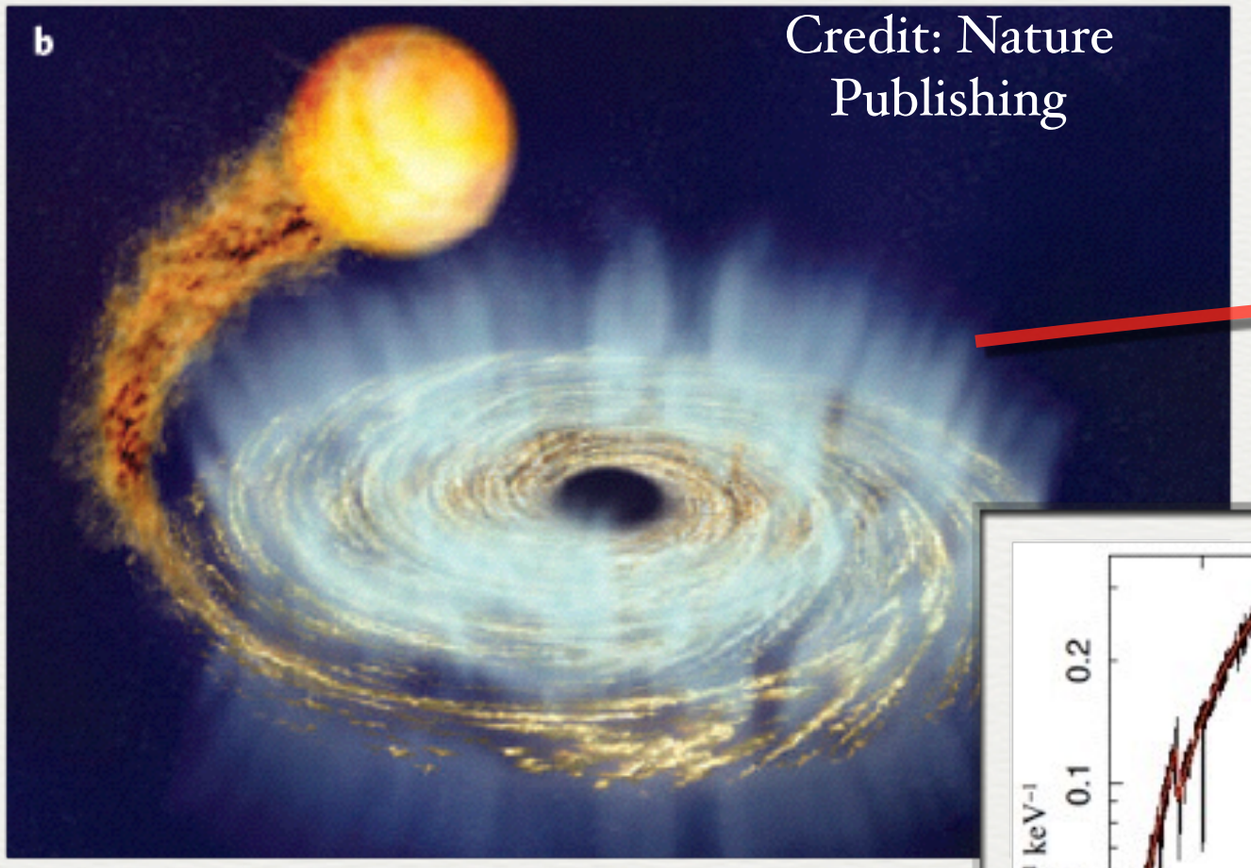
BEYOND PHOTOIONIZATION:

UNDERSTANDING THE LIFE CYCLE OF BLACK HOLE WINDS

Joey Neilsen, Hubble Fellow (MIT), Jeroen Homan

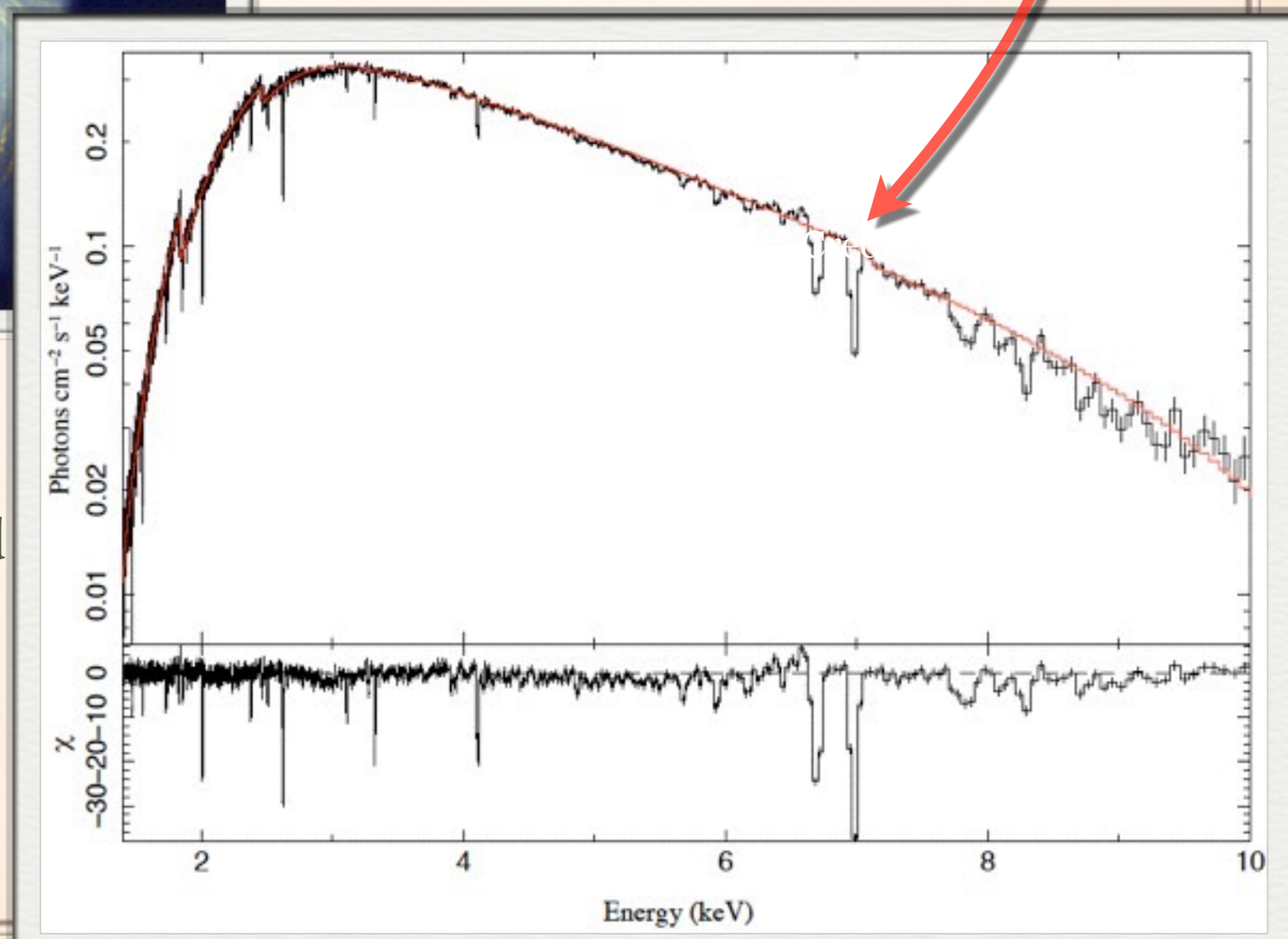
Chandra Science for the Next Decade. Aug. 17.

