How energetic are the fast ionised outflows in AGN?

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• outflows from AGN have been proposed as a means of quenching galaxy growth and in preventing cooling flows in cluster cores

• however direct observation of sufficiently powerful outflows has been generally lacking

• a notable exception is the luminous Seyfert/QSO PG1211+143 which – perhaps crucially – is probably accreting at a few times Eddington

• repeated XMM observations (also Suzaku) over 6 years have shown the outflow to be persisting

and now

• ionised emission in stacked XMM spectra indicate the fast outflow has a large covering factor, confirming a high mass rate and mechanical energy > 10% of L_{Edd}

PG1211+143 is a bright, narrow emission line quasar at z ~ 0.0809

L_{bol} ~ 6 x 10^{45} ergs/s
M_{BH} ~ 4 x 10^{7} M_{Sun} accretion ~ Eddington rate

XMM made a ~ 50 ks observation in June 2001 revealing strong, blue-shifted absorption lines, interpreted as an ionized outflow at v~0.1c. Similar observations by XMM/Chandra (2004), and Suzaku (2005) were consistent though the absorption was weaker.

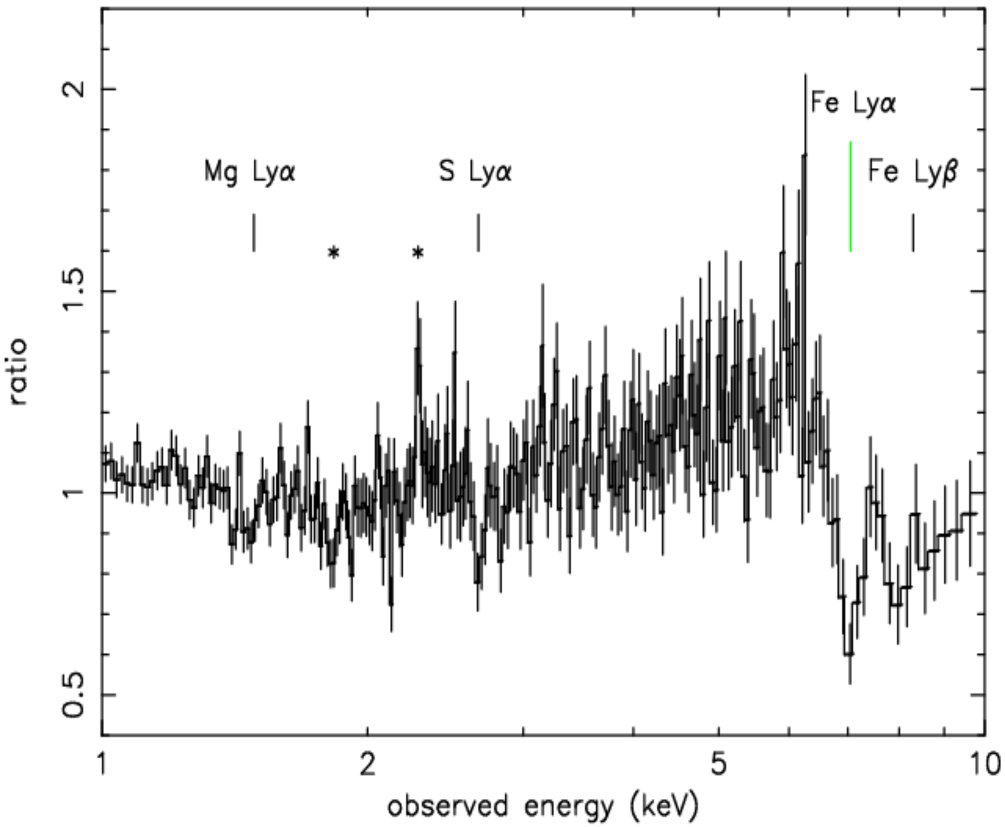
2 further XMM observations in 2007 have now confirmed the fast outflow is persisting while analysis of the ionised emission spectra have quantified the collimation/covering factor.

In turn that now allows the mass rate and mechanical energy in the flow to be determined.

