Gamma-Ray Emission from an Accretion Flow around a Kerr Black Hole

- measuring the spin of a central BH -

Kazutaka Oka (Kobe Univ.)

&

Tadahiro Manmoto (Chiba Univ.)

Motivation

- How can we measure the spin parameter of a central BH?

  → Do Kerr BHs exist in the universe?

- What is the sign of a Kerr BH?

We examine whether gamma-ray can be a useful tool to investigate the spin parameter

- Based on the *standard disk model*, relativistically smeared Fe K**α** line in the spectrum from some AGNs are considered to be a sign of near-extremal Kerr black hole. (Tanaka et al. 1995; Iwasawa et al. 1996)

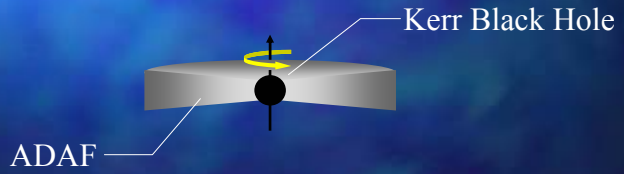
  How can we measure the spin of a black hole with *optically thin* accretion flow?

Schematic View

- Accretion flow:

  optically thin advection-dominated accretion flow (ADAF)

- BH: Kerr Black Hole



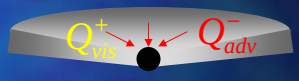
ADAF

Advection-dominated disk (Ichimaru 1977; Narayan & Yi 1994)

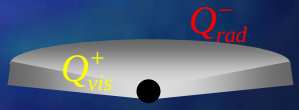
$$Q^{+}_{vis} \cong Q^{-}_{adv} >> Q^{-}_{rad}$$

- optically thin
- high temperature
- geometrically thick
- low radiative efficiency
- thermally stable

• Advection



• local radiative cooling



Spectrum of ADAF

- ADAF spectrum is determined by the electron cooling processes such as

  Bremsstrahlung, Synchrotron radiation, Comptonization

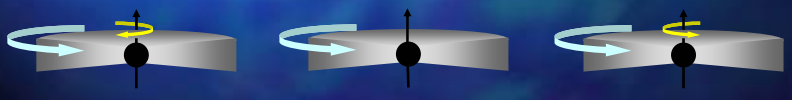
- *Gamma-ray emission* by proton cooling can be calculated with no additional parameters

  (Mahadevan et al. 1997)

Kerr Black Hole

- Kerr black hole is a rotating and non-charged black hole
- The rotational speed of the Kerr black hole is represented by the dimensionless spin parameter: a $(-1 < a < 1, a \equiv Jc/GM^2)$

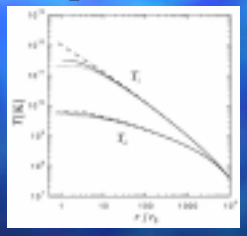
J: BH angular momentum, M: BH mass
c: speed of light, G: gravitational constant

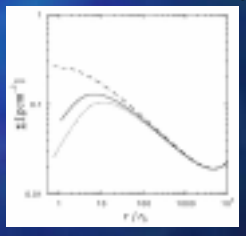


a<0 a=0 a>0

ADAF around Kerr Black Hole

- BH rotation modifies the inner structure of ADAF ($R \leq 10R_s$)
  - temperature
  - surface density





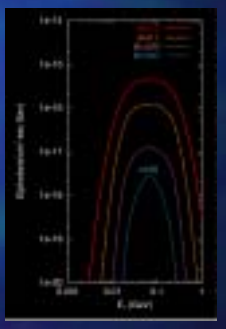
The temperature and the surface density for $a = 0$ (*solid line*), $a = 0.95$ (*dashed line*), and $a = -0.95$ (*dotted line*). At around R~1Rs, BH rotation ($-0.95 < a < 0.95$) modifies the ion temperature by an order of magnitude (Manmoto 2000)

