Athena and XRISM spectra for dense MHD winds around black hole binaries

by

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with
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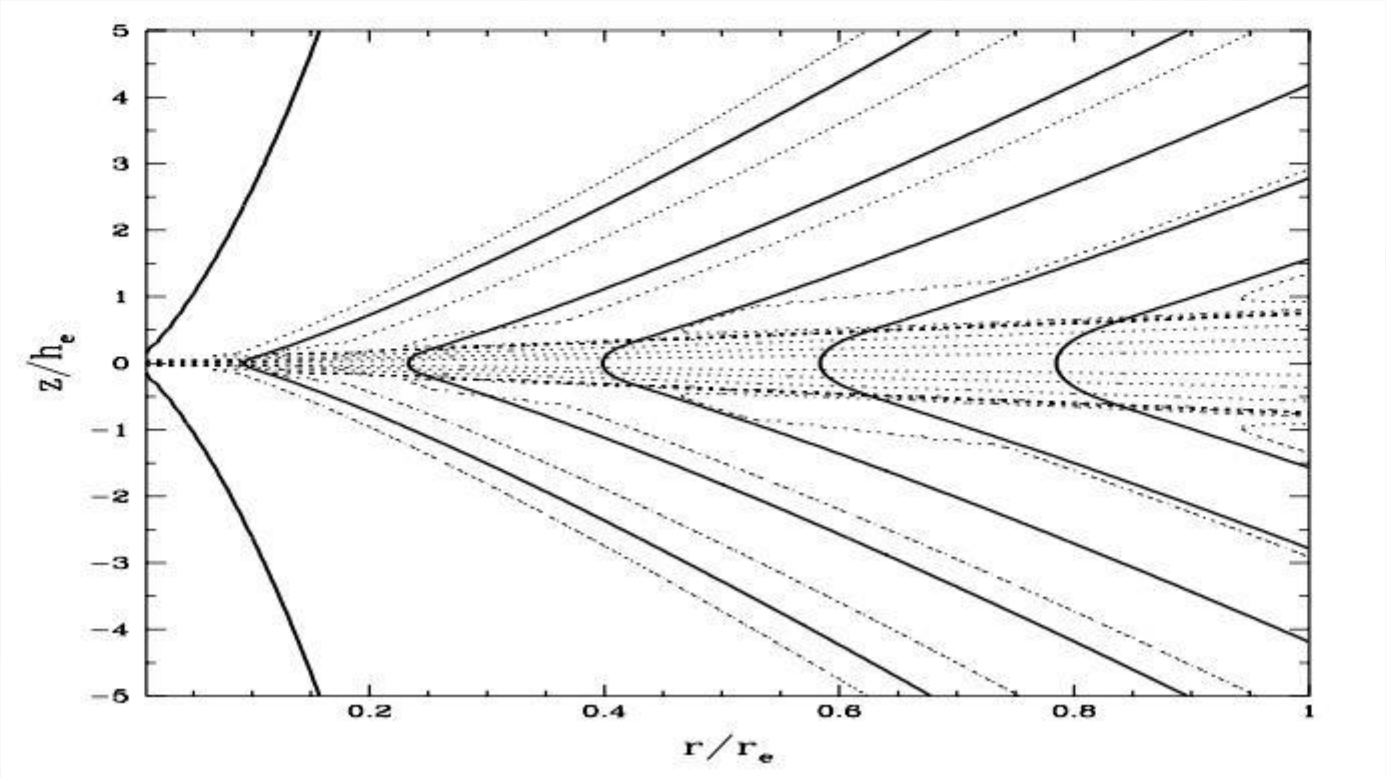
The Jet Emitting Disk (JED)

- The density at the base of the flow is NOT a free parameter

$$n^+ m_p = \rho^+ \simeq \frac{p}{\varepsilon} \frac{\dot{M}_{acc}}{4\pi \Omega_K r^3}$$

σ ~ 1/p, , V_{max} ~ $p^{-1/2}$



- Ejection efficiency p (where $\dot{M}_{acc} = r^p$)
- Important for parametrizing the outflow model

- Ferreira 1997, Casse & Ferreira 2000a, 2000b
- Ferreira and Casse 2004

The Jet Emitting Disk (JED)
and its scope for absorption line Winds

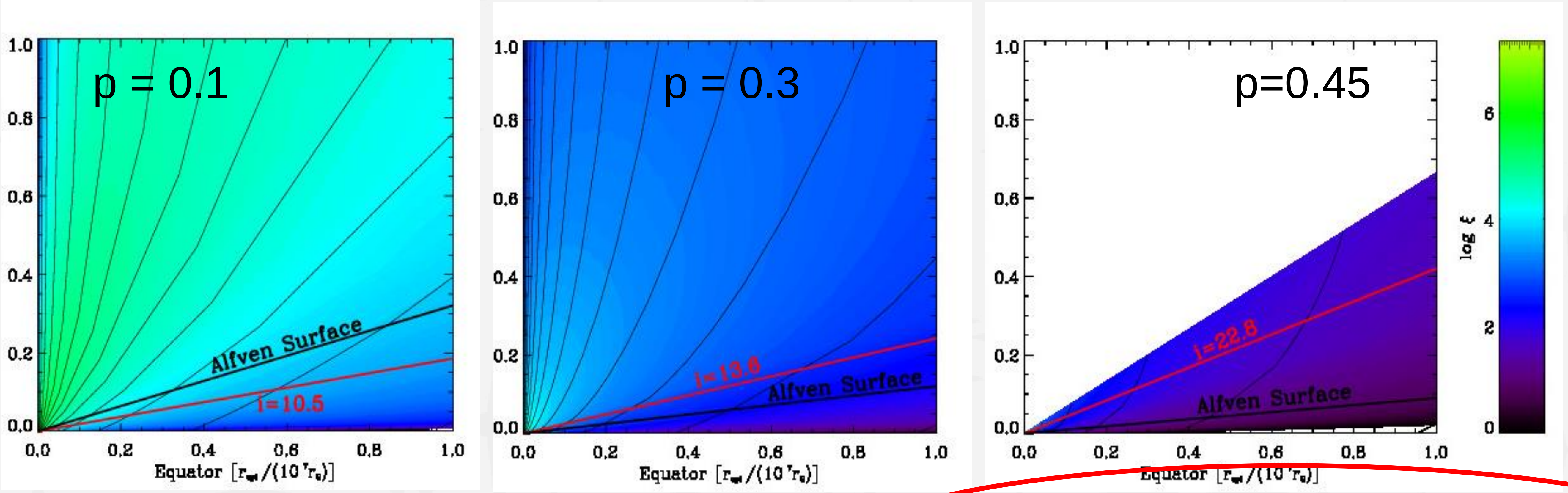
- The density at the base of the flow is NOT a free parameter

$$n^+ m_p = \rho^+ \simeq \frac{p}{\varepsilon} \frac{\dot{M}_{acc}}{4\pi \Omega_K r^3}$$

$\sigma \sim 1/p$, , $V_{max} \sim p^{-1/2}$

Warm Solutions

Symmetry Axis $[r_{cyl}/10^7 R_G]$



$\xi = L/nR^2$

Equator $[r_{cyl}/10^7 R_G]$

- Ejection efficiency p (where $\dot{M}_{acc} = r^p$)
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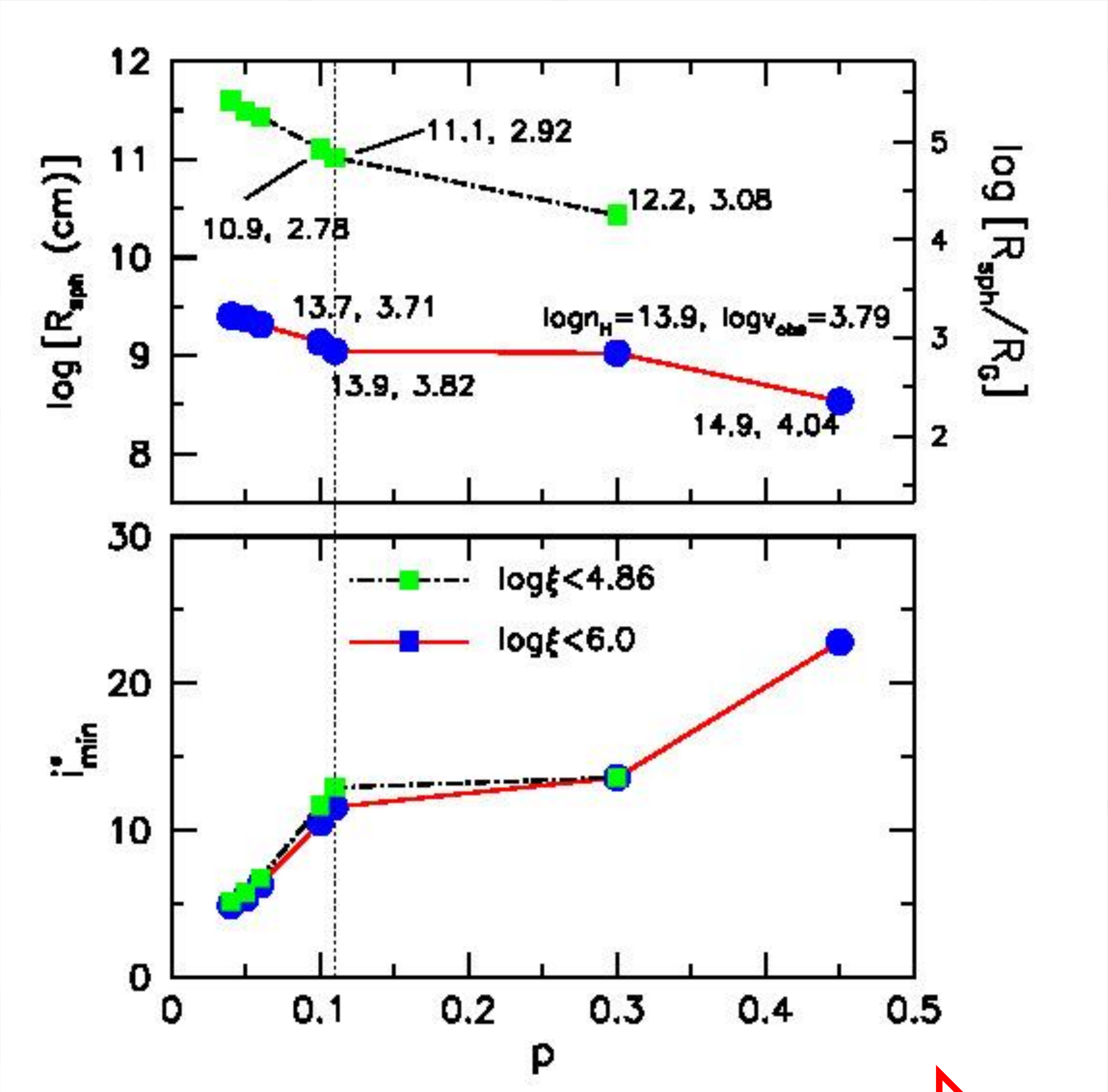
The Jet Emitting Disk (JED) and its scope for absorption line Winds

A suit of JEDs

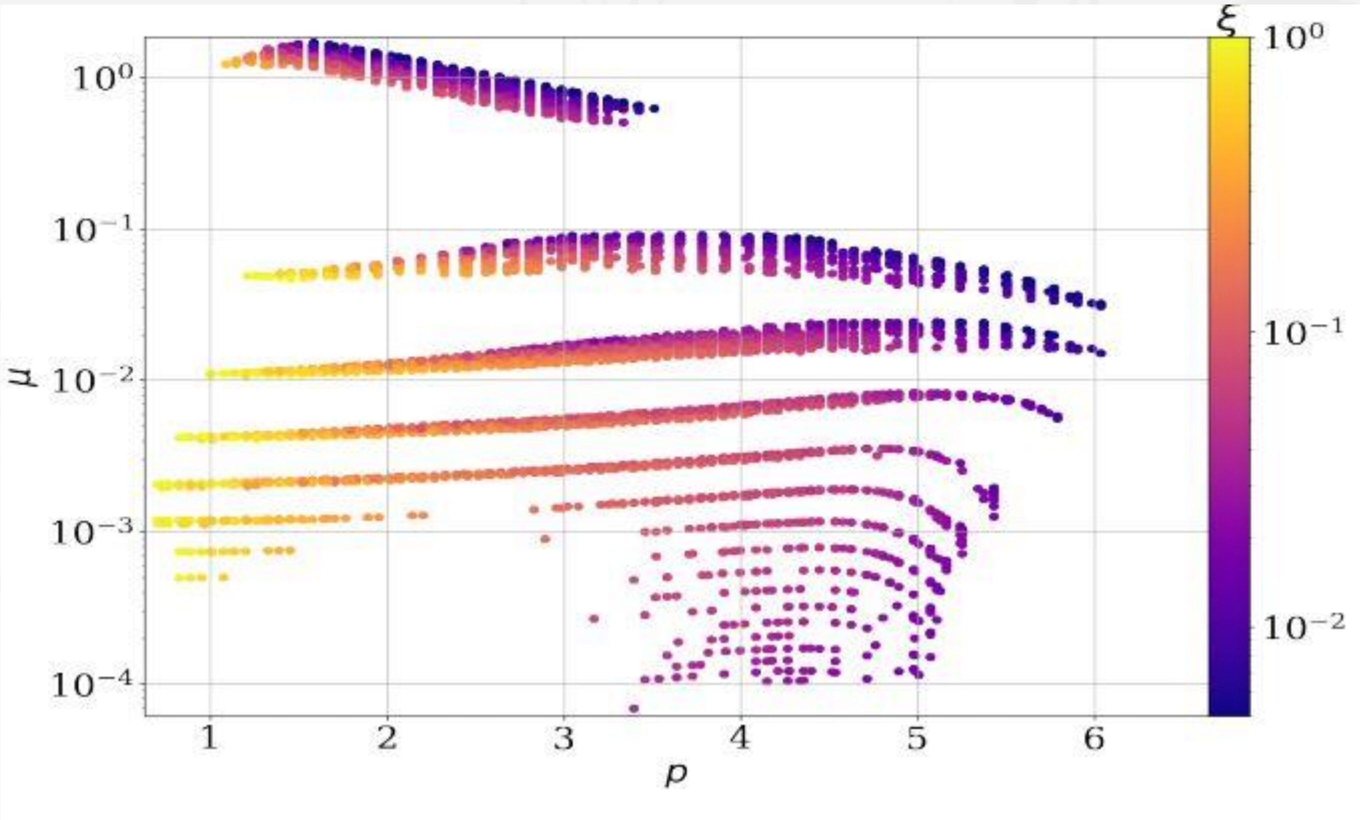


Increasing p == Denser outflow

- Ejection efficiency p (where $\dot{M}_{acc} = r^p$)
- Important for parametrizing the outflow model

