PENNSTATE

Astronomy & Astrophysics

The Correlation Between the Hard-X-ray Photon Index and the Accretion Rate in AGN: Probing Black-Hole Growth Across Cosmic Time

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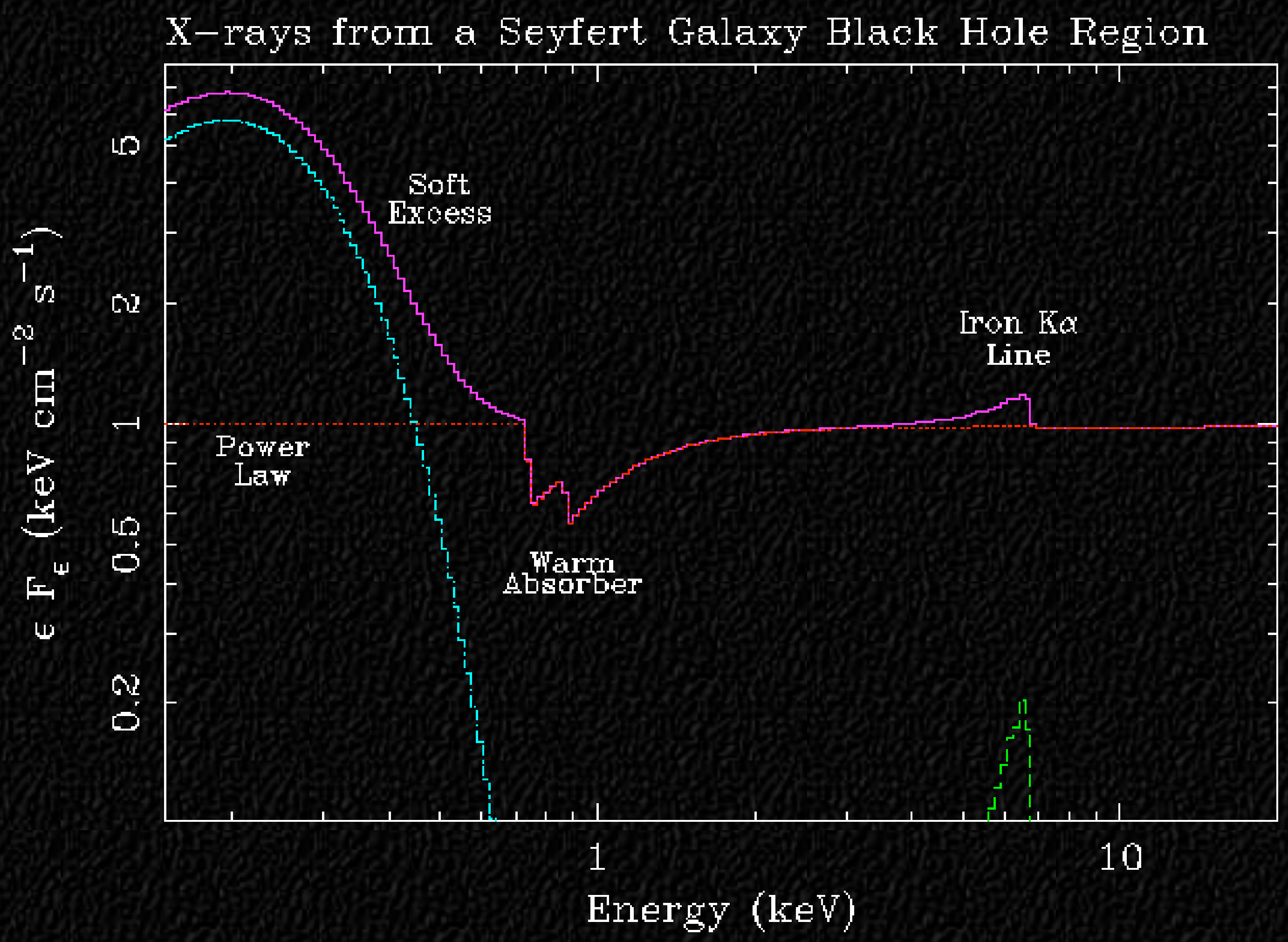
Obscured AGN Across Cosmic Time, Seeon, Bavaria, Germany, June 8, 2007

Outline

1. The hard-X-ray spectrum of AGN
2. Determining the black-hole mass and accretion rate in AGN
3. A line width - accretion rate degeneracy in nearby AGN
4. The hard-X-ray photon index as an accretion-rate indicator
5. Using X-rays to probe the history of black-hole growth
6. Summary, ongoing work, implications

1. The Hard-X-ray Spectrum of AGN



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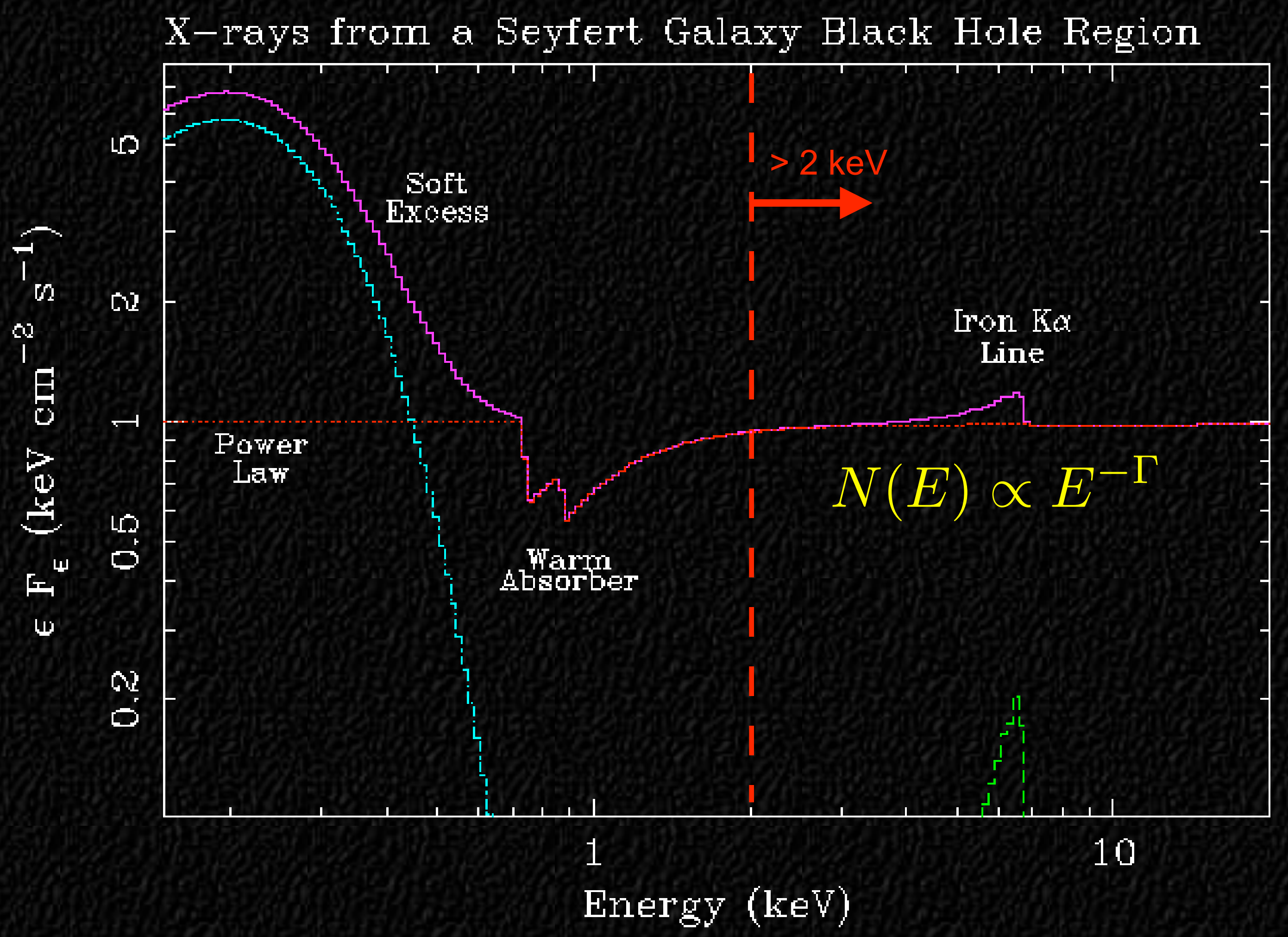