Recall the initial 2001 observation with XMM

- 2001 pn spectrum* showed absorption lines at ~7.1, 2.7 and 1.5 keV
- identified with Ly-alpha of Fe, S, Mg (del chi-sq: 69/3, 17/2, 16/2)
- >>> high velocity outflow (0.09+/-0.01c) in highly ionised gas

* GT observation of Martin Turner



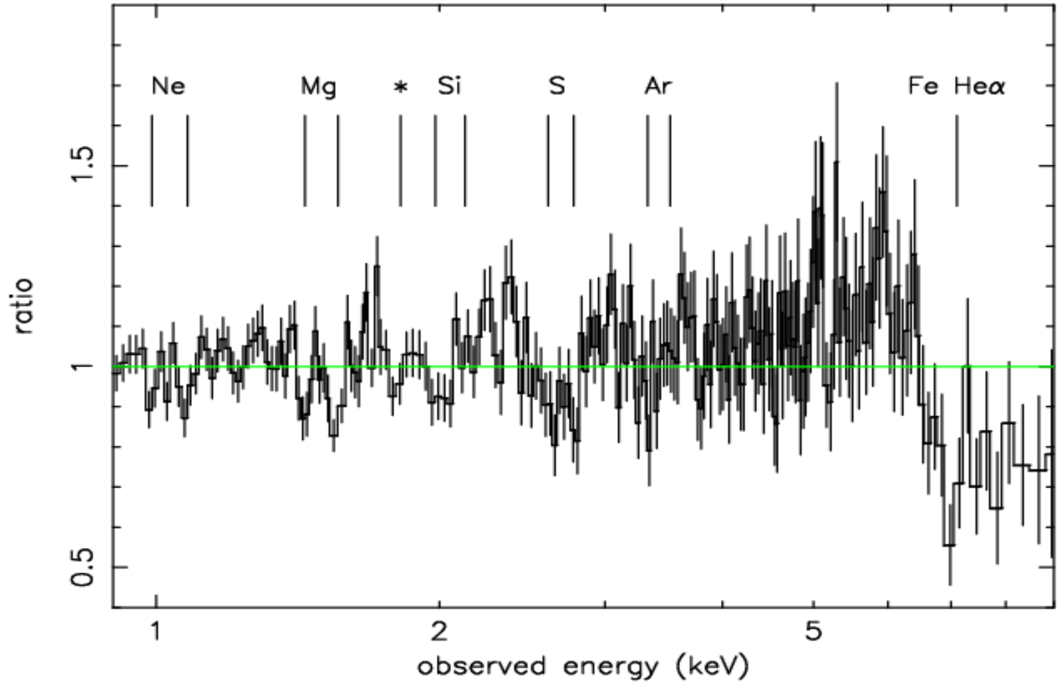
mass rate for radial outflow
~ 1 M_o/ yr assuming CF ~1

with mechanical energy
~ 10% of L_{bol}

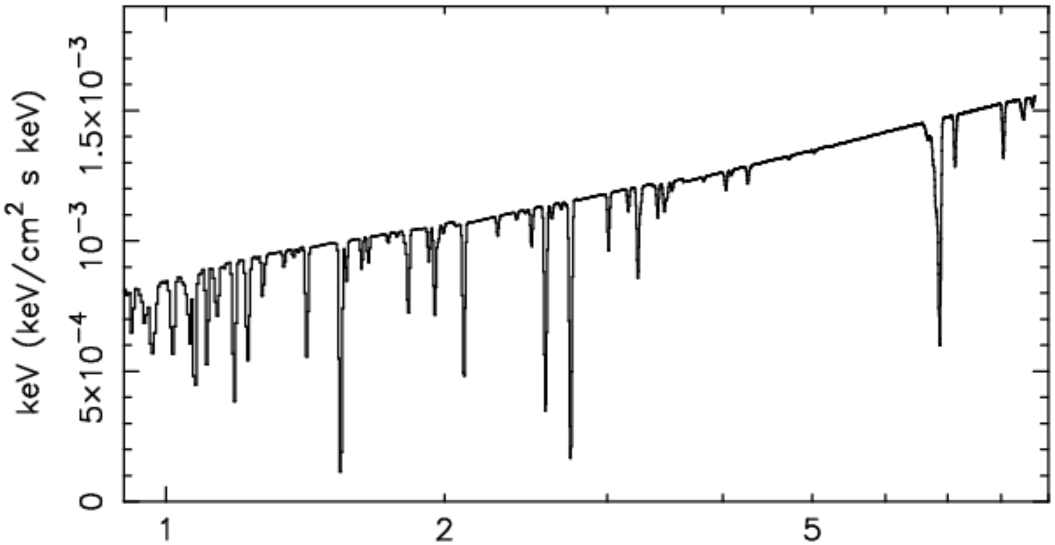
Questions:

v/c depends on correct i.d.

