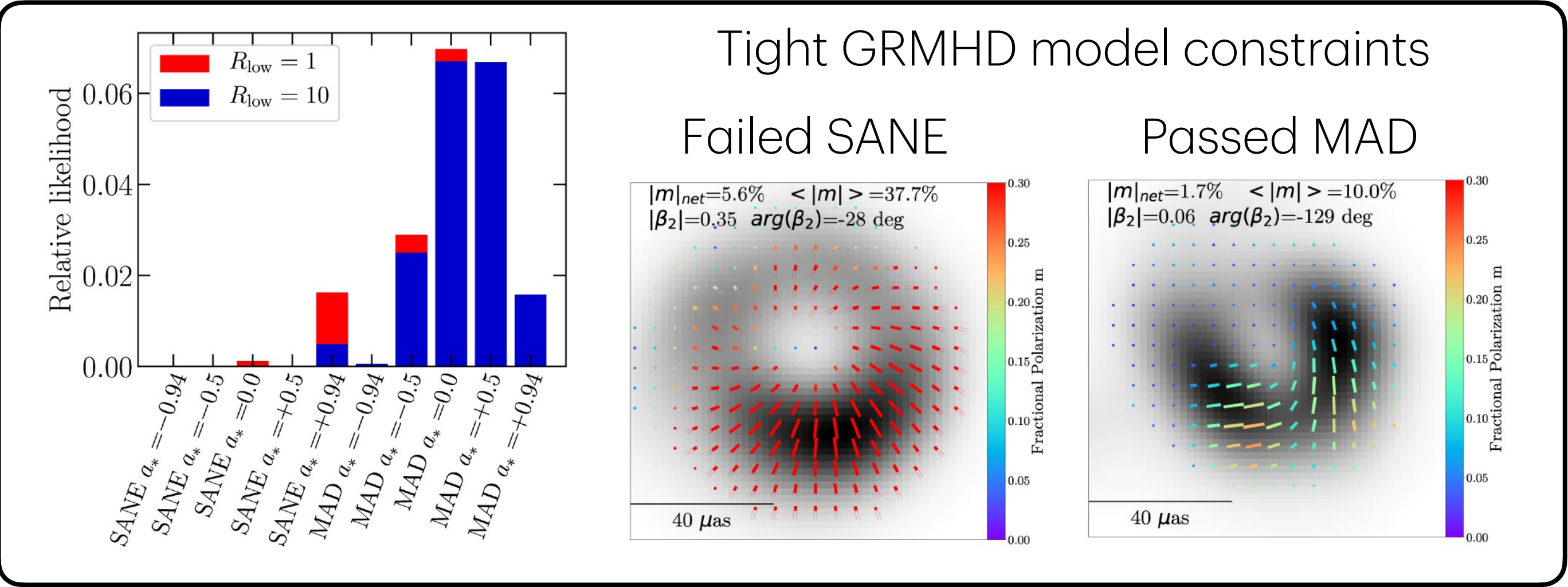


EHTC+21



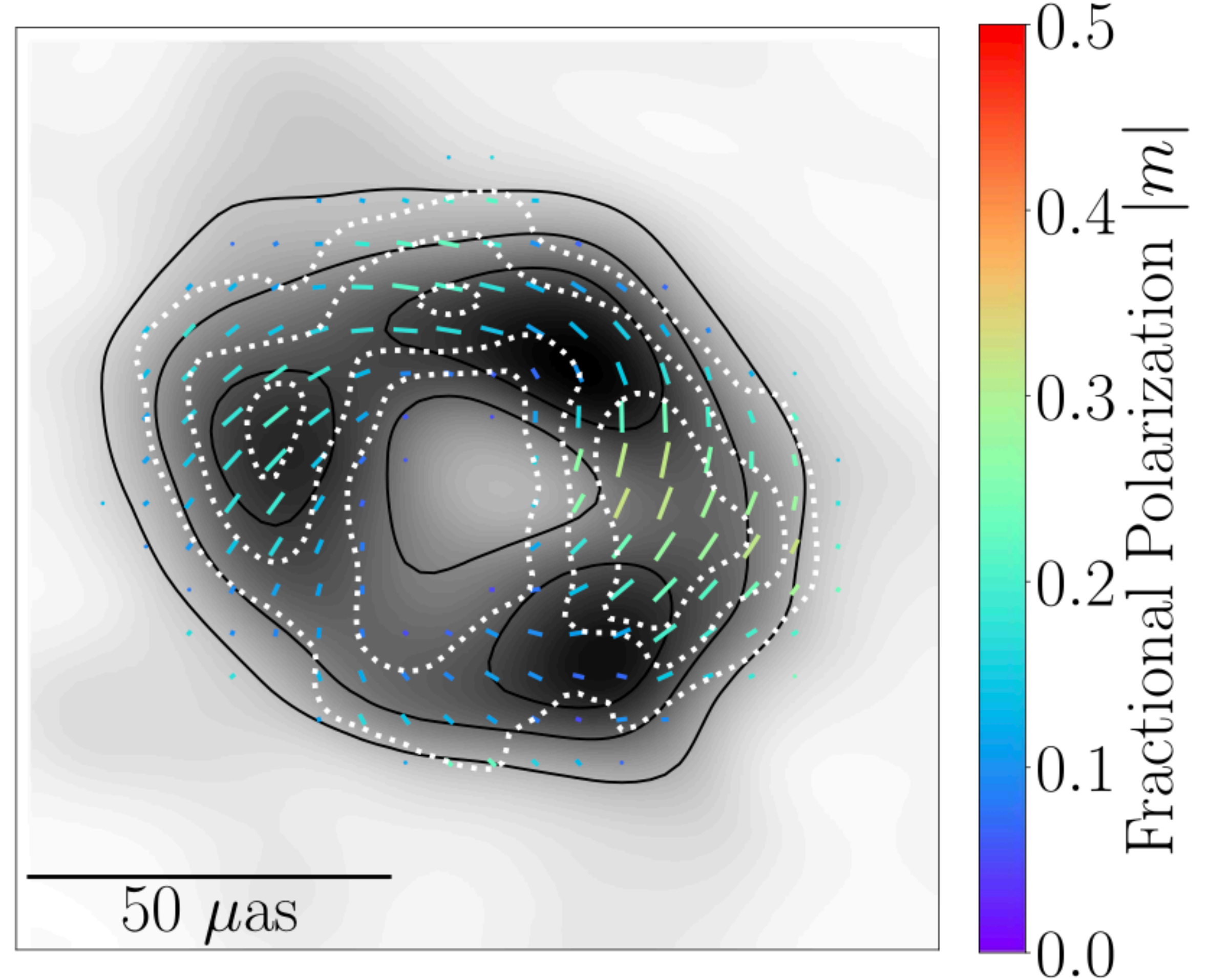
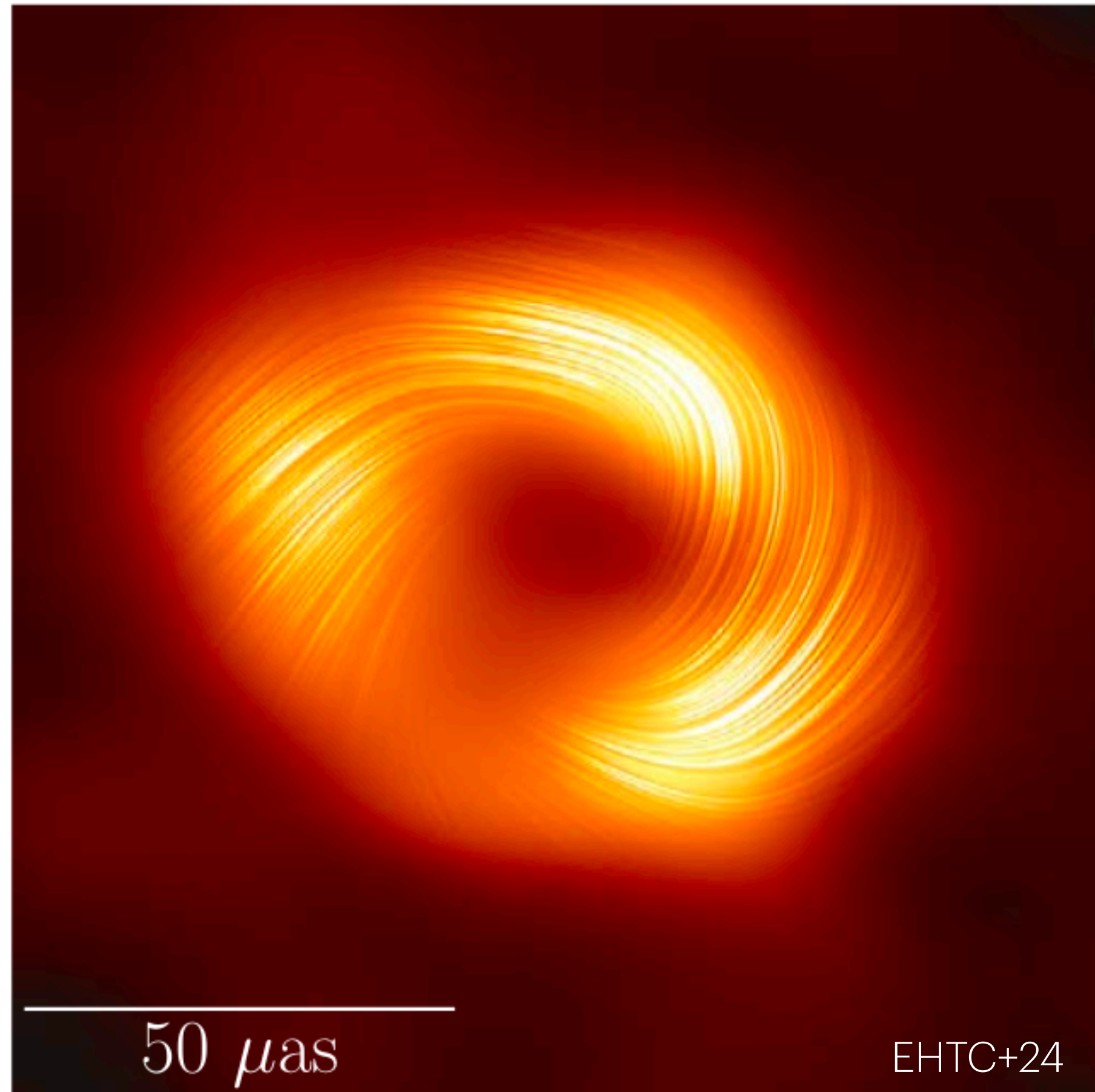
Riordan+18

- * Magnetically Arrested Disk (MAD)
: strong, ordered B-field → accretion halted by strong B pressure → powerful jet
- * Standard and Normal Evolution (SANE)
: weak, turbulent B-field → less efficient to generate jet



2017 SgrA* Polarization

Field Line Plot



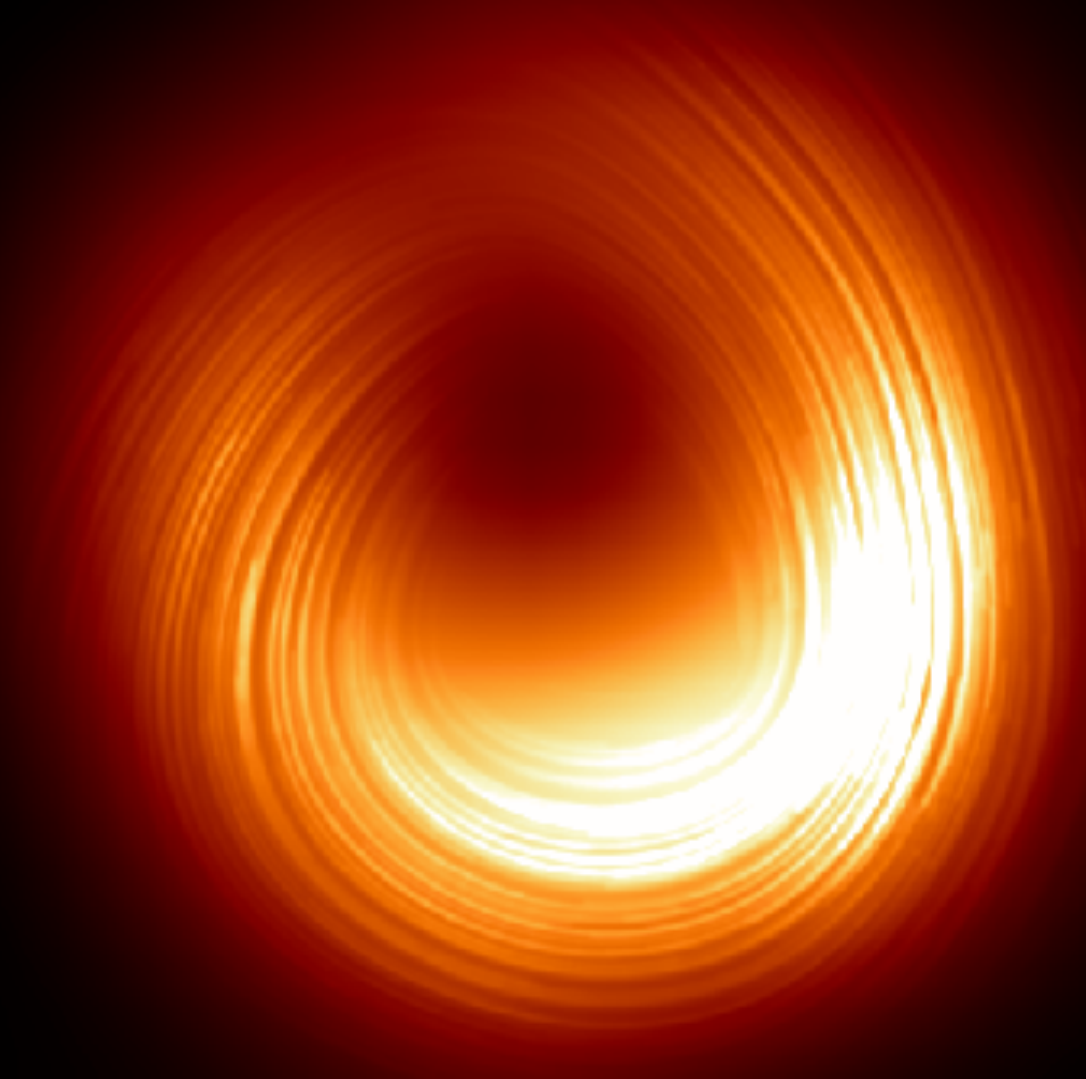
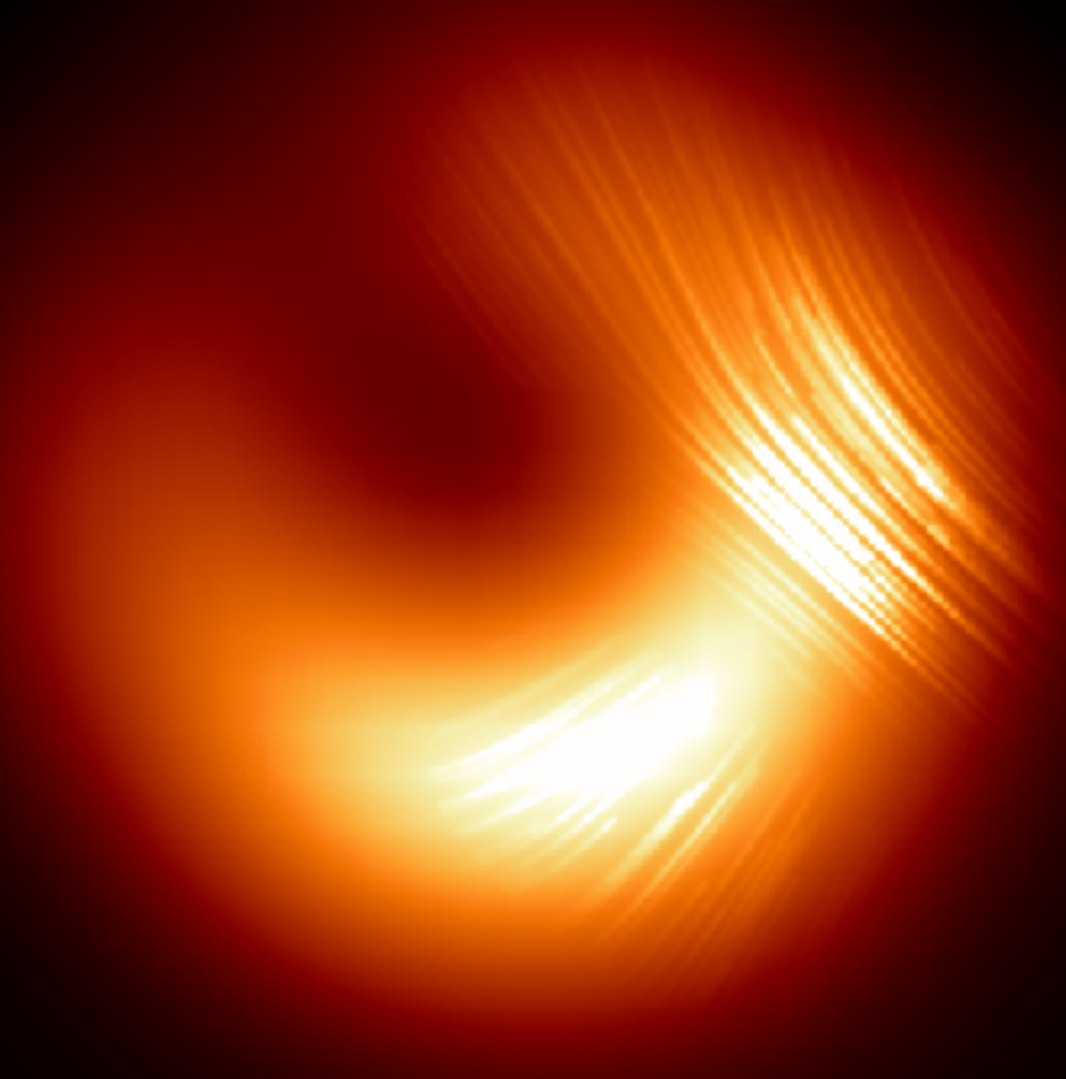
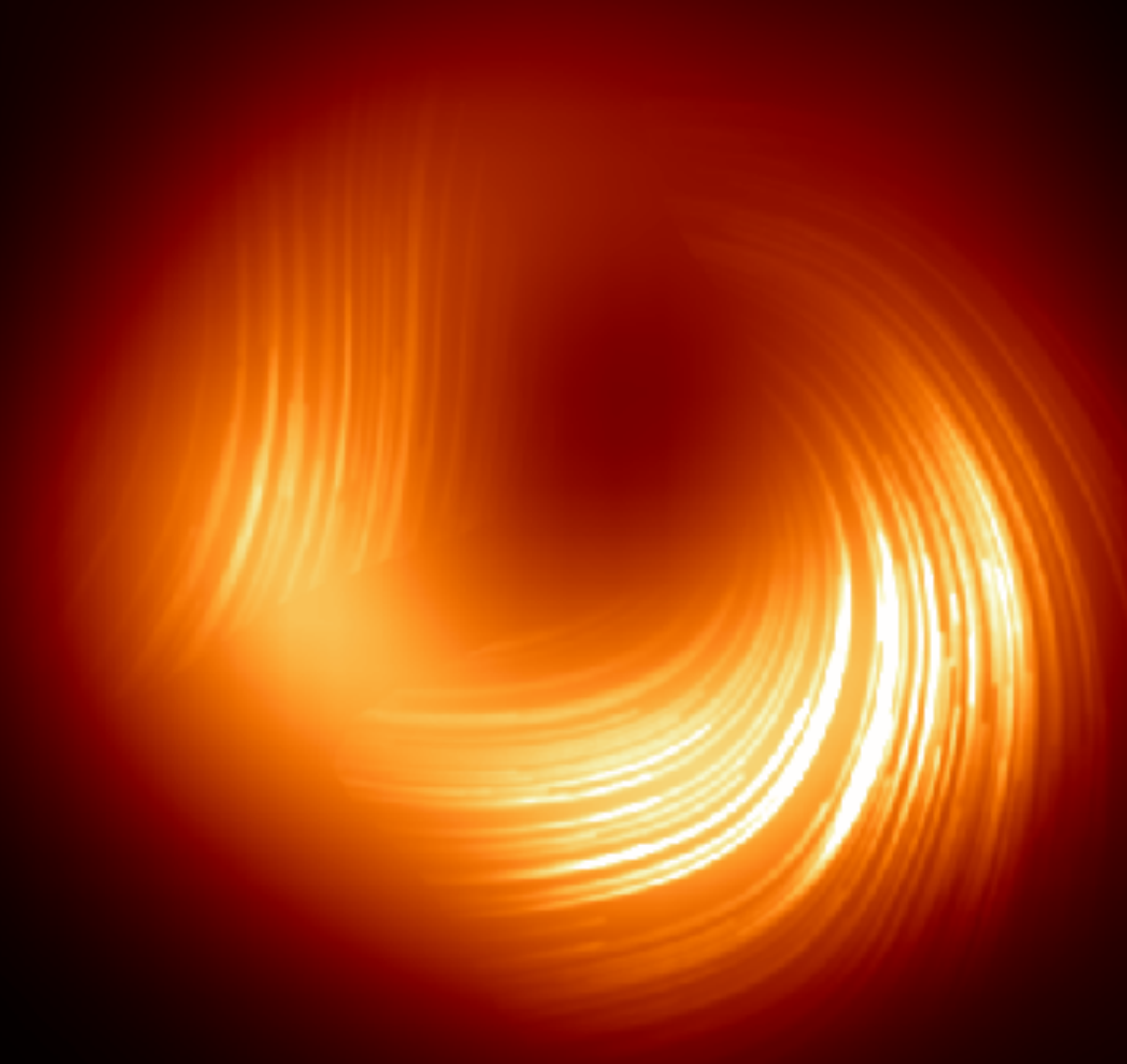
- ✓ As for M87, Sgr A* polarimetric data further supports the preference for GRMHD models characterized by dynamically significant magnetic fields (MADs)
- ✓ The high degree of polarization rules out models with excessive Faraday rotation, but constraining the Faraday rotation (and how much is internal) is essential to determine the intrinsic magnetic field structure and the plasma sense of rotation