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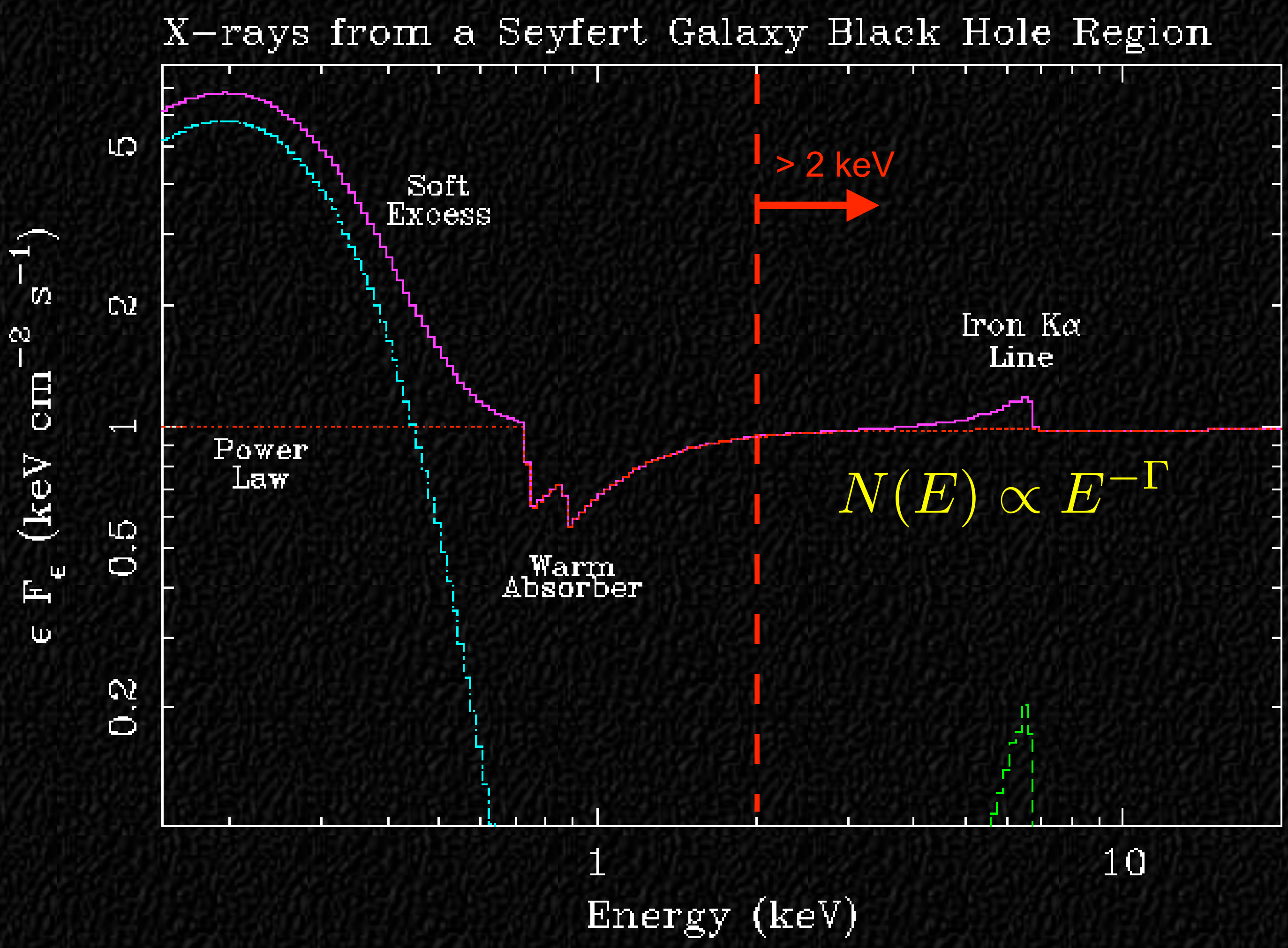

Typical Γ range for radio-quiet AGN: Γ≈2.0±0.5

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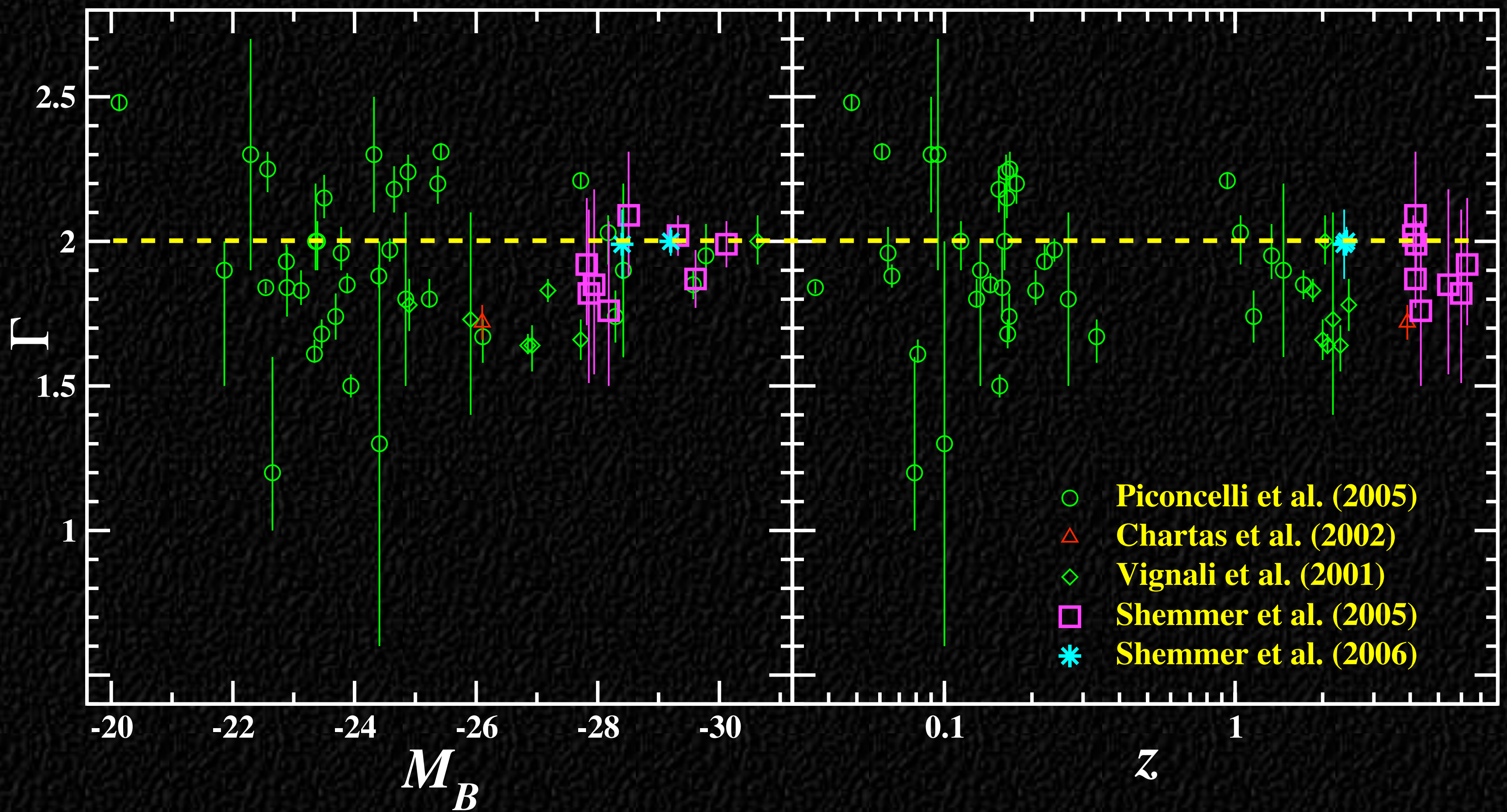

e.g. Vignali+03, 05; Shemmer+05, 06

No clear dependence of Γ on either luminosity or redshift.

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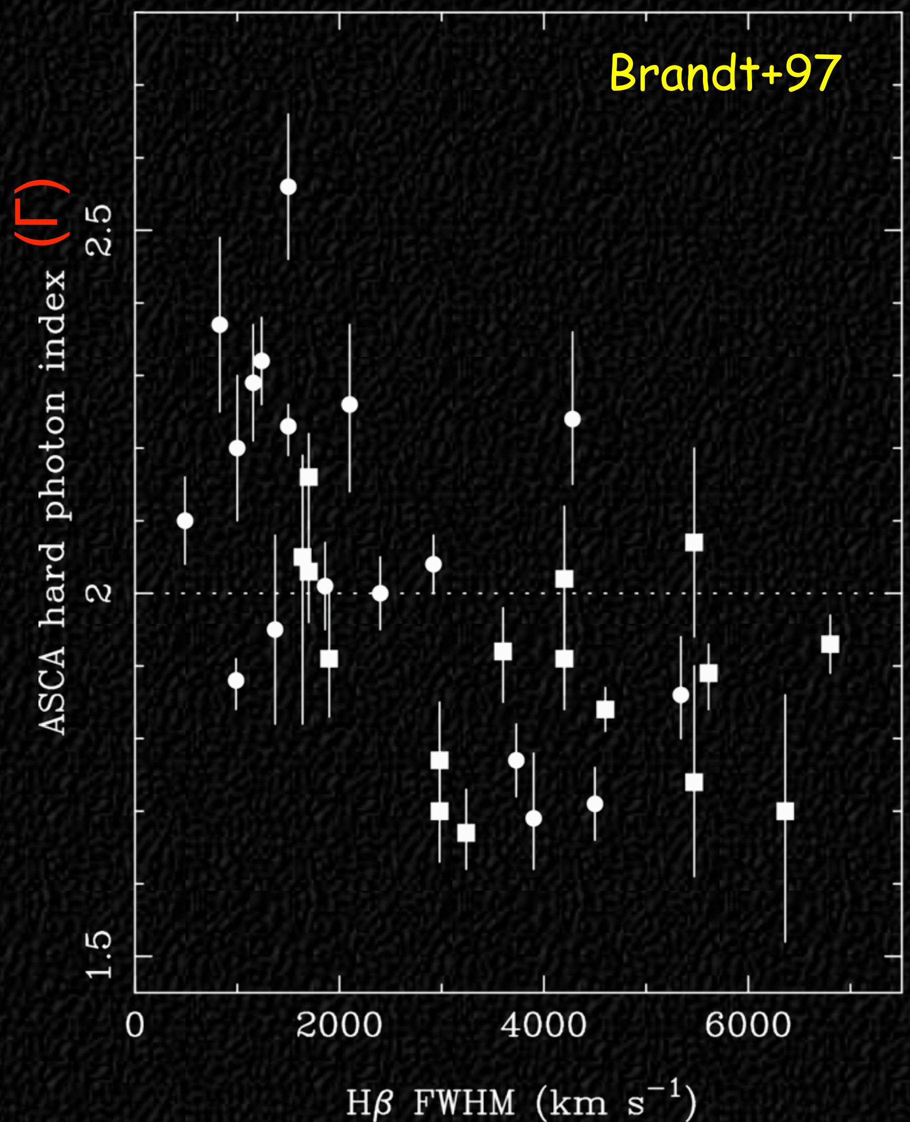

However...

