A NICE/NU/CHANDRA VIEW OF WINDS IN GRS 1915+105

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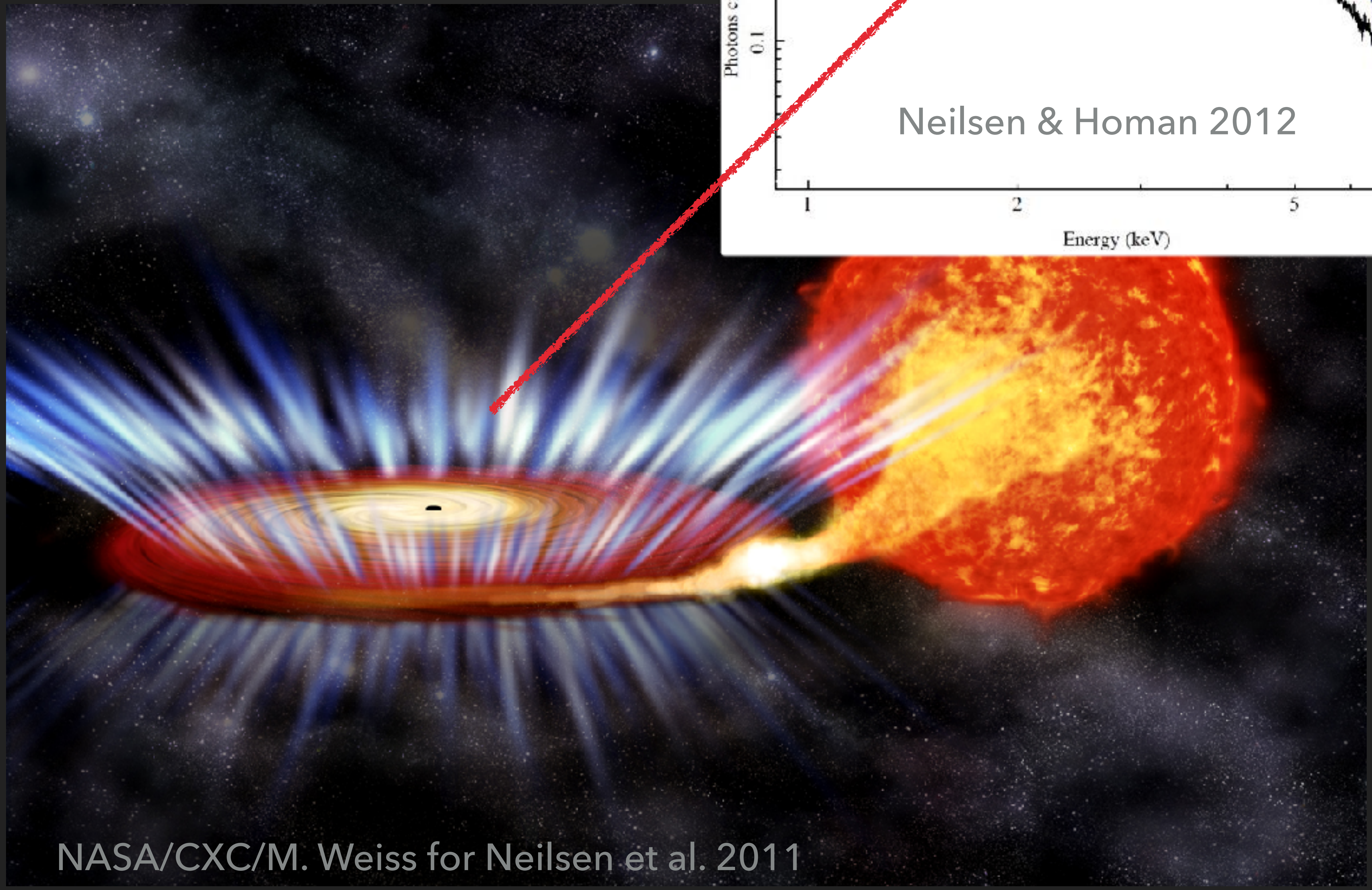
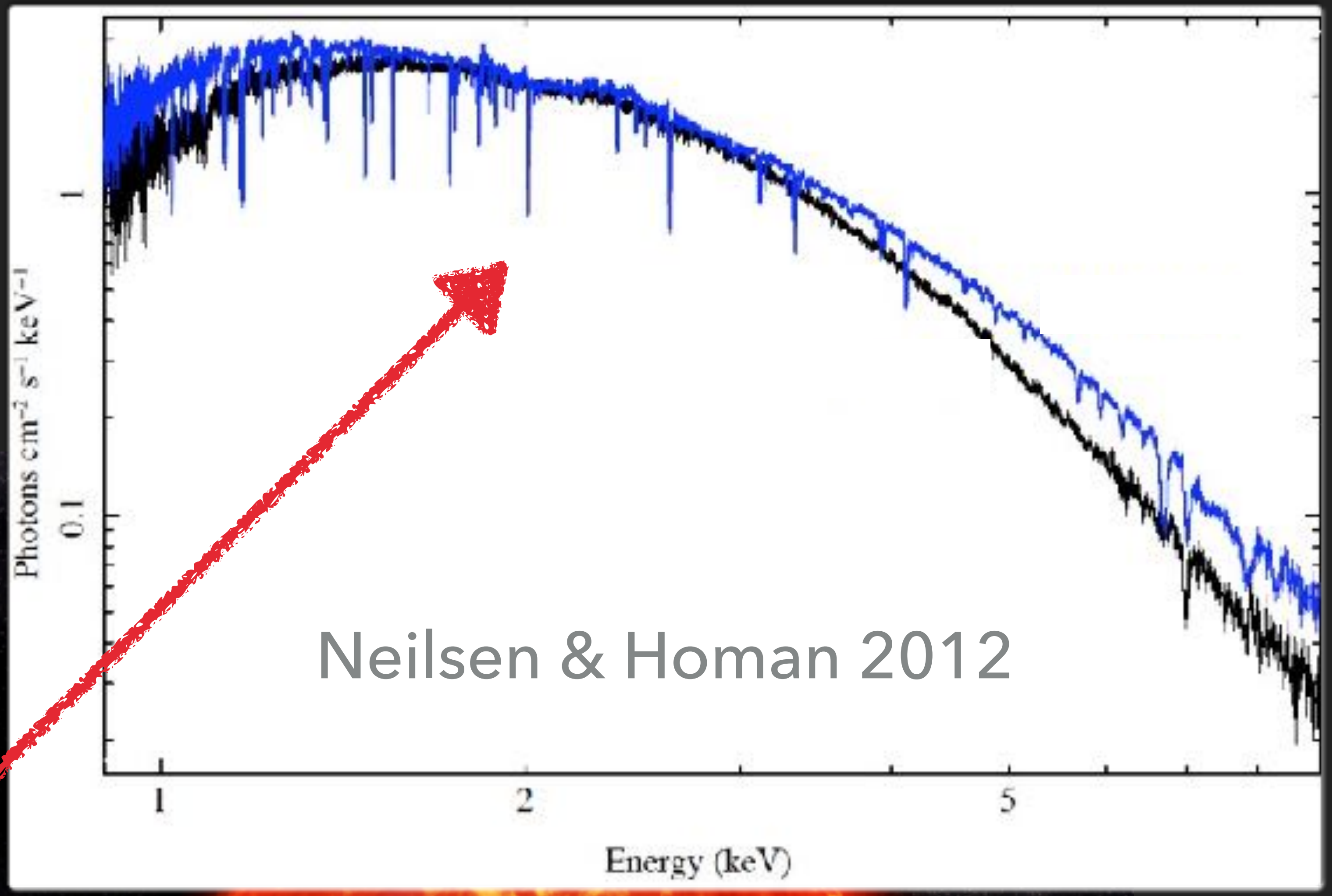
NEILSEN ET AL. 2018, APJ, 860, L19; ARUMBURU SANCHEZ & NEILSEN, IN PREP

DISK WINDS IN X-RAYS

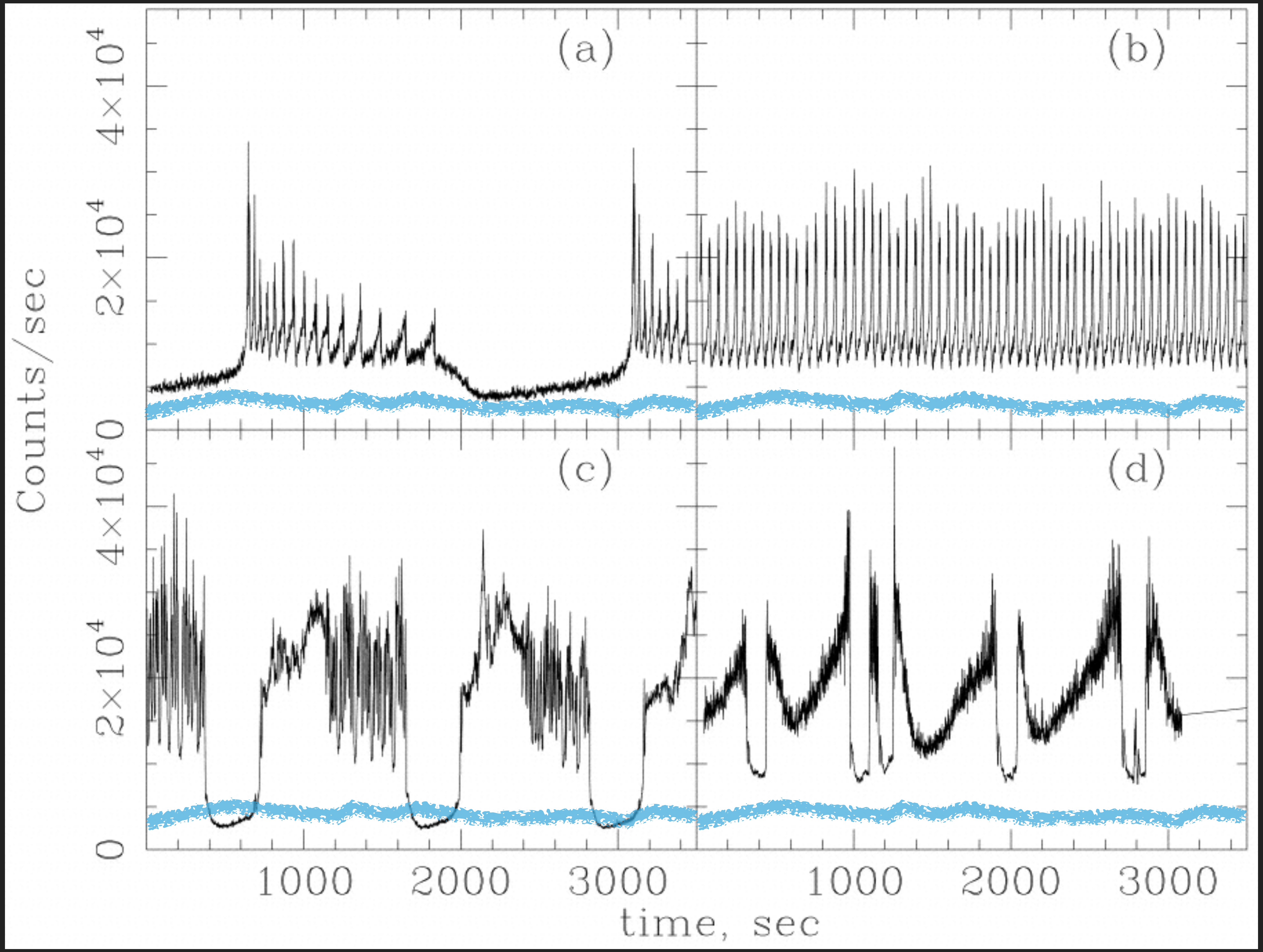
- Outflows of ionized gas; backlit by accretion disk, so visible as X-ray absorption
- Encode detailed atomic, dynamic information about BH environment
- Can carry vast majority (95%) of infalling matter AWAY from BH (Neilsen et al. 2011; Lee et al. 2002; Neilsen 2013; Neilsen et al. 2016)
- Critical to understand winds if we want to understand BH accretion





