Microlensing Black Hole Shadows

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In collaboration with Prof. Joe Silk, IAP, Paris, France

Frontiers in Particle Physics 2024

Centre for High Energy Physics (CHEP), IISc, Bengaluru, India

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Research Interest: Gravitational Lensing, Compact Objects, Exoplanets, Dark Matter, Data Analysis

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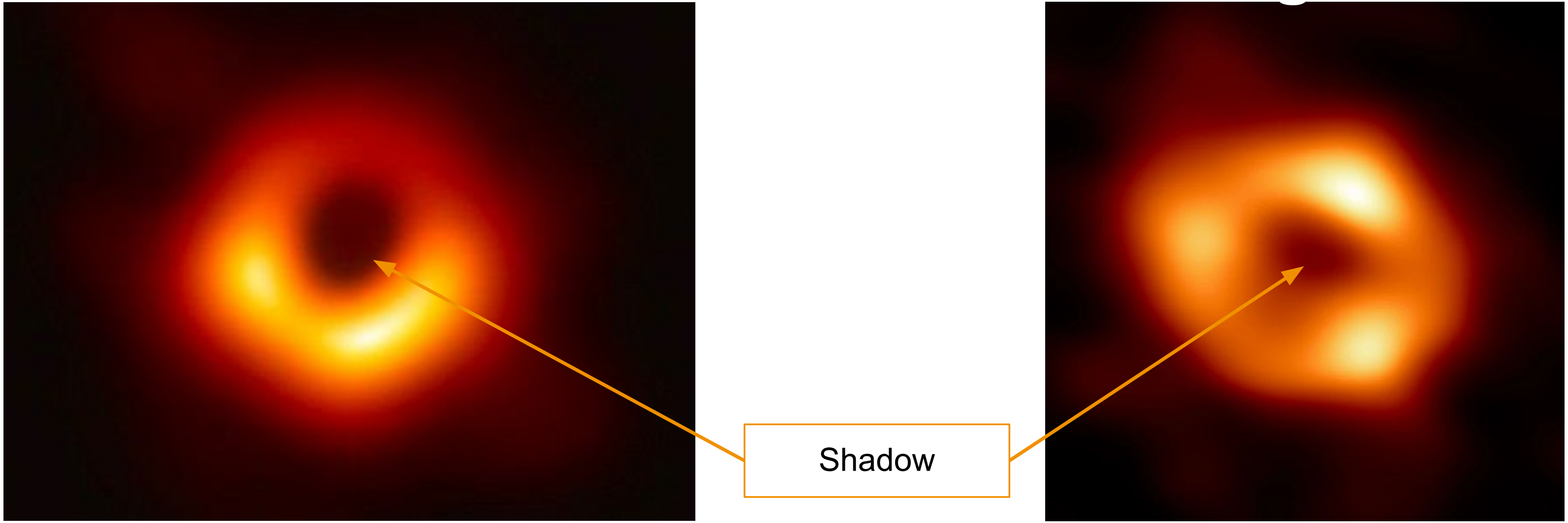
Motivation

Black Hole Images

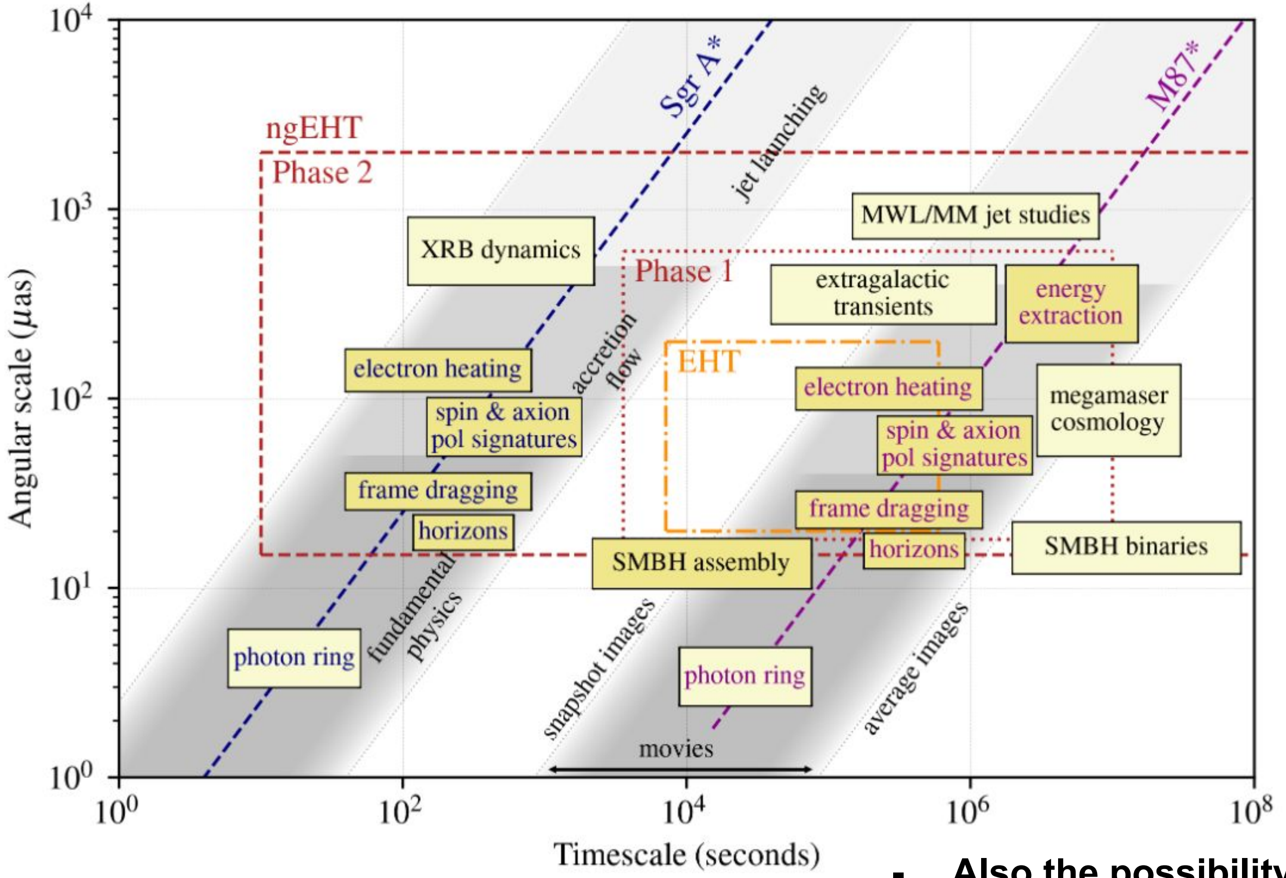


M87 (2019)

Sgr A* (2022)

PC: Event Horizon Telescope Collaboration

What is next?

