Shadow of Kerr black hole surrounded by an angular Gaussian distributed plasma

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Based on arXiv: 2206.04430

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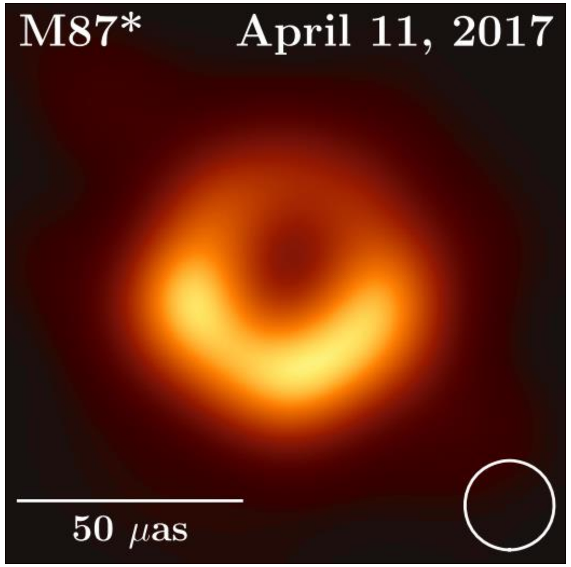
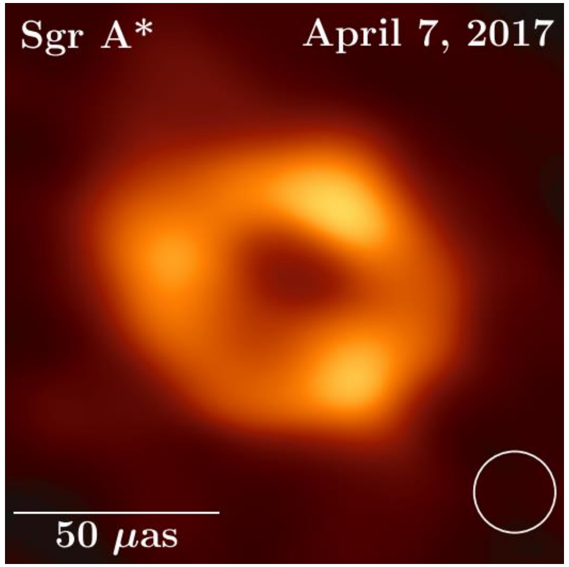
Motivation

- Event Horizon Telescope
  - Physical information near black holes
    - Spacetime background
    - Accretion flow
- Accretion Disk
  - Made of **plasma**
  - Type
    - Geometric thin, optical thick
    - **Geometric thick, optical thin**





(Image Source: https://www.nasa.gov/)

Theoretical basis

- Hamiltonian of photon motion in a cold non-magnetized plasma (Synge 1960)

$$H = \frac{1}{2}\left(g_{\mu\nu}p^{\mu}p^{\nu} + \boldsymbol{\omega_p^2}\right)$$

ω_p : plasma frequency

- According to plasma physics

$$\omega_p^2(x) = \frac{4\pi e^2}{m_e} N(x) \propto N(x)$$

- Analytical methods are only available for some special cases

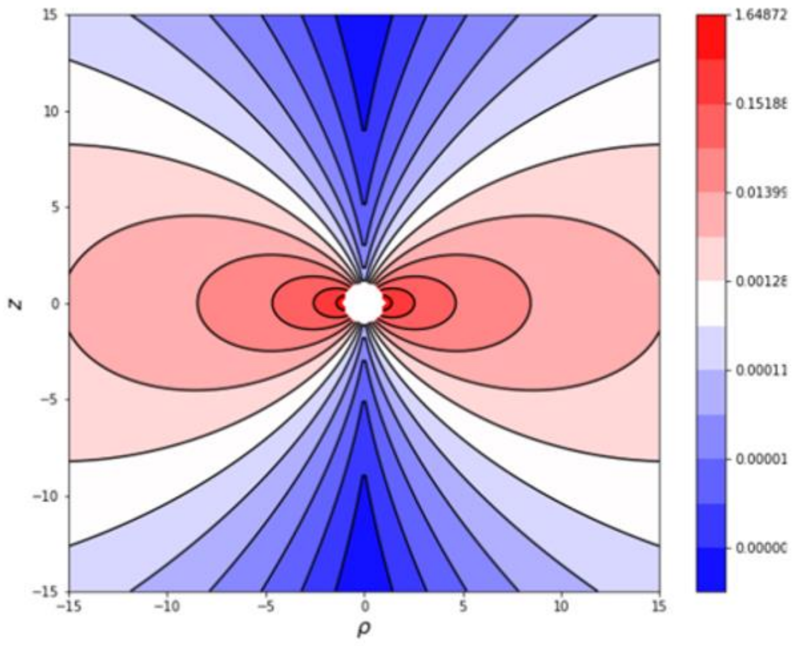
$$\omega_p^2(r,\theta) = \frac{f_r(r) + f_\theta(\theta)}{r^2 + a^2\cos^2\theta}$$

