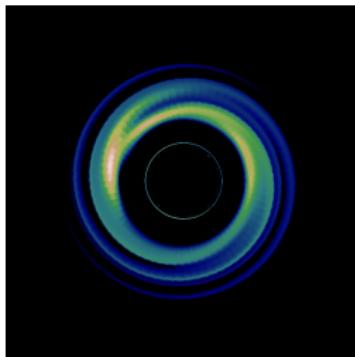


Sgr A*: the central black hole of the Galaxy

What can we learn from it?

Frédéric Vincent¹

¹CNRS/Observatoire de Paris/LESIA



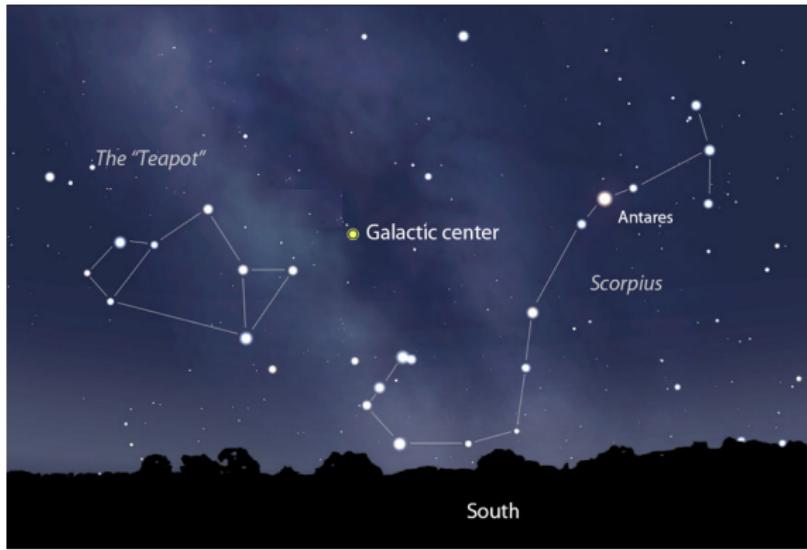
My topic

What can we learn from Sgr A* by using the new generation of infrared and millimeter interferometers GRAVITY and EHT?