ACCRETION DISK WINDS



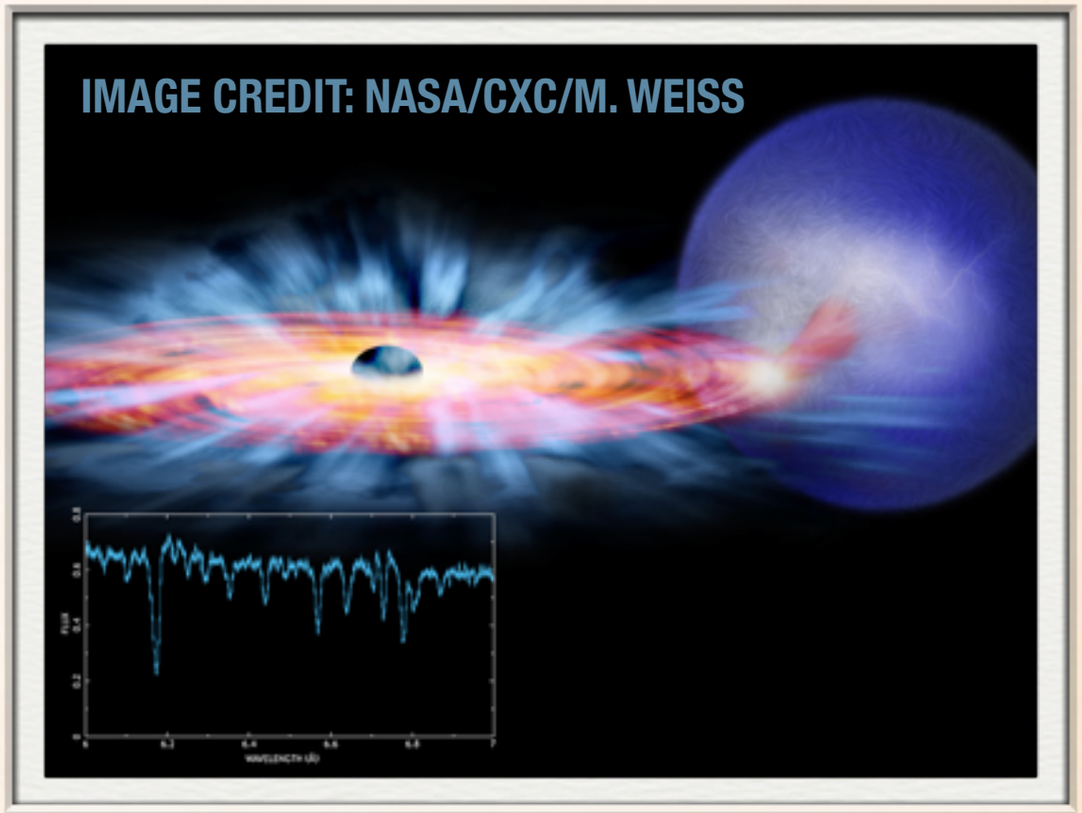
Credit: Nature Publishing

- Hot gas flowing off the disk
- Typically launched and ionized by intense radiation fields
- Visible in high-resolution X-ray spectra from Chandra

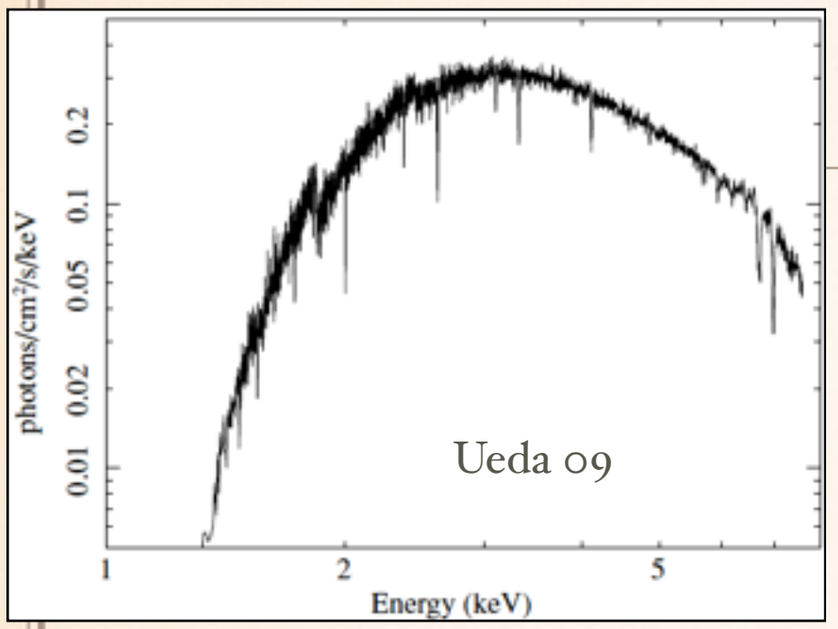


WHY STUDY WINDS?

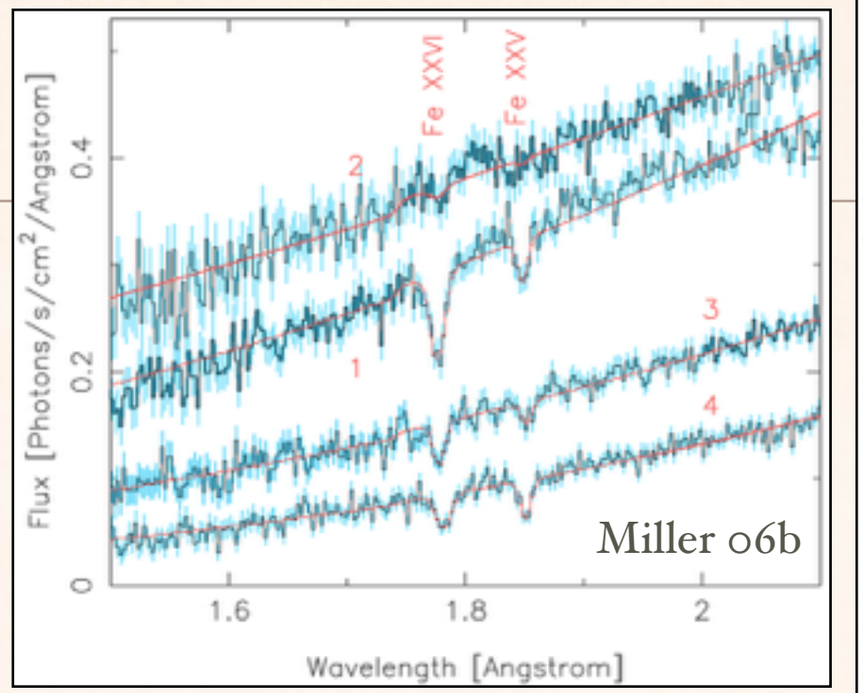
- Important part of the accretion process
- Universal questions: accretion/ejection physics across the mass scale
  - Young stars, QSOs, galaxy clusters
- Black hole mass/energy budget
  - Take significant mass out of systems
- Connections between black holes and their environments
  - Ionization/outflows: clues to radiative, mechanical feedback