- Numerical method is applied in our work for general case

Plasma distribution models

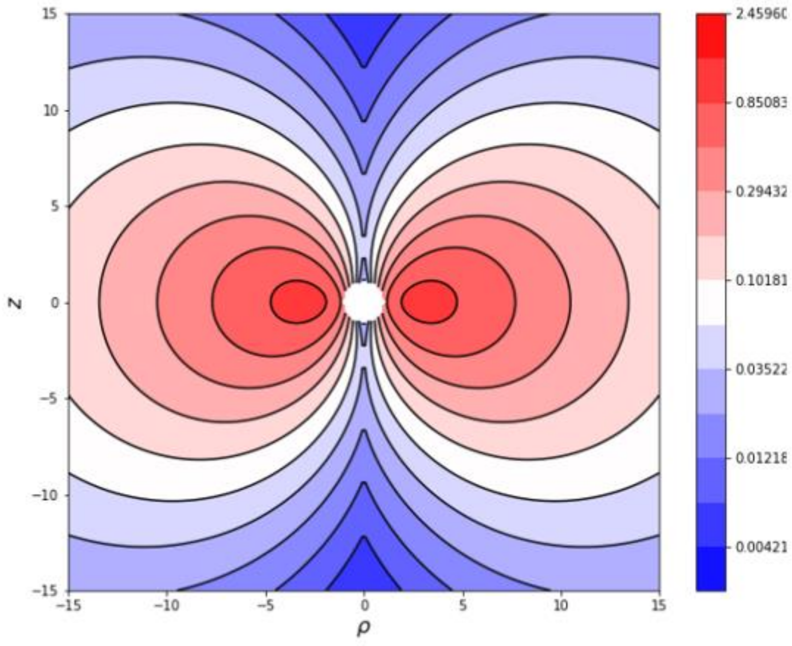
Model A (two parameters)

$$\omega_{pA}^2(r,\theta) = \frac{k_A}{r^2} e^{-\frac{\left(\theta - \frac{\pi}{2}\right)^2}{2\xi_\theta^2}}$$