Γ - FWHM(Hβ) anticorrelation

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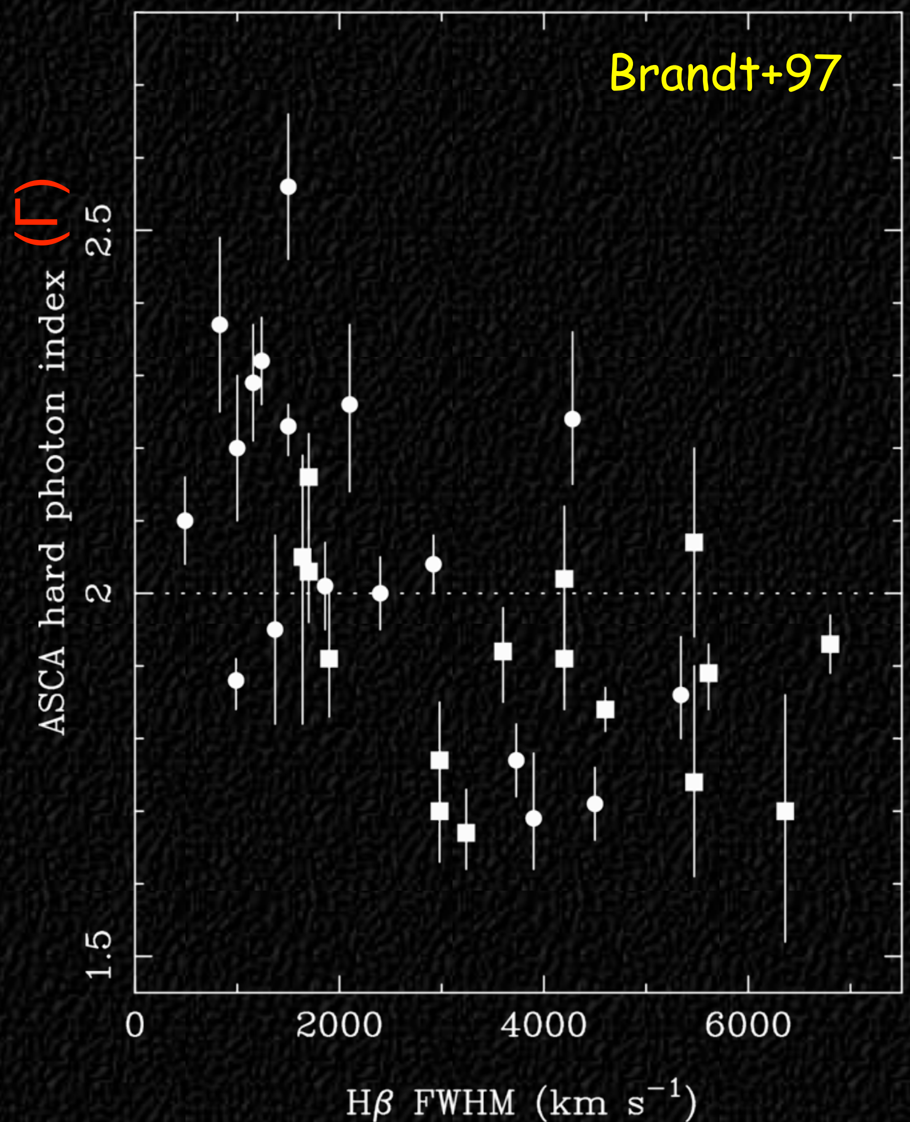


However...

Γ - FWHM(Hβ) anticorrelation

Analogous to the anticorrelation between the soft-X-ray spectral slope and the Hβ width.

(e.g. Boller+96; Laor+97)

2. Determining the BH Mass & Accretion Rate in AGN

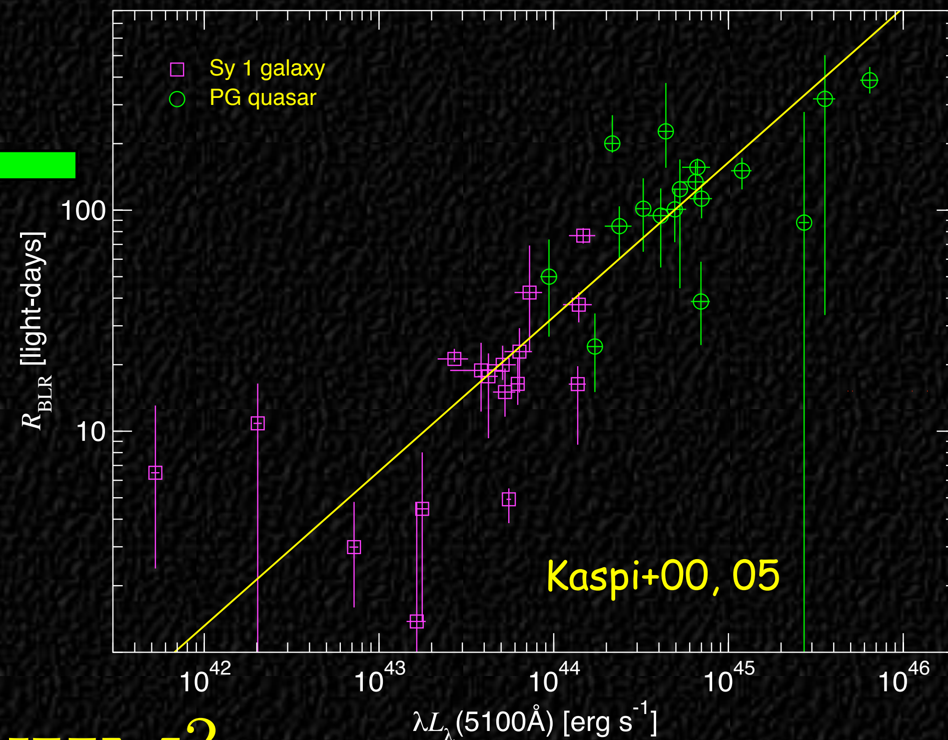
R_{BLR} is measured by reverberation ('light-echo') mapping

$$R_{\mathrm{BLR}} = c_1(\lambda L_\lambda)^\alpha$$

Assuming Keplerian motion:

$$M_{\mathrm{BH}} \propto R_{\mathrm{BLR}} v^2$$

$$M_{\mathrm{BH}} = c_2(\lambda L_\lambda)^\alpha \mathrm{FWHM}^2$$



2. Determining the BH Mass & Accretion Rate in AGN

Two observables determine $M_{\rm BH}$ and the Eddington ratio:

1. Luminosity
2. Line width

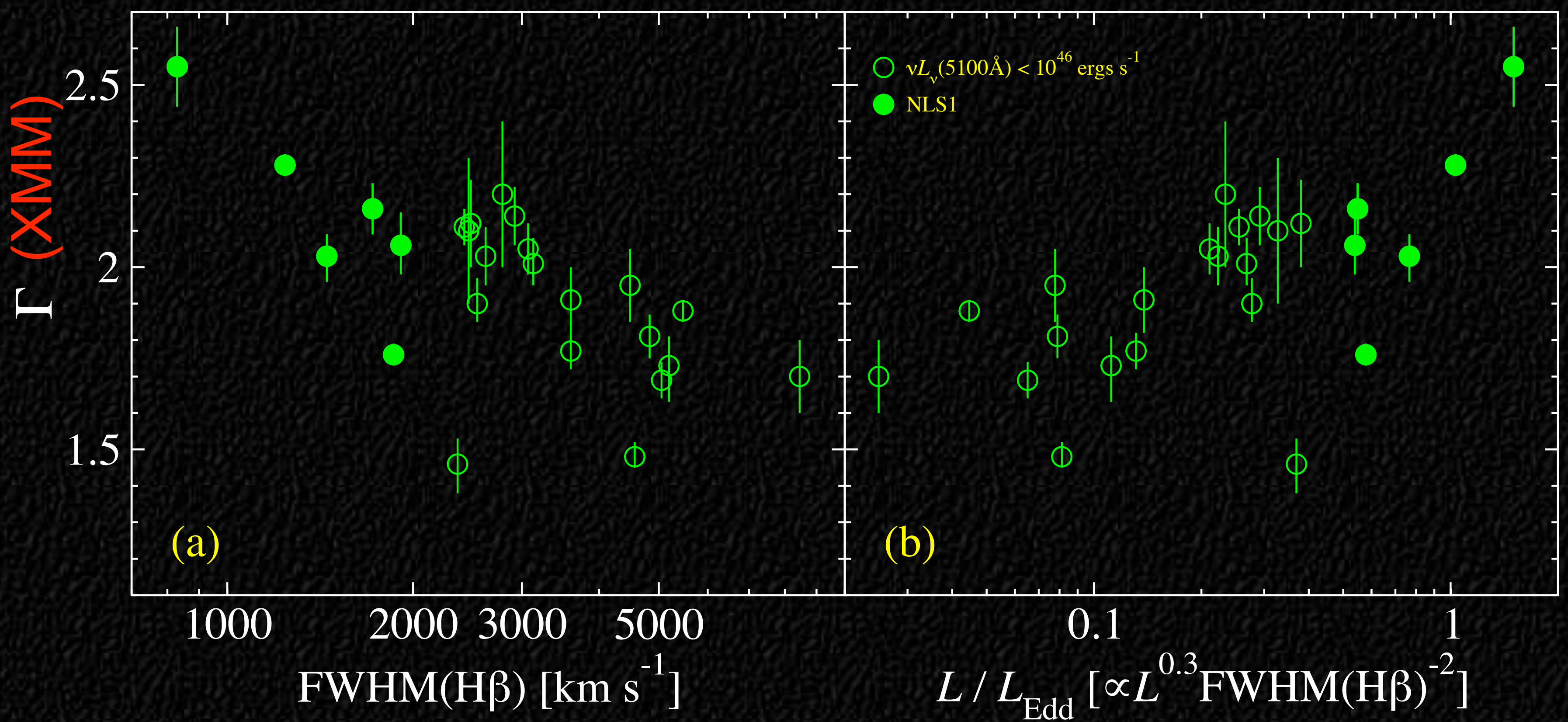
$$M_{\rm BH} = 4.35 \times 10^6 \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,{\rm ergs\,s^{-1}}}\right]^{0.7} \left[\frac{{\rm FWHM(H}\beta)}{10^3\,{\rm km\,s^{-1}}}\right]^2 M_\odot$$

