Relativistically blue- and red-shifted absorption lines in AGNs

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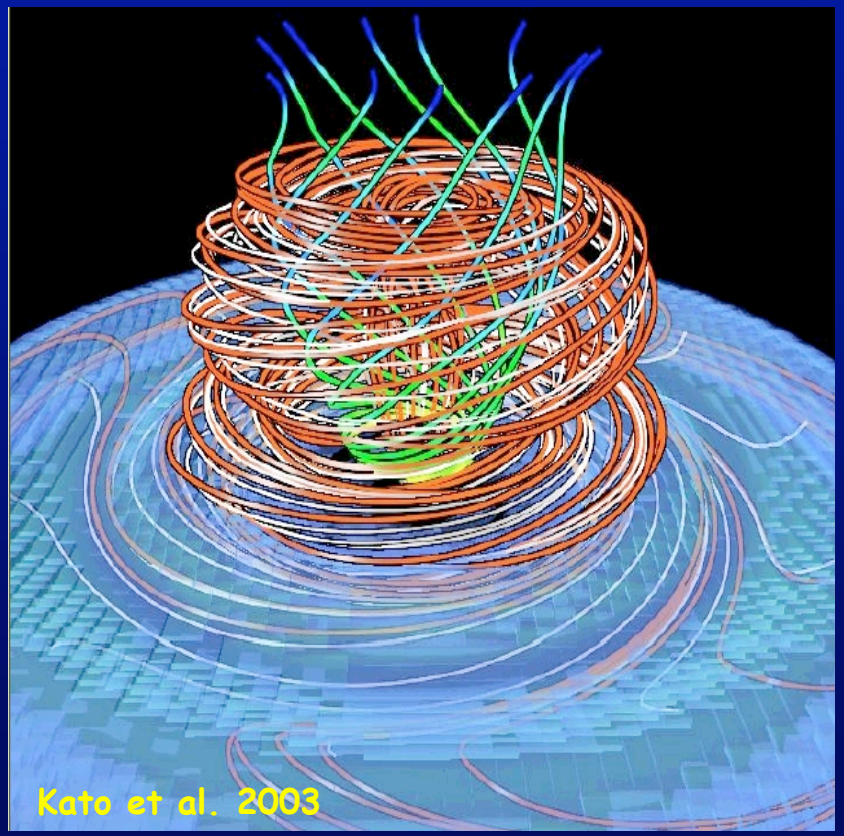
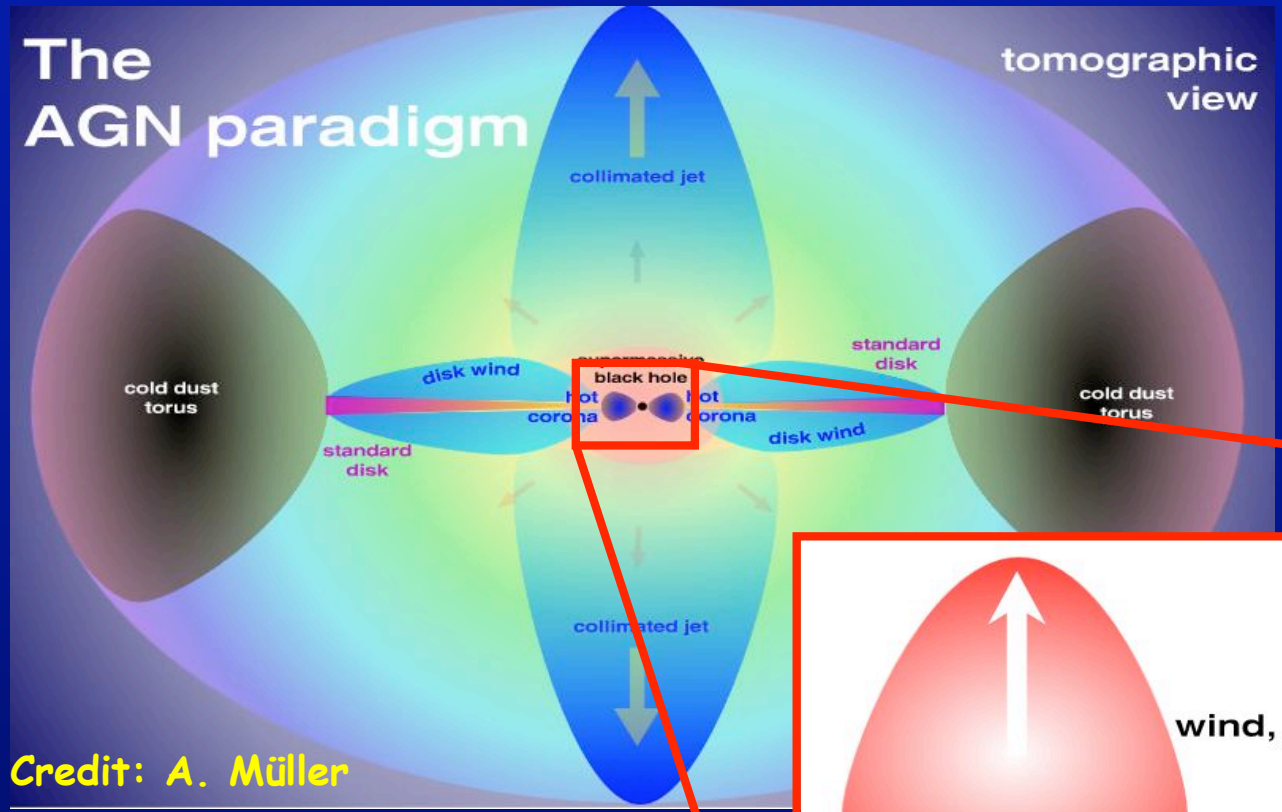
Outline



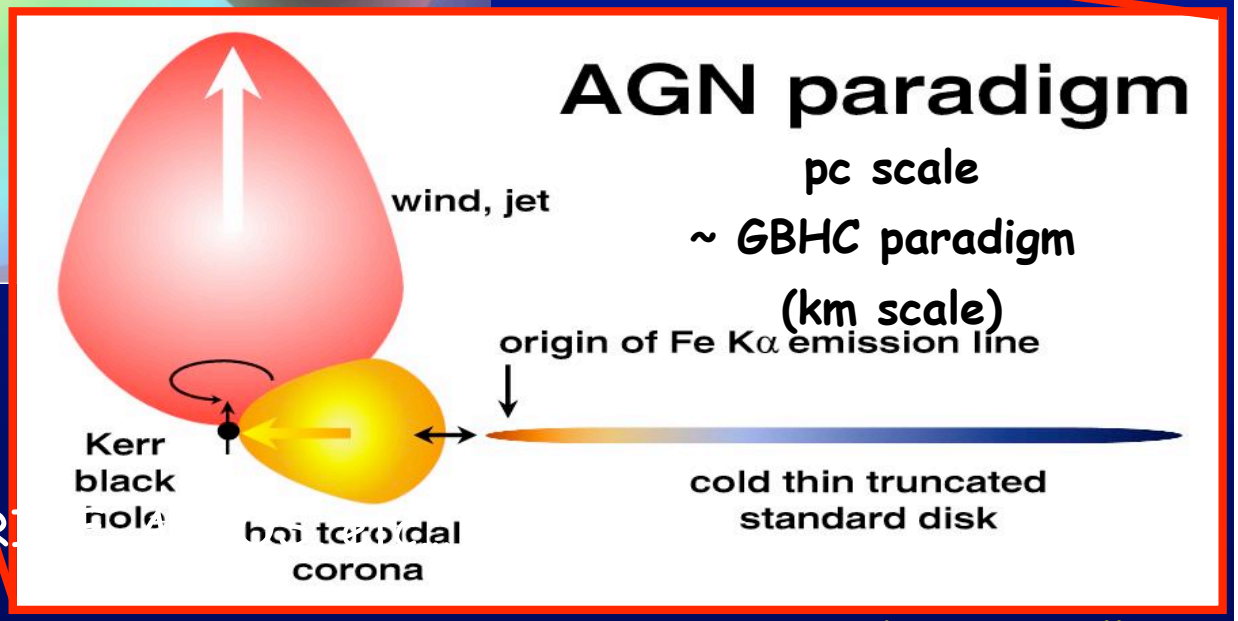
1. **Framework**
   Before XMM and Chandra…
2. **New X-ray Observations**
   Red- and blue-shifted abs. lines…
3. **Current Interpretations**
   Failed winds, aborted jets…
4. **Critical Issues**
   Identifications, significance…
5. **Importance**
   Astrophysics, cosmology…
6. **Future**
   High-E, High-throughput…

Credit to my collaborators: M. Dadina, G. Ponti, G. Malaguti, P. Grandi, G. Palumbo, F. Tombesi (INAF+Univ. in Bologna); B. DeMarco (Sissa); G. Matt, S. Bianchi (Roma3); Iwasawa (MPE); A. Longinotti (ESAC); K. Nandra (Imperial, London)

Framework (i/iii): The AGN paradigm



We know that:
Matter is flowing
in and out…



We don't know:

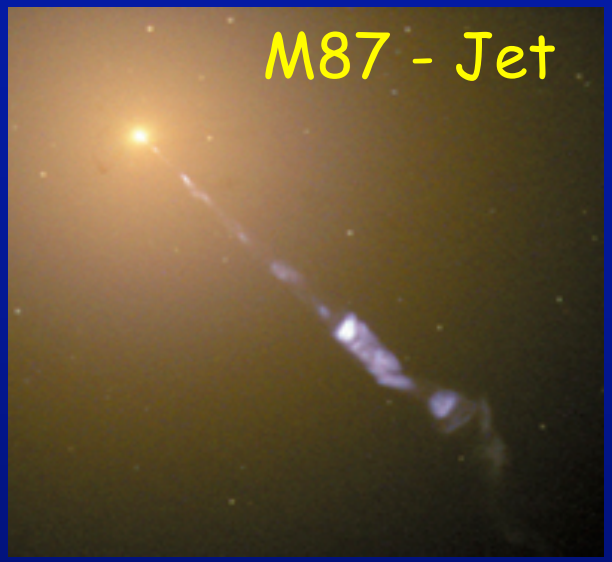
Accretion modes ? (SAD, ADAF, R

Geometry? (blobs, patchy, etc..)

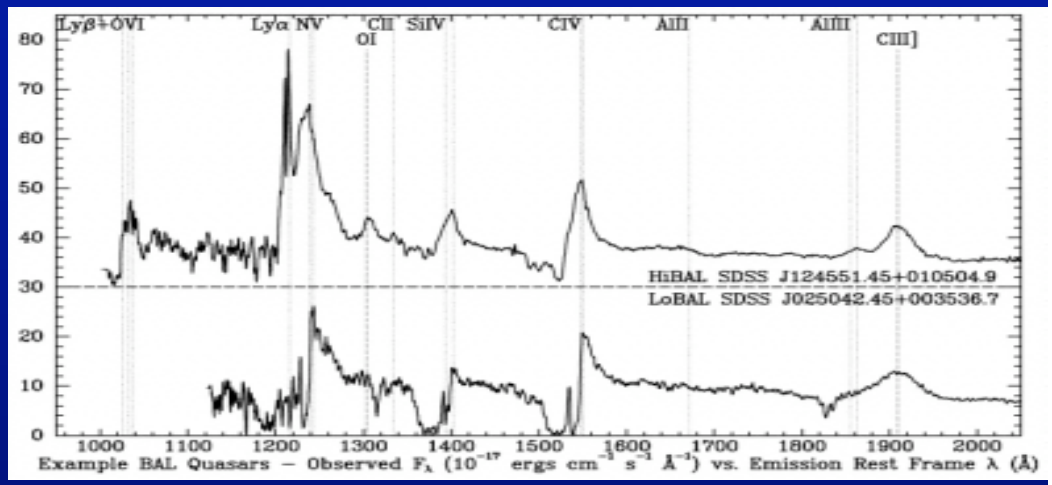
Framework (ii/iii): Fast winds/outflows/ejecta in AGNs

…known/seen in AGNs since long ago

Jets in radio-loud AGNs

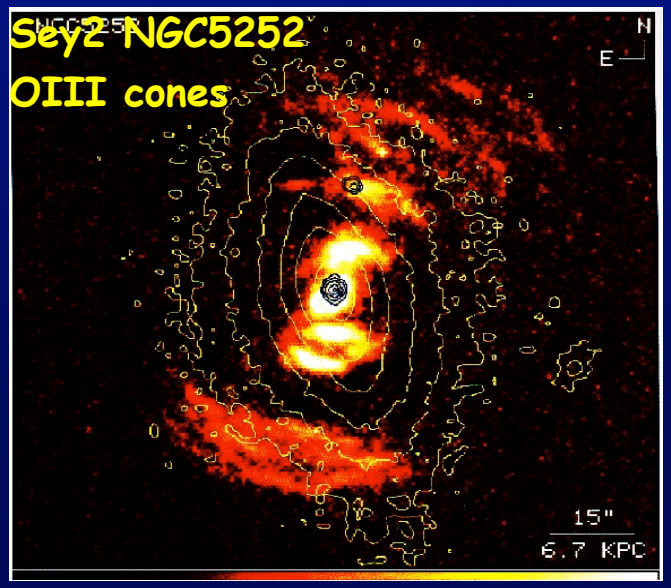


Fast (v up to ~ 50000 km/s) winds in BAL QSOs
(~ 20% of all QSOs)



Weymann et al., '91;
Reichards et al., '03

Wide-angle winds
& jets in Seyfert
galaxies

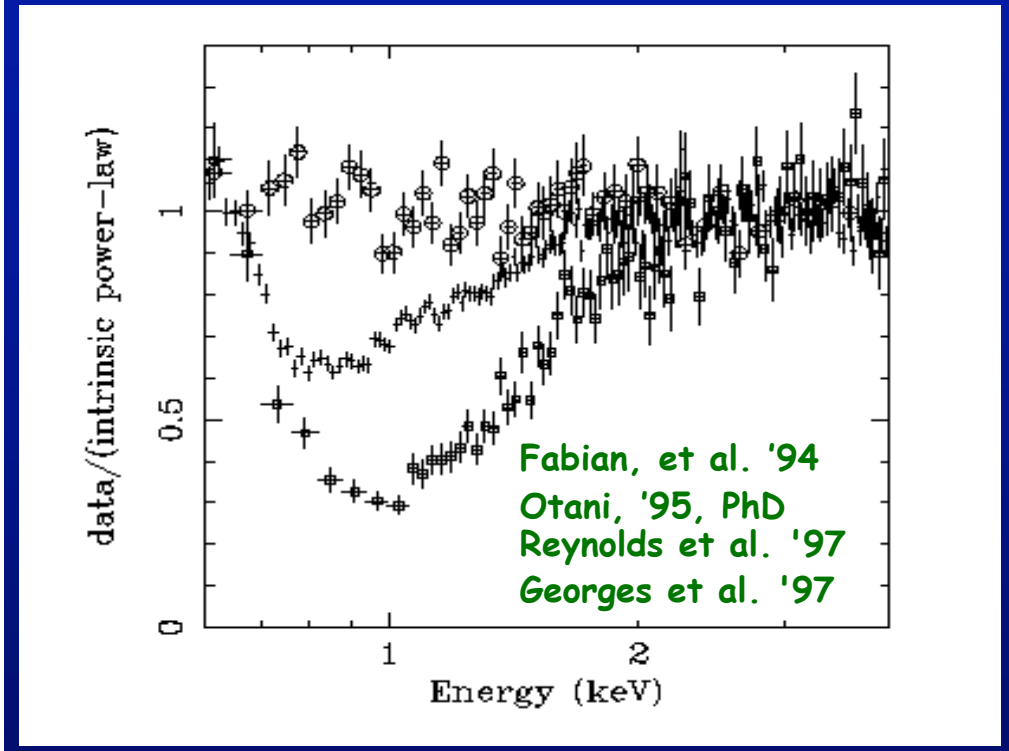


Tadhunter & Tsvetanov, Nature,
1989; Wilson & Tsvetanov, 1994
Cappi et al. 1995

Framework (iii/iii): Warm absorbers…complex

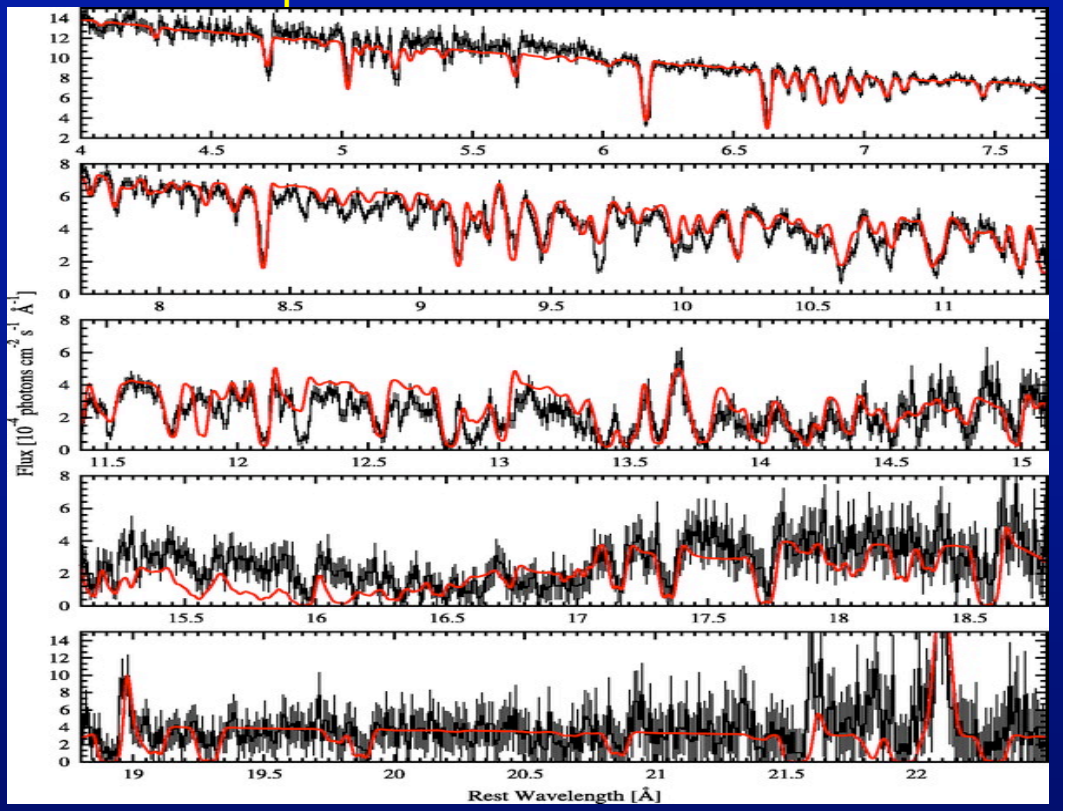
50% of all Sey 1s exhibit WAs

ASCA



Many details from Chandra/XMM gratings

NGC3783 Exp=900 ks



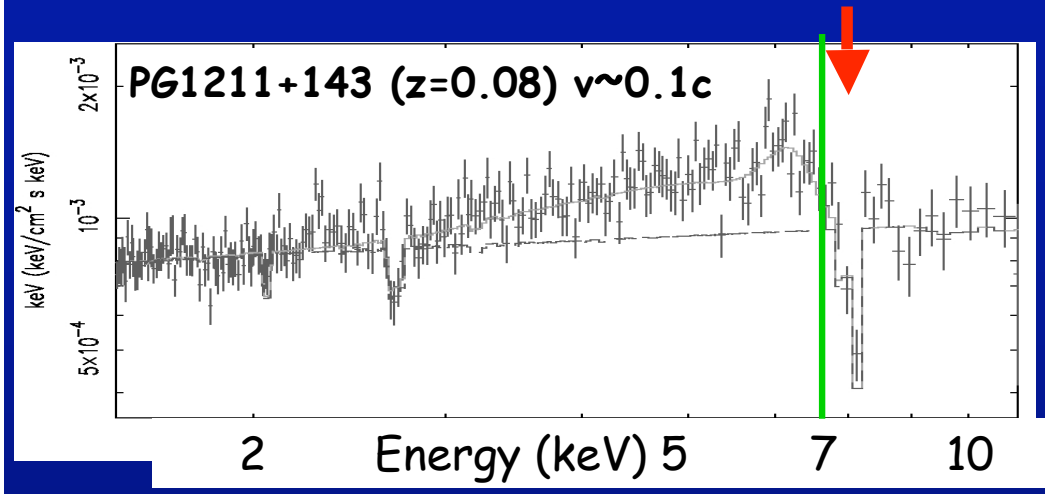
Kaspi et al. '01; Netzer et al. '02;
Georges et al. '03; Krongold et al. '03

