Warm absorbers (WAs) in Active Galactic Nuclei (AGN)

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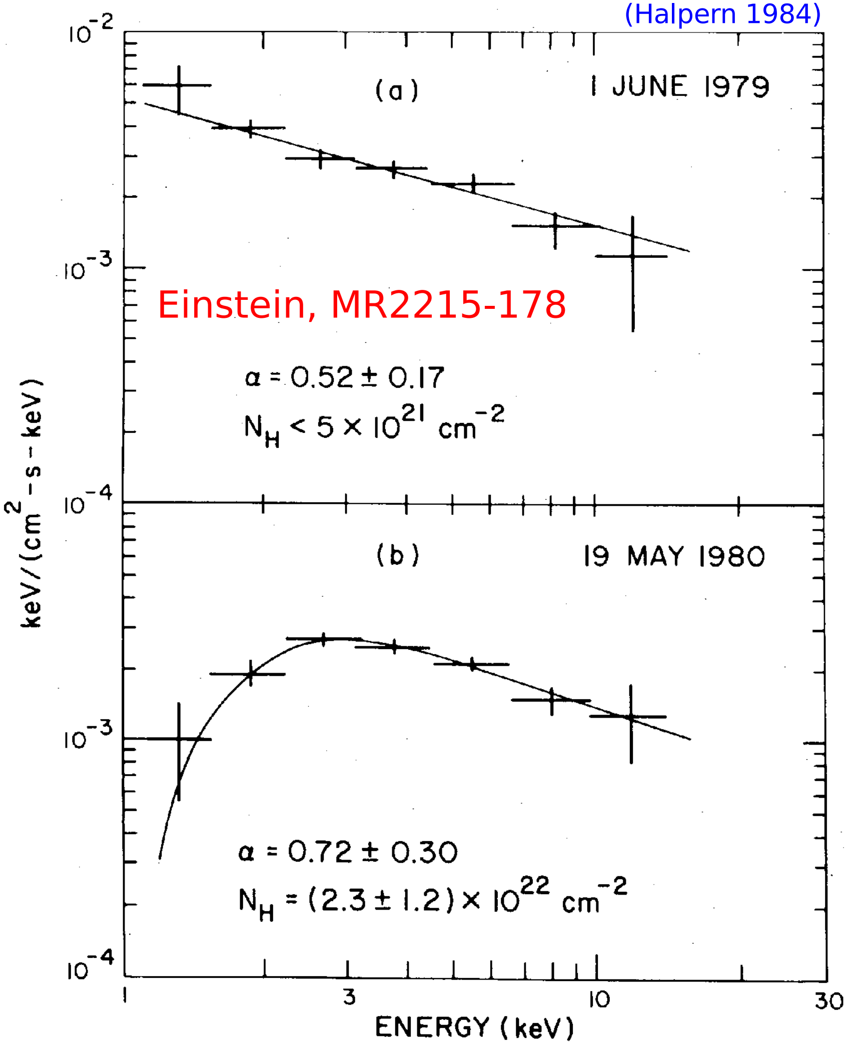
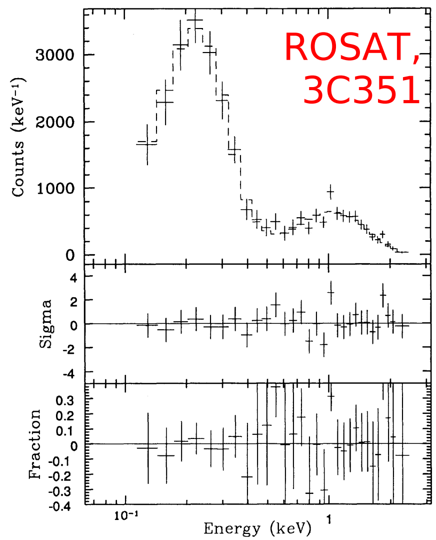
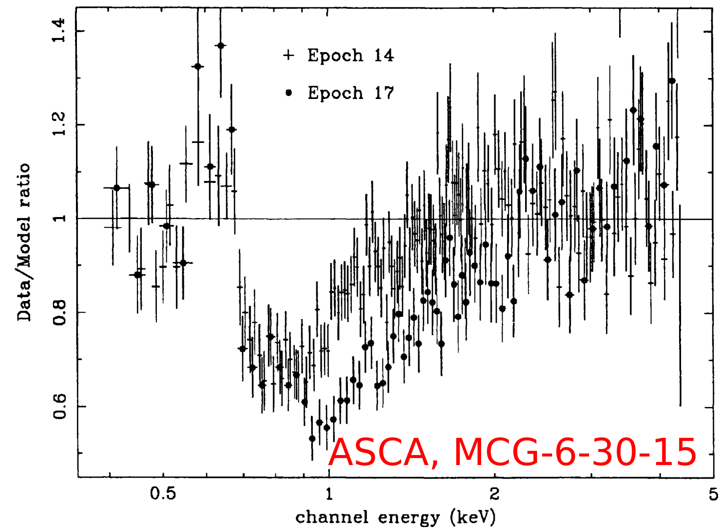
Moderate-resolution measurements of WA

(Halpern 1984)

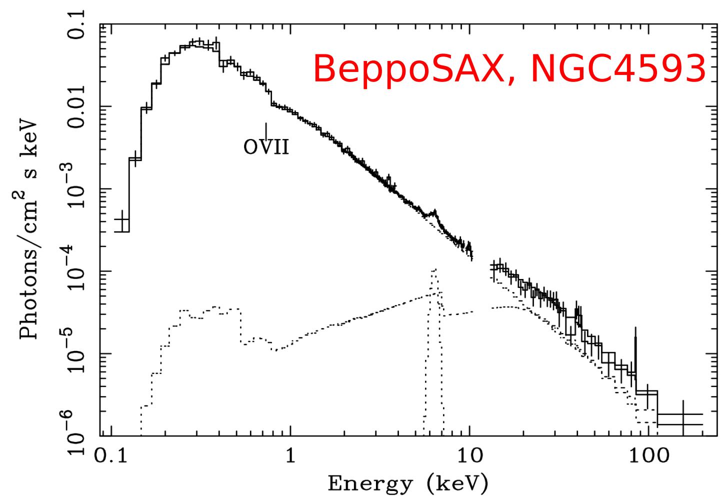


(Mathur et al. 1994)





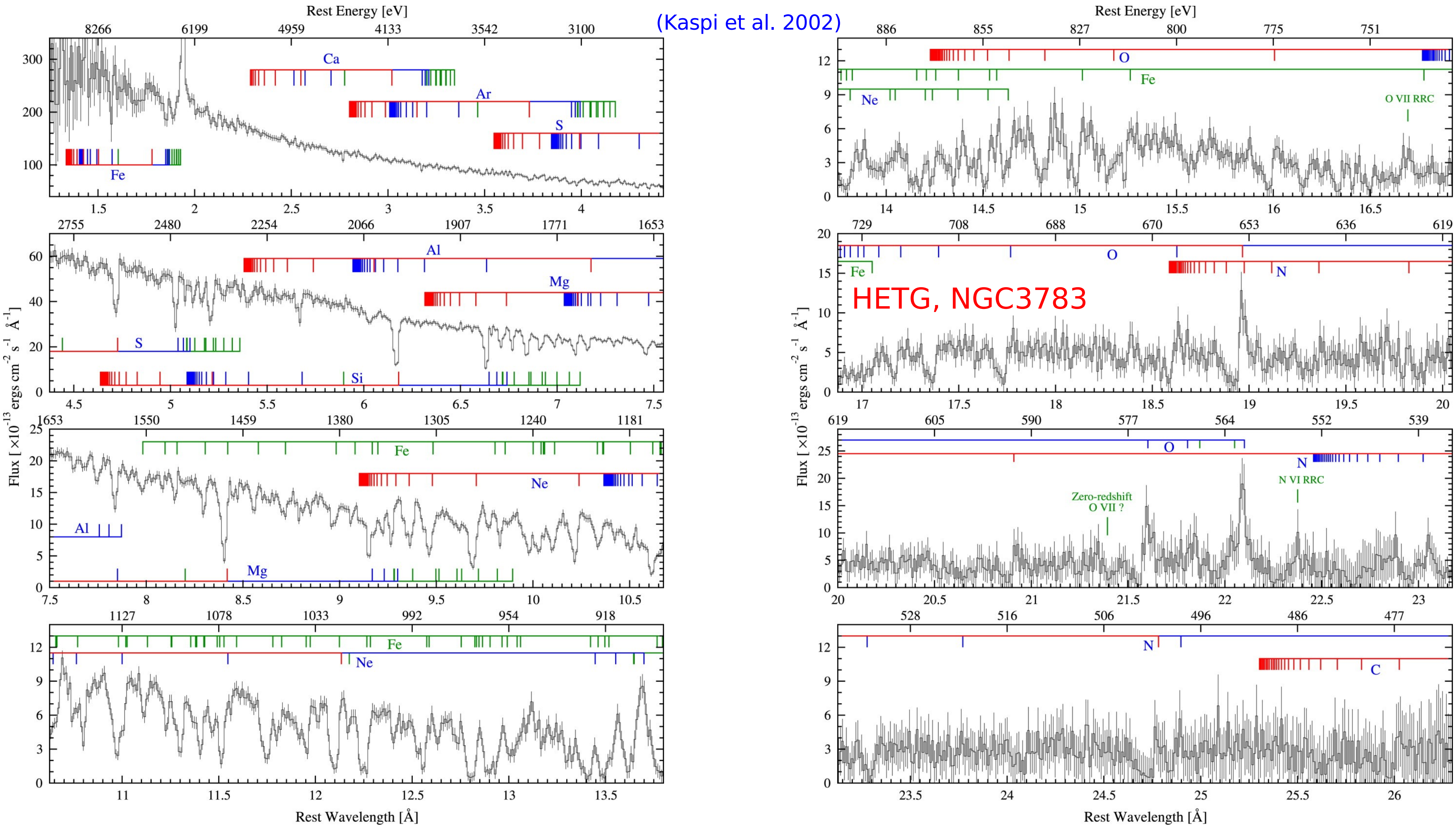
(Otani et al. 1996)