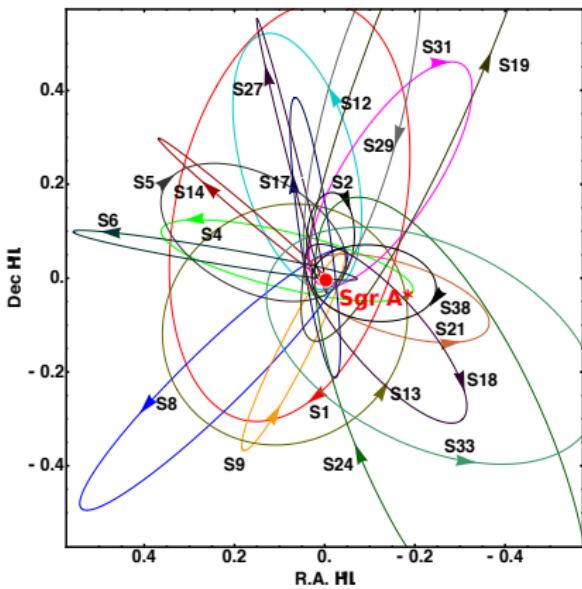
1 Sgr A* / EHT / GRAVITY

2 What EHT told us / might tell us

3 What GRAVITY told us / might tell us



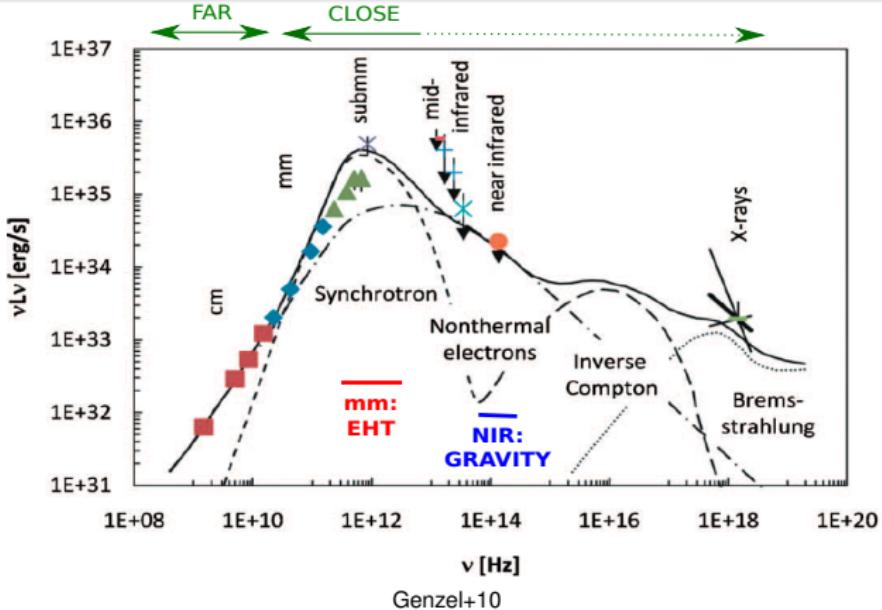
Credit : Stellarium, Bob King



S-stars cluster (Gillessen+09): size = $1'' \approx 0.05 \text{ pc}$

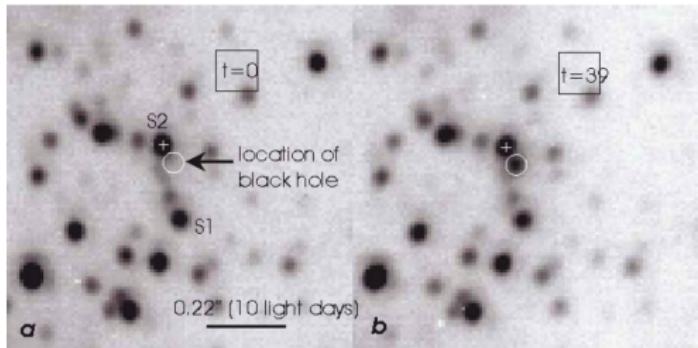
The central dark mass

- Astrometric measurements of close stars → central mass.
- $\text{Sgr A}^* \approx \text{SMBH of } 4.3 \times 10^6 M_\odot, \theta_{\text{app,Sch}} \approx 50 \mu\text{as}$

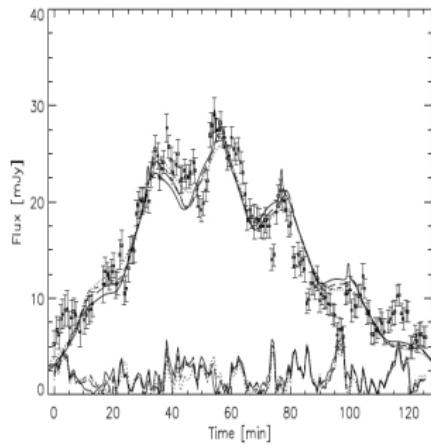


Sgr A* quiescent emission

- Different $\nu \rightarrow$ different r
- **Innermost accretion flow** at few 100 GHz
- **Synchrotron** emission dominates there



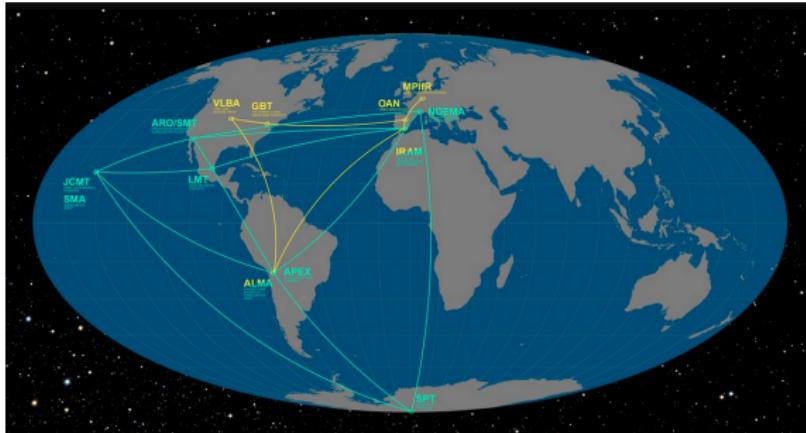
Source : Genzel et al. 2003



Source : Hamaus et al. 2009

Sgr A* flaring state

- Flare = outburst of radiation, lasts $\approx 1\text{h}$, quasiperiodic (?)
- Very debated origin



