A model for the X-ray absorption in Compton-thin AGN

A. Lamastra, G. C. Perola, G. Matt

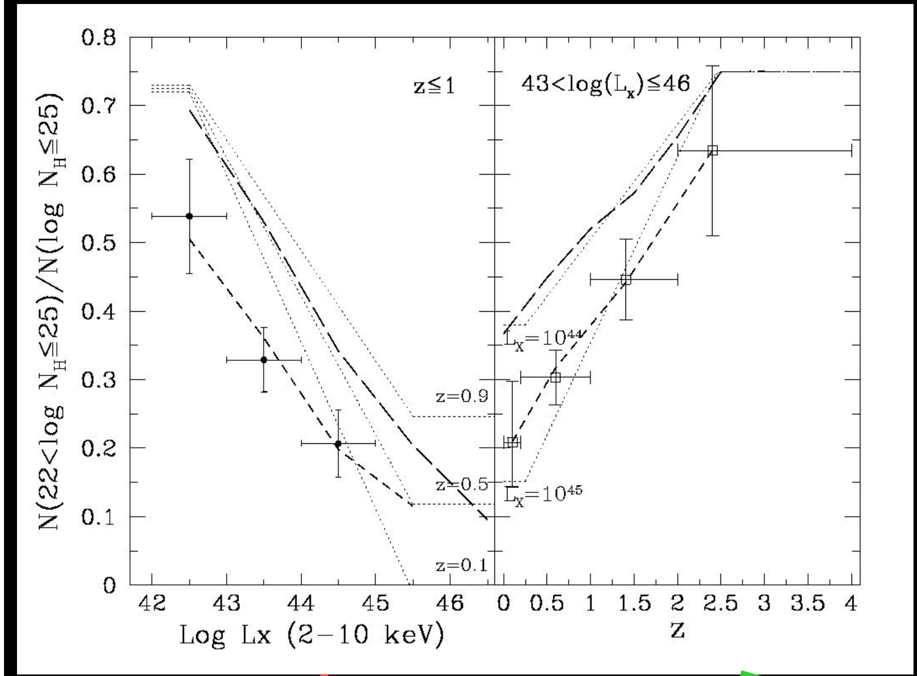
Dipartimento di Fisica, Università degli Studi "Roma Tre"

Outline

1. A new observational constraint: the luminosity-absorption anticorrelation.
2. The unified model: molecular torus → problems.
3. Obscuration by molecular gas in the galactic disk.

A new observational constrain:

the luminosity-absorption anticorrelation



Distribution of the X-ray absorbing column density, N_H, as a function of the intrinsic luminosity in the 2-10 keV band, L_X, and redshift, z (from La Franca et al. 2005).

$N_H < 10^{22}$ cm^{-2} → unobscured AGN

$N_H > 10^{22}$ cm^{-2} → obscured AGN

$$\xi = \frac{N(\log N_H > 22\, cm^{-2})}{N_{tot}}$$

ξ decreases with increasing Lx

(Ueda et al. 2003, La Franca et al. 2005)