(Guainazzi et al. 1999)

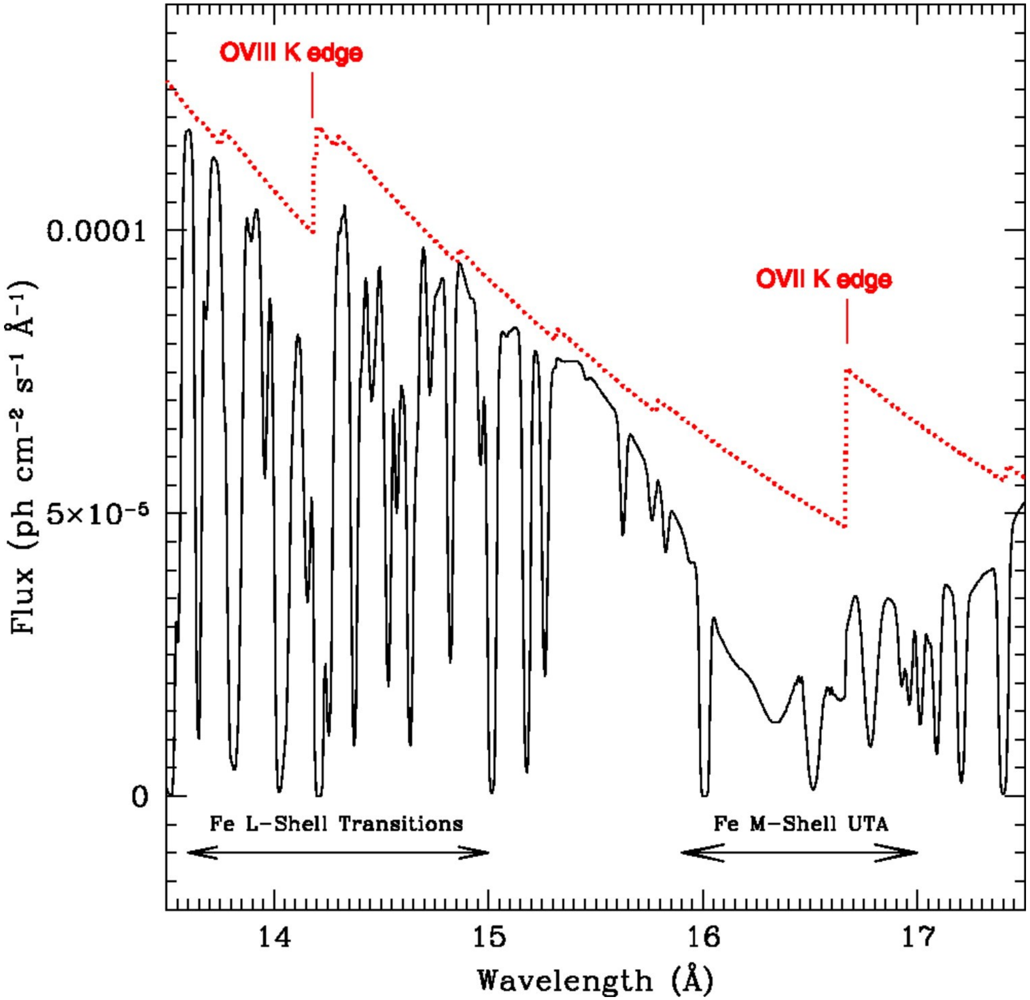
High-resolution measurements of WA

(Kaspi et al. 2002)

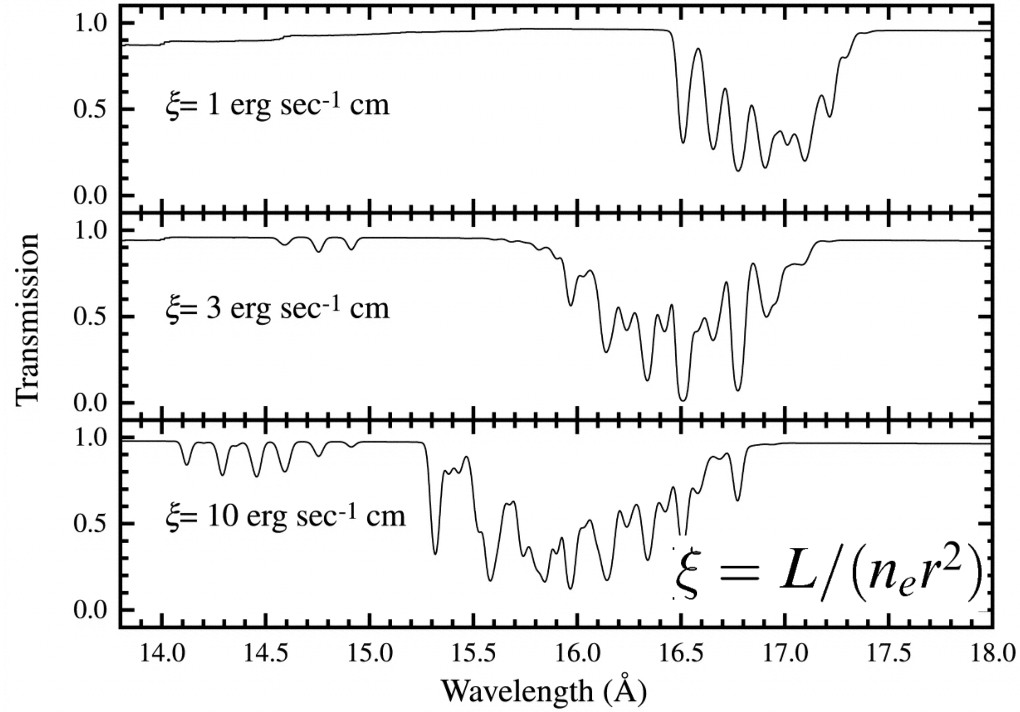


What fooled us at moderate resolution

(Krongold et al. 2003)



(Behar et al. 2001)

