Modeling the X-ray spectrum of AGN with Monte-Carlo simulations:

The case of a density gradient

Eva Lefa

Th. Akylas, A. Mastichiadis, A. Georgakakis

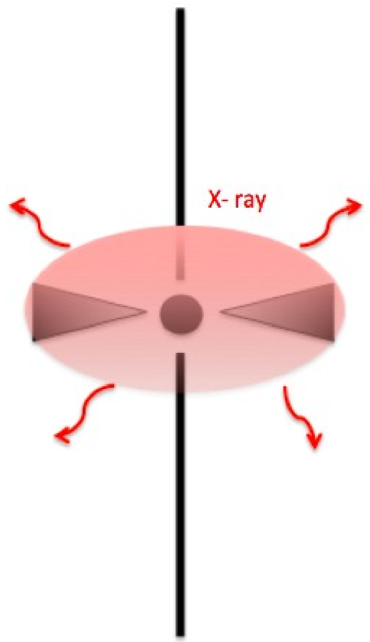
HEL.A.S. conference, June 30, 2015

X-rays from AGN

- **Intrinsic X-ray spectrum**

  Power-law X-ray photons

  Disk photons up scattered to
  hard X-rays from energetic particles
  in hot corona close to Black hole

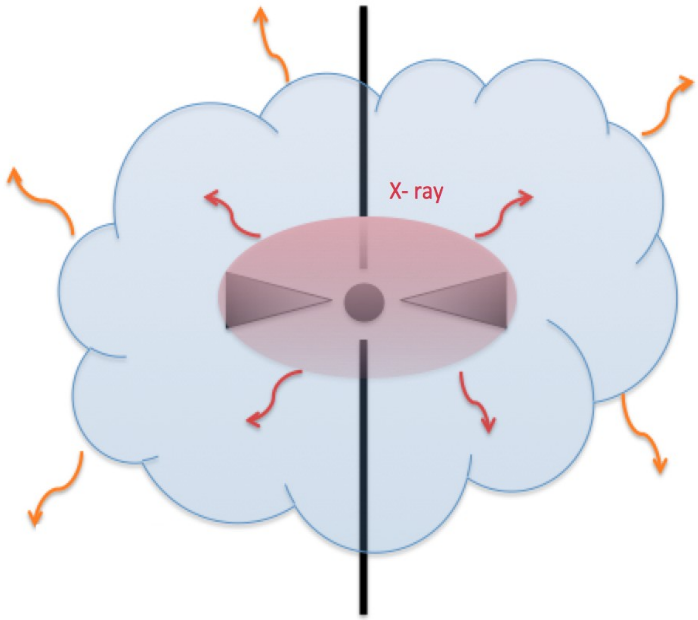


X-rays from AGN

- **Intrinsic X-ray spectrum**

  Power-law X-ray photons

  Disk photons up scattered to
  hard X-rays from energetic particles
  in hot corona close to Black hole



- **Observed X-ray spectrum**
- *Intrinsic photons reprocessed at surrounding material*

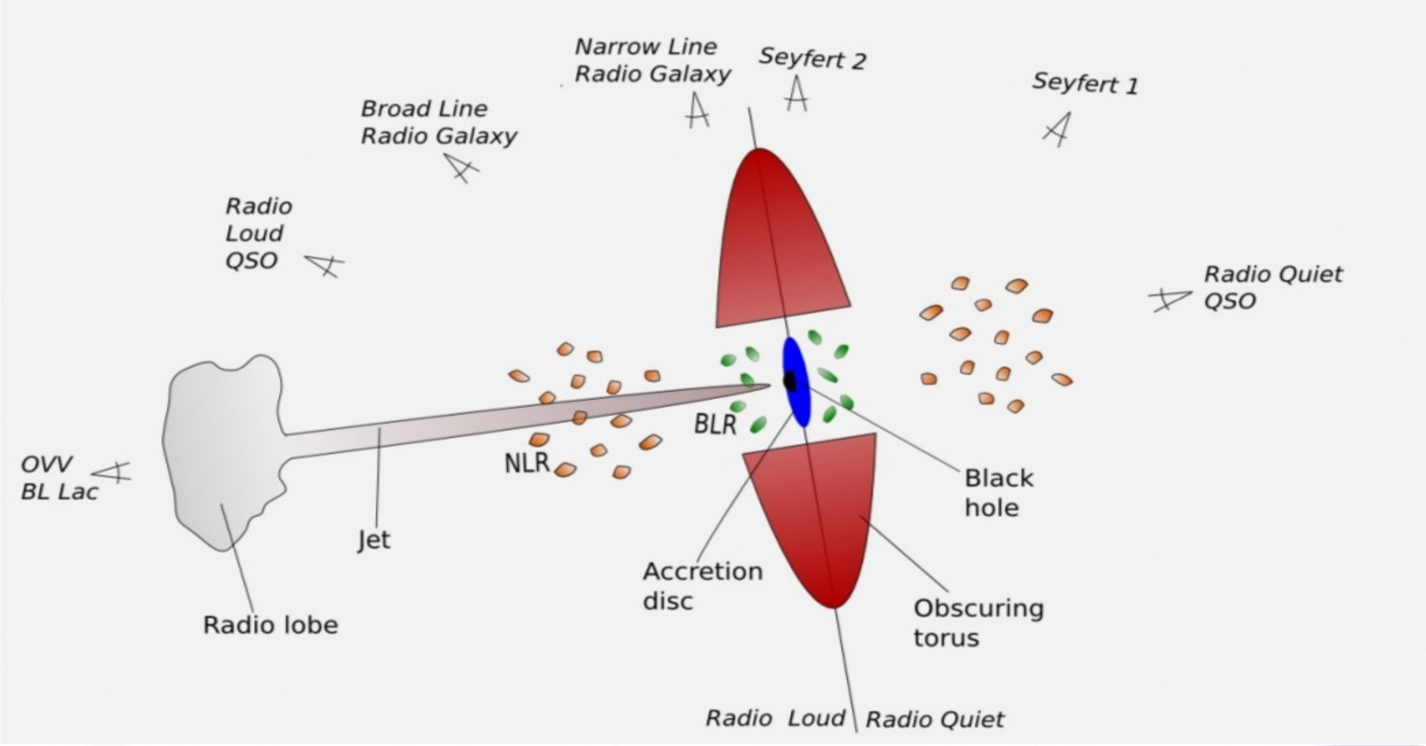
Relevant mechanisms:

Compton scattering

Photoabsorption

Studying Obscured AGN spectra

- Large fraction of AGN obscured by Compton thick gas
- Information for the central engine surrounding environment
- Understanding AGN unification scheme-geometry of obscuring material is important – observed spectrum depends on observer viewing angle
- X-ray Background (XRB) intensity composed by AGN X-ray radiation