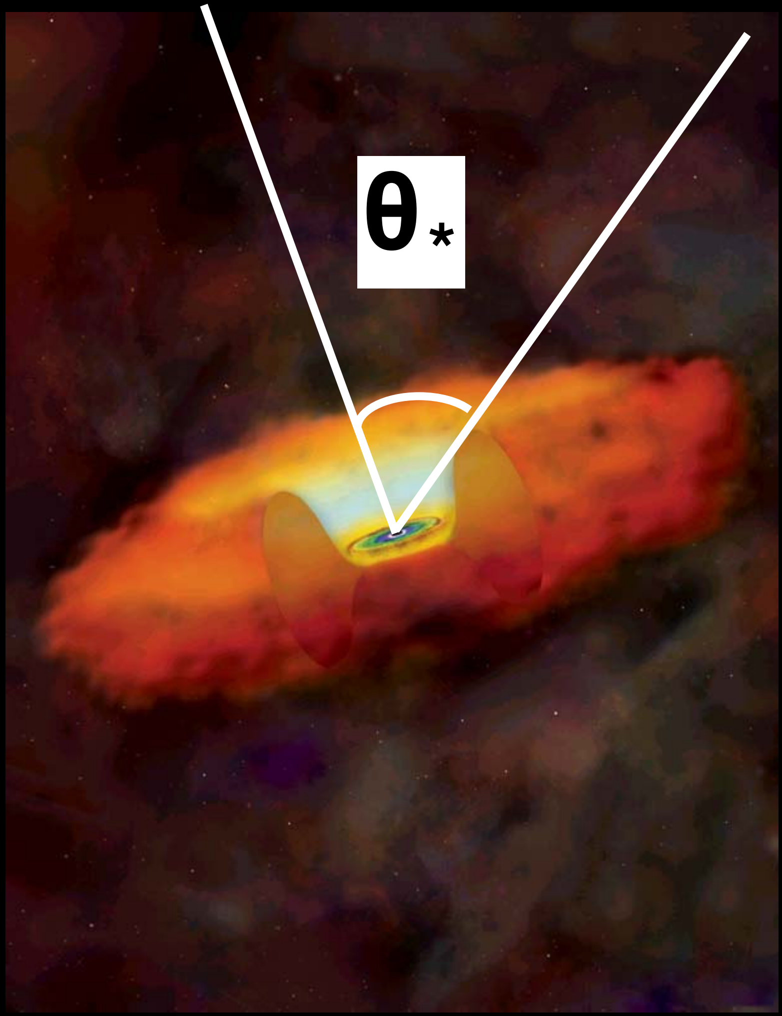
ξ increases with increasing z

(La Franca et al. 2005)

Surveys limited to 10 keV are doomed to miss almost completely the Compton-thick objects ($N_H > 10^{24}$ cm^{-2})

The unified model of AGN

In the unified model of AGN the major difference between obscured and unobscured sources is attributed to orientation effects, caused by an optically thick torus around the central source.



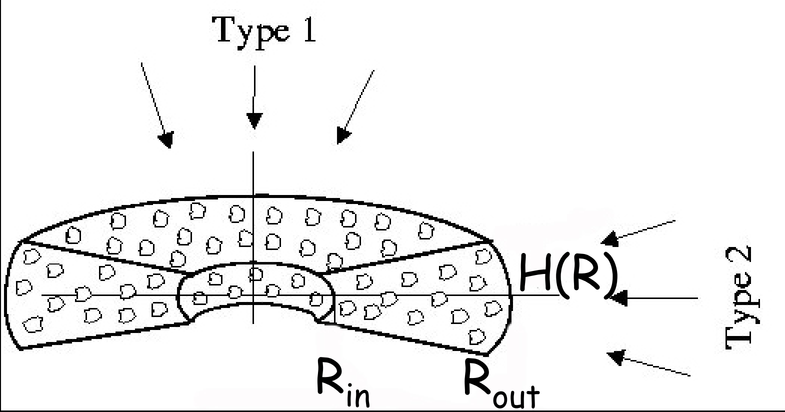
The fraction of obscured solid angle gives an estimation of the fraction of absorbed AGN

$$\xi = \cos\theta_*$$

θ_* → Half opening angle of the obscuring matter

The anticorrelation can be satisfied if θ_* increases with the intrinsic luminosity of AGN

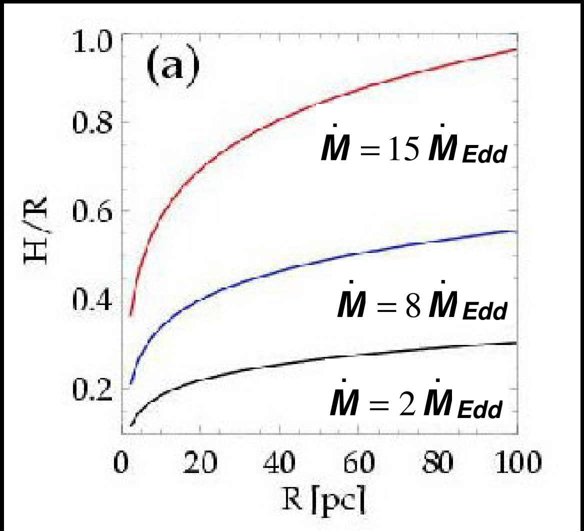
The molecular torus



R=distance from the nucleus
H(R)=geometrical thickness
$\dot{M}$=total mass accretion rate

- Cylindrically symmetric geometrical structure.
- The obscuring matter is sharply confined within 2H(R).
- The obscuring matter is assumed to be in the form of dense molecular clouds.
- Cloud-cloud collisions regulate the thickness of the torus and the mass accretion rate into the black hole.

