Black hole masses and Doppler factors of γ-ray active galactic nuclei

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Outline

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- Our model
- Sample
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Introduction

1.1 Radiative mechanisms of γ-ray blazars

- Hadronic models

- Leptonic models

1.2 Leptonic models

According to the different origins of the soft photons, the leptonic models can be classified as two groups:

- **SSC models:** The synchrotron photons are both produced and Compton up-scattered by the same population of relativistic electrons in the jets of gamma-ray blazars.
- **ERC models:** The origins of soft seed photons may include the cosmic microwave background radiation, the radiation of the accretion disk (including photons from the disk scattered by surrounding gas and dust), infrared emission from the dust or/and a putative molecular torus, and broad-line regions, etc.

1.3 several different approaches to estimate the Doppler factor

- Synchrotron self-Compton Doppler factor

derived from the VLBI core sizes and fluxes, and X-ray fluxes, on the assumption of the X-ray emission being produced by the SSC processes in the jets.

- equipartition Doppler factor

derived on the assumption of energy equipartition between the particles and the magnetic fields in the jet components.

- Variability Doppler factor

derived on the assumption that the associated variability brightness temperature of total radio flux density flares are caused by the relativistic jets.

Our model

2.1 Inverse Compton radiative processes

Assuming that blobs are moving with a constant velocity at an angle $\mu_{obs}=\cos i$ with respect to the line of sight, we have the inverse Compton scattered γ-ray flux density S_C (Dermer, Sturner & Schlickeiser 1997) :

$$S_C = \frac{\delta_\gamma^{4+2\alpha}}{\alpha+2}\frac{c\sigma_T u_i^* n_{eo} V_b}{16\pi d_L^2}(1+z)^{1-\alpha}\frac{(1+\mu_{obs})^{2+\alpha}}{\mu_{obs}}\frac{\epsilon_{obs}^{-\alpha}}{(\overline{\epsilon}^*)^{1-\alpha}}, \quad (1)$$

here is δ_γ the Doppler factor, α is the gamma-ray photon energy spectral index, d_L is the luminosity distance, ε is the dimensionless photon energy in units of the electron rest mass energy, u_i^* is the energy density of the soft seed photons in the blob's frame in units of ergs cm^{-3}, n_{eo} is the number density of electron in the blob, V_b is the volume of the blob, and σ_T is the Thomson cross section.

The total cross section $S_T \cong \sigma_T n_{eo} V_b = \xi \pi r_b^2$, where r_b is the radius of the blob. For the optically thin, homogenous spherical blob located near the central black hole, we have $\xi = 4\tau/3$, where $\tau = \sigma_T n_{eo} r_b$ is the optical depth of the blob. The parameter ξ, which is required $\xi < 1$, is adopted to describe the optical depth of the blob.

For γ-ray blazars, there is $\mu_{obs} \approx 1$. So Eq.(1) becomes:

$$S_C = \frac{\delta_\gamma^{4+2\alpha}}{\alpha+2} \frac{c\xi r^2 u_i^*}{16\pi d_L^2} (1+z)^{1-\alpha} 2^{2+\alpha} \frac{\epsilon_{obs}^{-\alpha}}{(\overline{\epsilon}^*)^{1-\alpha}}. \quad (2)$$

The soft seed photons are assumed to be from the different line emission. The observed γ-ray flux density is the sum of inverse Compton scattered flux densities contributed by different emission lines:

$$S_C = S_{C,H\beta} + S_{C,MgII} + S_{C,CIV} + S_{C,Ly\alpha} \cdots = \sum_i^n S_{C,i}. \quad (3)$$

2.2 Size of the blob

The size of the blob can be estimated from the observed γ-ray variability time-scale:

Hartman et al. (1996): ~100R_g for 3C279
Ghisellini et al. (1996): ~ 200R_g for a typical QSO
Montigny et al. (1997): ~ 123R_g for 3C273

(R_g is Schwarzchild radius, $R_g=2GM_{bh}/c^2$)

In this work, we take $r_b=120R_g$ in our calcutions.

2.3 Soft photon energy density in the blob's flame

The observed flux of the broad emission line is

$$f_{\rm line,i} = \frac{L_{\rm BLR,i}}{4\pi d_{\rm L}^2}, \qquad (4)$$

The energy density of this emission line in the blob is given by

$$u_{\rm i}^* = \frac{1}{c}\left(\frac{d_{\rm L}}{R_{\rm BLR,i}}\right)^2 f_{\rm line,i}, \qquad (5)$$

Eq.(5) is only valid for the blob near the central black hole. At this work, we only consider the case of the blob be located near the central black hole.