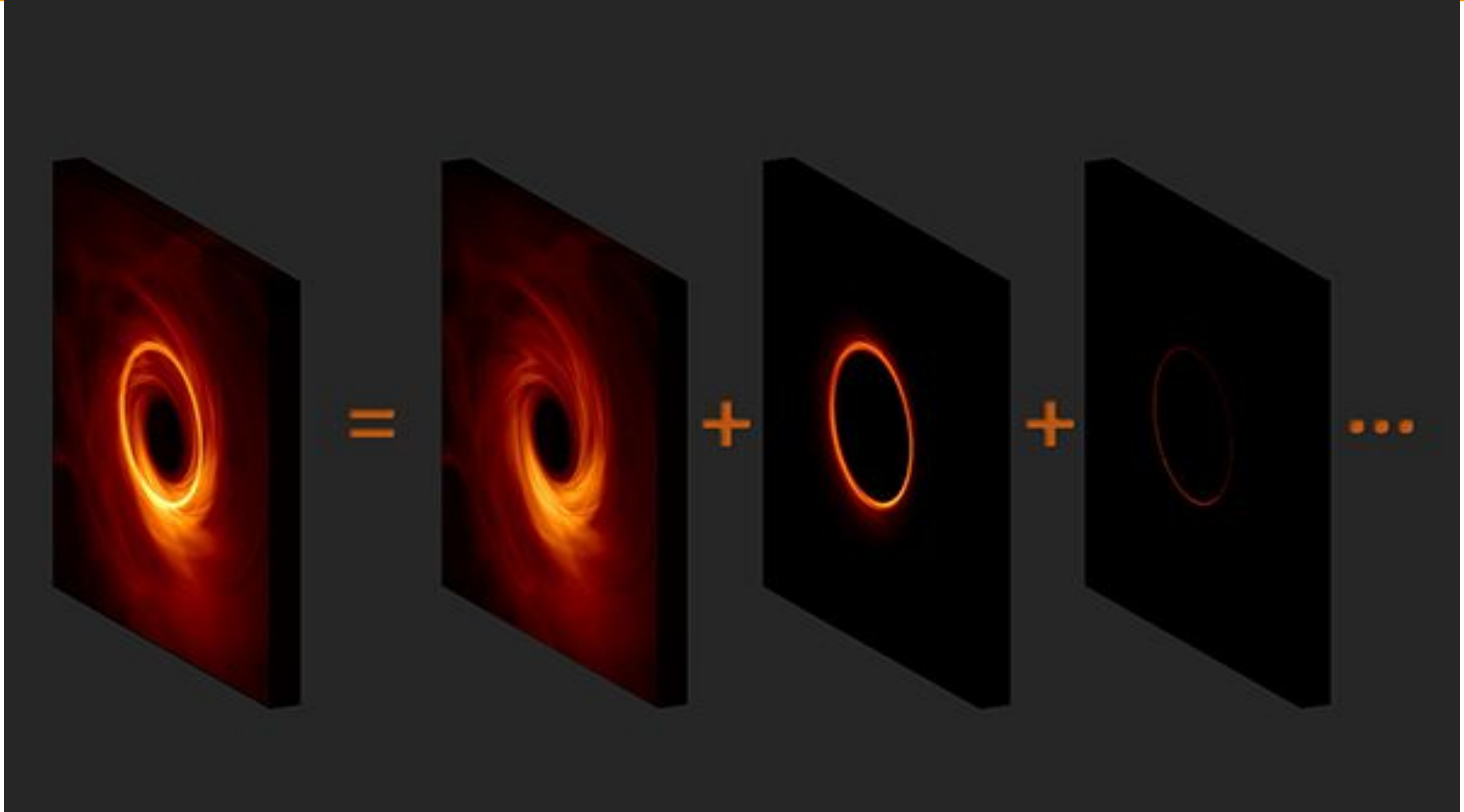


Movie of the shadow with much sharper resolution

Ref: Johnson et al. 2023

- **Also the possibility of putting space-based baselines (Moon, Earth-Sun 2nd Lagrange point)**
- **Other BH shadows (10^6)**

BH shadow depends on accretion disk & BH characteristics



Ref: Michael D. Johnson (CfA) and George Wong (UIUC)

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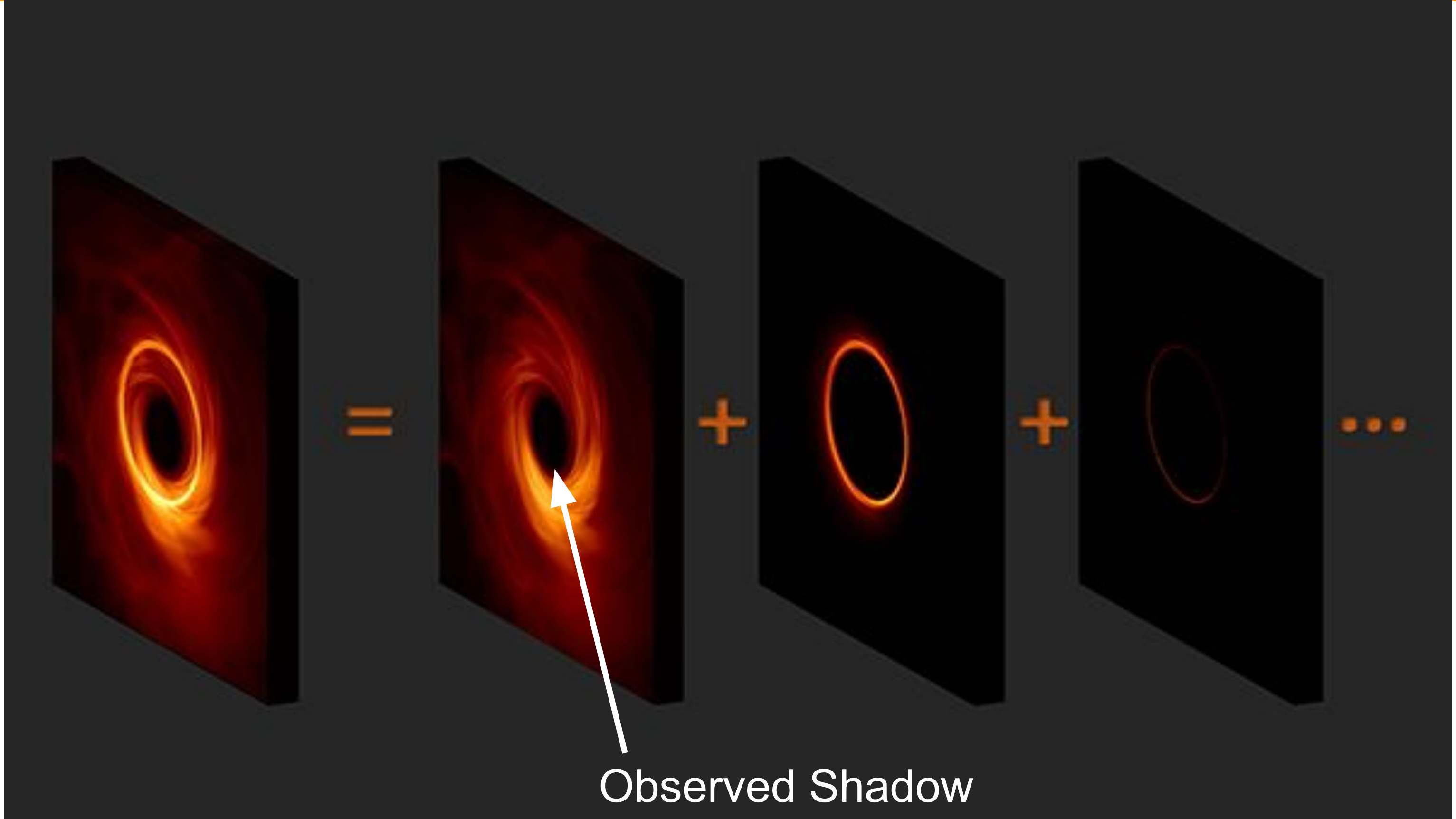