(Krolik & Begelmann 1986, 1988; Beckert & Duschl 2004; Vollmer et al. 2004; Beckert et al. 2004)



$$\frac{H}{R} \propto \sqrt{\dot{M}}$$

H/R, hence the fraction of obscured solid angle, increases with increasing intrinsic luminosity contrary to the novel constrain

Feedback due to irradiation by AGN

Evaporation radius:

(Krolik & Begelman 1988)

$$R_{evap} = \frac{0.79 M_{gas,5} L_{44}}{\dot{M}_{torus} R_{out} N_{cl,24} T_5^{1/2}} \, pc$$

H/R increases with R

$$tg\theta_{obs} = \left(\frac{H(R_{out})}{R_{out}} \right)$$

$R_{evap} < R_{out} \rightarrow$ $$\theta_{obs} = arctg \left(\frac{H(R_{out})}{R_{out}} \right)$$

$R_{evap} \geq R_{out} \rightarrow$ $$\theta_{obs} = 0$$

The fraction of obscured sources would be independent of the luminosity up to at certain value at which the illumination is so strong to forbid the formation of the torus

How many cold absorbers?

Several authors (Maiolino & Rieke 1995, Matt 2000 and Weaver 2001) proposed the presence of both a Compton-thick and a Compton-thin absorber.
While all these authors agree that the Compton-thick absorber should be compact (torus), there are several possibilities for the Compton-thin absorber:

1. The galactic disk (Maiolino & Rieke 1995)
2. Dust lanes (Malkan et al. 1998, Matt 2000)
3. Starburst clouds (Weaver 2002)

Obscuration by molecular gas in the galactic disk

<u>The "idealized" model:</u>

- The molecular gas is confined within a self-gravitating, starry galaxy disk.
- The molecular gas is assumed to be in form of molecular clouds (assumed spherically symmetric) in pressure equilibrium with an external hot gas.
- The vertical distribution of the clouds number density is assumed to follow an exponential law:

$M_c = 4.35\, M_{solar}$

$\rho_c = 10^4\, cm^{-3}$

$r_c = 0.167\, pc$

$N_{H,c} = 10^{22}\, cm^{-2}$

$T_c = 10\, K$

$$n(Z) = n_0 e^{-\left(\frac{Z}{H_c}\right)}$$

$n_o = \Sigma/2H_cM_c$ number density of the clouds at Z=0

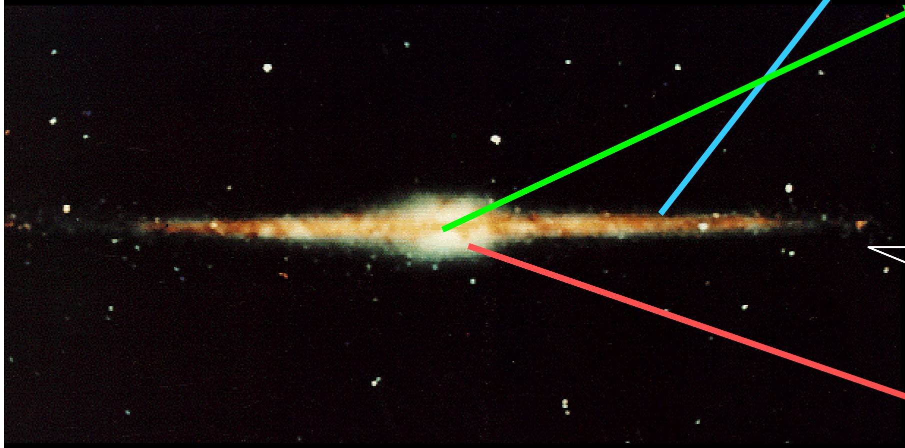
Σ surface density of the molecular gas

Hc scale height of the molecular gas

The gravitational effects of a central black-hole (and related Bulge)

At large distances from the galactic center the scale height, H_c, of the molecular gas is regulated by the disk gravity and the velocity dispersion, σ, of the clouds. When closing inwards, the bulge and black hole gravity become also relevant.