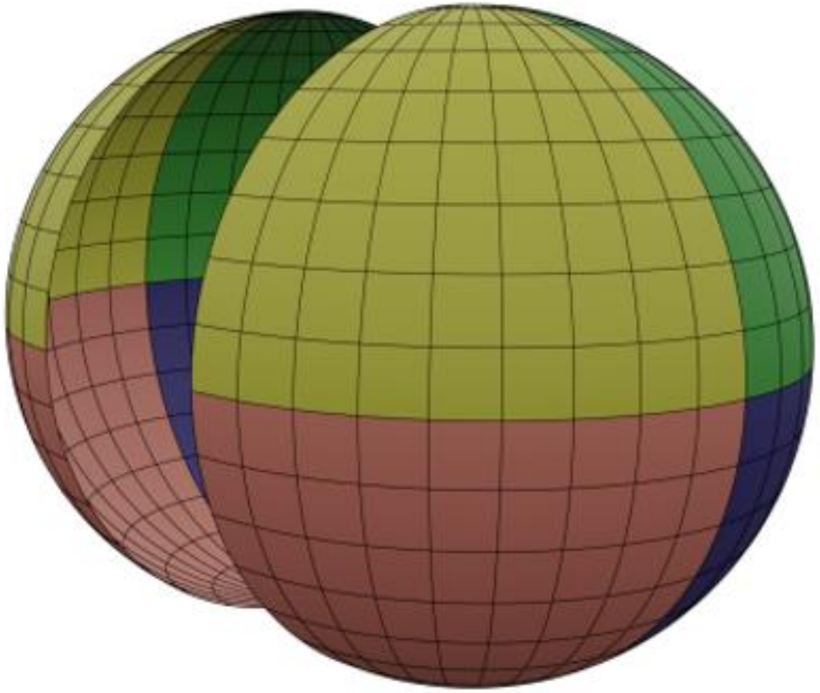


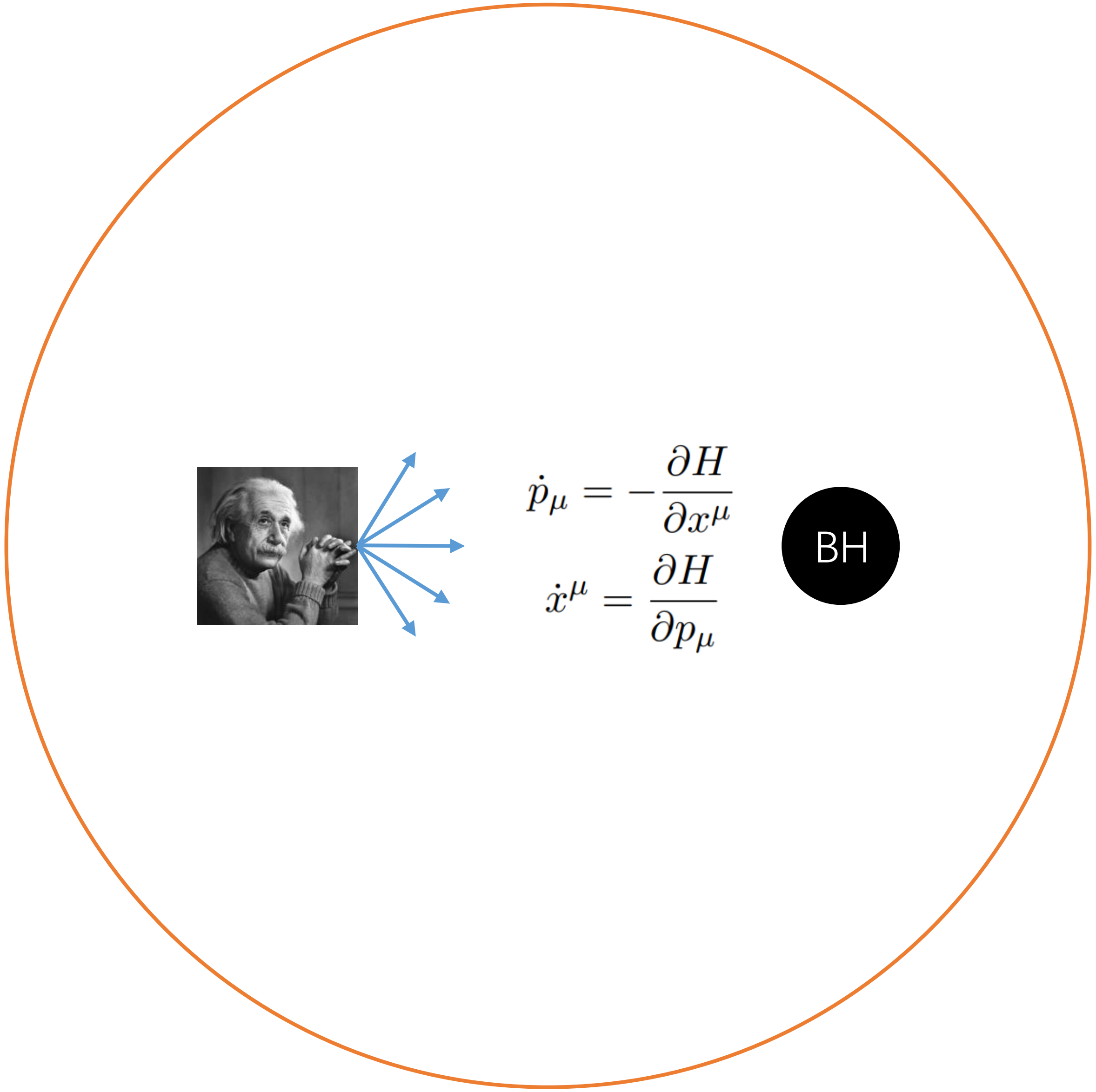
Model B (four parameters)

$$\omega_{pB}^2(r,\theta) = k_B e^{-\frac{\left(\log\frac{r}{r_m}\right)^2}{2\sigma^2}} e^{-\frac{\left(\theta - \frac{\pi}{2}\right)^2}{2\xi_\theta^2}}$$