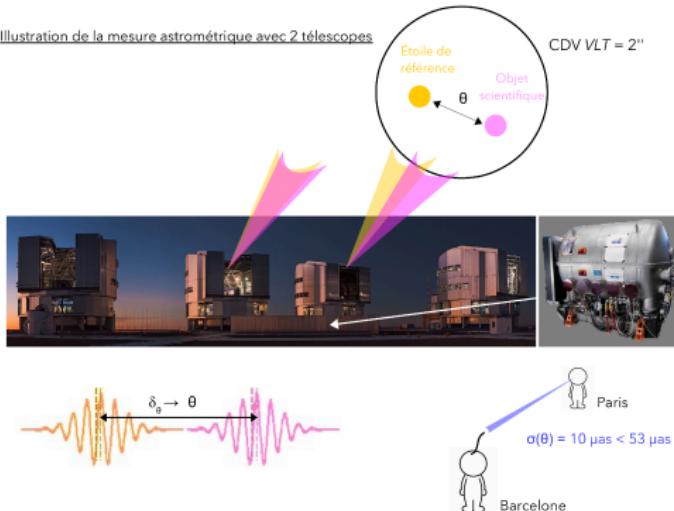
Event Horizon Telescope (2008+)

Quiescent state imaging

- EHT: **25 μ as** resolution (mm; 230 and 345 GHz)
- Goal: image the **black hole shadow** of Sgr A*

→ Doeleman+08, *Nature*, 455, 78; Doeleman+09, *Astro2010 White Paper*

Illustration de la mesure astrométrique avec 2 télescopes



GRAVITY (2016+)

Courtesy M. Gould

Stars follow-up + hot gas motion

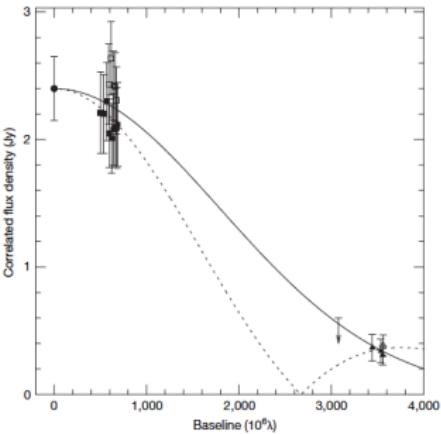
- GRAVITY: **30 μas** astrometric precision (NIR; $\approx 2.2 \mu\text{m}$)
- Goal: follow the motion of **stars / flares** around Sgr A*

