Warm absorbers in AGN

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18-22.07.11

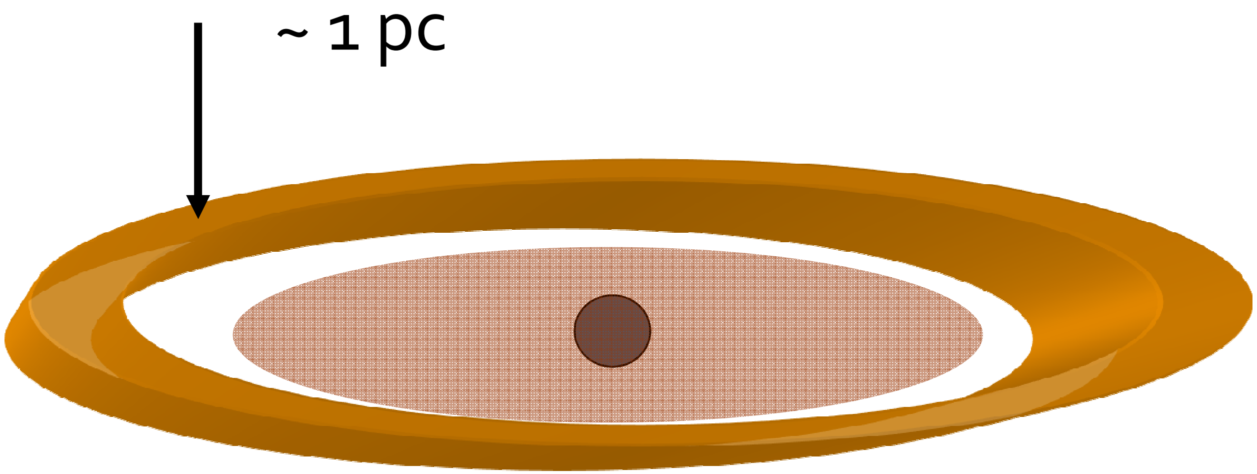
Outline

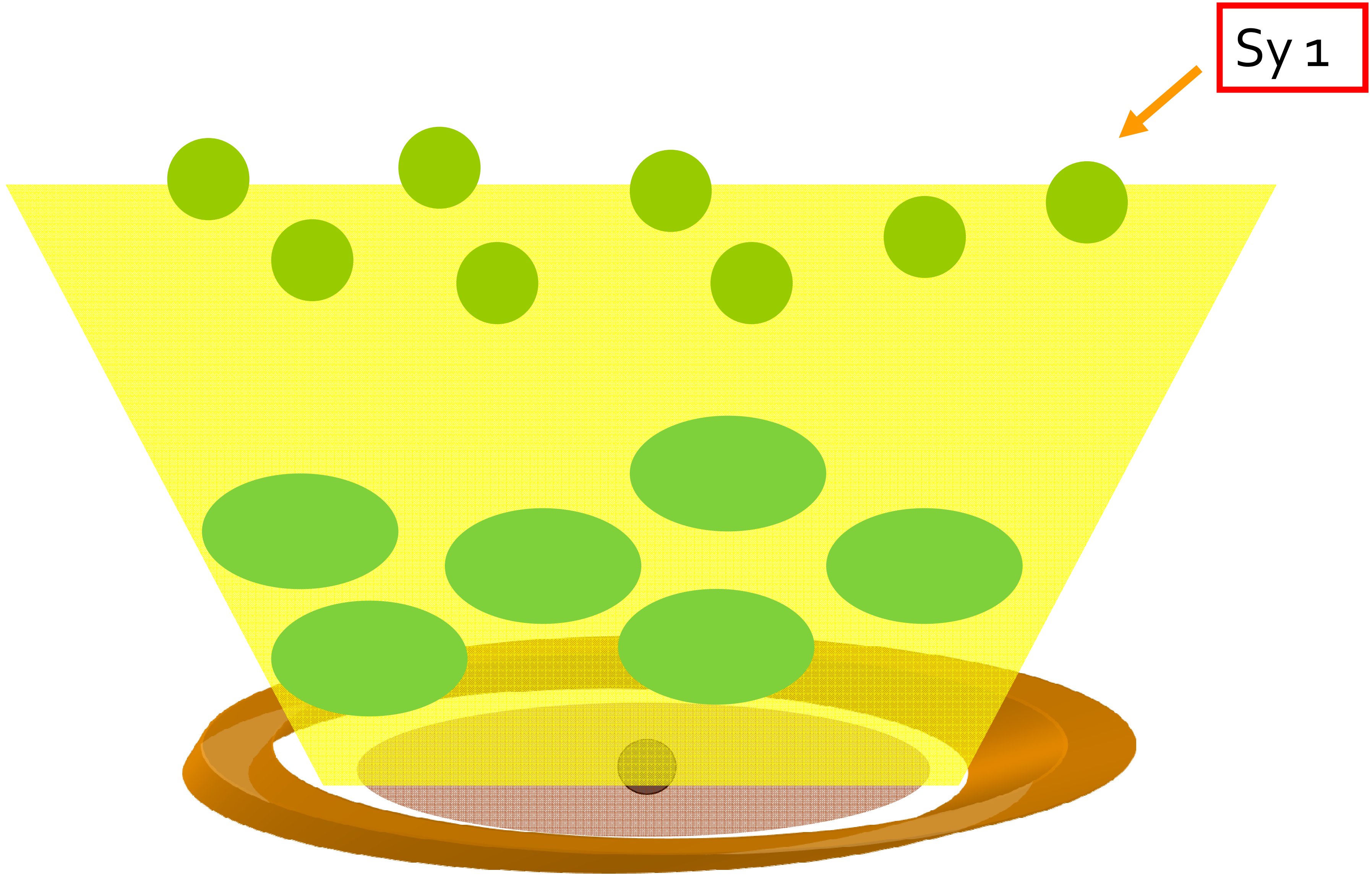
- What do we know about warm absorbers?
- What is their importance?
- A glance at the future

Absorbing gas (Warm Absorbers)

- Absorption by ionized gas in our line of sight is seen in ~50% of AGN
- Most of the gas is seen outflowing (100-1000 km/s)
- In general there is no clear connection between emission by the BLR or NLR and WA
  →Different opening angle of the gas
  →Different location
- The WA does not have a precise location in the classical unified model.