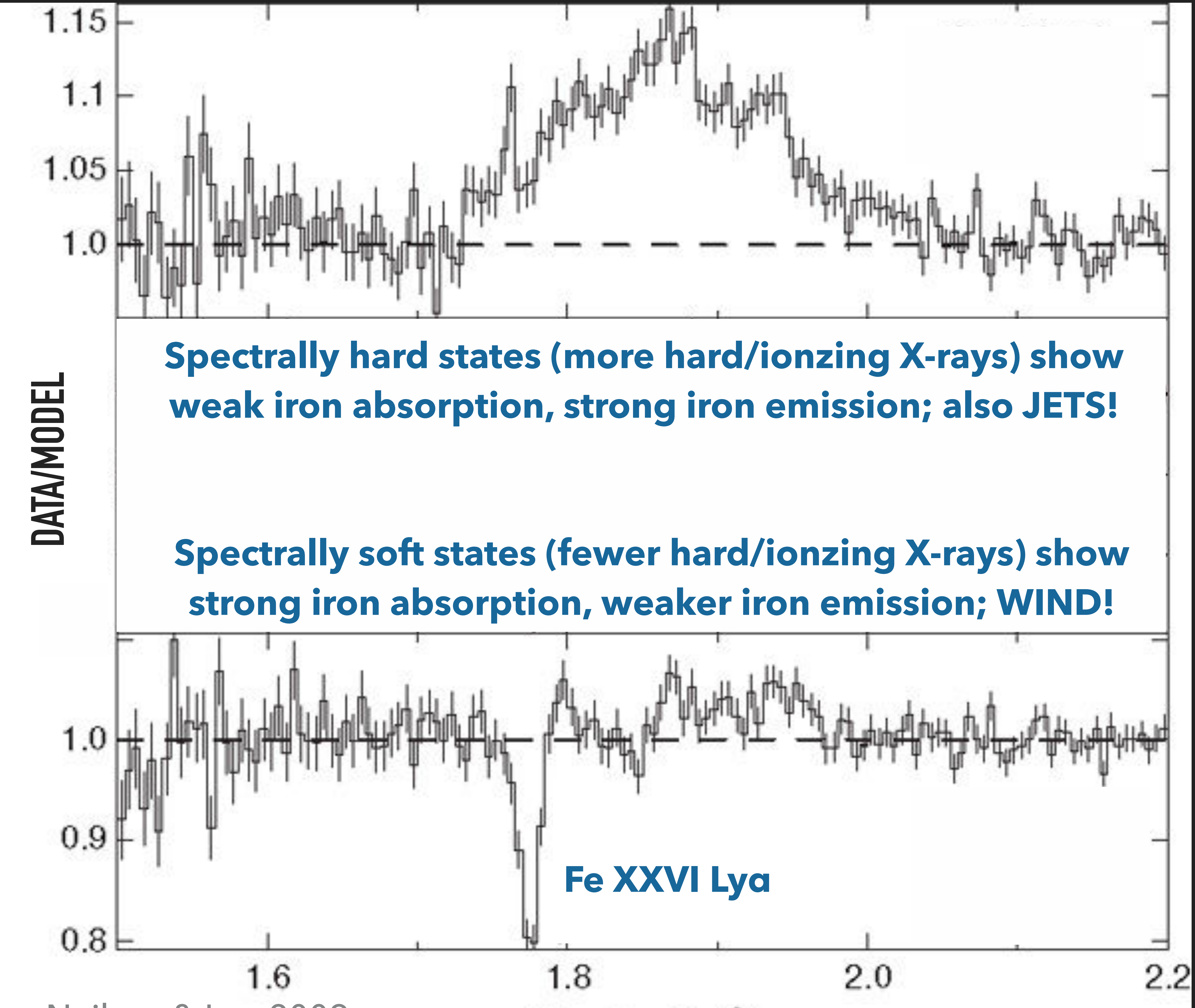
GRS 1915+105

- 12.4 $M_{\odot}$ rapidly spinning black hole (McClintock et al. 2006)
- Well-known source of disk winds (Lee et al. 2002; Miller et al. 2008; Neilsen & Lee 2009; Ueda et al. 2009)
- Famous relativistic jet ejections (Mirabel et al. 1994; Fender et al. 1999)
- Perhaps best known for its bizarre X-ray lightcurves (Greiner+ 1996; Belloni+ 00)
    - 14 classes ("states") of high-amplitude, structured variability, spectral changes



BLACK SHEEP OR ROSETTA STONE?

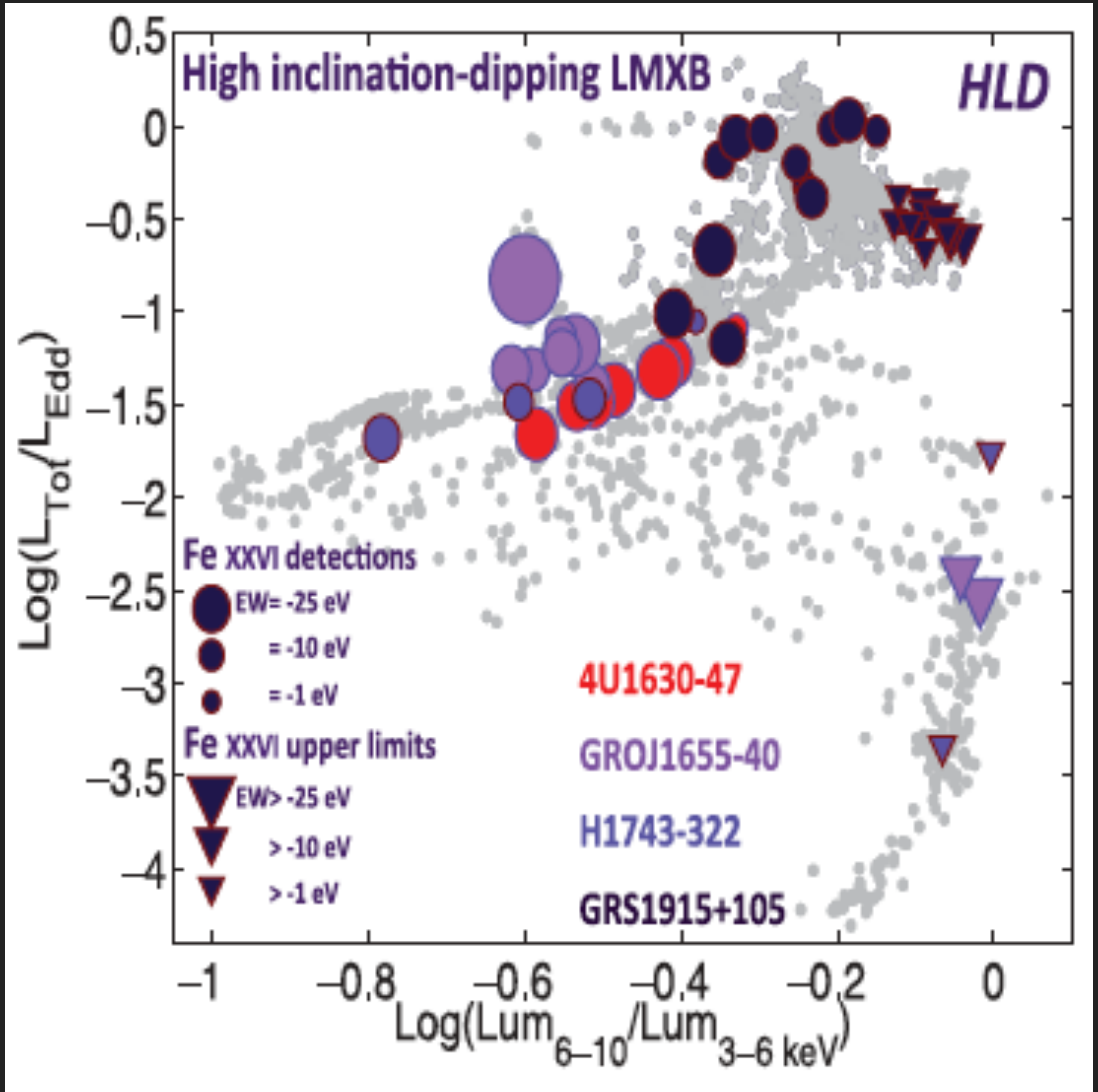
- Hint: Rosetta Stone!
- Extreme behavior is an opportunity to study the broad range of black hole behavior**
- GRS 1915 has history of driving advances in our understanding of accretion and ejection physics (Fender & Belloni 2004)
- Consider: State-dependent wind absorption (Miller et al. 2008, Neilsen & Lee 2009)



