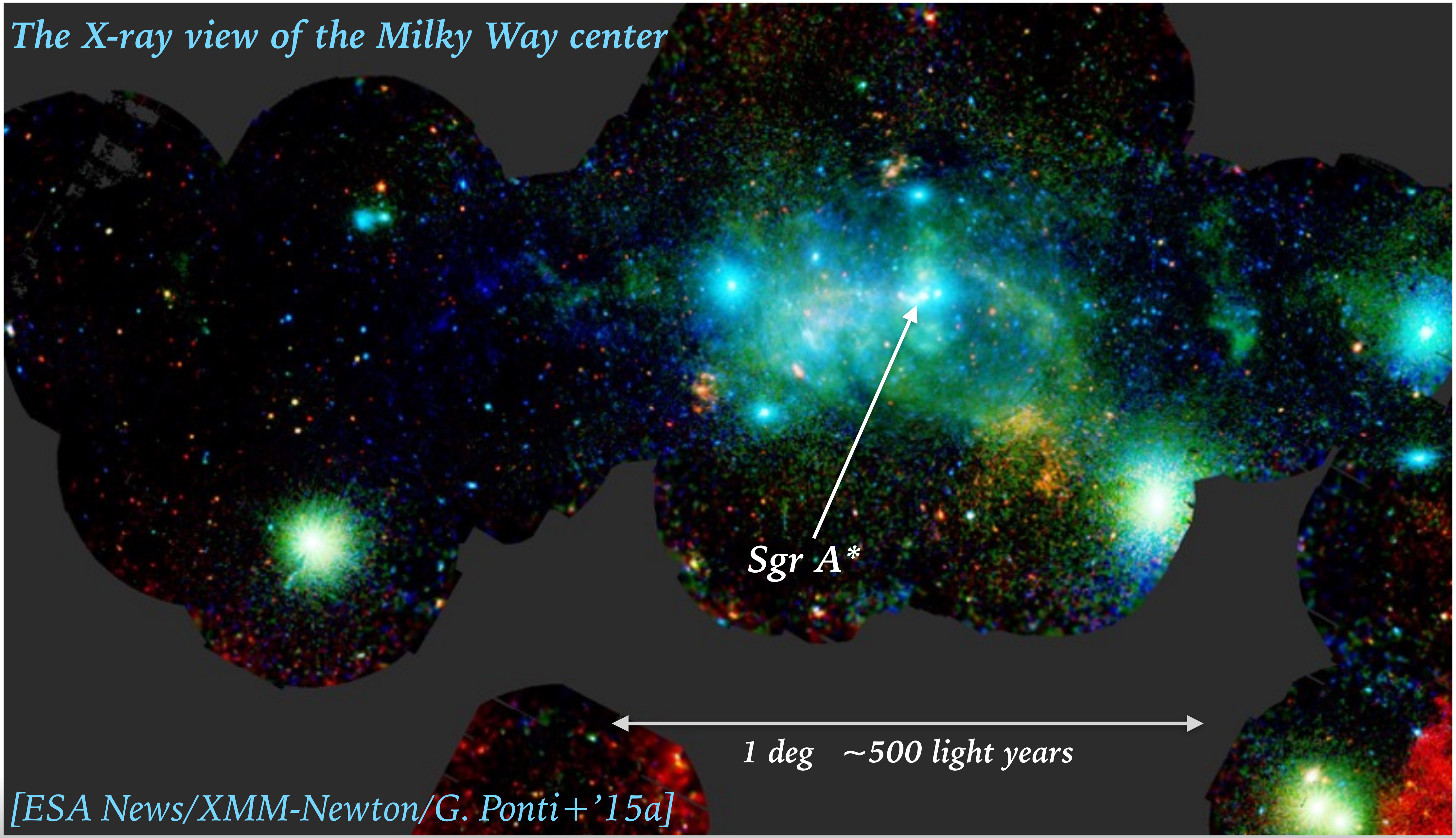
X-ray variability in accreting supermassive black holes and relations to X-ray binaries

