An X-ray spectral variability of fast disk winds in AGN

Kouichi Hagino (ISAS/JAXA)

H. Odaka, C. Done, S. Watanabe, T. Takahashi

K. Hagino et al. 2015, MNRAS, 446, 663
K. Hagino et al. 2016, MNRAS, 461, 3954

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Monitoring X-ray Transients
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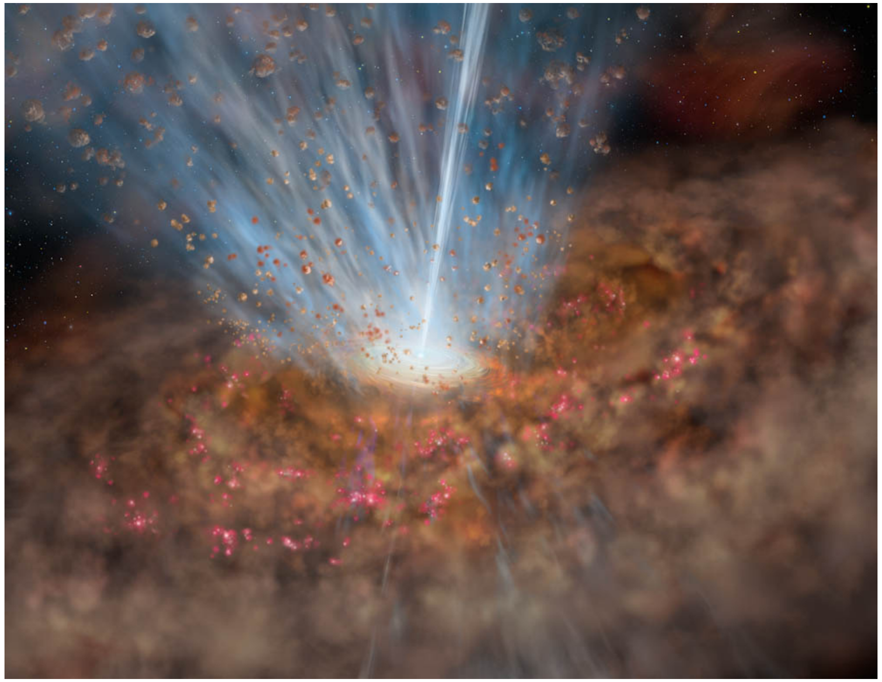
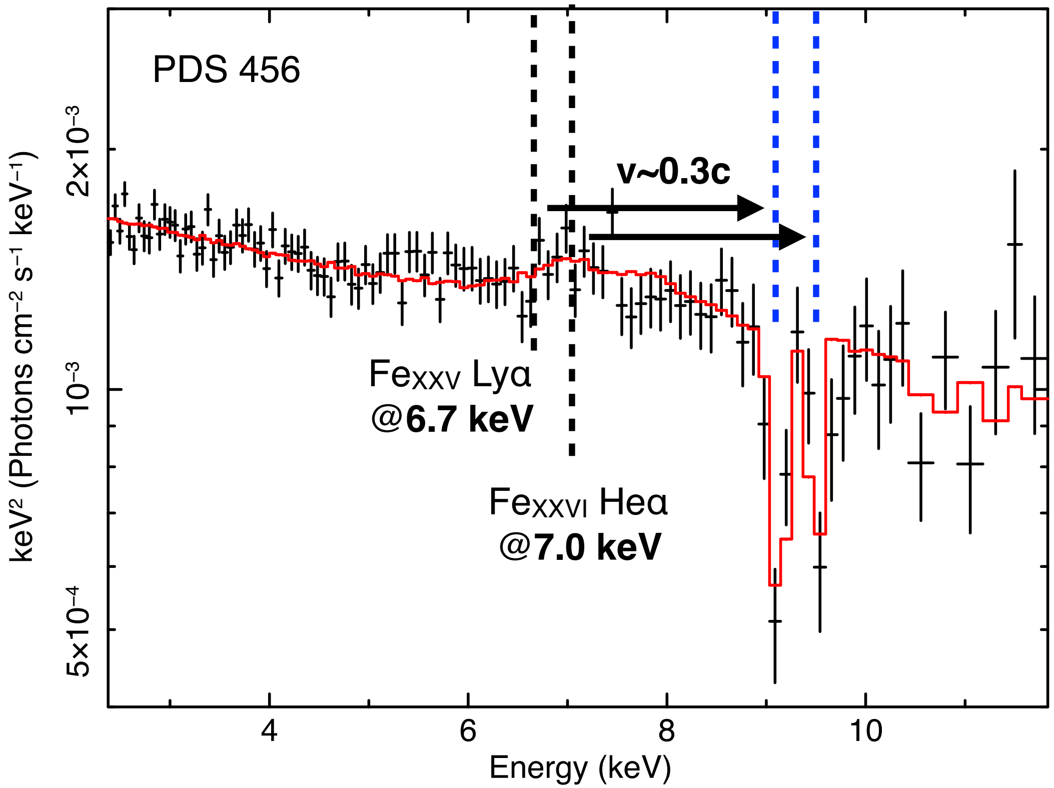
Ultra-fast outflows

- Blue-shifted absorption lines with v≳0.1c is found in a part of local AGN (Chartas + 2002; Reeves+ 2003; Pounds+ 2003a,b; Tombesi+ 2010)

➡ Absorbers moving from the black hole with v≳0.1c: **Ultra-fast outflow** (UFO)



