# Microlensing Black Hole Shadows

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

## 26th Microlensing Conference

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## Himanshu Verma

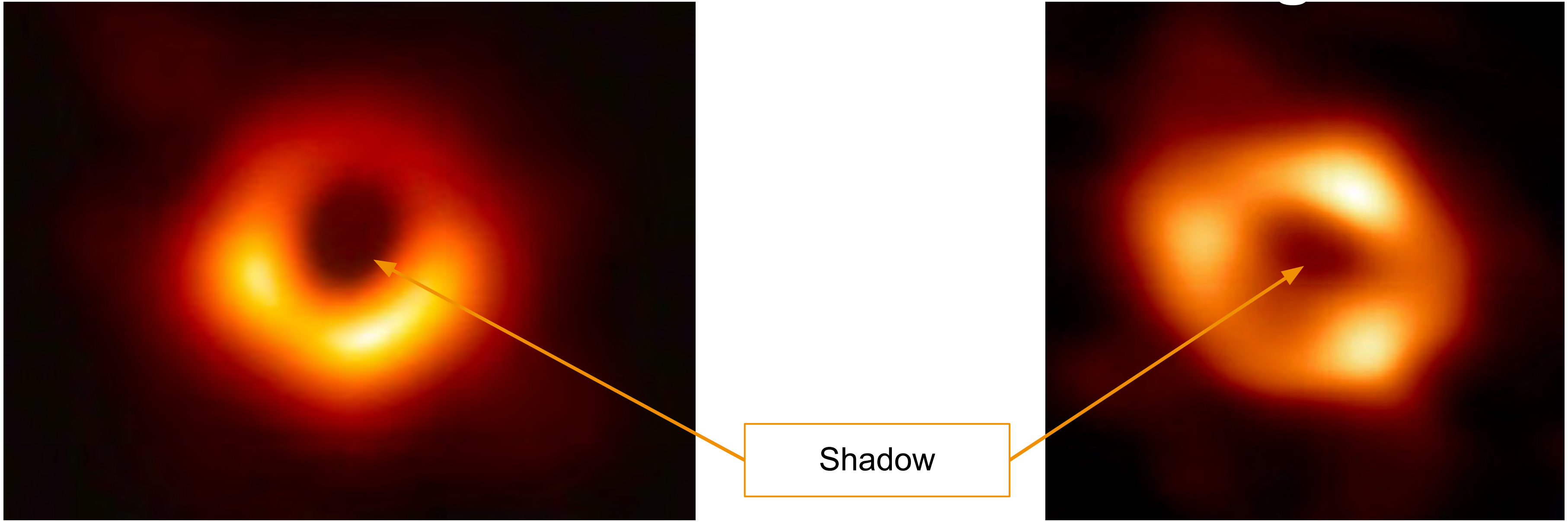
Ph.D. thesis submitted, Department of Physics, IIT Bombay, India

**Thesis Supervisor:** Prof. Vikram Rentala

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

# Motivation

# Black Hole Images




2019

2022

PC: Event Horizon Telescope Collaboration

# BH shadow depends on accretion disk & BH characteristics

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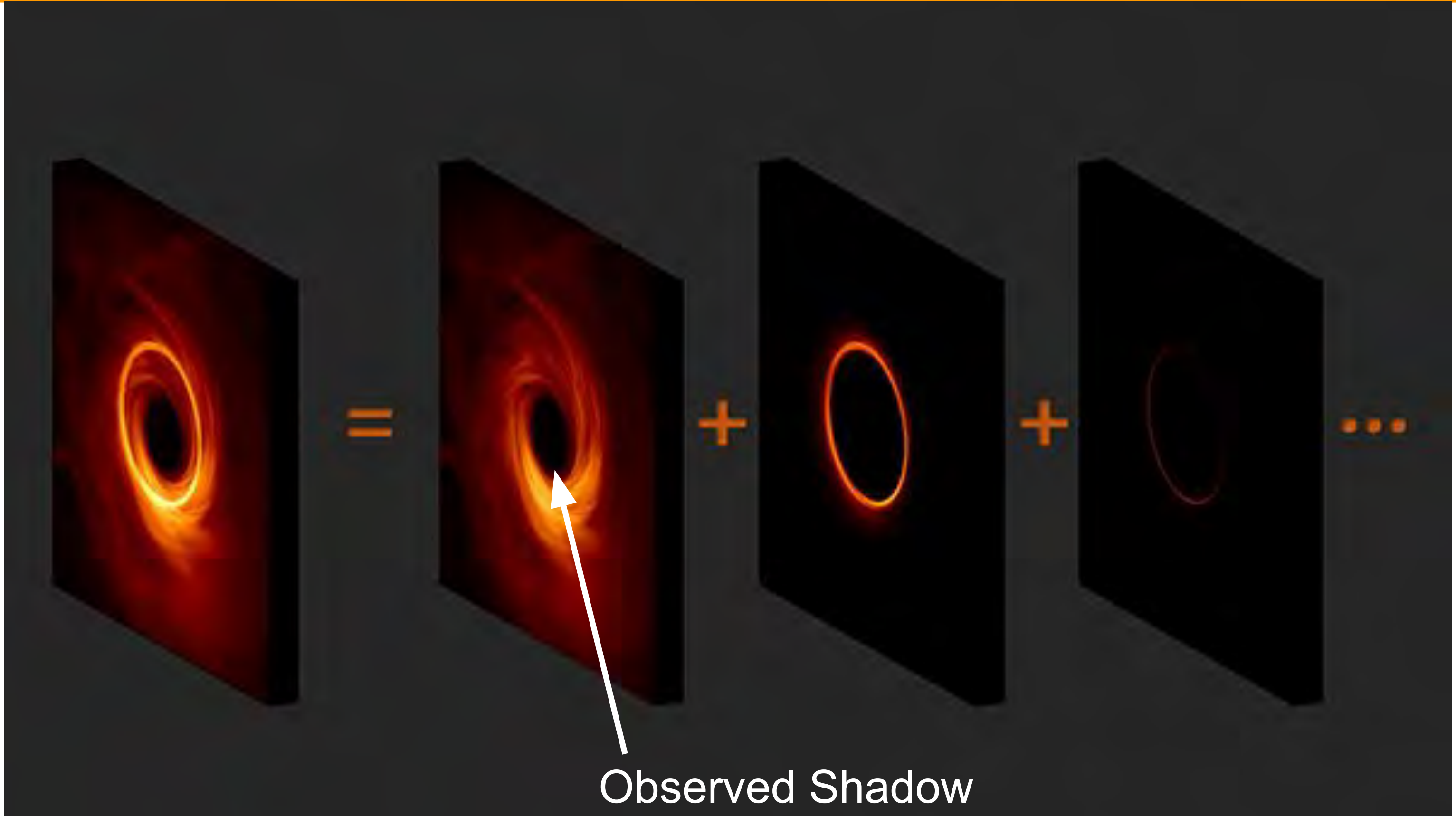