→ GRAVITY Collaboration 2017 A&A 602 A94

1 Sgr A* / EHT / GRAVITY

2 What EHT told us / might tell us

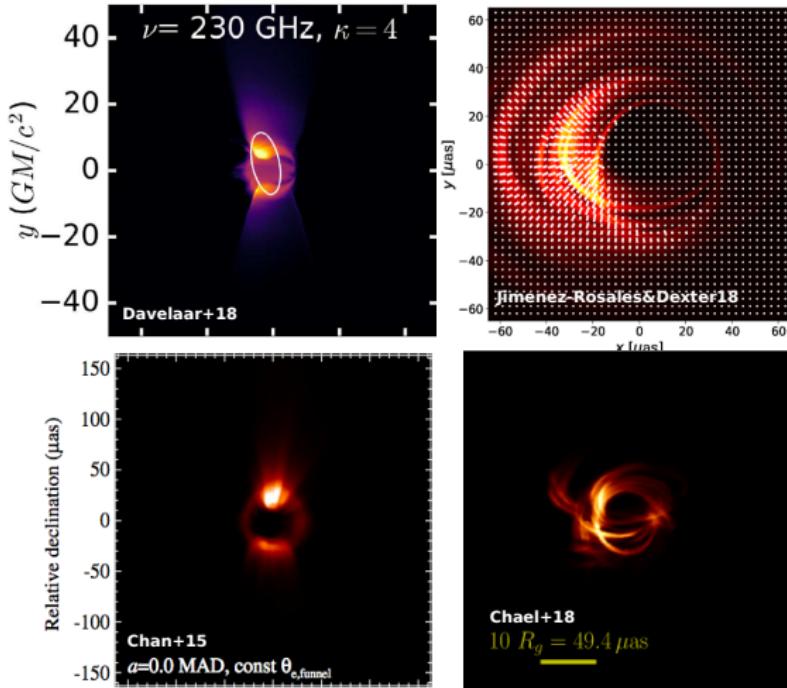
3 What GRAVITY told us / might tell us



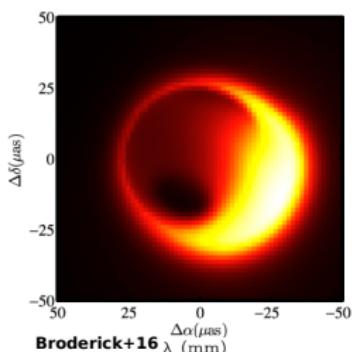
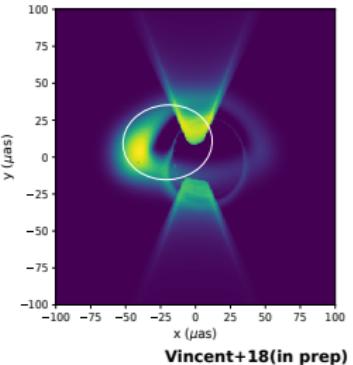
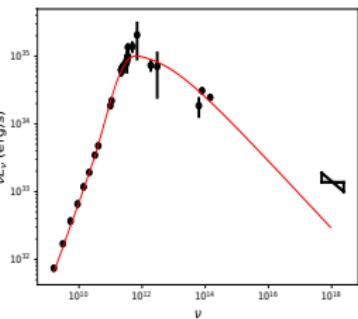
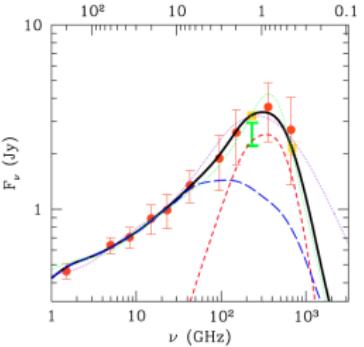
Doeleman+08

