

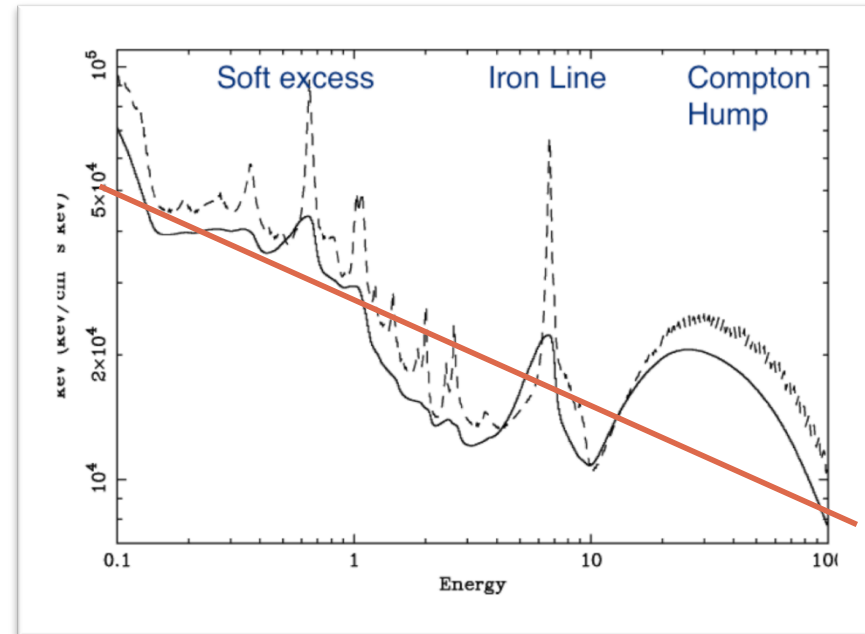
# AGN Reverberation Mapping with STOBEX

Abdu Zoghbi  
University of Michigan



# X-ray Reverberation

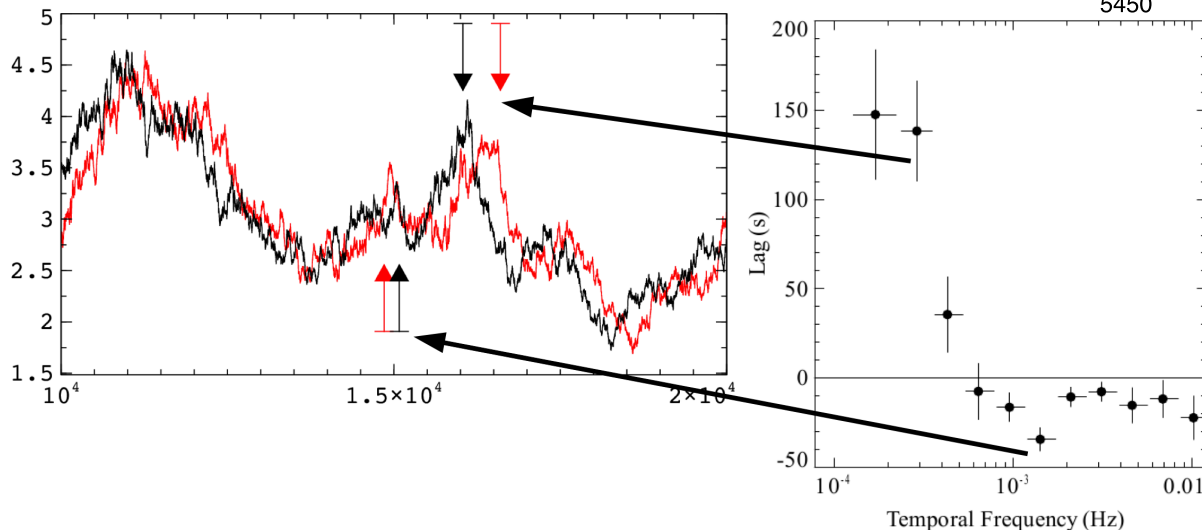
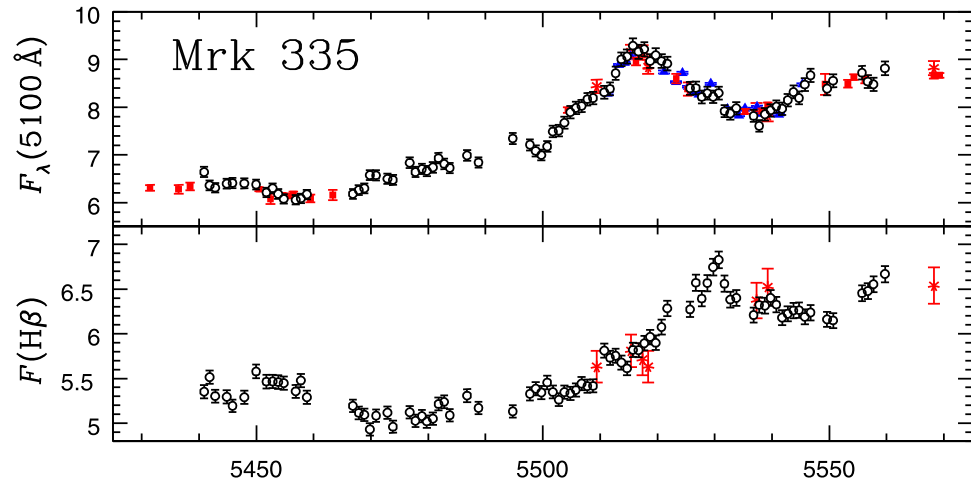
- X-ray emission originates **close** to the BH.
- Fast variability + Reflection: → Reverberation
- In AGN, the **reflection spectrum** reverberates.
- In BHB, the **blackbody** from the disk may reverberate (See Ed Cackett's talk).



# X-ray Reverberation

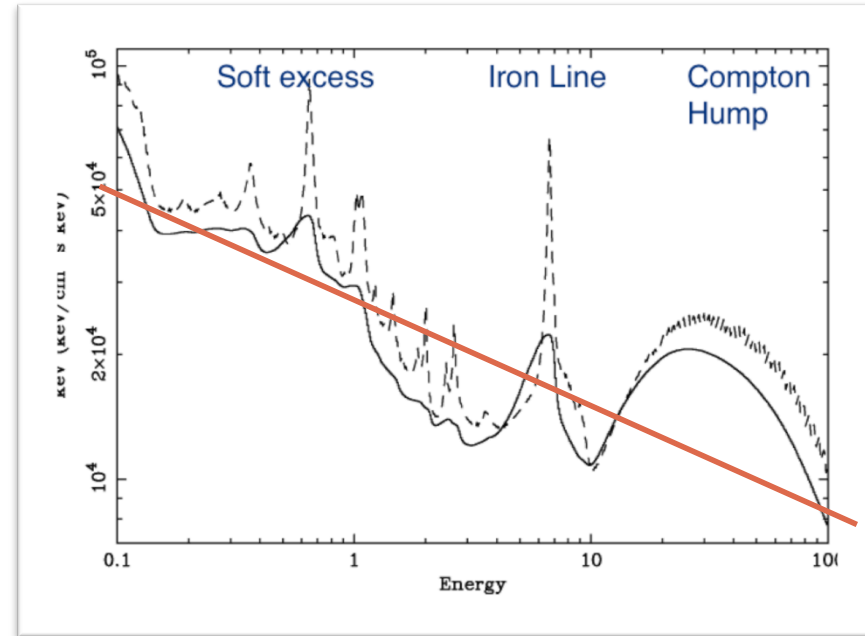
- Unlike optical reverberation, X-ray lags in AGN are **timescale-dependent** → Frequency-dependent

