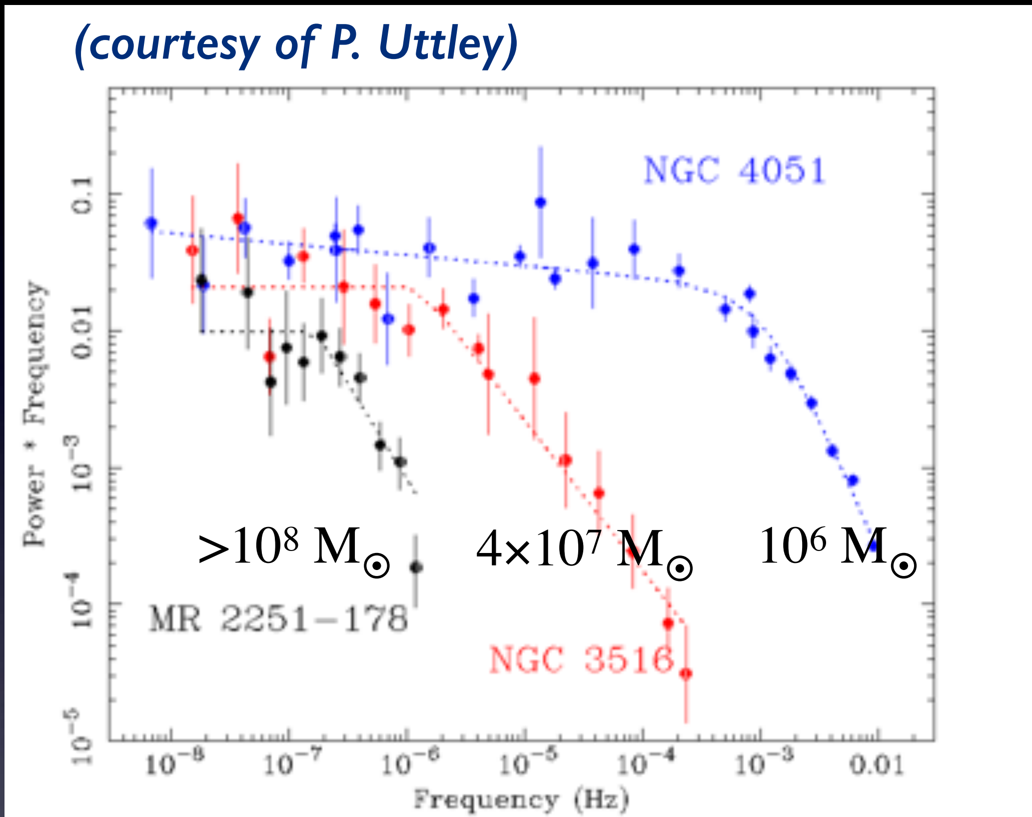
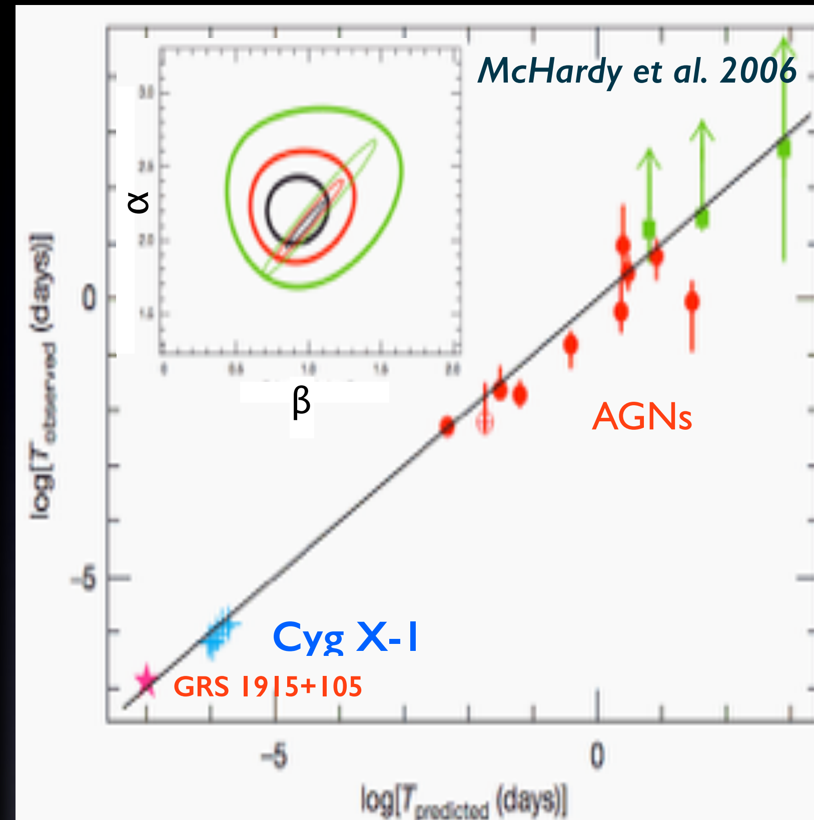
Probing AGN accretion history through X-ray variability

Maurizio Paolillo & the CDFS collaboration
(University Federico II of Naples)

Variability properties of AGNs





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

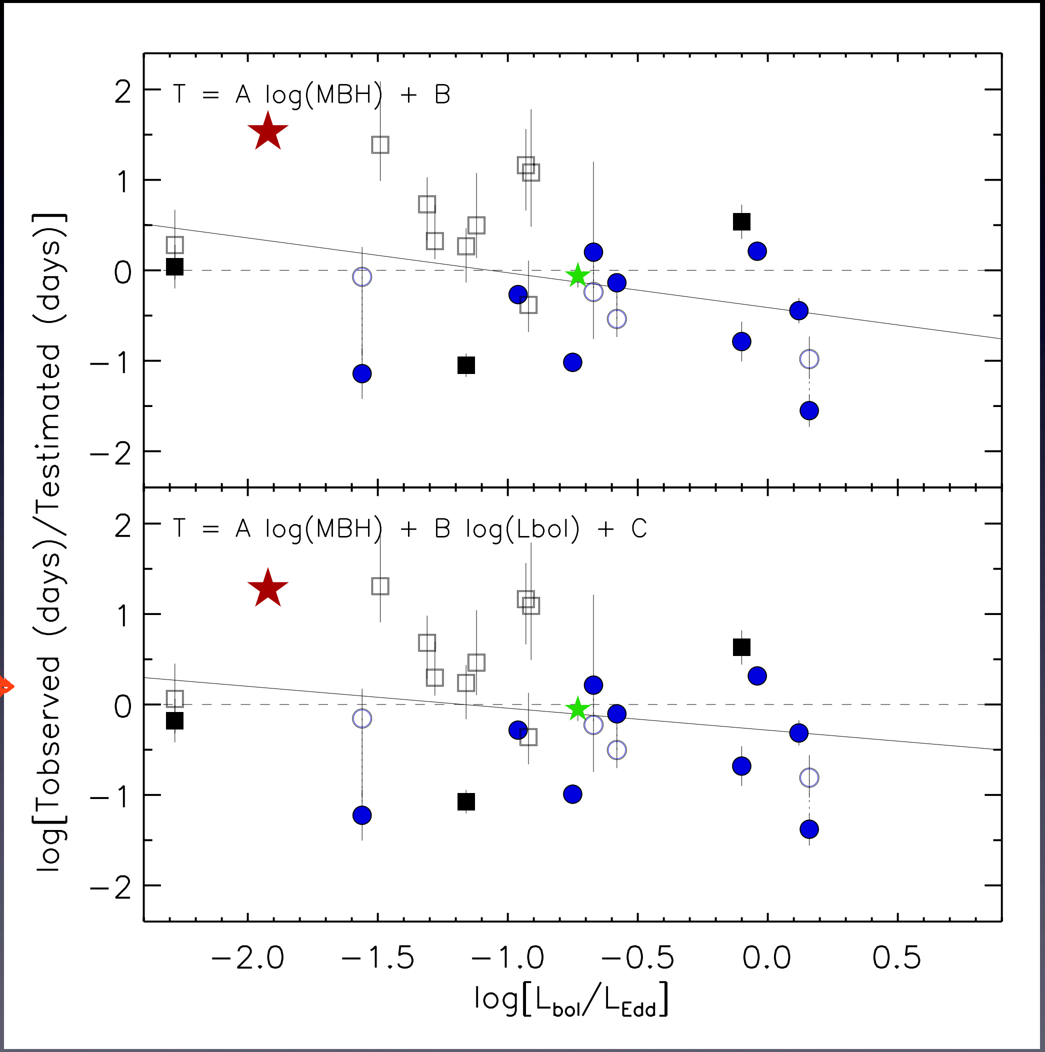
$$t_B \propto M_{BH}^{\alpha}/L_{bol}^{\beta}$$

Accretion dependence challenged by XMM studies.

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

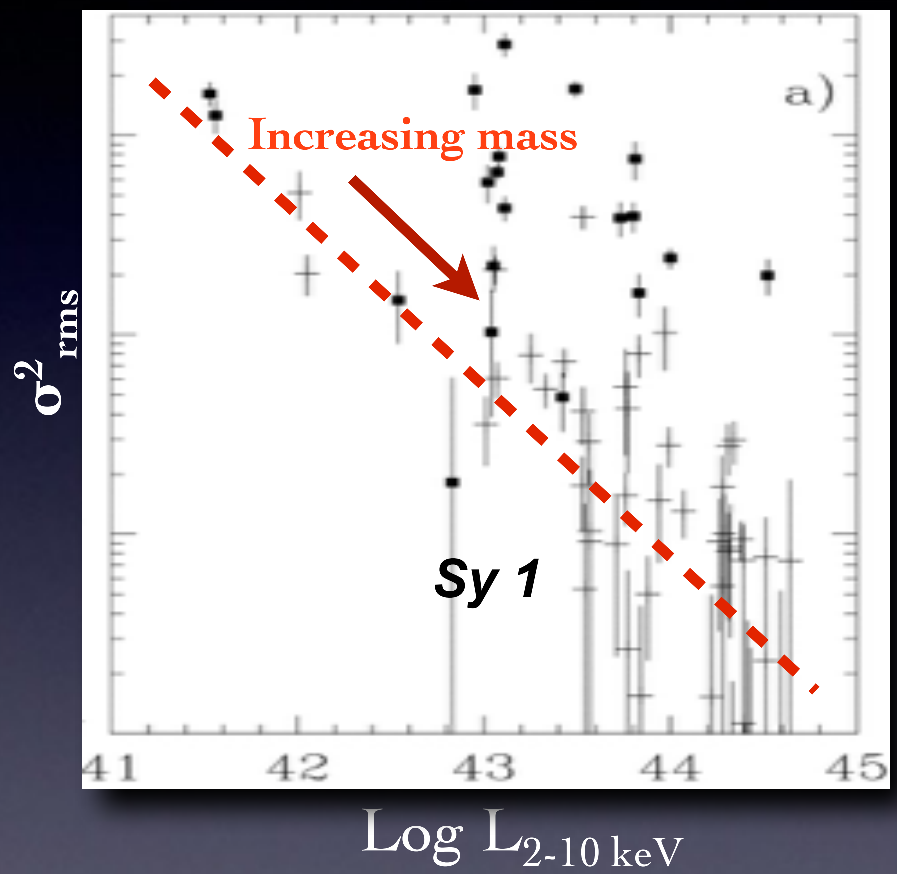
- Break timescale depends only on BH mass
- Break timescale depends on BH mass and accretion rate.