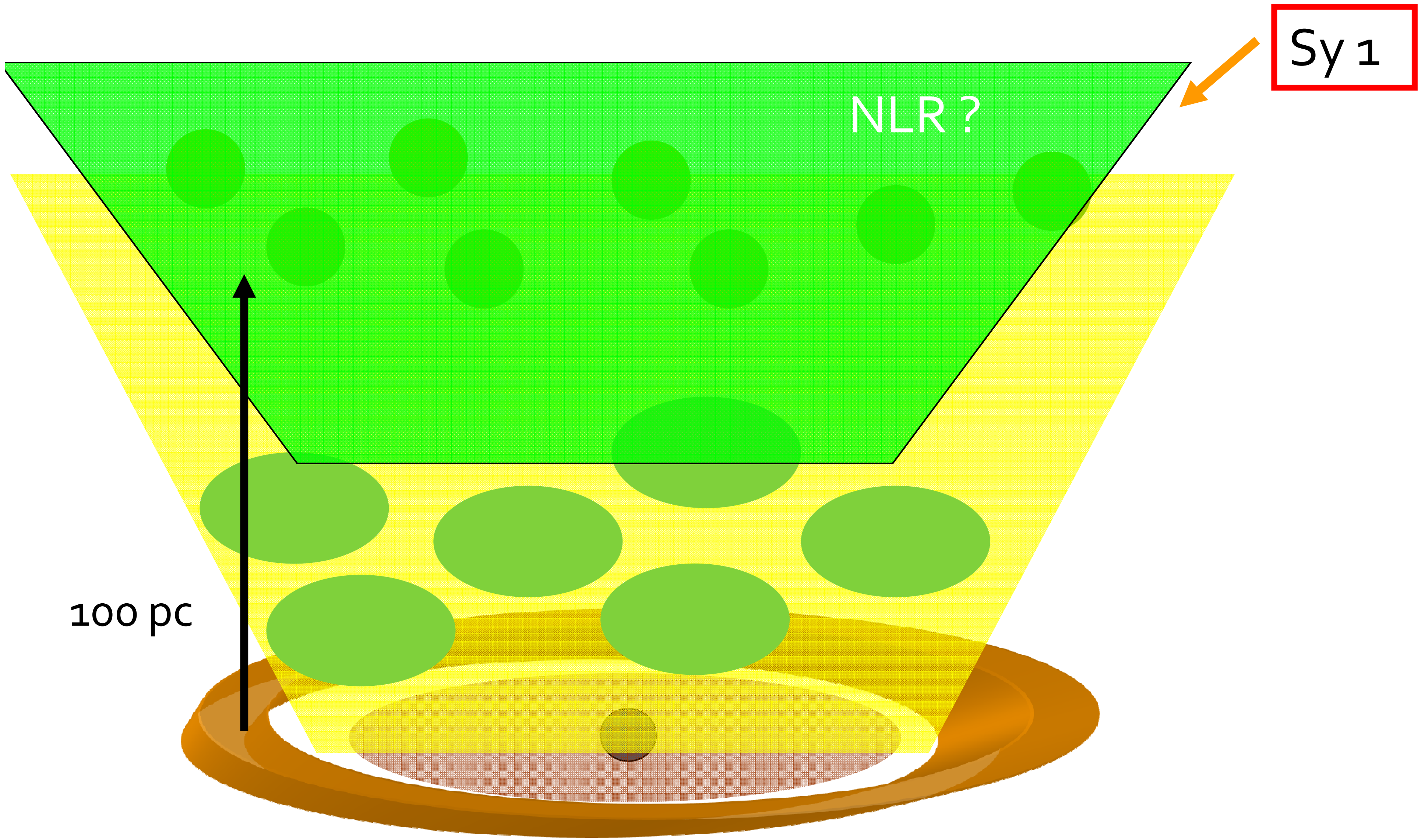
IONIZED (WARM) ABSORPTION

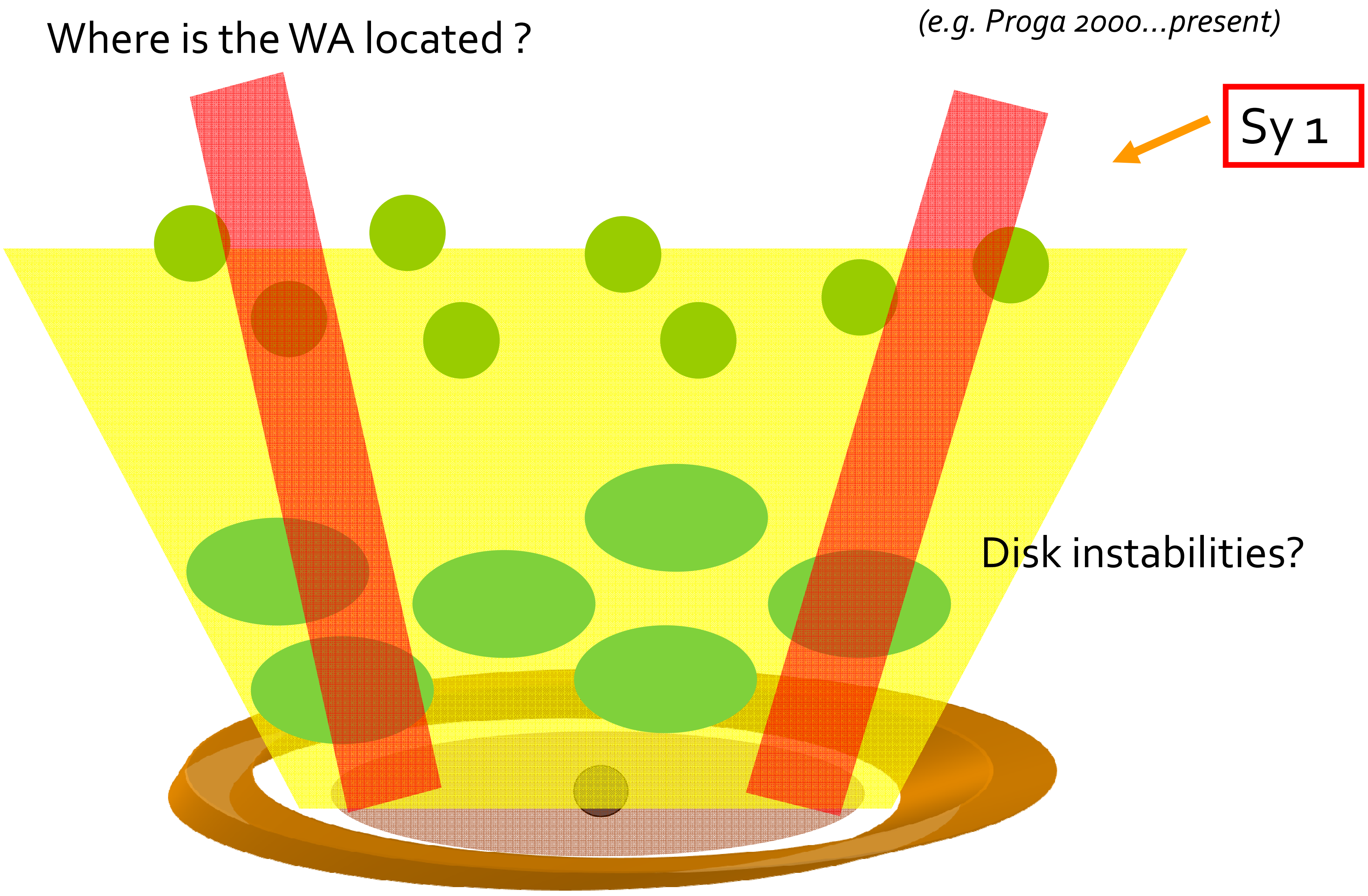



Sy 1

Where is the WA located ?

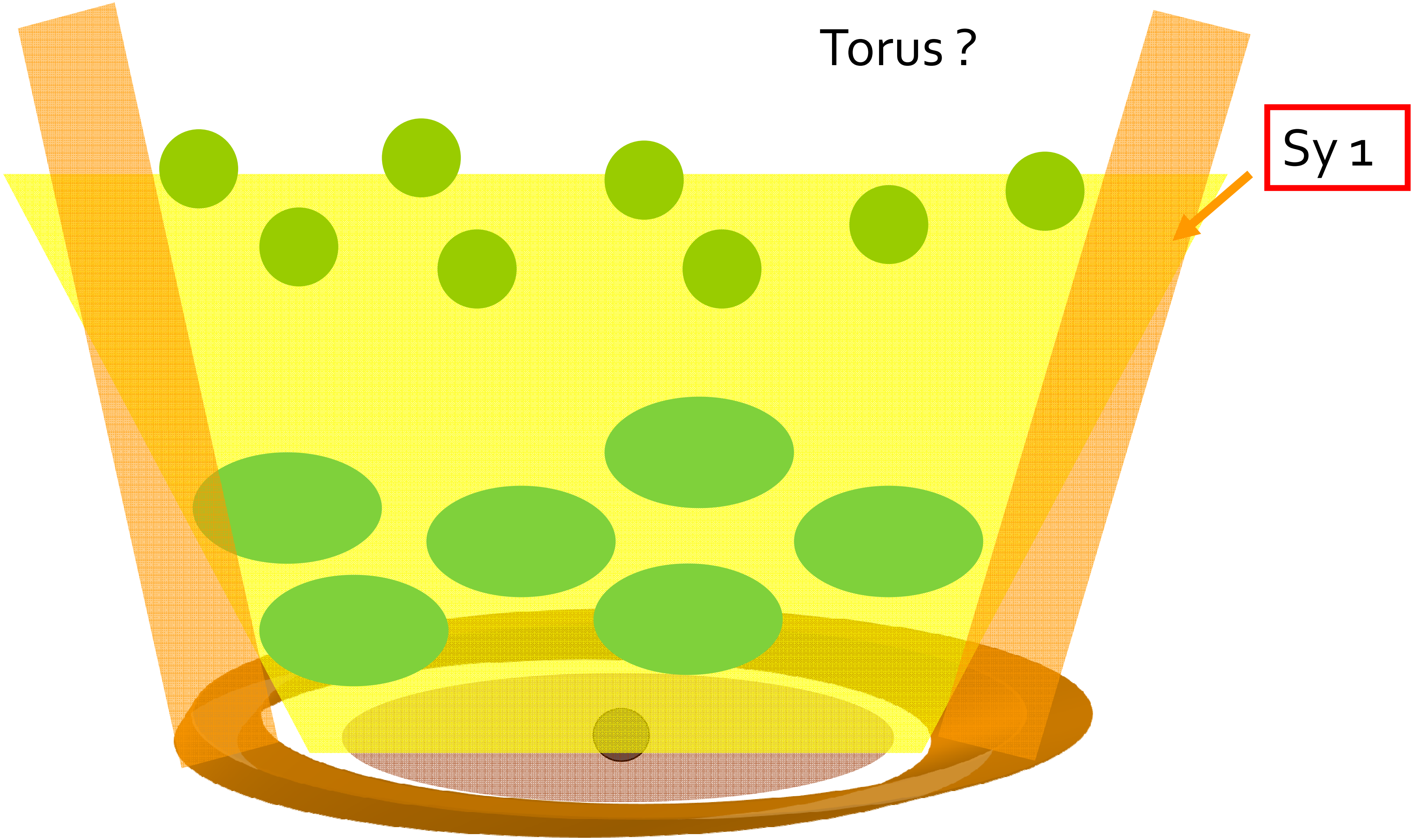
(e.g. Behar +03 Guainazzi&Bianchi 05)




Where is the WA located ?
(e.g. Proga 2000…present)
Sy 1
Disk instabilities?

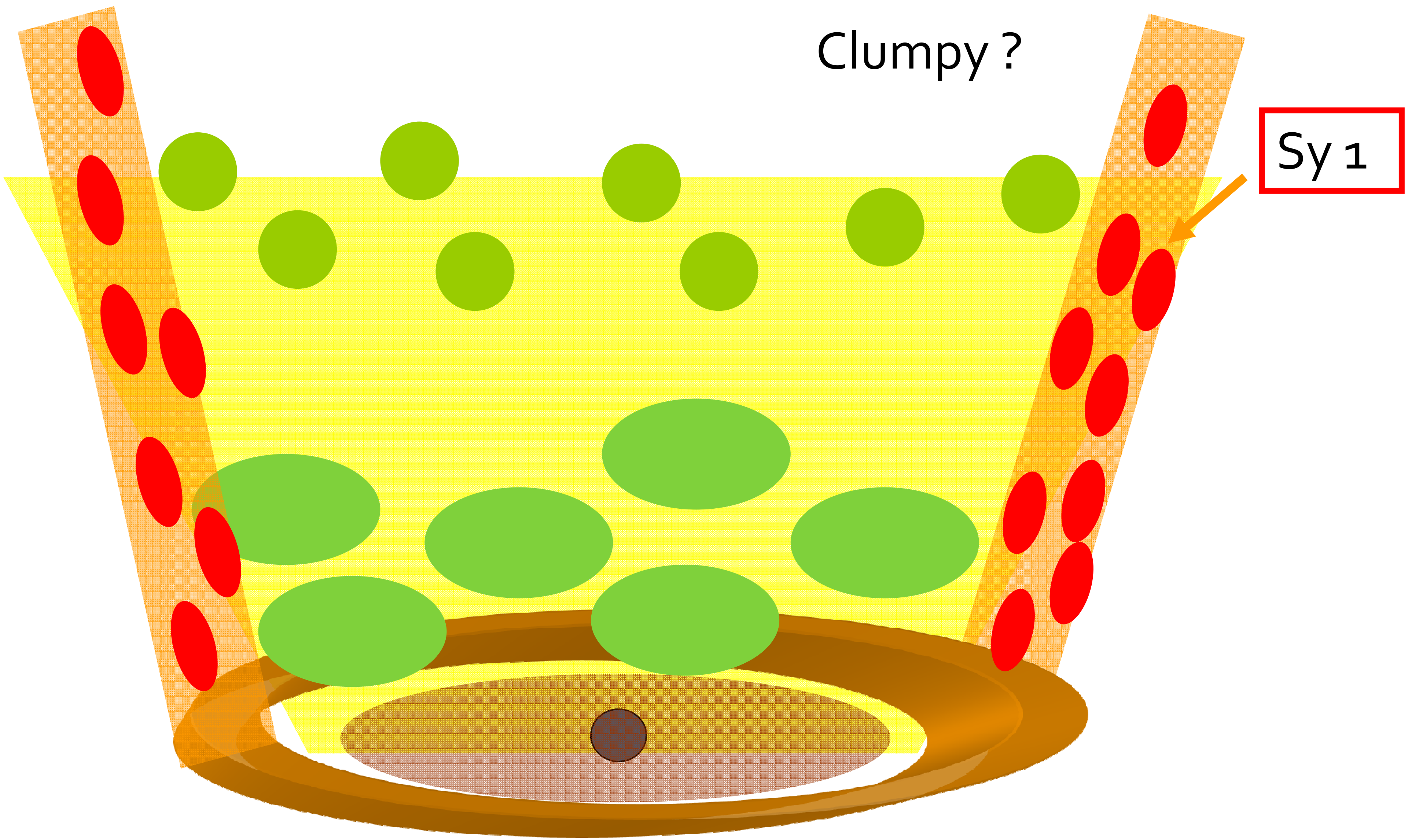
Where is the WA located ?

