Ultra-fast disk wind from a high accretion rate black hole 1H 0707-495

Kouichi Hagino (ISAS/JAXA)

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

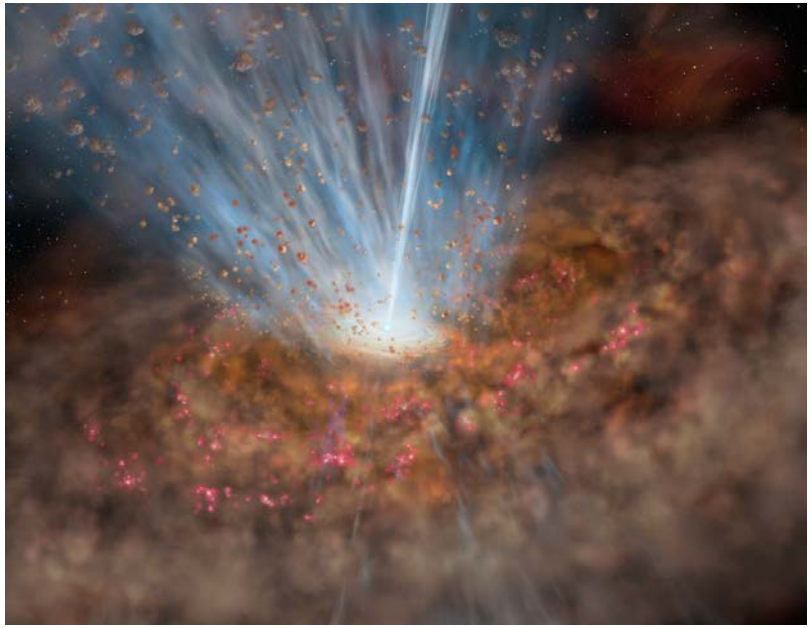
K. Hagino et al. 2016, MNRAS, 461, 3954

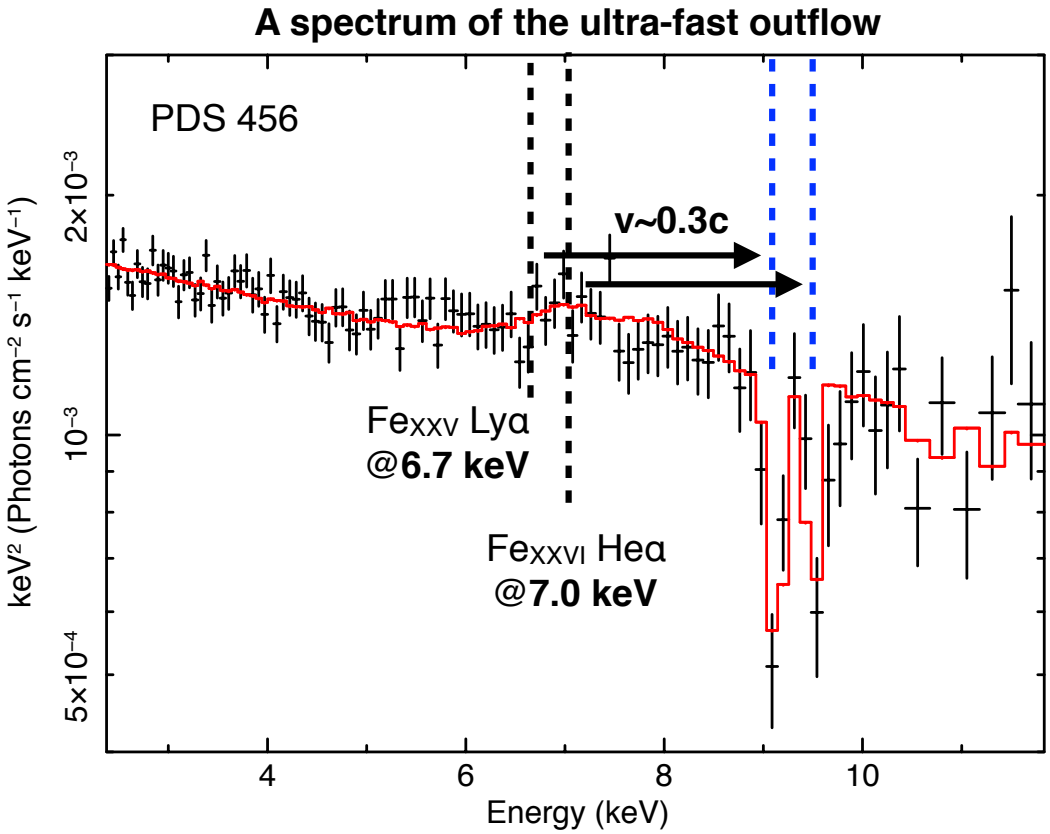
BREAKING THE LIMITS
Super-Eddington Accretion on Compact Objects
@Sardinia island

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)





- **The physical mechanism to launch / accelerate the UFO is unclear**

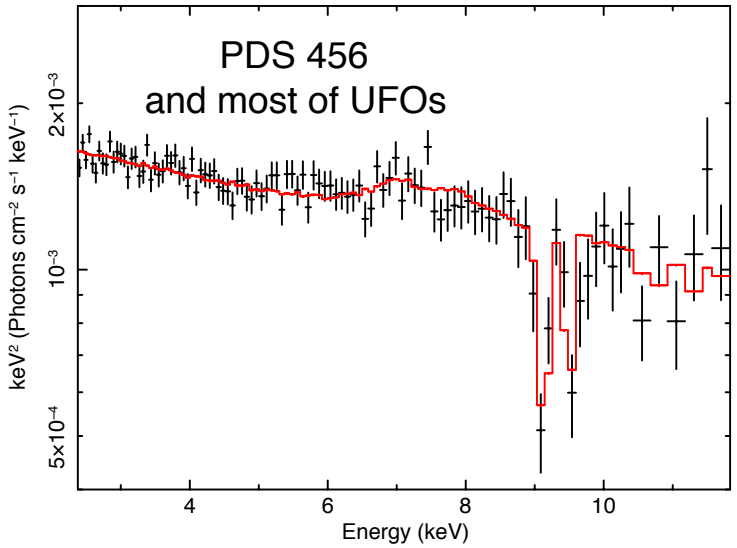
Physical mechanisms of disk winds

- Continuum radiation driving — **Working in super-Eddington AGN**
  - radiation pressure (via Thomson scattering) exceeds gravity
  - **need super-Eddington**
- UV line radiation driving — **Working in sub-Eddington AGN like PDS 456**
  - radiation pressure by bound-bound transition with UV photons
  - $\sigma_{bb} > 10^{3-4}\ \sigma_T$
  - efficiently accelerate if materials are moderately ionized
  - **AGN radiate lots of UV → may be working for UFOs**
- Thermal driving
  - thermal velocity exceeds the escape velocity
  - **slow velocity**
- Magnetic driving
  - **depends on unknown magnetic field configuration**