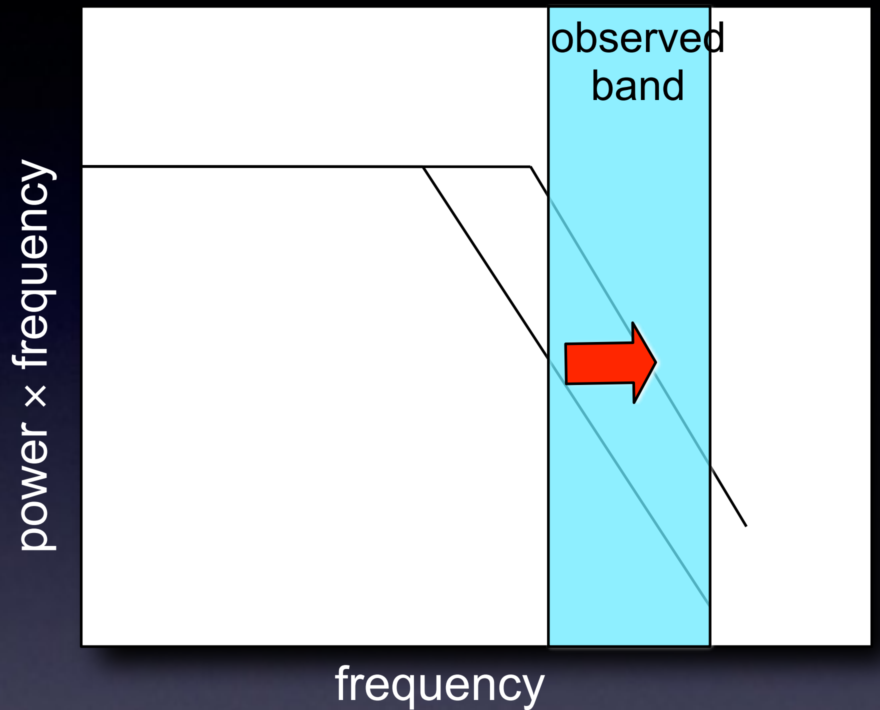
The coefficient B is consistent with zero, i.e. weak or no dependence on accretion rate.



Variability in poor statistics data

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





$$\sigma^2_{\rm NXV} = \frac{1}{N\overline{x}^2}\sum_{i=1}^{N}[(x_i - \overline{x})^2 - \sigma^2_{{\rm err},i}],$$

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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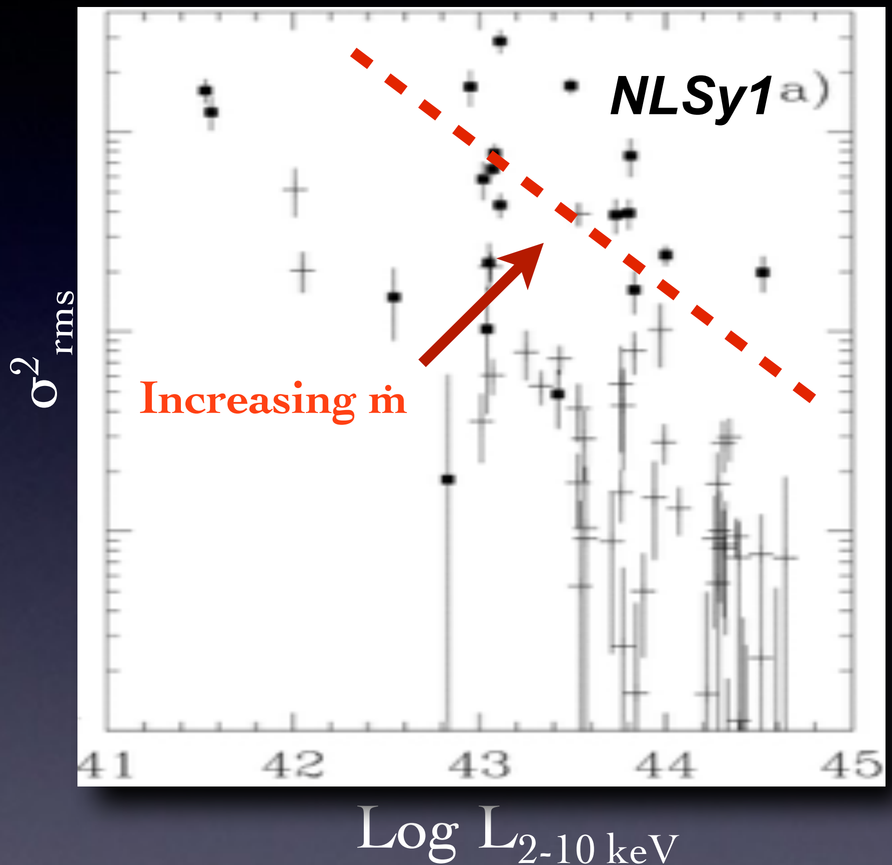
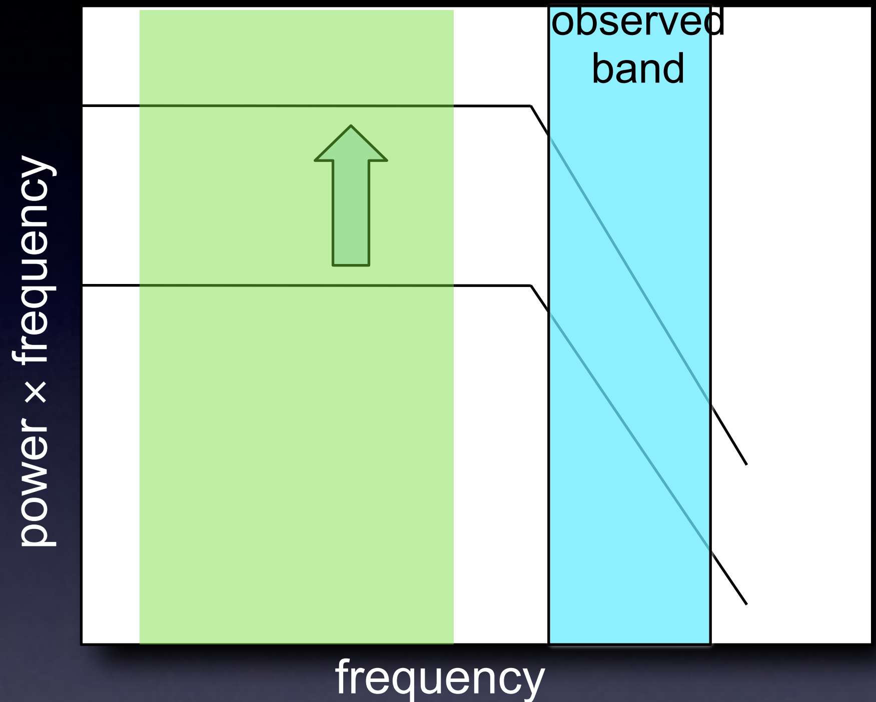




$$\sigma^2_{\rm NXV} = \frac{1}{N\overline{x}^2}\sum_{i=1}^{N}[(x_i - \overline{x})^2 - \sigma^2_{{\rm err},i}],$$

Does the normalization depend on accretion rate as well?

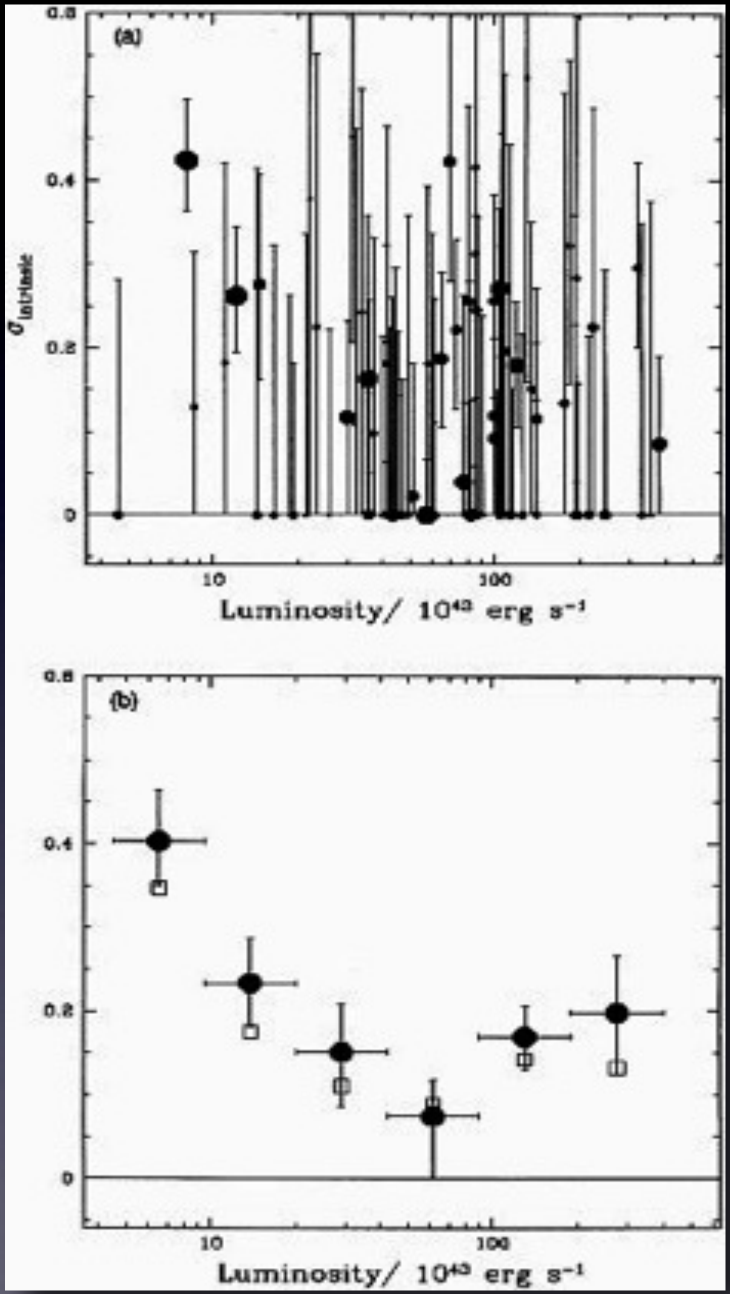
Best sampled on long timescales!

Increased variability at high z?

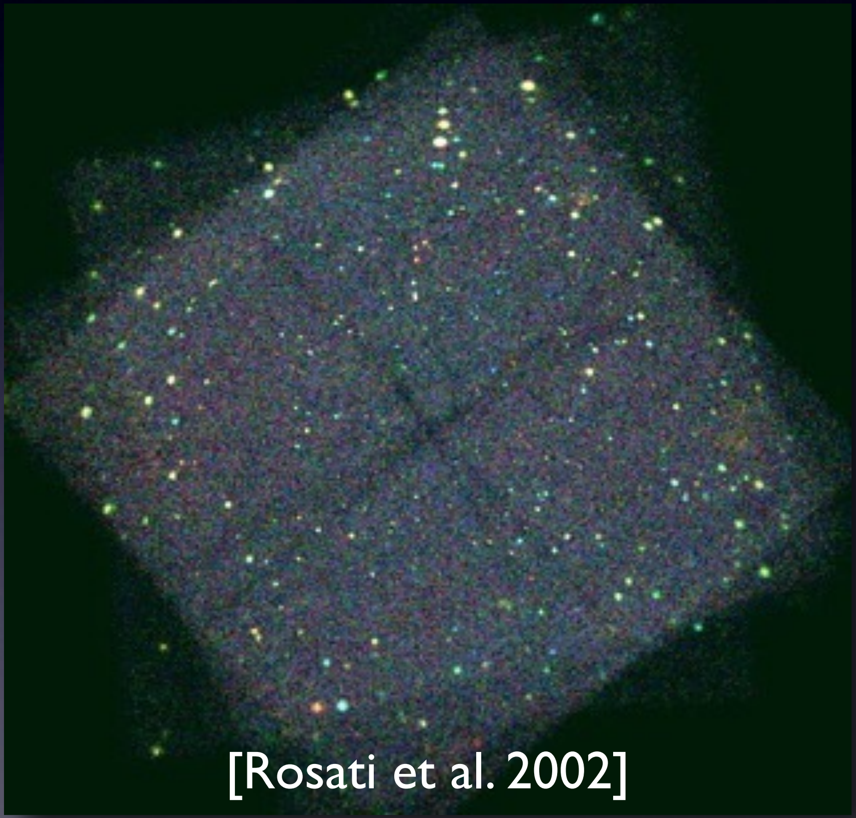
(Almaini et al. 2000)

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

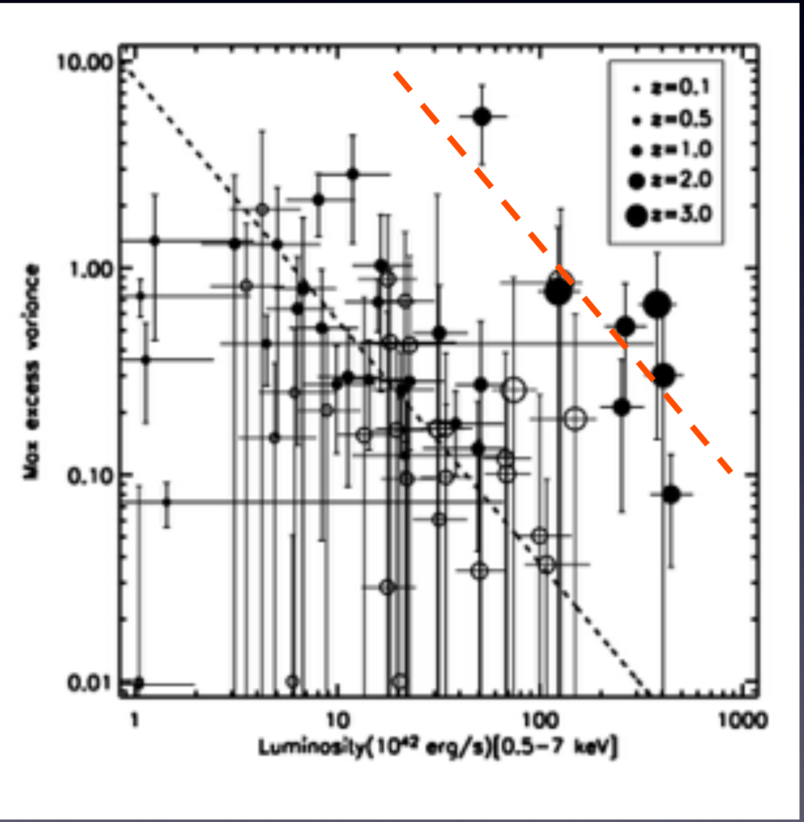
The evolution of the L_X-var. relation could be produced by increase of the accretion rates or a decrease of the X-ray emitting region with look-back time.