Grier+12



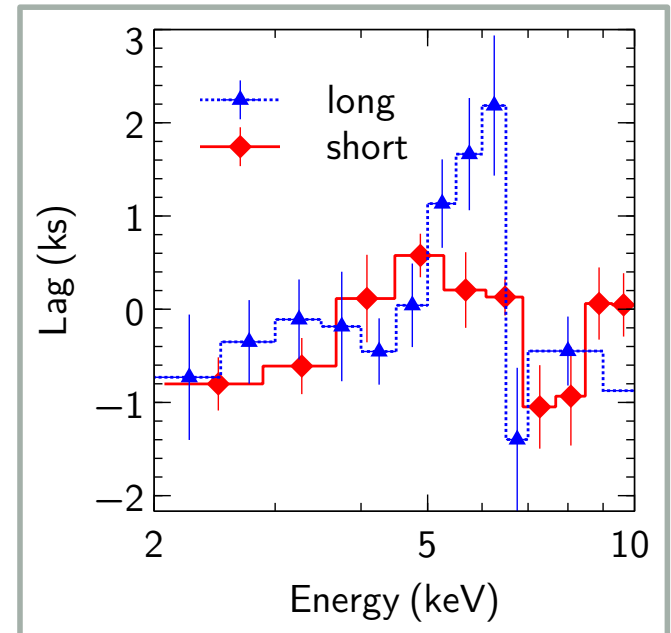
# Observed Reflection Lags

- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.)



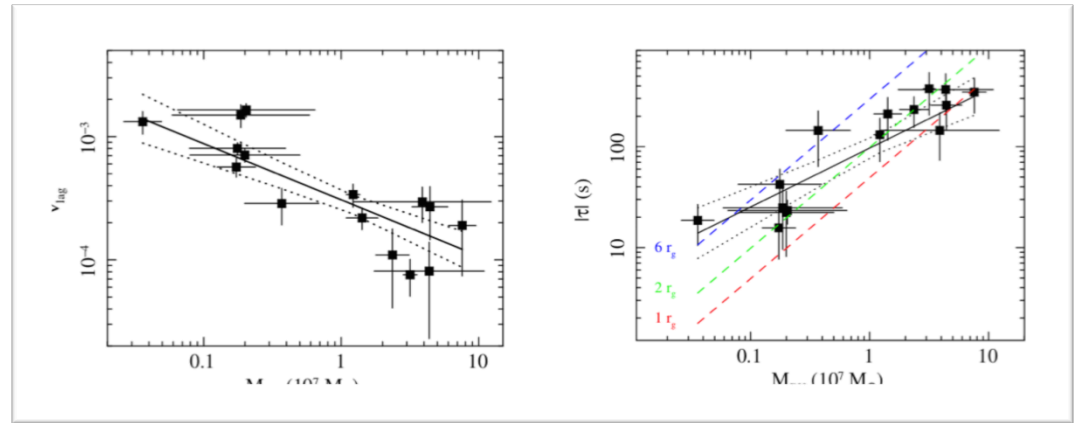
# Observed Reflection Lags

- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.).
- The **iron K Line** (AZ +12,13,15, Kara+13,14).

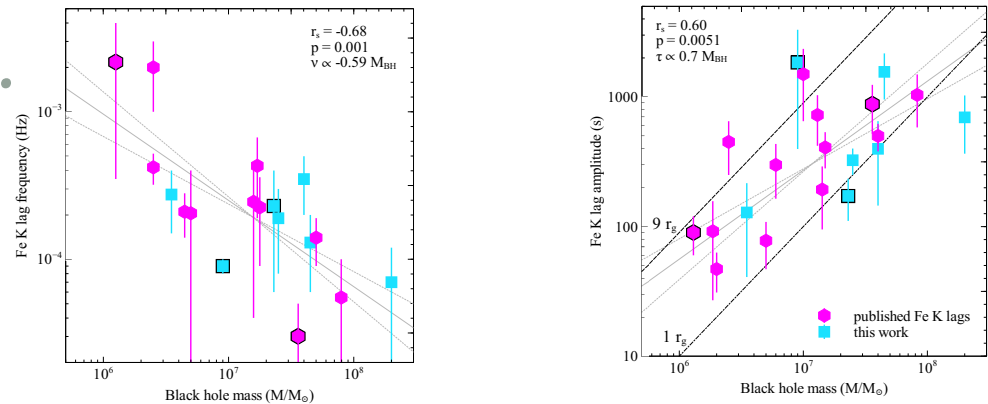


# Lags Are Correlated With Mass

- Seen in the **soft excess**.  
(De Marco+12)

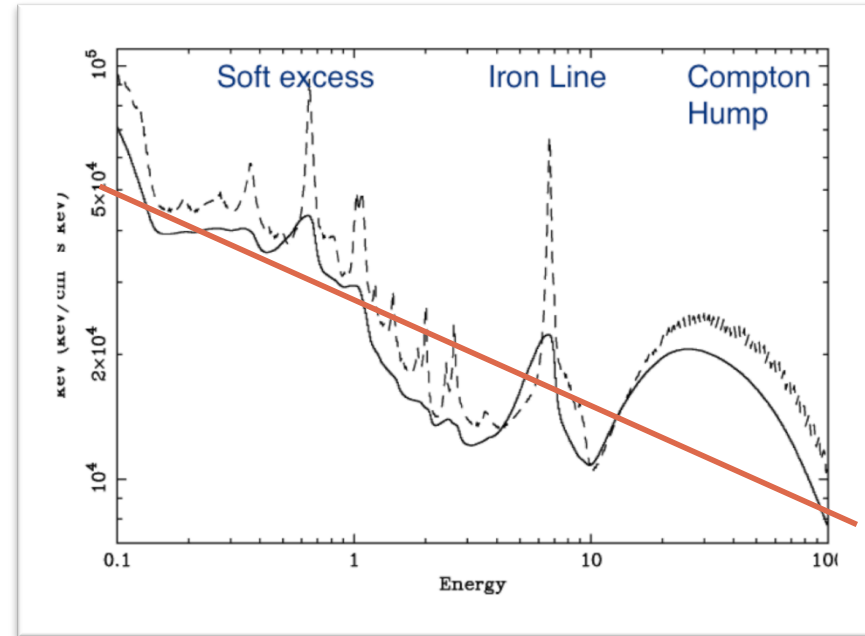


- Then in the **iron K Line**.  
(Kara+16)