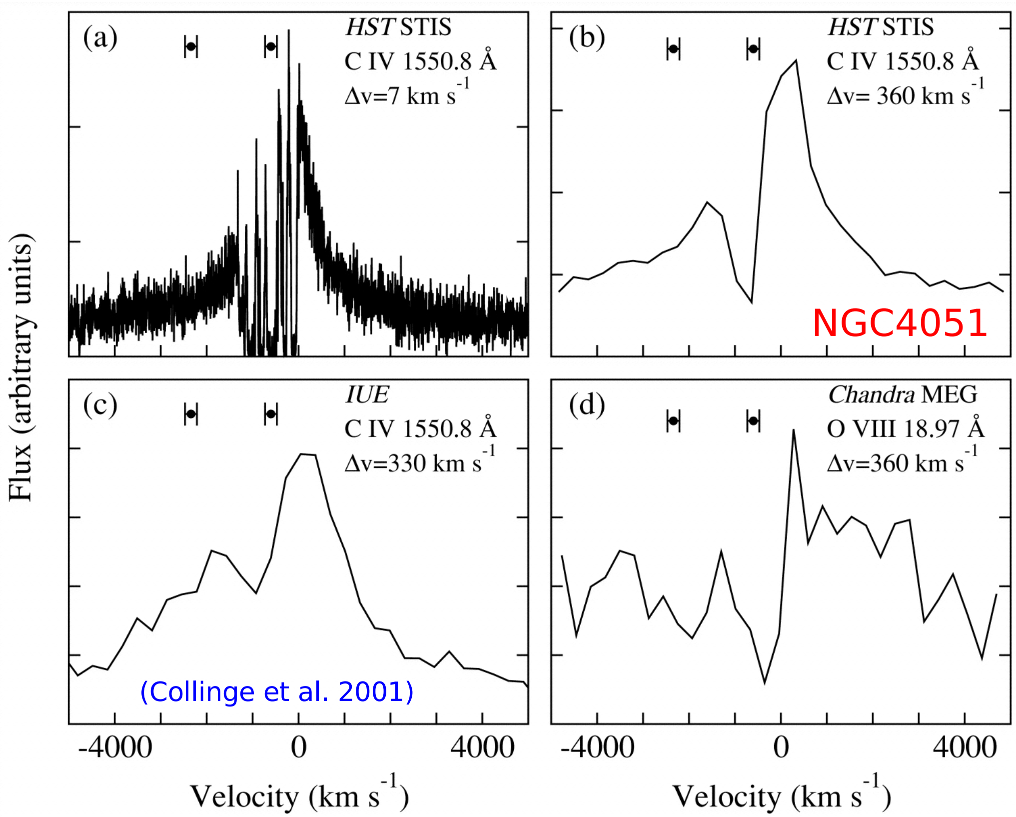


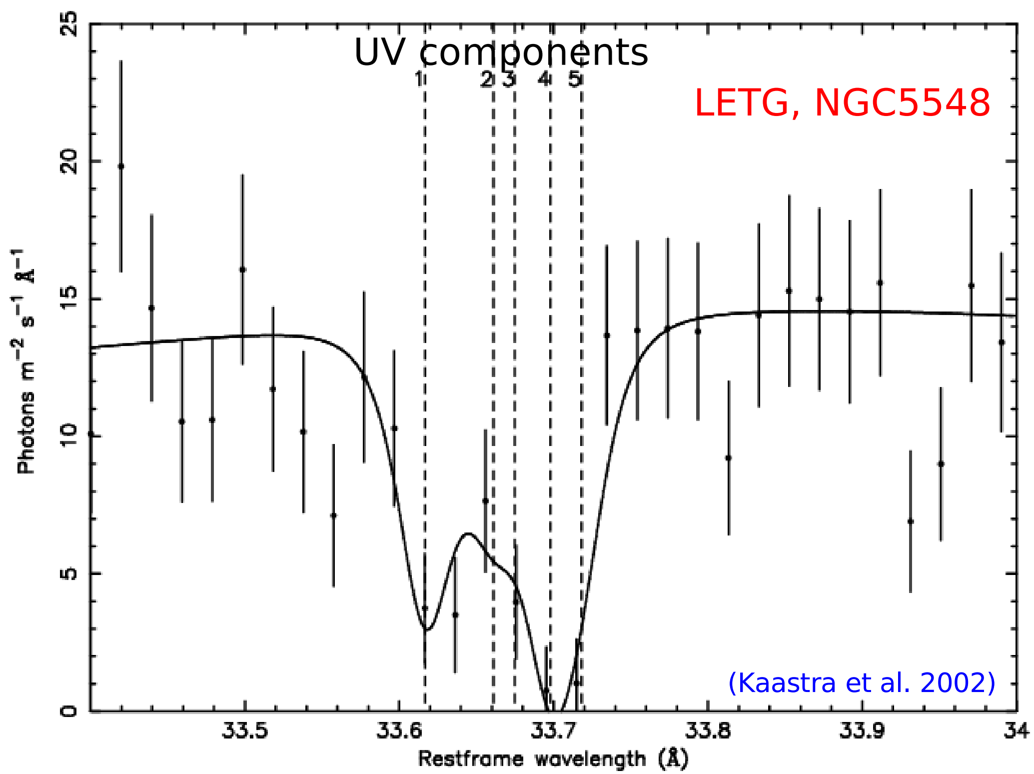
$$\xi = L/(n_e r^2)$$

The Fe M-shell *Unresolved Transition Array* is a sensitive diagnostics of the gas ionization state

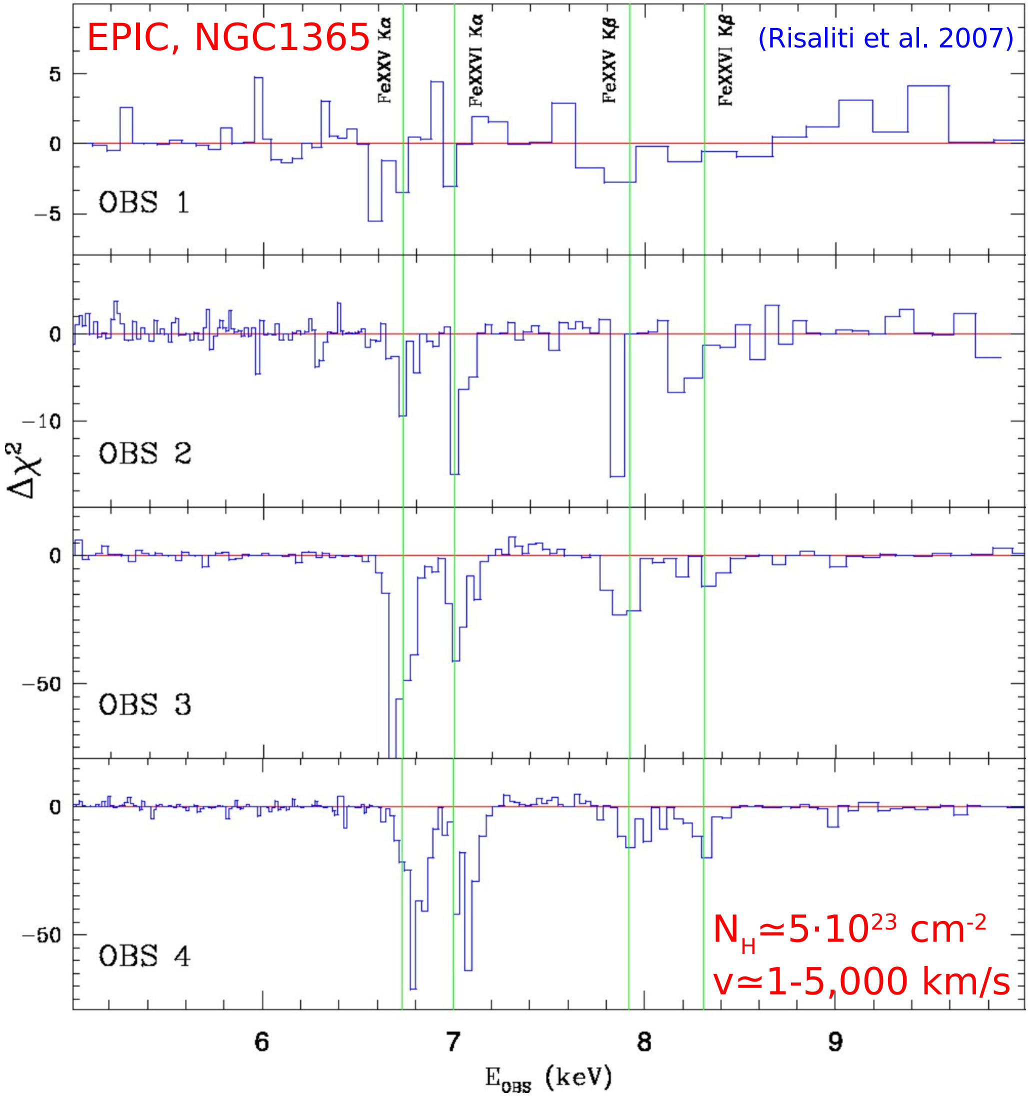
X-rays and UV absorbers

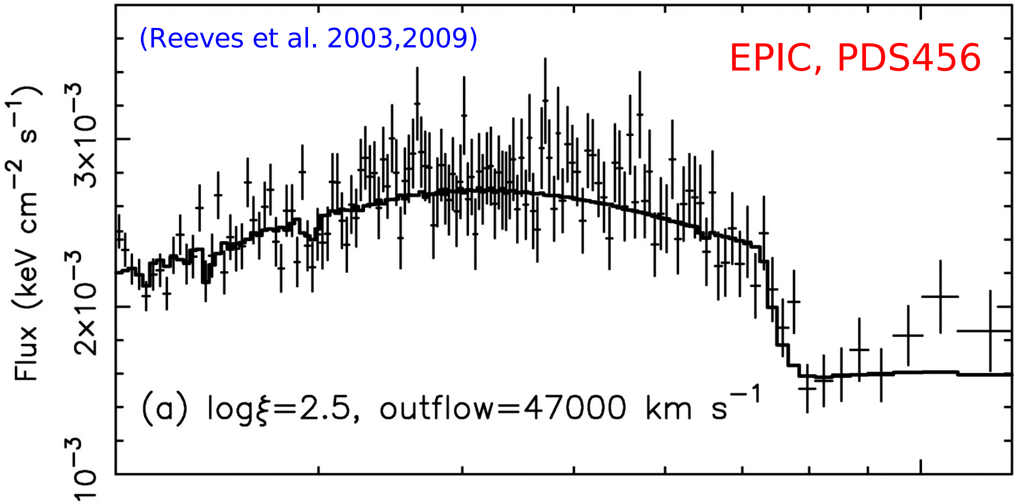
There is a one-to-one correspondence between X-rays and UV outflows. However, pinpointing the correspondence between dynamical components is severely hampered by the different resolution in the two bands
[Early works on this topic by Mathur+94, 95, 96, 97 ... 2001.]