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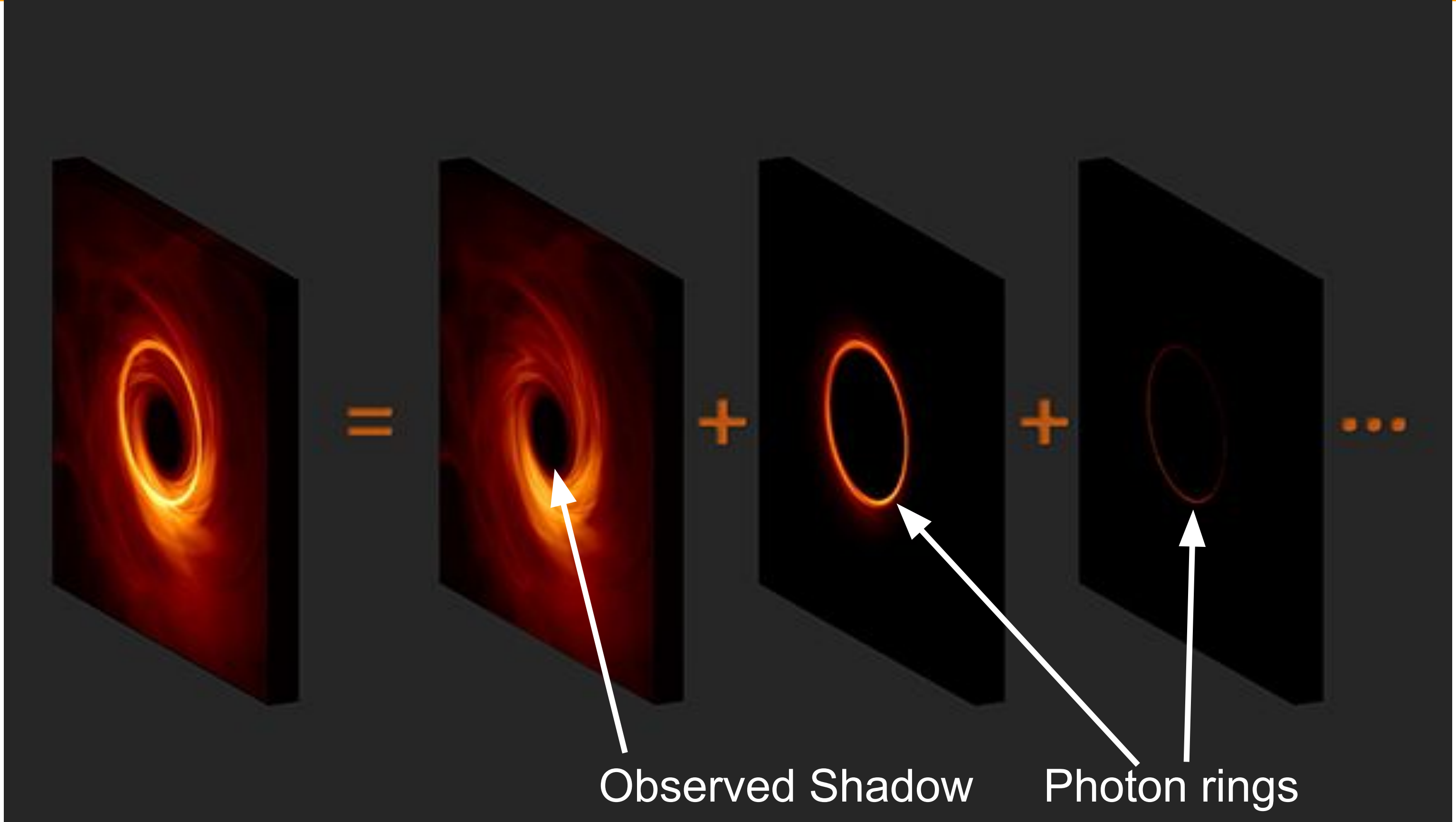

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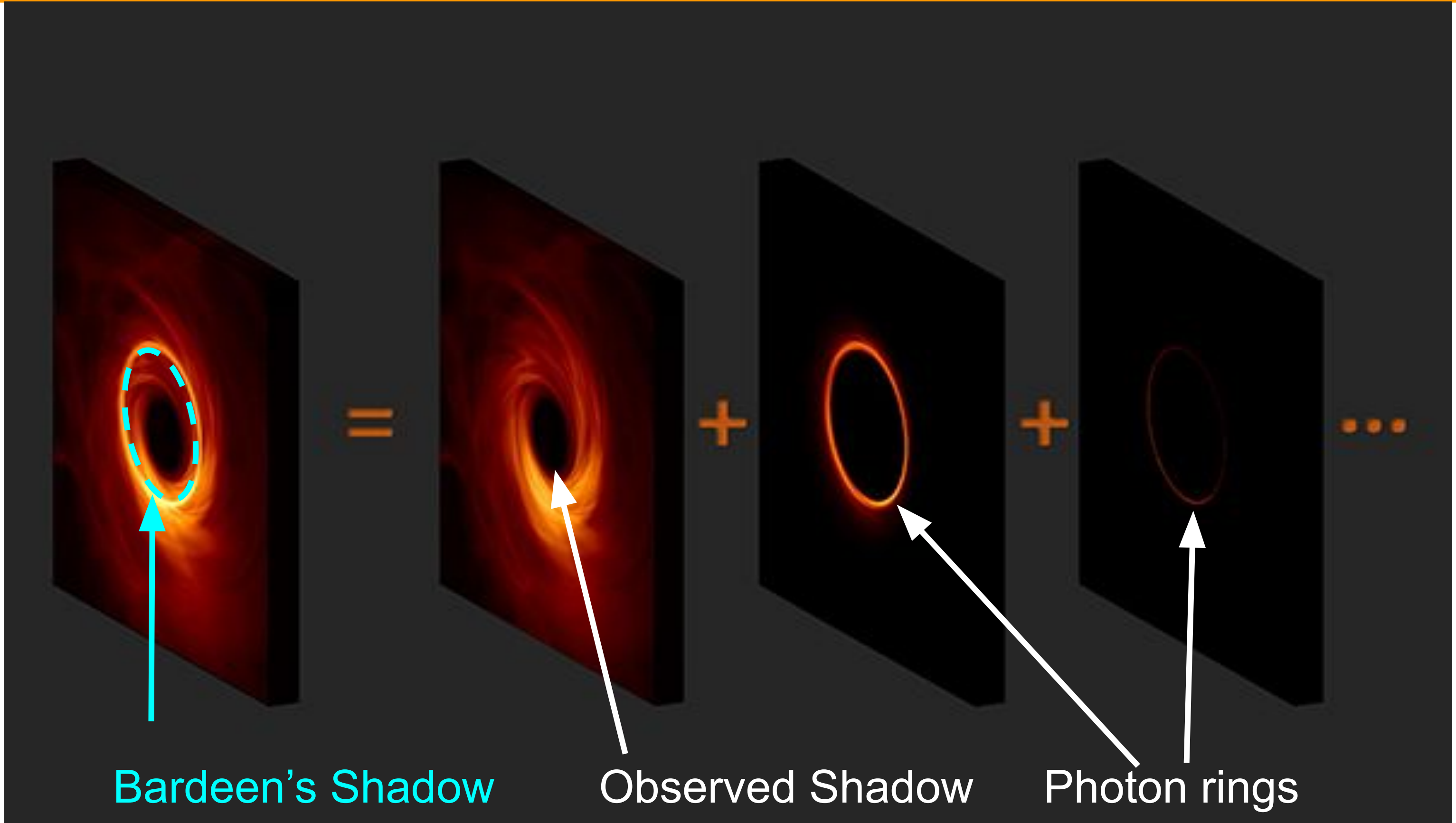