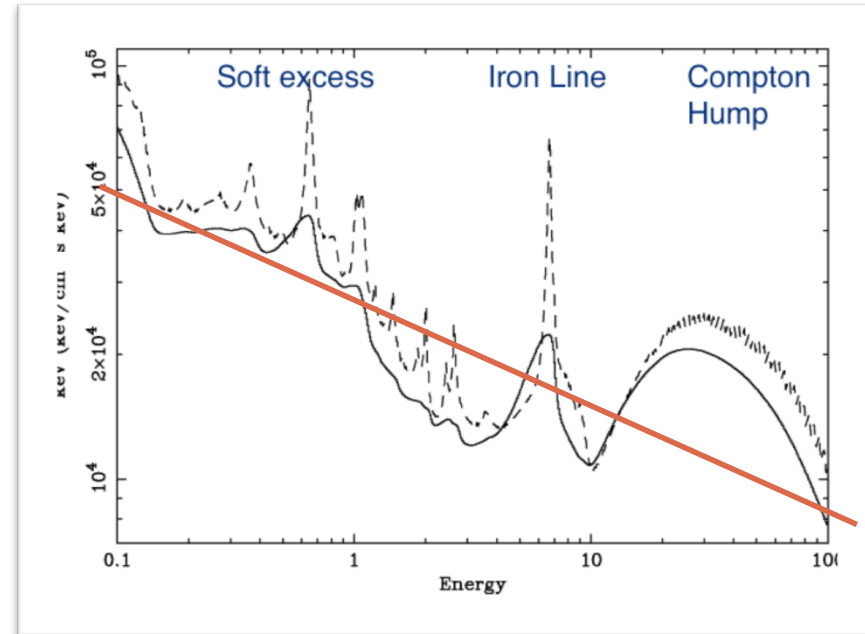
# Observed Reflection Lags

- First seen in the **soft excess** (Fabian+09, AZ +10,11 etc.).
- The **iron K Line** (AZ +12,13, Kara+13,14).
- The **Compton Hump** possibly (AZ+15, Kara +15).



# Observed Reflection Lags

- Lag vs frequency for two energy bands.
- Lag vs energy at some frequency  $\rightarrow$  reflection fraction.
- Current modeling attempts





# The Next Steps With STROBE-X: Sensitivity

- Signal considerations.

$$\Delta\phi(f) = N^{-1/2} \sqrt{\frac{2}{P_1 P_2 R_1 R_2} + \frac{1}{P_1 R_1} + \frac{1}{P_2 R_2}}$$

- **N**: Num. of Frequencies: observation length & frequency band.
- **P**: Intrinsic to the object.
- **R**: 'Noise factor' related to detector sensitivity.

- Assume:

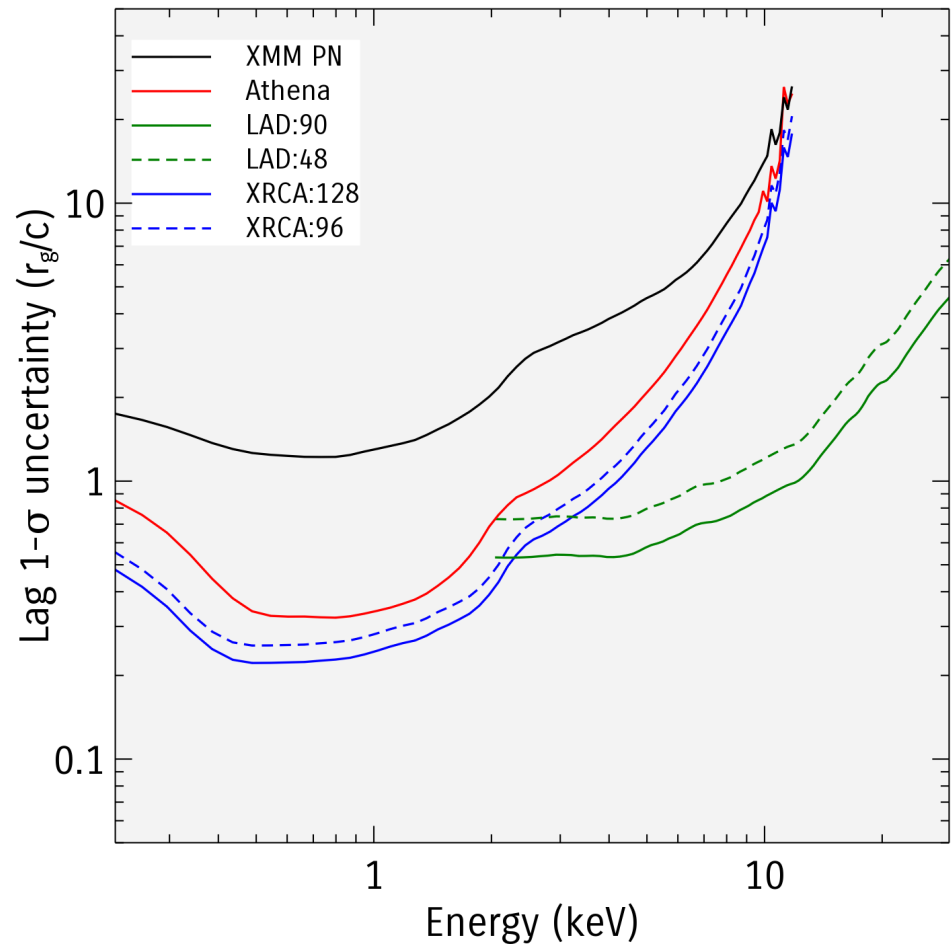
$$P \propto M_{\text{BH}}$$

$$F_{2-10\text{keV}} = 4 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$$

responses  $\rightarrow R$

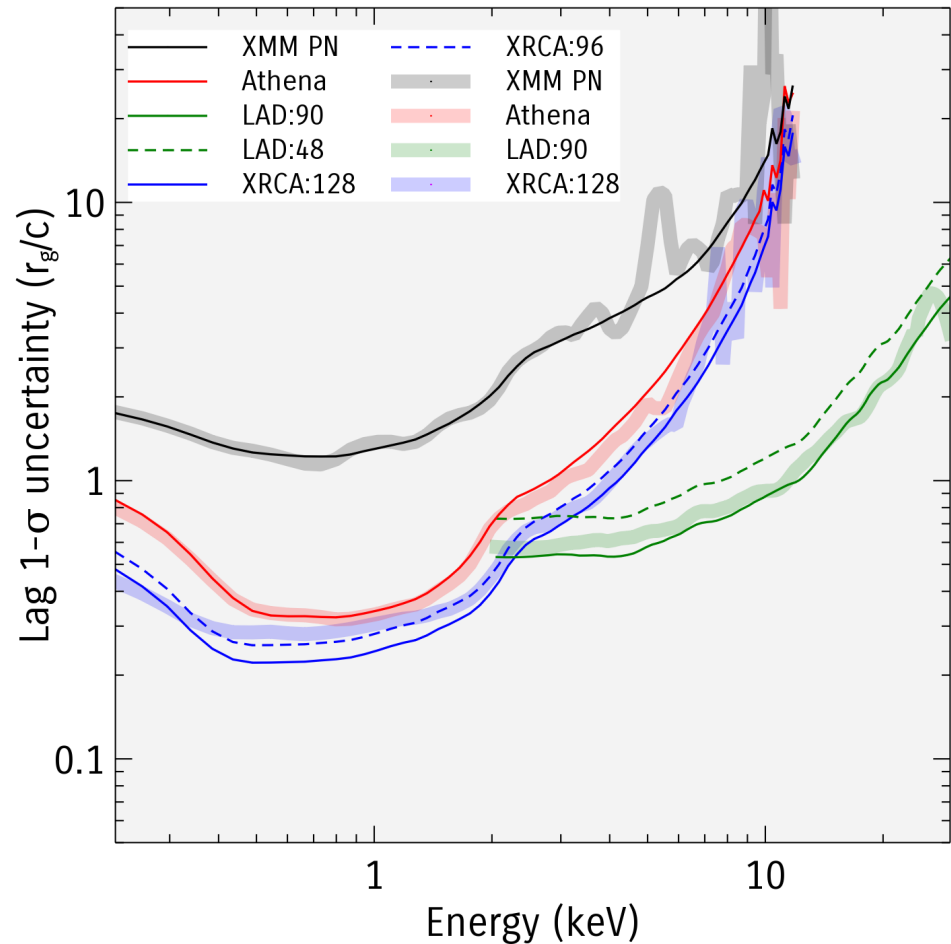
# The Next Steps With STROBE-X: Sensitivity