M87 black hole shadow evolution over 4 years

2017 Apr. 11

2018 Apr. 21

2021 Apr. 18



40 μ as

EHTC+ 2019,2021

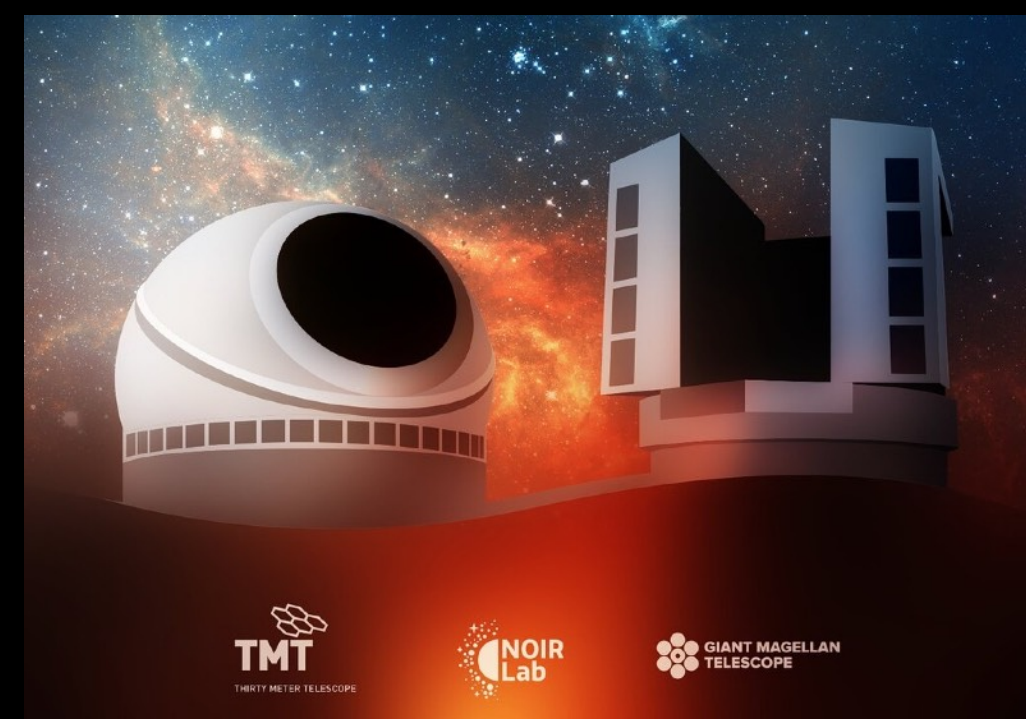
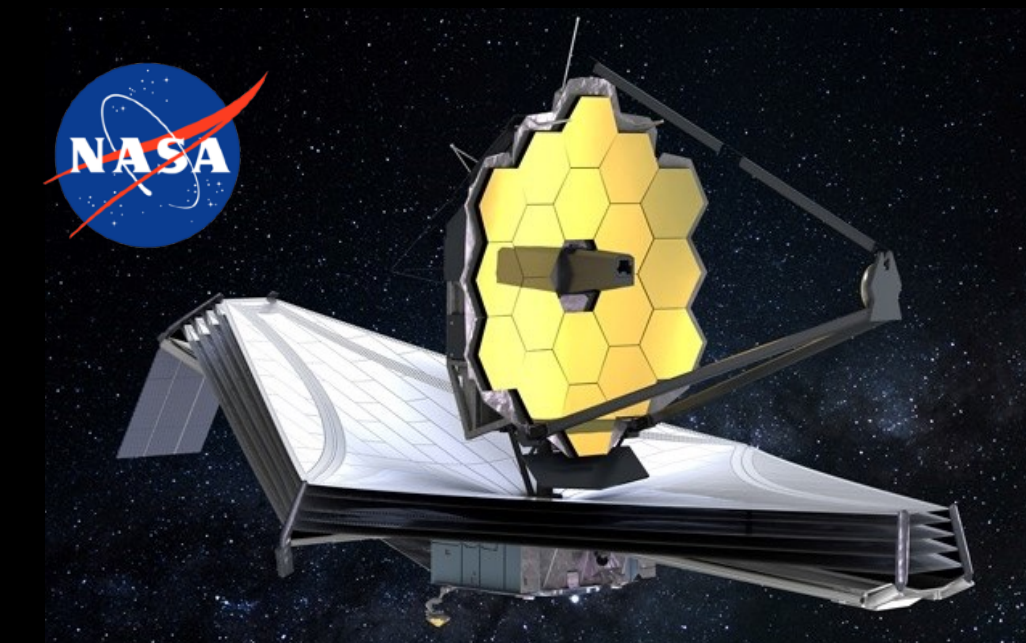
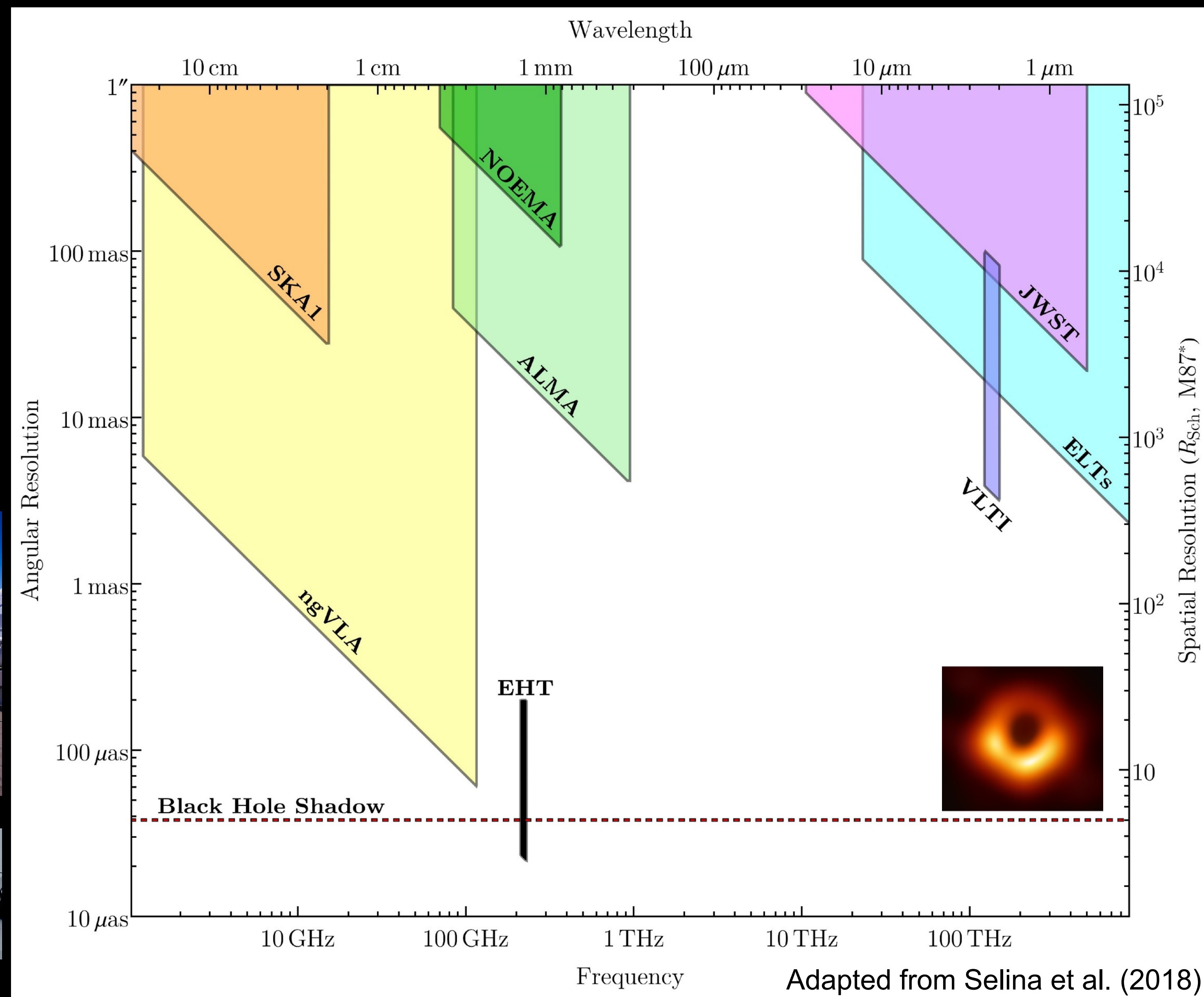
EHTC+ 2024

EHTC+ 2025

- Very stable ring size for the black hole shadow in M87 over the years
- Changes in the emission distribution around the ring compatible with turbulence
- Poloidal magnetic field but with changing ellipticity over the years

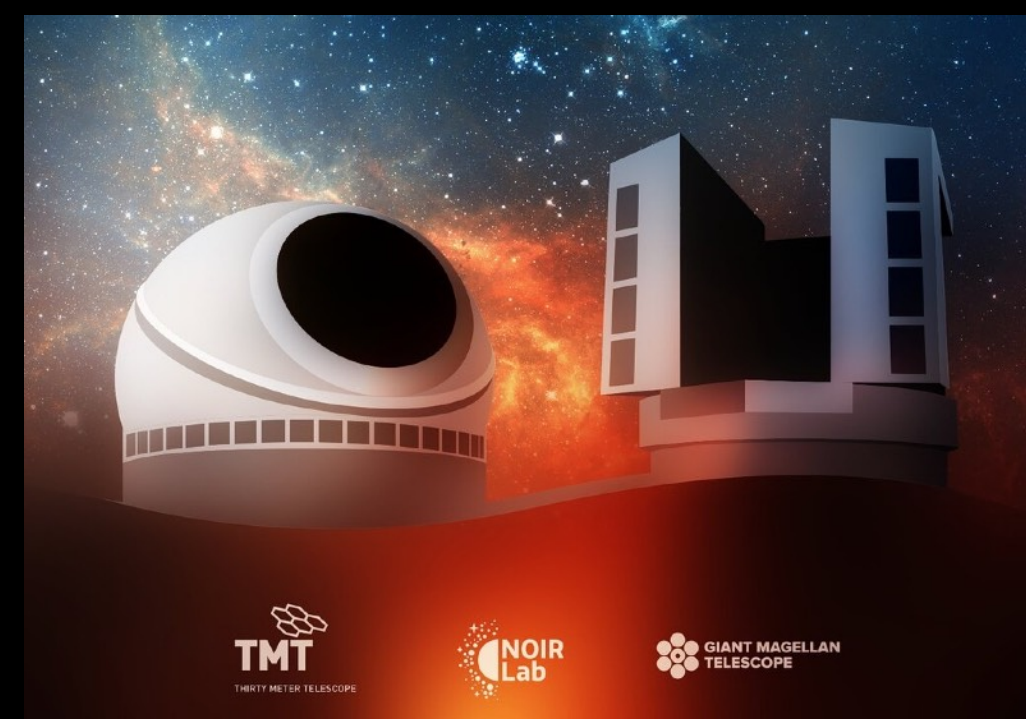
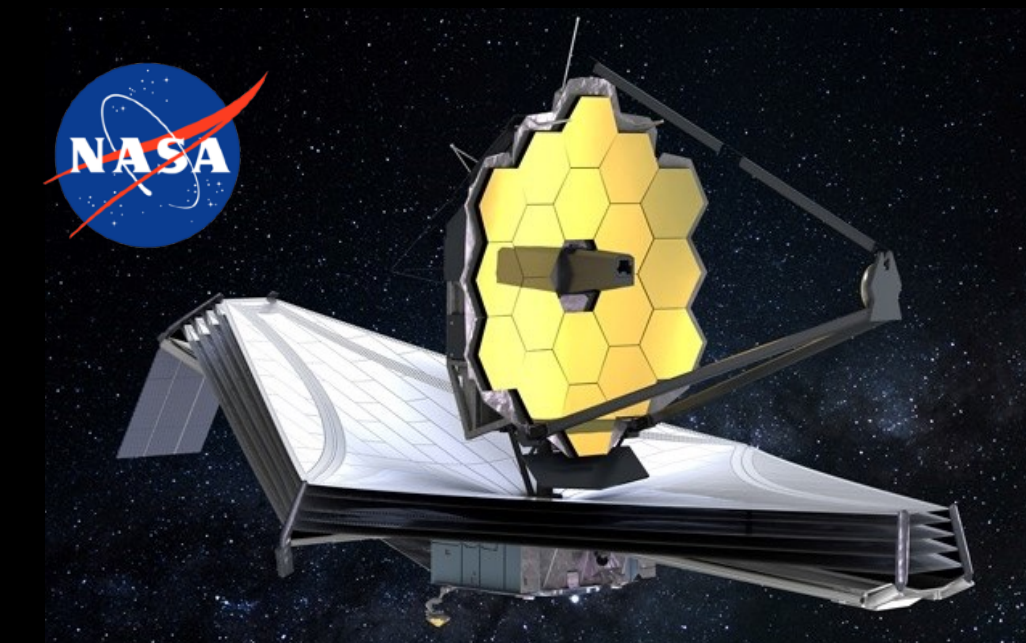
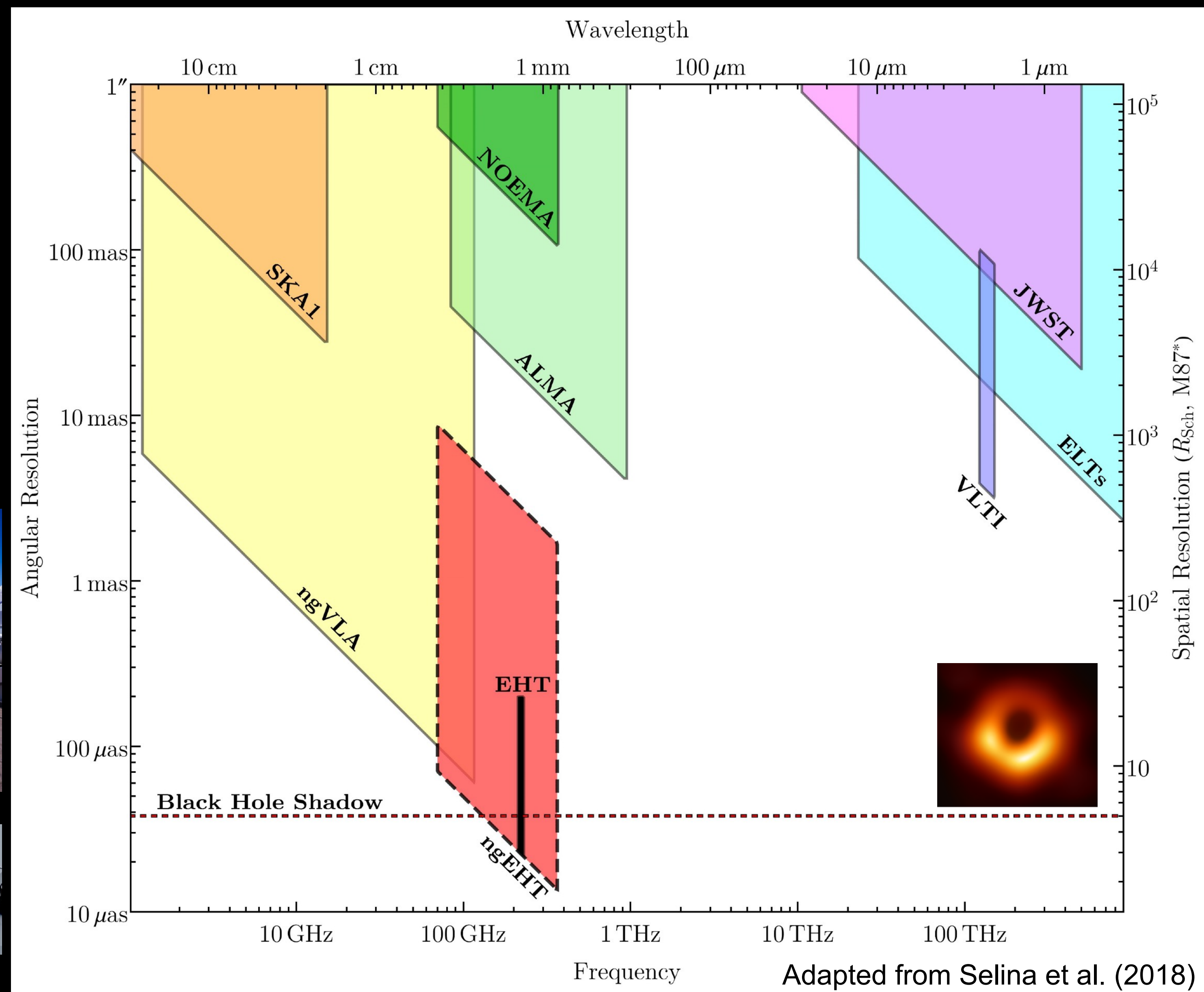


