

ULTRALUMINOUS X-RAY SOURCES WITH NUSTAR & FRIENDS



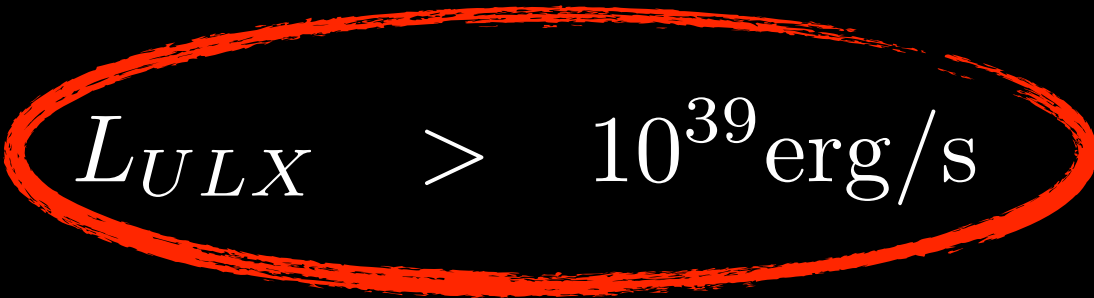
MATTEO BACHETTI

WITH D. BARRET, F. HARRISON, J. M. MILLER, V. RANA, D. WALTON,
THE NUSTAR ULX WG, AND THE NUSTAR TEAM
DUBLIN, JUNE 19TH, 2014

WHY "ULTRALUMINOUS" ?

$$\begin{aligned} L_{Edd} &\approx 1.38 \cdot 10^{38} \frac{M}{M_{\odot}} \text{erg/s} \\ &\approx 1.38 \cdot 10^{39} \frac{M}{10M_{\odot}} \text{erg/s} \end{aligned}$$

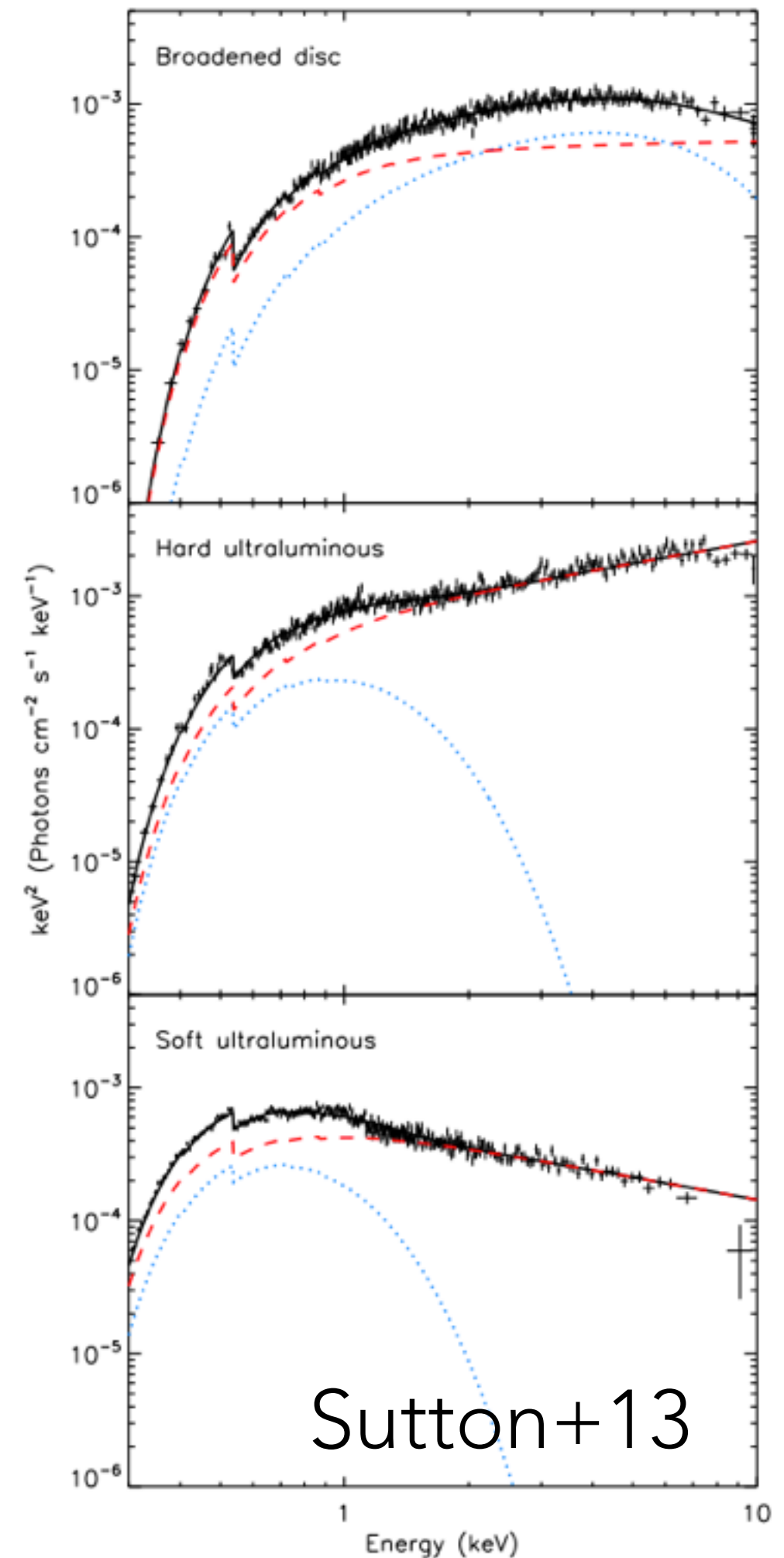
Standard accretion limit
on stellar-mass BHs


$$L_{ULX} > 10^{39} \text{erg/s}$$

High BH mass?
Super-Eddington accretion?

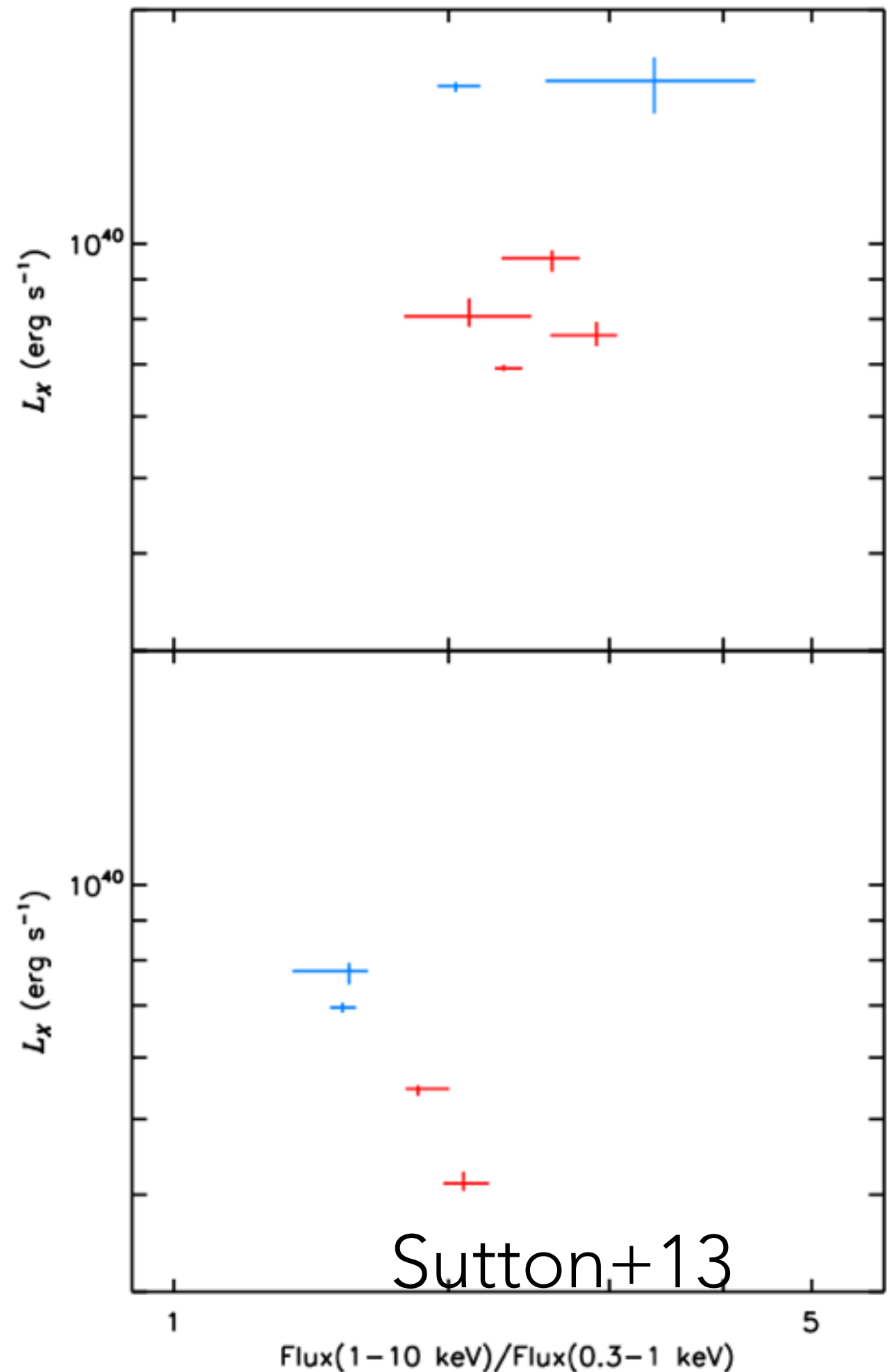
ULX SPECTRA IN THE XMM ERA

- Three main spectral shapes



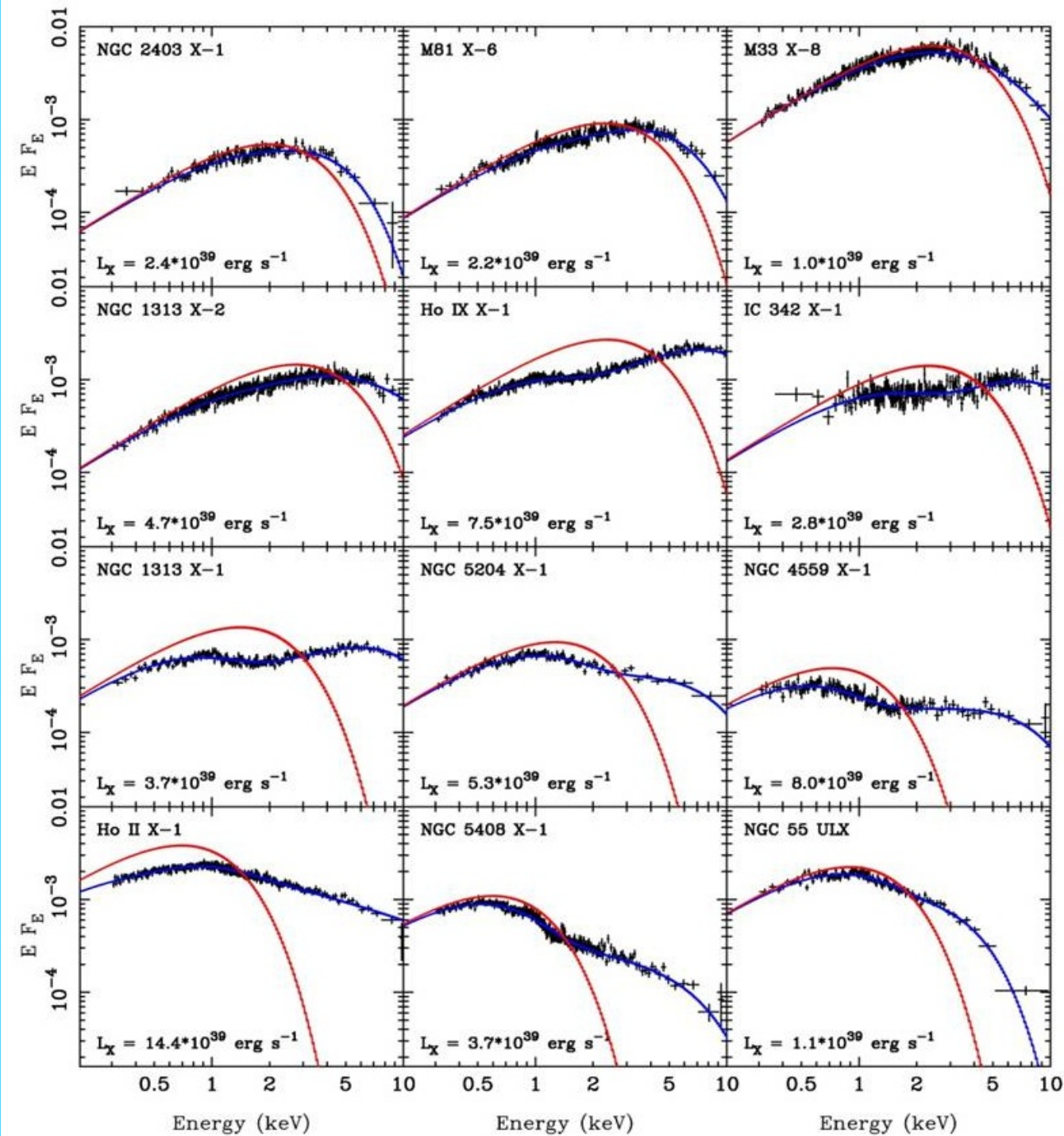
ULX SPECTRA IN THE XMM ERA

- Three main spectral shapes
- The same source can show one or more of these spectral states