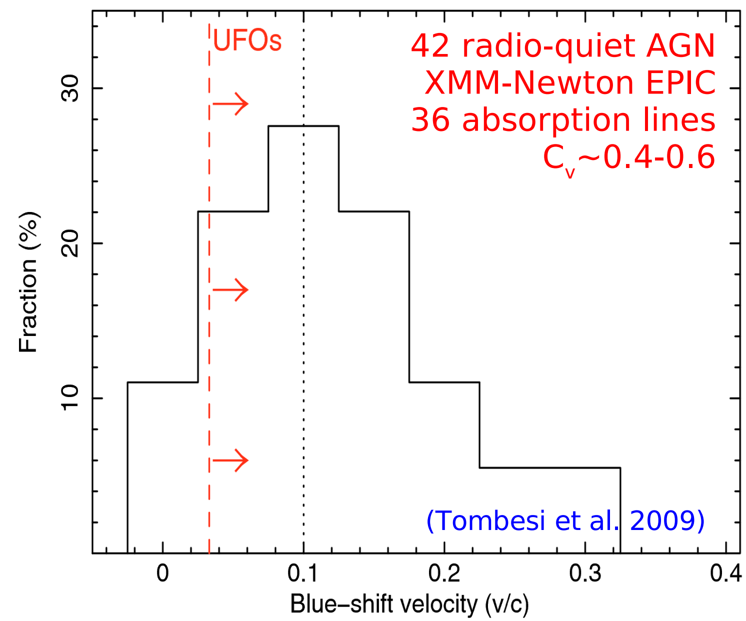




“Iron”-WA


EPIC, NGC1365
(Risaliti et al. 2007)
FeXXV Kα
FeXXVI Kα
FeXXV Kβ
FeXXVI Kβ
OBS 1
OBS 2
OBS 3
OBS 4
Δχ²
E_OBS (keV)
N_H≃5·10^23 cm^-2
v≃1-5,000 km/s


(Reeves et al. 2003,2009)
EPIC, PDS456
Flux (keV cm^-2 s^-1)
(a) logξ=2.5, outflow=47000 km s^-1


UFOs
42 radio-quiet AGN
XMM-Newton EPIC
36 absorption lines
C_v~0.4-0.6
Fraction (%)
Blue–shift velocity (v/c)
(Tombesi et al. 2009)

"My" main questions

- Are "warm" or "ionised outflows" an intrinsic, indispensable ingredient of any AGN?
  - Fraction of AGN (Seyferts/QSOs) which exhibit absorption features from ionized outflows
- Do ionised outflows have an impact on the host galaxy matter enrichment?
  - $\dot{M}_{\rm out} = 8\pi r N_H \mu m_p C_g v_r$ (spherical flow)
  - $\dot{M}_w = 0.8\pi m_p N_H v_r R f(\delta, \phi)$ (biconical outflow, Krongold et al. 2007)
- Do ionised outflows have an impact on the host galaxy evolution?

$$L_{\rm KE} = \frac{1}{2}\dot{M}_{\rm out} v^2$$

- Which contribution can ASTROSAT give to this field?

Fraction of ionised outflows among AGN

- ∽50% of Seyfert Galaxies (ASCA, Reynolds 1997)
- ~50% of Seyfert Galaxies (ASCA, George et al., 1997)
- ~50% of PG QSOs (XMM-Newton, Piconcelli et al. 2005)
- ≳90% of (nearby) AGN (XMM-Newton, Blustin et al. 2005)
- ≳60% of low-luminosity ($L_X \leq 5 \cdot 10^{43}$ erg s^{-1}), ≳30% of high-luminosity sources (XMM-Newton/Suzaku, Winter 2010)
- *[The two last papers agree that it is "likely" that **all** AGN in their samples have an outflow]*

- [in the UV, ≳50%, Crenshaw et al. 1999)]

Still, a physically motivated study from a **well-defined**, **unbiased** sample, taking into account the **sample sensitivity** (depending in turn on the N_H, covering fraction, ξ) is missing

WA observables

- In **X-rays** we measure: ionization state, multi-ion components, $\log(N_{H,i}) \backsim 20\text{-}23$, outflow velocity
- In **UV** we measure: line width, covering factors, abundances, ionization state, gas density
- From the **photoionization codes** (*CLOUDY, ION, PHASE, TITAN, XSTAR*) we can derive N_H, T, ξ, once energy and ionization balance and a Spectral Energy Distribution is assumed
- There is an intrinsic degeneracy between the volume density of the outflow and the distance between the absorber and the ionizing source:

$$\xi = \frac{L_{ion}}{n_0 R^2} \quad ; \quad U = \int_{\nu=0.1\,\mathrm{keV}}^{\nu=10\,keV} \frac{L_\nu / h\nu}{4\pi c\, n_0 R^2} d\nu \quad ; \quad \Xi = \frac{\xi}{4\pi c k T_0}$$

observed

un-observed

Volume density of the outflow ⟷ Distance to the absorber

(Costantini, Krongold, Różańska and many, many others)

Independent ways to estimates n_e or *R*

- Time-dependent photoionization

(Krolik & Kriss 1995, Nicastro et al. 1999, Bottorff et al. 2000)

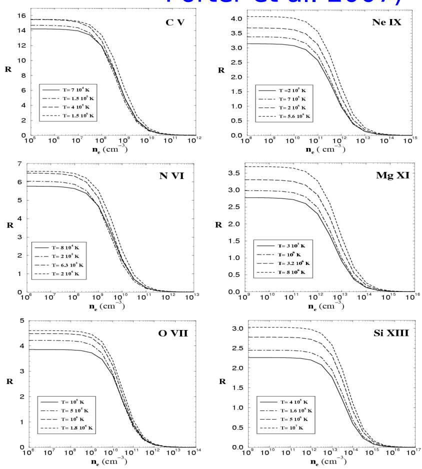
$$\tau_{\rm rec}(X_i) = \left(\alpha_{\rm r}(X_i) n \left[\frac{f(X_{i+1})}{f(X_i)} - \frac{\alpha_{\rm r}(X_{i-1})}{\alpha_{\rm r}(X_i)}\right]\right)^{-1}$$

- Meta-stable transitions (e.g., in the UV: CII, CIII, FeII, SiII; Gabel et al. 2003, Arav et al. 2008)

- Order-of-magnitide estimates (see, e.g., Blustin et al. 2005)
  - $r_{min} \Leftarrow v \geq v_{esc} = (2GM/R)^{1/2}$ (see, however, Krongold et al. 2011)
  - $r_{max} \Leftarrow \Delta R/R < 1$ (i.e., the number density for a given ξ falls off rapidly)

(Porquet & Dubau 2000, Porter et al. 2007)

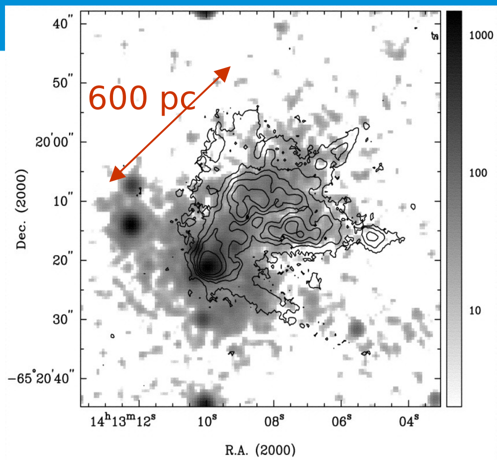
- Density diagnostics on *emission lines* (e.g., the He-like triplets; Singh talk)



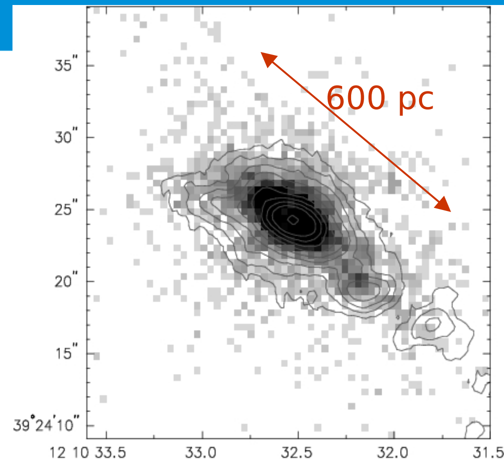
- Density diagnostics if the gas is heated by free-free absorption in soft spectra (Różańska et al. 2008)

Soft X-ray extended emission and NLR

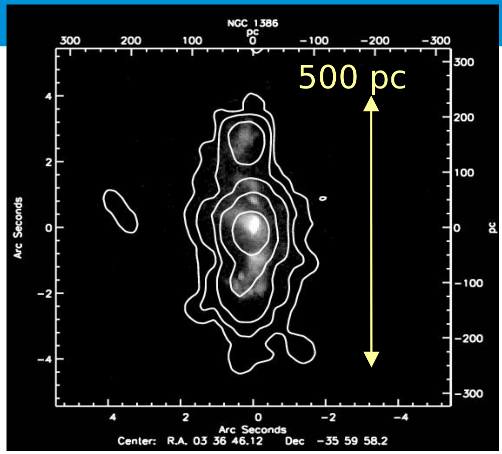
Images: O[III] – Contours: soft X-rays



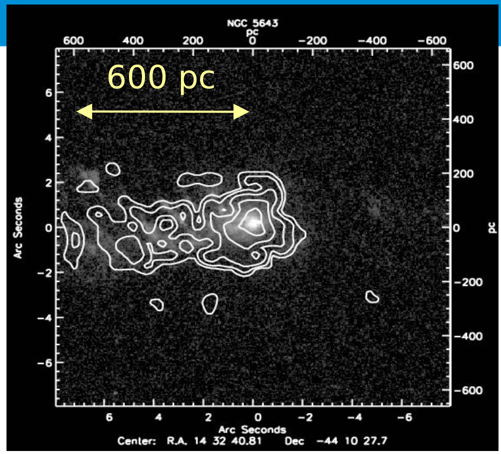
Circinus Galaxy
(Smith & Wilson 2001)



