

# **Novel Observable of BH's Mass and Spin**

**exponential gravitational redshift  
near BH horizon**

and a supplemental preliminary result for Sgr A\*  
found after registering for this conference ↓

# **Dark Matter Accumulation around Sgr A\***

**General Relativity fitting with S0-2 star**

### NASA × JAXA Radio Satellite BH Explorer (BHEX) Japan Member for GR theory

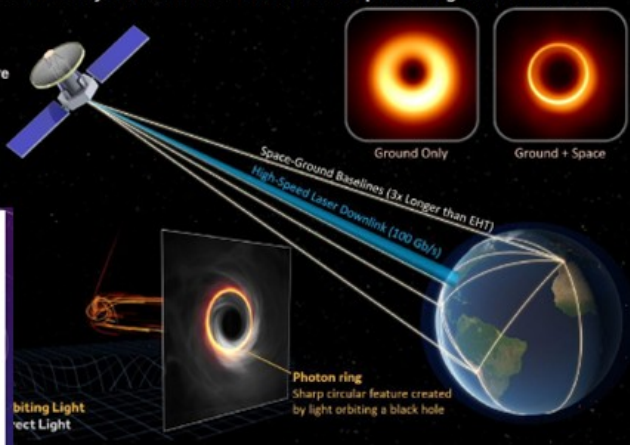
### Black Hole Explorer (BHEX) Mission

BHEX will achieve the highest angular resolution in history and would reveal a black hole's "photon ring" for the first time

- First direct measurement of a black hole's spin
- Opportunity to study dozens of black holes
- Leverages billions of dollars of ground infrastructure
- Explosion of community interest in the photon ring
- Targeting a 2025 SMEX proposal

**Science Goals**

- > Discover a black hole's photon ring



Space-Ground Baselines (3x Longer than EHT)  
High-Speed Laser Downlink (100 Gb/s)

Ground Only      Ground + Space

Photon ring  
Sharp circular feature created by light orbiting a black hole

biting Light  
ect Light

Control Room, Subaru Telescope

Observing the motion of stars orbiting around Galactic Central Black Hole

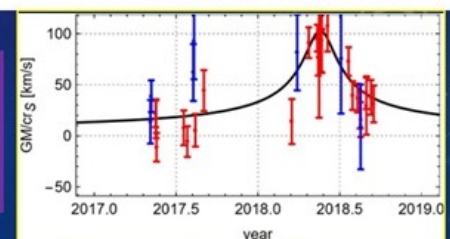
2024  
S0-2  
S2  
+ Sgr A\*  
0.5"

Our target, S0-2  
[Solar System Size] x40  
Galactic Center (Sagittarius)

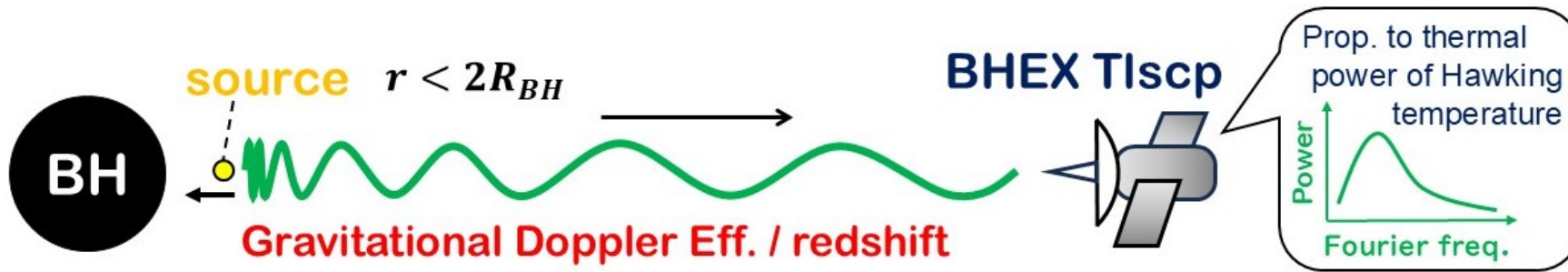
A black hole (Sgr A\*) may be near here, but invisible by definition.

Mauna Kea (Mt.), Hawaii Is.