Next-Generation Astronomy





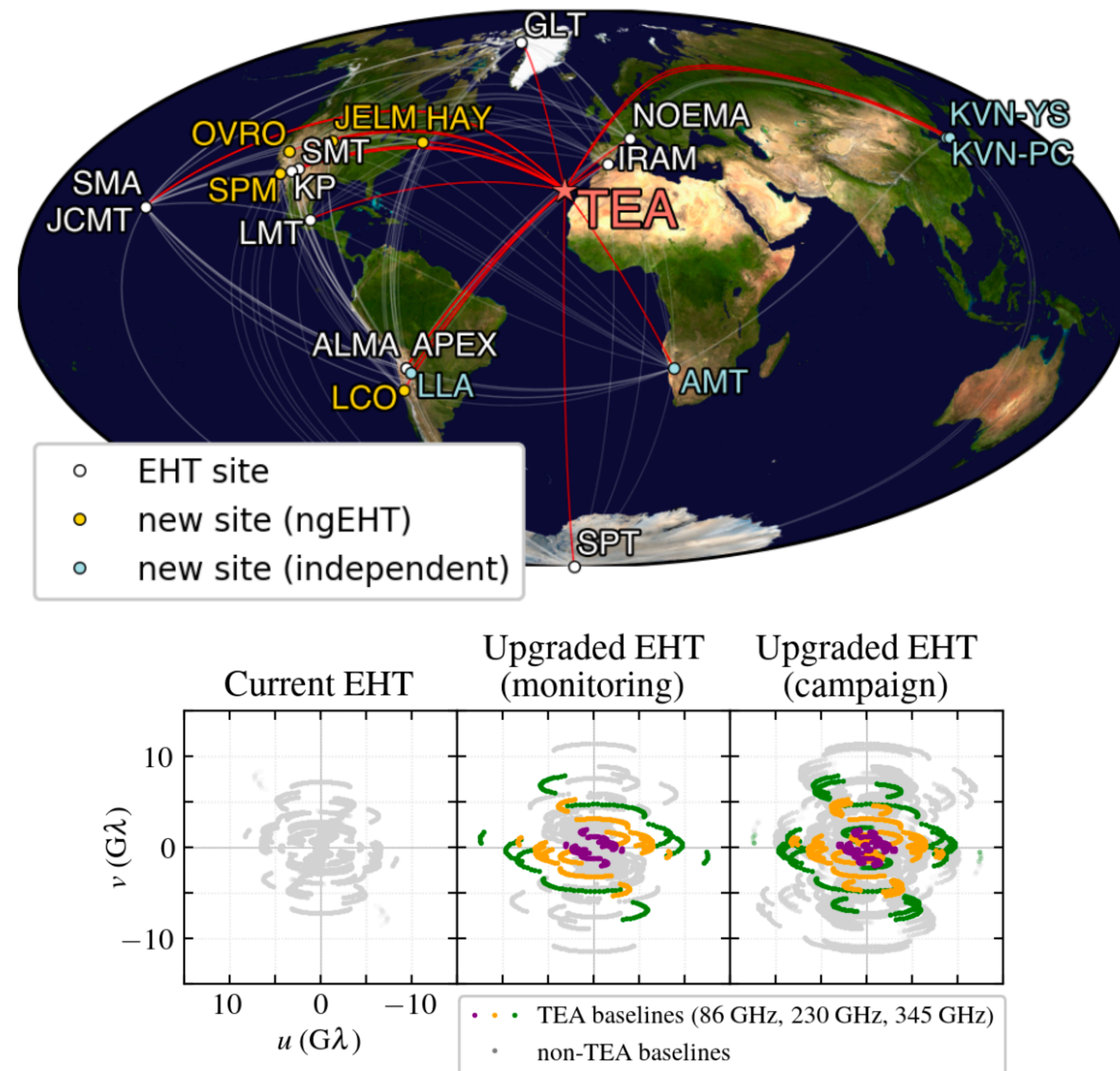
Next-Generation Astronomy





The ngEHT Program

- **Adding New Sites:**
 - Existing: OVRO (10m) & Haystack (37m).
 - Four new sites (9m): Canary Islands, Baja Mexico, Las Campanas, Mt. Jelm Wyoming.
- **Upgrading EHT sites with new backend systems.**
- **Multi-band receivers:** 86/230GHz at lower sites, 86/230/345GHz at high sites.
- **High Bandwidth backends:** 320Gb/s at tri-band sites, x5 the current EHT data rates.
- **Implement Frequency Phase Transfer** - applying low frequency solutions to high freq. bands.
- **Construct** a high throughput imaging pipeline
 - x16 data rates/volumes (distributed correlation).





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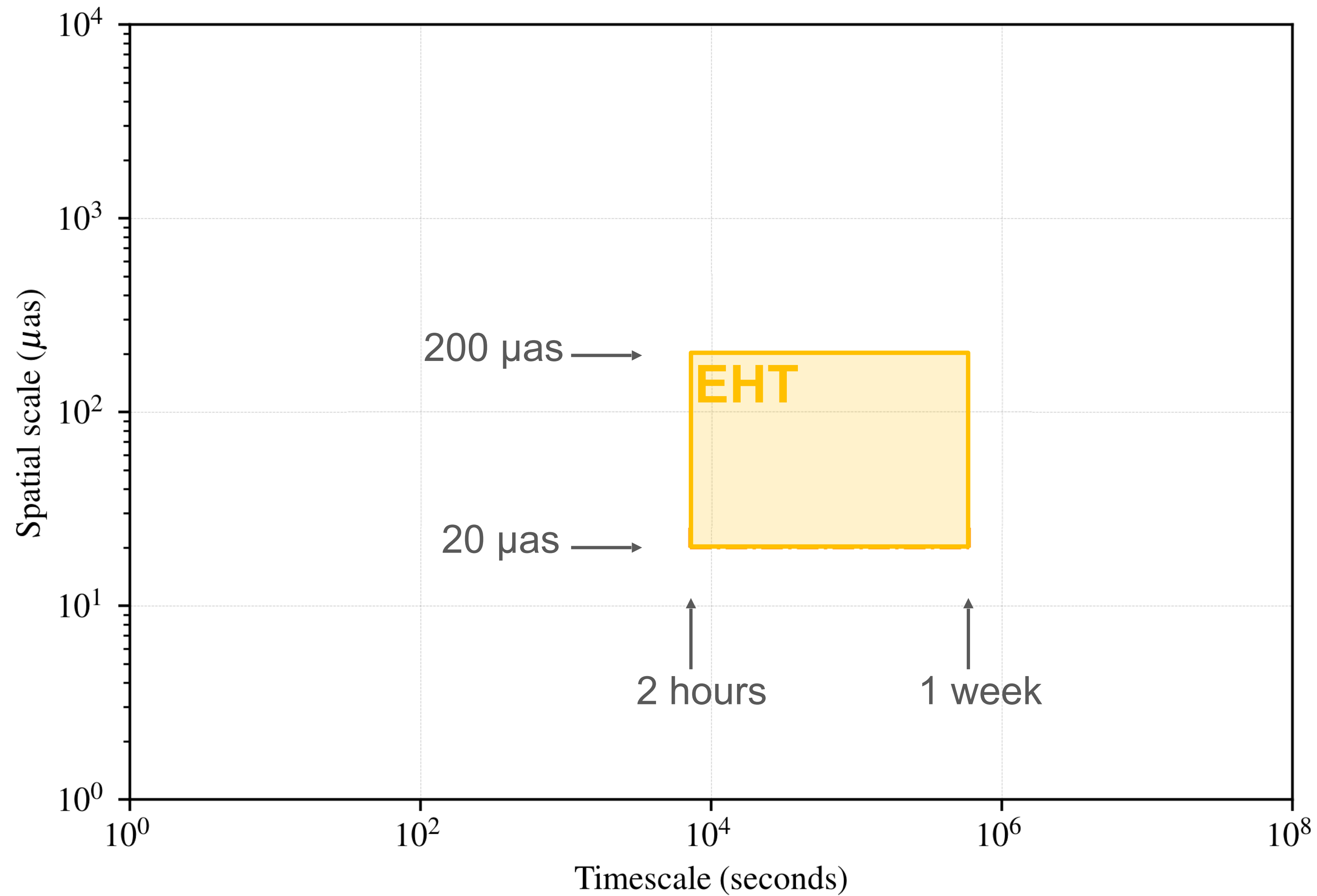
- x16 data rates/volumes (distributed correlation).

- **The Impact:**

- New sites and multi-color observations increase the Fourier spatial frequency coverage by x15.
- Snapshot coverage enables movies of SgrA*.
- Long-term monitoring will capture high-fidelity dynamics of M87.
- Sensitivities reach ~3mJy: a new population of black hole sources.