Neilsen & Lee 2009

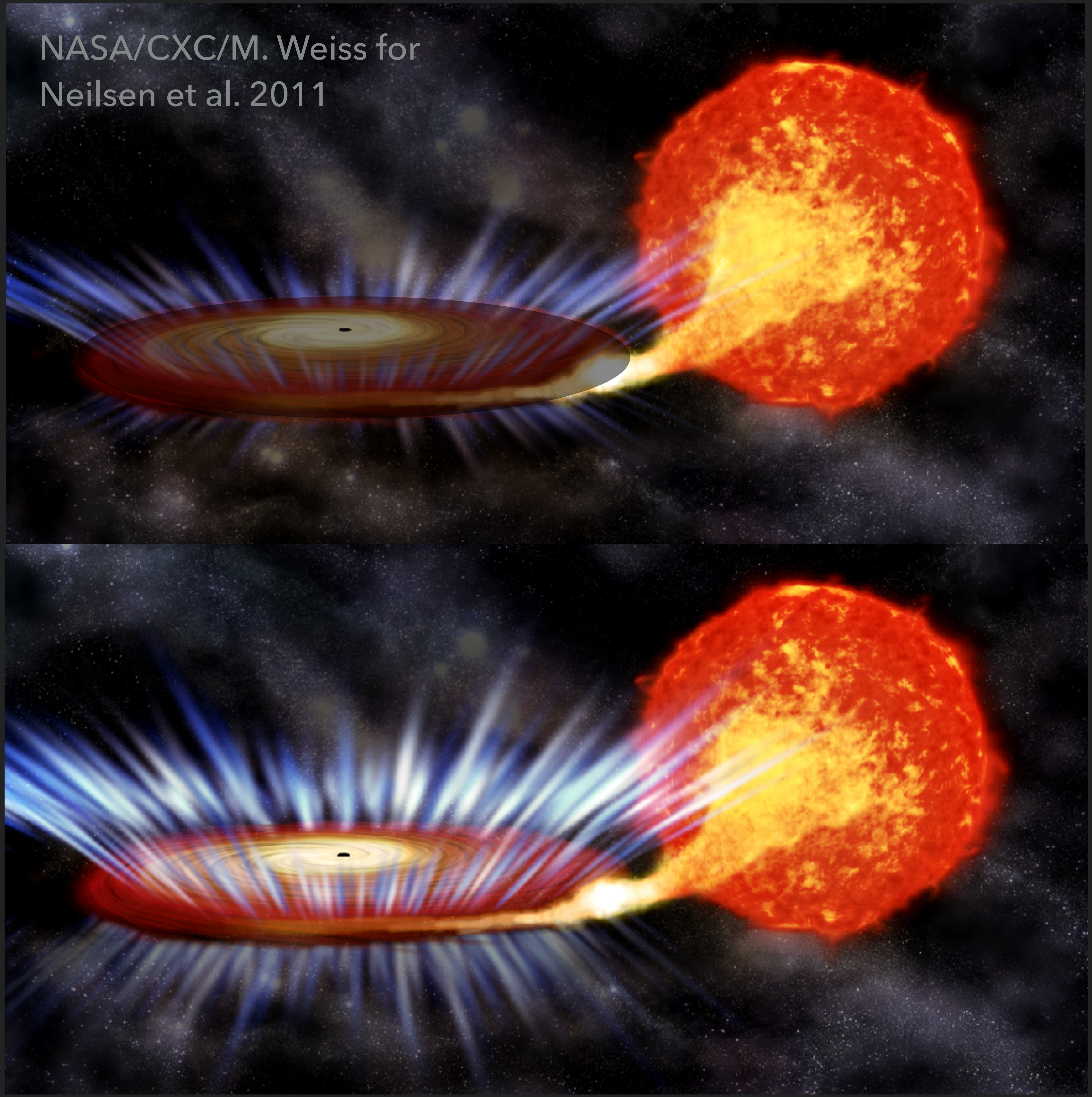
BLACK SHEEP OR ROSETTA STONE?

- State-dependent winds in GRS 1915+105 (Neilsen & Lee 2009) prompted global studies of disk winds
- As stellar mass black holes evolve in outburst ("q diagram"), show a similar trend to GRS 1915+105:
  - Winds preferentially detected during softer states, jets in harder states (Ponti et al. 2012; Homan, Neilsen et al. 2016)

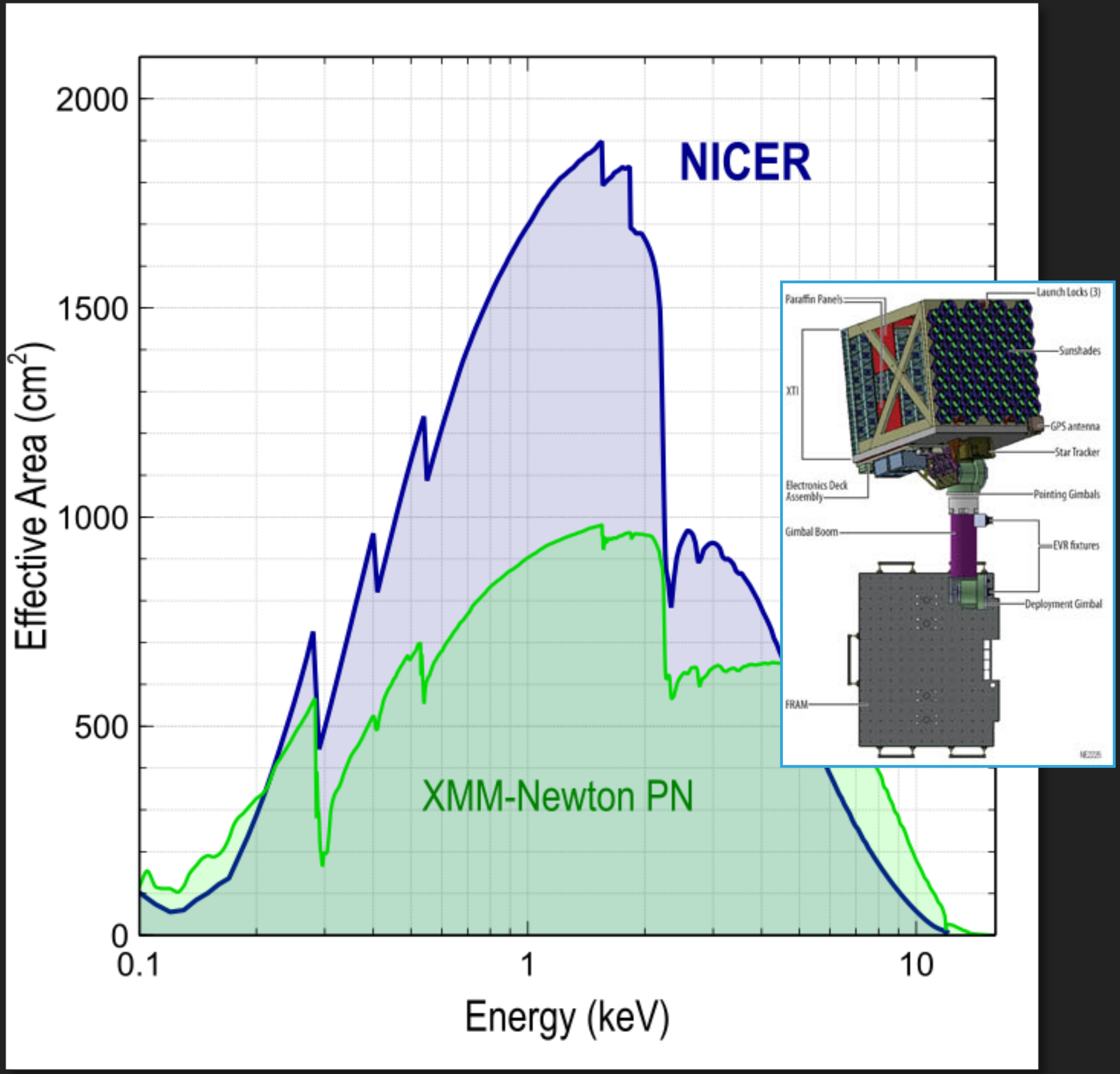


WHAT DON'T WE KNOW (YET)?

- How exactly do winds vary from state to state and across states?
- How do winds depend on physics @ the event horizon?
- Datasets capable of detecting and studying winds are relatively few, need more comprehensive statistics