Extracting GR effects by comparing the data and theoretical predictions for the motion of stars



Subaru Telescope Collaboration of GR theory and Infra-Red obs.

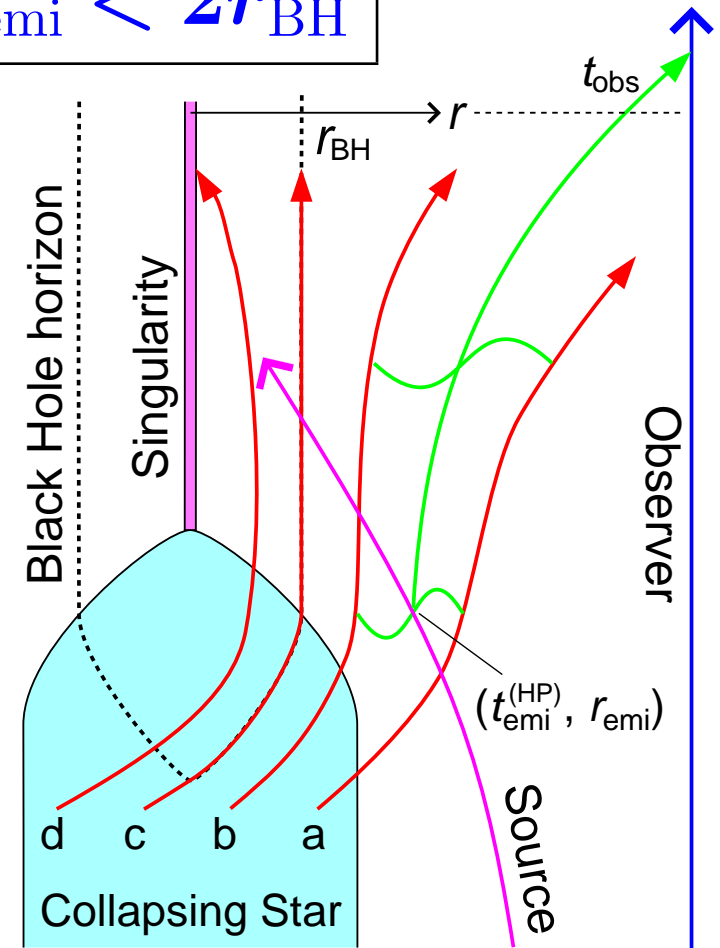
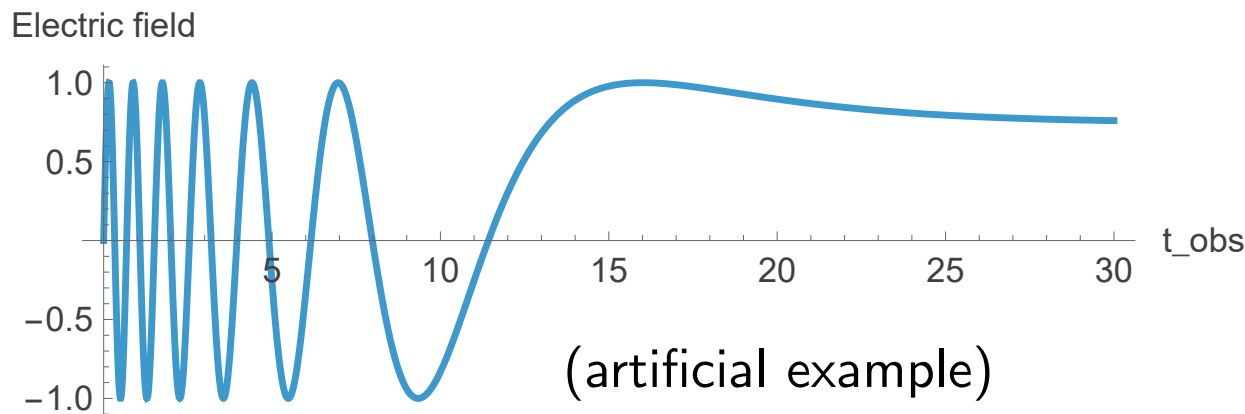


Exponential Redshift at Observer for  $r_{\text{emi}} < 2r_{BH}$

$$\Omega_{\text{obs}}(t_{\text{obs}}) \rightarrow \Omega_{\text{emi}} \exp(-\kappa t_{\text{obs}})$$

$$\kappa = \frac{\sqrt{1 - (a/m)^2}}{2r_{BH}} \quad \text{surface grav. at BH horizon}$$