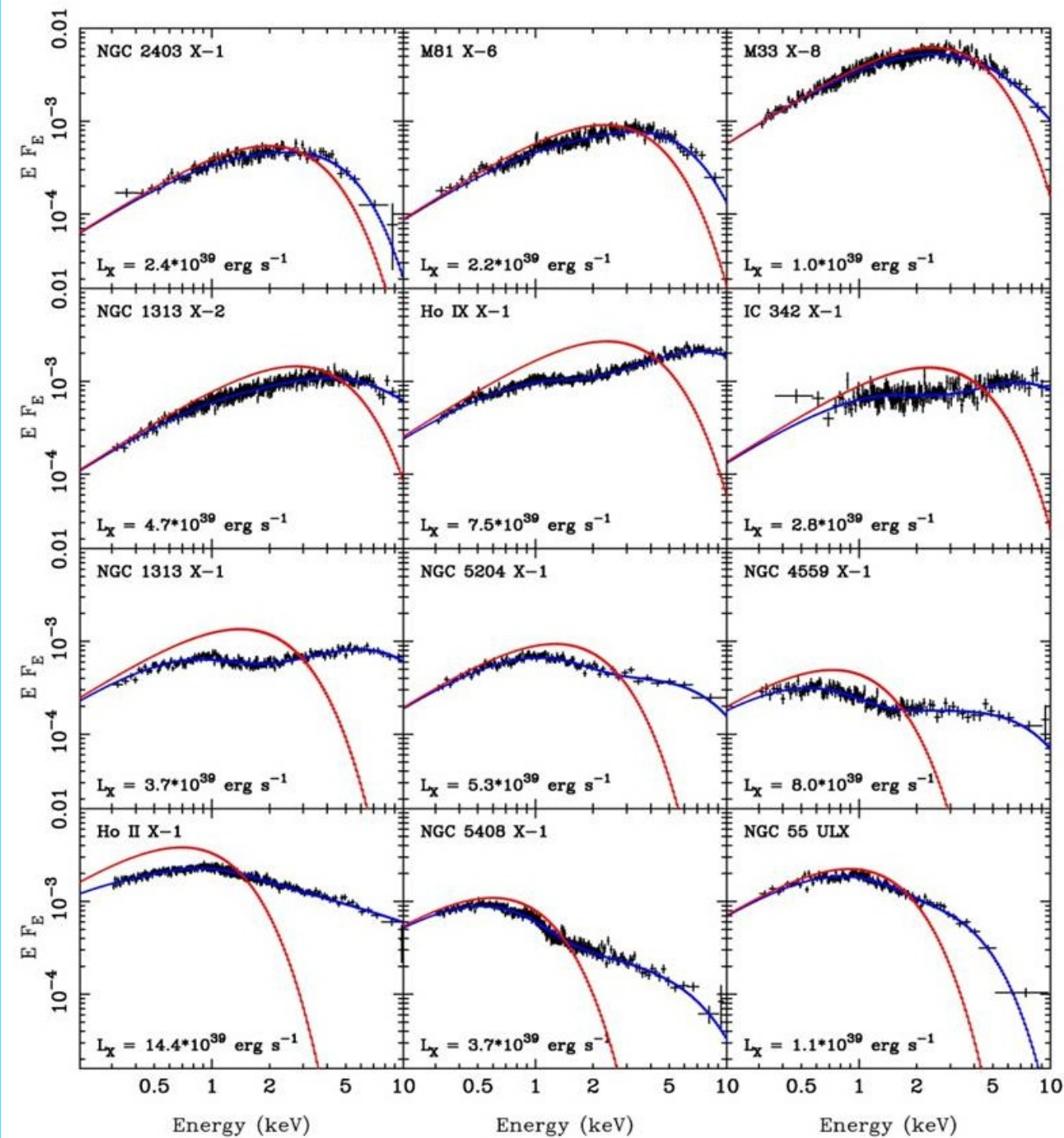
ULX SPECTRA IN THE XMM ERA

- Three main spectral shapes
- The same source can show one or more of these spectral states
- Broadened disk usually in low-luminosity sources



ULX SPECTRA IN THE XMM ERA

- Mostly **Persistent!**
- A **soft excess(?)**
- A **hard turnover(?)**



SPECTRAL PROPERTIES OF ULXS (< 10 KEV)

- Mostly **Persistent!**
- A **soft excess(?)**
- A **hard turnover(?)**

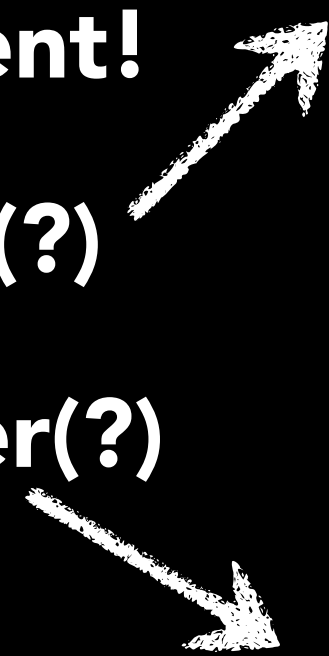
SPECTRAL PROPERTIES OF ULXS (< 10 KEV)

- Mostly **Persistent!**
- A **soft excess(?)**
- A **hard turnover(?)**



- Standard disk cut at the ISCO? (IMBH! e.g. Miller+04)
- Blurred emission lines? (e.g. Caballero-Garcia+10)
- A partially covered disk? (e.g. Gladstone+09)
- A soft *deficit*? (e.g. Gonçalves+06)

SPECTRAL PROPERTIES OF ULXS (< 10 KEV)

- Mostly **Persistent!**
 - A **soft excess(?)**
 - A **hard turnover(?)**
- 

- Standard disk cut at the ISCO? (IMBH! e.g. Miller+04)
- Blurred emission lines? (e.g. Caballero-Garcia+10)
- A partially covered disk? (e.g. Gladstone+09)
- A soft *deficit*? (e.g. Gonçalves+06)

- A cutoff? (e.g. Stobbart+06)
- A turnover due to a broadened iron complex? (e.g. Caballero-Garcia+10)
- A second disk component? (e.g. Miller+13)
- A conspiracy? An illusion?

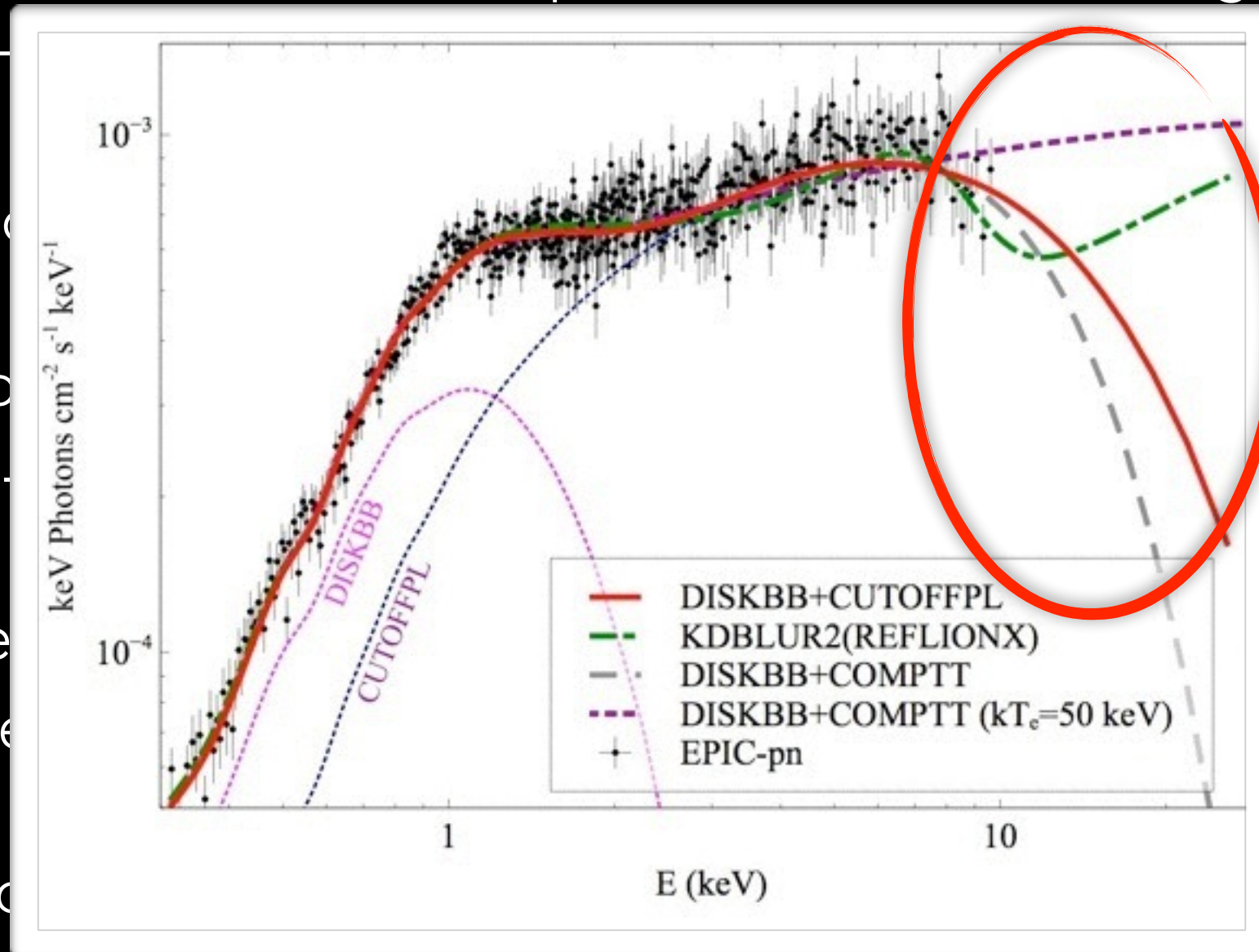
POSSIBLE MODELS BEFORE NUSTAR

POSSIBLE MODELS BEFORE NUSTAR

- Standard low/hard state: low T , powerlaw. Below Eddington (-> implies IMBH)
- Reflection-dominated (Caballero-García & Fabian '10)
- "Ultraluminous state" (Gladstone et al. 09)? Large "cold" corona, disk hidden -> favors stellar mass
- slim, or p-free, disk (Ebisawa et al, Kawaguchi et al.): deviation from SS73's temperature-radius relation. Super-Edd accretion possible.
- beaming and outflows: large apparent luminosity due to beaming.
- "Patchy disks"

POSSIBLE MODELS BEFORE NUSTAR

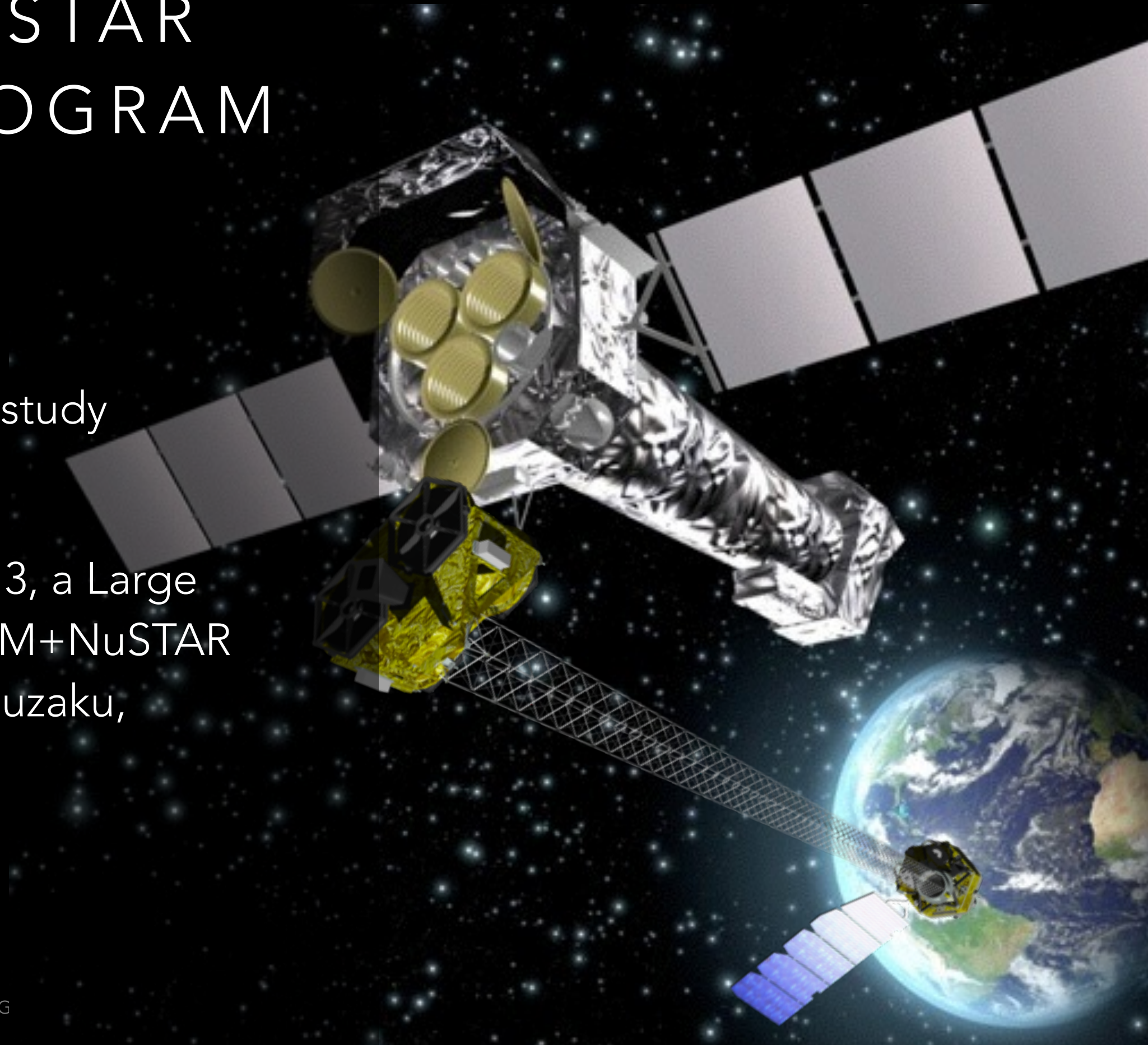
- Standard low/hard state: low T , powerlaw. Below Eddington (-> implies IMBH)
- Reflection-disk
- "Ultraluminous" disk hidden - corona,
- slim, or p-free SS73's temperature variation from possible.
- beaming and beaming.