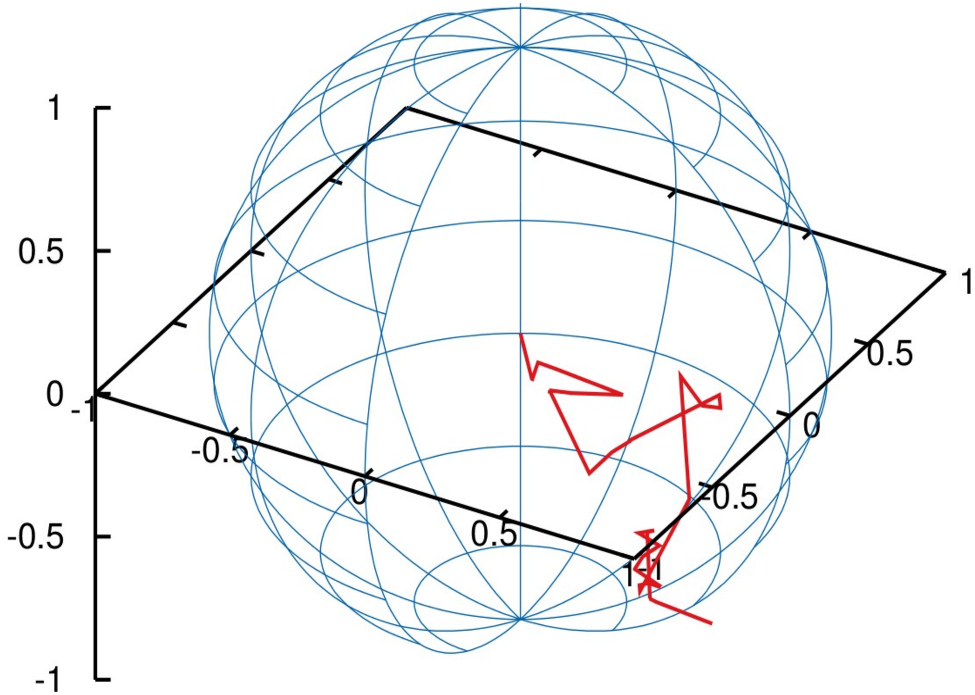


- **Develop a Monte-Carlo code to simulate the X-ray observed spectrum**
- **Power-law x-ray photons emitted from the center surrounded by obscuring material**
- Introduced mechanisms:

  Compton scattering on cold electrons

  Photoabsorption (+Line emission)
- **Apply a density gradient in the obscuring material**

Comptonization: first principles

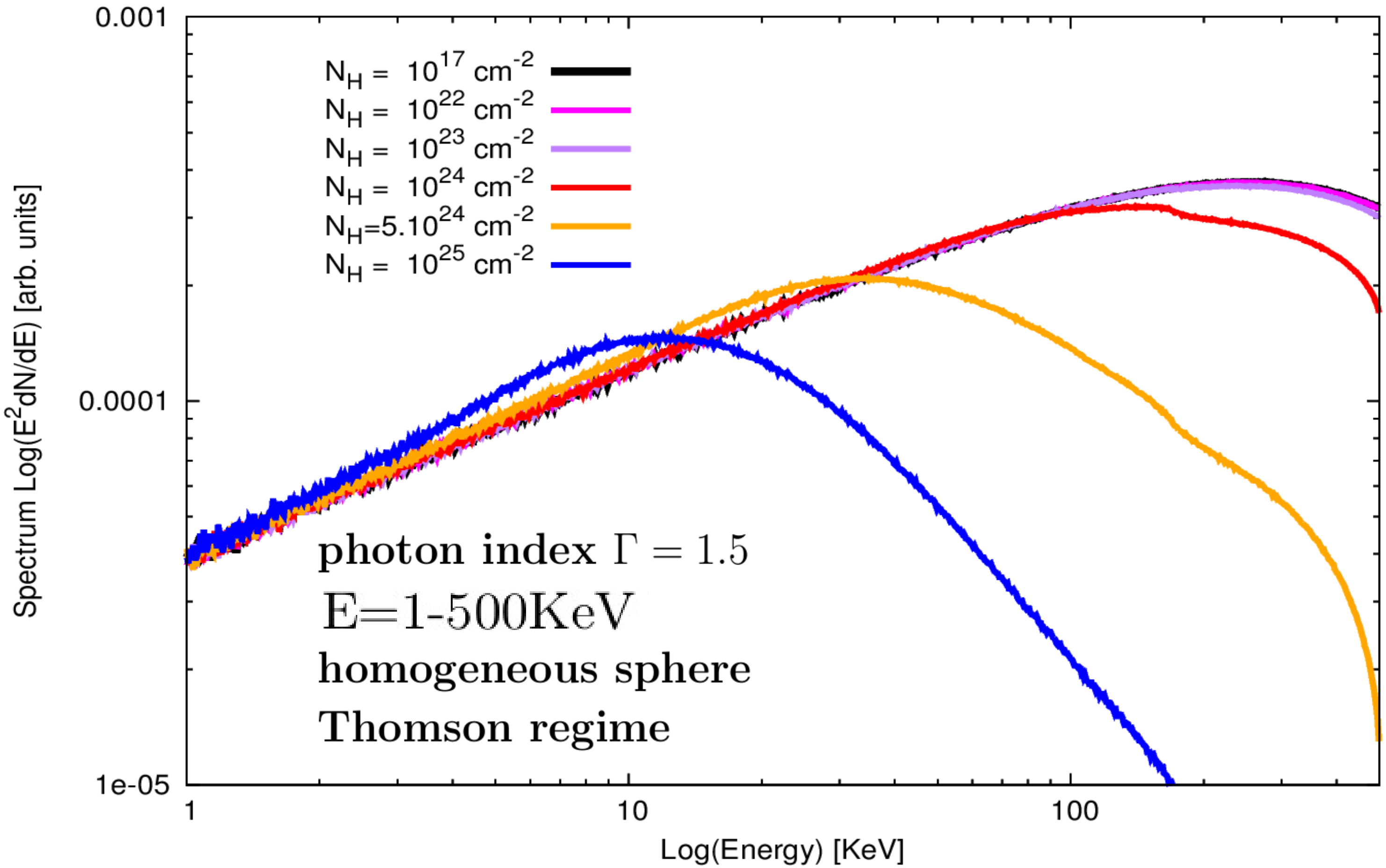


Spherical **homogeneous** region containing cold electrons

Photon emitted isotropically from the center

- Multiple scattering → diffusion in space → random walk
- Column density : $N_H = nR$
- $N_H > 1/\sigma_T \sim 10^{24} cm^{-2}$ Compton thick source
- $N_H < 10^{25} cm^{-2}$ Emission visible above 10 KeV (mildly Compton thick)