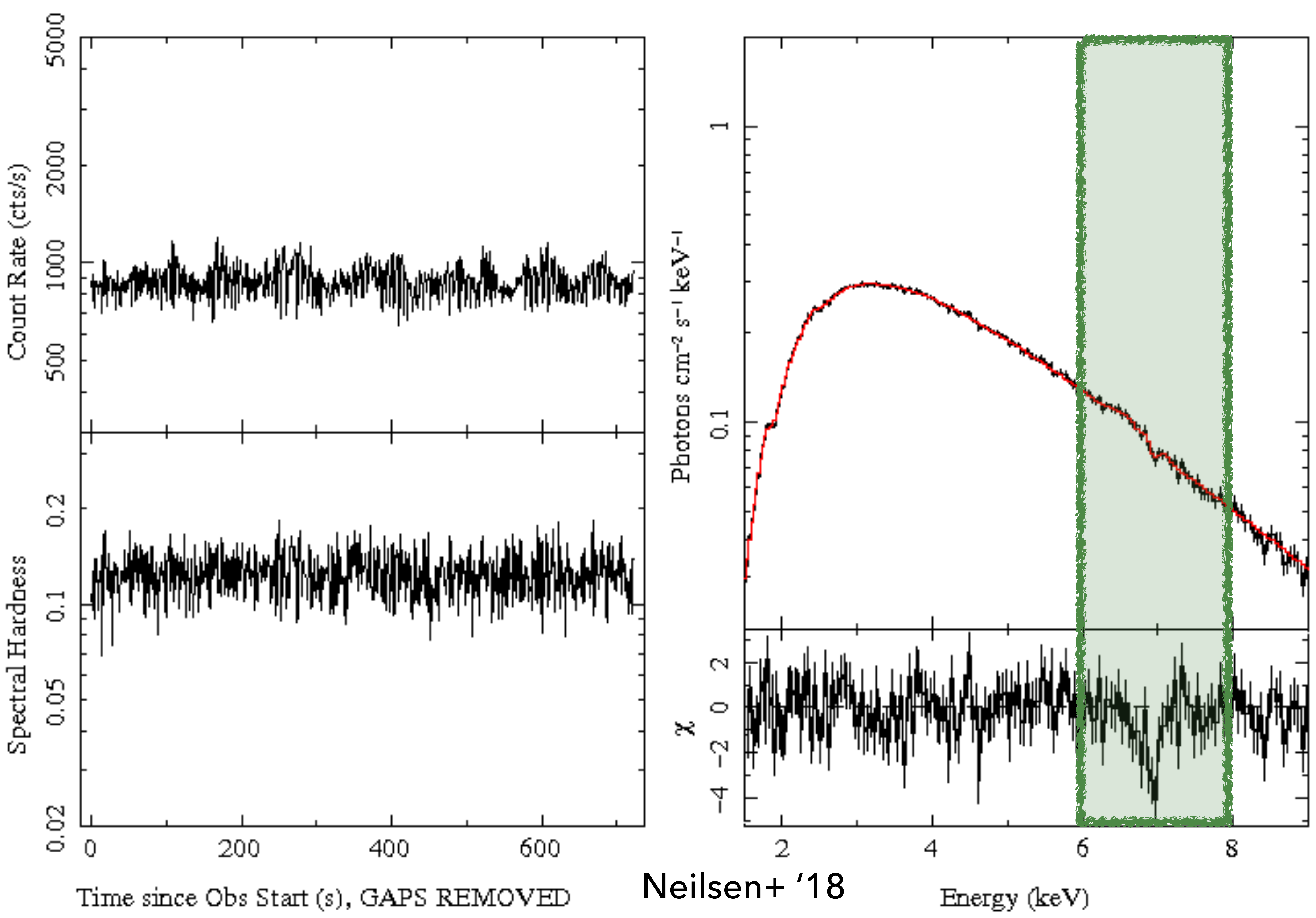

NASA/CXC/M. Weiss for Neilsen et al. 2011

- Highly sensitive spectroscopy, fast timing capabilities, flexible scheduling for frequent monitoring (PI: Gendreau)
- Perfect for studying GRS 1915+105!
- Dozens of observations during Performance Verification phase
- Spectral analysis to study wind variations across 39 observations, ~5 months
- Neilsen et al. 2018



NICER & GRS 1915+105

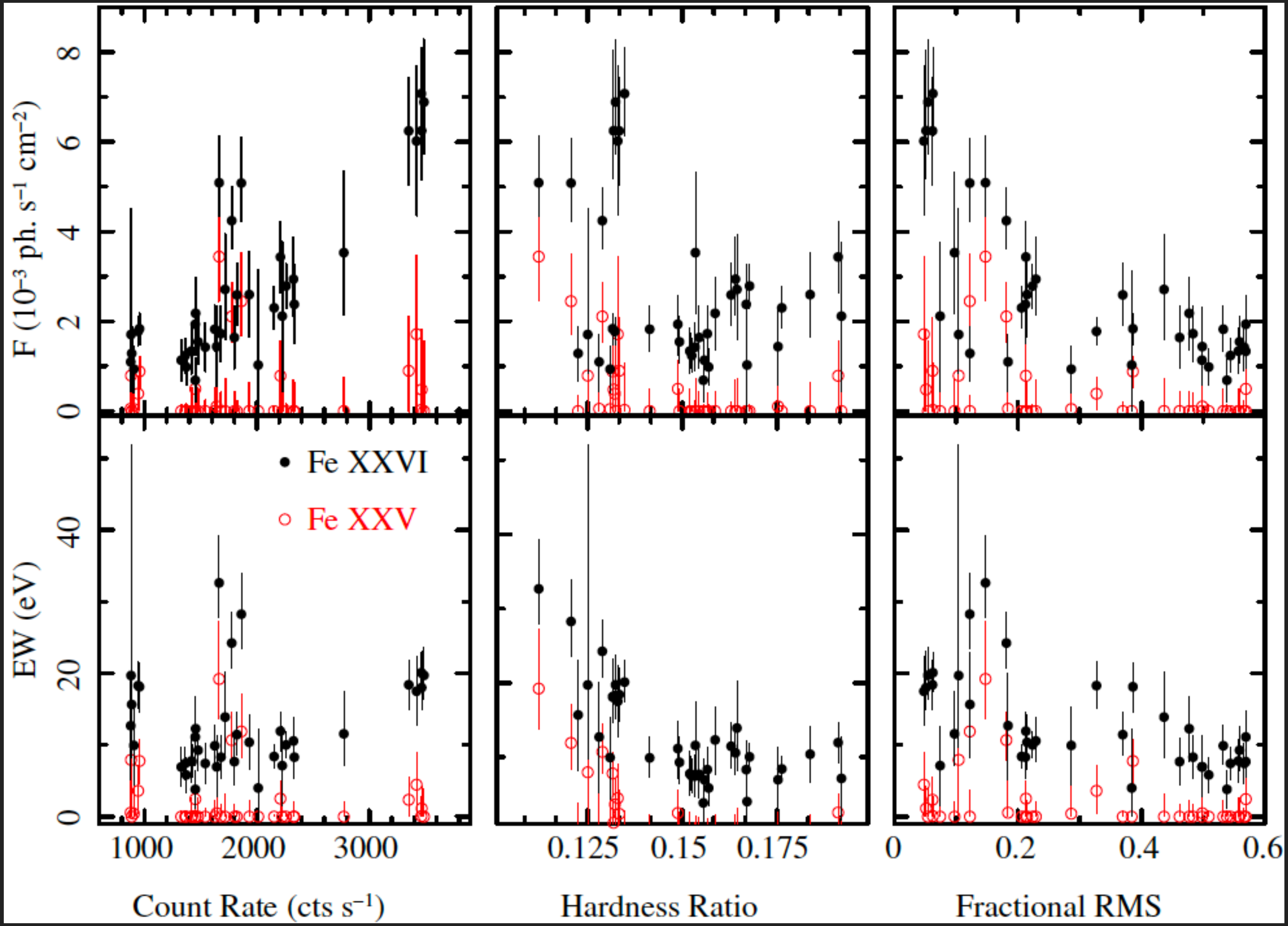
- Left: (top) lightcurve, (bottom) spectral hardness = (6-12 keV) / (2-4 keV), proxy for spectral slope or avg. photon energy
- Right: spectrum with best fit (absorbed, scattered disk+wind); residuals show 7 keV absorption = Fe XXVI Lya
- Very likely arising in the same sort of disk winds seen many times before (Neilsen et al. 2011, 2012a; 2009; Miller et al. 2016; Zoghbi et al. 2016)



Neilsen+ '18

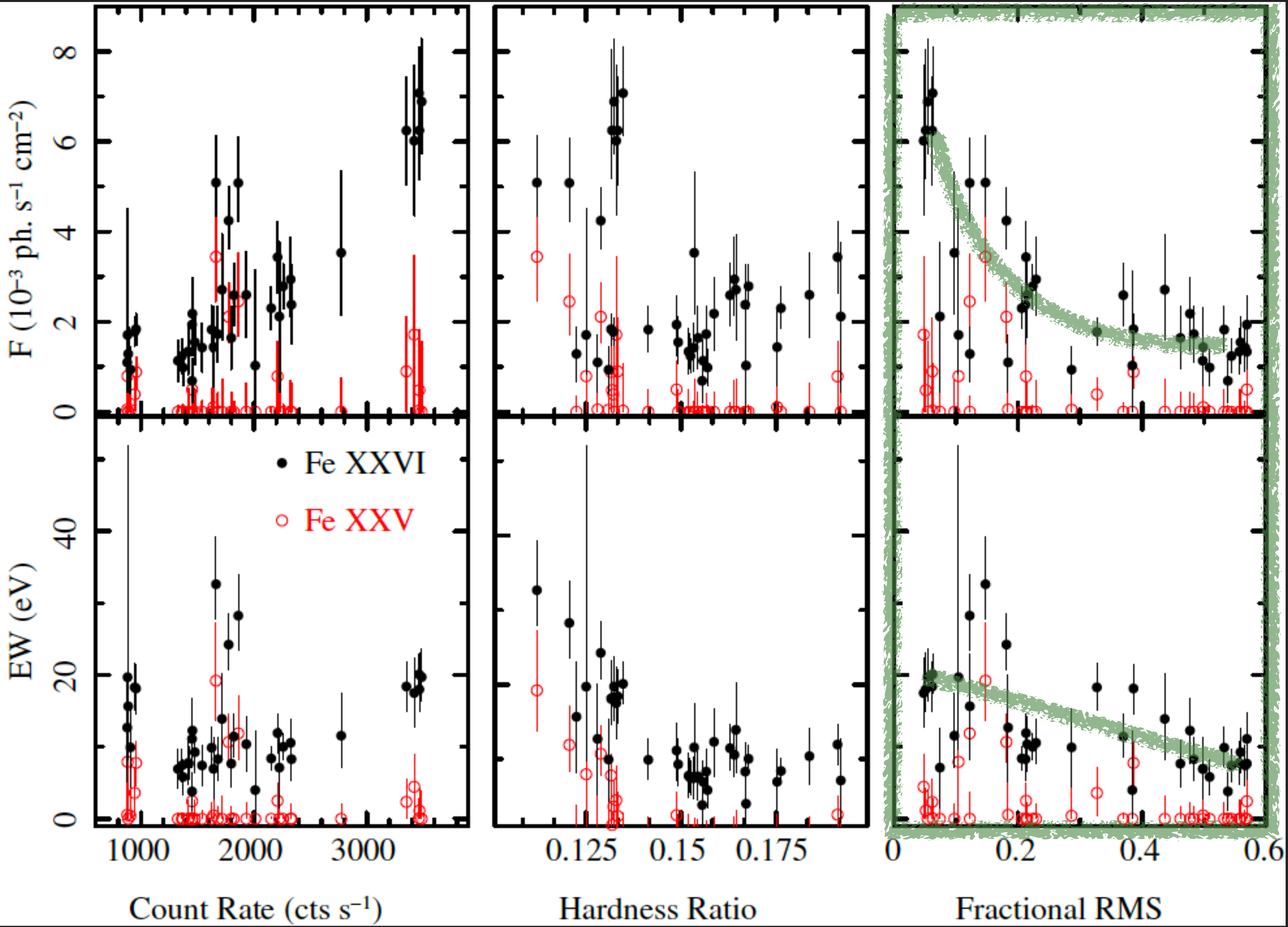
TRENDS?

