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Authors	Paolillo, Maurizio, Papadakis, I., Brandt, W. N., Xue, Y. Q., Luo, B., TOZZI, Paolo, Shemmer, O., Allevato, V., Bauer, F., Koekemoer, A., Vignali, C., Vito, F., Yang, G., Wang, J. X., Zheng, X.
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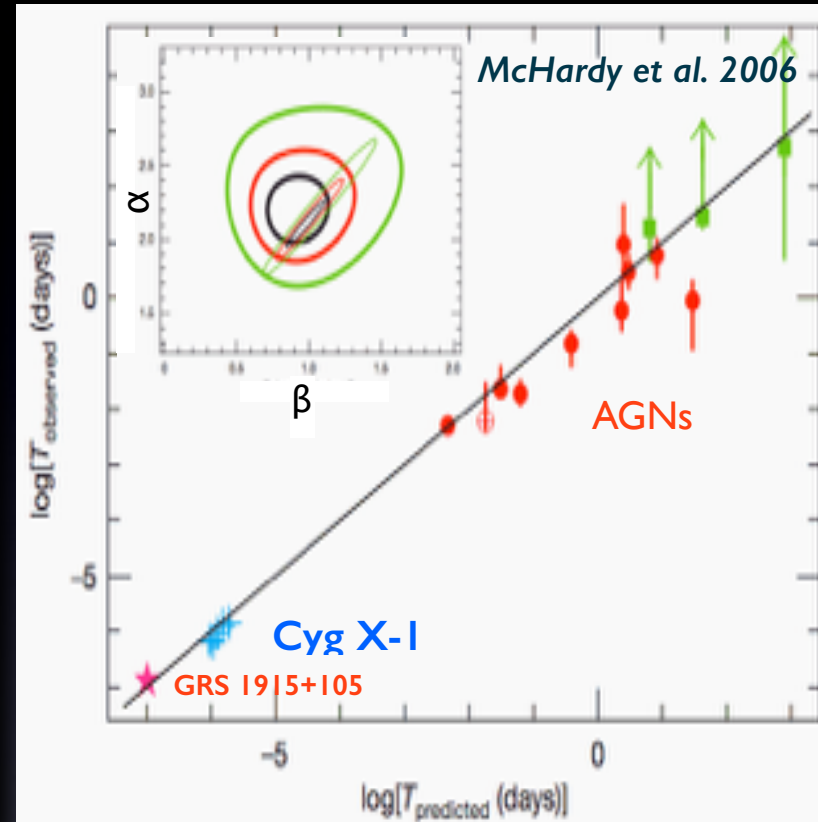
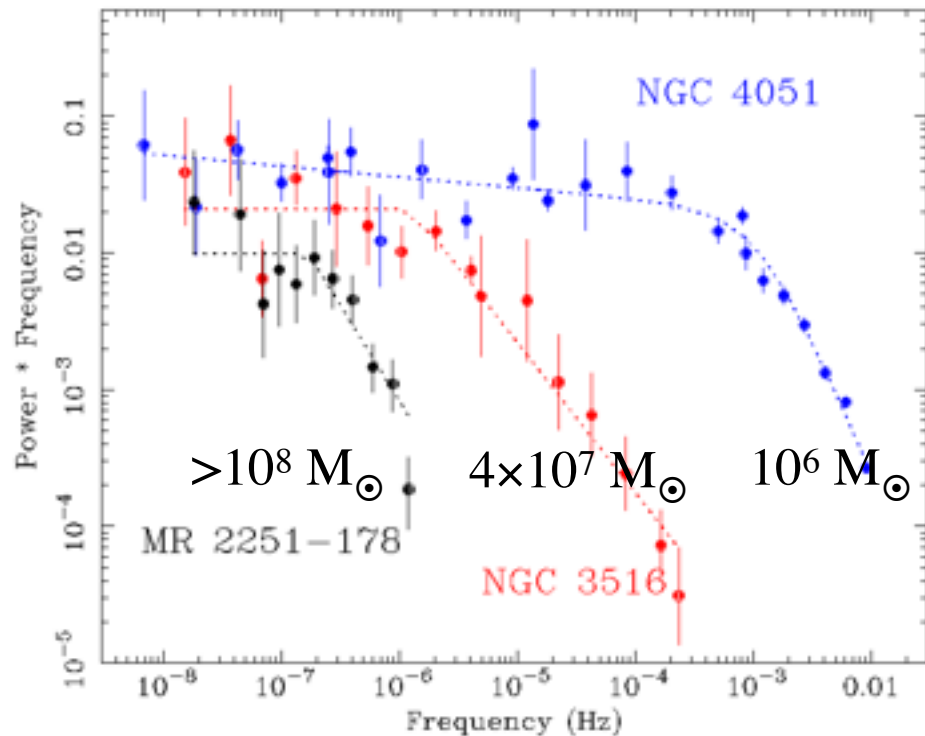
Probing AGN accretion history through X-ray variability

Maurizio Paolillo & the CDFS collaboration

(University Federico II of Naples)

Variability properties of AGNs

(courtesy of P. Uttley)



High frequency break seems to scale with BH mass and accretion rate
(Uttley & McHardy 2005, Markowitz & Uttley 2005, McHardy 2006)

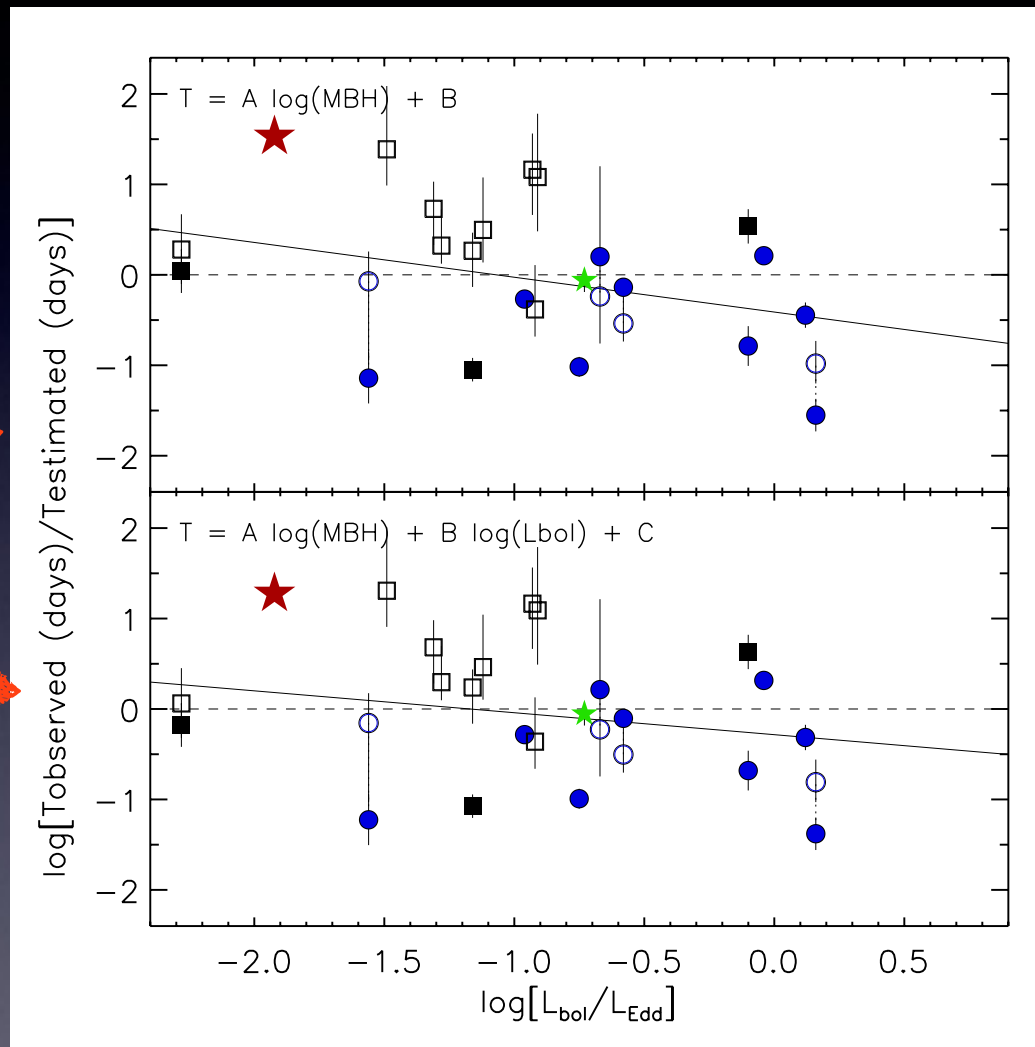
$$\tau_B \propto M_{\text{BH}}^{\alpha} / L_{\text{bol}}^{\beta}$$

Accretion dependence challenged by XMM studies.

Gonzales-Martin & Vaughan (2012) study 104 nearby AGN from XMM-Newton observations. They test different scenarios:

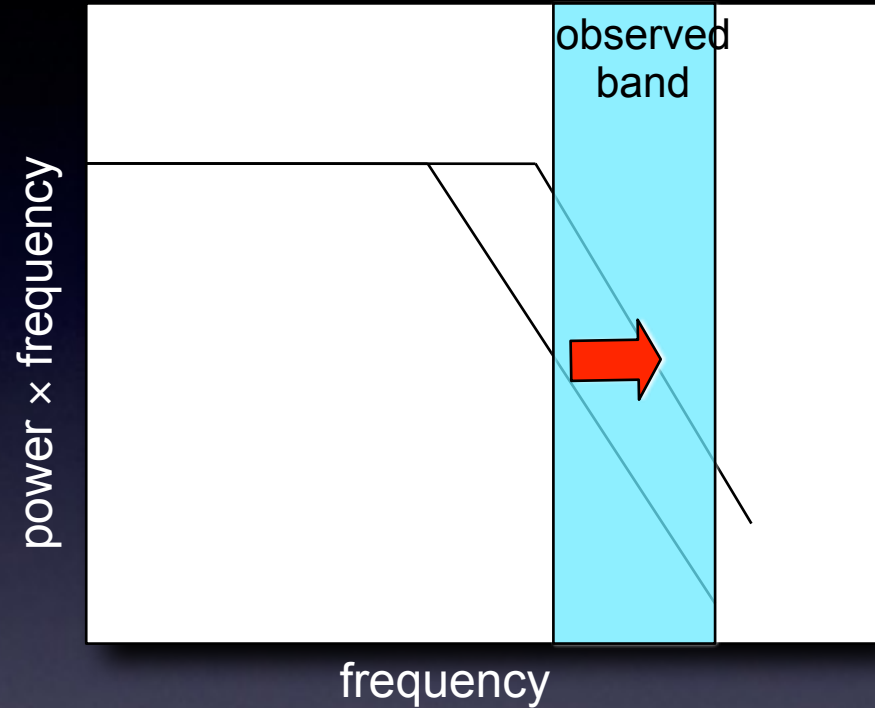
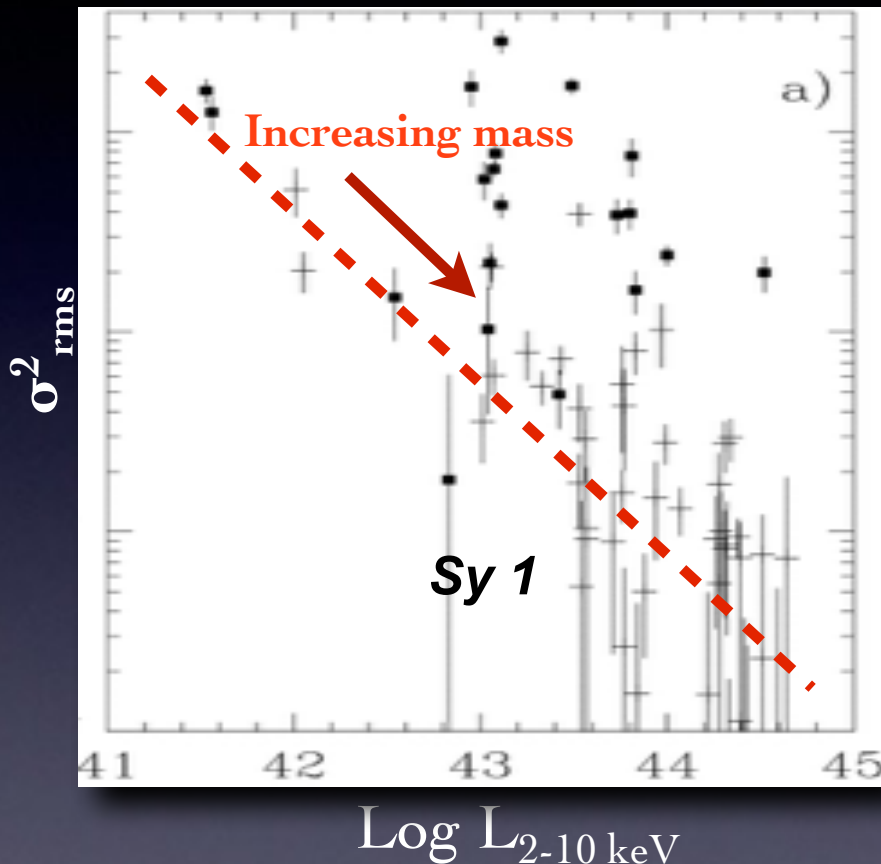
- Break timescale depends only on BH mass
- Break timescale depends on BH mass and accretion rate.