Effect of Comptonization on intrinsic spectrum

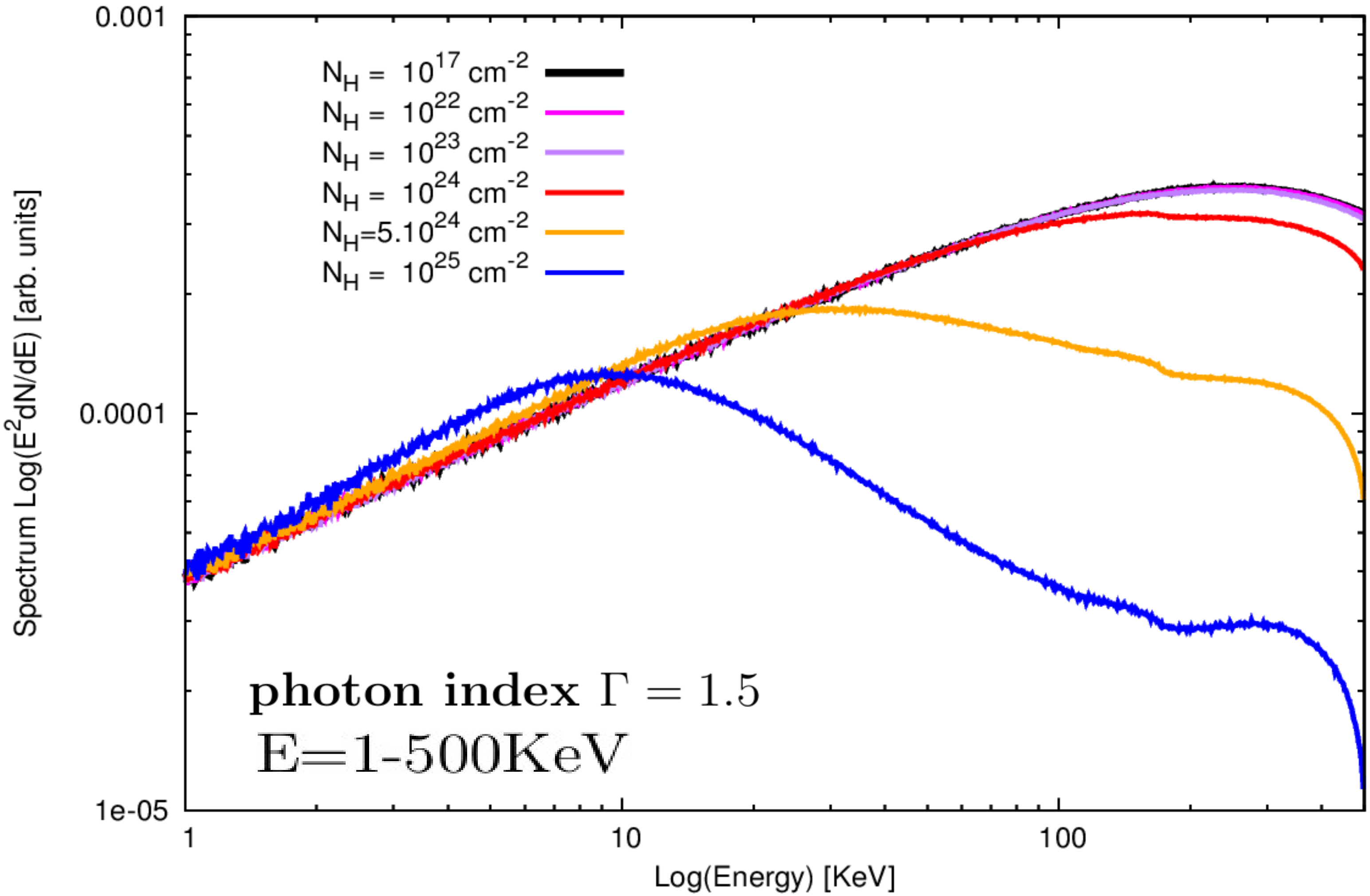


Photon energy change due to **recoil effect**

Spectrum of escaping photon breaks at $\sim mc^2/\tau$

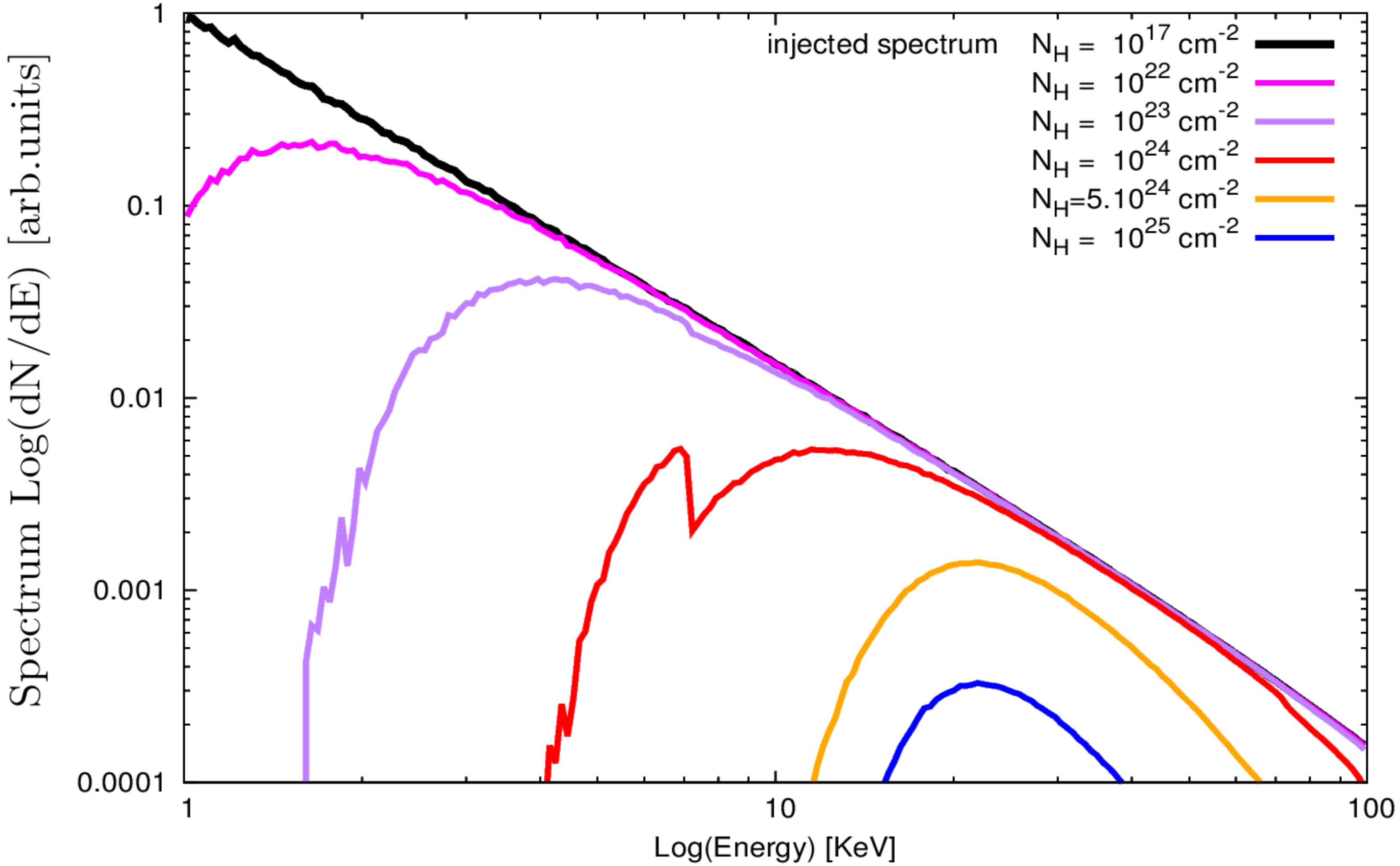
(*Sunyaev & Titartchuk 1980; Lighman 1981*)