Super-Eddington winds in AGN

Observation

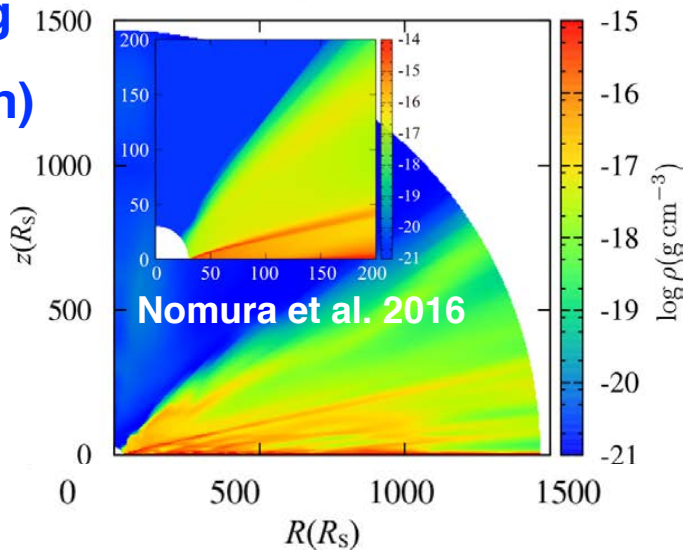
Theory

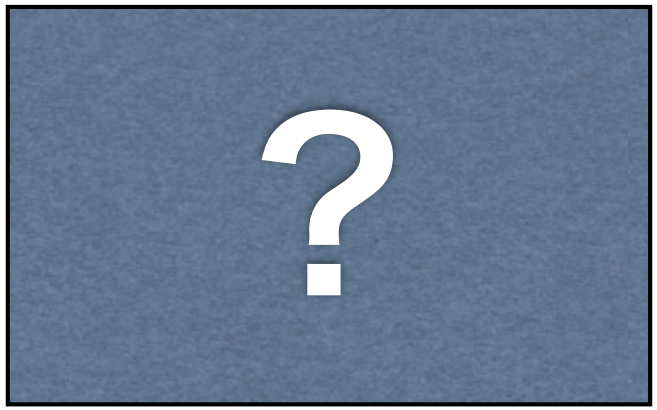


UV line driving

(Sub-Eddington)

$L_{bol}/L_{Edd}<1$

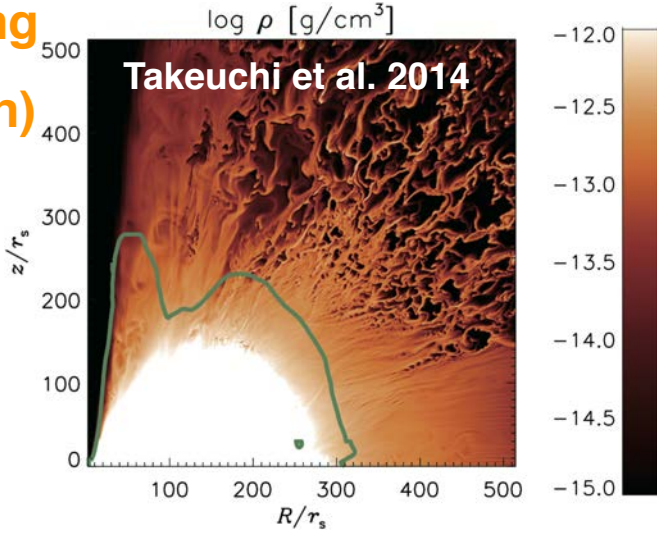




Continuum driving

(Super-Eddington)

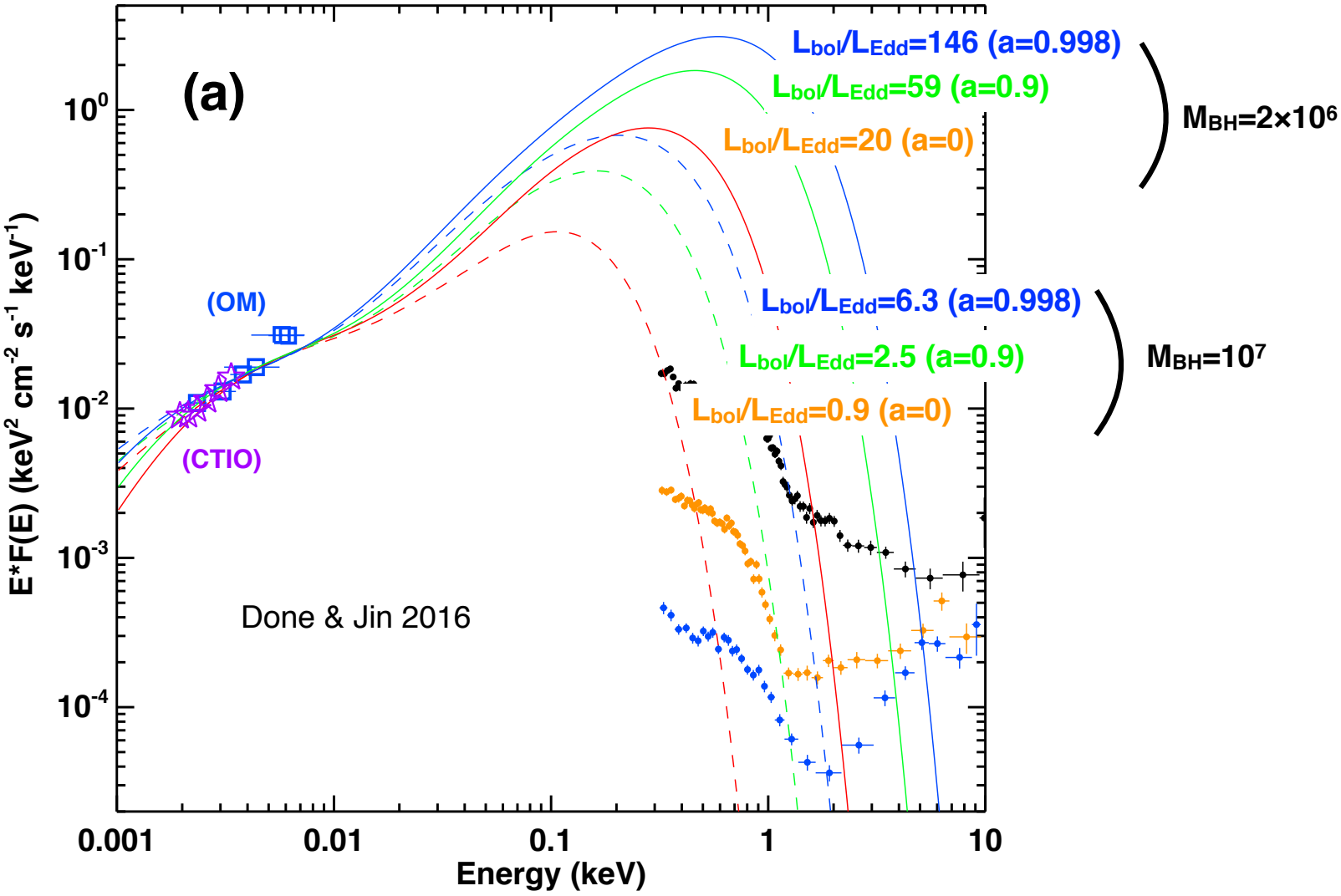
$L_{bol}/L_{Edd}>>1$



- **Are there any UFOs with high accretion rates (Super-Eddington AGN)?**

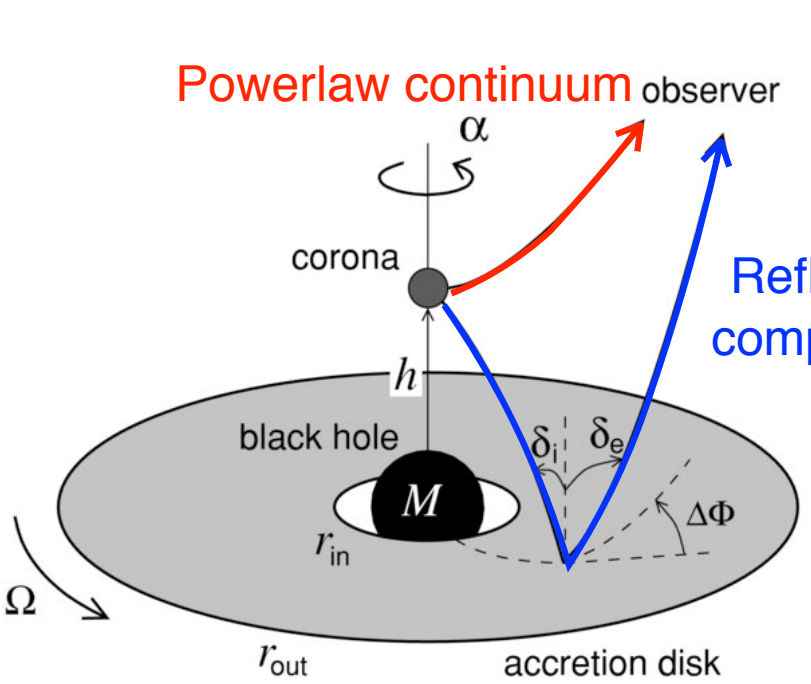
Super-Eddington AGN: 1H 0707-495

- A narrow line Seyfert 1 galaxy (M_{BH}~$10^{6\text{-}7}M_{\odot}$)
- **Super-Eddington is required by fitting the optical data**