Chakravorty+ 2016, A&A, 589A, 119
Chakravorty+ 2021 in preparation

Also see
Jacquemin-Ide, Ferreira & Lesur, 2019MNRAS.490.3112J
For other flavours or JED models



The Jet Emitting Disk (JED) and its scope for absorption line Winds

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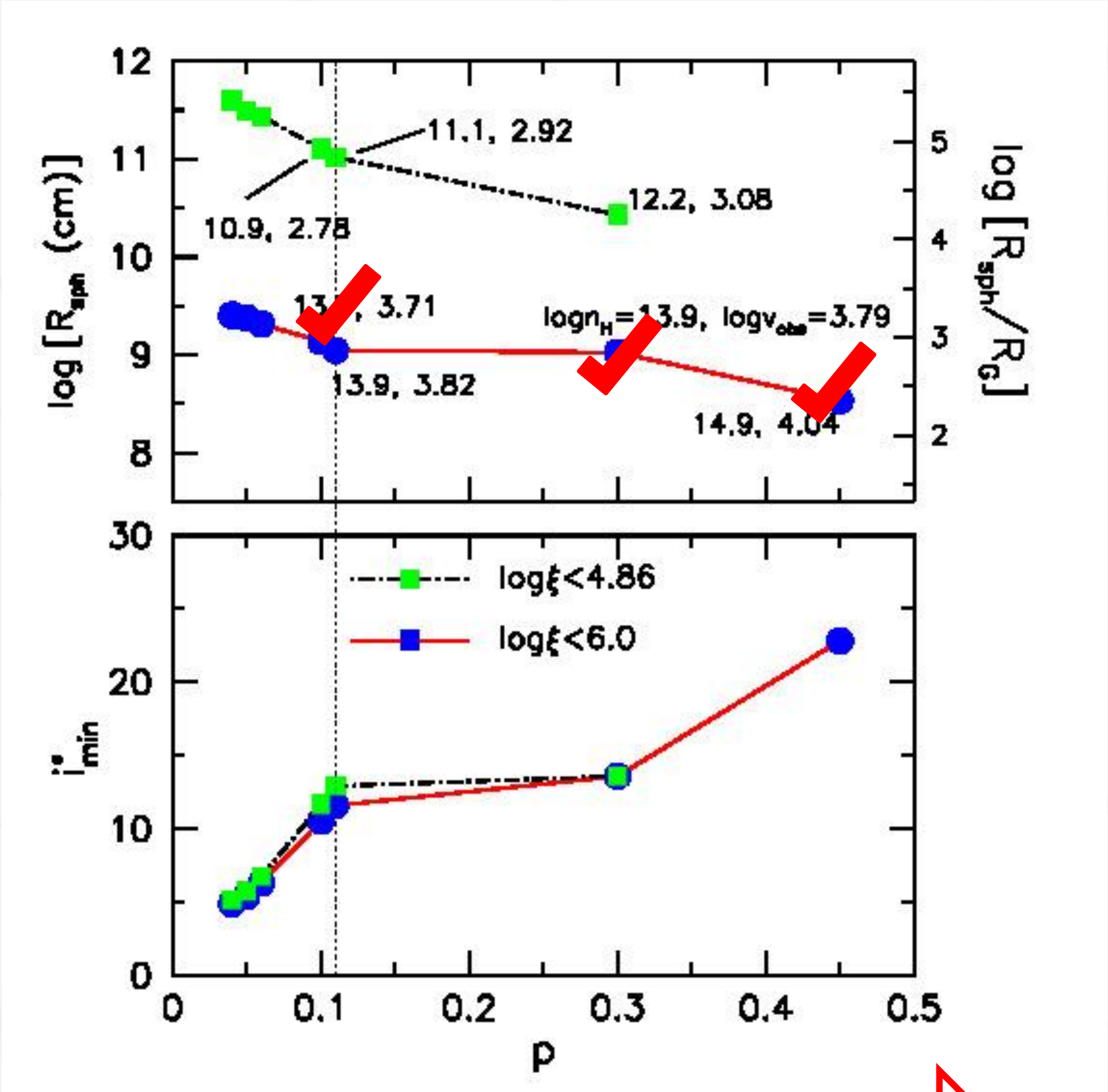

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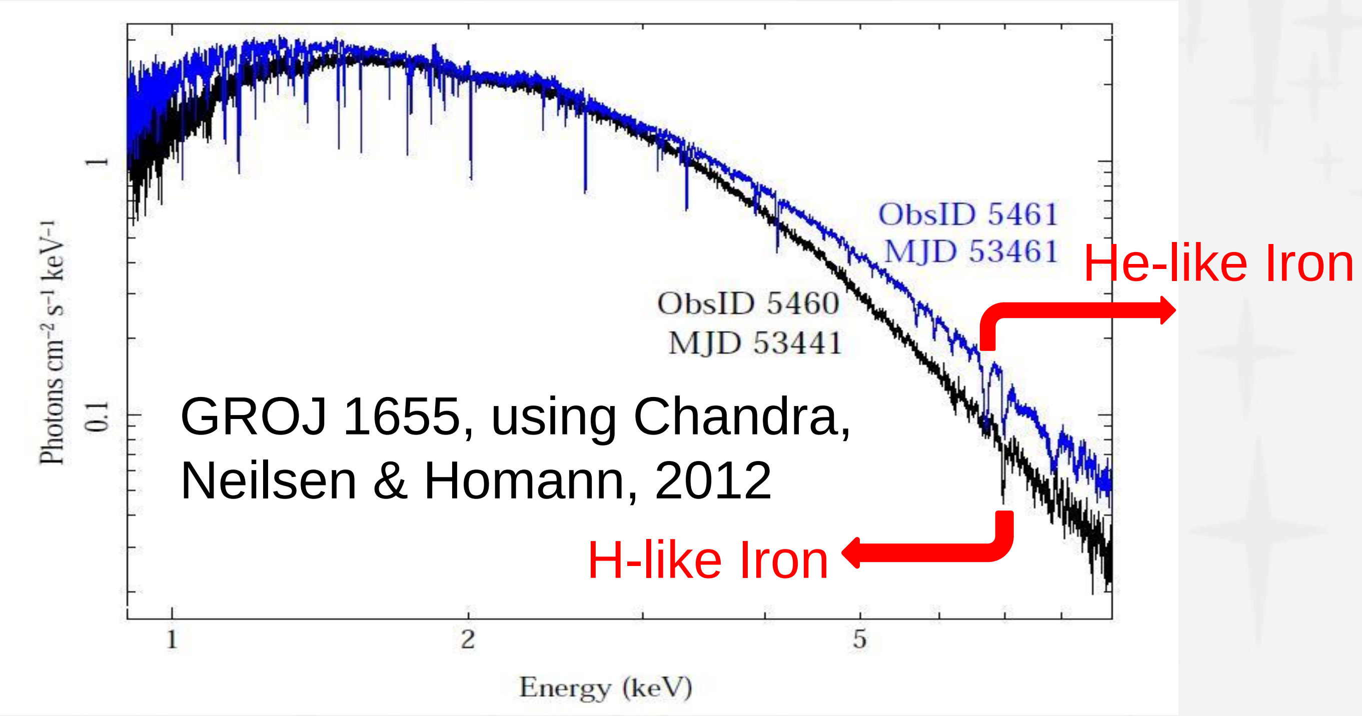
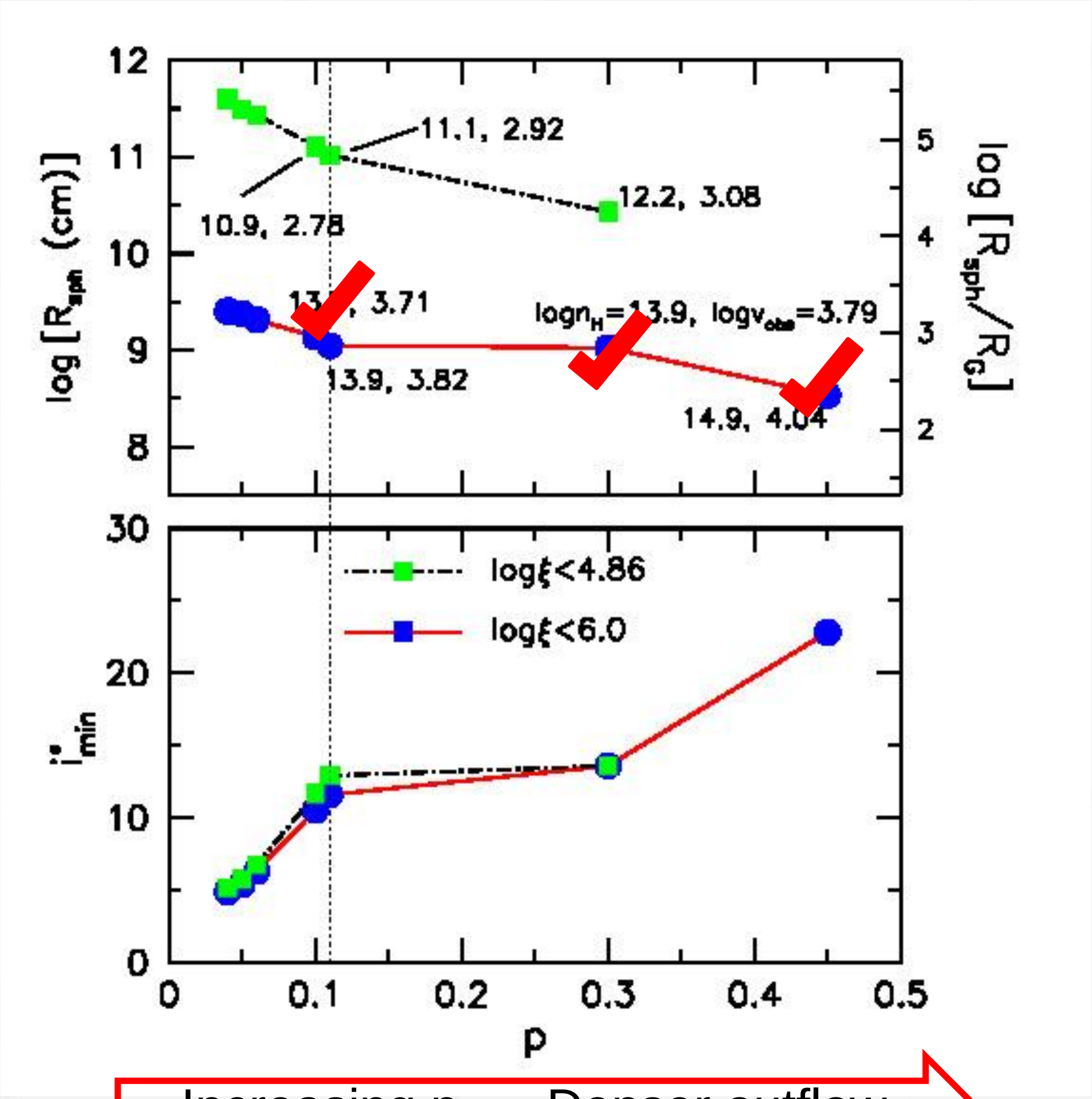
- We started spectral predictions with Dense Models
- Why Dense Solution?



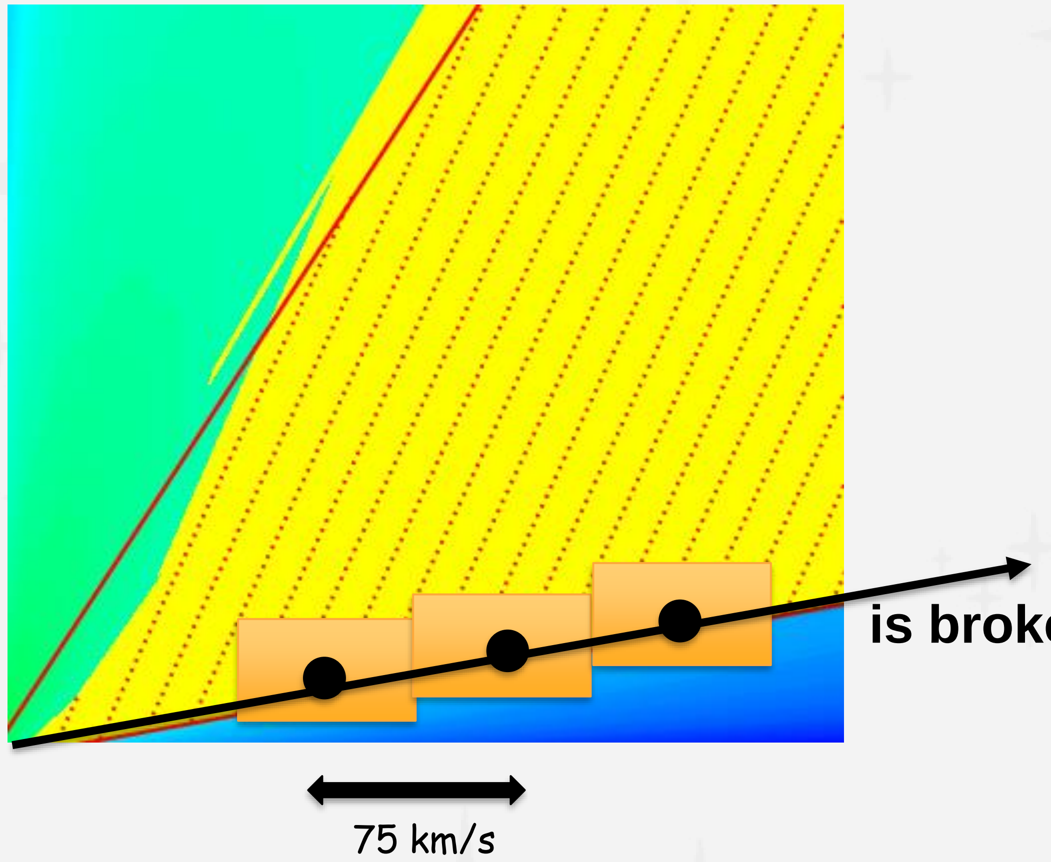
- If we can explain observations – absorption lines – in winds
- **The model parameters will relate to the accretion state of the BHB**