$$L/L_{\rm Edd} = 0.15 f(L) \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,{\rm ergs\,s^{-1}}}\right]^{0.3} \left[\frac{{\rm FWHM(H}\beta)}{10^3\,{\rm km\,s^{-1}}}\right]^{-2}$$

$$(L \equiv L_{\rm bol}\ ;\ f(L) \sim 5 - 15)$$

Kaspi+00; Marconi+04; Shemmer+06, ApJ, 646, L29

3. A Line Width - Accretion Rate Degeneracy



e.g. Lu & Yu 99; Porquet+04; Wang+04; Piconcelli+05; Kelly 07

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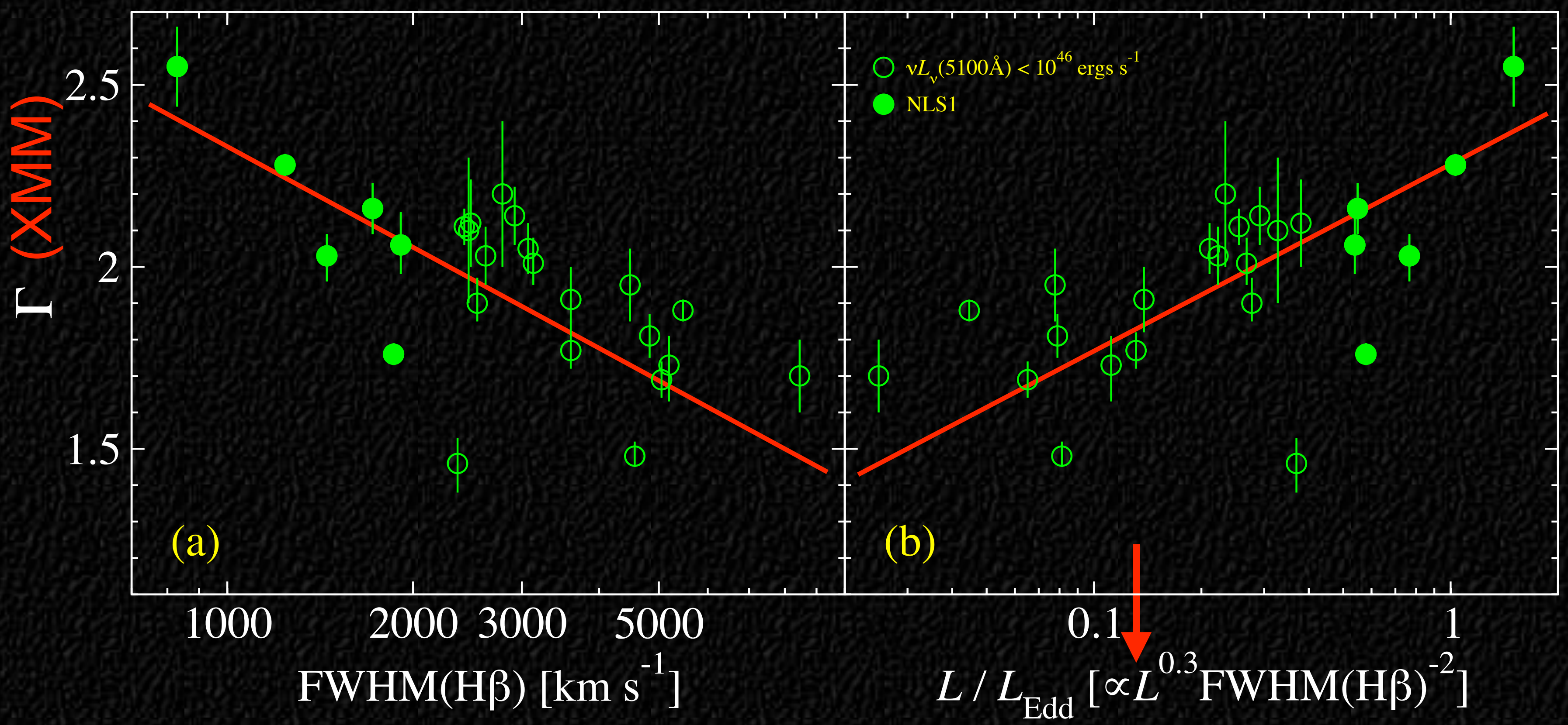

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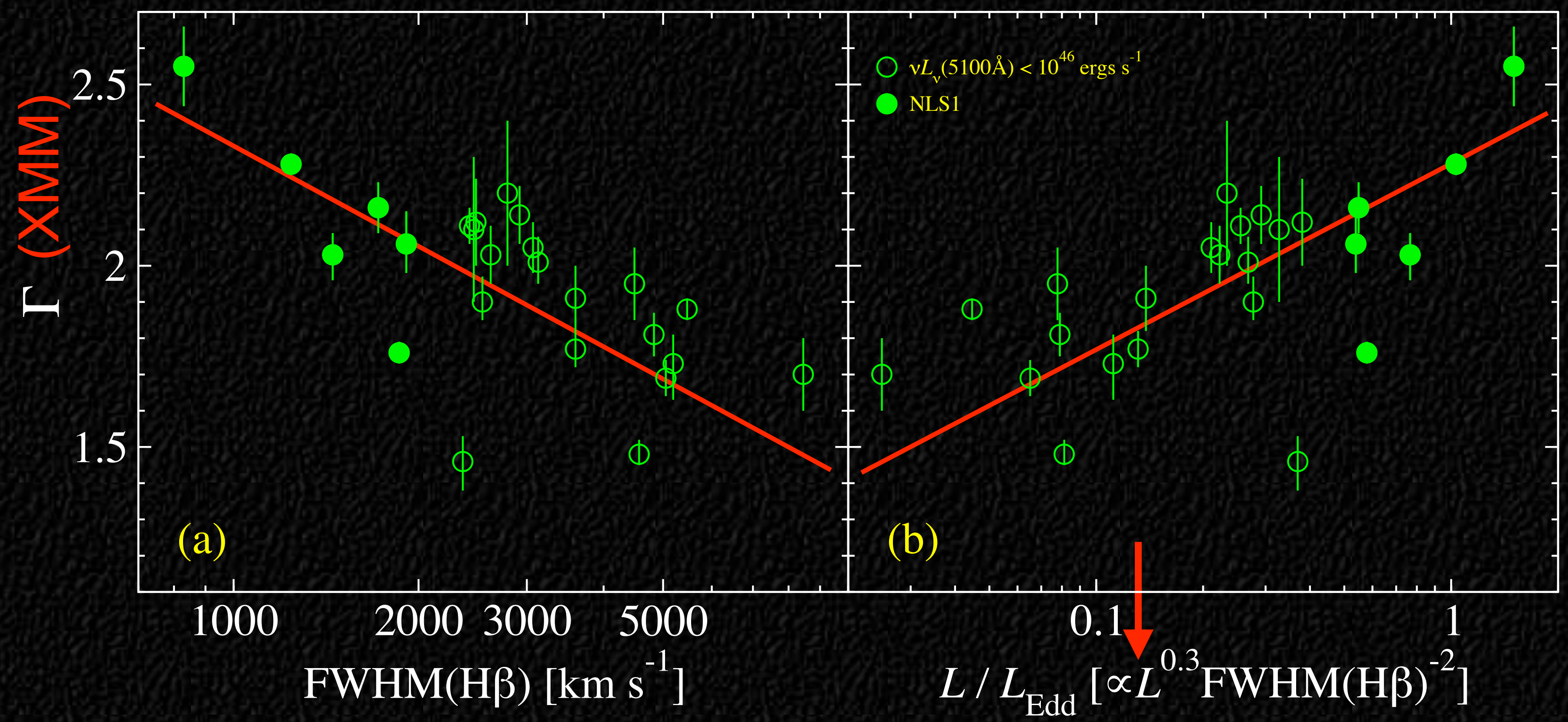