⇒ Clear now that often multiple ionization & kinetic components: outflows with v~100-1000 km/s

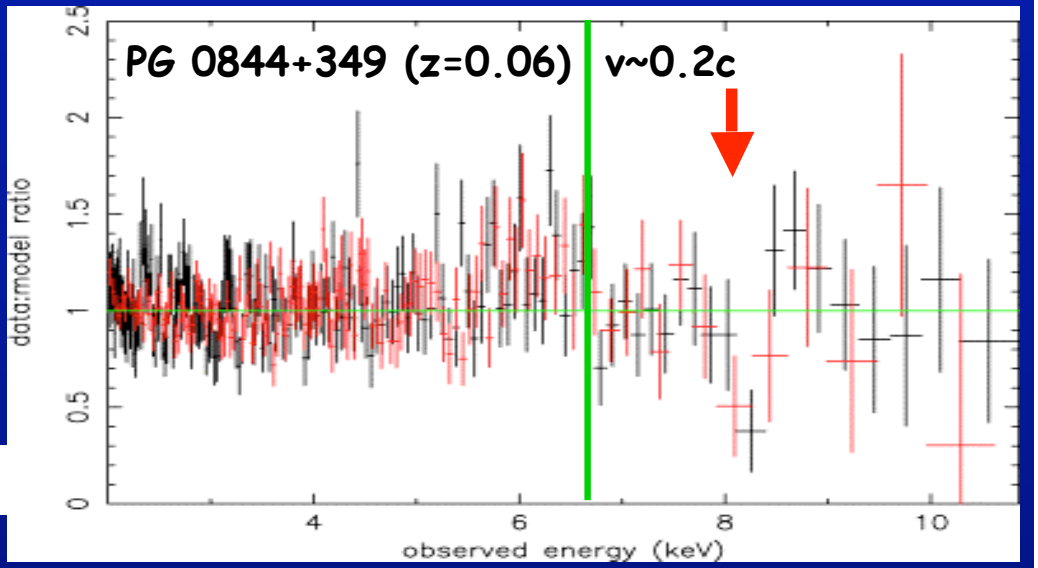
Blustin et al. 2004

New Observations I (i/iii): Blue-shifted absorption lines/edges

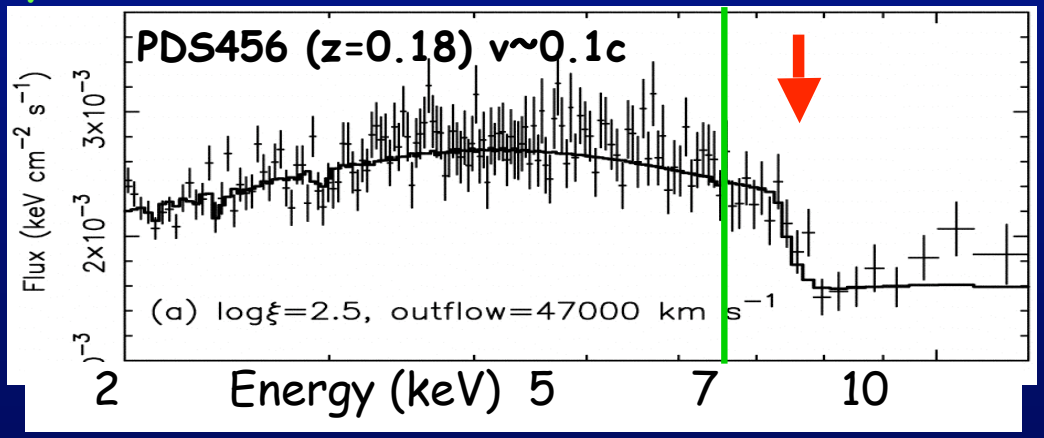
New and unexpected results from Chandra and XMM-Newton observations



Pounds et al. 2003a,b



(If) interpreted as Kα resonant absorption by Fe XXV (6.70 keV) or FeXXVI (6.96 keV)



Reeves et al. 2003

⇒ massive, high velocity and highly ionized outflows in several RQ AGNs/QSOs

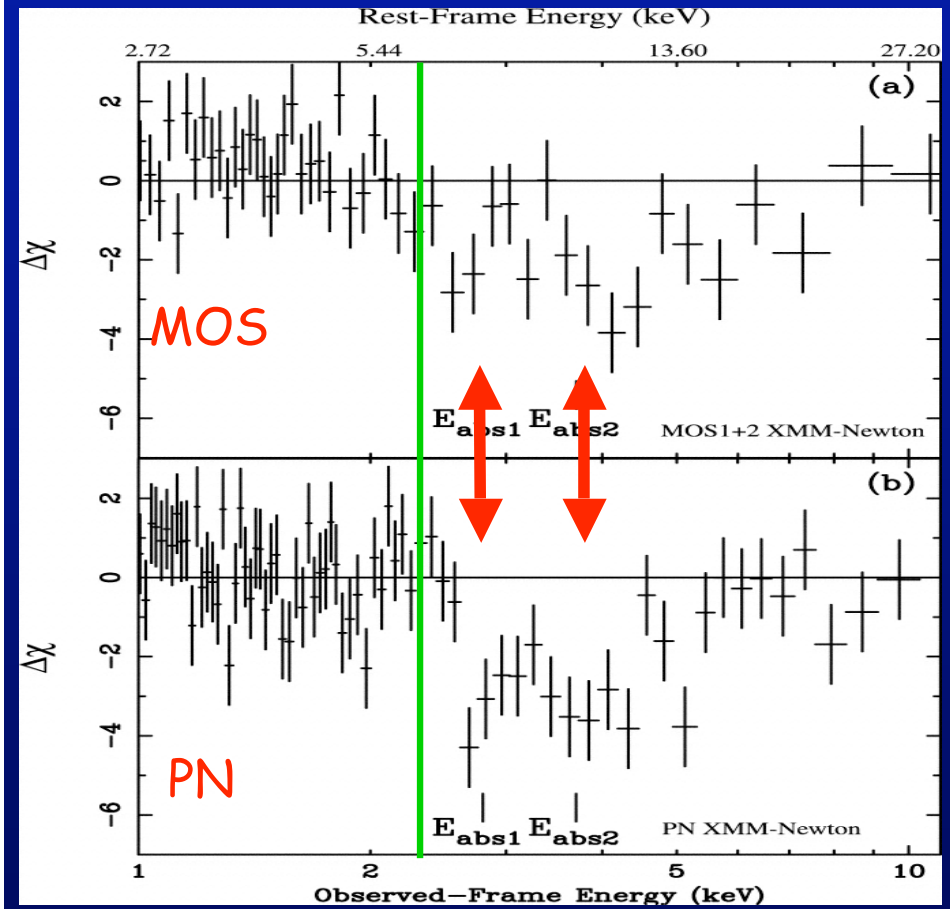
Mass outflow rate: comparable to Edd. Acc. rate (~$M_\odot$/yr); velocity ~0.1-0.2 c

New Observations I (ii/iii): Blue-shifted absorption lines/edges

Massive outflows…also (mostly?) at high redshift

2 high-z BAL QSOs

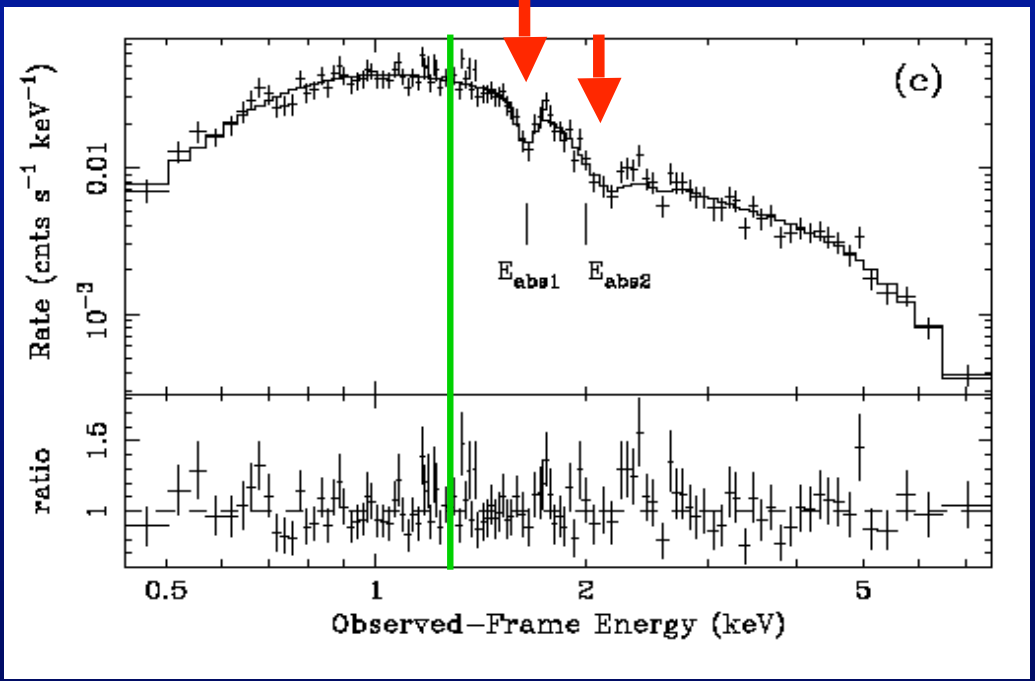
PG 1115+080 (z=1.72) v~0.1-0.3c



Chartas, Brandt & Gallagher, 2003

Chartas et al. 2002,
Hasinger, Schartel & Komossa 2002

APM 08279+5255 (z=3.91) v~0.2-0.4c



See also Wang et al. '05 (v=0.8c in qso@z=2.6)

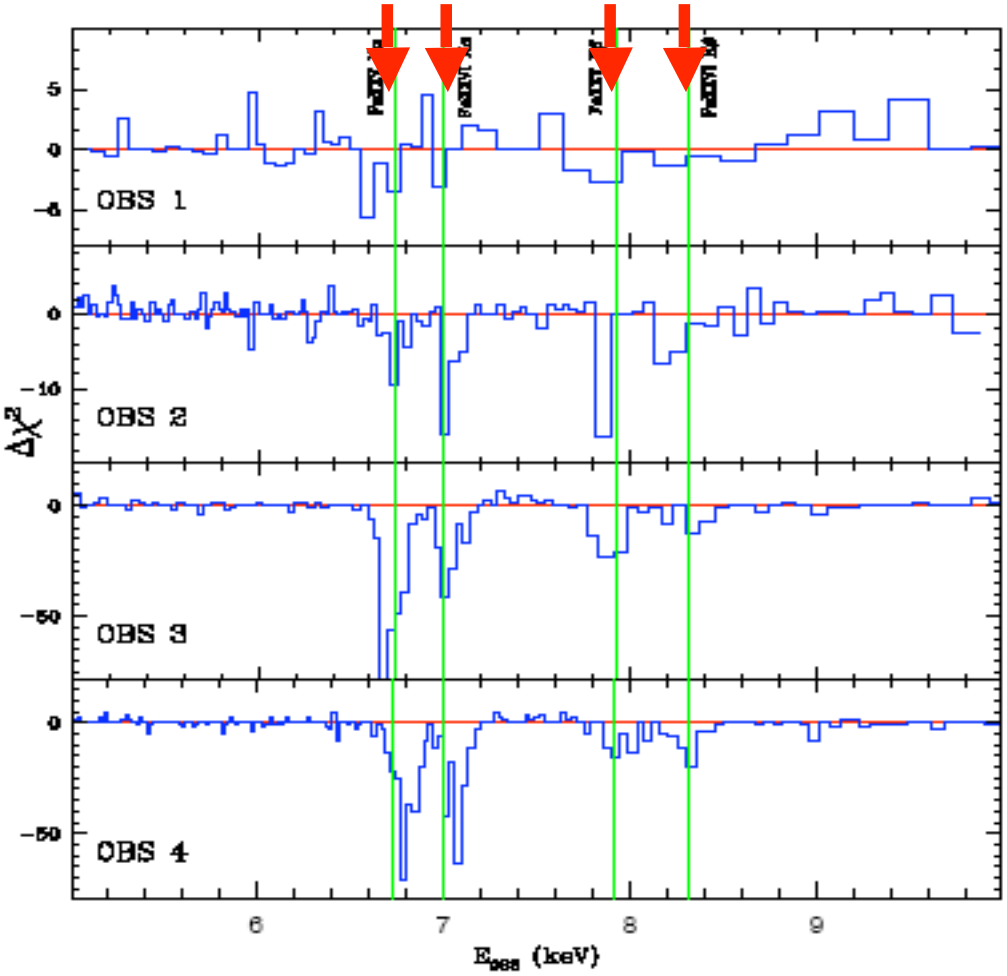
N.B.: Would have been undetected at z=0…

New Observations I (iii/iii): Blue-shifted absorption lines/edges

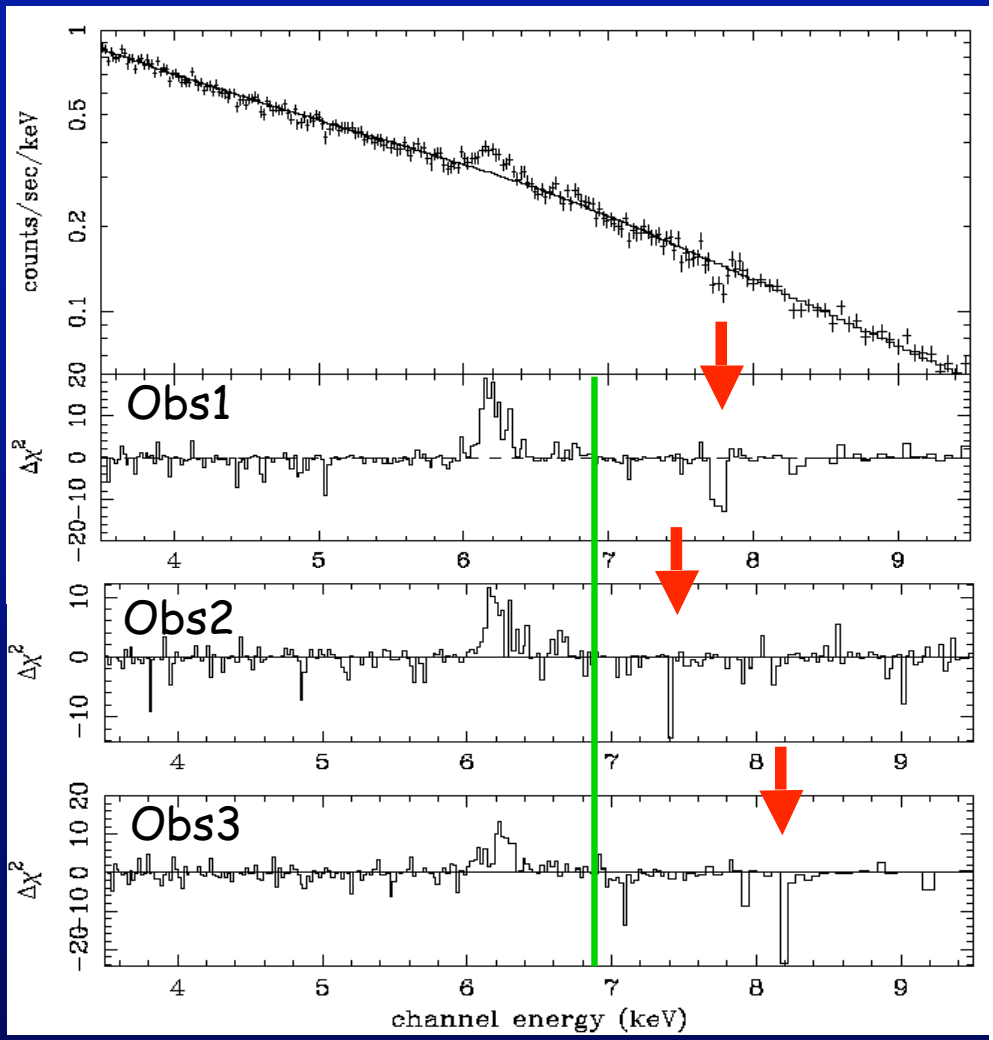
NGC1365

WA variability on timescales 1000-10000s

Mrk 509 (long-look, 200ks)



Risaliti et al. 2005

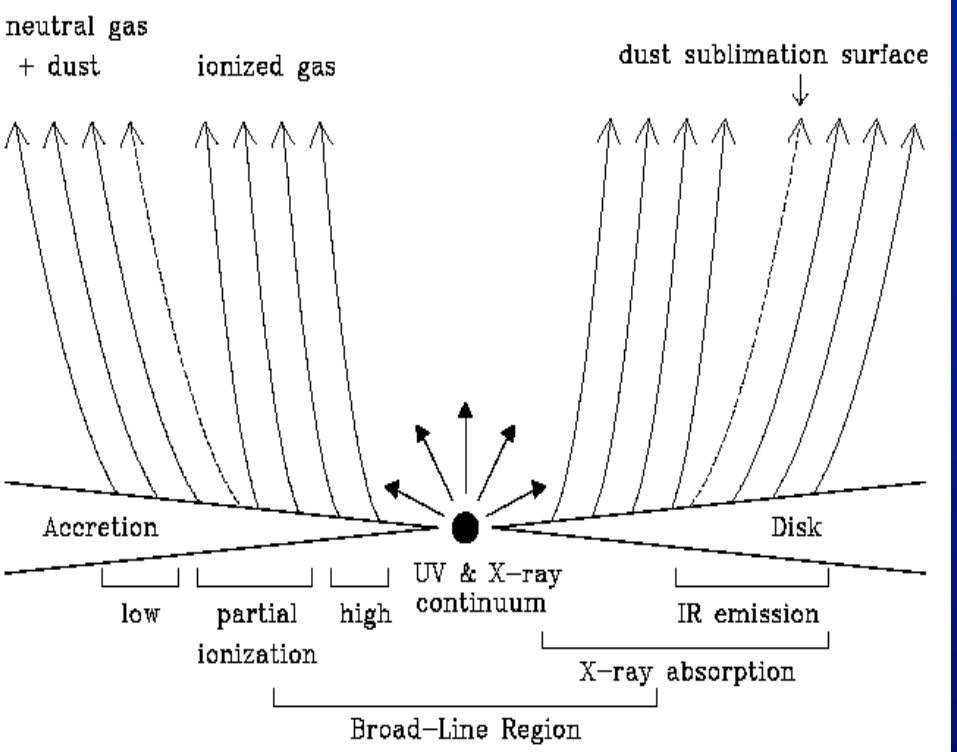


Cappi et al., in preparation
Dadina et al. '05

Different phases in WA shall respond differently in time...