The Jet Emitting Disk (JED) and its scope for absorption line Winds

A suit of JEDs



Increasing p == Denser outflow

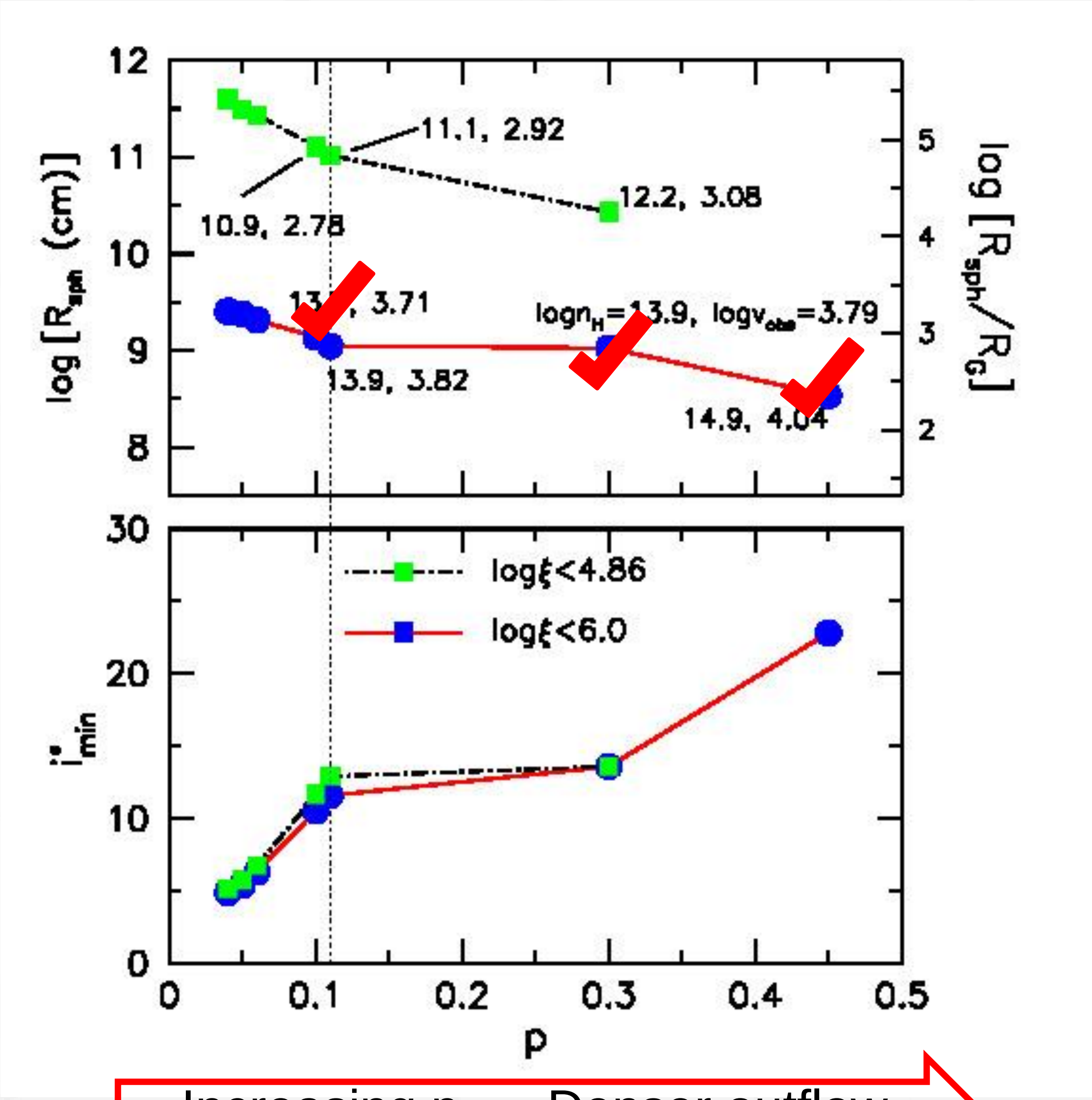


Line of sight is broken into slabs separated by Δv = 75 Km/s

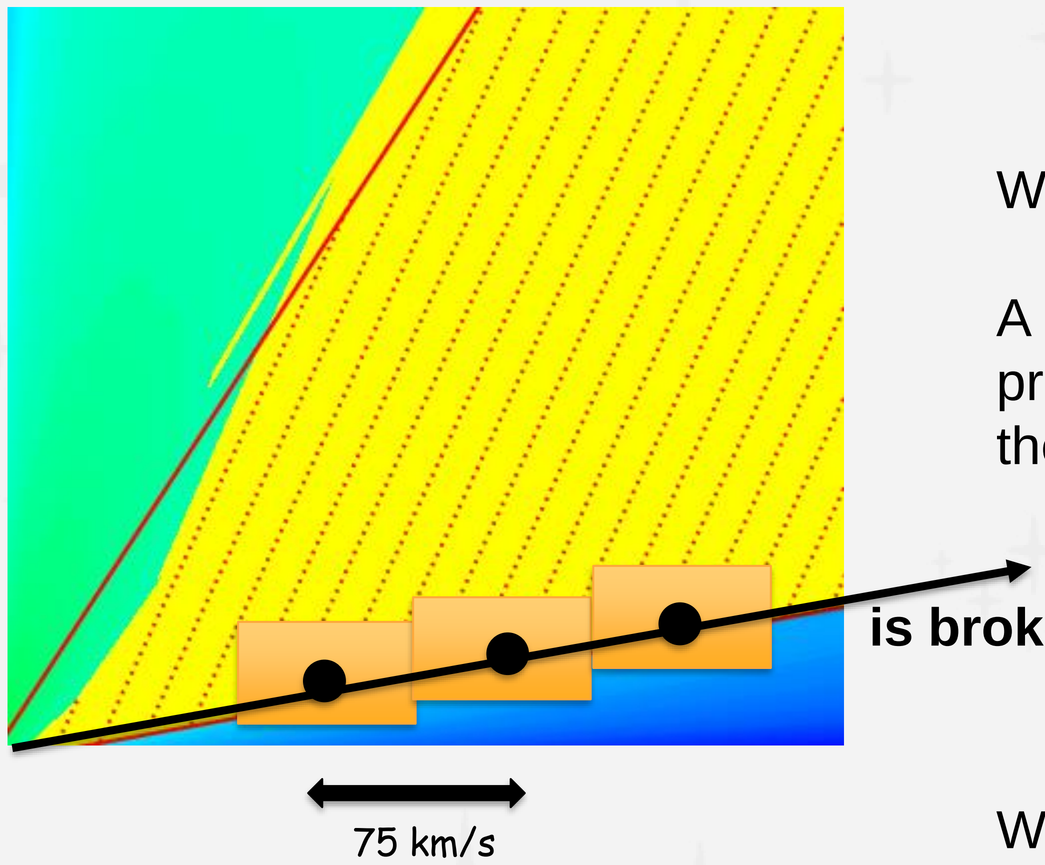
Final Aim: Library of Absorption spectra in terms of MHD flow parameters (p and ε) and i (inclination angle)

The Jet Emitting Disk (JED) and its scope for absorption line Winds

A suit of JEDs



Increasing p == Denser outflow



Line of sight is broken into slabs separated by Δv = 75 Km/s

Final Aim: Library of Absorption spectra in terms of MHD flow parameters (p and ε) and i (inclination angle)

Important Notes

We are keeping our methods generic

A code that can work for any outflow solution provided as an ascii file containing the values of the relevant physical parameters.

We use a velocity resolution that can take care of future missions –
At 6.5 keV,
XRISM will have resolution ~ 300 km/s;
Athena will have resolution ~100 Km/s

The limit 75 km/s comes from the limits of CLOUDY version C08.
Since its better than the instrument resolutions, we use this.
We use the same resolution in XSTAR

The Jet Emitting Disk (JED)
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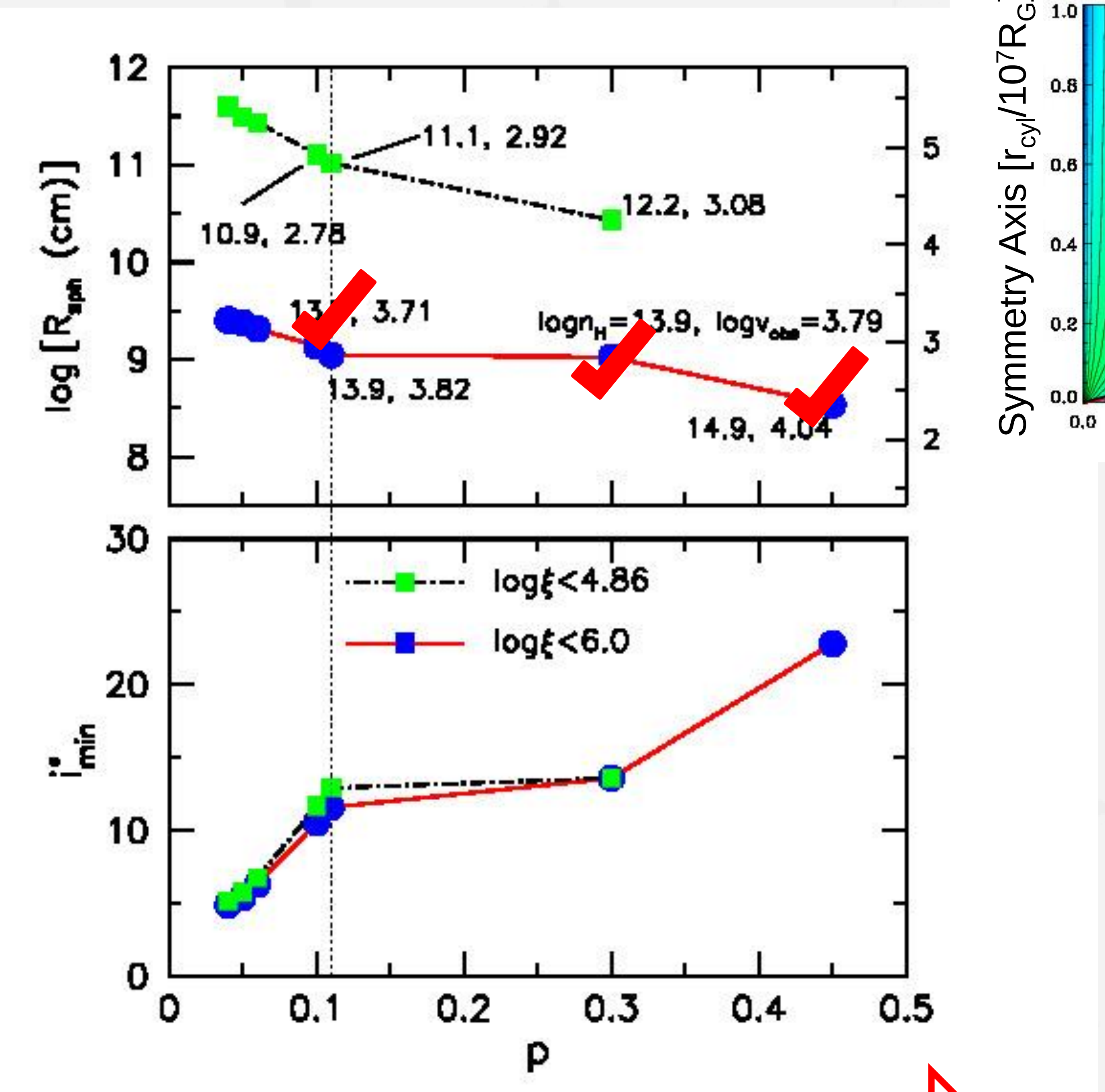
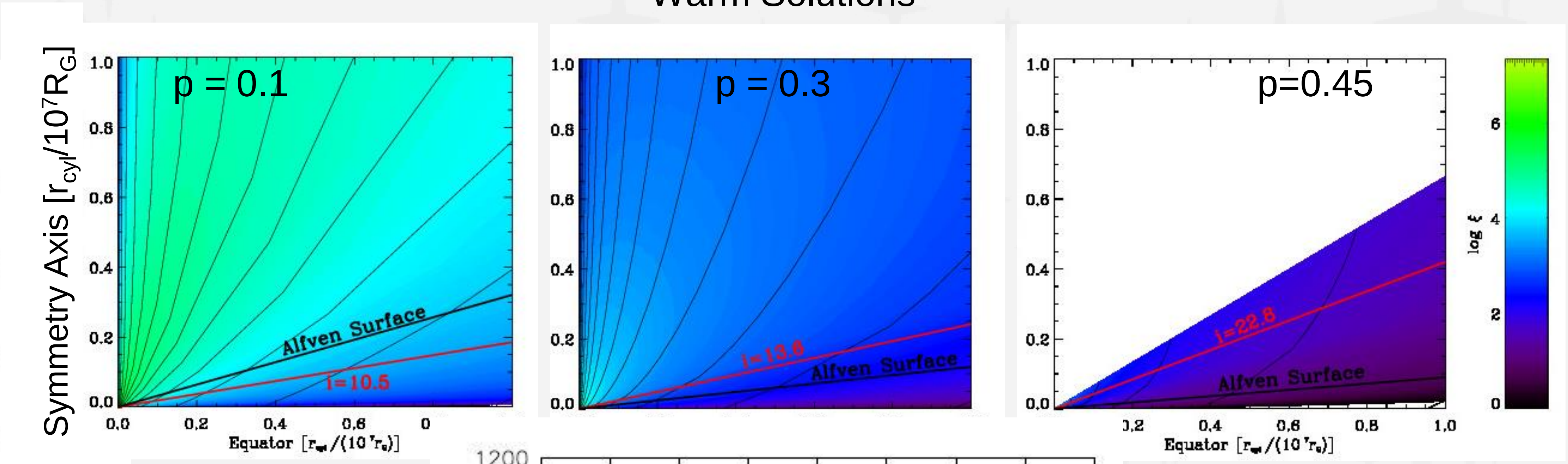
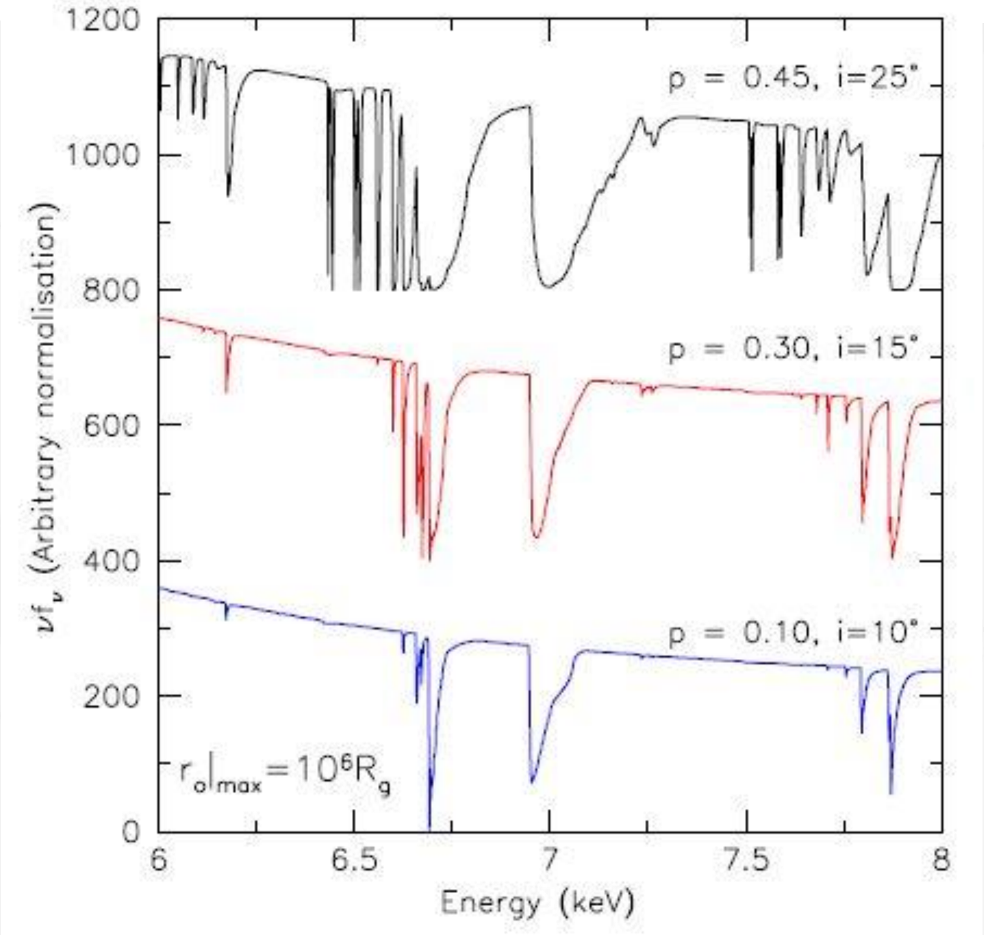
A suit of JEDs