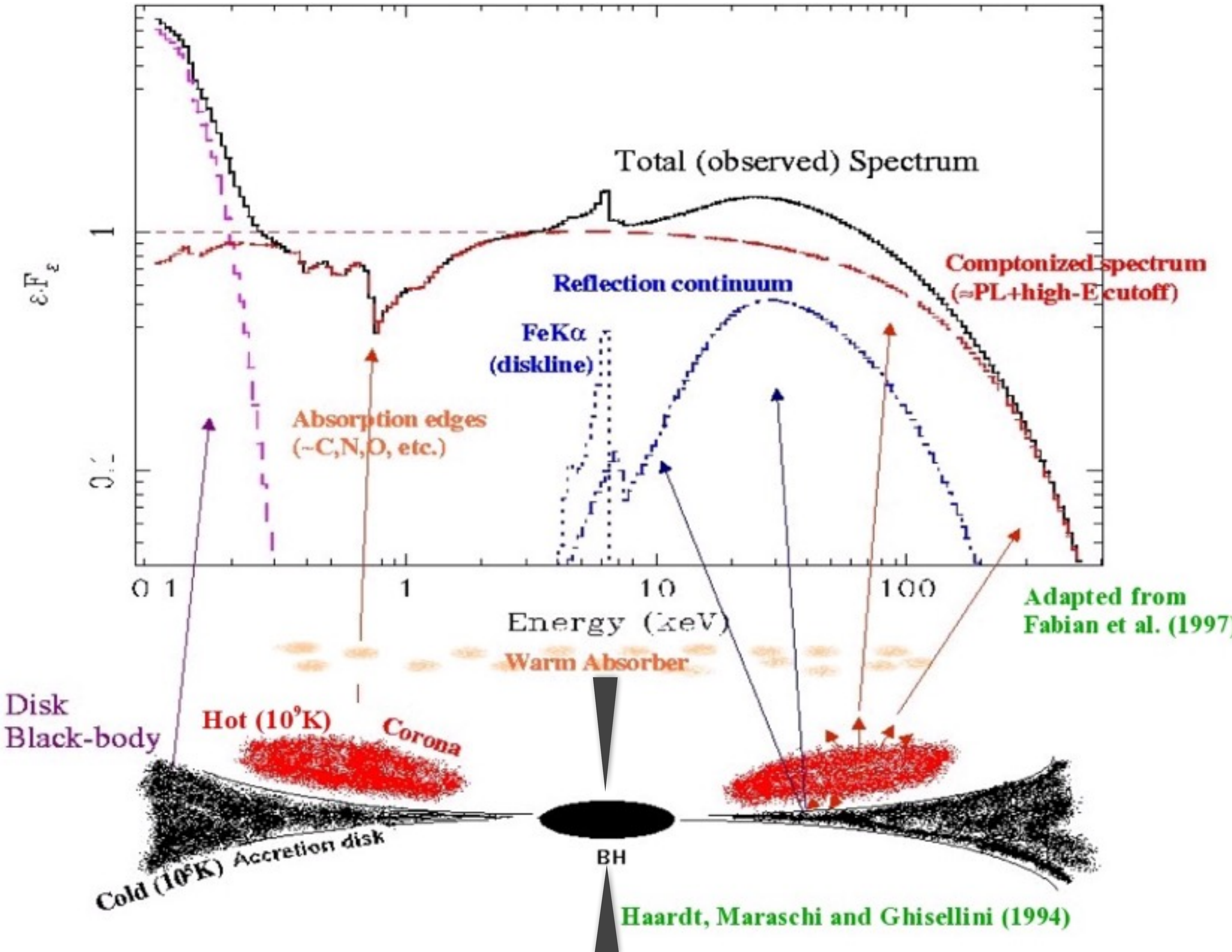


Gabriele Ponti & Barbara De Marco

Max-Planck-Institut für Extraterrestrische Physik

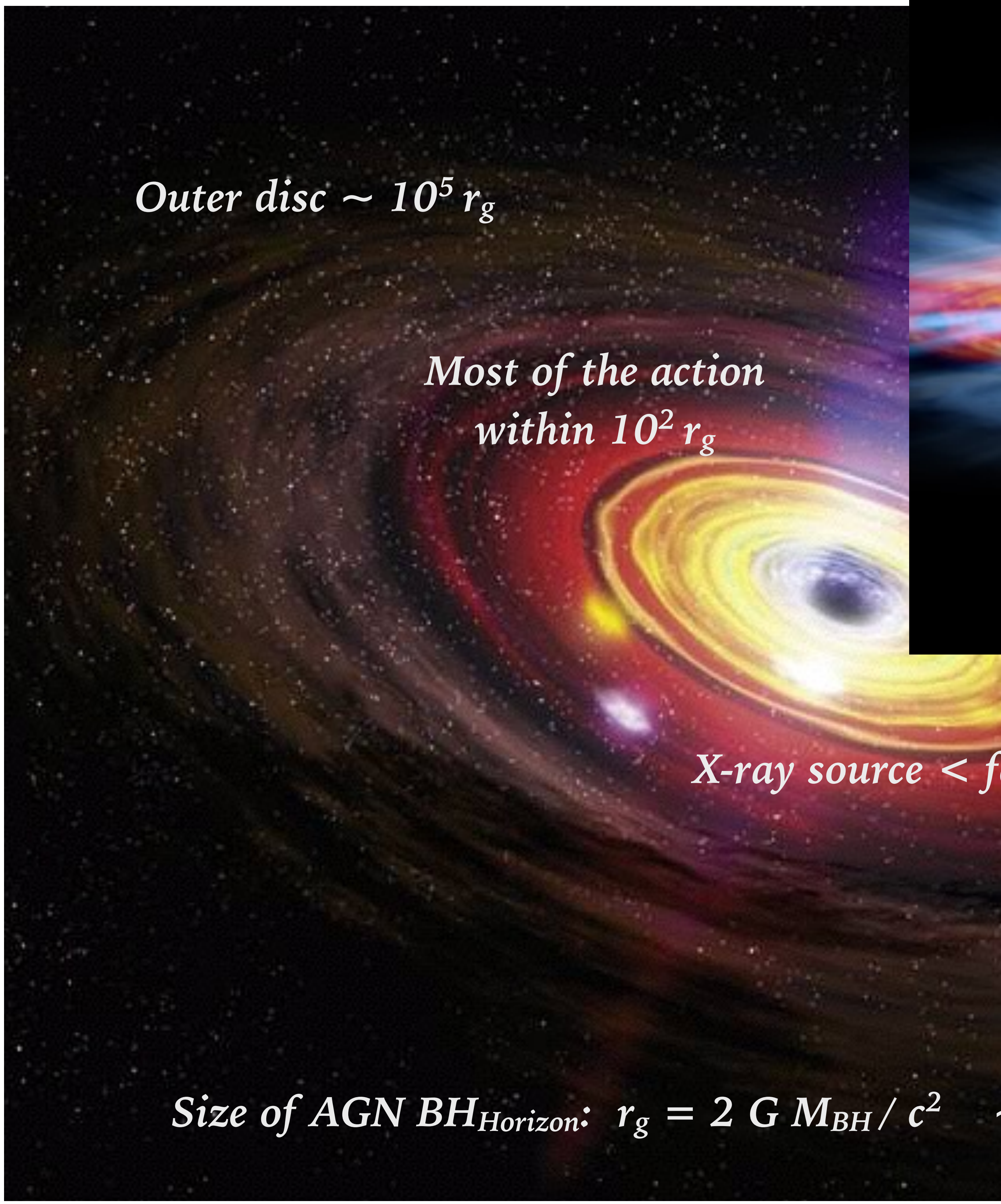
MAX-PLANCK-GESELLSCHAFT

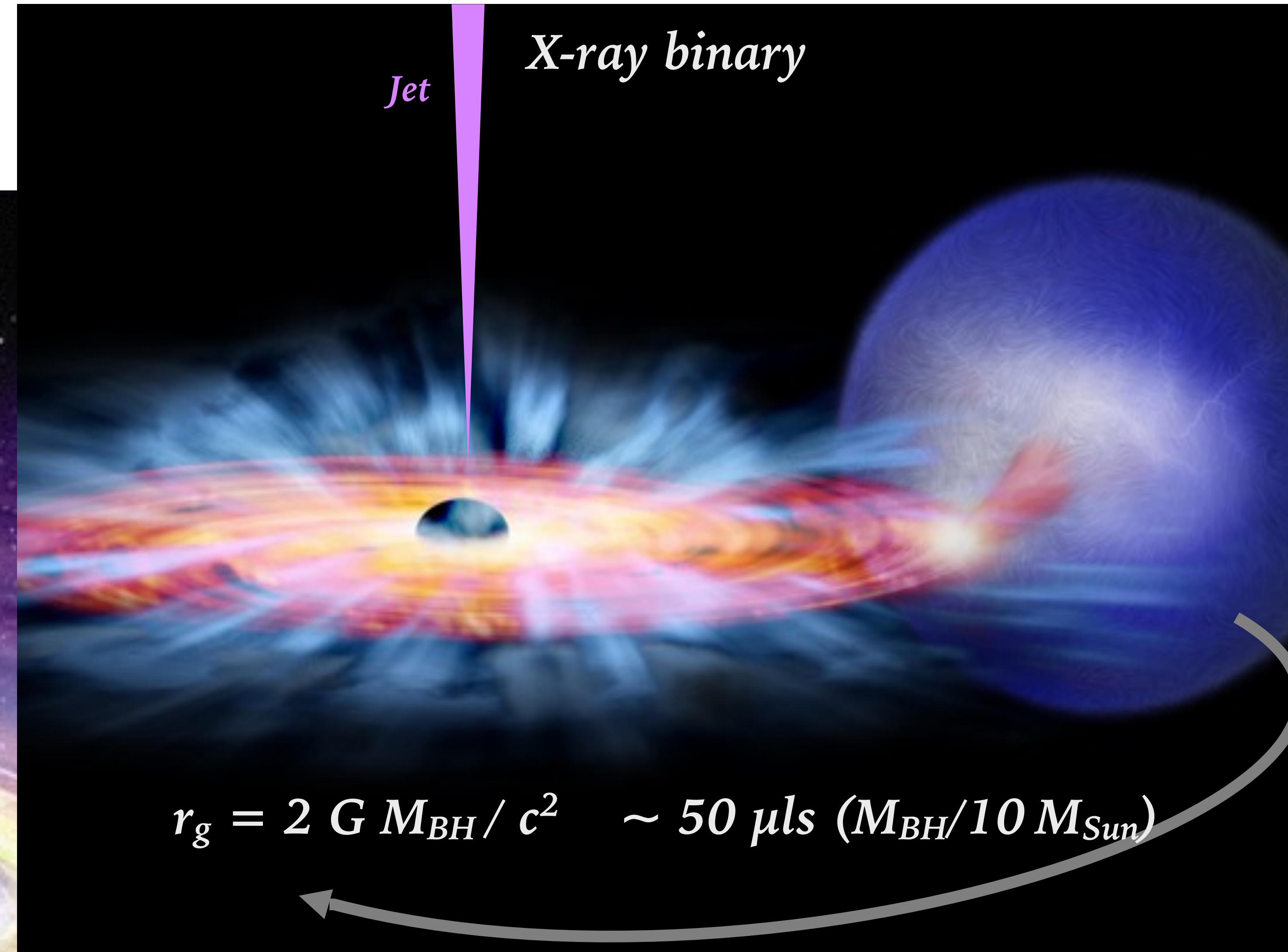
Typical X-ray spectrum of accreting super-massive black holes (AGN)

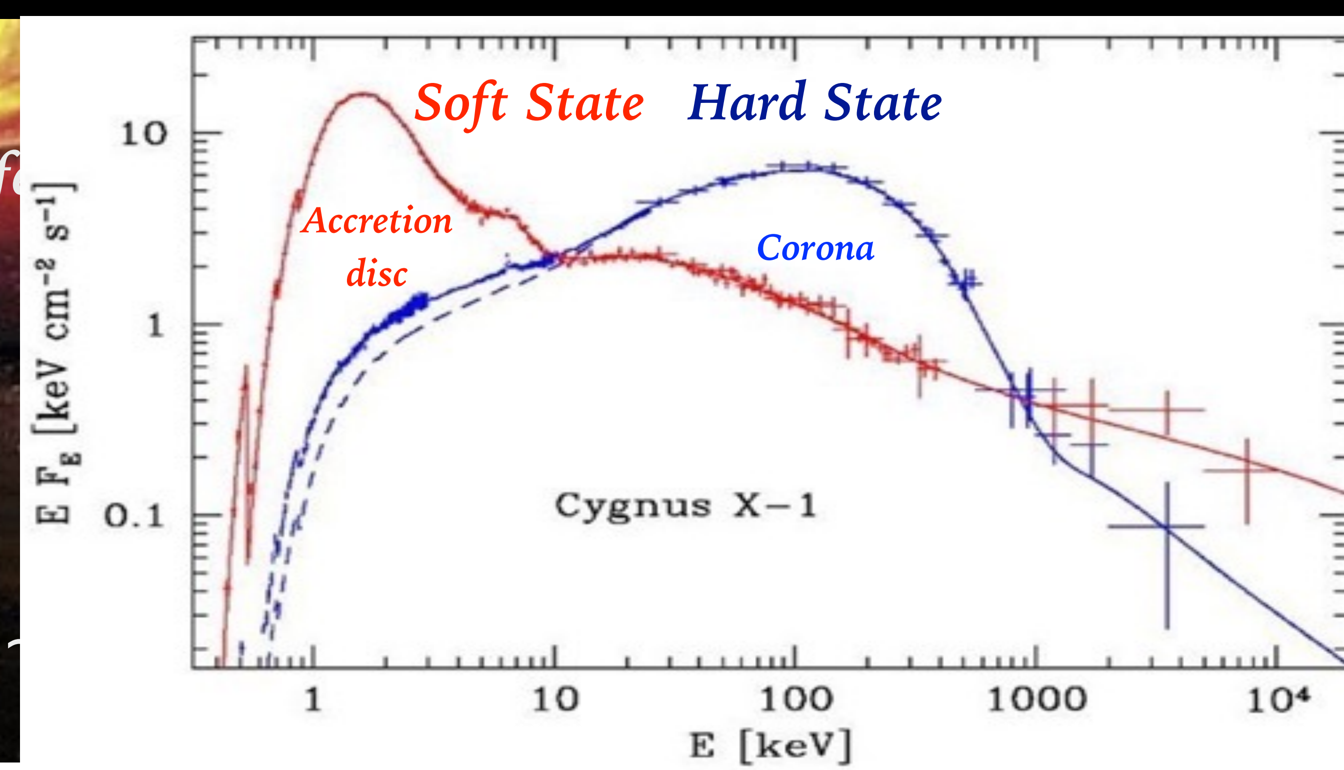


What is the geometry of space-time and matter flows around black holes?

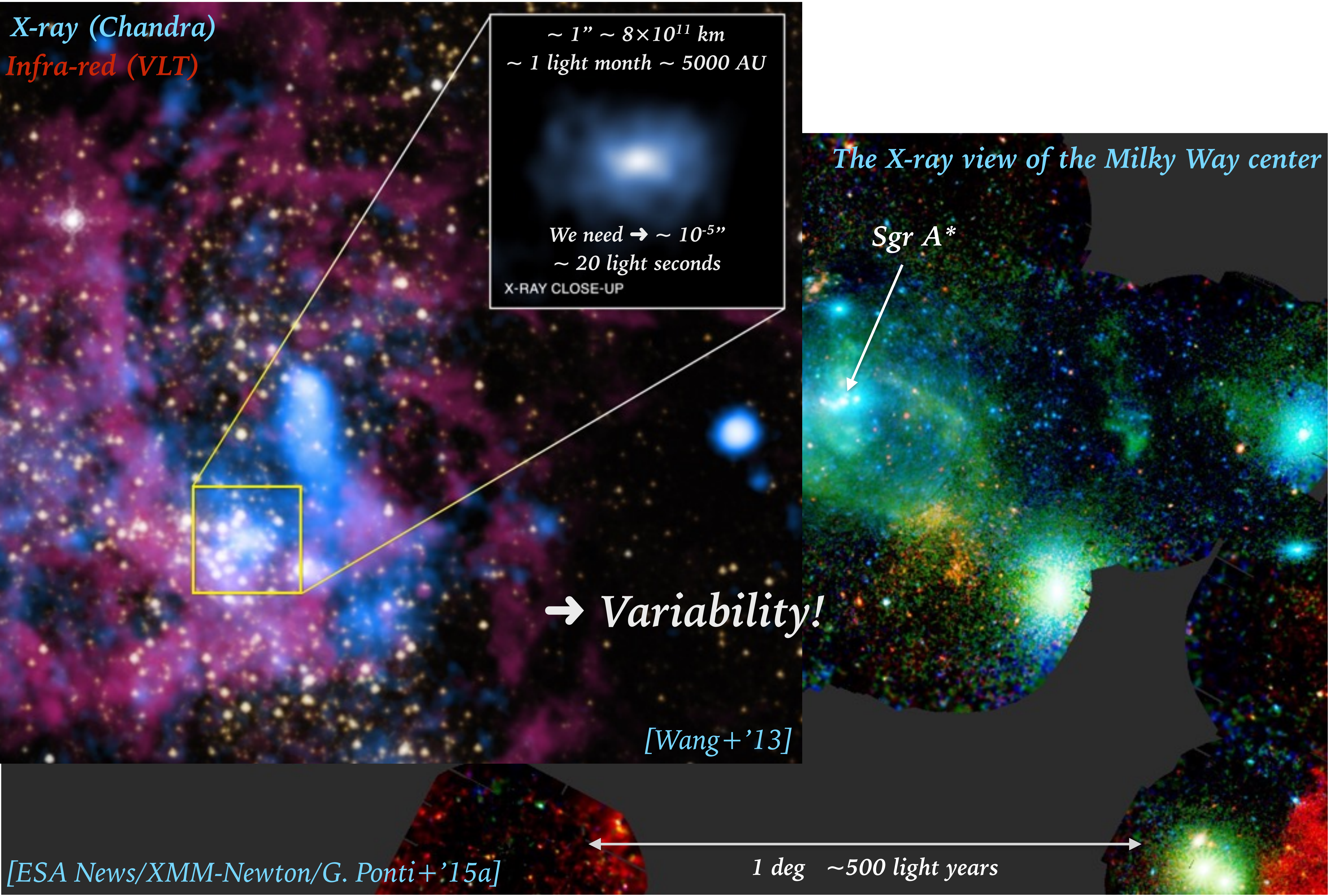
Black holes are frustratingly small !!