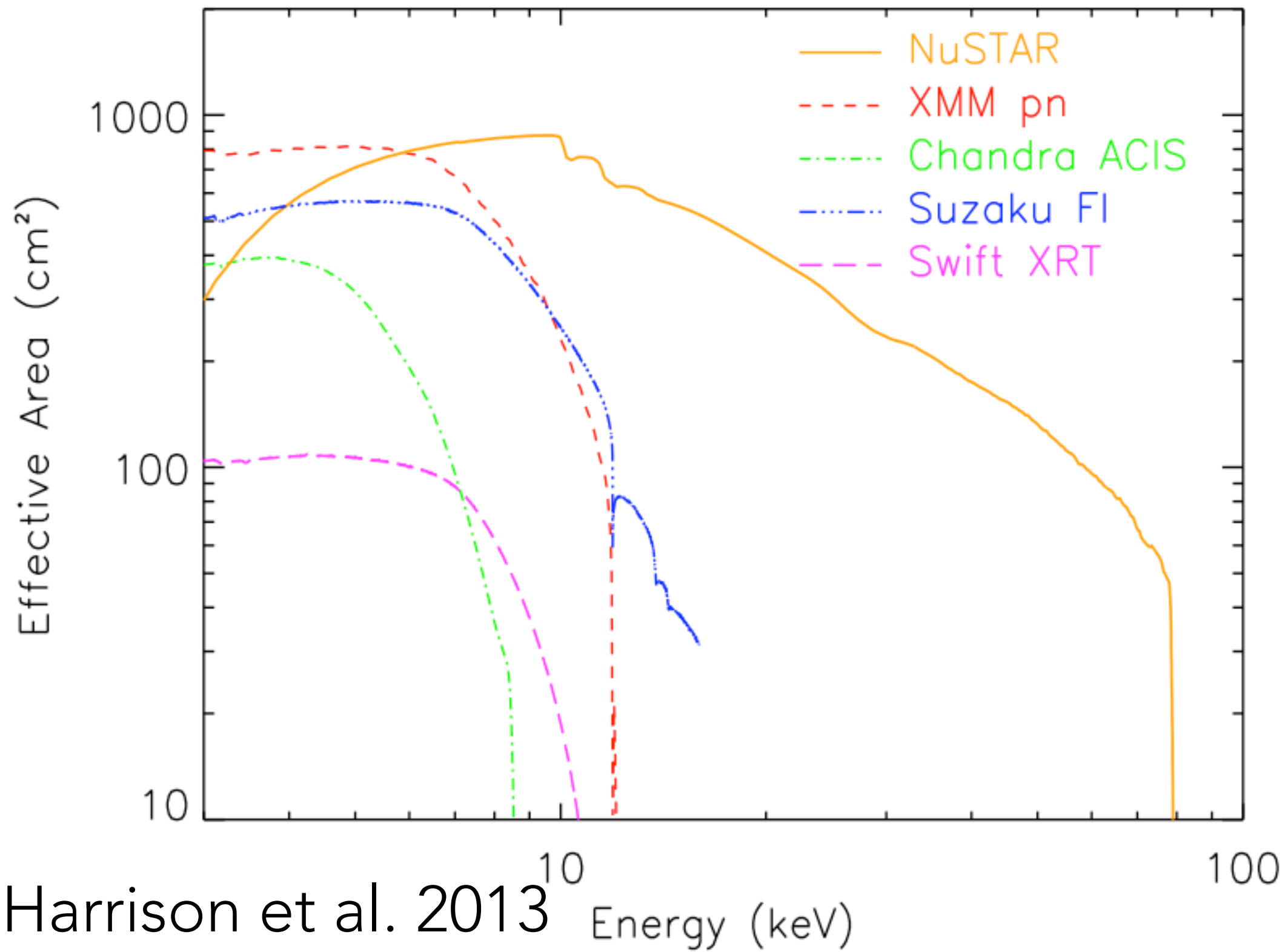


- "Patchy disks"

THE NUSTAR ULX PROGRAM

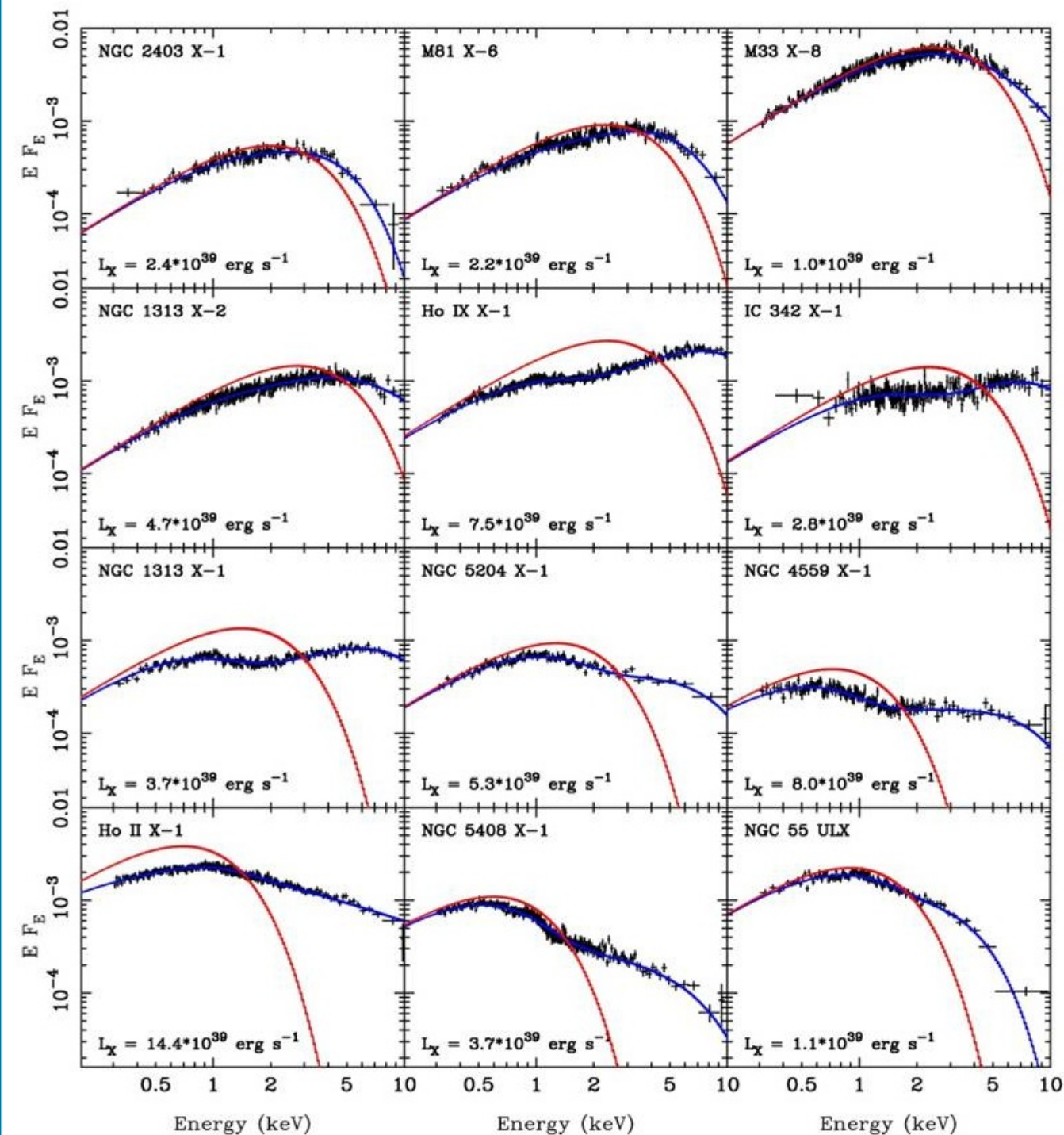
- ~10 ULXs to study
(6 this year)
- For 2012-2013, a Large
Program XMM+NuSTAR
(~400ks), + Suzaku,
Chandra





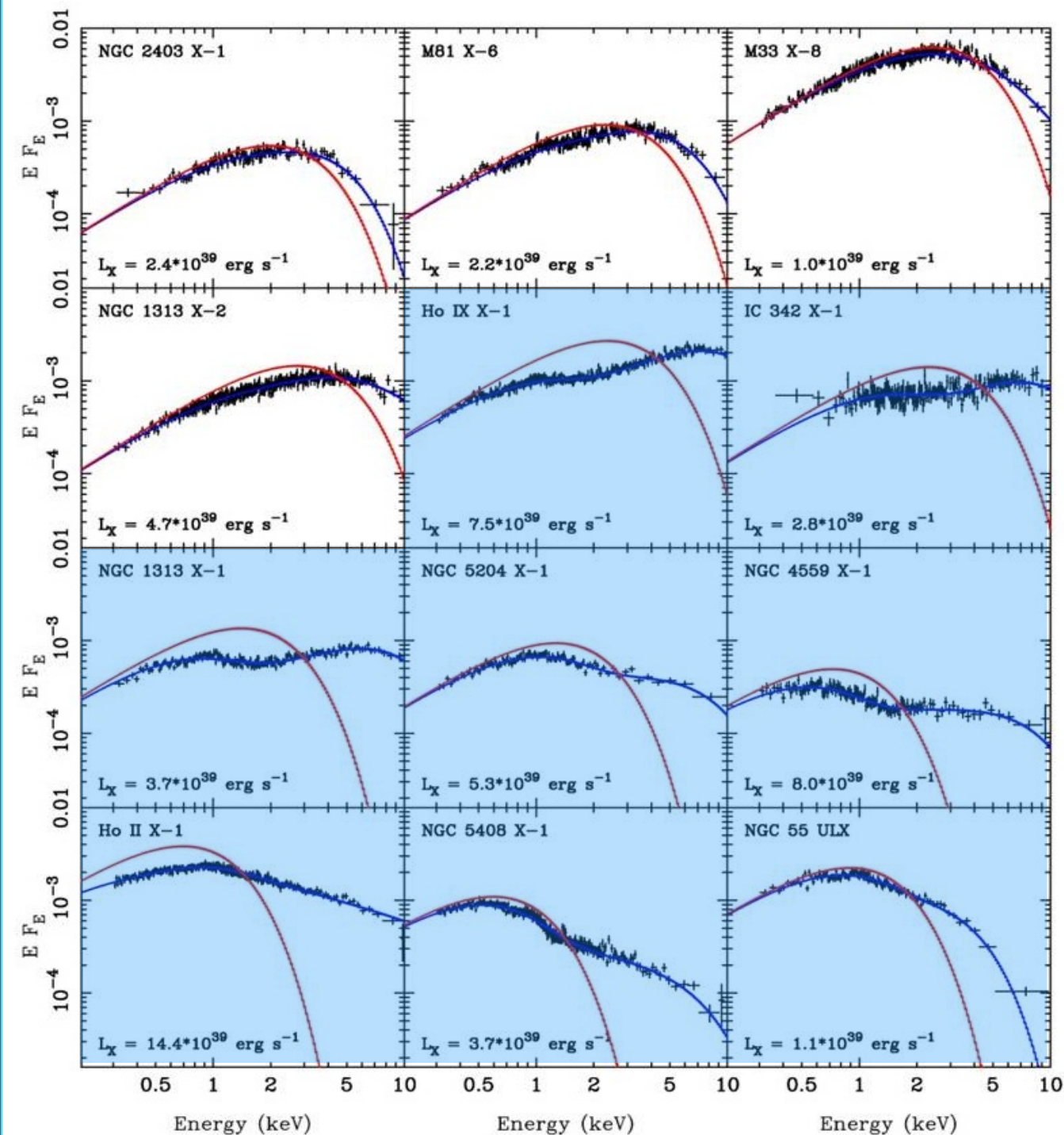
THE NUSTAR ULX PROGRAM

- Sources were selected for flux and hardness in the XMM band
- Most sources of the sample historically in the hard and soft ultraluminous states