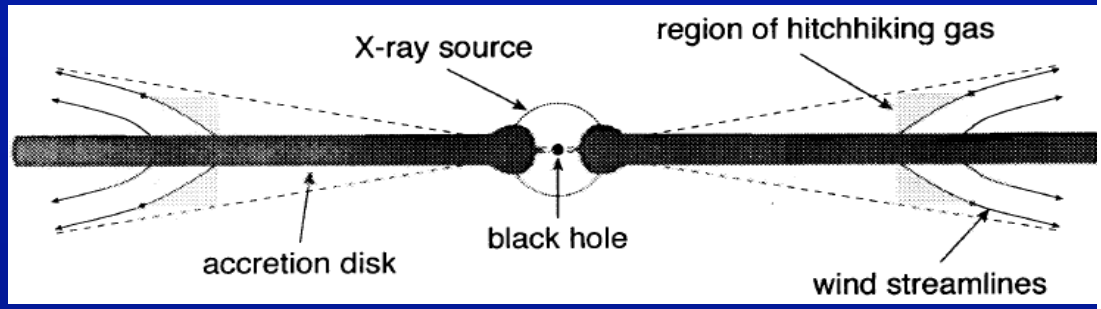
Interpretation I (i/i): (Three main) Wind dynamical models

i) Thermally driven winds from torus



Balsara & Krolik, 93; Woods et al. '96

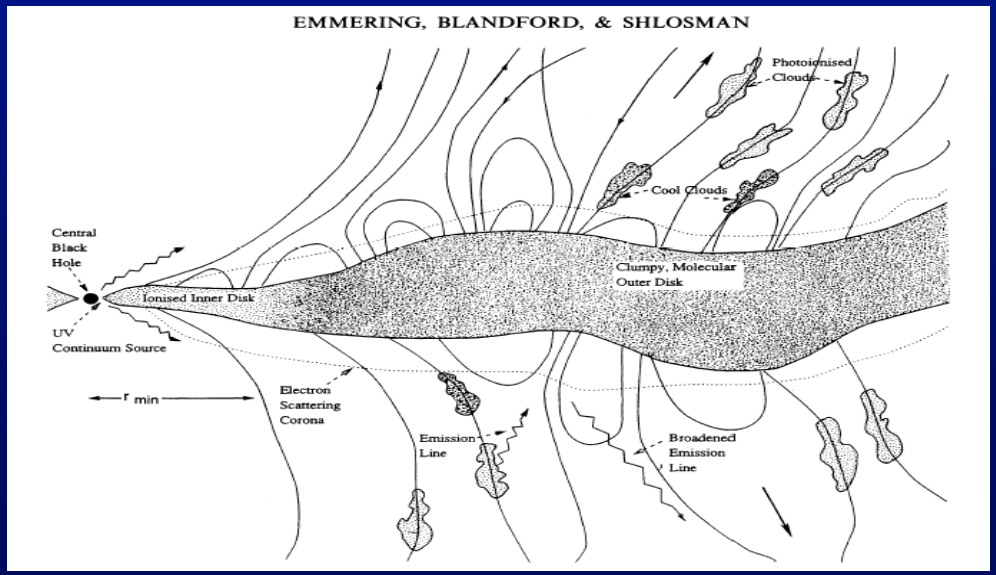
ii) Radiative-driven wind from accretion disk



Murray et al. '95, Proga et al. '00

...and/or...

iii) Magnetically driven winds from accretion disk

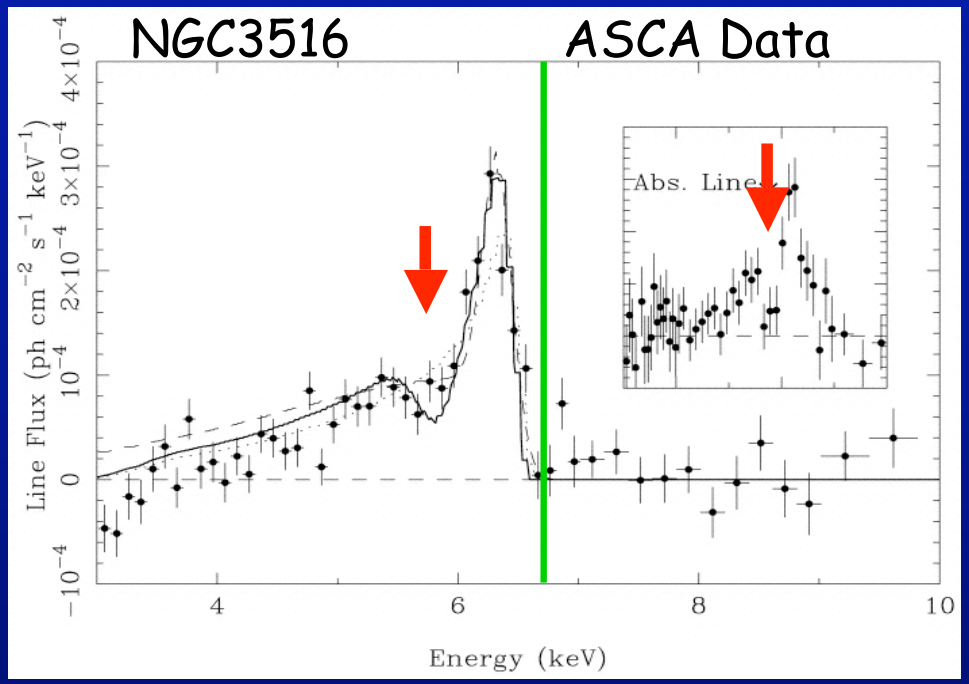


Emmering, Blandford & Shlosman, '92; Kato et al. '03

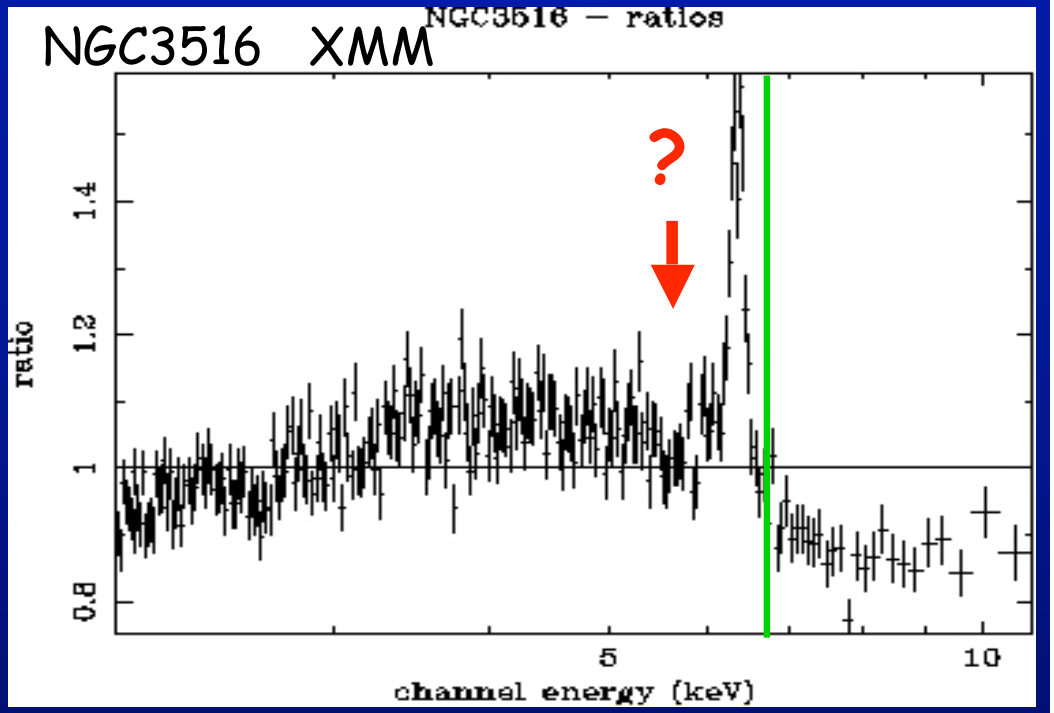
i) ⇒ Large R, low v
ii) and iii) ⇒ Low R and large v

New Observations II (i/iii): Red-shifted absorption lines

Narrow/broad(?) redshifted absorption lines?



(Nandra et al., 1999)



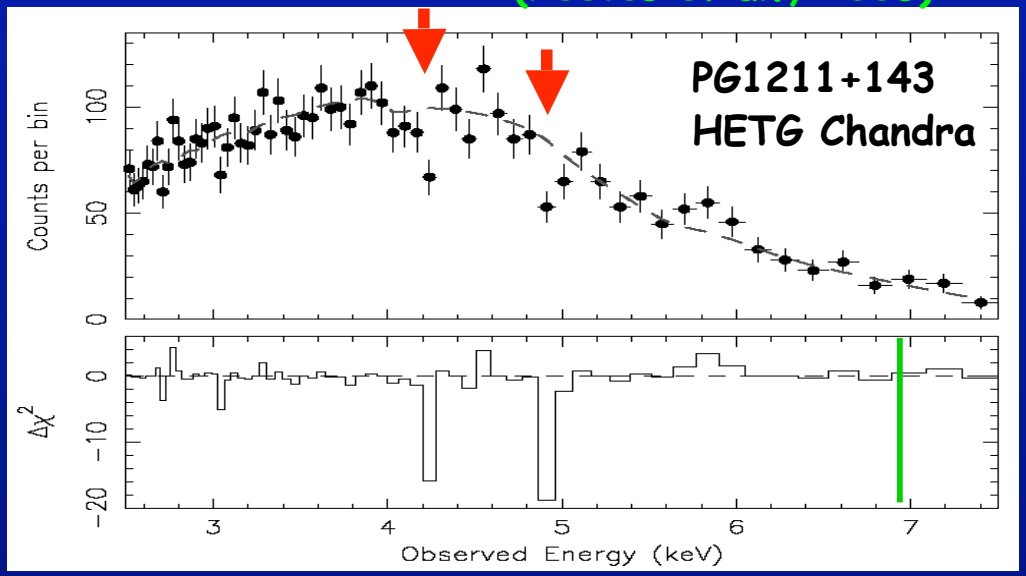
(but see Turner et al. '04 ⇒ rapidly varying energy-shift emission lines)

Redshift ⇒

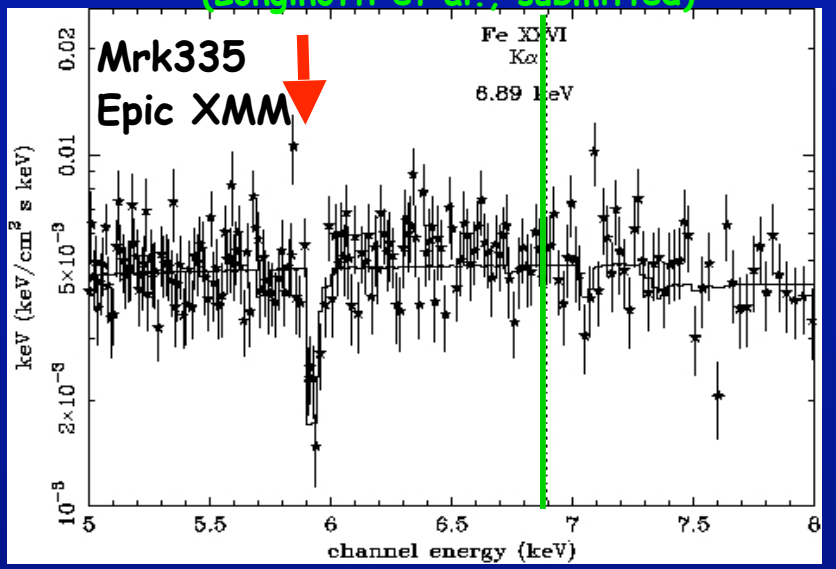
- Gravitational redshift?
- Inflow (v ~ 0.2c)?

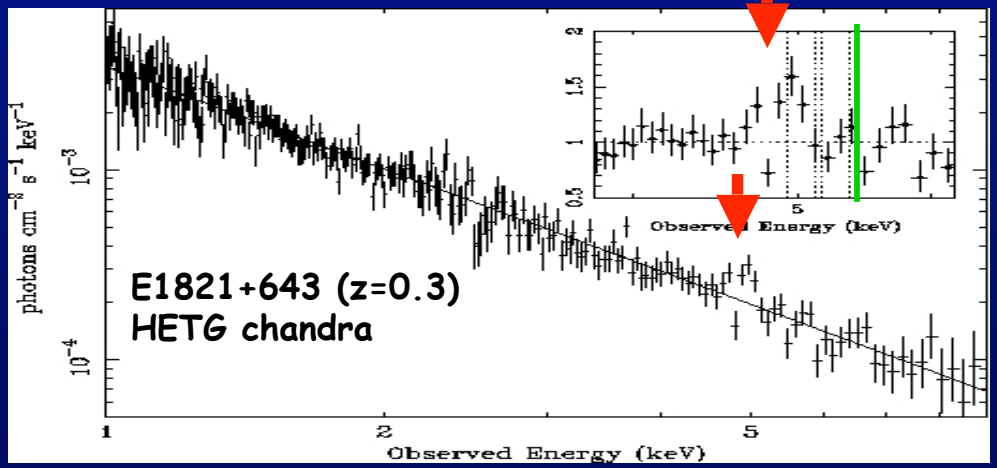
New Observations II (ii/iii): Red-shifted absorption lines

(Reeves et al., 2005)



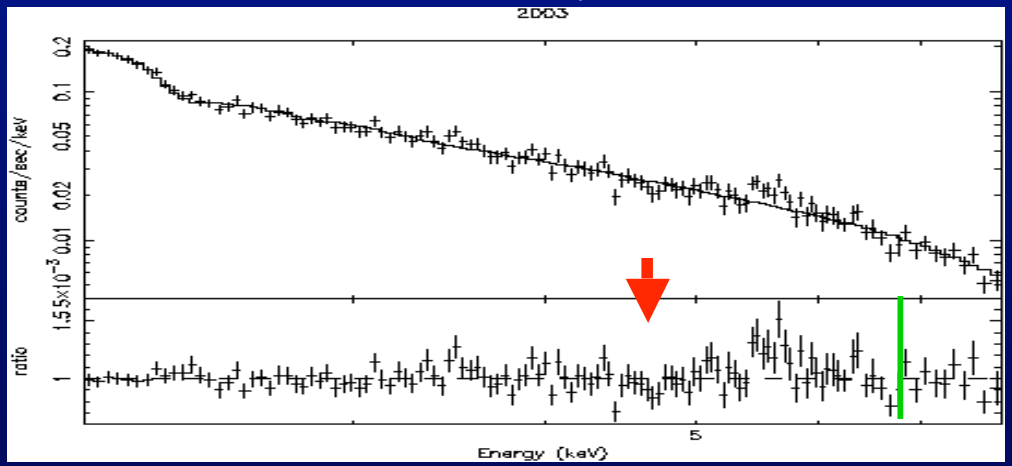
(Longinotti et al., submitted)





(Yaqoob & Serlemitsos, 2005)

Q0056-363 (z=0.162) XMM epic



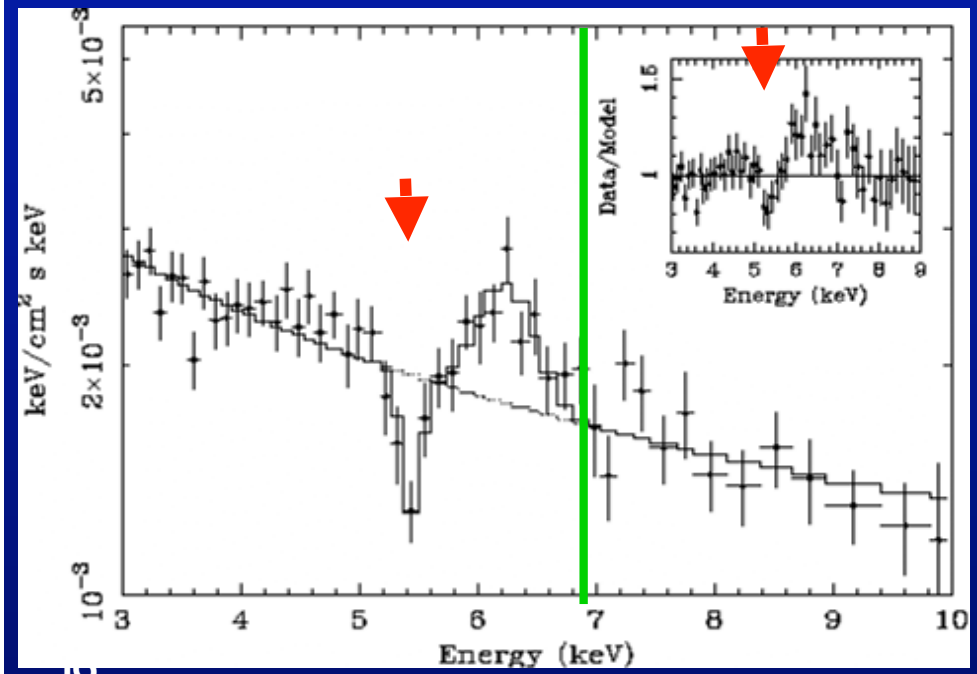
(Matt et al., '05)