2.4 Sizes of broad emission line regions

Deriving the sizes of broad emission lines Hβ, MgII and CIV from the optical or UV continuum luminosity by using the empirical relations (6),(7) and (8), respectively:

Hβ
(Kaspi et al. 2000):

$$R_{\rm BLR} = 32.9 \times \left(\frac{\lambda L_{5100}}{10^{37}{\rm W}}\right)^{0.7} {\rm lt-day}. \quad (6)$$

MgII
(Mclure & Jarvis 2000):

$$R_{\rm BLR} = 28.4 \times \left(\frac{\lambda L_{3000}}{10^{37}{\rm W}}\right)^{0.47} {\rm lt-day}, \quad (7)$$

CIV
(Vestergaard 2002):

$$R_{\rm BLR} = 10.9 \times \left(\frac{\lambda L_{1350}}{10^{37}{\rm W}}\right)^{0.7} {\rm lt-day}. \quad (8)$$

2.5 The black hole mass

The central black hole masses of AGNs can be estimated on the assumption that motions of the gases in BLRs are virilized from the width of the emission line. We use the empirical relation between the size of the BLR R_{BLR} and the optical continuum luminosity L_λ to estimate the size of the BLR R_{BLR}. The black hole mass is given by

$$M_{\rm bh} = 2.25 \times R_{\rm BLR} V_{\rm FWHM}^2 G^{-1}, \quad (9)$$

2.6 The Doppler factor δ_γ

The Doppler factor δ_γ is given by

$$\delta_\gamma = 2^{\frac{2-\alpha}{4+2\alpha}}(1+z)^{\frac{\alpha-1}{4+2\alpha}}(\alpha+2)^{\frac{1}{4+2\alpha}}\left(\frac{c\xi r_{\rm b}^2}{S_{\rm C}d_{\rm L}^2}\right)^{-\frac{1}{4+2\alpha}}\left(\sum\frac{u_{\rm i}^*}{(\bar{\epsilon}_{\rm i}^*)^{1-\alpha}}\right)^{-\frac{1}{4+2\alpha}}\epsilon_{\rm obs}^{\frac{\alpha}{4+2\alpha}}. \quad (10)$$

As the parameter ξ is required to be less than unit, the lower limit of the Doppler factor δ_γ can be obtained, if $\xi = 1$ is adopted.

Sample

- The selection criterion :

  the FWHM of at least one of the following broad emission lines Hβ, MgII and CIV and the fluxes are available.

- This leads to 36 sources.

  30 sources are the high-confidence identication blazars and 6 sources are the lower-confidence potential blazar identications listed in Hartman et al. (1999).

Results

- our model favors ERC models.

- The sizes of BLRs in AGNs are estimated.

- The photon energy density in the relativistic blobs near the massive BHs in AGN is derived.

- The Doppler factors δ of the blobs for a sample of 36 γ-ray AGNs are derived (range: ~3-17).

- The central BH masses of these γ-ray AGNs are estimated (range: ~10^8-$10^{10} M_\odot$).

- A significant correlation is found between the Doppler factor δ and the core dominance parameter *R*.

Doppler factors derived in this work are compared with the variability Doppler factors.