Early data: size constraint

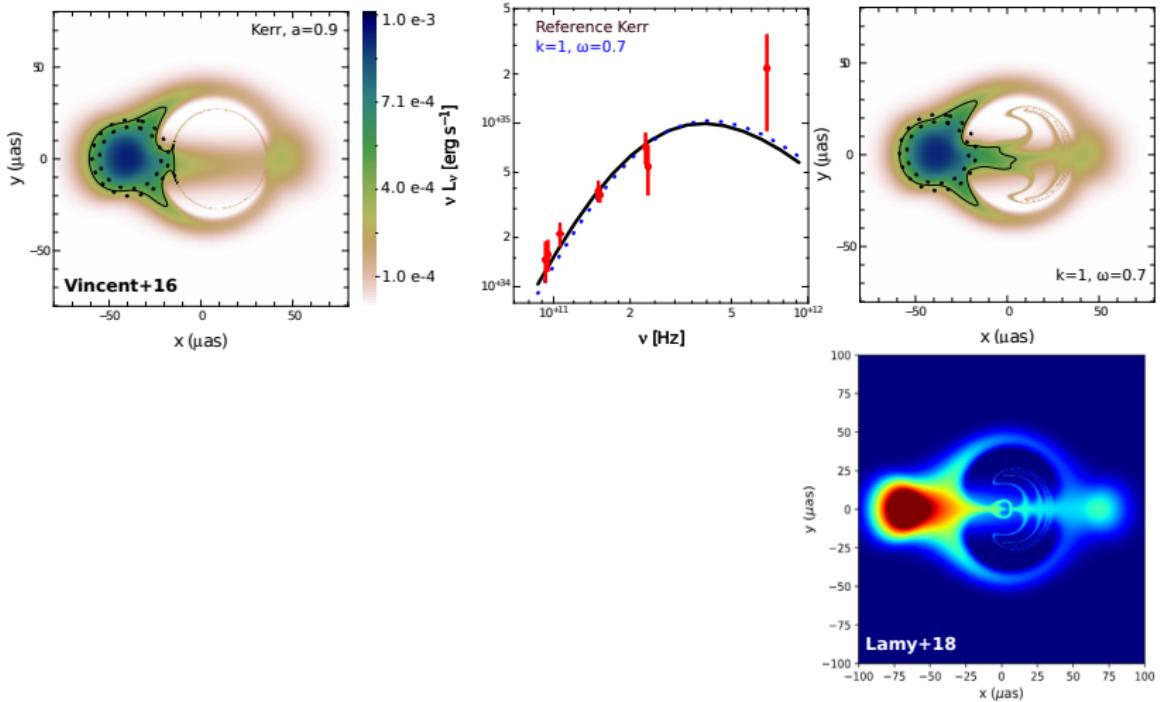
- $\theta = 37_{-10}^{+16} \mu\text{as}$ (3σ) @ 1.3 mm
- 3 stations (Arizona, California, Hawaii)
- Size smaller than apparent size of shadow!
- Since then: more stations, more data gathered



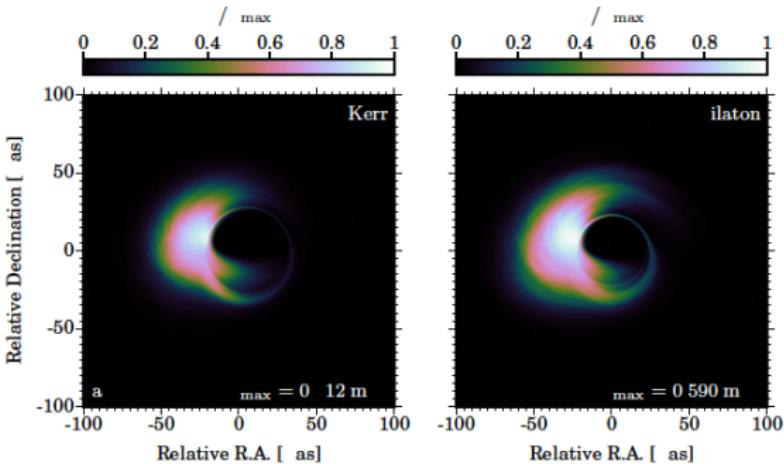
GRMHD modeling of Sgr A*

**Broderick+16** λ (mm)**Vincent+18(in prep)**

Analytical modeling of Sgr A*



Testing the nature of Sgr A*?