Increased variability evidence from the 1Ms CDFS
(Paolillo et al. 2004)



- Larger variability for high-z AGNs?



Increased variability in the Lockman Hole?

(Papadakis et al. 2008)

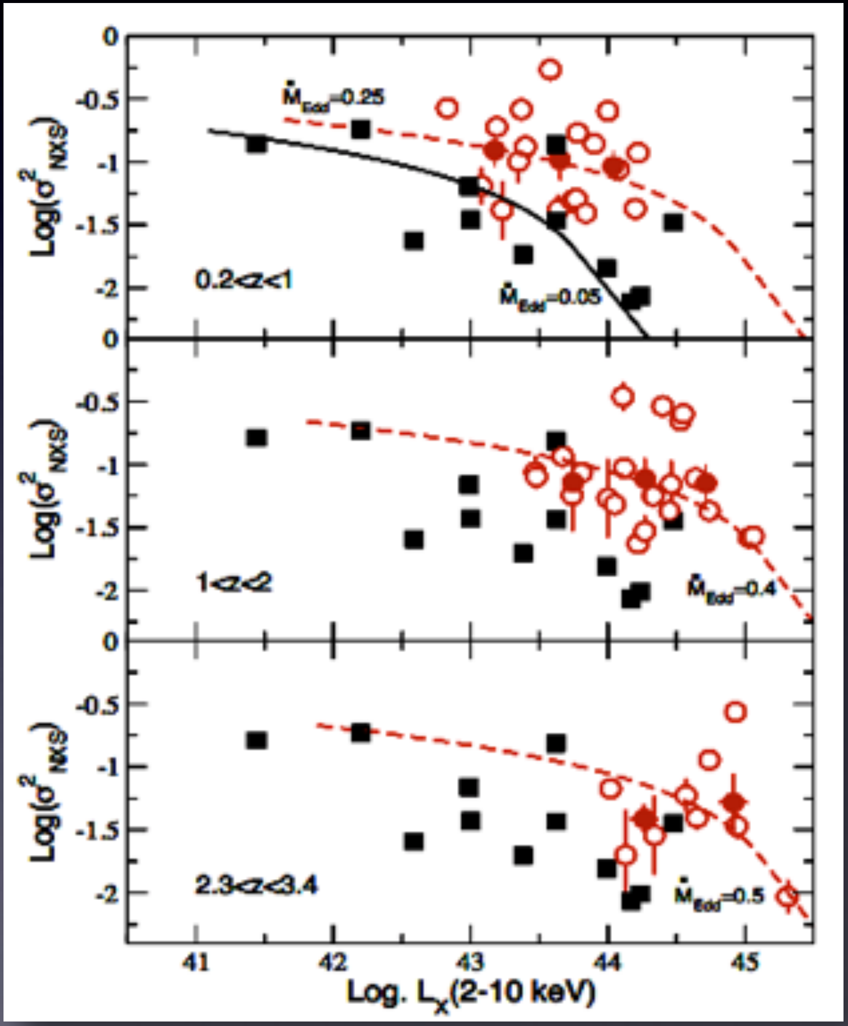
Fitting a more physically motivated model yields:

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

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

(N.B. assumes constant PSD amplitude)

- Fitting the Lx-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

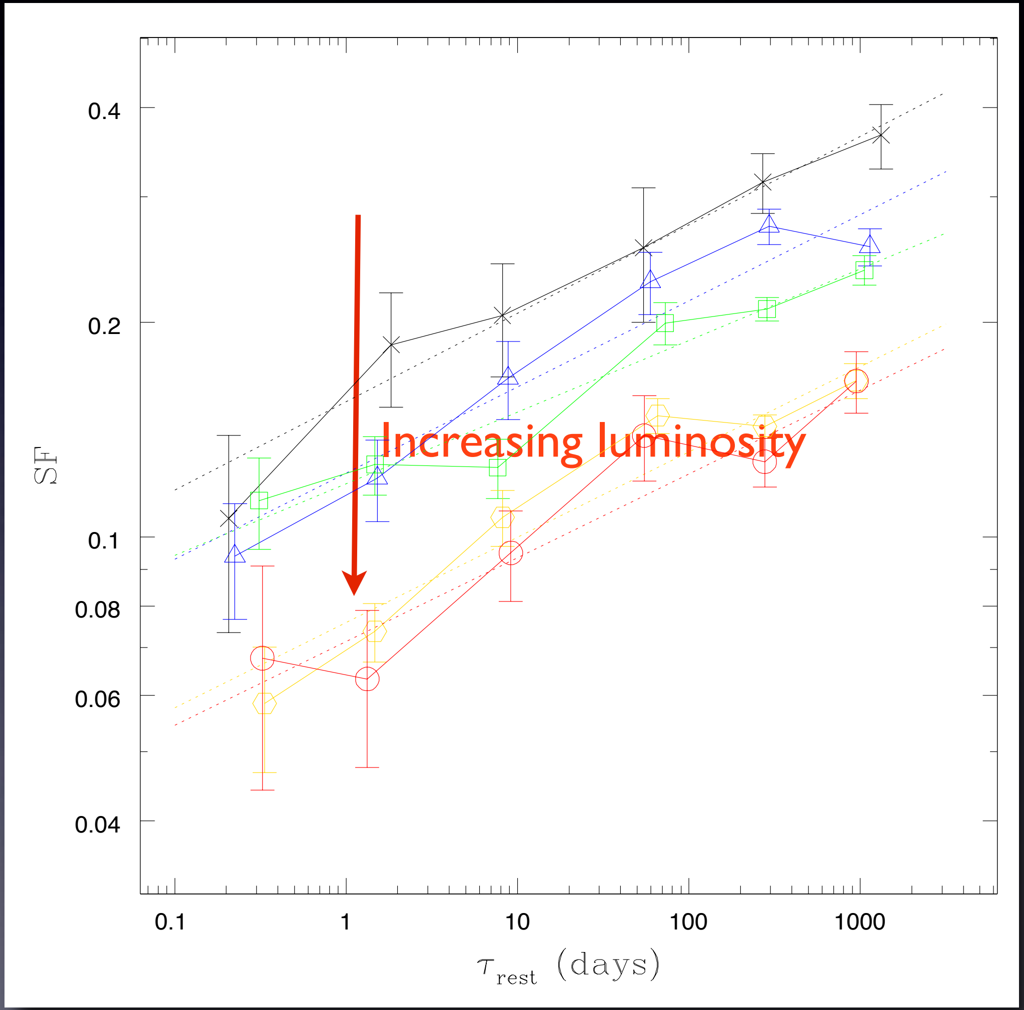


XMM and Swift serendipitous samples

(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 ~$10^{43\text{-}46}$ 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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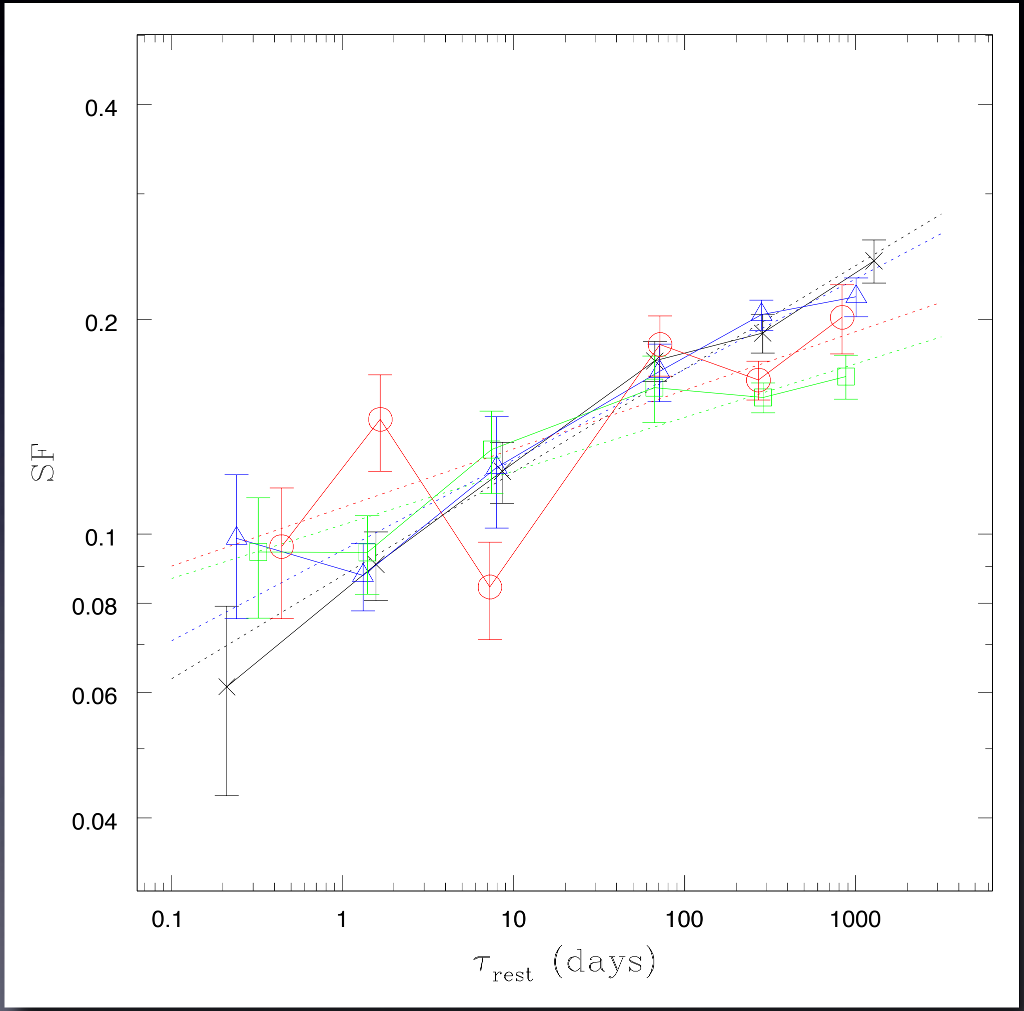
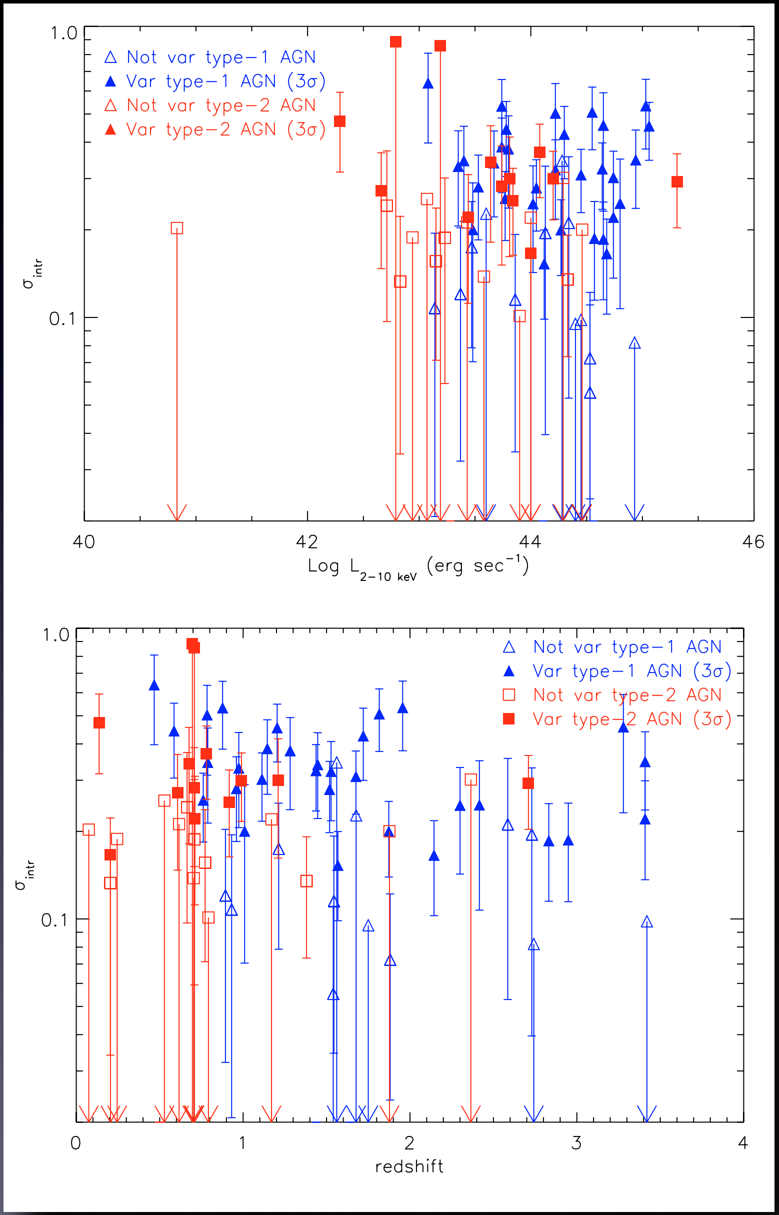