(e.g. Krolik & Kriss 2001)



What is the structure of the WA?

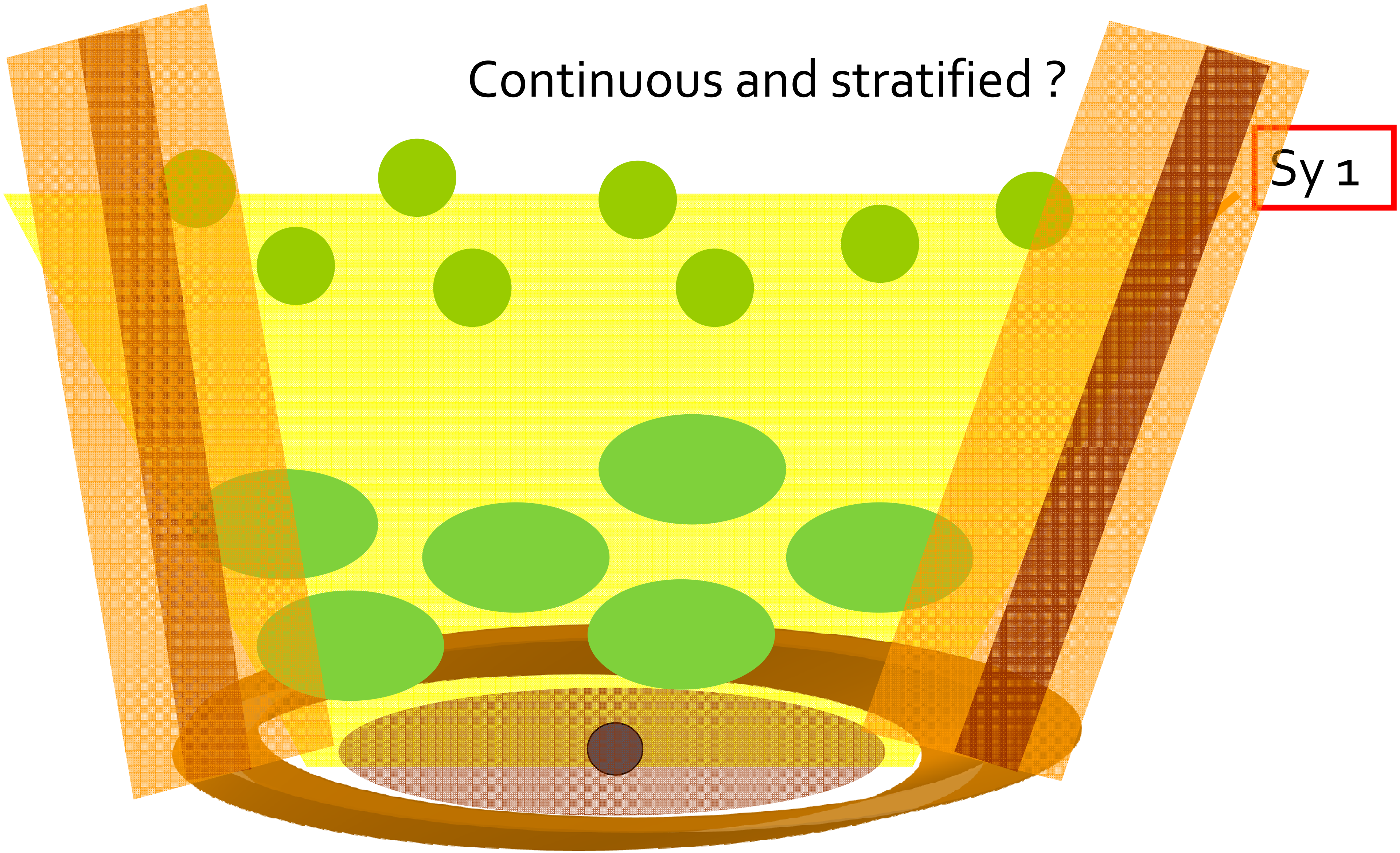
(e.g. Krongold +2003



What is the structure of the WA?

(e.g. Behar+2009)

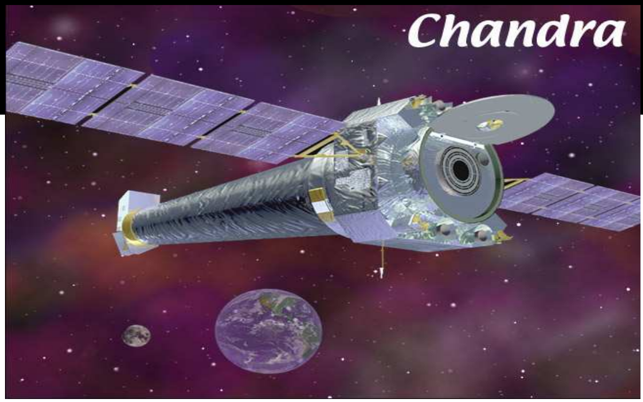
Continuous and stratified ?

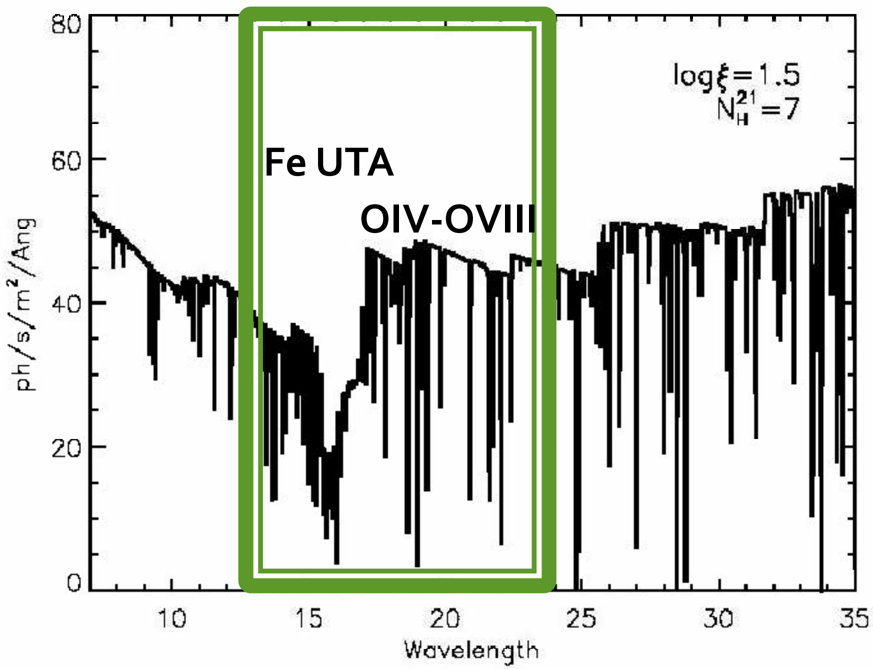


Importance of WA

- Geometry of the BH environment
- Self sustenance of the BH system (balance between accretion and ejection)
- Enrichment of the host galaxy *(Wyithe & Loeb 2003)*
- They may affect dispersal of heavy elements into the IGM and ICM *(Scannapieco & Oh 2004)*
- Invoked for quenching star formation in Galaxy Cluster

The X-ray instruments

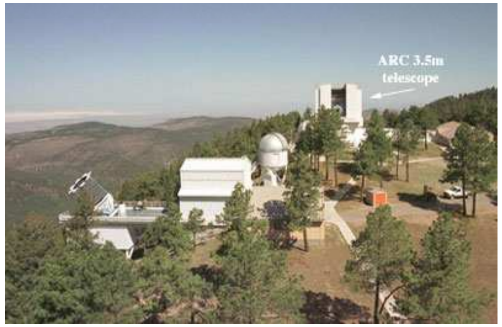




	Band (Å)	Resolution λ/Δλ
XMM-Newton RGS	7-35	400
Chandra-LETGS	2-80	500
Chandra-HETGS	1.5-20	1000

The UV instruments

COS Cosmic Origin Spectrograph	1150-2050 1700-3200	16,000-24,000
STIS Space Telescope Imaging Spectrograph	1150-10,000	10,000



With higher redshift → ground based telescopes

	Band (Å)	Resolution $\lambda/\Delta\lambda$	S/N
ARC @ Apache Point Obs.	3800-6300	3000-5000	100
VLT-UVES	3200-9000	40,000	80

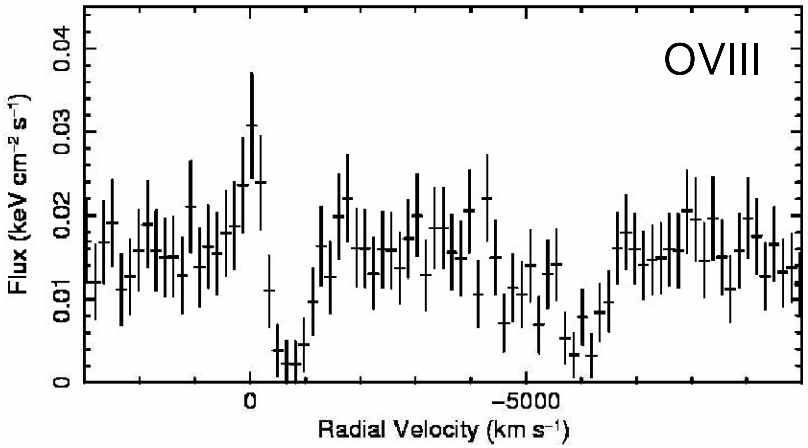
The multiwavelength approach

- UV spectra (STIS, COS, FUSE):
  - limited wavelength band → relatively few ions are represented (e.g. CIV, NV, Ly series), OVI (FUSE)
  - High resolution (R=20,000) → velocity resolved spectroscopy