- Lag sensitivity plot.



# The Next Steps With STROBE-X: Sensitivity

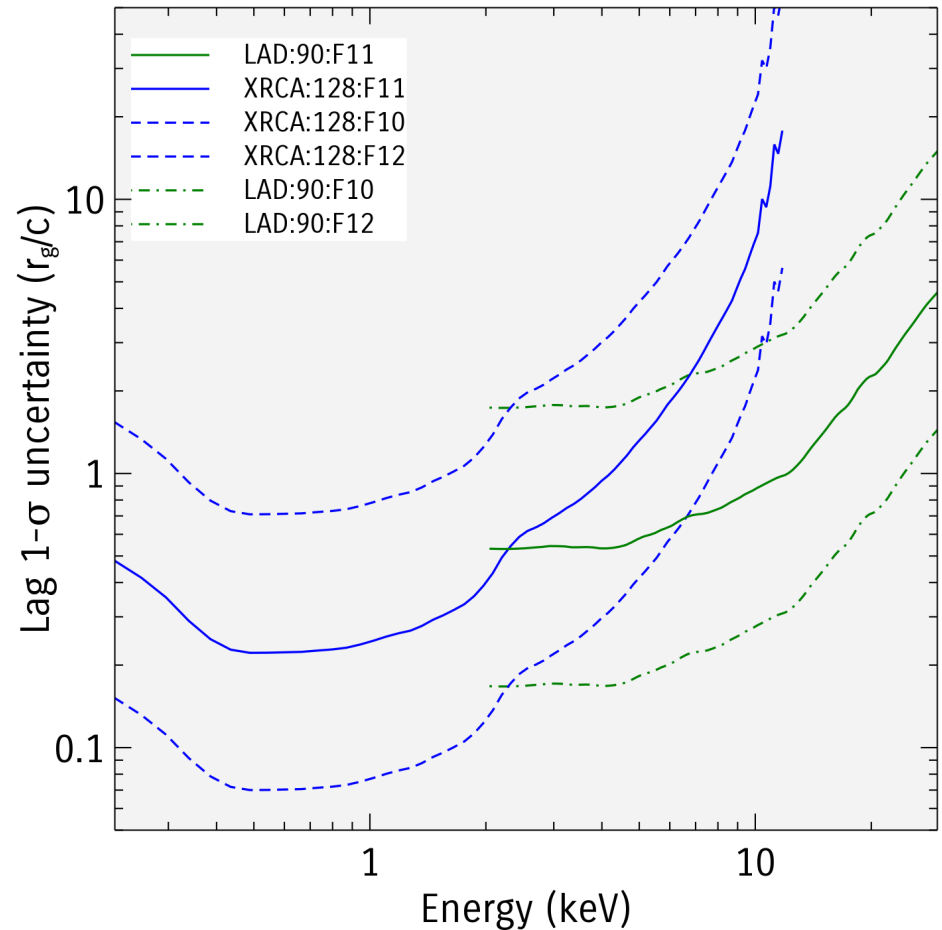
- Lag sensitivity plot.
- Curves match simulated light curves.



# The Next Steps With STROBE-X: Sensitivity

- Lag sensitivity plot.
- Curves match simulated light curves.
- Using a range of fluxes:

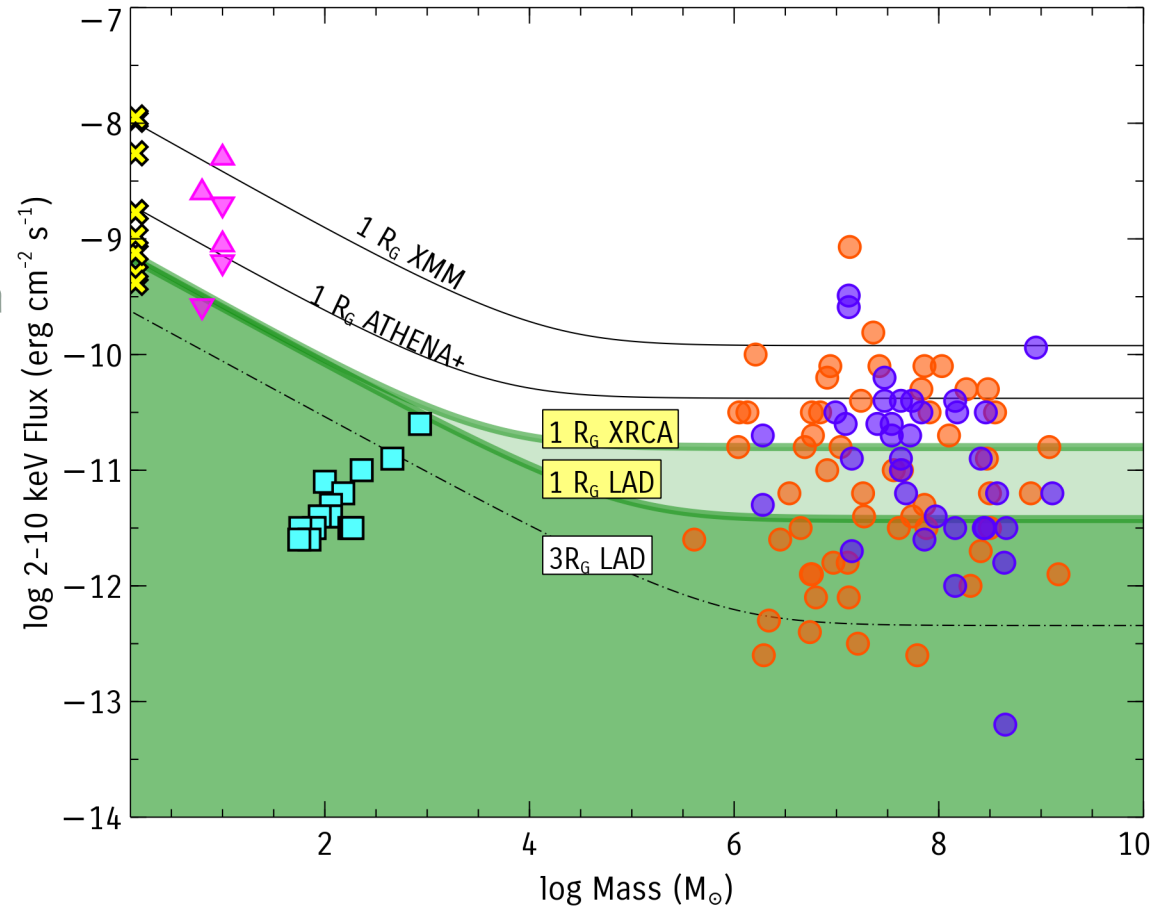
$$4 \times 10^{[-12, -11, -10]} \text{erg cm}^{-2} \text{s}^{-1}$$



# The Next Steps With STROBE-X: Sensitivity

- Sources to be explored:  
Using the Flux-Mass space.