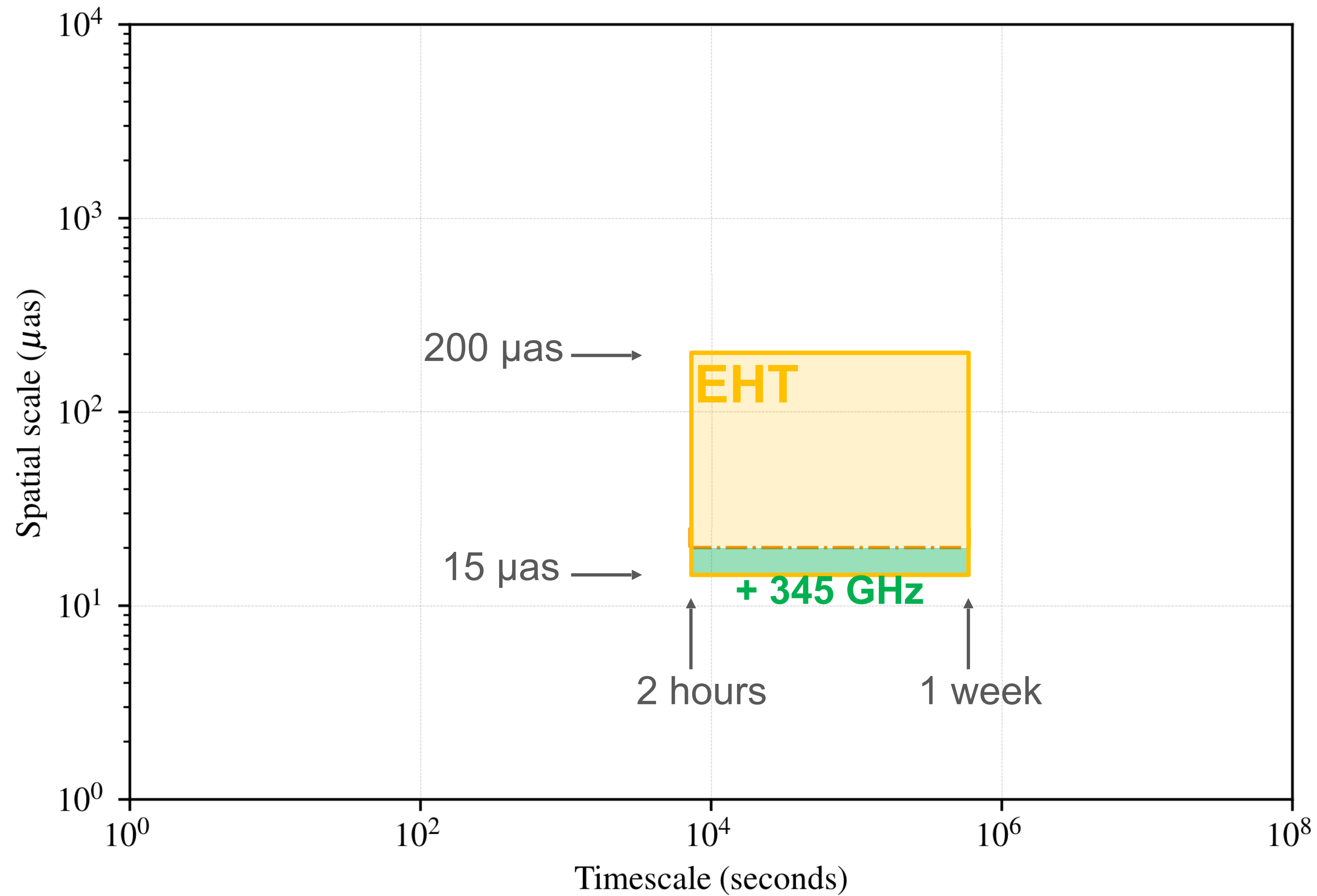


The parameter space



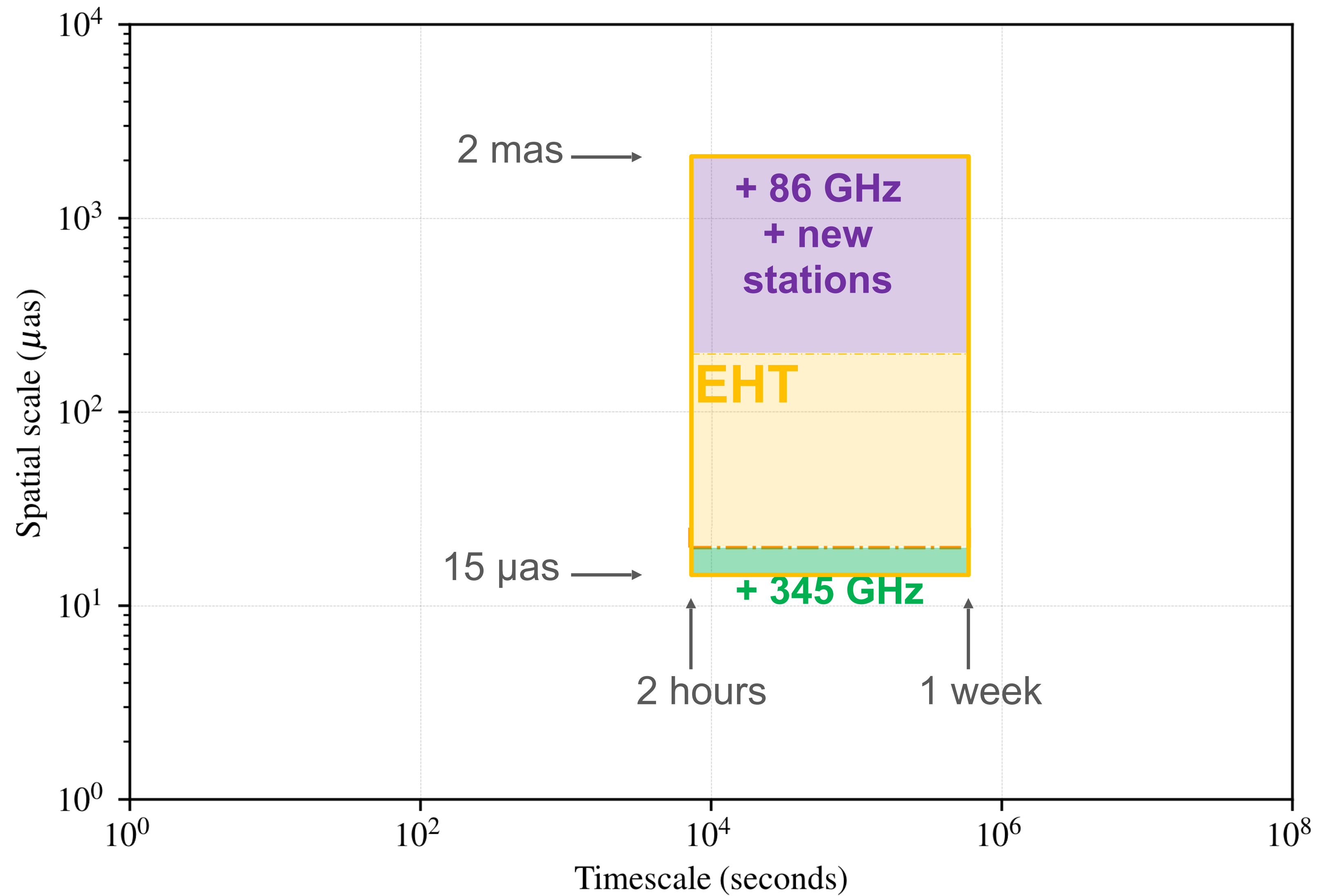


The parameter space



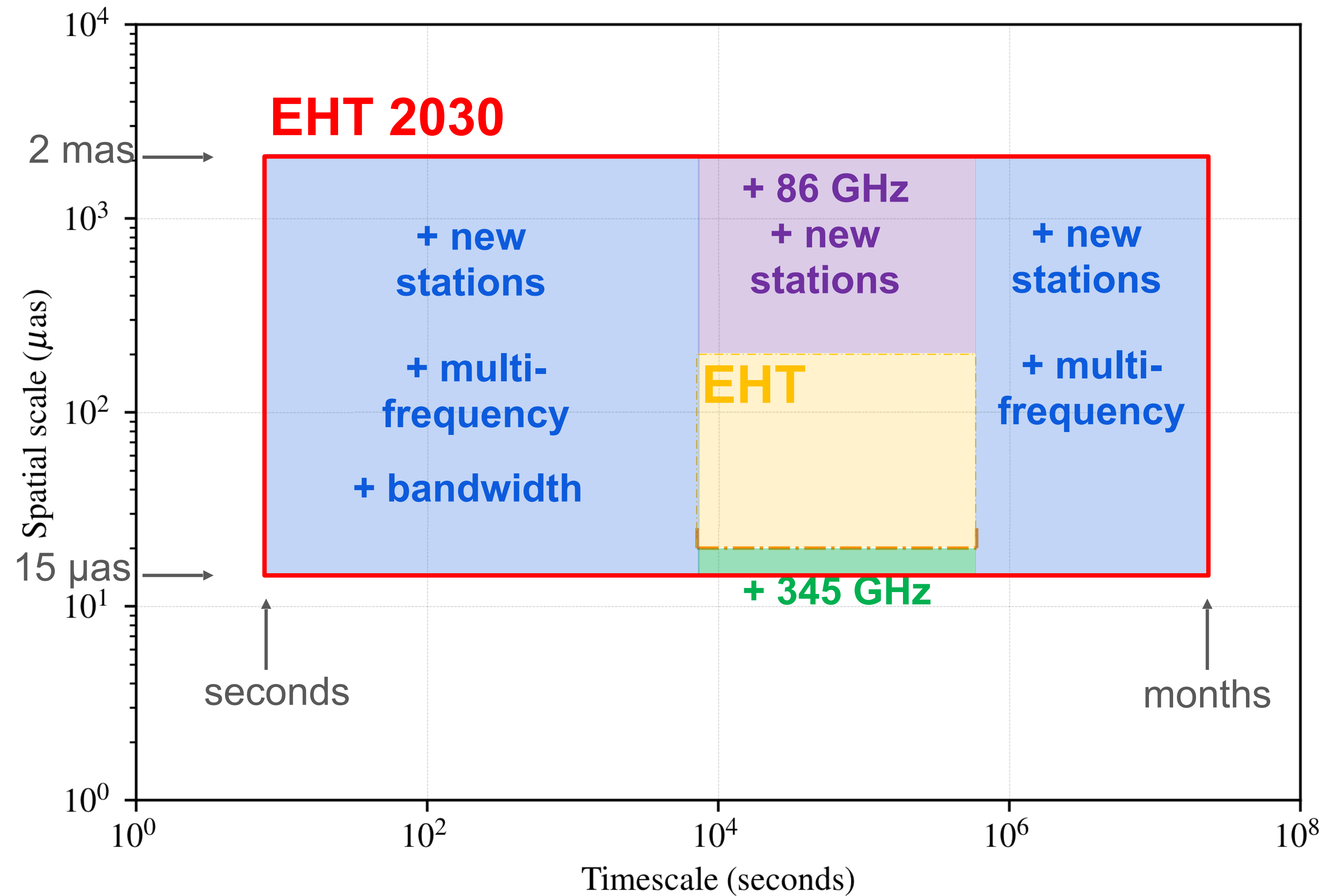


The parameter space





The parameter space



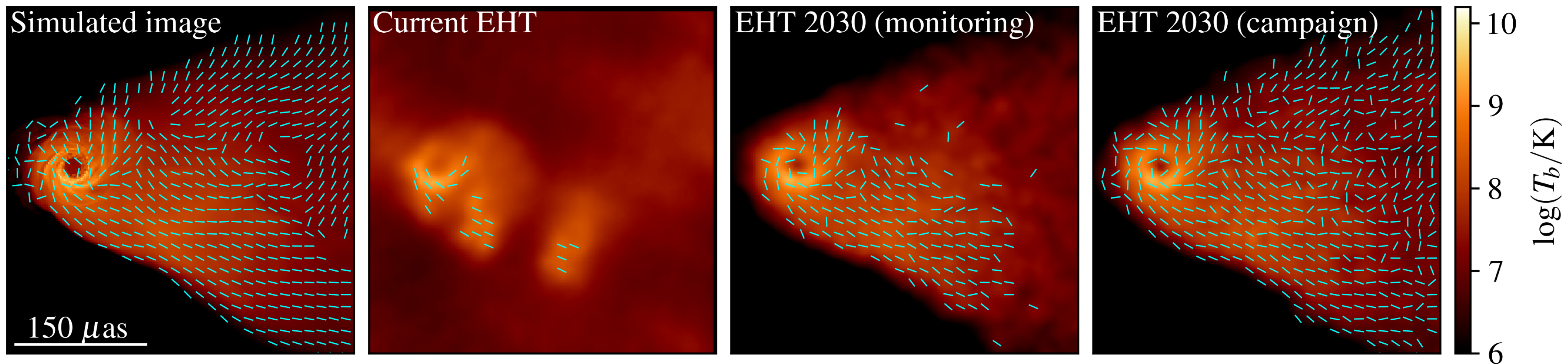


Improved imaging of M87

The EHT currently struggles to capture the large-scale jet emission expected around M87*

With the upgraded array, imaging the faint jet emission would be possible even using only a subarray that could be fielded for a large fraction of the year

The linear polarization information is expected to inform us about BZ ([Chael et al. 2023](#))



Simulation credit: Andrew Chael, [Chael et al. \(2019\)](#);

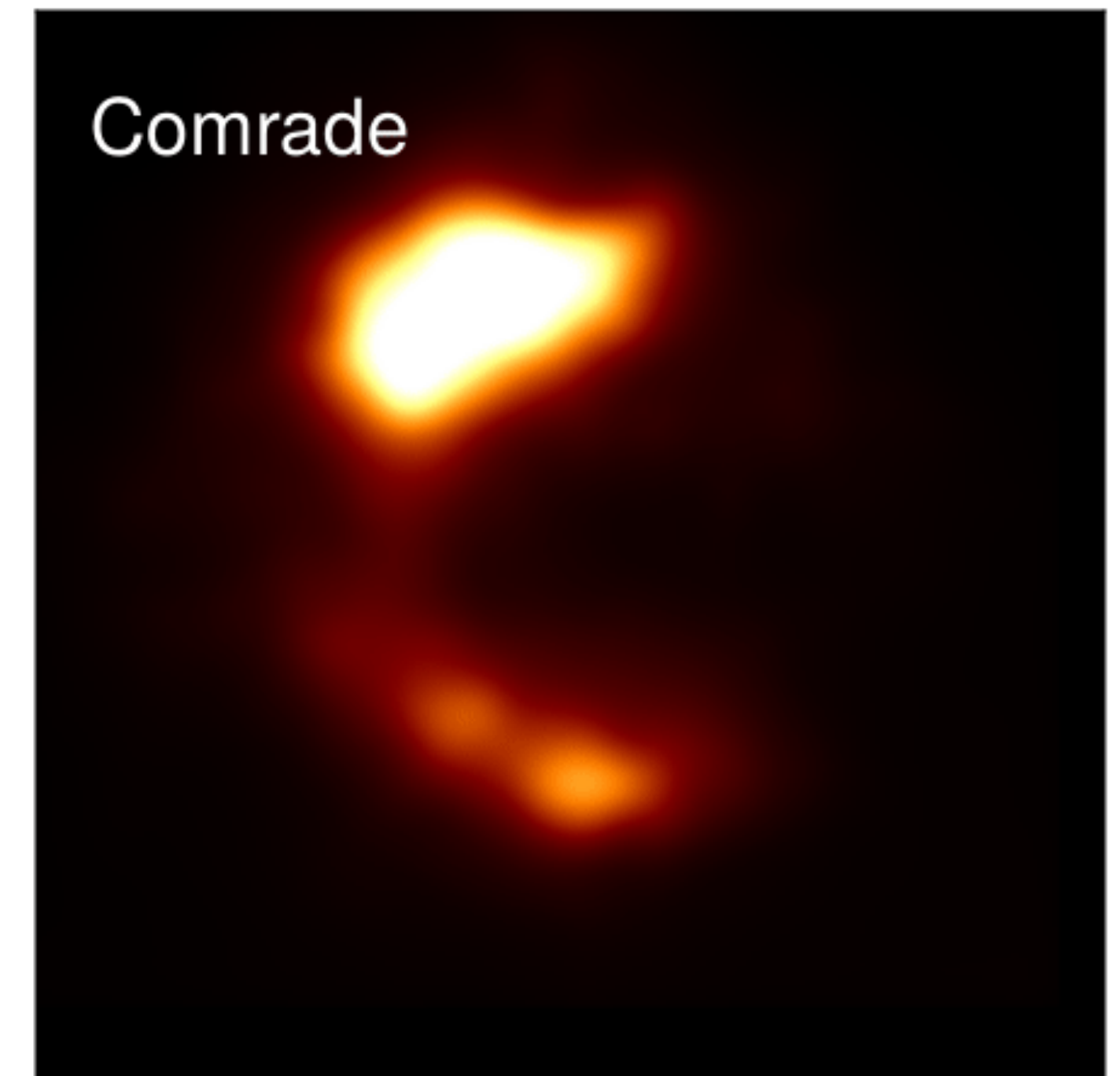
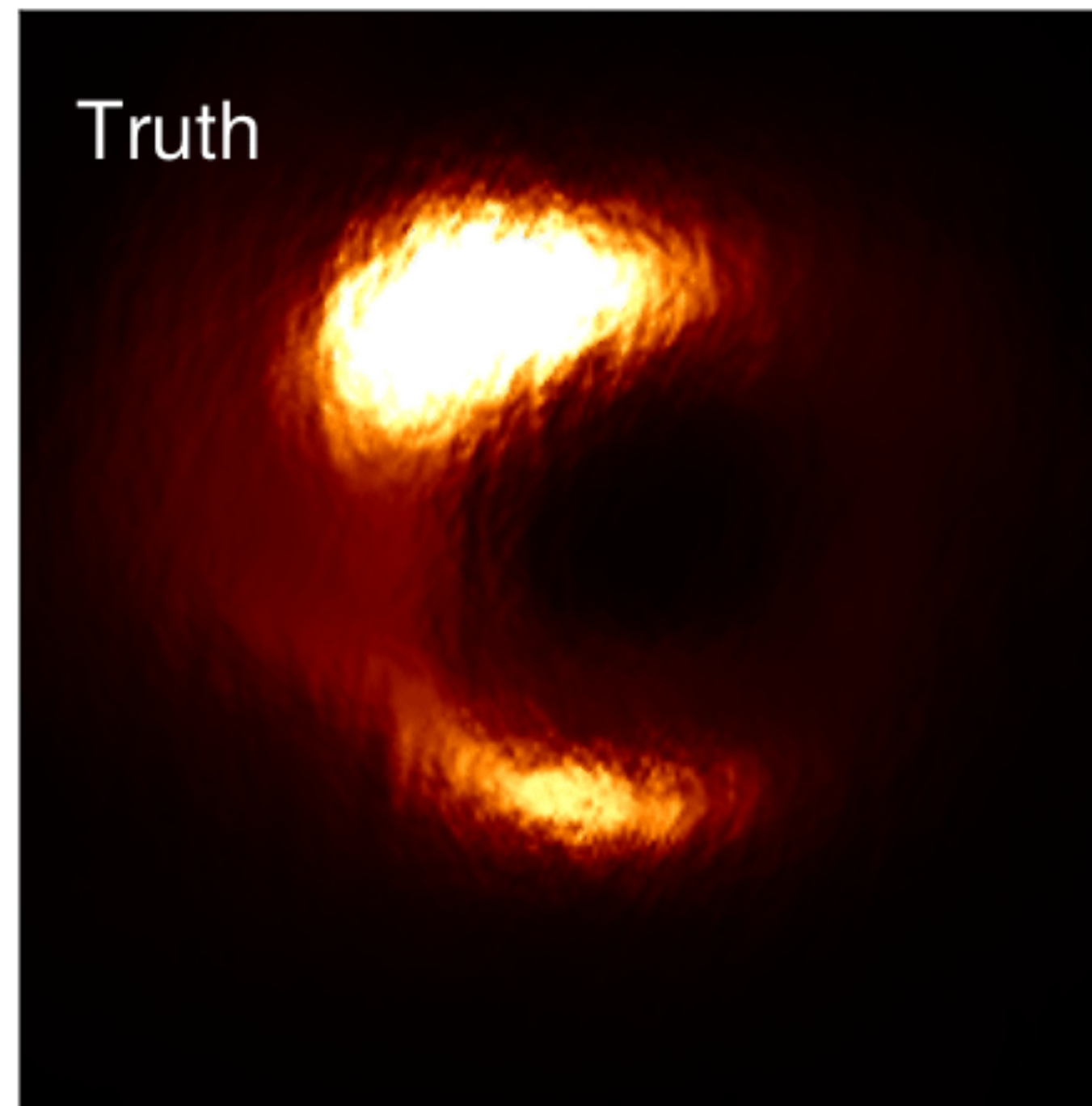
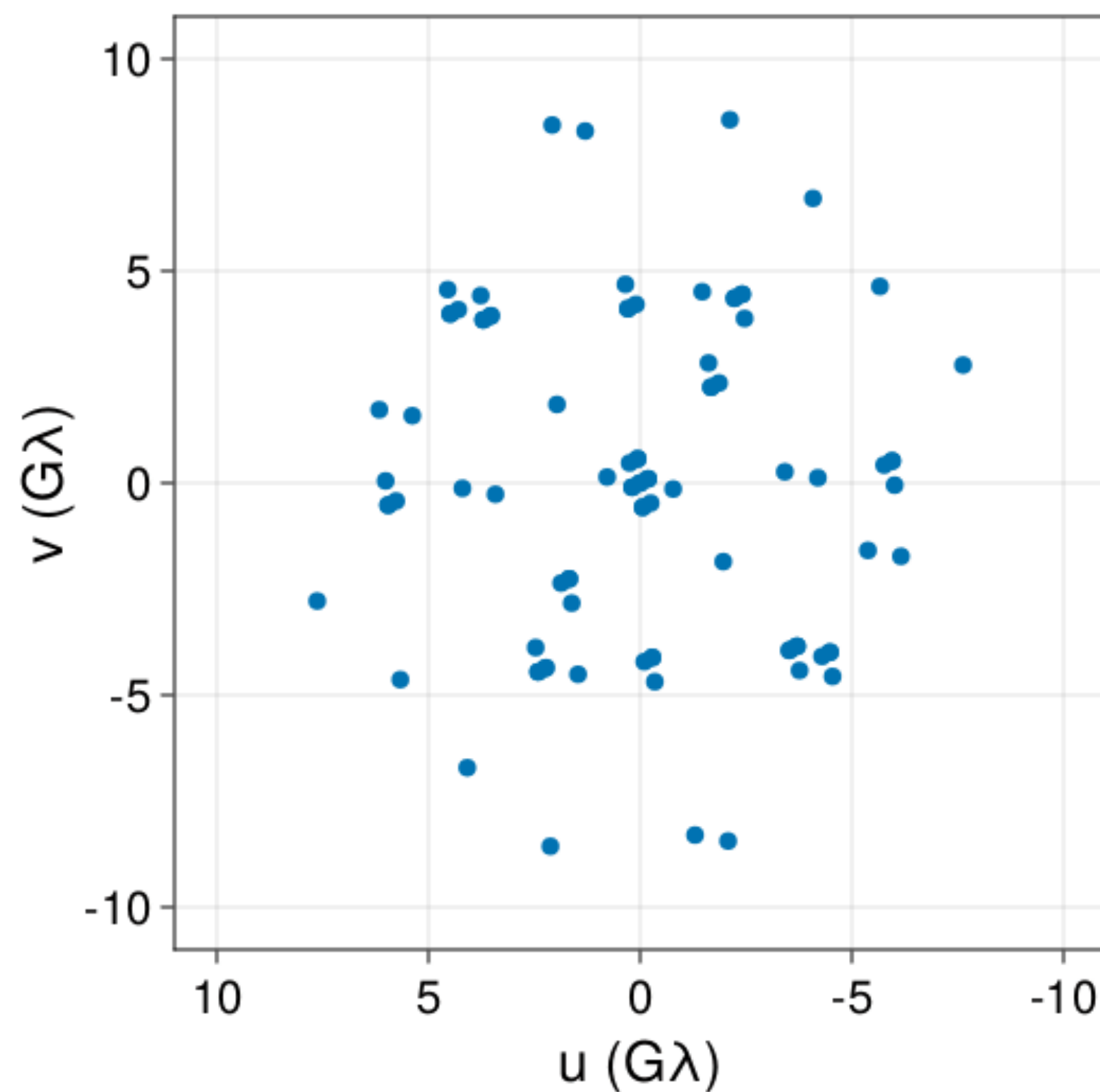
Figure credit: Lindy Blackburn, Paul Tiede. Slide credit: Dom Pesce