K_Z=gravitational force per unit mass exerted in the vertical, Z, direction



Disk: $$K_{Z,d} = -4\pi G\rho_d Z$$

Black hole: $$K_{Z,b} = -G\frac{M_{BH}}{R^3}Z$$

Magorrian 1998

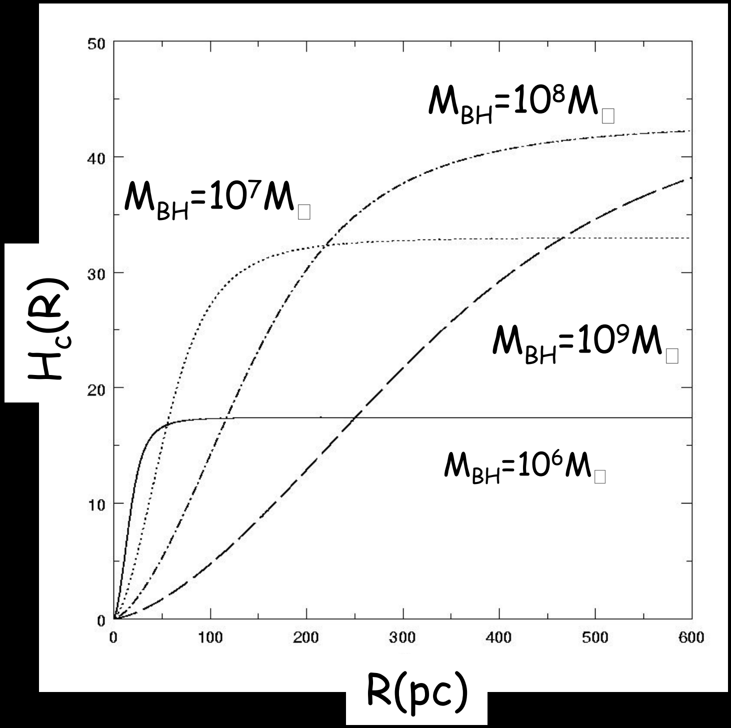
Bulge: $$K_{Z,b} = -G\frac{M_b(R)}{R^3}Z = -G\frac{4\pi\rho_b}{3}Z$$

$$\sigma^2 = 2\int_{H_c}^{0} (K_{Z,d} + K_{Z,BH} + K_{Z,b})dZ$$

$$H_c(R) = \left(\frac{\sigma^2}{4\pi\rho_d + \frac{GM_{BH}}{R^3} + \frac{4\pi G\rho_b}{3}} \right)^{\frac{1}{2}}$$

$$R_{infl} = \frac{1}{2}\left(\frac{M_{BH}}{4\pi\rho_d + \frac{4\pi\rho_b}{3}} \right)^{\frac{1}{3}}$$

Regulates the half opening angle, and increases with M_{BH}



$\rho_d = 0.84\ M_{solar}\, pc^{-3}$
$\sigma = 10\ Km\ s^{-1}$
$\rho_b(M_{BH}) = costant$

$M_{BH} = 10^6 M_{solar}$	$R_{infl} = 12pc$
$M_{BH} = 10^7 M_{solar}$	$R_{infl} = 39pc$
$M_{BH} = 10^8 M_{solar}$	$R_{infl} = 101pc$
$M_{BH} = 10^9 M_{solar}$	$R_{infl} = 226pc$

Obscuration in the galactic disk

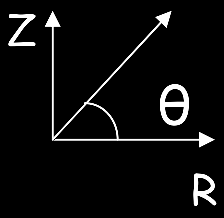
In order to evaluate the effective obscuration, this geometrical effect must be accompanied by assumptions on the number of clouds along a line of sight.