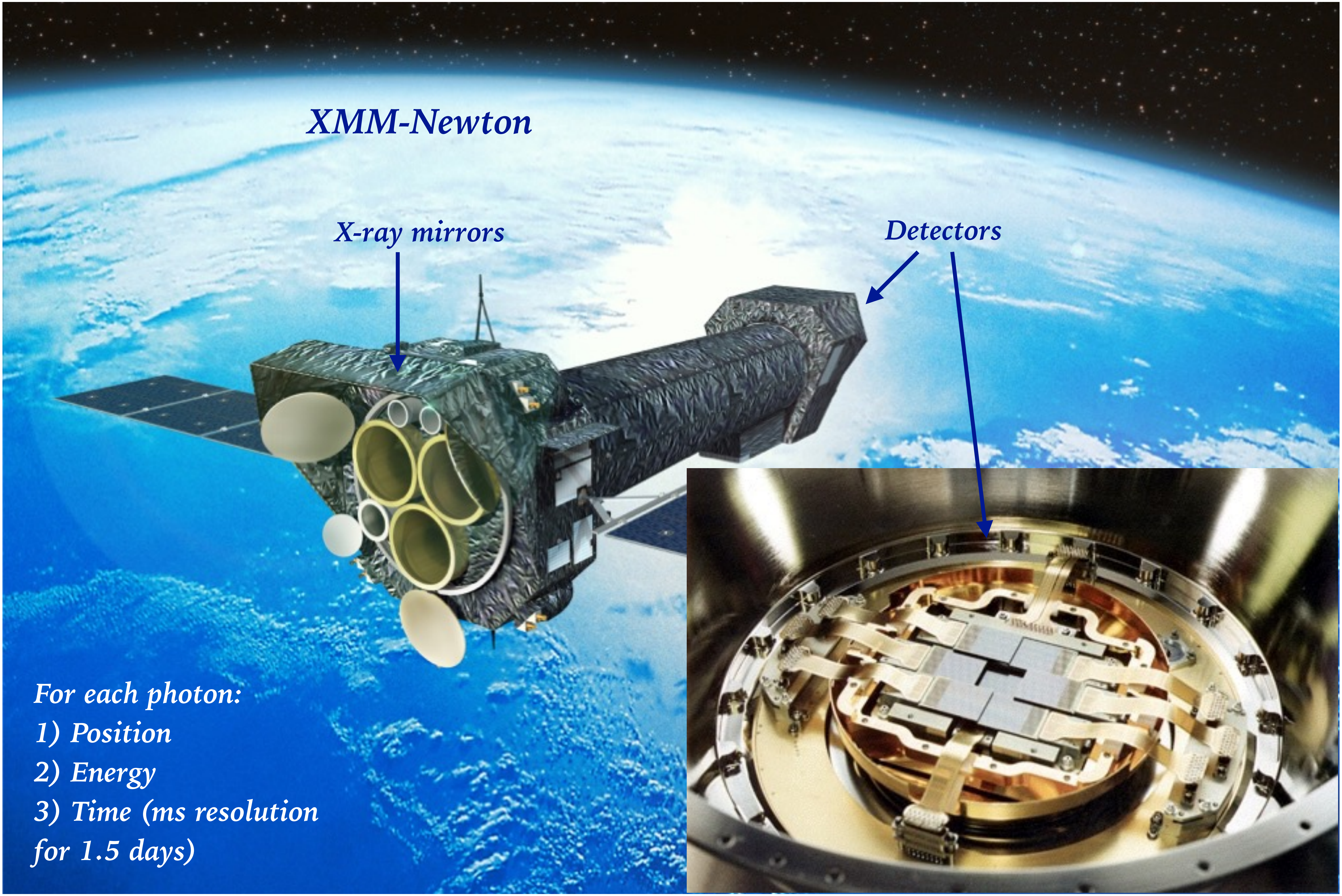




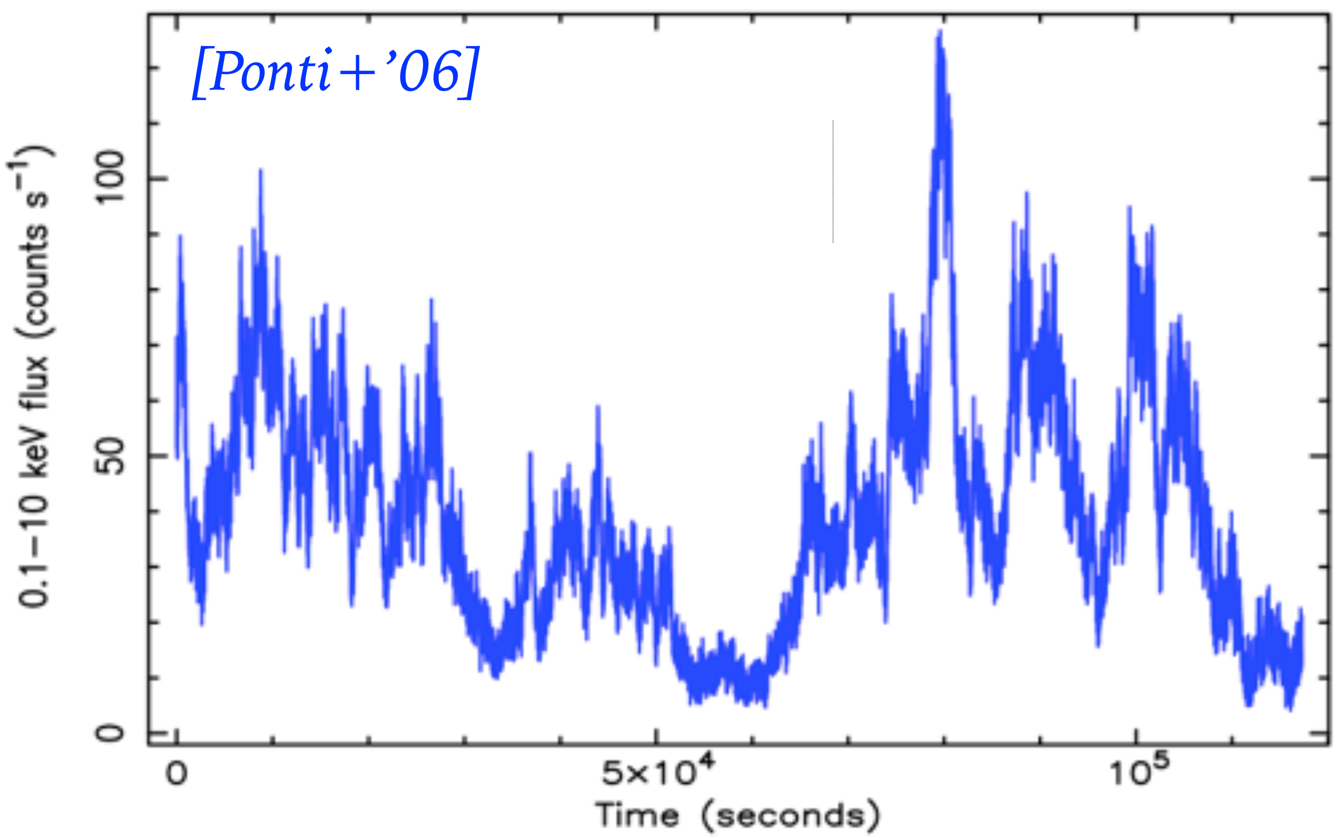
Pushing resolution of X-ray images to the limit…