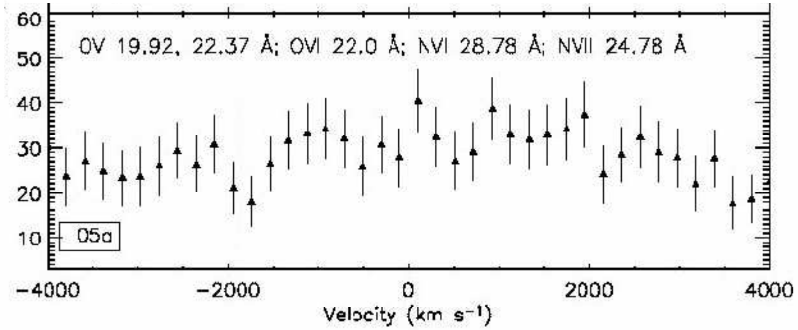
- X-rays spectra (RGS, LETGS, HETGS):
  - Broad band → dozen of transitions from most abundant element and variety of ionization states (note: no H!)
  - Low resolution (R=400-1000) → blurred vision of the lines

(Review in Costantini 2010)

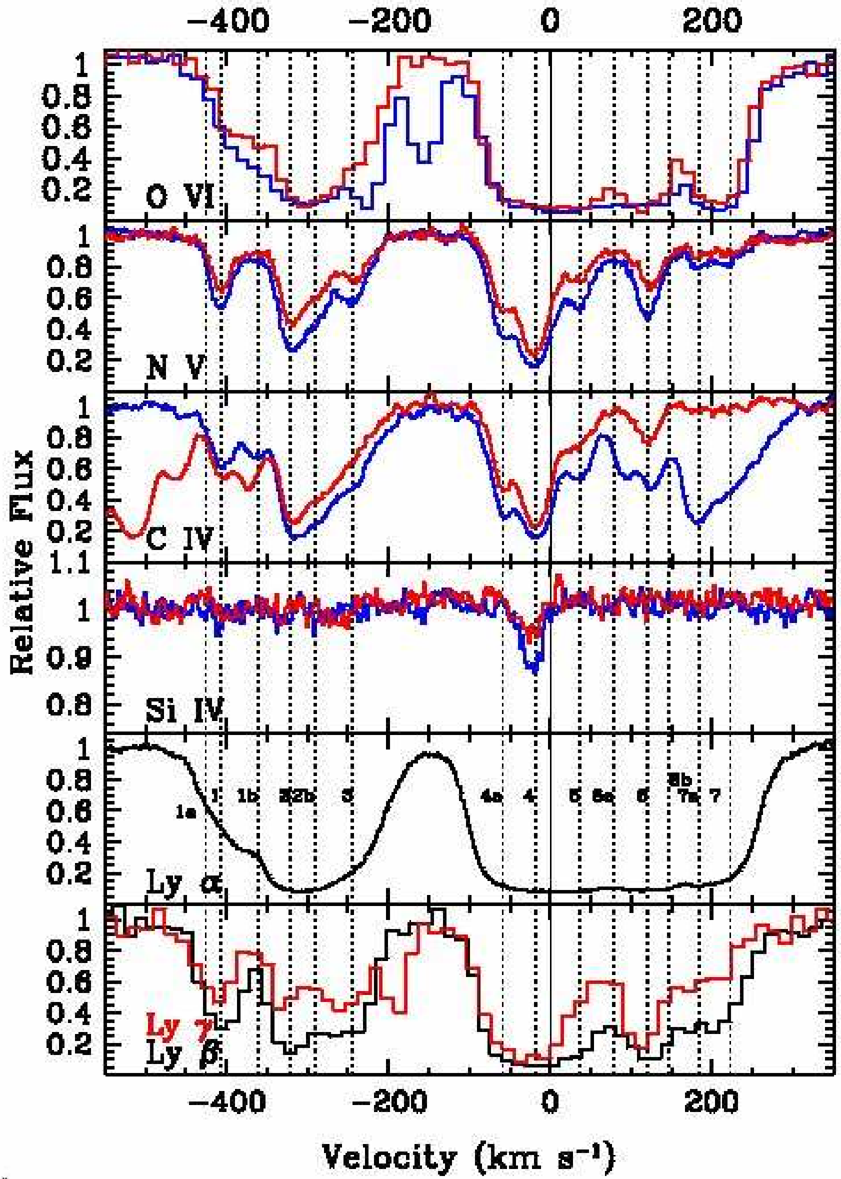
Kinematics



(NGC4051, Lobban+10)



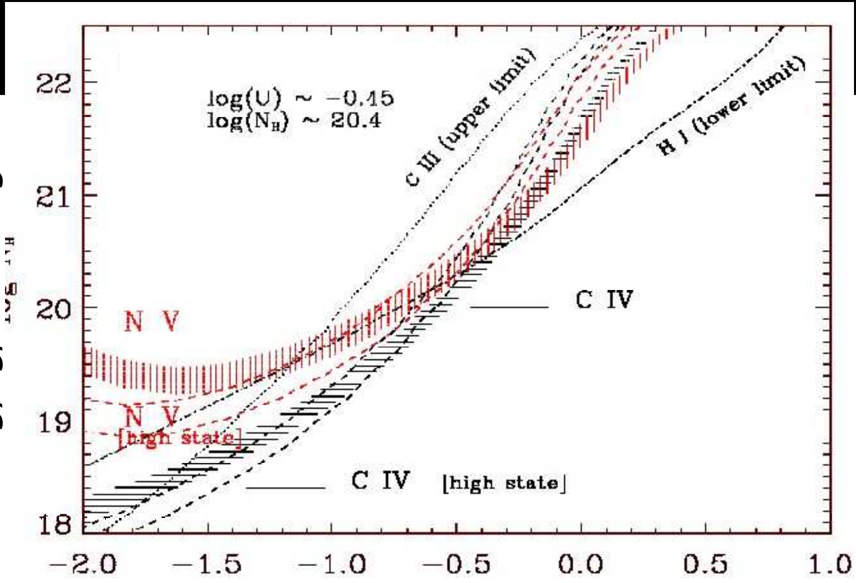
(IZw1, Costantini+07)



(Mrk509, Kriss+11)

Photoionization

NGC 3783, Gabel+05

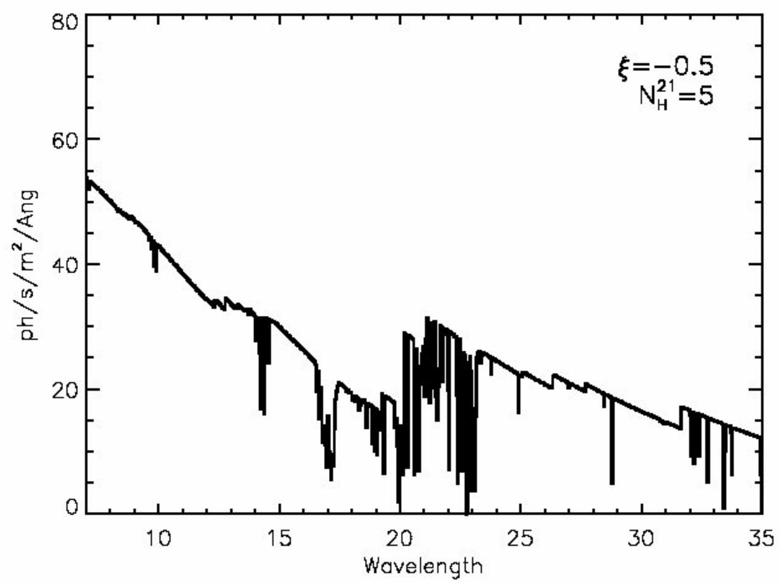


Given an SED → ionization balance → Solve for NH and ionization parameter.

UV → few, extremely detailed, ions
→ logU—NH grid (Cloudy, XSTAR)
→ uncertainty

$$U = \int \frac{L_\nu^{ion} / h\nu}{4\pi r^2 nc} d\nu$$

SPEX run



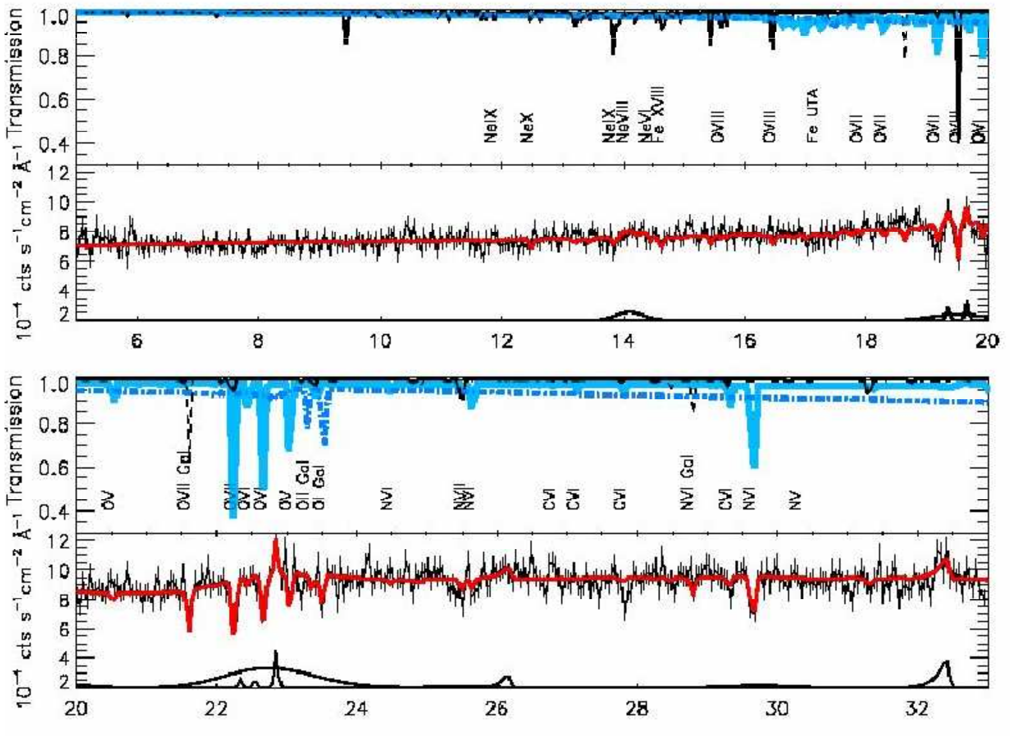
X-rays → hundreds of transitions (roughly defined)
→ Secure determination of U and NH
→ a wide range of ionization stages are probed
→iron UTA is very sensitive to ξ

$$\xi = \frac{L^{ion}}{nr^2}$$

The census of a WA

- Low ionization WA → UV
- Shared component UV/X (CIV, NV, OVI, OVII)
- (Higher-v) higher-xi, higher N_H component → OVIII, NeIX, absorption from Fe L and Fe K shell.