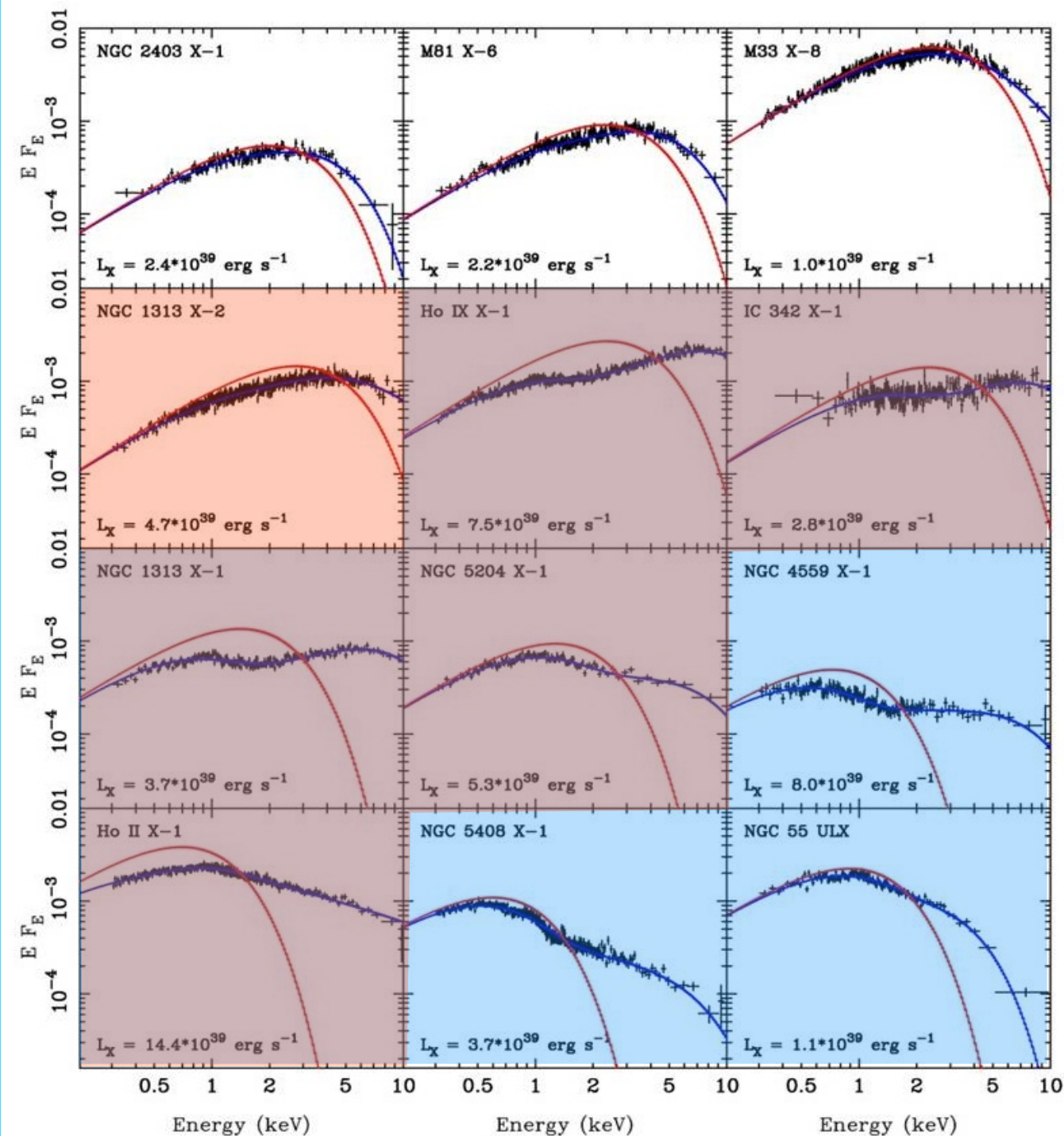
THE NUSTAR ULX PROGRAM

- Sources were selected for flux and hardness in the XMM band
- Most sources of the sample historically in the hard and soft ultraluminous states

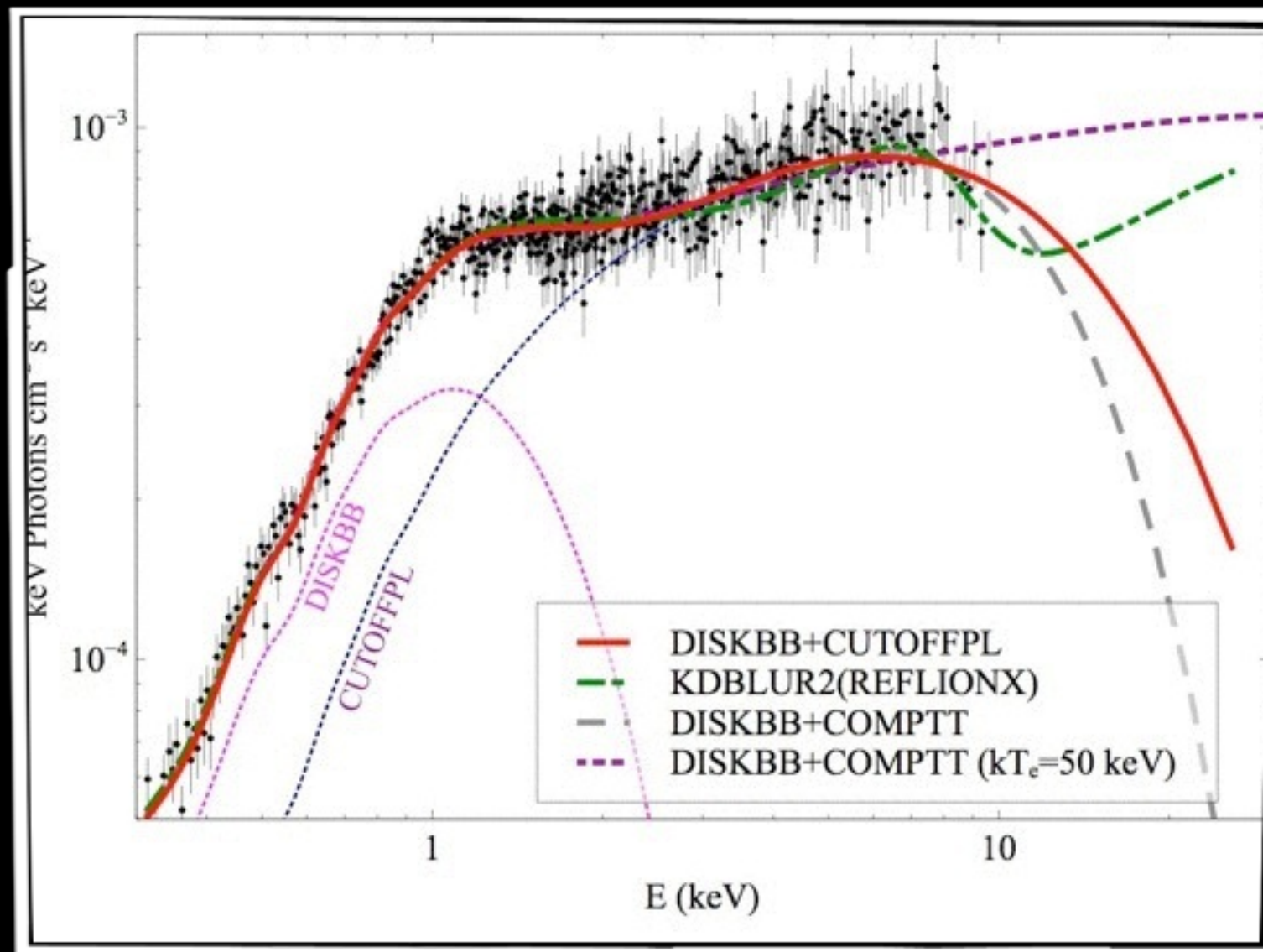


THE NUSTAR ULX PROGRAM

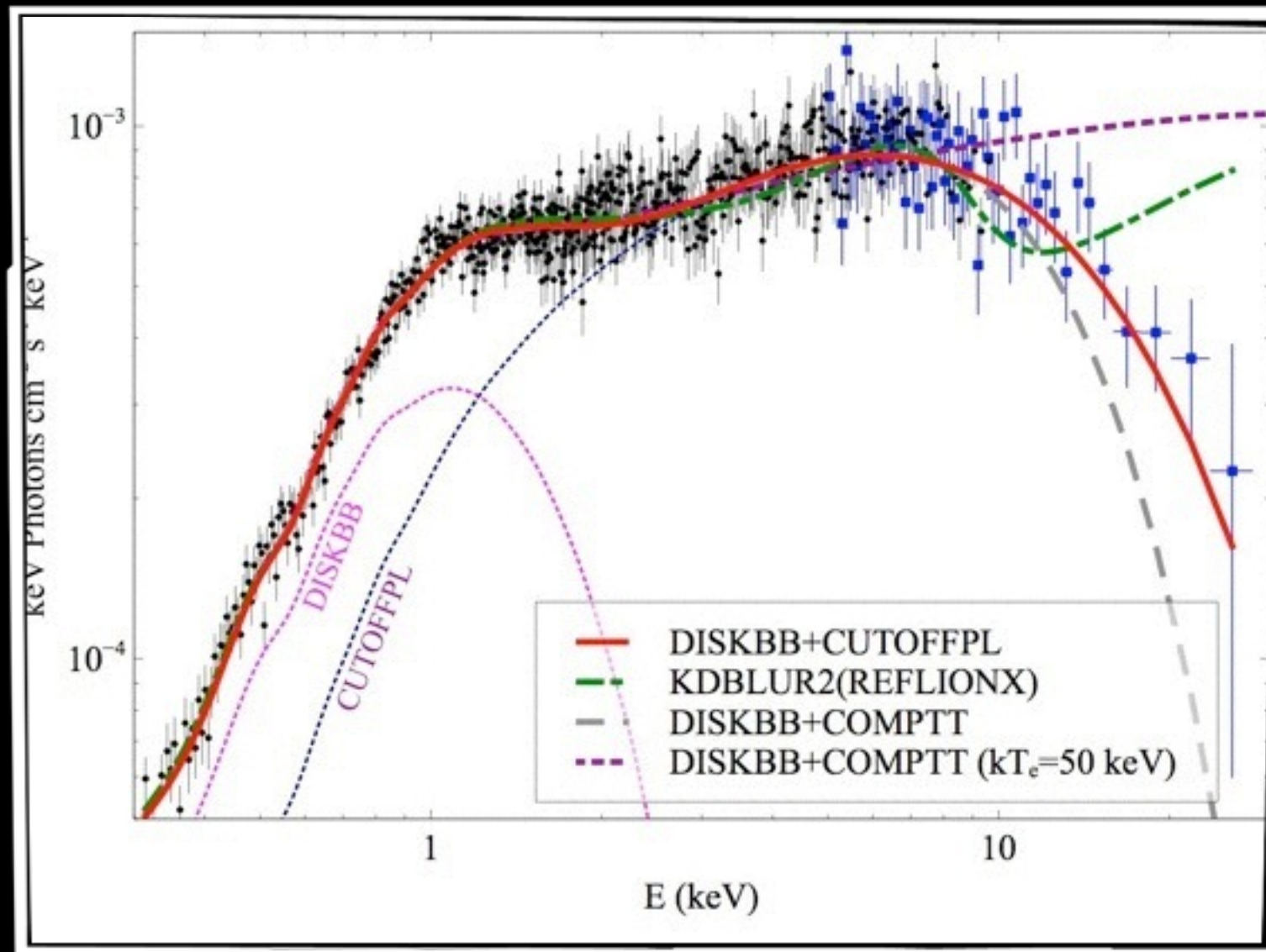
- Sources were selected for flux and hardness in the XMM band
- Most sources of the sample historically in the hard and soft ultraluminous states