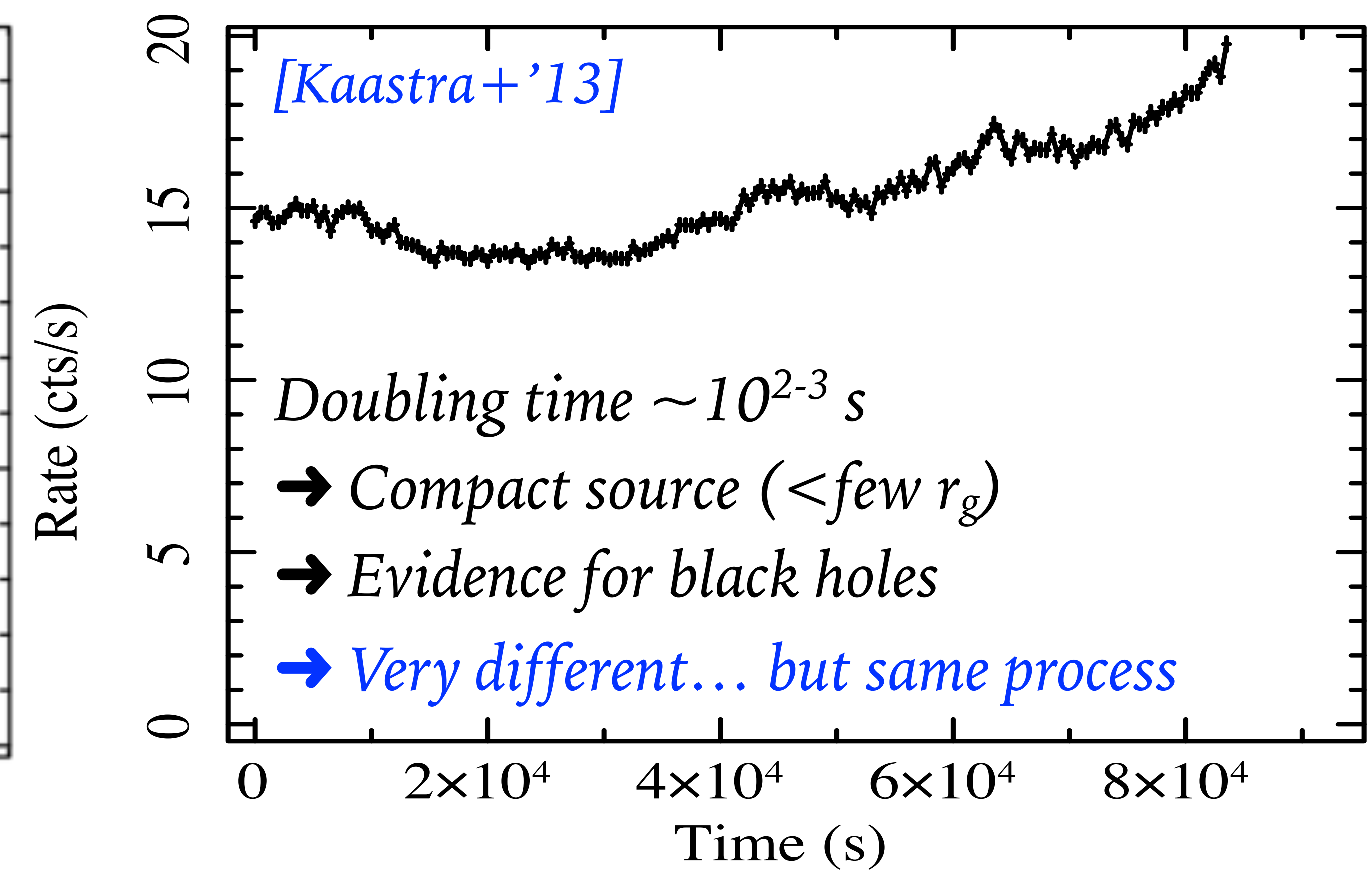


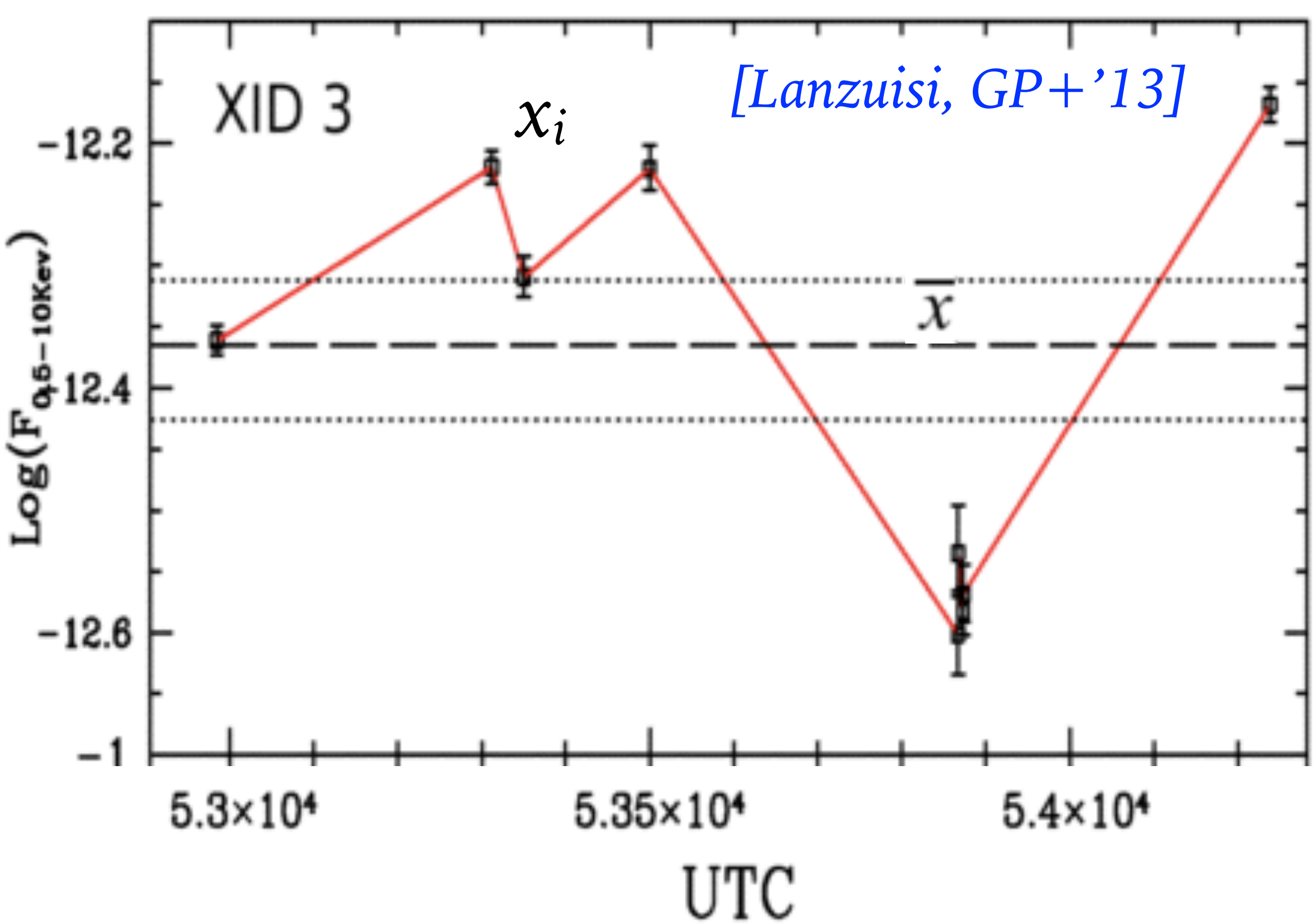
Our state of the art instruments...



Light curves of AGN







First question: Is it variable?

$$X^2 = \sum_{i=1}^{N_{obs}} \frac{(x_i - \overline{x})^2}{\sigma^2_{err,i}}$$

error on photon flux

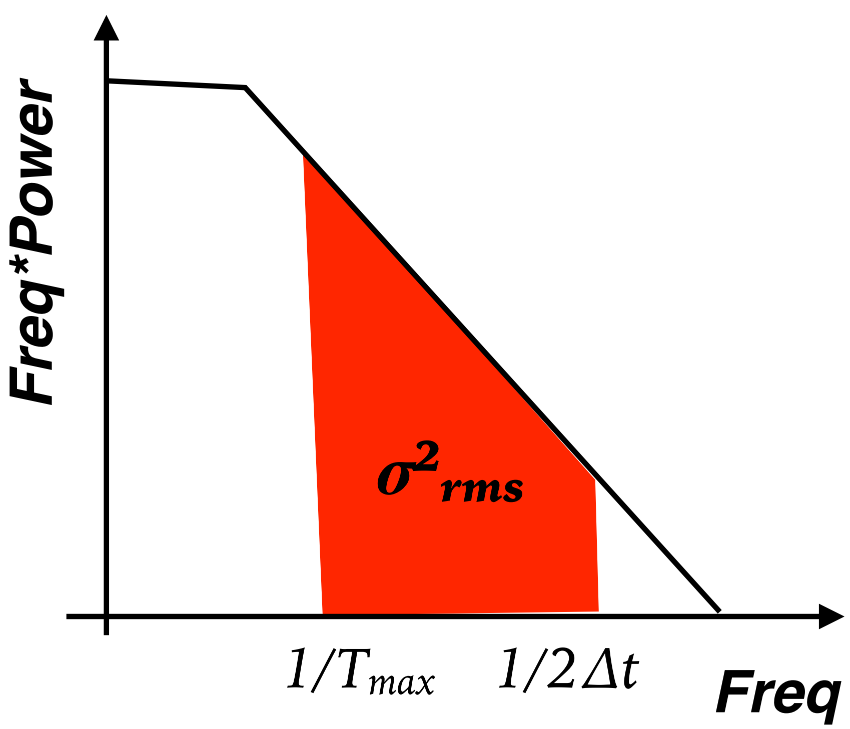
$X^2 \longrightarrow \chi^2$ *for large photon fluxes*

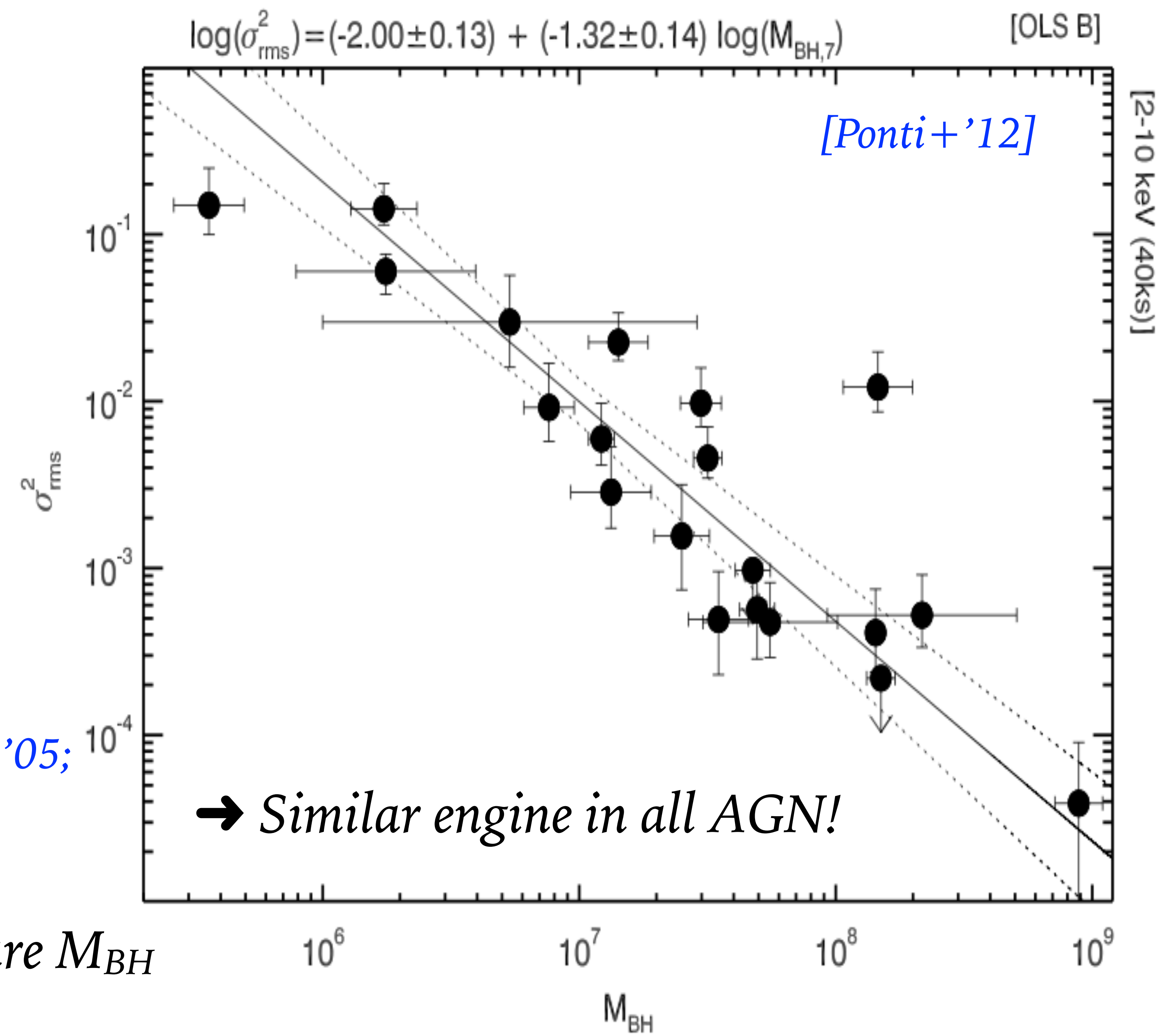
Quantifying variability: Excess variance

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

x_i= count rate/flux measurements
$\sigma^2_{err,i}$ = errors

➜ *Equivalent to PSD over $[1/T_{max}, 1/2\Delta t]$* *[e.g. Nandra +'97; Vaughan+'03; Ponti+'12; Soldi+'14]*





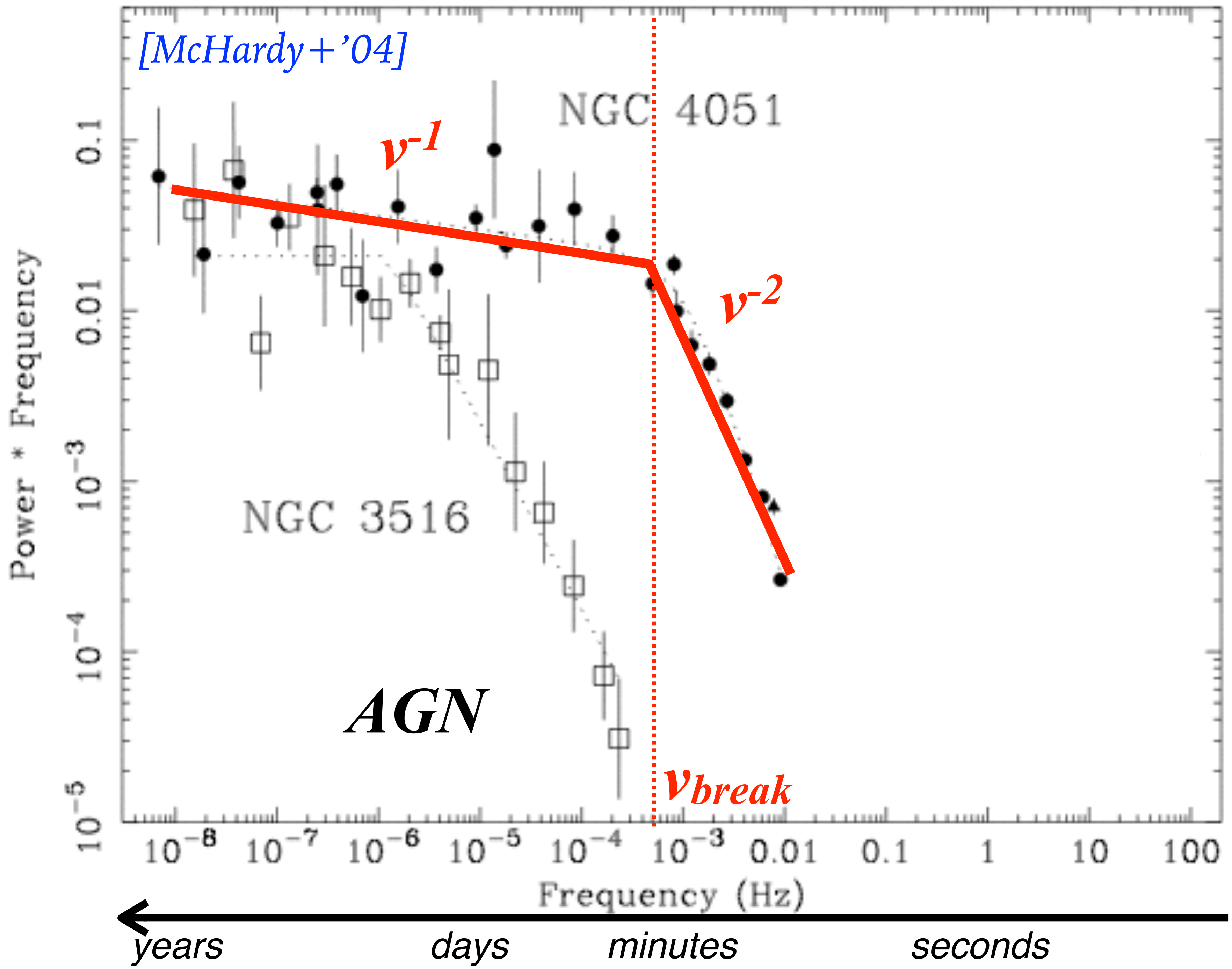
➜ *Variability scales with M_{BH}^{-1}*
[Lu+ '01; Bian+ '03; Papadakis '04; O'Neill+'05; Nikolajuk+'06; Zhou+'10]