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Problem Statement

Another lens positioned between us and the shadow

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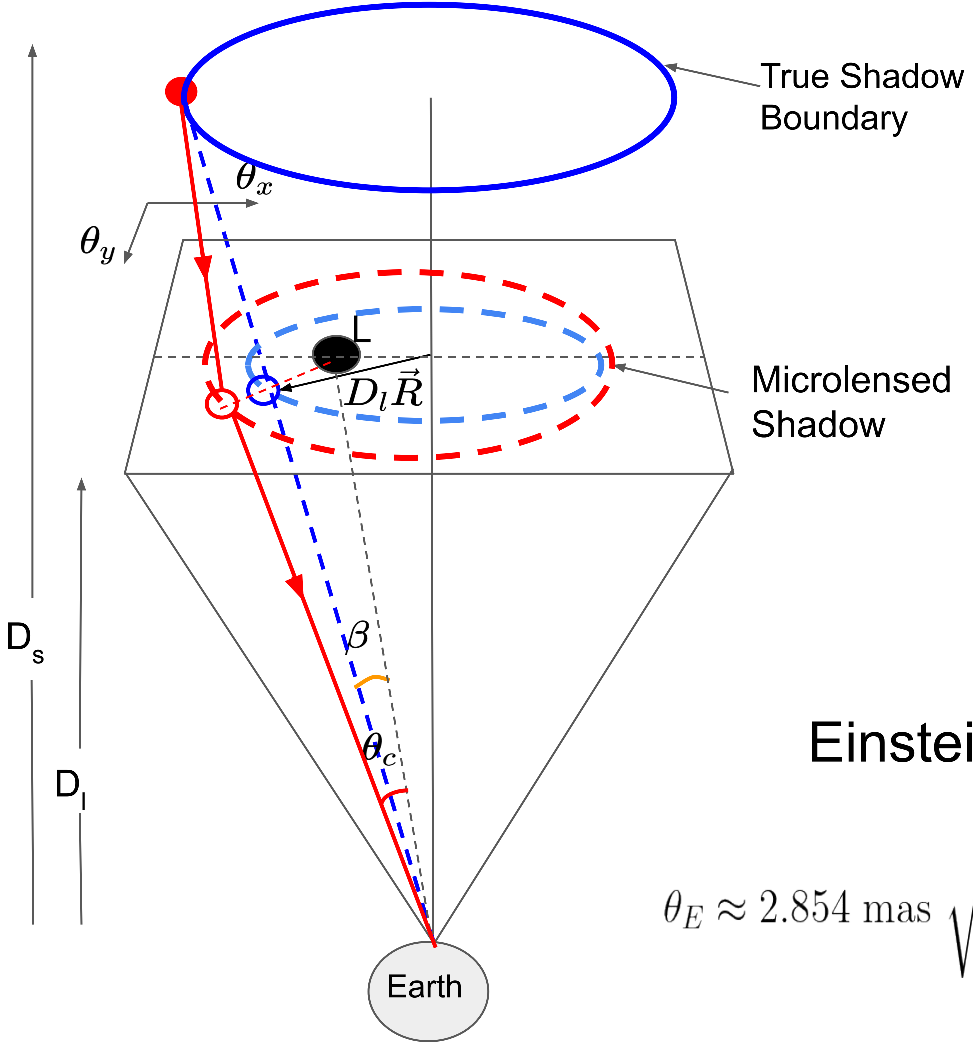
- What happens to the shape of a black hole shadow when a compact object (gravitational lens) passes in the foreground of the shadow?

- How plausible it is to observe the phenomenon in **Sgr A* shadow**?

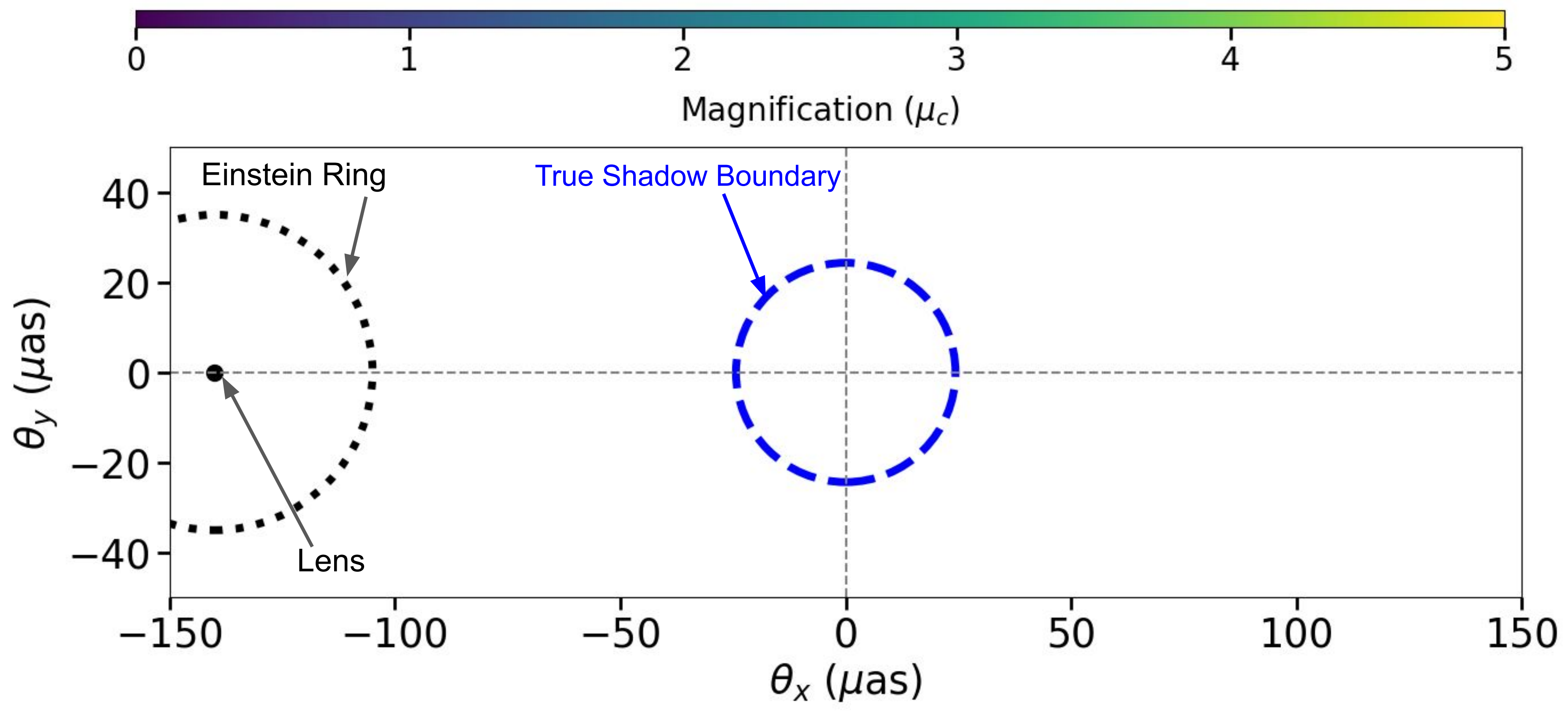
Microlensing BH shadow



Einstein Angle

$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ \mathrm{M}_\odot}\frac{10 \text{ kpc}}{D_s}\left(\frac{D_s}{D_l}-1\right)}$$