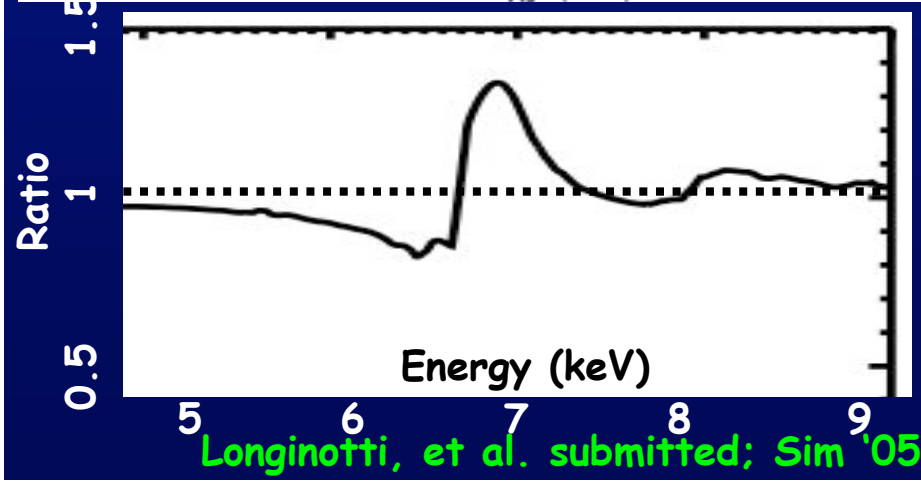
⇒ Are we probing relativistic bulk inflows? (v~0.1-0.4c)

New Observations II (iii/iii): Red-shifted absorption lines

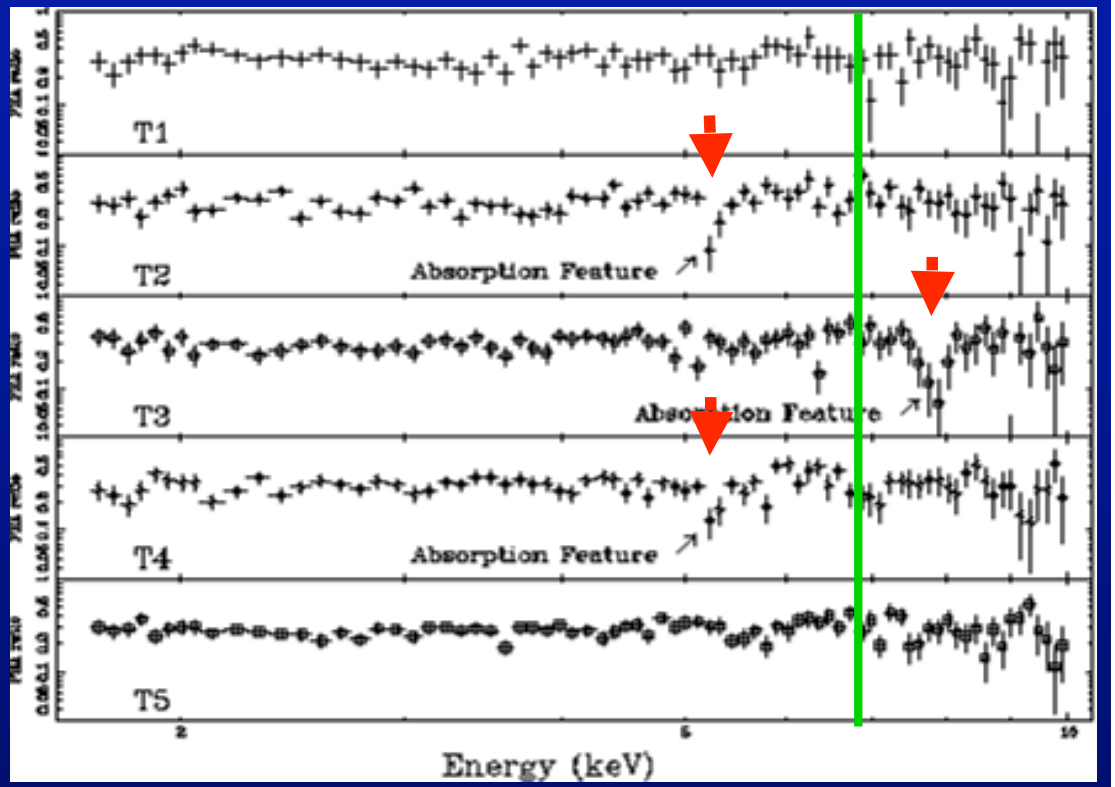
Red- and blue-shifted absorption lines, transient on timescales <20 ks

Mrk509 (z=0.03) SAX+XMM data





Longinotti, et al. submitted; Sim '05



Dadina et al., '05

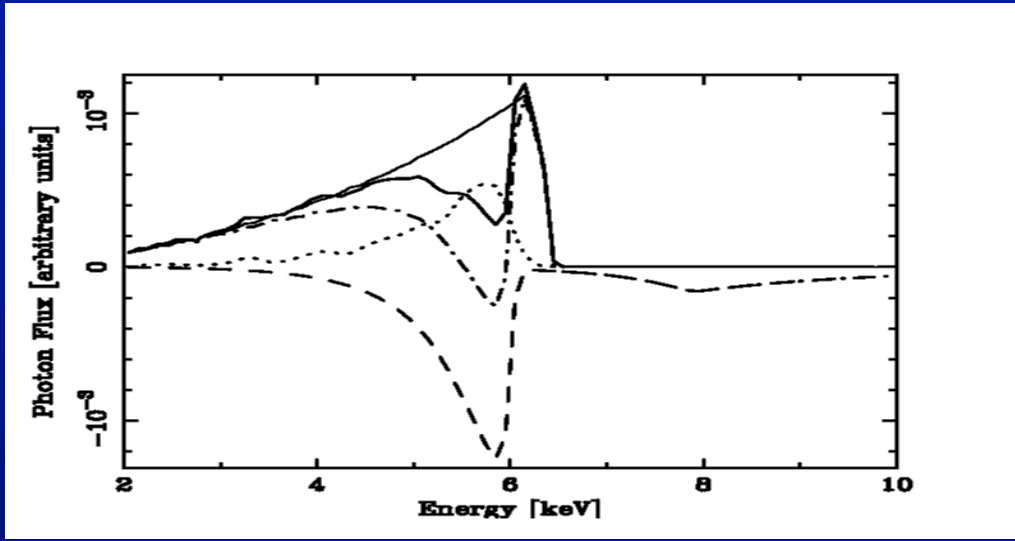
Inverted P-Cygni profile?

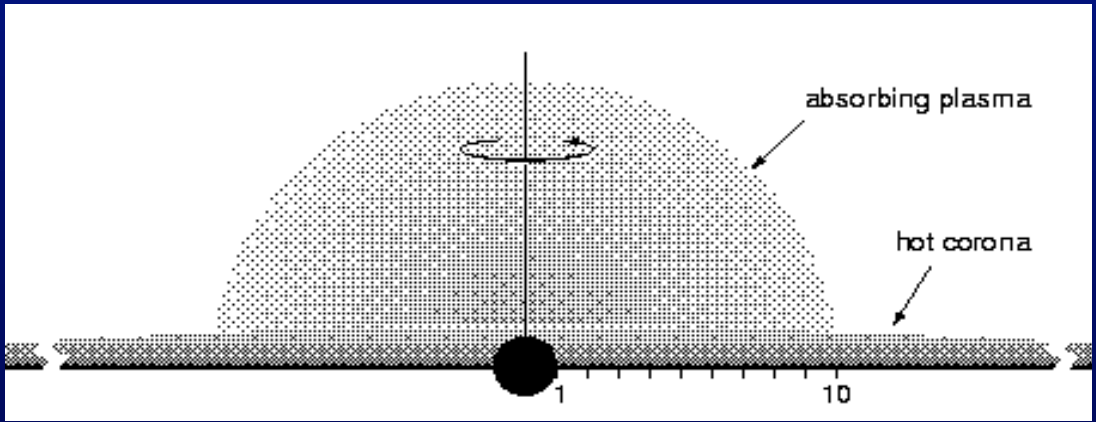
Mildly relativistic bulk inflow/wind? (v~0.2c)

Interpretation II (i/ii): Gravitational redshift

i) In a rotating absorbing corona

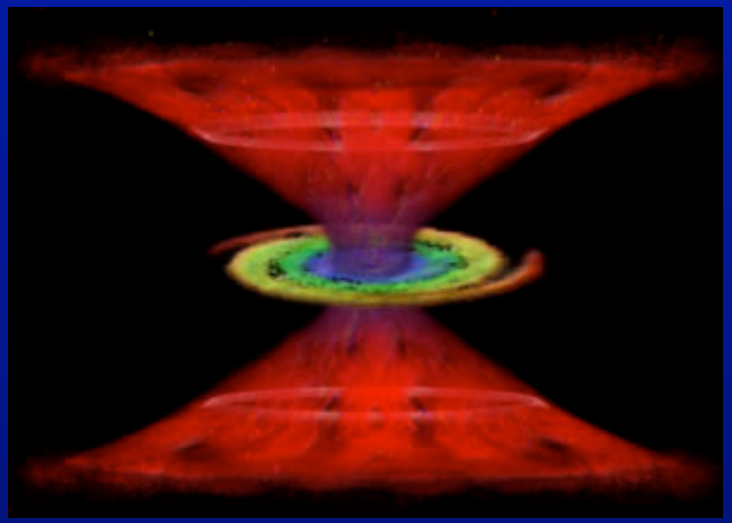
(Ruszkowski & Fabian, '00)





ii) In an outflowing nuclear wind/jet

(e.g. Reeves et al. '05)

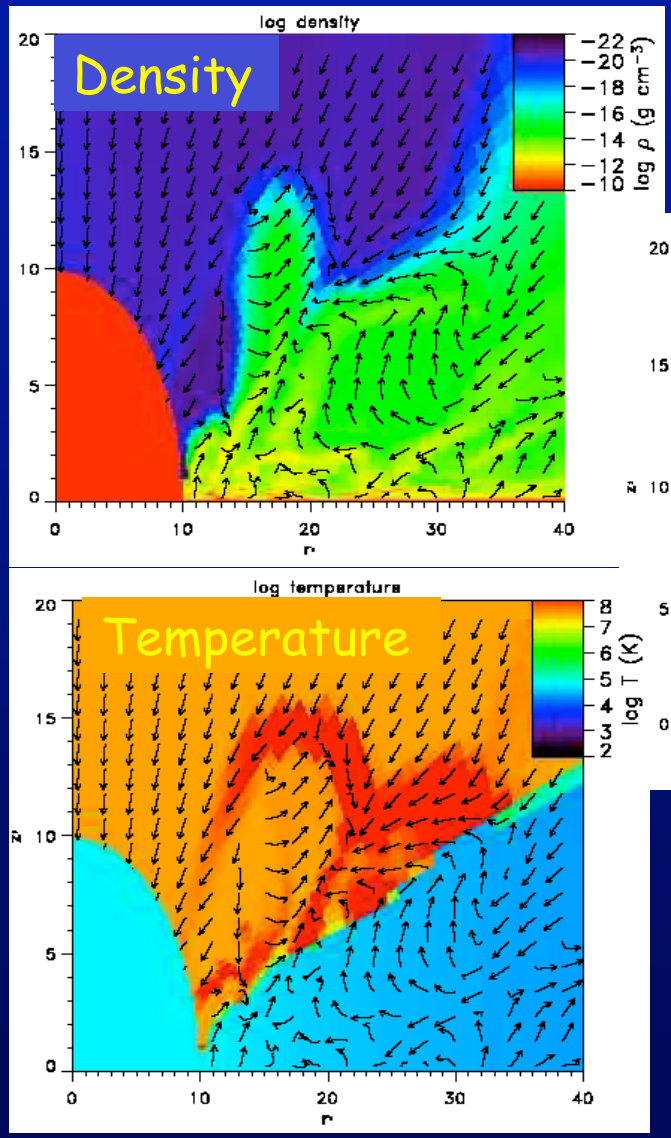


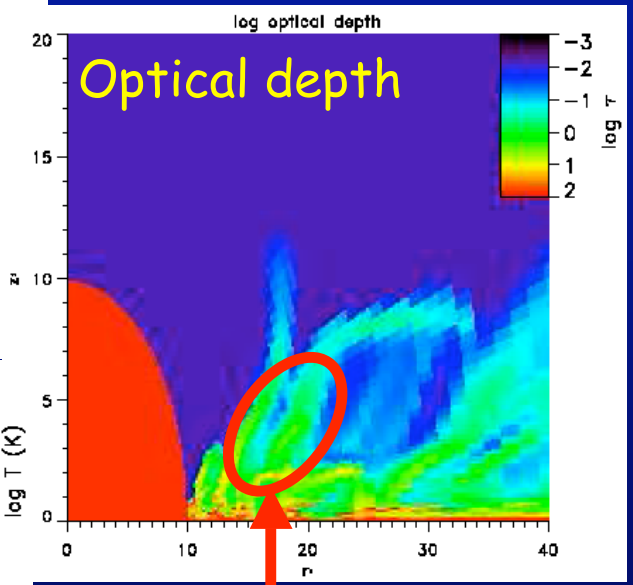
(Picture from Elvis '00)

N.B: Origin in gravitational redshift require R<few Rg

Interpretation II (ii/ii): Inflowing wind/blobs/clumps

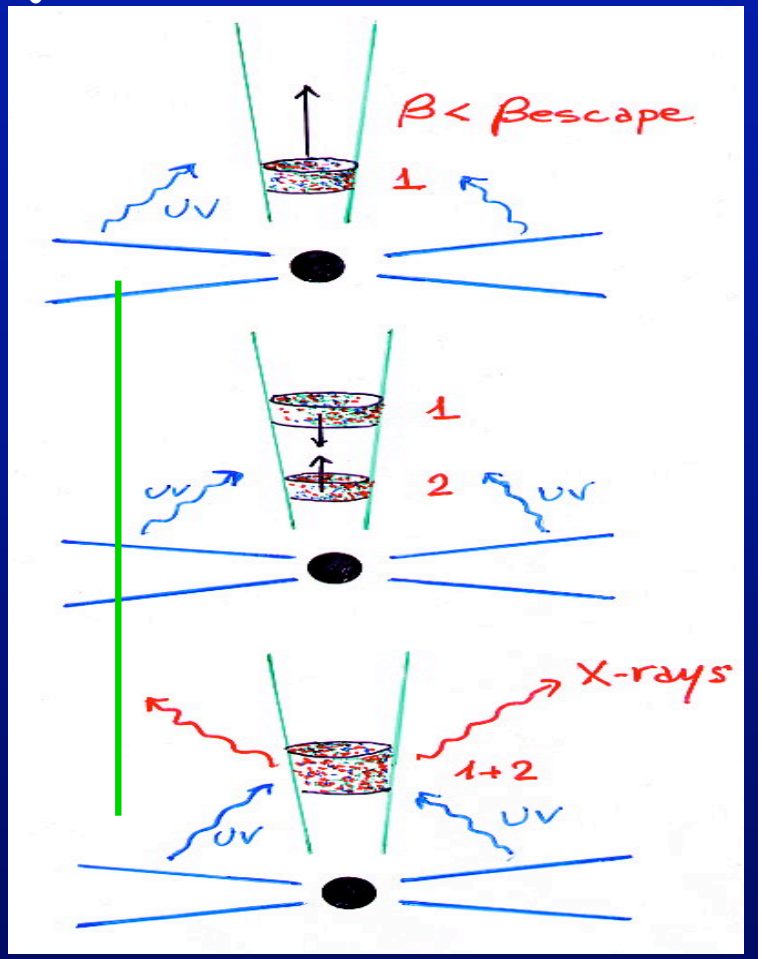
iii) Failed disk wind (Proga et al. '00)





τ > 1 out and inflow

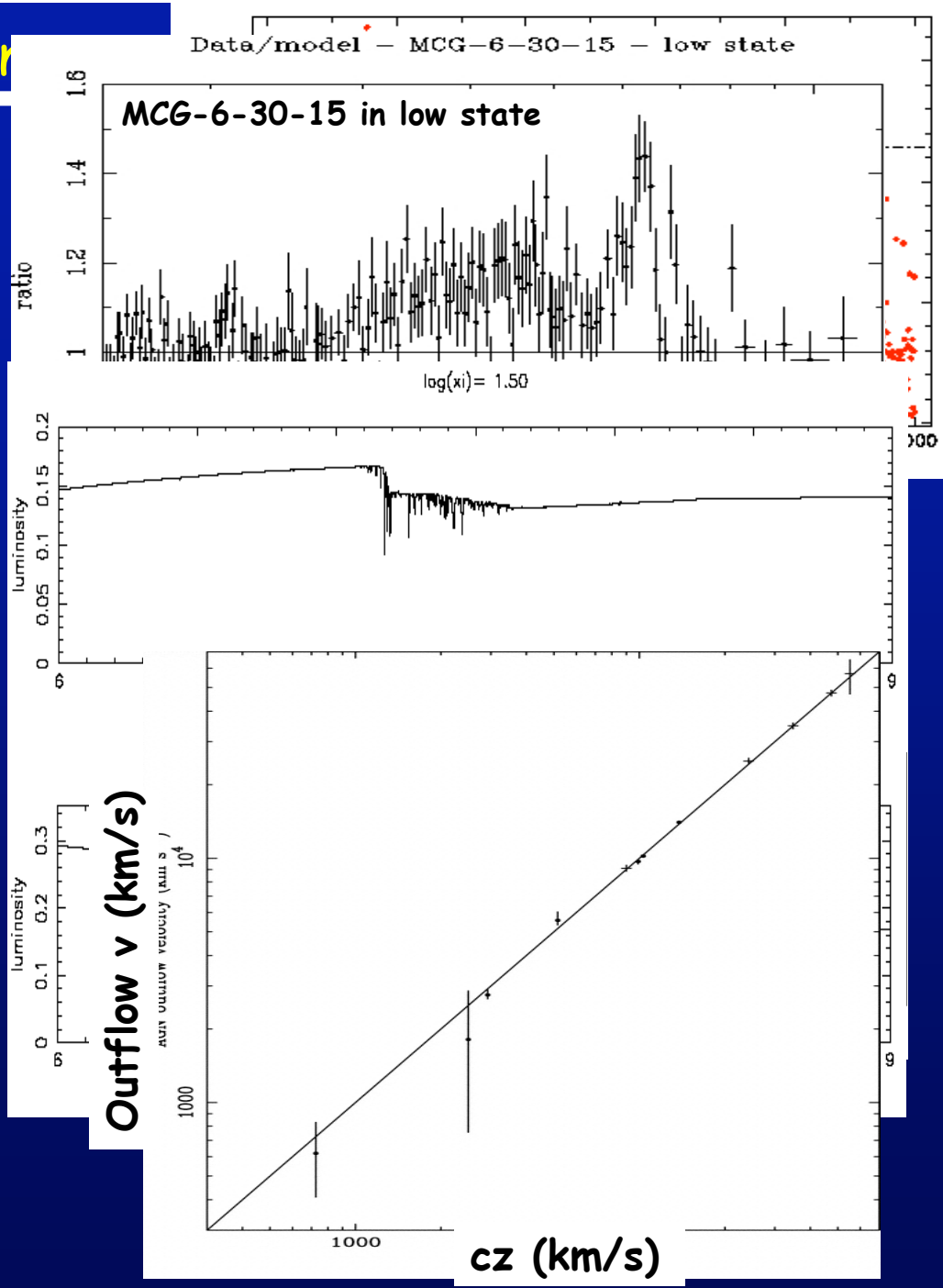
iv) "Aborted" jet (Ghisellini, Haardt, Matt '03)



N.B: If Infalling blobs/clouds ⇒ may represent suitable test-particles to probe GR under strong field

Critical Issues (i/ii): Observation

- ✓ Lines statistical significance? (transient features, number of trials in time and energy, etc…)
- ✓ Emission vs. absorption lines? (possible confusions with red- and blue-shifted emission lines…)
- ✓ Identifications of edges/lines energies? (Kallman et al. 2005, Kaspi et al. for PG1211)
- ✓ Local "contamination"? (PDS456 at risk? McKernan et al. '04, '05)
- ✓ Instrumental background?