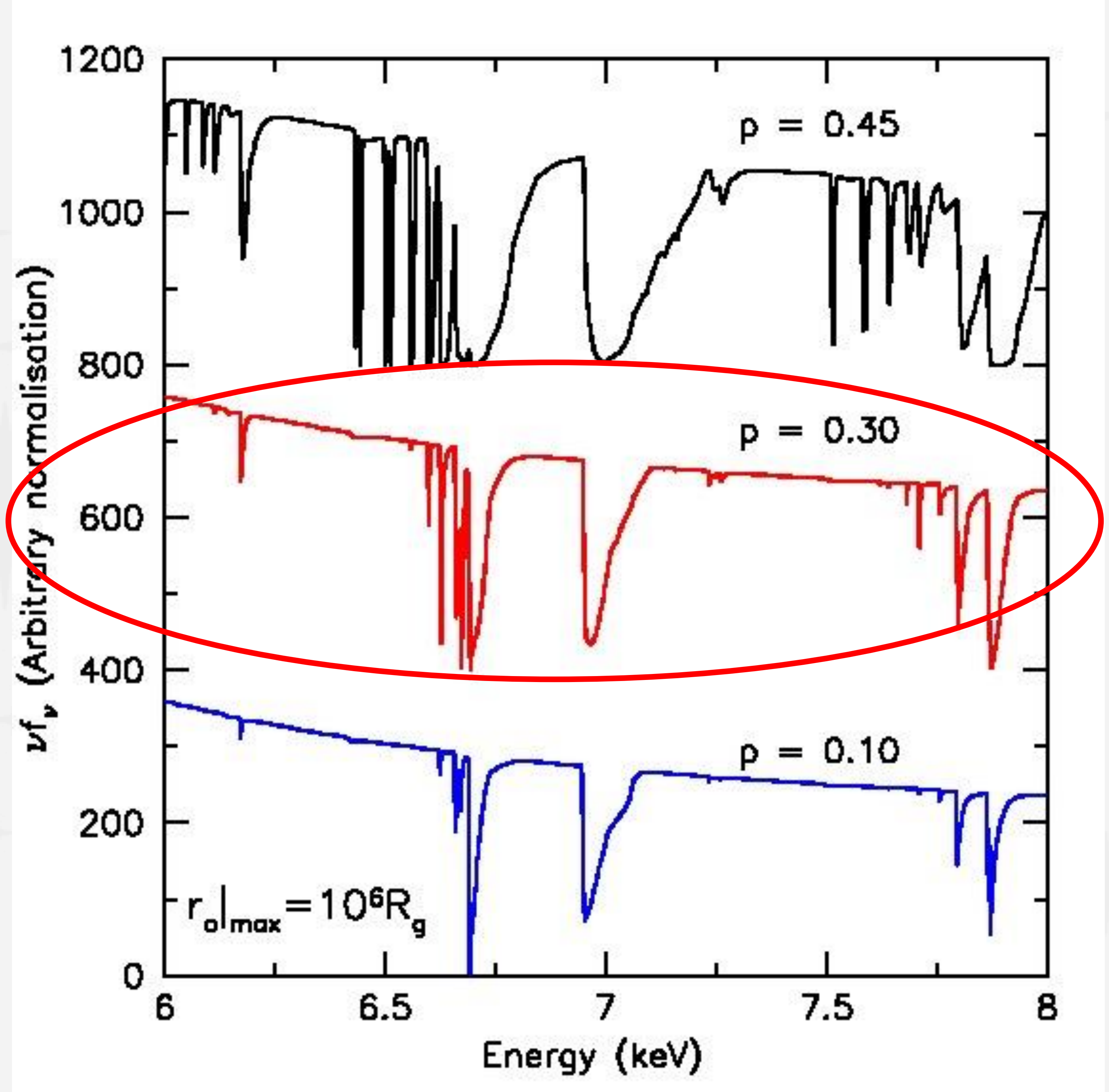
Increasing p == Denser outflow

Warm Solutions

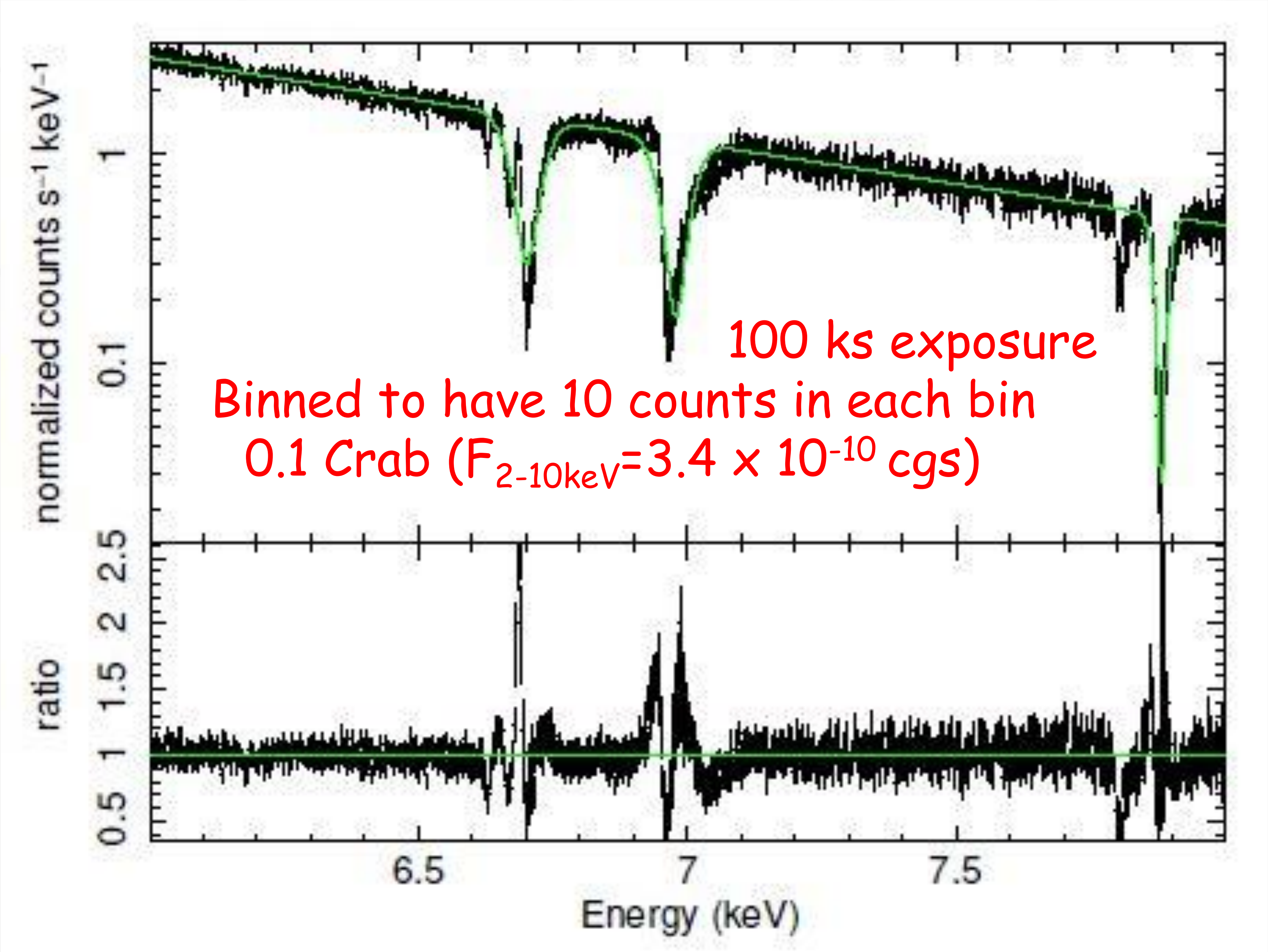




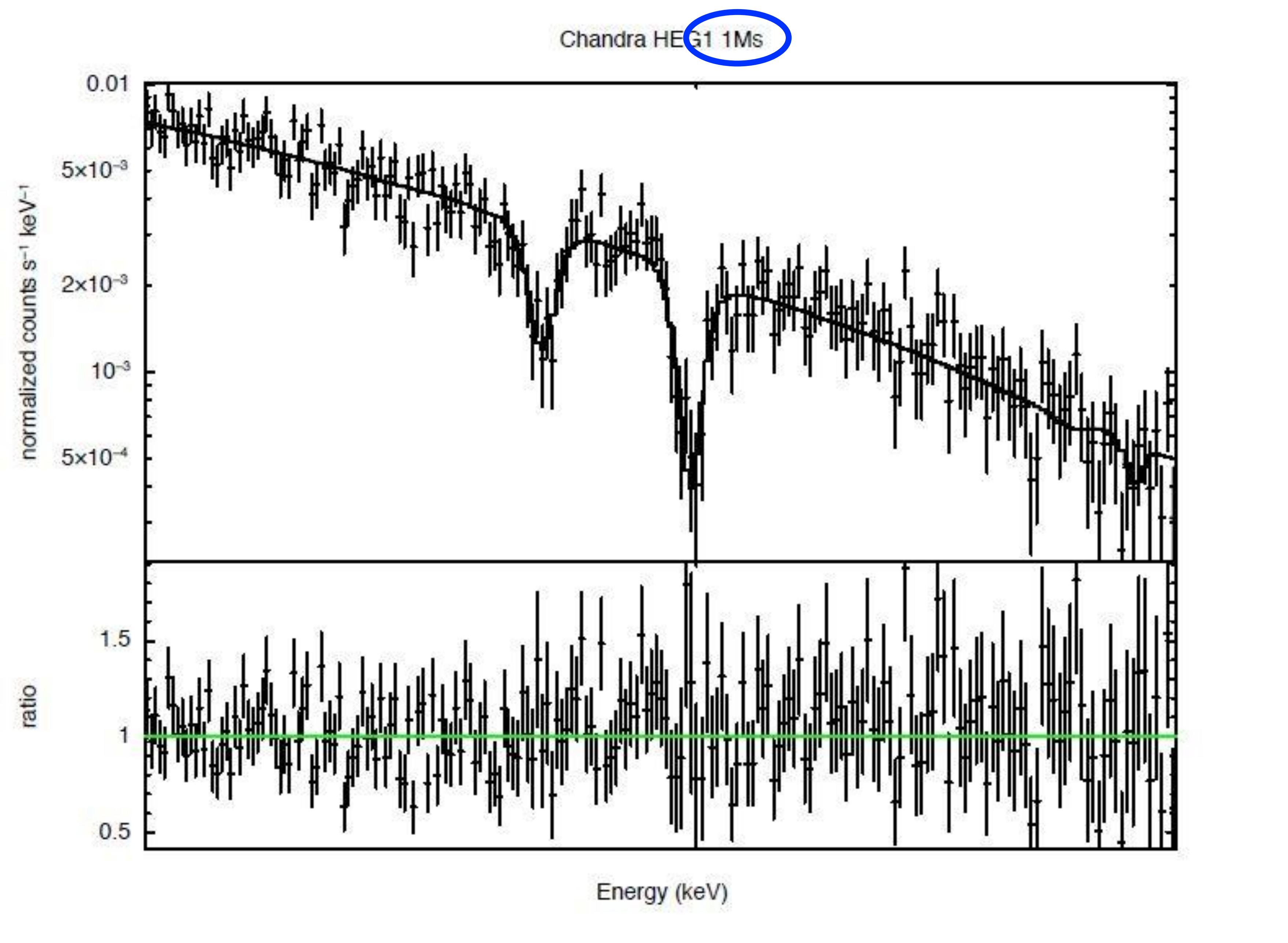
How will Athena and Xrism see these spectra
Interpretations