flow collimation unknown



higher resolution XMM MOS data removed FeK absorption line ambiguity, confirming (a higher) velocity



XSTAR photoionised absorber with xi~10^3

K-shell absorption from H- and He-like ions of Ne, Mg, Si, S and Fe

>> v~0.13+/-0.01c

Pounds and Page (MNRAS,2006)

In a radial outflow, with b the fractional solid angle of the flow the mass rate is

$$\dot{M}_{out} = 4b\pi r^2 n v m_p$$

We measure v directly and obtain nr^2 from L_{ion} / xi

but what is the value of ‘b’, the collimation of the outflow?

- increasing number of AGN with fast outflows suggests flows NOT tightly collimated (but note Vaughan and Uttley conclusion that many Fe K absorption line detections were of marginal significance)
- a direct measure of the collimation angle, or the covering factor can be obtained from emission (via scattering or recombination) from the ionised outflow

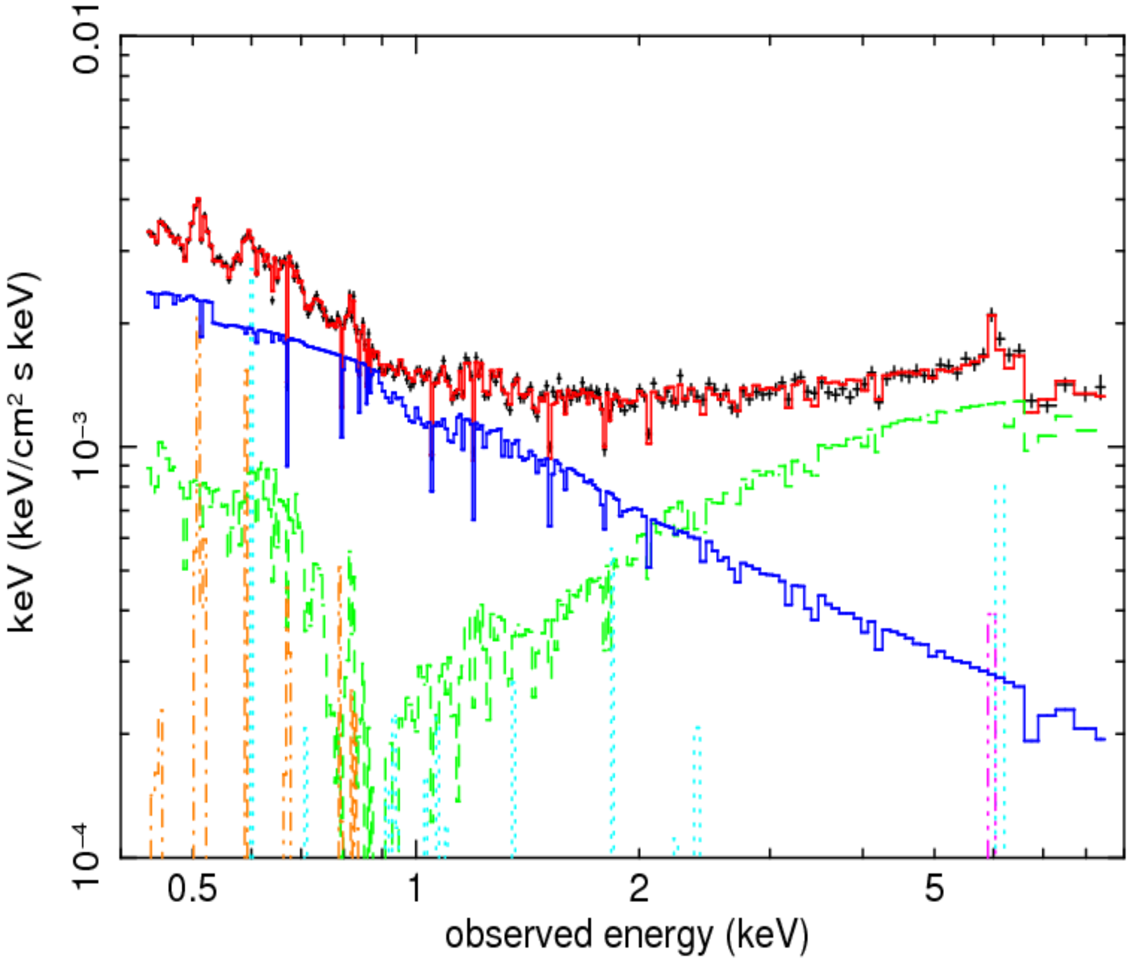
This has now been done for PG1211+143 by

i) quantitative modelling of the broad-band X-ray spectrum

ii) resolving the PCygni profile in FeK

Making full use of EPIC spectra of high statistical quality
NB response function very smooth away from known absorption edges