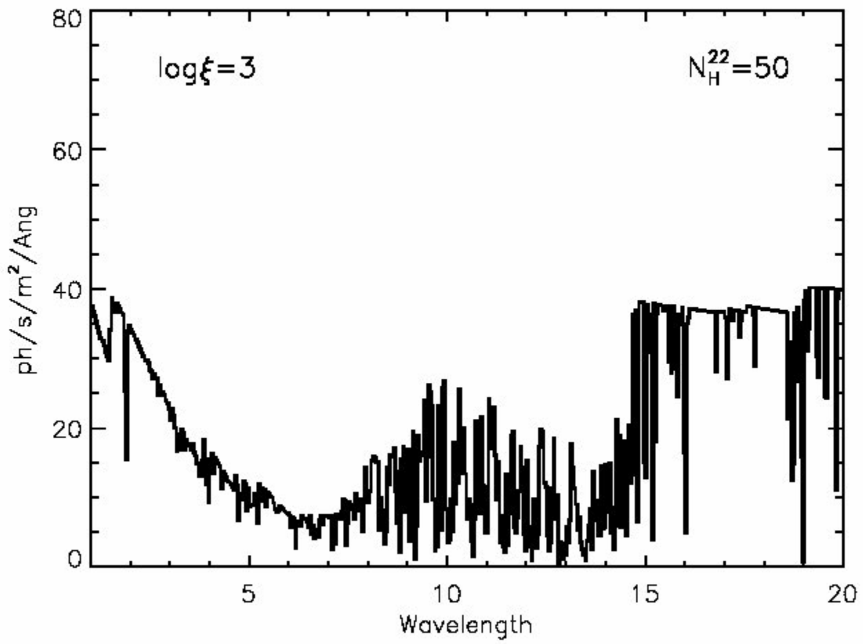
(Mrk279 Costantini+07a, Ebrero, EC+10)



See next talk by Ebrero for a case of complex connection between the UV and X-rays' ionized gas

High X-ray ionization gas

SPEX run



• High ionization gas is only visible if the column density is high enough

→ Observational bias (i.e. there must be also low-NH high gas)

→ high gas mass carried away by the outflow

UFOs: Ultrafast Outflows

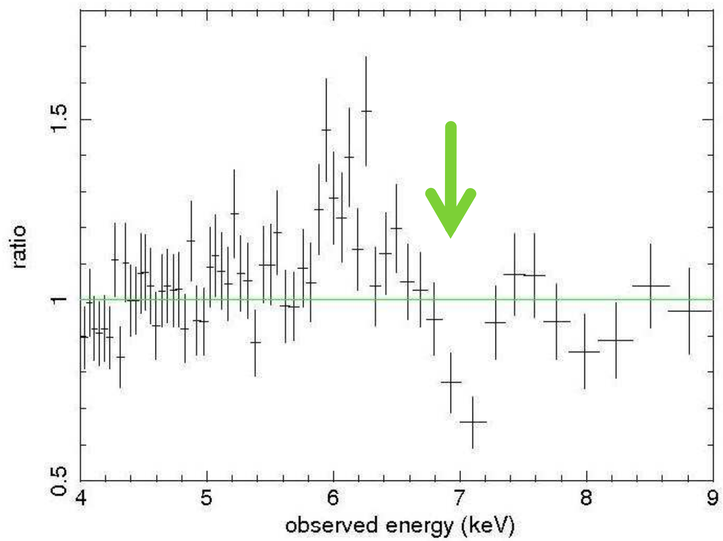
- Highly ionized, high column density and very high outflow velocity v=0.2-0.4c gas

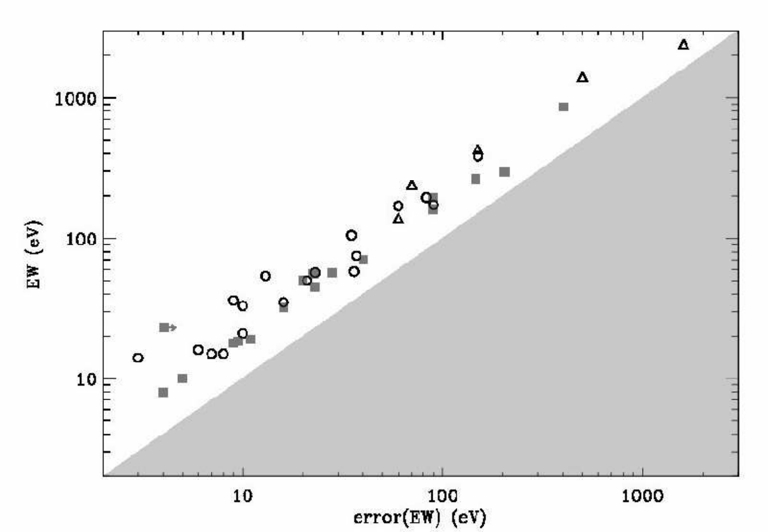
+ UFOs are very appealing from the theoretical point of view

But: elusive (often only 1 line is detected), transient, sometimes unsure detection

- Next generation instruments are needed to fully characterize them

(*PG 1211+143, Pounds & Reeves 09*)



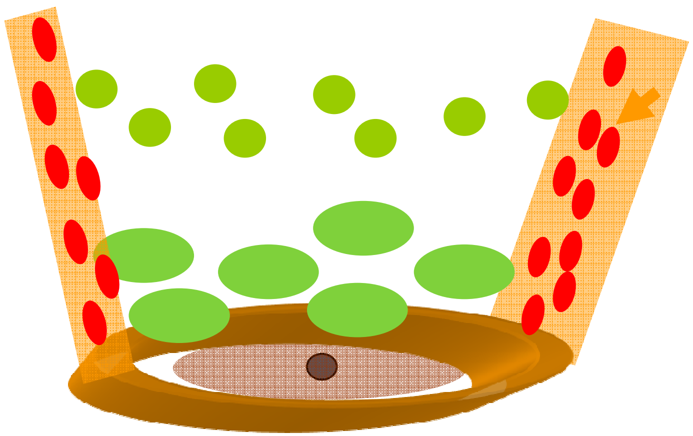


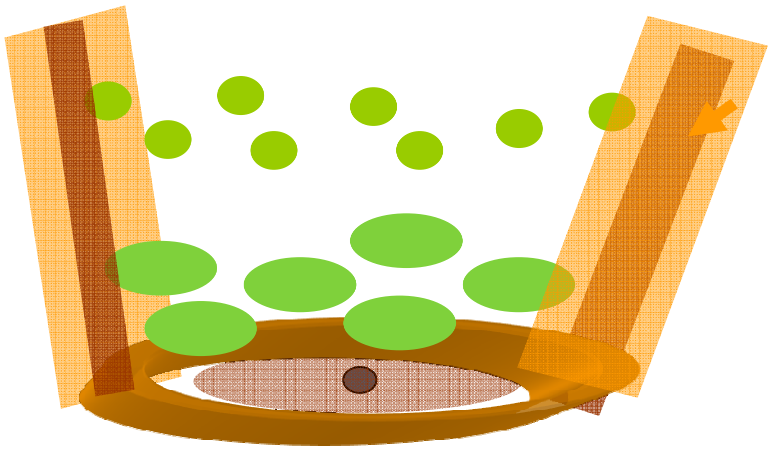
(*Vaughan & Uttley 08*)

Continuos vs discrete components

- Is the warm absorber composed by a handful of ionized components or is it a continuous stratification in ionization and/or density?

  - Is there a pattern in the ξ distribution?
  - Are those components in pressure equilibrium?
  - Does the gas respond promptly to flux variations?

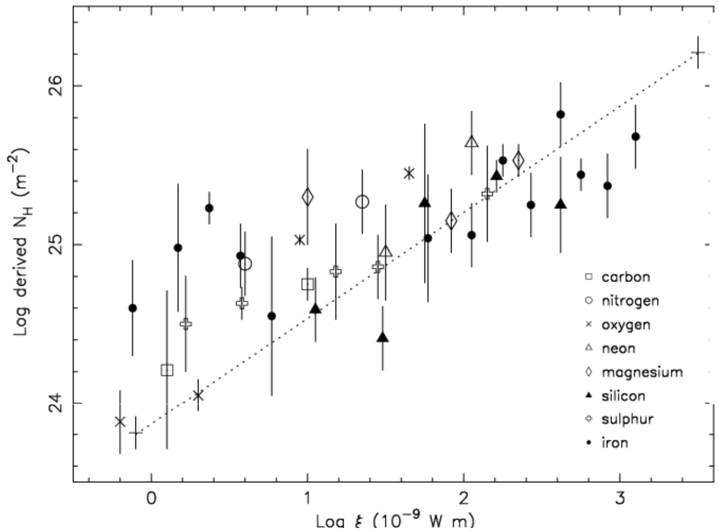




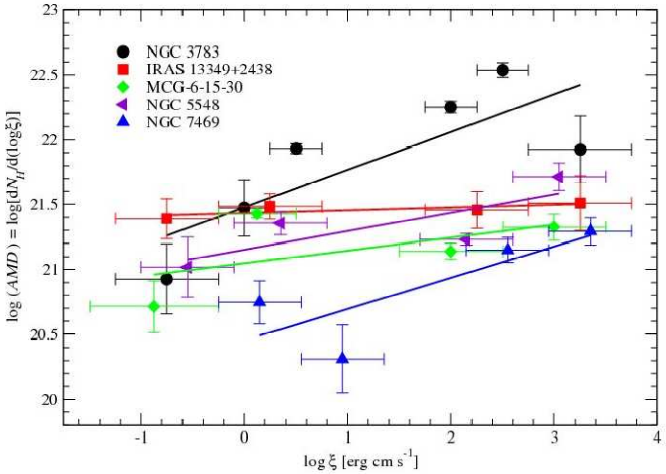
Ionization distribution

• Individual ionic column densities vs the Ionization parameter ξ at which the ion peaks
→ Powerlaw-like distribution
→ Is it a smooth monotonic distribution of ions

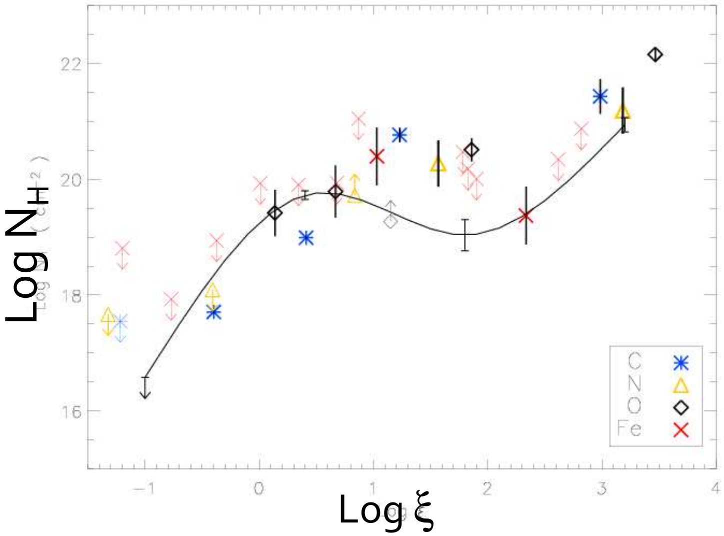
• Model of $dN_H/d\xi$ vs ξ
→ Continuous distribution (but not always!)



