Expanding the Event Horizon Telescope into Space
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Abstract

With very-long-baseline interferometry, the current Event Horizon Telescope is able to effectively form a radio telescope the size of Earth’s diameter and achieve resolution down to 20 μas. Expanding the array to space provides a way to increase resolution. We sample a multitude of satellites that span the orbital parameter space – height, inclination, and right ascension – and then, using quantities that define the quality of an orbit, try to uncover 1) the optimal orientation for a satellite pair and 2) the number of satellites required to achieve resolution of 2 μas across a wide variety of black hole targets. In the end, we find that with 2 satellites we are able to resolve 2 μas, but the addition of a 3rd and 4th increases fidelity and possible sources across the sky.

Background

- The Event Horizon Telescope (EHT) is an array of telescopes using very-long-baseline interferometry (VLBI) to study black hole shadows at a frequency of 230 GHz
- With a ground-based array, the EHT’s resolution is limited to 20 μas, restricting horizon-scale observations to M87 and Sagittarius A* (Sgr A*)
- To expand the EHT’s angular resolution and observation targets down to shadow diameters of 2 μas at 230 GHz, multiple satellites above Geostationary orbit (GEO) are needed

Motivation

- While M87 and Sgr A* are scientifically significant, a larger sample of sources is needed to understand the physical drivers behind black hole activity
- To expand the EHT’s angular resolution and observation targets down to shadow diameters of 2 μas at 230 GHz, multiple satellites above Geostationary orbit (GEO) are needed

Goals

To achieve a resolution of 2 μas at 230 GHz ...

- How many satellites are needed?
- What are the orbital characteristics of those satellites?

Method

1. Generate satellites that sample all orbital characteristics
   Rotations per Day (height), inclination, right ascension node
2. Define parameters to test array’s performance:
   - uv-plane filling: higher filling → better image fidelity
   - beam circularity: more circular beam → symmetric sampling
   - beam size: smaller beam → more resolution
3. Generate all possible arrays first observing M87

Double Satellite Arrays: Orbital Characteristics

- When looking at M87, a polar satellite plus a satellite in either prograde or retrograde orbit results in the greatest filling factor
- Given a polar satellite paired with either a prograde or retrograde element, the arrays with the most filling tend to be separated by between 30 and 60 degrees in inclination

Double Satellite Arrays: Resolution

- With increasing height, beam size (resolution) decreases but uv-plane filling also decreases, reducing image fidelity
- A pair of 2 satellites at around an orbital height of ~10 Earth Radii can fully resolve a 2 μas shadow

Adding Satellites to Double Array

- Adding a 3rd satellite greatly improves the ring resolution from the double array
- But a 4th satellite increases filling at smaller baselines and improves the general beam size and beam circularity across the sky

Imaging Performance Across the Sky

- Not much difference between images at small angular sizes and limits of resolution (M81)
- A 4-satellite array sharply resolves larger structure (M104) and the shadow (IC 1459) across multiple sources

Conclusions

Orientation:

- A 2-satellite array consisting of a polar satellite with either a prograde or retrograde element tends to result in the greatest filling factor for M87
- A 2-satellite pair at inclination separations of 30 to 60 degrees results in a higher filling factor than a pair that is orthogonal when looking at or near M87

Few targets lie on the poles, making this a viable configuration for multiple sources

Number:

- Adding 3 satellites allows for resolution of near 2 μas across multiple targets
- Adding 4 satellites increases filling and the fineness of the resolved photon ring, and improves beam characteristics across the sky

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