Fitting a broad band spectral model * quantifies physically consistent absorption and emission spectra



power law continua with photon indices ~2.1 and ~2.9

high ionisation absorber and moderate ionisation absorber

plus scattering and recombination emission from absorbing gas

* Pounds and Reeves MNRAS 2007, 2009

Component luminosities from modelling the stacked EPIC spectra

- observed luminosity (0.4-10 keV) ~ 1.5 x 10^{44} ergs/s
- absorption-corrected luminosity ~ 2.2 x 10^{44} ergs/s (mainly in PL1)

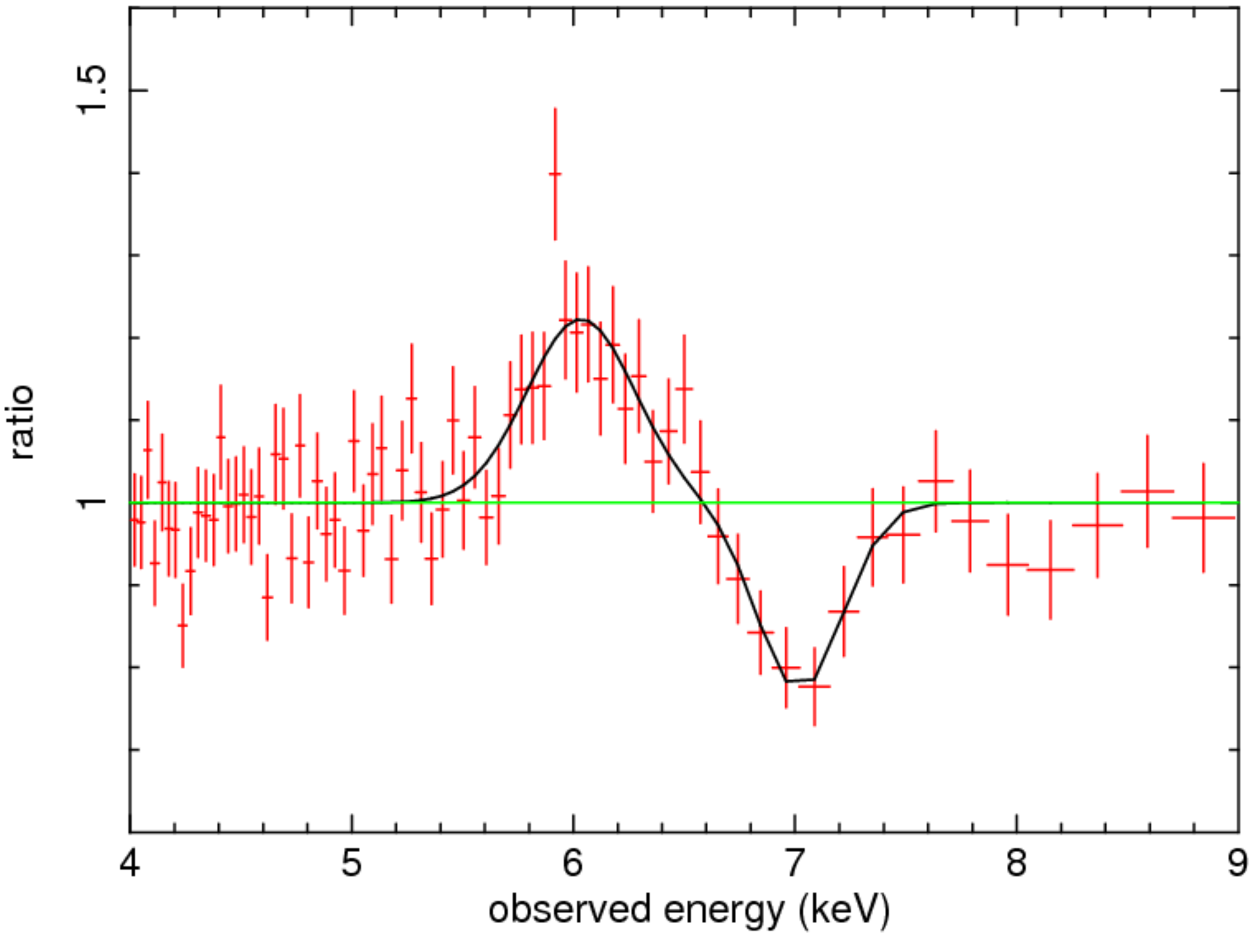
in particular:

- absorption by high ionisation outflow ~ 1.3 x 10^{43} ergs/s
- luminosity of high ionisation emitter ~ 4 x 10^{42} ergs/s

→collimation/covering factor b ~ 0.3

Nb emission line spectrum required Gaussian broadening to get good fit

Individual spectral features sufficiently well determined to provide separate estimates of outflow geometry



PCygni profile of Fe K emission and absorption principal components of PCygni profile are identified with FeXXV in the primary outflow. Information on flow geometry from strength and width of emission line

FeXXV absorption line at ~7.6 keV (rest frame) yields v ~ 0.12c
width ~ 150 eV (1 sigma) >> velocity spread ~ 0.11- 0.13c

FeXXV emission line at ~6.7 keV (rest frame), mean v ~ 0
width ~ 300 eV (1 sigma)
>> velocity broadening ~ 27000 km/s FWHM

---> collimation factor b ~ 0.5 for radial flow

Comparable EWs suggest b ~ 1 for pure resonance scattering;
lower if significant recombination from FeXXVI and XXVII

From all the above estimates we conservatively assume b ~0.4 for the highly ionised outflow in PG1211+143, yielding:

a mean outflow mass rate ~ 3 $M_{\mathbf{sun}}$/ yr (M$_{\mathbf{acc}}$ ~ 2 M_{sun}/ yr)

with mechanical energy ~ 10^{45} ergs/s (L_{Edd} ~ 6 x 10^{45} ergs/s)

BHW model* offers a physical framework for such a powerful outflow

At low optical depth (tau~1) we expect single scattering of each photon, providing an outflow momentum

$$\dot{M}_{out}.v \simeq \frac{L_E}{c}$$

and since

$$L_E = \eta \dot{M}_E c^2$$

we expect

$$\frac{v}{c} \simeq \frac{\eta \dot{M}_E}{\dot{M}_{out}} \sim 0.1$$

while the mechanical energy in the outflow is of order

$$\dot{M}_{out}.v^2 \simeq \frac{v L_E}{c}.$$

* King and Pounds MNRAS 2003

BUT how much mechanical energy in the outflow reaches the bulge gas?

Mechanical energy ~ 10^{45} ergs/s launched from R~100 R_S

- will shock (and snowplough) when hitting the ISM, the shocked gas being cooled to its Compton temperature by radiation from strong BBB

- cooling time then critical in determining how much of the initial outflow energy is radiated away (UV or soft X-rays ?)

- if cooling times are short then the outflow will be momentum driven (*)

(*) Andrew King will discuss this possibility in relation to the M-sigma relation on Thursday afternoon. Meanwhile we can ask the question ---

Can the residual flow energy unbind the ISM in the galaxy bulge?

consider a merger event which doubles the black hole mass and the bulge mass, noting $\sim M_b \sim 10^3 M_{BH}$

Accretion at the Eddi $E_{mech} \times 10^8\ yr \sim 3 \times 10^{60} \eta_{mech}\ erg$ nechanical energy into the bulge

$$\sim M_b \sim 10^3 M_{BH}$$

The bulge mass increases by

$$E_{bind} \sim M_b \sigma^2 \sim 8 \times 10^{58}\ erg$$

and thus $\sigma = 200\ \mathrm{km/s}$ to unbind it,

taking from the M-sigma relation

$$\eta_{mech} > 0.02$$

Provided the outflow retains a fraction of the original energy it will unbind the bulge gas (and curtail further growth of bulge and BH)

Summary

- blue-shifted absorption lines in the luminous Seyfert 1 galaxy PG1211+143 show persistent highly ionized outflow of v ~ 0.11-0.13c

- the outflow mass rate and mechanical energy in the high velocity outflow is quantified by estimates of the covering fraction, CF ~ 0.4

- outflow mass rate is then ~ Eddington accretion rate

- mechanical energy is of order $v.L_{Edd}/c$ and could unbind the bulge gas if continued through a merger event of 10^8 years