(Steenbrugge+05)



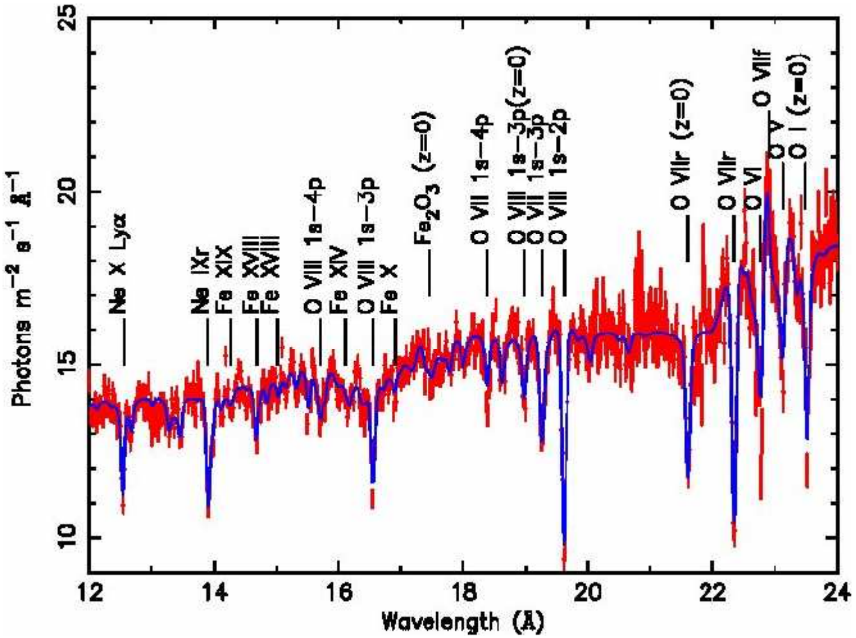
(Behar+09)

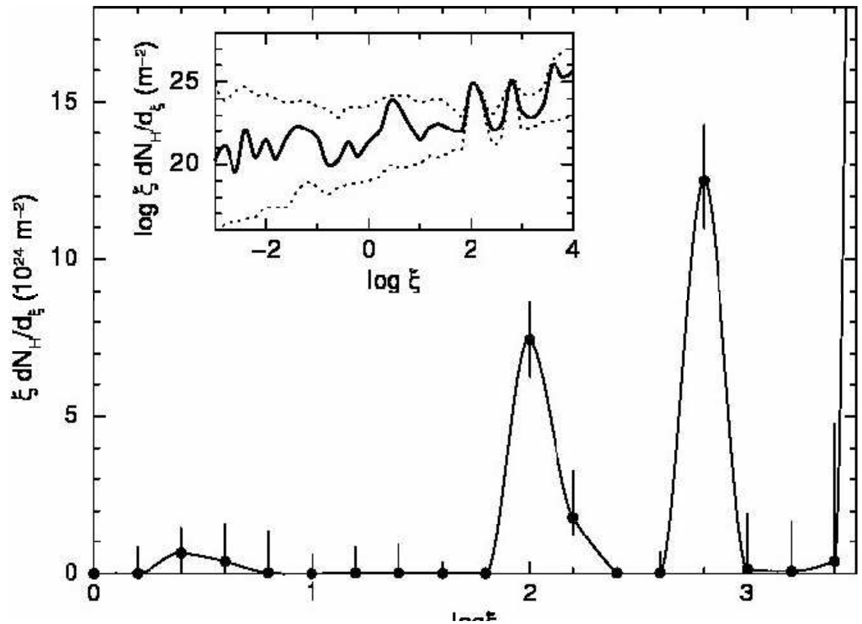


(Costantini+07a)

The case of Mrk509

- 600 ks XMM + Chandra+ COS +Integral +Swift





(Detmers+ 2011)

The $dN_H/d\xi$ shows a strongly peaked distribution, correspondent to positively detected components

+ possible fast response to the continuum flux changes *(Kaastra+11 in prep)*

→ evidence of the discrete component nature of the warm absorber

What we measure directly of a WA:

- **UV**: kinematics, line width, covering factors, abundances, ionization state

- **X-rays**: ionization state, multi-ion components,
  $N_H = 10^{20-23}$ cm^{-2}, outflow velocity.

What we do NOT measure directly:

- Gas density and its distribution, gas distance, gas thickness, opening angle

$$\xi = \frac{L^{ion}}{nr^2}$$

Outflows and feedback

Mass outflow rate:

$$\dot{M}_{out} = 4\pi r N_H m_H C_g v_r \quad M_{sun} yr^{-1}$$

Mass accretion rate:

$$\dot{M}_{acc} = \frac{L_{bol}}{c^2 \eta} \quad M_{sun} yr^{-1}$$

Kinetic Luminosity:

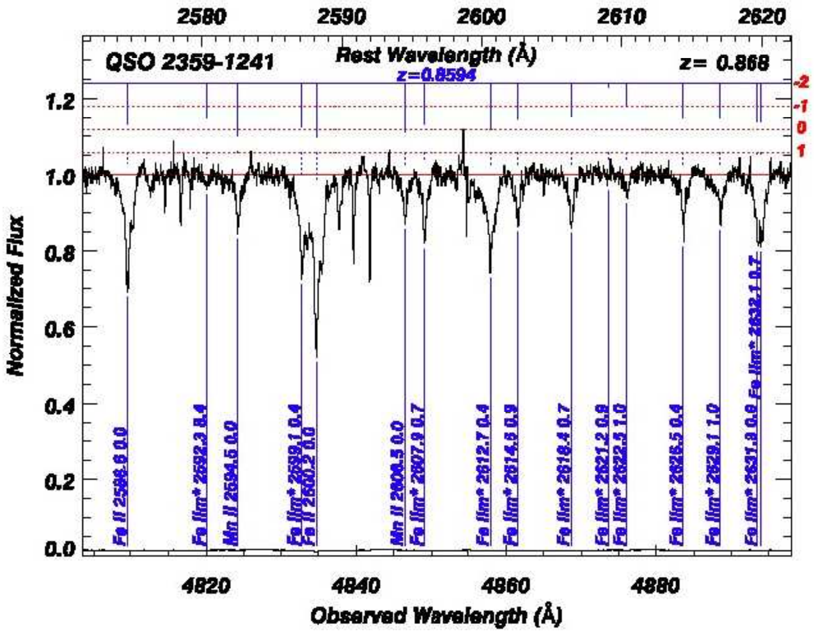
$$L_{kin} = 1/2\, \dot{M}_{out}\, v^2$$

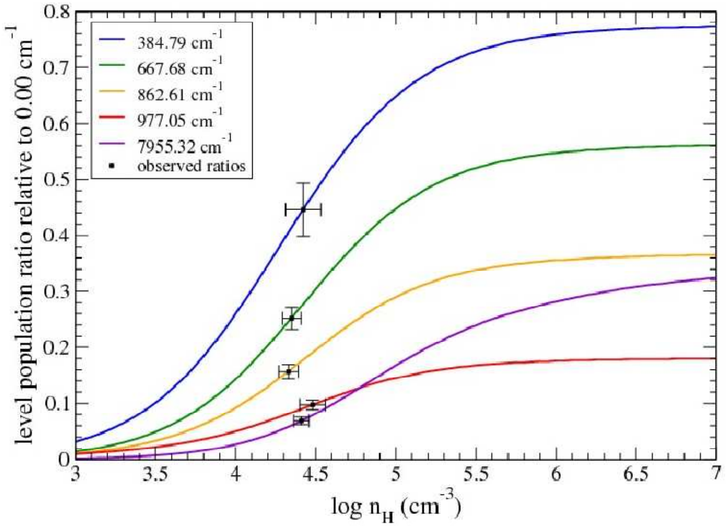
→Density is important for

- AGN physics
- AGN relation with surroundings

UV density diagnostic

- Metastable levels, detected in the UV: e.g. CIII*, FeII*. These are levels just above the ground level, which are populated by collisions → strong dependence on density.
- X-ray metastable levels are weak and sensitive to higher densities (e.g OV* *Kaastra+04*) + λ still uncertain





QSO 2359-1241, Arav, Moe, Costantini+08, Korista+08

Density estimate through variability

- Metastable levels detection are sensitive only to given densities.
- Monitoring the variability of the WA ionization as a function of the continuum flux is in principle sensitive to any density.

$$t_{eq}^{X^i,X^{i+1}}(t \rightarrow t+dt) \sim \left[\frac{1}{\alpha_{rec}(X^i,T_e)_{eq} n_e}\right] \times \left[\frac{1}{\left(\frac{\alpha_{rec}(X^{i-1},T_e)}{\alpha_{rec}(X^i,T_e)}\right)_{eq} + \left(\frac{n_{X^{i+1}}}{n_{X^i}}\right)_{eq}}\right]_{t+dt}$$

(Krolik & Kriss 95, Nicastro+99)

→If the flux varies on a certain t → the variability of the WA provides a lower limit on the density → Upper limit on the distance