ATHENA XIFU resolution is ~100 km/s at ~ 6.5 keV

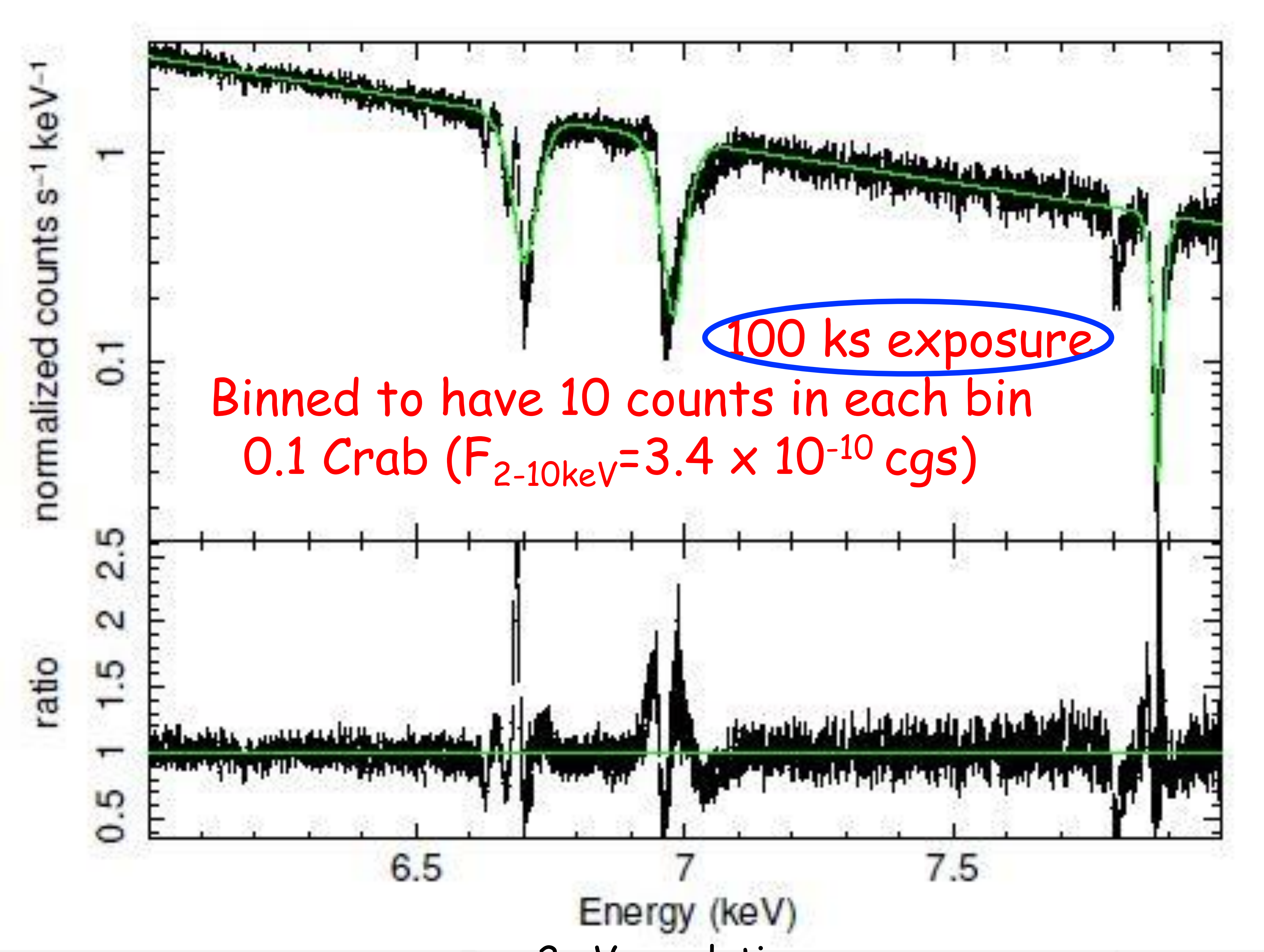


Athena and Chandra comparison



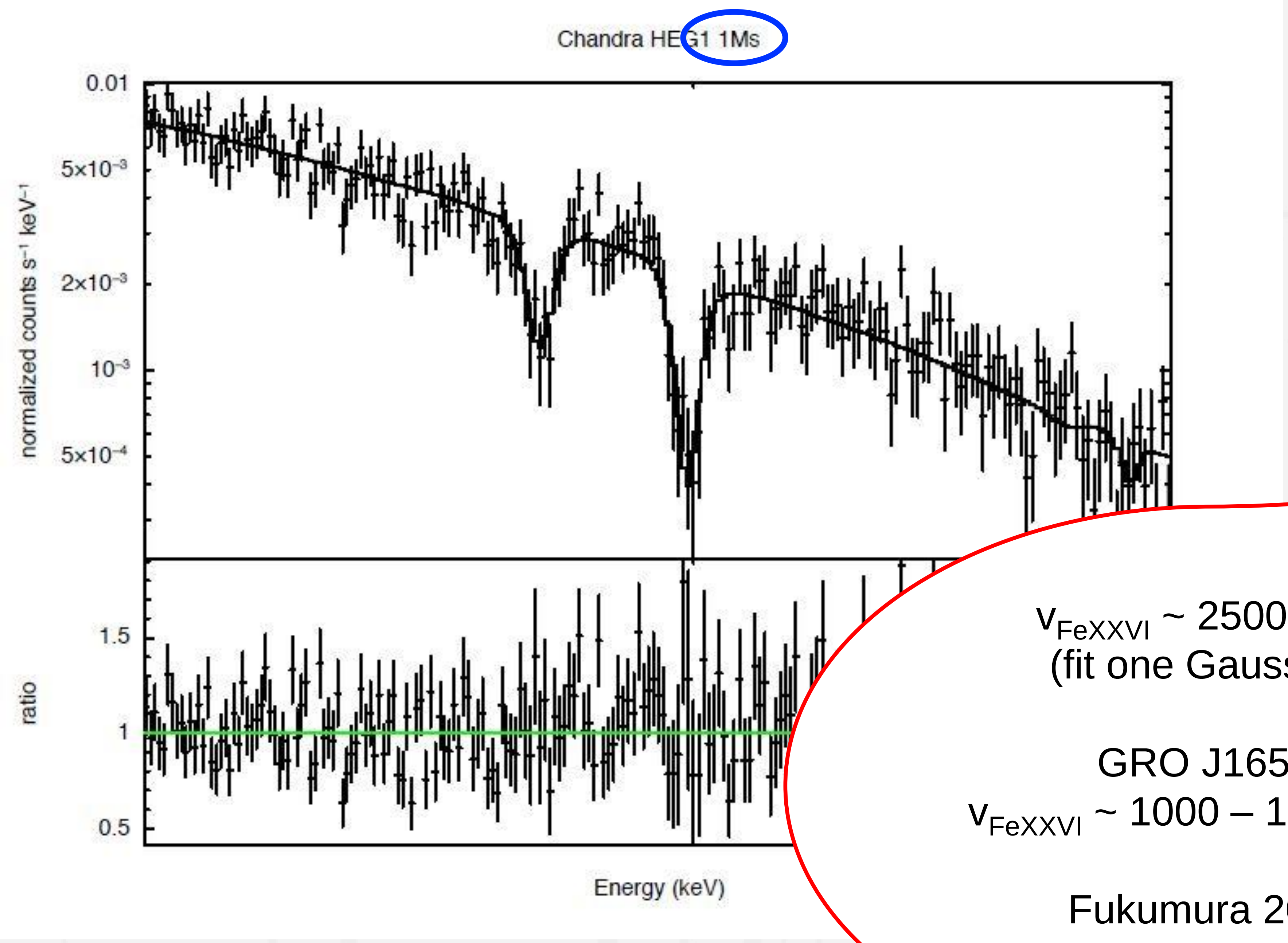
~ 50 eV resolution
In Chandra 3rd order

ATHENA XIFU resolution is ~100 km/s at ~ 6.5 keV



~ 2 eV resolution

Athena and Chandra comparison



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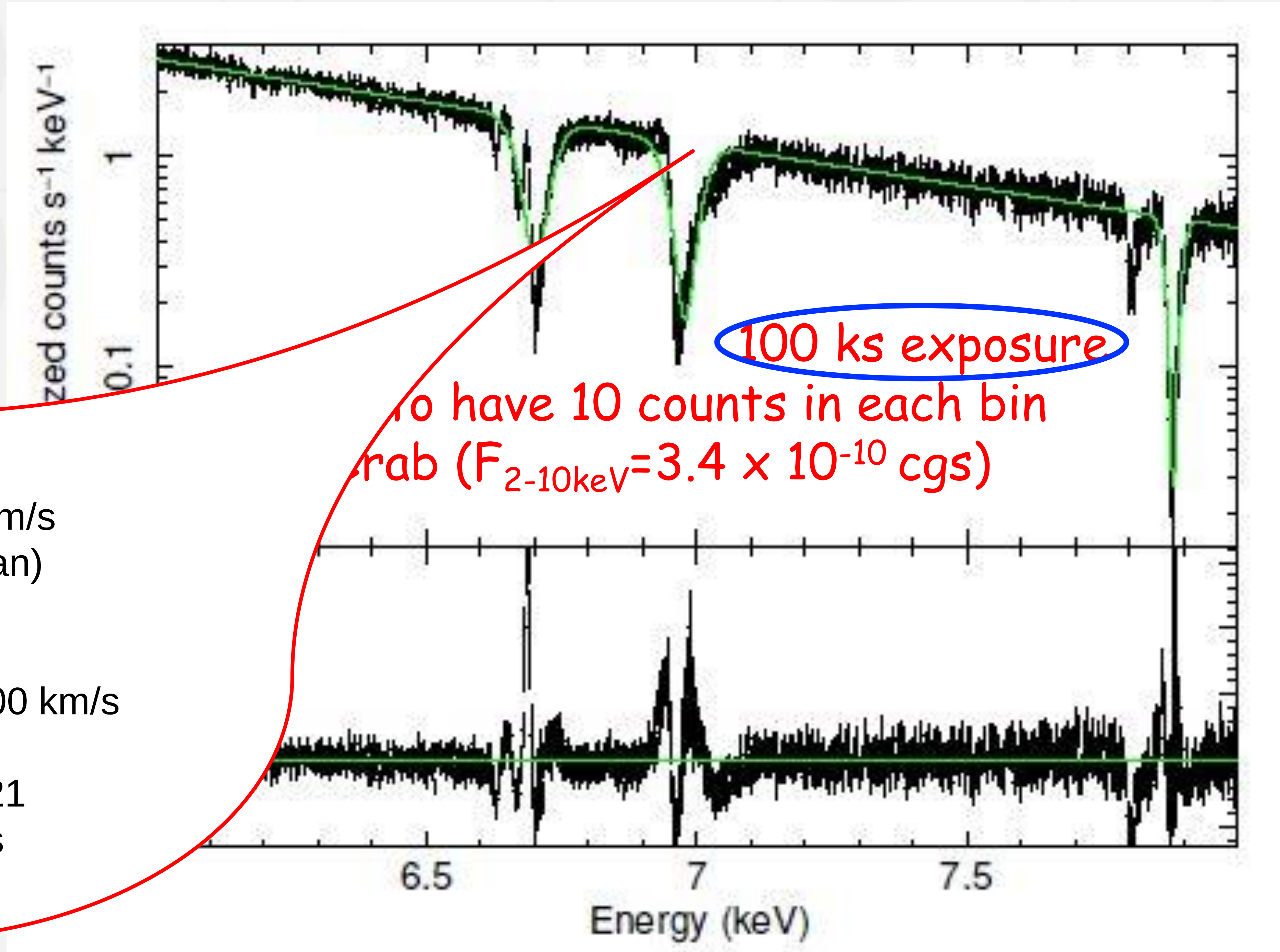

~ 2 eV resolution

v_{FeXXVI} ~ 2500 km/s
(fit one Gaussian)

