Stratified Warm Absorbers in AGN: Do we need them ?

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+ astro-pf group

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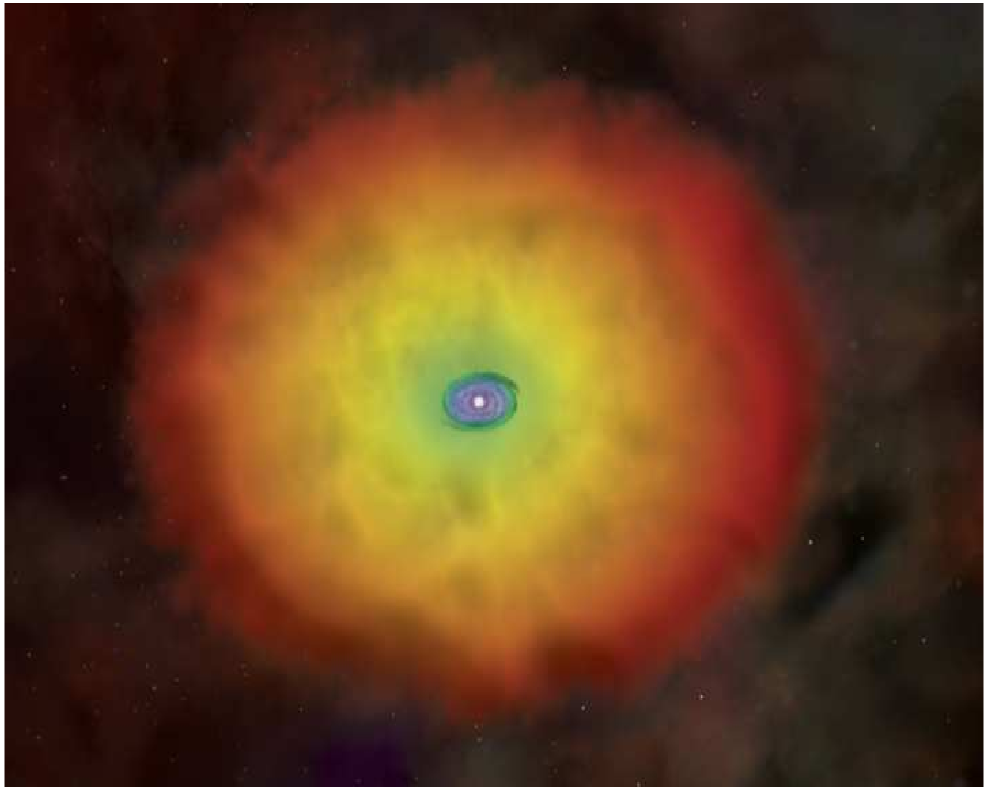
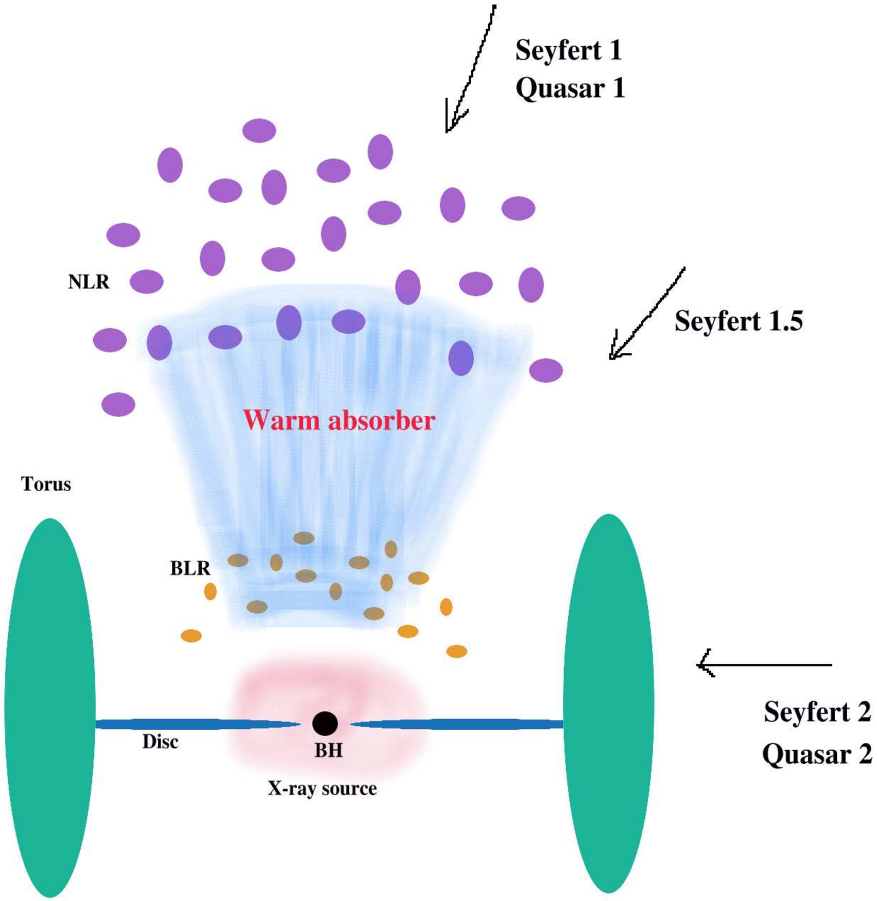
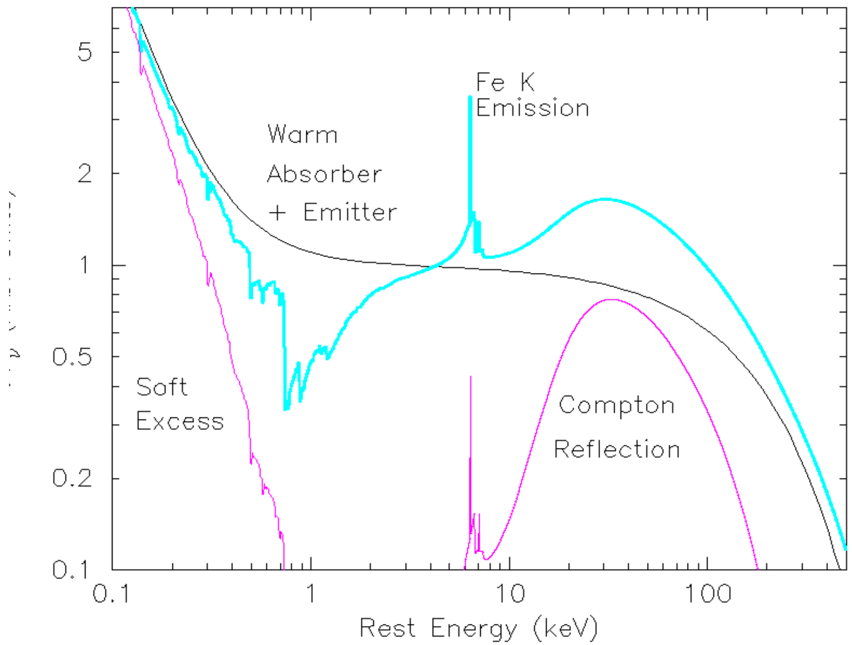


Radio-quiet **AGN**



Possible origin of soft X-rays
in Seyfert galaxies:

- direct emission from an X-ray source
- reflection from an accretion disc
- absorption or reflection by a warm absorber
- interaction with a dusty torus



Plan:

1) Basic approach to the modeling of warm absorber in AGN.

2) Commonly used parameters.

3) Physical values of parameters and distances from the center of AGN.

4) Thermal instabilities – are they dengerous ?

5) Spectra from stratified warm absorbers.

6) Summary ....