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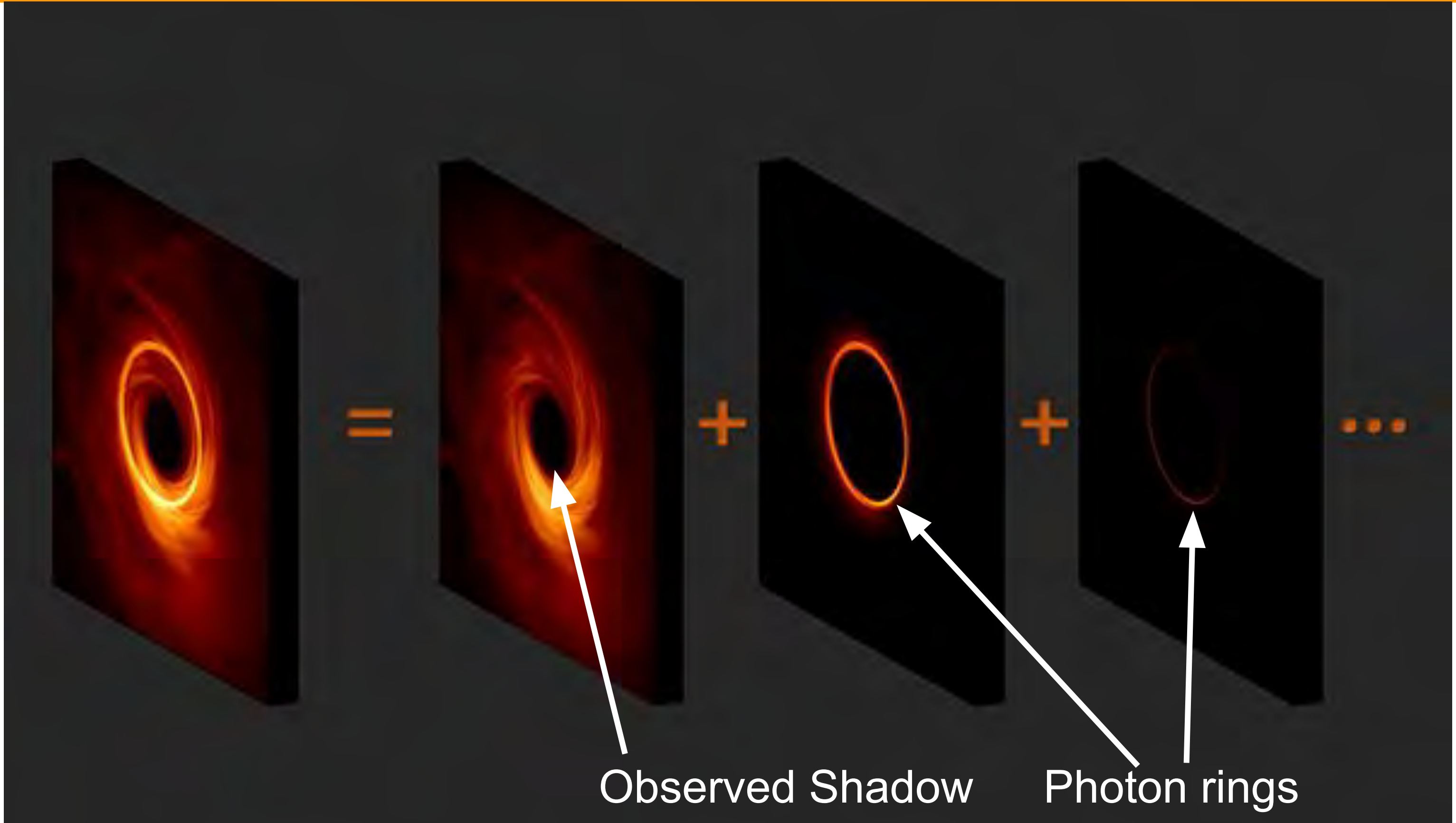


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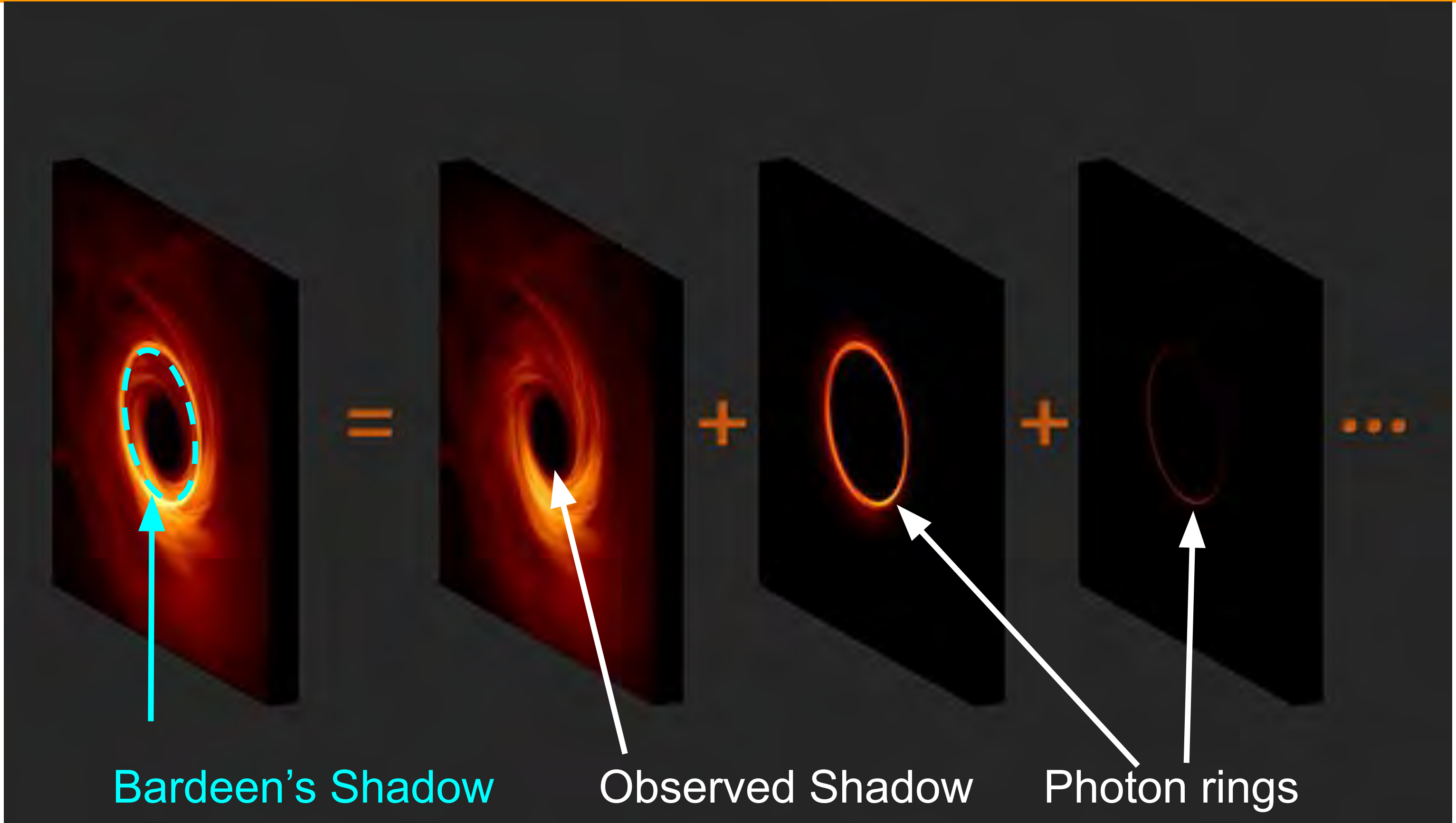


