Event Horizon Telescope
- expansion plans

Maciek Wielgus
on behalf of the EHT Collaboration

Black Hole Initiative, Harvard University
Smithsonian Astrophysical Observatory

NEROC, Haystack
1 November 2019
Event Horizon Telescope: the Team

Nijmegen, Netherlands, November 2018

- over 200 scientists
- contributors from 18 countries
- over 60 institutions
Results so far: M87 (EHTC+)

Nearby LLAGN

Redshift: 0.00428 (53 mln ly)

BH mass: $6.5 \times 10^9 \, M_{\odot}$

EHT resolution: 400 au $\sim$ 3 Rs

Kim et al. 2018

Event Horizon Telescope
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Nearby LLAGN

Kim et al. 2018
Results so far: M87 (EHTC+)

Nearby LLAGN

ψ_{im} = 165°
ψ_{jet} = 288°

ψ_{sim} = 170°
ψ_{bh} = 288°
Results so far: M87 (EHTC+)

Nearby LLAGN

EHT published so far on about 5% of the 2017 campaign data, MUCH MORE to come!
Event Horizon Telescope

EHT 2019. Paper II. Instrument

Maciek Wielgus

NEROC, Haystack, 1 November 2019
Improvement considerations

1. **Coverage:**
   
   N telescopes gives N(N-1)/2 visibility measurements
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2. **Dynamic range:**
   
   Improves with number of baselines
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   Improves with shorter wavelength / longer baseline
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   N telescopes gives $\frac{N(N-1)}{2}$ visibility measurements

2. **Dynamic range:**
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3. **Resolution:**
   Improves with shorter wavelength / longer baseline

4. **Sensitivity:**
   Improves with bandwidth
Improvement considerations

1. Coverage:
   N telescopes gives \( N(N-1)/2 \) visibility measurements

2. Dynamic range:
   Improves with number of baselines

3. Resolution:
   Improves with shorter wavelength / longer baseline

4. Sensitivity:
   Improves with bandwidth

5. Speed of the aperture synthesis:
   Can be improved with space VLBI
Improvement considerations

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5. Speed of the aperture synthesis:
   Can be improved with space VLBI

6. Algorithmic improvements:
   Will reduce systematics and increase sensitivity
Astro2020 APC White Paper

Studying Black Holes on Horizon Scales with VLBI Ground Arrays

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Astro2020 APC White Paper

Studying black holes on horizon scales with space-VLBI

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Astro2020 APC White Paper

Extremely long baseline interferometry with Origins Space Telescope

DOMINIC W. PESCE\textsuperscript{1,2}, KARI HAWORTH\textsuperscript{1}, GARY J. MELNICK\textsuperscript{1}, LINDY BLACKBURN\textsuperscript{1,2}, MACIEK WIELGUS\textsuperscript{1,2}, MICHAEL D. JOHNSON\textsuperscript{1,2}, ALEXANDER RAYMOND\textsuperscript{1,2}, JONATHAN WEINTROUB\textsuperscript{1}, DANIEL C. M. PALUMBO\textsuperscript{1,2}, SHEPERD S. DOELEMAN\textsuperscript{1,2}, DAVID J. JAMES\textsuperscript{1,2}

Abstract: Operating $1.5 \times 10^6$ km from Earth at the Sun-Earth L2 Lagrange point, the Origins Space Telescope equipped with a slightly modified version of its HERO heterodyne instrument could function as a uniquely valuable node in a VLBI network. The unprecedented angular resolution resulting from the combination of Origins with existing ground-based millimeter/submillimeter telescope arrays would increase the number of spatially resolvable black holes by a factor of $10^6$, permit the study of these black holes across all of cosmic history, and enable new tests of general relativity by unveiling the photon ring substructure in the nearest black holes.
Array expansion

Studying Black Holes on Horizon Scales with VLBI Ground Arrays
Array expansion

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NEROC, Haystack, 1 November 2019
Array expansion

Studying Black Holes on Horizon Scales with VLBI Ground Arrays
Array expansion + dual frequency

Studying Black Holes on Horizon Scales with VLBI Ground Arrays
Dynamic range improvement


Studying Black Holes on Horizon Scales with VLBI Ground Arrays

Maciek Wielgus

NEROC, Haystack, 1 November 2019
Expansion of the EHT ground array

- multiple new sites with 6-12 m dishes,
- upgrading powerful anchor stations, able to connect weaker array elements,
- developing double-frequency technology,
- expanding bandwidth, possibly to 256 Gbps
- data transport developments
Adding a LEO dish: aperture synthesis speed

Studying black holes on horizon scales with space-VLBI

Maciek Wielgus
NEROC, Haystack, 1 November 2019
Adding a LEO dish: aperture synthesis speed

Observing rapidly varying Sgr A*

Studying black holes on horizon scales with space-VLBI

45min of observations

Maciek Wielgus
NEROC, Haystack, 1 November 2019
More shadows with higher resolution!

Studying black holes on horizon scales with space-VLBI
EHT expansion with a LEO antenna

- single 3-4 m dish on the low Earth orbit,
- strong anchor stations (ALMA, NOEMA, LMT) allow for small orbiting dish,
- 2 polarizations x 2 bands x 8 GHz,
- enabling observations in up to 690 GHz frequency with detections to limited number of suitable ground stations (ALMA, SPT),
- technical developments on digital processing system and local oscillator (e.g. high-performance oven-controlled quartz crystal oscillators),
- solid state recorders,
- laser downlink (hundreds Gbps),
- possibly computationally challenging fringe fitting with imperfect position information

Studying black holes on horizon scales with space-VLBI
VLBI on extreme space baselines

Extremely long baseline interferometry with Origins Space Telescope

**Johnson et al. ArXiv: 1907.04329**
Universal interferometric signatures of as black hole’s photon ring
VLBI on extreme space baselines

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Extremely long baseline interferometry with Origins Space Telescope

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Universal interferometric signatures of as black hole’s photon ring
Thanks!

Also check out
Lindy Blackburn’s poster
on the future of the EHT