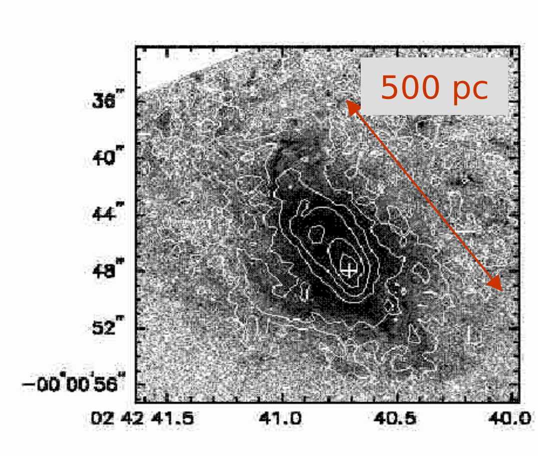
NGC4151
(Yang et al. 2001)



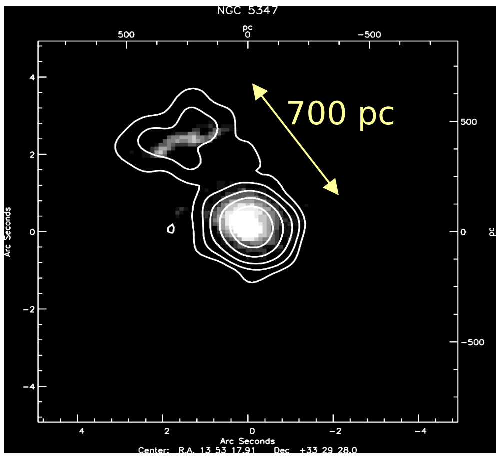
NGC1386
(Bianchi et al. 2006)



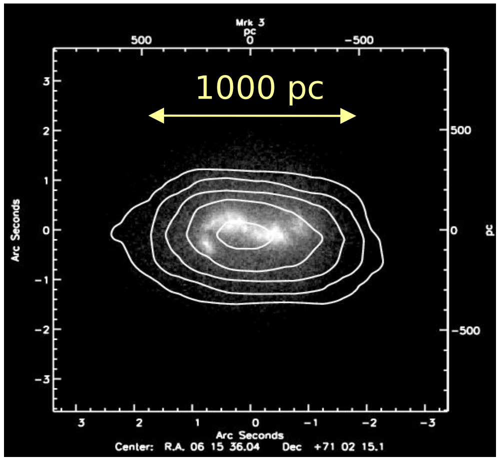
NGC5643
(Bianchi et al. 2006)



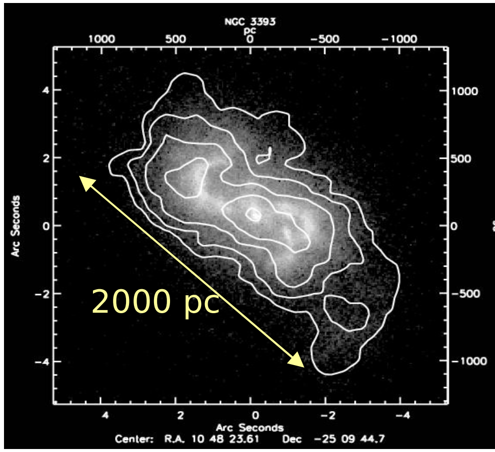
NGC1068
(Young et al. 2001)



NGC5347
(Bianchi et al. 2006)

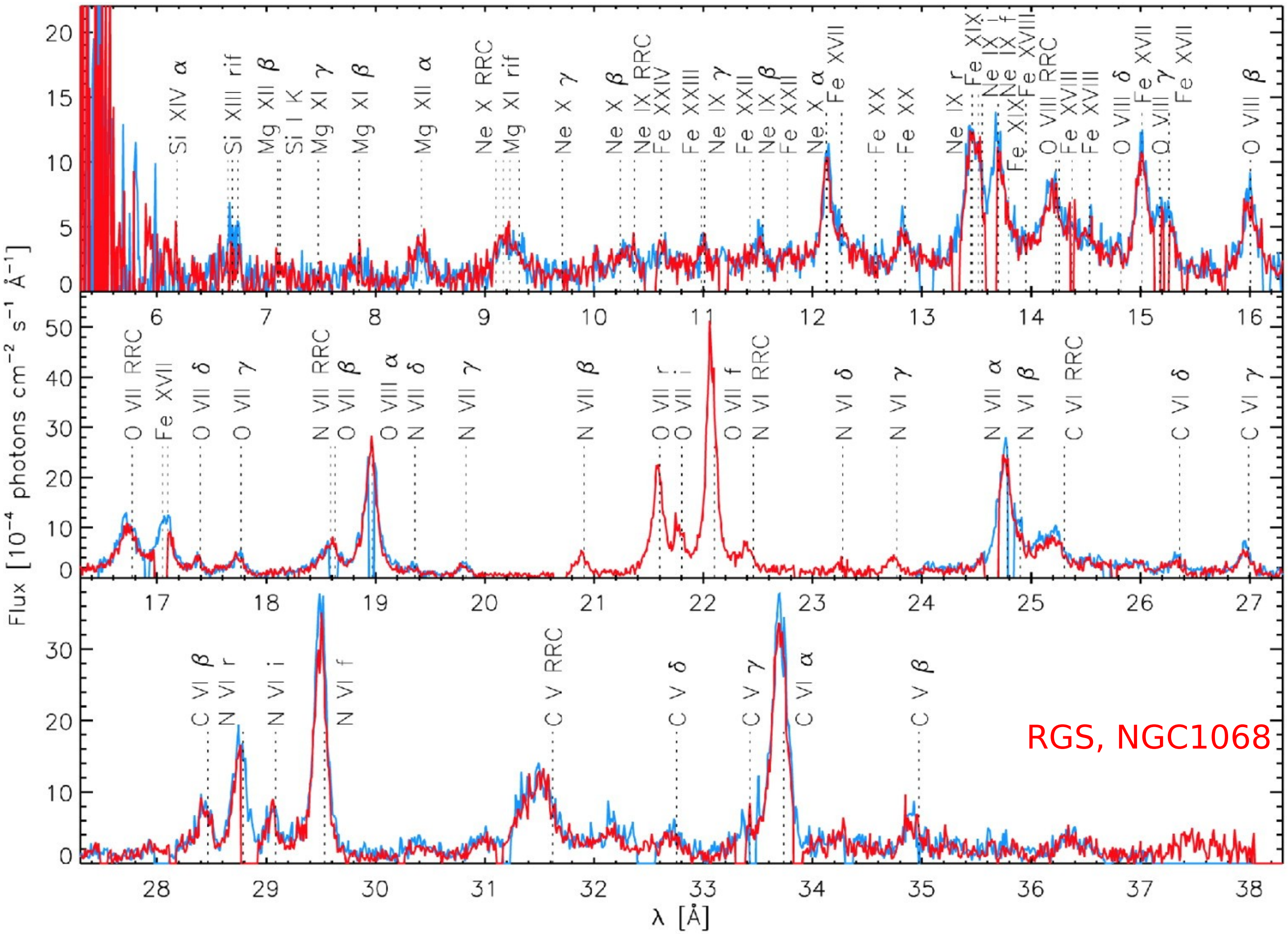


Mkn3
(Sako et al. 2000)



NGC3393
(Bianchi et al. 2006)

Photoionised emitters in obscured AGN



(Kinkhabwala et al. 2002)

Similarly in:
- Mkn3
(Sako et al. 2000)
- Circinus Galaxy
(Sambruna et al. 2001)
- NGC4151
(Armentrout et al. 2007)
- Mkn573
(Bianchi et al. 2010)
- NGC5252
(Dadina et al. 2010)
- NGC424
(Marinucci et al. 2011)
- and many others ...
(Guainazzi & Bianchi 2007)

They could be associated to (or the continuation on larger scale of) WAs (Behar et al. 2003, Krongold et al. 2007, Ebrero et al. 2009, Nucita et al. 2010)

Independent ways to

- Time-dependent photoionizati ... Kriss 1995, Nicastro et al. 1999, Bottorff et al. 2000)