Null result for the XMM Lockmann Hole bright sample
(Mateos 2007)

- 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.

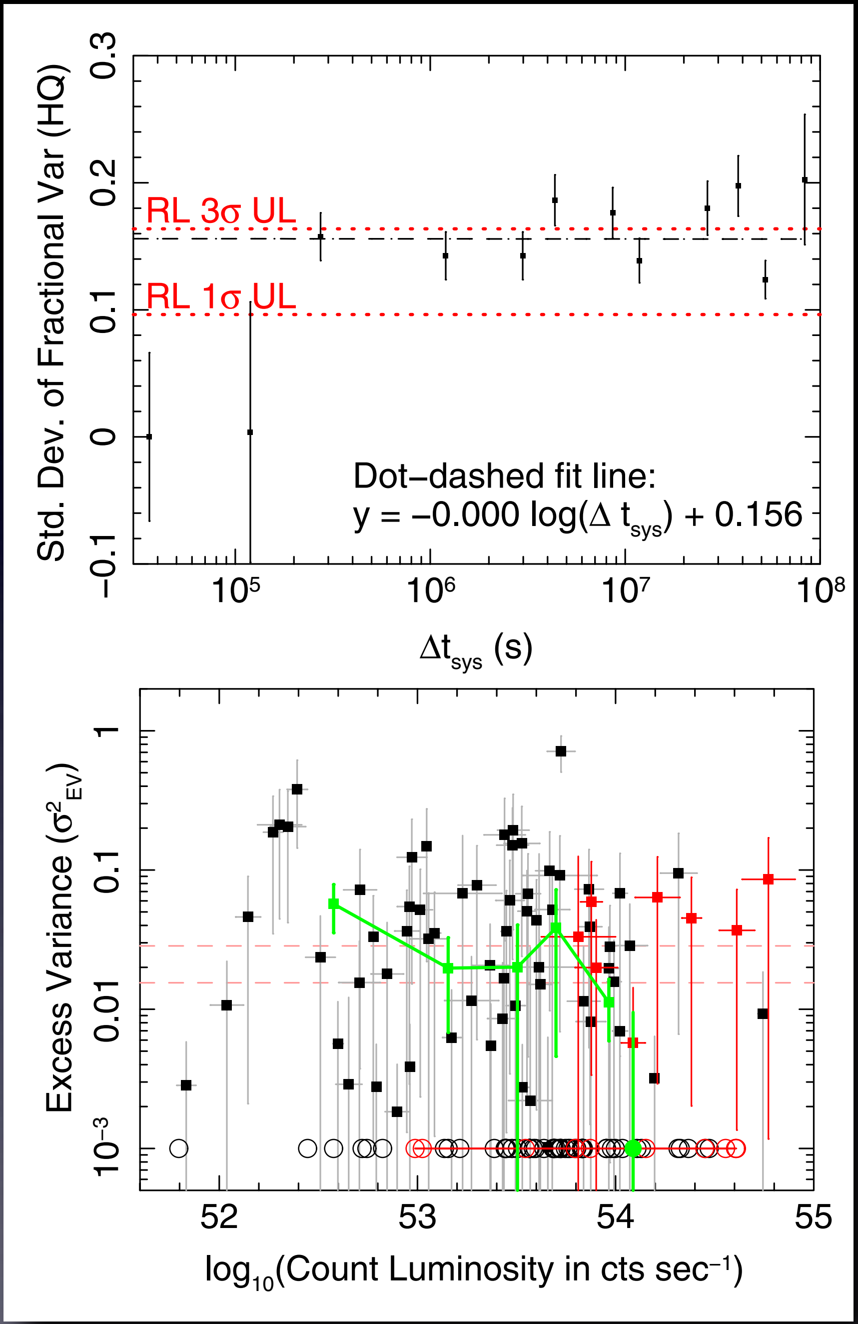
But....if complex dependence on redshift, luminosity and variability we need to <u>take all of them into account simultaneously</u>!



Null result for the Chandra-SDSS sample:

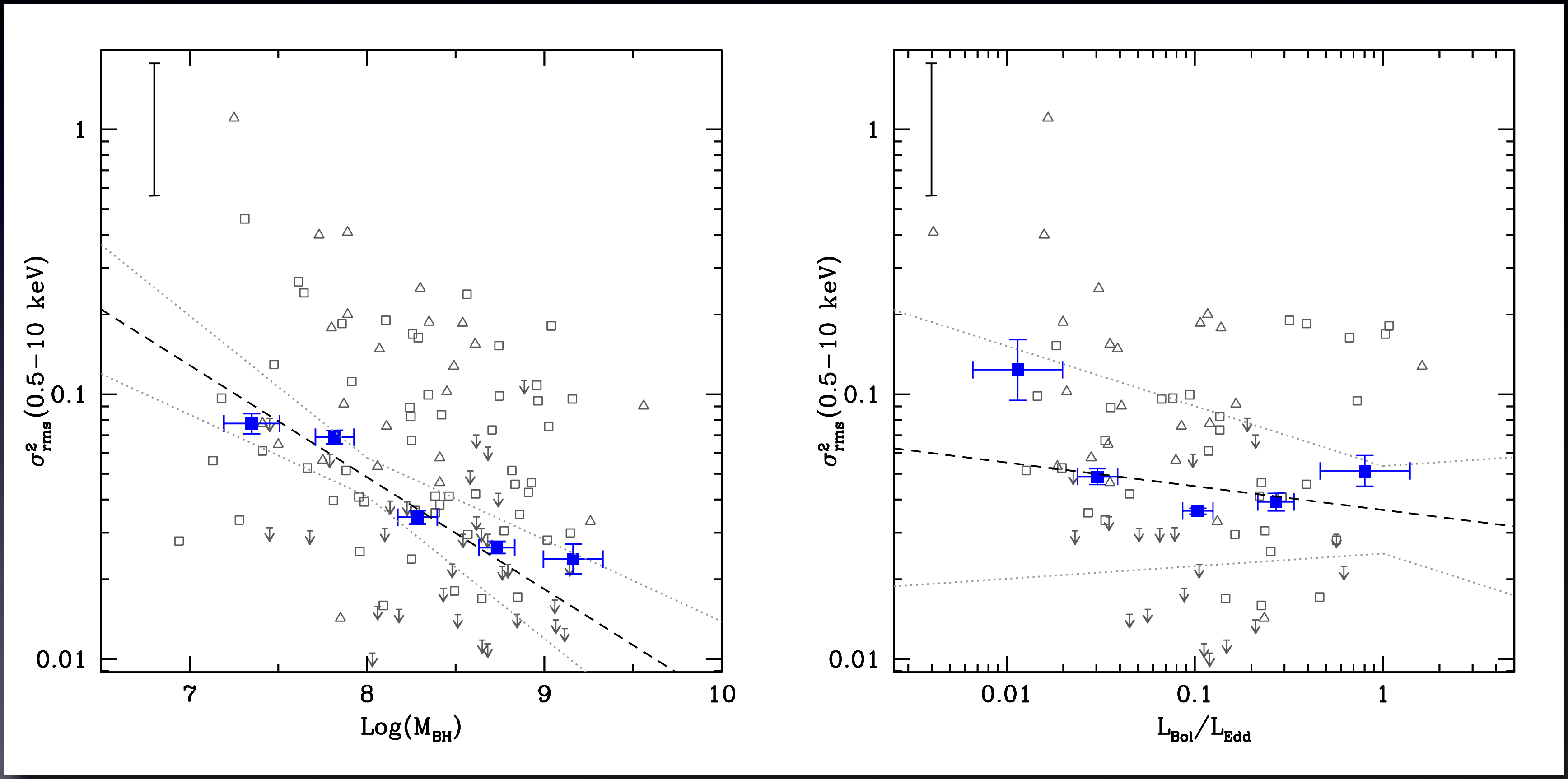
(Gibson & Brandt 2012)

- 264 SDSS spectroscopic quasars in the Chandra archive (z<5) and with rest-frame timescales $<\Delta t_{sys} \approx 2000$ days,
- Significant (>3σ) variation in ≈30% of the quasars overall(≈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*)