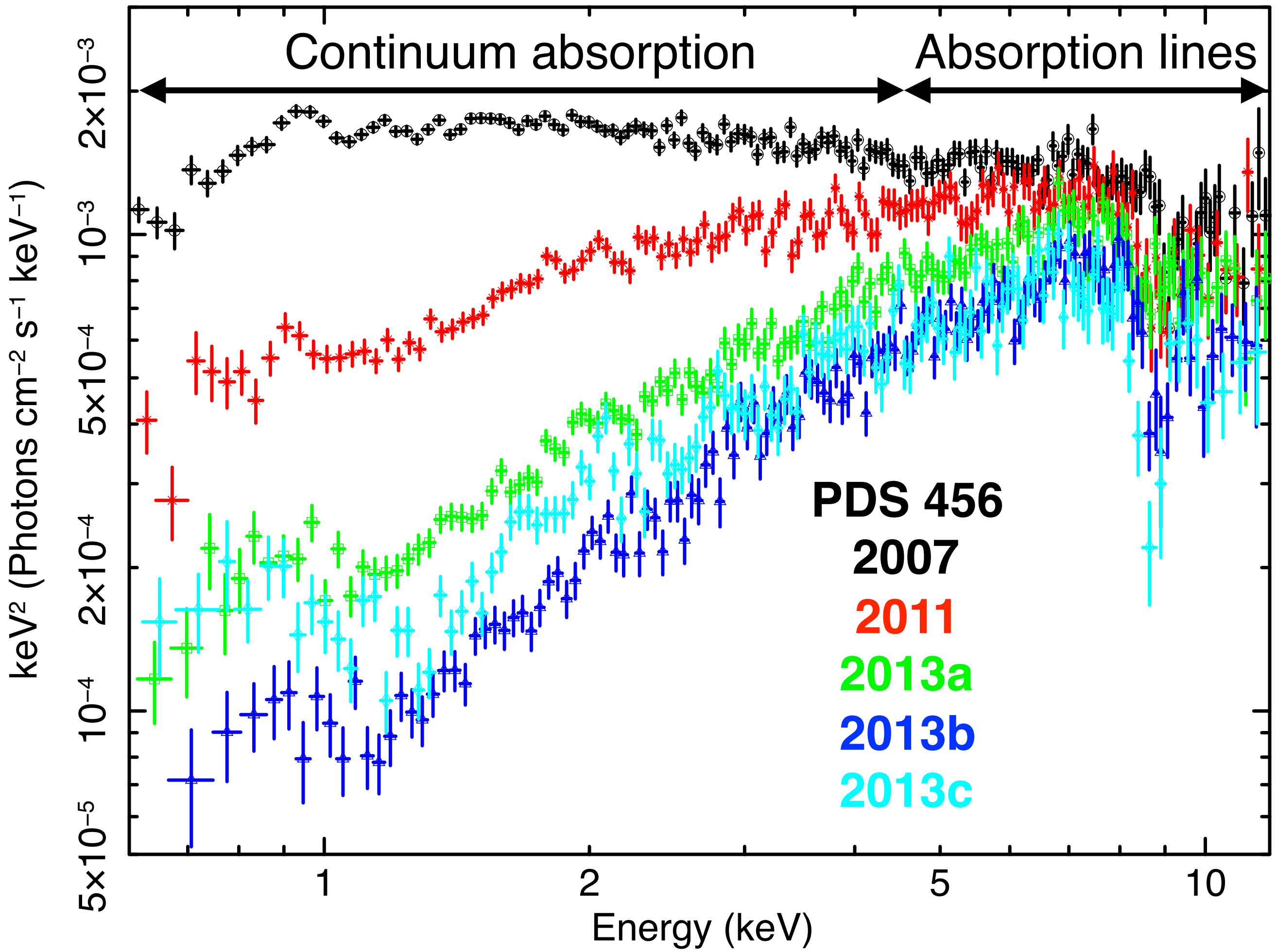
A spectrum of the ultra-fast outflow



- **Due to its extreme velocity, the ultra-fast outflows are thought to have a significant impact on the coevolution of black holes and galaxies**

Spectral variability of the ultra-fast outflow

- Spectra of the ultra-fast outflow often shows strong variability in both continuum absorption and absorption lines



- Absorption lines:

  usually modeled by the **highly ionized gas** (ξ~10^{3-4})

  ➡ **Hot disk wind**

- Continuum absorption:

  Low ionized gas (ξ=L/$nr^2 \lesssim 10^2$) is required

  ➡ **Cool clumps**

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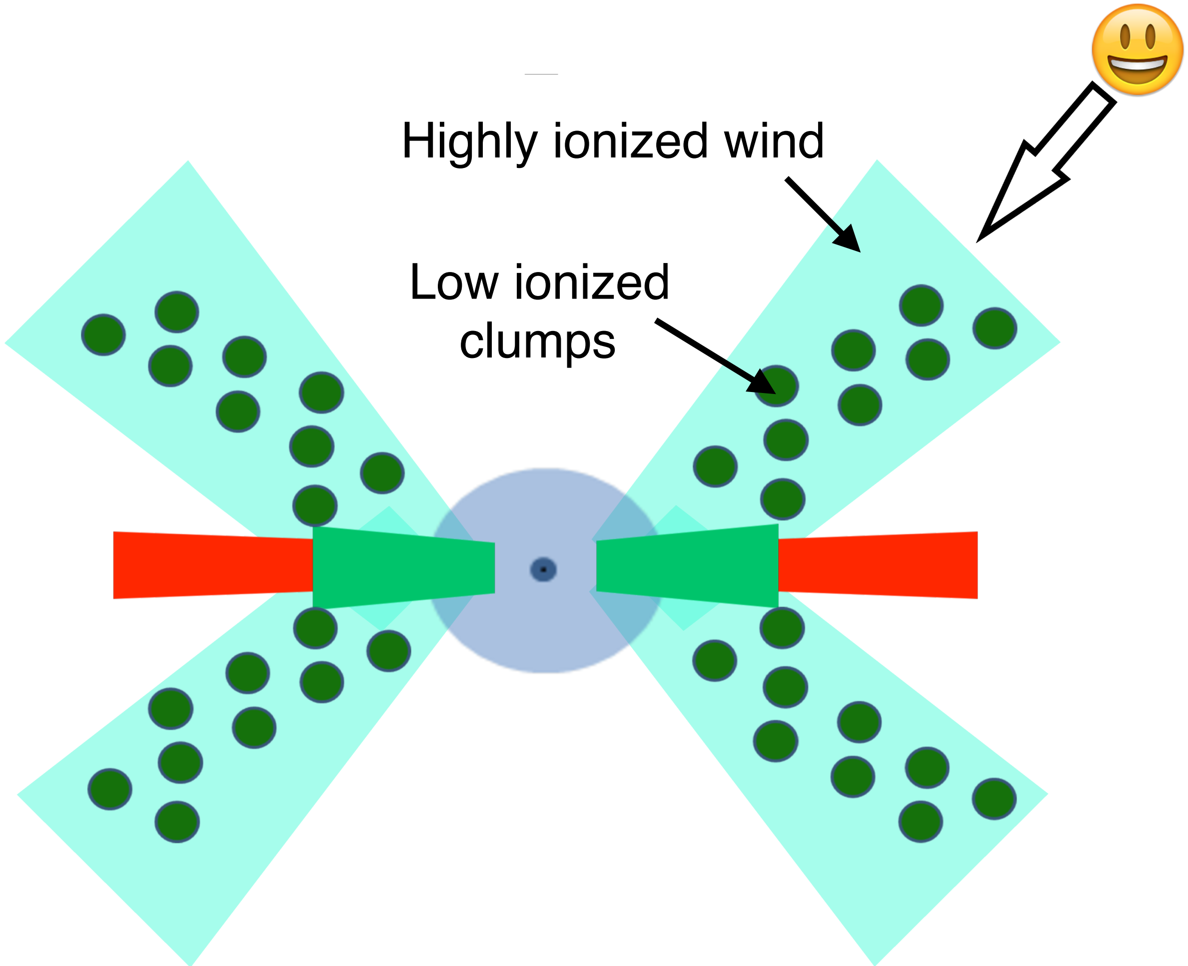