Assuming that the surface density, Σ, of the molecular gas remains costant within $2R_{infl}$, the vertical distribution of the clouds number density becomes:

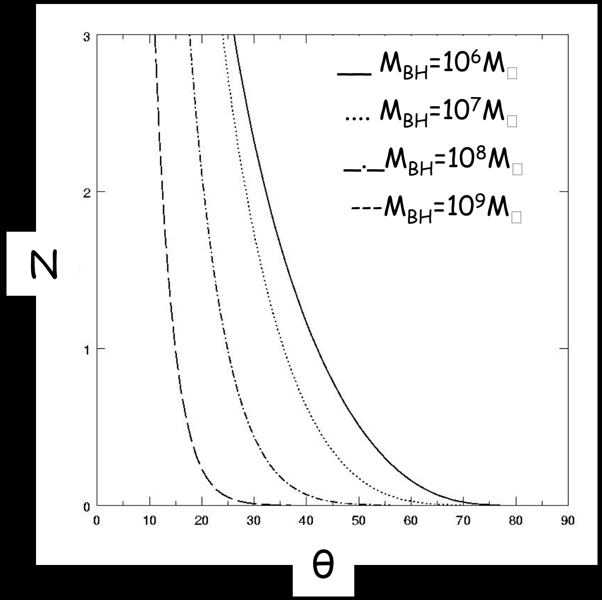
$$n(Z,R) = n_0(R)\, e^{-\left(\frac{Z}{H_c(R)}\right)}$$

$$n_0(R) = n_0 \frac{H_c}{H_c(R)}$$

Defining the line of sight through the angle θ ($tg\theta = Z/R$) than the number of encountered clouds is given by:



$$N = \pi r_c^2 \int_{R_{in}}^{R_{out}} n(\theta,R)\,dR$$



Fraction of absorbed AGN

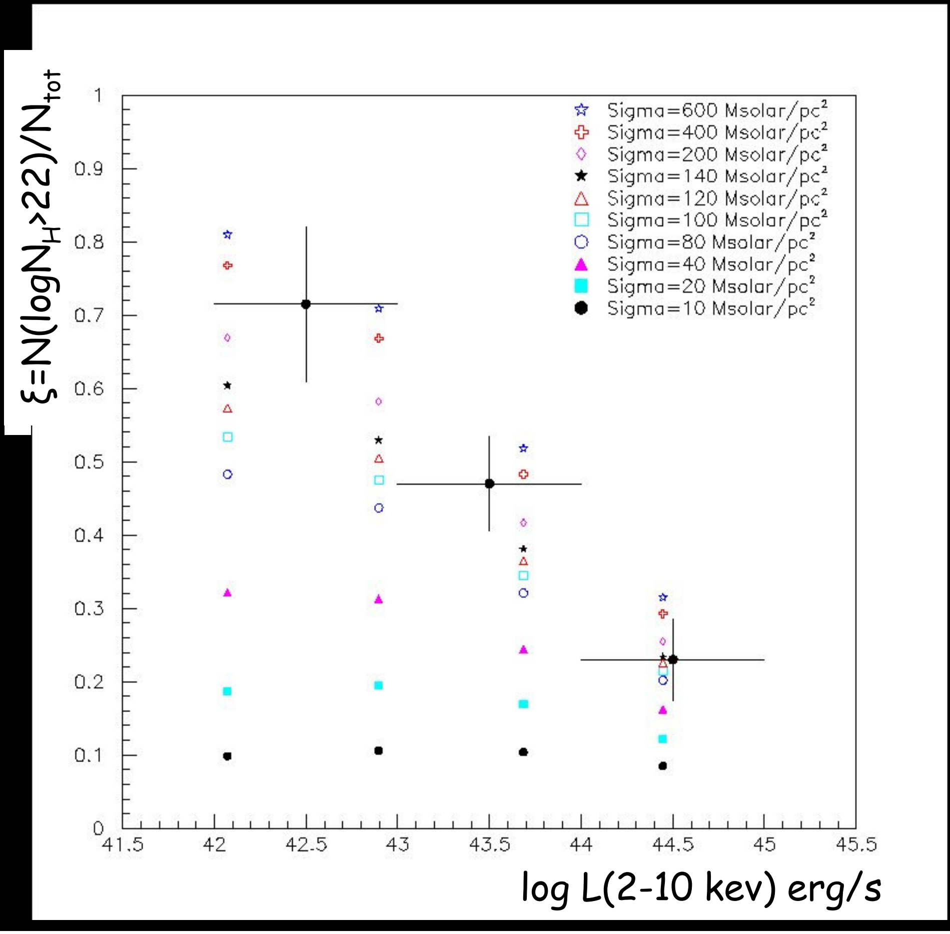
We assumed for each cloud $N_{H,c}=10^{22}cm^{-2}$, which is the value chosen to discriminate Seyferts with no absorption and Compton-thin absorbed one.