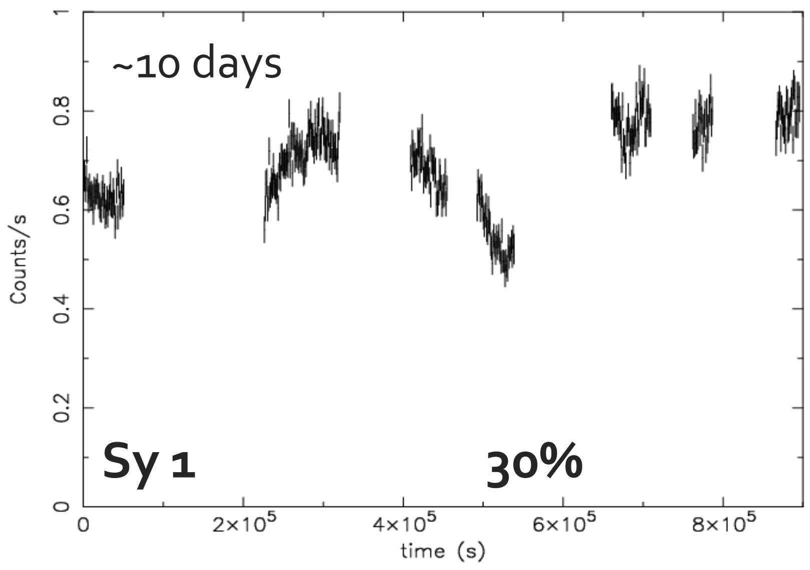
$$\xi = \frac{L^{ion}}{nr^2}$$

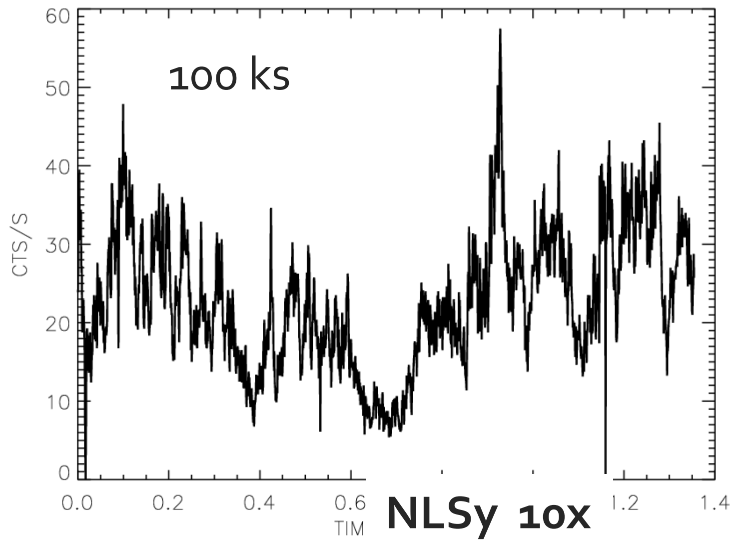
(e.g. Netzer+02, Krongold+05, Detmers+08, Longinotti, Costantini +10)

Density estimate through variability: problems

- If the source varies slowly → comparing observations taken years apart provides loose constraints on *n*
E.g.: QSO and even Seyfert 1

- If the source varies wildly on a short time scale
 → good monitoring but low statistics in different flux bins
E.g. Narrow line Seyfert 1





Gas Location and feedback budget

- NGC3783: ~25pc *(Gabel+05)*
- NGC4151: ~0.1 pc *(Crenshaw & Kraemer 09)*
- NGC5548 < 7pc *(Kraemer+09)*
- Mrk279 < 29 pc *(Ebrero, EC+10)*
- NGC3516: 0.2 pc *(Netzer+02)*
- NGC 4051 0.5-3 l.d.→ 1-3pc *(Krongold+07, Steenbrugge+09)*

- Rate M_{out} = 0.01—0.06 $M_{sun} yr^{-1}$ ~ Rate M_{acc} for many cases
- In some outliers, M_{out} > 10 M_{acc}

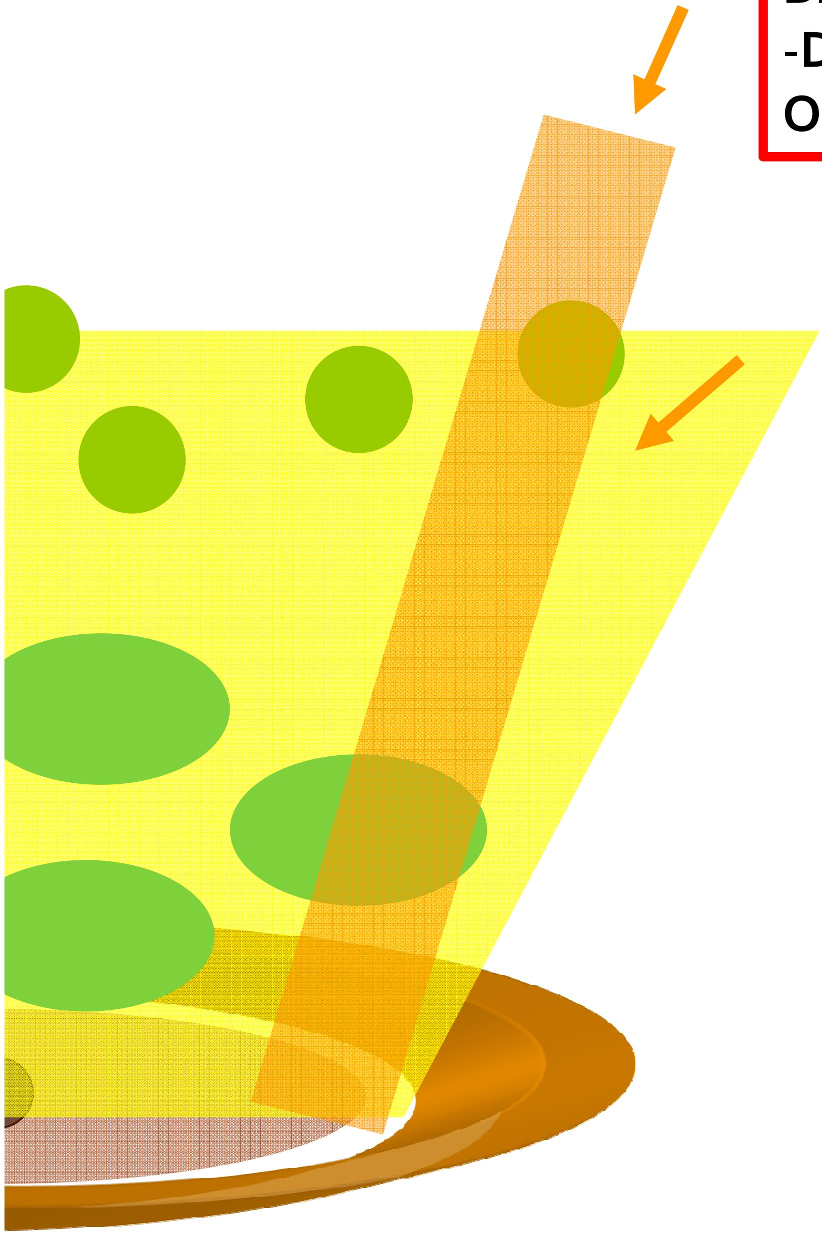
- **Kinetic luminosity is < 1% L_{bol}**

→**Little contribution to the energetics. But is that all?**

→ only one component is measured (but multi-comp. in WA)

→ WAs originate from different locations

Are Seyfert 1 representative ?



Broad Absorption Line QSO
-Deep blend of lines with
Outflows=1000-40,000 km/s

Seyfert 1
-Narrow absorption lines
Outflows=100-1000 km/s

→If different class of AGN are due solely to orientation effects
→ For every AGN there exists a BAL component!

VLT campaign on BAL QSO z=0.8-2

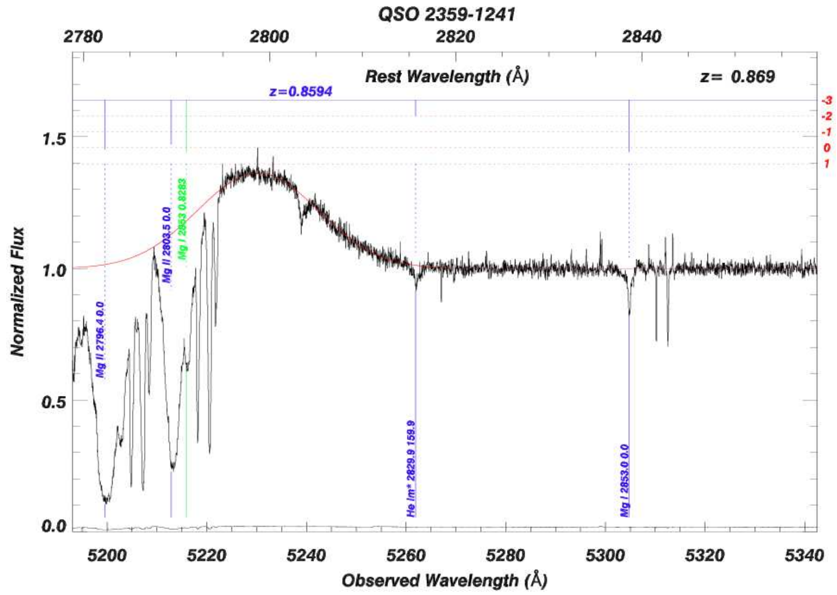
Broad absorption line systems:
V_{out}=2000-40,000 km/s

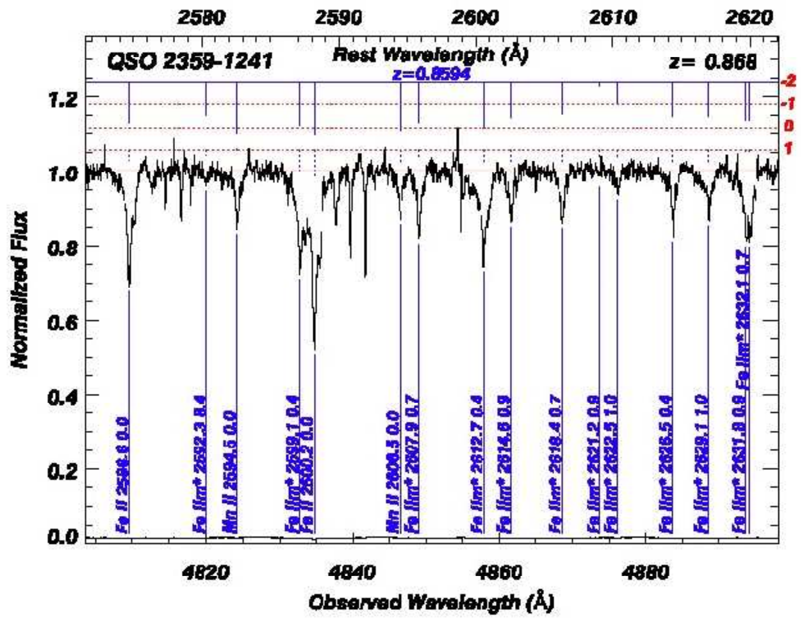
Density is solidly calculated using FeII* diagnostic.