The coefficient B is consistent with zero, i.e. **weak or no dependence on accretion rate.**



Variability in poor statistics data

AGN variability is anti-correlated with L_X (Barr & Mushotzky 1986, Lawrence & Papadakis 1993, Nandra et al. 1997)

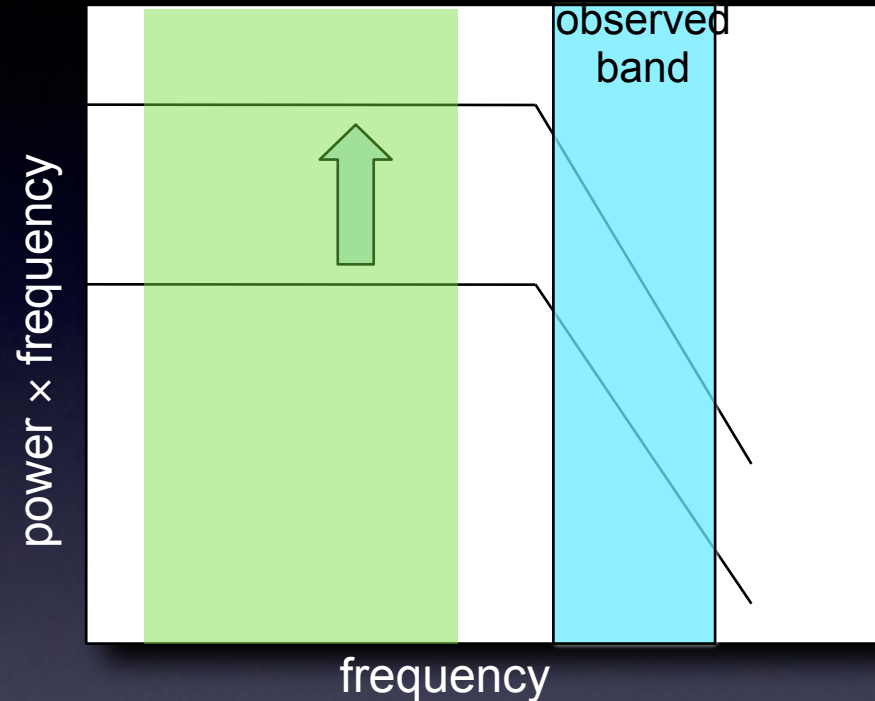
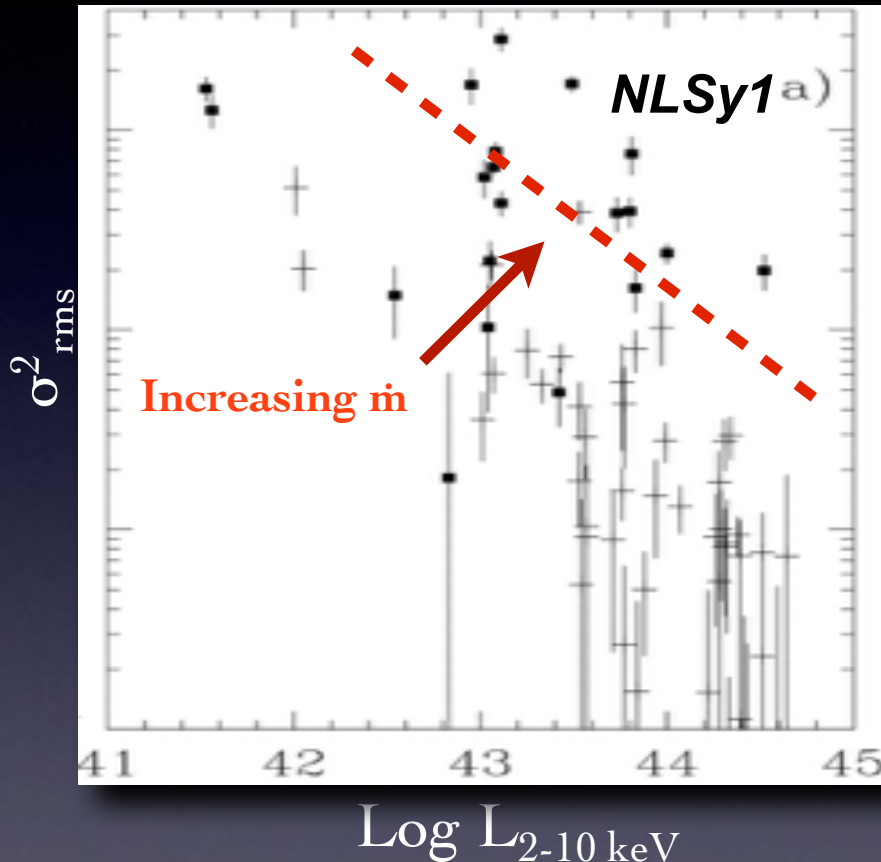


$$\sigma_{\text{NXV}}^2 = \frac{1}{N\bar{x}^2} \sum_{i=1}^N [(x_i - \bar{x})^2 - \sigma_{\text{err},i}^2],$$

Can use 'excess-variance' to estimate mass (e.g. O'Neill et al., Gierlinski et al. 2007) but should take accretion rate into account!

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$$\sigma_{\text{NXV}}^2 = \frac{1}{N\bar{x}^2} \sum_{i=1}^N [(x_i - \bar{x})^2 - \sigma_{\text{err},i}^2],$$

Does the normalization depend on accretion rate as well?

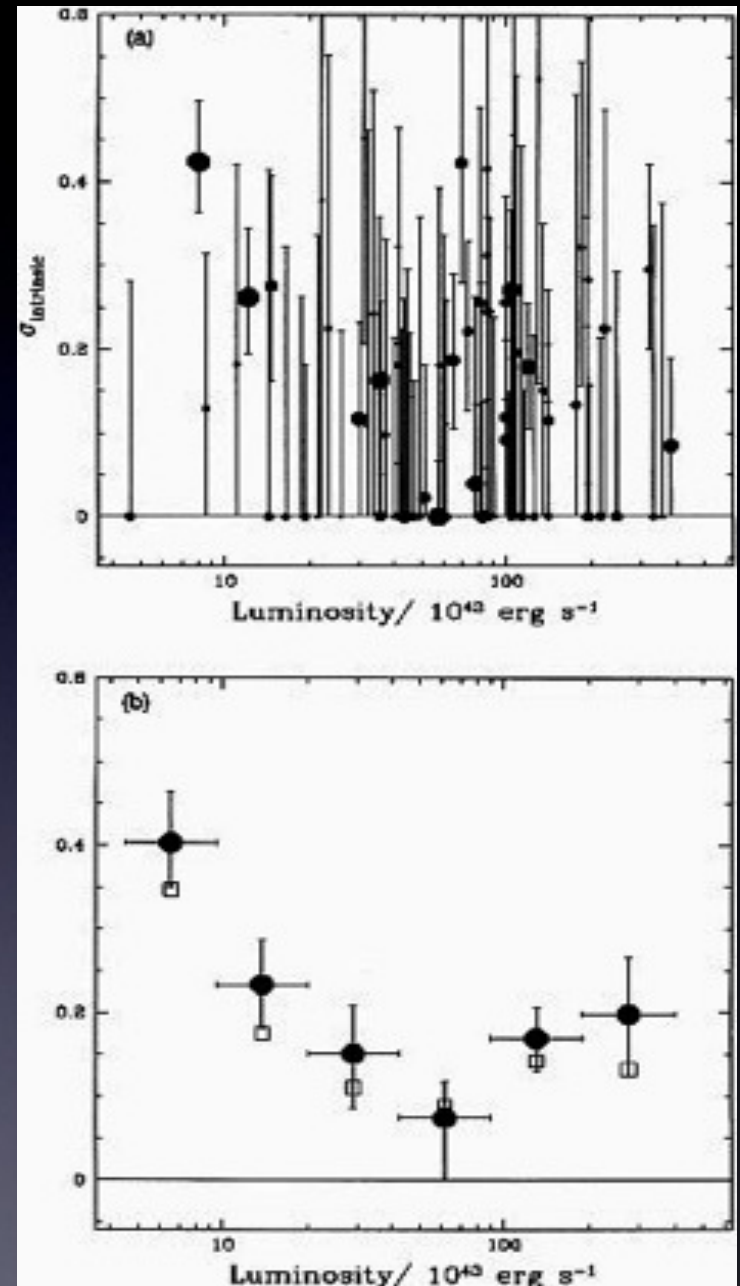
Best sampled on long timescales!

Increased variability at high z ?

(Almaini et al. 2000)

- A similar L_X -variability anticorrelation was found in Rosat data.
- Their anticorrelation is valid only for moderate luminosity AGNs ($L_X < 10^{45}$)
- At high luminosities there is an “upturn” in the correlation: luminosity or redshift effect?

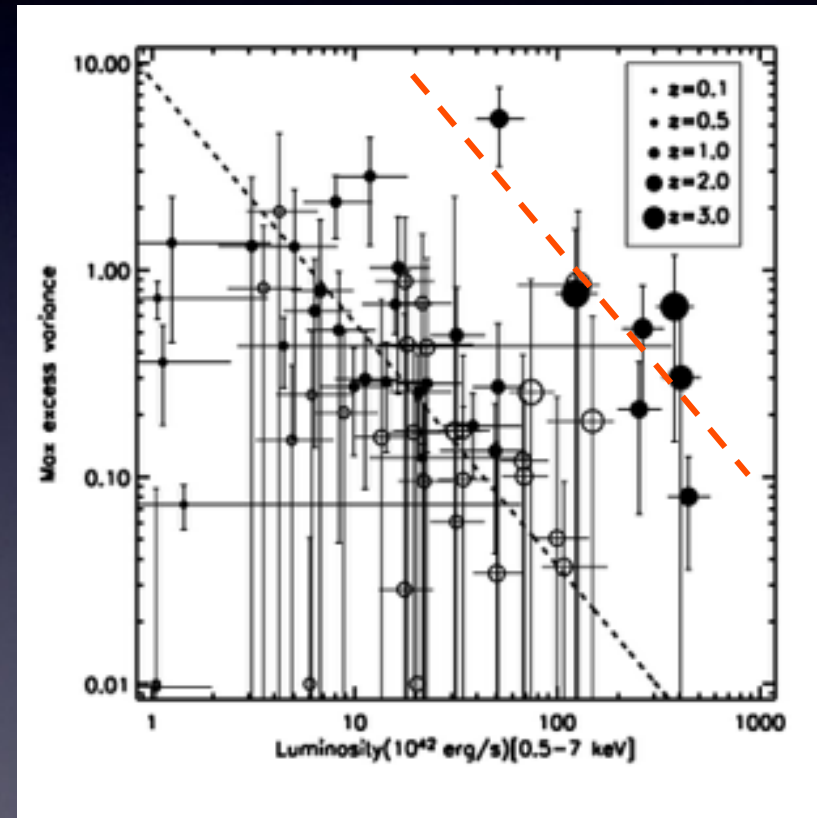
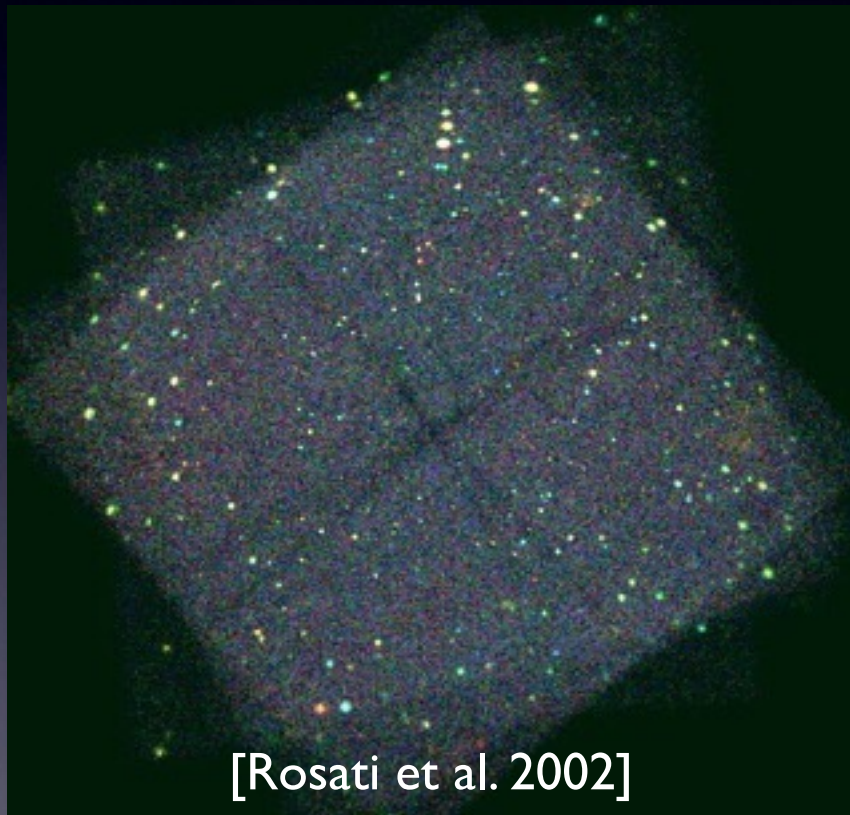
The evolution of the L_X -var. relation could be produced by increase of the accretion rates or a decrease of the X-ray emitting region with look-back time.