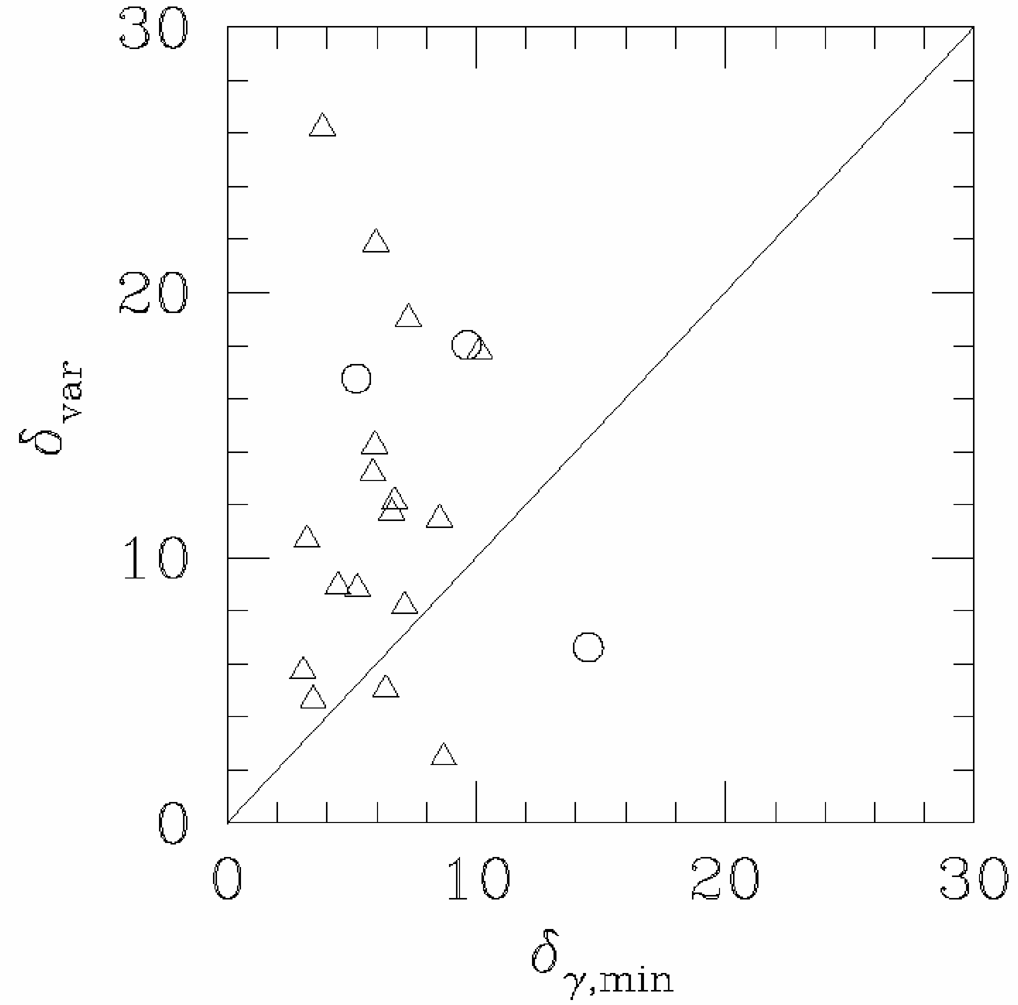

Fig. 1.— The variability Doppler factor δ_{var} vs. the Doppler factor $\delta_{\gamma,min}$ derived in this work. The circles represent BL Lac objects, while the triangles represent quasars.

Range:

10^{8}-$10^{10}M_{\odot}$

Average:

$2\times10^{9}M_{\odot}$

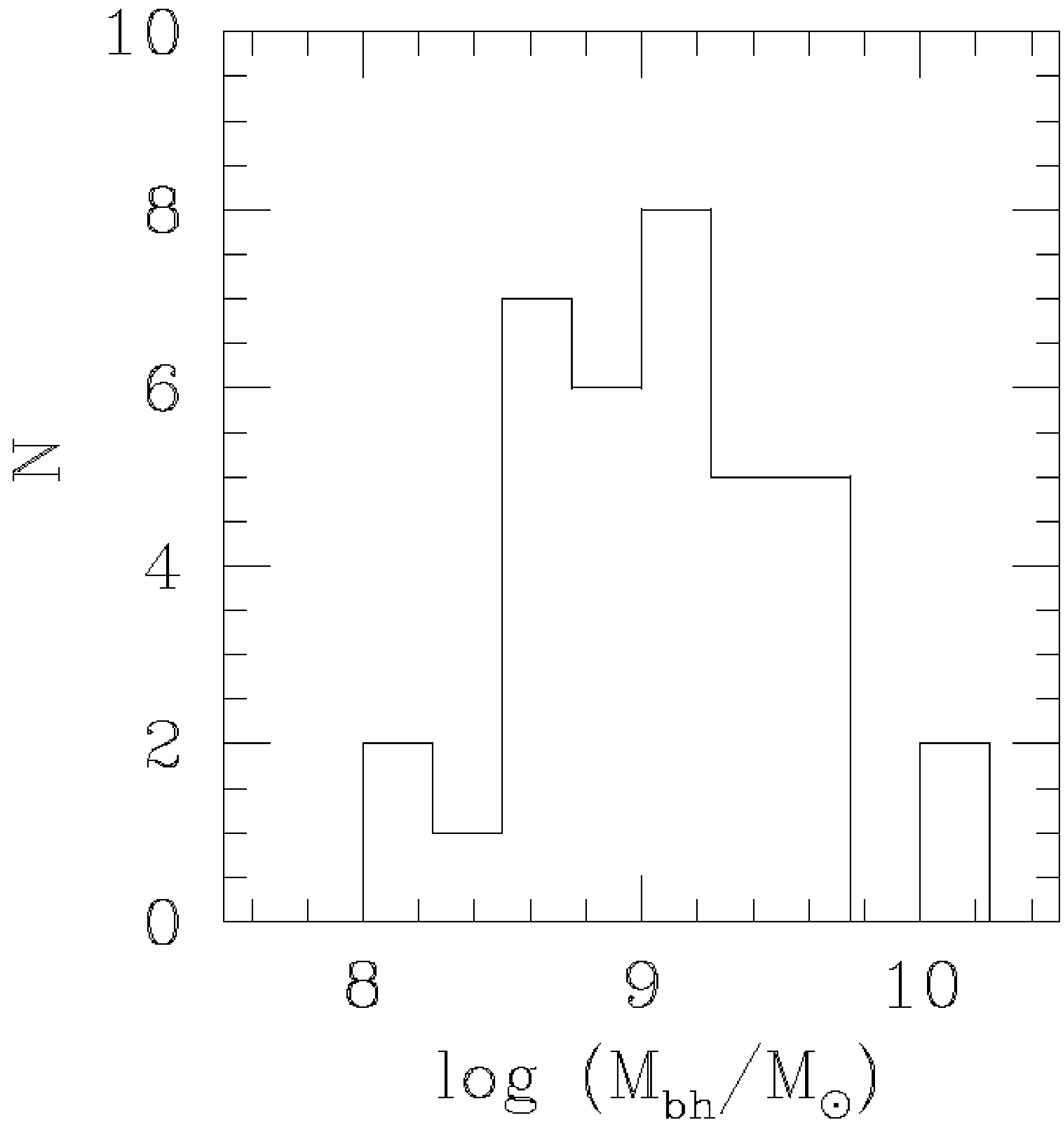

Fig. 5.— The distribution of the black hole masses.

A correlation between the Doppler factor δ_γ and the core dominance parameter *R* is found at a significant level of 97.5 per cent.

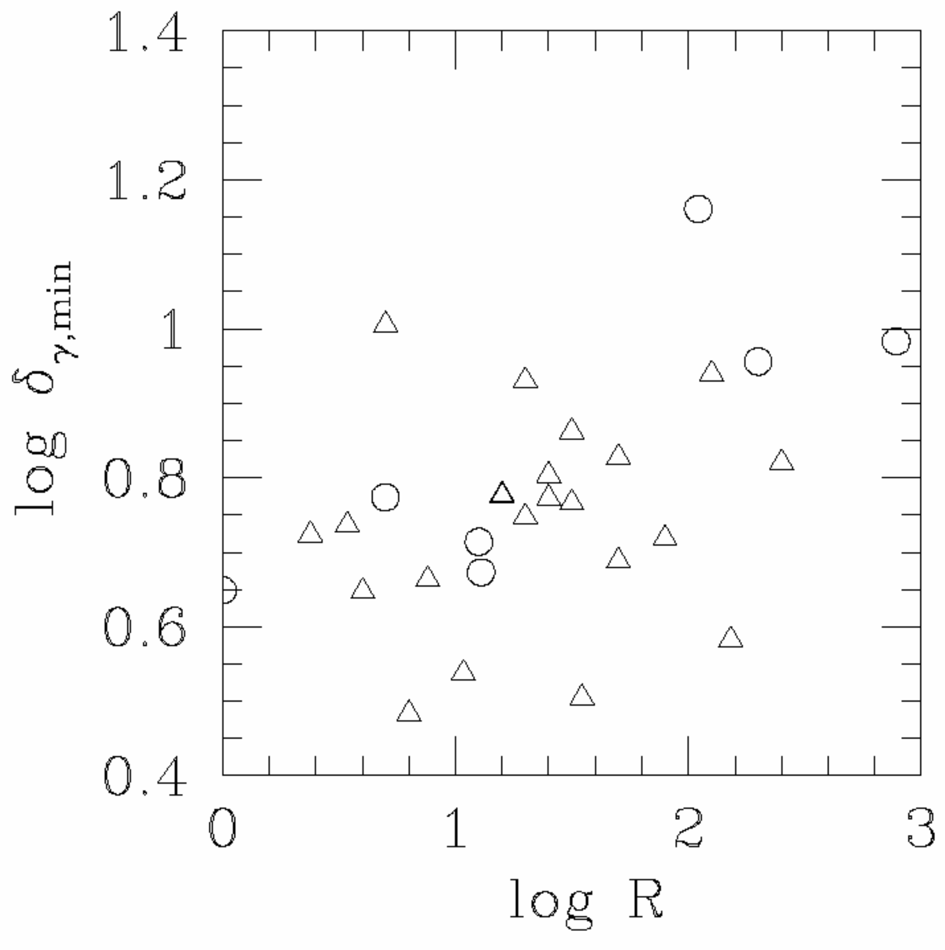

Fig. 3.— The core dominance parameter R vs. the Doppler factor $\delta_{\gamma,\mathrm{min}}$.

Thank you!