Basic approach to the warm absorber problem:

1) Energy balance in the local reference frame:

conductive flux

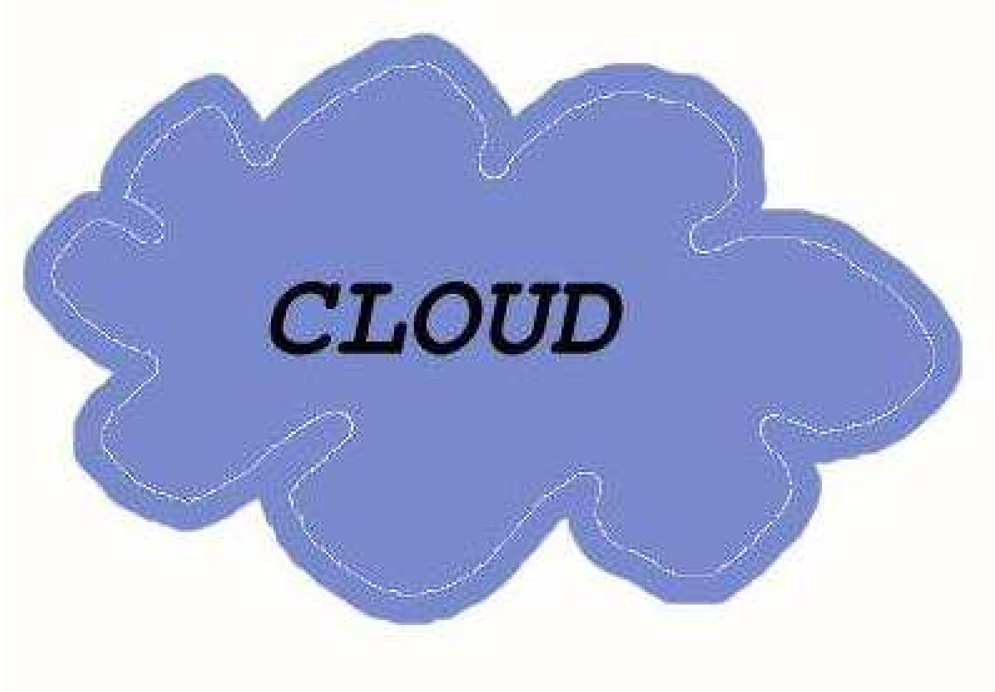
$$\frac{\partial}{\partial t}\left(\frac{1}{2}\rho V^2+\rho\varepsilon\right)+\nabla\cdot\left[\left(\frac{1}{2}\rho V^2+\rho\varepsilon+p\right)\vec{V}\right]=\vec{f}\cdot\vec{V}-\nabla\vec{F}_{rad}-\nabla\vec{q}\;,$$

external forces

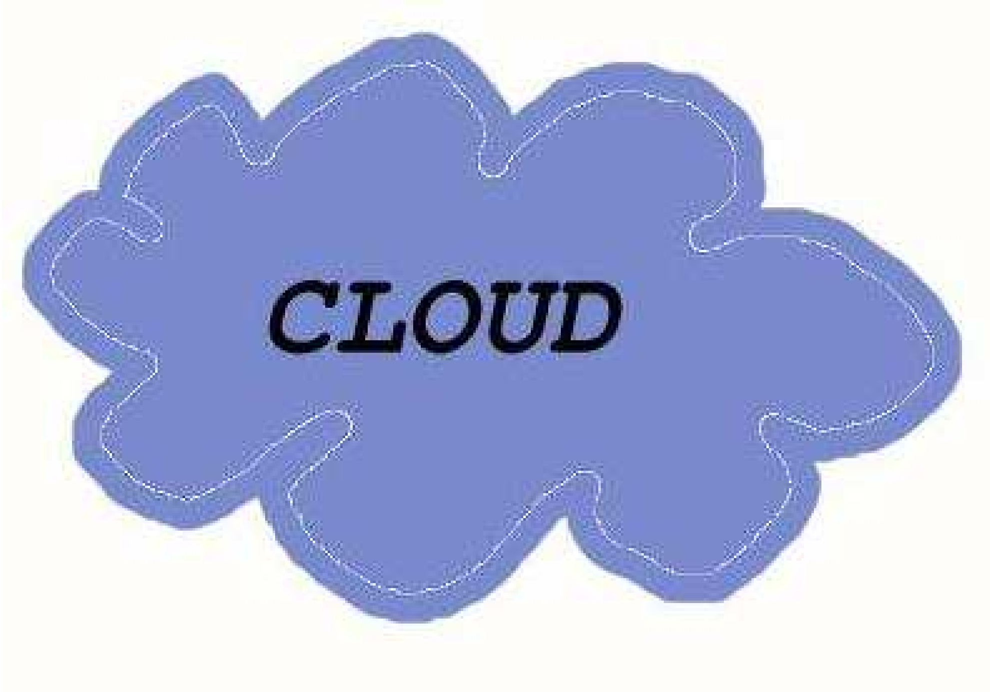
radiative flux

$$\varepsilon=\frac{3}{2}\frac{k}{\mu m_H}T\;,\qquad p=\frac{k}{\mu m_H}\rho T\;,$$

internal energy and pressure



2) Continuity equation:



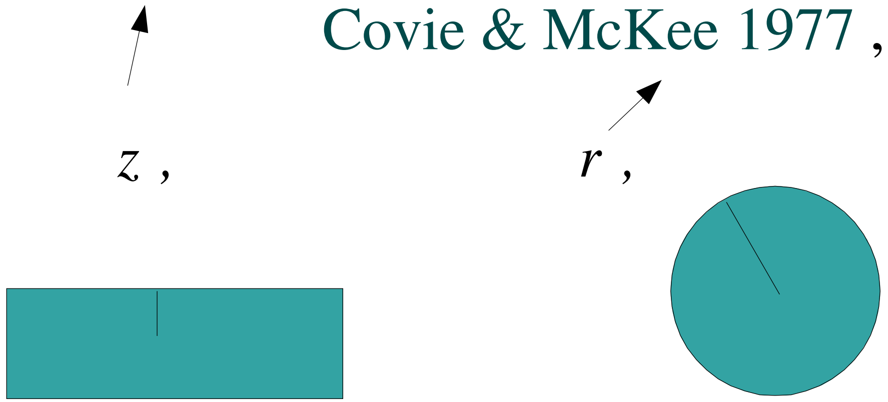
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \,,$$

3) Equation of momentum:

$$\rho \frac{\partial V}{\partial t} + \rho \vec{V} \nabla \cdot (\vec{V}) = -\nabla P - \rho g + \rho \vec{f} \,,$$

Gravity

•Plane-parallel geometry (other geometries have been studied by Covie & McKee 1977 , and McKee & Begelman 1990).



•Cloud does NOT change in time. NO external forces including gravity and NO viscous stresses are assumed:

$$\frac{\partial}{\partial t} = 0 , \qquad \vec{f} = 0 , \qquad g = 0$$

• The equation of momentum (3) is NOT solved i.e. V_cloud=0. Insteed we sovle cases:

$$\rho = const , \qquad P = const$$

$$\frac{d}{dz}\left[V_z\left(\frac{1}{2}\rho V^2+\frac{5}{2}P\right)\right]+\frac{dq_z}{dz}=-\rho\,\Lambda(\rho,T); \qquad \frac{d}{dz}(\rho V_z)=0.$$

Rate of outflow or inflow through the cloud boundary

Radiative Cooling and Heating functions

We have two possibilities:

1) " Stationary solution " outflow or inflow are possible throught the boundary of the cloud, depending on the integral of energy equation.

$V_z \neq 0$

$V_z > 0$ - evaporation of matter outward the cloud

$V_z < 0$ - condensation of matter into the cloud

In general case we have two velocities:

-outflowing velocity V_cloud from equation of motion

-velocity of evaporation V_z from energy equation

But evaporation is subsonic , because goes under constant pressure, so:

$$c_s = \left(\frac{P_{gas}}{\rho} \right)^{1/2} \approx 10 - 500\,[km/s]; \qquad n_0 = 10^{12}\,[cm^{-3}]$$

$$\approx 100 - 1000\,[km/s]; \qquad n_0 = 10^{5}\,[cm^{-3}]$$

From observations: few hudrends per sec.

2) “ Static solution ”   no mass exchange through the boundary of the cloud.

$$V_z = 0$$

$$\frac{dq_z}{dz} = -\rho\,\Lambda(\rho, T),$$

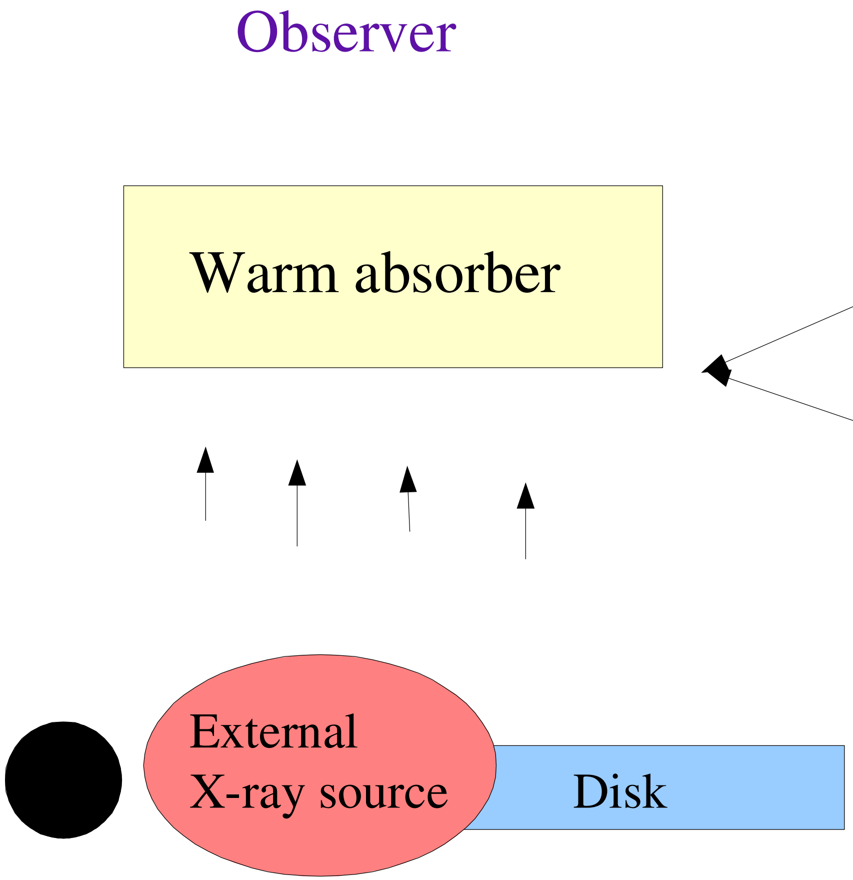
Neglecting conductive flux, we achive standrad radiative equilibrium, used in all photoionization codes.

$$\frac{dF_{rad}}{dz} = \rho\,\Lambda(\rho, T) = 0$$

TITAN calculates the gradient of radiation flux, solving radiative transfer in non-LTE approach, with boundary conditions.....