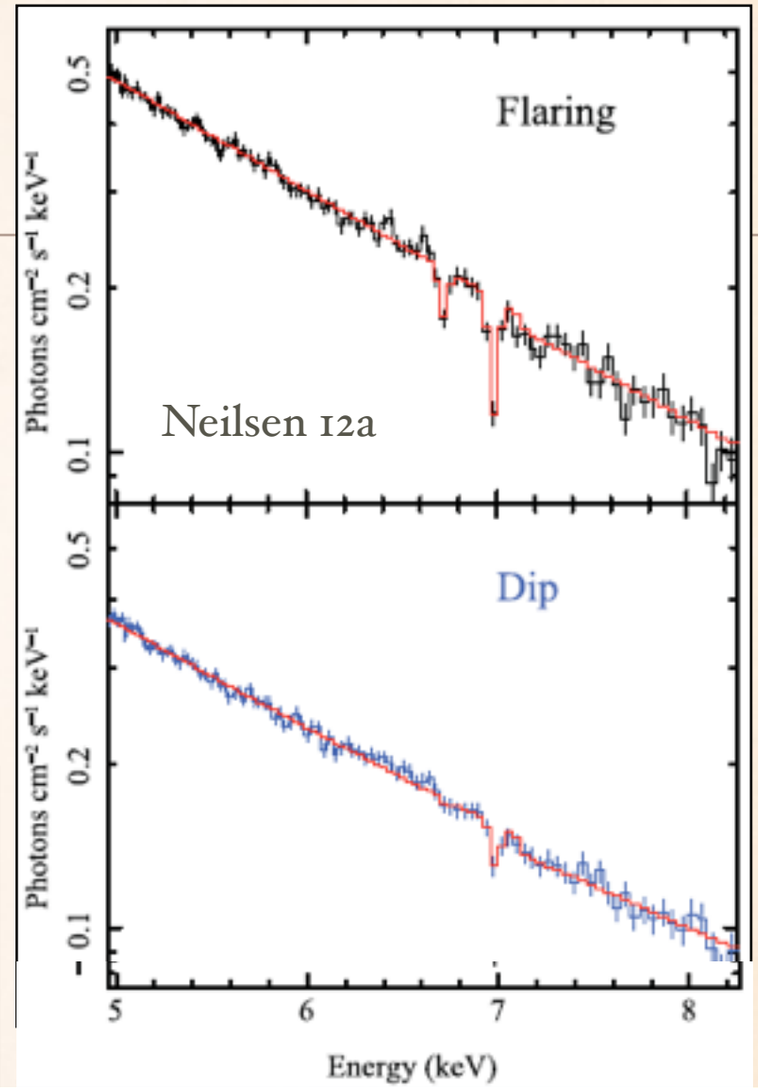
LOTS OF WINDS!