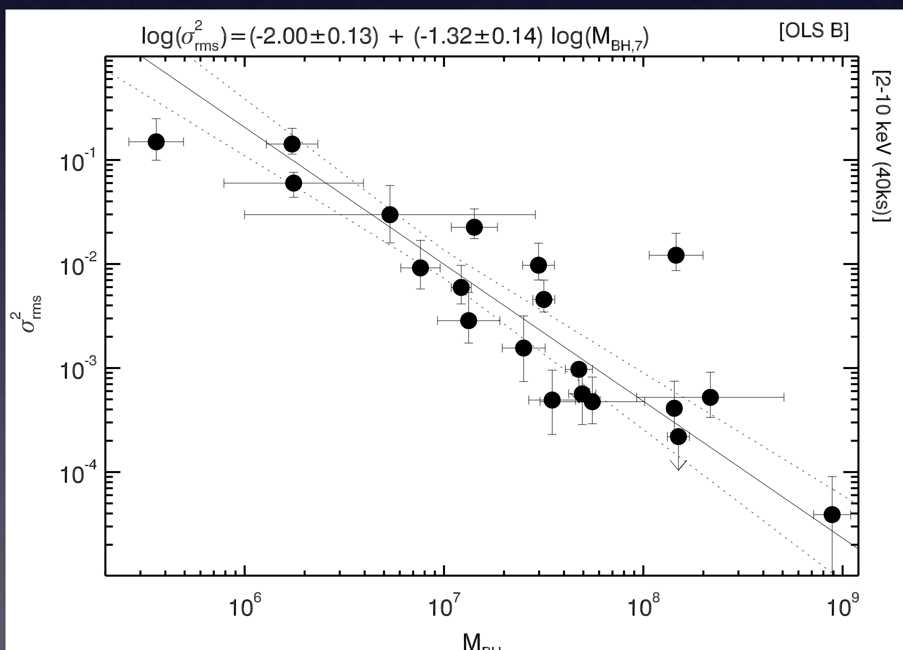


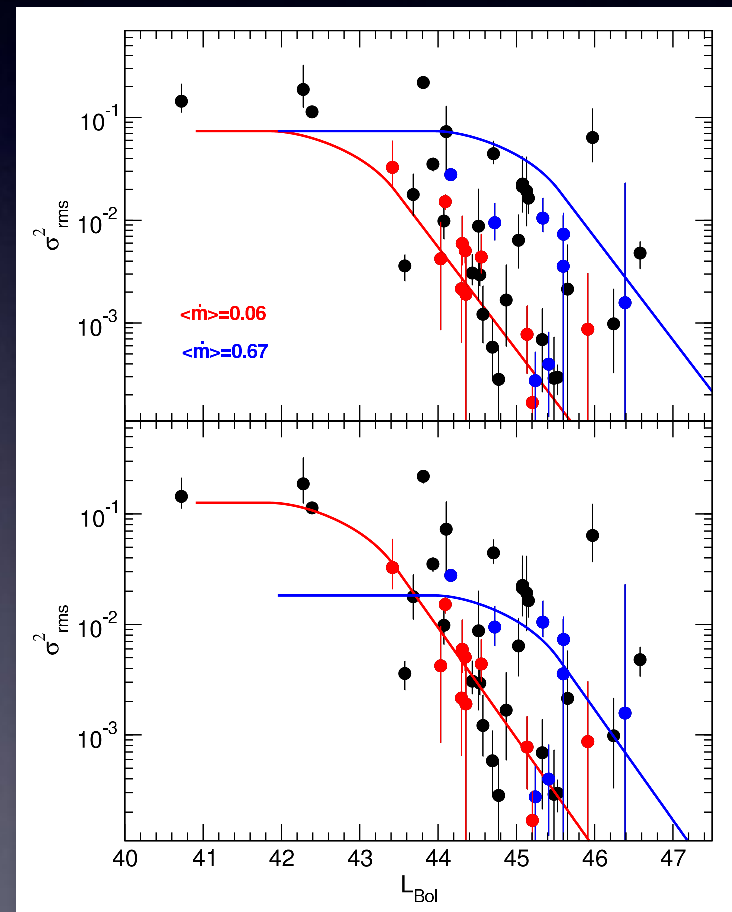
Dependence on mass, but no dependence on accretion!

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

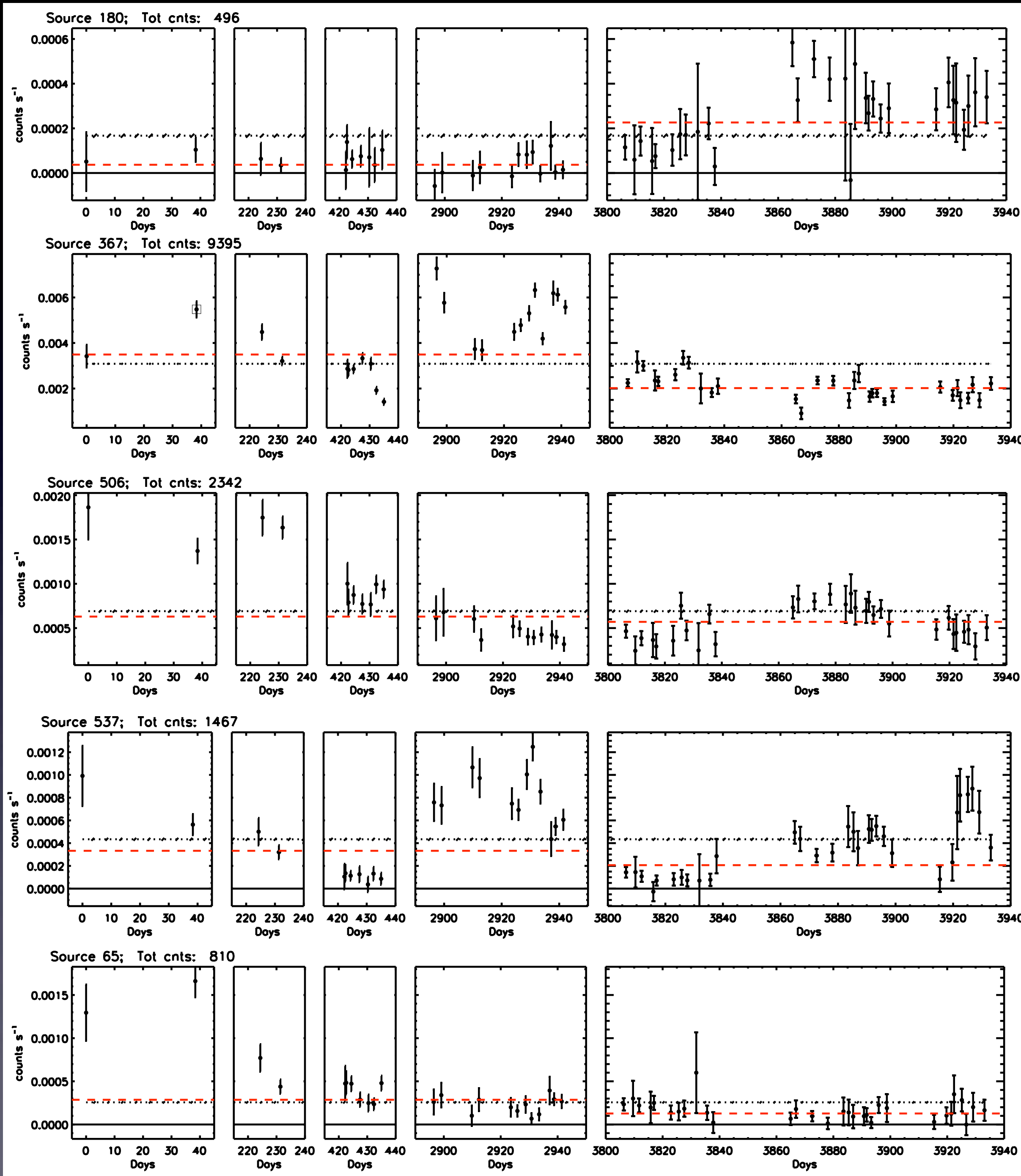
XMM-Newton sample of 161 radio quiet, X-ray un-obscured AGN studied on time scales less than a day. Mostly local (z<0.3) AGNs.

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





4Ms CDFS lightcurves (*Chandra data*)

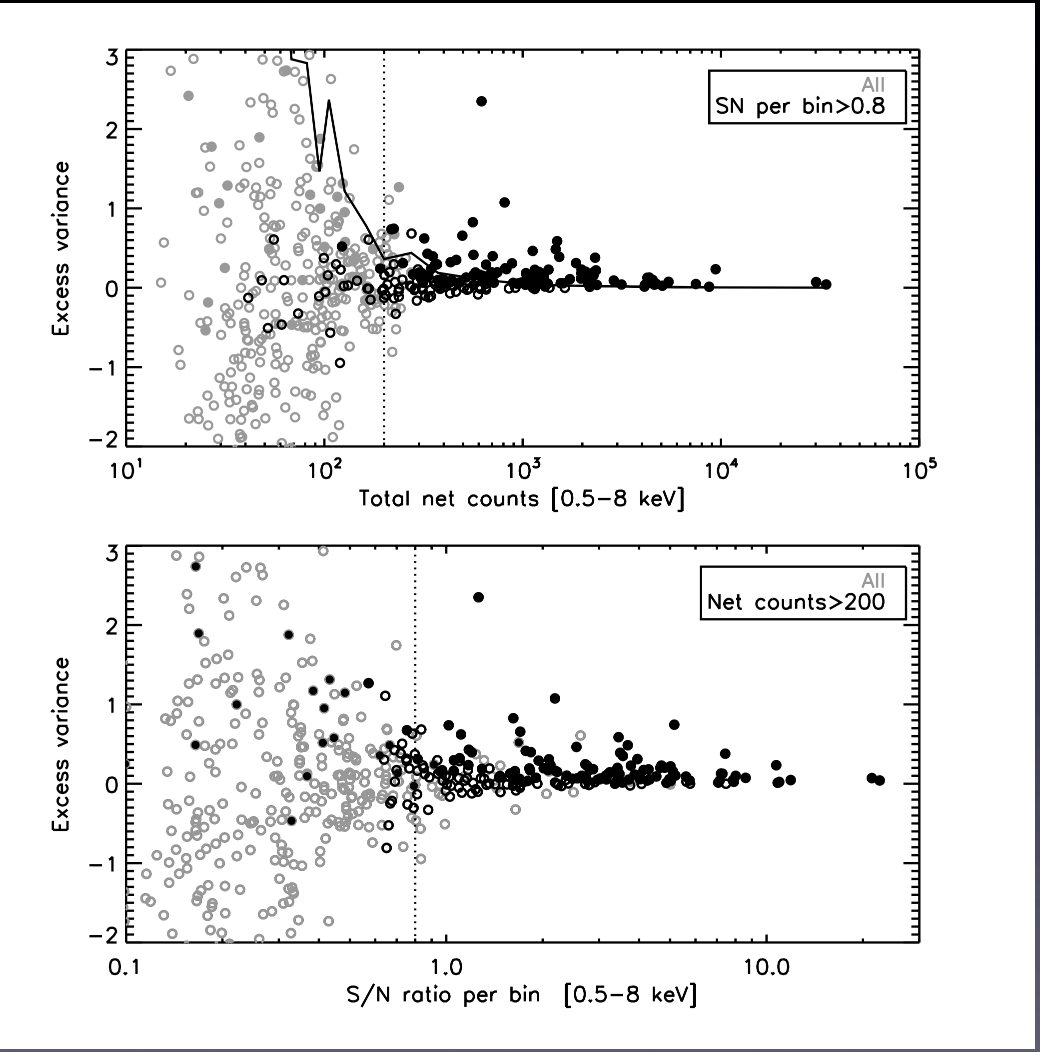


The 4Ms data allow to sample AGN variability on different timescales, from a few days up to 11 yrs.

A proxy to a proper PSD analysis

Need for proper statistical sample

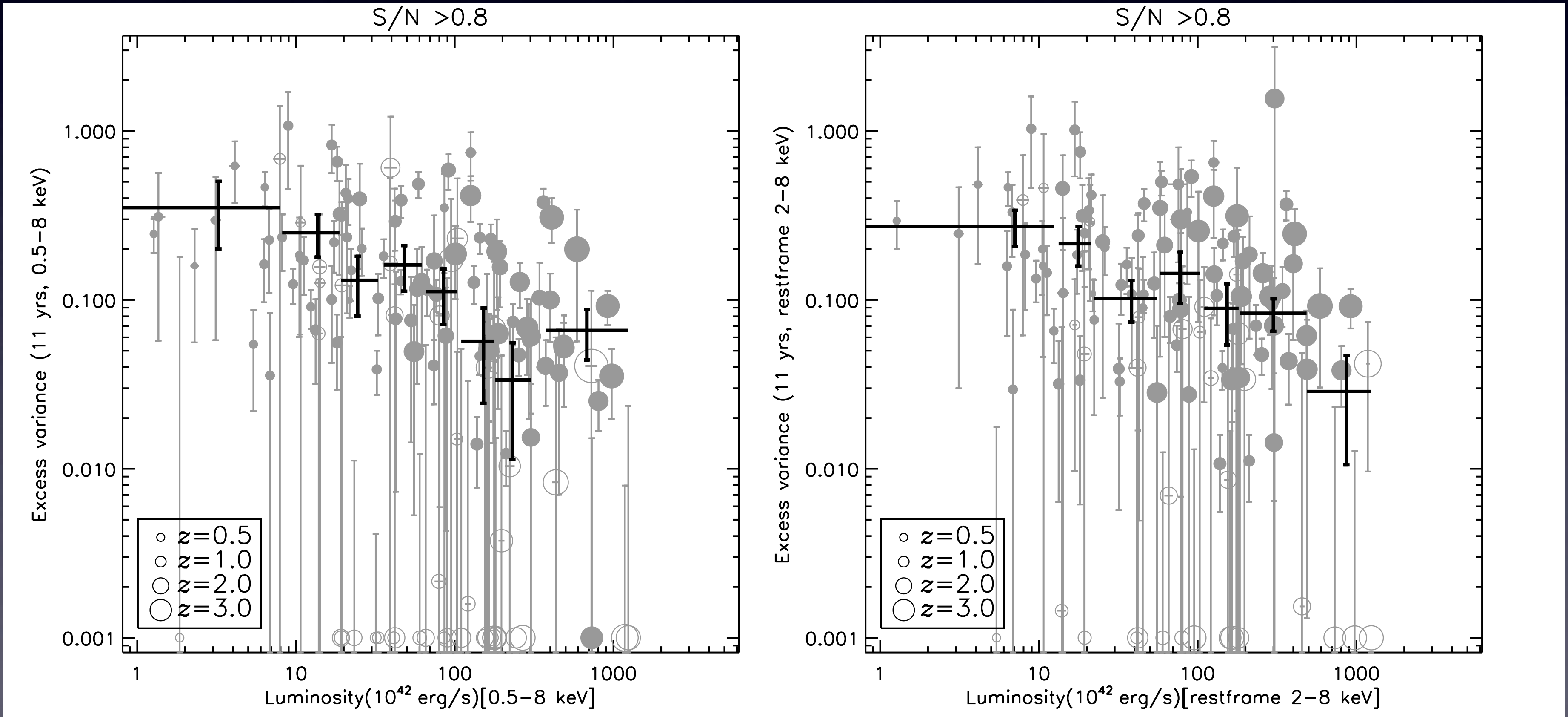
The CDFS allows to work with a complete and unbiased (in terms of variability) sample.