GRO J1655:
v_{FeXXVI} ~ 1000 – 1700 km/s

Fukumura 2021
v ~ 600 Km/s

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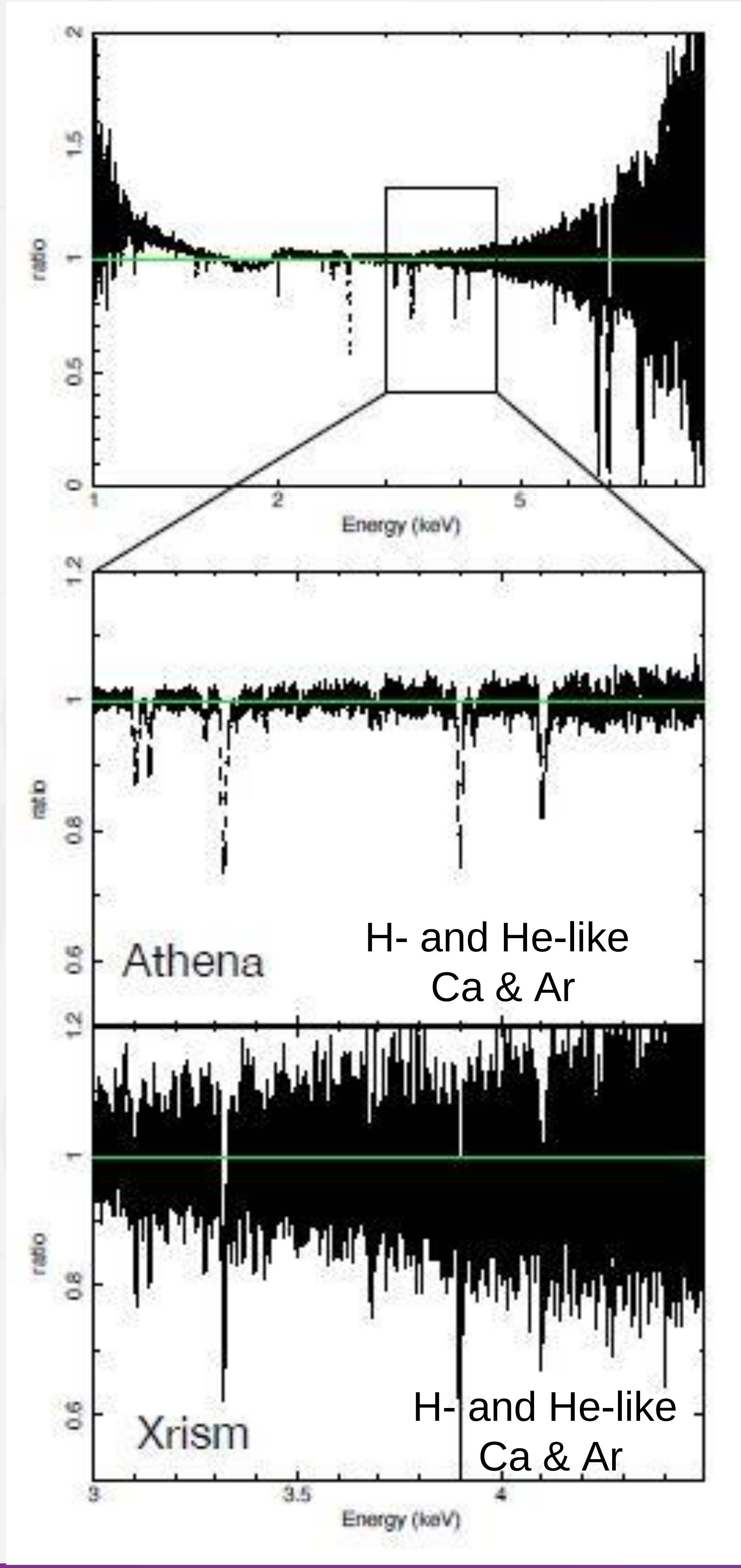
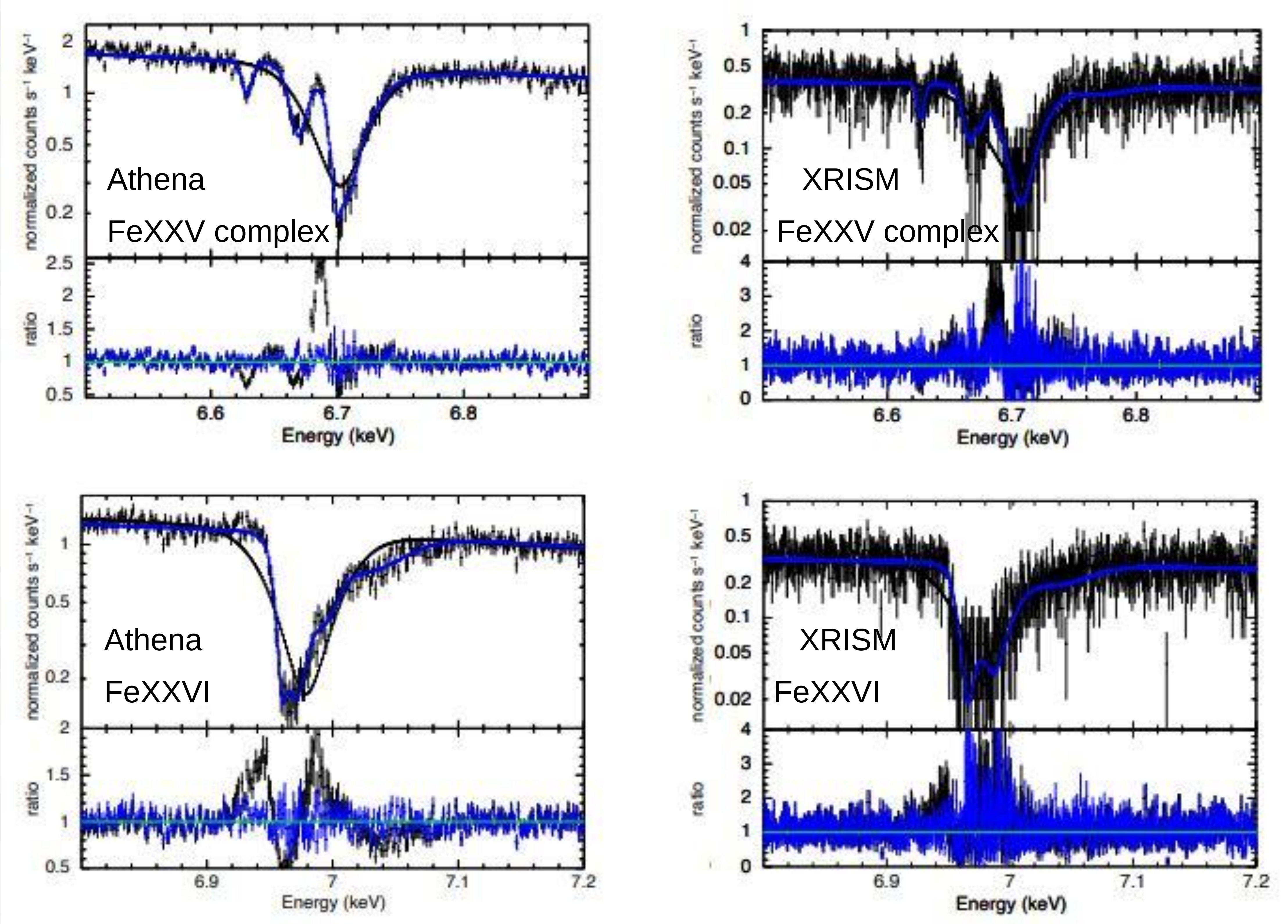
Interpretations





The FeXXVI Lyα Doublet

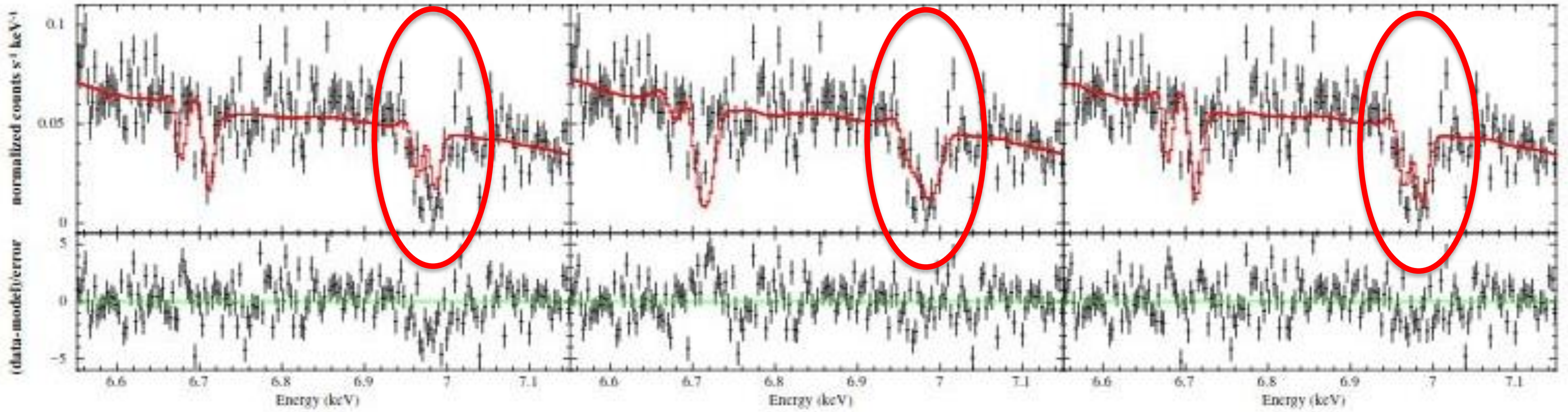


Figure 10. The observed Chandra third order HEG spectra (co-added from the 4 TE observations) compared to our models with $v_{\rm turb} = 0$(left), v_R (middle), and v_ϕ (right). It is clear that the models with $v_{\rm turb} = v_R$ overestimate the observed line widths. All models underestimate the depth of the Fe XXVI K$\alpha_{1,2}$ lines, and overestimate the blueshift of the Fe XXV y intercombination line. The best fit inclination angles for each are $\cos\theta = 0.35, 0.47, 0.37$.

Chandra 3rd Order Spectrum for GX 13+1 Neutron Star wind
Tomaru et.al. 2007.14607

Those reduced grid's density and velocity are input into the radiation transfer code MONACO (Odaka et al. 2011). This code uses the Geant4 toolkit library (Agostinelli et al. 2003) for photon tracking in arbitrary three-dimensional geometry, but has its modules handling photon interactions Watanabe et al. (2006); Odaka et al. (2011) so that it can treat the interactions such as photo-ionisation or photo-excitation, and photons generated via recombination and atomic de-excitation. The energies and oscillator strengths for the H and He-like ions were calculated from the Flexible Atomic Code (Gu 2008) as detailed in Tab. 1.

Table 1. Detailed parameters for each line included in these MONACO simulations. Note that we list only lines which have oscillator strength larger than 10^{-3}. These are listed by increasing energy of the transition.

Line ID	Energy [keV]	Oscillator strength
Fe XXV Heα y	6.668	6.57×10^{-2}
Fe XXV Heα w	6.700	7.26×10^{-1}
Fe XXVI Lyα_2	6.952	1.36×10^{-1}
Fe XXVI Lyα_1	6.973	2.73×10^{-1}
Ni XXVII Heα y	7.765	8.50×10^{-2}
Ni XXVII Heα w	7.805	7.06×10^{-1}
Fe XXV Heβ y	7.872	1.37×10^{-2}
Fe XXV Heβ w	7.881	1.39×10^{-1}
Ni XXVIII Lyα_2	8.073	1.36×10^{-1}
Ni XXVIII Lyα_1	8.102	2.72×10^{-1}
Fe XXVI Lyβ_2	8.246	2.55×10^{-2}
Fe XXVI Lyβ_1	8.253	5.23×10^{-2}
Fe XXV Heγ y	8.292	5.18×10^{-3}
Fe XXV Heγ w	8.295	5.10×10^{-2}

The FeXXVI Lya Doublet

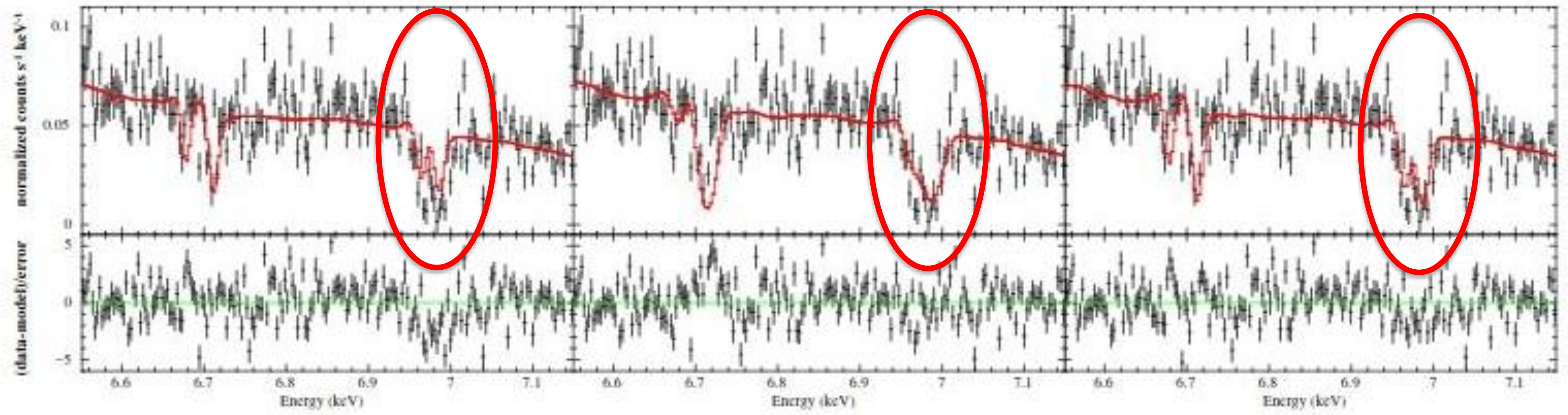


Figure 10. The observed Chandra third order HEG spectra (co-added from the 4 TE observations) compared to our models $v_{turb} = 0$(left), v_R (middle), and v_ϕ (right). It is clear that the models with $v_{turb} = v_R$ overestimate the observed line widths. All m… underestimate the depth of the Fe XXVI K$\alpha_{1,2}$ lines, and overestimate the blueshift of the Fe XXV y intercombination line. The best fit inclination angles for each are $\cos\theta = 0.35, 0.47, 0.37$.