Gamma-ray Emission Mechanism

- In the vicinity of a central BH, ADAF becomes extremely hot. In such a extremely hot plasma, the gamma-rays are produced through the proton-proton collisions

$$P + P \rightarrow P + P + \pi^0$$
$$\pi^0 \rightarrow \gamma_1 + \gamma_2$$

P : proton
π : neutral pion
γ : gamma-ray



Gamma-ray spectrum from the thermal protons.
θ is the dimensionless proton temperature

Model Description

Physical Assumptions

- Viscous dissipations mainly heat the ions
- ADAF forms two temperature plasma

  The ions transfer only a small fraction of their energy to electrons via Coulomb scattering
- Electron energy distribution is thermal

  The electrons are thermalized with $\dot{m} > 10^{-4}$

  (Mahadevan & Quataert 1997)

Physical Assumptions

The mechanism of the viscous heating in the ADAF is not well understood.

(Mahadevan & Quataert 1997)

Thus, we consider the following 3 cases

- proton energy distribution is
  - thermal distribution
  - power-law distribution
  - mixture of the two

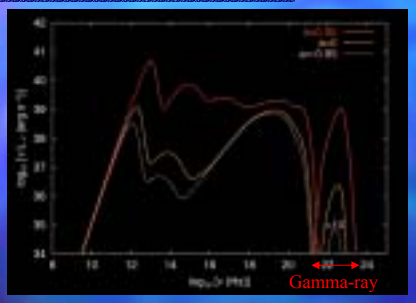
Parameters for ADAF

- mass of the central BH: $m\ (= M / M_{sun})$
- mass accretion rate: $\dot{m}\ (= \dot{M} / \dot{M}_{Edd})$
- viscous parameter: α
- pressure ratio: β

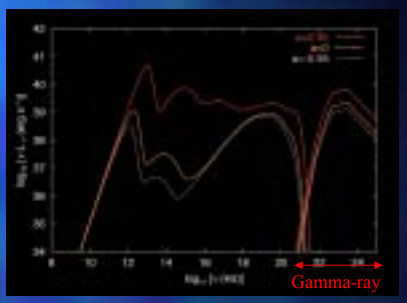
  = gas pressure / (gas + magnetic pressure)
- spin parameter: a

Results

Result 1: Supermassive Black Hole



thermal



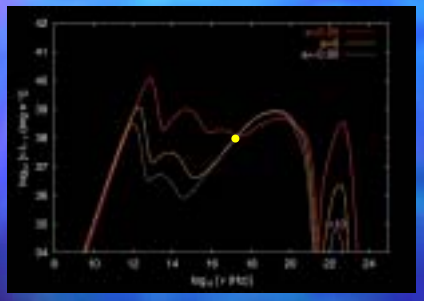
power-law

$m = 10^8$ $\beta = 0.5$

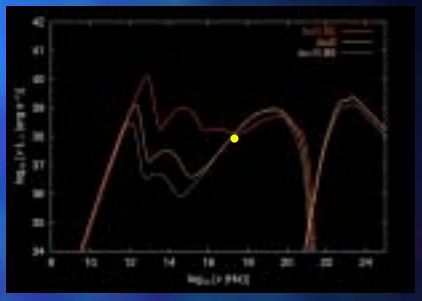
$\dot{m} = 10^{-3}$ $a = -0.95, 0, 0.95$

$\alpha = 0.1$

Spectrum from the radio to the gamma-ray. All parameters except the spin parameter are fixed



thermal



power-law

$m = 10^8$ $(a, \dot{m}) =$

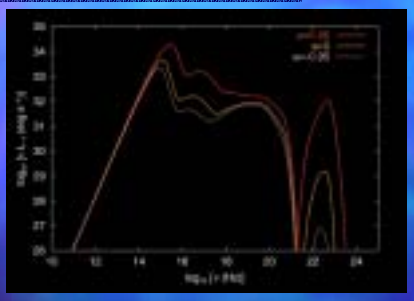
$\alpha = 0.1$ $(-0.95, 1.03\times10^{-3})$