Distance estimation puts the Outflow far from the source:
3-6 kpc

Contribution to feedback is non null: 0.1-1% of bolometric Luminosity

Note: distance determined for the Slowest component (4900 km/s)





QSO 2359-1241, Arav, Moe, EC+08, Korista+08, Moe+09, Dunn+10,

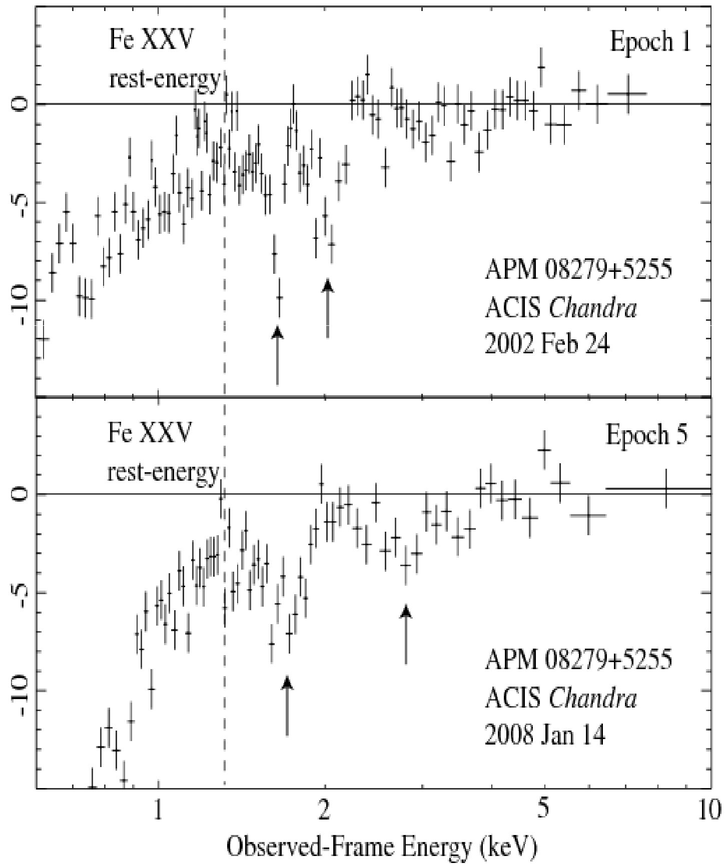
BAL outflows in X-rays

BAL QSO are X-ray weak →
Very difficult to study!

→V_{out} up to 0.76*c*
→ M rate =16-64 M_{sun}/yr
→**L_{kin}/L_{Bol}=0.18-1.7!!**

Implications:
Considering a reasonable AGN life-time (4x10^{8} yr, *Ebrero+09*)

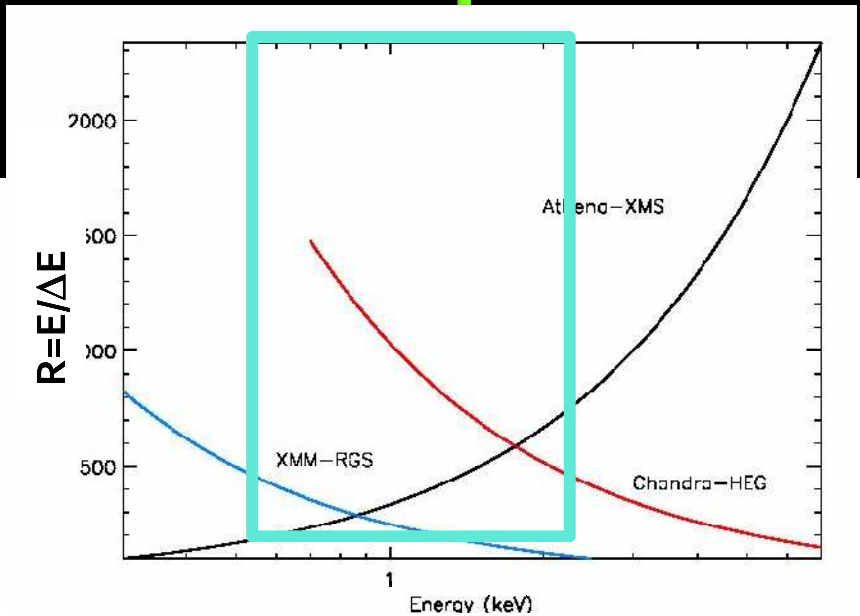
E_{kin} ~10^{59} erg
E_{kin} >> 10^{55} erg
(evaporation in the ISM, *Krongold+10*)
E_{kin} ≅10^{60} erg
(ejection in the IGM, *Scannapieco & Oh, 2004*)

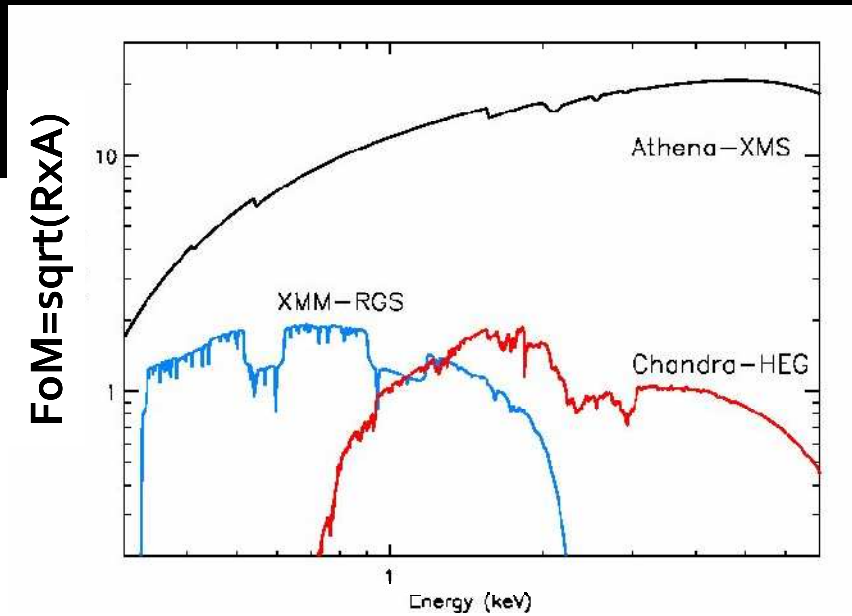


(Chartas+08)

See talk by Giustini on BAL QSOs

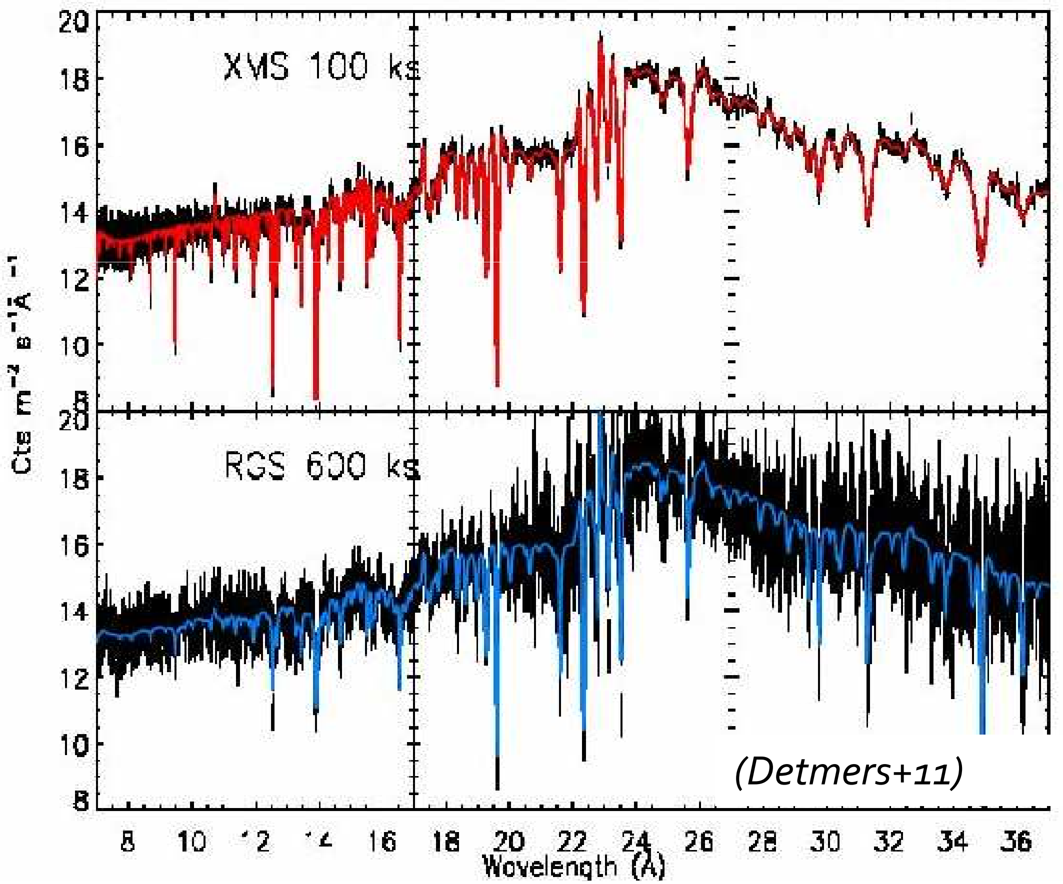
A new hope: Athena-XMS





- → **census of the wa**
- → **variability studies**
  - → Calculate density/distance for multiple components
  - → Understand the relative location of the WAs (disk, torus)
  - → Feedback and AGN physics
- → **abundances**

Mrk 509 seen by Athena



(Detmers+11)

- Mrk 509 (F=3.8e-11cgs)
- → Large multiwavelength campaign *(PIs:Kaastra, Petrucci)* → main goal: monitoring of the WA
- → 12 ks of XMS are sufficient to get the same s/n of RGS
- → Monitoring of the WA will be a routine!

Conclusions

- Status of the art of WA studies:
  - Important for AGN self-sustenance
  - Important for Feedback
  - Current analysis pushes at the limit the performances of present high-res instruments
    - Time Expensive observations

- The future: Athena-XMS will have the resolution (3eV), and Area (0.5m2) to untie the crucial knot:
  - **Density of the multi-components gas**