Klein-Nishina effect



Cross section decreases → flatter spectrum at high energies

Effect of Photoabsorption



$\sigma_{ph} \propto \epsilon^{-3}$ → Increases steeply with decreasing energy

Spectral turnover at low energies

Density gradient along polar θ angle

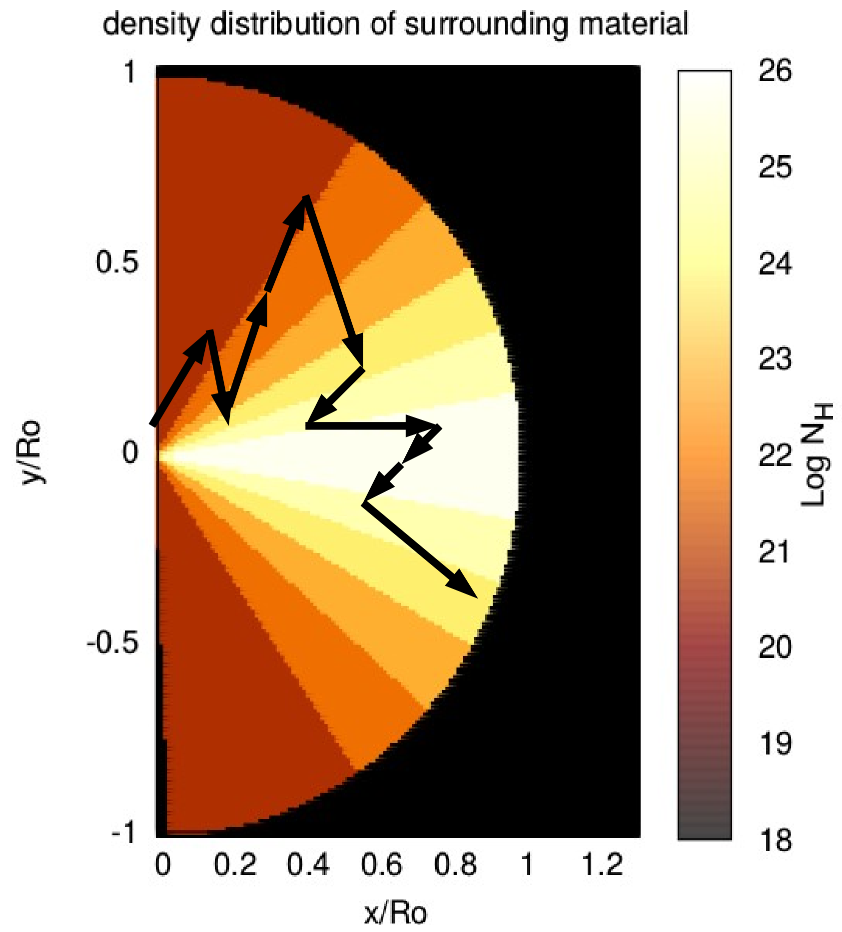
- Previous works include sphere (e.g. Leahy & Creighton 1993, Matt et al. 1999), spherical-toroidal (e.g. Ghisellini et al. 1994, Ikeda et al. 1994), disk-reflection (e.g. Magdziarsk & Zdziarski 1995), torus (e.g. Yaqoob & Murphy 2009)

- **Why consider an inhomogeneous obscuring material?**
- More realistic – motived by HD simulations (e.g. Wada et al. 2012)

- Density gradient can approximate different geometries, e.g. toroidal

- Grad along θ angle due to unification scheme

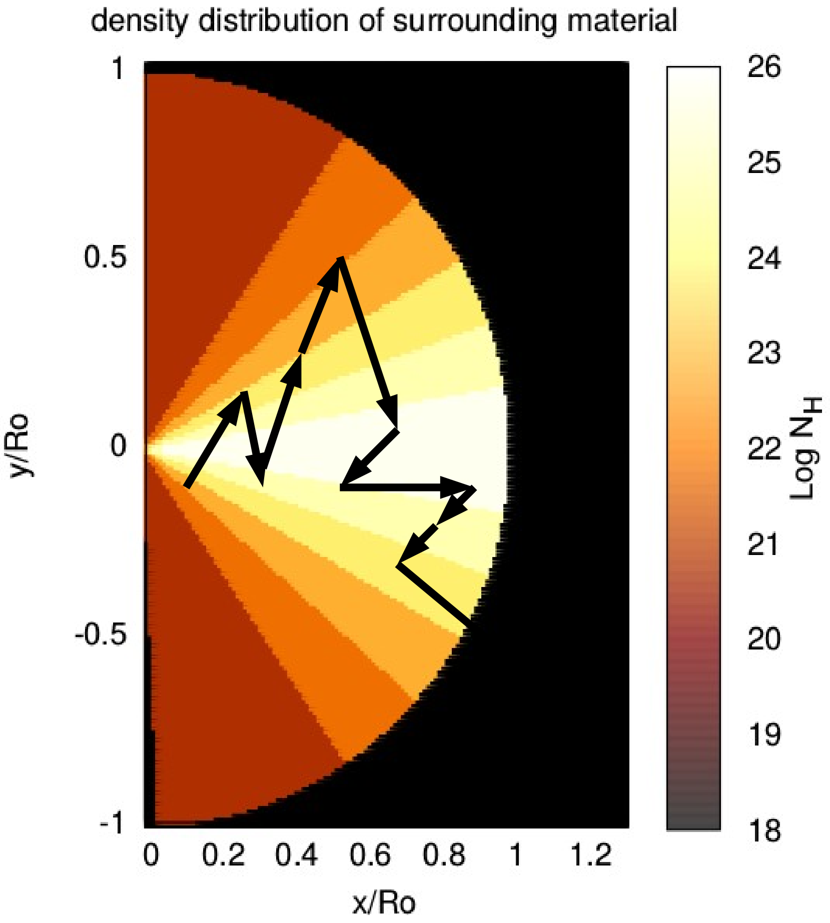
- **Viewing angle severely changes the output spectrum**