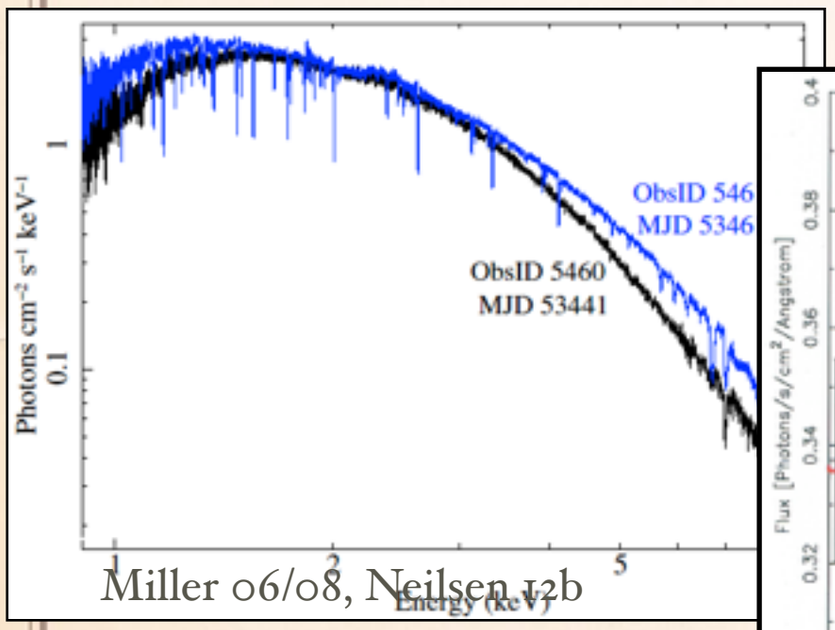


Ueda 09

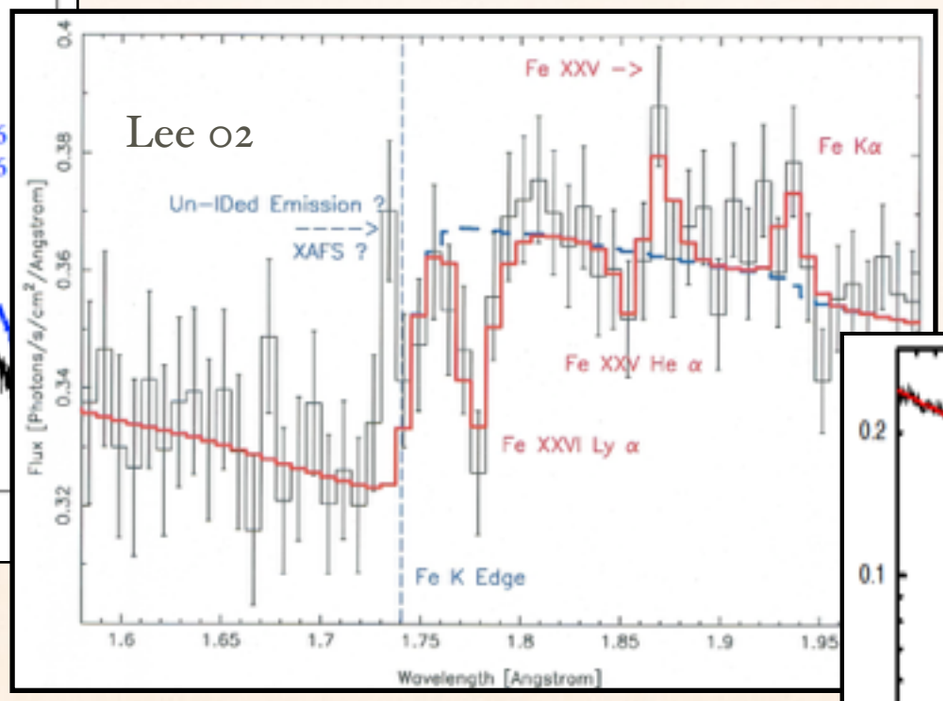


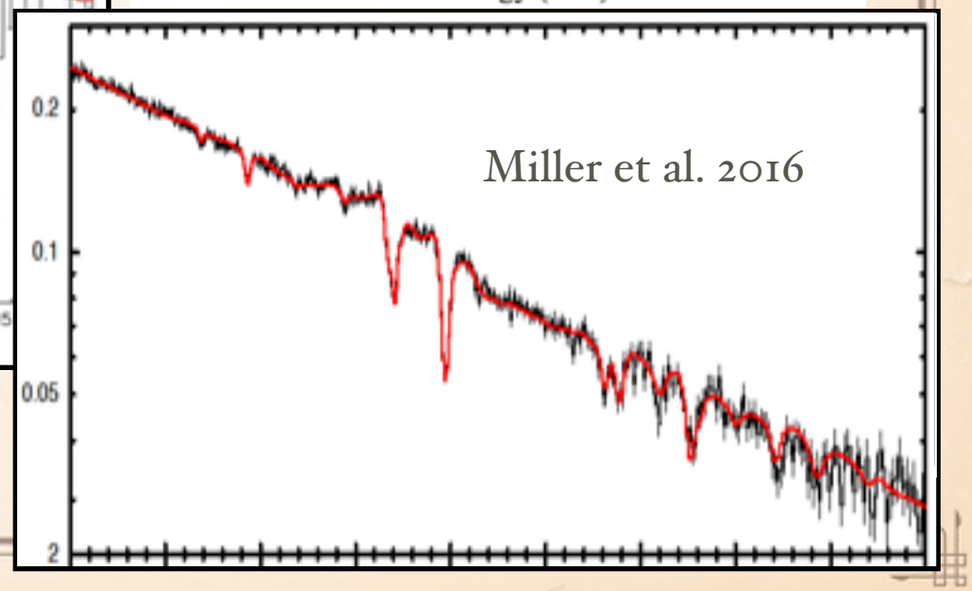
Miller 06b





Miller 06/08, Neilsen 12b

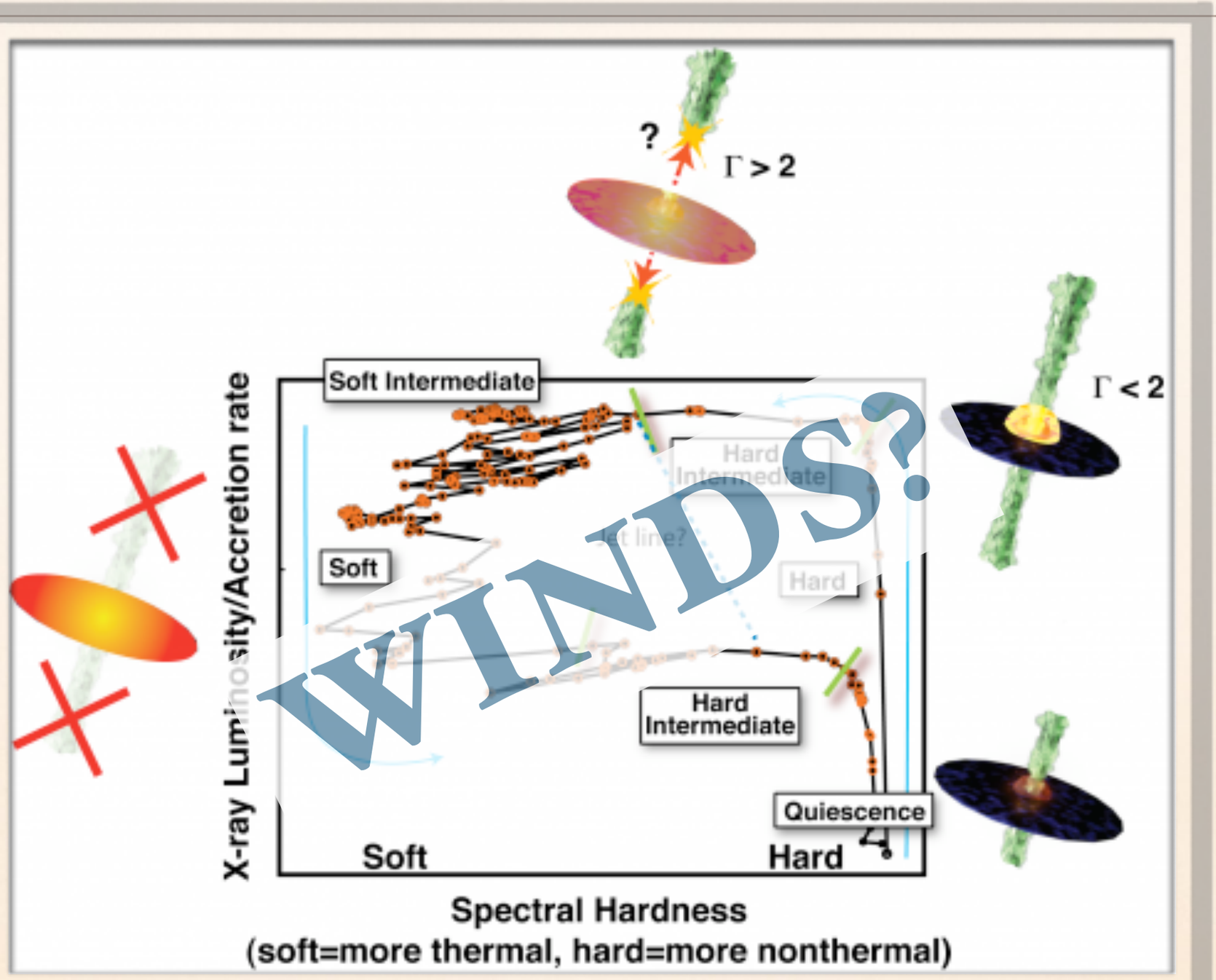




Highly ionized, can be extremely variable (**Neilsen**+ 11, 12a)

BLACK HOLE OUTBURSTS

Fender et al 2005
Belloni et al 2010,
Corbel et al 2011
S. Markoff

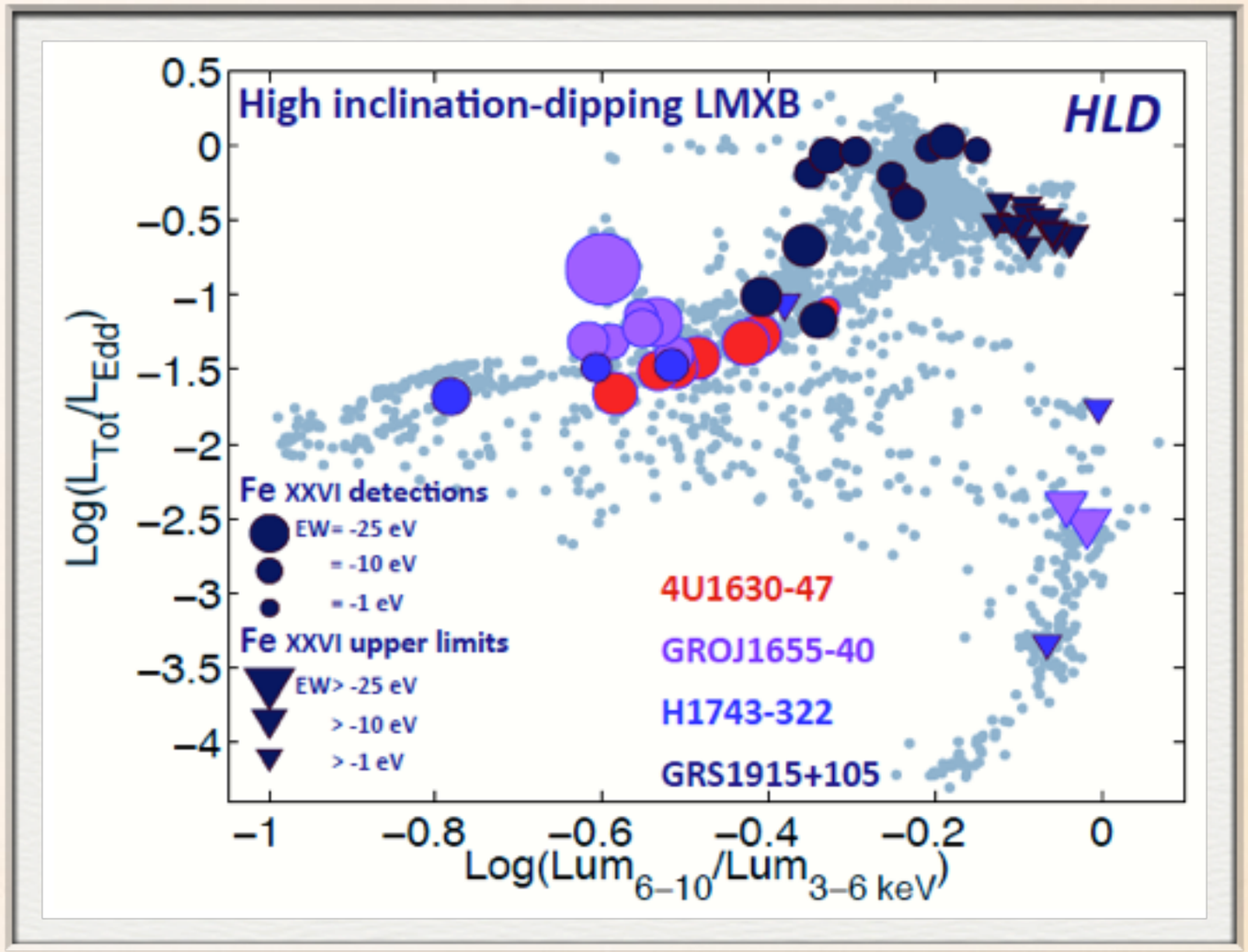


WINDS IN OUTBURSTS

- Ponti et al. (2012) showed that winds are preferentially detected in softer, brighter states (as opposed to harder, jet-producing states)