Microlensing Black Hole Shadow



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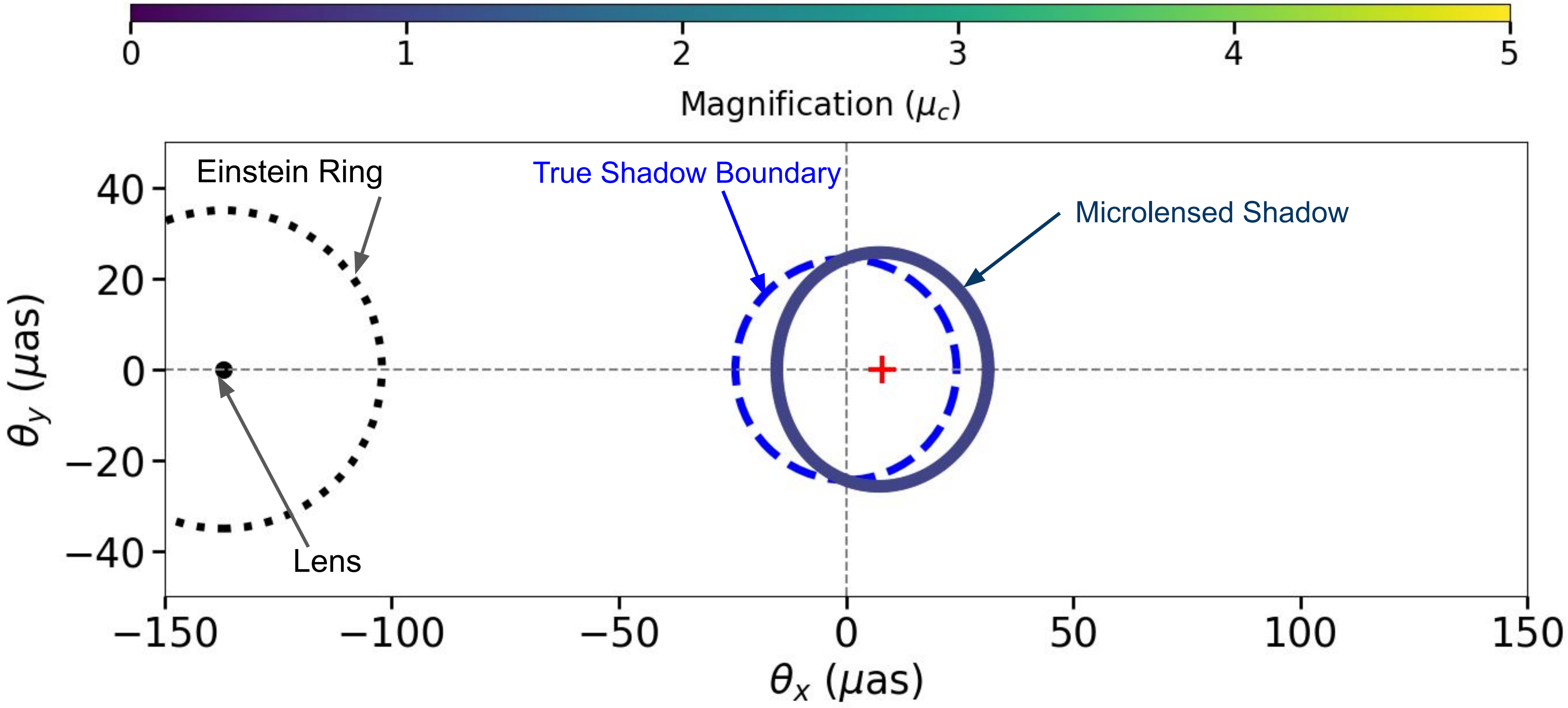
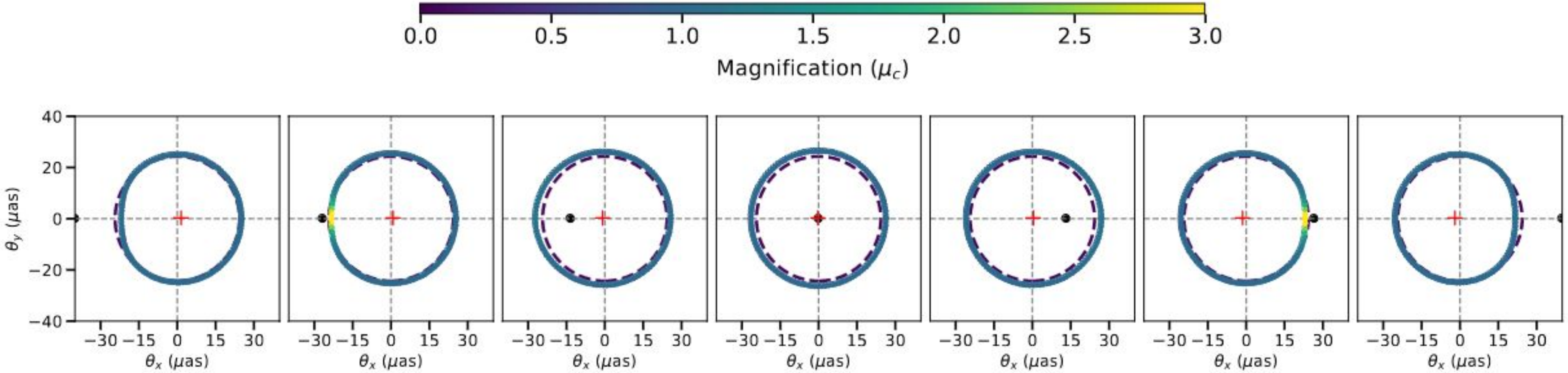


Microlensing Black Hole Shadow: Sgr A*



Einstein Angle = 7.8 micro-arcsec

M = 1 Solar Mass, r = 0.5 pc

Derived Observables

1. Shift in the center

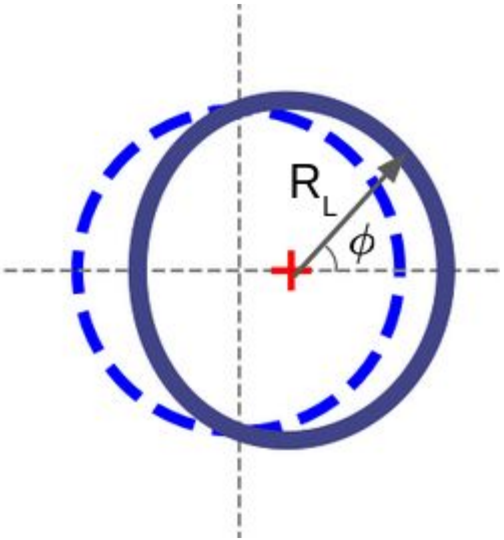
$$\overrightarrow{OC} \equiv \frac{\overrightarrow{OI}_c(\pi) + \overrightarrow{OI}_c(0)}{2}.$$

2. Magnification of the size

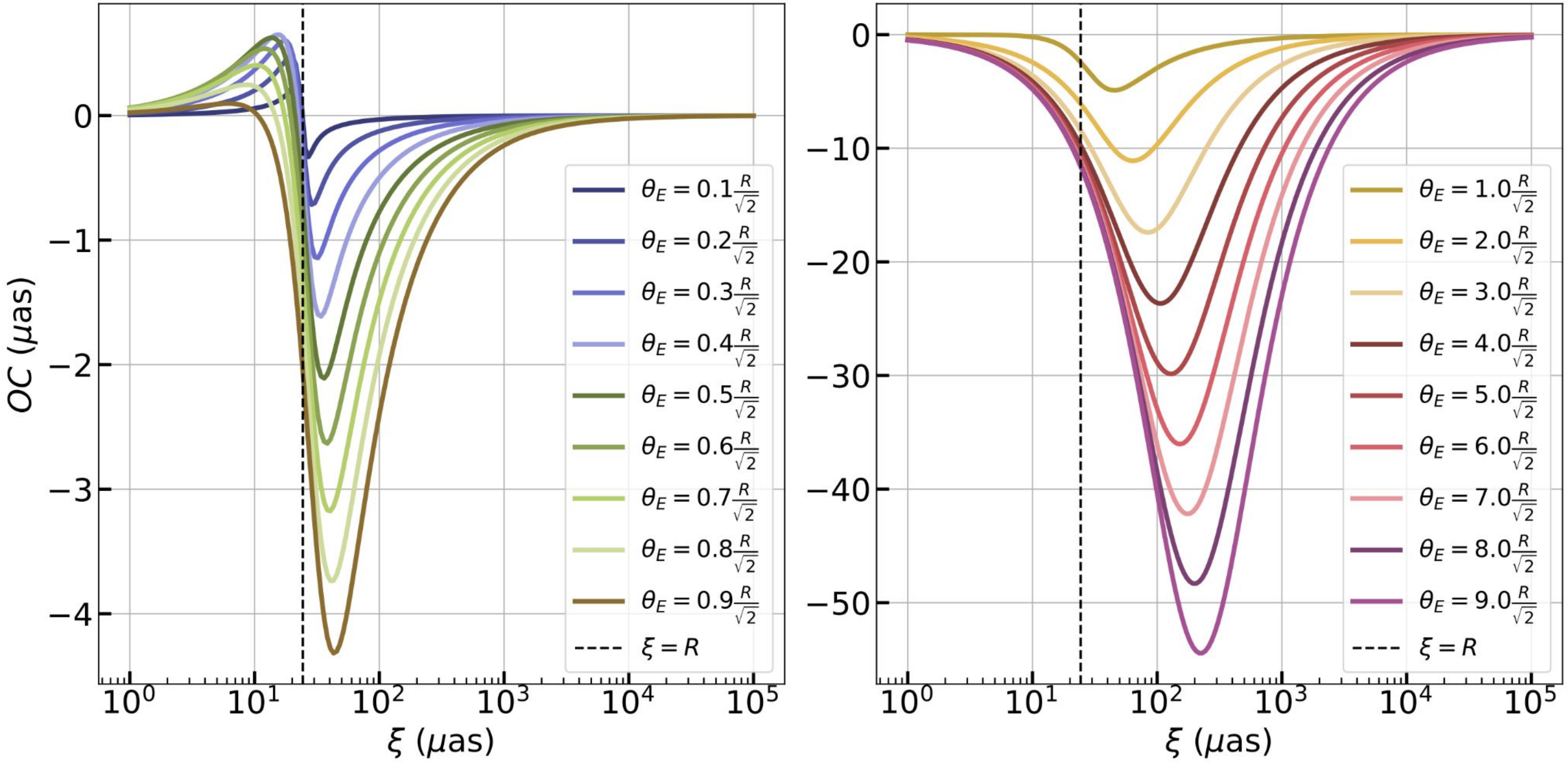
$$\langle R_L \rangle = \frac{1}{2\pi} \int_0^{2\pi} |\vec{R}_L(\phi)| d\phi.$$