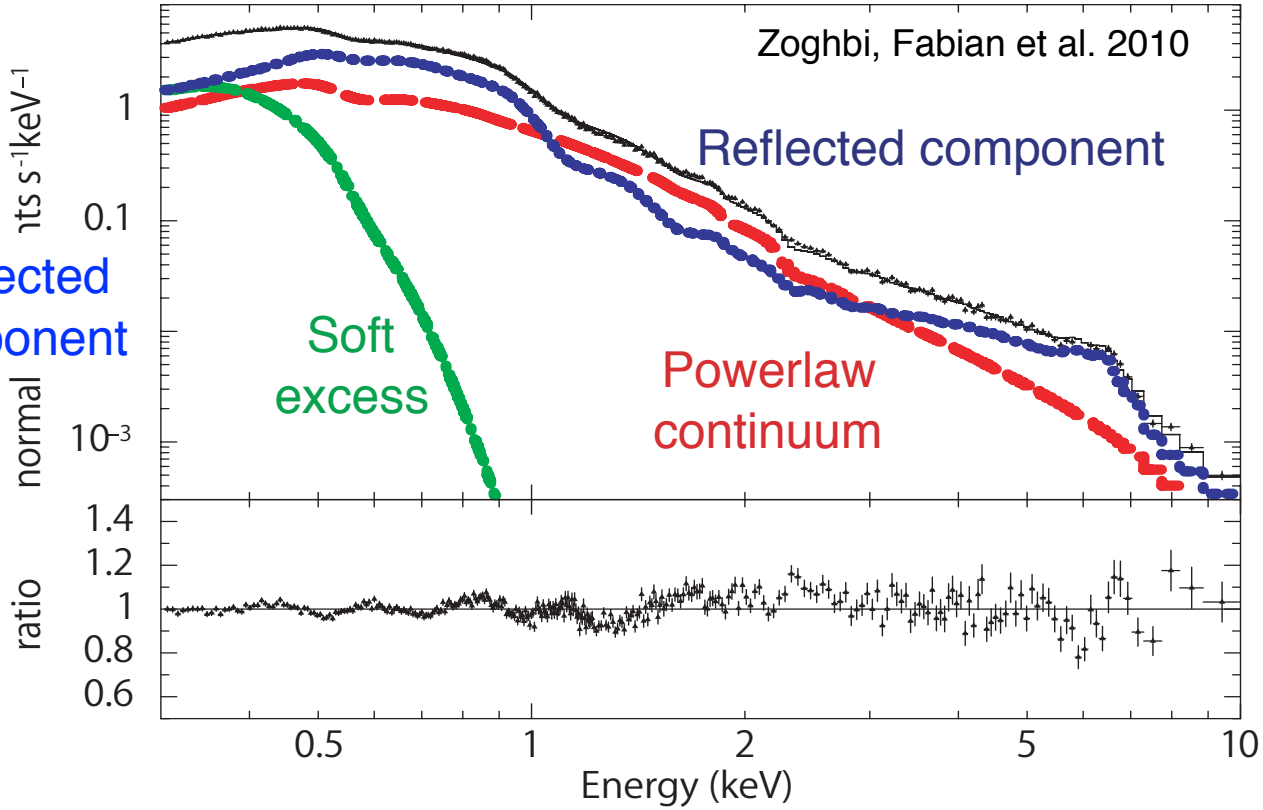


X-ray spectra of 1H 0707-495

- A most convincing evidence of a rapidly spinning black hole (Fabian+ 2004).



Dovciak et al. 2011

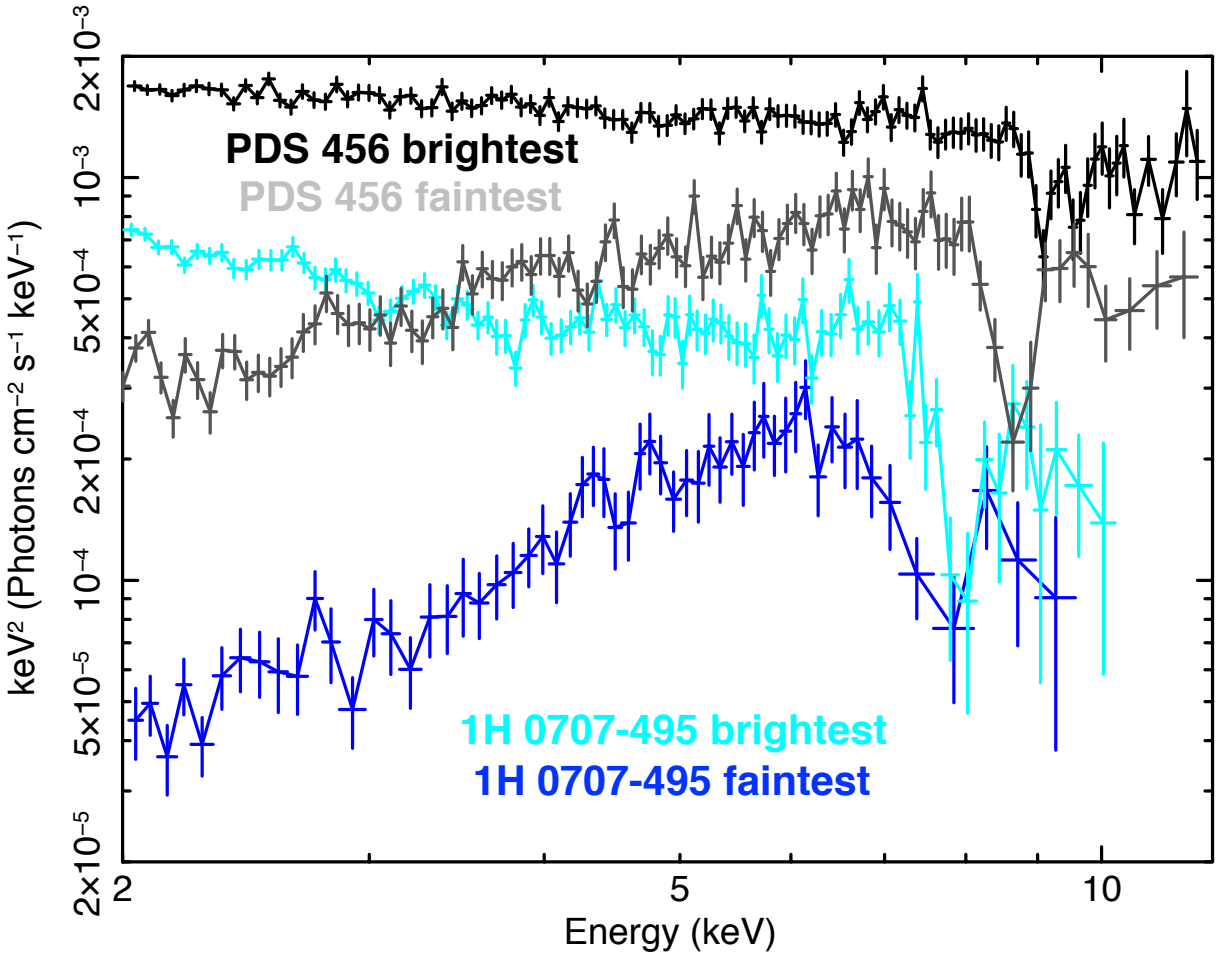


- This model requires **extreme** conditions:
  - **Black hole spin is close to maximum.**
  - **Incident radiation is strongly focused on the disk inner edge**