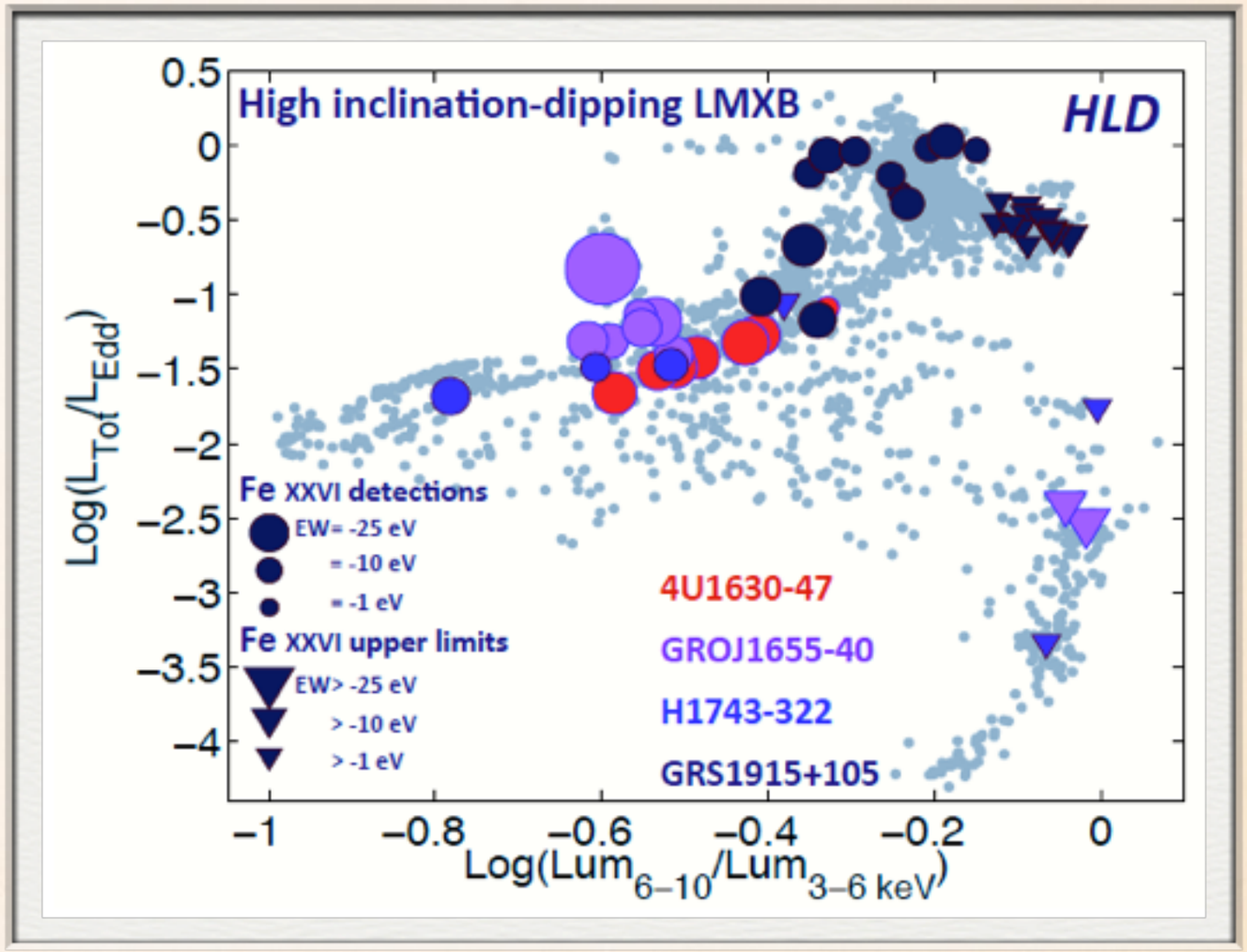
- ***Question:*** What is the origin of this dichotomy?

- Interpretation affects inferred launching process



BLURRY LINES

- Not strictly soft vs hard. Details in Homan, **Neilsen** et al. 2016 (1606.07954)
- Winds can coexist with jets and can be found in harder states (see GRS 1915+105, GRO J1655-40, V404 Cyg; **Neilsen** & Lee 2009, **Neilsen** & Homan 2012, King et al. 2015)
- Similar behavior apparent in some NSs (e.g., GX 13+1)
- Still a trend worth understanding



WHY THE HARD/SOFT SPLIT?

- Several possible contributions:

1. Photoionization: harder (bluer) spectra are observed during hard states, maybe winds are over-ionized?

2. Geometry, astrophysics: maybe winds aren't being produced during hard states?

3. Heating/cooling: maybe gas isn't thermodynamically stable at relevant ionization parameters

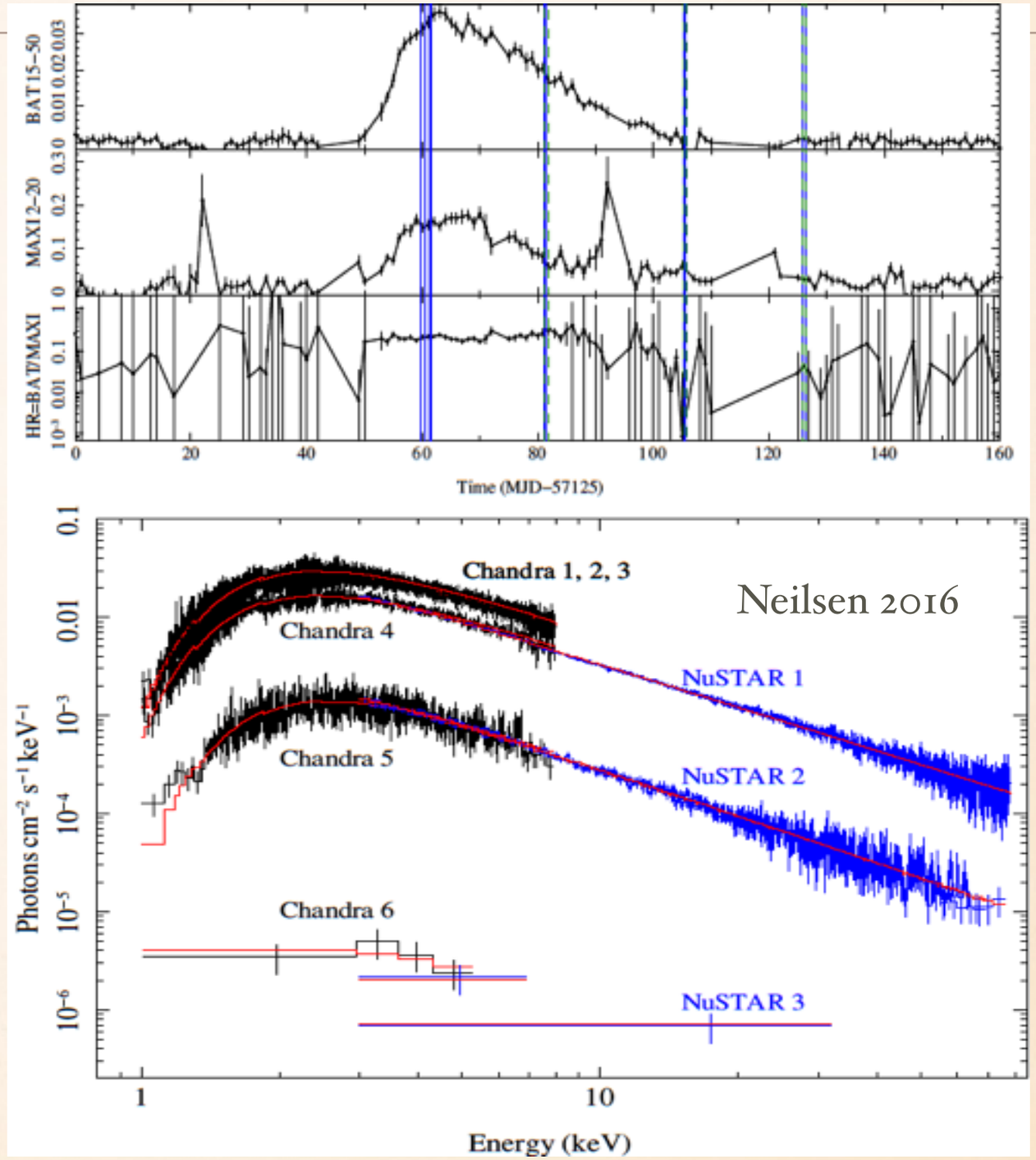
WHAT IF WE COULD RULE OUT PHOTOIONIZATION?