Improved imaging of Sgr A*

The enhanced array would be capable of high-quality “snapshot” imaging of Sgr A* on timescales of minutes, enabling the tracking of flaring features and other dynamics in the emission structure

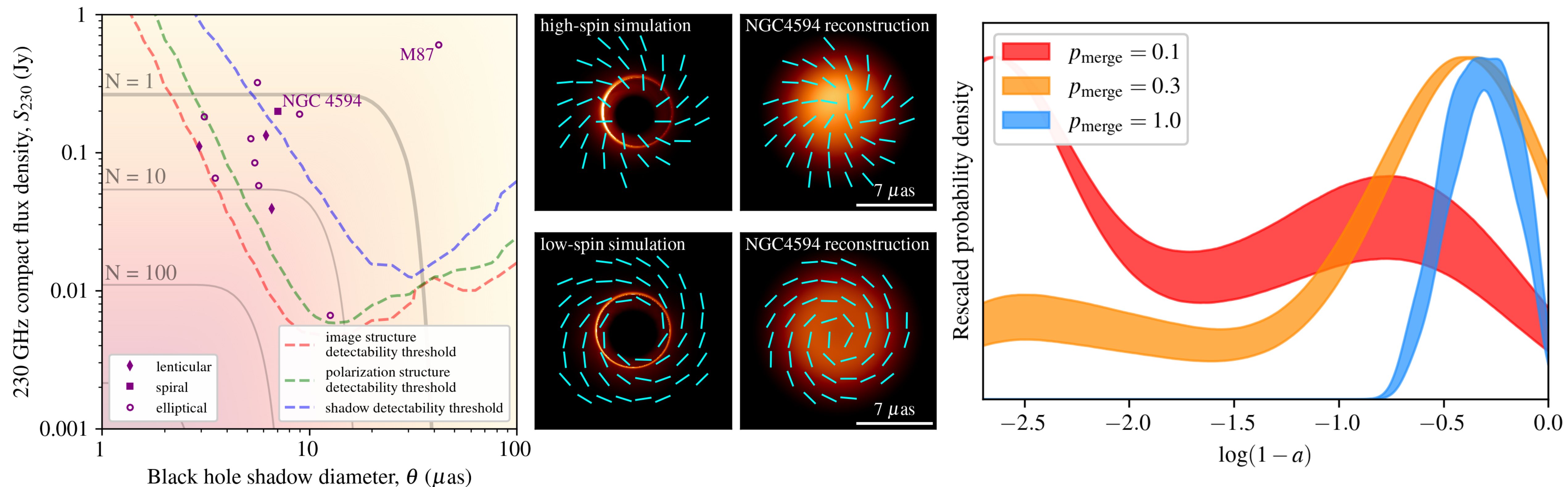
Time Elapsed 0.0 minutes



Horizon-scale BH science beyond M87 and Sgr A*

The improved sensitivity would permit horizon-scale observations of a population of potentially dozens of new targets

- estimates of the emission ring size (corresponding to mass) and linear polarization structure (corresponding to spin) would be accessible
- population-level spin measurements can distinguish the dominant SMBH growth mechanisms





Testing alternatives to GR

Detectable differences in the size and depth of the “inner shadow” region, along with the details of the surrounding emission profile, can be sensitive to the surrounding spacetime

- provide opportunities for null tests of GR

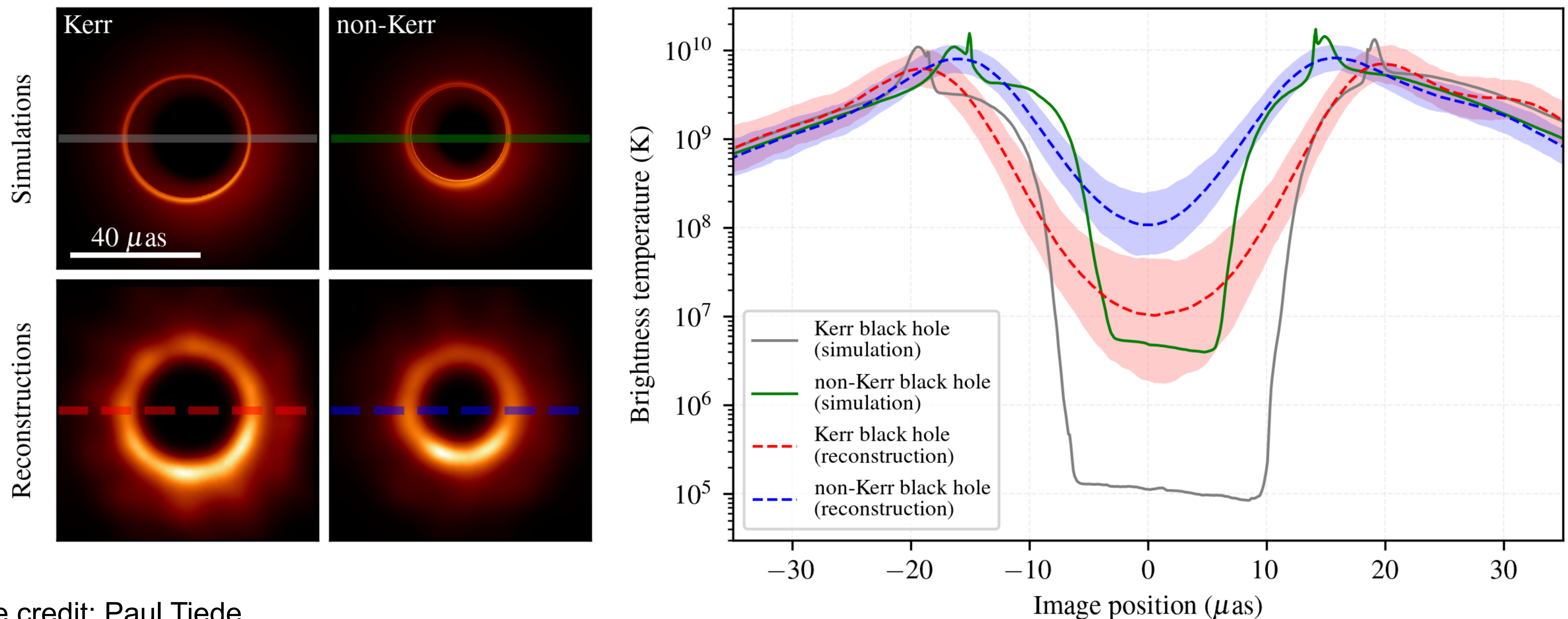


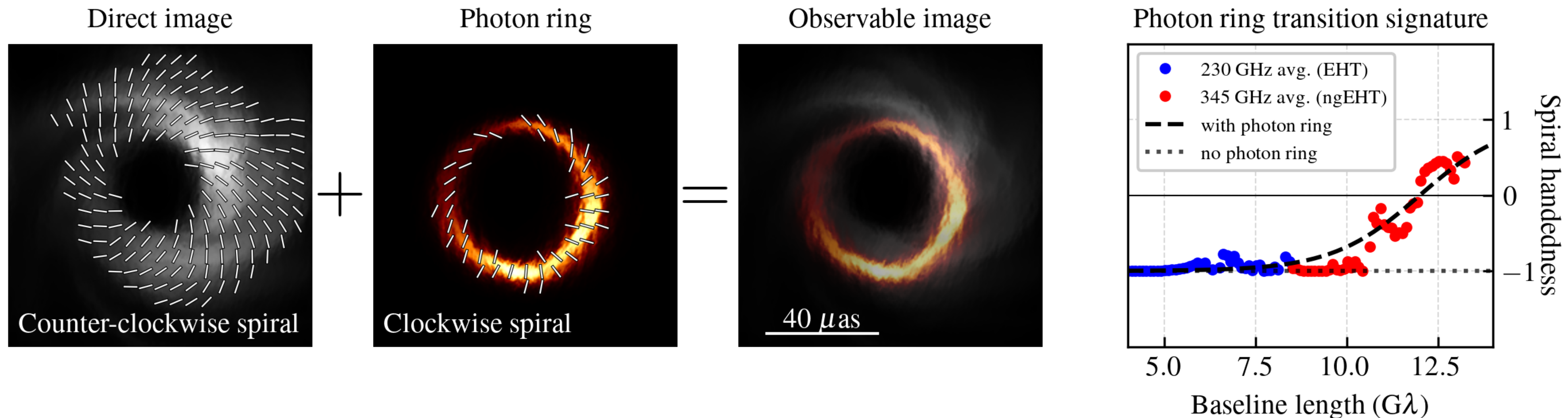
Figure credit: Paul Tiede

Simulation credit: Koushik Chatterjee, Prashant Kocherlakota, [Chatterjee et al. \(2023\)](#). Slide credit: Dom Pesce

Polarimetric photon ring signatures

Repeated 345 GHz observations of Sgr A* on the longest north-south baselines of an enhanced array could reveal the spiral handedness reversal expected as the Fourier signature of the linear polarization pattern transitions from being dominated by the direct emission to being dominated by the lensed emission (photon ring)

- 345 GHz is necessary to suppress scattering and to access sufficiently long baselines



Tenerife Event-horizon Antena (TEA)

TEA is an international project lead by **SAO-CfA**, **IAA-CSIC**, and **IAC** to deploy a 13 m mm-submillimeter antenna for observations of black holes with the EHT and ngEHT.

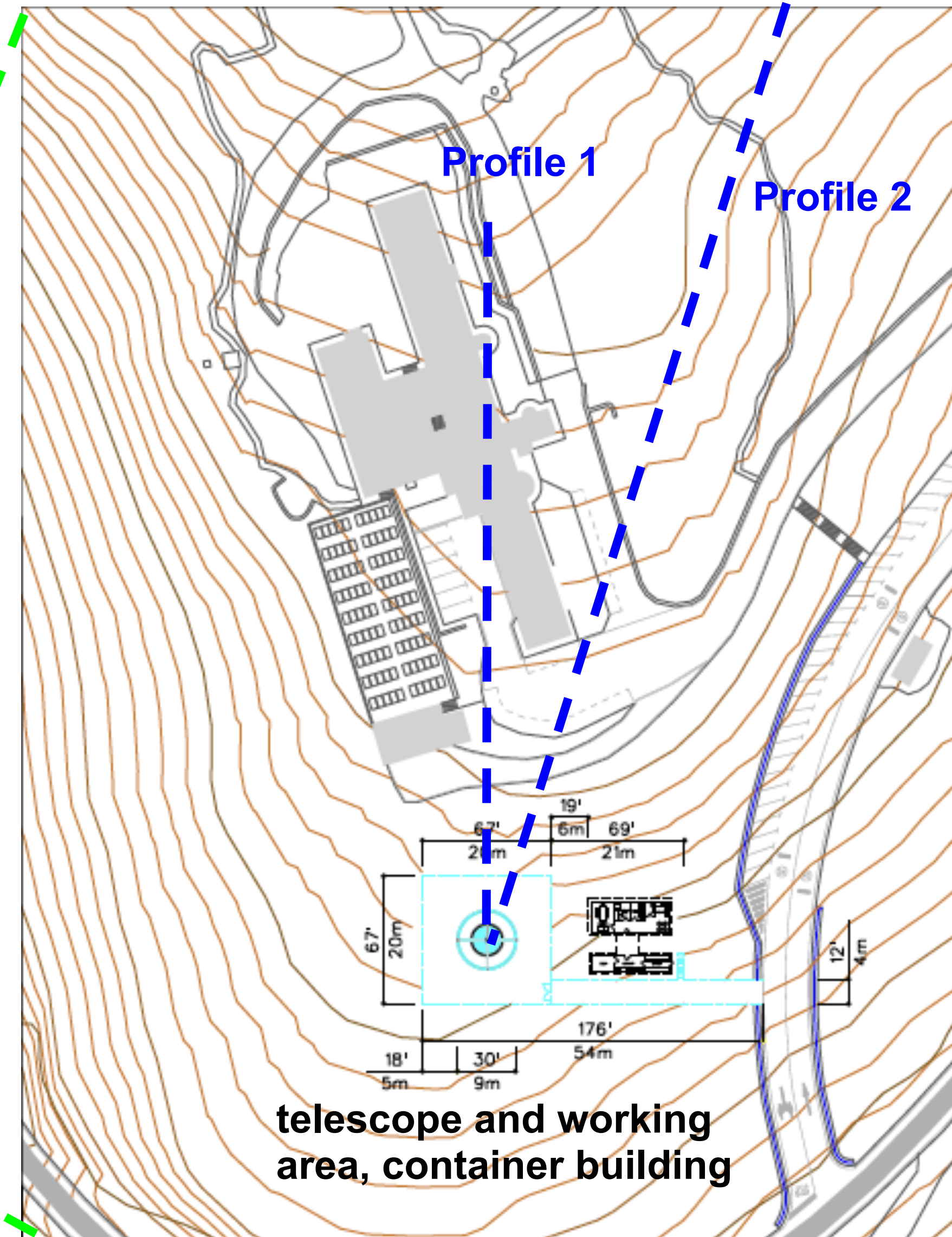
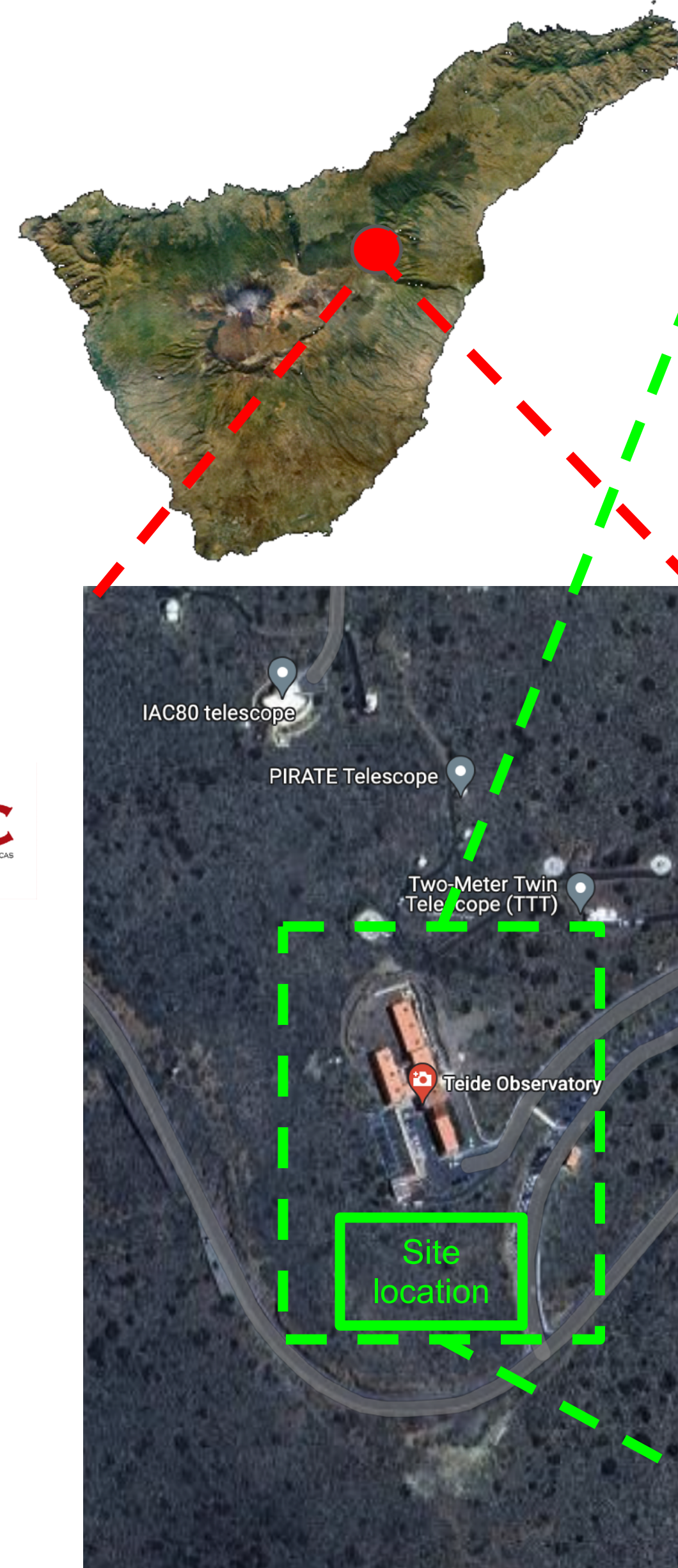
CENTER FOR
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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



