XMM-Newton and the study of powerful AGN winds

Ken Pounds and Andrew Lobban (University of Leicester, UK)

15 years of XMM observations have established that:

- ultra-fast, highly ionised winds (`UFOs') are common in radio-quiet AGN
- a simple theory of Eddington-limited accretion correctly predicts the typical velocity (~ 0.1c) and high ionisation state of such winds
- providing a thrust ~ L_Edd /c accounting for the M – sigma relation

However, a recent extended XMM observation of PG1211+143 suggests that a static and axisymmetric accretion disc is too simple a picture

- targetted XMM observations of AGN over the next decade offer exciting potential for probing the structure of the inner accretion disc and exploring how the SMBH grows in the lengthy period between mergers

Shakura & Sunyaev (1973) first noted that a BH supplied with mass at a super-Eddington rate would expel matter from its accretion disc so as to never exceed the local Eddington luminosity

developing that concept for a Black Hole Wind (*), with unit optical depth and single photon scattering yields a wind momentum $\dot{M}_{out}.v \simeq \frac{L_E}{c}$

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

we expect a wind velocity $\frac{v}{c} \simeq \frac{\eta \dot{M}_E}{\dot{M}_{out}} \sim 0.1$

with mechanical energy $\dot{M}_{out}.v^2 \simeq \frac{vL_E}{c}.$

(*) King and Pounds MNRAS 2003

such an Eddington wind also has a high ionisation parameter $\xi = \frac{L_i}{NR^2}$

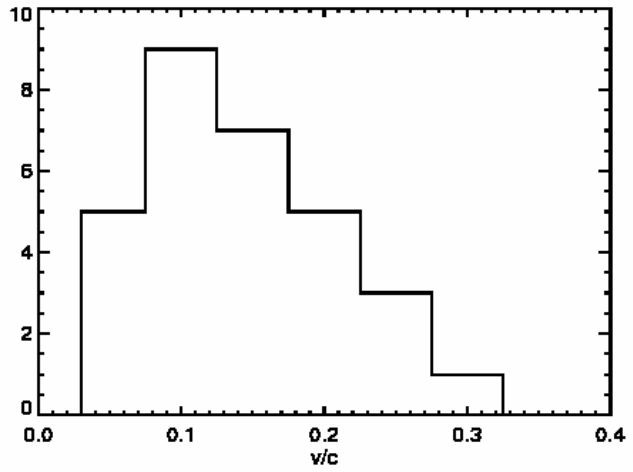
by combining $\dot{M}_{out}.v \simeq \frac{L_E}{c}$ and $\dot{M}_{out} = 4b\pi r^2 nvm_p$

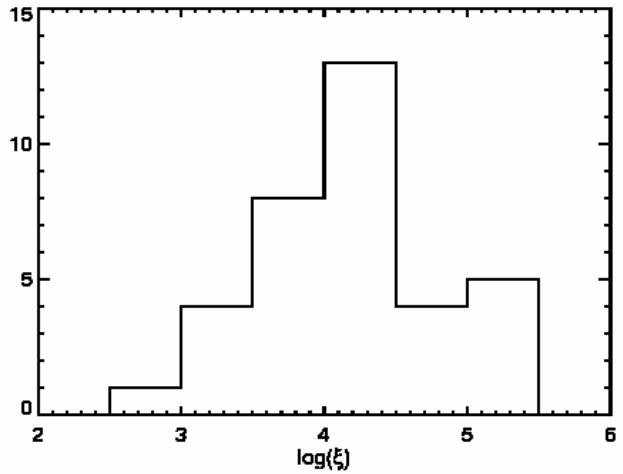
we find $\xi = 3 \times 10^4 \eta_{0.1}^2 l_2 \dot{m}^{-2}$,

