Spins of the SMBH in M87: new constraints from TeV observations

Yan-Rong Li

Jian-Min Wang

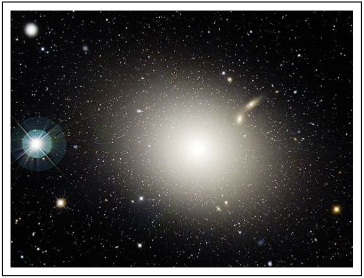
Key Laboratory for Particle Astrophysics, Institute of High Energy Physics, CAS

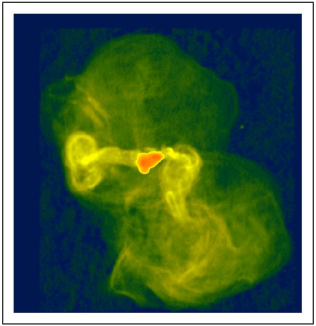
2008.04

1. Introduction

- This work uses the TeV variability detected in M87 to constrain the spin of the central SMBH (published in ApJ 2008,676,L109).
- The TeV variability implies an extremely compact emission region near the black hole. We find the transparent radii of 10 TeV photons are strongly dependent on the black hole's spin.
- The black hole in M87 is spinning fast.

2. TeV Variability in M87





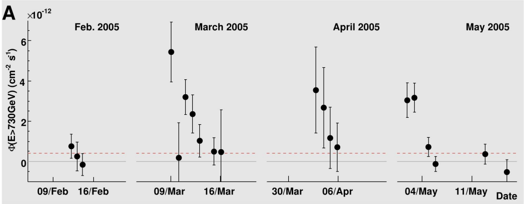
M87

a radio galaxy (z=0.0043),

$M_\bullet = 3.2 \times 10^9 M_\odot$,

inclination of the jet: $\sim 30^\circ$ (Bicknell 1996) .

2. TeV Variability in M87



(Aharonian 2006)

- H.E.S.S.(Aharonian 2006) observed TeV variabilities on time scales of $\Delta t \sim 2$ days.
- The characteristic size $R \leq c\Delta t\delta \approx 10\delta R_g$.
- The possible source of the TeV γ-rays is the nucleus of M87 itself (Aharonian 2006).

Due to interaction with radiation field of the accretion disk around the BH, the TeV photon are diluted via pair production. When the energies of the colliding photons satisfy the relation,

$$\epsilon_1 \epsilon_2 = \frac{2}{(1-\mu)(1-v^2)},$$

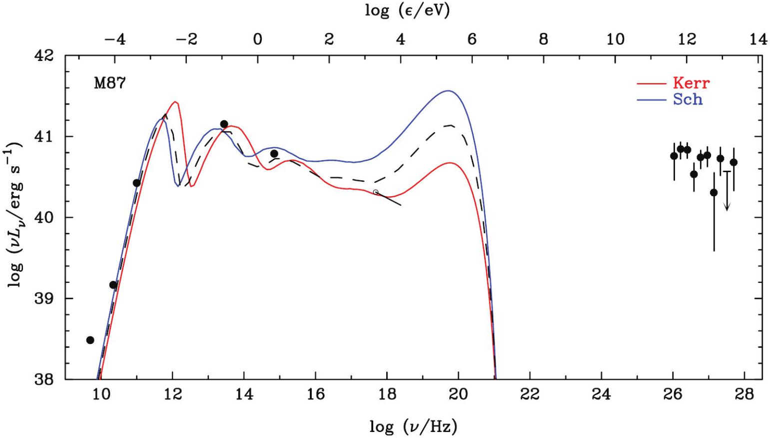
pair production will occur (Gould & Schérder 1967),

$$\gamma + \gamma \rightarrow e^{\pm}.$$

Naturally, We may think about

- Can TeV photons escape out of the radiation field?
- The differences between the maximally rotating and nonrotating BHs in term of the optical depth to the TeV photons?

3. ADAF in M87



radio, VLBI; IR, Gemini observation; optical, HST; X-ray, Chandra.

$L \sim 10^{41}$ergs s^{-1}, indicating an Eddington ratio $\sim 10^{-6}$ and ADAF at work.

For simplicity, we use a self-similar solution of the ADAF (Naranyan & Yi 1994)

There are five free paremeters (α, β, $\dot{m}$, $M_\bullet$, $R_{\rm in}$). Typically,

- $\alpha = 0.3$ and $f = 0.99$,
- β and $\dot{m}$ are determined by fitting the spectrum,
- $R_{\rm in}$ is related to the spin.

Radiation mechanics in ADAF,

1. Synchrotron emission from moderately relativistic electrons,
   $L_{\rm Syn} \sim \dot{M}$.
2. Multiple inverse Compton scatterings,
   $L_{\rm IC1} \sim \dot{M}^2$, $L_{IC2} \sim \dot{M}^3$.
3. Bremsstrahlung emission,
   $L_{\rm Brem} \sim \dot{M}^2$.