Increased variability evidence from the IMs CDFS

(Paolillo et al. 2004)

- Larger variability for high- z AGNs?



Increased variability in the Lockman Hole?

(Papadakis et al. 2008)

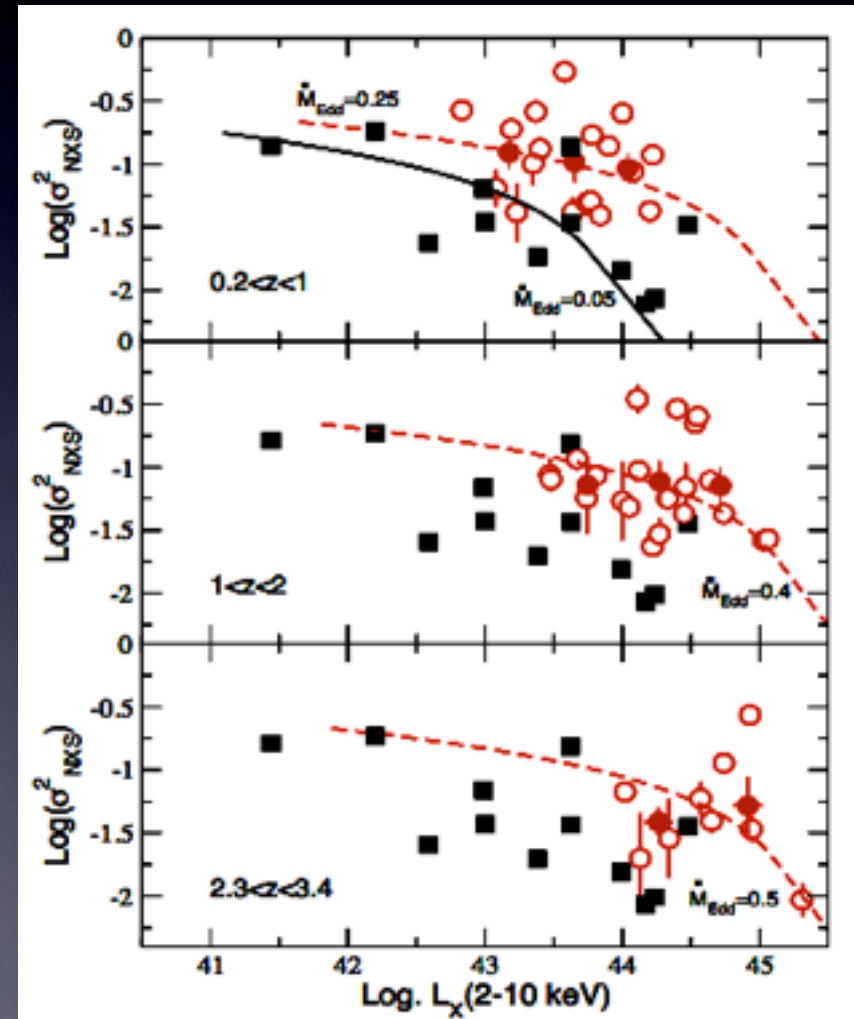
Fitting a more physically motivated model yields:

$$v_{bf} = 0.029 \eta \dot{m}_{\text{Edd}} (M_{\text{BH}} / 10 M_{\odot})$$

$$L_{\text{bol}} = 1.3 \eta \dot{m}_{\text{Edd}} 10^{39} (M_{\text{BH}} / M_{\odot}) \text{ erg/s}$$

(N.B. assumes constant PSD amplitude)

- Fitting the L_X - σ^2 anticorrelation requires higher accretion at high redshift.
- Variability-LX relation can be used in principle to probe both accretion rate and BH mass

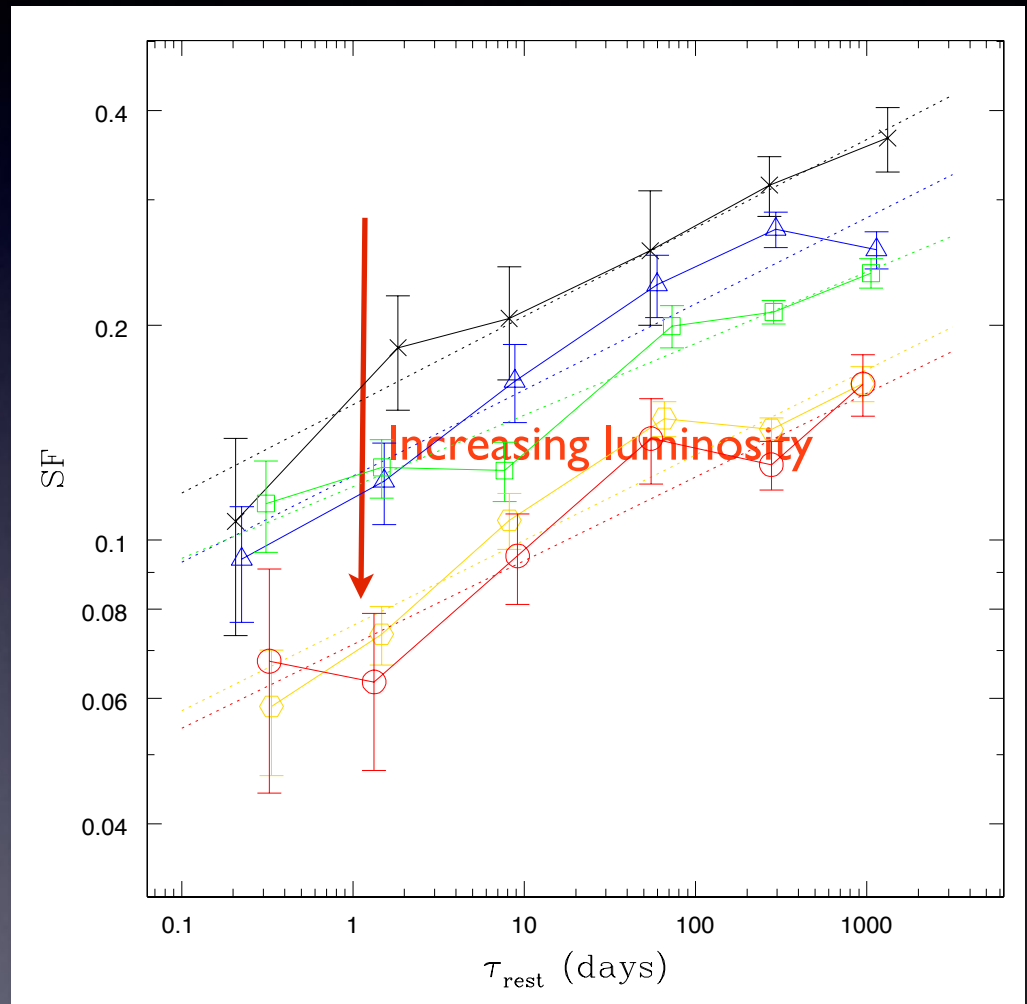


XMM and Swift serendipitous samples

(Vagnetti, Turriziani & Trevese, 2011; Vagnetti et al. 2016)

XMM-Newton and Swift, with redshift between ~ 0.2 and ~ 4.5 , and X-ray luminosities, in the 0.5–4.5 keV band, between $\sim 10^{43-46}$ erg/s.

- Ensemble analysis through Structure Function analysis (SF): a power law $SF \propto \tau^{0.1}$.
- No evidence of the break in the SF, at variance with PSD of lower luminosity AGNs [*but SF may be less sensitive than PSD, see Emmanoulopoulos et al. 2010*]
- Strong **anti-correlation of the variability with X-ray luminosity**, accompanied by a change of the slope of the SF.
- **No average increase of X-ray variability with redshift.**