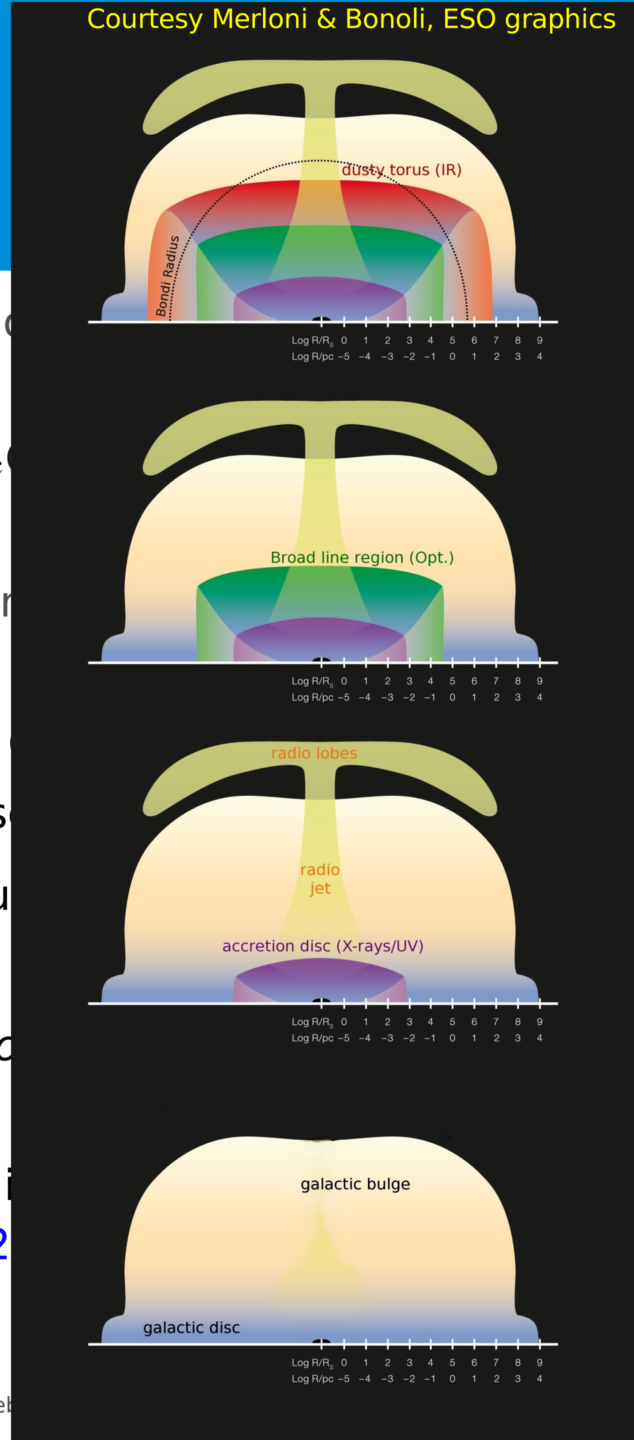
$\tau_{\rm rec}($

- Meta-stable transitions (e.g., i ... bel et al. 2003, Arav et al. 2008)

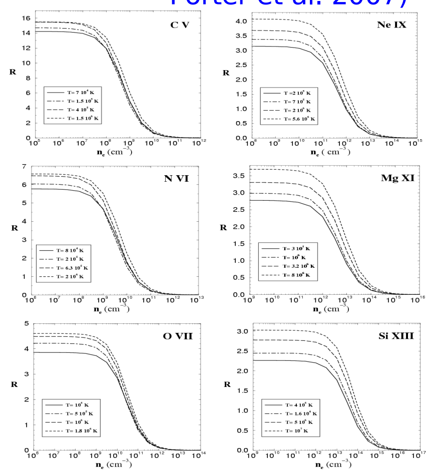
- Order-of-magnitide estimates (
  - $r_{min} \Leftarrow v \geq v_{esc} = (2GM/R)^{1/2}$ (s ... 011)
  - $r_{max} \Leftarrow \Delta R/R < 1$ (i.e., the nu ... s off rapidly)

- Density diagnostics on *emissio* ... ts; Singh talk)

- Density diagnostics if the gas i ... on in soft spectra (Różańska et al. 2



(Porquet & Dubau 2000, Porter et al. 2007)

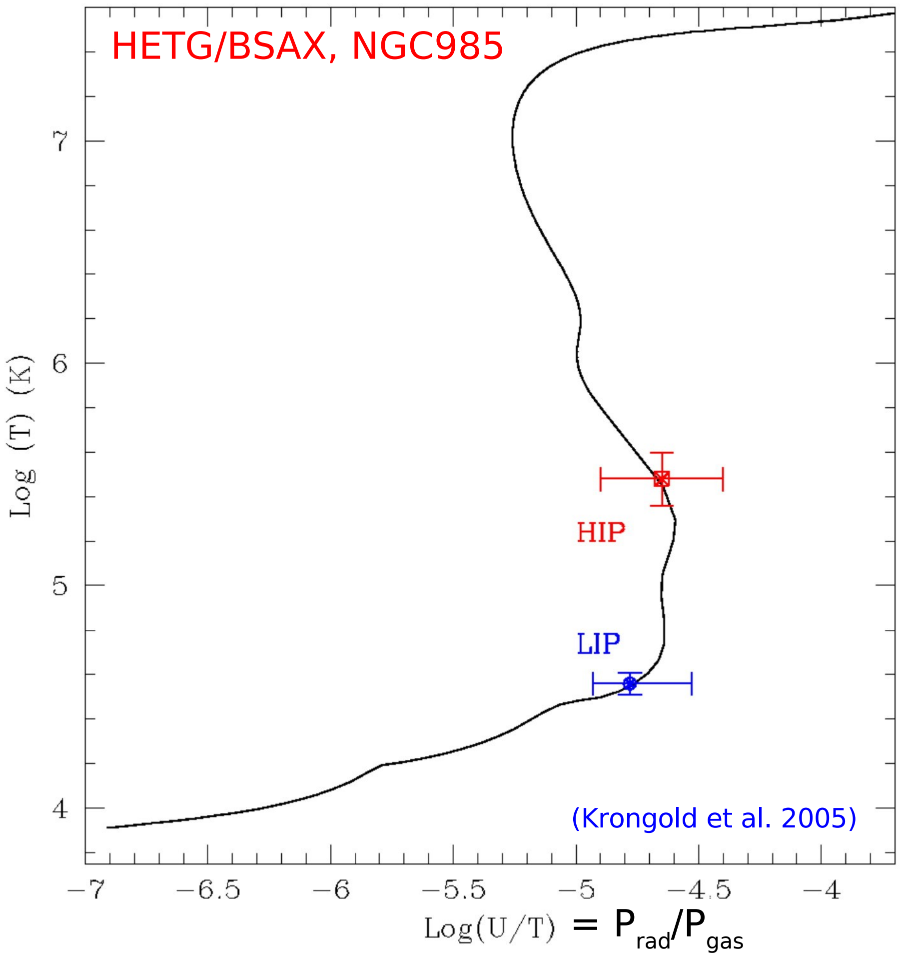


Independent ways to estimates n_e or R

- Time-dependent photoionization
  - NGC3783: $r_{[O-K]} \gtrsim 0.5$ pc, $r_{[Fe-M]} \gtrsim 2.8$ pc (Behar et al. 2003); $r_{[FeXXV-XXVI]} \lesssim 0.1$ pc (Reeves et al. 2004)
  - NGC3516: $r \lesssim 0.2$ pc (Netzer et al. 2002)
  - NGC4051: $r_{LIP} \simeq 0.05\text{-}0.1$ pc, $r_{HIP} \lesssim 0.03$ pc (Krongold et al. 2007)
  - NGC5548: $r_{LIP} \lesssim 3$ pc, $r_{HIP} \gtrsim 0.03$ pc (Detmers et al. 2008, Krongold et al. 2010)
- Meta-stable transitions
  - Mkn279: $r \lesssim 0.07\text{-}0.6$ pc (Kaastra et al. 2004)
  - [2-20 kpc in UV Broad Absorption Line Quasars: Moe et al. 2009, Korista et al. 2009, Bautista et al. 2010]
- Order-of-magnitide estimates:
  - $r \simeq r_{torus}$, $r \gg r_{BLR}$ (except high-N_H, high-ξ WA, where $r \leq r_{BLR}$; Ashton et al. 2004, Blustin et al. 2005-7)
- Density diagnostics on *emission lines:*
  - Mkn335: $r \simeq 0.01\text{-}0.1$ pc (Longinotti et al. 2009)
  - NGC5548: $r \simeq 1\text{-}15$ pc (Detmers et al. 2009)
  - NGC4051: $r \gtrsim 0.02$ pc (Nucita et al. 2010)
- Density diagnostics if the gas is heated by free-free absorption in soft spectra:
  - HS1603+3820: $r \lesssim 0.05$ pc (Różańska et al. 2011)