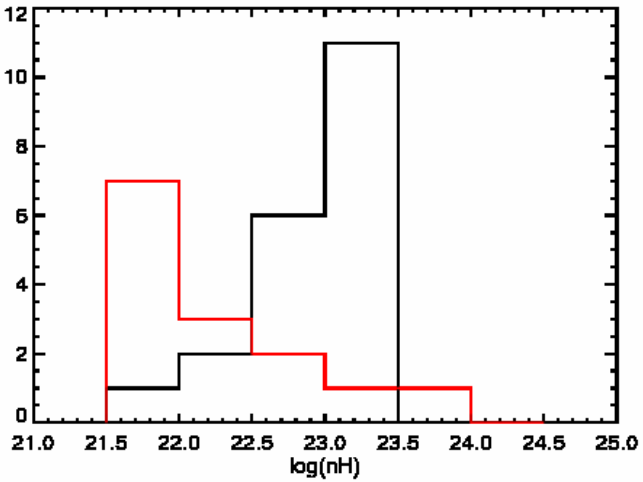
where $l_2 = l_i/10^{-2}$, and $\eta_{0.1} = \eta/0.1$

powerful X-ray winds are best/only seen in Fe K

Comparison with generic UFO properties from XMM-Newton and Suzaku







UFOs in 29 radio quiet AGN (~ 1 in 3)

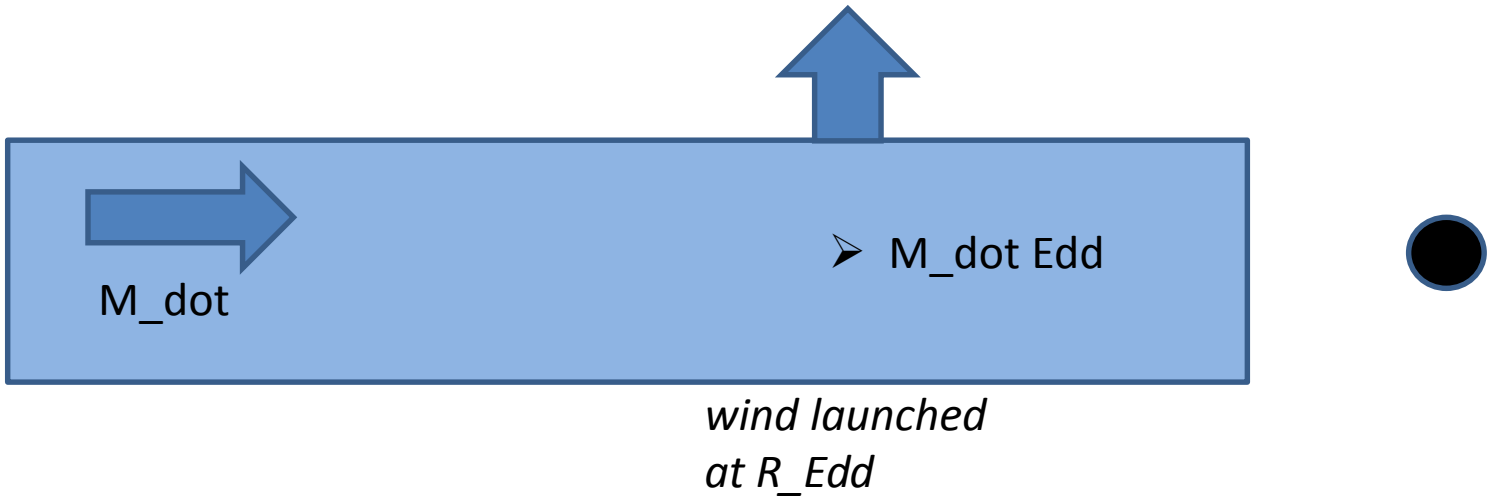
Tombesi et al 2010, 2011

Gofford et al 2013

UFO properties consistent with predictions of BHW model

King and Pounds ARAA 2015

In a static axisymmetric disc a unique wind is launched where the accretion rate exceeds the local Eddington rate