NGC 1313 X-1



NGC 1313 X-1



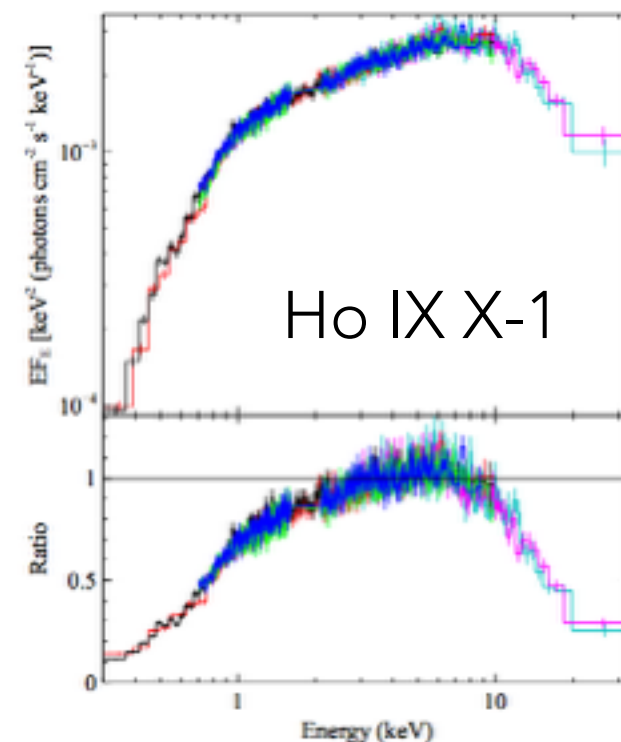
Bachetti+13, ApJ

CUTOFFS, CUTOFFS EVERYWHERE

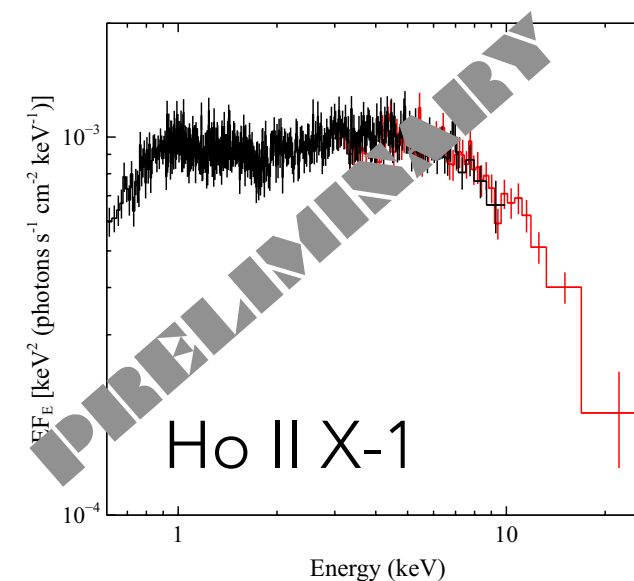
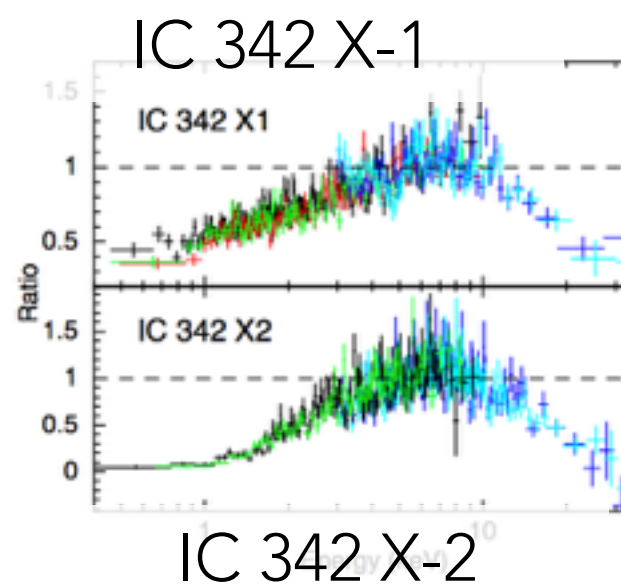
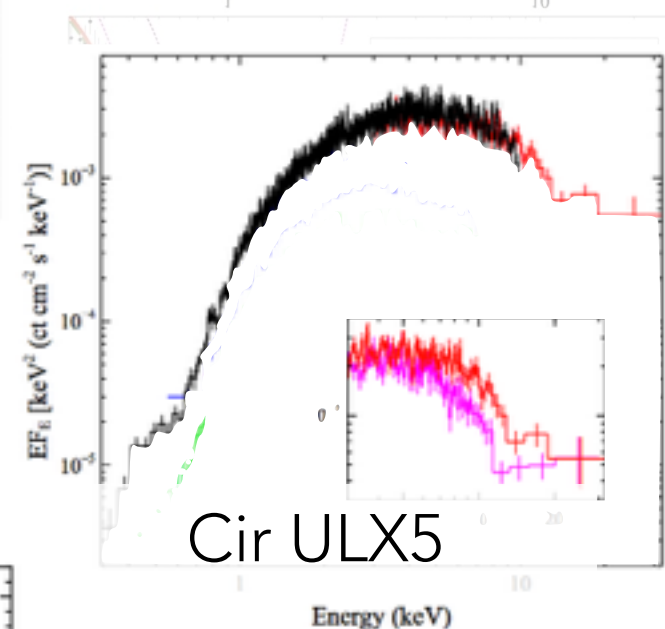
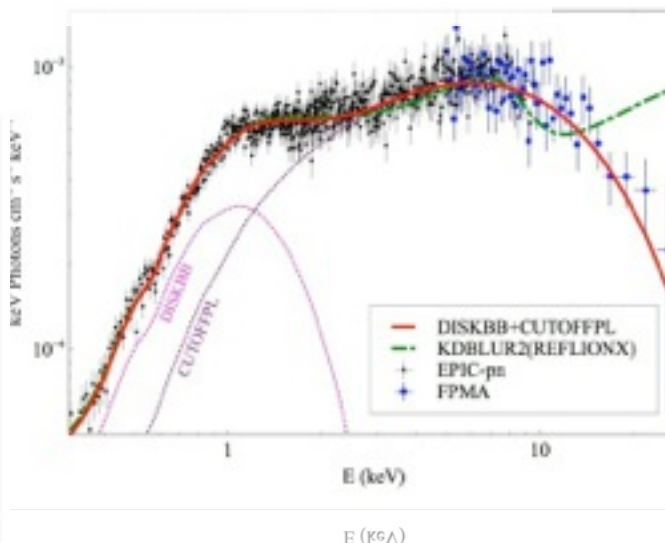
ALL sources in our sample
show a cutoff above 10 keV

CUTOFFS, CUTOFFS EVERYWHERE

ALL sources in our sample
show a cutoff above 10 keV



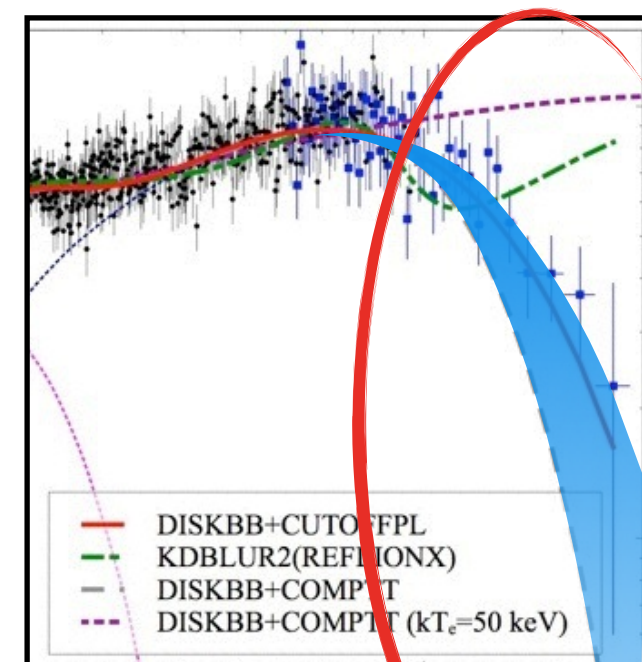
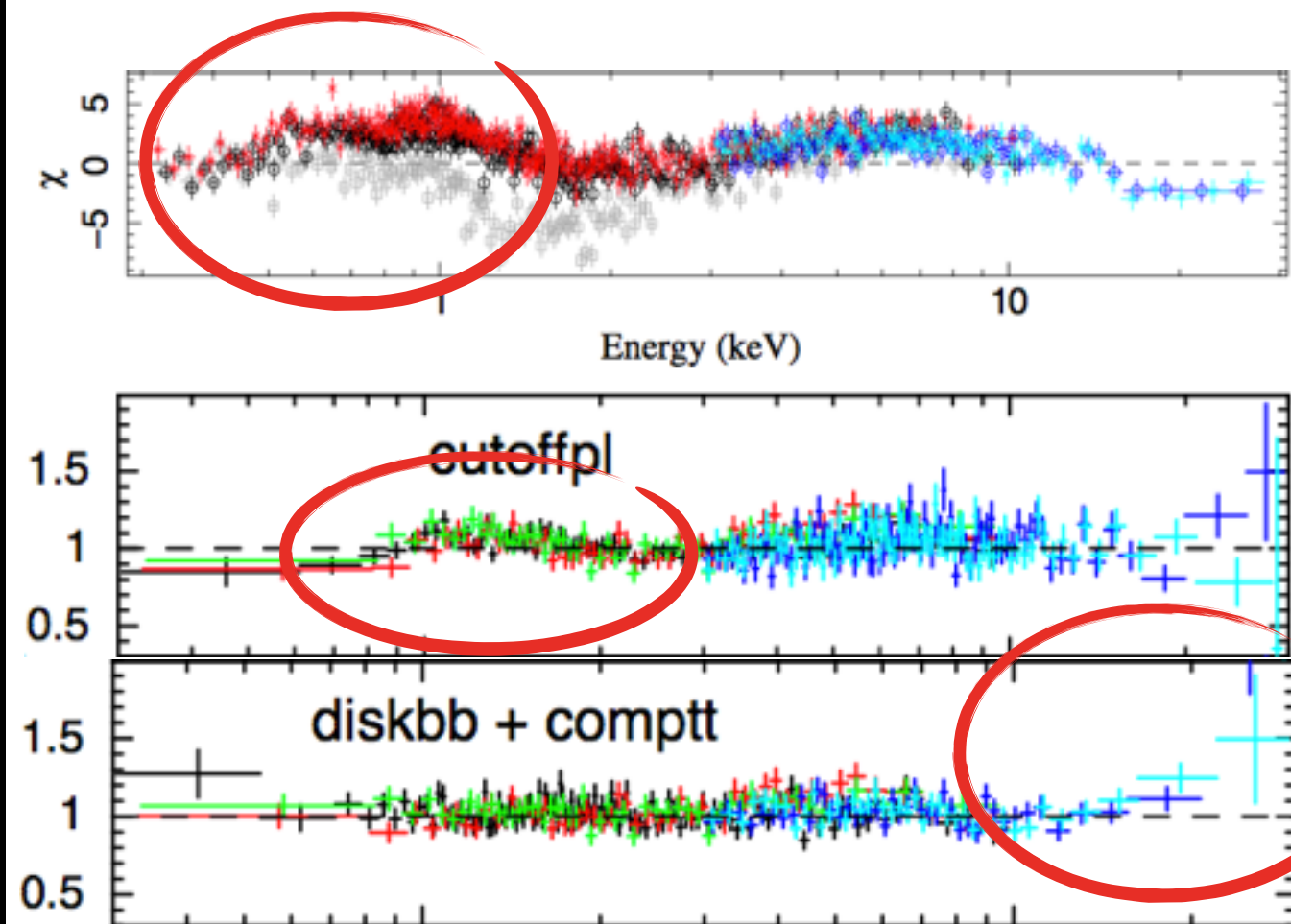
N1313 X-1



EXCESSES, EXCESSES EVERYWHERE(?)

Low energy: a disk-like component is detected in most sources below 1 keV.