Disk wind interpretation

- We propose a disk wind interpretation for the strong Fe-K spectral feature.
- 1H 0707-495 is very similar to an archetypal wind source PDS 456 (M_{BH}~$10^9 M_\odot$, v_{wind}~0.3c, $\dot{M}_{wind}$~$10 M_\odot$/yr)

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

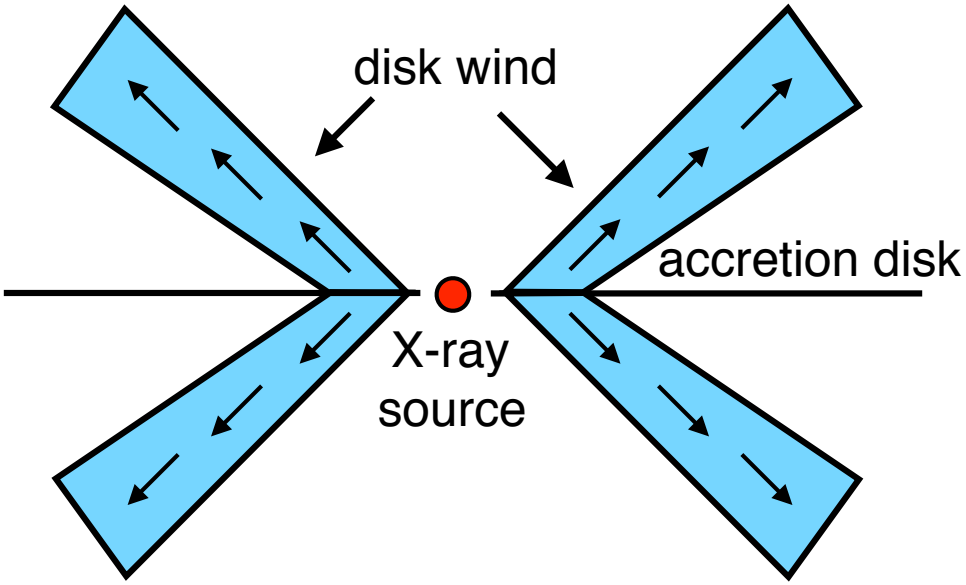


- Absorption line is very broad, which cannot be explained by turbulence

➡ **A new spectral model of the wind is required to explain the broad absorption line**

Our disk wind model

- "A new X-ray spectral model" of an accretion disk wind has already been constructed for the UFO in PDS 456 (Hagino et al. 2015).



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

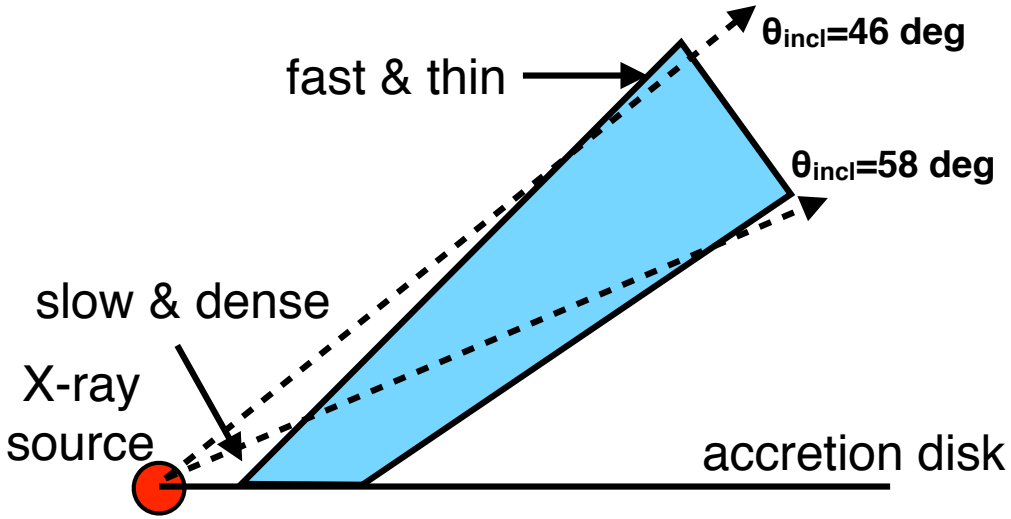
$$v_r(l) = v_0 + (v_\infty - v_0)\left(1 - \frac{R_{min}}{R_{min}+l}\right)^{\beta}$$

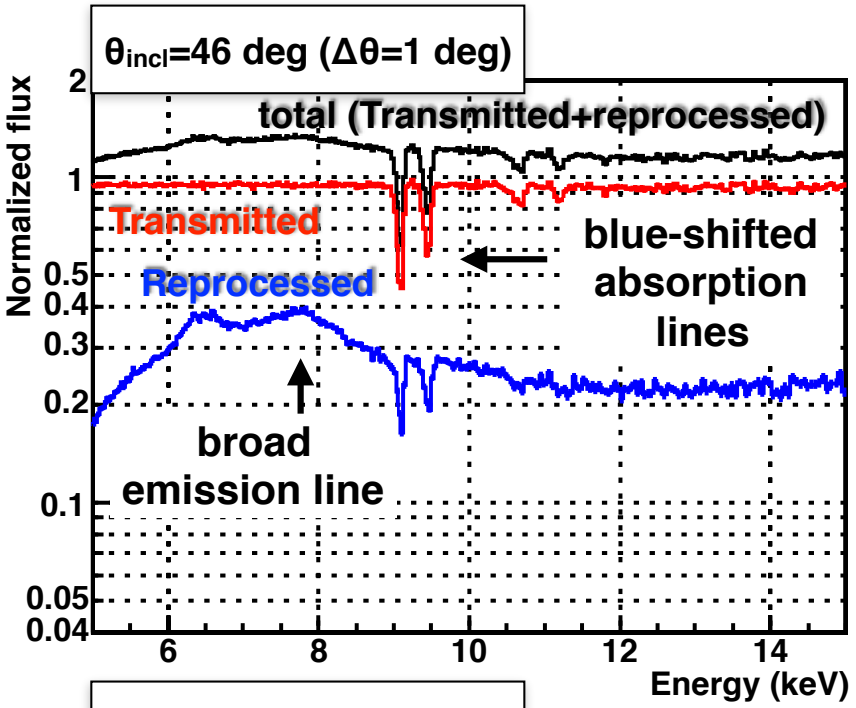
Based on the UV-line driven disk wind

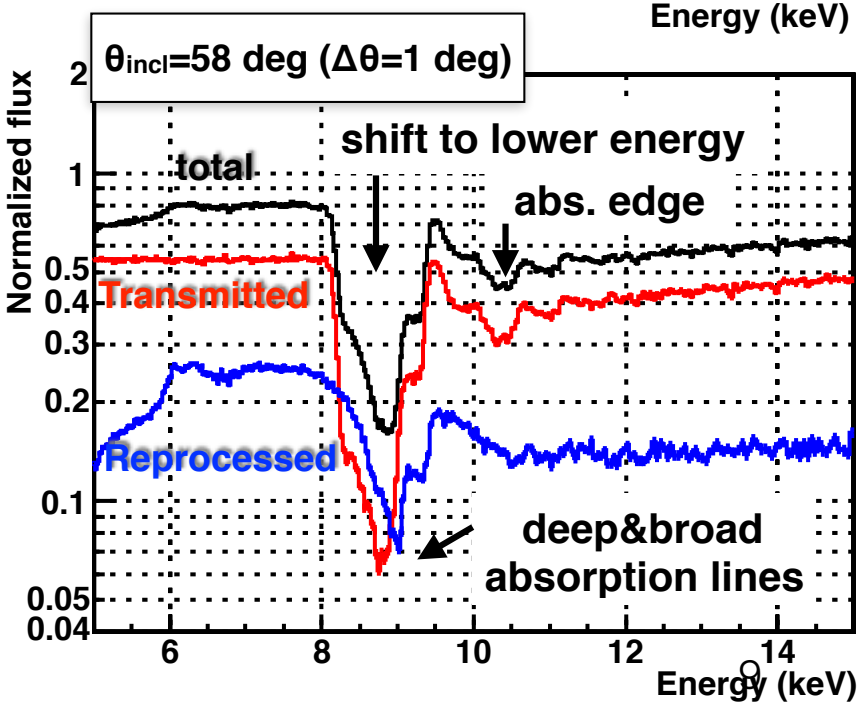
- Ionization structure: 1-D along the stream line
- Monte Carlo radiation transfer simulation: "MONACO" (Odaka+ 2011)
- Self-consistently calculate both of the emission and absorption