$(0, 10^{-3})$

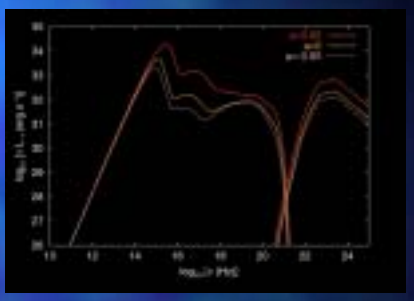
$\beta = 0.5$ $(0.95, 5.8\times10^{-4})$

Spectrum from the radio to the gamma-ray. Mass accretion rates are modified so that the X-ray flux is the same

Result 2: Stellar-mass Black Hole



thermal



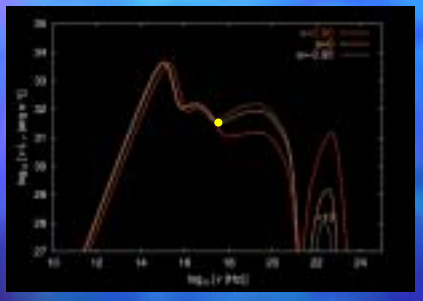
power-law

$m = 10$ $\beta = 0.5$

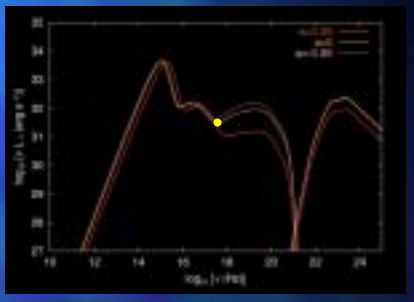
$\dot{m} = 10^{-3}$ $a = -0.95, 0, 0.95$

$\alpha = 0.1$

Spectrum from the radio to the gamma-ray. All parameters except the spin parameter are fixed



thermal



power-law

$m = 10$ $(a, \dot{m}) =$

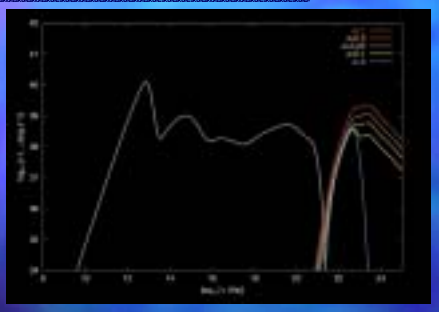
$\alpha = 0.1$ $(-0.95, 1.36\times10^{-3})$

$(0, 10^{-3})$

$\beta = 0.5$ $(0.95, 3.7\times10^{-4})$

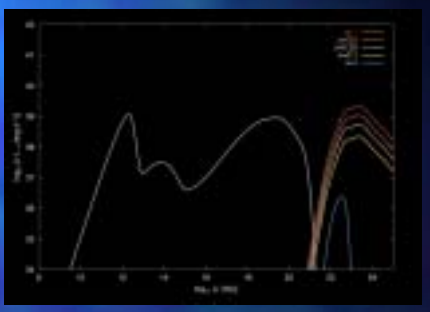
Spectrum from the radio to the gamma-ray. Mass accretion rates are modified so that the X-ray flux is the same

Result 3: mixture distributions



a=0.95

Same parameters as in result 1



a=0

Δ =0 ; all viscous energy goes to the thermal

Δ =1 ; all viscous energy goes to the power-law

Summary (thermal distribution)

- If the proton energy distribution is thermal, the gamma-ray intensity increases by orders of magnitude when the spin parameter is varied from –0.95 to 0.95

  → Gamma-ray spectrum can be a probe to investigate the spin parameter

Summary (power-law distribution)

- If the proton energy distribution is power-law, the gamma-ray intensity is much less sensitive to the changes in the spin parameter than in the thermal model
  - → It is not easy to estimate the spin parameter from gamma-rays

Summary (mixture distribution)

- If the proton energy distribution is mixture of the thermal and the power-law, the gamma-ray intensity from the thermal component is overwhelmed by the power-law component.
  - → It is also not easy to estimate the spin parameter from gamma-rays