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

High-z AGN do follow the Lx-variability relation but ….

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



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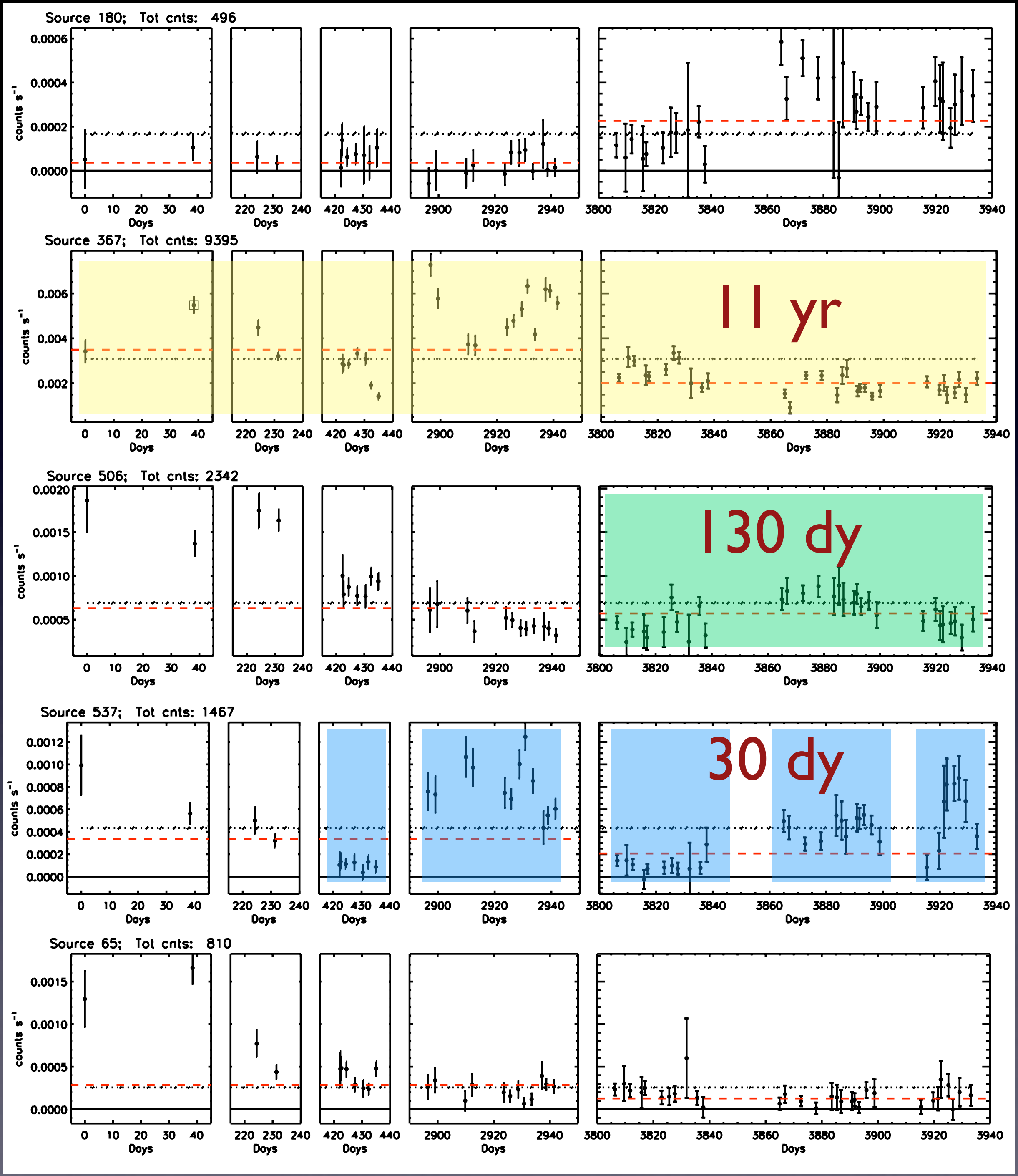

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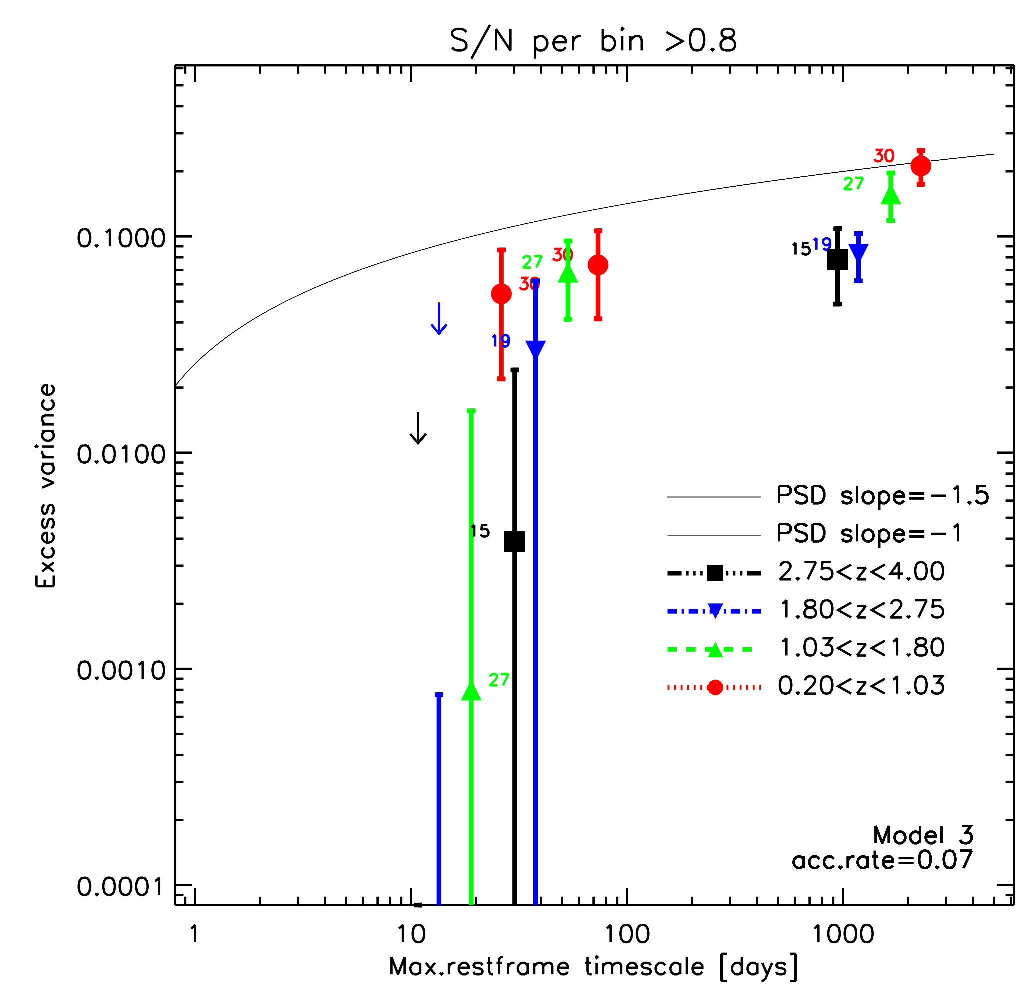
A proxy to a proper PSD analysis

What PSD for high-z AGNs?

- A single flat ($\sigma_{NXV}=\nu^{-1}$) power-law PSD only fits long timescales and low redshift sources (independent of z).
- Steeper PSD slopes ($\sigma_{NXV}=\nu^{-1.5}$) 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:

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



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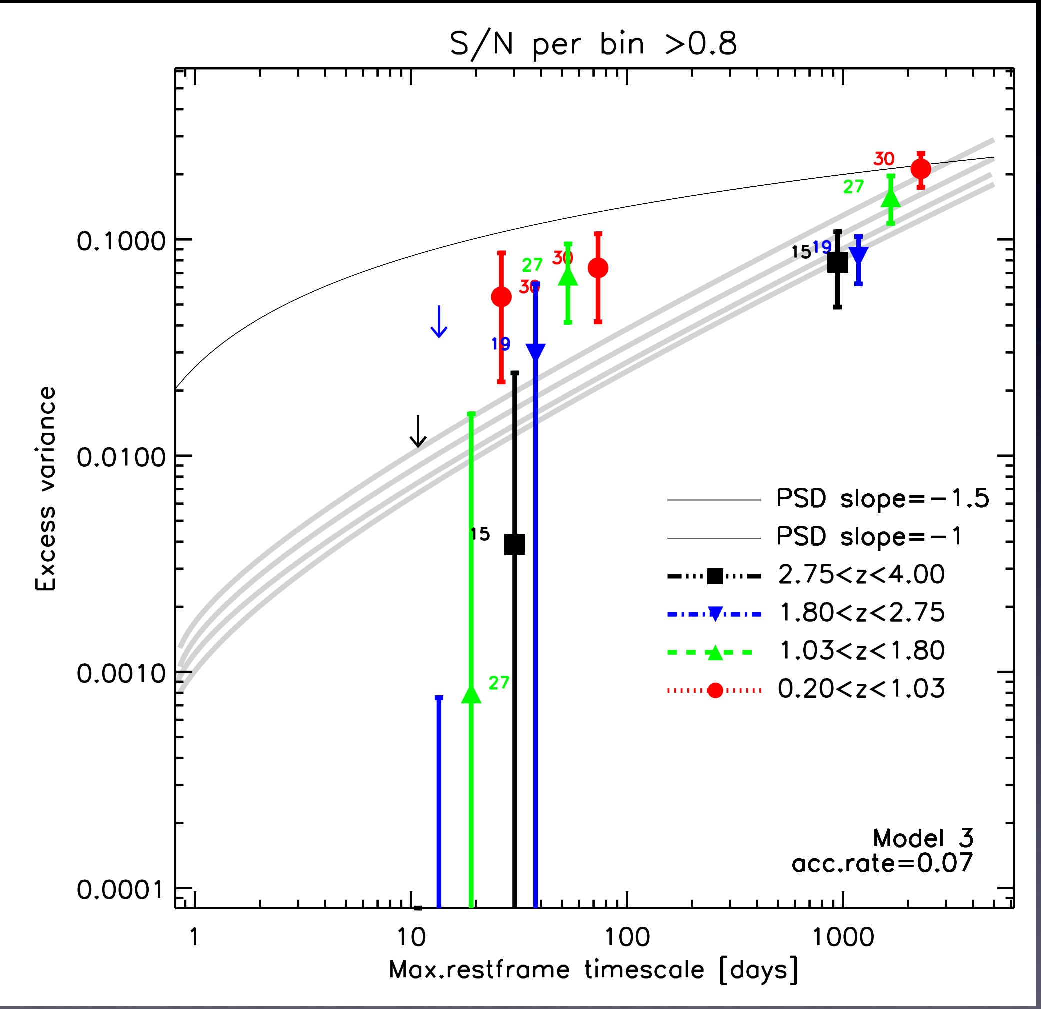