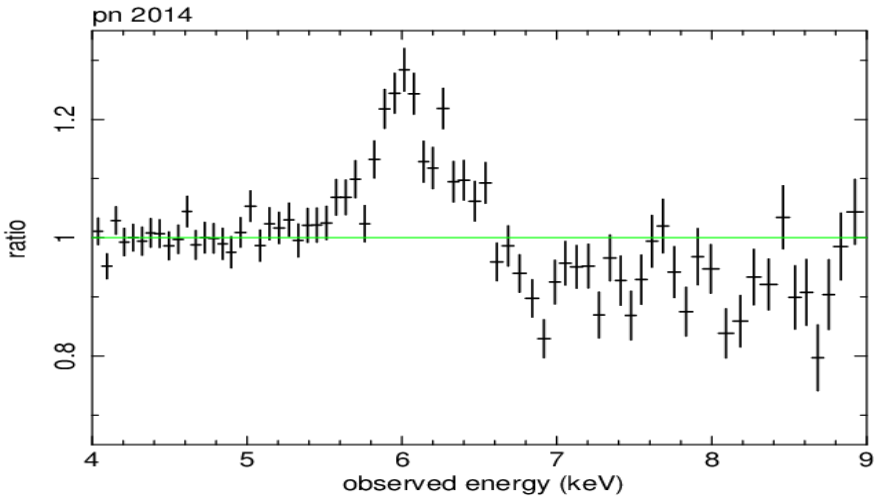
R > R_Edd - no wind

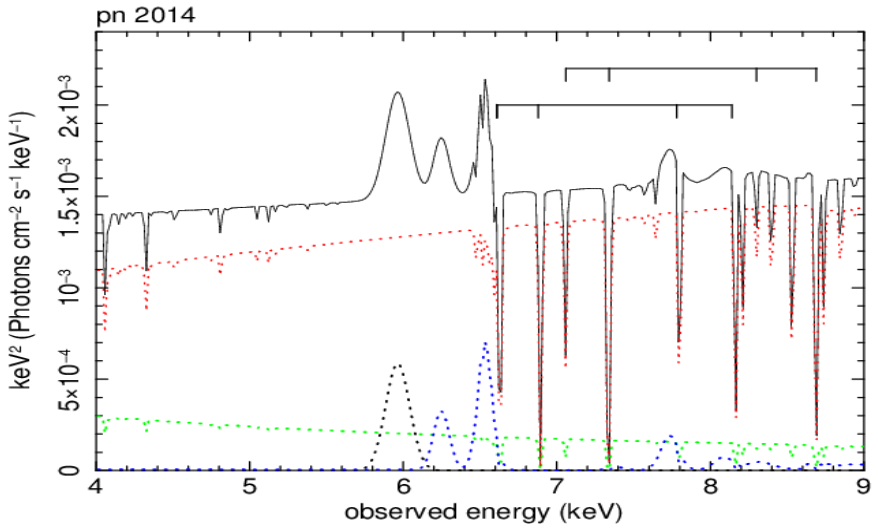
R < R_Edd - wind faster/weaker

excess matter is expelled as a wind with the local escape velocity v_esc ~ 0.1c corresponding to a launch radius R_Edd ~ 100 Rg