Critical Issues (ii/ii): Interpretation/Theory

- ✓ Frequency in AGNs
- ✓ Nw (cm^{-2})
- ✓ Location (R, DeltaR)
- ✓ Covering factor
- ✓ Ionization state (ξ)
- ✓ Velocity (blue and red!)

Fundamental to:

i) Physics of accelerated and accreted flows (winds?, blobs?, etc.), i.e. understand how BHs accelerate earth-like quantities of gas to relativistic velocities

ii) Cosmology: i.e. estimate the mass outflow rate, thus the impact of AGN outflows on ISM and IGM enrichment and heating!

Blustin et al., Creenshaw et al., King et al., Yaqoob et al., Chartas et al., Elvis et al.

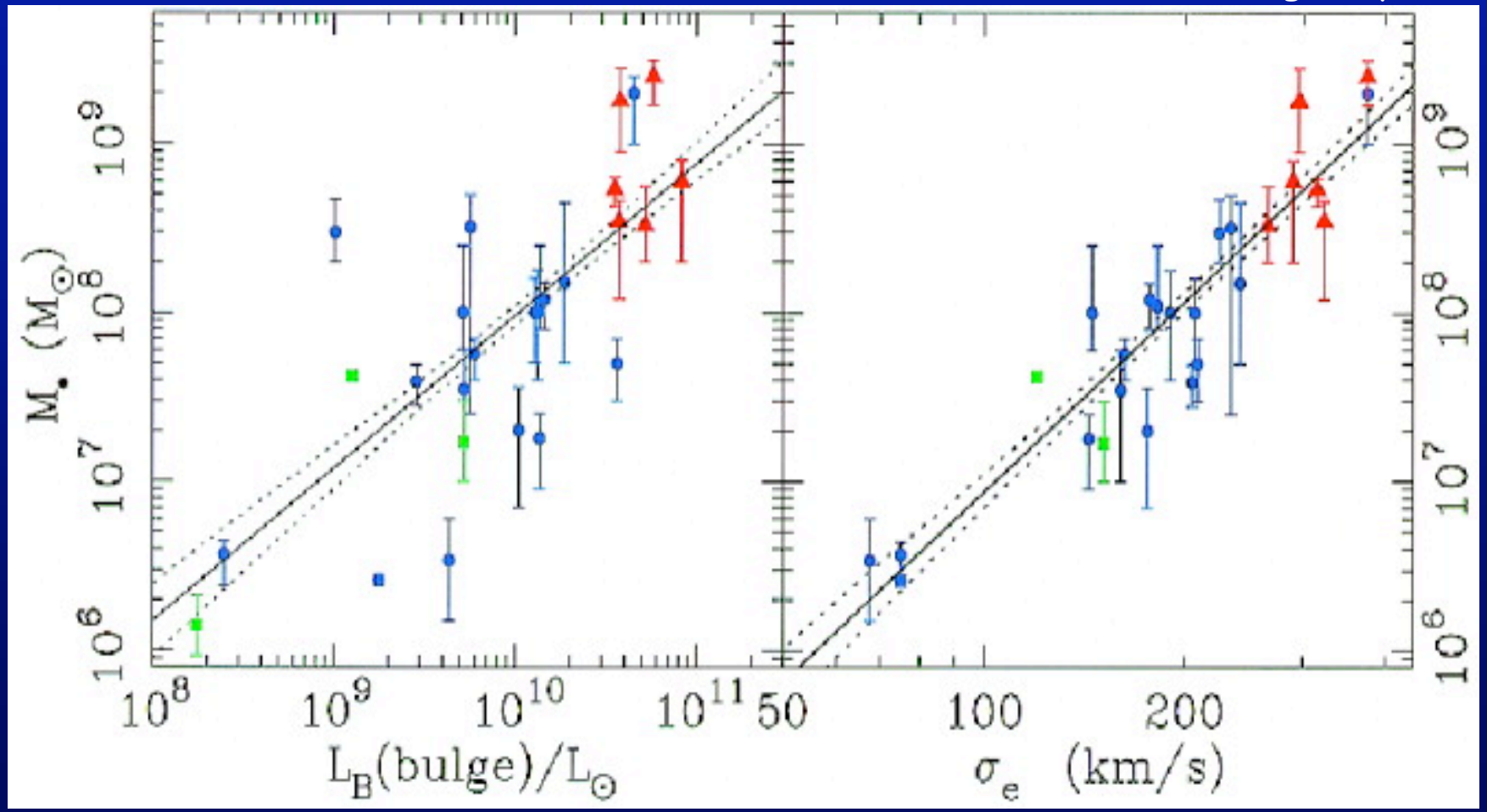
Current estimates have order of magnitude uncertainties, they go from:

dM/dt ($\propto L_{kin}$) few % to several times dM_{acc}/dt ($\propto L_{edd}$)

This is a fundamental (open) issue

Importance (i/ii): Feedback in the (co?)evolution of galaxies

First unexpected "revolution" in extragal. astrophysics: not only most (all?) galaxies have SMBHs in their centers, but these correlate with bulge properties ⇒evidence for feedback mechanism between SMBH(AGN) and its' host galaxy?

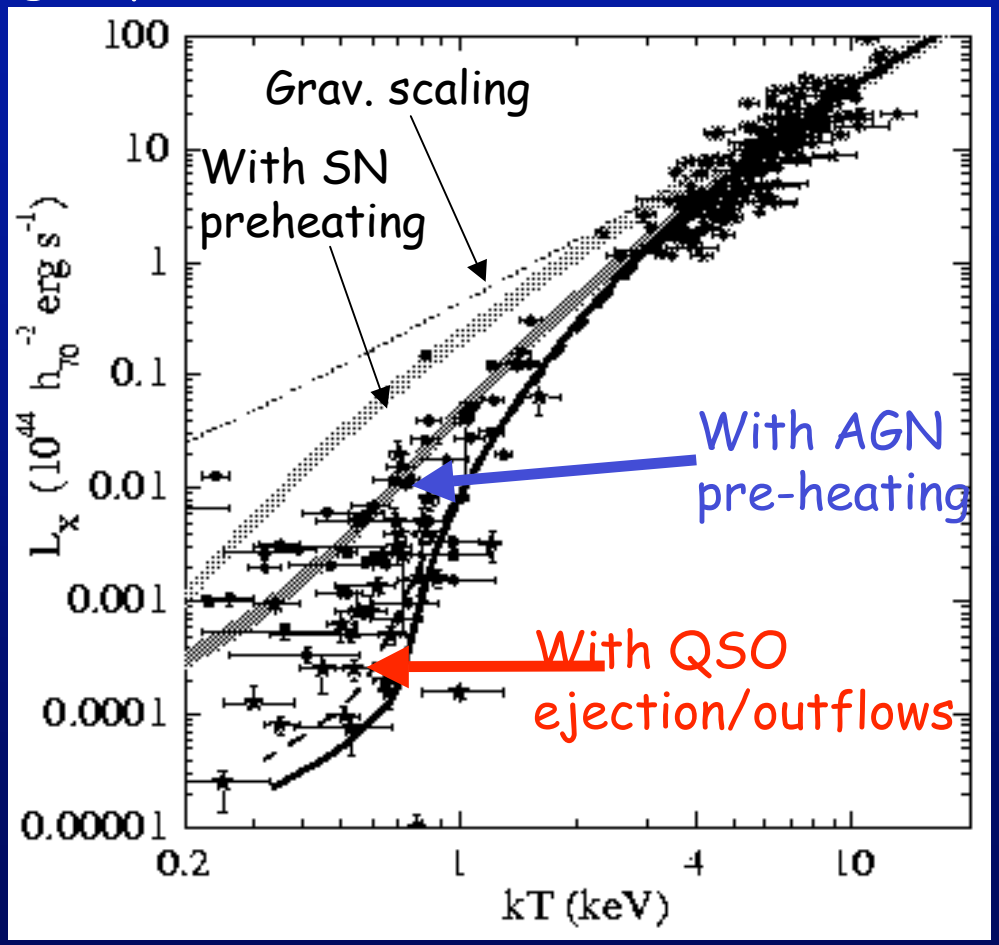


Magorrian et al. '98
Tremaine '02; Gebhardt '02...etc
(see e.g. King and Pounds '03, Crenshaw, Kraemer & George '03, ARA&A)

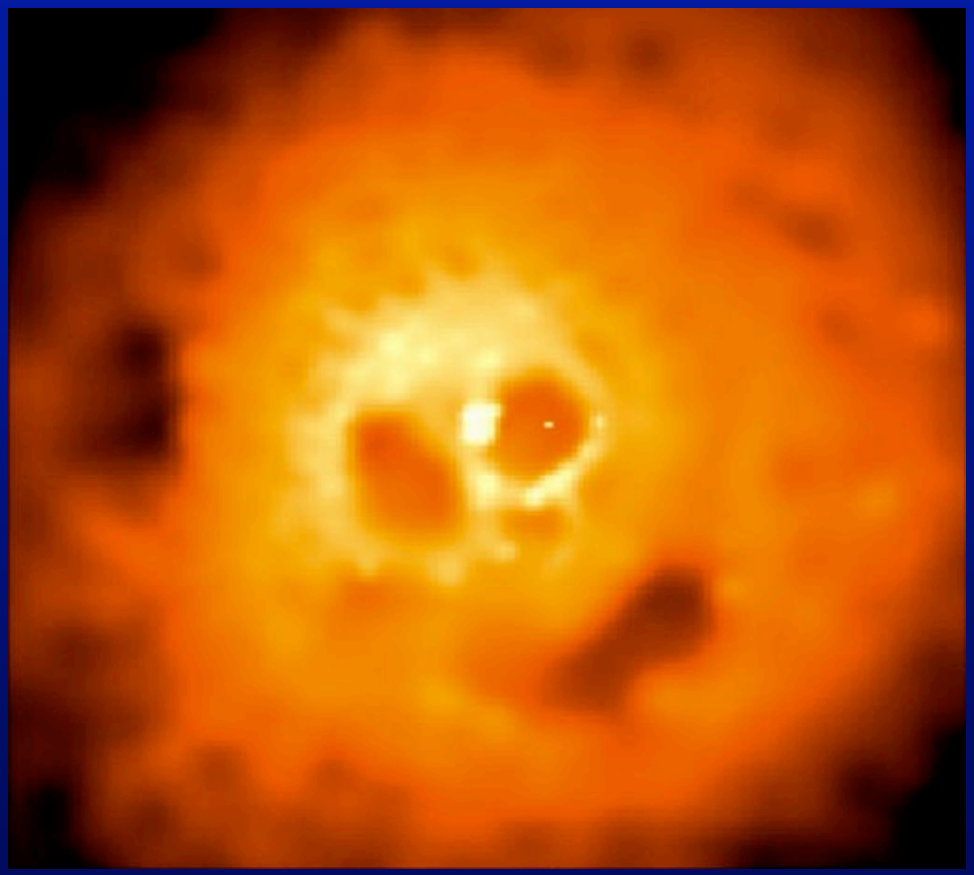
$M_{bh} \sim \sigma^4$

Importance (ii/ii): Reheating of groups and clusters of galaxies

Second unexpected "revolution" in extragal. astrophysics: need preheating to recover L-T relations & cooling flows extra-heating ⇒ Energy feedback from AGNs/QSOs and groups&clusters?



Lapi, Cavaliere & Menci, '05



Perseus Cluster, Fabian et al. '05

Future (i/vii): In my opinion

The tip of the Iceberg?

BECAUSE

- "Physical bias" against highest ionization in/outflowing gas (detectable only with Fe)
- "Detection bias" against transient features
- "Observational bias" against highest-v blueshifted features (poor high-E sensitivity…cut-off at ~7 keV)

WHILE

Transient (blueshifted and redshifted) absorption lines are naturally expected in models involving blobby/winds ejecta and downfalls, such as in MHD simulations of failed disk winds, and analogous models.

Future (ii/vii): One way is to reduce timescales…

…to probe the flow dynamics ($\Delta v/\Delta t$) of innermost regions by means of detection and time-resolved spectroscopy of red- and blue- shifted emission and absorption lines.

Fiducial numbers:

We wish to follow abs. lines from, say, ~1 to ~10 Rs, with intervals of 1Rs

Let assume v~0.2c, then for

BH mass= 10^8 M• ⇒ ΔTime-scale ~ 5000 s

BH mass= 10^6 M• ⇒ ΔTime-scale ~ 50 s (Note: 1μs if 1 M•)

Scaling from Mrk509 and XMM, and assuming EW(Fe)=-100 eV ⇒

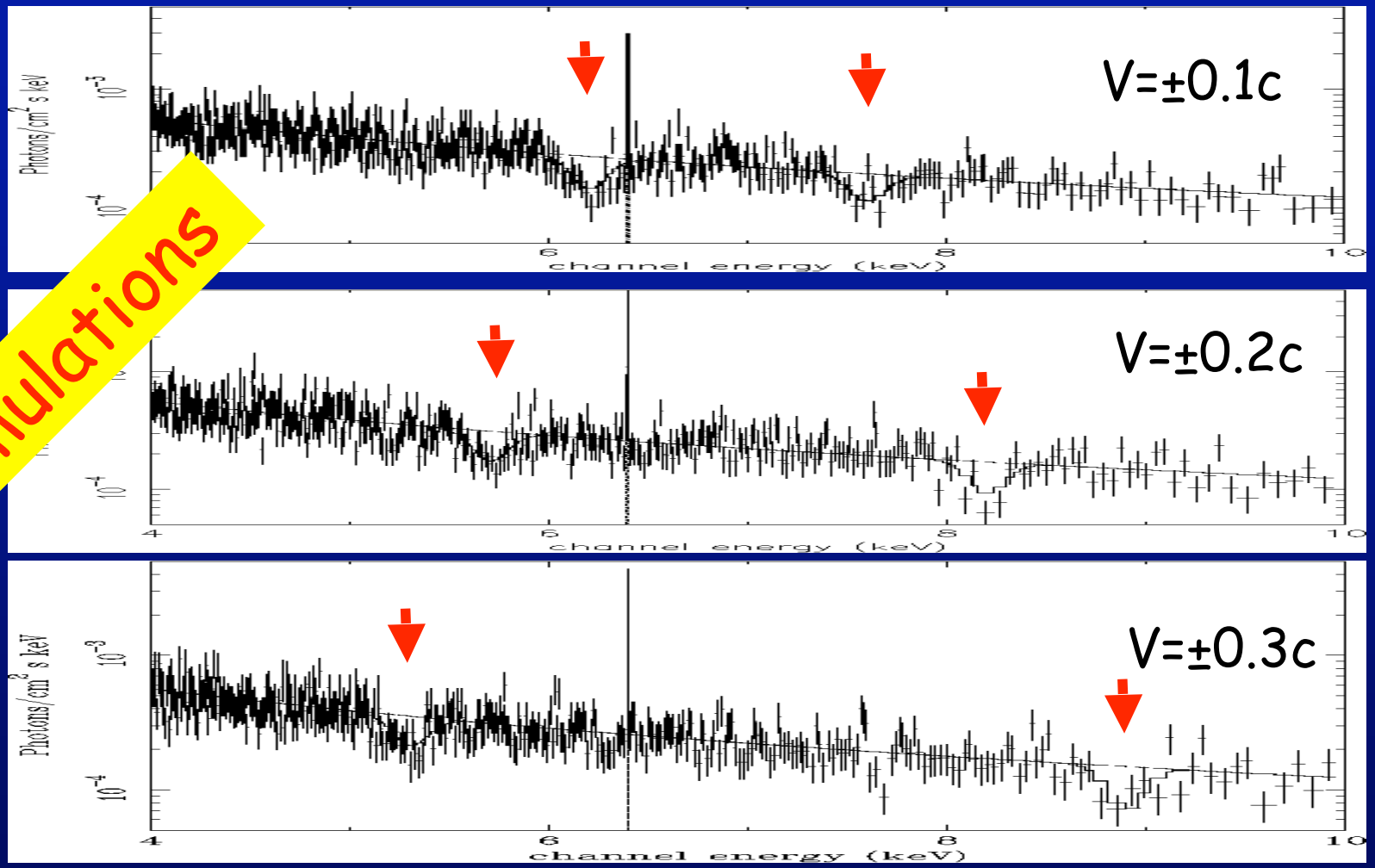
	Con-X(6000cm^2)	XEUS(60000cm^2)@6keV
F(2-10)=2x10^{-11}cgs (~ 15 sources)	1000s	100s
F(2-10)=2x10^{-12}cgs (~ 50 sources)	10000s	1000s
F(2-10)=2x10^{-13}cgs (~ 250 sources)	100000s	10000s

Really needed because mostly BH mass≤ 10^7 M•

N.B.: If v>0.2c, timescales consequently reduced

Future (iv/vii): XEUS simulation TES (2 m^2@6 keV)