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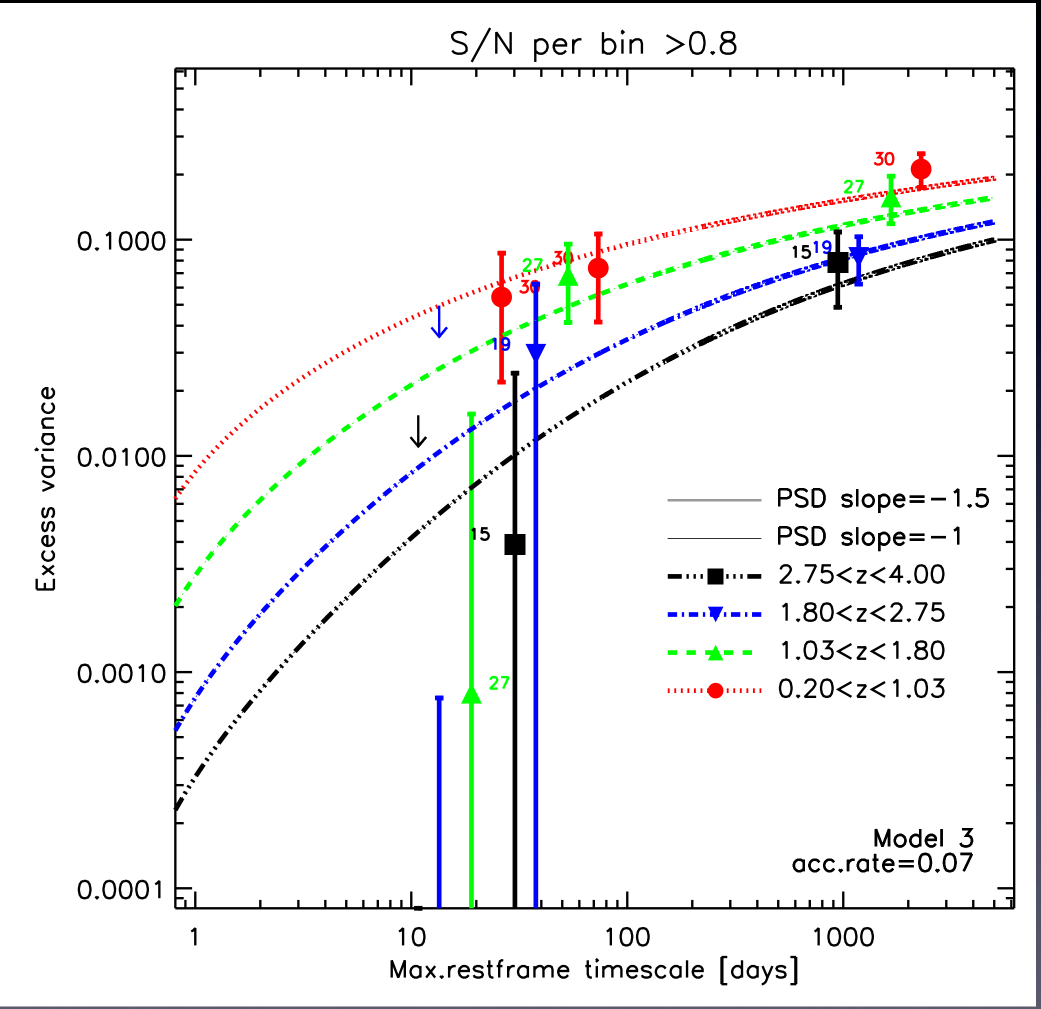
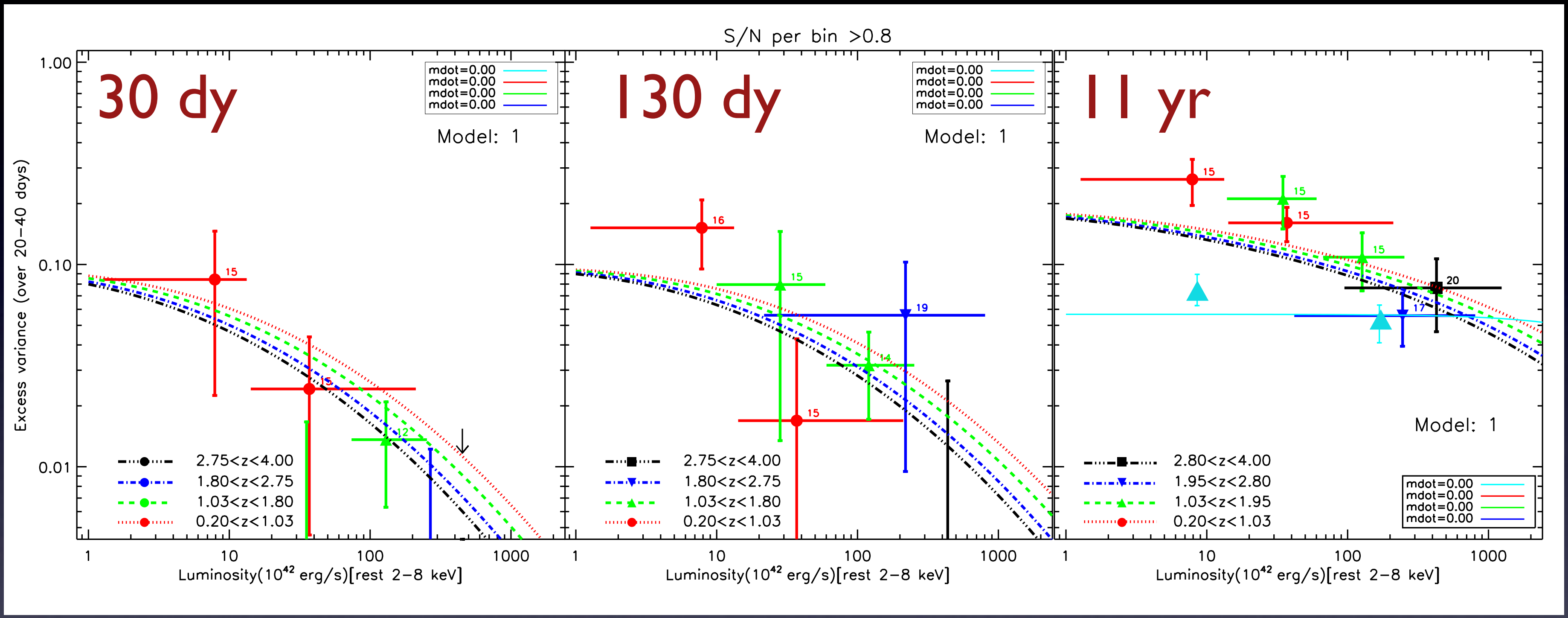


Constraining the model: fit results



<u>Model 1:</u> 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 $P_{null}<10^{-2}$ level when $\lambda_{Edd}>0.03$.

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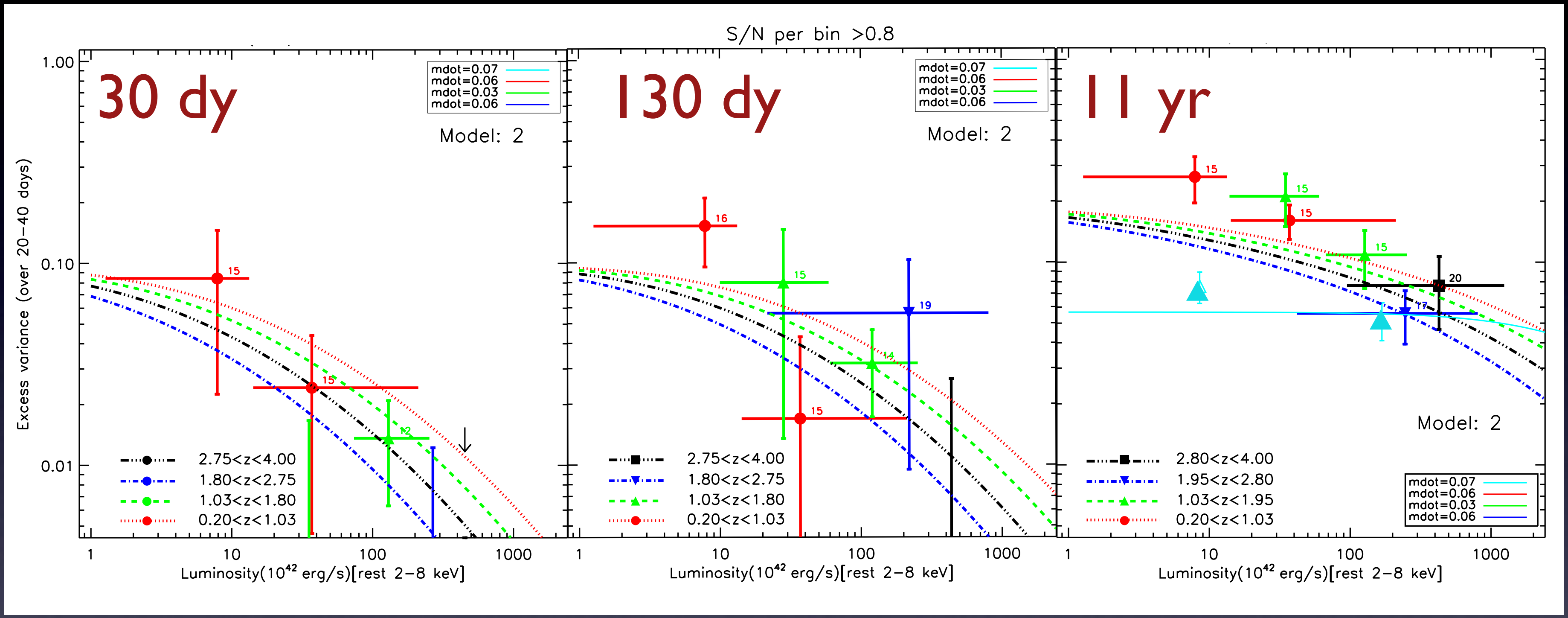
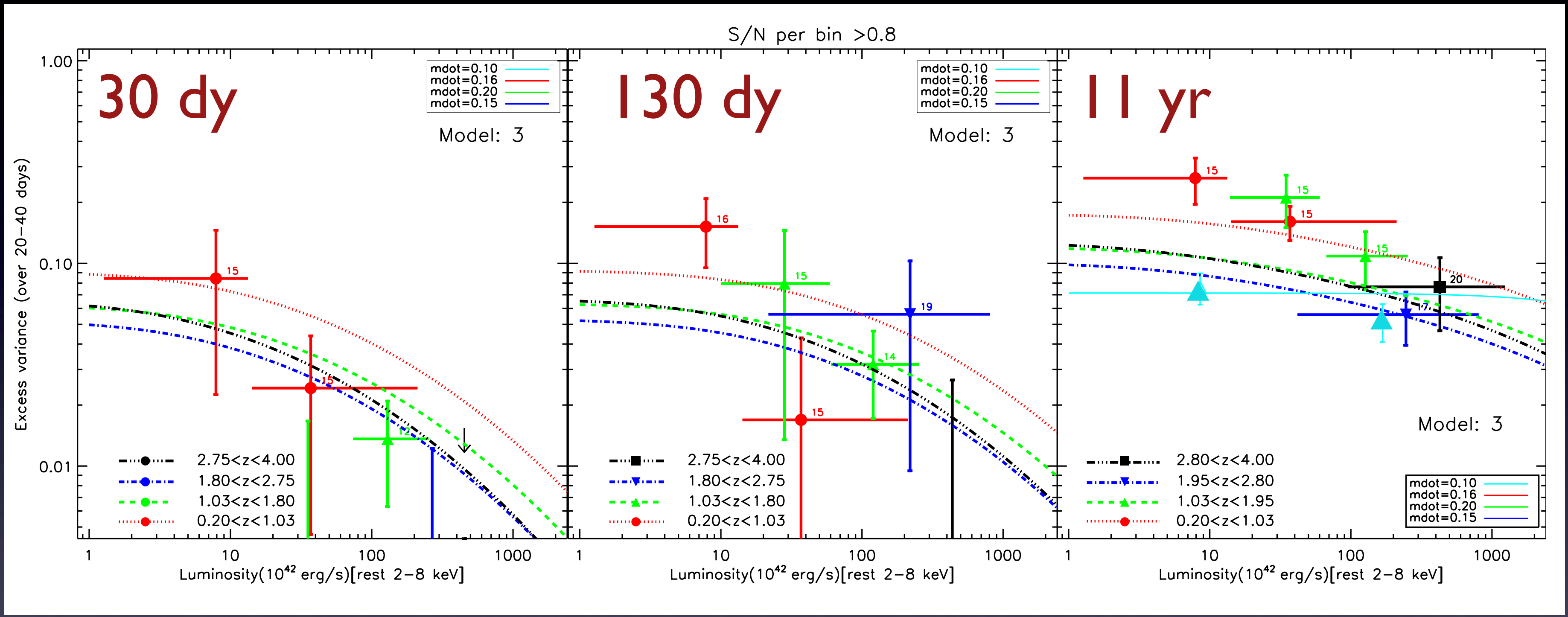