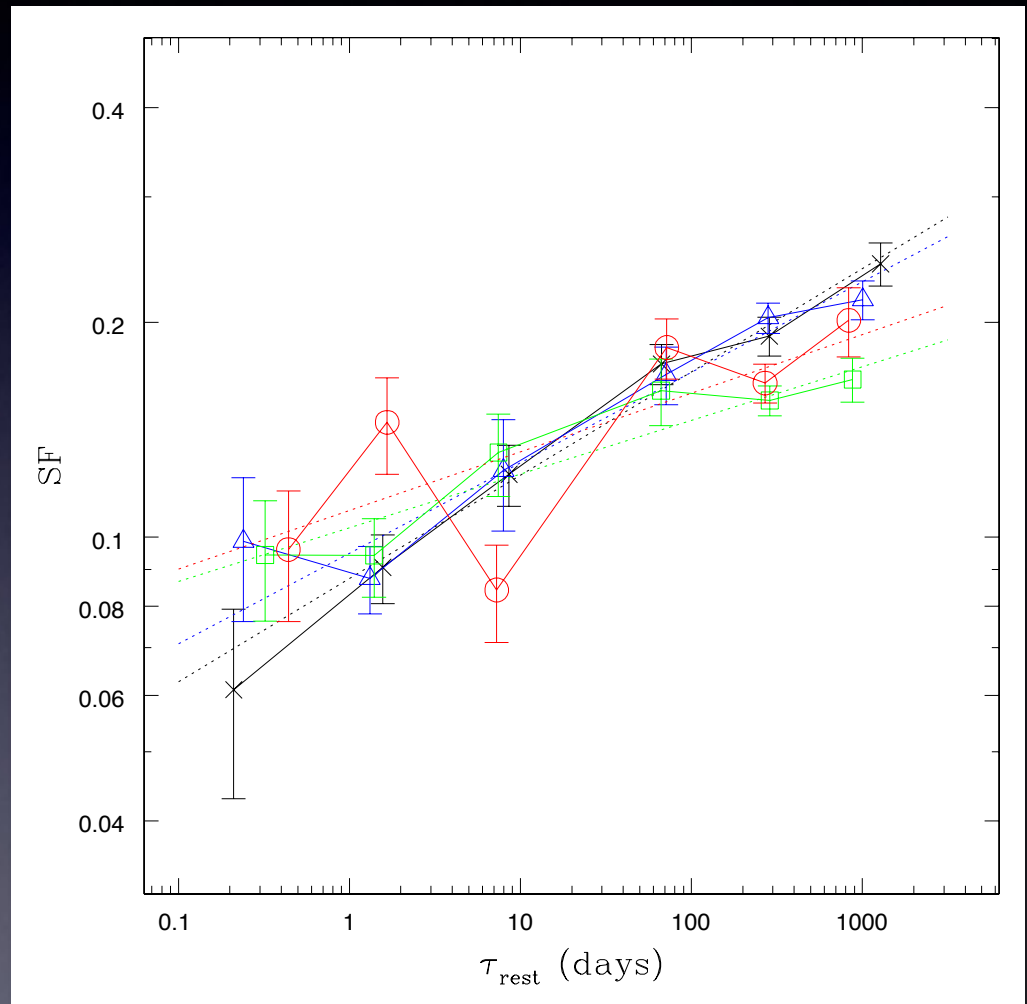


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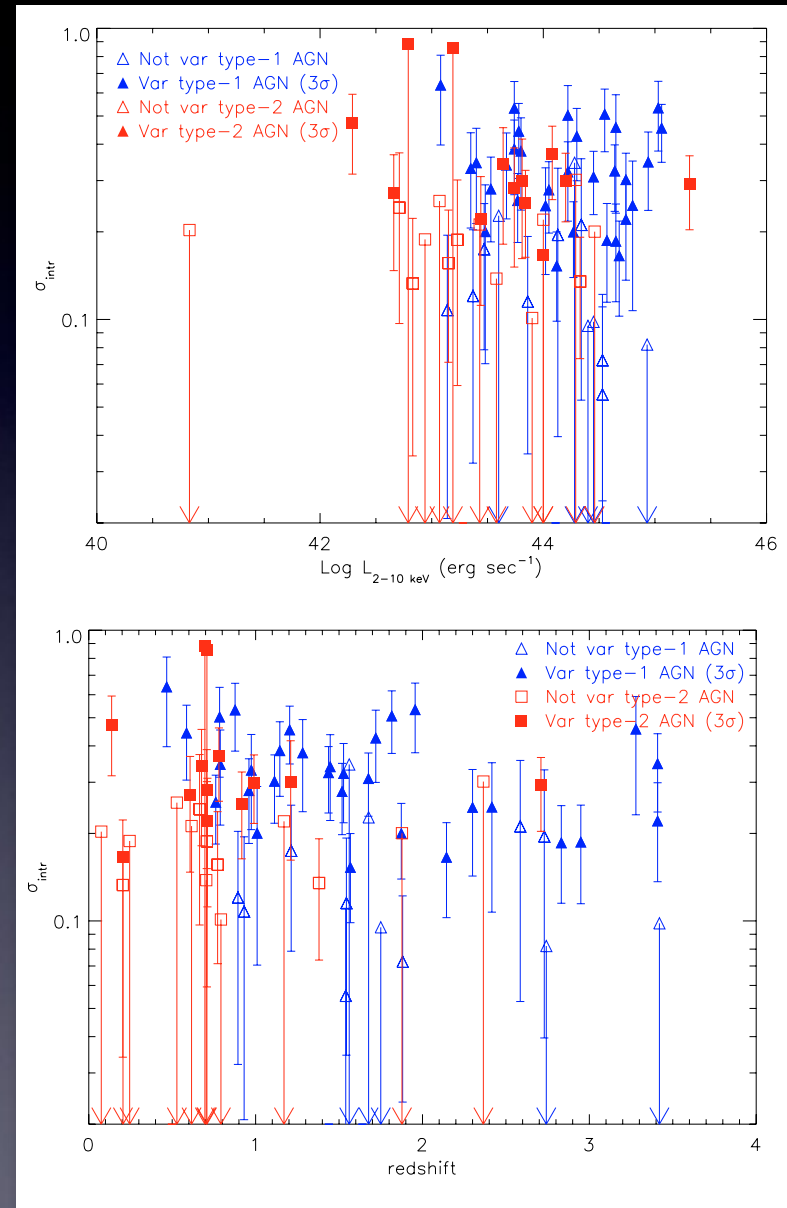
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Null result for the XMM Lockmann Hole bright sample (Mateos 2007)

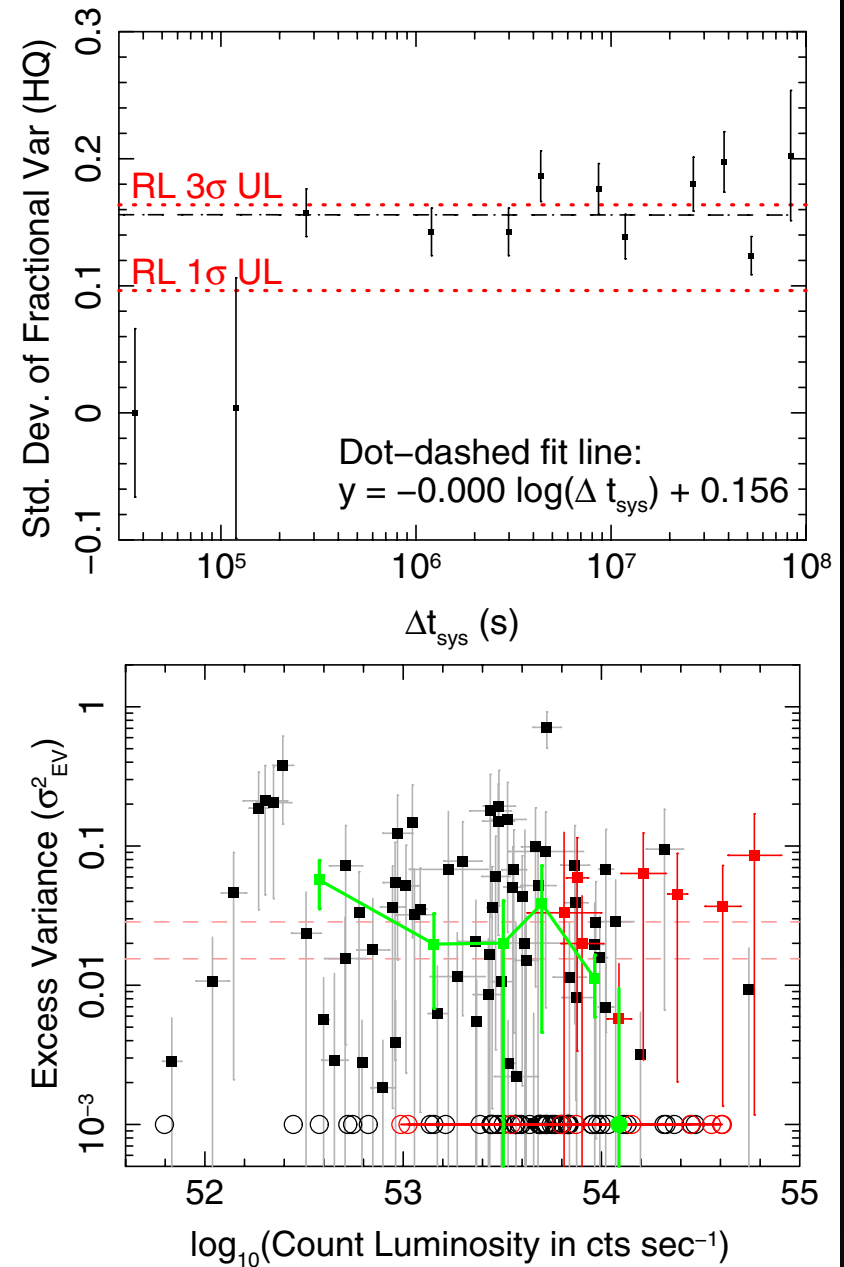
- Variability on time scales from months to 2 years, of the 123 brightest objects detected with XMM-Newton in the Lockman Hole field.
- No dependence on redshift, X-ray luminosity or AGN type.

But....if complex dependence on redshift, luminosity and variability we need to take all of them into account simultaneously!

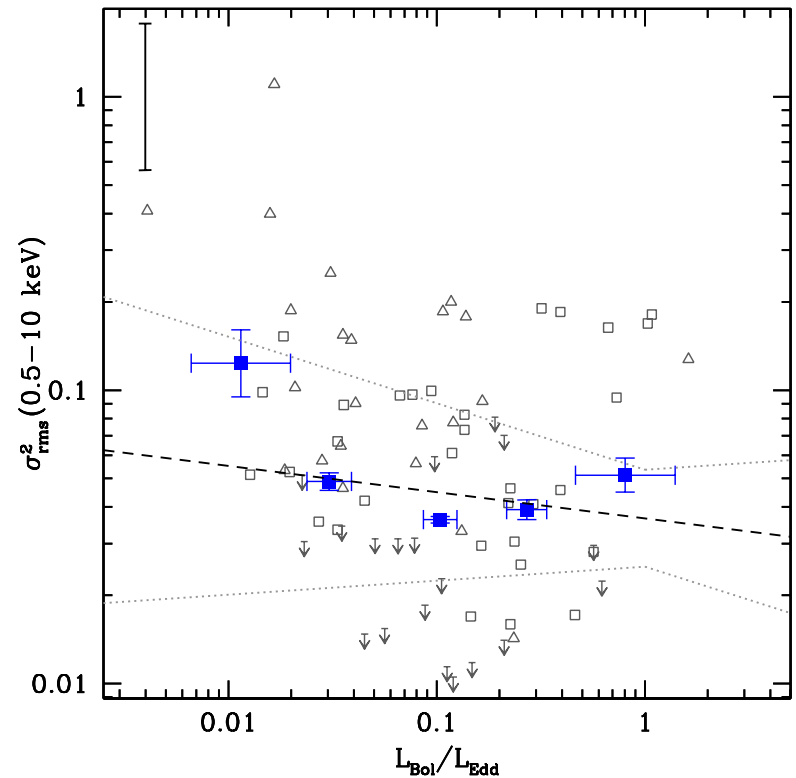
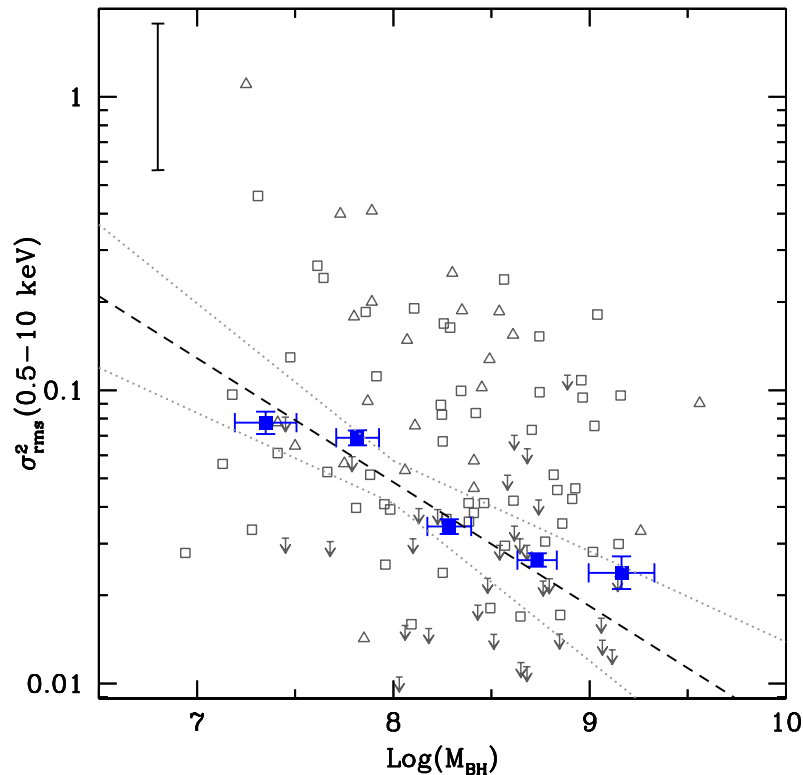


Null result for the Chandra-SDSS sample: (Gibson & Brandt 2012)

- 264 SDSS spectroscopic quasars in the Chandra archive ($z < 5$) and with rest-frame timescales $< \Delta t_{\text{sys}} \approx 2000$ days,
- Significant ($> 3\sigma$) variation in $\approx 30\%$ of the quasars overall ($\approx 70\%$ for sources with > 1000 counts per epoch).
- No evidence in our sample that quasars are more variable at higher redshifts ($z > 2$)
- X-ray spectra steepen as they brighten, with evidence for a constant, hard spectral component that is more prominent in fainter stages.