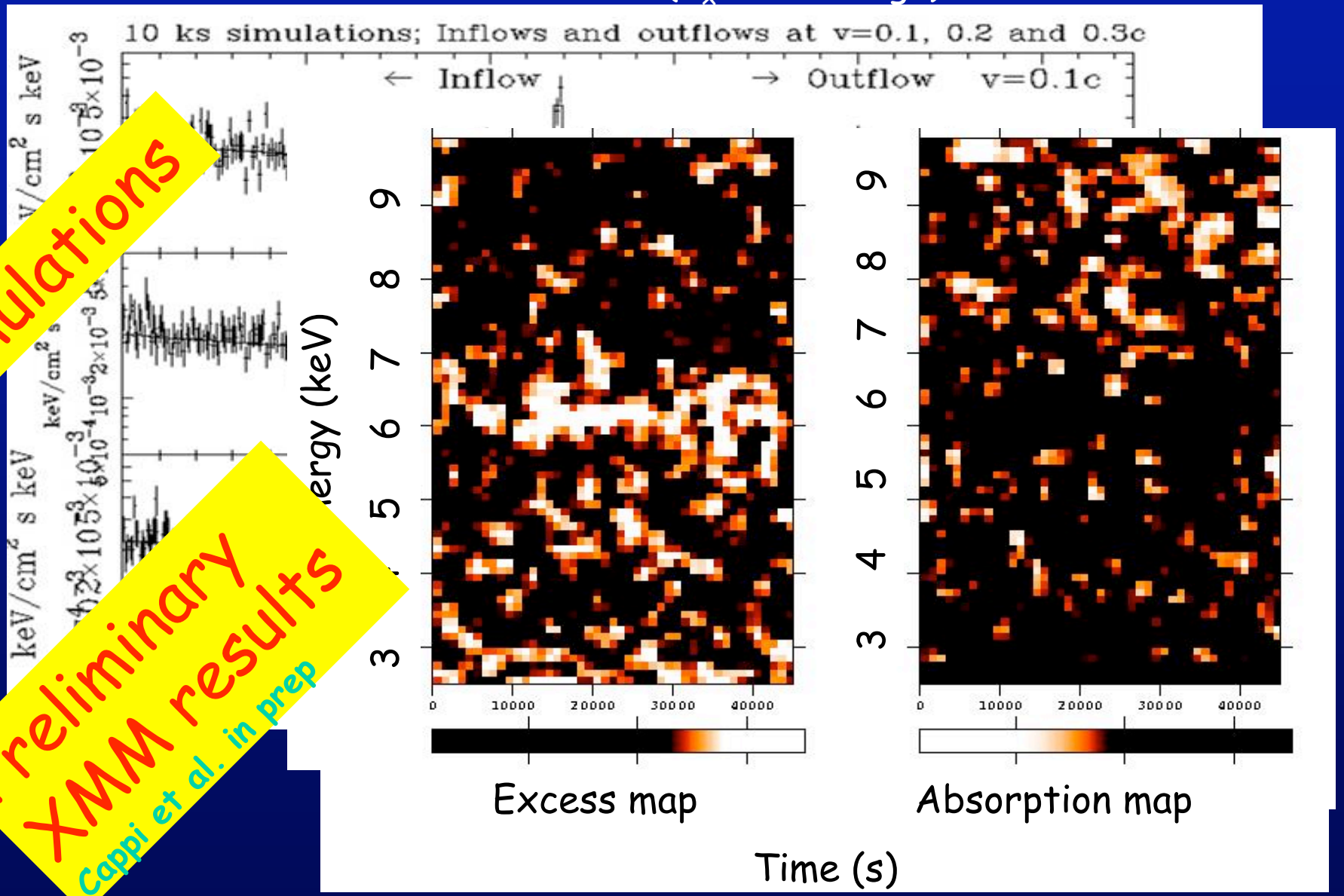
Mrk509: XEUS TES F(2-10)=10^{-11}cgs Exposure=100s S/N>3



Highest throughput for time-resolved detections of abs. lines
⇒ real-time, extreme dynamics, i.e. inward and outward accelerations!?
(line $\Delta v/\Delta t$) ....blob=test particle to test Kerr vs. Schwarzschild GR

Future (iii/vii): XMM-Newton long observations on brightest sources

Mrk 509: XMM-Newton simulation (F_x=2x10^{-11} cgs)



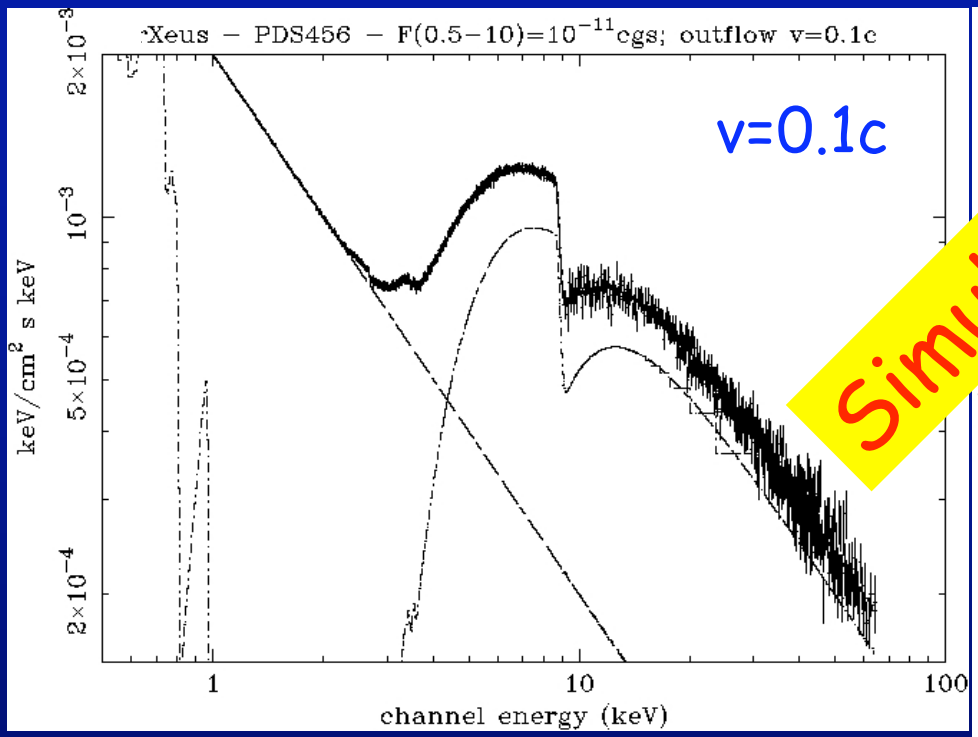
Simulations

Preliminary XMM results

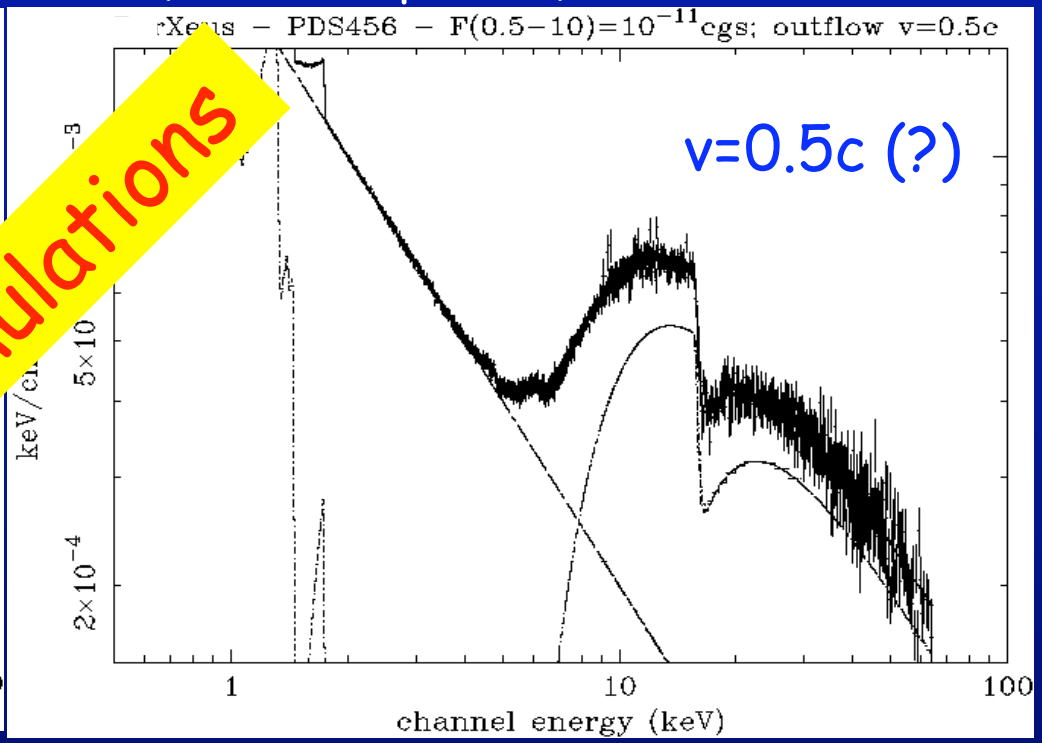
Cappi et al. in prep

Future (v/vii): XEUS simulation (with CdTe)

PDS456: XEUS WFI + CdTe (100 ks exposure)



Simulations



(Wfi: S/N=100; Cdte: S/N=10)

(Wfi: S/N=50; Cdte: S/N=10)

Edges at E~7.1-9.0 keV (rest-frame) + v_{out}~ 0.1-0.5c

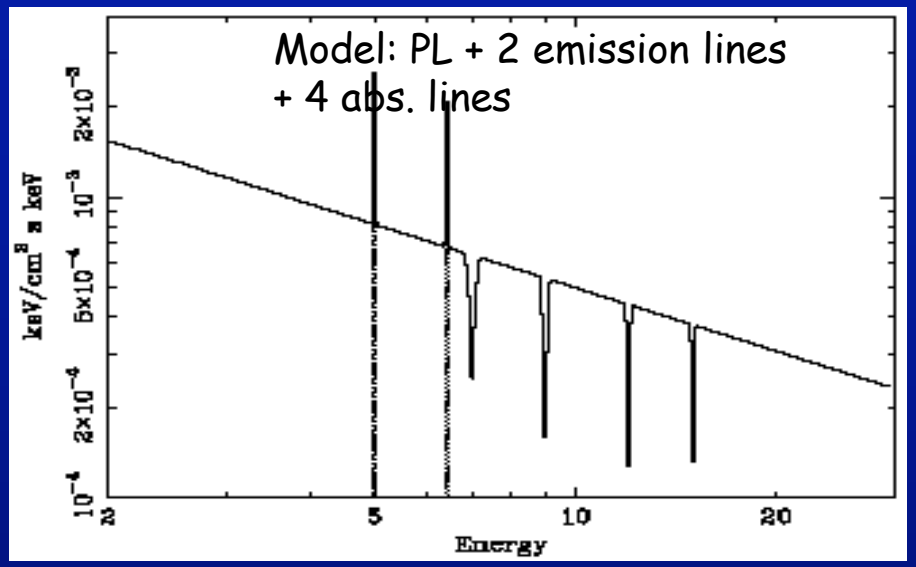
⇒ $E_{observed}$~ 8-14 keV !!

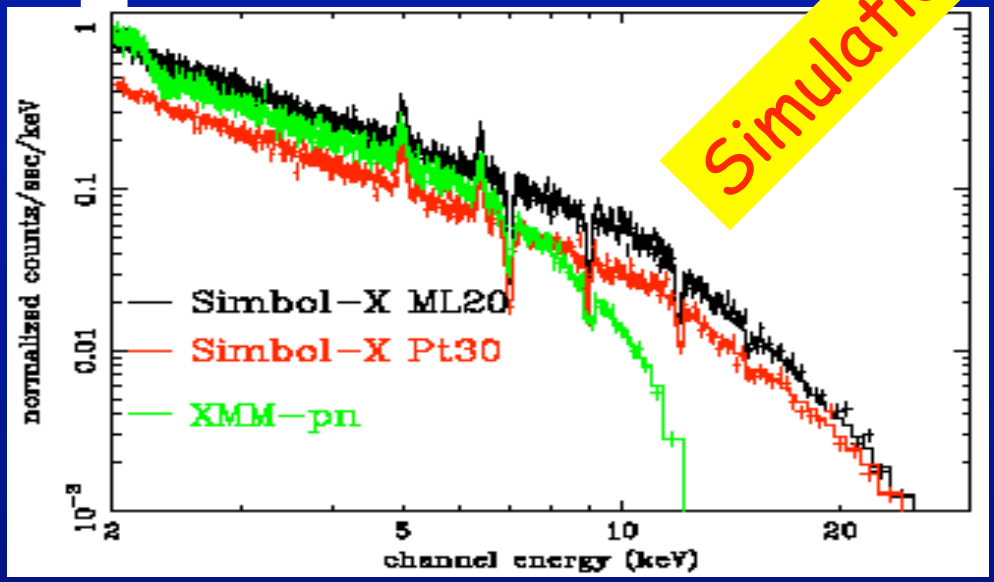
(maybe the reason why never seen earlier, except for high-z sources)

➡ High energies is a MUST HAVE to study relativistic outflows!!

Future (vi/vii): Simbol-X simulation (SDD+CdTe)

Simulations of narrow emission and absorption lines



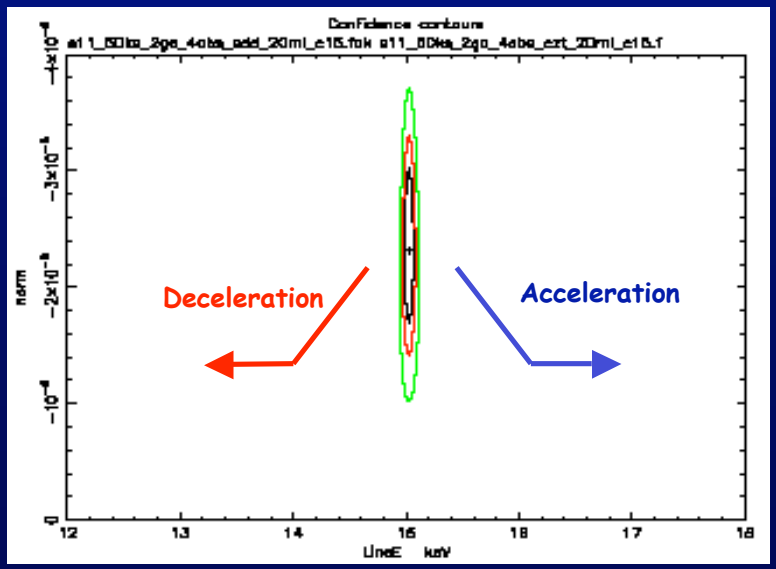


Model with **narrow** emission and absorption lines: PL (Γ=1.9, F(2-10)=10^{-11}erg/cm2s, Exp.=50 ks) + 2 FeK emission lines (E_1=5 keV, E_2=6.4 keV, σ_1= σ_2=50 eV, EW_1=EW_2=100eV) + 4 FeK absorption lines ($E_{1,2,3,4}$=7, 9, 12, 15 keV, $\sigma_{1,2,3,4}$<50 eV, $EW_{1,2,3,4}$=-100eV)

Edges and absorption lines at E~7.1-9.0 keV

(rest-frame) + v_{out}~ 0.1-0.5c

$\Rightarrow E_{observed}$~ 8-14 keV !!



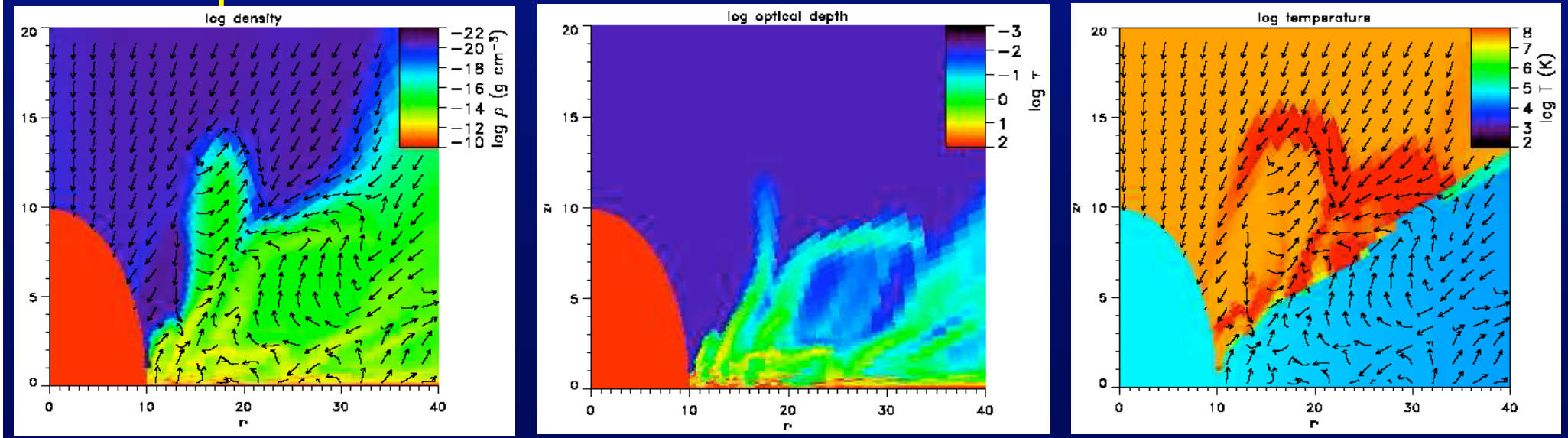
ΔE_{abs}<100 eV $\Rightarrow$ Idee would be to follow the evolution of blob ejections (or injections)

N.B: Masses involved can be greater than M_{earth} (10^{27}g/ejecta) >>10^{-11}g in accelerators

Future (vii/vii): Two main directions

1) Probe the flow **DYNAMICS !**
(i.e. accelerations in innermost regions, near BHs)
- Measure delta v, not only v!
- On short time-scales (less than few 1000s)
- For both outflows and inflows

2) Probe the **HIGHEST VELOCITIES** (0.5 c < v < 0.99c), and thus masses/kinetic energy, in outflowing components



Daniel Proga, 2005 (failed disk winds)

Summary

I reviewed the growing evidence for transient, red- and blue-shifted, absorption lines from highly ionized Fe in AGNs (both Sey and QSOs)

These indicate existence of highly-ionized, high velocity, massive outflows and inflows around AGNs, BUT STILL ORDER OF MAGNITUDES UNCERTAINTIES on energy/momentum and mass involved.