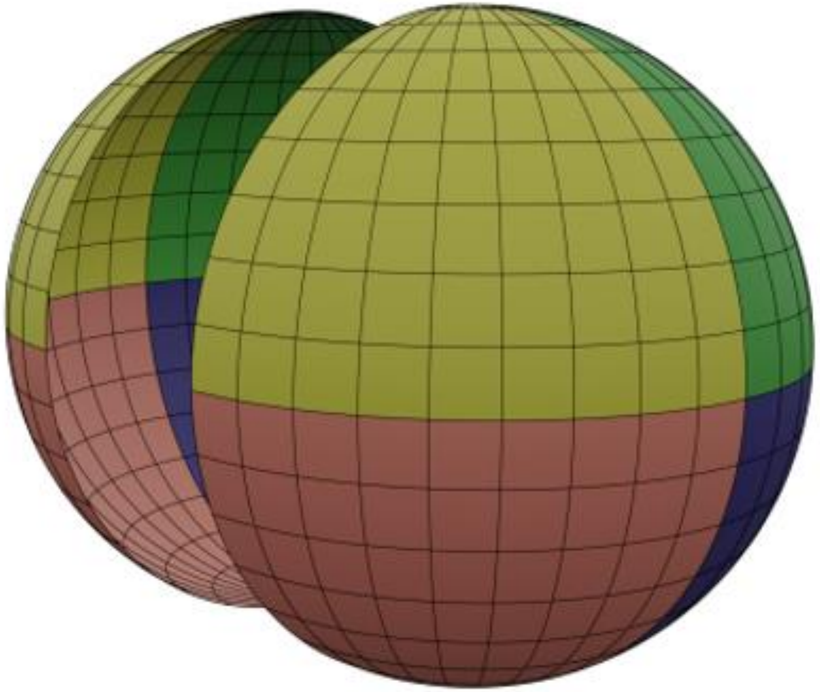


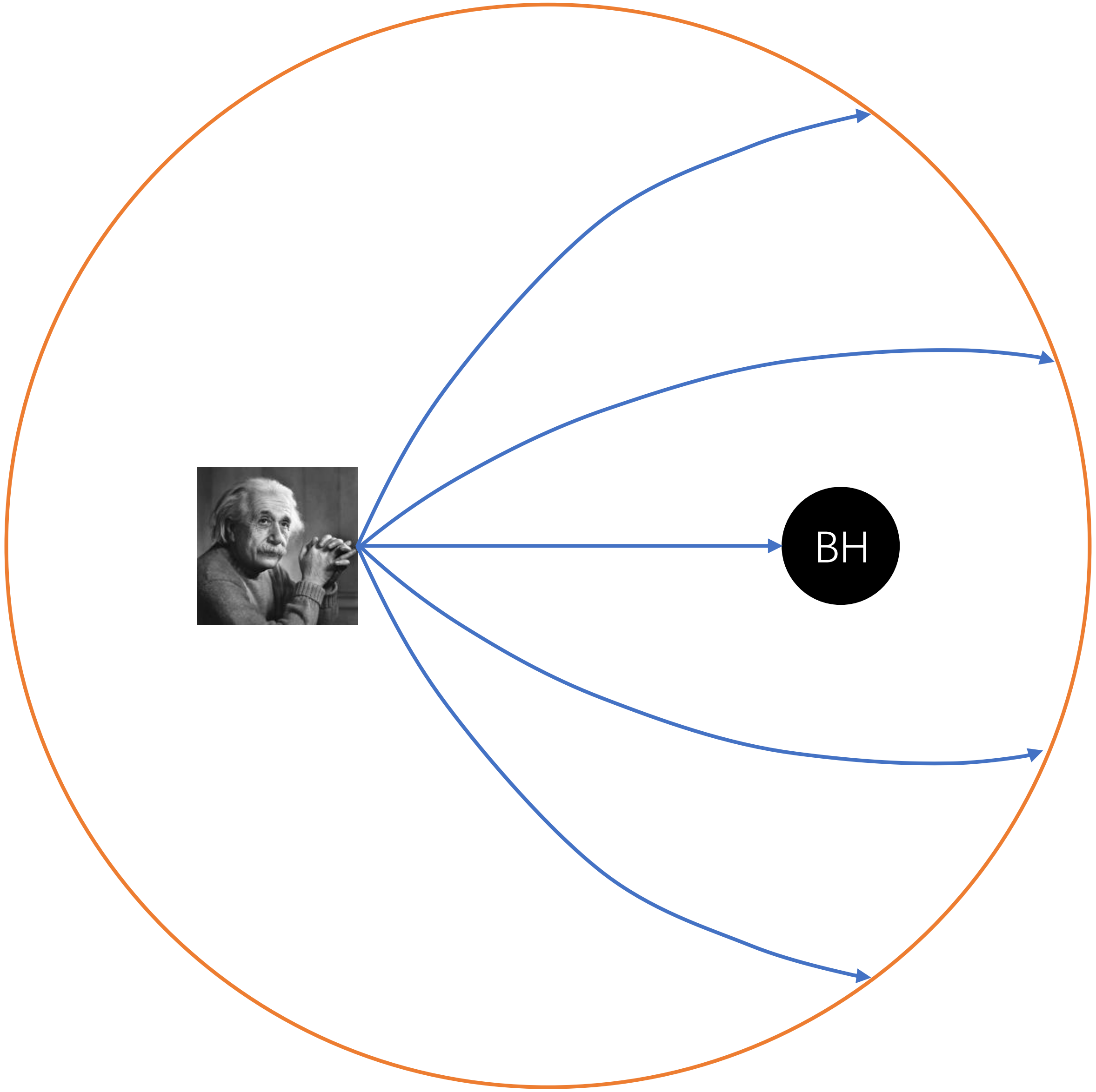
Numerical method: backward ray-tracing





Numerical method: backward ray-tracing

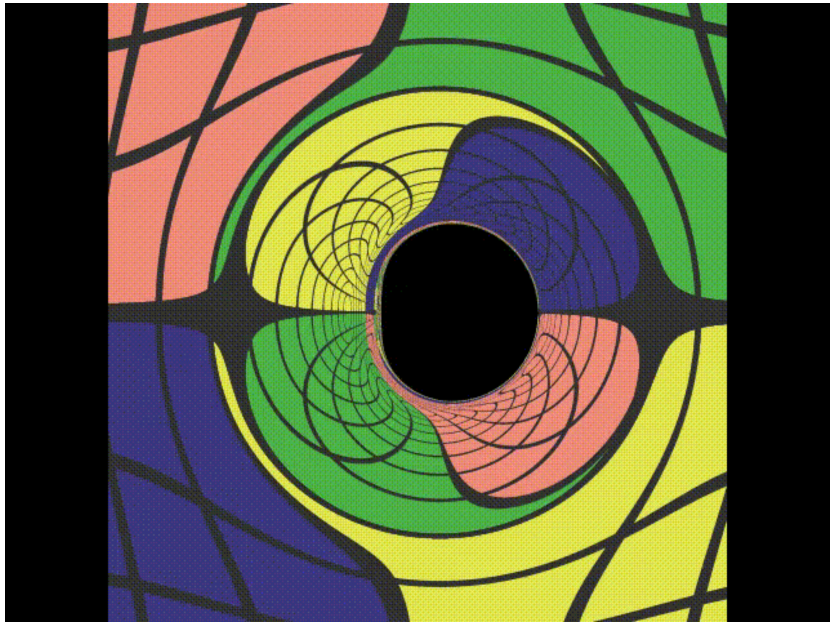