NB for a BH mass of 10^7 M_sun, the viscous timescale at R_Edd ~ 1 year

A long XMM-Newton observation of PG1211+143 in 2014





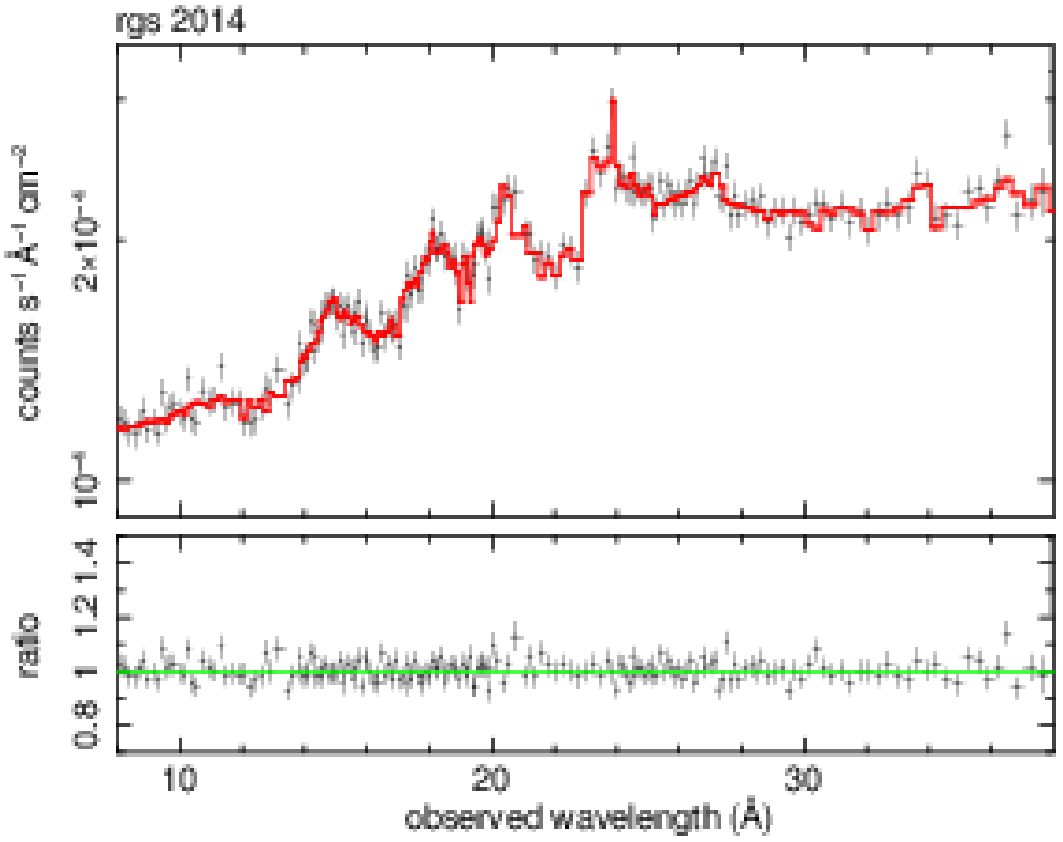
deep (630 ks) exposure revealed fine structure in FeK absorption line spectrum (*)

finding dual high column UFO components with velocities

v ~ 0.13c and v ~ 0.066c

* Pounds et al MNRAS 2016, 457, 2951

RGS data identified the same dual velocities in the soft X-ray spectrum
a lower ionisation parameter indicating embedded higher density matter



plus confirmation of a still higher outflow velocity
v ~ 0.19c, seen with marginal significance in the pn data

Pounds et al, MNRAS, 2016, tmp. 710

the diagnostic potential of multiple velocity winds

- continuum driving from a static axisymmetric disc produces only a single **primary** (high column) wind
- but extended XMM-Newton observations of PG1211+143 have shown multiple outflow velocities
- suggesting the inner disc structure is *not* static and axisymmetric
- with BH growth (between mergers) dominated by random accretion episodes
- warping and 'tearing' of a putative disc (Nixon et al 2012) could lead to accretion dumps in the inner disc region, with local super-Eddington events marked by the launch of a wind
- the timescale for related changes in the wind profile are likely to match well-sampled XMM observations over several years

Torn fragments of the putative disc form in rings centred on the BH. As the rings precess at different rates they collide, shock and cool, losing momentum and energy, with matter being dumped on the inner disc.
Multiple rings→different amplitude variations in mdot→multiple wind velocities