This topic still requires better measurements of intensity, energy and frequency/recurrency but has a great potential for the study of:

i) innermost regions of accretion flows (blobs=test particles!?)

ii) launching mechanisms/characteristics of outflows/jets (mechanical energy emerging from BH)

Important not only for (relativistic) physics but also for link with cosmology + analogies with other sources

Prospects for future progress are to:

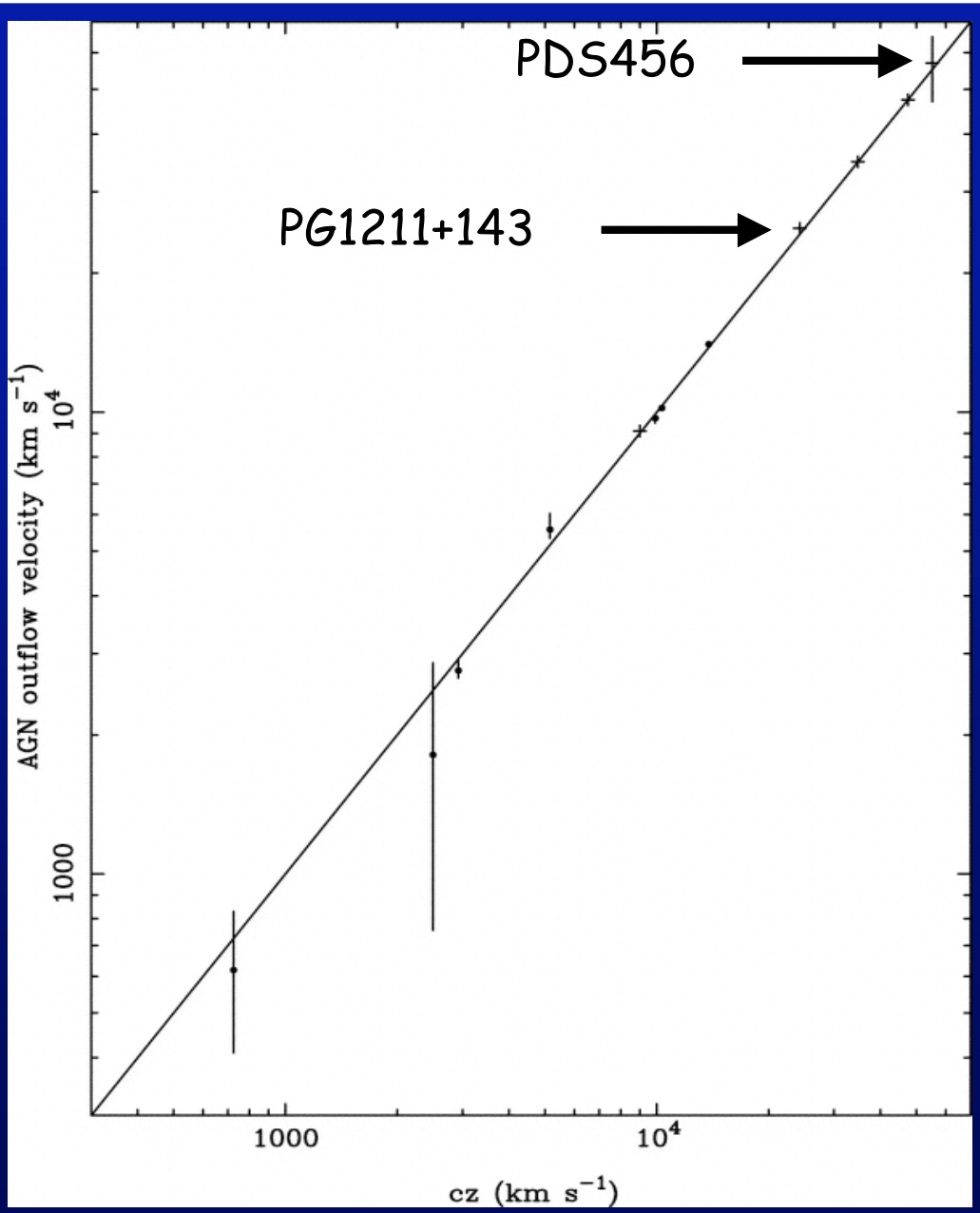
i) Confirm/secure these findings with long XMM/Chandra observations

ii) Probe lower time-scales (with XEUS-like mission)

iii) Probe high-velocity gas with high-energies (Simbol-X and/or XEUS hxd)

Thanks for your attention

Ejection/outflows: Massive outflows (ii/iii)

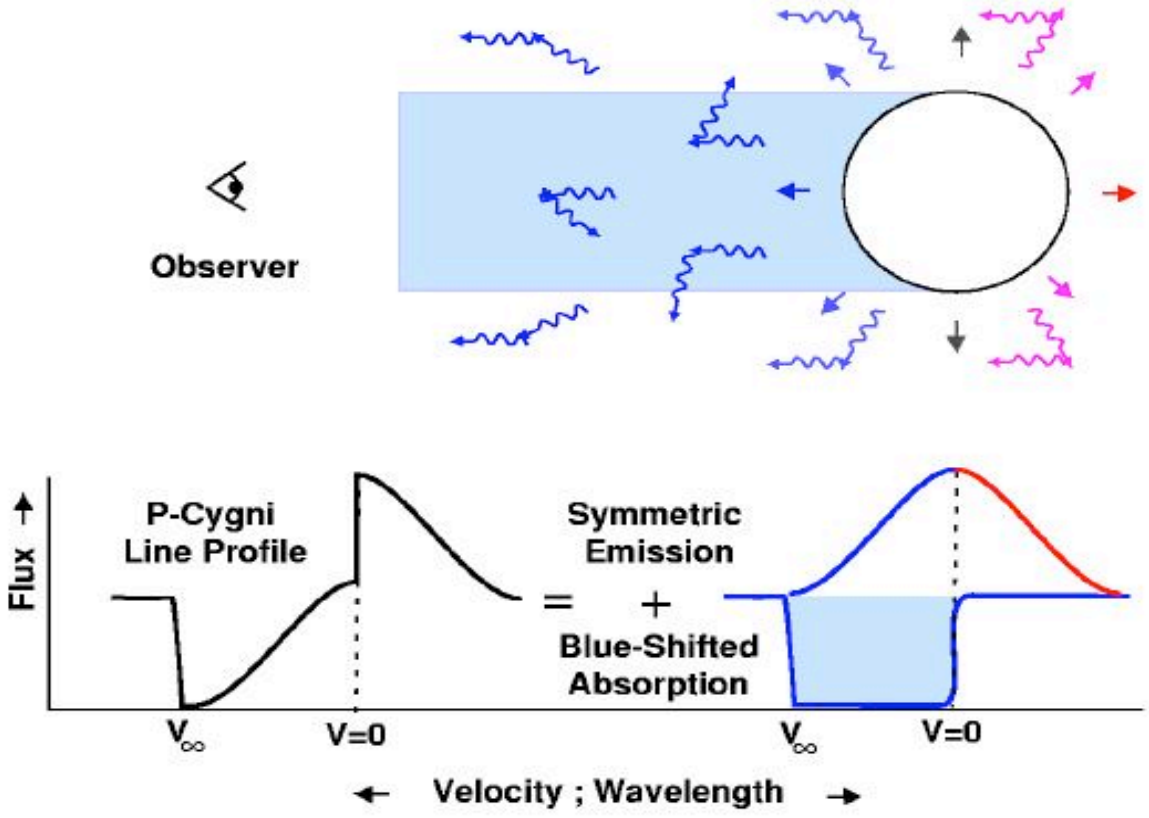


McKernan, Yaqoob & Reynolds 2004

Cast doubts on the AGN origin of high-velocity absorption gas...because consistent with local WHIGM (N.B.: PDS456 is along Gal. Plane)

X-ray spectra of winds/outflows

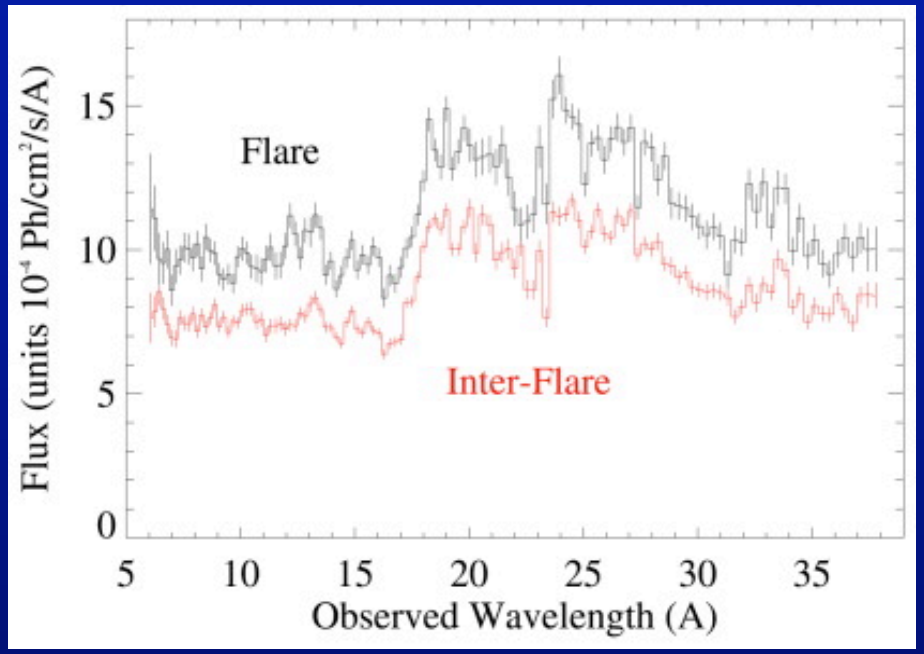
Formation of a P-Cygni Line- Profile



Framework (iv/iv): Warm absorbers…variable

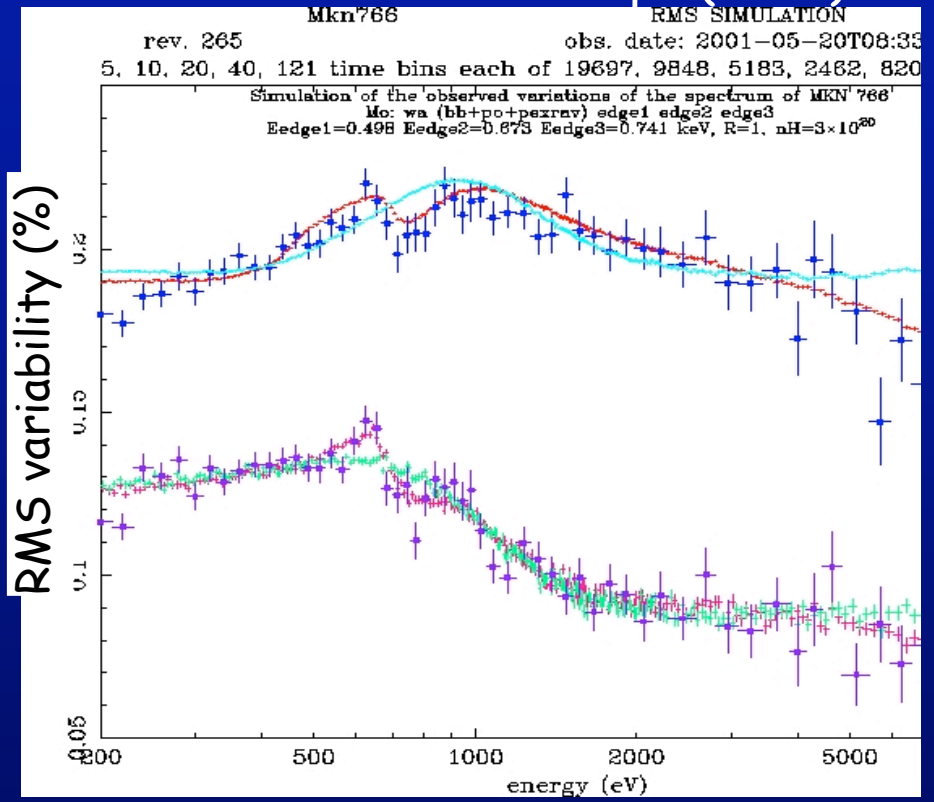
WA variability on timescales 1000-10000s

Mrk766 RGS



Mason et al. 2003

Mrk766 EPIC pn (RMS)



Ponti et al., PhD thesis

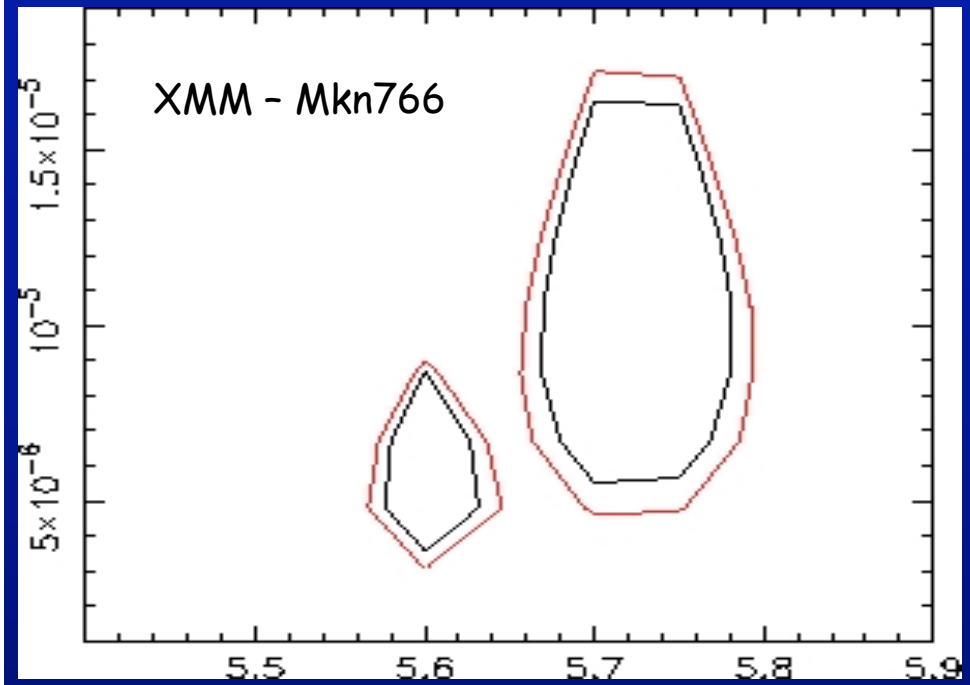
Different phases in WA shall respond differently:
e.g. with a range of response times in a radially segregated flow.
This will be crucial to determine location and covering factor …

Accretion/inflows: Observations (7/8)

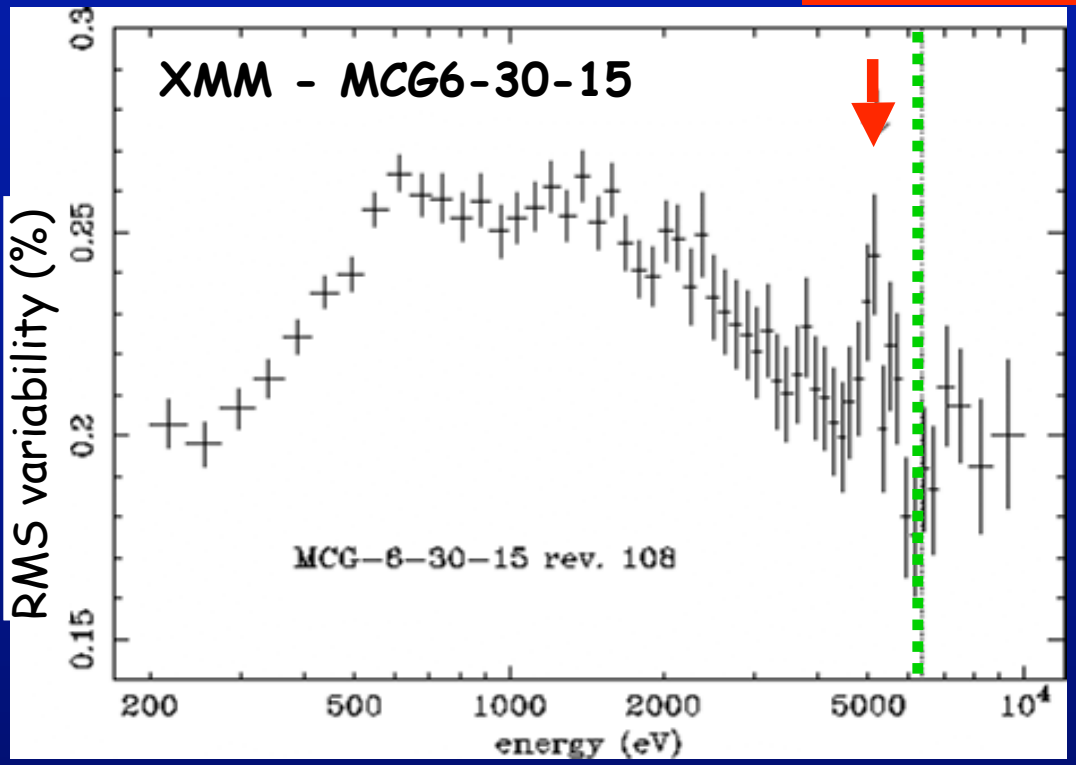
Post-Chandra & XMM-Newton

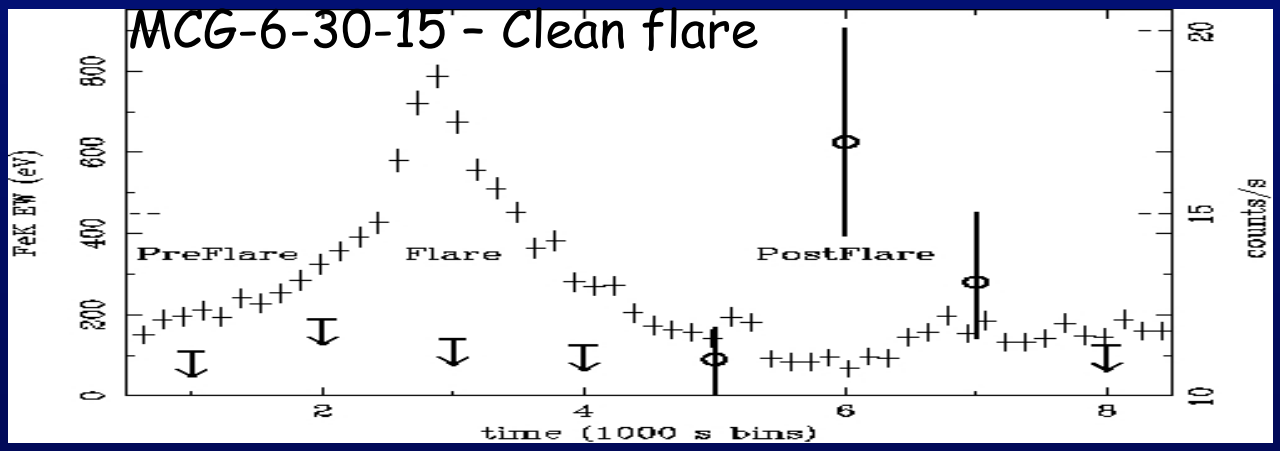
...other independent evidence of FeK line variability...