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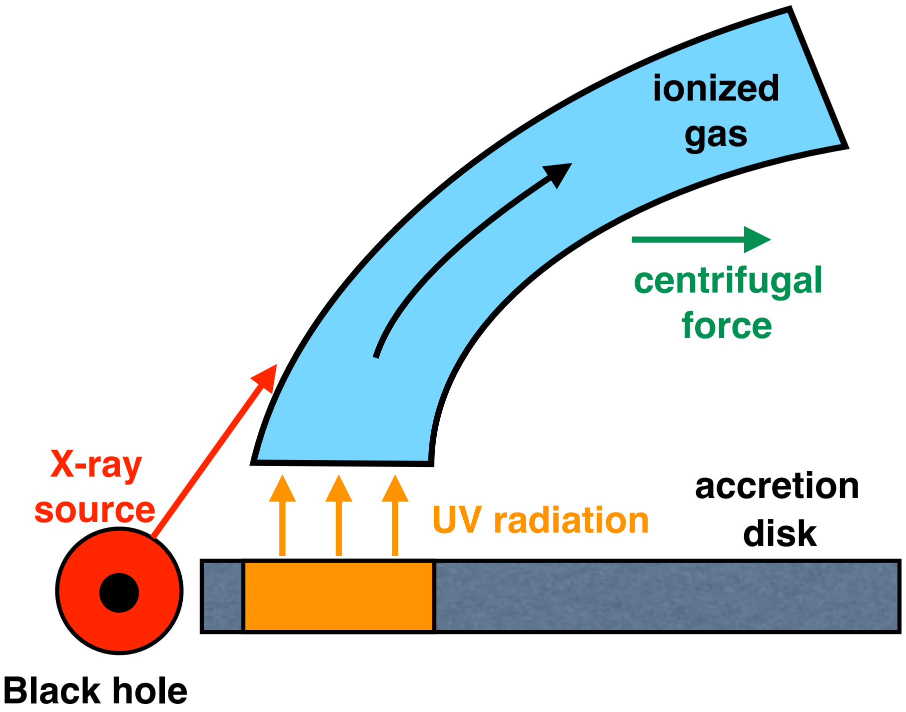
▶ **But the origin of the variability in the absorption lines is not clear**

Modeling the disk wind spectra

- To understand the absorption line variability, we construct "a new X-ray spectral model" of the disk wind on the assumption of the UV-line driven disk wind

- **"UV-line driven disk wind" = Best candidate of the ultra-fast outflow**

  - Accelerated by radiation pressure via **bound-bound transition with UV photons**
  - $\sigma_{bb} > 10^{3-4}\ \sigma_T$ →**efficiently accelerate**
  - Radiation from AGN peaks at UV band

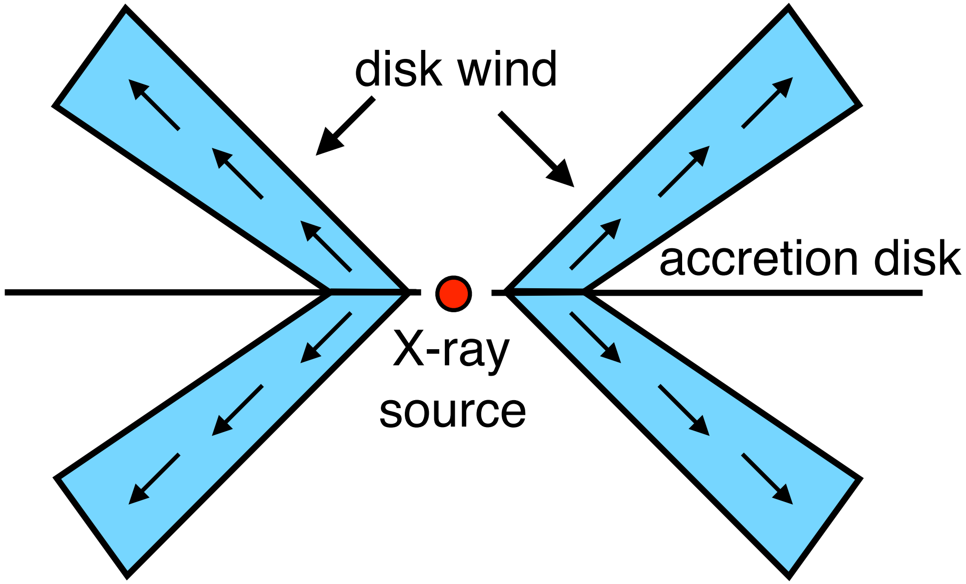


- Asymmetric wind geometry is expected

➡ **It is very difficult to calculate the spectra from the asymmetric wind geometry**

Our disk wind model

- By using a Monte Carlo radiation transfer simulation, we calculate the disk wind spectra in the realistic wind geometry



- 3-D biconical geometry with $\Omega/4\pi=0.15$
- Velocity distributions:

$$v_r(l) = v_0 + (v_\infty - v_0)\left(1 - \frac{R_{min}}{R_{min} + l}\right)^\beta$$