Results of model A

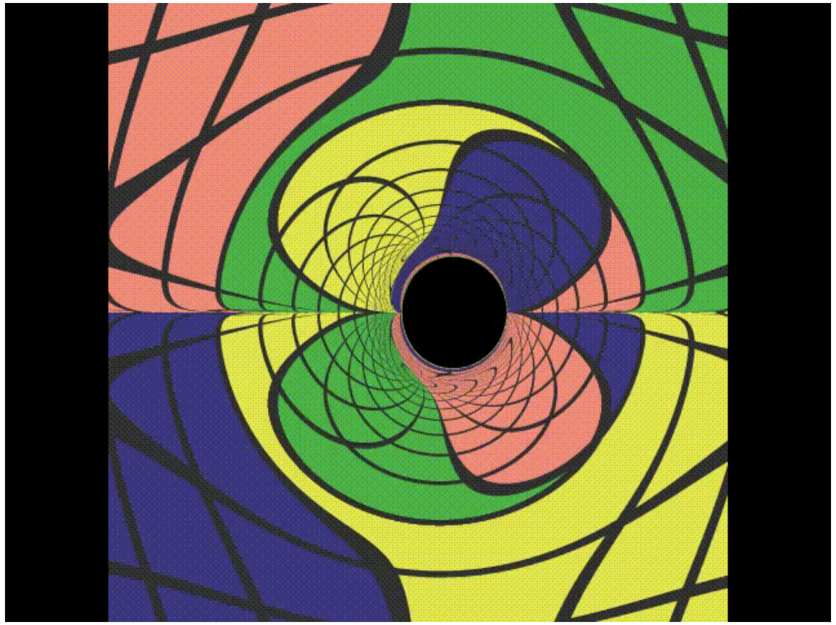
$$\omega_{pA}^2(r,\theta) = \frac{k_A}{r^2} e^{-\frac{\left(\theta - \frac{\pi}{2}\right)^2}{2\xi_\theta^2}}$$