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# Problem Statement

## Another lens positioned between us and the shadow

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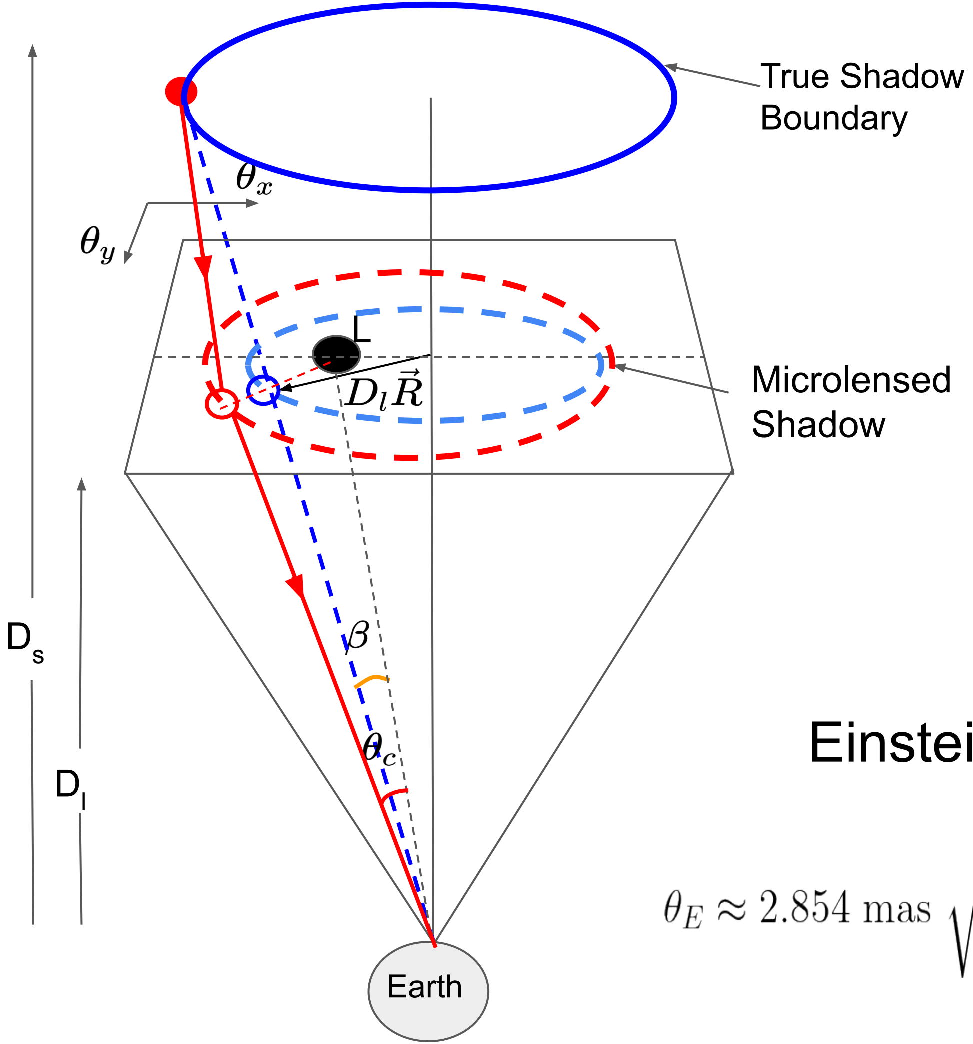
Another lens positioned between us and the shadow

- 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**?