3. Asymmetric Shape

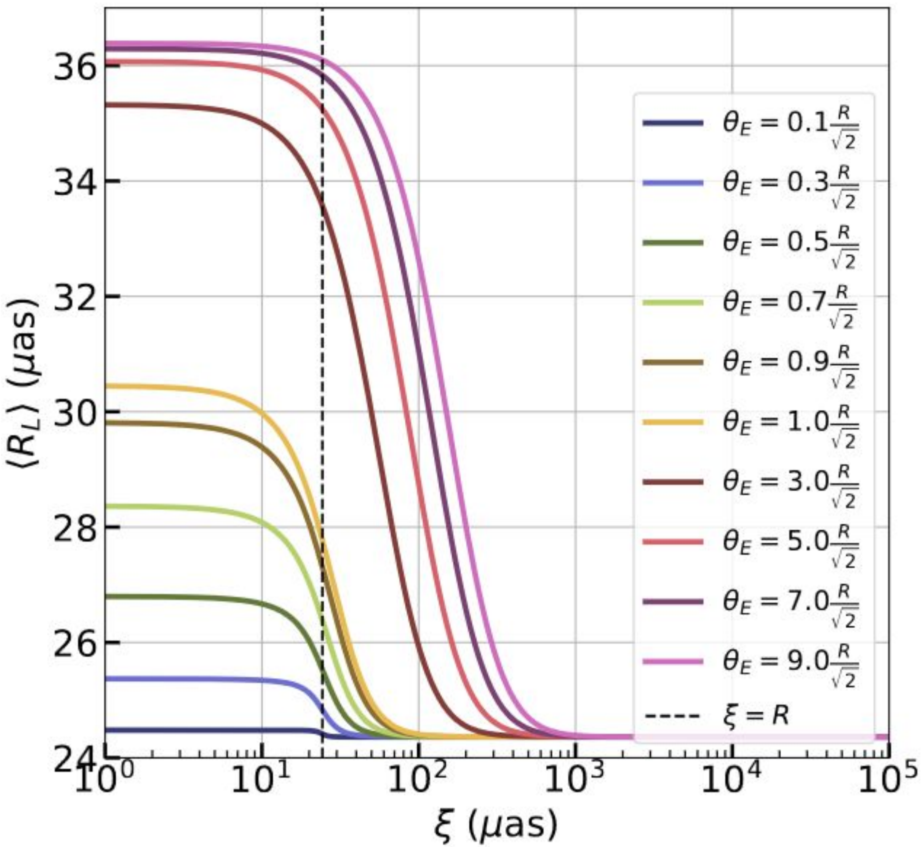
$$A = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (R_L(\phi)^2 - \langle R_L \rangle^2) d\phi}.$$