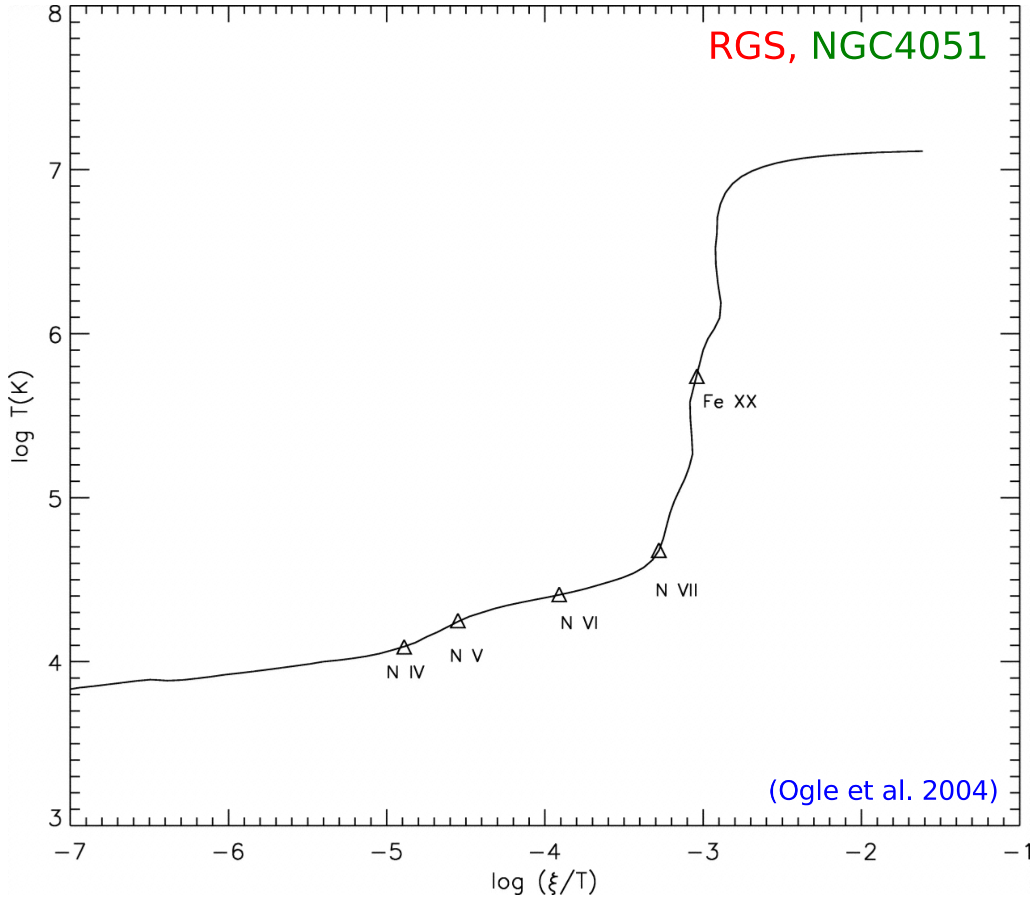
The outflow structure

Discrete phases in pressure equilibrium



Likewise NGC3783 (Krongold et al. 2003), TONS180 (Różańska et al. 2004), NGC4051 (Krongold et al. 2007), Mkn279 (Fields et al. 2007), UGC11673 (Cardaci et al. 2009), NGC5548 (Andrade-Velázquez et al. 2010)

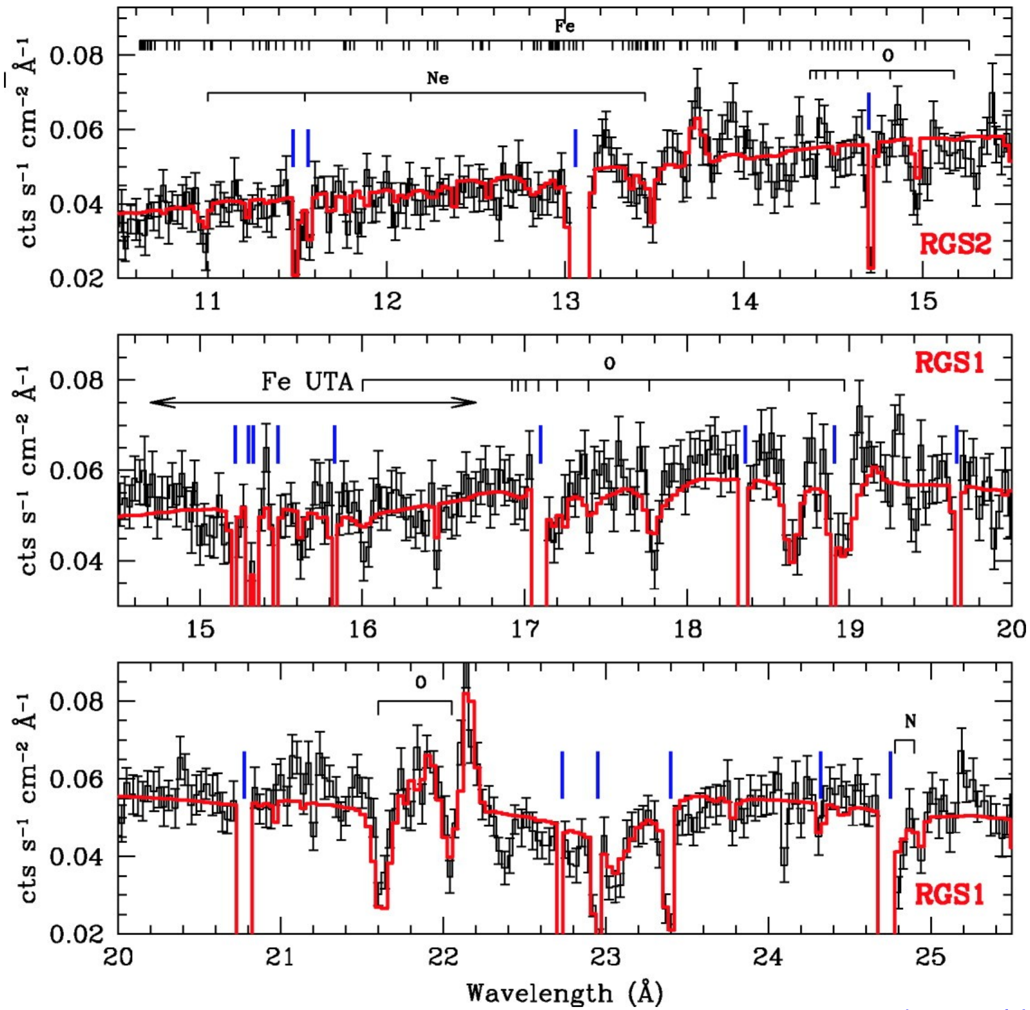
Continuum flow out of pressure equilibrium



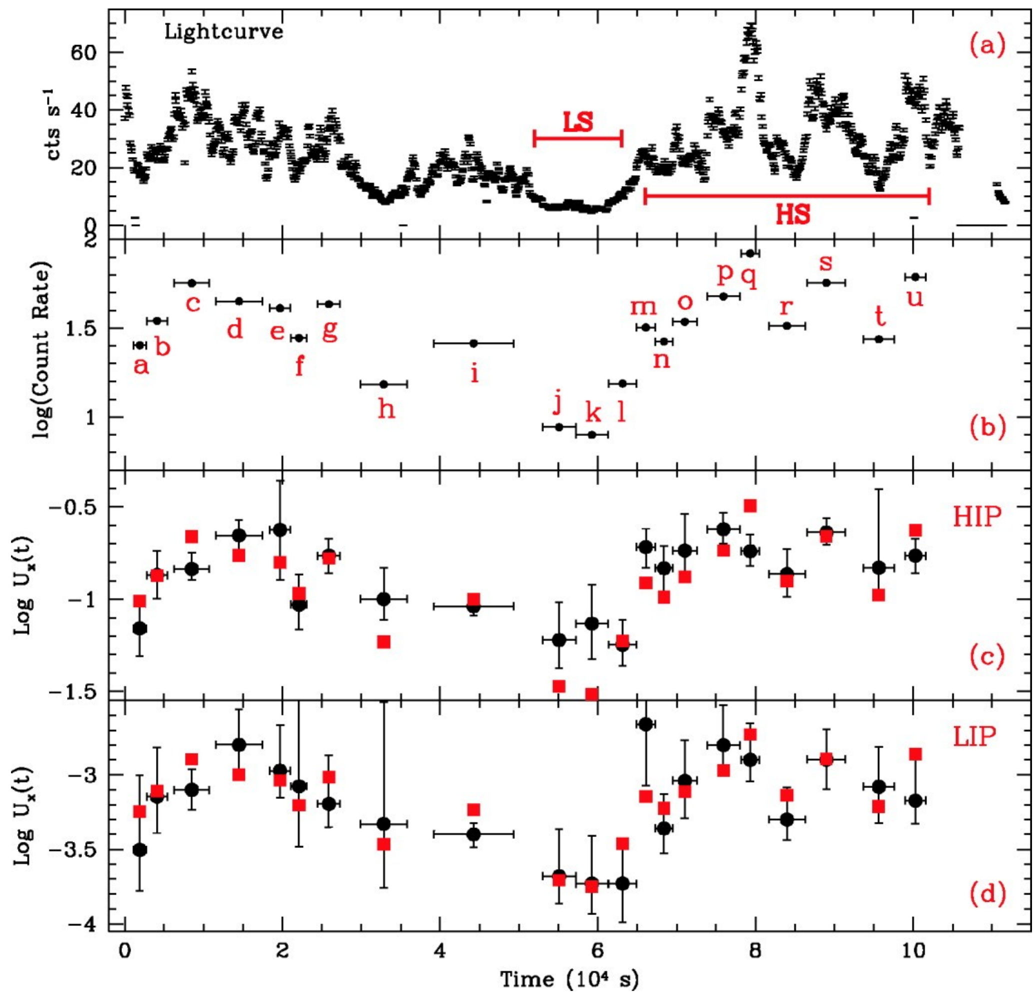
Likewise NGC5548 (Steenbrugge et al. 2005), Mkn279 (Costantini et al. 2009)