Constraining the relevant parameters: COSMOS field (Lanzuisi et al. 2014)

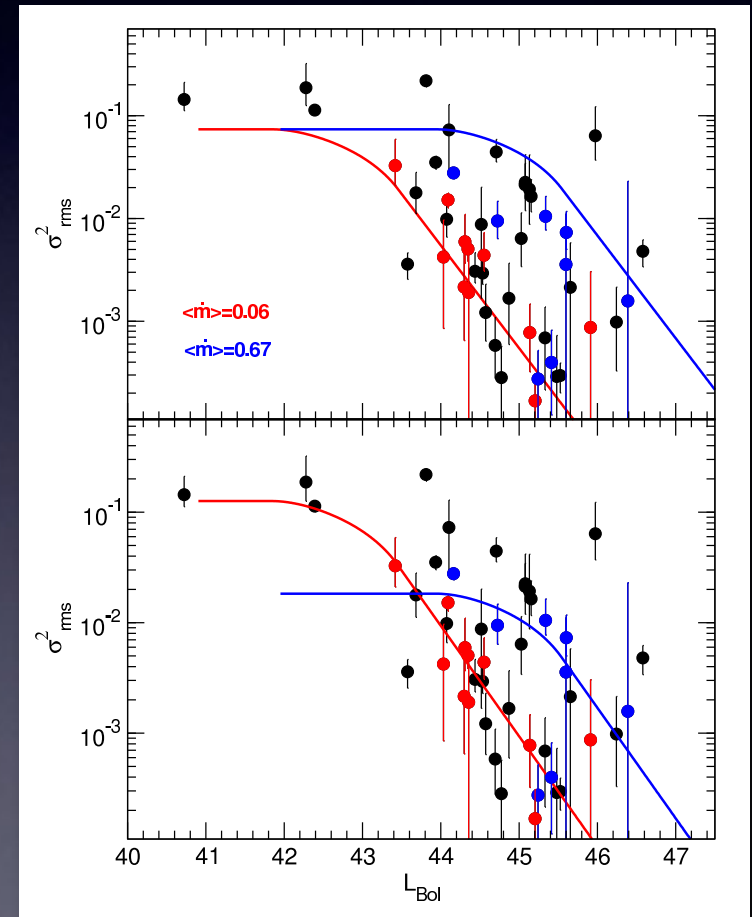
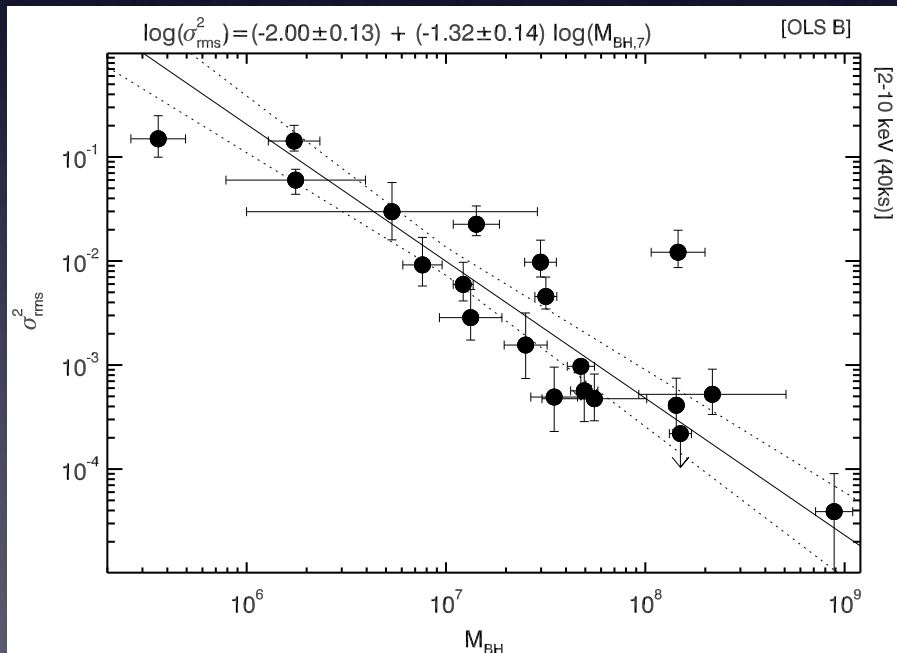


Dependence on mass, but no dependence on accretion!

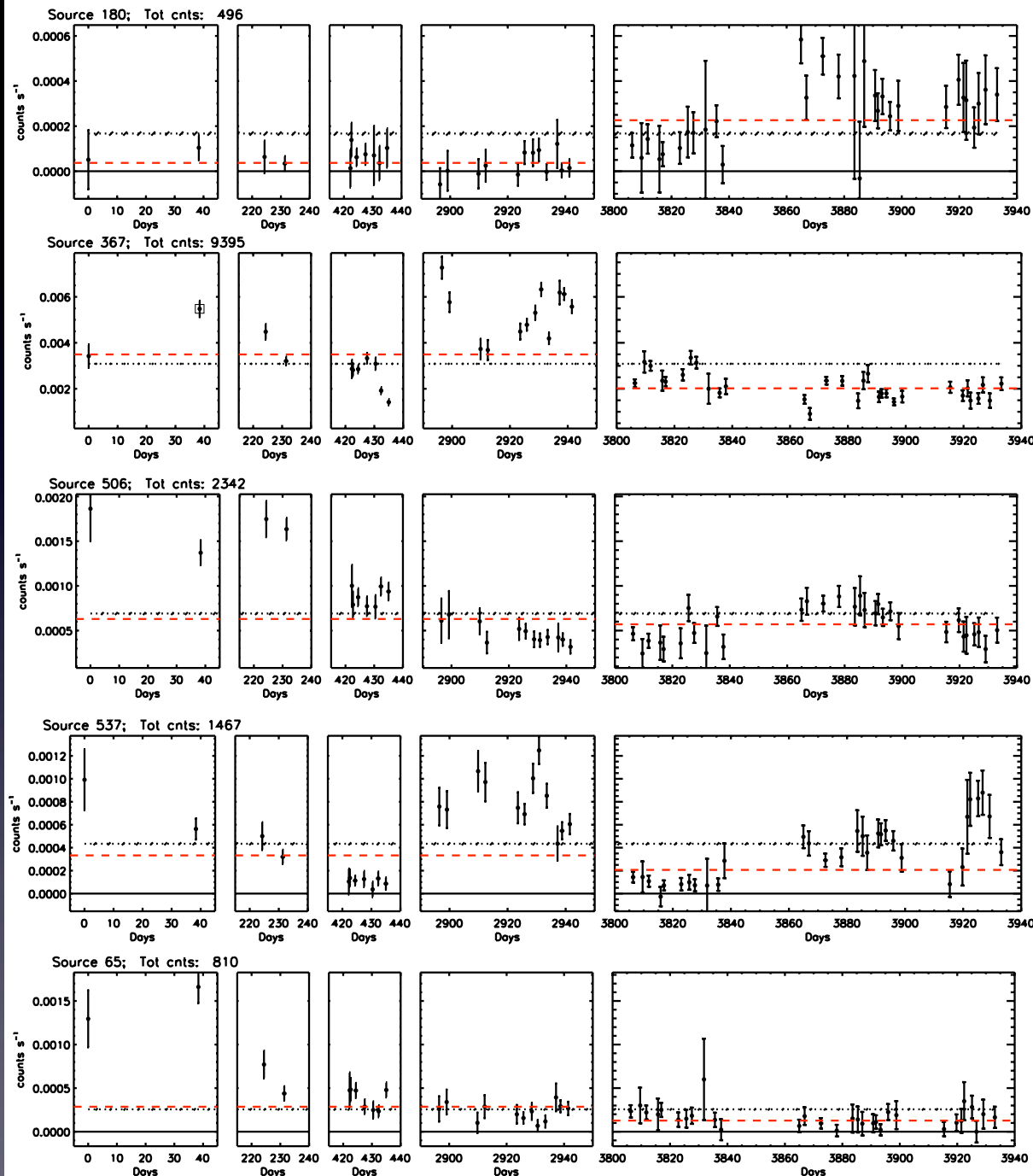
Constraining the relevant parameters: the CAIXA sample (Ponti et al. 2011)

XMM-Newton sample of 161 radio quiet, X-ray un-obscured AGN studied on time scales less than a day. Mostly local ($z < 0.3$) AGNs.

Tight (~ 0.7 dex) correlation between σ^2 and M_{BH} , but variable PSD amplitude



4Ms CDFS lightcurves (Chandra data)

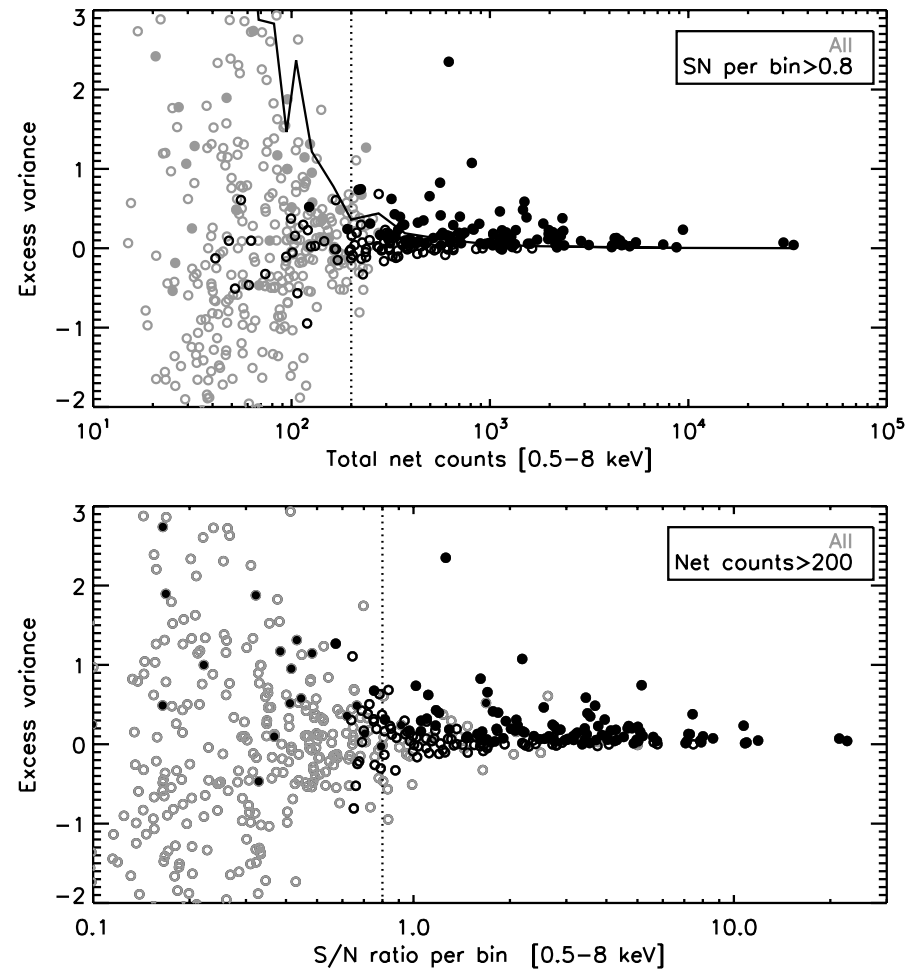


The 4Ms data allow to sample AGN variability on different timescales, from a few days up to 11 yrs.

A proxy to a proper PSD analysis

Need for proper statistical sample

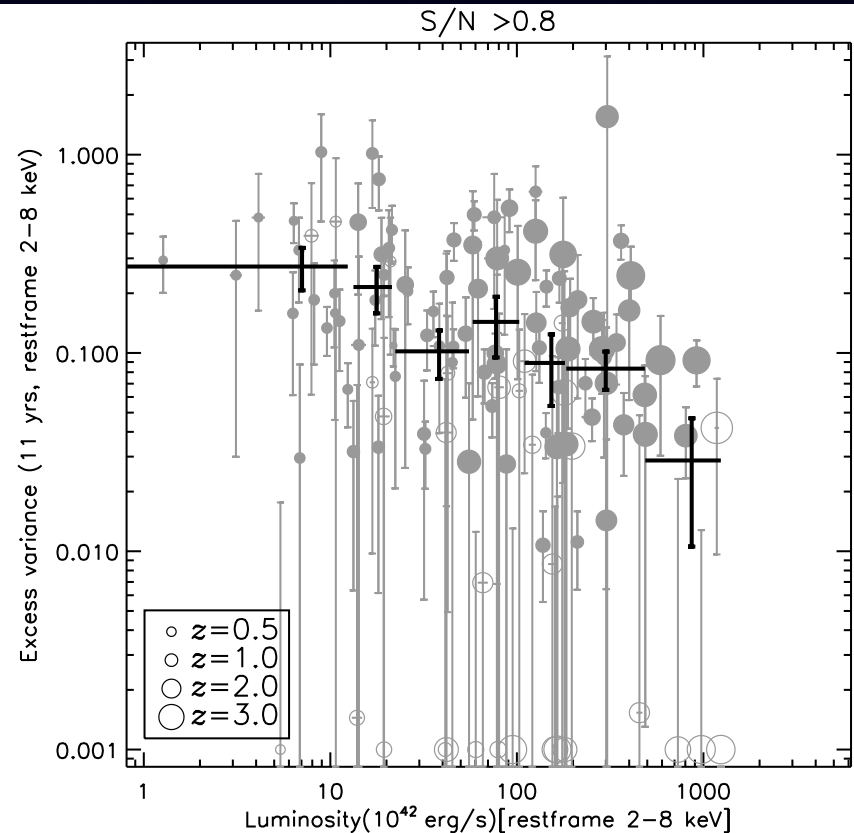
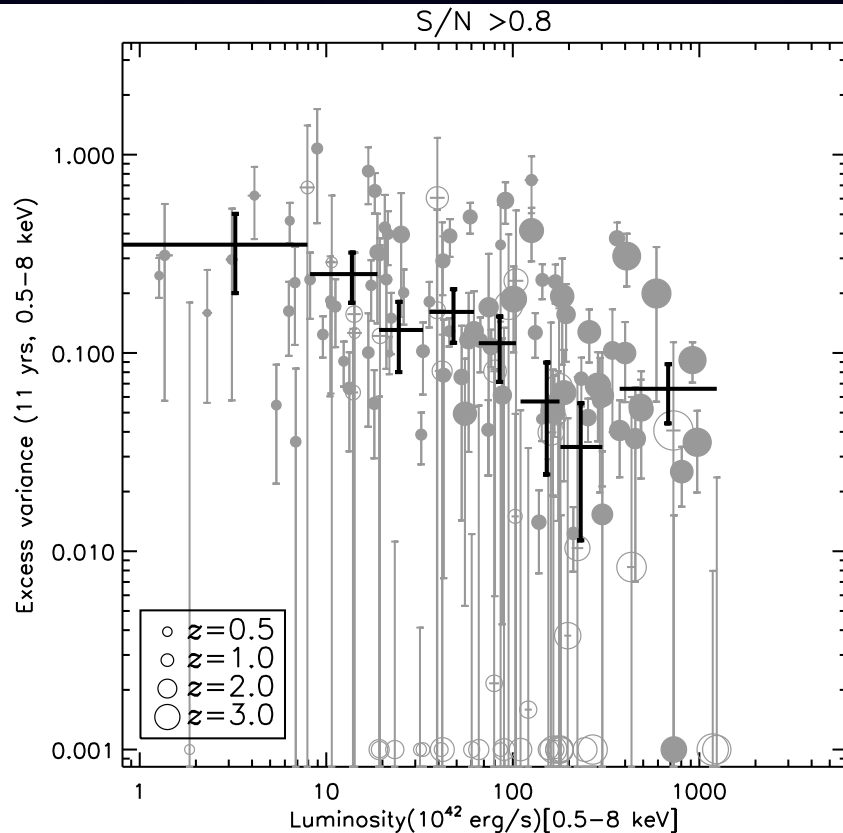
The CDFS allows to work with a complete and unbiased (in terms of variability) sample.