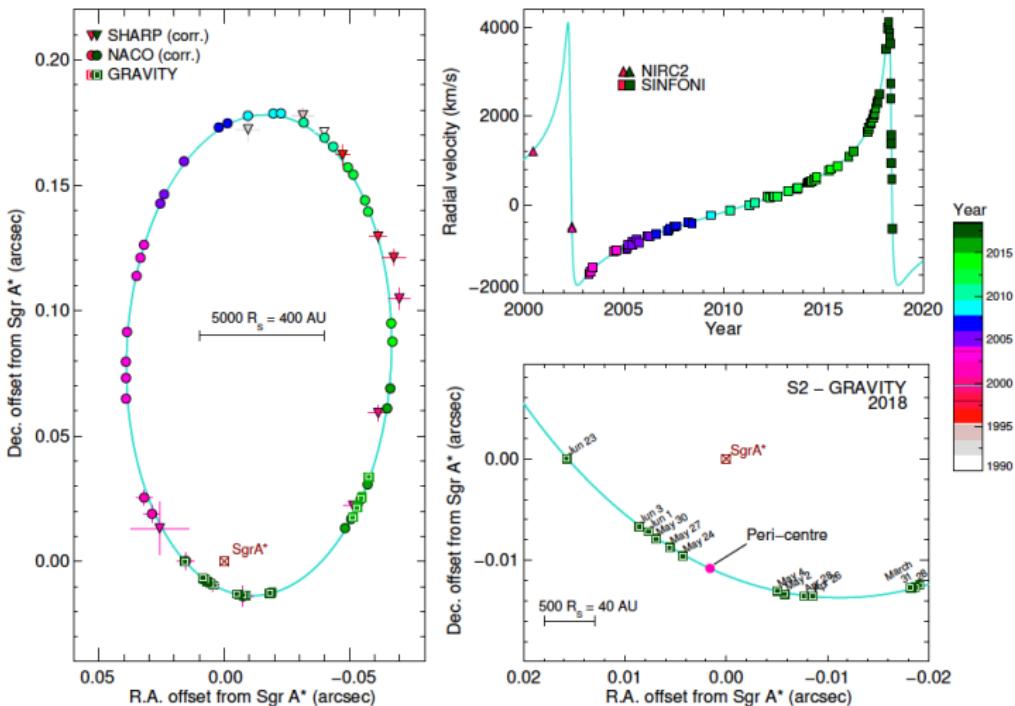
Mizuno+18

Testing gravity?

1 Sgr A* / EHT / GRAVITY

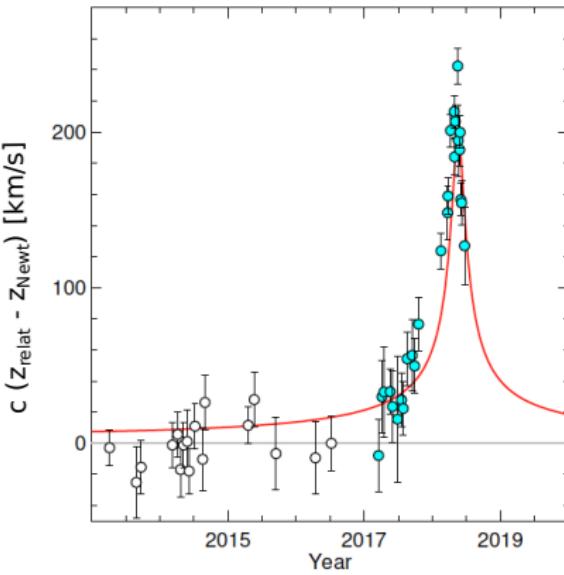
2 What EHT told us / might tell us

3 What GRAVITY told us / might tell us



GRAVITY Collaboration 2018

Following S2 at pericenter passage



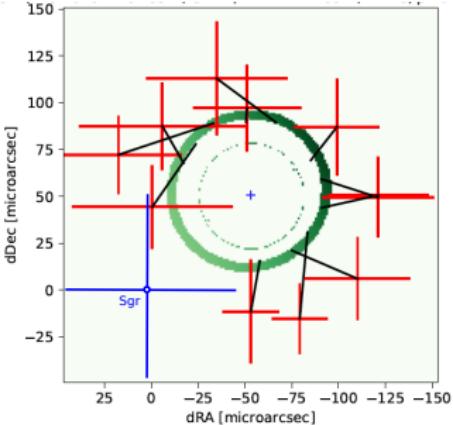
GRAVITY Collaboration 2018

Newtonian vs. Parametrized Post-Newtonian (order 1 in v^2/c^2)

$$\bullet \quad c z = \underbrace{c(z_0 + \text{Doppler} \times \beta)}_{\text{Newtonian}} + \underbrace{c(\text{Transverse Doppler} + \text{Grav. Redshift}) \times \beta^2}_{\text{Relativistic } \approx 200 \text{ km/s}}$$

$\beta = v/c = 2.5\%$





GRAVITY Collaboration 2018 (submitted to A&A)

Breaking news: Orbital motion at the horizon

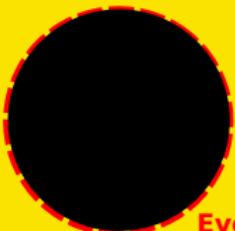
- Flare of July 22: $\Delta t = 30$ min, Flux $m_K = 14.5$ (quiescence: $m_K = 17$)
- Flare location **coincident with Sgr A***
- Motion consistent with **GR circular orbit at $r \approx 7 M$ at spin 0**
with **low inclination** favored $\approx 20^\circ$ (no spin constraint)

Conclusion

- Era of routine strong-field electromag observation starting
- Wealth of information on innermost accretion flow
- Testing the nature of Sgr A* / gravity theory: unclear yet...
...but starts to become less science fiction!