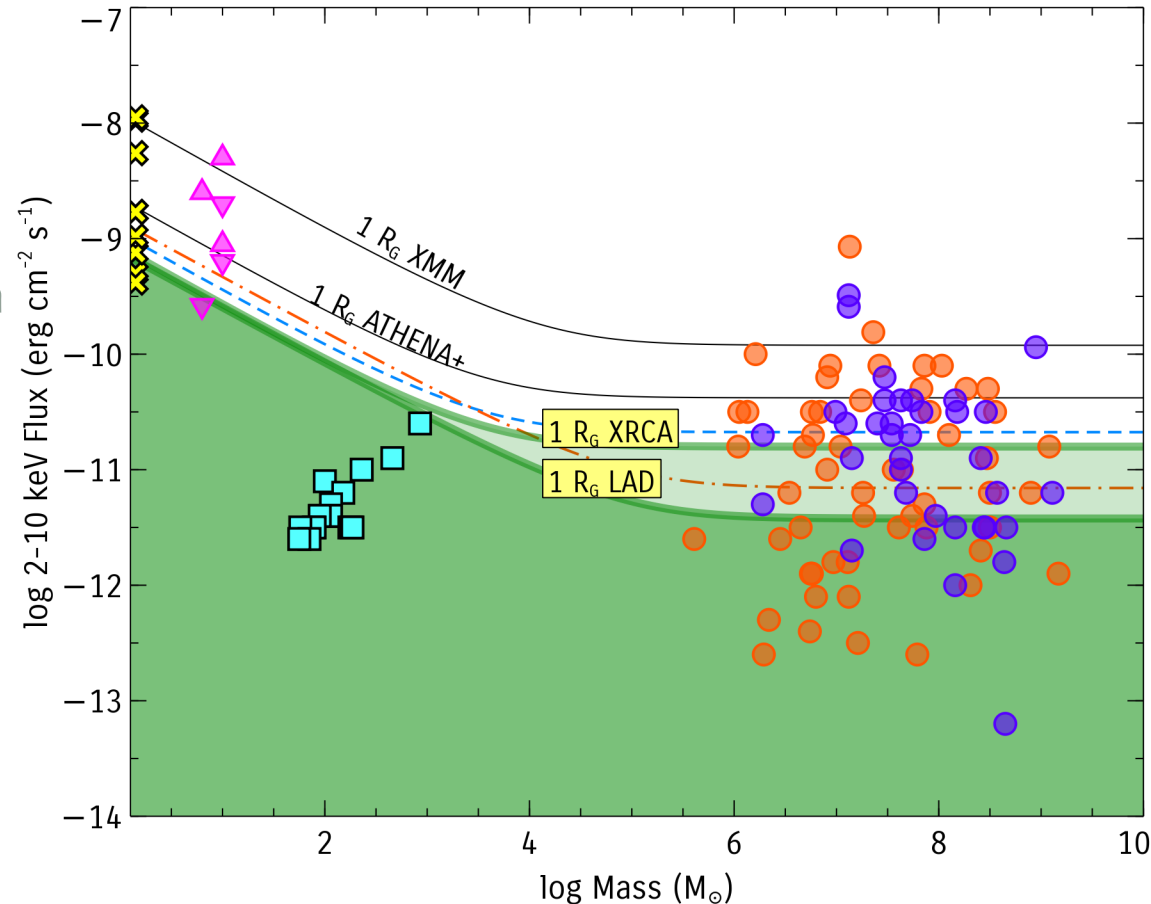
- Blue: AGN with reverberation masses.
- Orange: AGN with mass from masses from  $H\beta$  widths.
- Cyan: ULX, assuming IMBH.
- Magenta: Stellar Mass BH.
- Yellow: NS



# The Next Steps With STROBE-X: Sensitivity

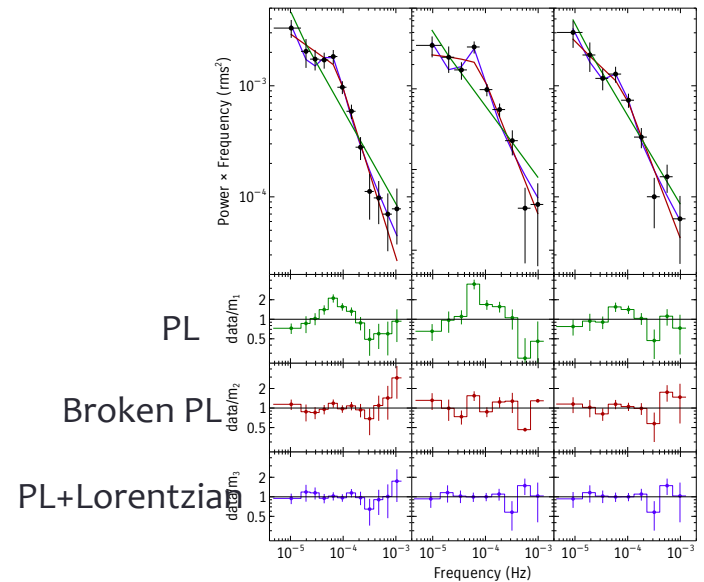
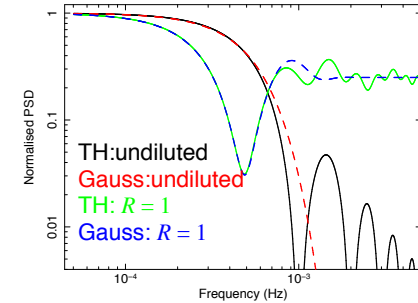
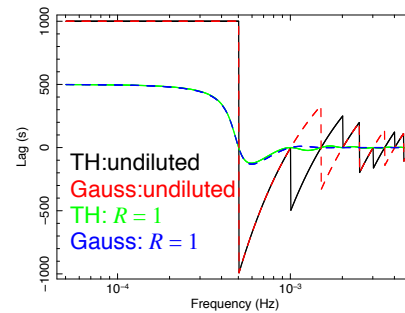
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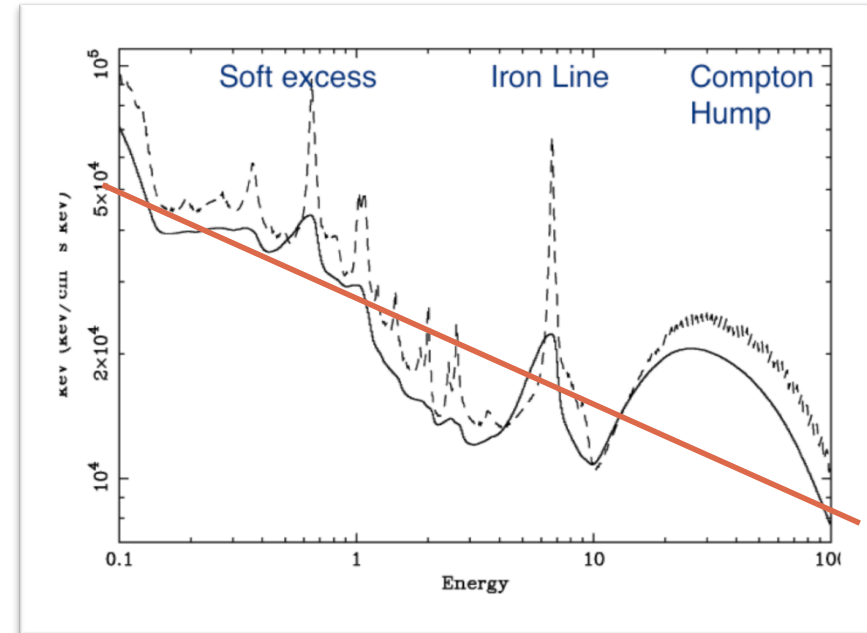
# STROBE-X: The Measurements