How to optimally use moderate-resolution data …

1. Fit the average high-resolution spectrum (two components in pressure eq.^{m}: LIP, HIP)

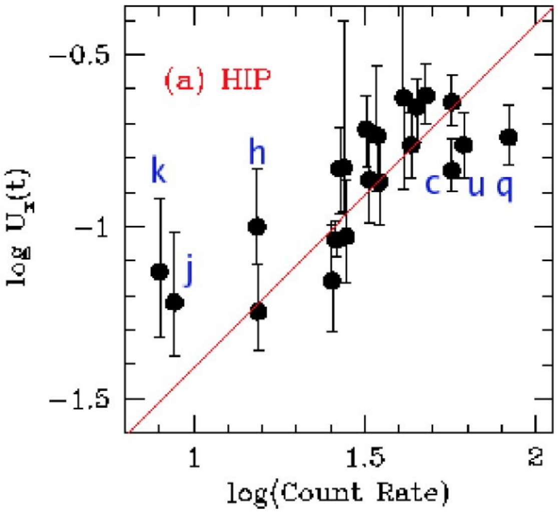


2. Fit the time-resolved moderate resolution spectra using σ_{turb} v_{out} and N_H from previous step

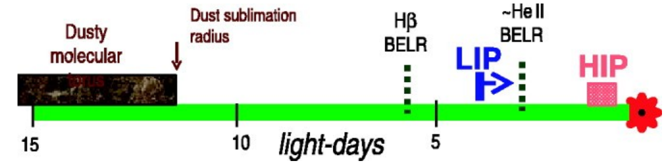


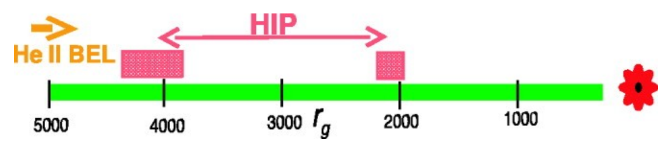
(Krongold et al. 2007, NGC4051)

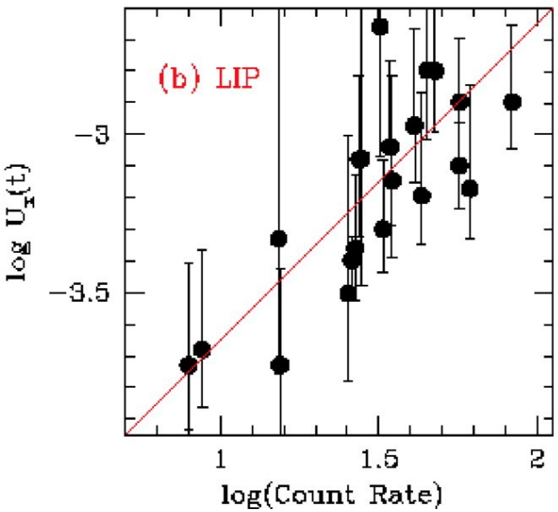
⇒ The most stringent constraints on WA geometry



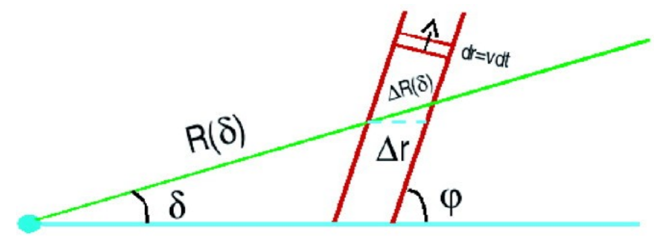
HIP:
Out of equilibrium at extreme fluxes, in equilibrium elsewhere
t_{rec}(HIP)>10 ks
t_{eq}(HIP)<3 ks
n_e(LIP)>(0.6-2)·10^7 cm^{-3}
R(LIP)=0.5-1 lt-days







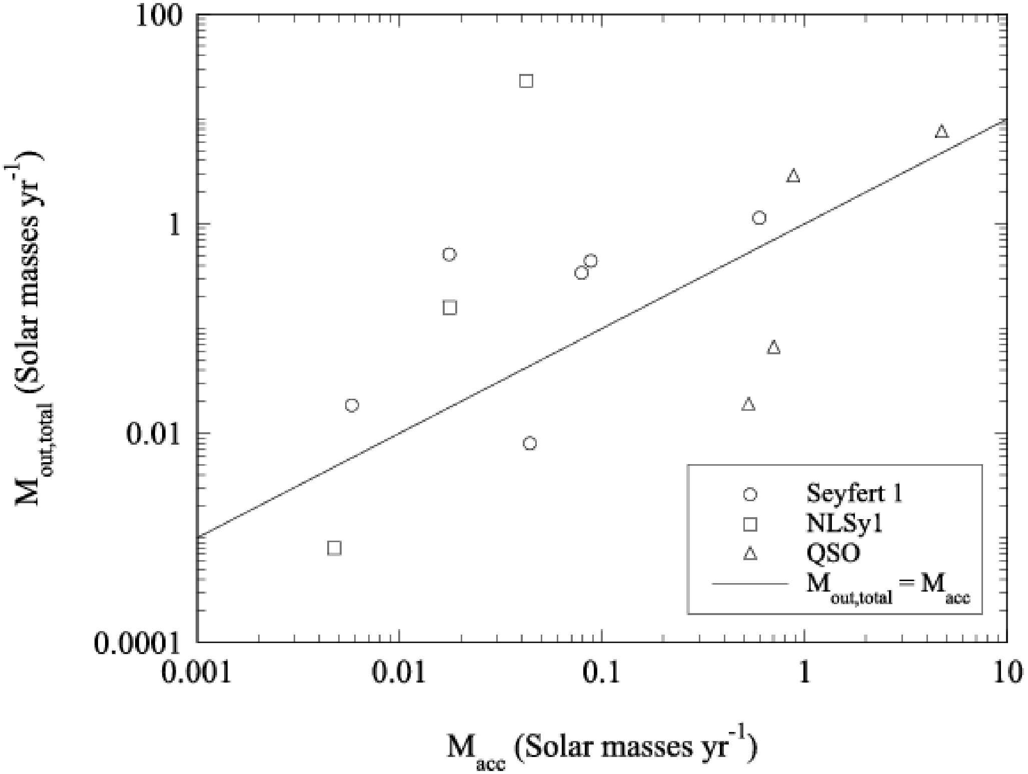
LIP:
Always in equilibrium on τ≃3 ks
t_{eq}(LIP)<3 ks
n_e(LIP)>8·10^7 cm^{-3}
R(LIP)<3.5 lt-days



(Krongold et al. 2007, NGC4051 – similar analysis on NGC5548, Krongold et al. 2010)

Outflow mass rates

(Blustin et al. 2005)



$(dM/dt)_{out} \simeq (dM/dt)_{accr}$ with

huge uncertainties

- More detailed analysis indicate:
  - PG1211+143: $M_{out} \simeq M_{accr}$ (Pounds et al. 2003)
  - PDS456: $M_{out} \simeq M_{accr}$ (Reeves et al. 2003)
  - NGC3783: $M_{out} \simeq 10M_{accr}$ (Behar et al. 2003)
  - NGC4051: $M_{out} \simeq 0.04\ M_{accr}$ (Krongold et al 2007)
  - NGC4151: $M_{out} \simeq 10M_{accr}$ (Crenshaw & Kramer 2007)
  - NGC5548: $M_{out} \simeq 30M_{accr}$ (Crenshaw et al. 2009)
  - NGC5548: $M_{out} \gtrsim 2.5M_{accr}$ (Krongold et al. 2010)
- Still, at least the most powerful AGN, and maybe even more prosaic Seyferts, could release to the ISM the required $10^8\ M_\odot$ of hot gas in bulges across their lifetime
- Outflow interactions with ISM **are** important (NGC4151, Crenshaw et al. 2000; GPS/CSS)

Outflow energy and feedback

- Some reference energies
  - 10^{57} ergs are needed to heat the ISM to a temperature ($\sim 10^7$ K) required to “evaporate” it
  - 10^{59} ergs is the binding energy of a $10^{11} M_\odot$ bulge with $\sigma \sim 300$ km/s
  - 10^{60} ergs are required to control host-galaxy and surrounding IGM evolution (King 2003, Scannapieco & Oh 2004, Hopkins et al. 2005, Natarayan et al. 2006)
    - The initial momentum or energy requirement for an outflow to induce feedback can be relaxed by a factor ~10 if the outflow drives a secondary wind in the ISM (Hopkins & Elvis 2010)

- Some estimates:
  - NGC4051 (low M_{BH} and L_{bol} Seyfert): $KE_{out} \sim (0.4\text{-}1) \cdot 10^{53}$ ergs (Krongold et al. 2007)
  - NGC5548 (standard Seyfert): $KE_{out} \sim 3.3 \cdot 10^{57}$ ergs (Krongold et al. 2010)
  - PG1211+143 (QSO): $KE_{out} \sim 10^{60}$ ergs (King & Pounds 2003)
  - PDS456 (powerful QSO): $KE_{out} \sim 10^{61\text{-}62}$ ergs (Reeves et al. 2009)

*[More discussion in several papers by Blustin, Elvis, King, Krongold, Page, Pounds, Reeves and many, many others … and **huge uncertainties** on the true geometry, covering factor etc. etc.]*

Conclusions

- Are "warm" or "ionised outflows" an intrinsic, indispensable ingredient of an AGN?
  - **We don't know**
  - Most likely they are (Elvis' talk)

- Do ionised outflows have an impact on the host galaxy matter enrichment?
  - **We don't know**
  - Probably at least some QSO outflows may feed hot ISM phase in galaxy spheroids

- Do ionised outflows have an impact on the host galaxy evolution?
  - **We don't know**
  - Probably at least powerful QSO outflows could control star formation and host evolution

- Which contribution can ASTROSAT give to this field?
  - We **do** know
  - In combination with high-resolution spectroscopy, it can constrains on the outflow geometry in not too rapidly variable AGN