Model 2: bending frequency depends on BH mass and acc.rate through $\nu_b \propto L/M^2$ (McHardy et al. 2006), fixed PSD normalization (Papadakis et al. 2004, 2008)

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

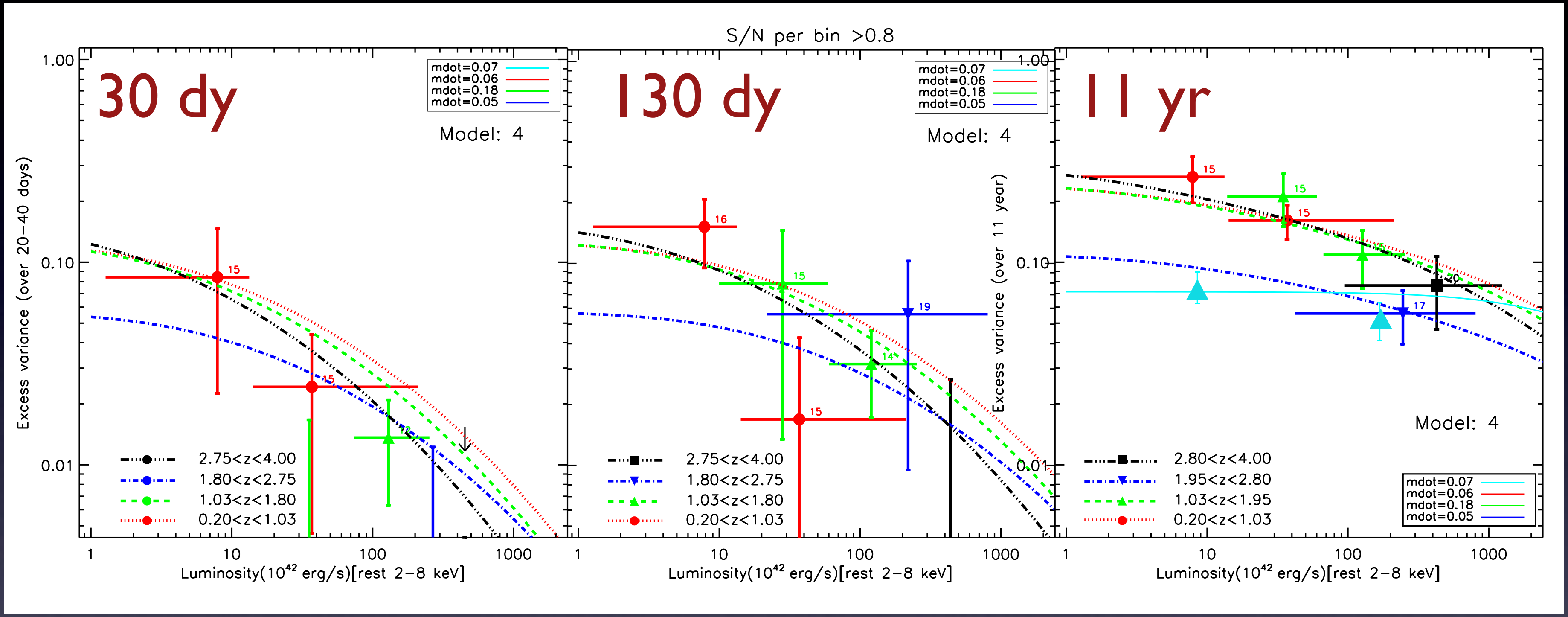
Constraining the model: fit results



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 $P_{null}<0.013$

Constraining the model: fit results



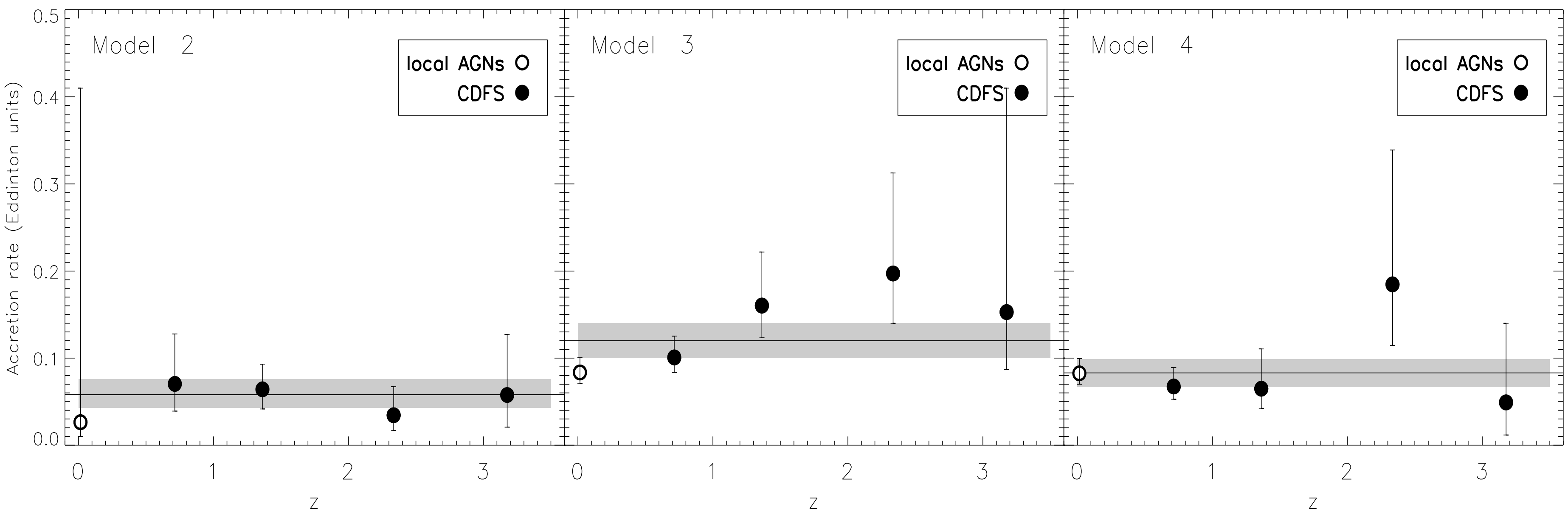
__Model 4:__ bending frequency depends on BH mass and acc.rate through $\nu_b \propto L/M^2$ (McHardy et al. 2006), PSD normalization depends on acc.rate (Ponti et al. 2011)

Model is consistent with the data: P_{null}~0.16

Accretion history results

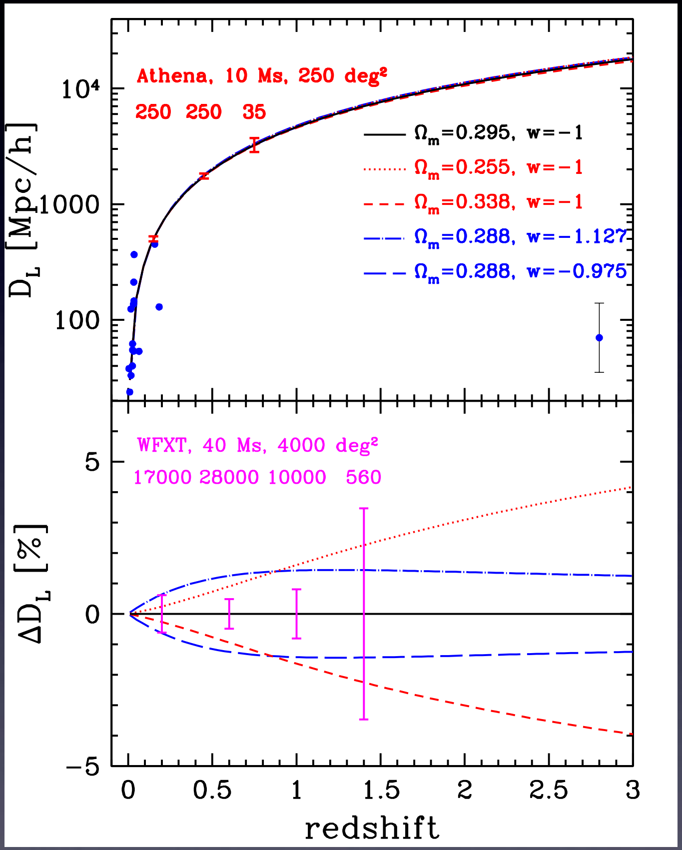
- A constant $\lambda_{Edd} \leq 0.1$ is consistent with the data, although some models indicate a possible increase of $\lambda_{Edd}(z)$ peaking at z~2÷3.

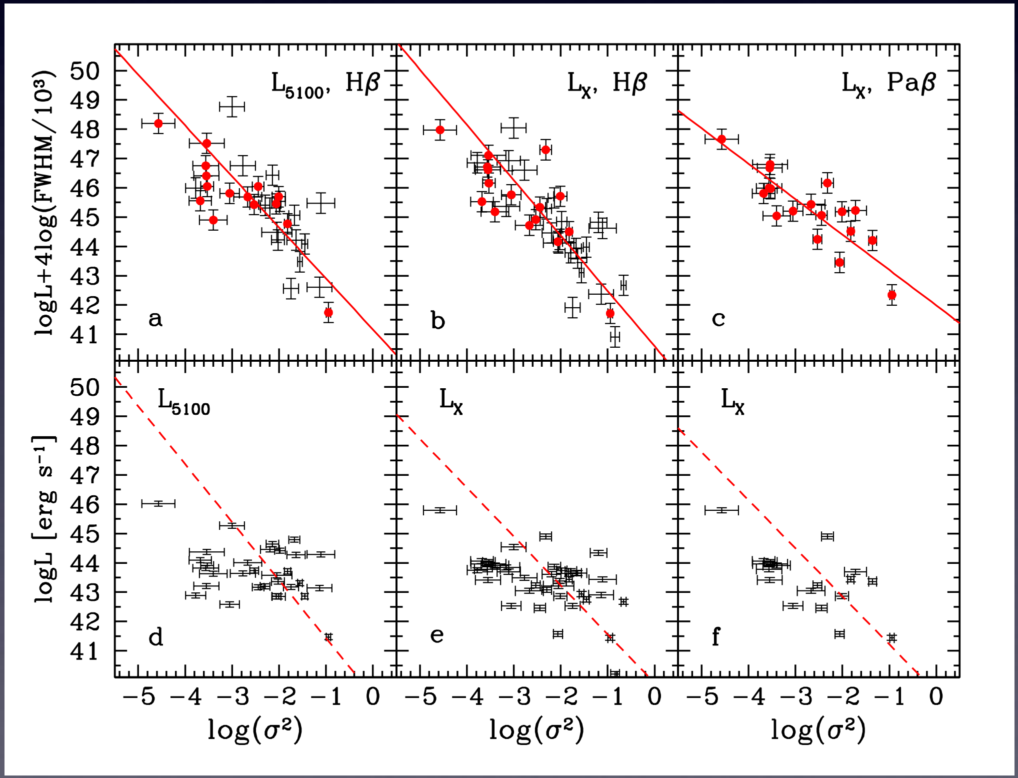
- The low redshift data are consistent with variability of local AGNs (Zhang et al. resuls).

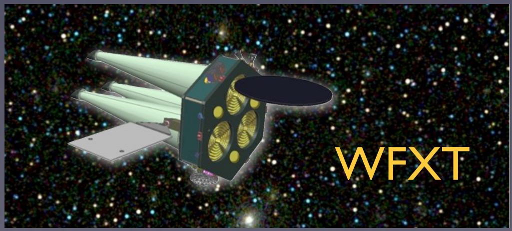


The future?
(*La Franca et al. 2014*)

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.