- What will we measure?
  - Signature of Reverberation in PSD



# STROBE-X: The Measurements

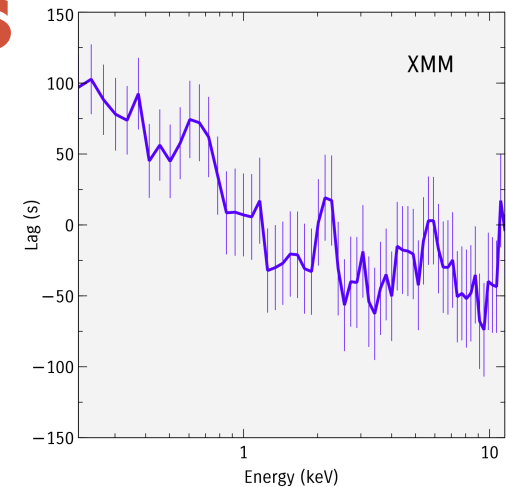
- **What will we measure?**
  - Signature of Reverberation in PSD.
  - Detailed Lag-energy Spectra.





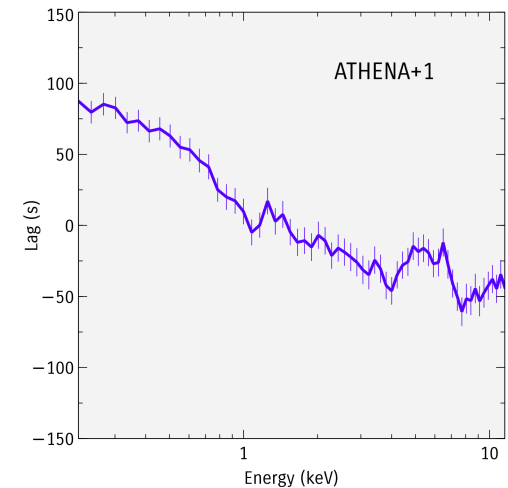
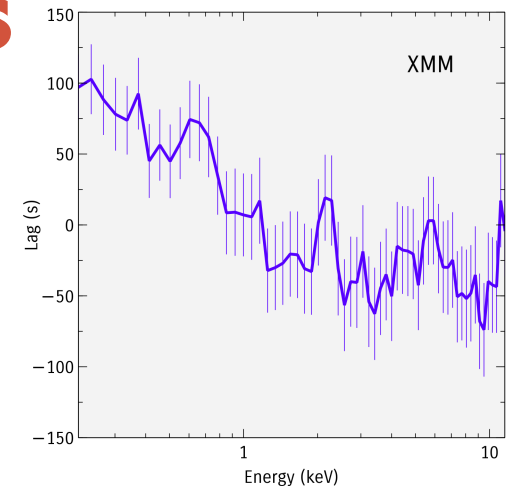
# STROBE-X: The Measurements

- **What will we measure?**
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  - Detailed Lag-energy Spectra across the whole band.