Physical processes
- Photoionization
- Photoexcitation
- Compton scattering
- Doppler effect

Simulated spectra





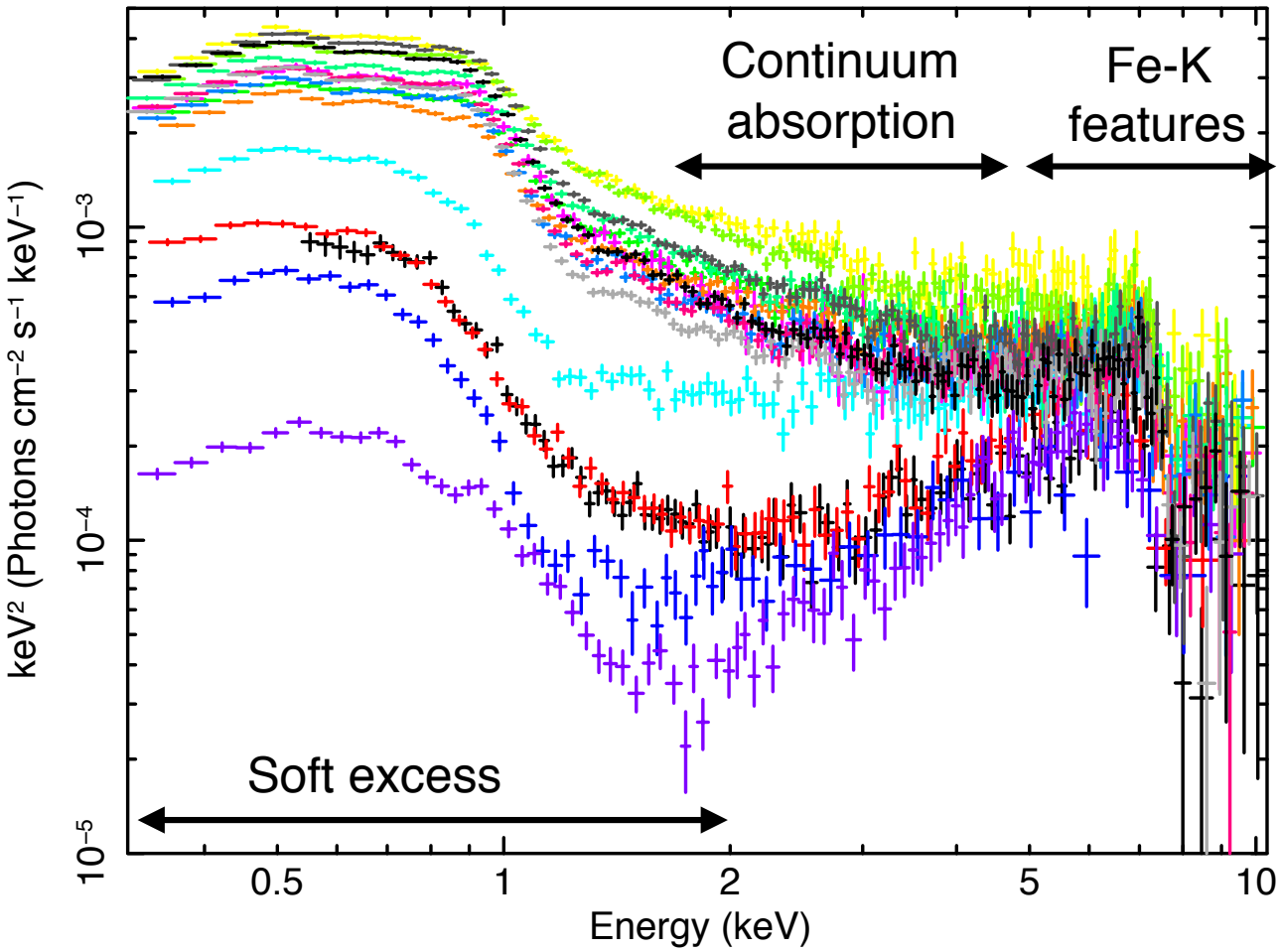


- Blue-shifted absorption & broad emission like the observation
- At large θ_{incl}
  - high density→deep absorption
  - observe slower component→broad

➡ **Larger inclination angle produces a very broad absorption line just like 1H 0707-495**

Application to the observations of 1H 0707-495

- Spectra of 1H 0707-495 are composed of 3 components.



- Fe-K feature:

  created by the **highly ionized gas** ($\xi \sim 10^{3\text{-}4}$)

  ➡ **our disk wind model**

- Continuum absorption:

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

  ➡ **partial covering absorption**

- Soft excess:

  not consider in this work

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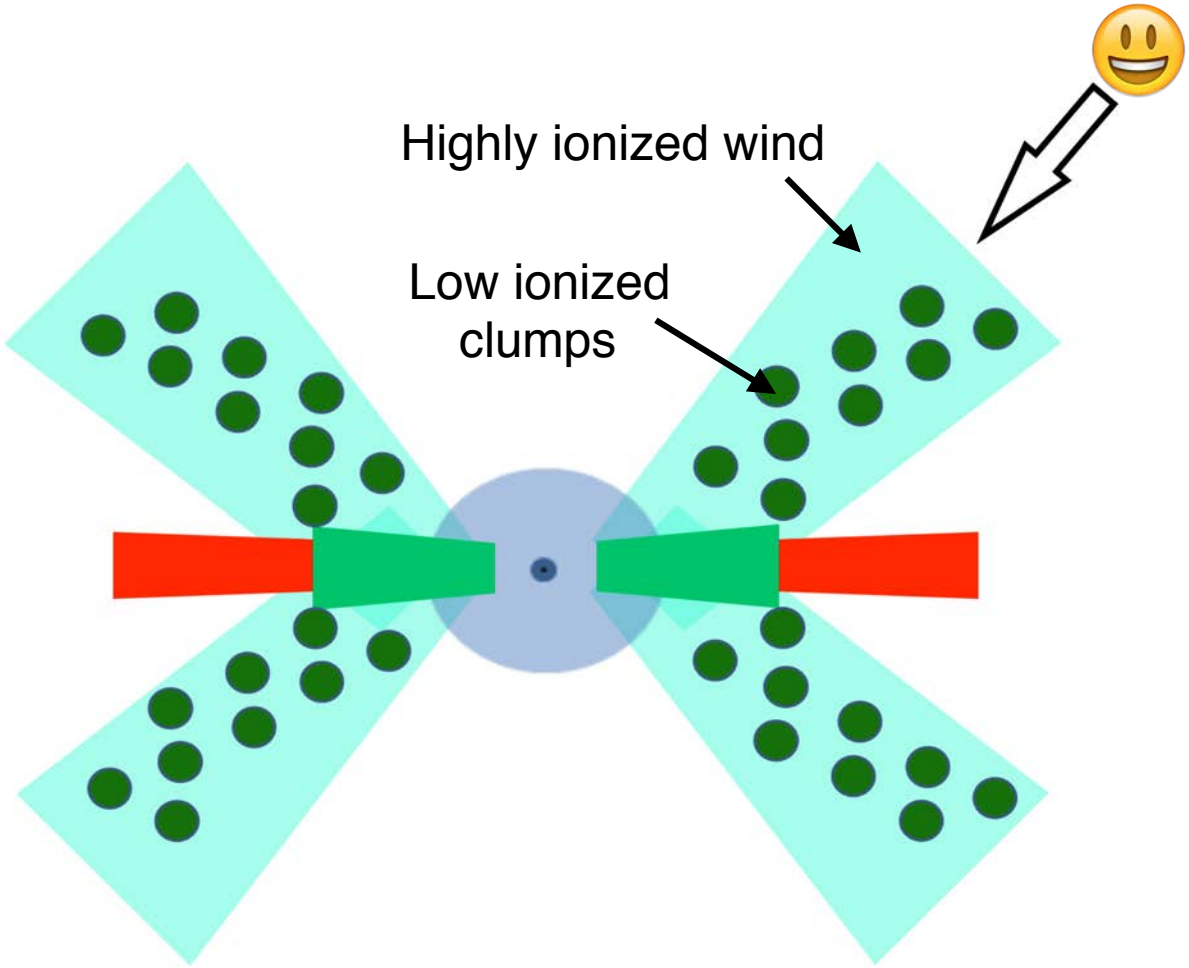