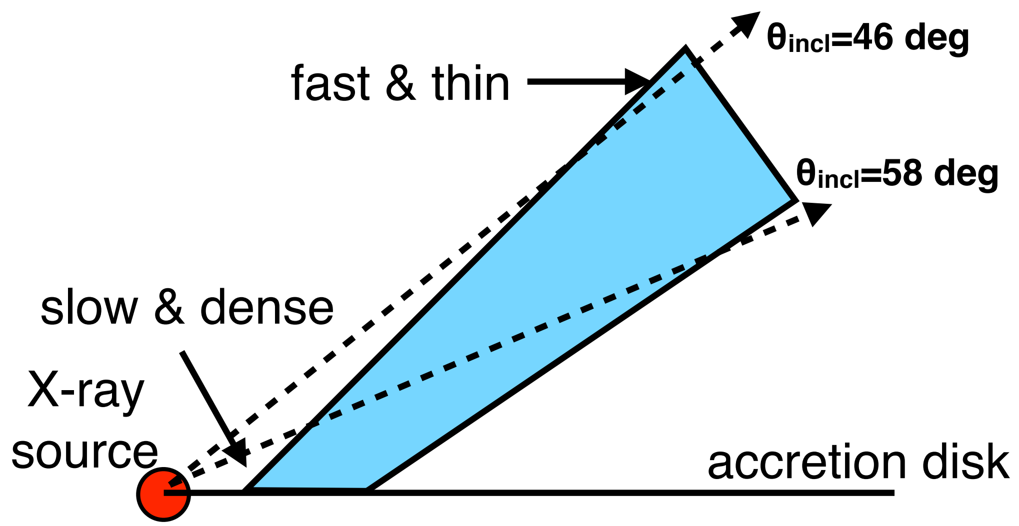
Based on the UV-line driven disk wind

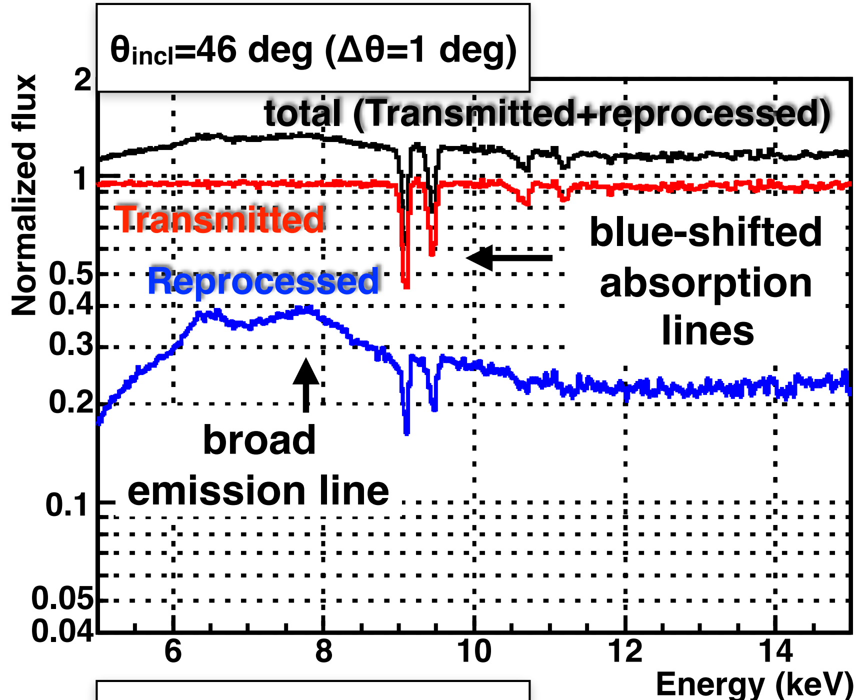
- Ionization structure: 1-D along the stream line
- Monte Carlo radiation transfer simulation: "MONACO" (Odaka+ 2011)
- Self-consistently calculate both of the emission and absorption

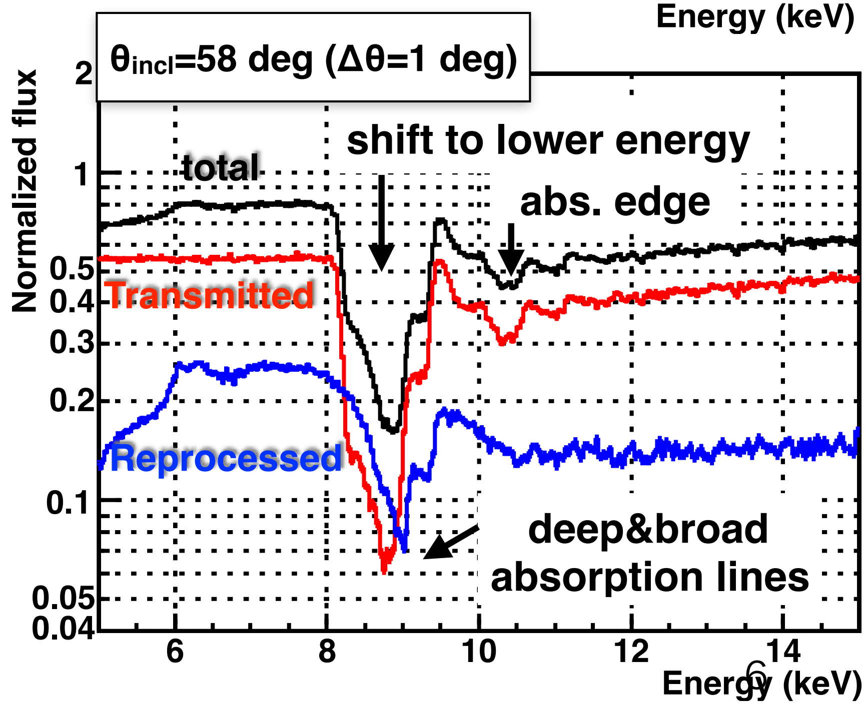
Physical processes

- Photoionization
- Photoexcitation
- Compton scattering
- Doppler effect

Simulated spectra







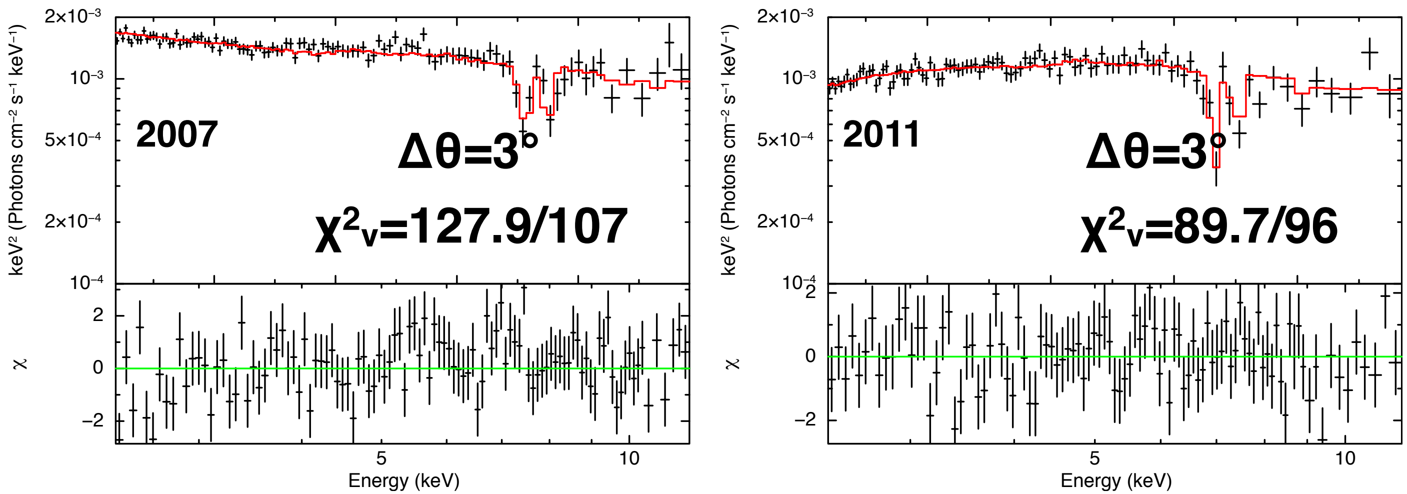
- Blue-shifted absorption & broad emission like the observation
- At large θ_{incl}
  - high density→deep absorption
  - observe slower component→broad

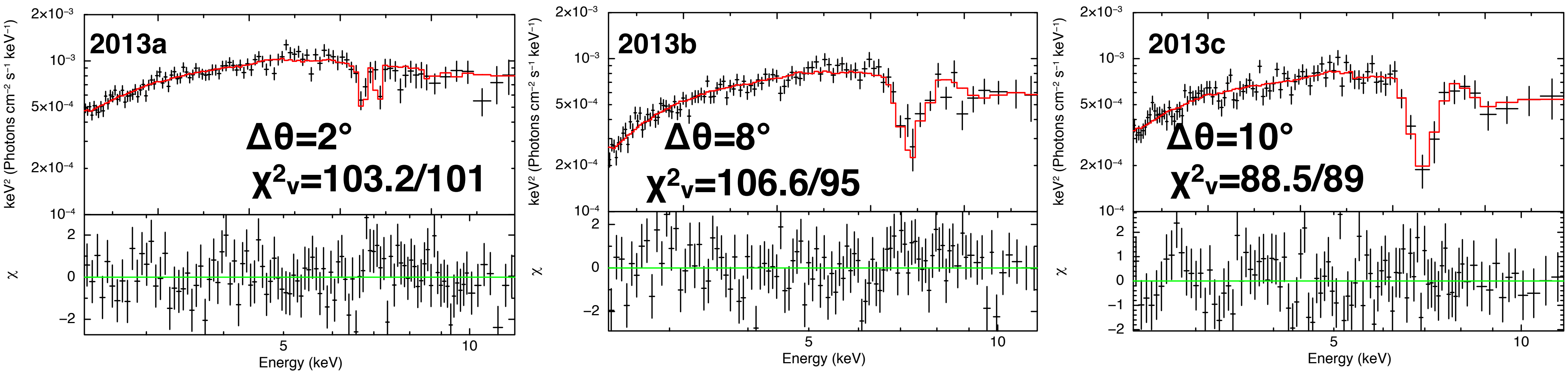
➡ **Spectral features of absorption lines strongly depend on the inclination angle**