Radiative equilibrium is solved to produce spectra and fit them to the data.

Boundary conditions: ionization parameter



$$\xi = \frac{L_{ion}}{n_0 R^2} = \frac{4\pi F_{ion}}{n_0}$$

$$\Xi = \frac{\xi}{4\pi c k T_0} = \frac{F_{ion}}{c P_{gas}}$$

On the cloud surface: $\xi\,;\quad n_0\,;$

on the end of the cloud $N_{tot}\,;$

$$\xi = \frac{4\pi F_{ion}}{n_0}\,;$$

$$L_{ion} = L_X$$

Hot corona or magnetic flares above the disk ???

L_x cannot be larger than flux achived from accretion energy, assuming that all generated energy is converted into radiation.

$$L_{ion} \leqslant L_{Edd} = 1.47\times 10^{46}\ \frac{erg}{s} \qquad for \qquad M = 10^{8} M_{Sun}$$

$\xi\,;\quad N_{tot}\,;\quad L_X$

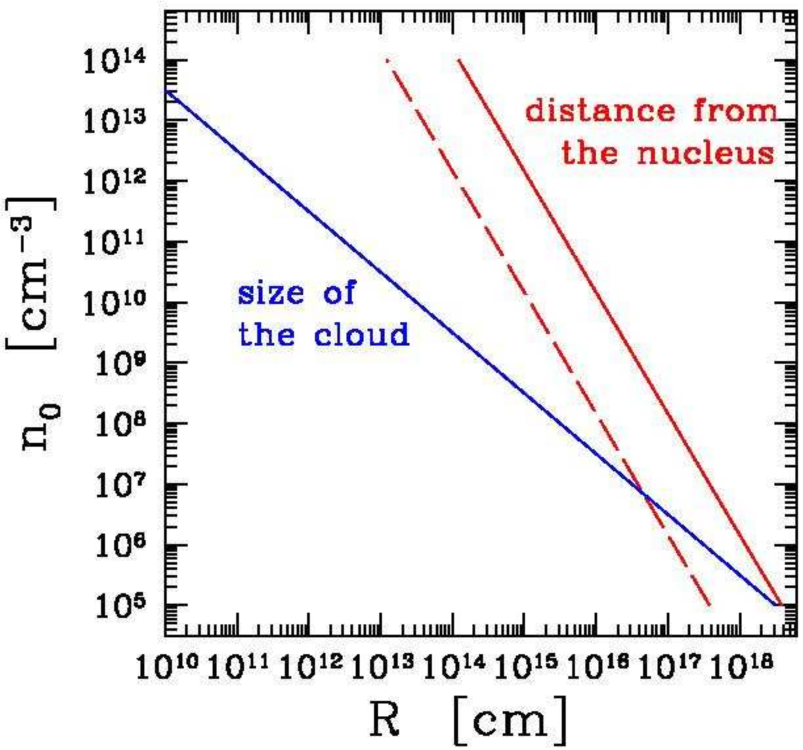
We can find the space of possible densities of clouds and their distances from the nucleus, n_0, R

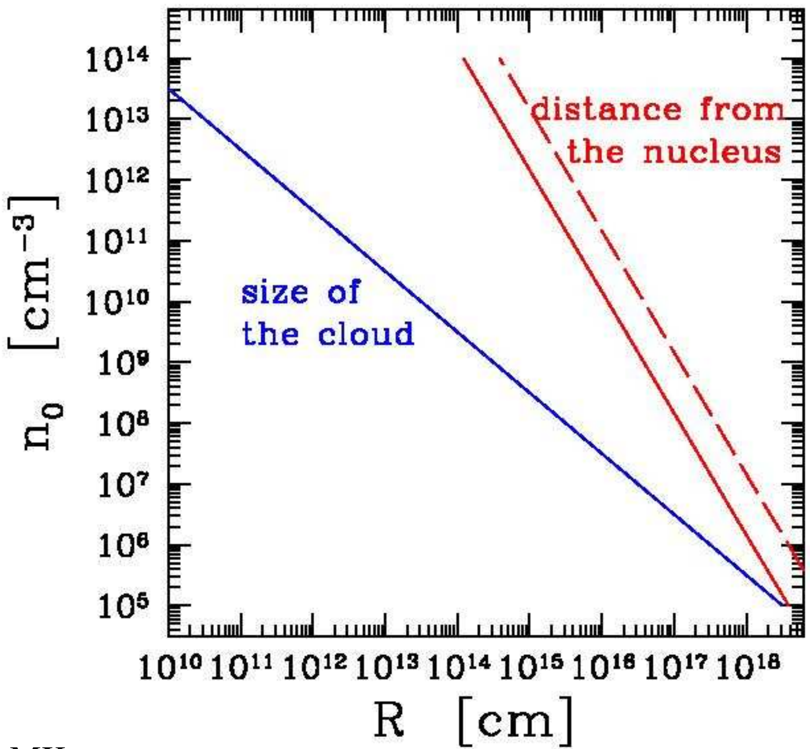
In case of constant density clouds for:

$$\xi = 10^4; \quad N_{tot} = 3.16 \times 10^{23}; \quad L_X = 1.47 \times 10^{46}$$

Dense cloud: $n_0 = 10^{12}\ cm^{-3}$ $\quad R \leqslant 10^{14}\ cm \approx 4\ R_{Schw}$

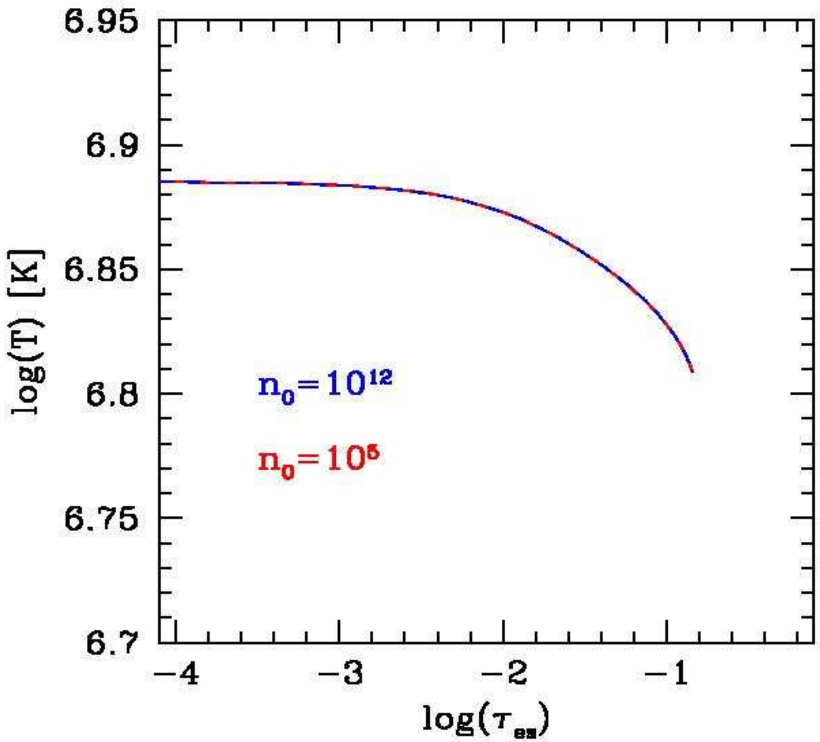
Rare cloud: $n_0 = 10^{5}\ cm^{-3}$ $\quad R \leqslant 10^{18}\ cm \approx 40000\ R_{Schw}$