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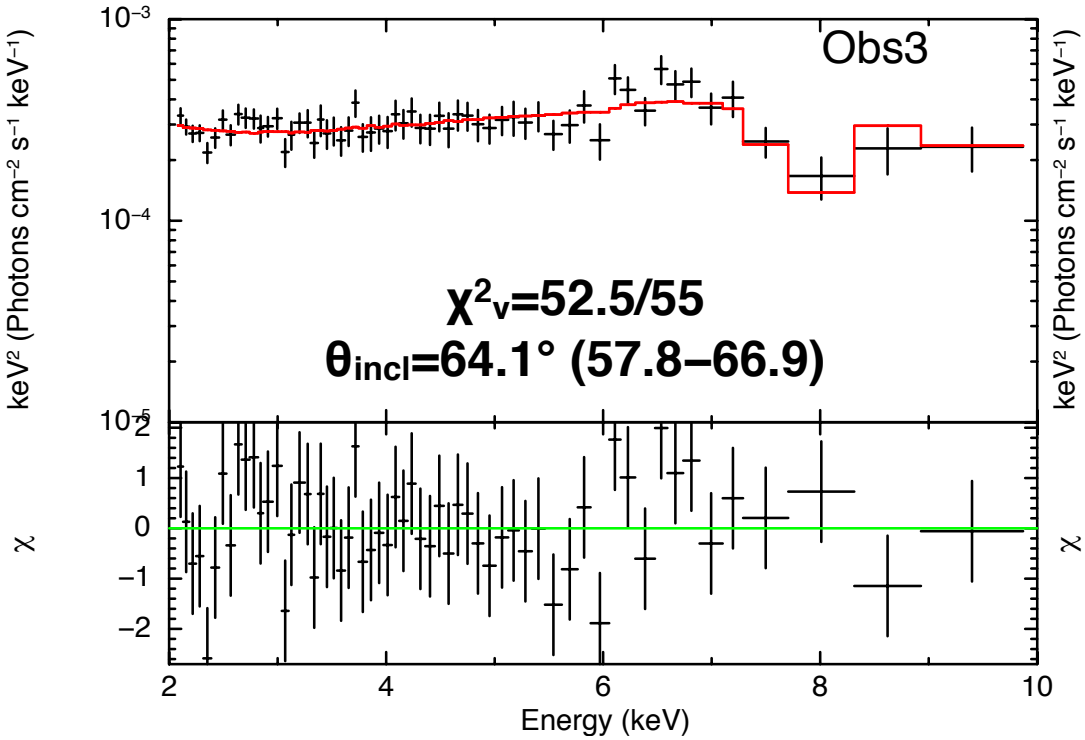
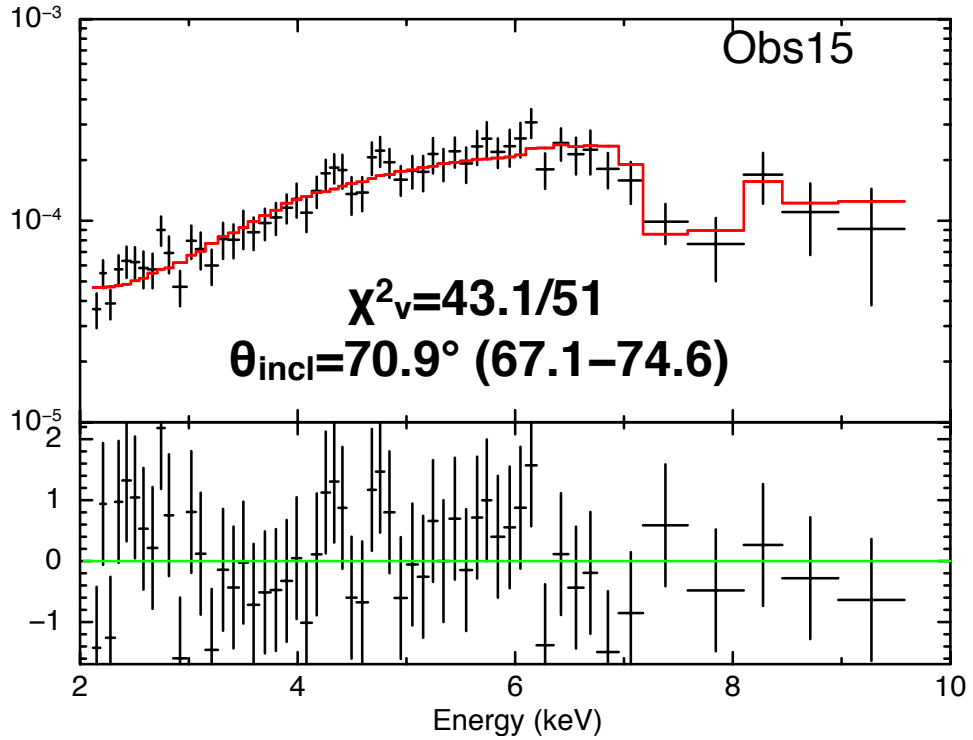
Spectral fit with the disk wind model