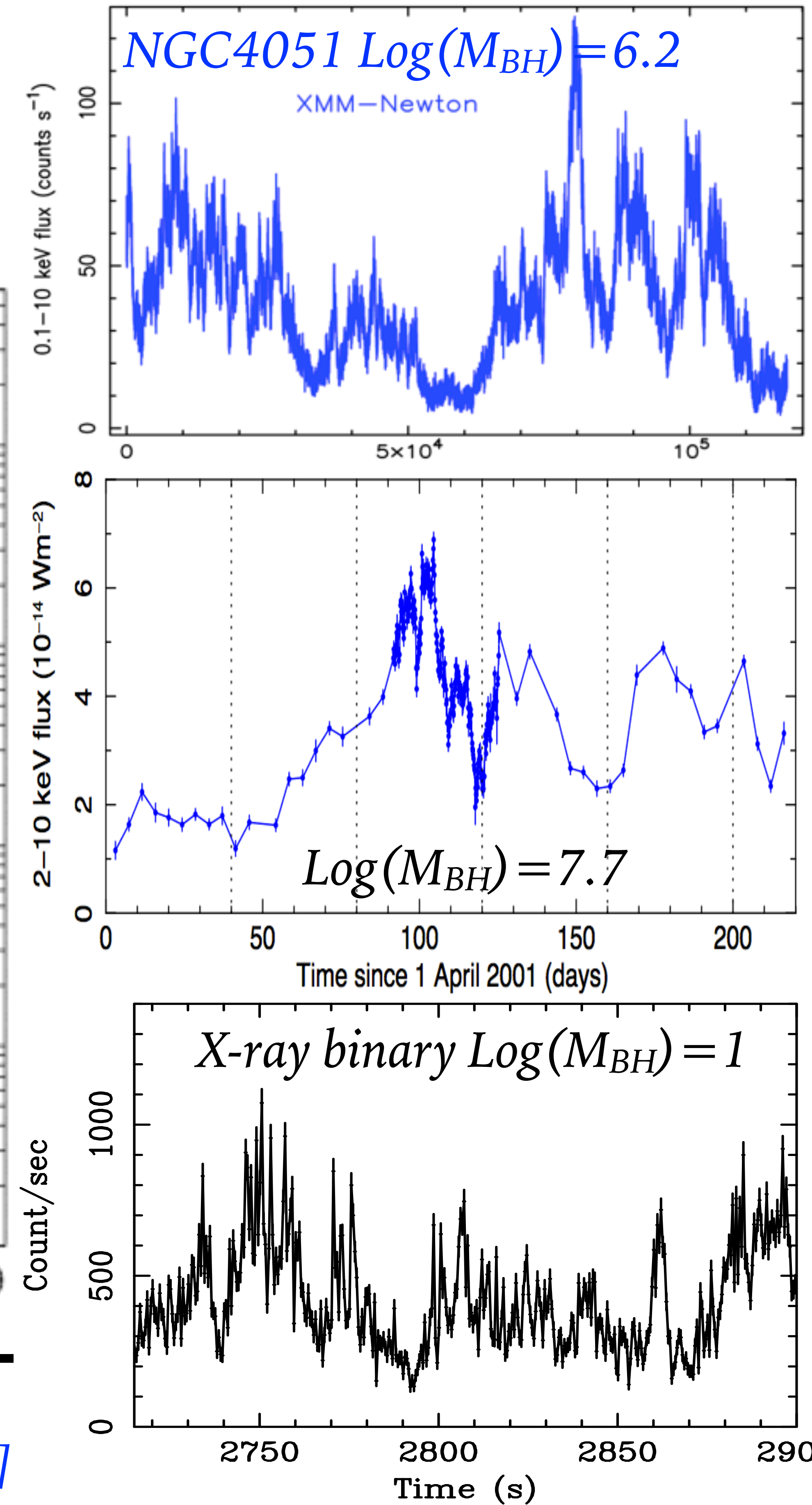
➜ *Small scatter (~0.4 dex)* ➜ *measure M_{BH}*

Characterising variability: The power spectrum

Power spectrum: Red noise breaking to pink noise at $\nu_{break} \propto M_{BH}^{-1}$

➜ Similar engine in AGN and X-ray binaries!

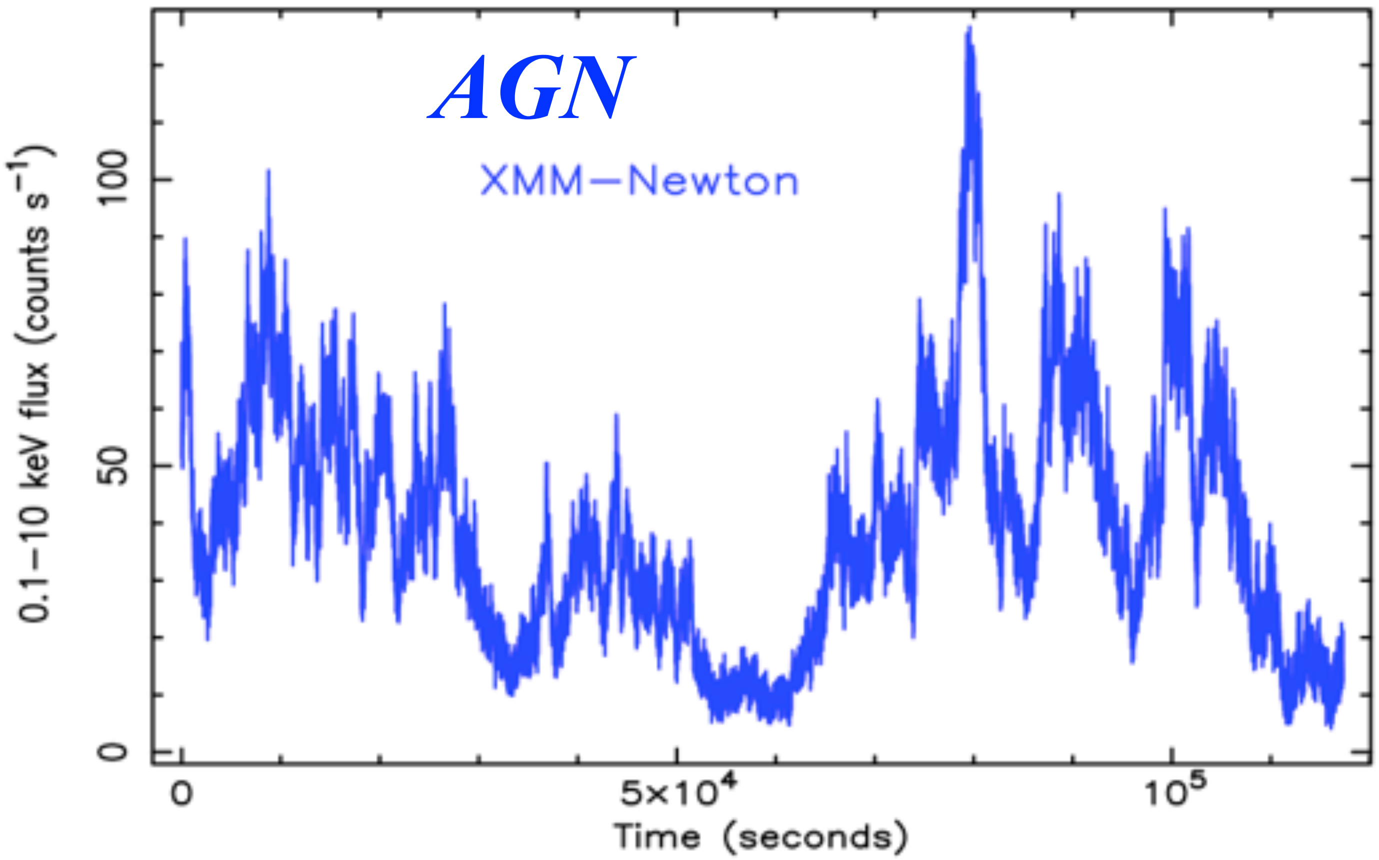


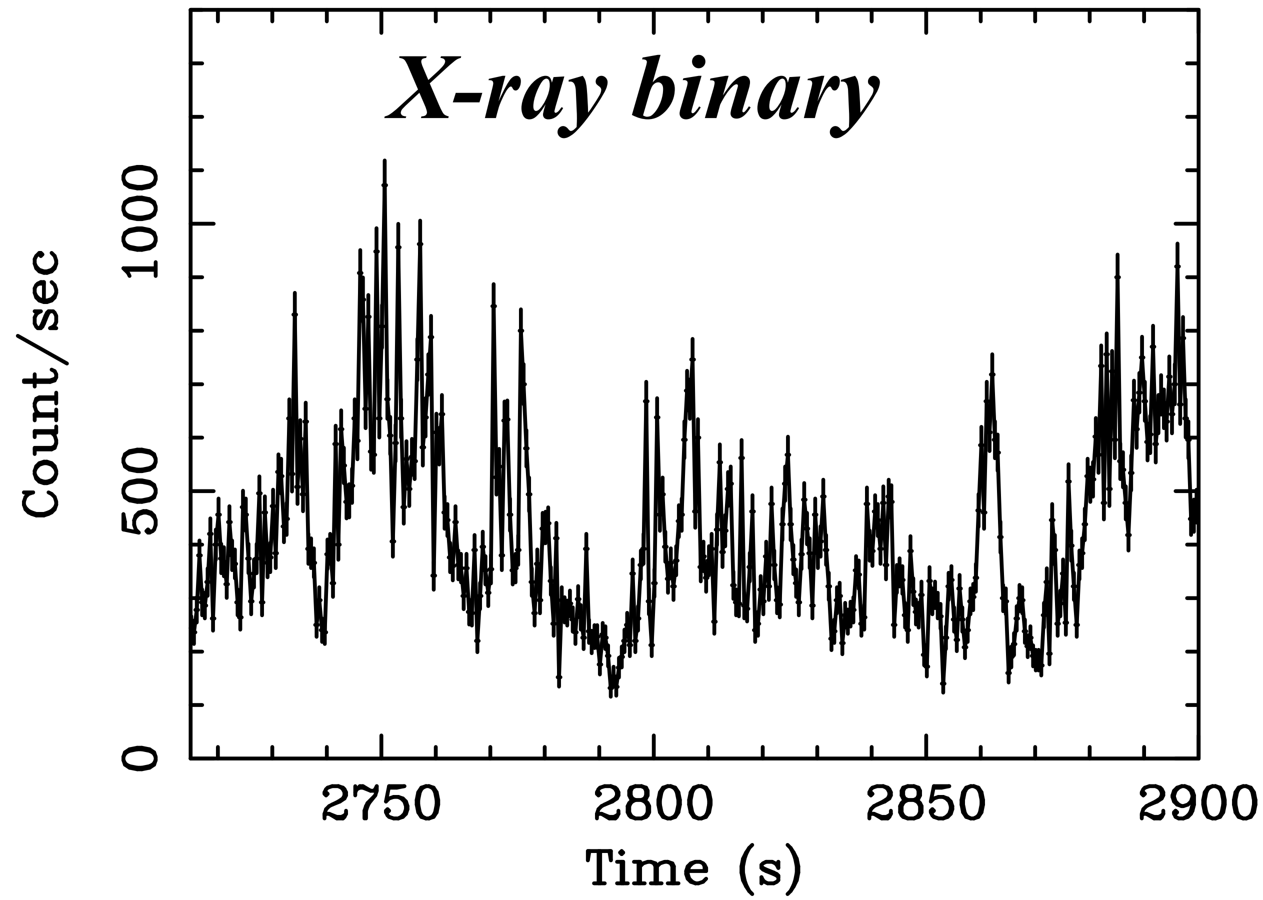


[see also e.g. Edelson+'99; Czerny+'01; Uttley+'02; Gonzalez-Martin+'12]

Similar engine in AGN and X-ray binaries!