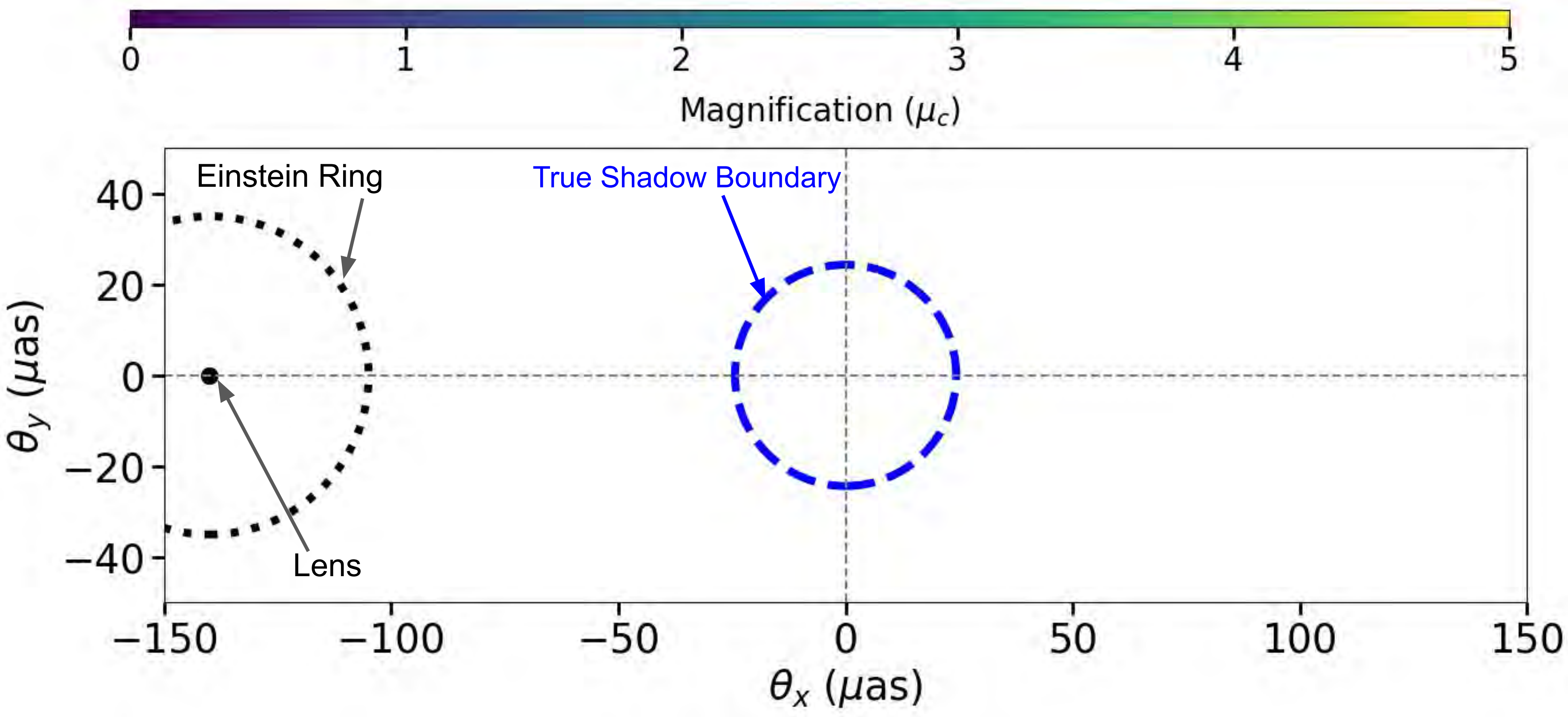
**Microlensing BH shadow**




## Einstein Angle

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

# Microlensing Black Hole Shadow



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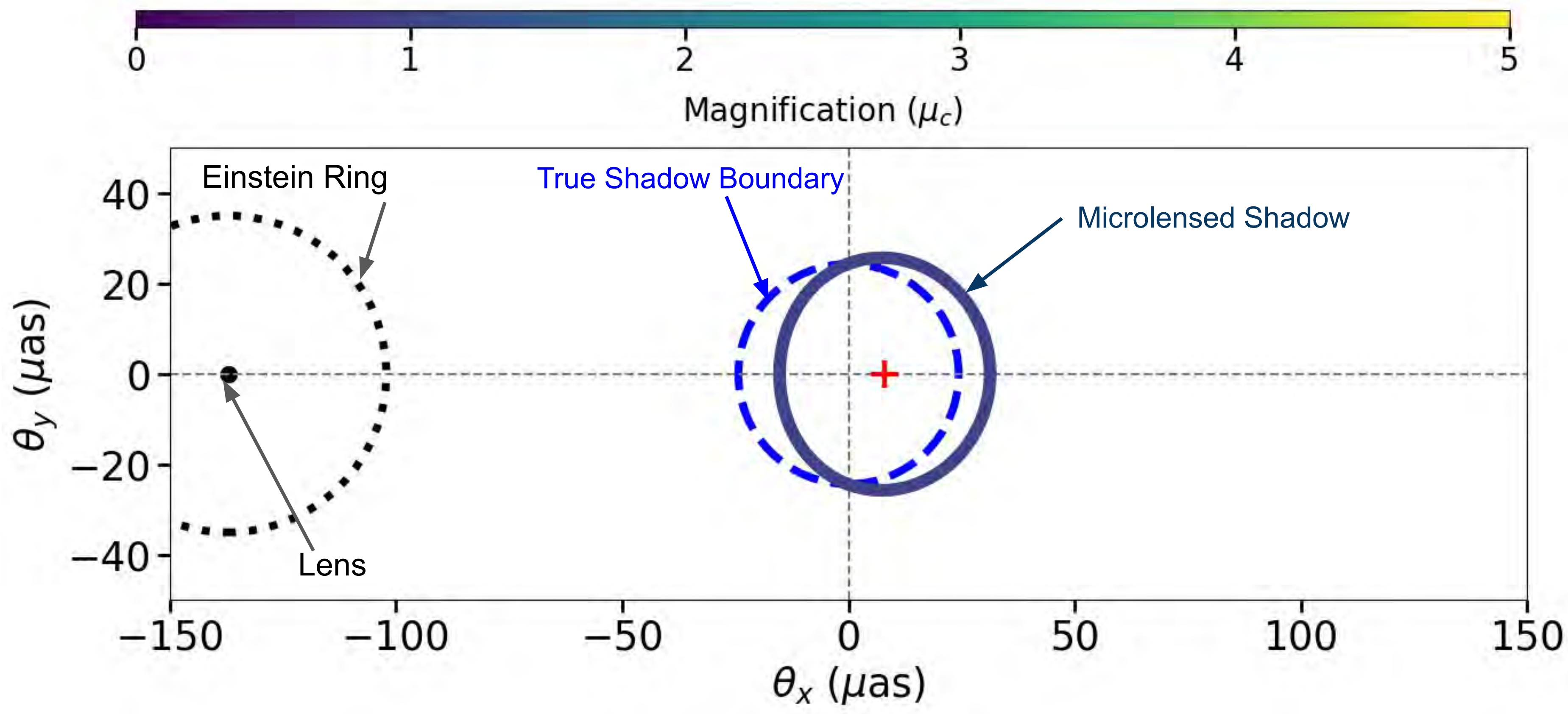

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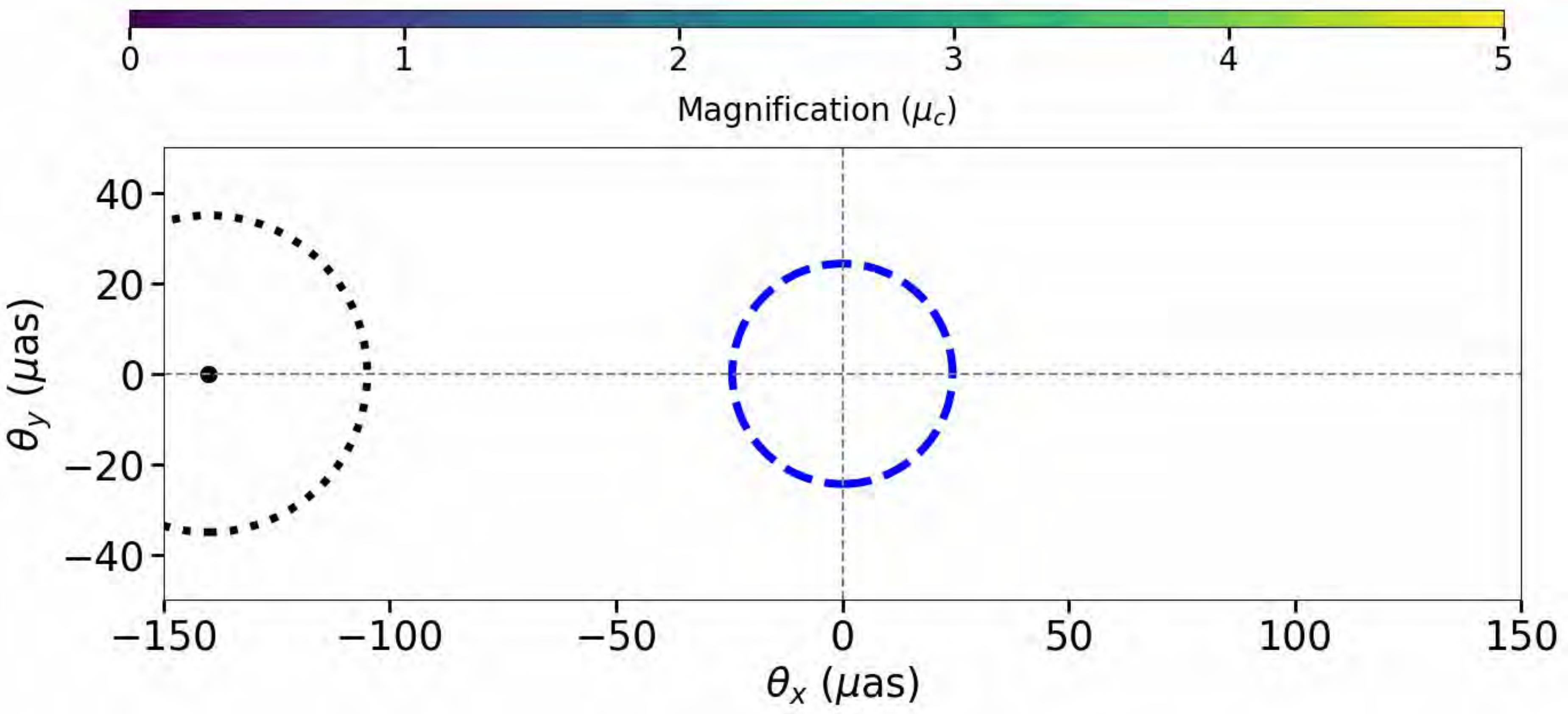