- How does wind absorption vary with behavior of the BH?
- Line Flux (top) and Equivalent Width (bottom) vs:
  - Left: Count rate (intensity)
  - Middle: Hardness ratio (spectral shape)
  - Right: Fractional RMS variability

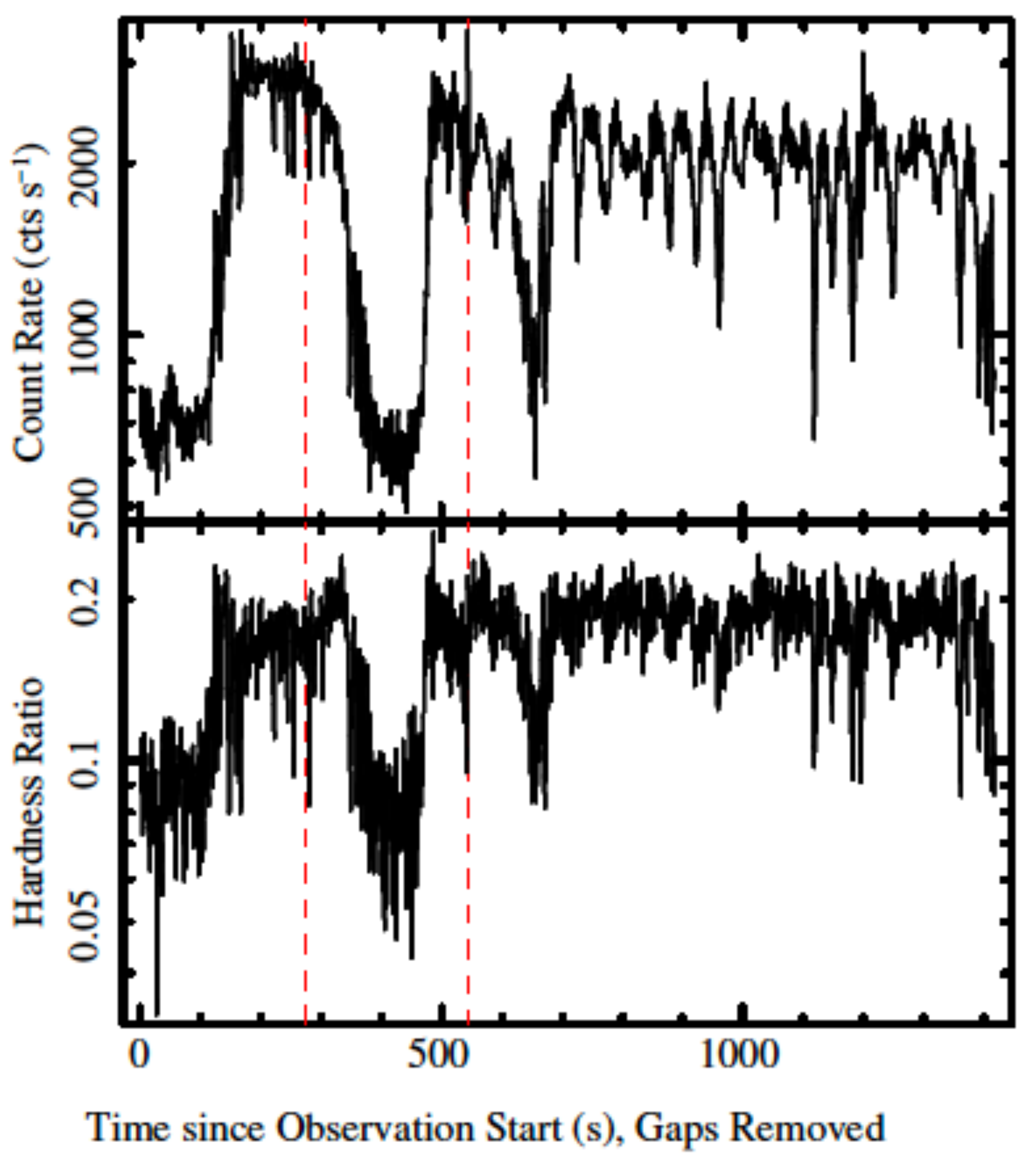


RMS VARIABILITY

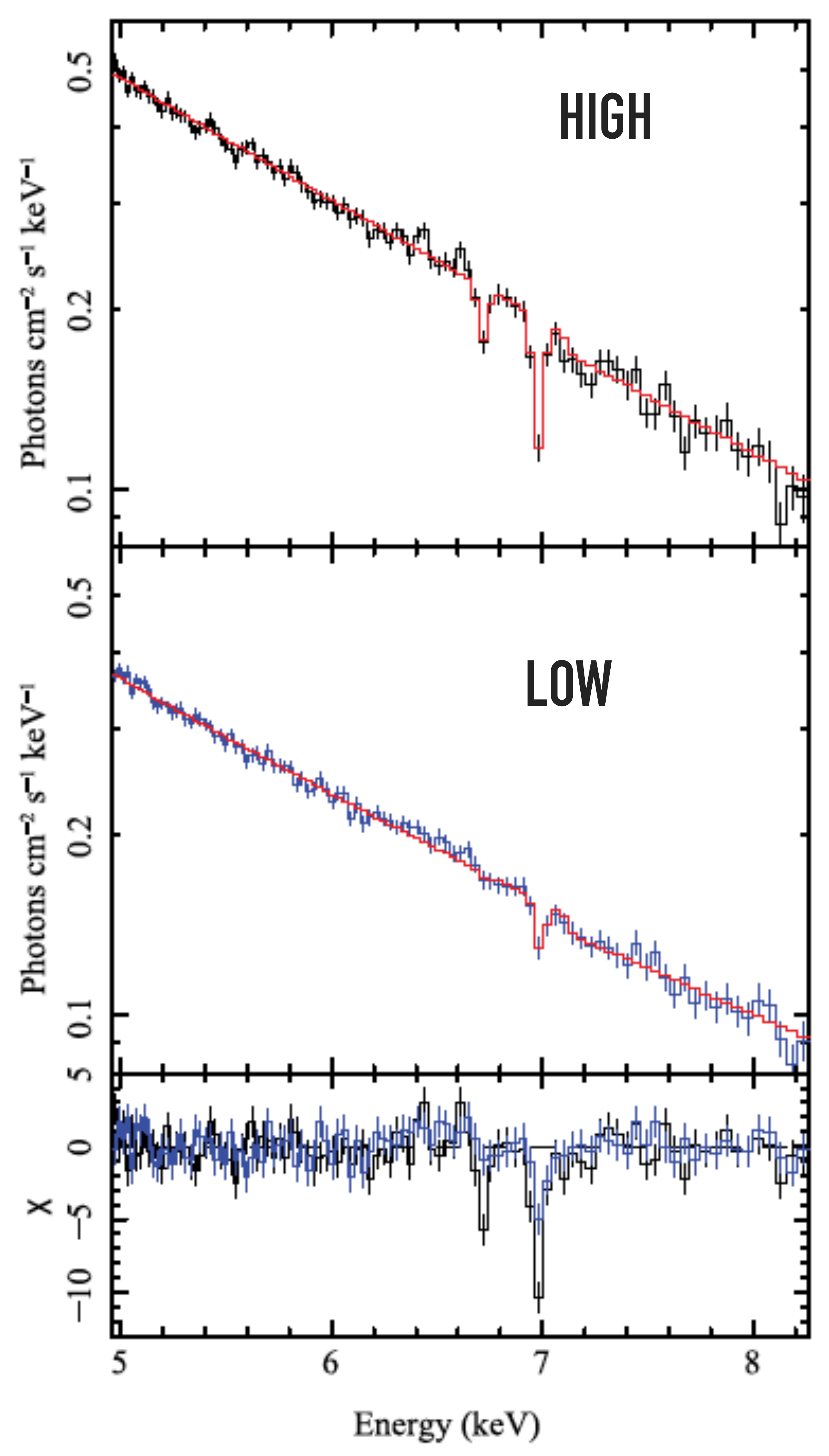
- Wind absorption is weaker when GRS 1915+105 is more variable (r=-0.71)
- Why does variability make lines look weaker?
- Expected if wind toggles on and off with variability!
    - Seen before by Neilsen et al. 2012a



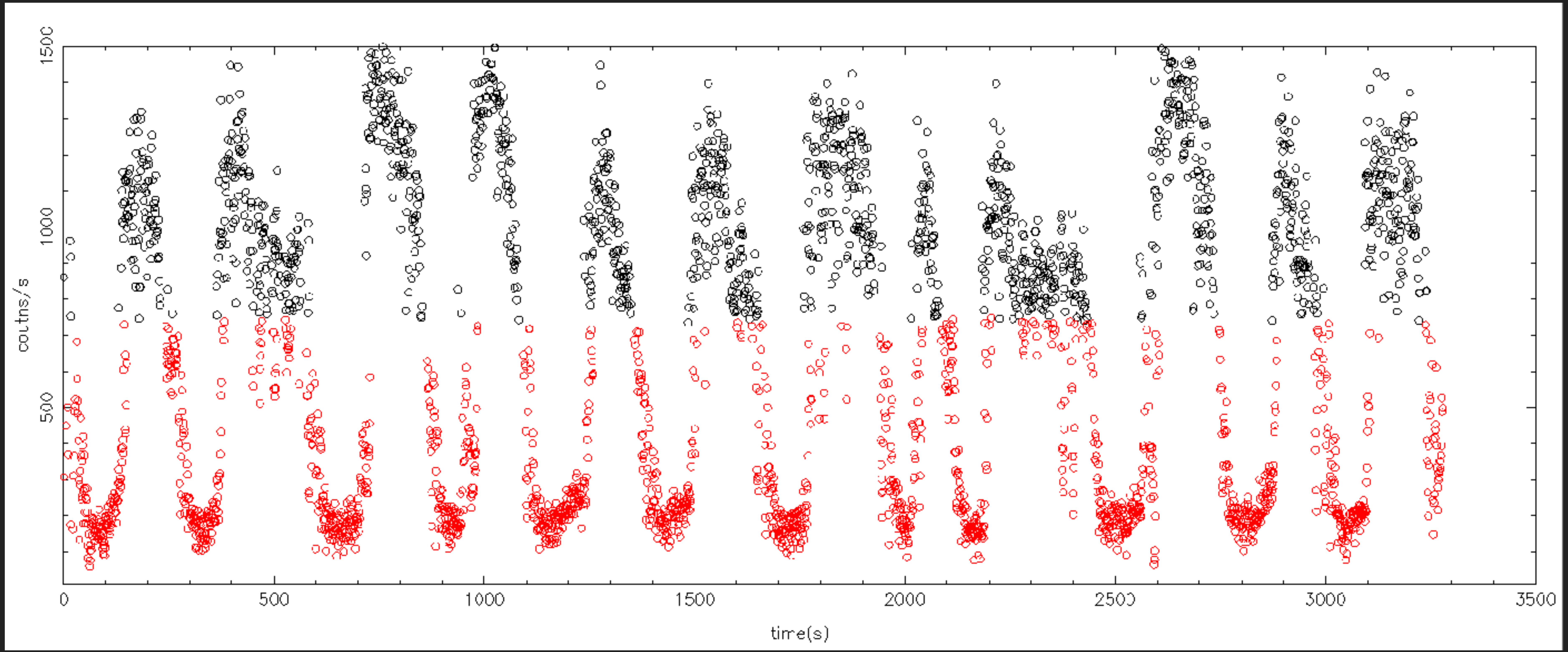
HOW DOES IT WORK?