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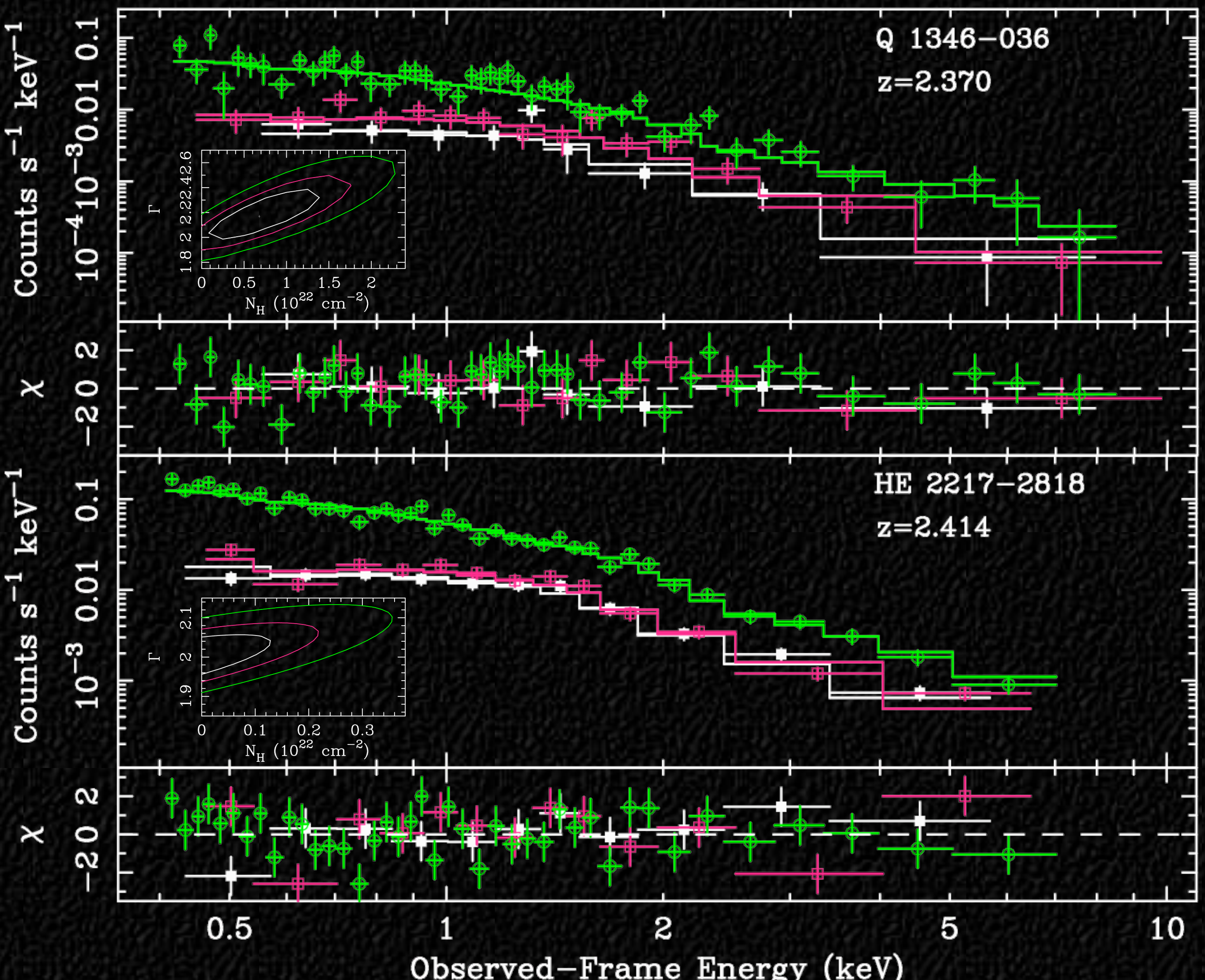
Breaking the degeneracy requires Γ and FWHM(Hβ) measurements in luminous, radio-quiet AGN (at high redshift).

3. A Line Width - Accretion Rate Degeneracy

XMM-Newton Spectroscopy of Luminous, High-Accretion Rate Quasars



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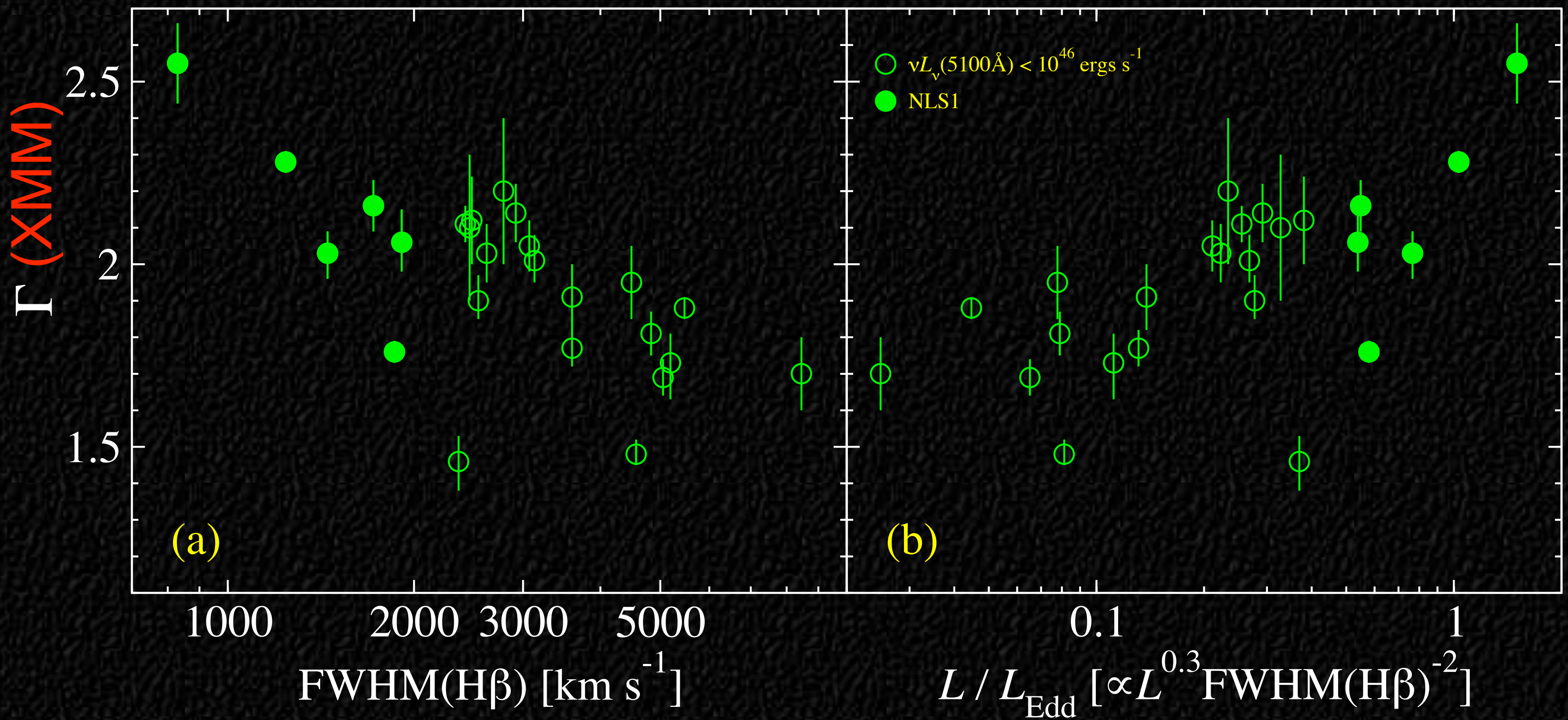
4. The hard-X-ray photon index as an accretion-rate indicator



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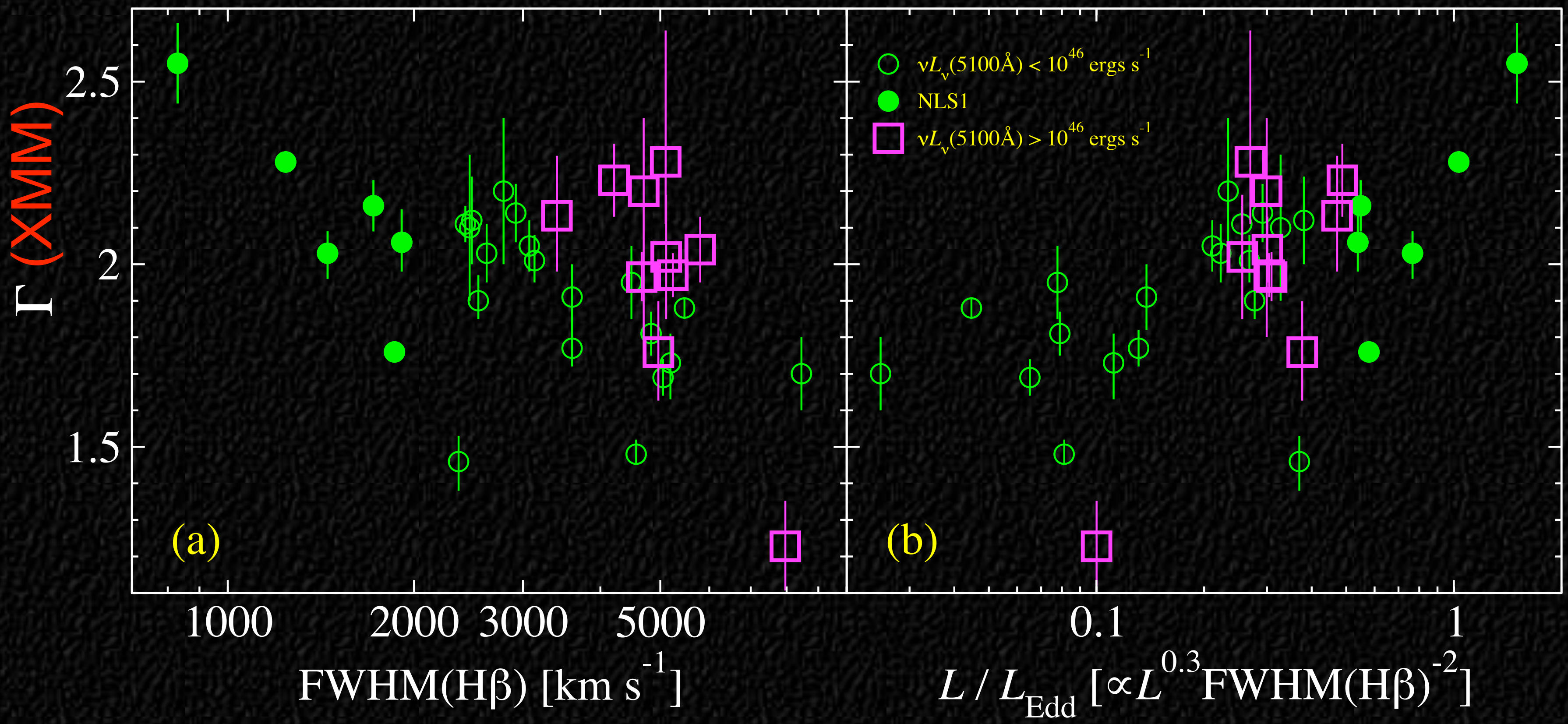
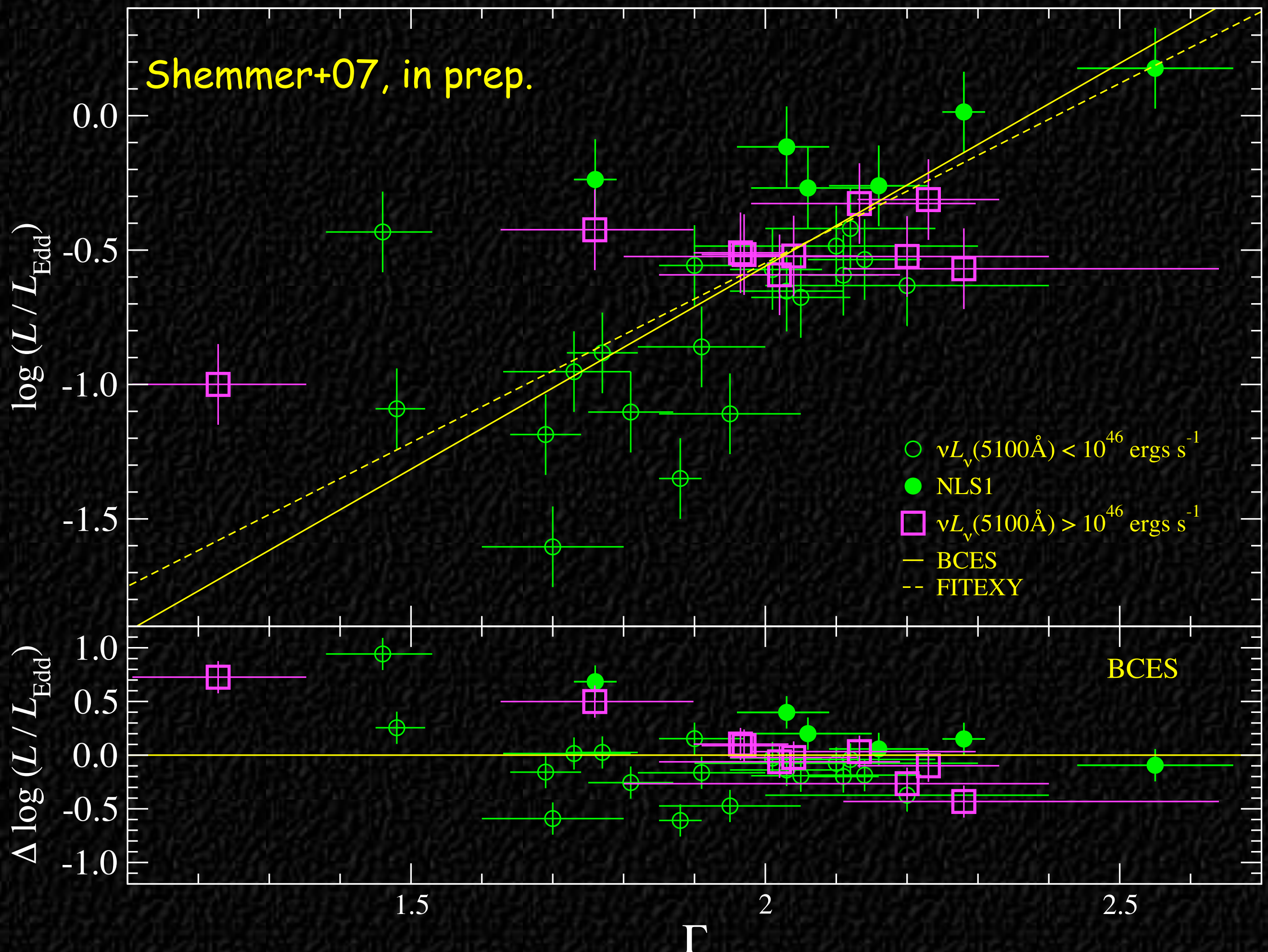