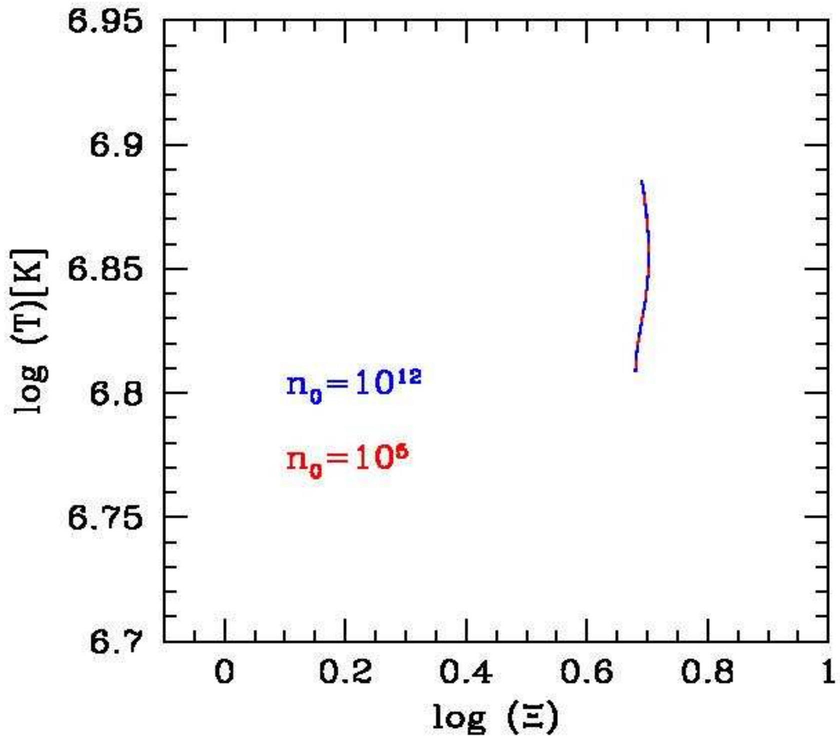




Constant density clouds:

$$\xi = 10^4 \; ; \quad N_{tot} = 3.16 \times 10^{23} \; [cm^{-2}];$$

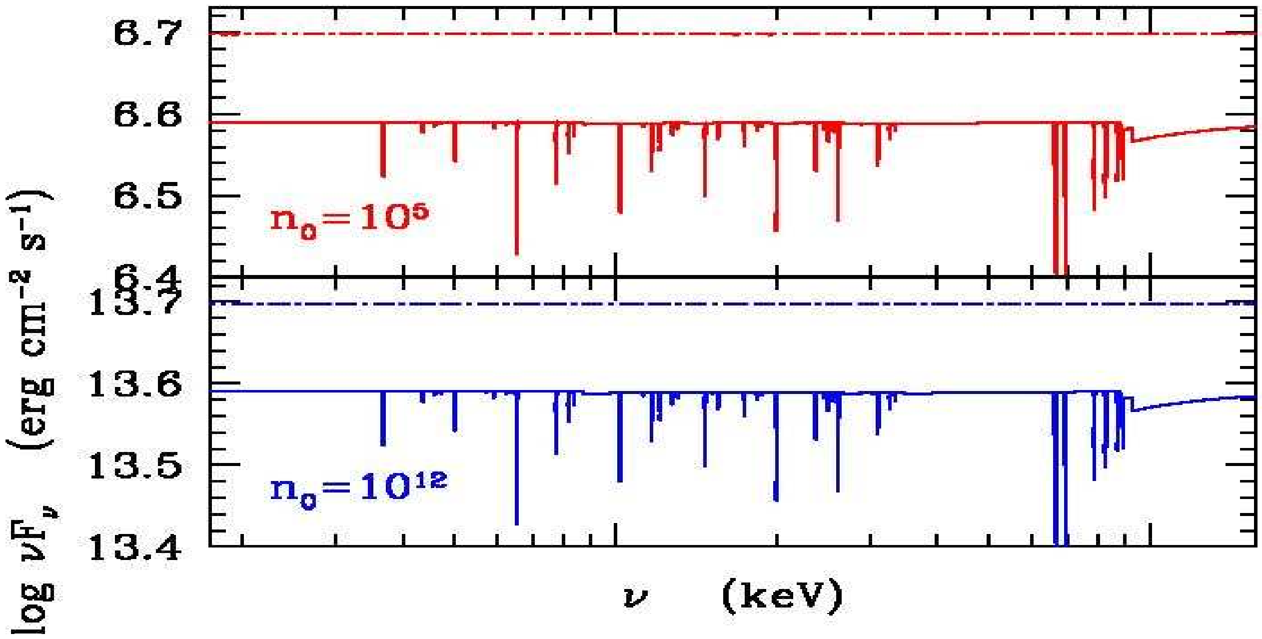


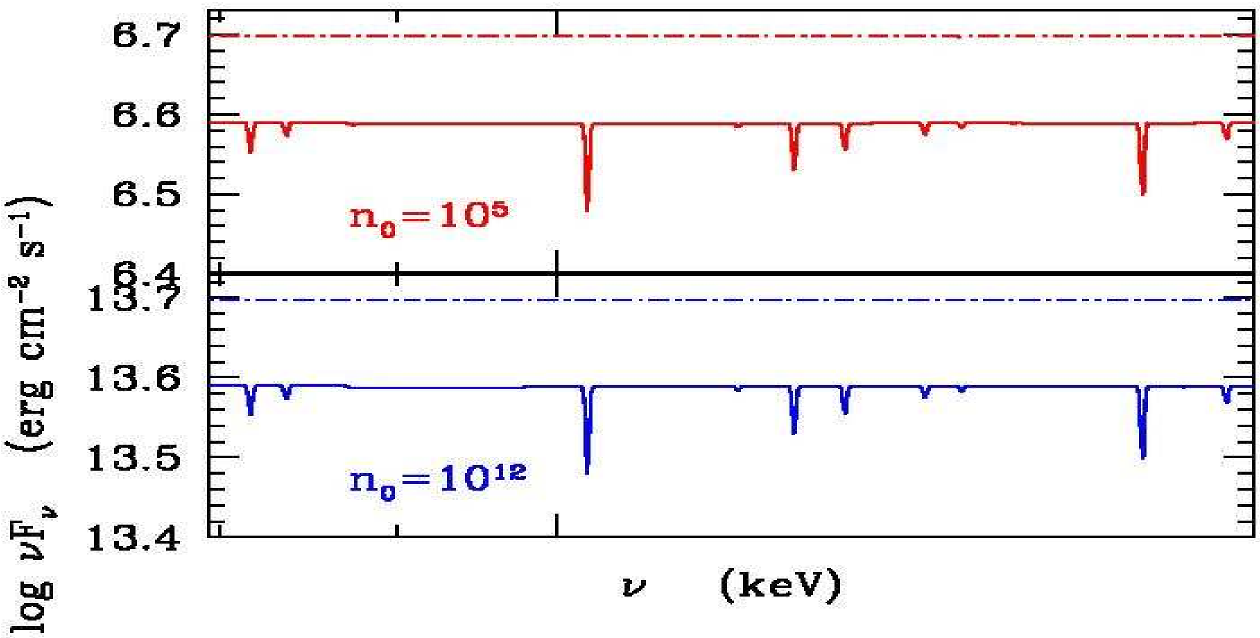


Constant density clouds:

$$\xi = 10^4 \,;$$

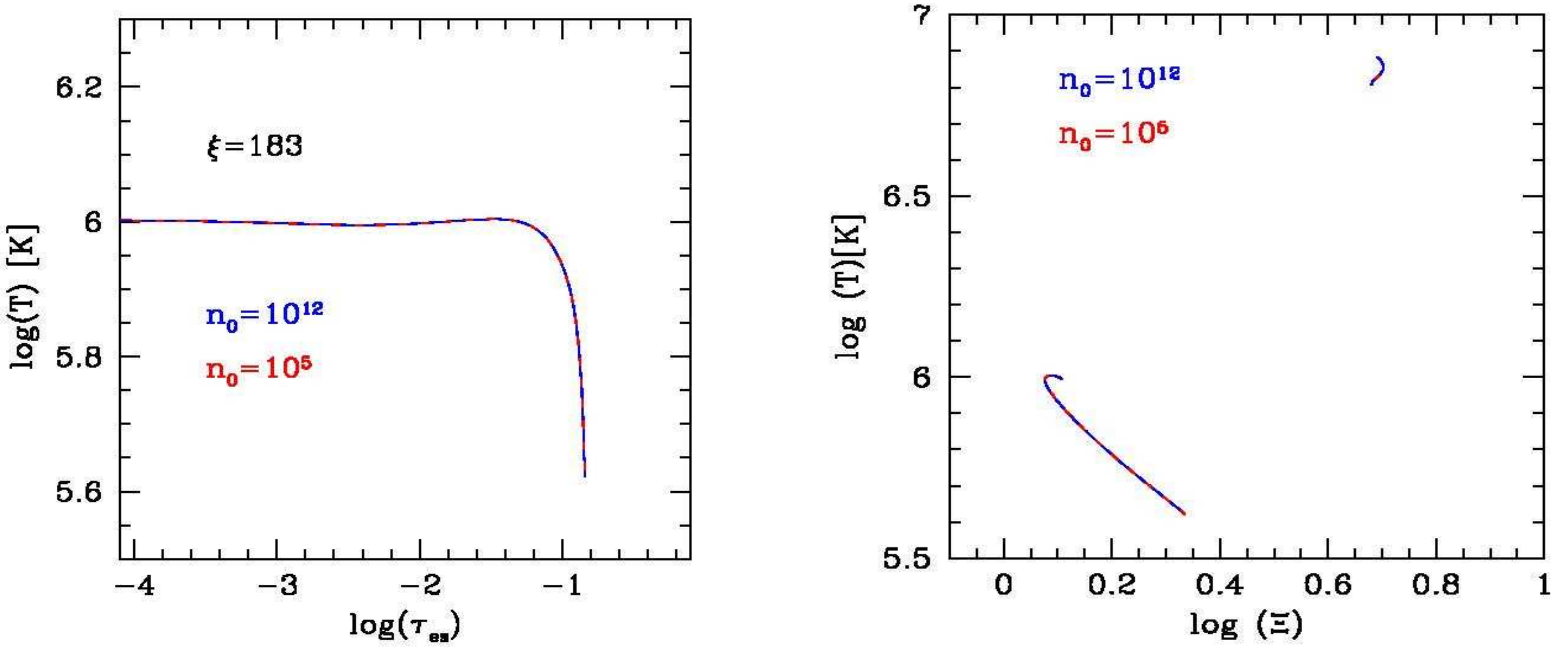
$$N_{tot} = 3.16 \times 10^{23} \,;$$





Constant density clouds:

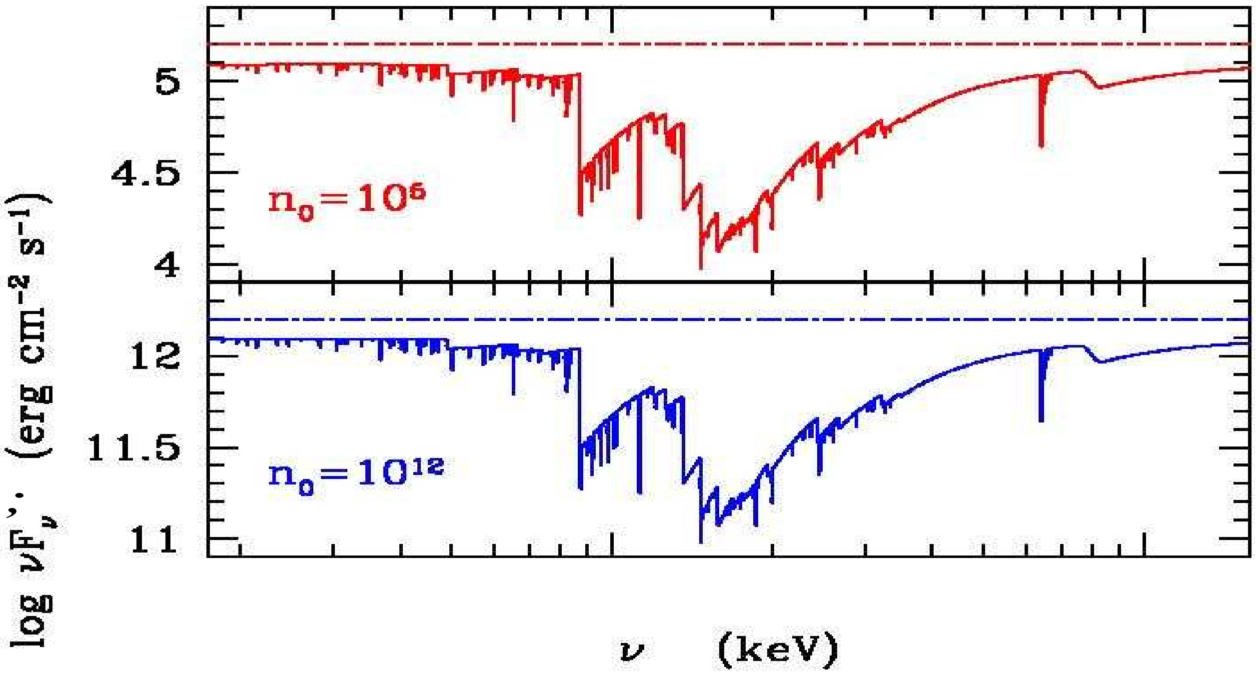
$$\xi = 183\,; \quad N_{tot} = 3.16 \times 10^{23}\,;$$

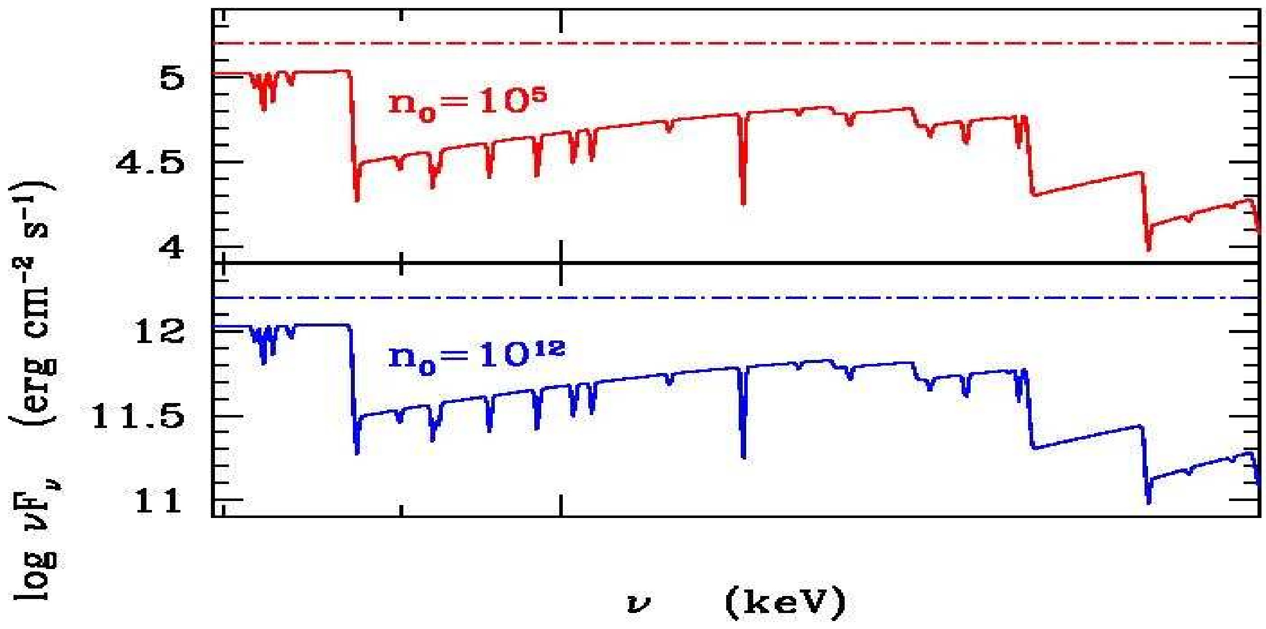


Constant density clouds:

$\xi = 183\ ;$

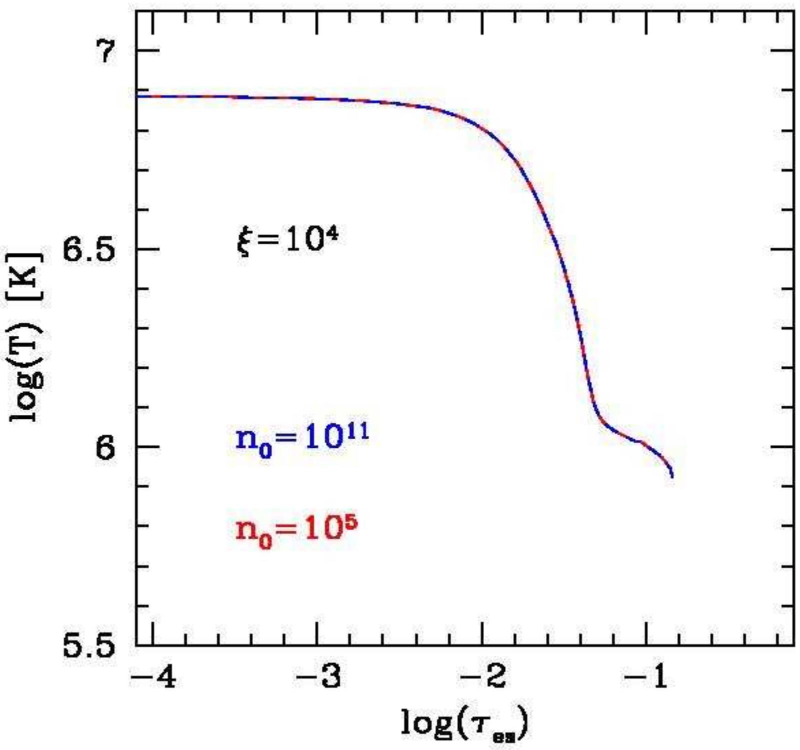
$N_{tot} = 3.16 \times 10^{23}\ ;$

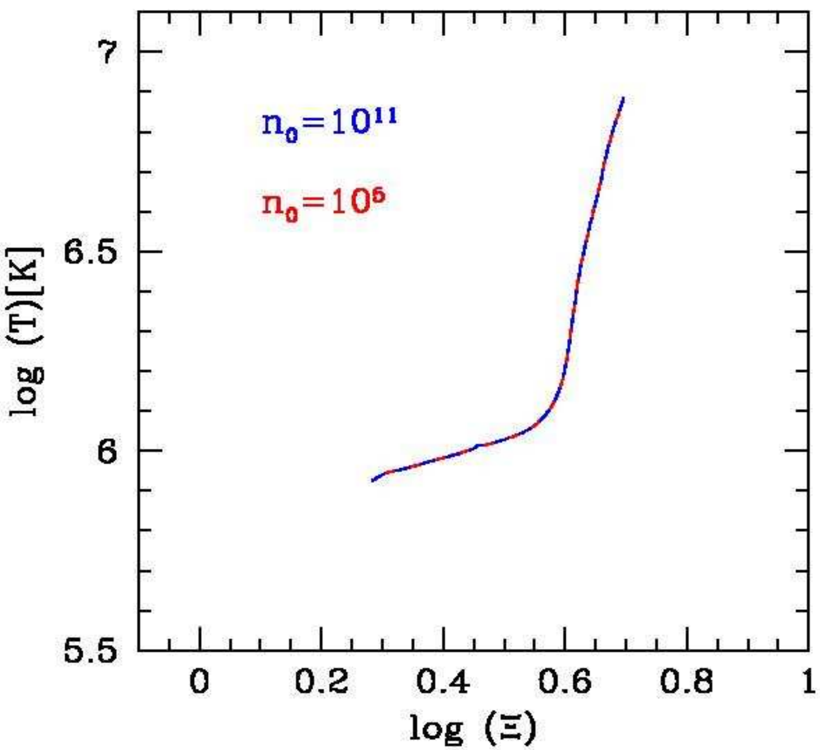




Constant pressure clouds:

$$\xi = 10^4; \quad N_{tot} = 3.16 \times 10^{23};$$

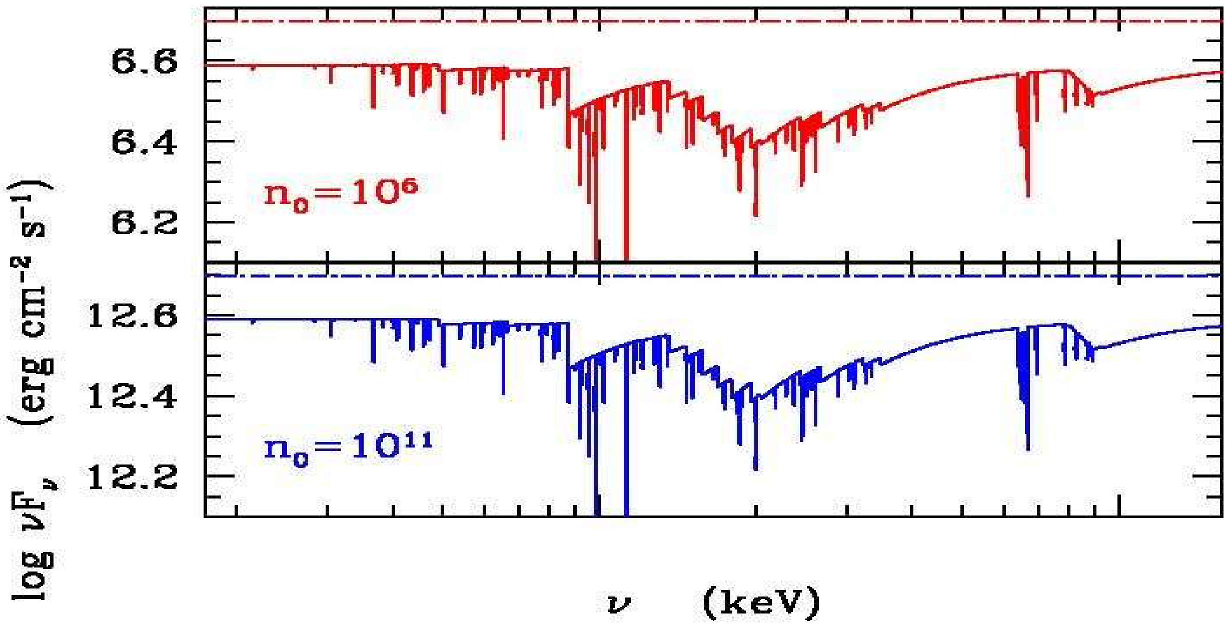


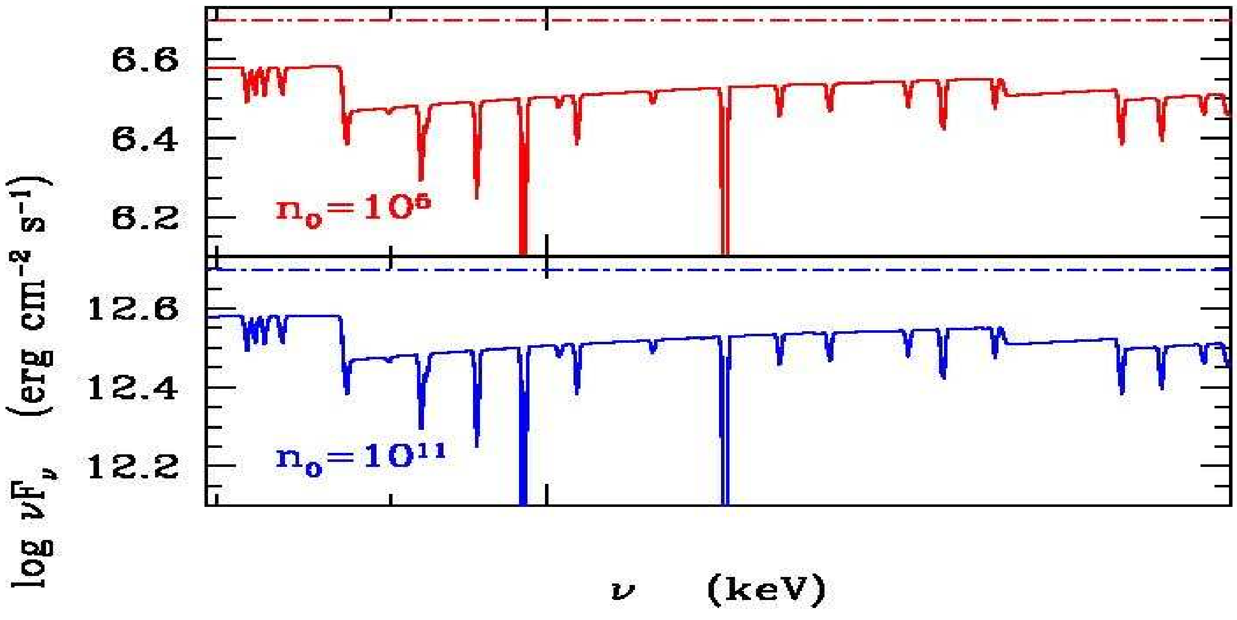


Constant pressure clouds:

$$\xi = 10^4 ;$$

$$N_{tot} = 3.16 \times 10^{23} ;$$





In both cases i.e. constant density cloud and constant pressure cloud, for the given ionization parameter ξ, and total column density absorbed spectrum looks the same for the wide range of surface densities n_0.

From fitting the data we achive ξ, but this is not enought to find the distance of the cloud from the nucleus and its density.

When dense clouds are situated closer to the nucleus the gravity may become important:

$$\frac{P_{tot}}{H} = m_H N_{tot} \frac{GM}{R^3}$$

Dense cloud:	$n_0 = 10^{12}\, cm^{-3}$	4.49×10^{-8}	3.94×10^{-12}
Rare cloud:	$n_0 = 10^{5}\, cm^{-3}$	7.97×10^{-22}	1.24×10^{-22}