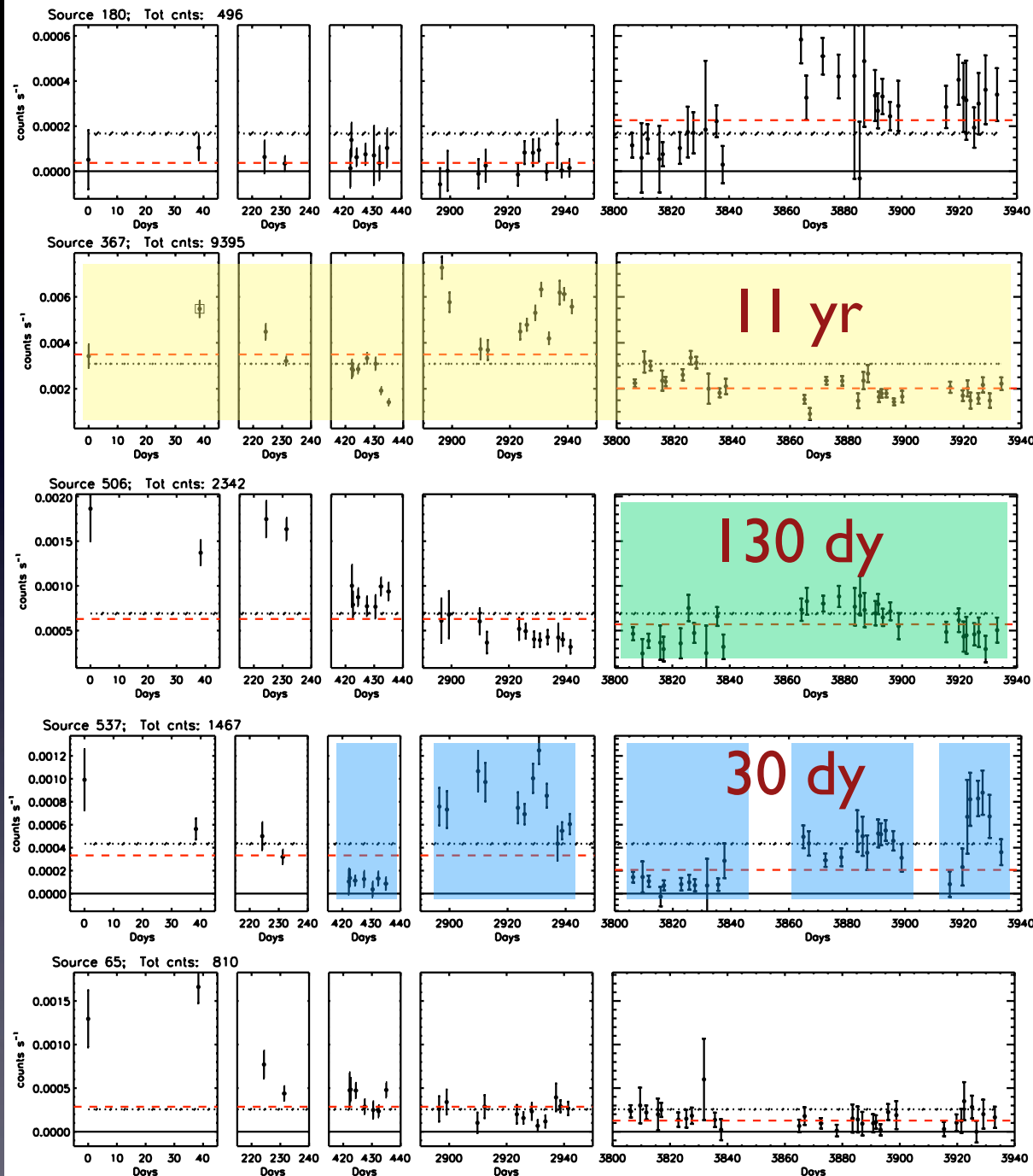
Lx-variability correlation holds for high-z sources as well

High-z AGN do follow the L_x-variability relation but

AGNs at different redshift sample different timescales, so need to correct or model this effect!



4Ms CDFS lightcurves (Chandra data)



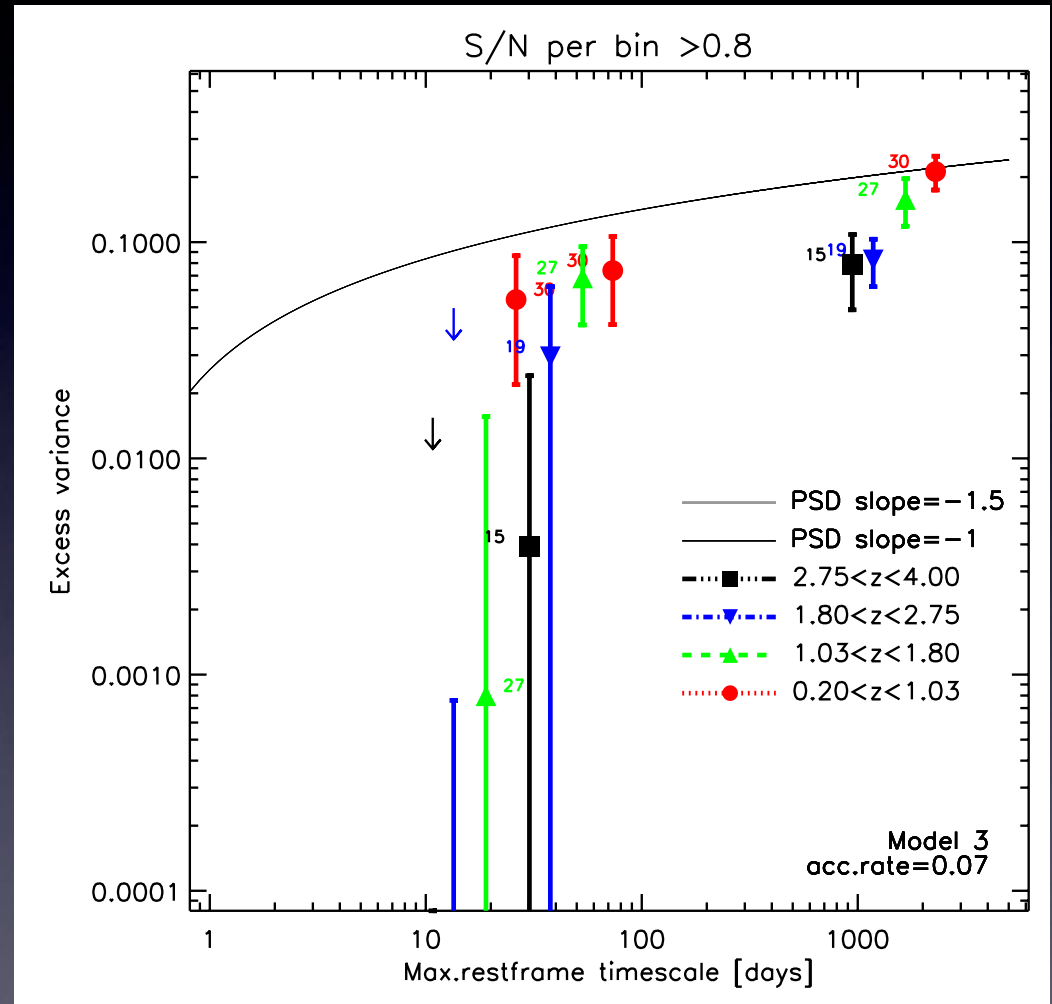
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A proxy to a proper PSD analysis

What PSD for high-z AGNs?

- A single flat ($\sigma_{NXV}=V^{-1}$) power-law PSD only fits long timescales and low redshift sources (independent of z).
- Steeper PSD slopes ($\sigma_{NXV}=V^{-1.5}$) provide poor fits to some timescales
- A bending power-law seems the best fit for high-z AGNs, reproducing both the high frequency cutoff and the redshift dependence:

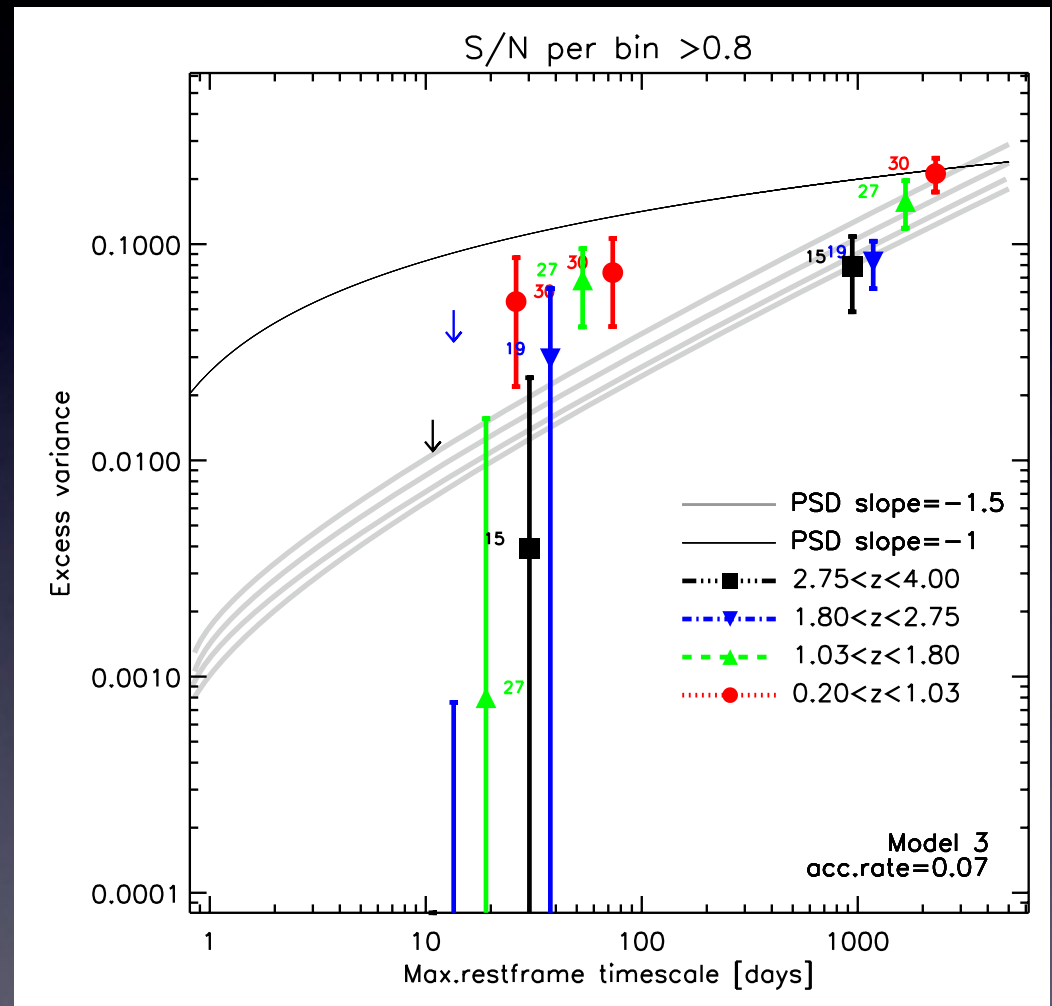
$$\text{PSD}(\nu) = A\nu^{-1} \left(1 + \frac{\nu}{\nu_b} \right)^{-1}$$