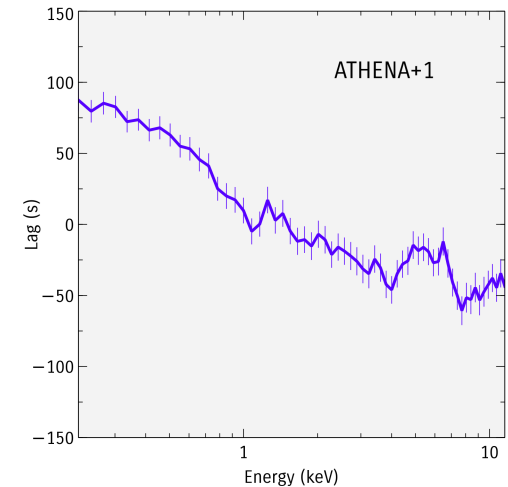
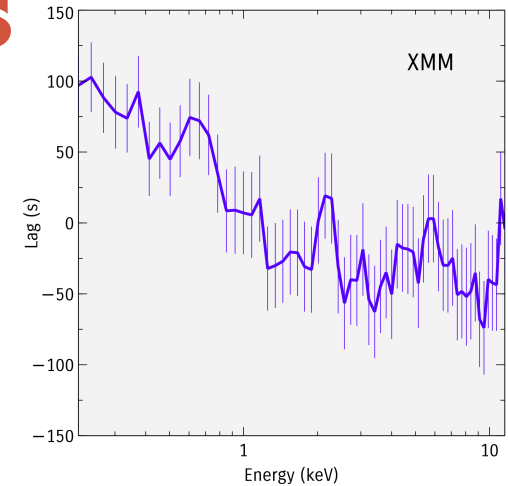
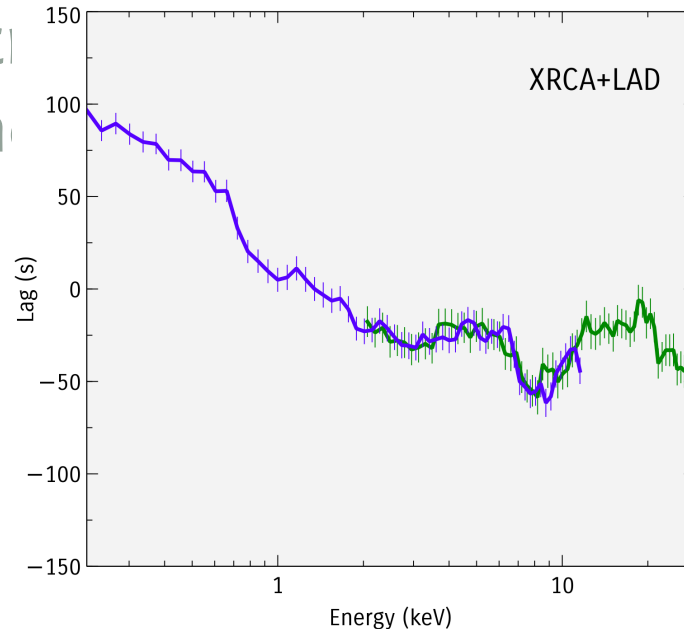
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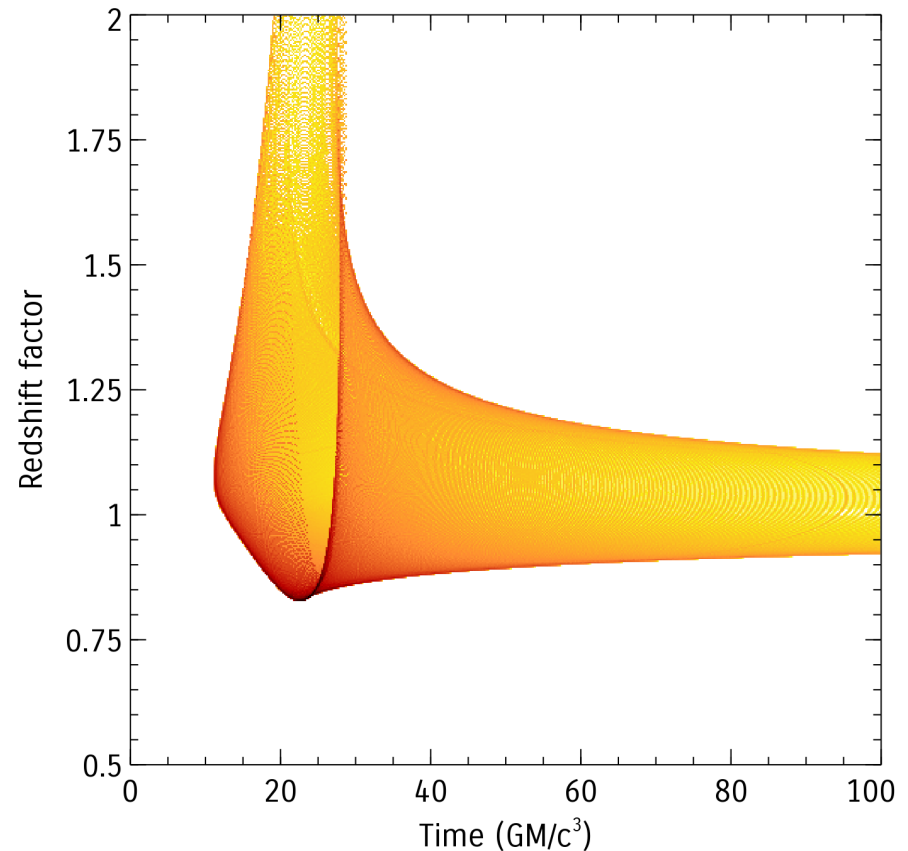
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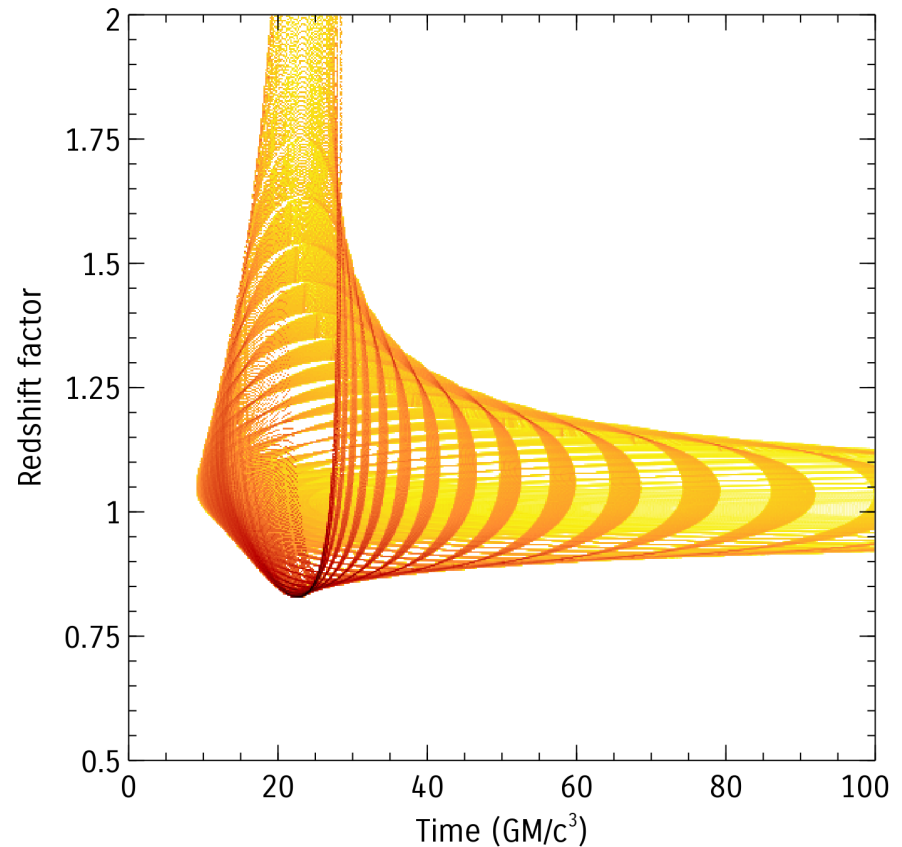
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- **What will we measure?**
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  - Relativistic Response Function  $\rightarrow$  Geometry (Wilkins+15,16).