Shift in the center of the shadow Sgr A*

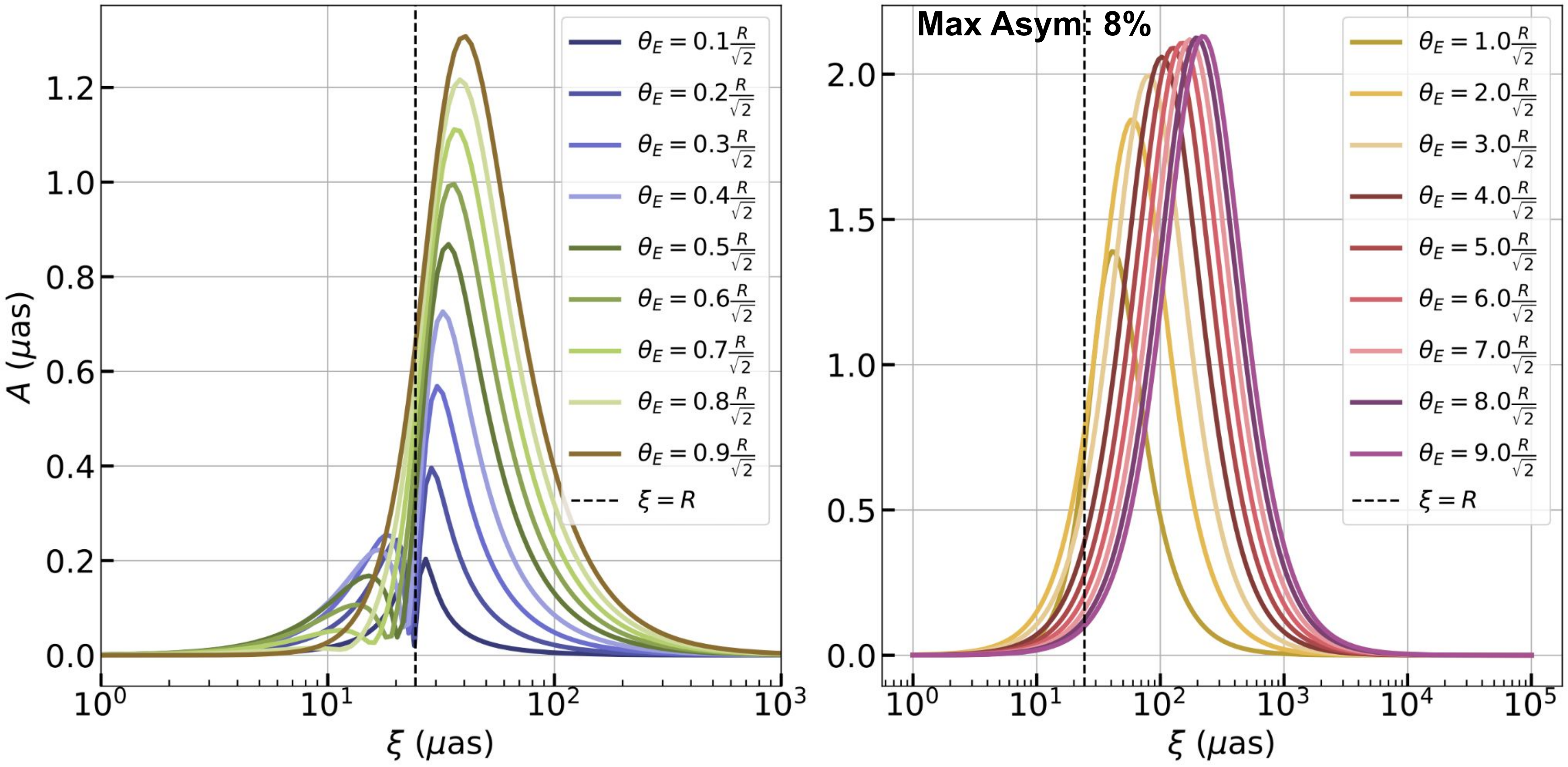


Size of the shadow



Max Enhancement:
50% of the true size

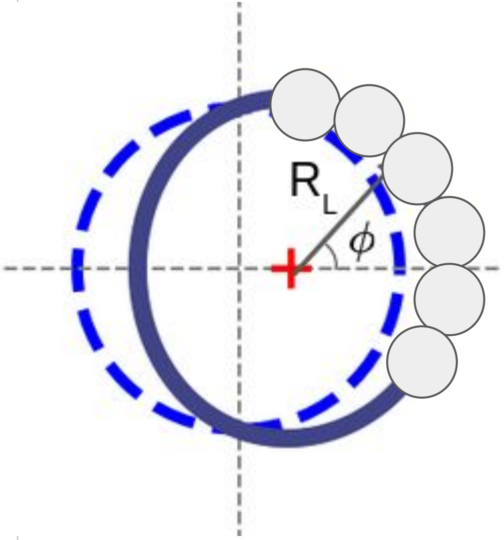
Asymmetry in the shadow shape Sgr A*



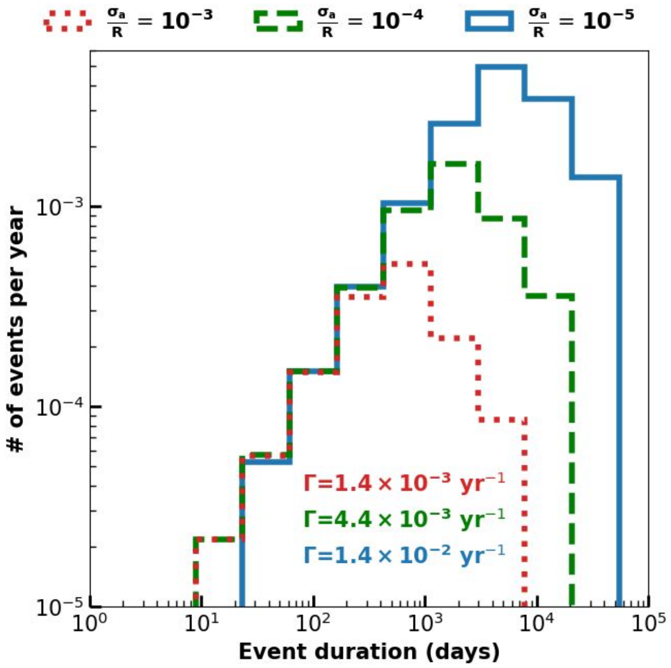
Detectability of the microlensed shadow of Sgr A*

Estimating the uncertainty in the radius

D (km)	θ_{res} (μas)	N	# of epochs	σ_a (μas)	% error
$\lambda = 1.3$ mm					
10,700 (Earth)	25.06	1.9	1	17.98	73.8
300,000 (Earth-Moon)	0.89	54.5	1	0.121	0.50
1,500,000 (Earth-L_2)	0.18	272.4	1	0.011	0.04
$\lambda = 0.5$ mm					
10,700 (Earth)	9.64	5.1	1	4.288	17.61
300,000 (Earth-Moon)	0.34	141.7	1	0.029	0.12
1,500,000 (Earth-L_2)	0.07	708.3	1	0.003	0.01

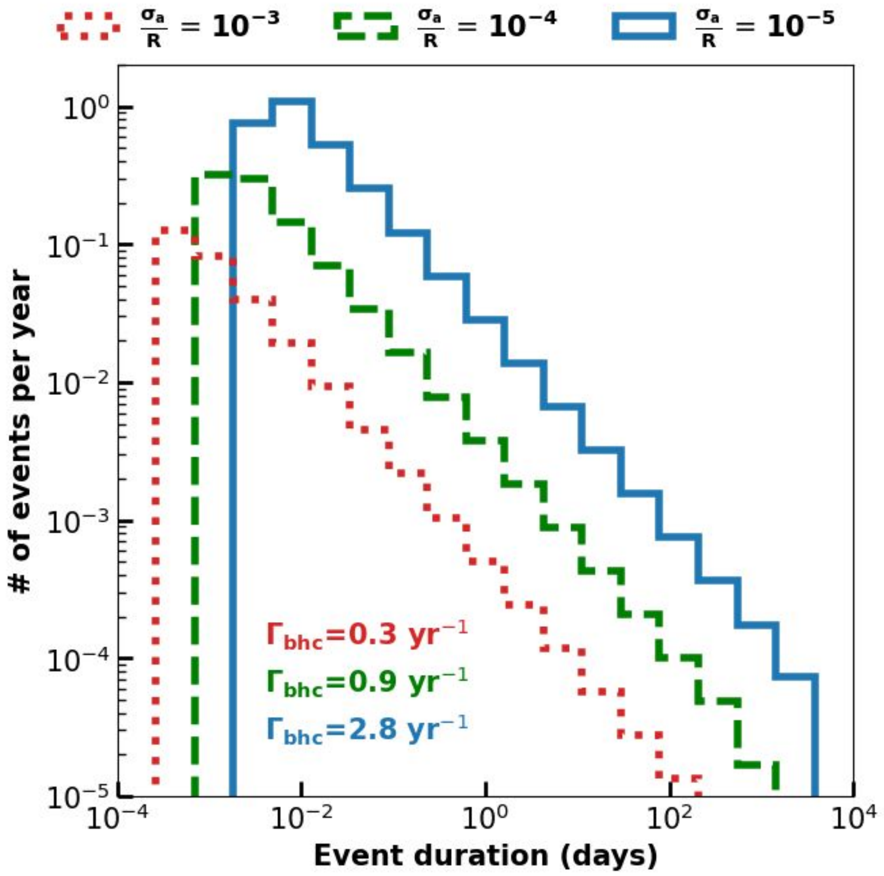


Event rate due to stellar components of Milky Way



$$\Gamma \approx 1.4 \times 10^{-3}\ \mathrm{yr}^{-1} \frac{v}{100\ \mathrm{km/s}} \left(\frac{D_s}{8.2\ \mathrm{kpc}}\right)^{3/2} \sqrt{\frac{1\ \mathrm{M}_\odot}{M} \frac{10^{-3}}{\sigma_a/R}}.$$

Potential enhancement in the event rate



- **20,000 astrophysical black hole cluster within central parsec due to *dynamical friction***

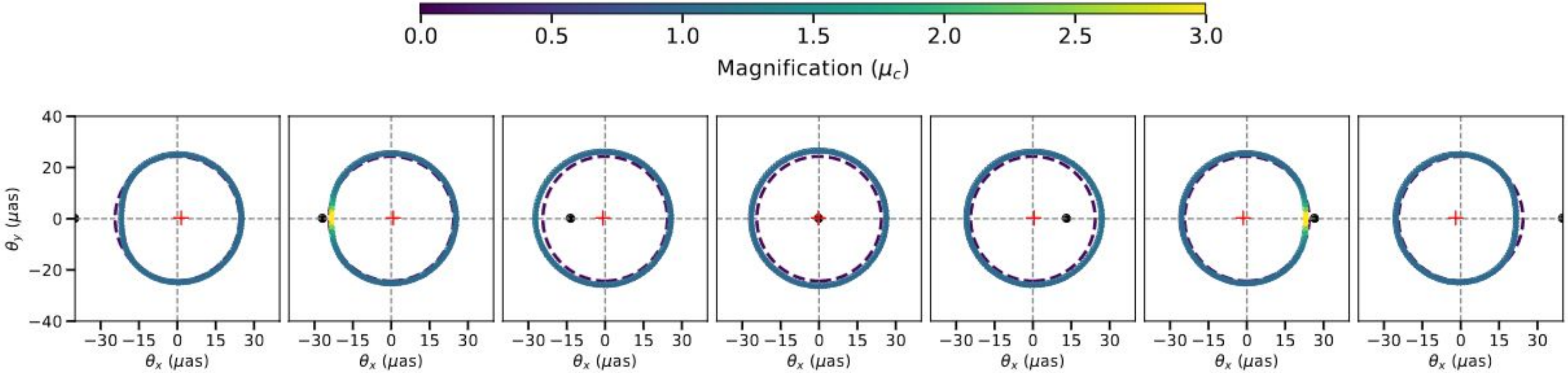
  [Miralda-Escude & Gould 2000]

- **Observational Hint: X-ray density cusp**

  [Hailey et al. 2018]

1. M87?
2. Other shadows?

Summary



- **Asymmetry can reach upto 8% (twice due to the spin of SMBH)**
- Size can become 150% of the true size
- Low event rate (0.0014 per yr) for Sgr A* due to solar mass stellar objects
- Novel technique to probe the compact object population around galactic center
- A standard background effect for the tests of gravity/beyond standard physics