# Derived Observables

1. Shift in the center

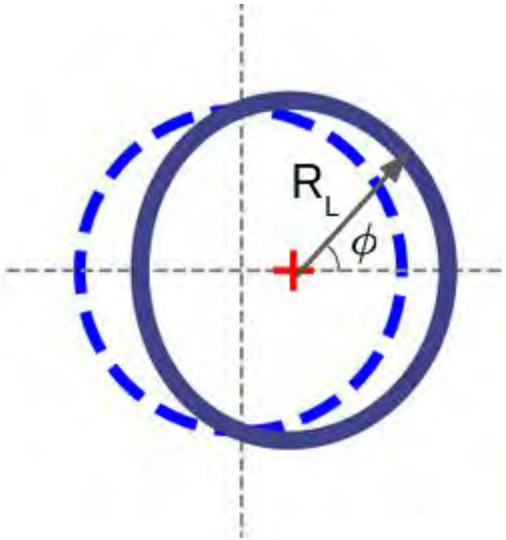
$$\overrightarrow{OC} \equiv \frac{\overrightarrow{OI}_c(\pi) + \overrightarrow{OI}_c(0)}{2}.$$

2. Magnification of the size

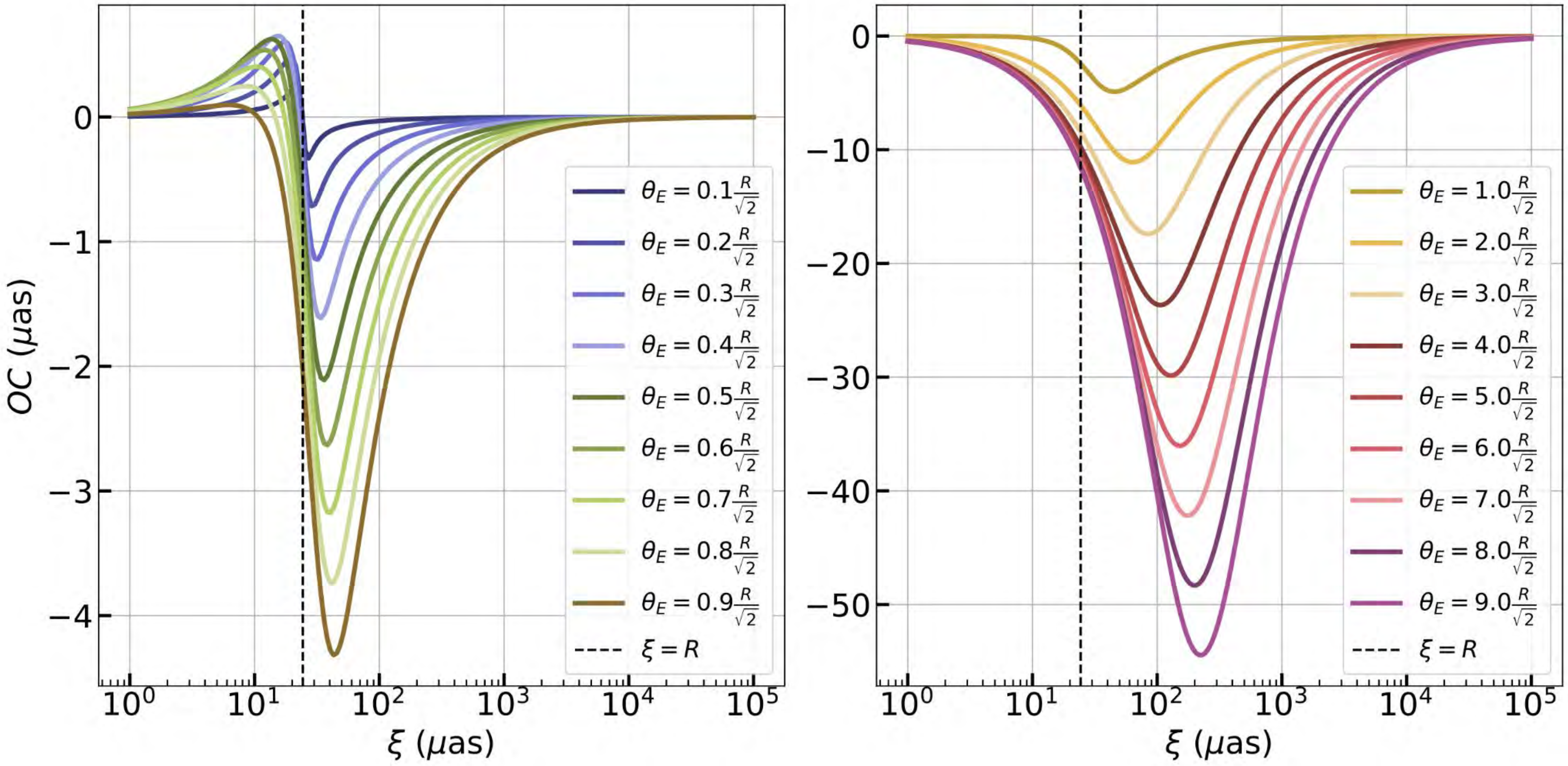
$$\langle R_L \rangle = \frac{1}{2\pi}\int_0^{2\pi} |\vec{R}_L(\phi)| d\phi.$$

3. Asymmetric Shape

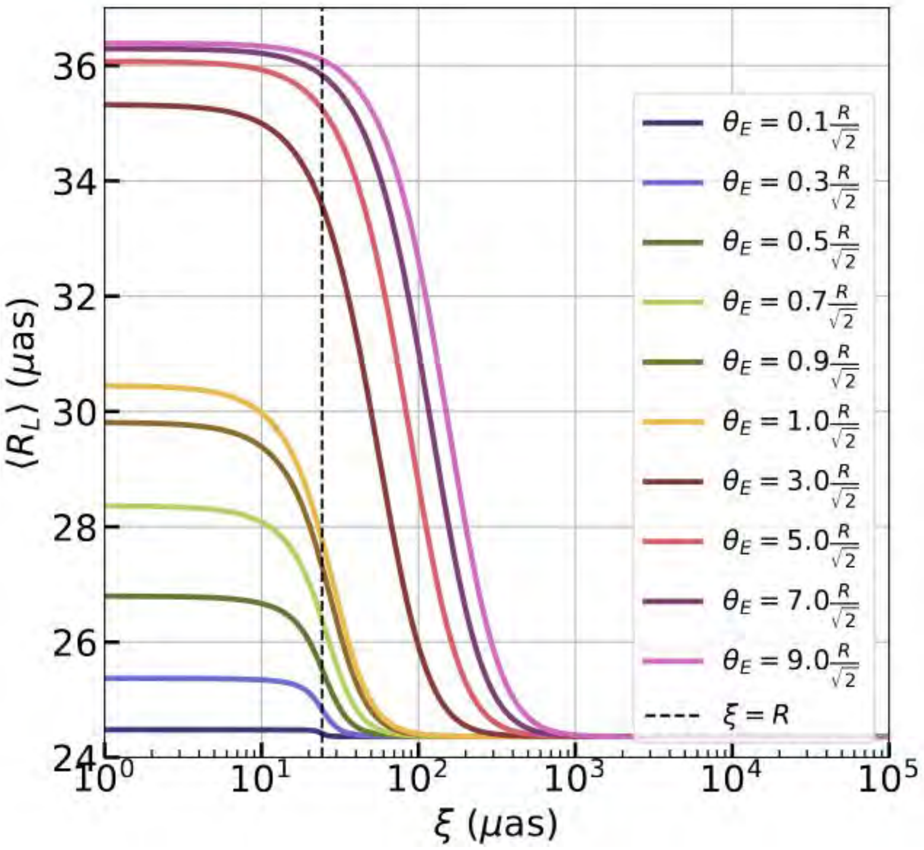
$$A = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (R_L(\phi)^2 - \langle R_L \rangle^2) d\phi}.$$