Application to the archetypal wind in PDS 456

- Fit all the spectra of PDS 456 observed by Suzaku by changing only the viewing angle and the outflow velocity

Δθ：angle between line of sight and wind



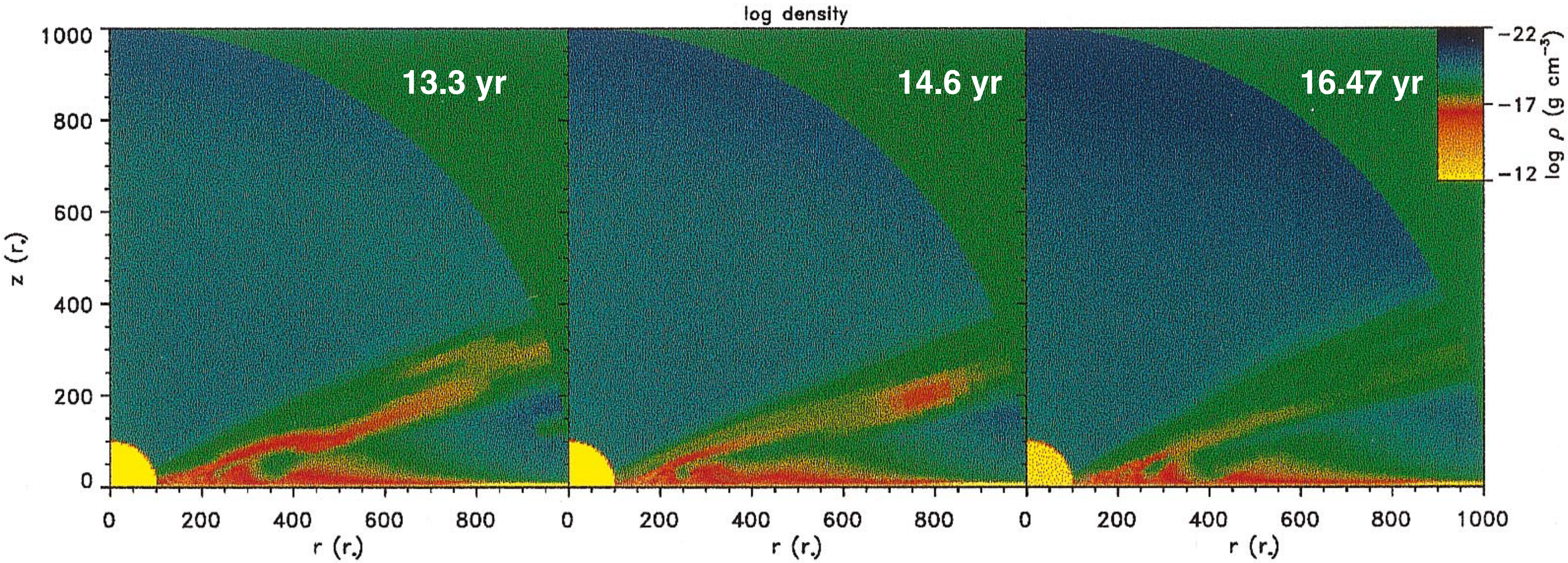


- **Successfully reproduce all the spectra without changing the global parameter, mass outflow rate ($\dot{M}_{wind}/\dot{M}_{Edd}$~0.13($\dot{M}_{wind}$~10$M_{\odot}$/yr), v_{wind}~0.3c)**

Instability / inhomogeneity of the disk wind

- The variability of the absorption lines can be explained **by the change of the outflowing angle**
- Theoretically, the flapping or/and the inhomogeneity of the disk wind is naturally expected due to the hydrodynamic instability

Hydrodynamic simulation of the UV-line driven disk wind (Proga+2000)