$\Rightarrow$  Temporal Oscillation of this wave



– Novel Obs. of BH's mass & spin / comments on left panels –

- A light source is falling into Black Hole. (see left figures)
  - Far observer keeps receiving  
photons emitted by the falling source.
  - BH gravity causes **Gravitational Redshift** on each photon.
  - The Grav.Redshift is given by the difference of grav. potential between the emission point ( $r_{\text{emi}}$ ) and obs. point ( $r \rightarrow \infty$ ) and independent of plasma physics.
  - As the falling source approaches to BH horizon, the Grav.Redshit on observed photon get stronger.
  - After the source falling into the BH's vicinity of  $r_{\text{emi}} < 2r_{\text{BH}}$ , the observed frequency decays exponentially as  $t_{\text{obs}}$  goes !
- Left graph is **a typical observed oscillation** of EM wave.

## ⇒ Fourier Power Spectrum of this time series data

$$\left| f_{\text{obs}}(\omega) \right|^2 = \frac{A_{\text{obs}}^2}{\omega} \frac{1 + O(\varepsilon)}{\exp[2\pi\omega/(c\kappa)] - 1} \quad \text{for } r_{\text{emi}} < 2r_{\text{BH}}$$

$$\varepsilon := r_{\text{emi}}/r_{\text{BH}} - 1 \quad (< 1)$$

∝ Thermal spectrum of Hawking temperature  $T_{\text{H}}$

$$T_{\text{H}} = \frac{\hbar c}{k_{\text{B}}} \frac{\kappa}{2\pi} = \frac{\hbar c}{k_{\text{B}}} \frac{\sqrt{1 - (a/m)^2}}{4\pi r_{\text{BH}}}$$

→ **Measuring  $m$  and  $a$  indep. of Plasma effects**

Note: A fluid analog system has already been simulated

(H.Furuhashi, Y.Nambu & [H.Saida](#), 2006, *Class.Quant.Grav.*23, pp.5417)

(gr-qc/0601066)

→ A hint for detecting  $\kappa$  or  $|f_{\text{obs}}(\omega)|^2$  in BHEX?

- The decay rate  $\kappa$  of Grav.Redshift is independent of plasma, and given by only the BH's mass  $m$  and spin  $a$  !
- Further, the Fourier Power of the observed oscillation is proportional to Thermal spectrum of Hawking temperature, which is given by  $\kappa$  indep. of plasma.
- By measuring the Grav.Redshift's decay rate  $\kappa$  through  $\Omega_{\text{obs}}(t_{\text{obs}})$  or  $|f_{\text{obs}}(\omega)|^2$ , BH's mass  $m$  and spin  $a$  can be determined well, independent of plasma physics !

### **Novel Observable of BH's mass and spin**

After the light source falls into  $r < r_{\text{BH}}$ , Measuring the observed EM wave oscillation of exponentially decaying frequency  $\Omega_{\text{obs}}(t_{\text{obs}})$  or its Fourier power spectrum  $|f_{\text{obs}}(\omega)|^2$ , gives us  $\kappa$  to determine BH's mass  $m$  and spin  $a$ .

– DM Accumulation around Sgr A\* / comments on right panel –

- InfraRed obs. of S0-2 star orbiting around Sgr A\* (16yr period)
- GR model including parameters  $A$  and  $B$ 
  - $\left\{ \begin{array}{l} A : \text{Deviation from vacuum BH environment in time} \\ B : \text{Deviation from vacuum BH environment in space} \end{array} \right.$
  - So-called “Parametrized-Post-Newtonian (PPN)” model
  - If BH has vacuum environment,  $(A, B) = (0, 1)$
- Fitting this PPN model with obs. data of S0-2’s motion, the Posterior Prob. Density of  $(A, B)$  is obtained recently.
- Preliminary result is  $(A, B) \neq (0, 1)$  with 98% credibility
  - **Dark Matter Accumulation around Sgr A\* !?**
- Amount of DM around Sgr A\* is under estimation, using an exact GR model of “BH+DM” system.

# Posterior Probability Density of (A,B)

$$p(A, B | \text{data})$$