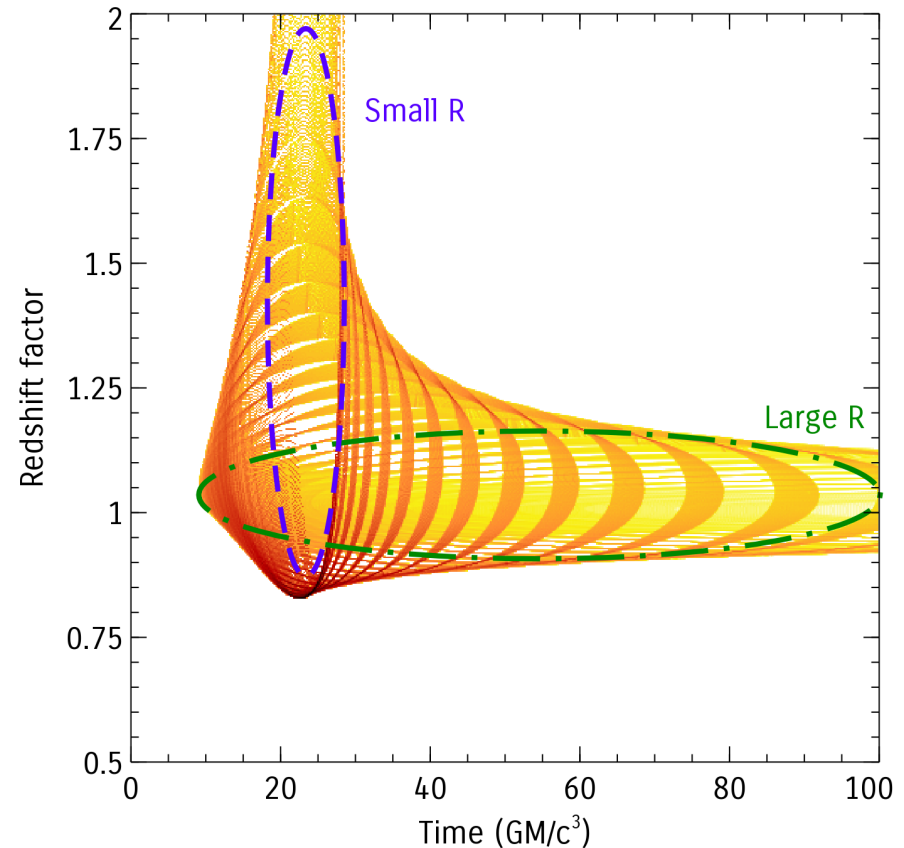
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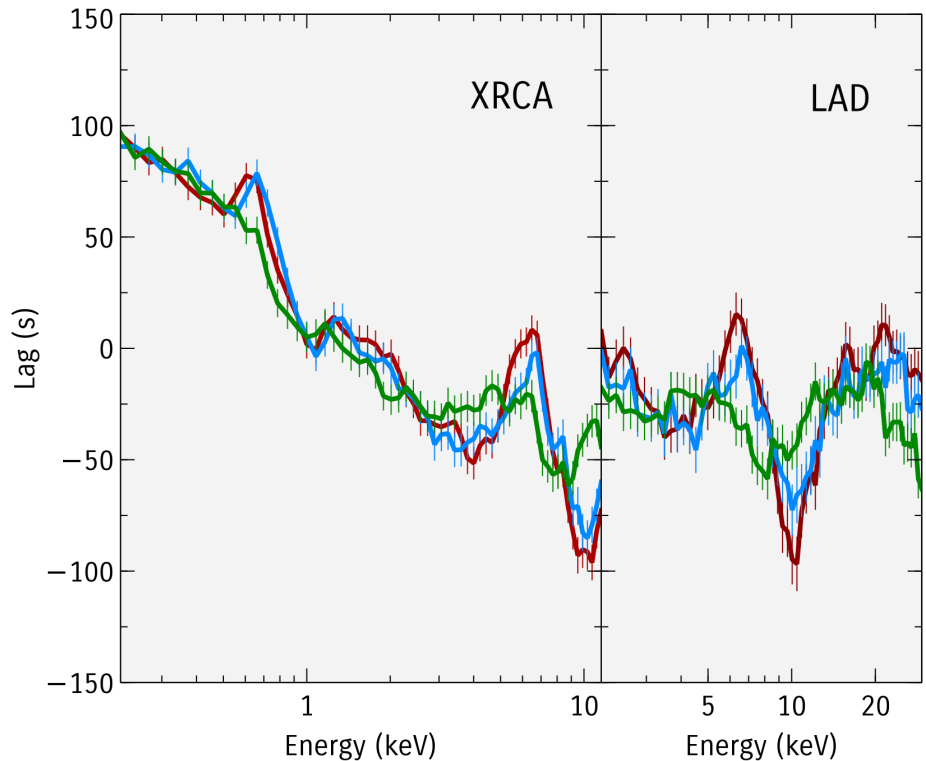
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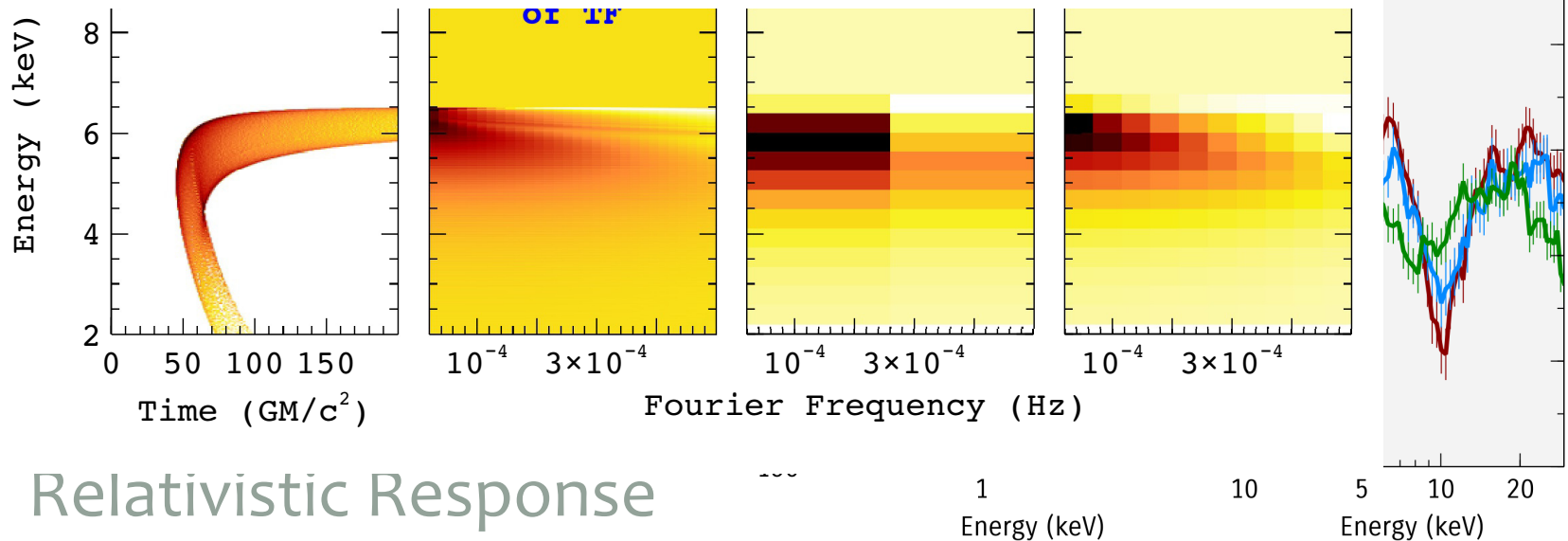
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# STROBE-X: The Measurements

- What will we measure?

- Signature of



- Relativistic Response Function  $\rightarrow$  Geometry.



# Summary

- Current measurements explores the tip of the iceberg of **relativistic reverberation in AGN**.
- **Orbital gaps**: we know how to handle them. Cons: missing some time-scale. Pros: gain long time-scales.
- With Strobe-X, tens of of sources will have **sub-Rg lag measurements**, opening new frontiers.
- Direct **measurement of Response function** of the iron line (& the whole spectrum) through frequency-resolved lag-energy → Geometry at horizon scales.
- Trade-off time: XRCA is downgrade is less sensitive to lag measurement than LAD.