- Consider *Chandra* HETGS/ *NuSTAR/JVLA* observations of a failed outburst of H1743-322 (June 2016)

- Failed outburst = BH never leaves hard state, no disk

- Data show jet but no evidence of a wind. Two options:

- 1. Source never gets bright enough to drive a wind? Jet/ MHD config. never changes?

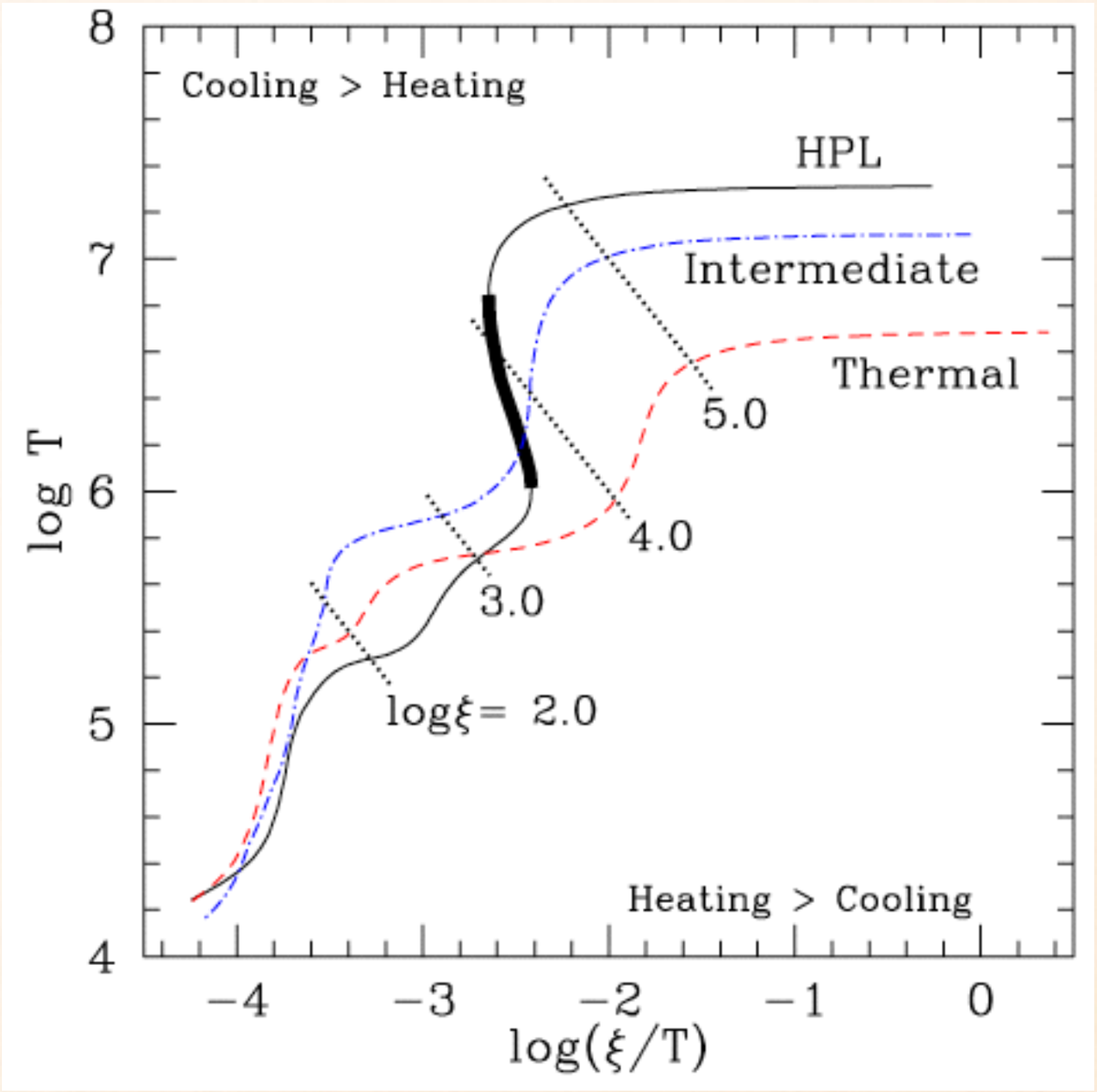


WHAT IF WE COULD RULE OUT PHOTOIONIZATION?

- 2. Wind is present but thermodynamically unstable (e.g. Krolik 1981, Higginbottom & Proga 2015, Chakravorty 2013, 2016)

- Cold gas jumps rapidly to higher temperature, ionization, certain ξ excluded

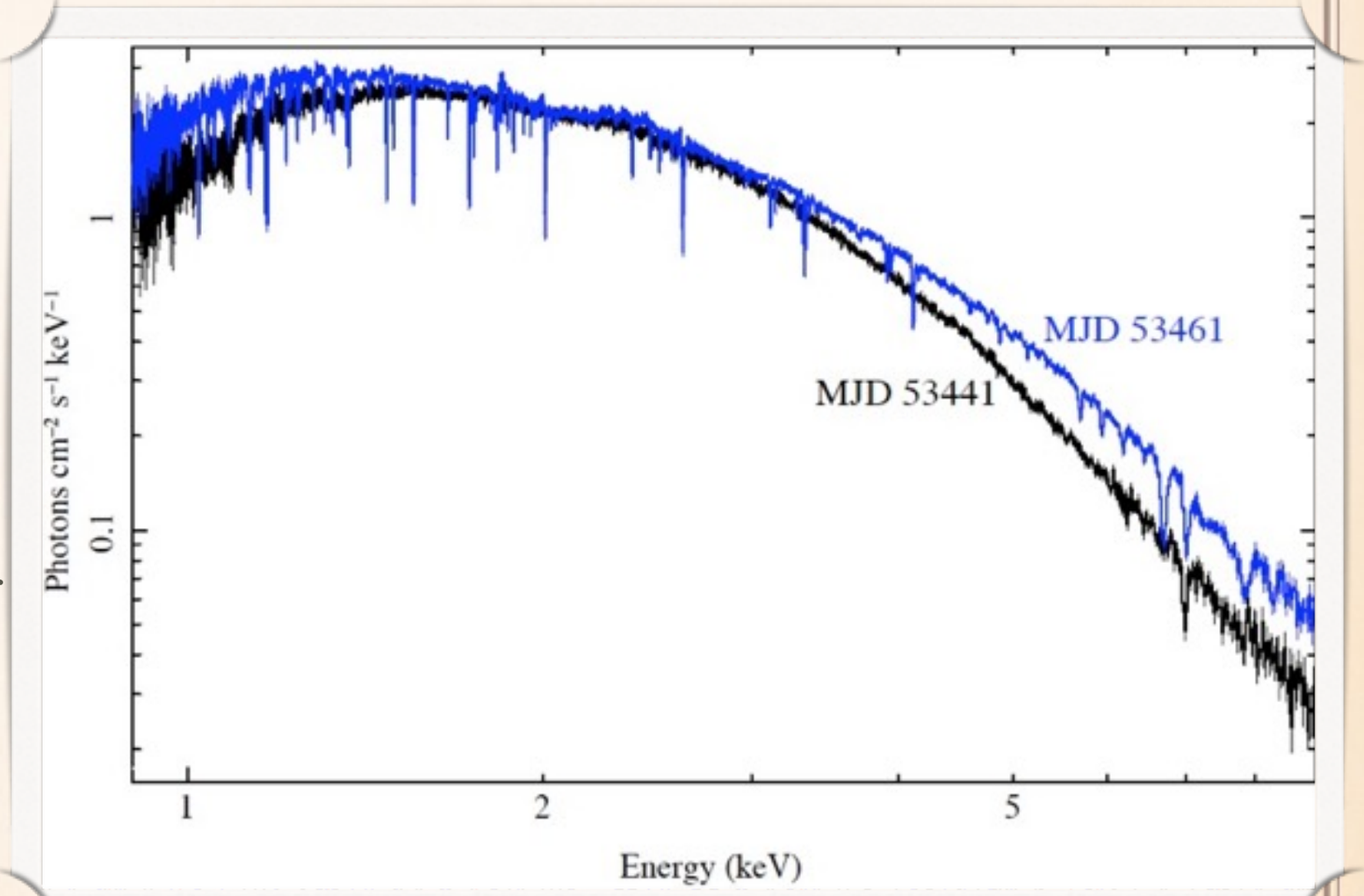
- Higginbottom & Proga: ΔT drives expansion: T.I. *responsible* for efficiently accelerating the wind!