[McHardy +'04; see also e.g. Edelson+'99; Czerny+'01; Uttley+'02; Ponti+'12; Gonzalez-Martin+'12; Soldi+'13]





For each photon:

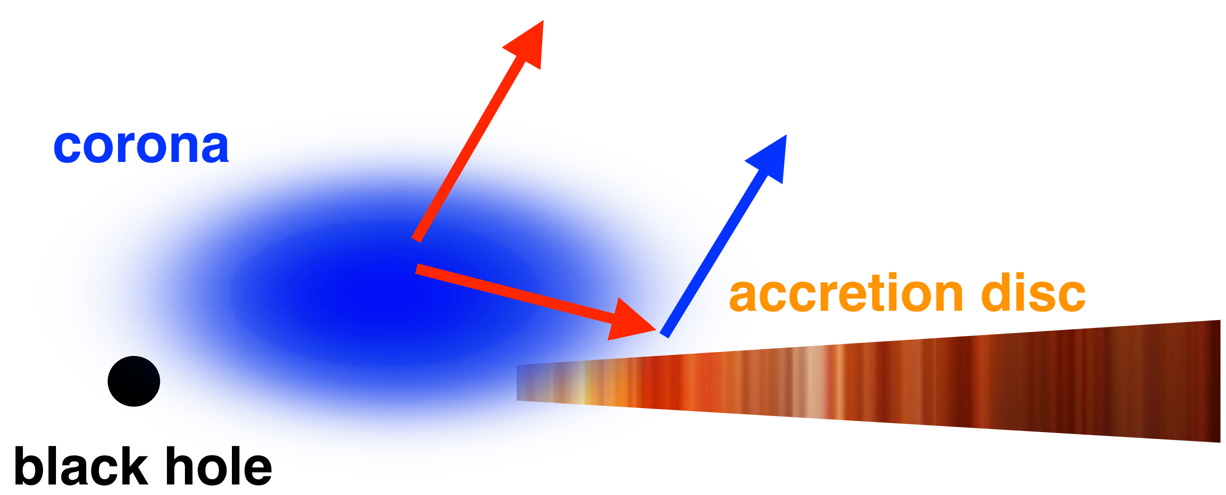
1) Position

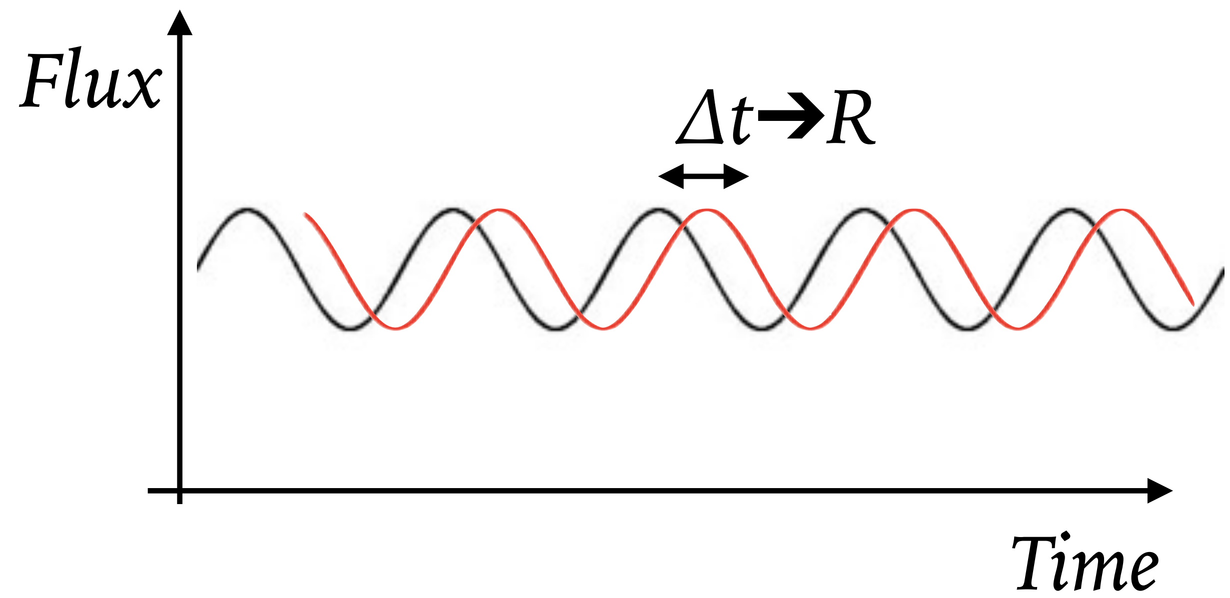
2) Energy

3) Time (ms resolution for 1.5 days)

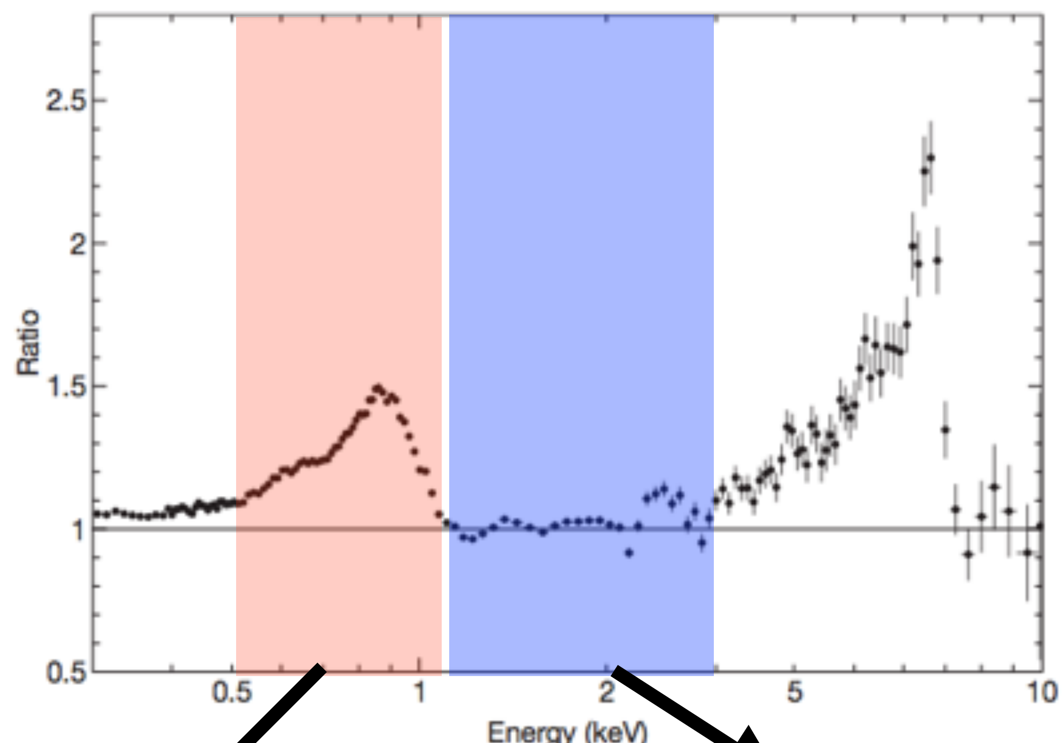
➜ *Energy dependent variability*

Reverberation: Mapping the corona & disc





[Blandford & McKee '82]