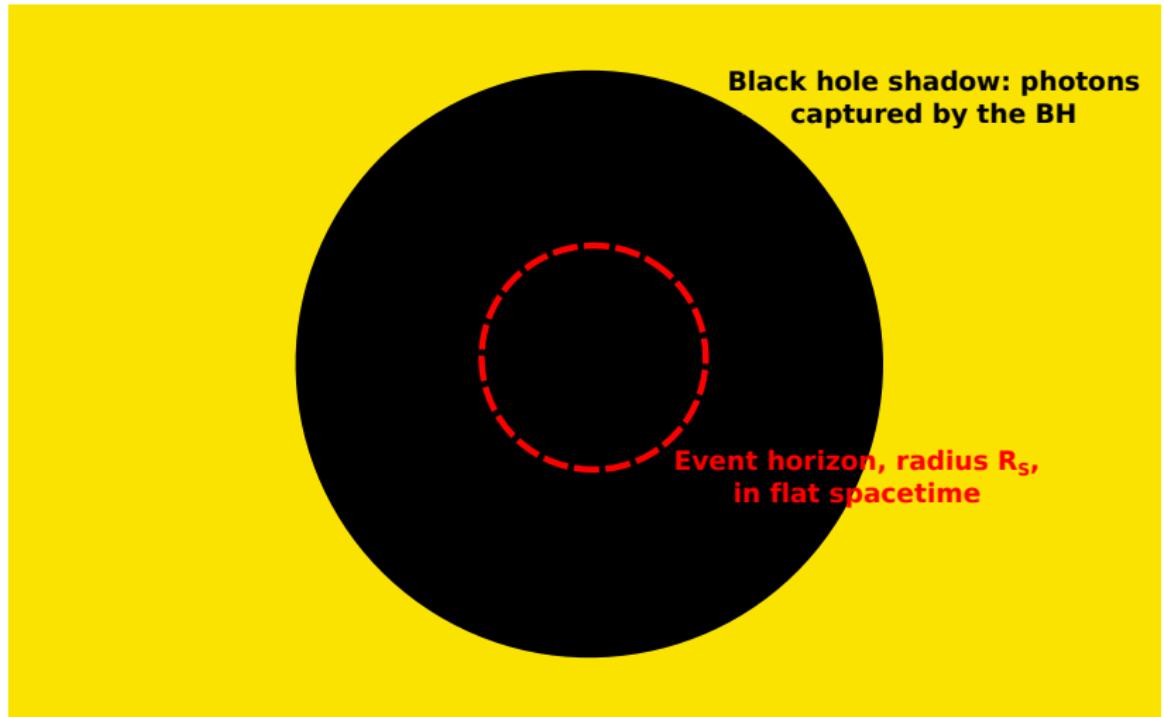
Black hole shadow

Black hole shadow

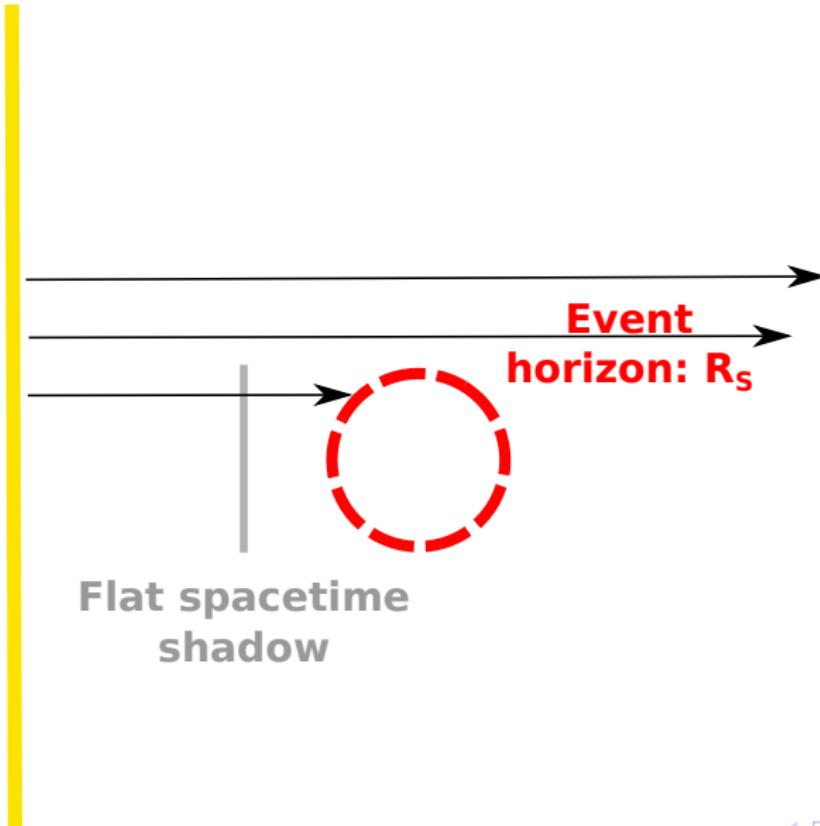


Event horizon, radius R_s ,
in flat spacetime

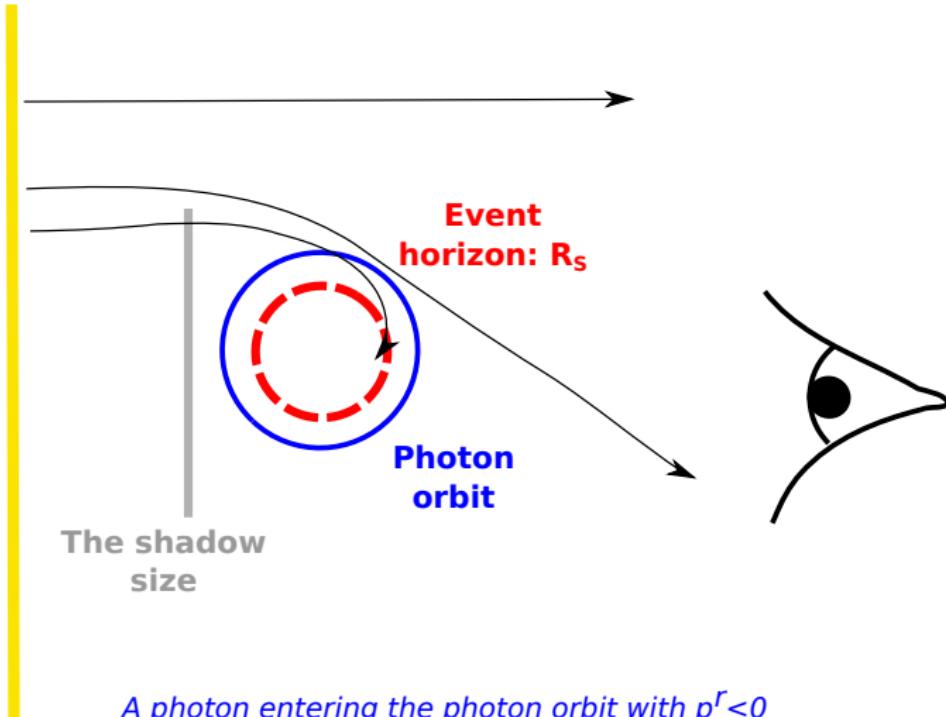
Black hole shadow



Flat spacetime shadow



Black hole shadow



A photon entering the photon orbit with $p^r < 0$ will fall into the event horizon.

So the boundary of the shadow coincides with the image of the photon orbit, called the **photon ring**.

Black hole shadow