$$\frac{dF_{rad}}{dz} = \rho \Lambda(\rho, T) = 0 \qquad P_{tot} = const$$

TITAN Dumont et al. 2000 A&A, 357, 823

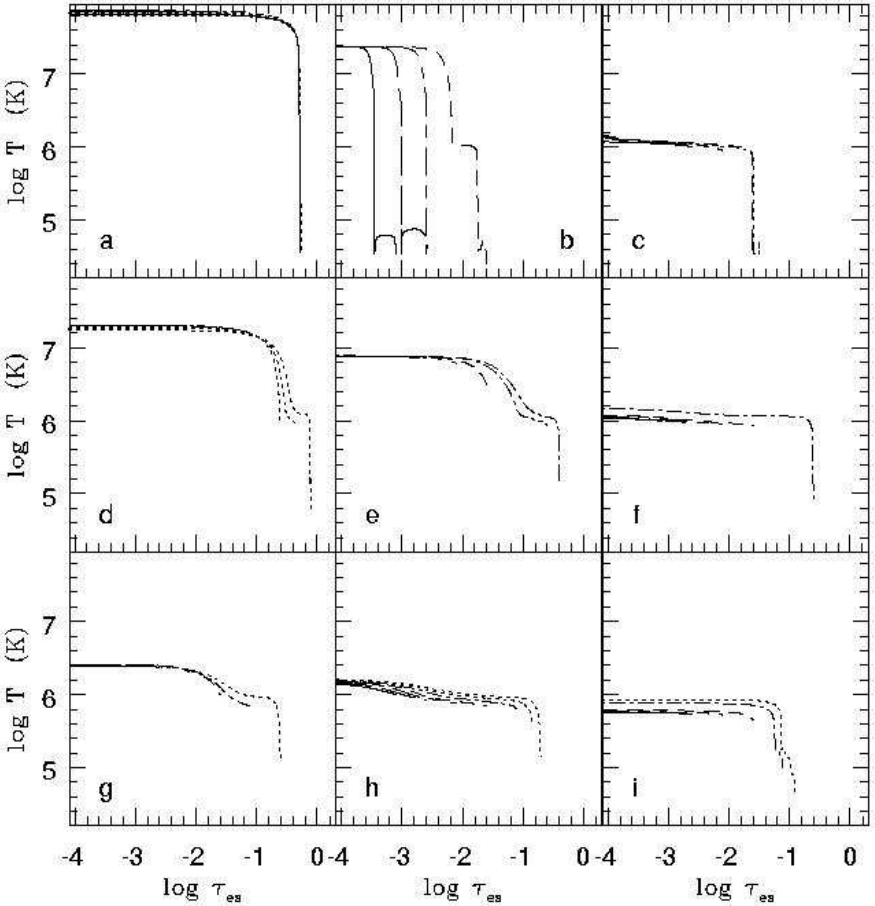
0) ALI transfer for lines and continuum.
1) Atomic data from NIST (Los Alamos). We transfer “only” 900 lines of 10 major elements: H, He, C, N, O, Ne, Mg, Si, S, Fe
2) NLTE equation of state.
3) Compton heating and cooling are included.
4) Radiative equillibrium are solved.

Assumptions:

- The shape of intrinsic radiation (power-law). $\Gamma = 1.5, 2, 2.5$ $10 - 10^5$ eV
- Ionization parameter on the suface (luminosity). $\xi = 100, ..., 10^5$
- Total column density of the cloud $N_{tot} = 10^{21}, ..., 10^{23.5}$
- The warm absorber is on the line of sight (Seyfert 1).
- Turbulent velocity =0, (not a problem to change).

Temperature and ionization structure of constant pressure clouds:

$\xi = 10^5$ $\xi = 10^4$ $\xi = 10^3$

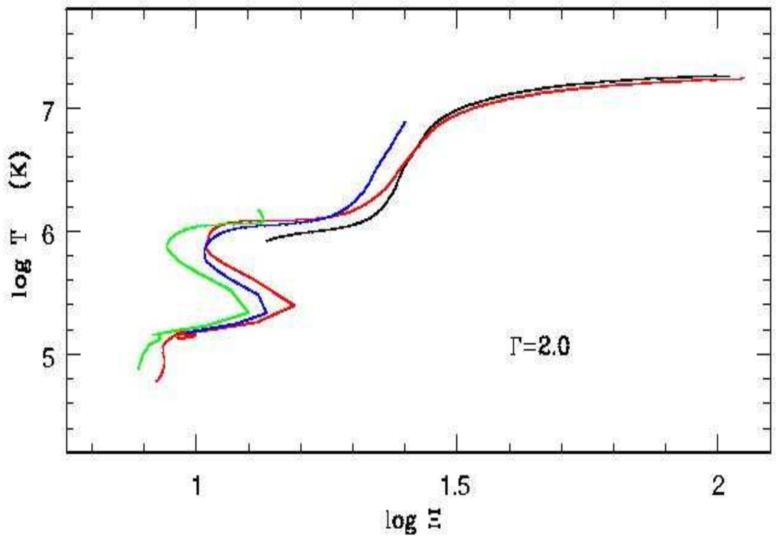


$\Gamma = 1.5$

$\Gamma = 2.0$

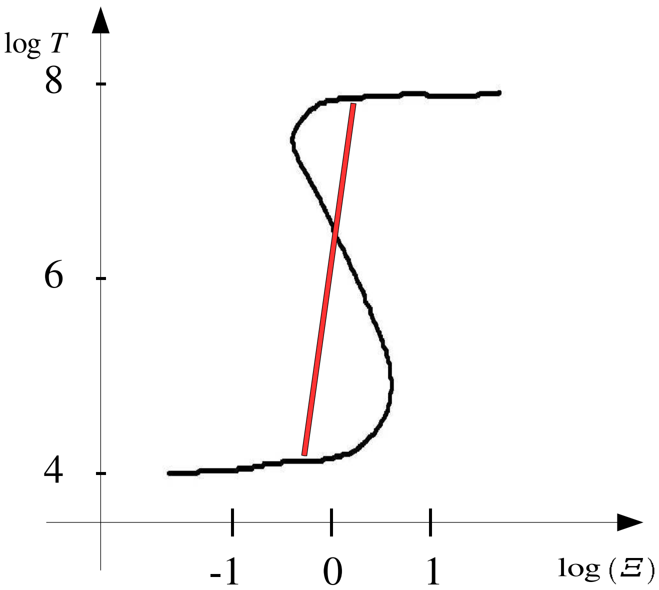
$\Gamma = 2.5$

P_tot=const



The solution of radiative transfer problem requires iterations between temperature and density profiles, which are functions of optical depth.

Radiative transfer approach does not treat properly any thermal instabilites.