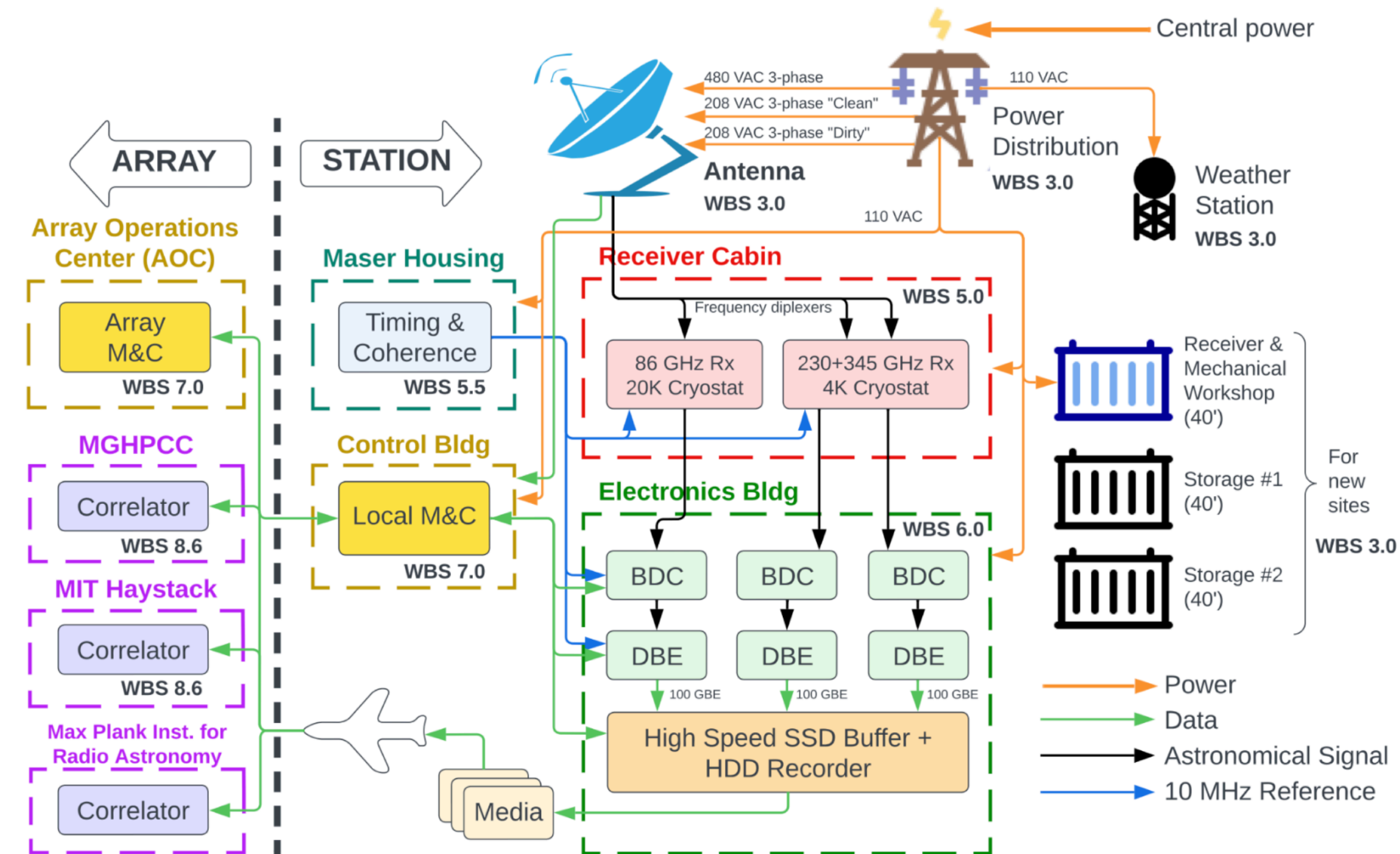
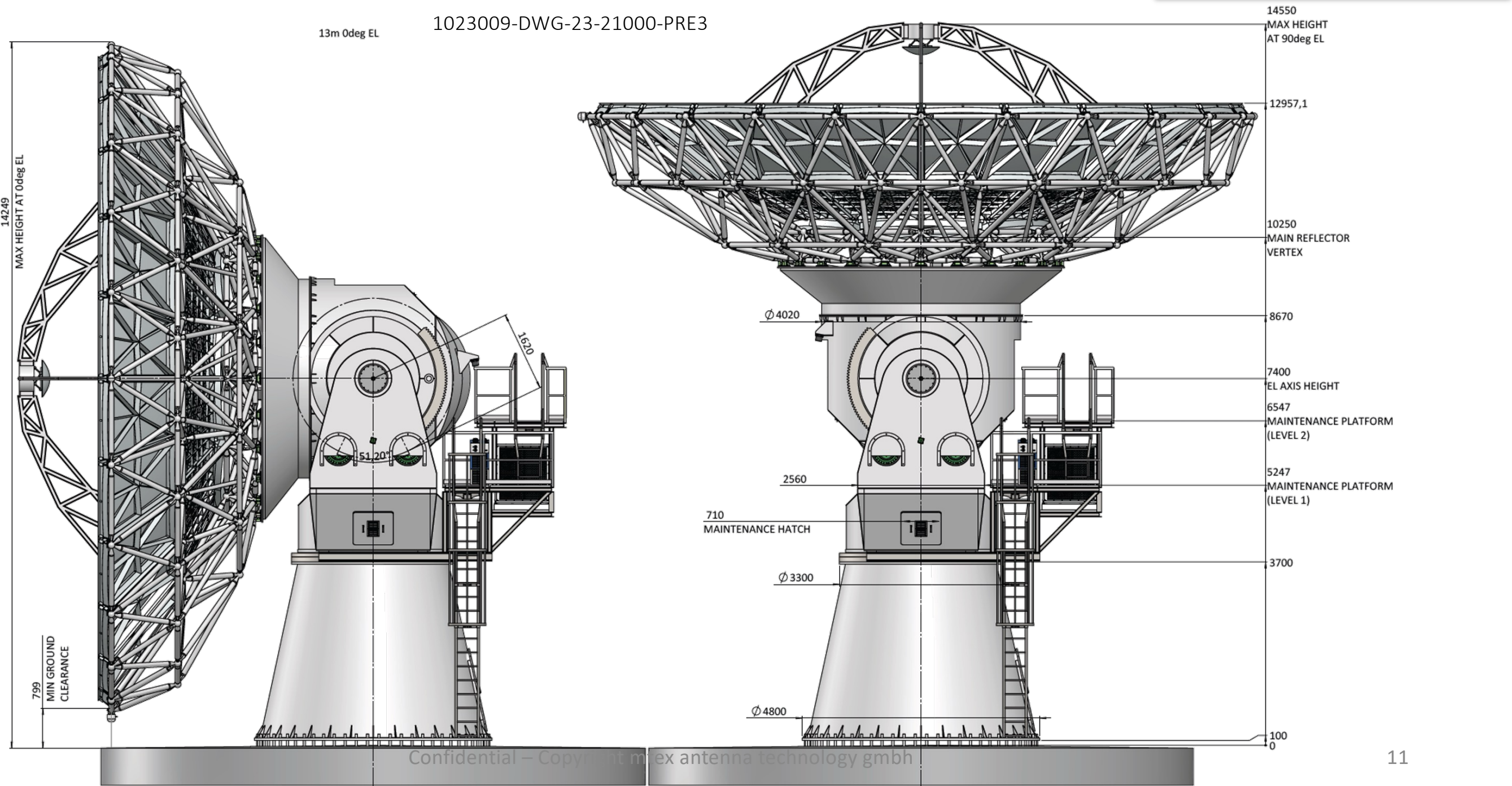
GORDON AND BETTY
MOORE
FOUNDATION



Tenerife Event-horizon Antena (TEA)

GENERAL DESIGN INFORMATION

13m Overall Dimensions



- Tri-band receiver built into two cryostats (230+345 & 86 GHz)
- Block Downconverters (BDC): twelve signal processing chains, one per receiver IF
- Next Generation Digital Backends (ngDBE) sample four 8 GHz IF bands for each frequency (dual pol, two sidebands). 86 GHz at 64 Gps, 230 and 345 at 128 Gps. Total 320 Gps
- VLBI data recorders containing solid-state drives (SSDs)

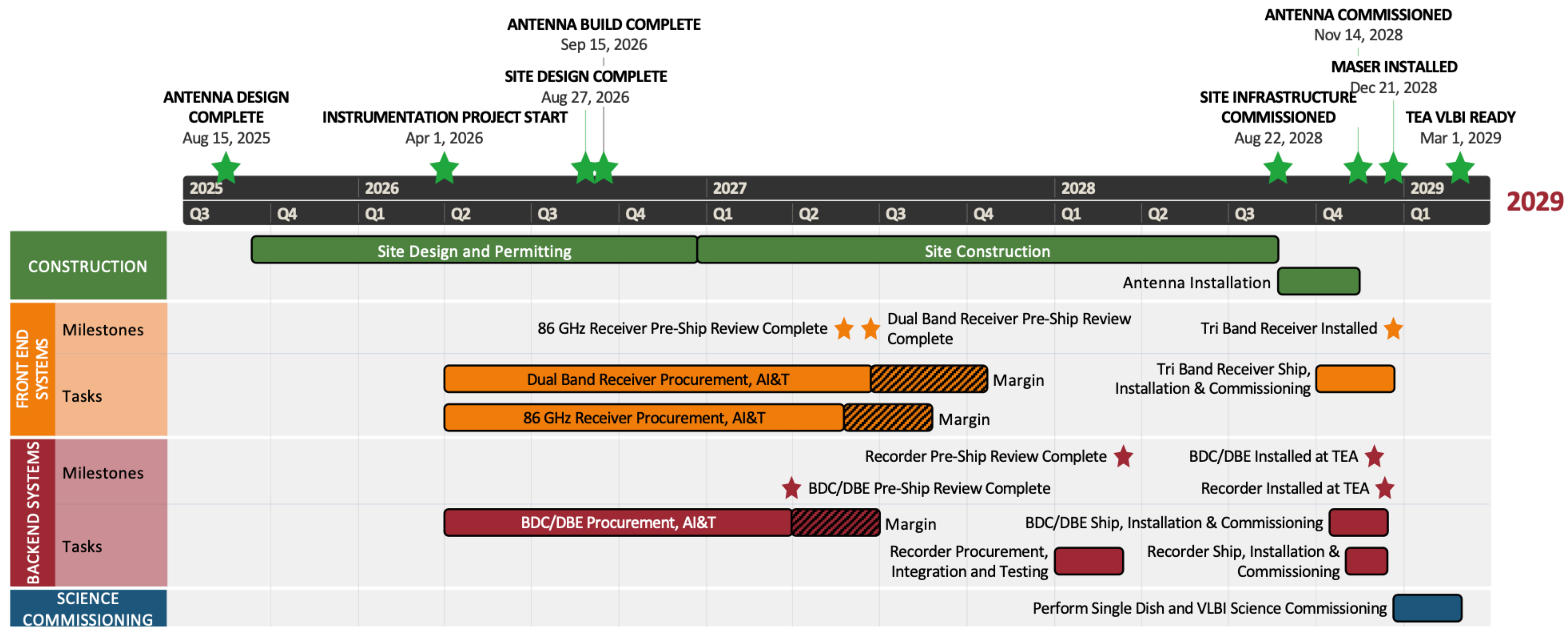
Tenerife Event-horizon Antena (TEA) - Timeline

- Antenna installation official approval by the Observatory International Scientific Committee (Oct. 2024)
- Kickoff meeting held on October 21-23, 2024