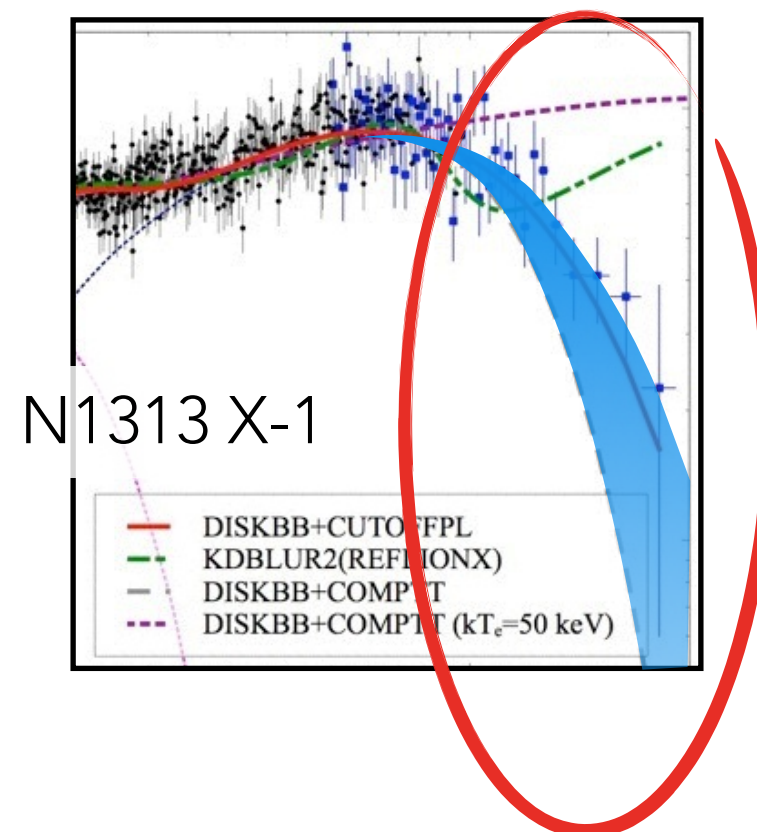
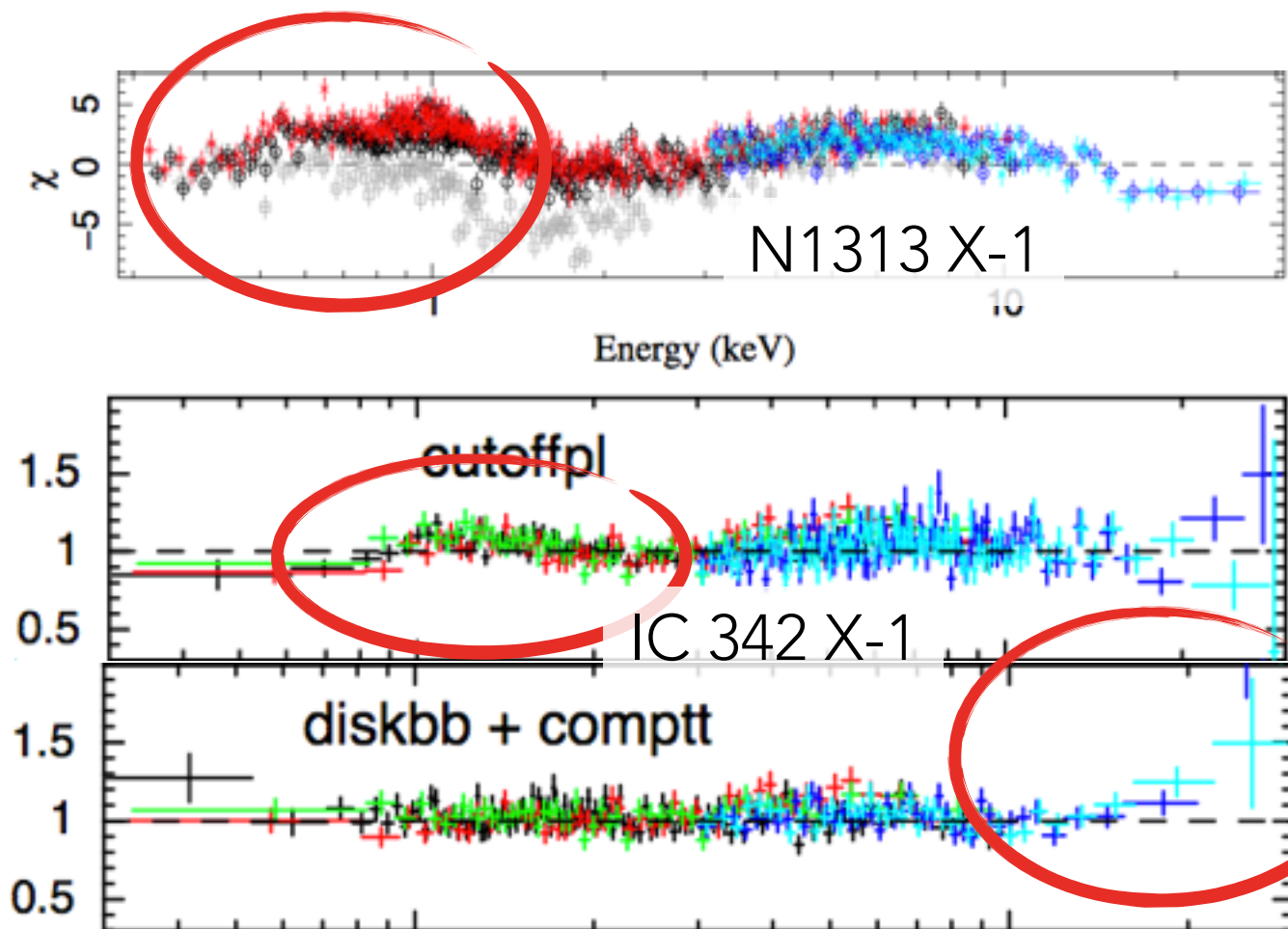
High energy: In most cases the cutoff is not correctly described by single-kT Comptonization



EXCESSES, EXCESSES EVERYWHERE(?)

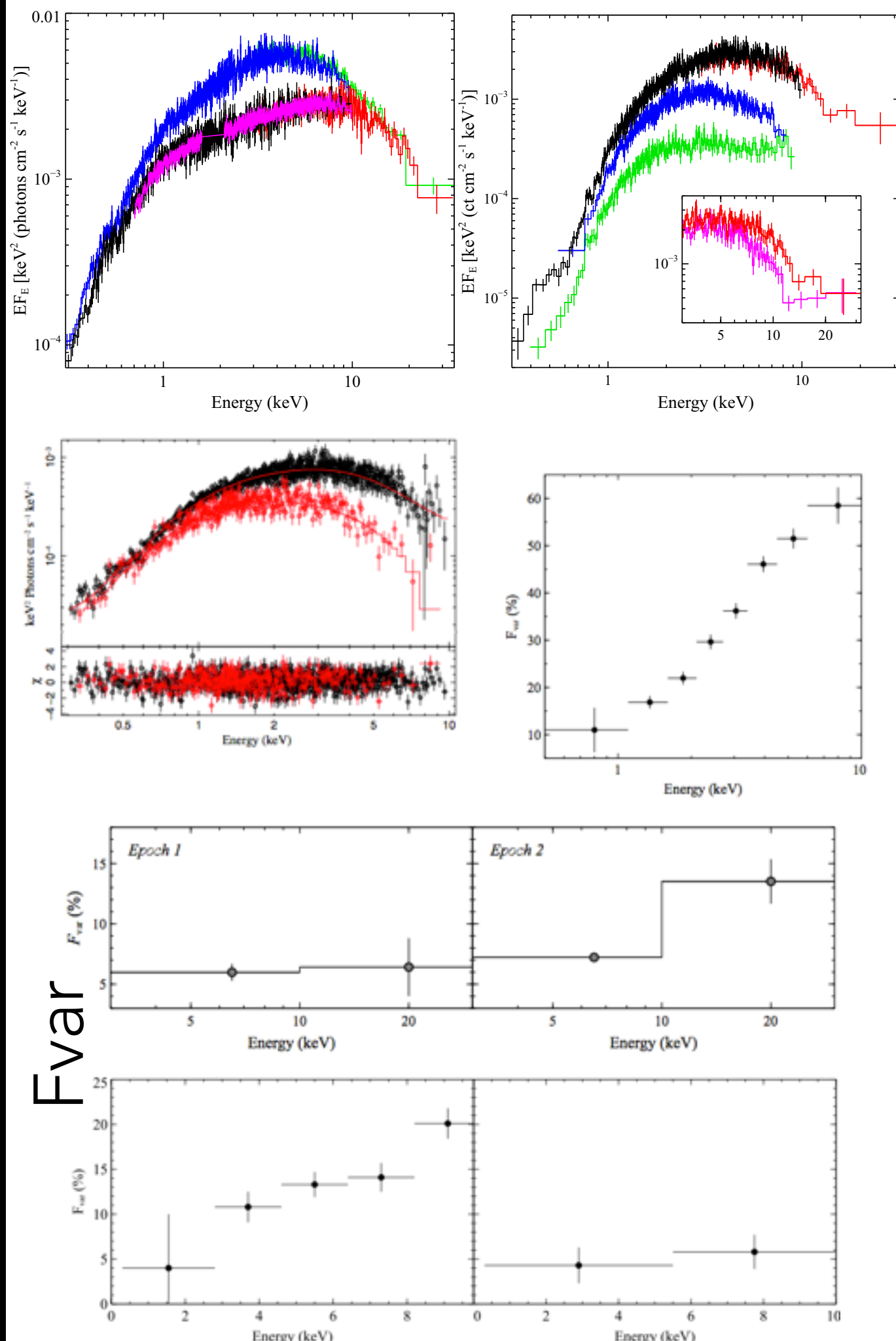
Low energy: a disk-like component is detected in most sources below 1 keV.

High energy: In most cases the cutoff is not correctly described by single-kT Comptonization



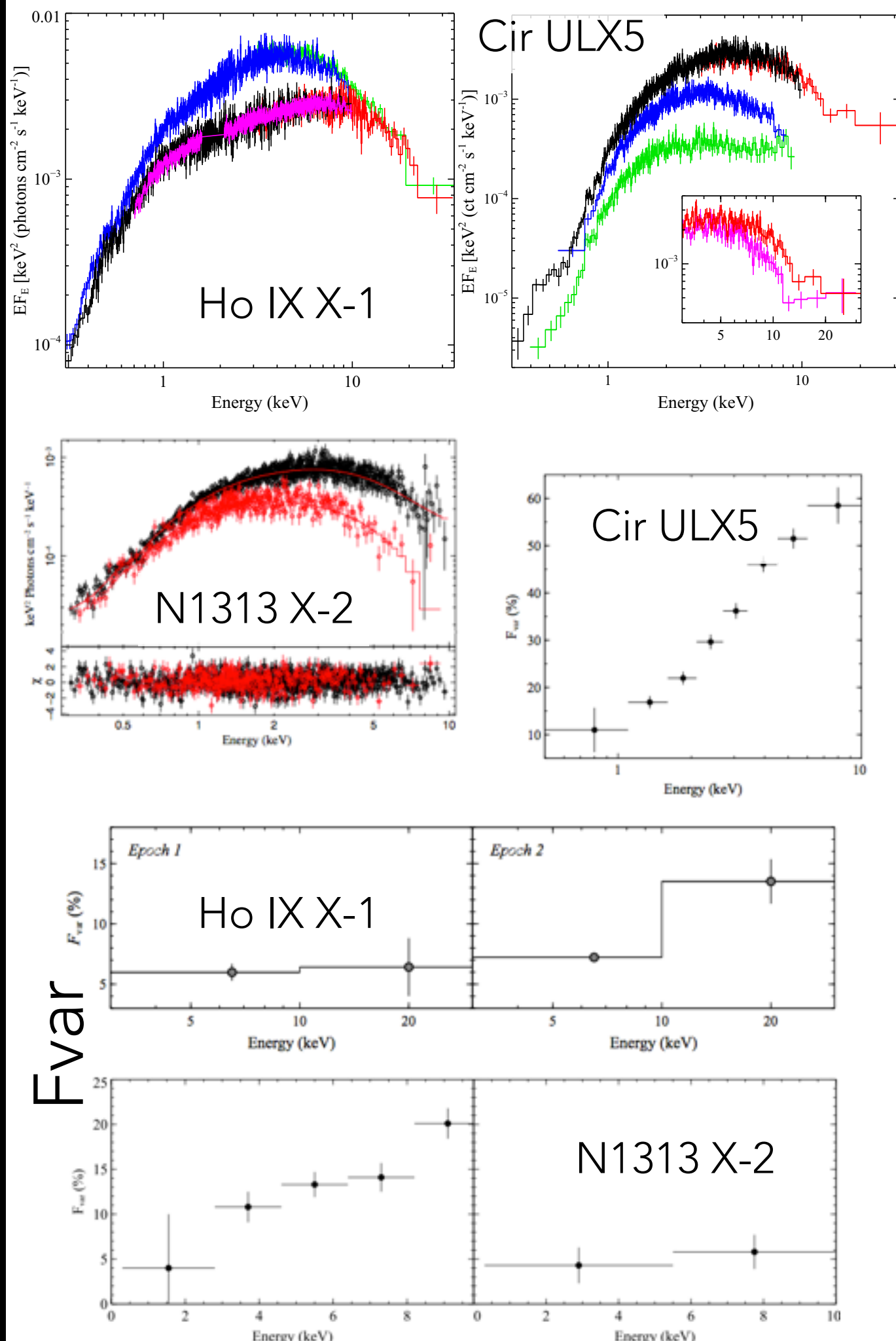
VARIABILITY, VARIABILITY EVERYWHERE(~)

- Several sources showed a fast (~weeks) evolution of spectral shapes.
- Short-term variability appears mostly in the soft intermediate and broad disk states (as previously known).