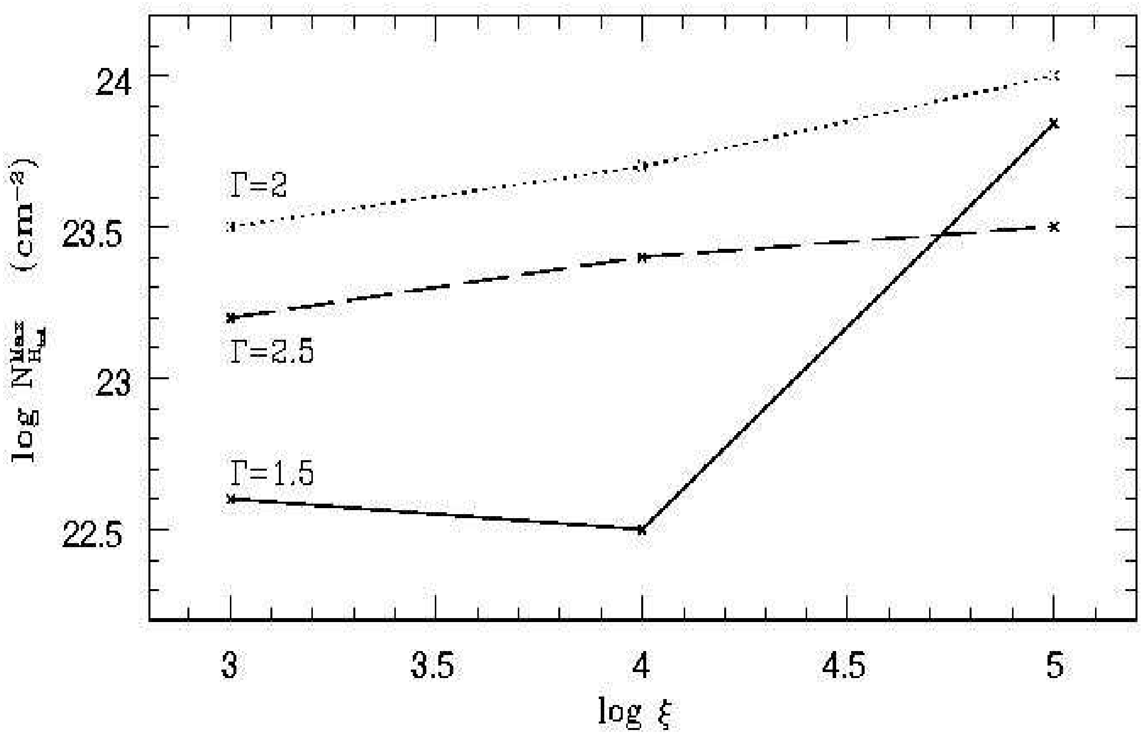


Thermal-conduction scale length ~ 10^{-7} cm

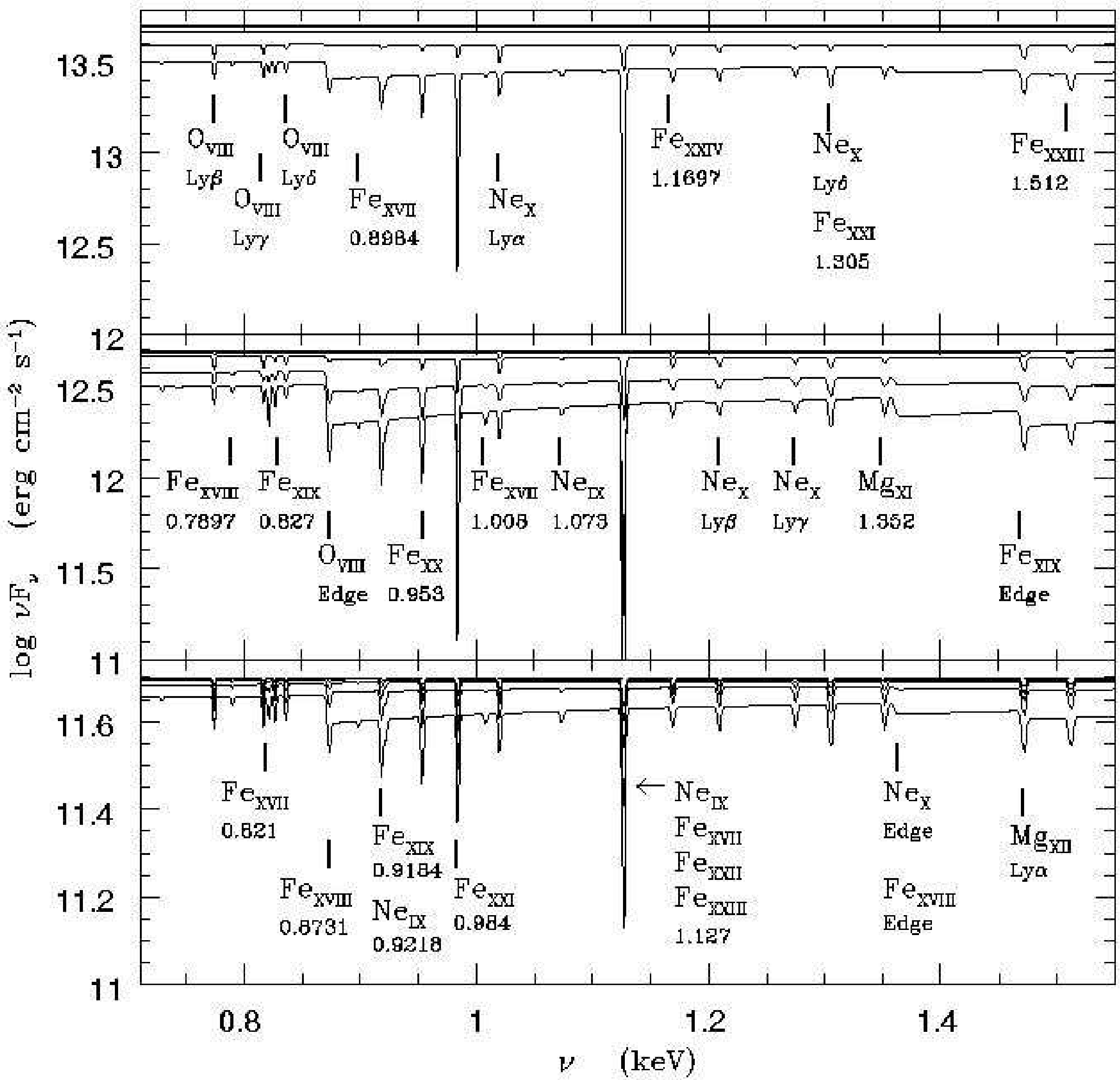
$$\Xi = \frac{\xi}{4 \pi c k T} = \frac{F_{ion}}{c P_{gas}}$$

For each set of Γ and ξ there is a maximum total column density for which instabilities start to be important, and computations failed.

Cooling in lines exceeds free free cooling by two orders of magnitude.



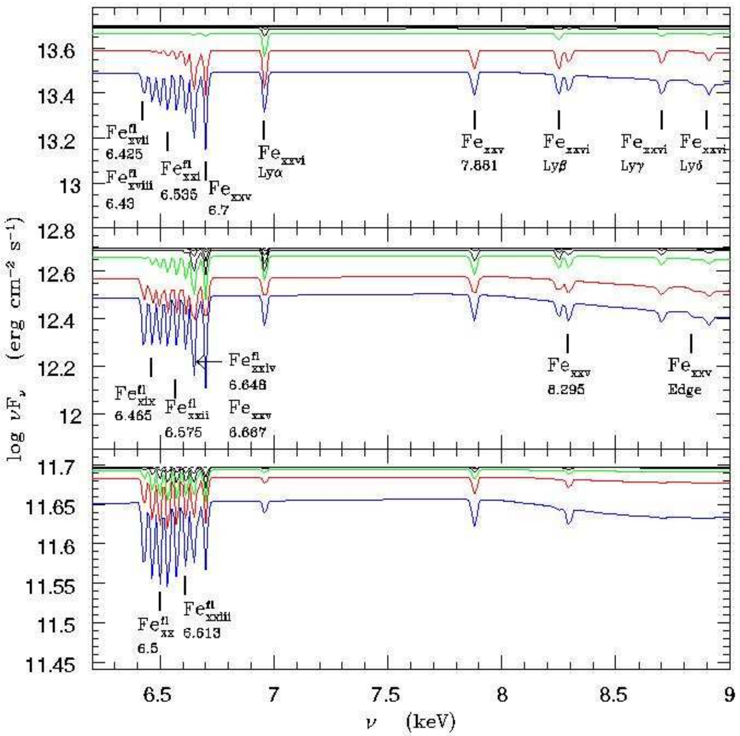
Spectra from the constant pressure cloud:

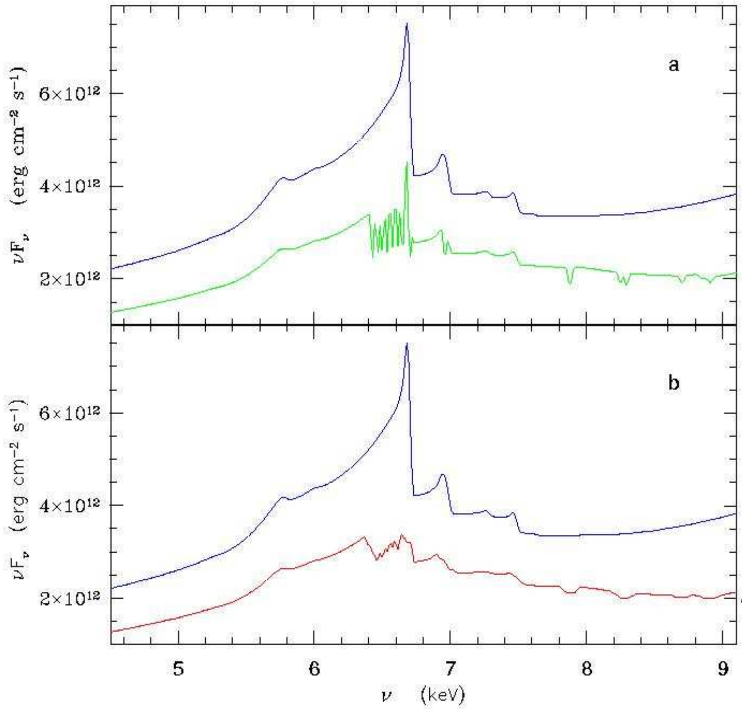


Γ=2

Lines have EW about 1 ev from different ioniztion levels.

Absorption in the vicinity of iron line





$\Delta E / E = 390$

$\Delta E / E = 200$

Relativistic iron-line profile from Czerny et al. 2004 A&A 420, 1.

The ratio of EWs of two different lines from the same element at the given ionization level.

In the limit of optically thin lines (i.e. weak-line case): we are on the linear part of the curve of growth, where EW is proportional to the column density of the absorbed ion:

$$EW_{\nu} = \frac{\pi e^2}{m_e c} N_i f_{ij} \qquad \frac{EW_{ij}}{EW_{ik}} = \frac{f_{ij}}{f_{ik}}$$

	Theoretically:	From observations:	Our model:
CVI (1-2/1-5)	29.86	$0.62^{(+3.53)}_{(-0.59)}$	0.7 TonS180 Różańska et al.2004
OVIII (1-2/1-4)	14.34	0.89 ± 0.55	NGC 3783 Kaspi et al.2002
CVI (1-2/1-3)	8.49	2.33 ± 2.99	Kaastra et al.2002 NGC 5548

Summary:

The assumption of constant pressure gives natural stratification of the illuminated medium in temperature and ionization state, therefore it can explain different ionization states observed in the spectra.

We don't have to be arfaid about the size of the cloud since for the same ionization parameters and total column densities the absorbed spectra do not vary considerably with surface densities and distances from the nucleus.

Thermal instabilities should be treated taking into account conductive flux, otherwise they give natural limit on the total column density of the cloud.

Radiative transfer computations properly transfer optically thick lines, which are most common in the X-ray spectroscopic observations.