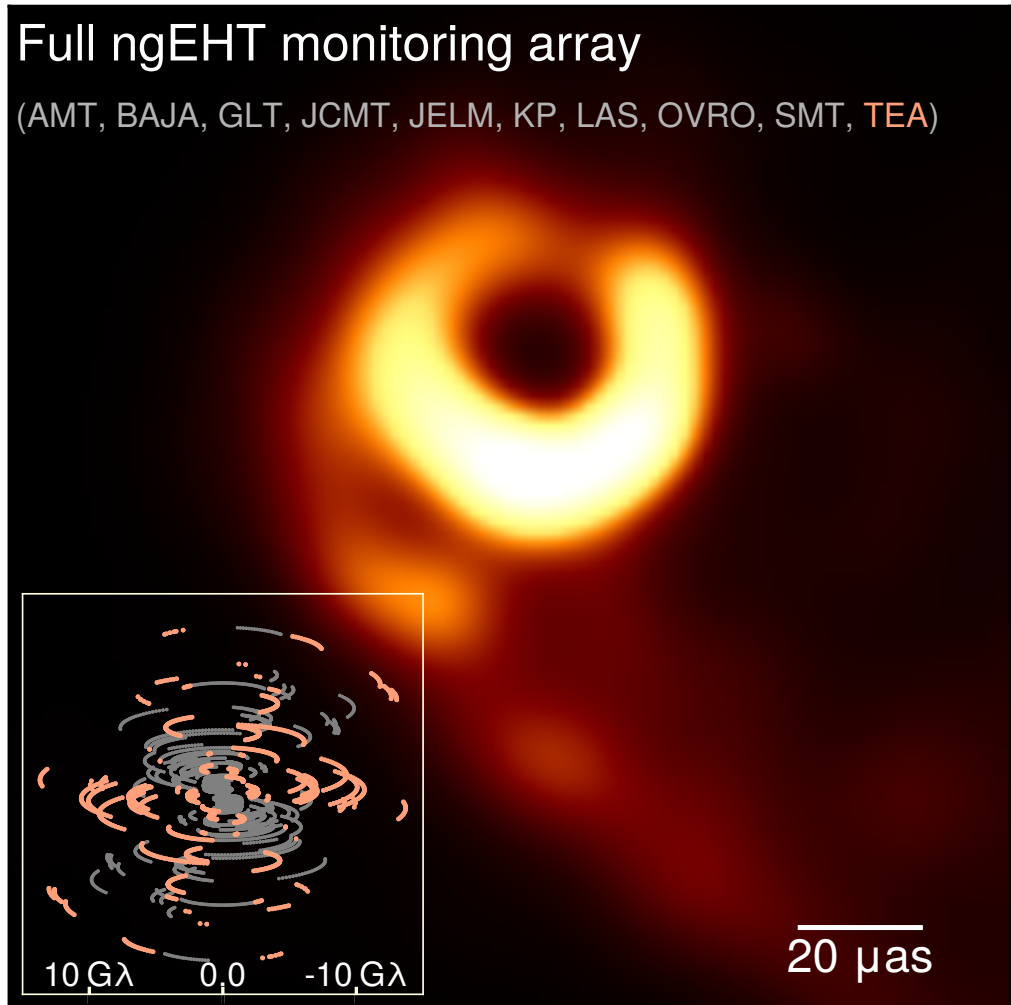
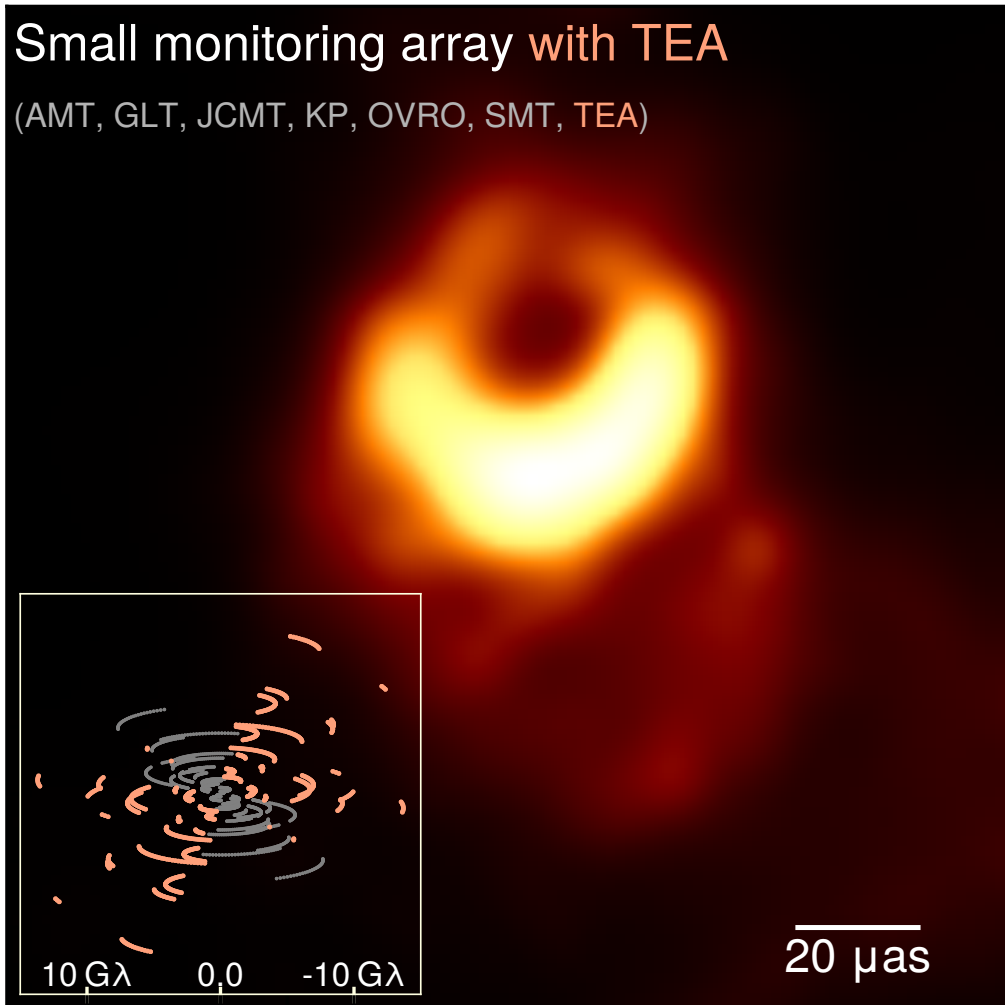
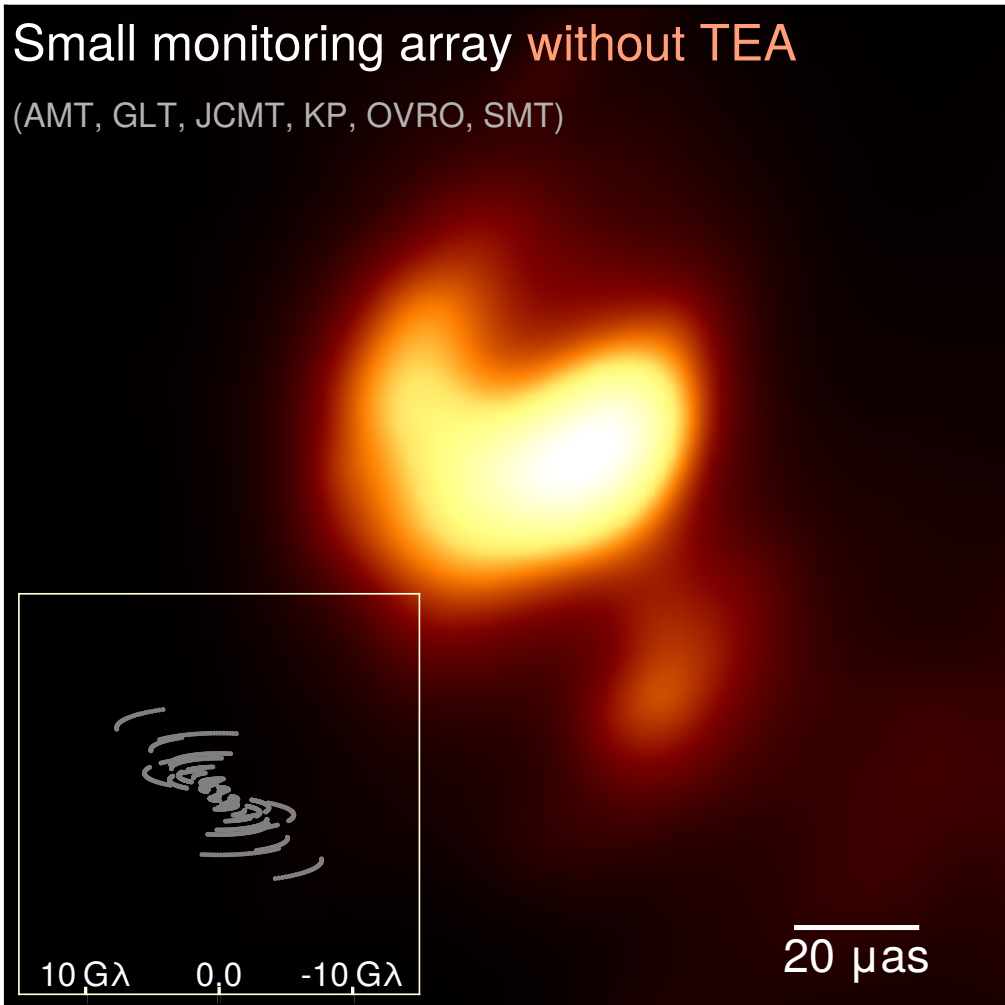
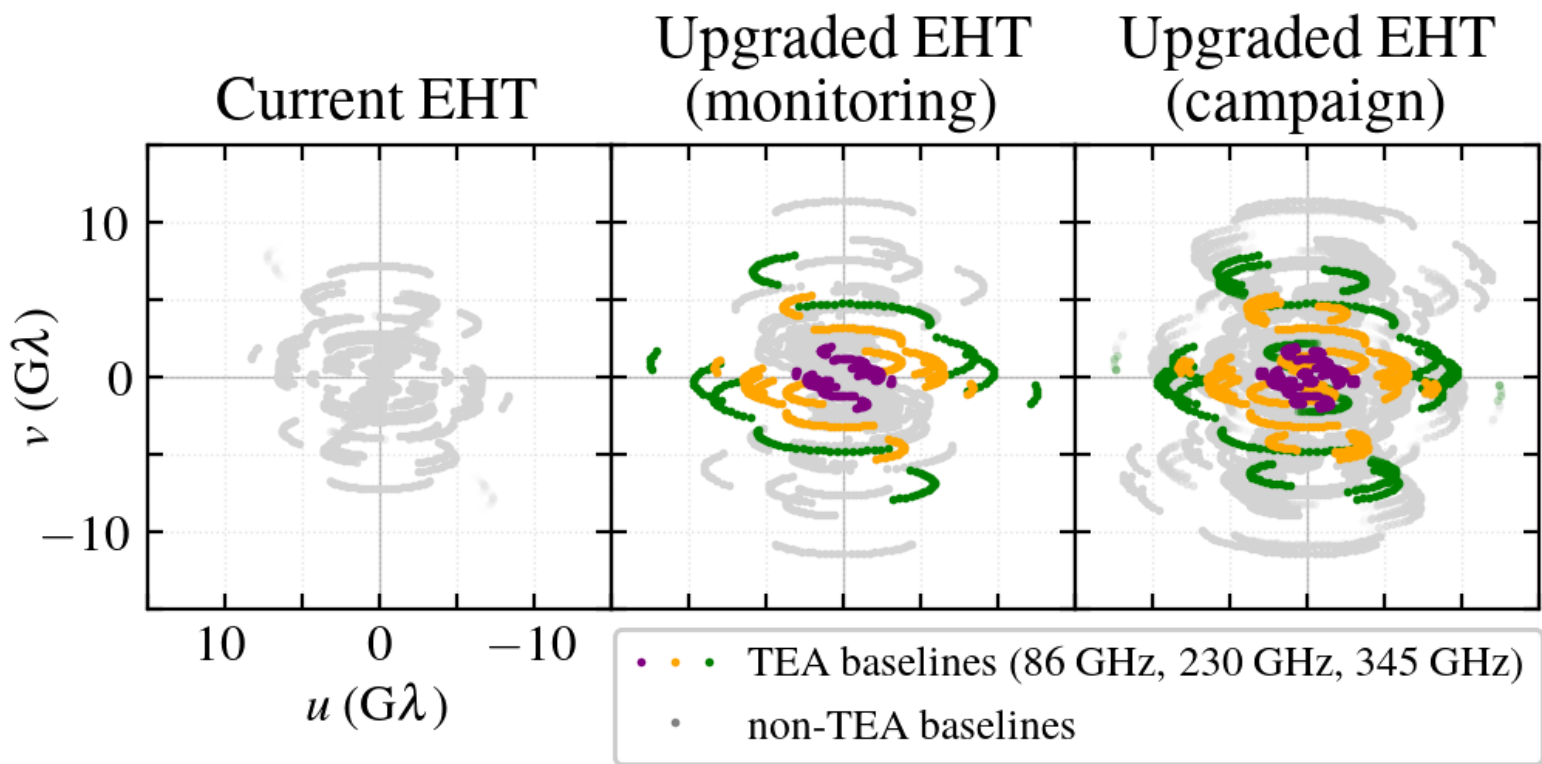
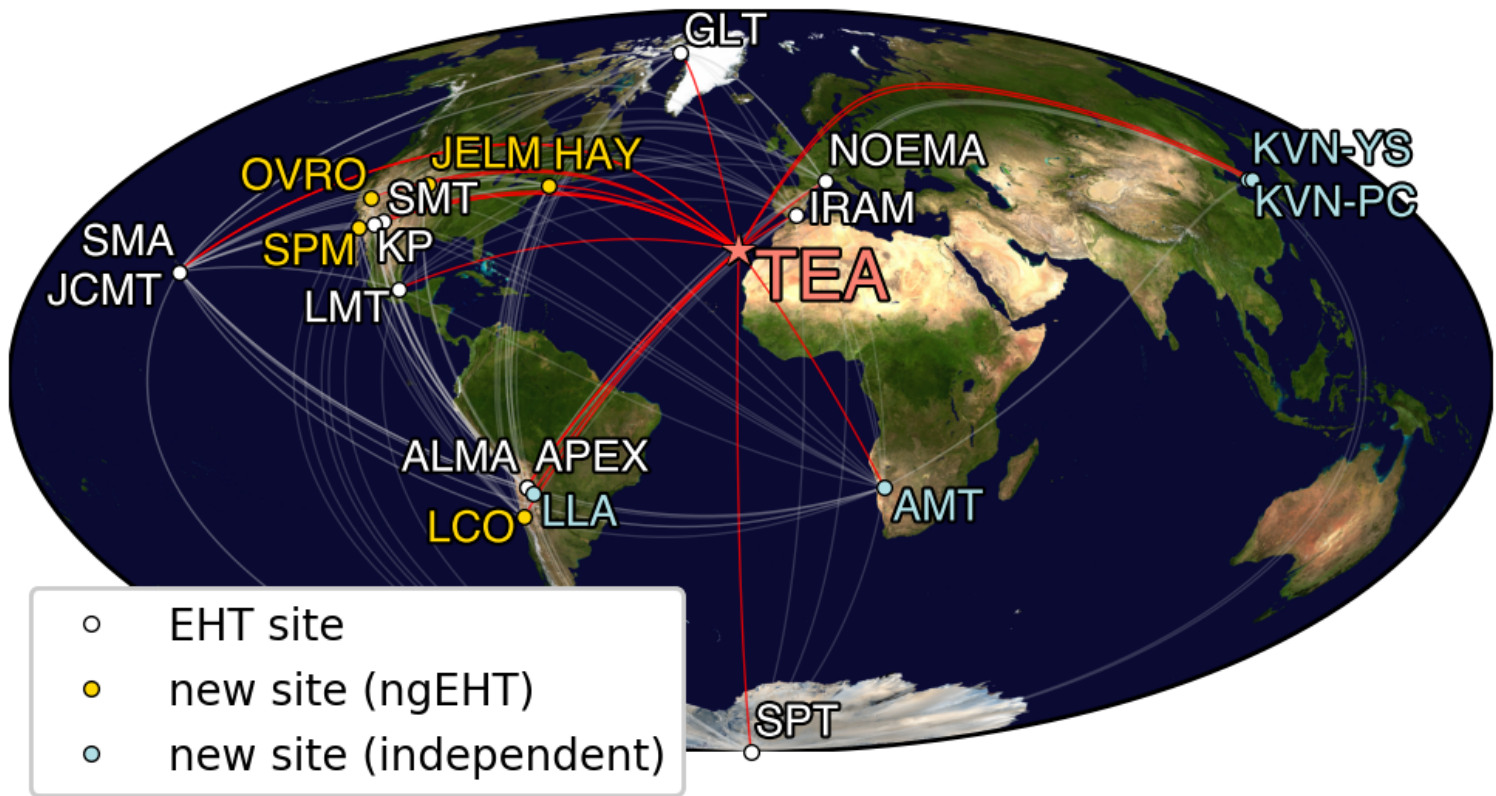
Tenerife Event-horizon Antena (TEA) - Timeline

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- Final antenna design accepted in July 2025
- Site and building construction by Q4 2028, followed by antenna deployment
- TEA station commissioning and readiness by Q1 2029



Tenerife Event-horizon Antena (TEA)

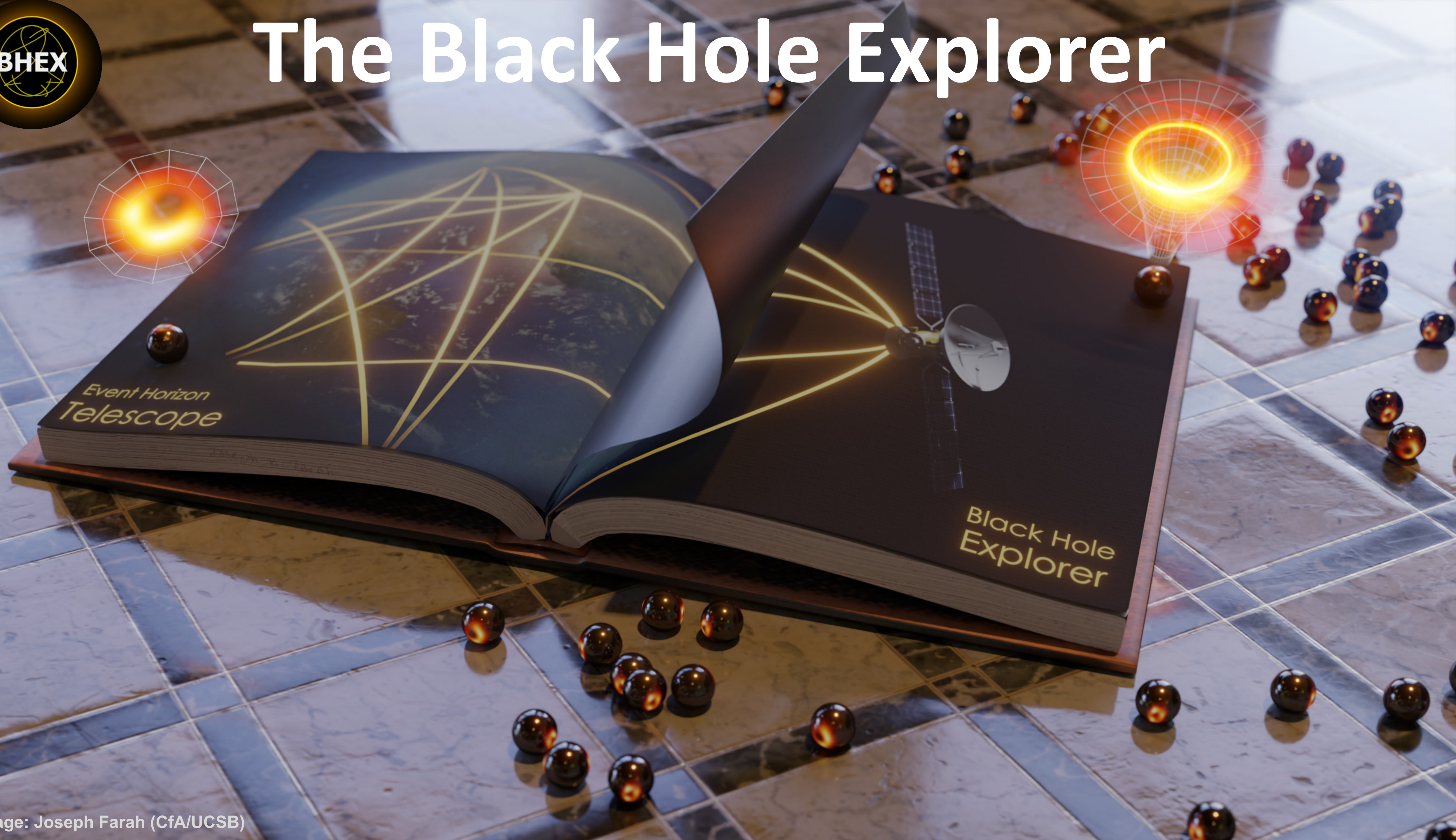
The exceptional antenna location allows imaging of black holes in monitoring mode without the need for the large antennas of the EHT