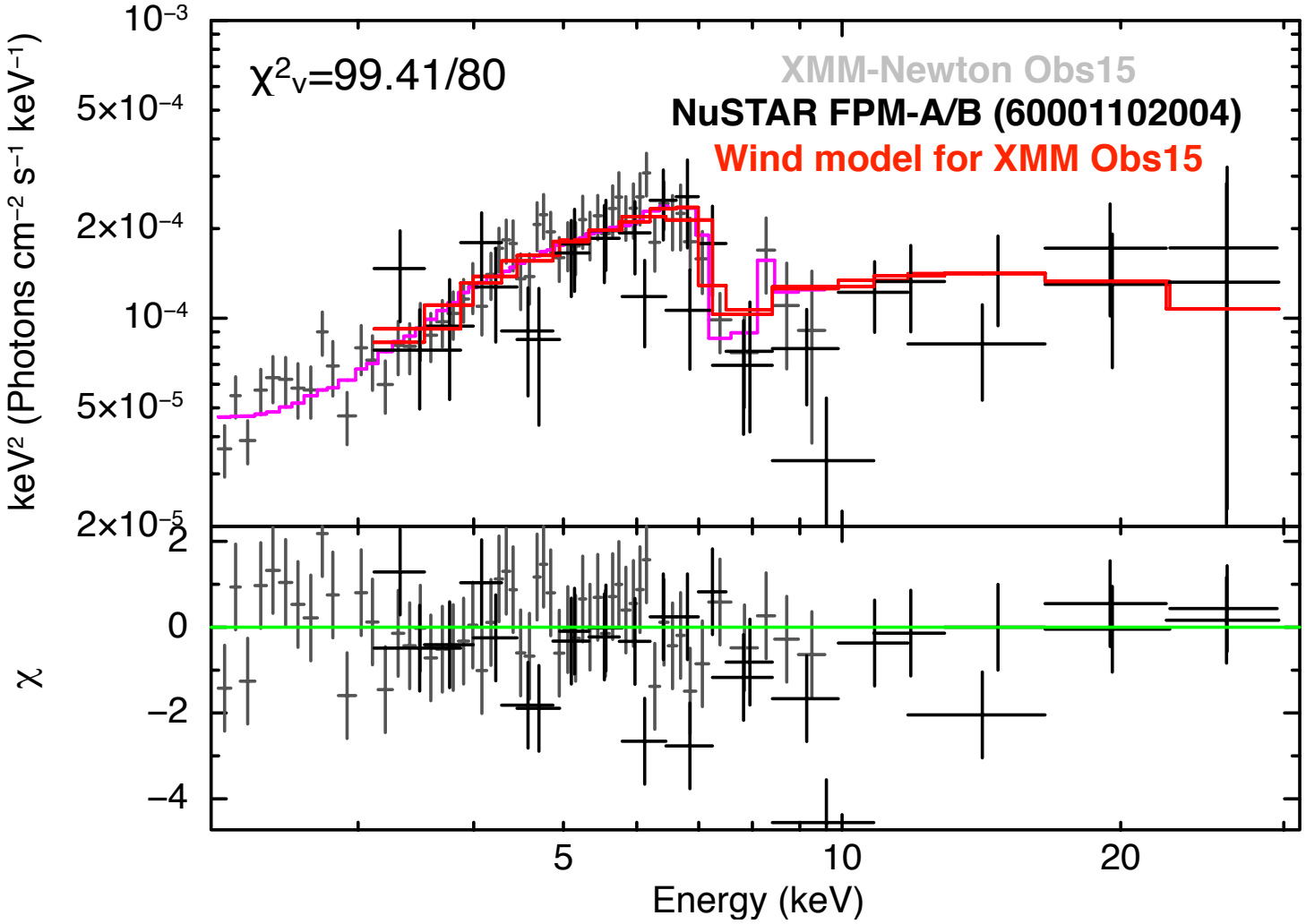


- Reproduced the structure above ~7 keV

➡ **The spectra of 1H 0707-495 can be explained by the ultra-fast outflow (M_{wind}/M_{Edd}=0.2, v=0.2c)**

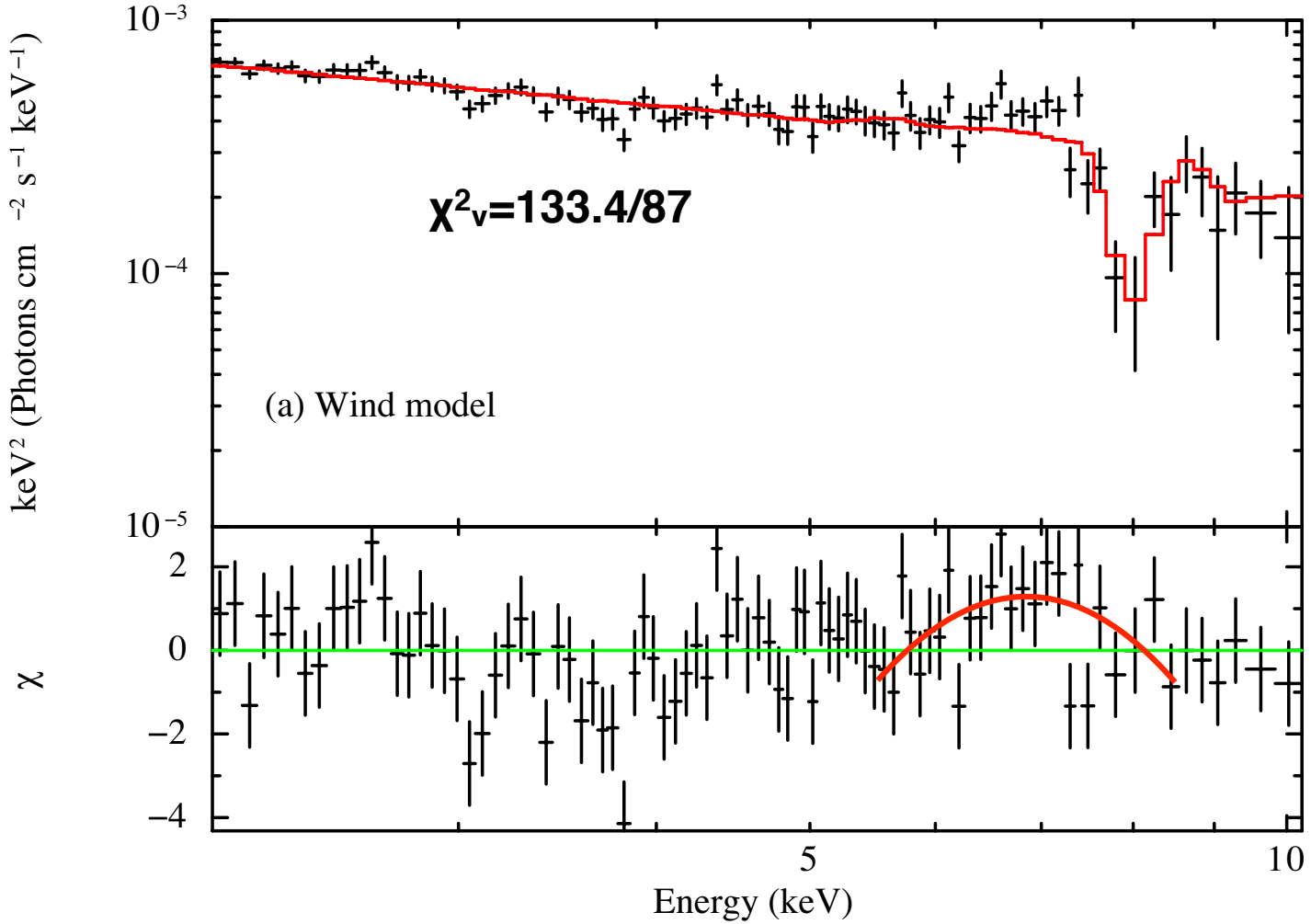
Comparison with NuSTAR data

- 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!!**



Small residuals at ~6-7 keV

- However, there is a small residual at ~6-7 keV
- This could be residual reflection from the disk…

