Determining parameters of a black-hole accretion-disk system from the observation of shadow

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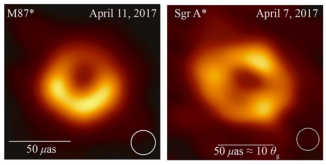
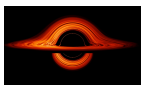
Introduction

- Shadows of BHs (M87 and Sgr A*) were observed by EHT!!
- We will (hopefully) observe many BH shadows near future.
- Shadows of BH w/ and w/t Accretion Disk (AD) contain much info.
  - M: mass
  - $J = Ma$: angular momentum ($0 \leq \frac{a}{M} < 1$)
  - i: inclination angle
  - r_o: distance between BH & observer
- Q: Can we determine these parameters solely by observing shadows?



BH shadow of M87 and Sgr A*
(credit: Event horizon Telescope)

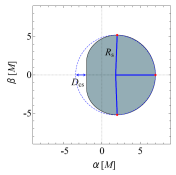


BH w/ Accretion Disk
(credit: NASA)

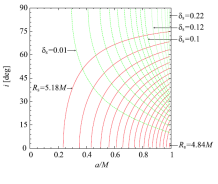
Works so far & Question

- Many papers study BH shadow
  - Bare BHs (Synge '66, Bardeen '73, ...)
  - BHs with AD (Luminet '79, Falcke et al '00, Takahashi '04, ...)
- Determining $(\frac{a}{M}, i)$ of Kerr BH from shadow (Hioki-Maeda '09)
- Most works assume $r_o \to +\infty$
  Info. of distance is lost.
  (Exceptions: Grenzenbach et al '14, Abdolrahimi-Mann-Tzounis '15)
- Q: If we allow r_o to be FINITE, can we determine all parameters (e.g. M) from shadow?
  ➔ Let's consider Sch. BH with AD as 1st step.

(Hioki-Maeda '09)

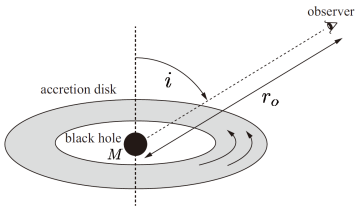


R: radius of an approx. circle
D: size of dent
$\delta := D/R$



∃ 1-to-1 corresp. between $(\frac{a}{M}, i)$ and (R, δ)

Setup: 3 parameters of our system
(Schwarzschild BH + thin AD + observer)

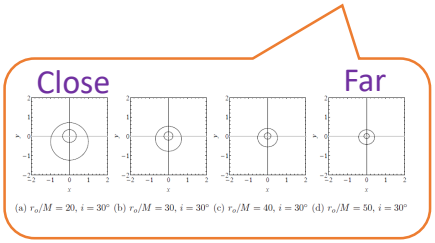


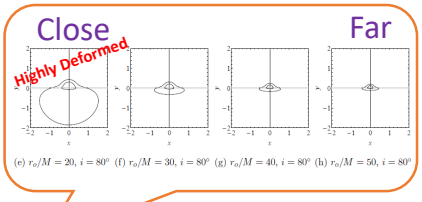
$(c = G = 1)$

Mass: $M \in (0, +\infty)$
Inclination angle: $i \in [0^\circ, 90^\circ)$
Emitter on AD: $r_e \in [6M, 20M]$
Observer: $r_o \in [20M, +\infty)$

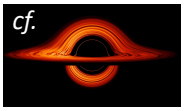
Results: Apparent shape of Accretion Disk

$i = 30^\circ$

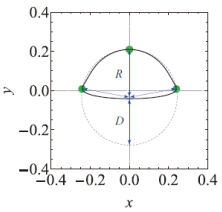




$i = 80^\circ$

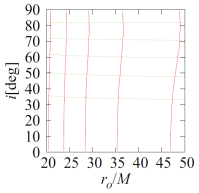


Determine $(\frac{r_o}{M}, i)$ from BH's Apparent Shape



Apparent shape of BH

R: radius of an approx. circle
D: size of dent
$\delta := D/R$



Contours of R & δ
Red: R=const.
Green: δ=const.

∃ 1-to-1 corresp. between $(\frac{r_o}{M}, i)$ and (R, δ)

Determine (M, r_o, i) from flux & accretion rate

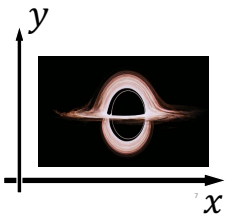
- Energy flux on AD $F_o(x, y)$ can be estimated (Page-Thorne '74)

$$F_o(x,y) = \frac{\dot{M}}{M^2} F_{o*}(x,y)$$

Unknown factor — Known function of (x,y)

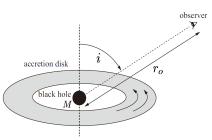
- Assuming that we know $\dot{M}$, we can estimate M by observing $F_o(x, y)$ and comparing it with $F_{o*}(x, y)$.

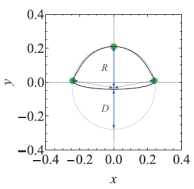
$$M = \sqrt{\dot{M} \frac{F_{o*}(x,y)}{F_o(x,y)}}$$

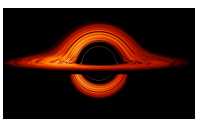


Conclusion & Prospects

- We considered system of (Sch. BH) + (thin AD) + (Observer) w/ 3 parameters (M, r_o, i).
- $\left(\frac{r_o}{M}, i\right)$ can be determined by (R, δ) (size & shape of shadow).
- (M, r_o, i) can be determined by (R, δ, F_o) and $\dot{M}$.
- Future works
  - Kerr BH w/ and w/t AD
  - Determining BH parameters from shadow's movie







BH w/ Accretion Disk
(credit: NASA)

Appendix: How to draw 2d image: ***Stereographic projection*** onto (x,y) plane