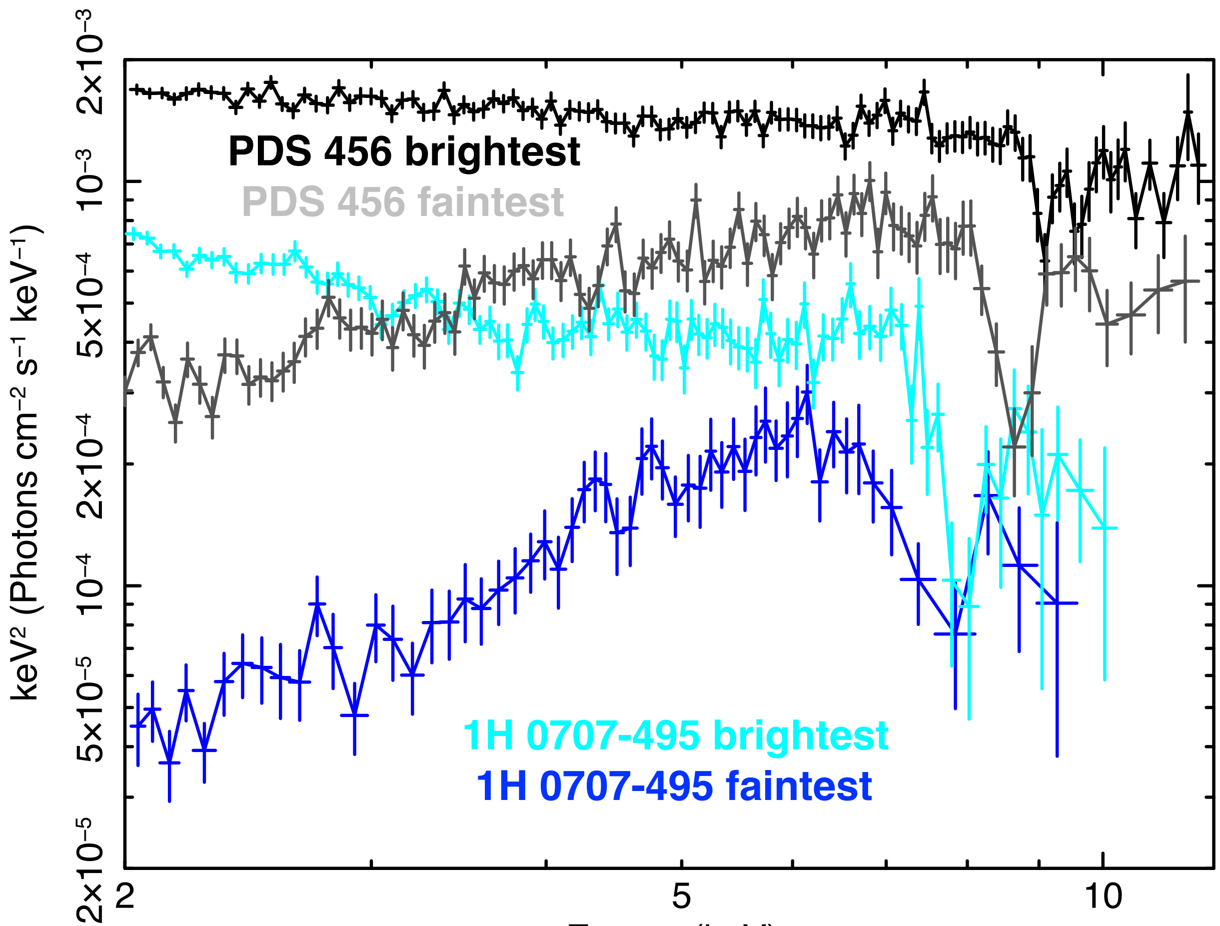


➡ **Our result indicates that the strong spectral variability could originate from the local instability of the wind, not from the global change of the wind**

Similar spectral variability in the “disk-line” source

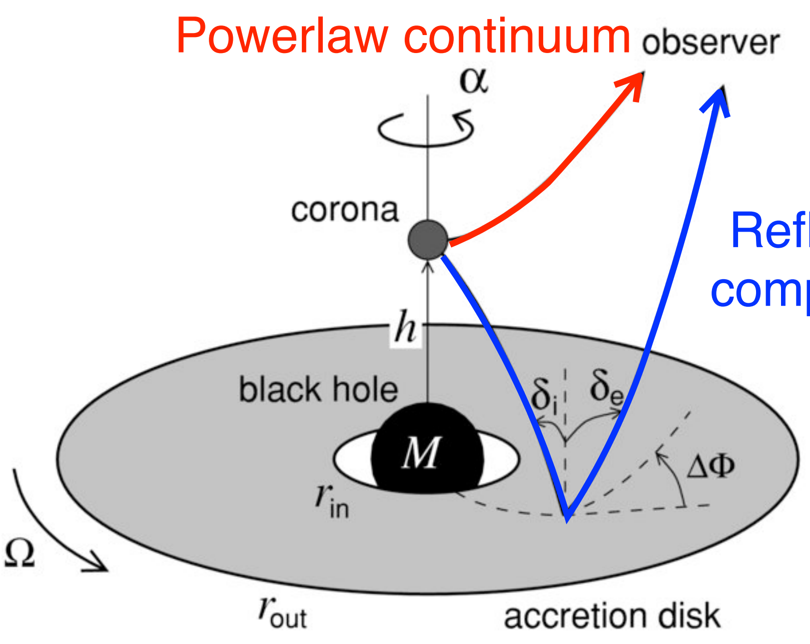
- The most extreme “disk-line” source 1H 0707-495 is very similar to an archetypal wind source PDS 456

➡ **The spectral feature in 1H 0707-495 seems to be made by the disk wind**

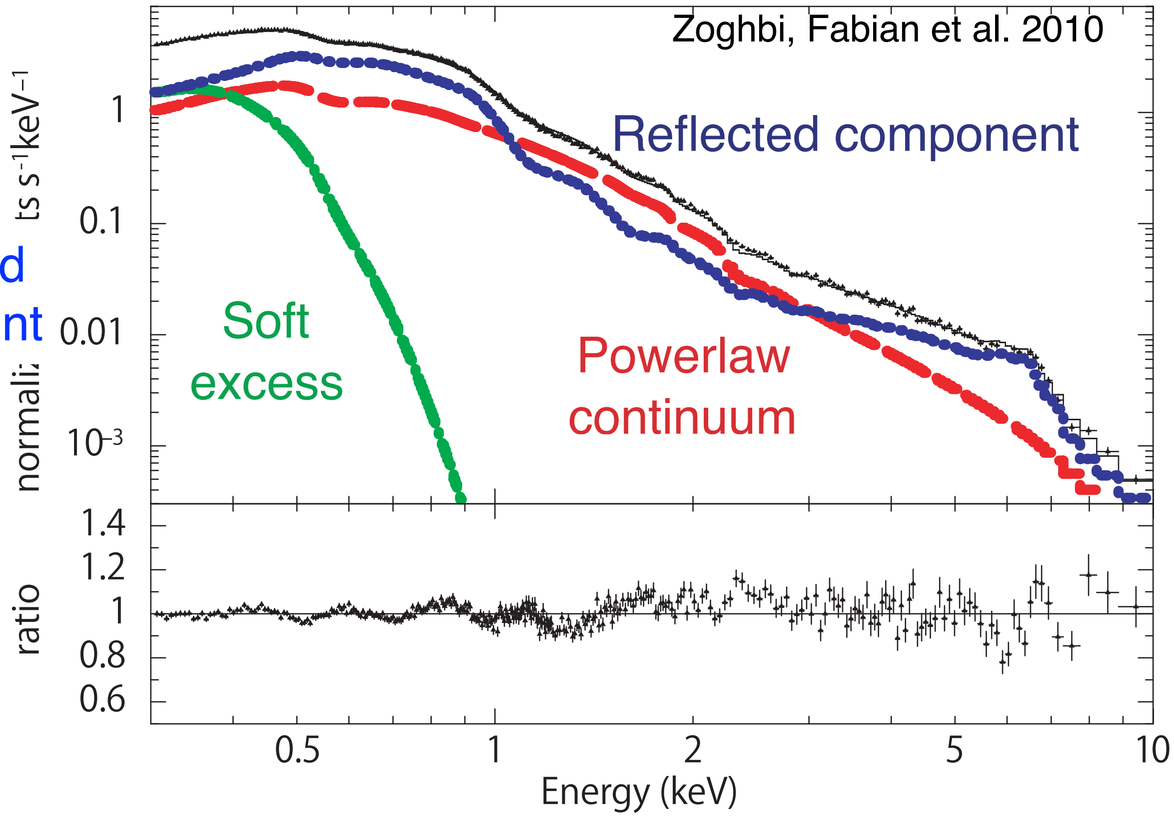


- The broader absorption line in 1H 0707-495 can be reproduced by our disk wind model with a higher inclination angle