# Shift in the center of the shadow Sgr A*

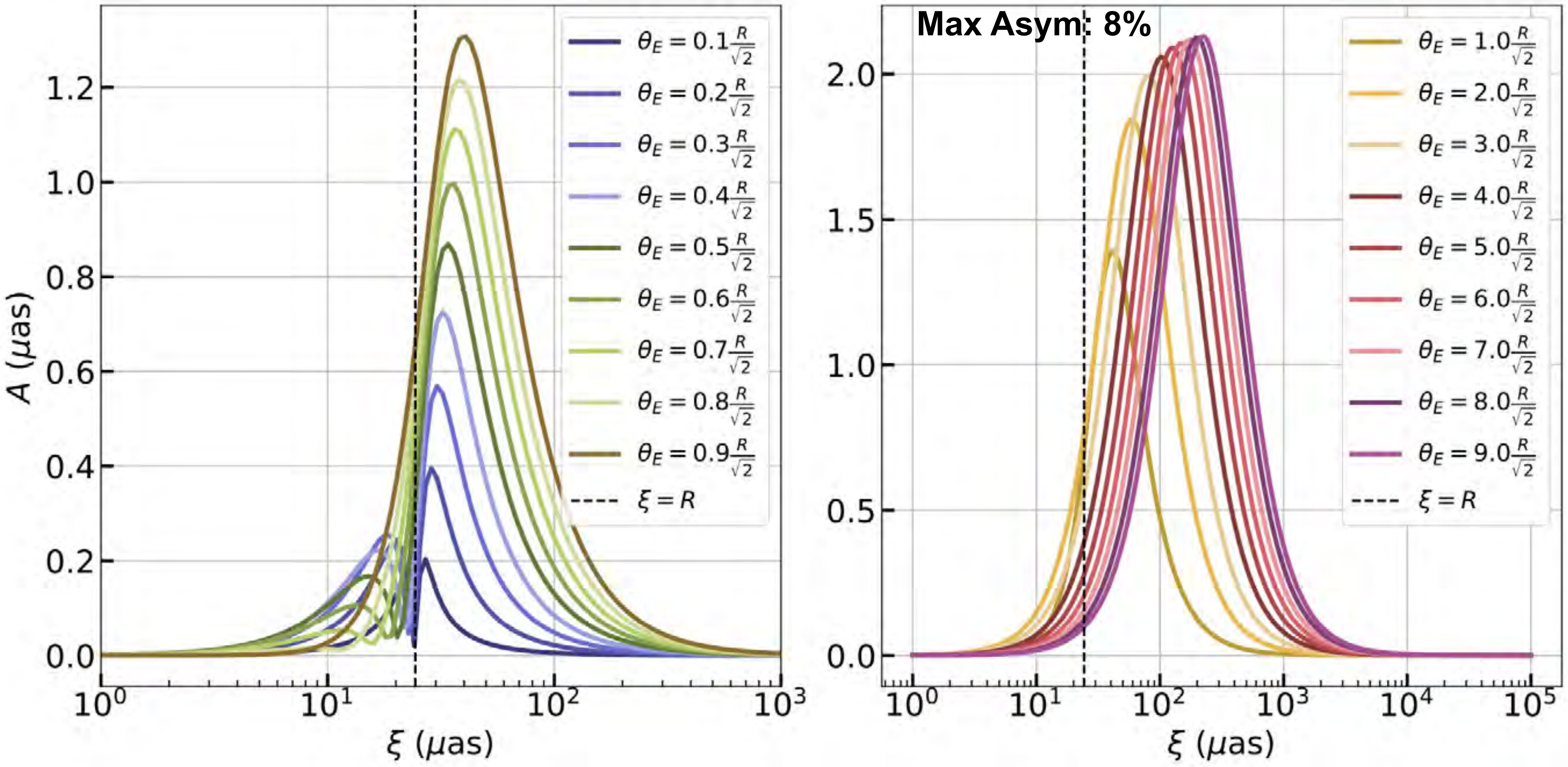


# Size of the shadow




Max Enhancement:
**50% of the true size**

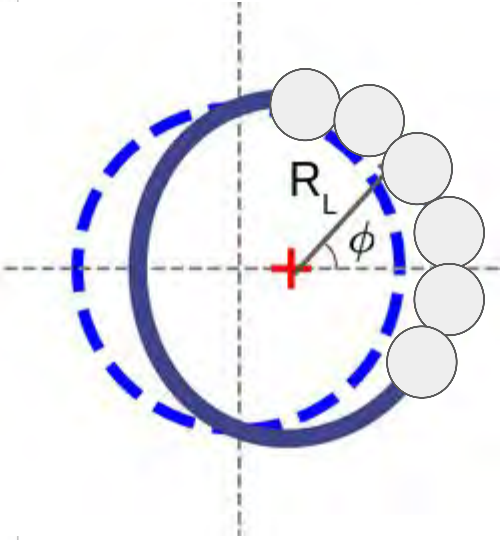
# Asymmetry in the shadow shape Sgr A*



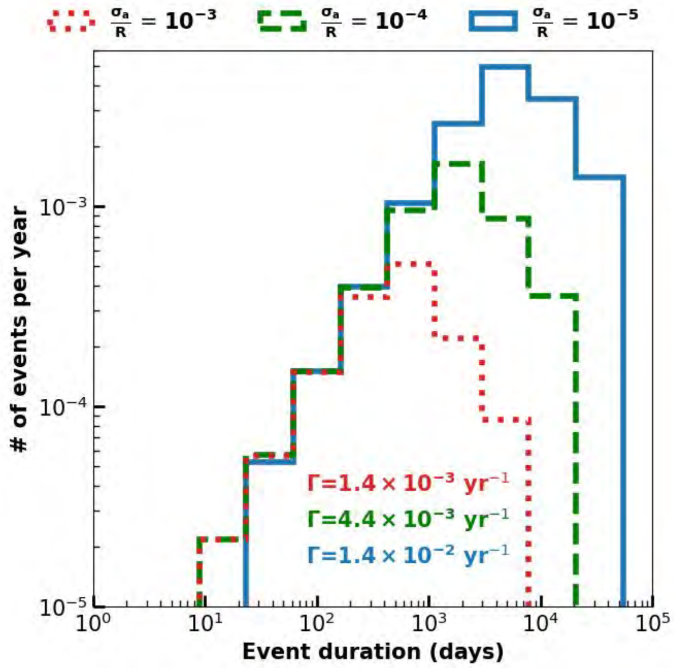
# Detectability of the microlensed shadow of Sgr A*

# Estimating the uncertainty in the radius

| $\lambda = 1.3$ mm | | | | | |
|---|---|---|---|---|---|
| $D$ (km) | $\theta_{res}$ ($\mu$as) | N | # of epochs | $\sigma_a$ ($\mu$as) | % error |
| 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 |