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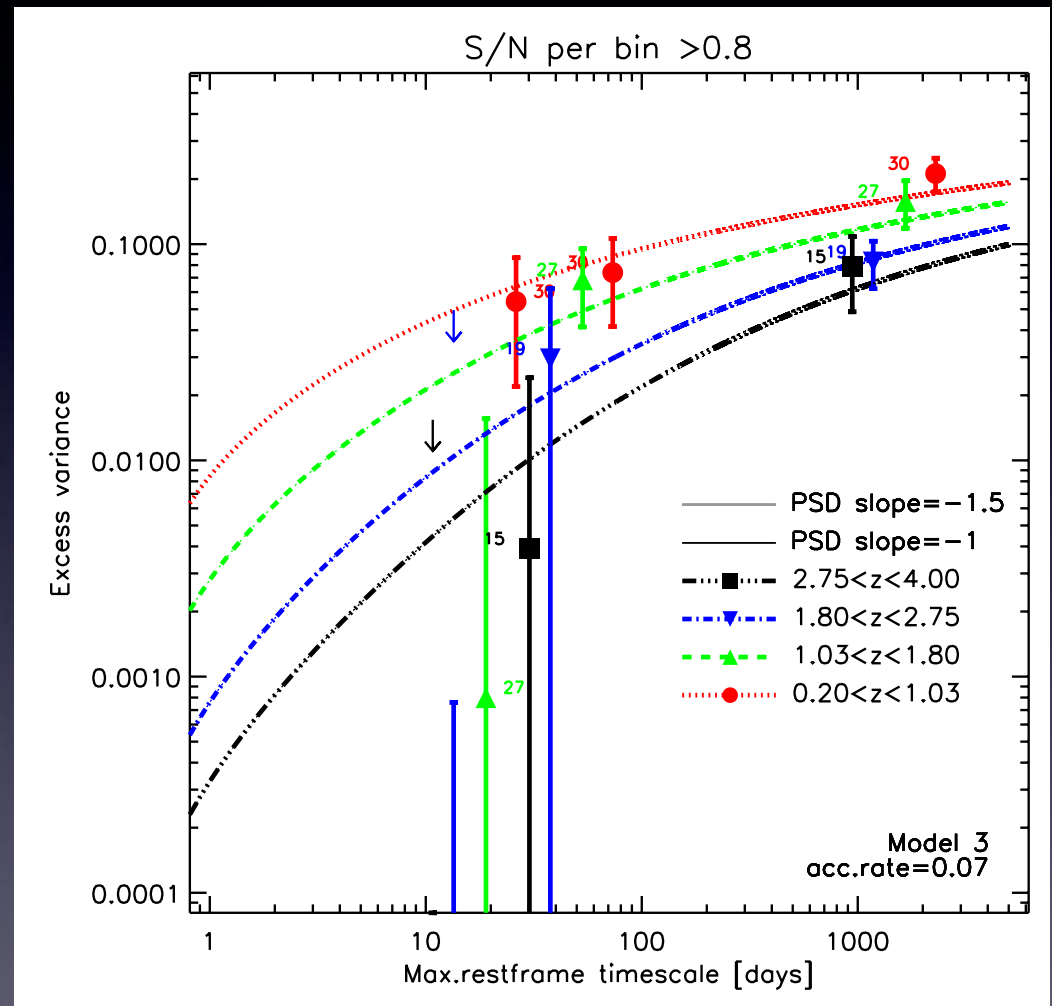
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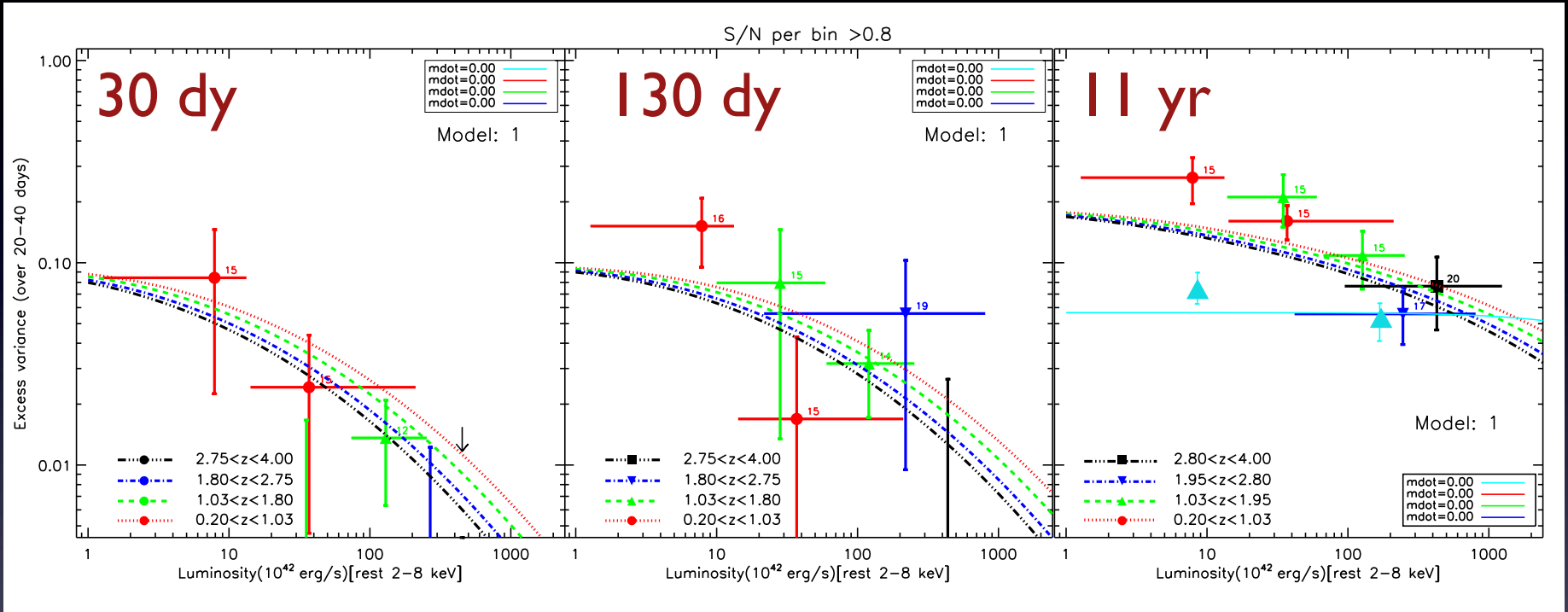
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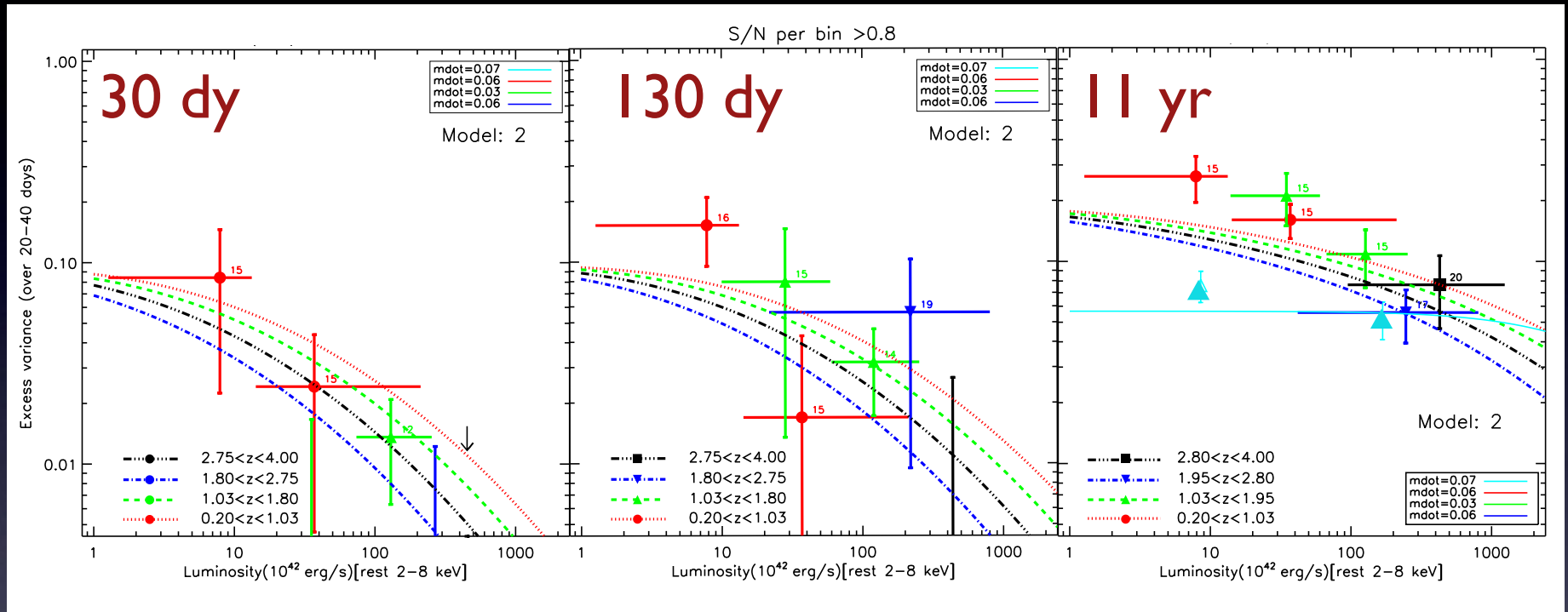
Constraining the model: fit results



Model I: bending frequency depends only on BH mass as $\nu_b \propto M^{-1}$ (Gonzales-Martin & Vaughan, 2012) with fixed PSD normalization (Papadakis et al. 2004, 2008)

Model is rejected $P_{\text{null}} < 10^{-2}$ level when $\lambda_{\text{Edd}} > 0.03$.

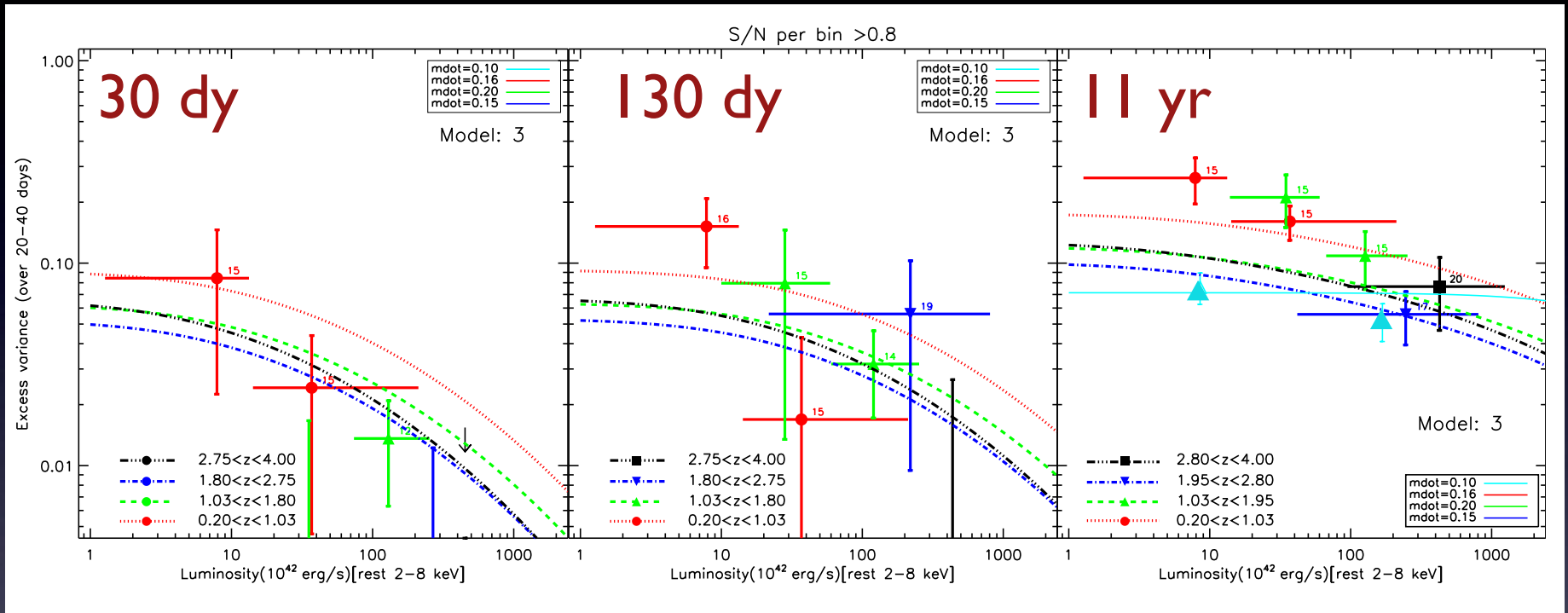
Constraining the model: fit results



Model 2: bending frequency depends on BH mass and acc.rate through $\nu_b \propto L/M^2$ (McHardy et al. 2006), fixed PSD normalization (Papadakis et al. 2004, 2008)