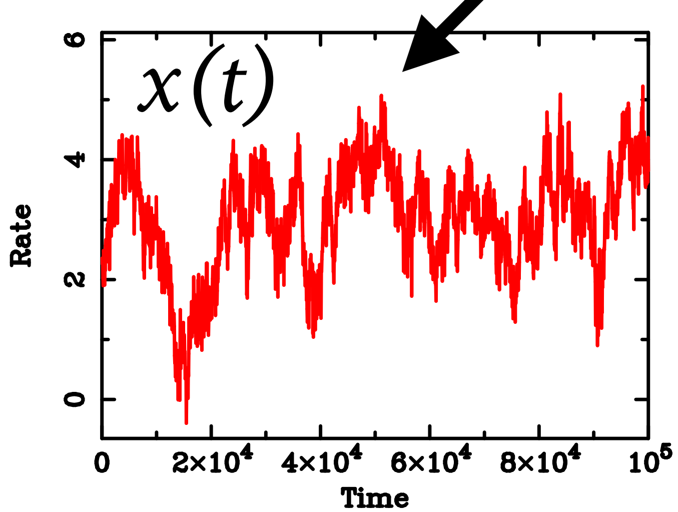


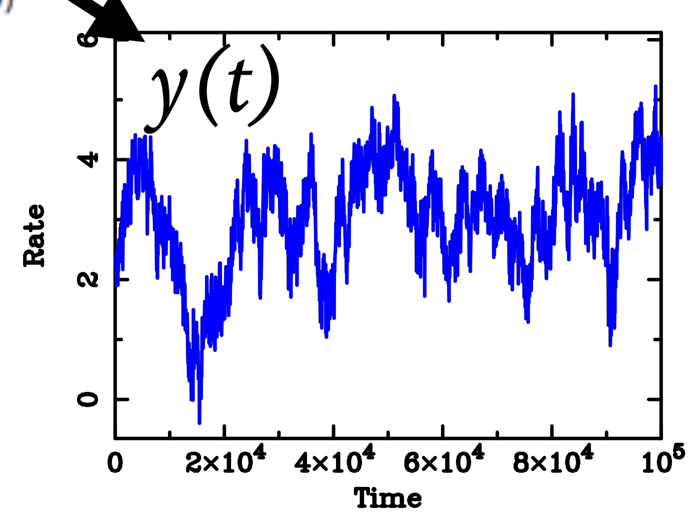
corona dominated band

disc dominated band

$$x(t) \Rightarrow X(\nu)$$
$$y(t) \Rightarrow Y(\nu)$$

$$Cross\ spectrum = C_i(\nu) = X^*(\nu)Y(\nu)$$



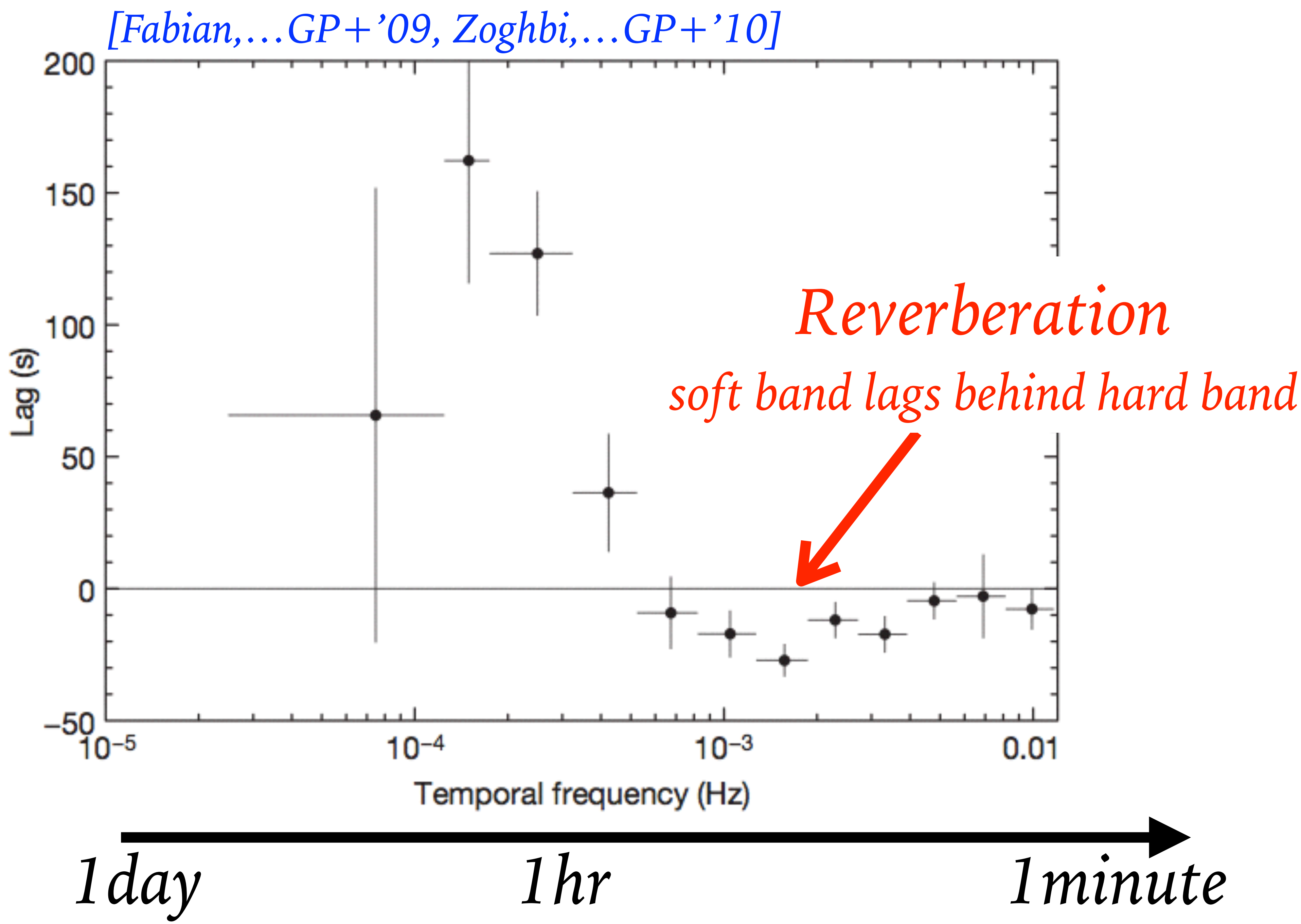


Lag as a function of frequency

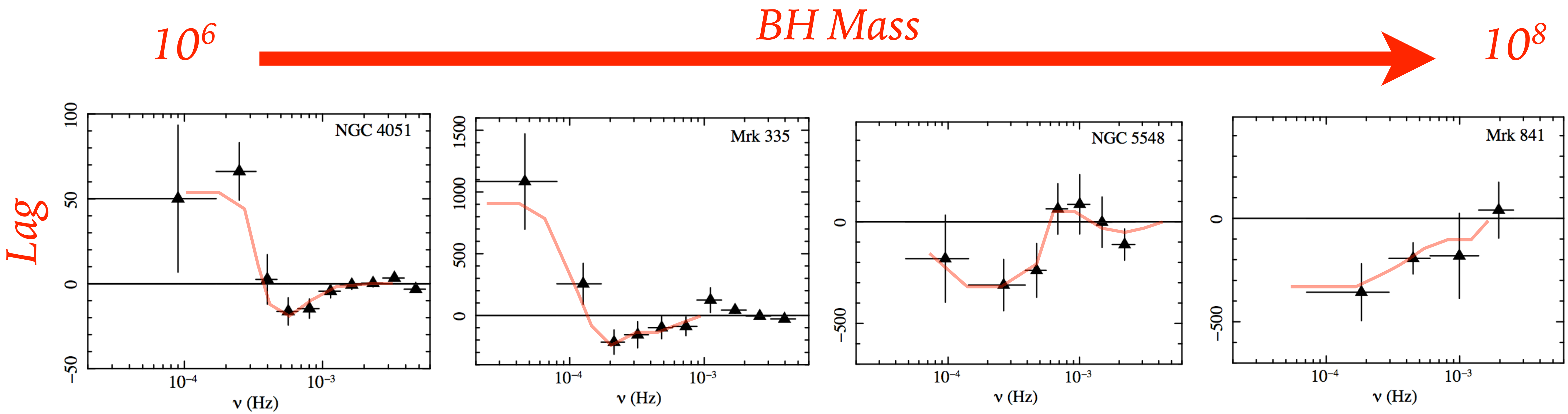
phase lag= argument of cross spectrum=arctg Im[C(ν)]/Re[C(ν)]

time lag=phase lag/2πν

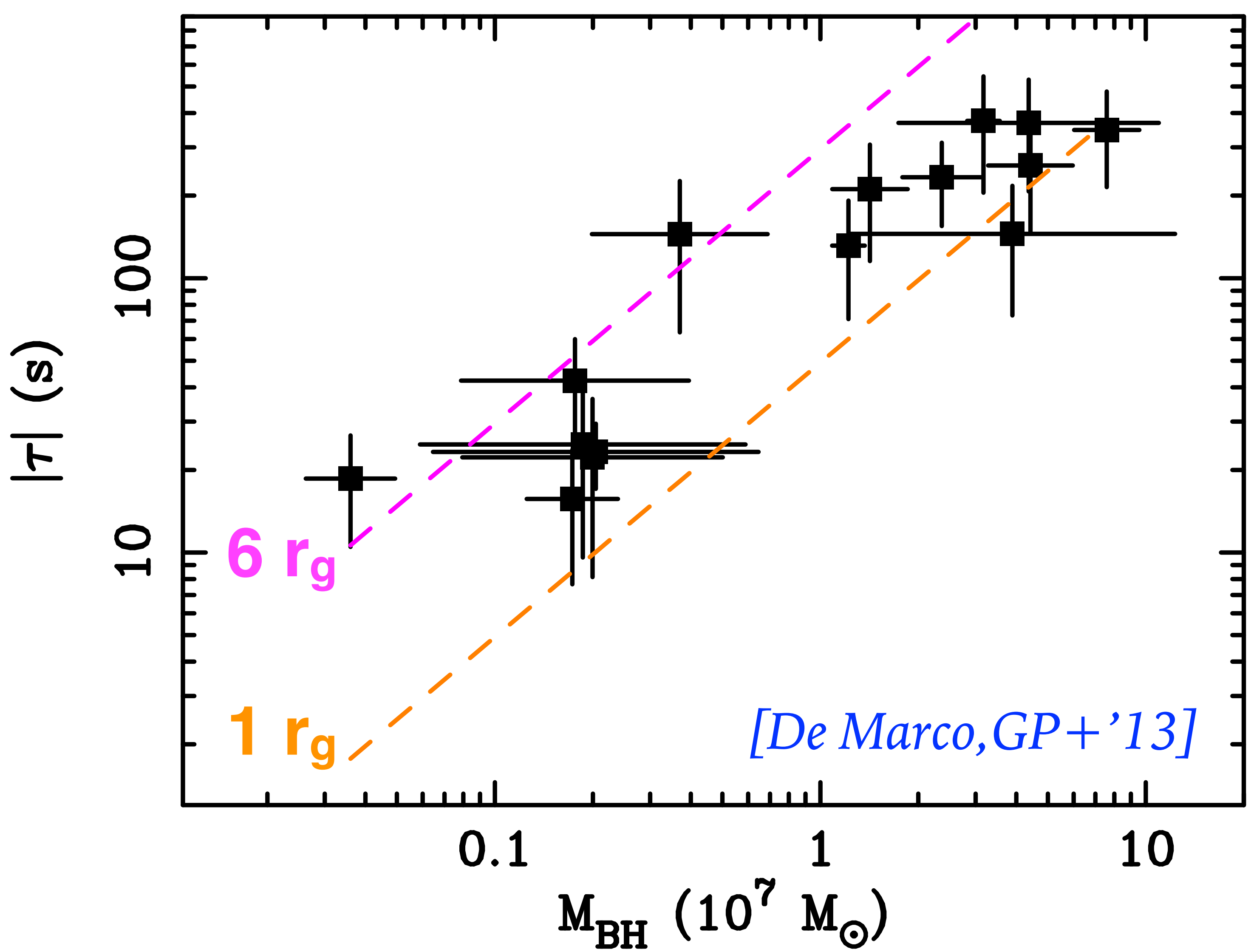
First robust detection of reverberation



How does geometry change with M_{BH}?



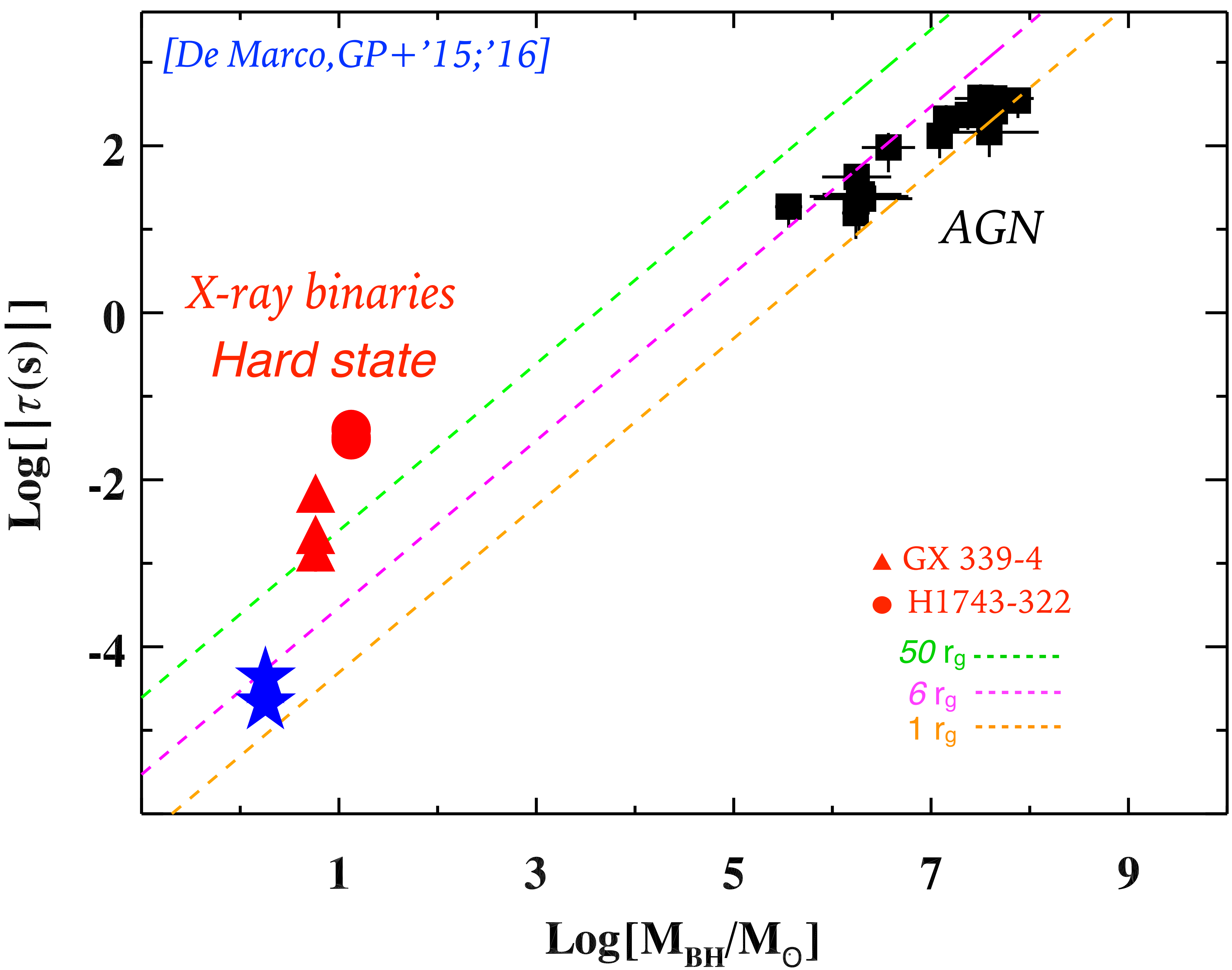
[De Marco,GP+'13]