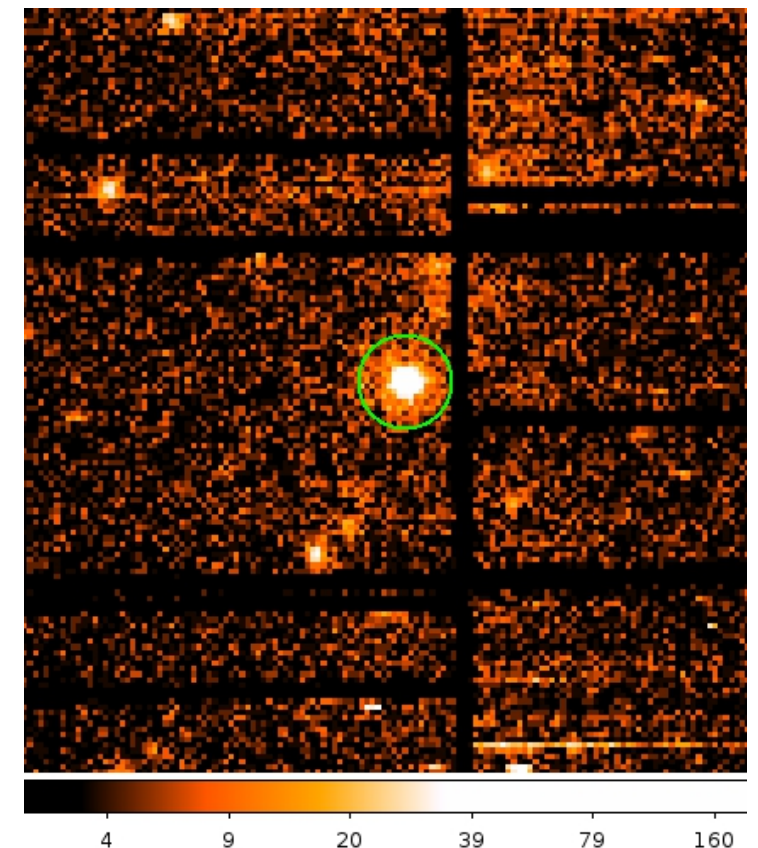
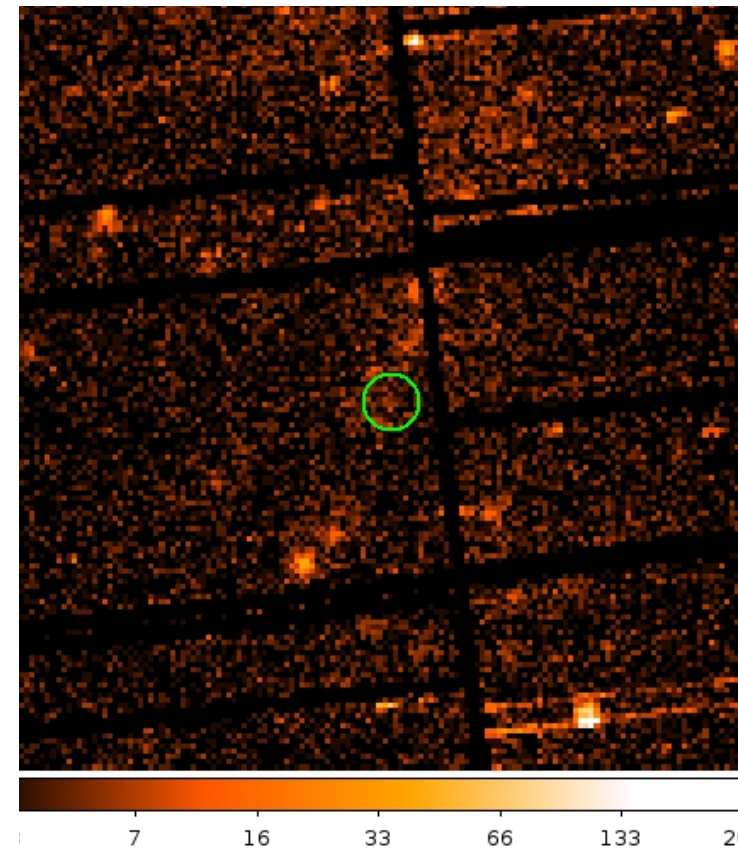
VARIABILITY, VARIABILITY EVERYWHERE(~)

- Several sources showed a fast (~weeks) evolution of spectral shapes.
- Short-term variability appears mostly in the soft intermediate and broad disk states (as previously known).



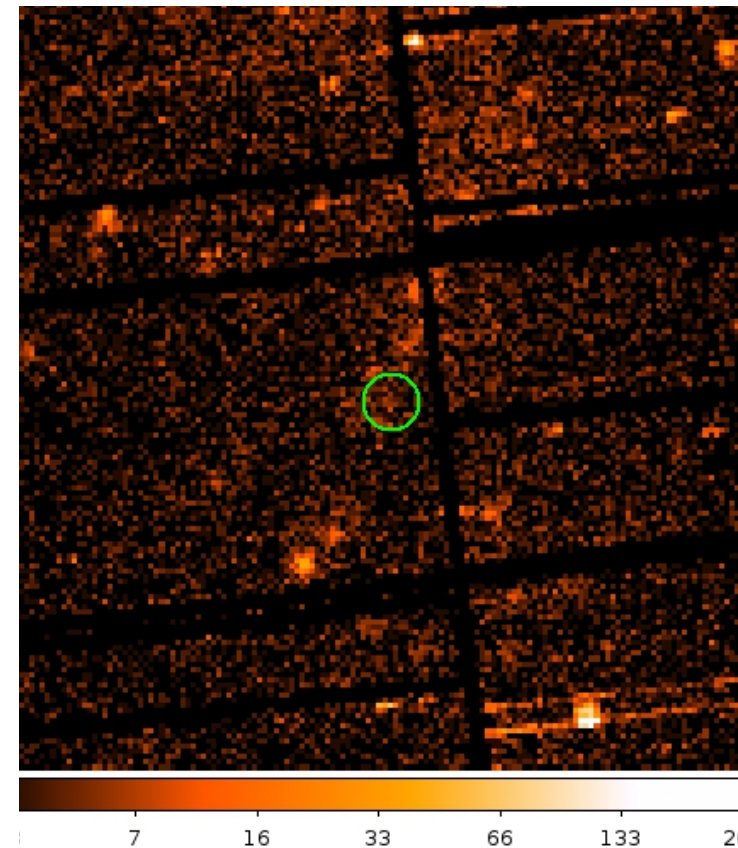
VARIABILITY, VARIABILITY EVERYWHERE(~)

- Several sources showed a fast (~weeks) evolution of spectral shapes.
- Short-term variability appears mostly in the soft intermediate and broad disk states (as previously known).

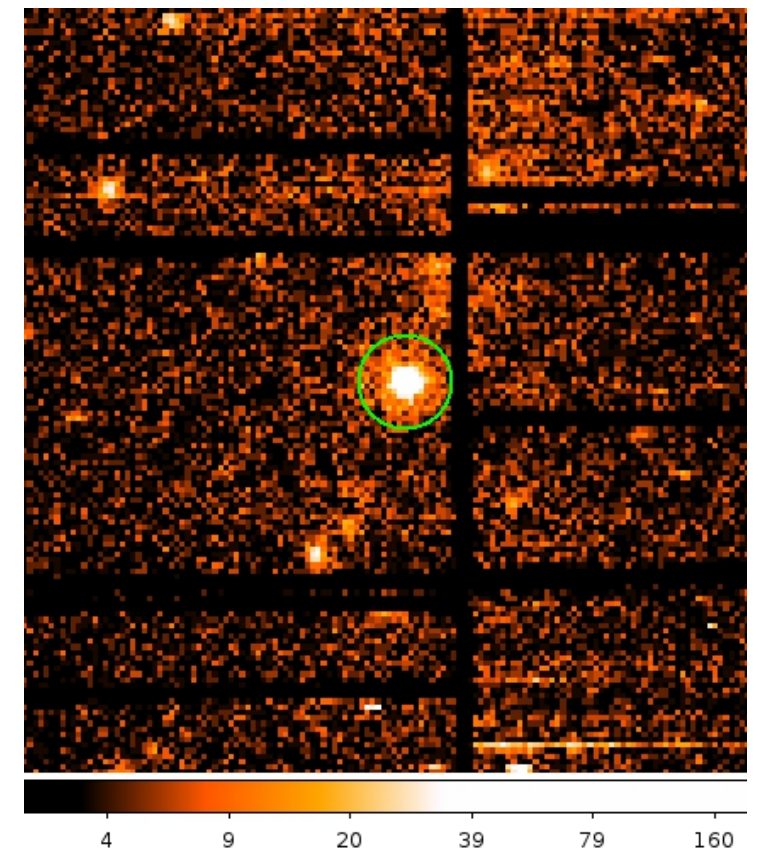


VARIABILITY, VARIABILITY EVERYWHERE(~)

- Several sources showed a fast (~weeks) evolution of spectral shapes.
- Short-term variability appears mostly in the soft intermediate and broad disk states (as previously known).



N5907 X-1



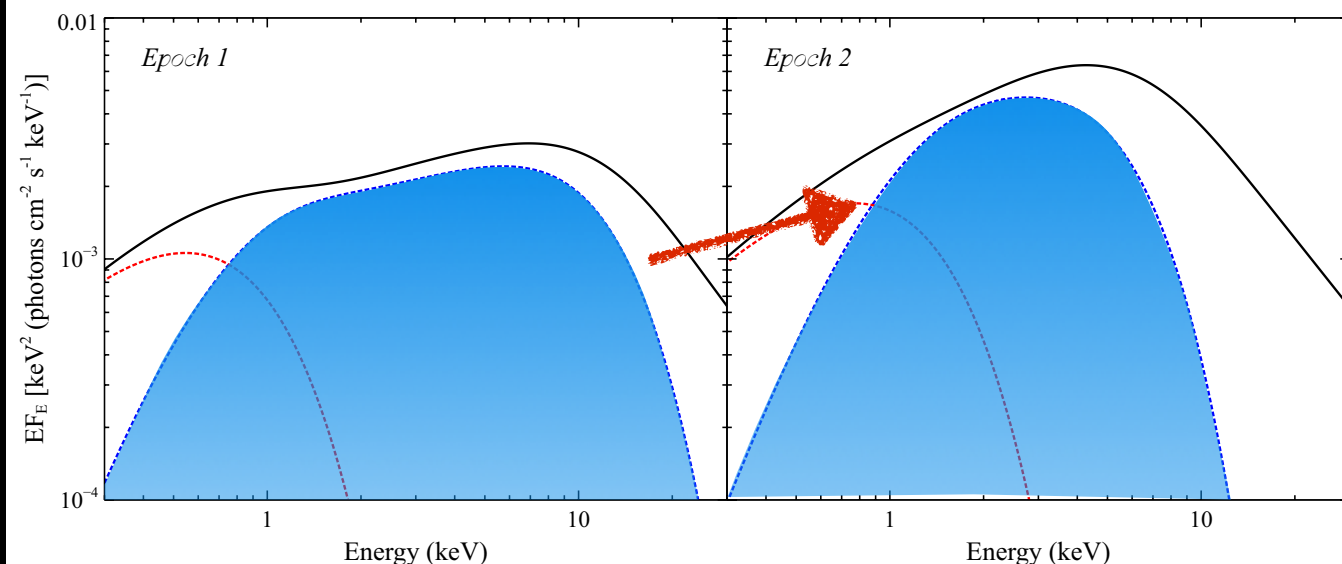
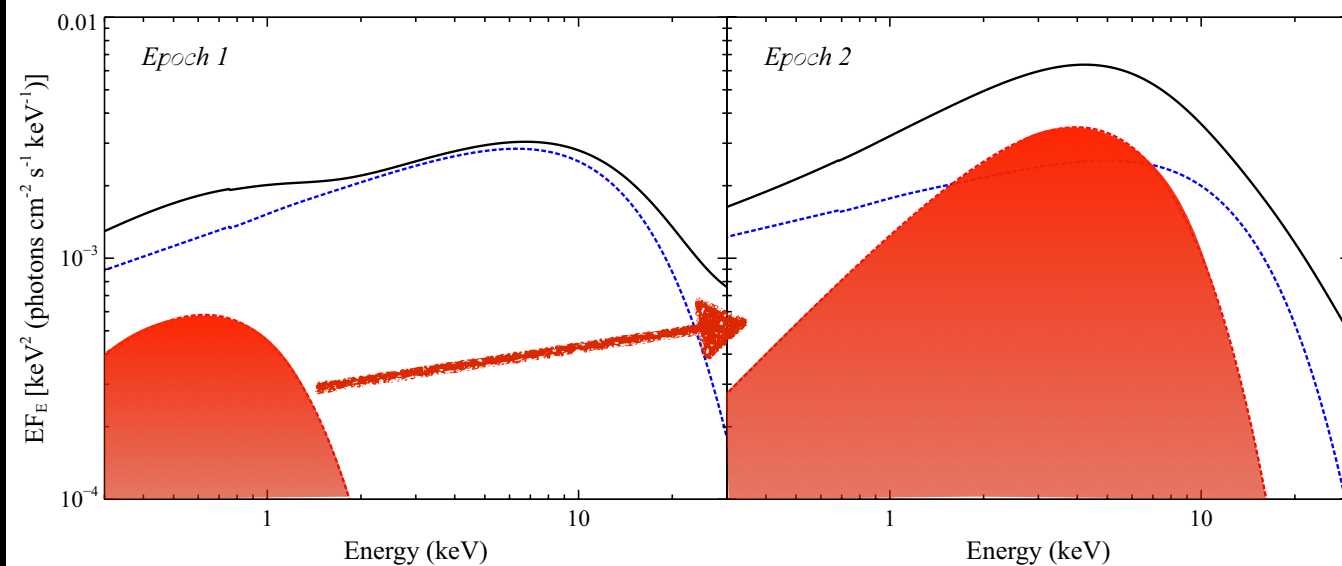
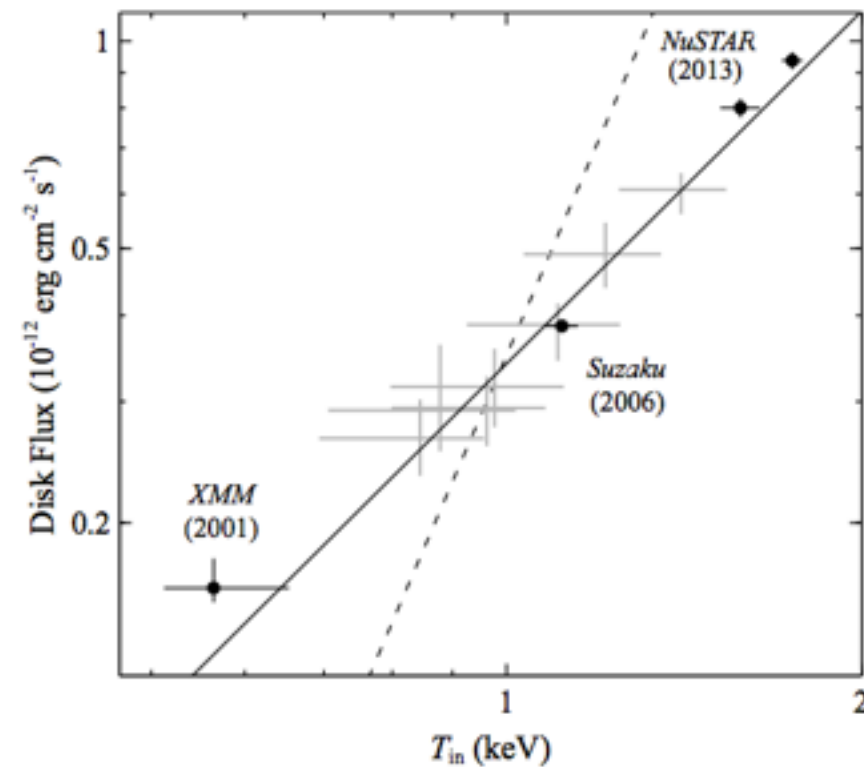
Walton+ in prep.