By defining θ_1 the angle where N=1 than:

$$\xi = \frac{N(\log N_H > 22)}{N_{tot}} = \cos(90-\theta_1)$$

$L_{bol}=0.1L_{EDD}$

Bol. Correction of Marconi et al. 2004



Summary & Conclusions

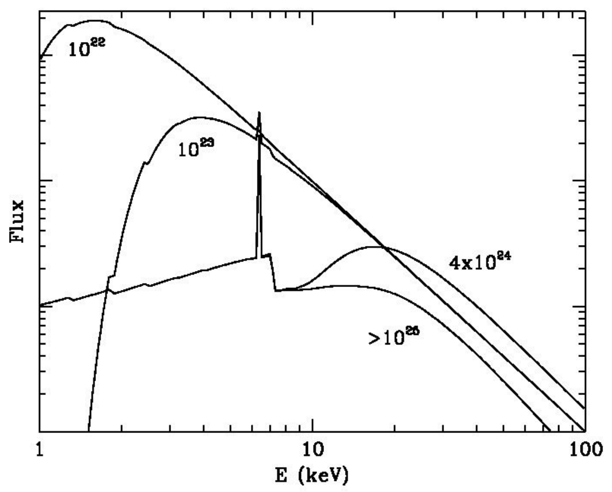
- ✓ The observed fraction of Compton-thin AGN is anticorrelated with the X-ray luminosity.
- ✓ The molecular torus, invoked in the unified picture of AGN, does not conform to this new constraint.
- ✓ The effects of the black hole on the molecular gas in a disk, within 25-450 pc (depending on the black hole mass) leads naturally to the observed anticorrelation provided that:

  1. There is a sufficiently large number of molecular clouds within the radius where the black hole gravitational influence is dominant (Σ>150-200 M_{solar} pc^{-2}).
  2. There is a statistical correlation between black hole mass and the AGN luminosity (L_{bol}=0.1L_{EDD}).

[redacted]

The X-ray spectum of absorbed AGN

$$F(E) \propto E^{-\Gamma} e^{-(E/E_{cut})} \times e^{-(\sigma(E) N_H)}$$



Matt, Guainazzi, Maiolino 2003

The observed X-ray spectrum depends on the column density, N_H, of the absorber.

Compton-thin: 10^{22}cm^{-2}<N_H<10^{24}cm^{-2}

Compton-thick: N_H>10^{24} cm^{-2}

Compton scattering adds to photoelectric absorption to reduce the intensity along the line of sight

Surveys limited to 10 keV are doomed to miss almost completely the Compton-thick objects

Effects of the stellar bulge

M-σ relation: $M_{BH} \propto \sigma_b^{\alpha}$

Virial mass of the bulge: $GM_b \approx \sigma^2 R_b$

Merritt & Ferrarese (2001): $M_{BH} \cong 10^{-3} M_b$

$$R_b \propto \frac{M_b}{\sigma_b^2} \propto \frac{M_{BH}}{M_{BH}^{2/\alpha}} \propto M_{BH}^{1-2/\alpha}$$

$\alpha \cong 5$

$$R_b \propto M_{BH}^{3/5}$$

Density profile of the bulge: $\rho(R) = \dfrac{\rho_b}{1+(R/R_c)^2}$

$R_c \propto R_b \propto M_{BH}^{3/5}$

$\rho_b \propto M_{BH}^{-4/5}$

$R_{c,MW} \cong 400pc$

$M_{BH,MW} \cong 4\times10^6 M_{solar}$

$M_{BH} = 10^6 M_{solar}$	$R_c = 180pc$	$\rho_b = 15.1 M_{solar} pc^{-2}$
$M_{BH} = 10^7 M_{solar}$	$R_c = 700pc$	$\rho_b = 2.4 M_{solar} pc^{-2}$
$M_{BH} = 10^8 M_{solar}$	$R_c = 2.7Kpc$	$\rho_b = 0.4 M_{solar} pc^{-2}$
$M_{BH} = 10^9 M_{solar}$	$R_c = 11Kpc$	$\rho_b = 0.06 M_{solar} pc^{-2}$