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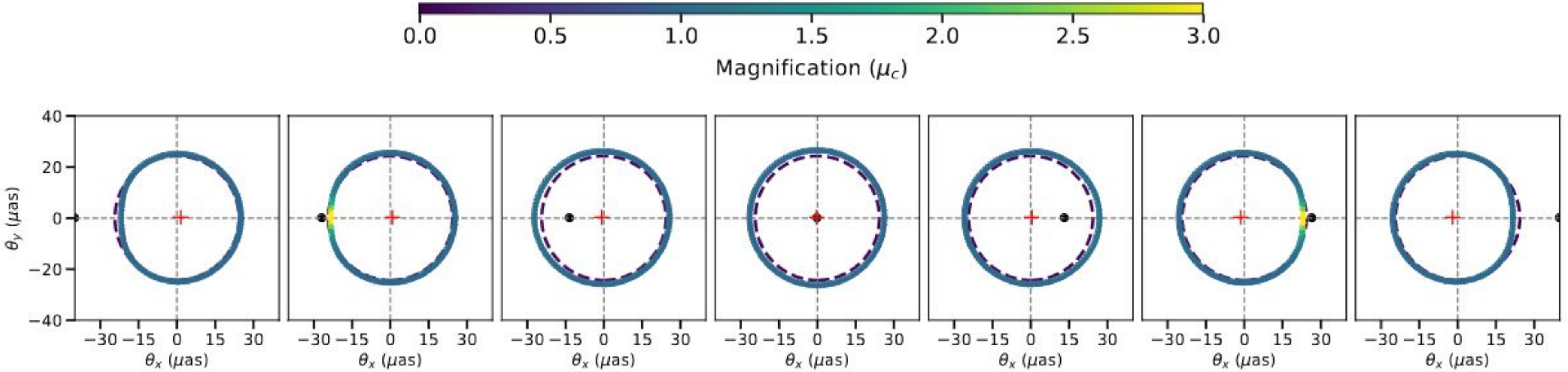

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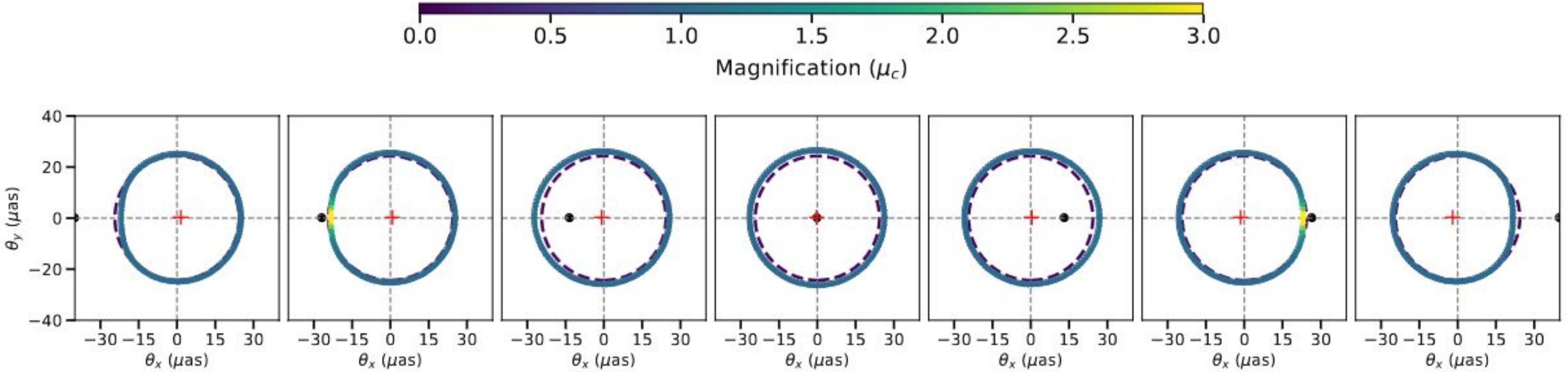

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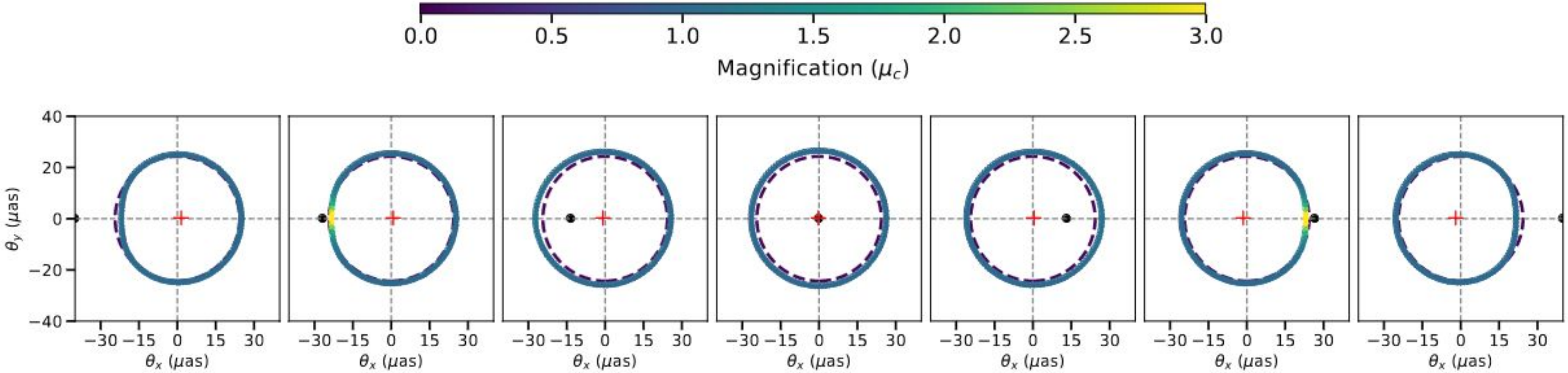

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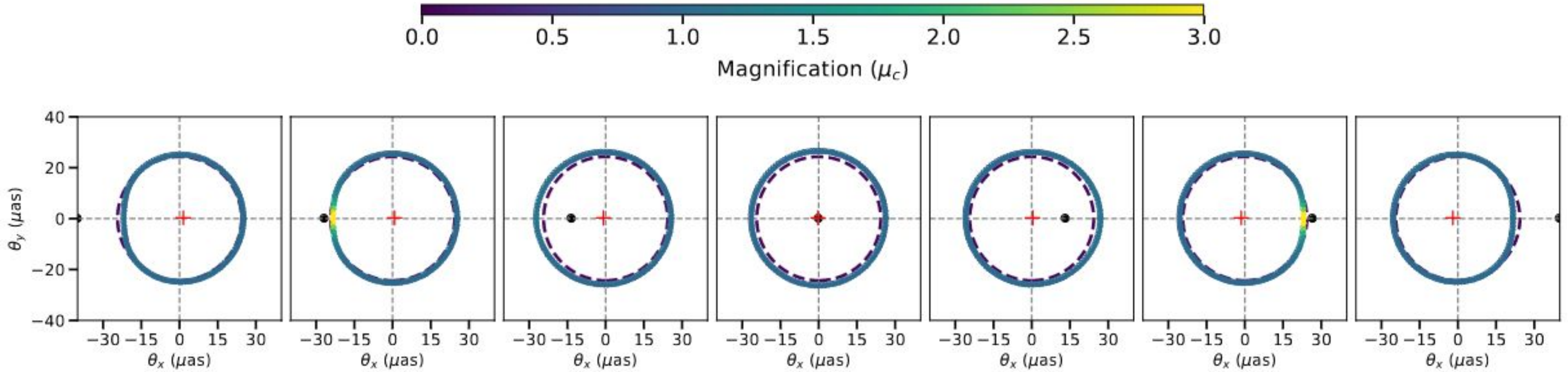

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Thank You!

Backup Slides (EHT)

$$\rho(r) = \frac{5}{16\pi} \frac{N_{\rm bh} M}{r_0^3} \left(\frac{r}{r_0}\right)^{-7/4},$$

$$v(r) = 68.5\ {\rm km/s} \sqrt{\frac{1{\rm pc}}{r}}.$$

$$\Gamma_{\rm bhc} \approx 0.3\ {\rm yr}^{-1} \frac{N_{\rm bh}}{20,000} \left(\frac{1\ {\rm pc}}{r_0}\right)^3 \left(\frac{D_s}{8.2\ {\rm kpc}}\right)^{3/2} \sqrt{\frac{7\ {\rm M}_\odot}{M} \frac{10^{-3}}{\sigma_a / R}}.$$