Chakravorty, Lee, & **Neilsen** 2013

SO LET'S TRY TO RULE OUT PHOTOIONIZATION!!

- There are good reasons to think that photoionization isn't the whole story
- Case study on GRO J1655-40
- Two very different spectra: one soft with a strong absorber (Miller et al. 2006, 2008) and one harder with a much weaker absorber
- Using XSTAR, we were able to show that difference could not be explained simply by over-ionization (**Neilsen** & Homan 2012)



Neilsen & Homan 2012

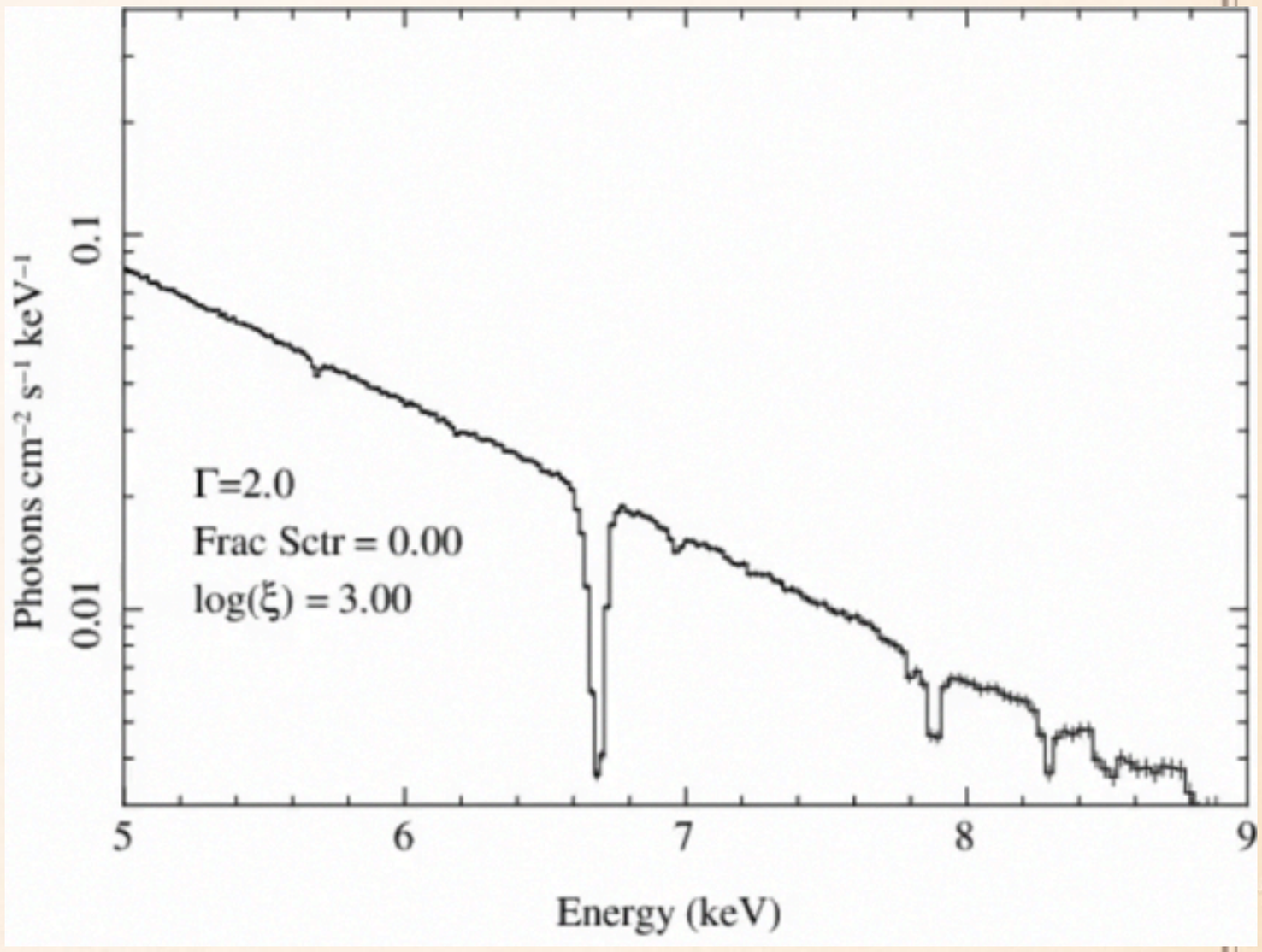
BUT GRO J1655 IS AN EXTREME CASE...

- Over-ionization in harder states doesn't explain the data in 1655. But most winds are not so extreme. Over-ionization in the general case? HT to J. Krolik

- Perfect for XSTAR simulations!

- 1 disk spectrum scattered into 4 different power laws 5 different ways and absorbed by a wind with 3 possible column densities, 9 ionization parameters, spanning 5 orders of magnitude in density

- 2295 different simulated *Chandra* HETGS spectra



Neilsen 2016

WHAT CAN WE DO WITH THIS?

- Determine the influence of over-ionization in hard states!

1. Pick a set of "observed" Fe XXV/Fe XXVI lines from a wind in a hypothetical soft state
2. Use line ratios to infer ionization parameter, line strengths to infer column density
3. Find new ionization balance for a hypothetical hard state
4. Decide: would this wind be detectable in the hard state?

AND?

- Consider pairs of Fe XXV and Fe XXVI lines (6.7, 6.96 keV) with equivalent widths from 7.5 eV (weak) to 37.5 eV (strong)
- How often can I render these lines undetectable simply by making the ionizing spectrum harder?
  - Preliminary: in 1937 out of 4865 cases (roughly 40% of the time), lines would not be detectable in 30 ks.
- Need to dig into parameters, but suggestive: ionization isn't main effect?
- Interestingly: non-detections at lower flux correspond to *lower* ionization! ~~Overionization~~ vs S/N?