Density gradient along azimuthial θ angle

MC code: free path L depends on photon position

- Discretize gradient → layers
- **Distance S** of photon to boundary analytically calculated
- L < S the photon interacts and change direction
- L > S the photon is transferred to the boundary



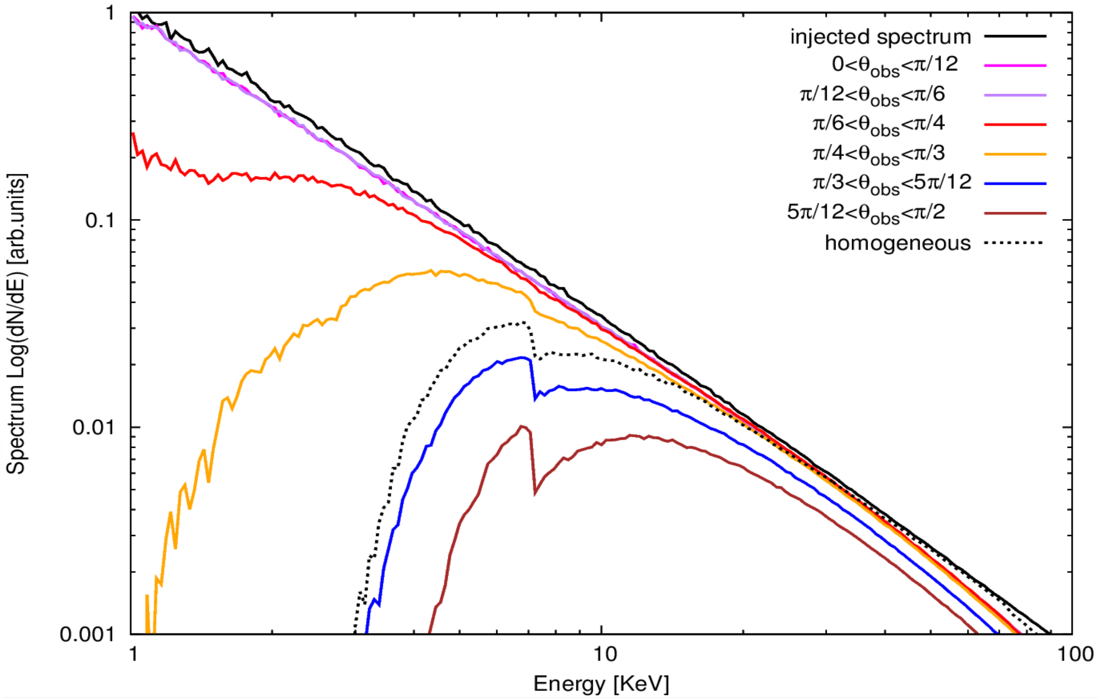
Density profile?

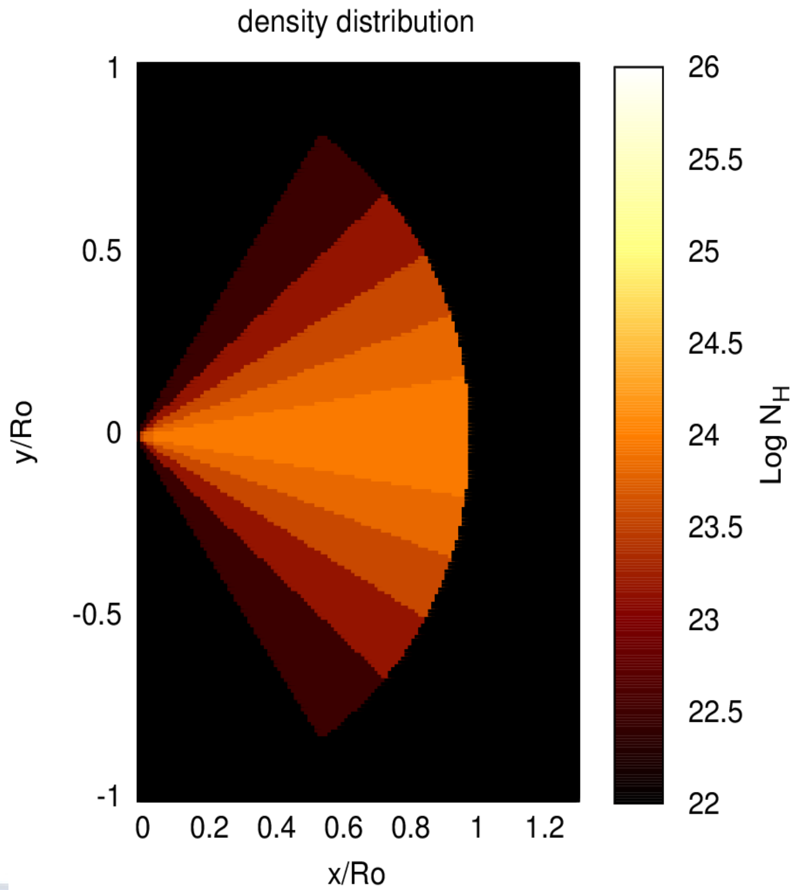
Analytical function, e.g. *Nenkova et al. 2011*

$$\rho_\theta = \rho_0 \exp\left[-\left(\frac{\pi}{2} - \theta\right)^2 / \sigma^2\right]$$