Model is consistent with the data: $P_{\text{null}} \sim 0.23$

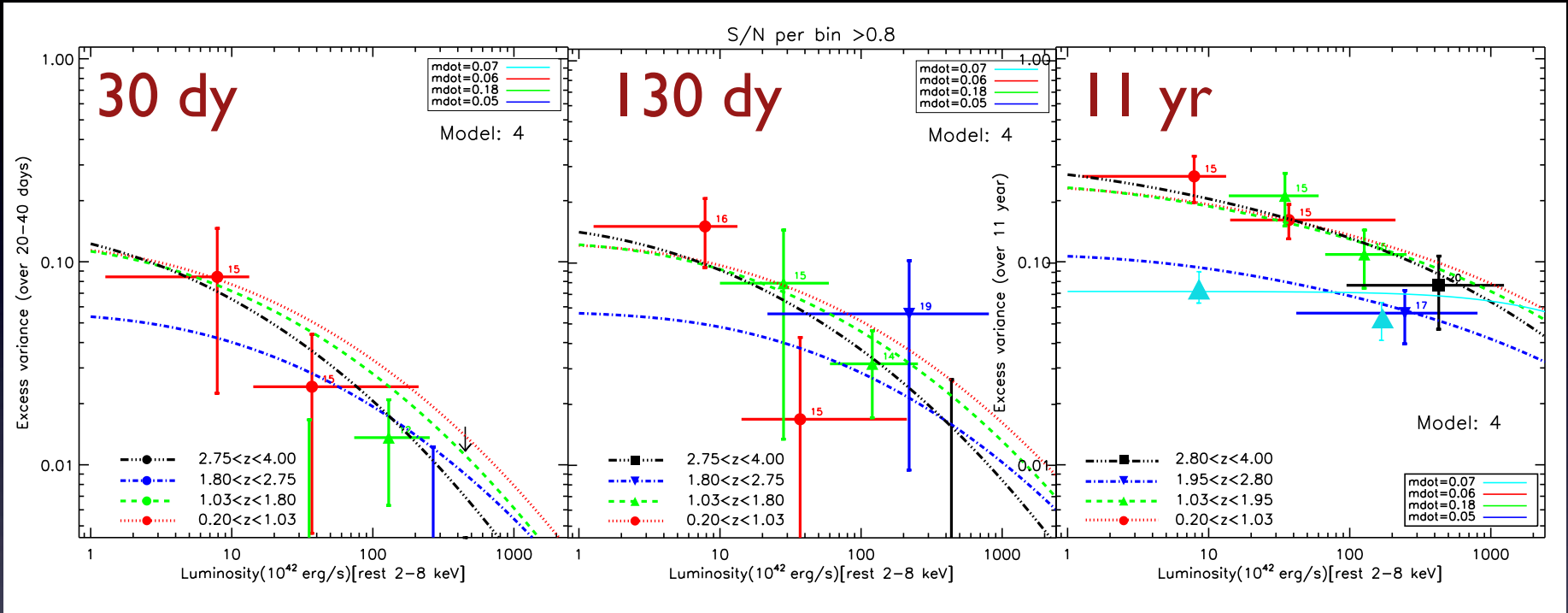
Constraining the model: fit results



Model 3: bending frequency depends only on BH mass as $\nu_b \propto M^{-1}$ (Gonzales-Martin & Vaughan, 2012), PSD normalization depends on acc.rate (Ponti et al. 2011)

Model disfavored with $P_{\text{null}} < 0.013$

Constraining the model: fit results

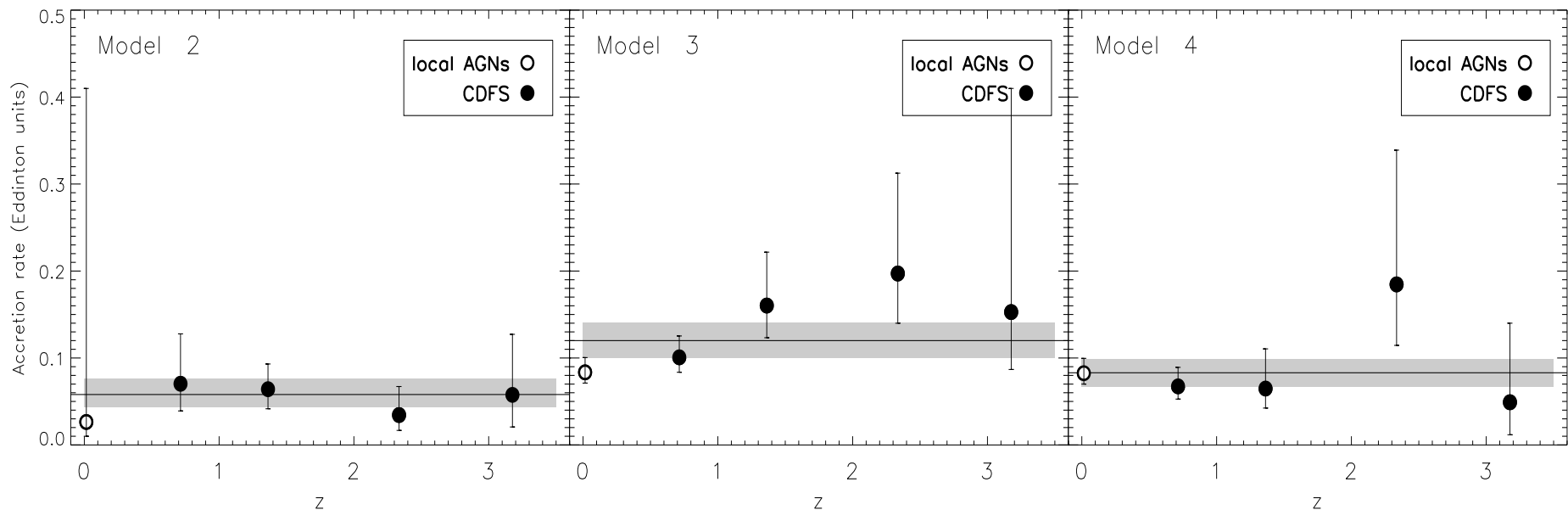


Model 4: bending frequency depends on BH mass and acc.rate through $\nu_b \propto L/M^2$ (McHardy et al. 2006), PSD normalization depends on acc.rate (Ponti et al. 2011)

Model is consistent with the data: $P_{\text{null}} \sim 0.16$

Accretion history results

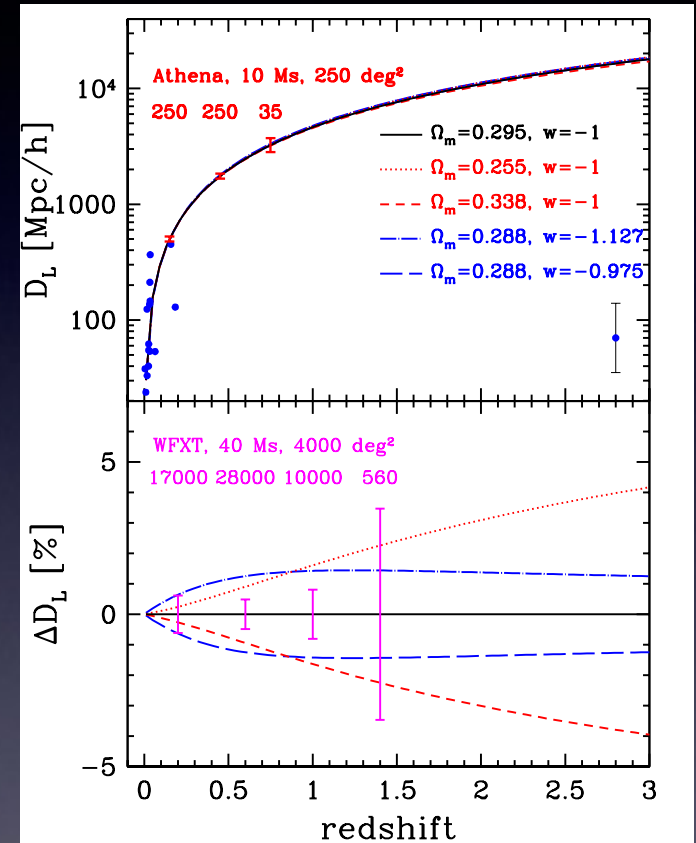
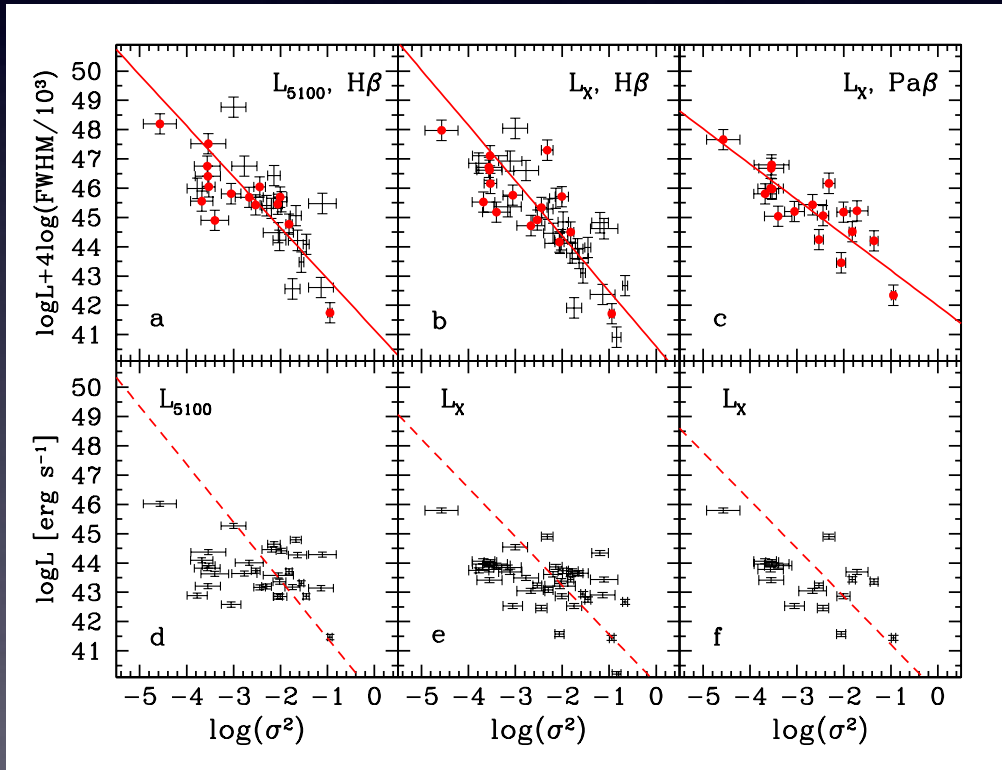
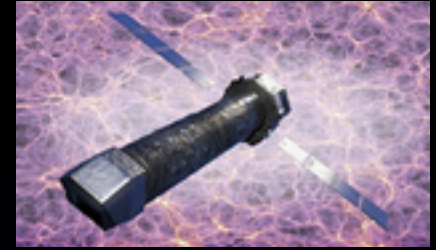
- A constant $\lambda_{\text{Edd}} \leq 0.1$ is consistent with the data, although some models indicate a possible increase of $\lambda_{\text{Edd}}(z)$ peaking at $z \sim 2 \div 3$.
- The low redshift data are consistent with variability of local AGNs (Zhang et al. results).



The future?

(La Franca et al. 2014)

Calibrated variability correlations can provide cosmological constraints. But what about other parameters (e.g. accretion rates)?



Conclusions

- Multi-epoch surveys offer the opportunity to investigate the timing properties of distant AGN populations.
- Luminosity-variability anticorrelation verified over large redshift range.
- High- z AGNs share similar PSD of local AGNs
- Variability dependence on both mass and accretion is favored
- With correct statistical approach and accounting for biases we can constrain the best physical model
- Variability allows to constrain the average accretion rate over cosmic time

Wide-field multi-epoch surveys may allow constrain the evolution of the AGN population.