Shemmer+06, ApJ, 646, L29; Shemmer+07, in prep.

Γ values for luminous radio-quiet AGN, while consistent with those expected from their accretion rates, are higher than expected from the width of their Hβ lines.

5. Using X-rays to Probe the History of BH Growth

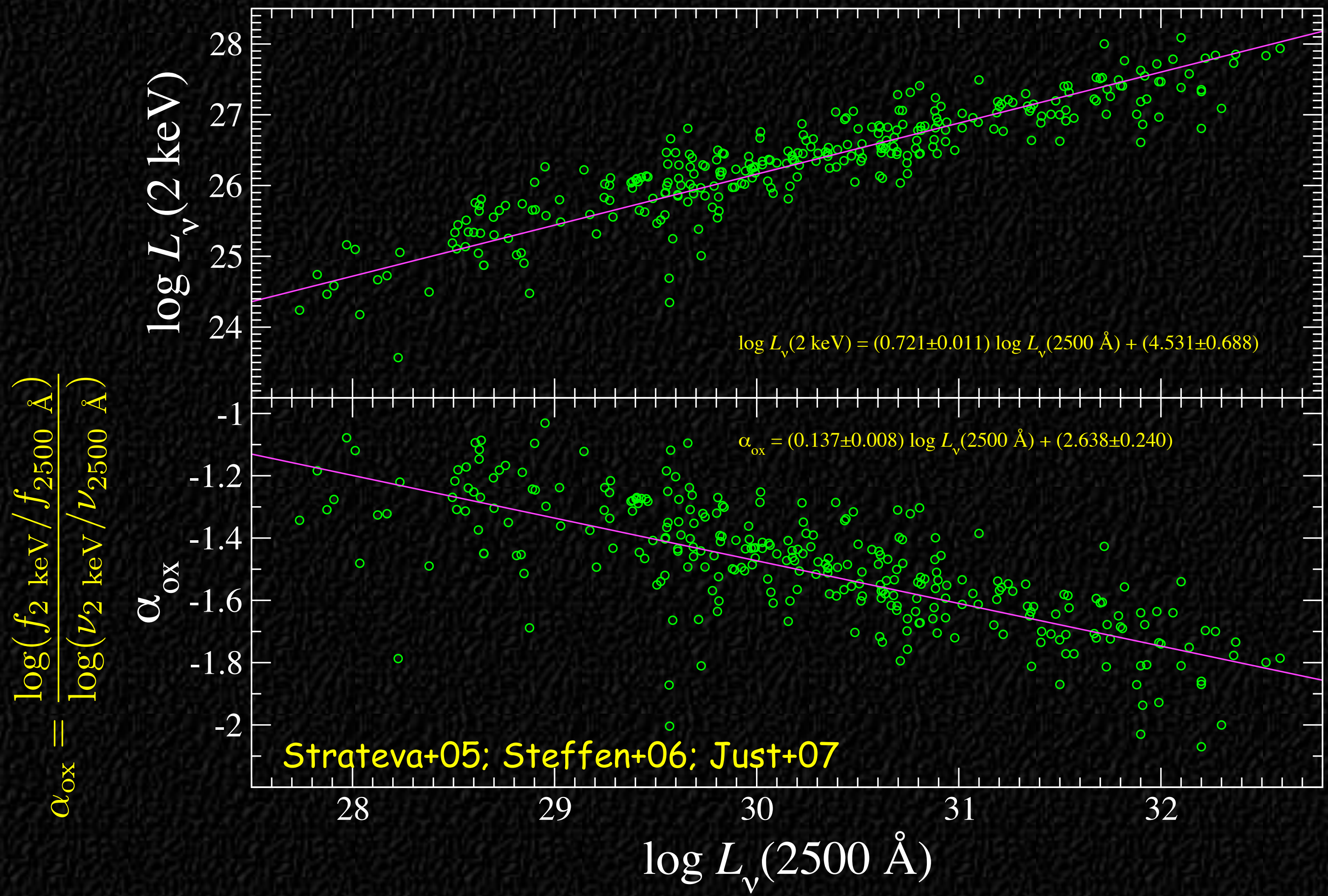
L/L_{Edd} - Γ correlation



$$\log(L/L_{\rm Edd}) = (1.6 \pm 0.3)\Gamma - (3.8 \pm 0.7)$$

5. Using X-rays to Probe the History of BH Growth

X-ray flux - optical flux relation



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5. Using X-rays to Probe the History of BH Growth

The ‘X-ray Method’

Γ → $L/L_{\rm Edd}$

L_X → νL_ν (2500Å) → νL_ν(5100Å)

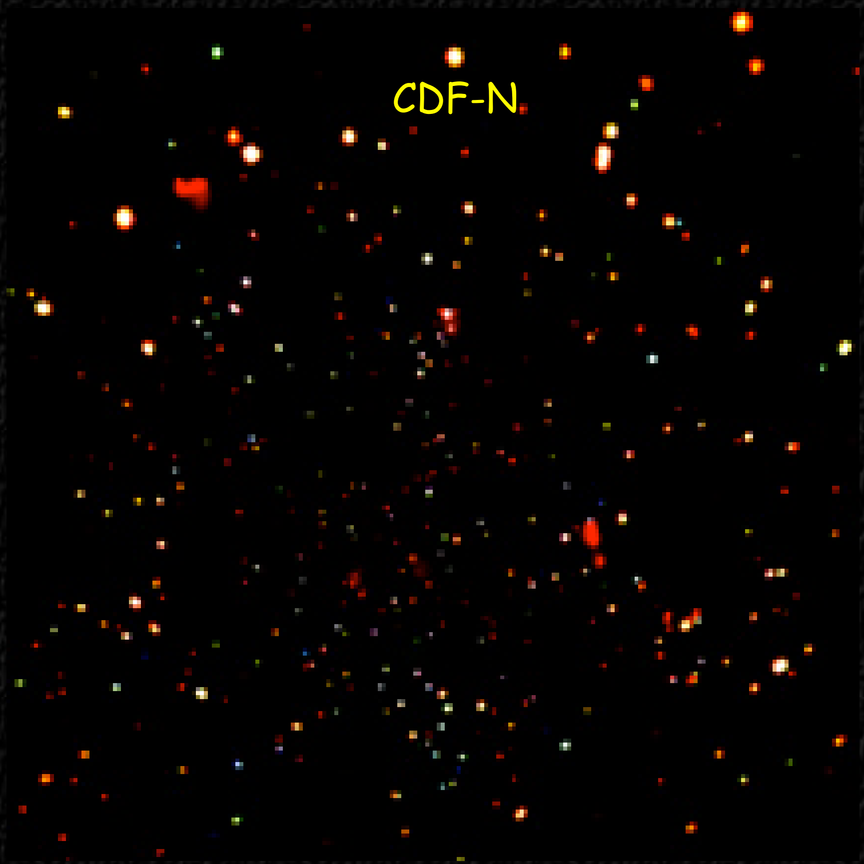
$L/L_{\rm Edd}$ + νL_ν(5100Å) → $M_{\rm BH}$