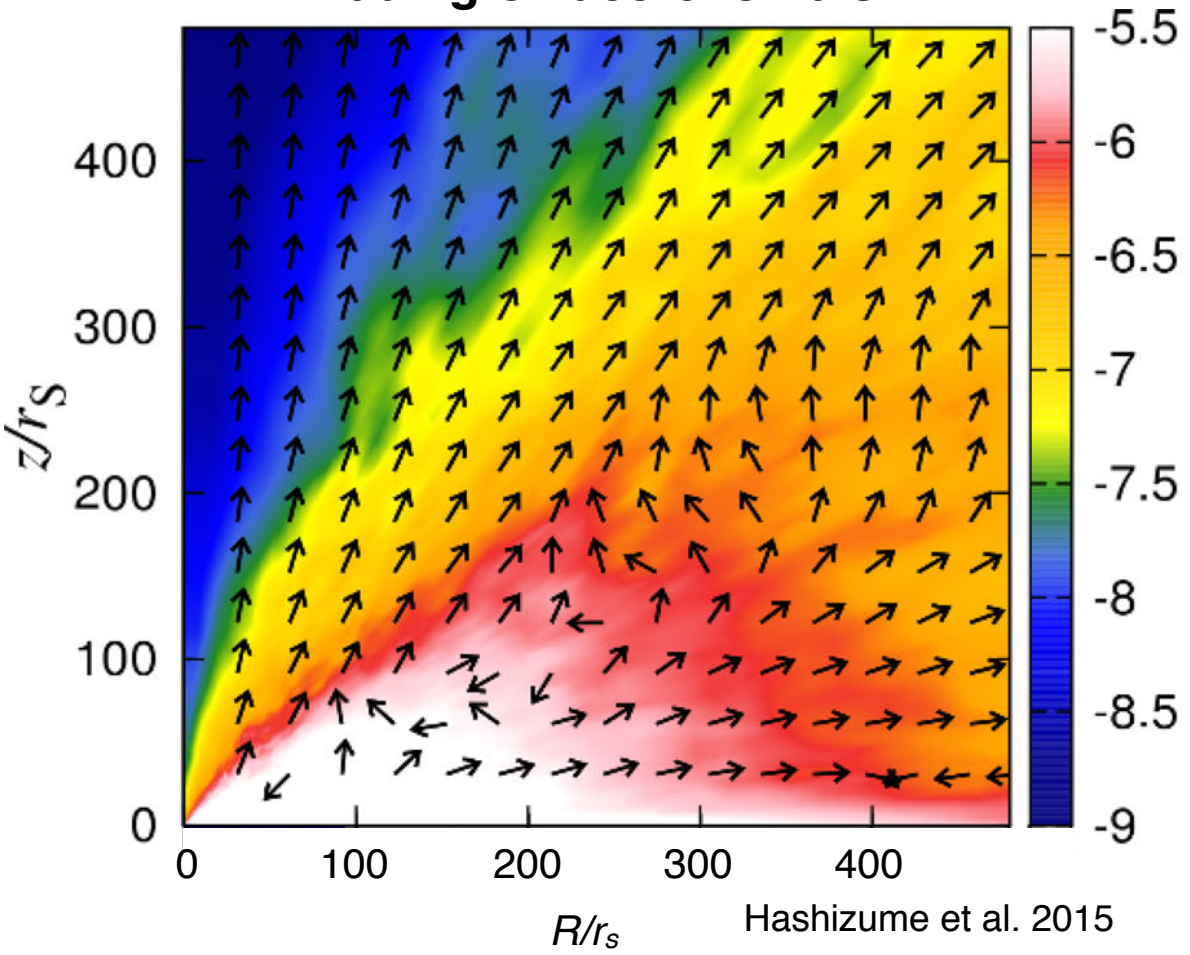


Reflection from the wider angle wind?

- Alternatively, the additional emission is possibly from a wider angle wind.

- Naturally expected in super-Eddington accretion
- Driven by the radiation pressure via **Thomson scattering**, not bound-bound transitions: **"Continuum-driven disk wind"**

Continuum-driven wind in super-Eddington accretion disk

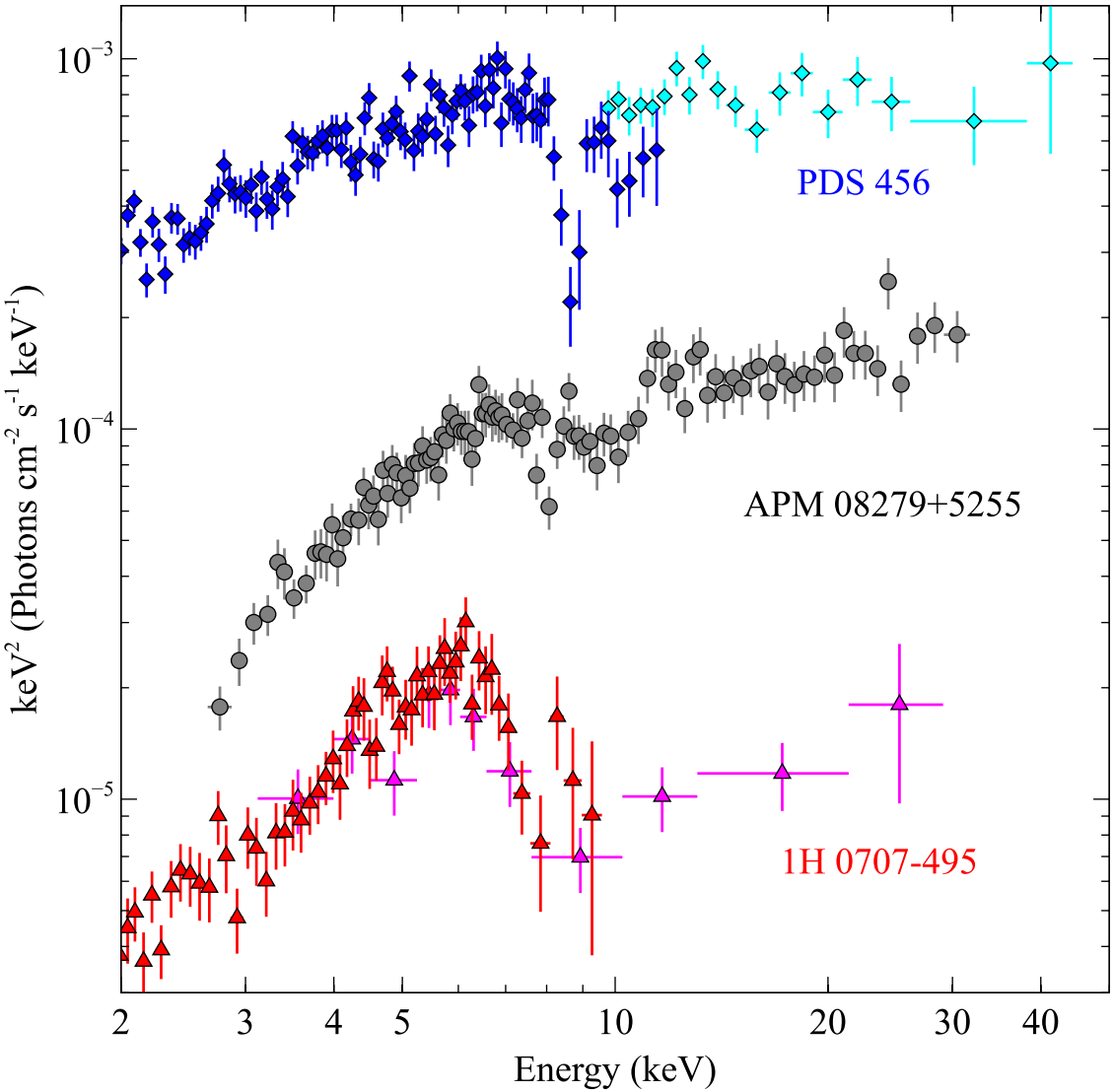


Hashizume et al. 2015

➡ **The wind in 1H 0707-495 is possibly a continuum-driven disk wind**

An extremely fast wind in APM 08279+5255

- Now, we are working on the extremely fast wind in APM 08279+5255
- v~0.7c is reported in this source by Chartas et al. (2009)



- Clearly, the absorption line in APM 08279+5255 is **less blue-shifted** than that of PDS 456
- We are trying to model the spectra without extremely fast wind

Conclusions

We applied our new X-ray spectral model for the ultra-fast outflows to a super-Eddington AGN: 1H 0707-495.

- ✓ The strong Fe-K feature in *XMM-Newton/Suzaku/NuSTAR* spectra of 1H 0707-495 are successfully reproduced by our disk wind model.
- ✓ Our disk wind model under-predict the emission lines, suggesting a wider angle wind by the continuum radiation driving mechanism.

➡ **A super-Eddington AGN 1H 0707-495 has an ultra-fast outflow**