Traditional “disk-line” interpretation for 1H 0707-495



Dovciak et al. 2011

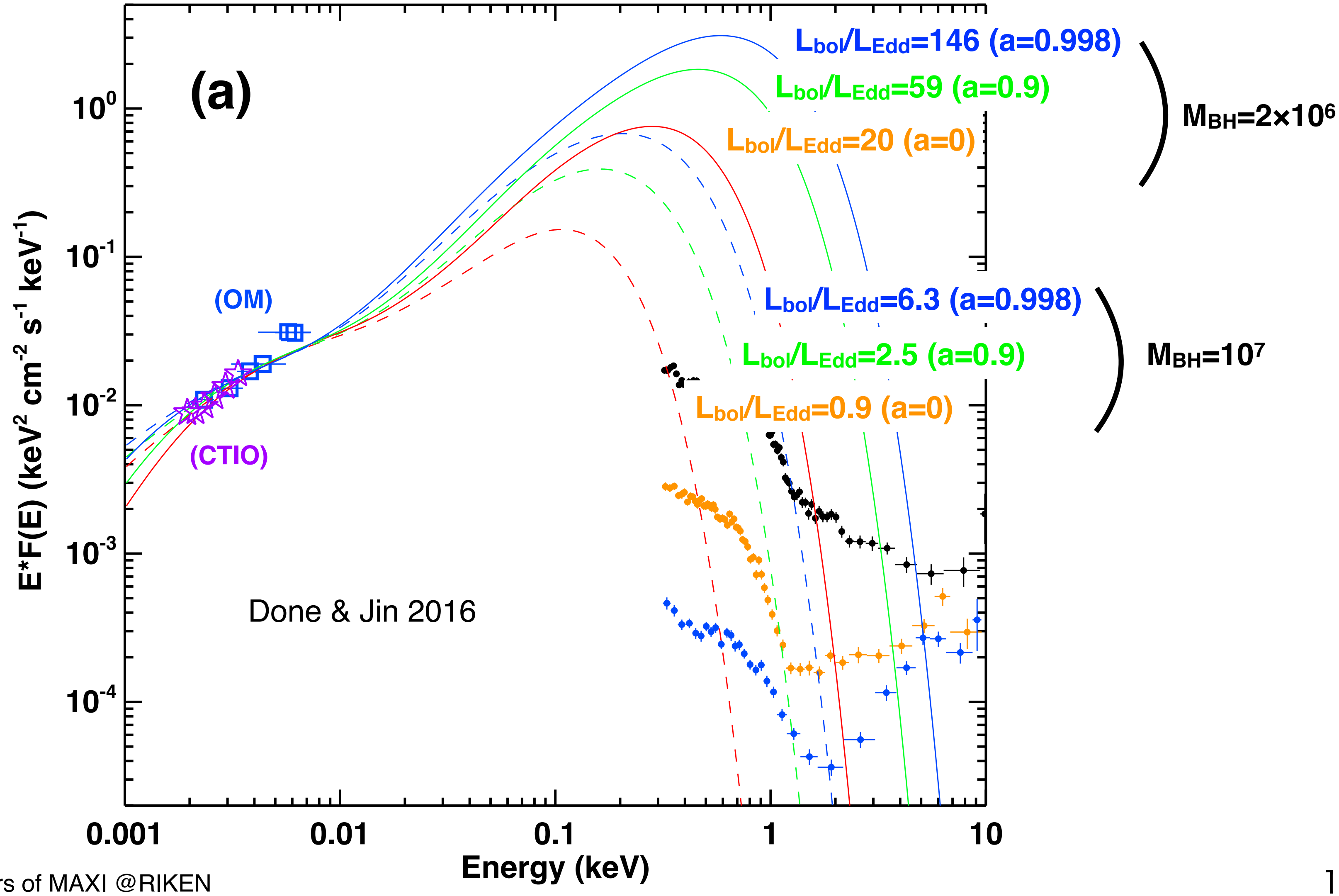


- This model requires **extreme** conditions:
  - **Black hole spin is close to maximum.**
  - **Incident radiation is strongly focused on the disk inner edge**

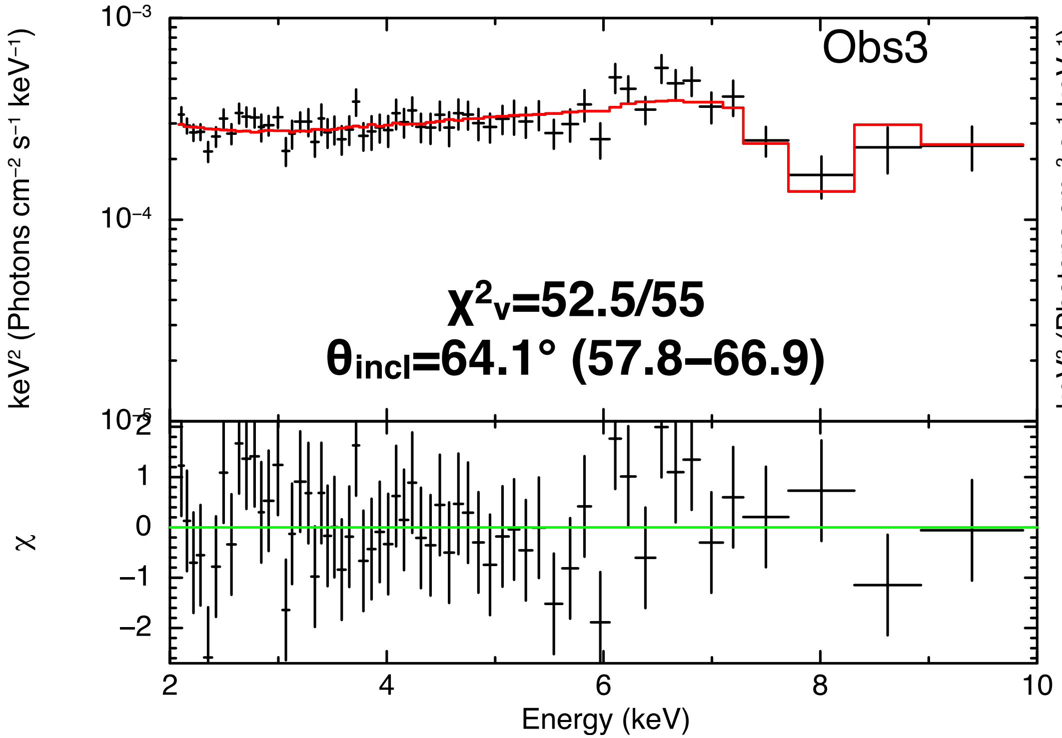
Super-Eddington accretion in 1H 0707-495