Change k_A: 1 ~ 26



$a = 0.998, \theta_{obs} = \frac{\pi}{2}, \xi_\theta = 0.36$

Change ξ_θ: 0.09 ~ 0.72



$a = 0.998, \theta_{obs} = \frac{\pi}{2}, k_A = 16$

Set $G = c = M = 1$

The effect of changing the position of the observer is also studied in our paper

Results of model B

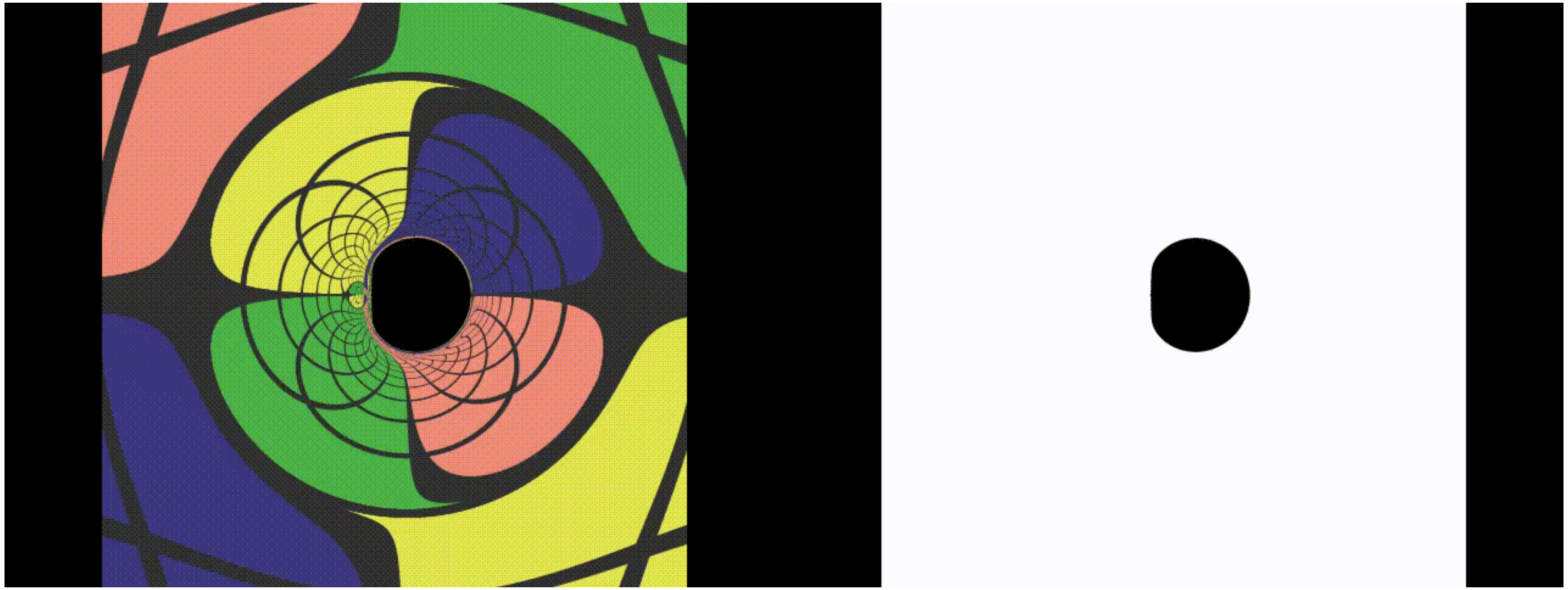
$$\omega_{pB}^2(r,\theta) = k_B e^{-\frac{\left(\log\frac{r}{r_m}\right)^2}{2\sigma^2}} e^{-\frac{\left(\theta-\frac{\pi}{2}\right)^2}{2\xi_\theta^2}}$$

$$r_1 = \frac{r_m - r_h}{10} i\,, \quad i = 1, 2, \ldots, 10$$

$$r_{1,2} = r_m e^{\pm\sqrt{2\log 10}\sigma}$$

$(r_m, \sigma) \to$ $(\boldsymbol{r_m}, \boldsymbol{i})$ a smaller i corresponds to a faster decay rate