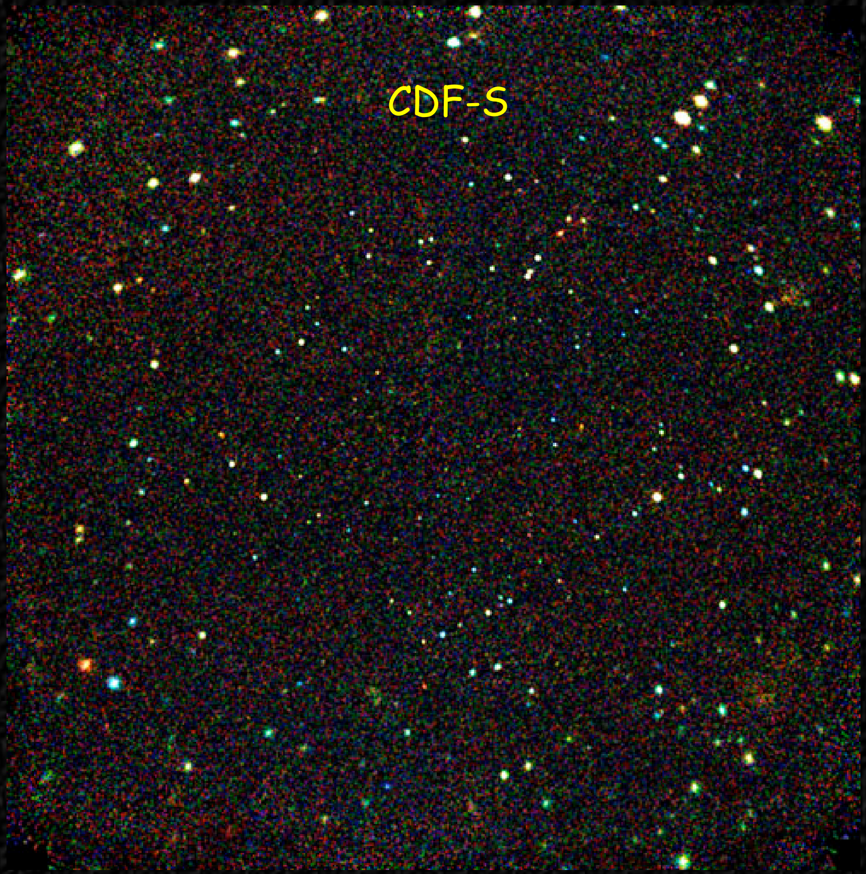
$$M_{\rm BH} = 4.35 \times 10^6 \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,\text{ergs}\,\text{s}^{-1}}\right]^{0.7} \left[\frac{\text{FWHM(H}\beta)}{10^3\,\text{km}\,\text{s}^{-1}}\right]^2 M_\odot$$

$$L/L_{\rm Edd} = 0.15 f(L) \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,\text{ergs}\,\text{s}^{-1}}\right]^{0.3} \left[\frac{\text{FWHM(H}\beta)}{10^3\,\text{km}\,\text{s}^{-1}}\right]^{-2}$$

5. Using X-rays to Probe the History of BH Growth

Applying the 'X-ray method'





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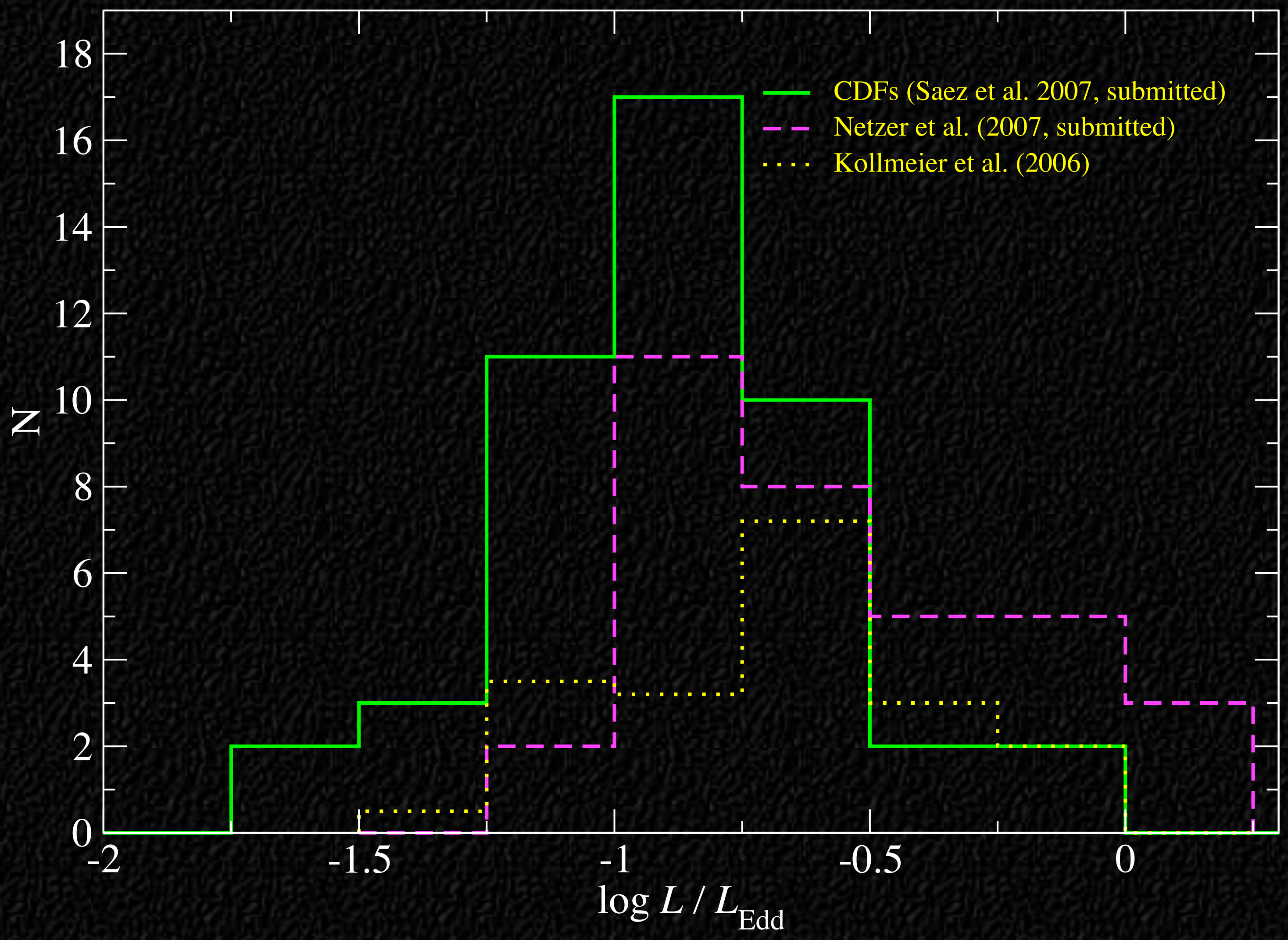

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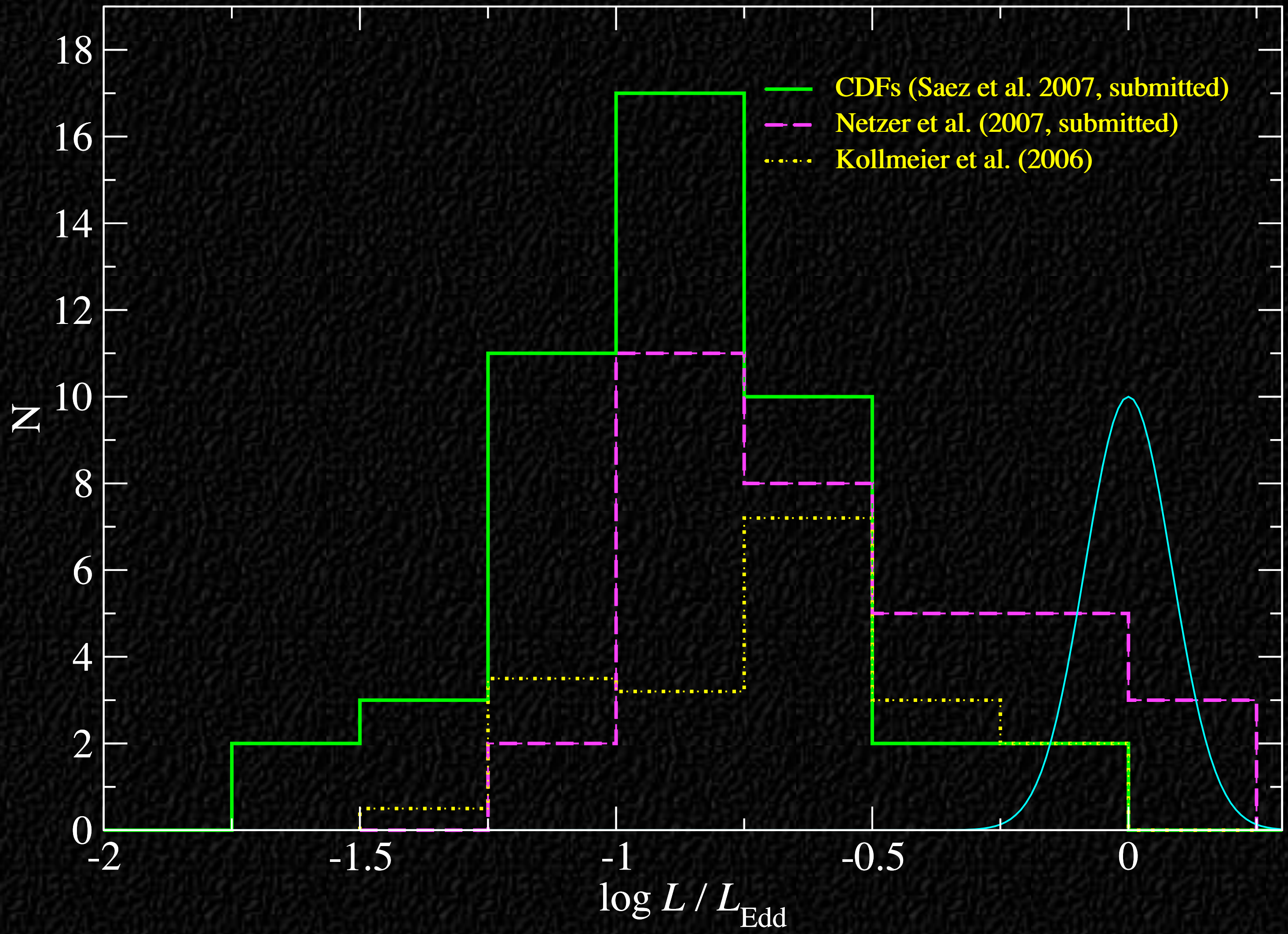