$\sigma = \pi / 3$: angle below which density drops significantly

"Equivalent" N_H=3.6 10^{23} cm^{-2}

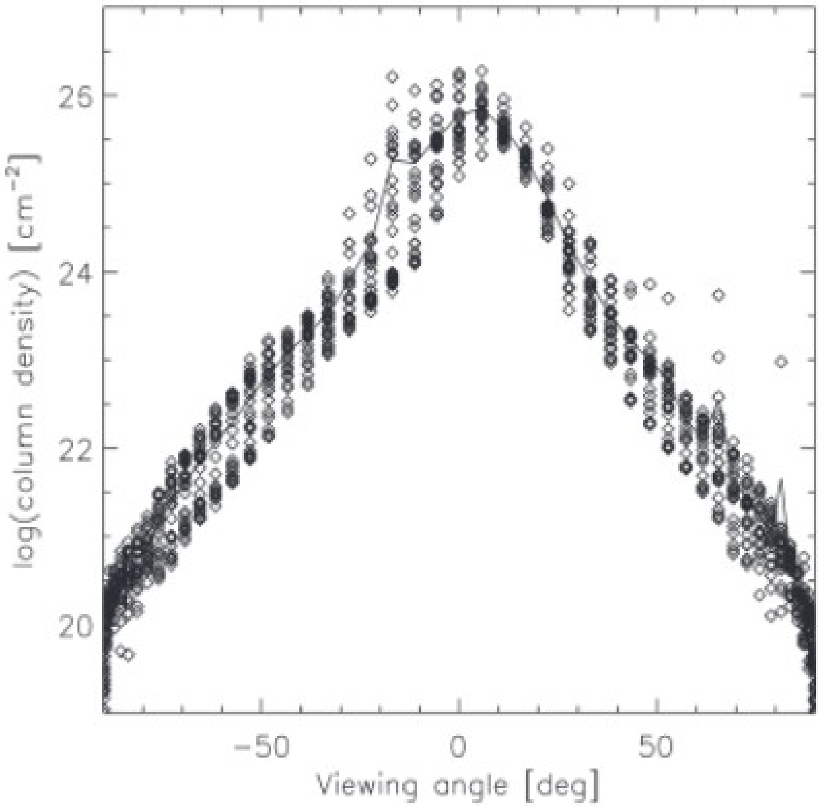


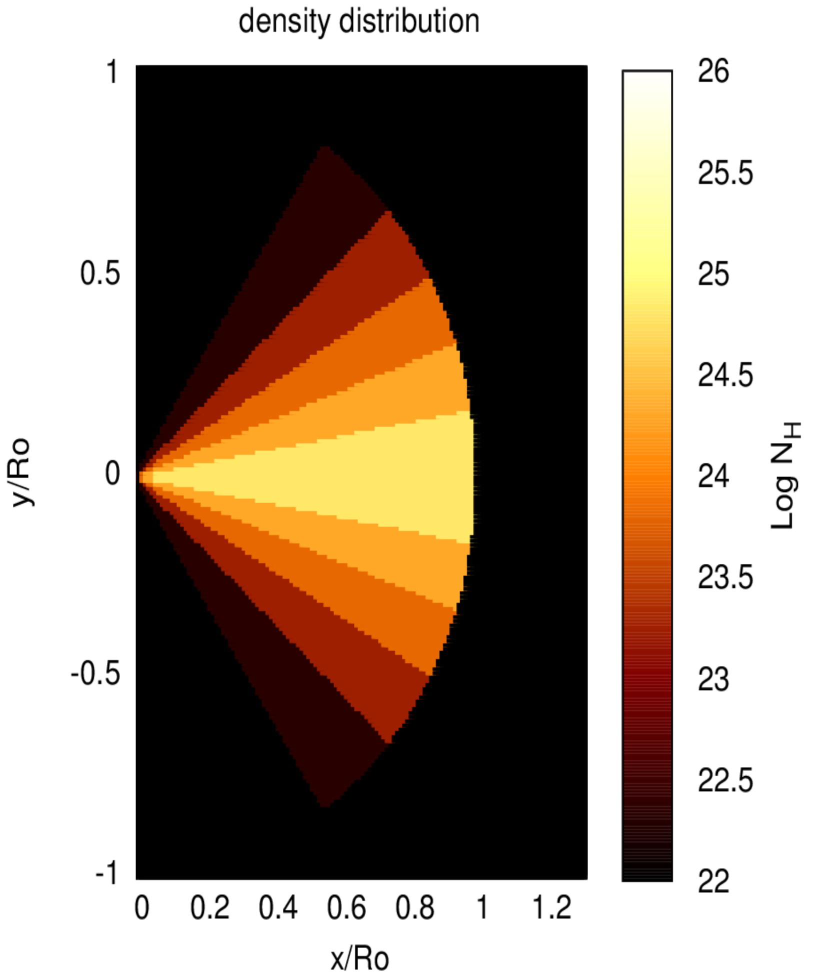


Density profile?

HD simulation of torus formation,

Wada 2012

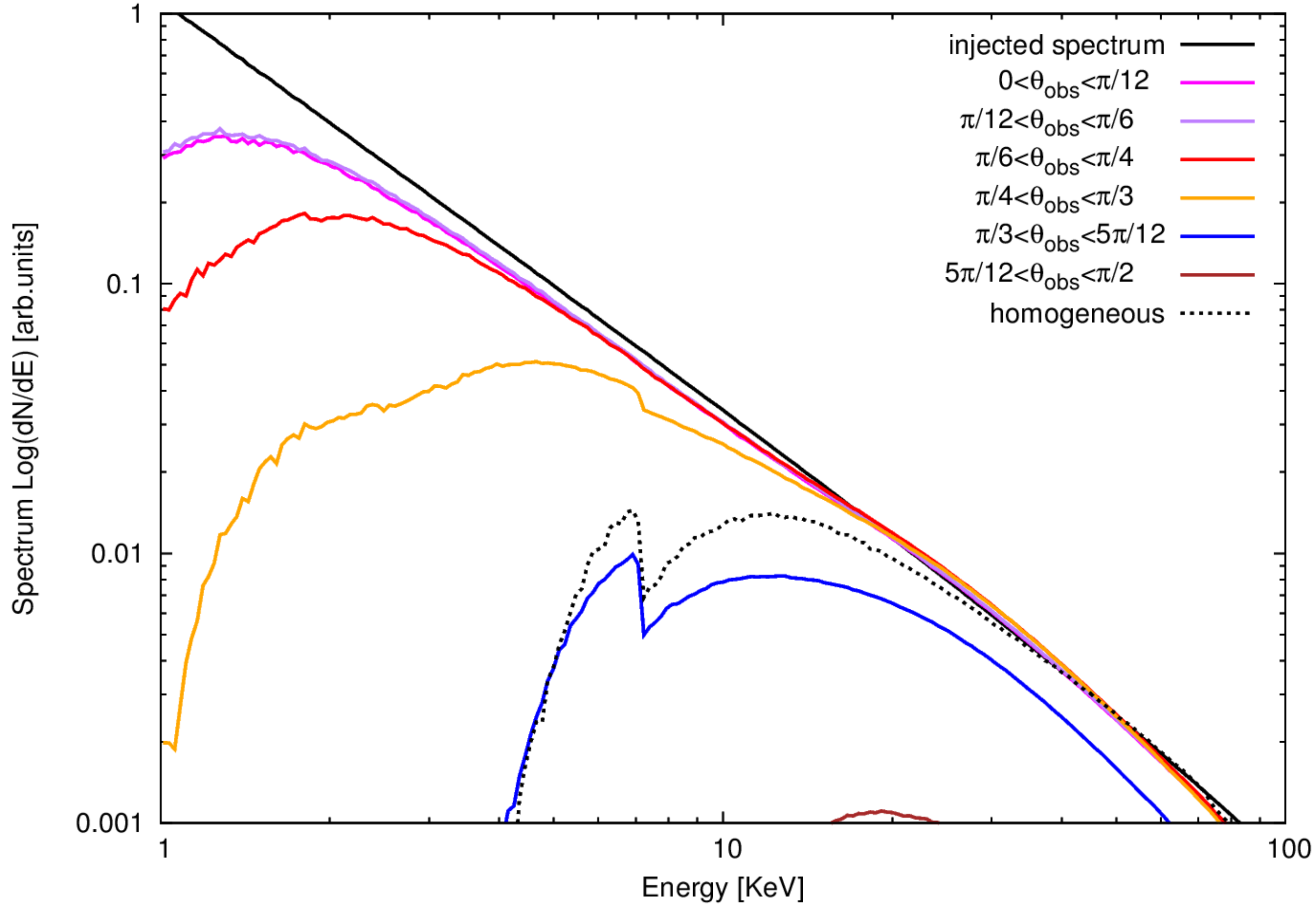




Density profile?