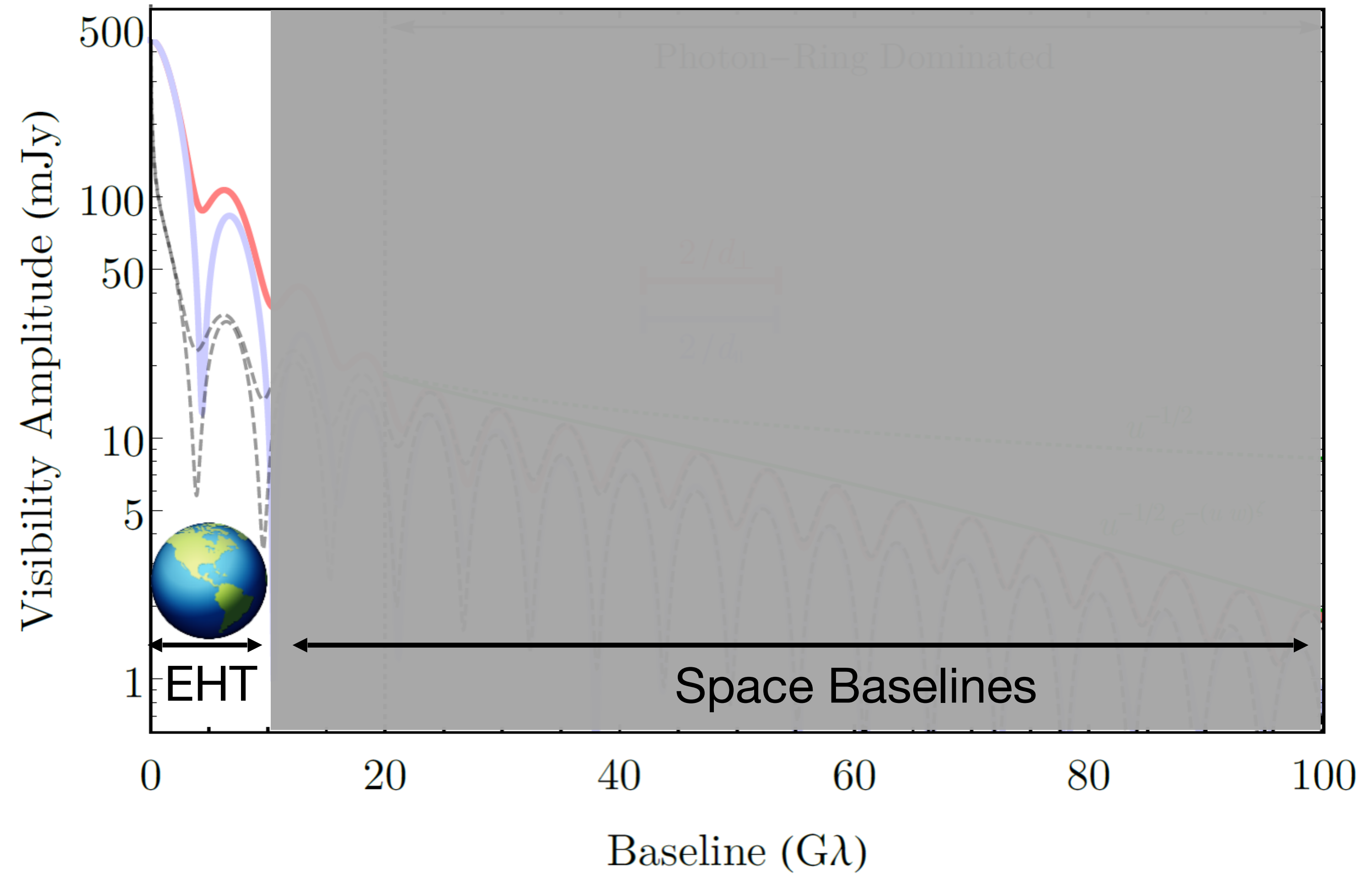
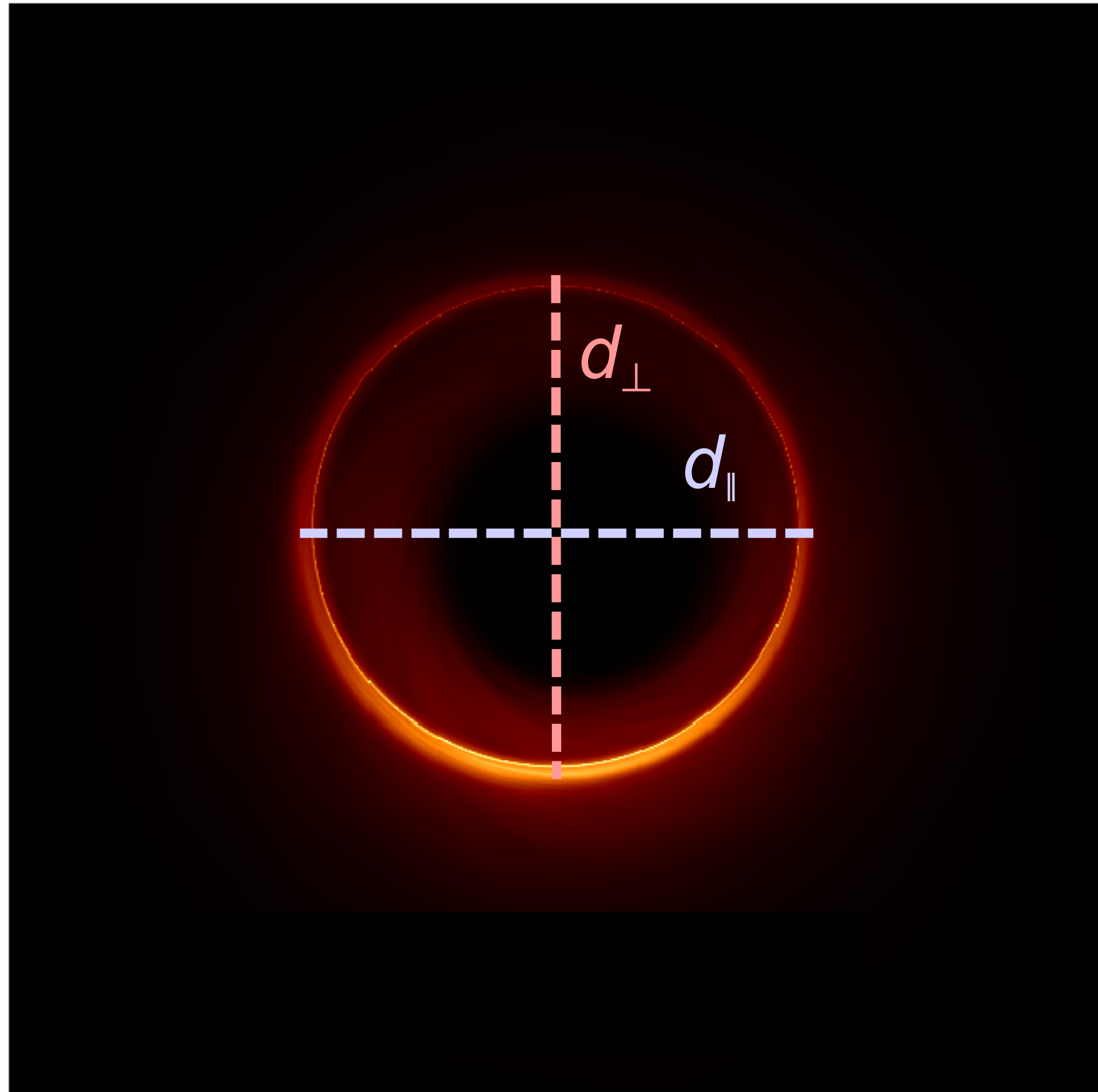
Simulations for observations of M87



The Black Hole Explorer

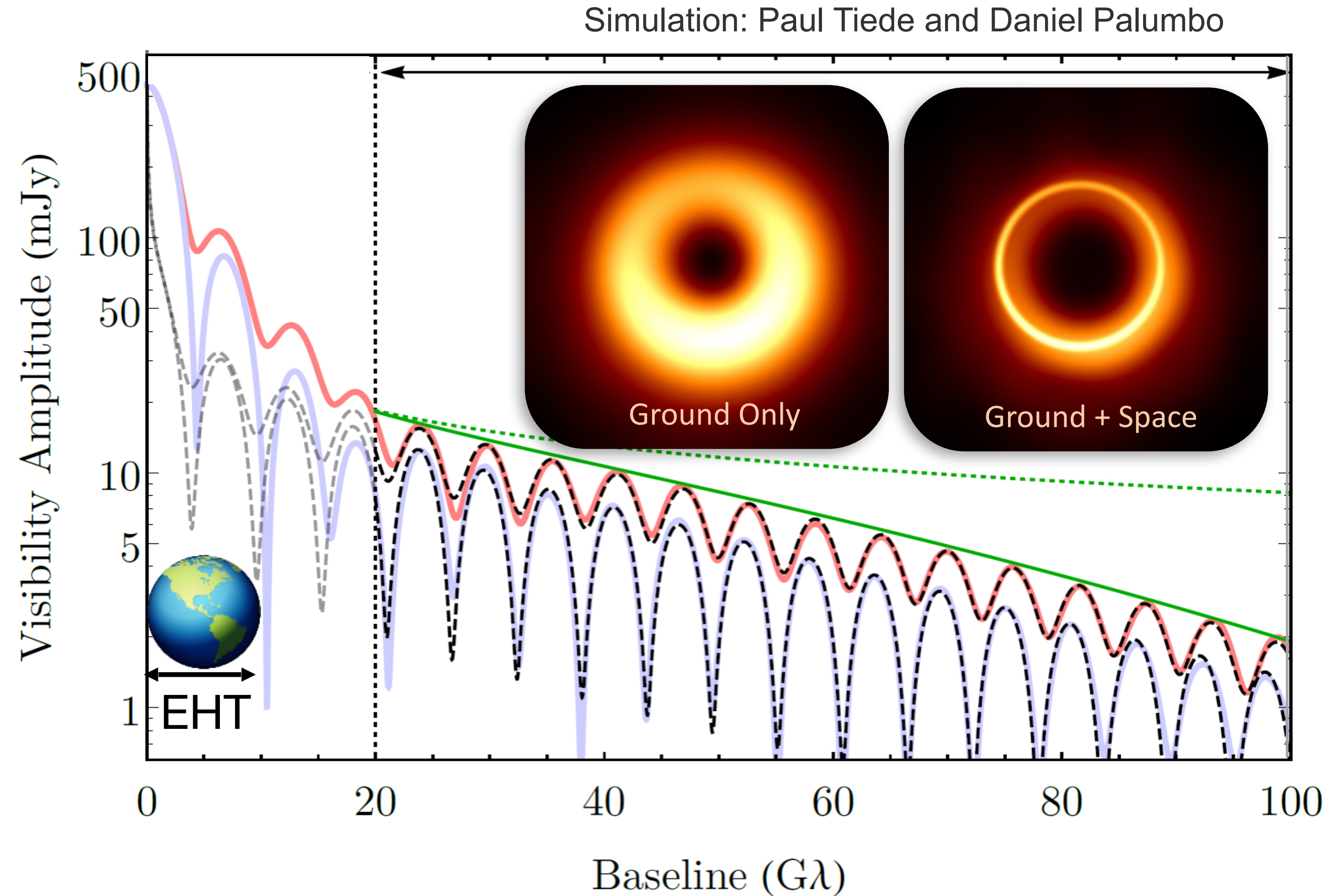
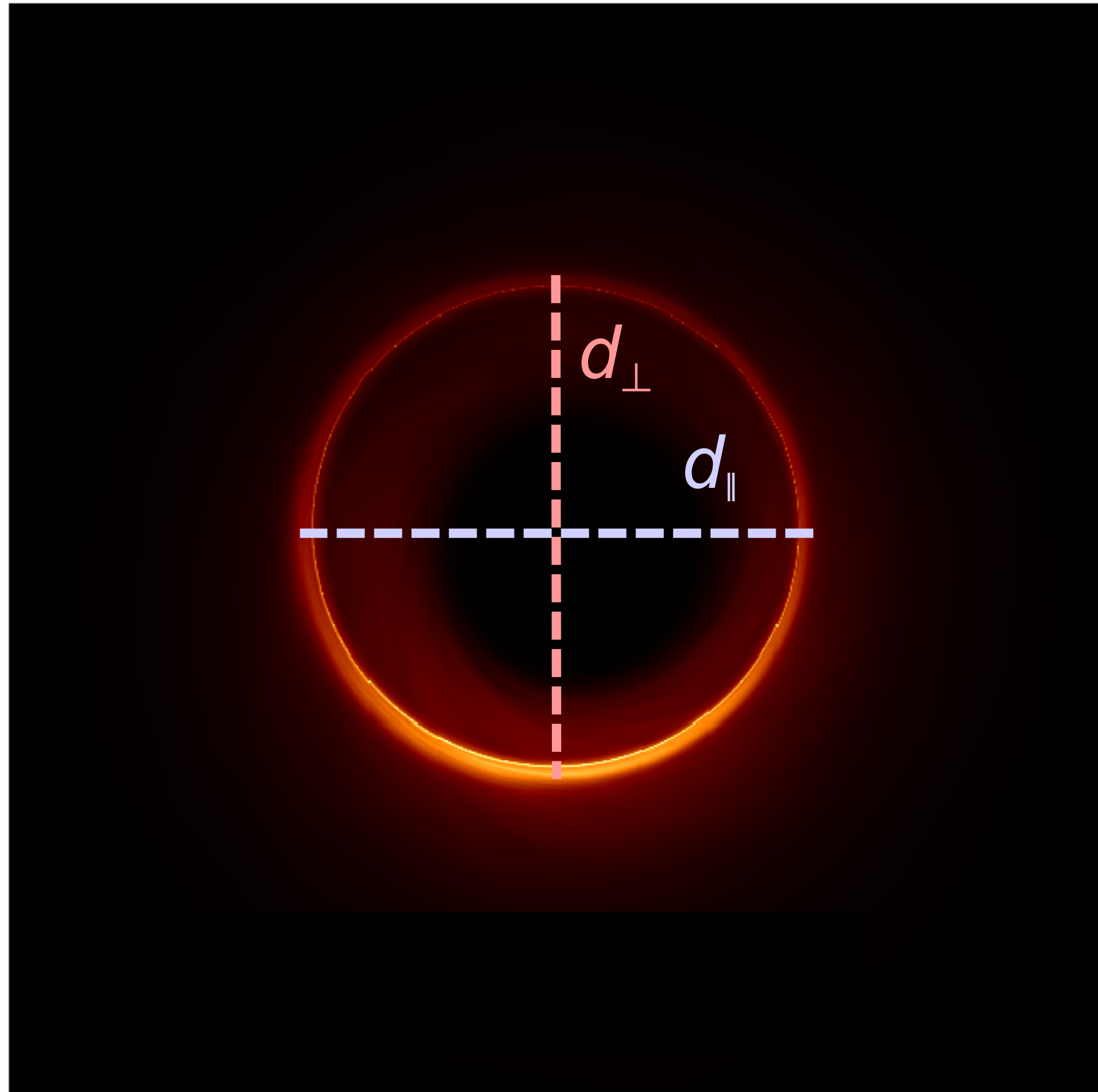


Why Space? Long Baselines Isolate the Photon Ring!



Baselines accessible from Earth are dominated by the complex $n = 0$ image

Why Space? Long Baselines Isolate the Photon Ring!



Longer ground-space baselines are dominated by the $n = 1$ photon ring

A single long ground-space baseline can measure the photon ring!

The Black Hole Explorer

BHEX will achieve the highest angular resolution in history and would reveal a black hole's "photon ring" for the first time

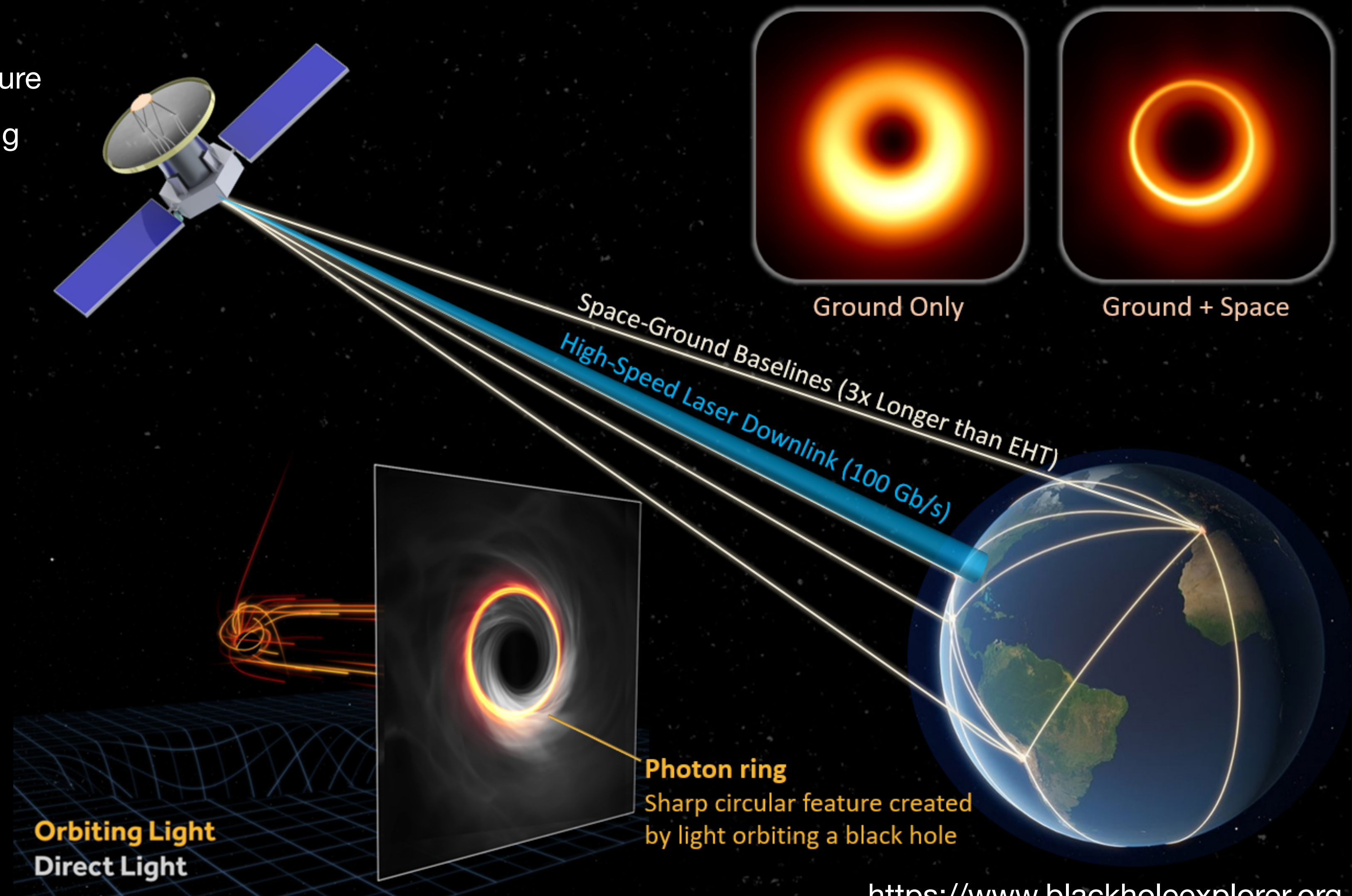
- First direct measurement of a black hole's spin
- Opportunity to study *hundreds* of black holes
- Leverages billions of dollars of ground infrastructure
- Explosion of community interest in the photon ring
- Targeting a 2025 SMEX proposal

Science Goals

- Discover a black hole's photon ring
- Make direct measurements of a black hole's mass and spin
- Reveal the shadows of *hundreds* of supermassive black holes

Necessary Parameters for Space-VLBI

- High radio frequencies (>100 GHz)
- Orbits of at least $\sim 30,000$ km
- High-speed (~ 100 Gb/s) downlink



- We now have the images of two black holes, in M87* and SgrA*, but this only marks the beginning of a new era in the study of black holes.
- **EHT+ngEHT+BHEX**. Revolutionary instruments for the next decade to address the most important questions related to black hole physics, relativistic jets, and AGN.

Key science goals:

- GR tests of the Kerr metric at horizon scales
- Energy extraction from black holes. We'll make movies of black holes!
- Accretion (flares, magnetic field dynamics, precision orbits) and jet launching.
- Black hole demographics, supermassive binary black holes and GW connection, spin measurements
- MWL connection to understand high energy emission (incl. neutrinos) from AGN
- AGN populations (radio power vs. BH spin and accretion rate)