3. ADAF in M87

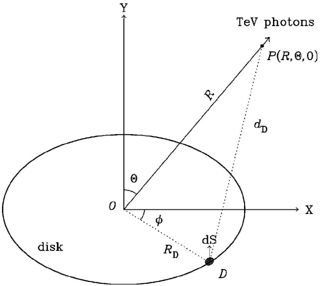
Giving a spin, we adjust $(\beta, \dot{m})$ to fit the spectrum.

$$v = -2.12 \times 10^{10} \alpha c_1 r^{-1/2} \text{ cm s}^{-1},$$
$$\Omega = 7.19 \times 10^{4} c_2 m^{-1} r^{-3/2} \text{ s}^{-1},$$
$$c_s^2 = 4.50 \times 10^{20} c_3 r^{-1} \text{ cm s}^{-2},$$
$$\rho = 3.79 \times 10^{-5} \alpha^{-1} c_1^{-1} c_3^{-1/2} m^{-1} \dot{m} r^{-3/2} \text{ g cm}^{-3},$$
$$p = 1.71 \times 10^{16} \alpha^{-1} c_1^{-1} c_3^{1/2} m^{-1} \dot{m} r^{-5/2} \text{ g cm}^{-1} \text{ s}^{-2},$$
$$B = 6.55 \times 10^{8} \alpha^{-1/2} (1-\beta)^{1/2} c_1^{-1/2} c_3^{1/4} m^{-1/2} \dot{m}^{1/2} r^{-5/4} \text{ G},$$
$$q^{+} = 1.84 \times 10^{21} \epsilon' c_3^{1/2} m^{-2} \dot{m} r^{-4} \text{ ergs cm}^{-3} \text{ s}^{-1},$$
$$n_e = \rho/\mu_e m_u = 2.00 \times 10^{19} \alpha^{-1} c_1^{-1} c_3^{-1/2} m^{-1} \dot{m} r^{-3/2} \text{ cm}^{-3},$$
$$\tau_{es} = 2 n_e \sigma_T H = 12.4 \alpha^{-1} c_1^{-1} \dot{m} r^{-1/2},$$

(Narayan & Yi 1995)

1. For a=1 (Kerr BH),
   $\beta = 0.35, \ \dot{m} = 5.5 \times 10^{-4}.$
2. For a=0 (Schwarzschild BH)
   $\beta = 0.35, \ \dot{m} = 2.0 \times 10^{-3}.$
3. For a=0.65,
   $\beta = 0.35, \ \dot{m} = 1.1 \times 10^{-3}.$

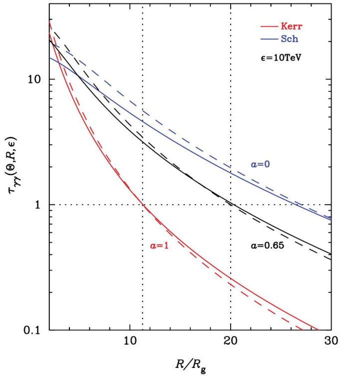
Once the spectrum is obtained, the optical depth of the radiation field to the TeV photons reads,



$$\tau_{\gamma\gamma}(\Theta, R, \epsilon) = \int_R^{\infty} \mathrm{d}R \int_{R_{\rm in}}^{R_{\rm out}} R_{\rm D} \mathrm{d}R_{\rm D} \int_0^{2\pi} \mathrm{d}\phi$$

$$\times \int_{\epsilon_t} \mathrm{d}\epsilon' \sigma_{\gamma\gamma}(\epsilon, \epsilon', \mu) n_{\rm ph}(\Theta, R, \epsilon', R_{\rm D}).$$

4. The Hole's Spin estimated from the TeV Variability

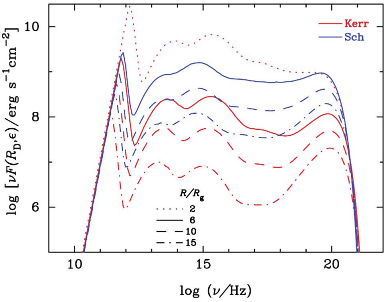


The transparent radius R_c ($\tau_{\gamma\gamma=1}$) are,

1. $R_c = 11R_g$ for a=1.
2. $R_c = 26R_g$ for a=0.
3. $R_c = 20R_g$ for a=0.65.

4. The Hole's Spin estimated from the TeV Variability

The underlying physics,



- Given a bolometric luminosity, most of the gravitational energy is released in a more compact region for a rapidly spinning black hole,
- This leads to a steeper $\tau_{\gamma\gamma} - R$ relation around a Kerr black hole and therefore facilitates the escape of TeV photons from the small radii.

5. Conclusions

- The detection of ∼10 TeV photons in M87 indicates $\tau_{\gamma\gamma} < 1$ for these photons. The results based on ADAF model show that the spin of SMBH in M87 probably
$$a > 0.65.$$
- The TeV variability can be used to probe the innermost regions around the central black hole and allows us to disentangle the spin from other parameters in modeling the continuum spectrum.

5. Conclusions

- For simplicity, we use the self-similar solution of ADAF under the Newtonian time-space. However, accurate measurements of the spin rely on global calculations of the fully relativistic ADAF and timescale measurements of TeV variability to confine the dimensions of the emission region.
- Future H.E.S.S. observations may reveal the TeV variability similar to that of M87 in LLAGNs,such as radio galaxies and LINERs.

The fully relativistic calculations are ongoing...

THANK YOU!