HD simulation of torus formation, *Wada 2012*

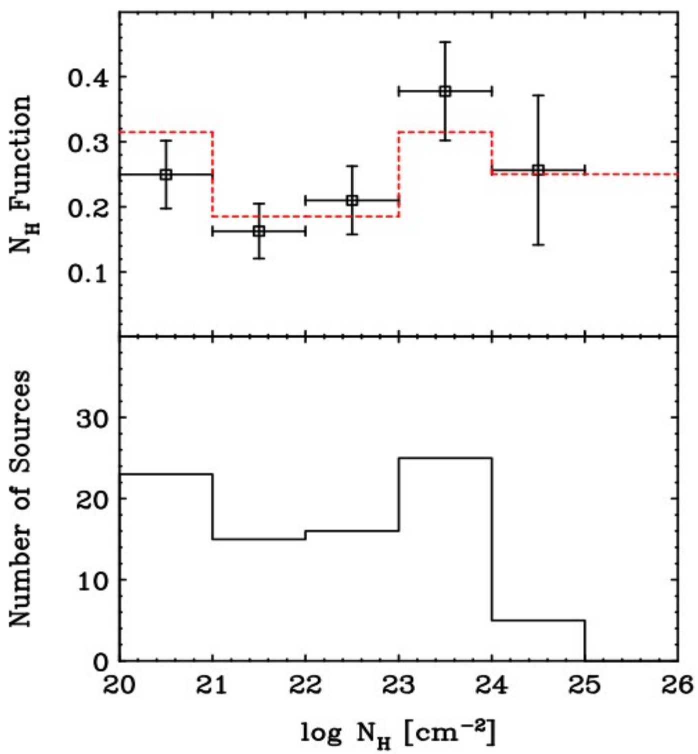
equivalent N_H=8. 10^{23} cm^{-2}



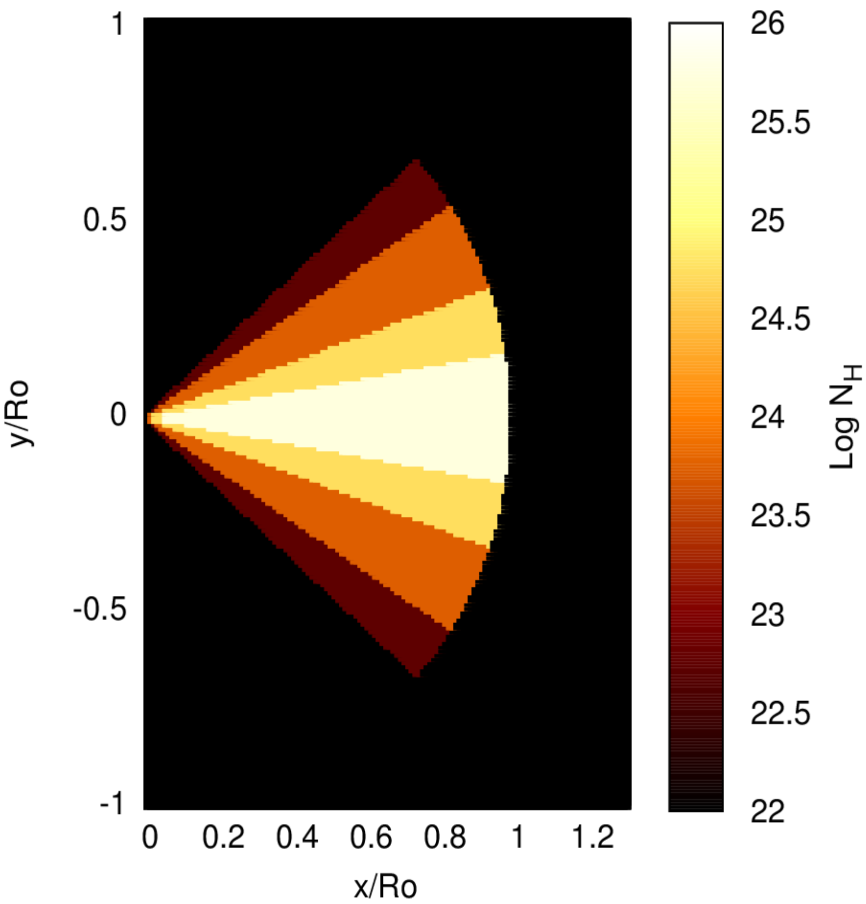
Density profile?

- Mimic observational survey on AGN N_H distribution, *Ueda 2002, 2009, 2014,* discrete gradient
- Number of sources at a specific $N_s \sim \Delta V$ (layer volume) with the same N_H

Ueda et al.