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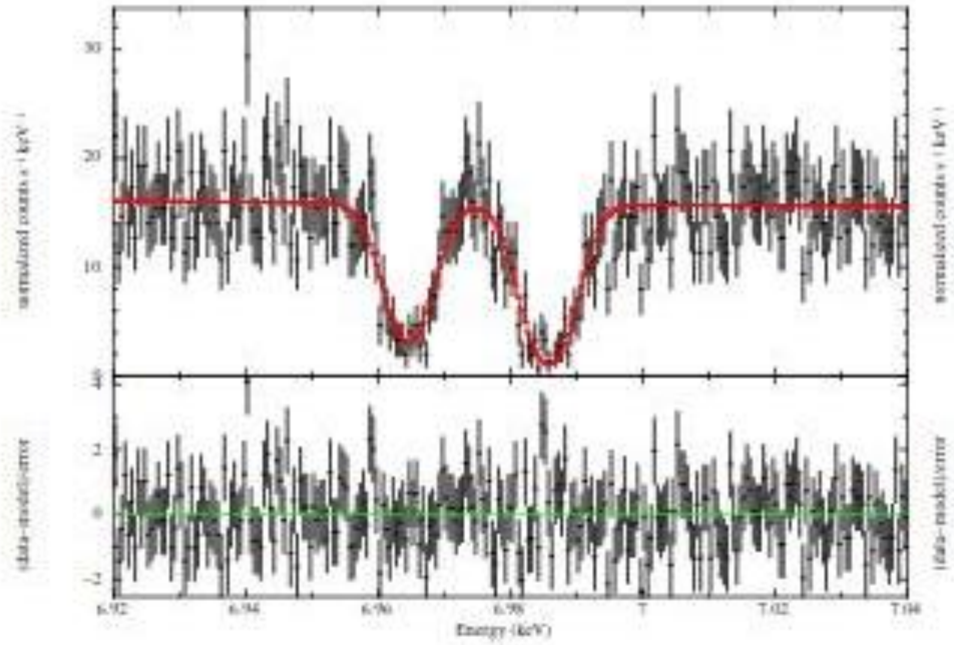

Expected XRISM spectrum of the FeXXVI Lya doublet

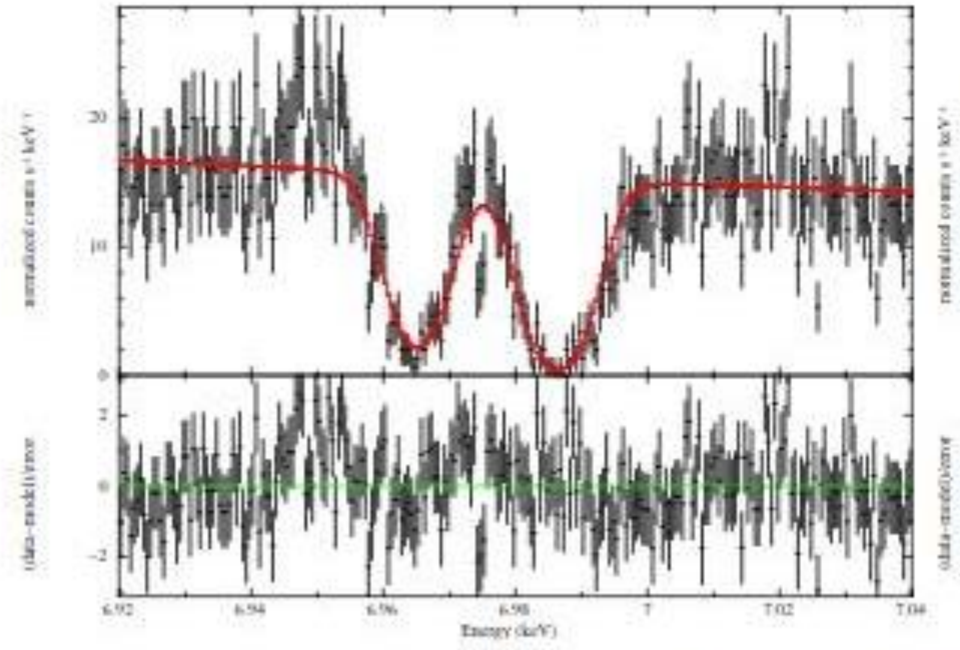

Figure 13. As in Fig.12 but $v_{turb} = v_\phi$. Th…

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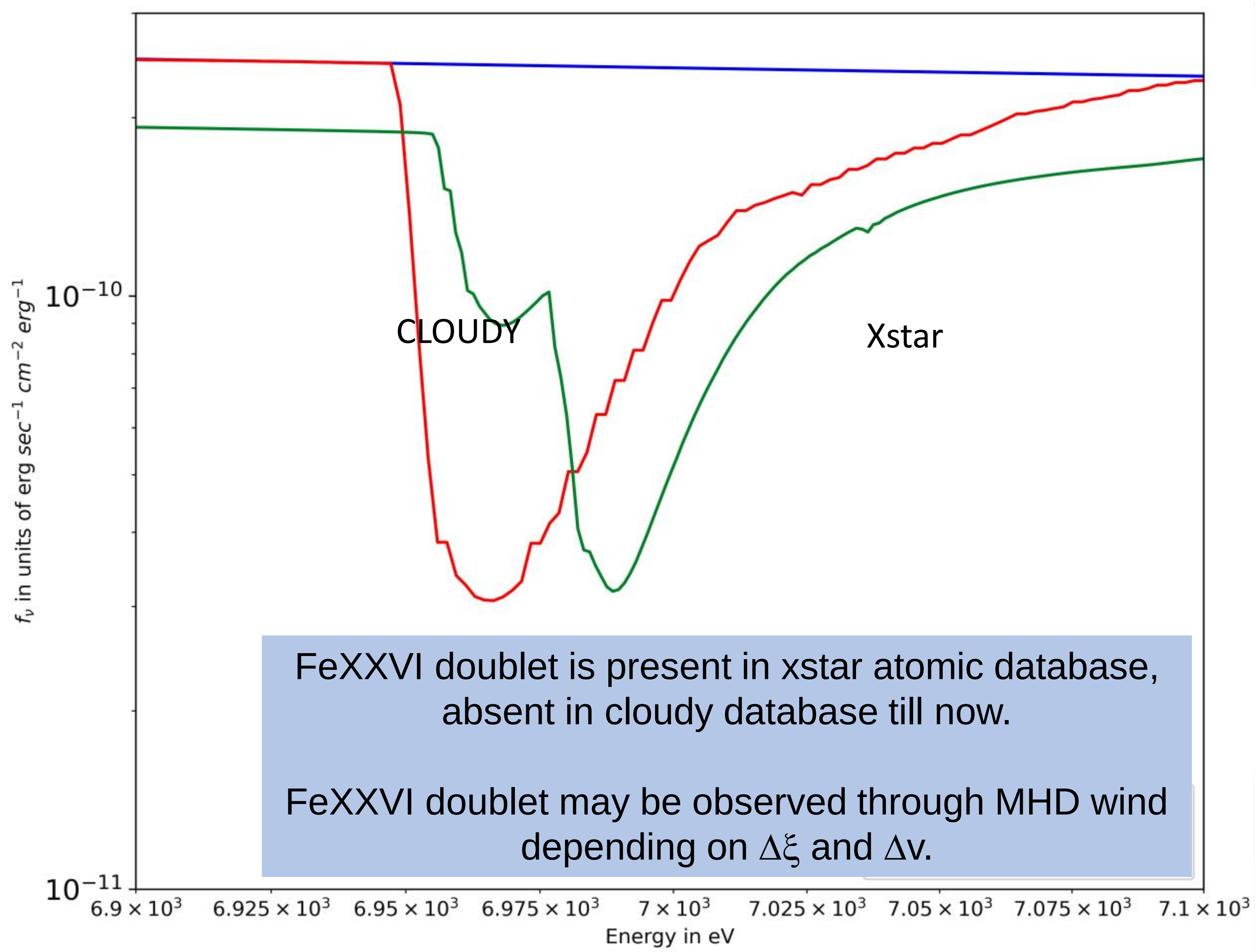
Will Athena and Xrism see the Doublet from MHD Winds?

Comparison between output absorption spectra generated using cloudy and xstar for MHD wind

Typical MHD wind:

Outer radius is fixed at 1.0e6 gravitational radii.

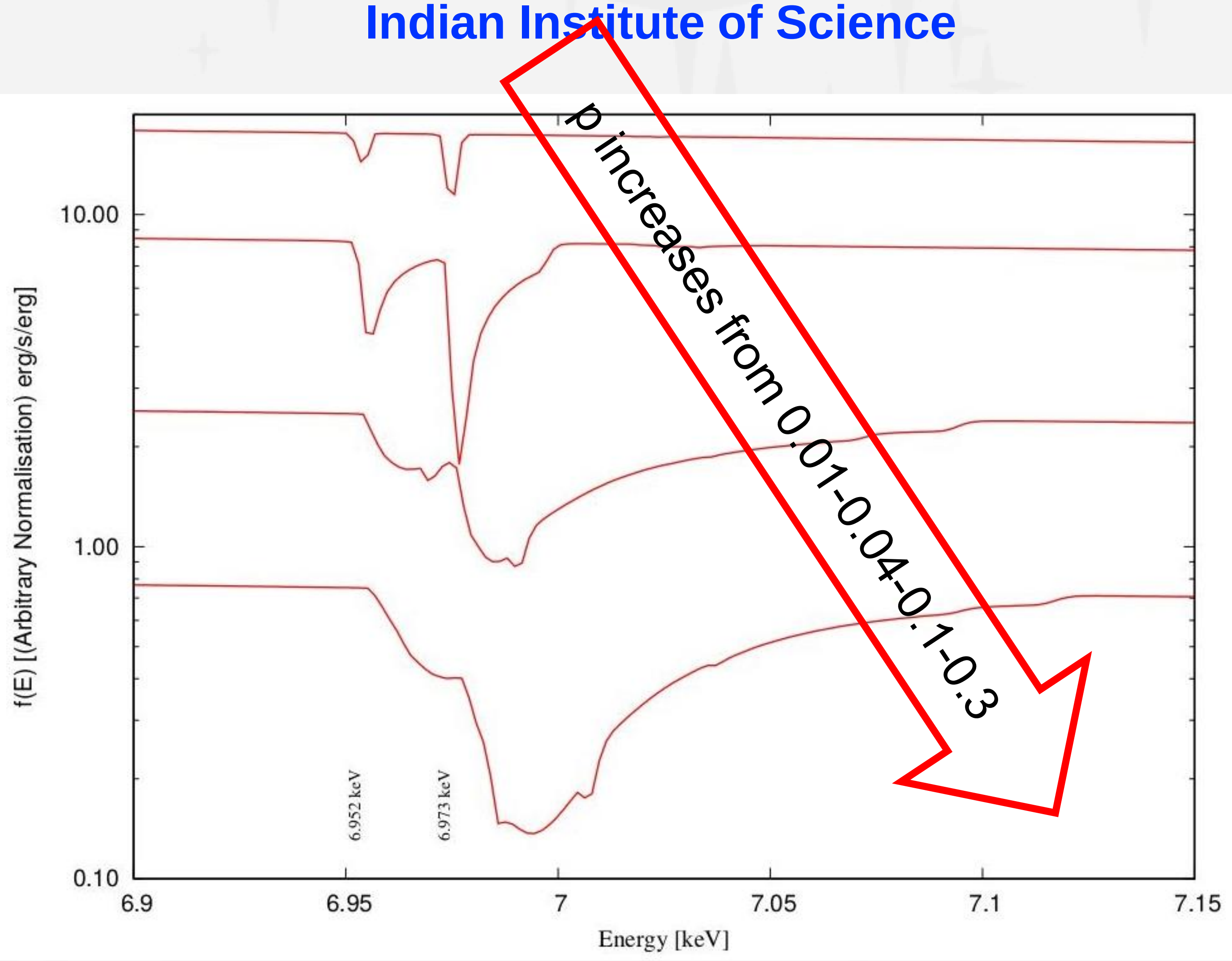
p=0.3, ep=0.01, inclination angle=15 degree



FeXXVI doublet is present in xstar atomic database, absent in cloudy database till now.

FeXXVI doublet may be observed through MHD wind depending on $\Delta\xi$ and Δv.