VARIABILITY-WHAT WE HAVE LEARNED FROM IT

- Temperature-luminosity relation deviates from SS disk in Cir ULX-5:

$$L \propto T^\alpha, \alpha \sim 1.7$$

- Spectral evolution highly non-standard

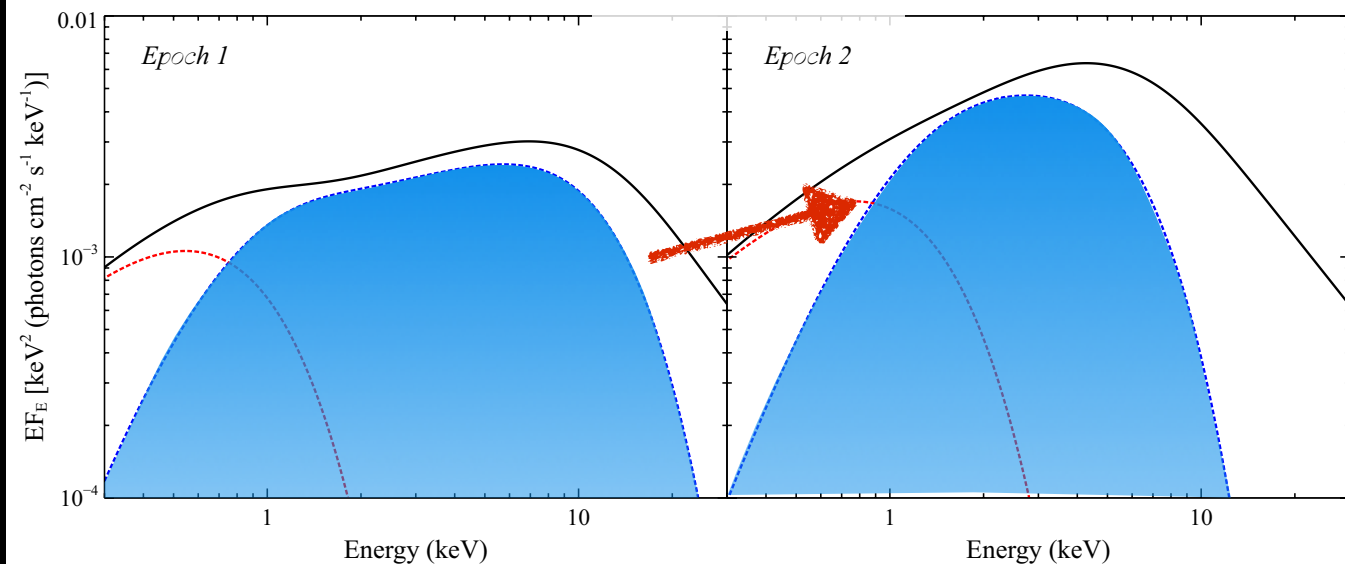
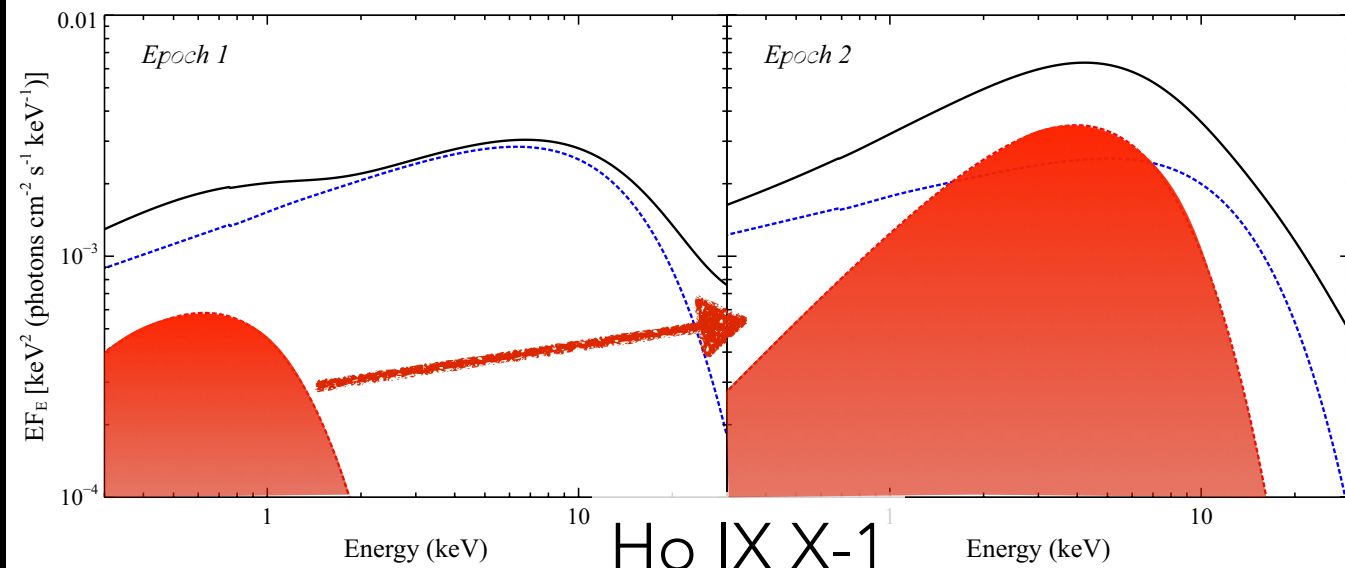
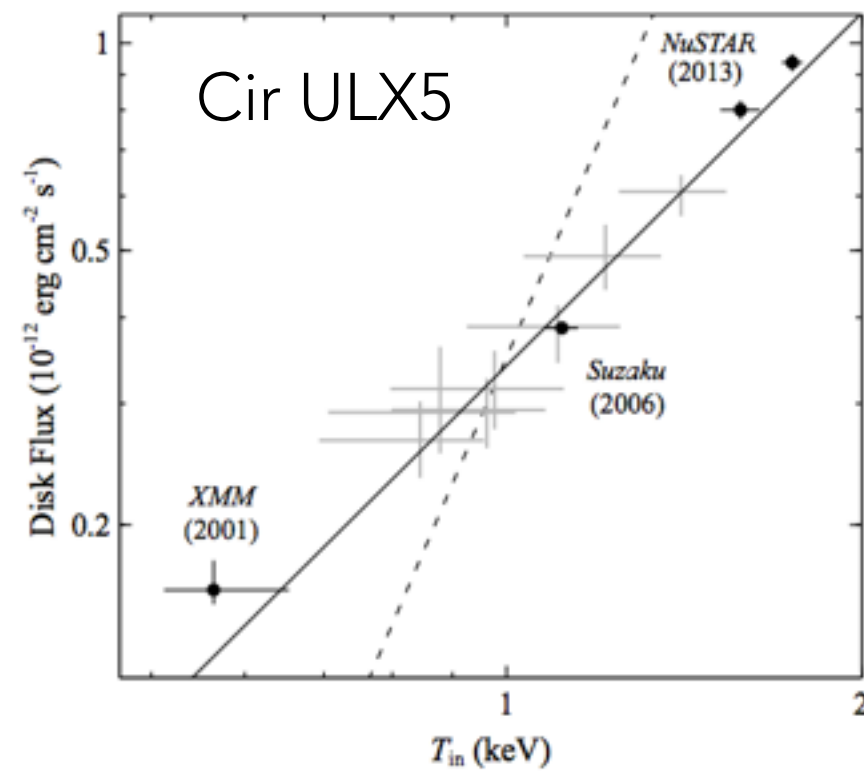


VARIABILITY-WHAT WE HAVE LEARNED FROM IT

- Temperature-luminosity relation deviates from SS disk in Cir ULX-5:

$$L \propto T^\alpha, \alpha \sim 1.7$$

- Spectral evolution highly non-standard



Walton+13, Walton+14

SUMMARY OF THE PROGRAM

SUMMARY OF THE PROGRAM

- Sample of ULXs observed:
 - **NGC 1313 X-1, X-2** (XMM, NuSTAR, Chandra) -> Bachetti+13 ApJ, Miller+14 ApJL
 - **Cir ULX-5** (XMM, NuSTAR) -> serendipitous, Walton+13, ApJ
 - **IC 342 X-1, X-2** (XMM, NuSTAR) -> Rana+14, sub.
 - **Holmberg IX X-1** (or M81 X-9) (XMM, NuSTAR, Suzaku) -> Walton+14, acc.
 - **NGC 5204 X-1** (XMM, NuSTAR, Chandra) -> Mukherjee+ in prep.
 - **NGC 5907 X-1** (XMM, NuSTAR, Suzaku) -> Walton+ in prep.
 - **Holmberg II X-1**

SUMMARY OF THE PROGRAM

- Sample of ULXs observed:
 - **NGC 1313 X-1, X-2** (XMM, NuSTAR, Chandra) -> Bachetti+13 ApJ, Miller+14 ApJL
 - **Cir ULX-5** (XMM, NuSTAR) -> serendipitous, Walton+13, ApJ
 - **IC 342 X-1, X-2** (XMM, NuSTAR) -> Rana+14, sub.
 - **Holmberg IX X-1** (or M81 X-9) (XMM, NuSTAR, Suzaku) -> Walton+14, acc.
 - **NGC 5204 X-1** (XMM, NuSTAR, Chandra) -> Mukherjee+ in prep.
 - **NGC 5907 X-1** (XMM, NuSTAR, Suzaku) -> Walton+ in prep.
 - **Holmberg II X-1**
- (+ HLX-1, M82 X-1, M51, ...)

SUMMARY OF THE PROGRAM

- Sample of ULXs observed:
 - **NGC 1313 X-1, X-2** (XMM, NuSTAR, Chandra) -> Bachetti+13 ApJ, Miller+14 ApJL
 - **Cir ULX-5** (XMM, NuSTAR) -> serendipitous, Walton+13, ApJ
 - **IC 342 X-1, X-2** (XMM, NuSTAR) -> Rana+14, sub.
 - **Holmberg IX X-1** (or M81 X-9) (XMM, NuSTAR, Suzaku) -> Walton+14, acc.
 - **NGC 5204 X-1** (XMM, NuSTAR, Chandra) -> Mukherjee+ in prep.
 - **NGC 5907 X-1** (XMM, NuSTAR, Suzaku) -> Walton+ in prep.
 - **Holmberg II X-1**
- (+ HLX-1, M82 X-1, M51, ...)
- Data analysis ongoing

CONCLUSIONS

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.
- Observed ULXs show common features (low-T cutoff, low-T disk or p disk-like spectra)

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.
- Observed ULXs show common features (low-T cutoff, low-T disk or p disk-like spectra)
- No clear emission lines

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.
- Observed ULXs show common features (low-T cutoff, low-T disk or p disk-like spectra)
- No clear emission lines
- The hard state-like model is ruled out in all of them, as is the reflection-dominated regime in its simplest form. Spectrum more similar to “non-standard” very luminous BHs.

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.
- Observed ULXs show common features (low-T cutoff, low-T disk or p disk-like spectra)
- No clear emission lines
- The hard state-like model is ruled out in all of them, as is the reflection-dominated regime in its simplest form. Spectrum more similar to “non-standard” very luminous BHs.
- An excess from single-component Comptonization?

CONCLUSIONS

- Thanks to NuSTAR, degeneracy of spectral models reduced drastically.
- Observed ULXs show common features (low-T cutoff, low-T disk or p disk-like spectra)
- No clear emission lines
- The hard state-like model is ruled out in all of them, as is the reflection-dominated regime in its simplest form. Spectrum more similar to “non-standard” very luminous BHs.
- An excess from single-component Comptonization?
- -> No standard BH state. Favored interpretation **quasi- or super-Eddington** accretion in massive StMBHs

FUTURE PLANS

FUTURE PLANS

- Accepted (Swift+)*XMM*+*NuSTAR* program to sample more spectral states in NGC 1313 X-[12]

FUTURE PLANS

- Accepted (Swift+)XMM+NuSTAR program to sample more spectral states in NGC 1313 X-[12]
- New observations of NGC 5907 X-1 and other sources already planned



That's all Folks!