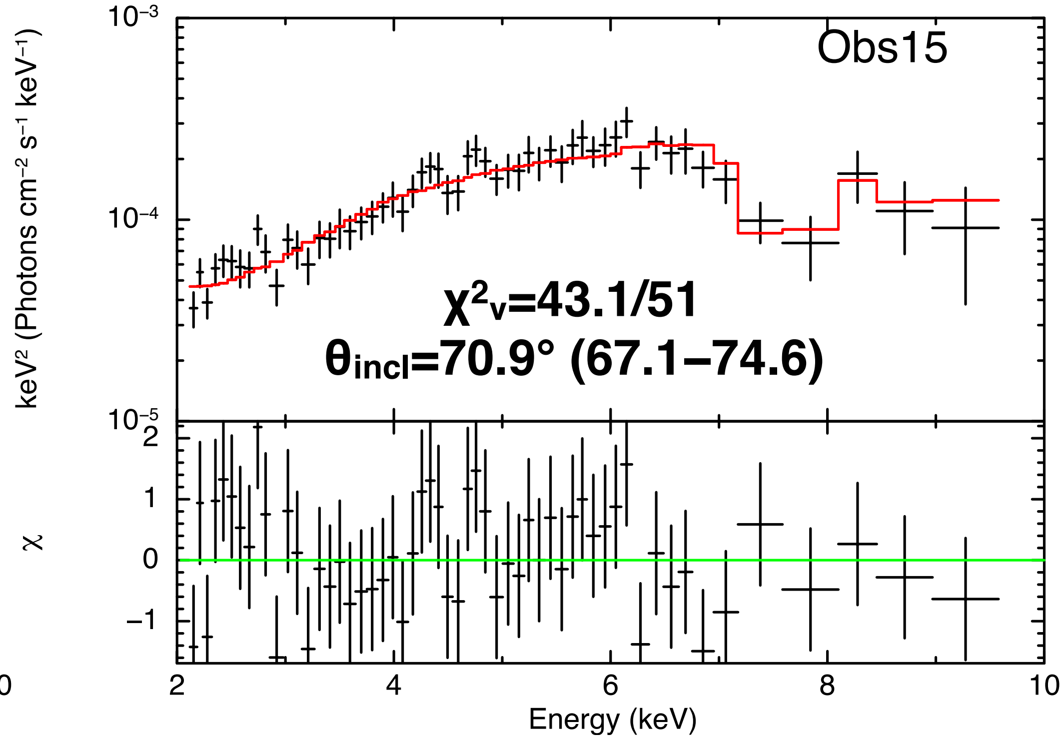
- Super-Eddington accretion is required by fitting the optical data (Done & Jin 2016)

➡ **In such a situation, the accretion disk must not be the standard thin disk, which is assumed in the disk-line model**



Spectral fit with the disk wind model



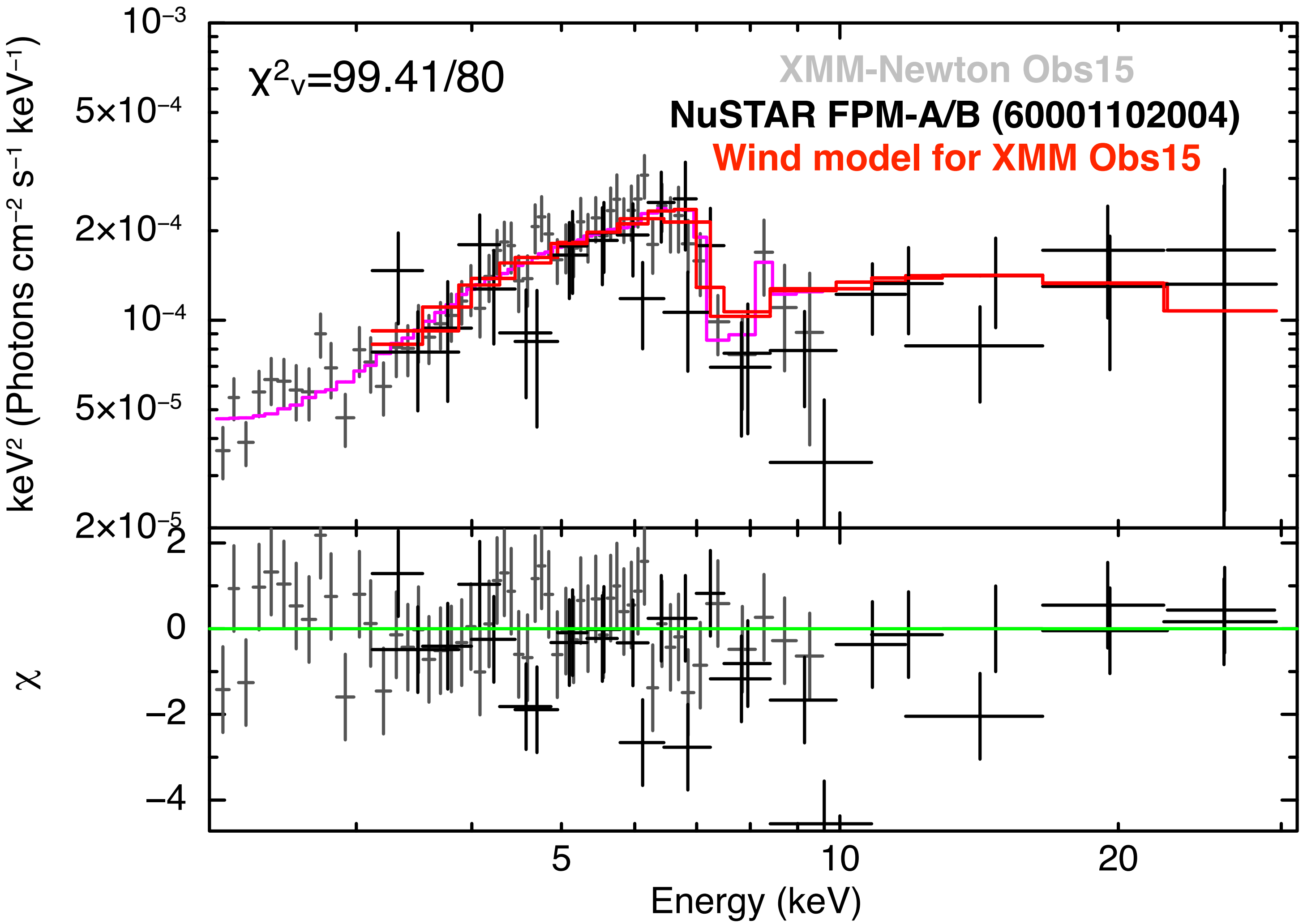


- Reproduced the structure above ~7 keV in all the *XMM-Newton/Suzaku* observations by changing only the viewing angle.

➡ **The spectra of 1H 0707-495 can be explained by the ultra-fast outflow ($\dot{M}_{wind}/\dot{M}_{Edd}$=0.2, v_{wind}=0.2c)**

Comparison with NuSTAR data

- The extrapolation of our wind model for Obs15 gives a good fit to the NuSTAR spectra
- **Higher energy spectrum is also explained by our disk wind model!!**



Conclusions

We have constructed a new spectral model by calculating the radiation transfer in the realistic wind geometry.

- Archetypal wind source PDS 456 (Hagino et al. 2015)

  ✓ Strong spectral variation in this source can be explained by the change of the viewing angle without changing mass outflow rate

  ✓ It indicates that the spectral variability is due to the local instability or inhomogeneity of the wind.

- "Disk-line" source 1H 0707-495 (Hagino et al. 2016)

  ✓ The strong Fe-K feature in all the spectra of 1H 0707-495 observed by *XMM-Newton/Suzaku* are successfully reproduced by our disk wind model.

  ✓ Higher energy spectra by *NuSTAR* are also explained by our disk wind model.