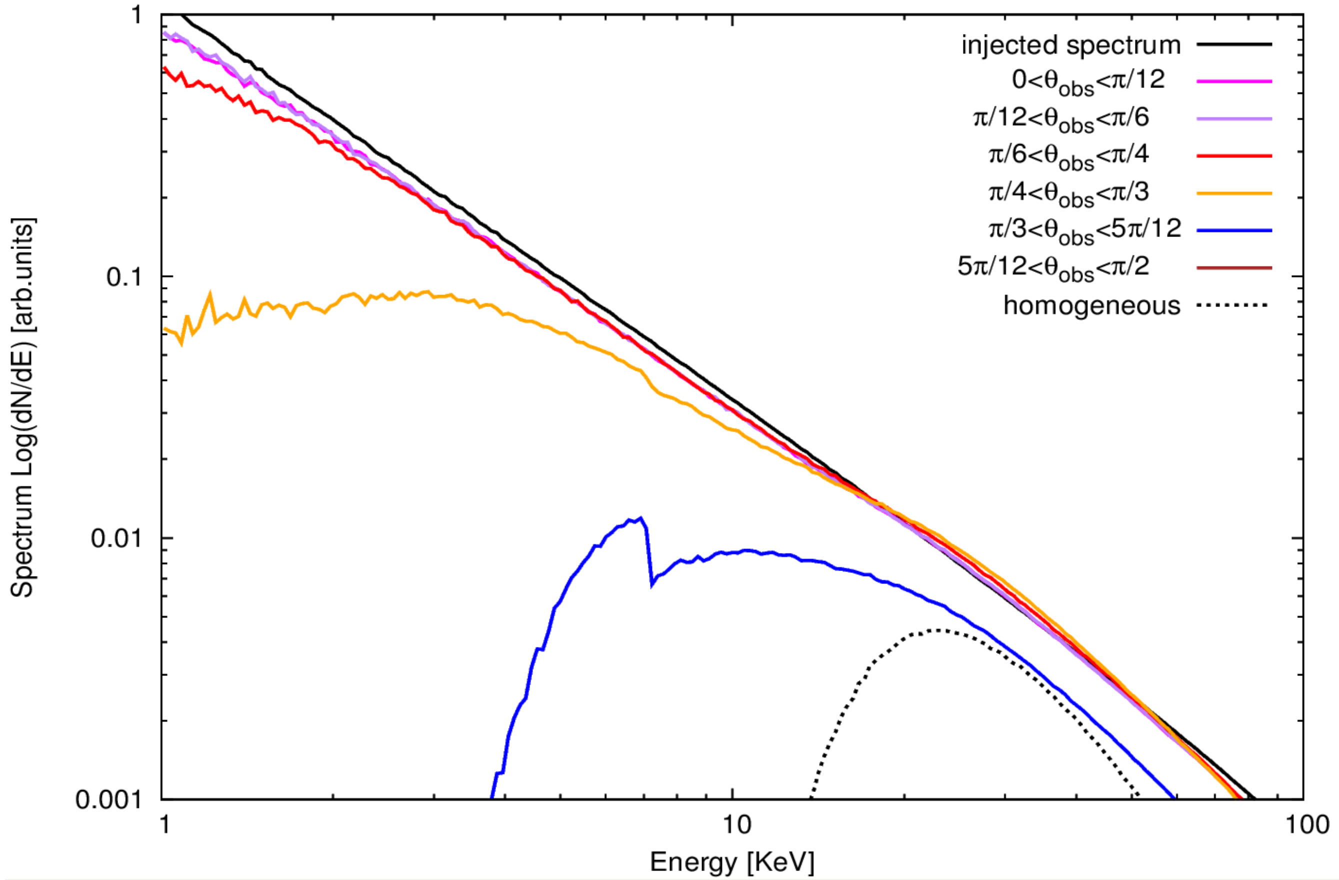


density distribution

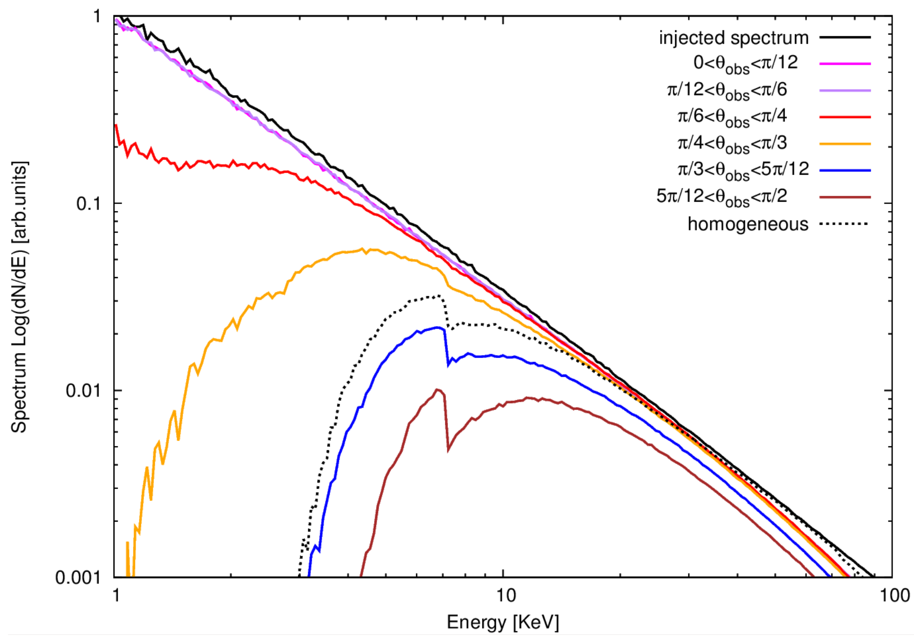


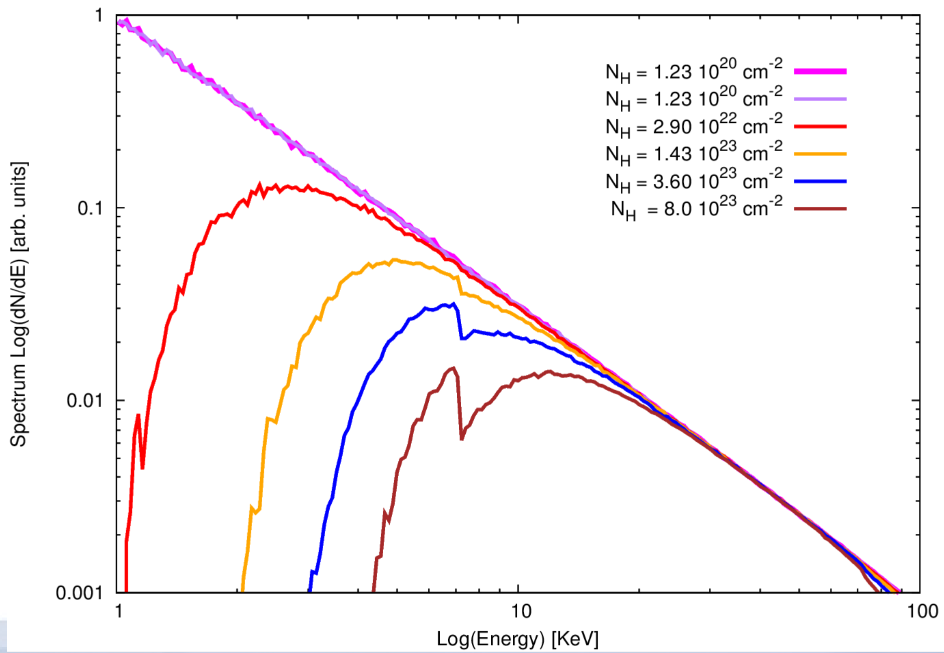
Density profile?

- Following *Ueda 2014* - equivalent N_H=5. 10^{24} cm^{-2}



Comparison to homogeneous case?





- Density gradient-analytical profile

$$\rho_\theta = \rho_0 \exp\left[-\left(\frac{\pi}{2} - \theta\right)^2 / \sigma^2\right]$$

- Homogeneous sphere-different N_H

$N_H \sim \rho(\theta)R$

Summary

- Monte-Carlo code developed for simulating the reprocessed X-ray spectrum after Comptonization and Photoabsorption
- Inhomogeneous surrounding environment has been introduced – density changes along θ angle
- Inhomogeneous environment: Strong dependence of the output spectrum with the viewing angle
- Different density distribution around the central source (analytical description, HD simulations, observational survey) → Density profile plays important role
- Different surrounding media or different viewing angle? The two models can be distinctive

Emission lines