Change r_m: 2 ~ 12



Set $G = c = M = 1$

$a = 0.998, \theta_{obs} = \frac{\pi}{2}, k_B = 0.8, \xi_\theta = 0.36, i = 10$

Results of model B

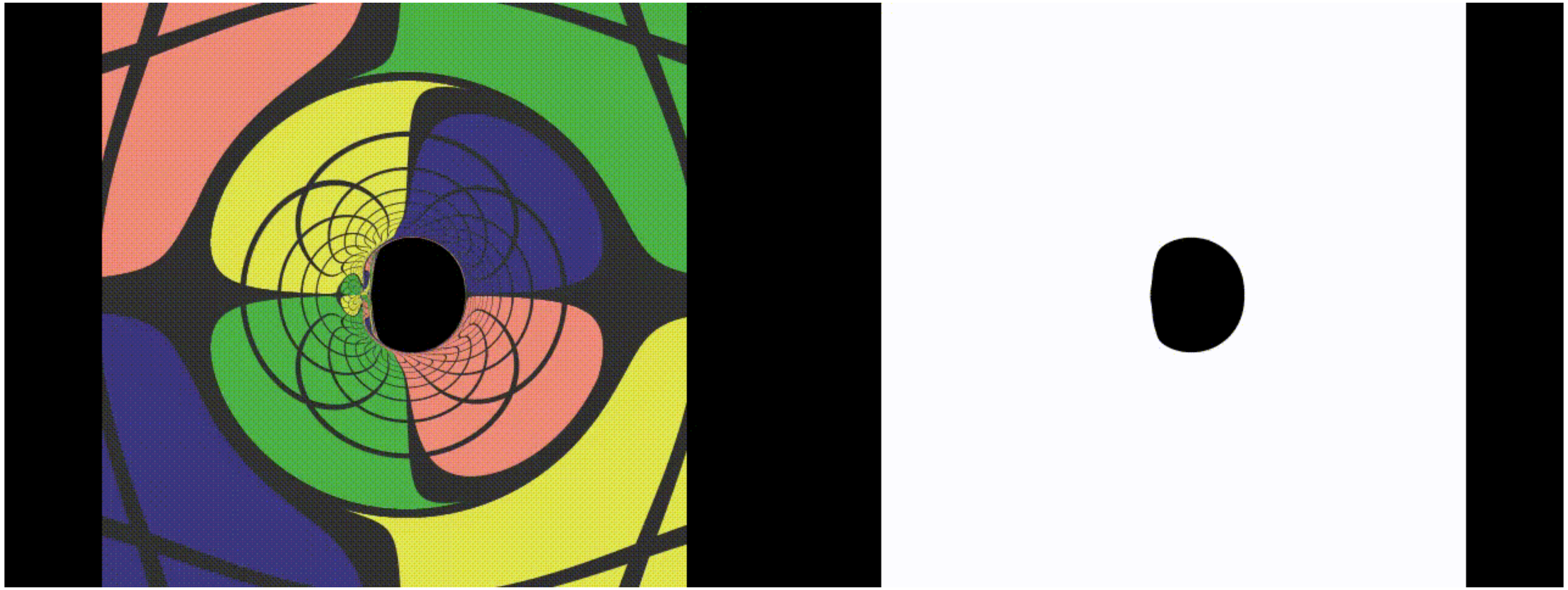
$$\omega_{pB}^2(r,\theta) = k_B e^{-\frac{\left(\log\frac{r}{r_m}\right)^2}{2\sigma^2}} e^{-\frac{\left(\theta-\frac{\pi}{2}\right)^2}{2\xi_\theta^2}}$$

$$r_1 = \frac{r_m - r_h}{10} i\,, \quad i = 1, 2, \ldots, 10$$

$$r_{1,2} = r_m e^{\pm\sqrt{2\log 10}\sigma}$$

$(r_m, \sigma) \rightarrow$ $\boldsymbol{(r_m, i)}$ a smaller i corresponds to a faster decay rate