VERY NEW!



Turner et al., 2003





Ponti et al., 2004,
(and INAF press-release)

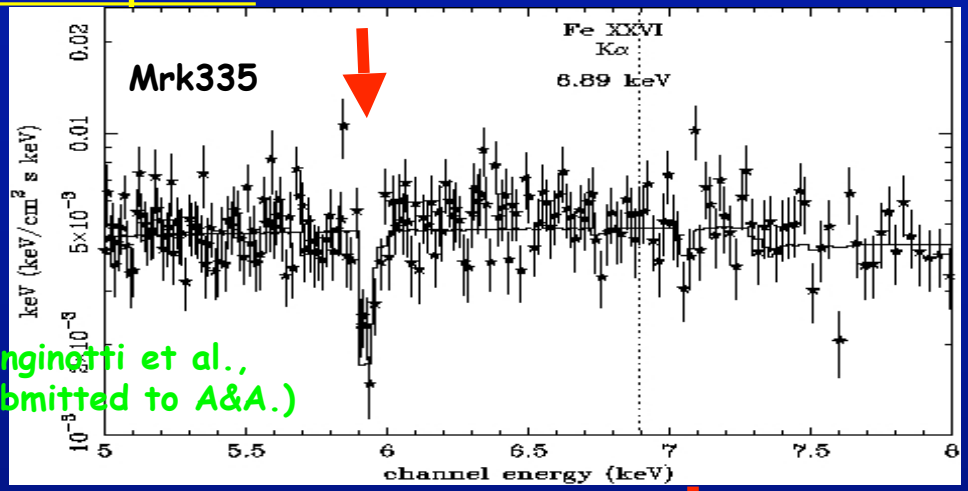
⇒ Origin in innermost regions of accretion disk

Accretion/inflows: Observations (8/8)

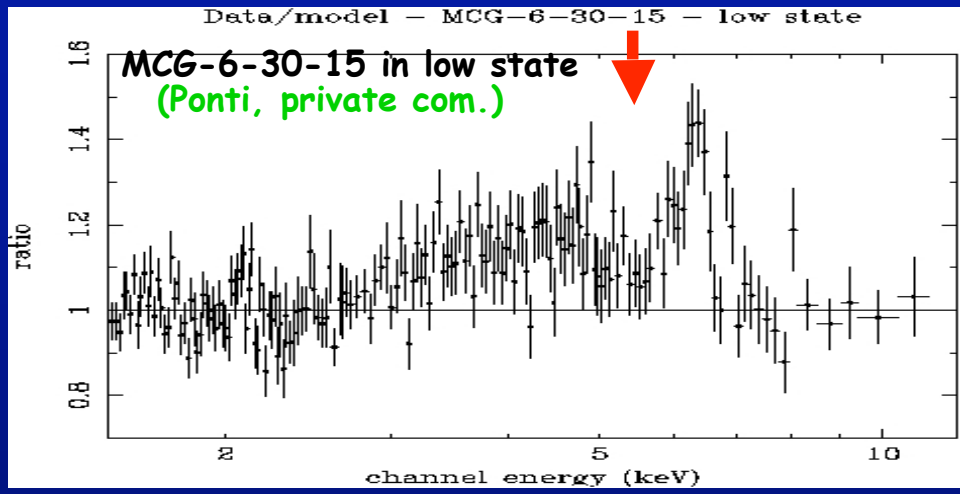
Post-Chandra & XMM-Newton

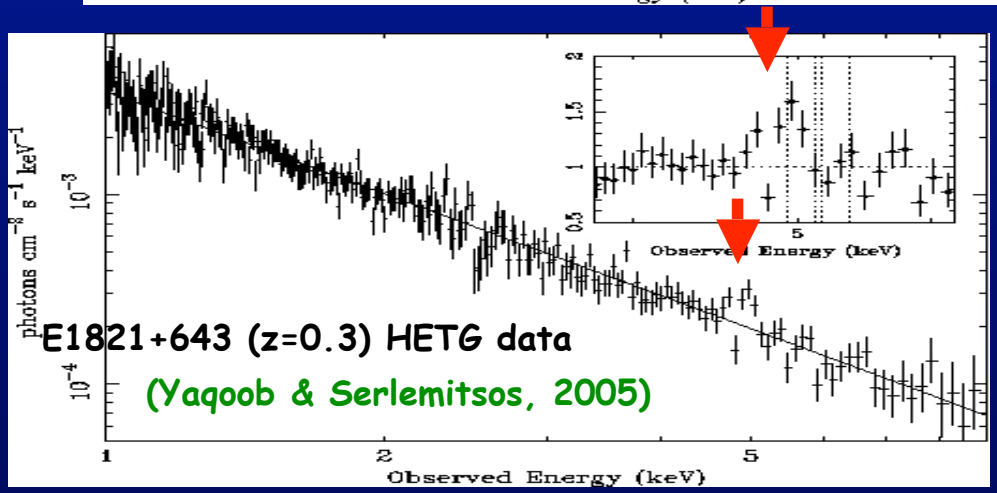
III- Complex Absorption FeK lines: Narrow/broad(?) redshifted absorption lines:

VERY NEW! and much debated

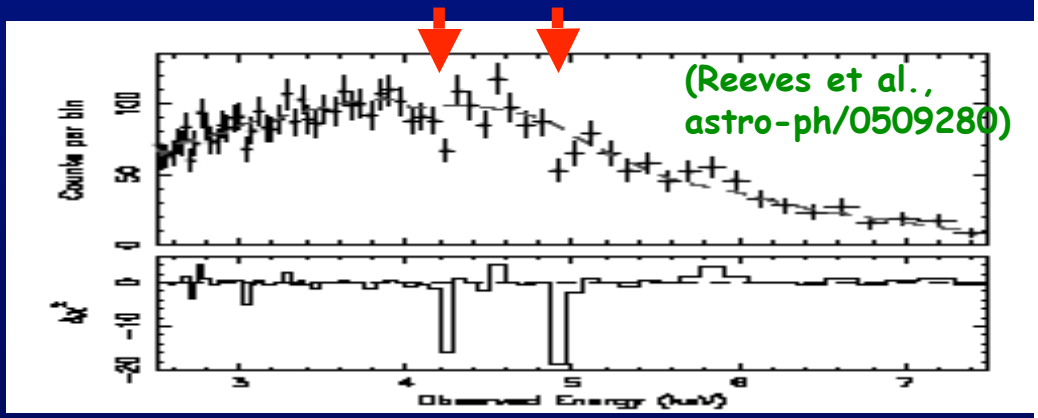


(Longinotti et al., submitted to A&A.)





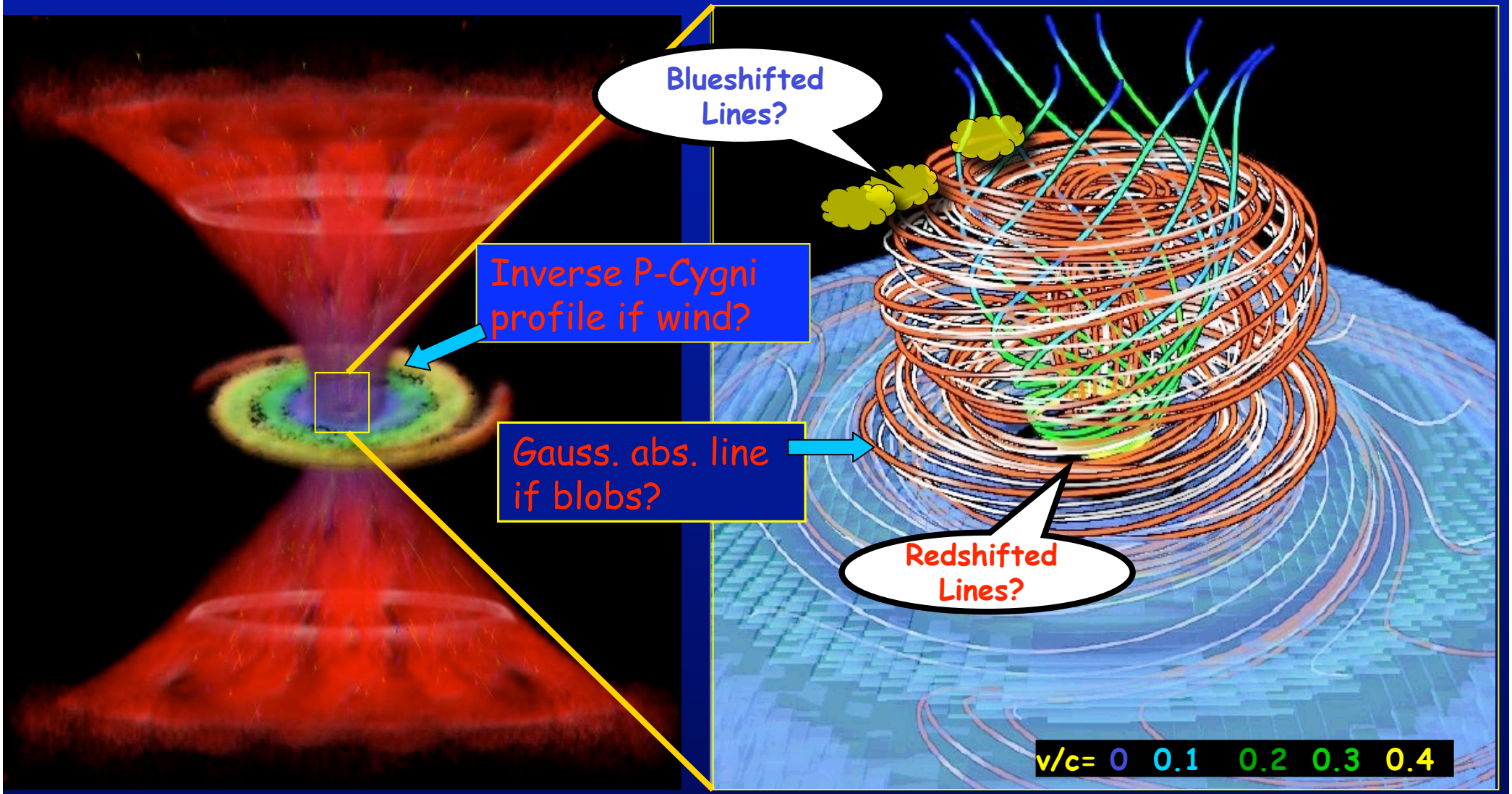
PG1211+143 (z=0.08) Chandra data



i) Fake lines?
ii) (very) wrong continuum (WA)?
iii) 2 different lines? ⇒ 1 narrow + 1 Kerr (red, reverberation, tail of a Kerr line ?)
iv) 1 relativistic line with resonant absorption?

⇒ Direct probe of relativistic bulk inflows! (v~0.1-0.3c)

Not only winds and accretion disk, but also outflowing and inflowing clouds?...



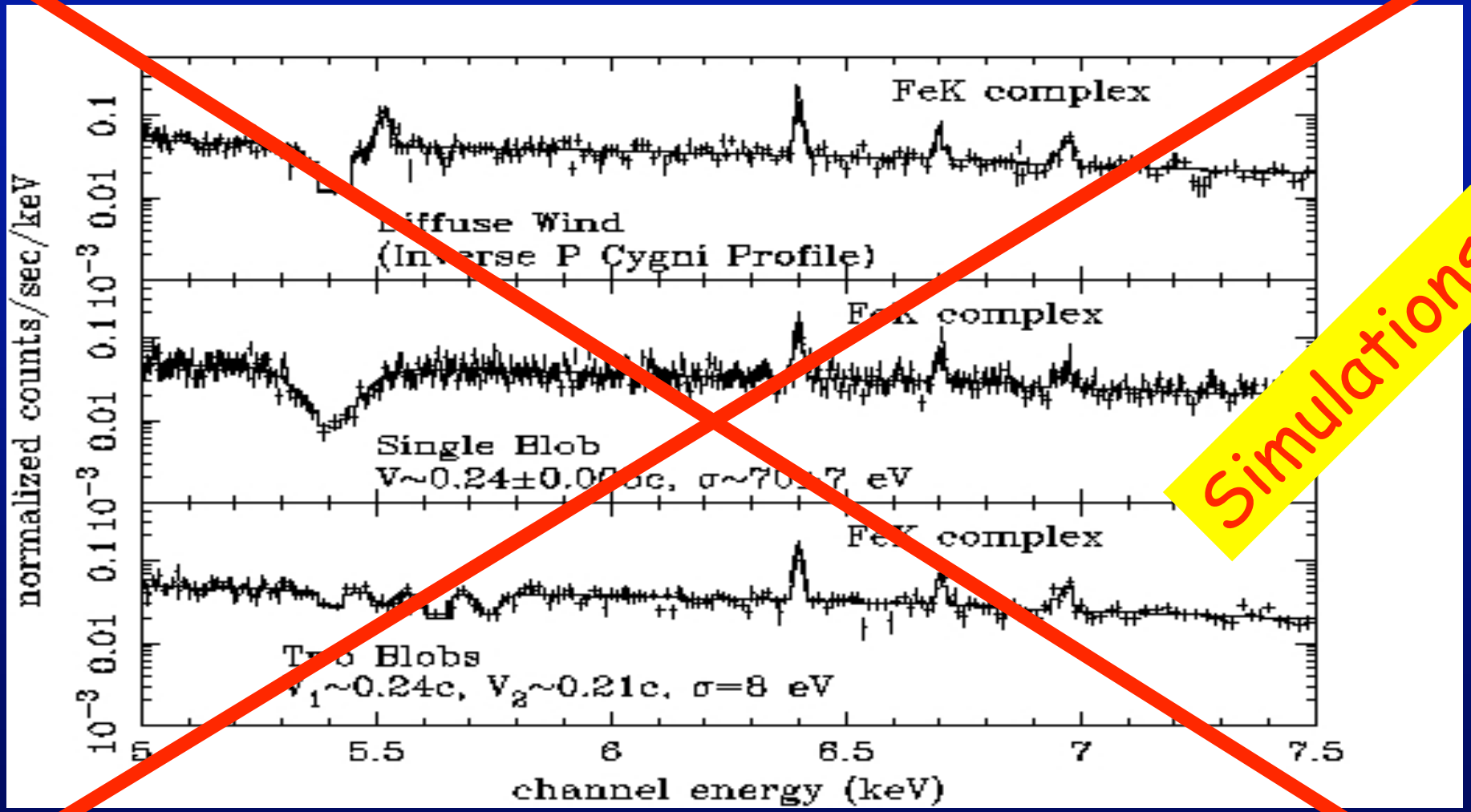
Quasar wind model by Elvis 2000

Magnetic Tower by Kato et al. 2003

(see also Lynden-Bell 2003)

Unfortunately XRS on-board ASTRO-E2 is lost

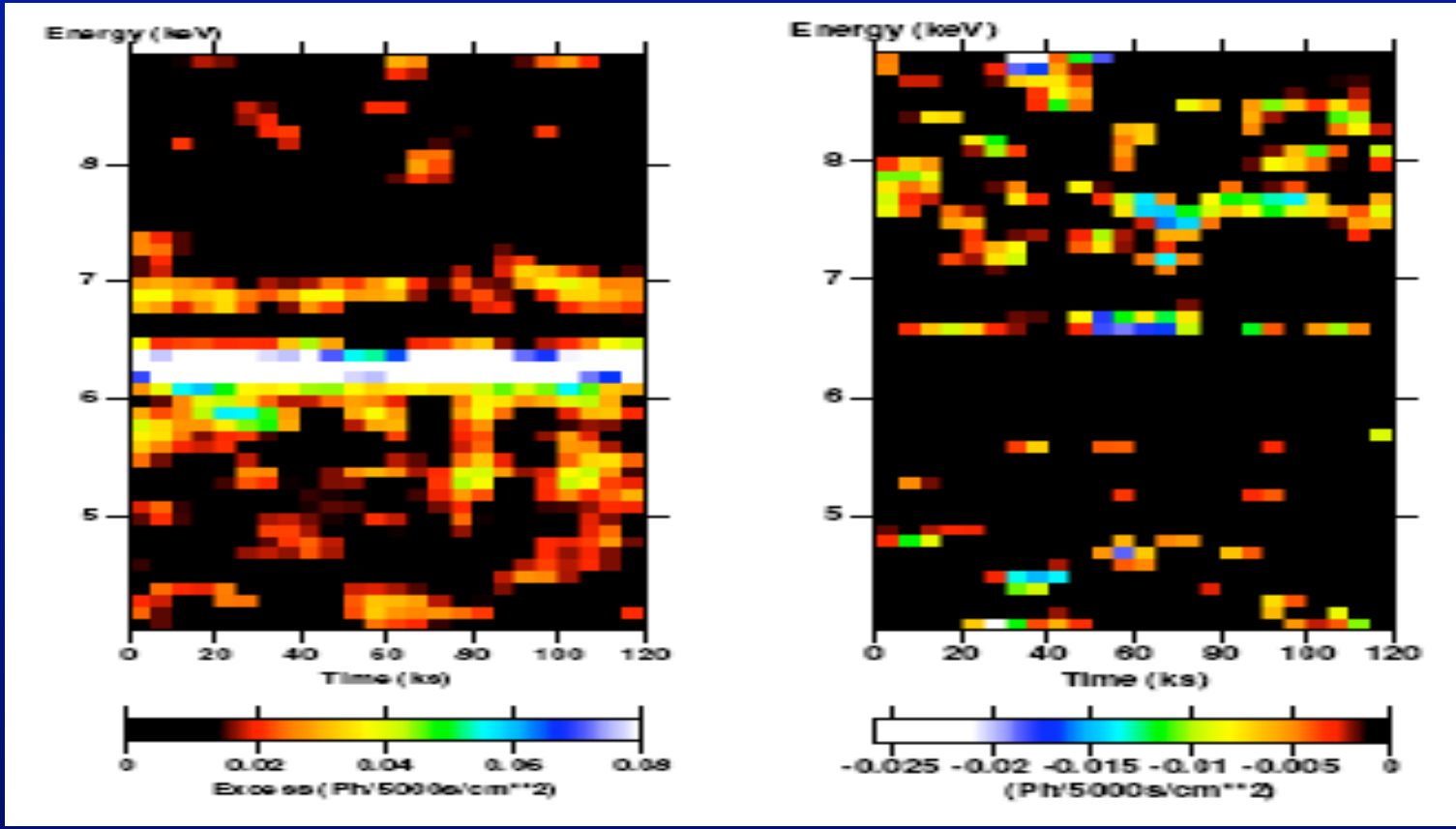
Mrk 509, Astro-E2 simulation 100 ks



Simulations

High energy resolution to distinguish beetwen wind and blob(s) (line profile)

Smeared disc emission? Or Smeared outflow/jet absorption?



This is the way to go!

Map on dynamical timescales not only in emission but also in absorption!