- Consider lightcurve at left
- Suppose: changes that produce dips also turn off wind
- Spectra at high, low fluxes might look like those on right (from Neilsen et al. 2012a)
- Averaging over entire obs mixes strong wind lines with weak lines; more variability = weaker lines!



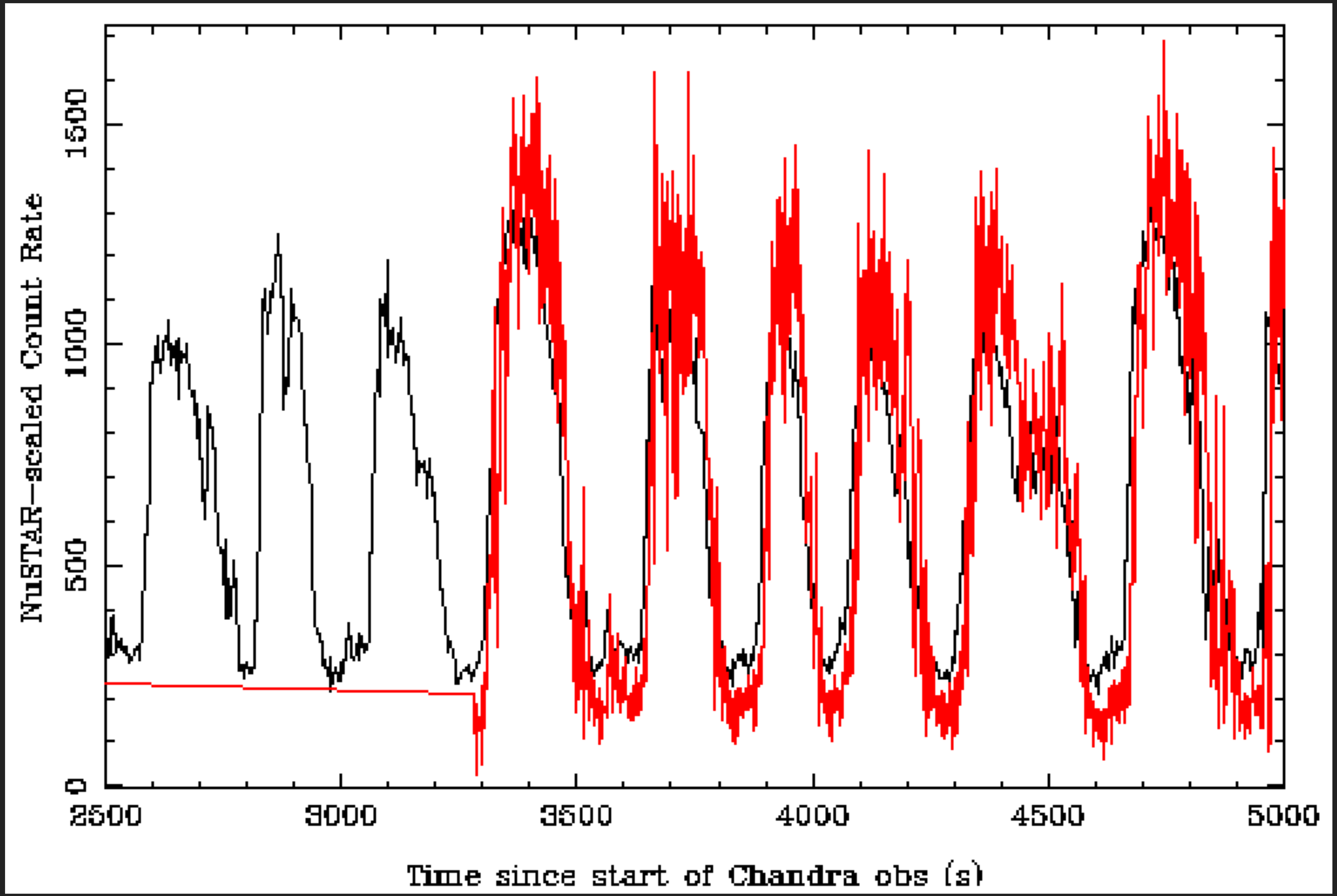
A NEW CASE STUDY



- *NuSTAR*, *Chandra, NICER* observations of GRS 1915+105 (PI: Neilsen, Canizares, Gendreau)
- *NuSTAR* analysis performed by Pablo Arumburu Sanchez, Villanova sophomore

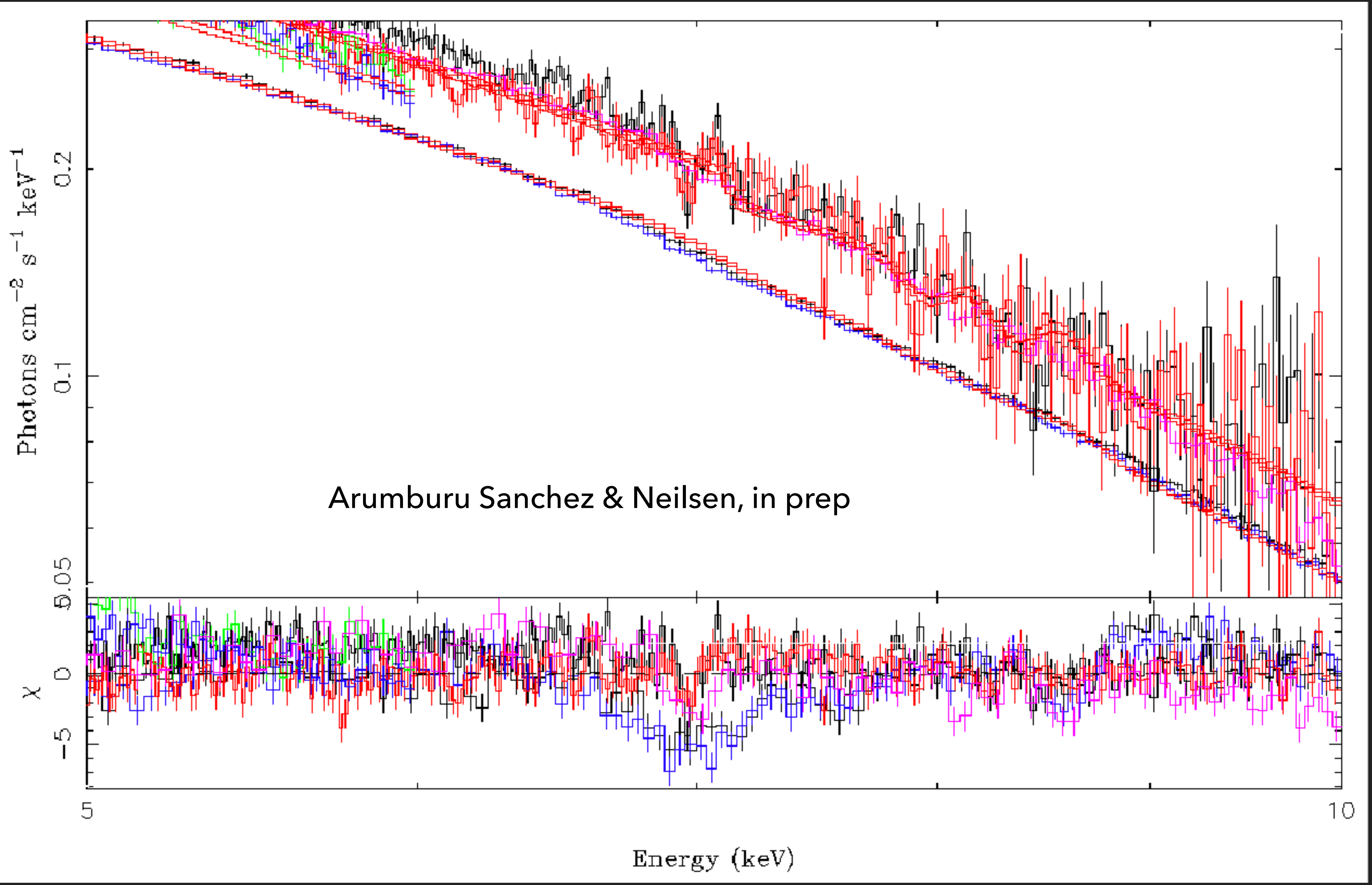
A NEW CASE STUDY

- Very good agreement between *NuSTAR, Chandra*
- *NICER* data (not shown) brackets other observations, shows similar variability
- Rapid on/off variability, typical timescale of a few hundred seconds