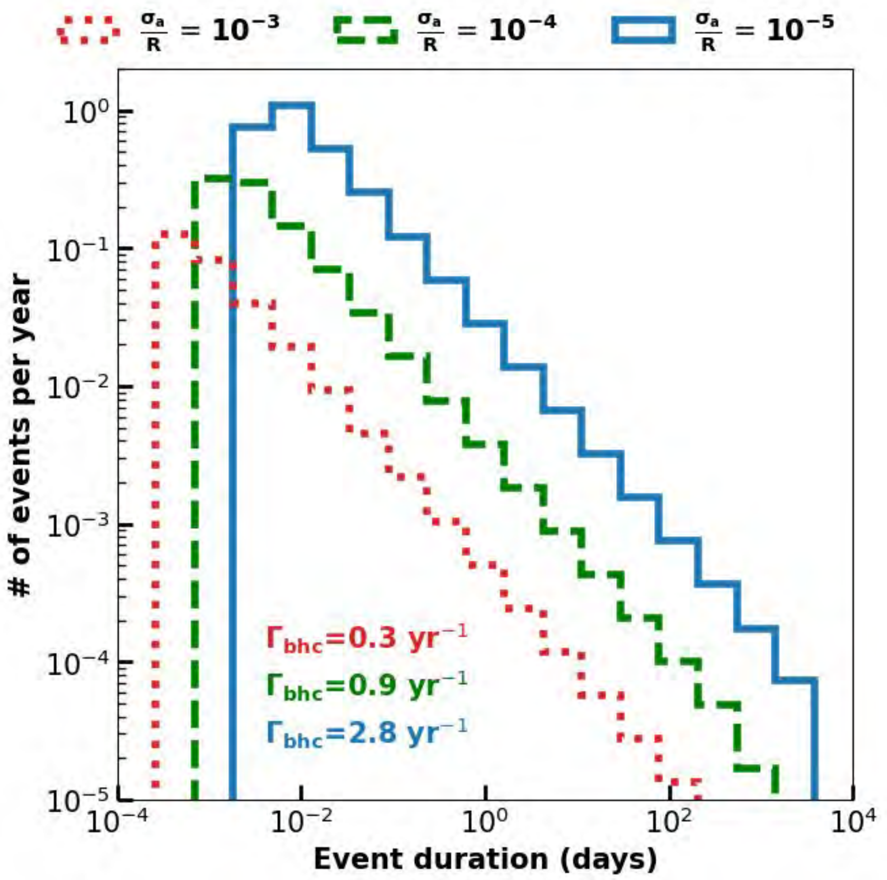


# Event rate due to stellar components of Milky Way




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

# Potential enhancement in the event rate




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

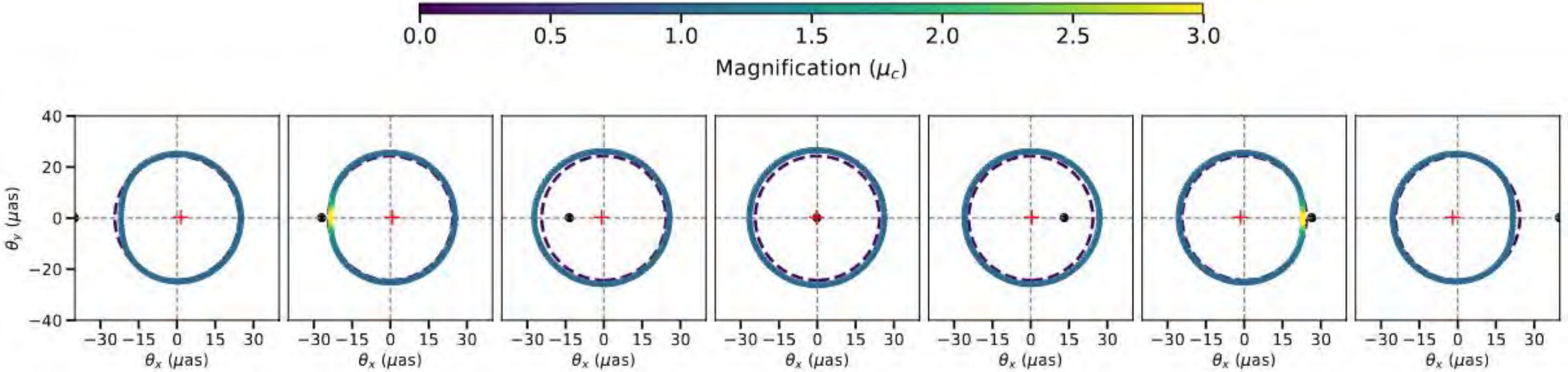
  [Miralda-Escude & Gould 2000]

- **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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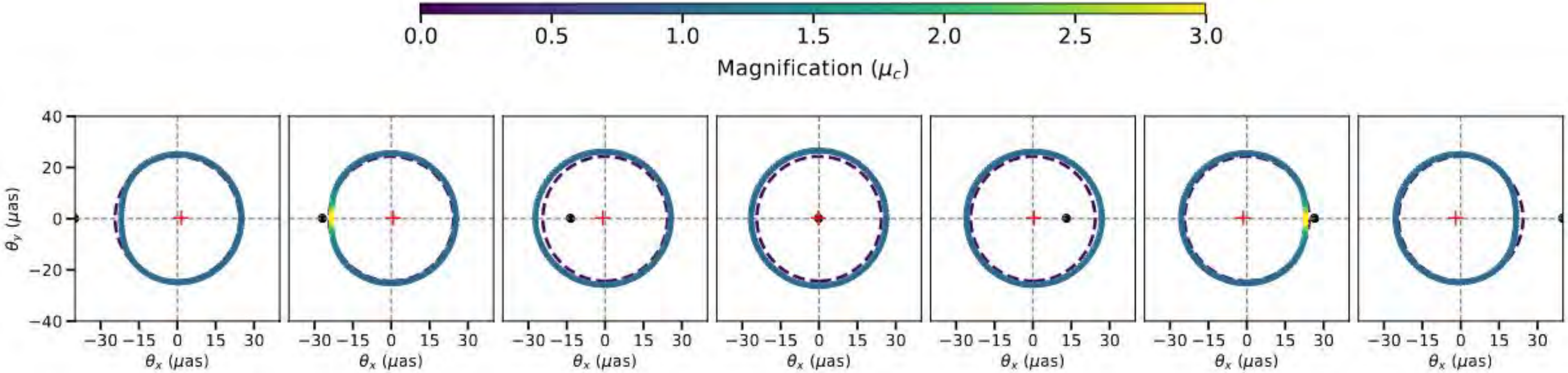