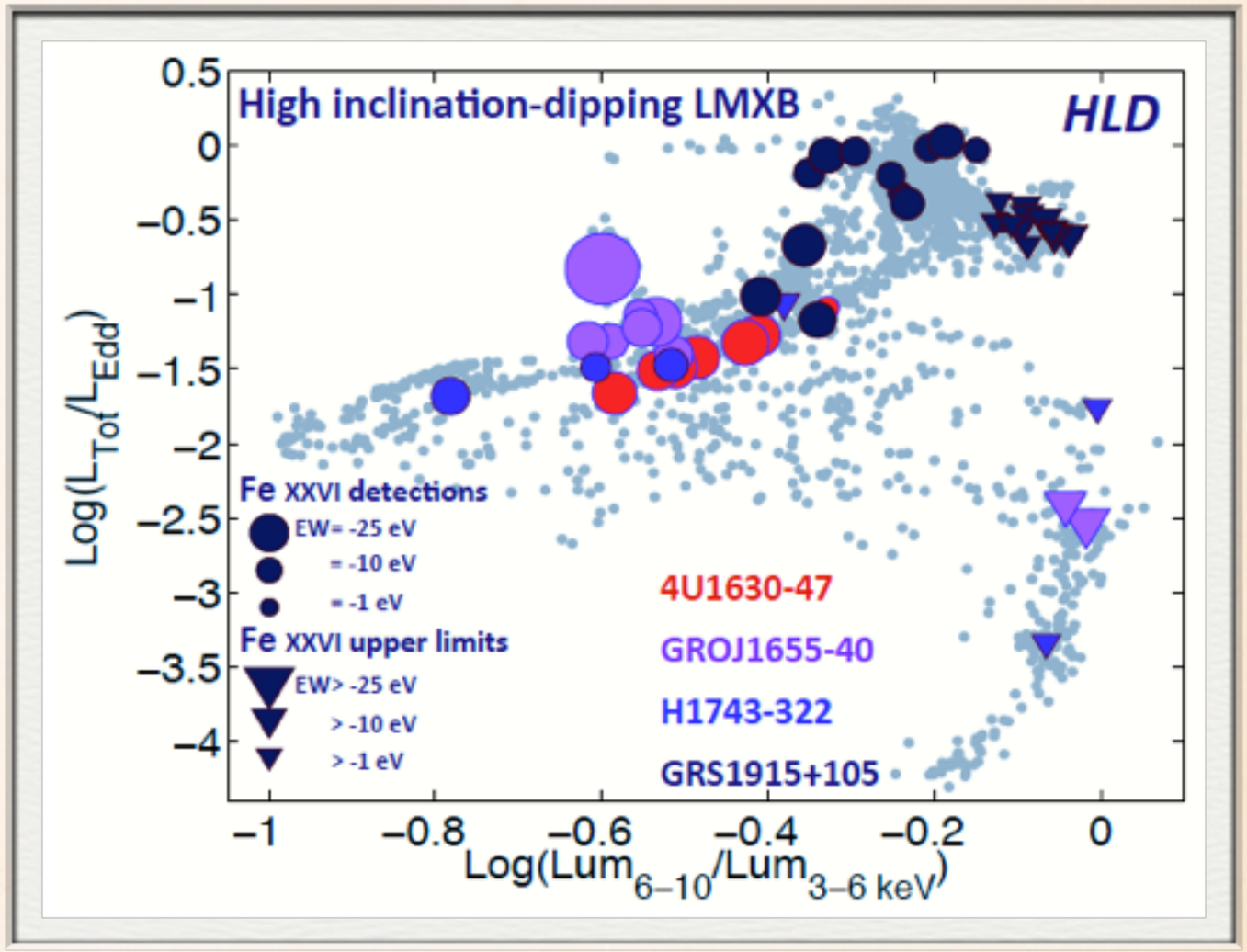
UPSHOT

- Long-term evolution of wind absorption around black holes is important to understand

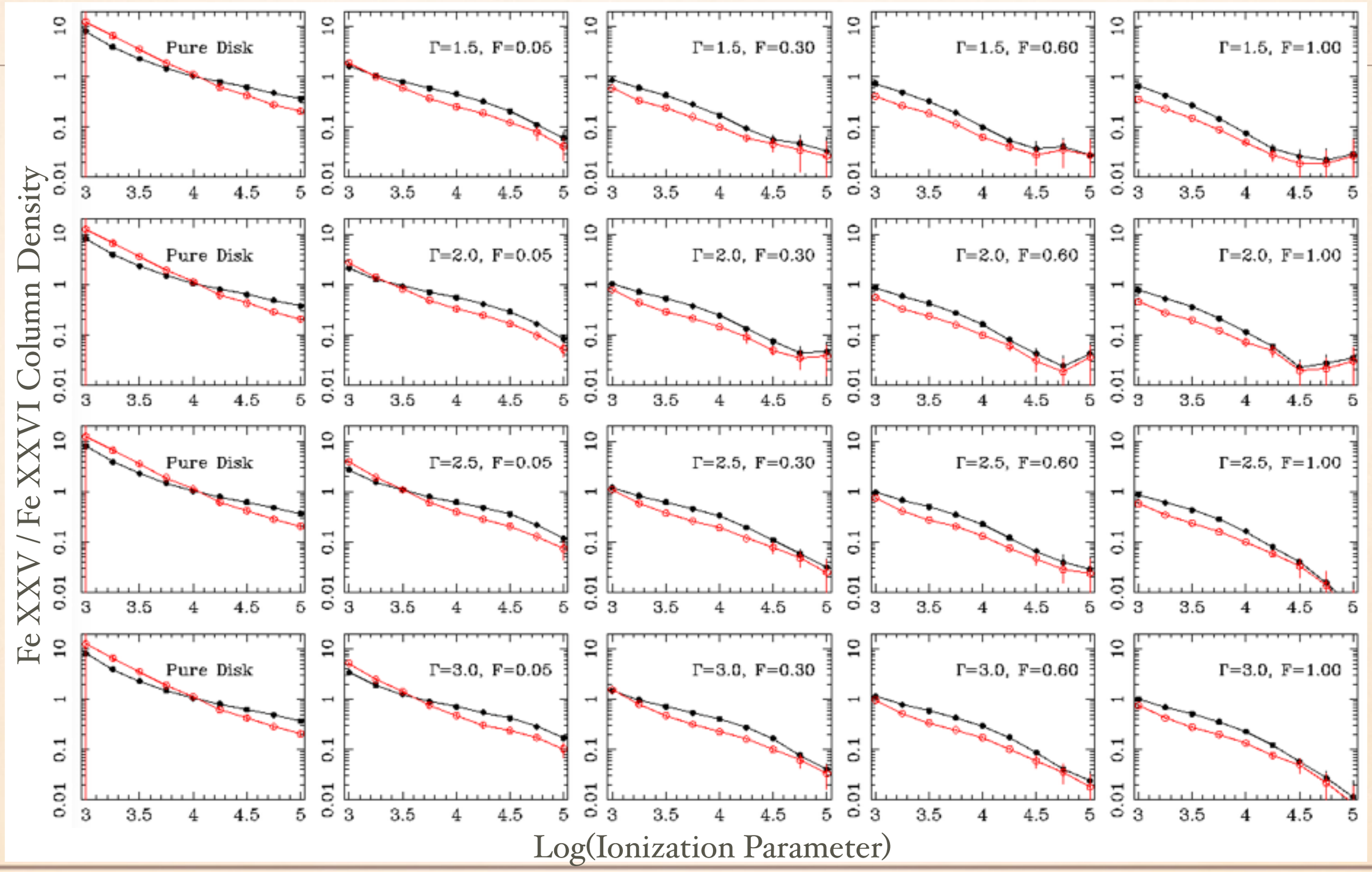
- Could be due to more ionization in harder states, but may be affected by thermodynamics, or may hint at wind driving physics

- **<u>For now</u>:** Yes, hard state shifts ionization balance, but lower fluxes imply *less* ionization!

- Tricky/next step: disentangling line significance and X-ray flux



WHAT DO WE SEE?



WHAT DO WE SEE?