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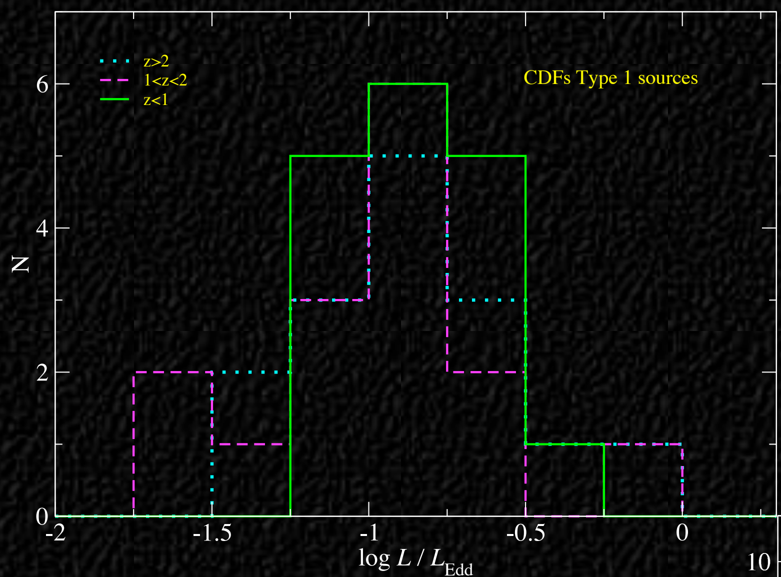
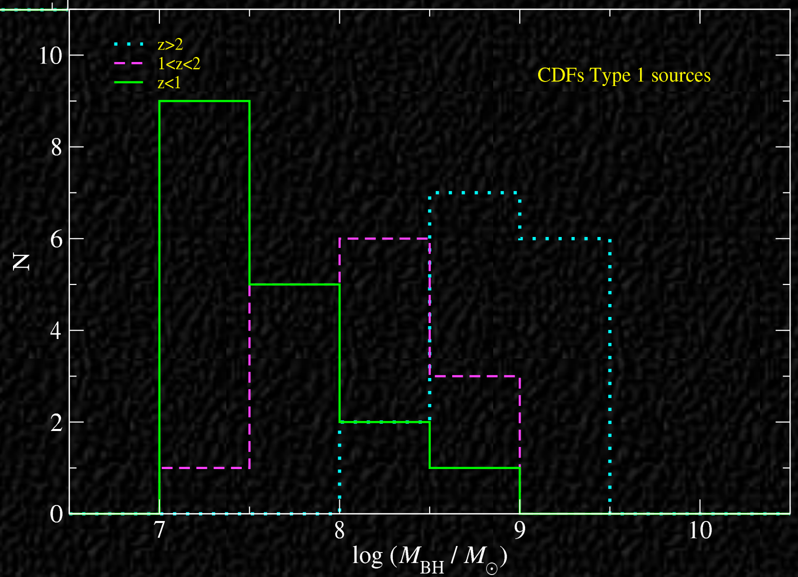


- L/L_{Edd} evolution?

- Did high-*z* SMBHs have enough time to form at their current rate?

- Did some SMBHs experience faster growth in the past?

- At what *z* have they grown much faster?



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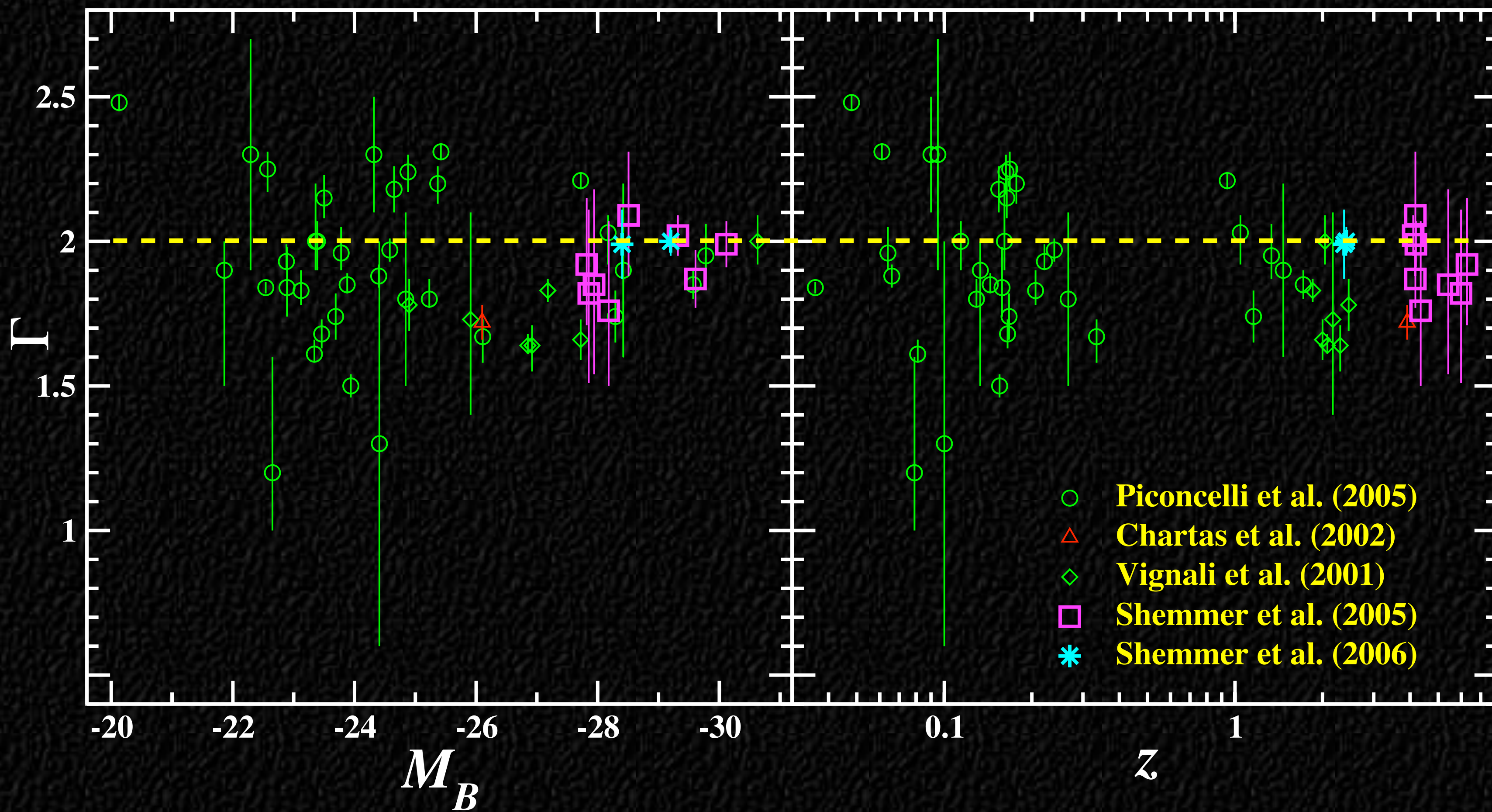

Next: L/L_{Edd} and M_{BH} determinations at the highest redshift.

6. Summary, Ongoing Work, Implications

- ✳Γ is strongly correlated with L/L_{Edd} in radio-quiet AGN across three orders of magnitude in luminosity.
- ✳Γ and L_X may be used as L/L_{Edd} and M_{BH} indicators.
- ✳Implications for accretion-disk/corona models and the history of black-hole growth in the universe.
- ✳Strengthening the Γ- L/L_{Edd} correlation requires a large inventory of FWHM(Hβ) and Γ data for luminous, radio-quiet AGN.This involves:
  1. Accurate Γ measurements with *XMM-Newton*/*Chandra.*
  2. FWHM(Hβ) measurements from near-IR spectroscopy.
- ✳Reducing the scatter on the Γ- L/L_{Edd} correlation requires (near) simultaneous X-ray and optical observations.

6. Summary, Ongoing Work, Implications

Advantages of the 'X-ray method':

- ✳Measuring the slope of the X-ray power-law spectrum vs. detailed optical/near-IR spectroscopy.
- ✳Imaging (many sources) vs. spectroscopy (individual sources).
- ✳No redshift restriction vs. near-IR atmospheric bands.
- ✳Relatively easy determinations of L/L_{Edd} and M_{BH} for faint and/or distant type 1 AGN.
- ✳Perhaps the only way to determine L/L_{Edd} and M_{BH} for type 2/obscured AGN.