Small distance between source and disc reprocessing region

Similar (scaled) geometry in all these AGN

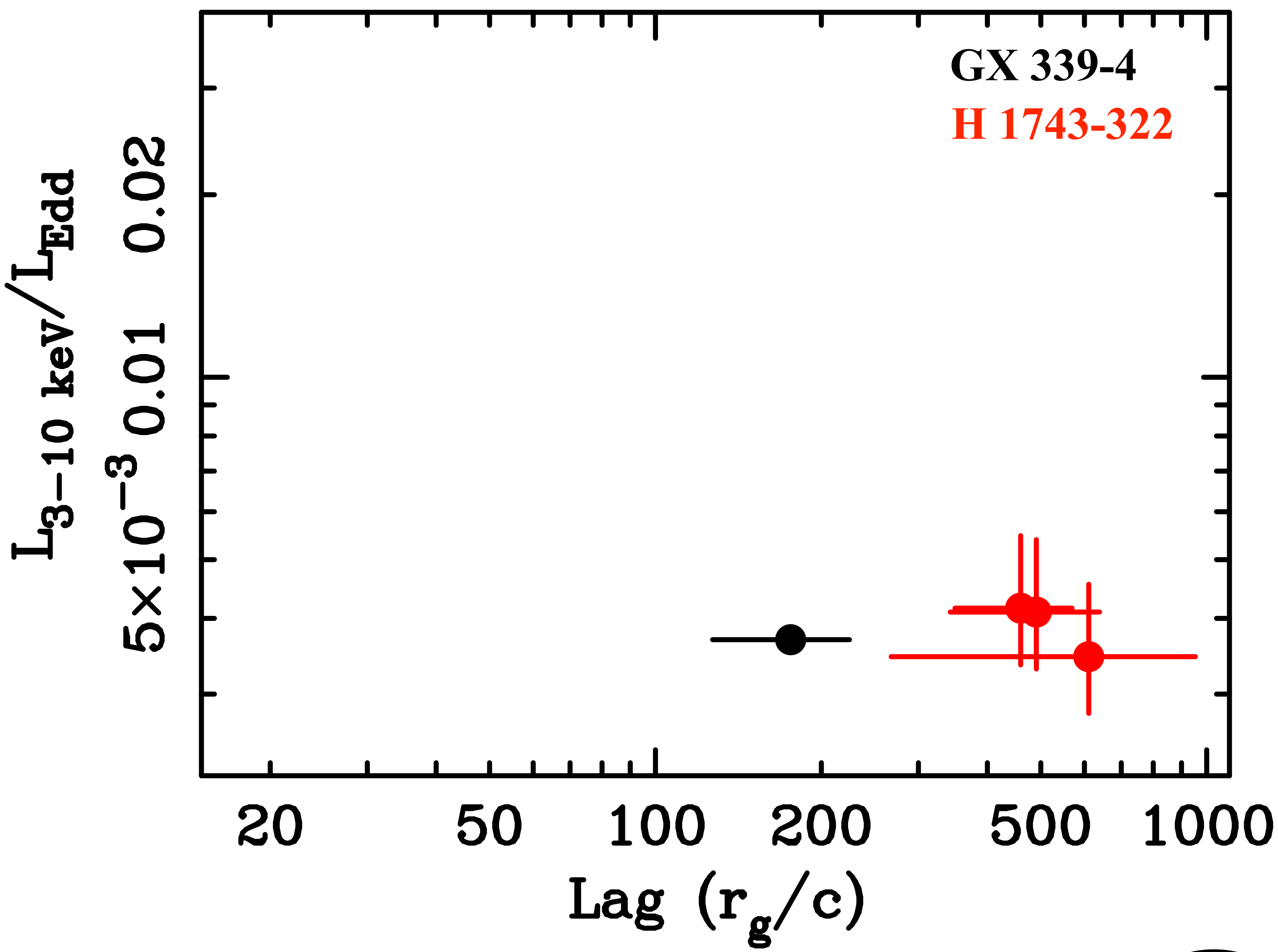
What geometry in X-ray binaries?



Offset AGN scaled and X-ray binaries ➜ *different disc-corona geometry!*

Variation of geometry in the hard state

[De Marco,GP+'15;'16]

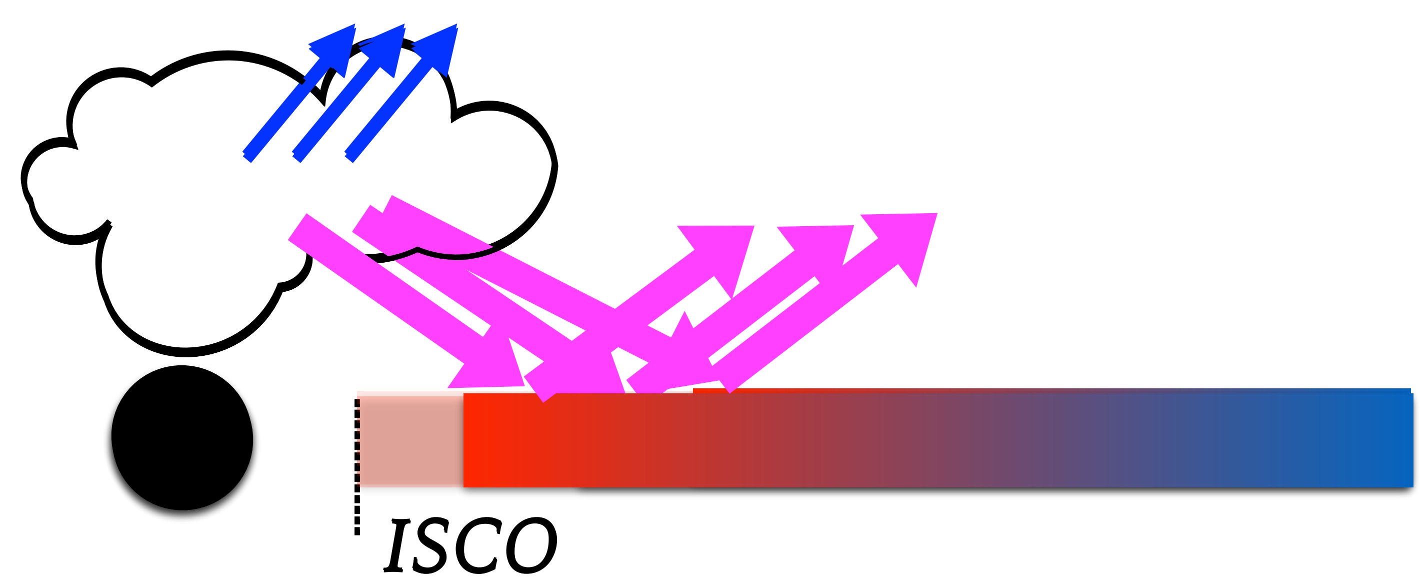


Reverberation lag decreases with luminosity

➜ Evolving disc-corona geometry

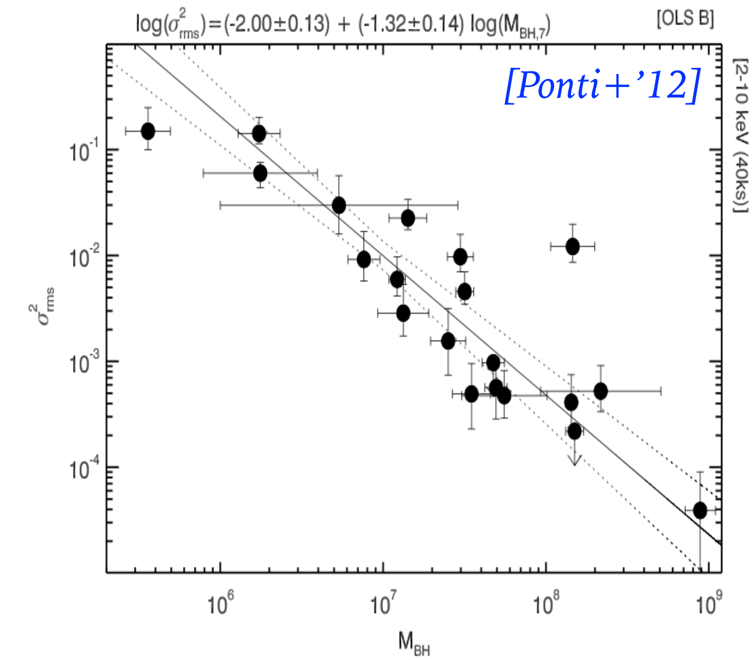
➜ Variation of disc-corona distance

(inner radius accretion disc?)



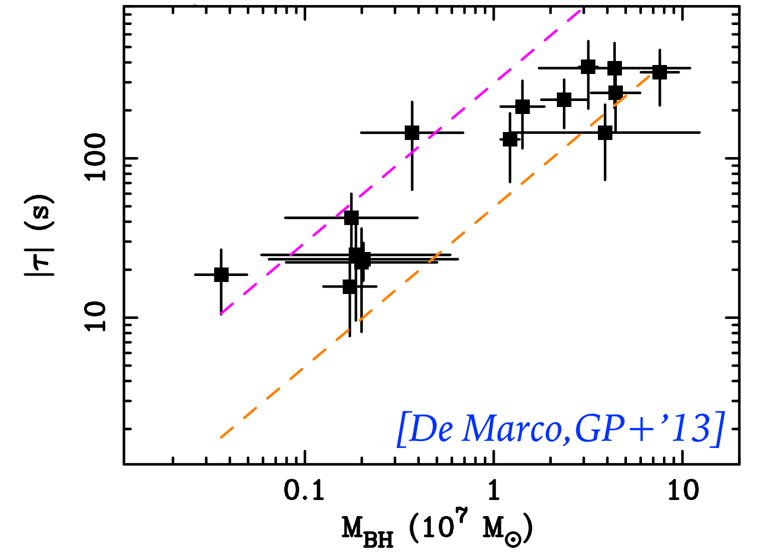
Summary

➜ *Through variability we can grasp geometrical information of accreting black holes*



➜ *A similar (scaled) engine (PSD) powers AGN and X-ray binaries*

➜ *The X-ray source in AGN is compact ($r < 1$-$2\ r_g$)*
All studied AGN have the same compact disc-corona geometry (1-10 r_g)



➜ *X-ray binaries in hard state have large disc-corona distances (20-10^3 r_g)*
The disc-corona distance decreases with luminosity
(disc more truncated at low L)