Xstar simulations done by Sudeb Ranjan Datta, Indian Institute of Science



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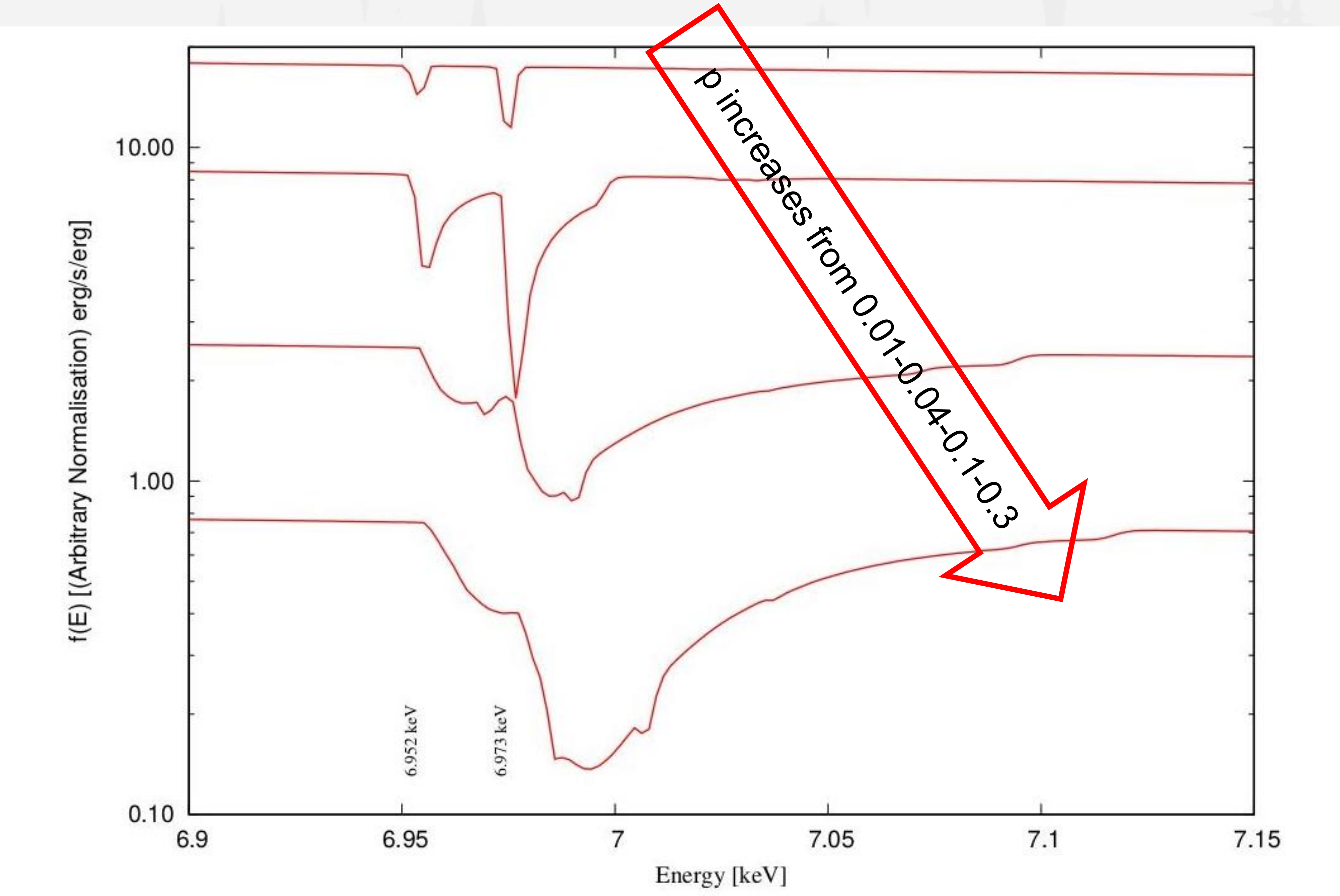
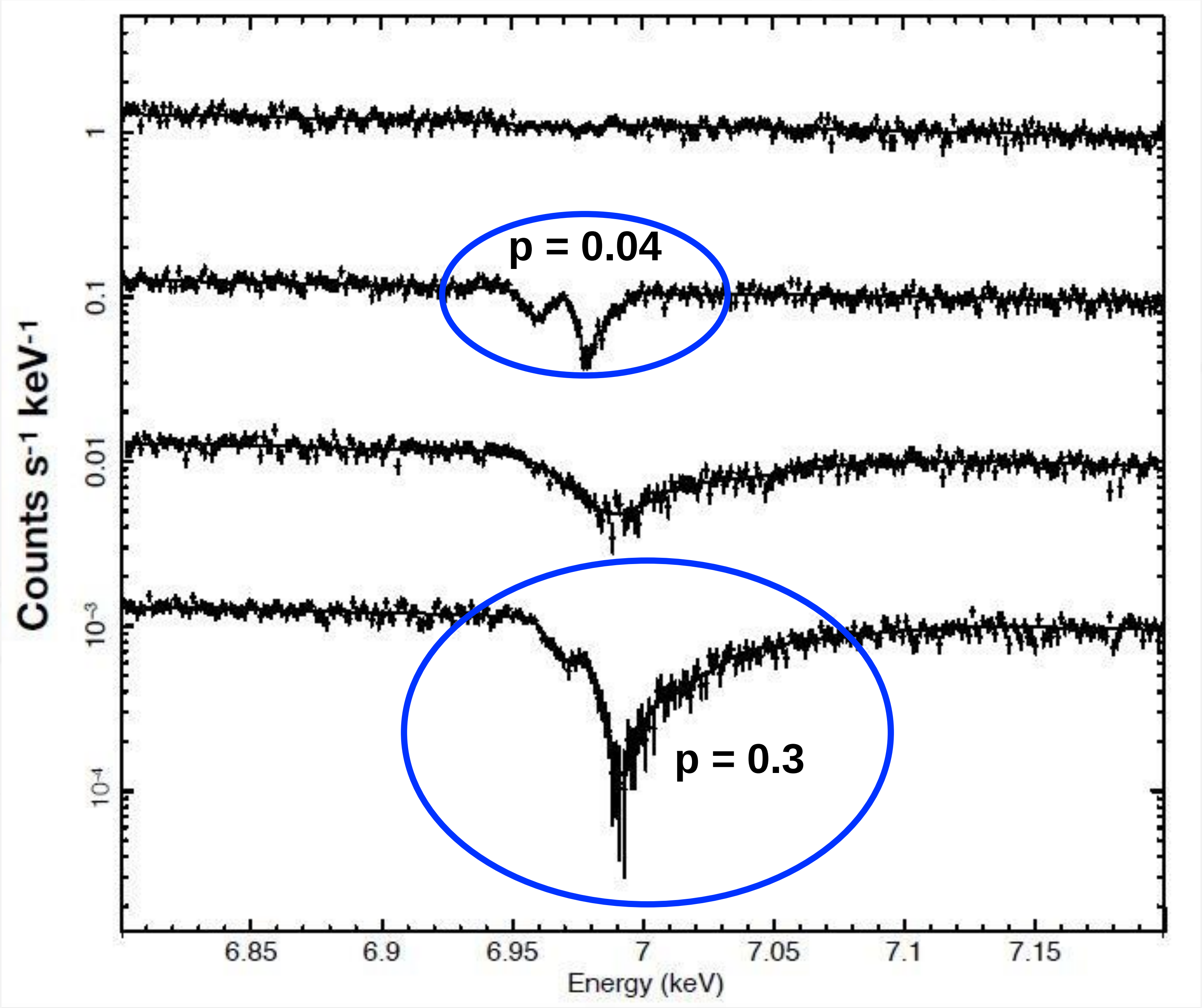


ATHENA, 100 ks for 100 mJy (1-10 keV)

- For detected lines profile are assymetric - non gaussian
- Especially for the line at 6.973, 2-3 gaussians are necessary for fit.



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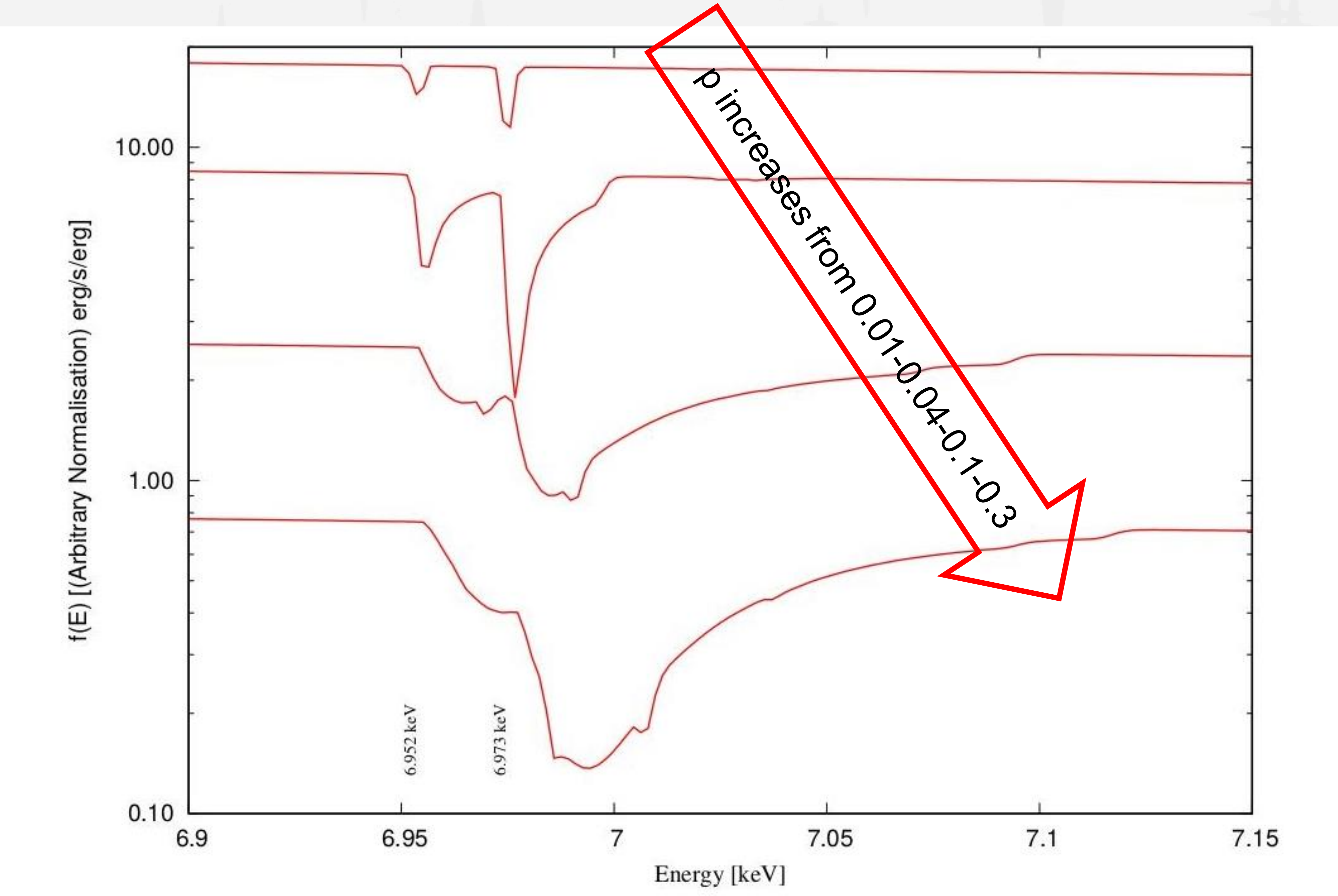
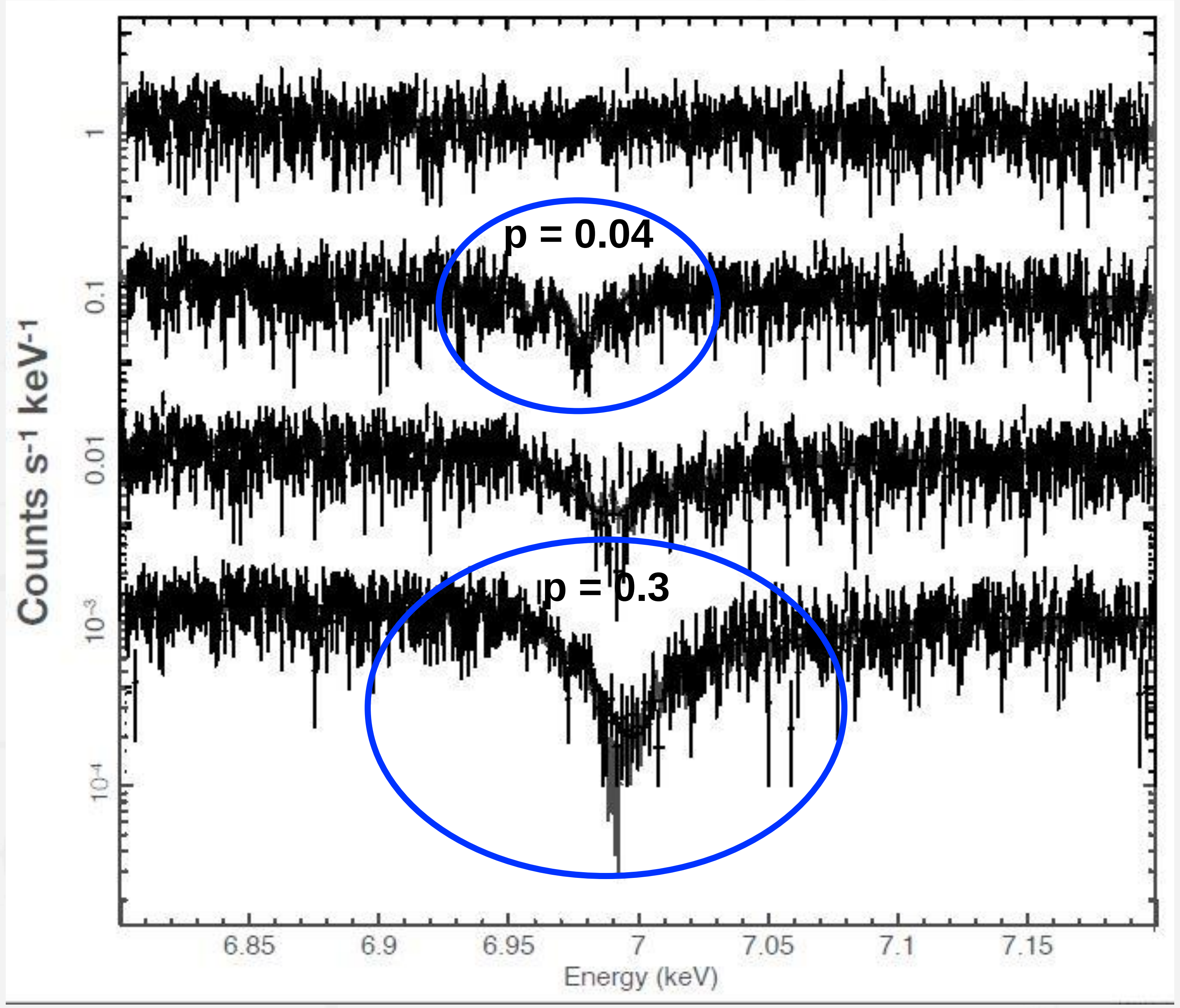


XRISM, 100 ks for 100 mJy (1-10 keV)

- For detected lines profiles are symmetric
- No need for multiple gaussian components



Conclusions

- We have studied the Jet Emitting Disk as outflow models for BHB Winds – Detected via Absorption Lines in Xrays

- Creating the methodology to get spectra from these models for Absorption Lines

- We simulated Athena and XRISM spectra to check
- ❑ The asymmetry in the absorption lines can be easily traced with Athena.
- ❑ FeXXVI Lyα doublet features from these models can be detected by Athena and XRISM
- ❑ Athena can even trace asymmetry in the individual lines of the doublets
- ❑ Presence or absence of asymmetries in actual observations can thus answer – “MHD or Thermal winds?”

- Two Caveats we are working on
- ❑ The simulation of each spectrum takes a LONG time ~> 12 hrs. Because the spectrum is calculated for each slab
- ❑ We have not been able to include EMISSION LINES in our methods YET.