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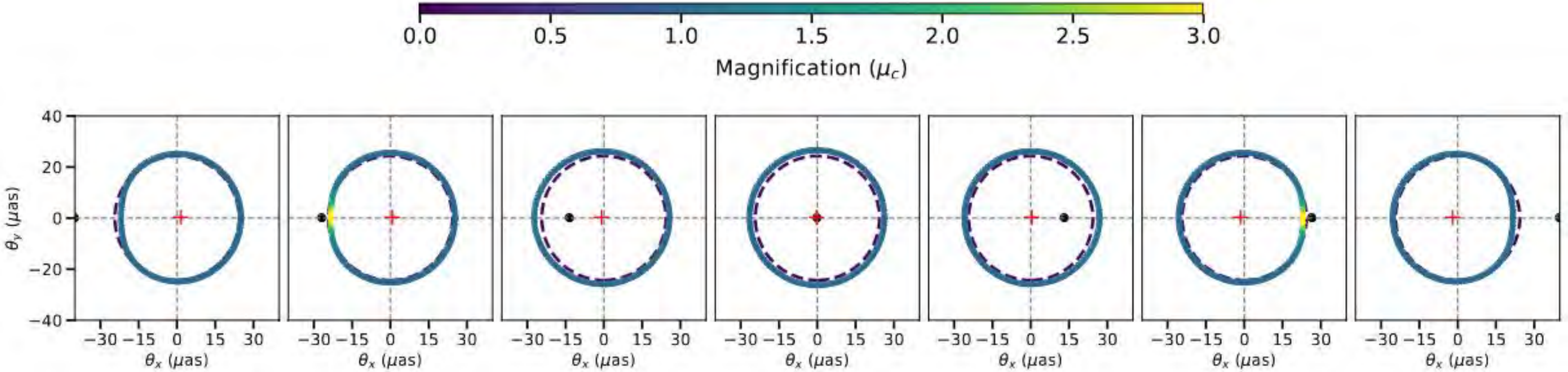


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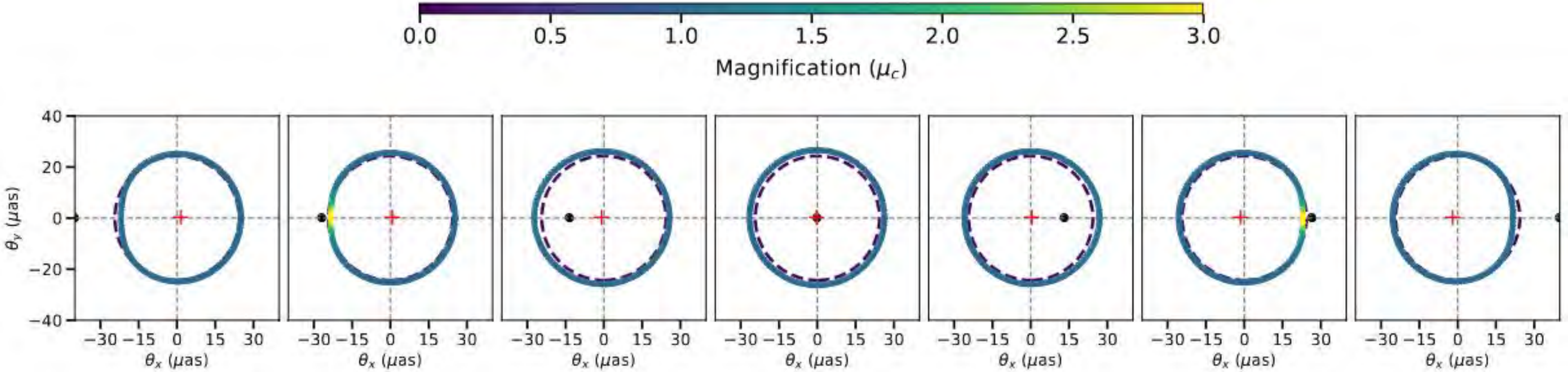


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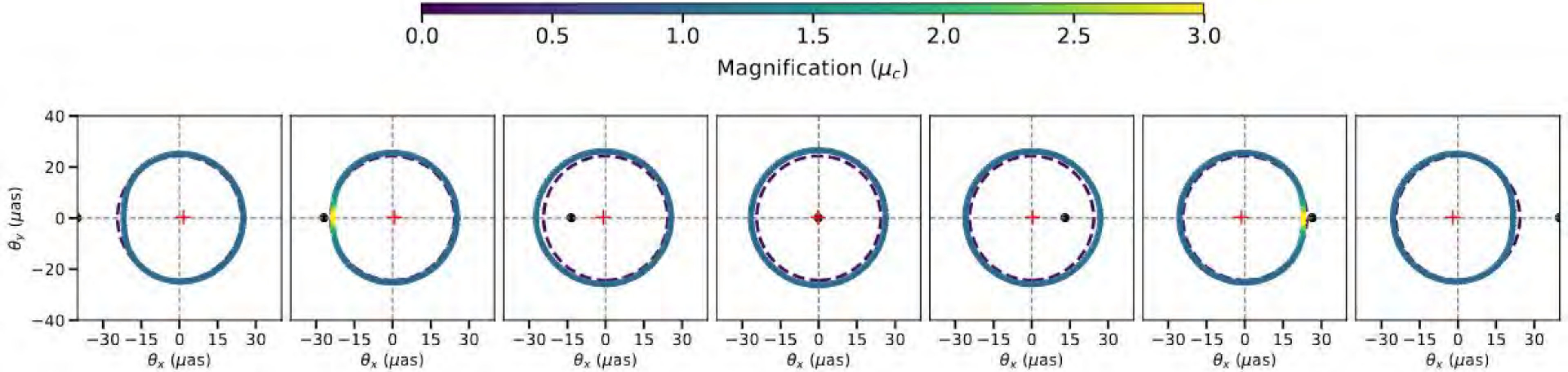


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# Thank You!

# Backup Slides (EHT)

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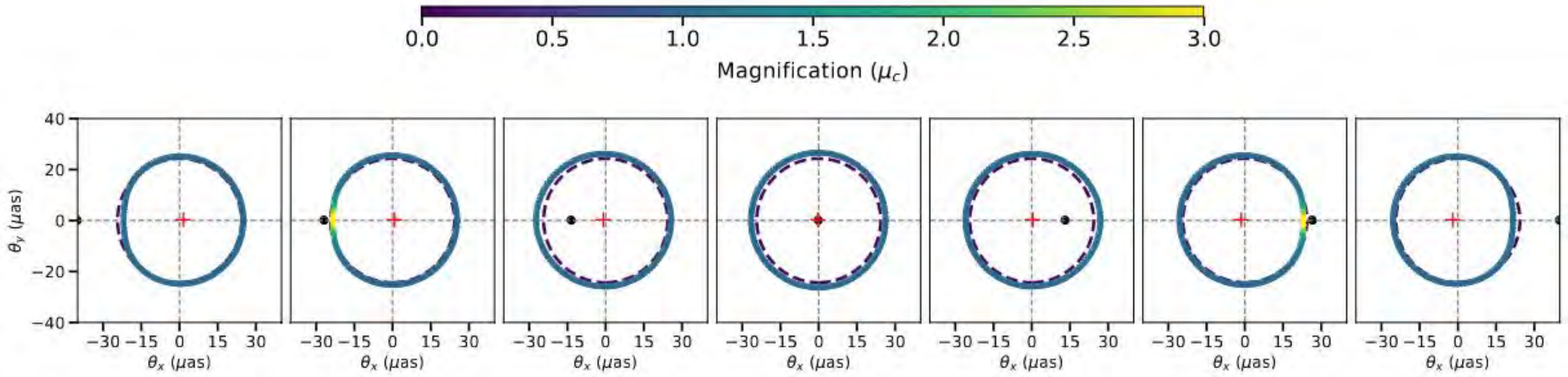


Einstein Angle = 7.8 micro-arcsec

M = 1 Solar Mass, r = 0.5 pc

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

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

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