Change i: 10 ~ 1



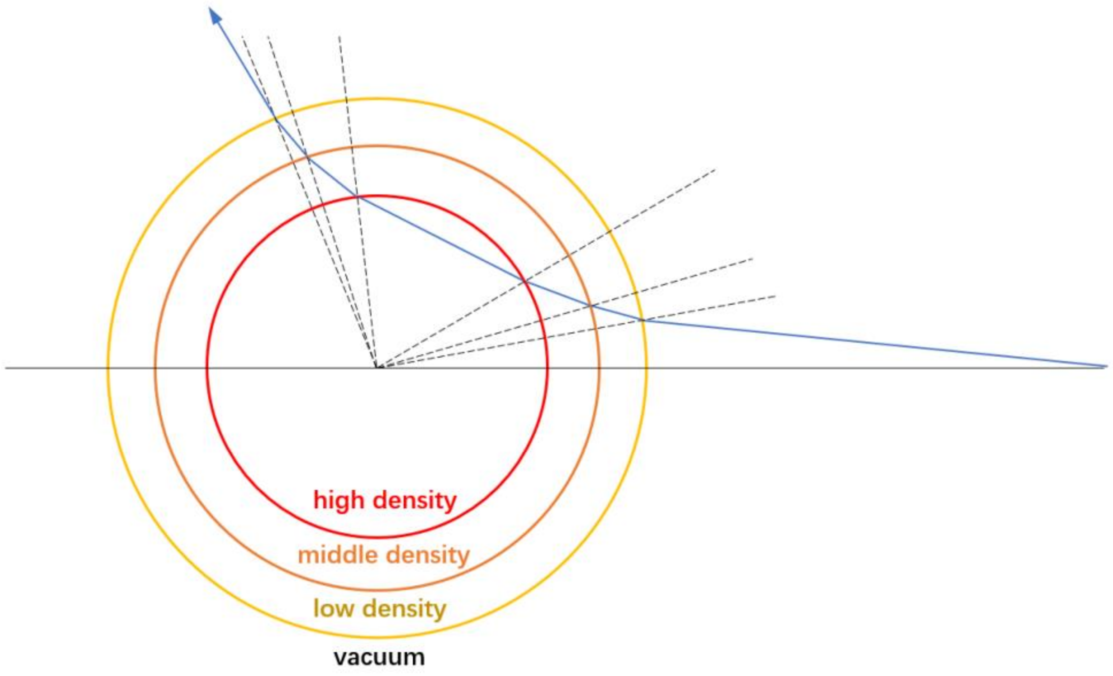
Set $G = c = M = 1$

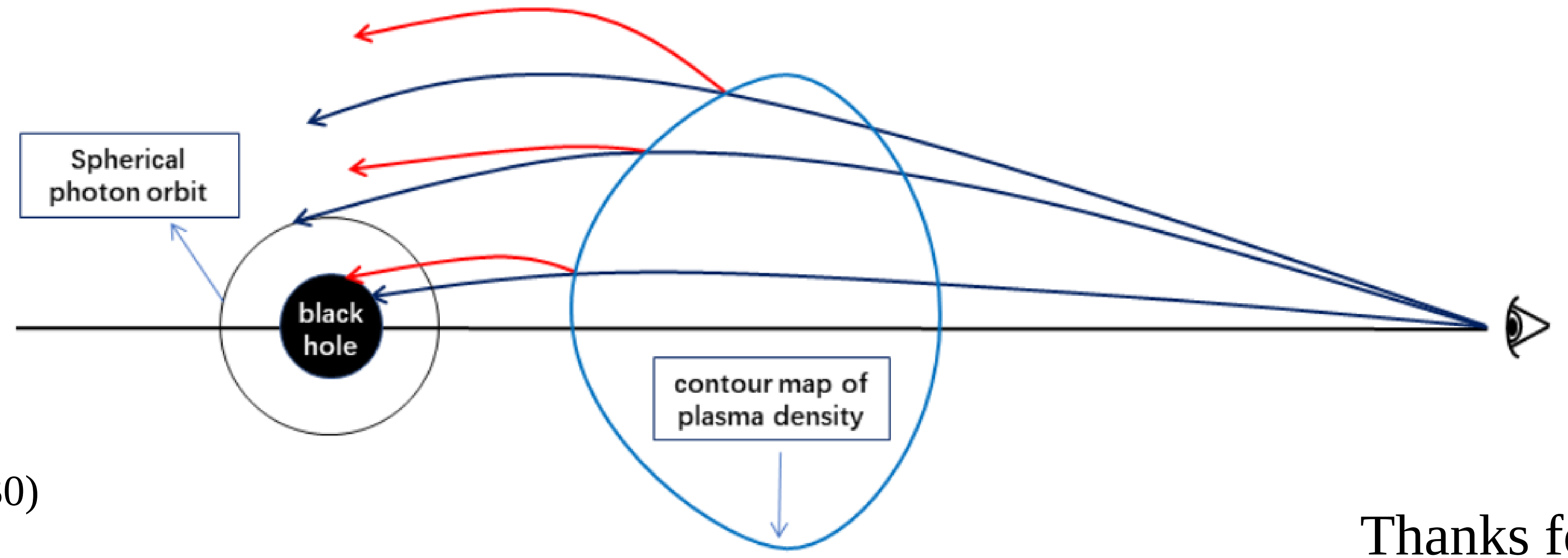
$a = 0.998, \theta_{obs} = \frac{\pi}{2}, \xi_\theta = 0.36, r_m = 3$

Qualitative explanation

- The refractive index $n^2 = 1 - \frac{\omega_p^2}{\omega^2} < 1$

- Fewer rays hit the black hole





See our paper (arXiv:2206.04430) for more details

Thanks for listening!