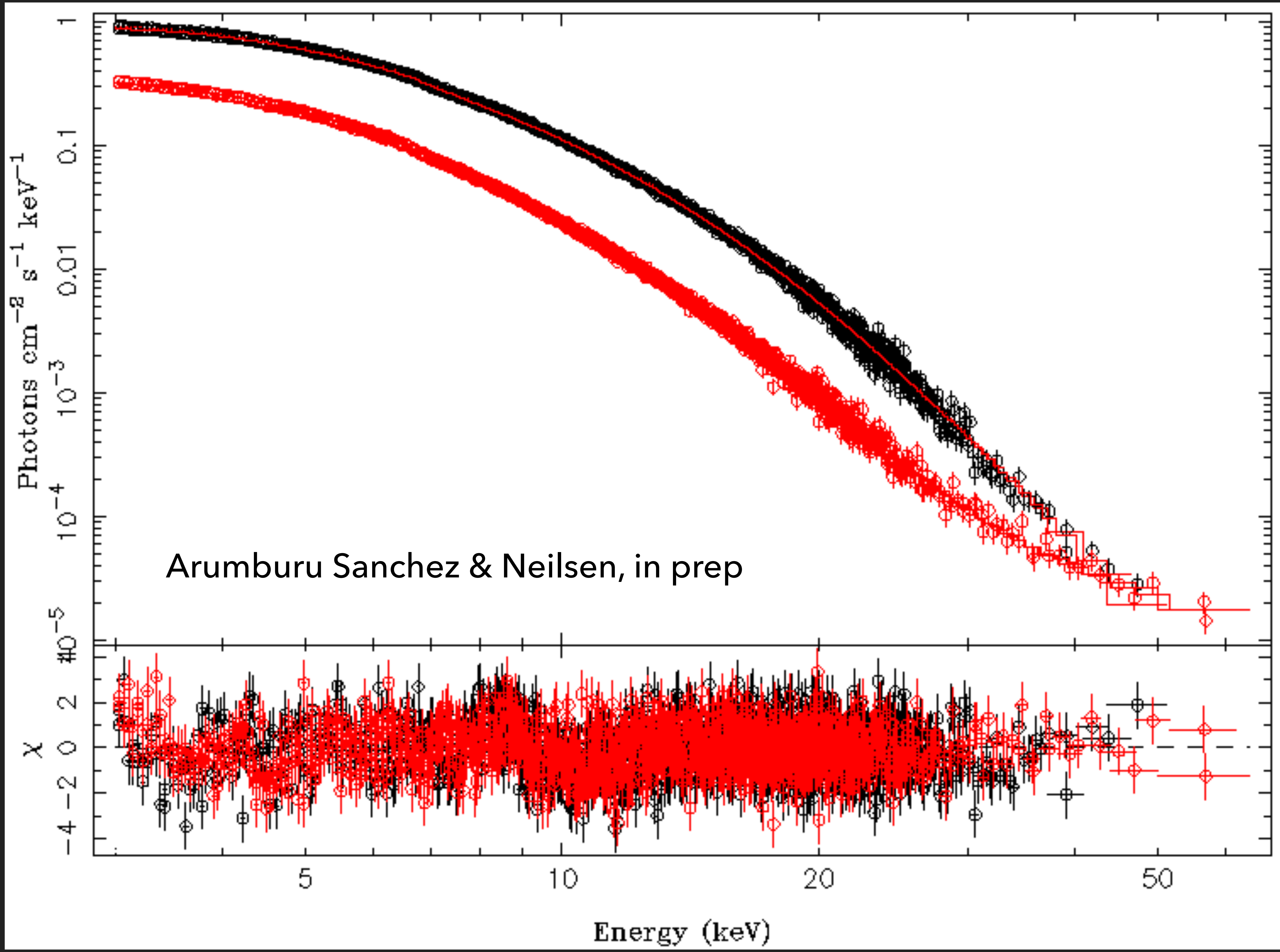
AVERAGE SPECTRUM

- Joint fit to time-averaged *NuSTAR, Chandra, NICER* data; variable norms
- Broadband continuum still needs improvement but 5-10 keV shows clear absorption lines in all data
- All missions fit with a single average line flux: (2.6+/-0.3)x1e-3 ph/s/cm^2
- Possible Fe He/Lyβ lines, Ni too?



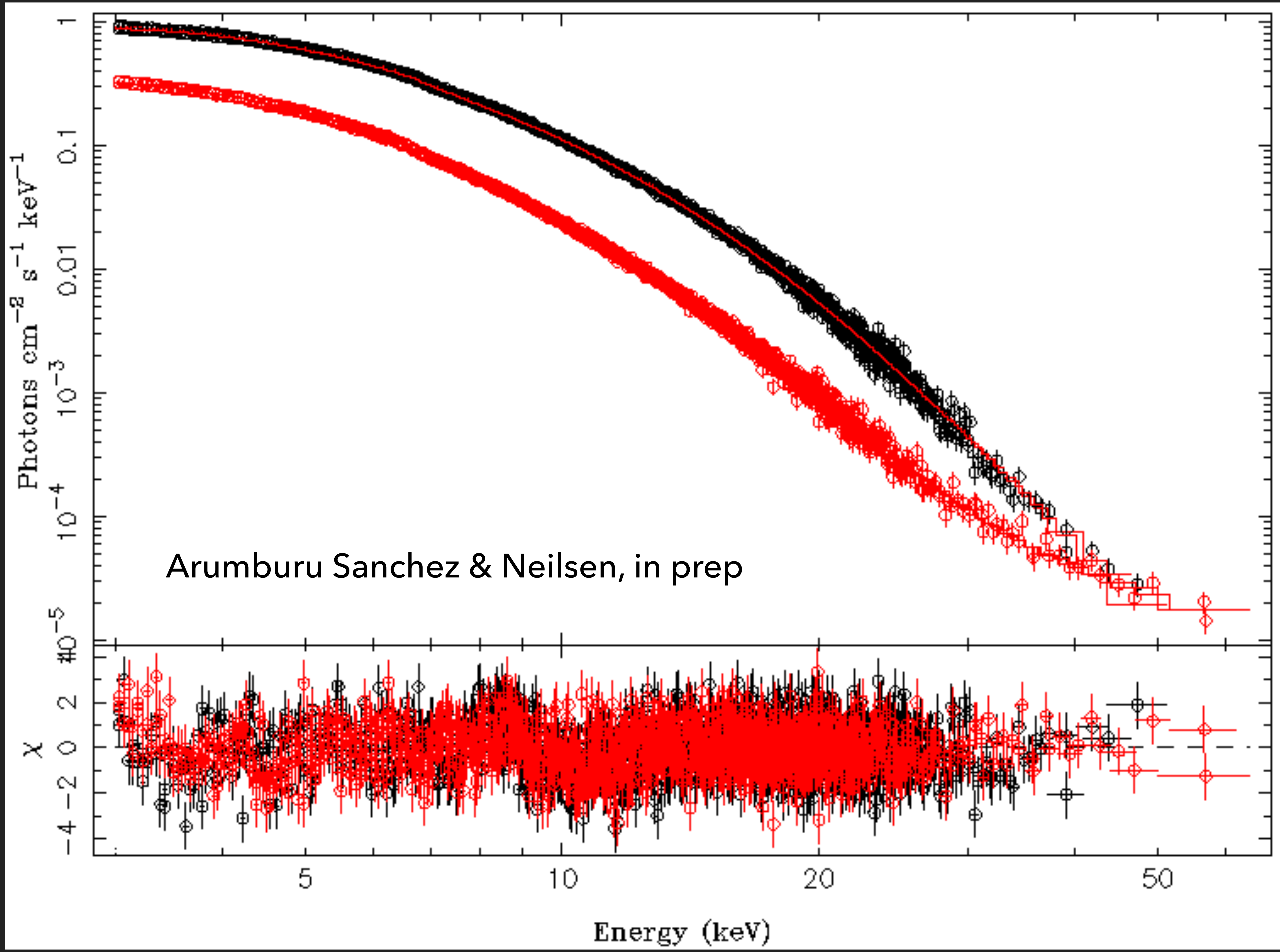
TIME-DEPENDENT SPECTRA

- Pablo extracted *NuSTAR* spectra corresponding to high flux, low flux intervals
- Modeled as a sum of eqpair, ezdiskbb, and Gaussian absorption, with ISM absorption
- Continuum: varies primarily due to changing disk luminosity
- See: radiation pressure instability (Nayakshin+ 00, Neilsen+ 11, 12abc)



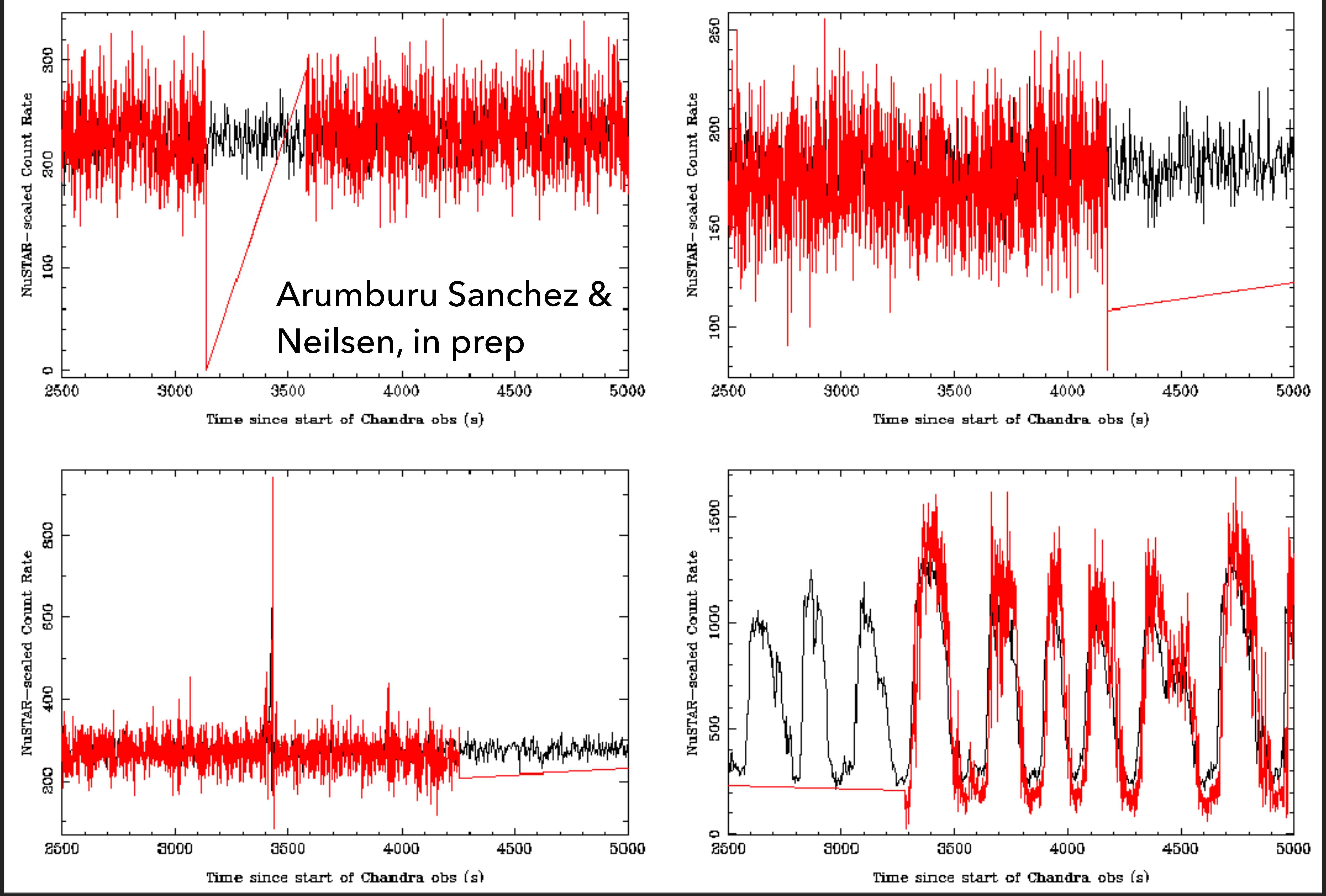
TIME-DEPENDENT WIND?

- Iron absorption line present in both flux states
- E~7.04+/-0.02 keV, consistent with disk wind
- Absorbed line flux is higher during high flux state
    - Confirms dilution in avg spectrum
- Equivalent width is a bit lower
    - For fast variability: tricky to track wind lags (Neilsen+ 11; Zoghbi+ ’16)



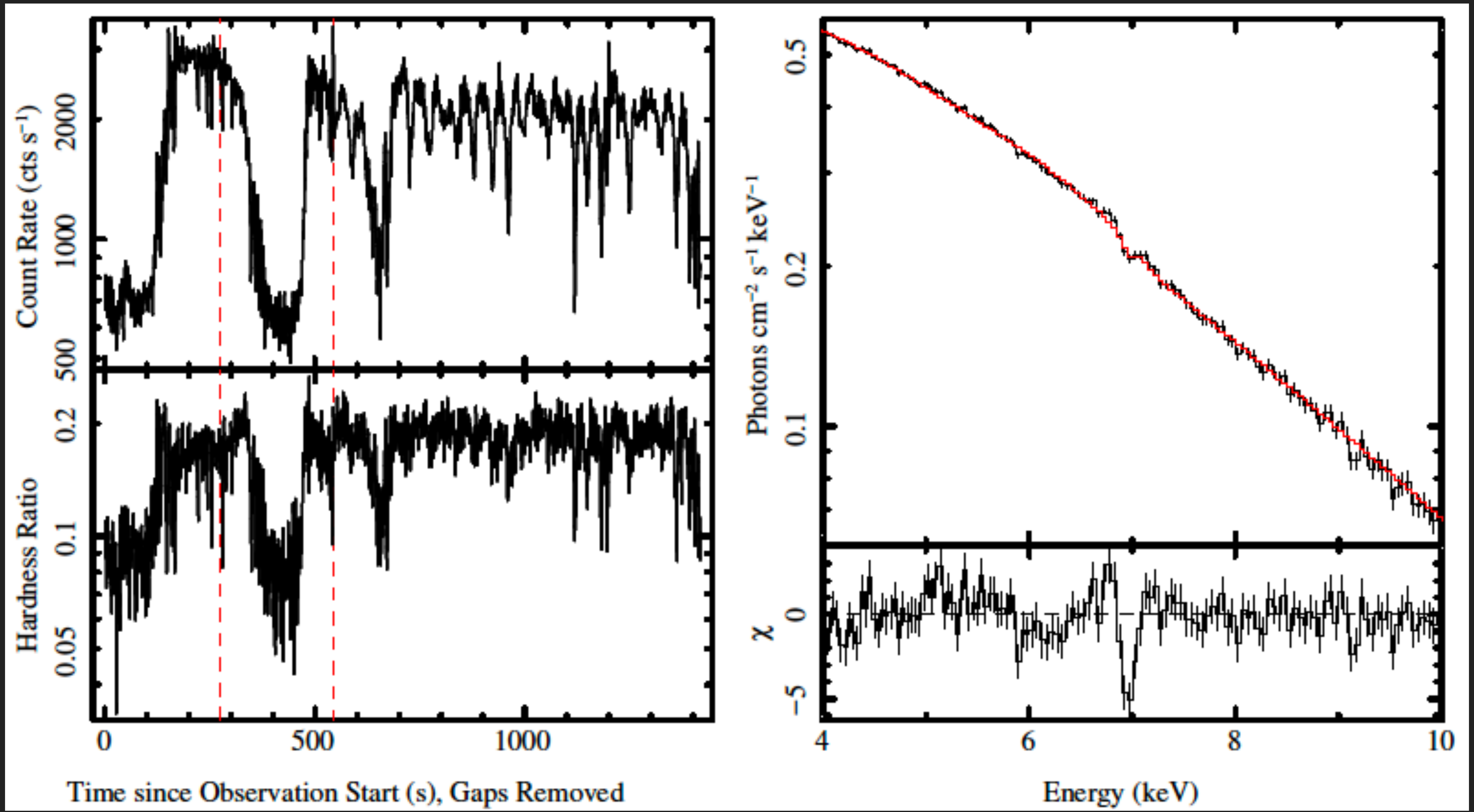
MORE TO DO!

- Actually have several observations with *Chandra, NuSTAR*
- Observations cover several different variability classes, including some steady states and some rapid bright flares
- Great opportunity for studying winds, variability, and relativistic reflection



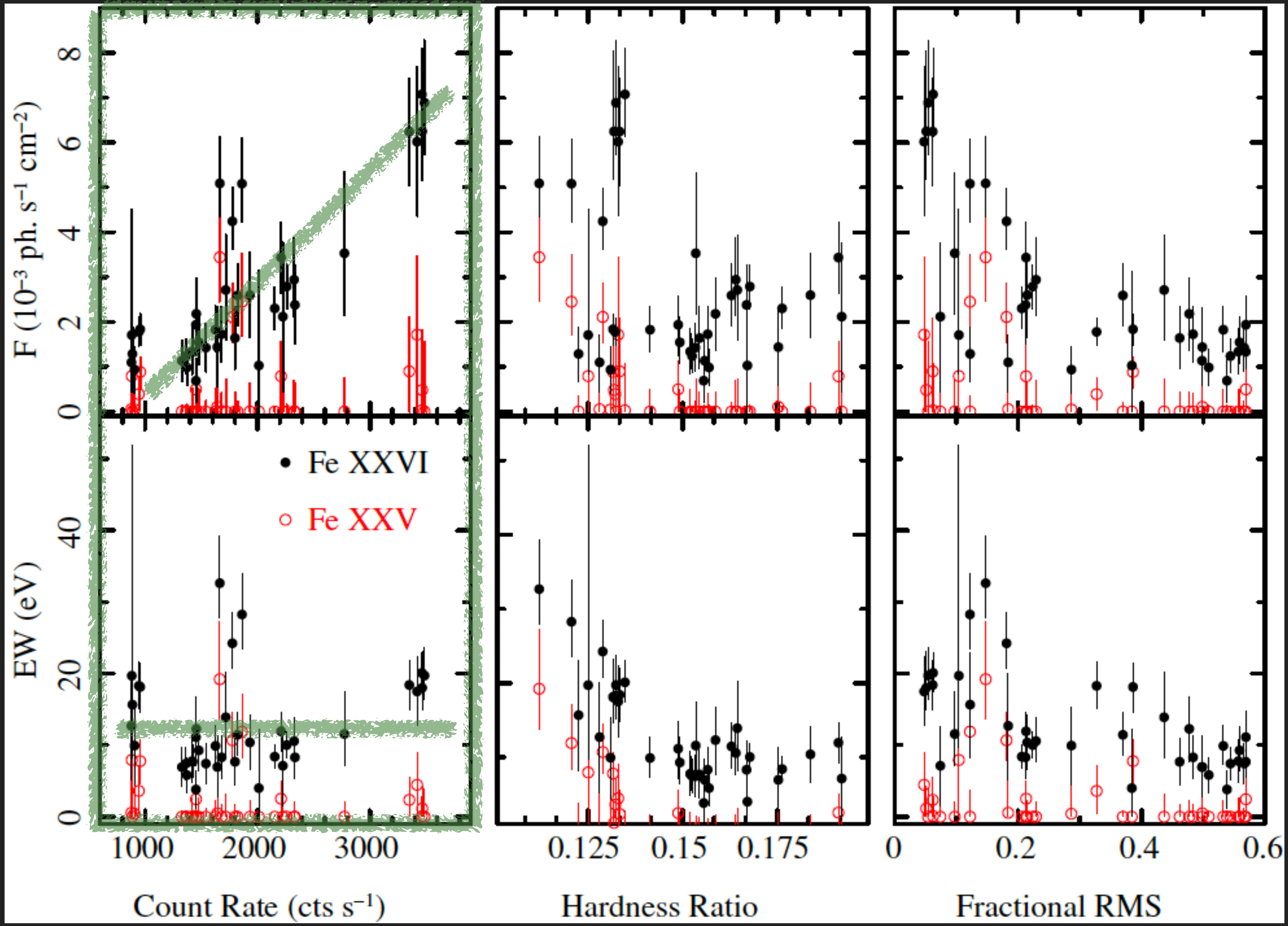
SUMMARY

- With a relatively large new dataset, NICER makes a substantial contribution to wind studies in GRS 1915+105
- Evidence of a wind that persists over months but can flip on and off on timescales of seconds
- *NICER* results confirmed by detailed follow-up and joint observations with *Chandra, NuSTAR*
- GRS 1915+105 continues to provide new insights, future looking good!



COUNT RATE

- Lines look stronger when source is brighter (r=0.83)
- Consistent with a [very] roughly constant wind column density over 5 months: a very persistent wind!
- Caveat: are these lines saturated? Optically thick absorber could possibly mimic this effect



SPECTRAL HARDNESS

- Lines get relatively weaker when spectrum is harder (r=-0.71)
- Could indicate (Neilsen & Homan 2012)
  - (a) more photoionization when harder
  - (b) physical links between outflow, spectral state
- Tracks with the global state dependence of winds around black holes (Ponti et al. 2012; Homan, Neilsen et al. 2016)