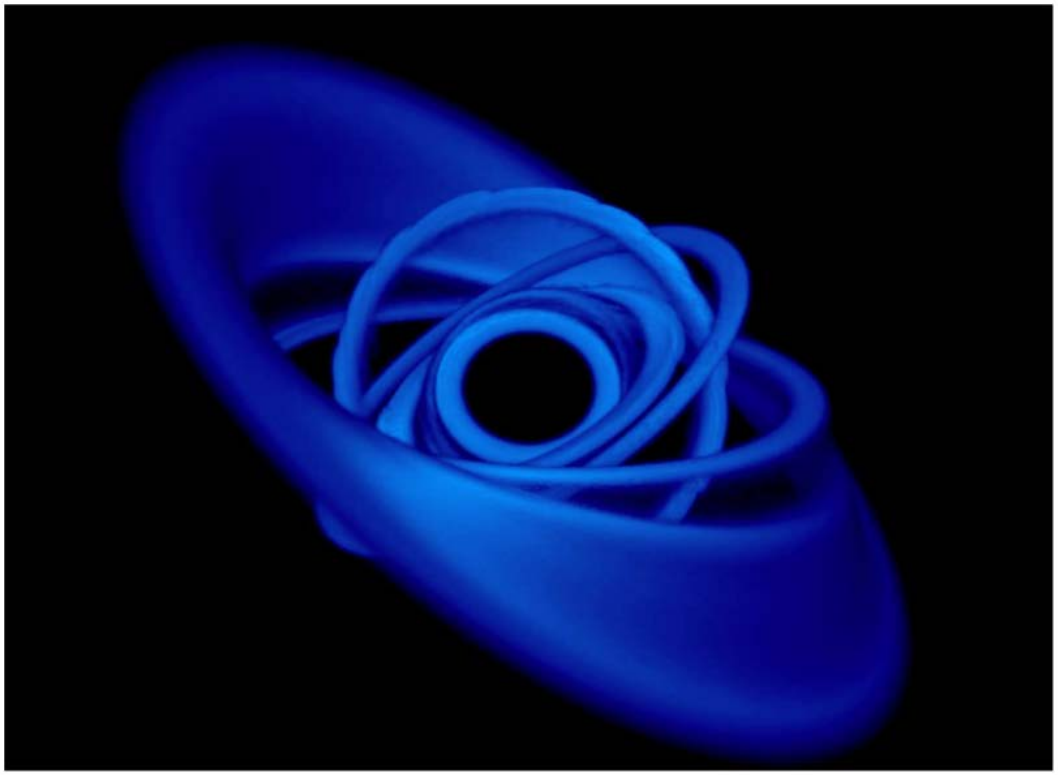
Tearing radius $\sim 100 R_{\rm g}$

$\Longrightarrow \quad v_{\rm wind} \sim v_{\rm esc} \sim 0.1c$

Precession timescale:

$$t = \frac{1}{2a}\left(\frac{R}{R_{\rm g}}\right)^3 \frac{GM}{c^3}$$

$$\sim 1.5 \text{ yr} \left(\frac{a}{0.5}\right)^{-1} \left(\frac{R}{100 R_{\rm g}}\right)^3 \left(\frac{M}{10^7 M_\odot}\right)$$



well-sampled observations of multiple UFOs over several years could reveal such complex feeding of the inner disc and illustrate the means by which SMBH grow

Powerful AGN winds - the next 10 years of XMM-Newton

- the discovery that powerful sub-relativistic winds are common in luminous AGN is a major outcome of 15 years of XMM-Newton observations
- such winds offer an explanation of the observed coupling of SMBH and host galaxy growth (the M-sigma effect)
- the recent discovery of multiple primary (massive) outflow velocities suggests the inner accretion disc is fractured, resulting in locally enhanced (super-Eddington) accretion events
- short variability timescales of such events are predicted to be well matched to a further decade of XMM-Newton observations
- combining well-sampled wind observations with accretion disc theory is potentially transformative for understanding the details of AGN accretion and SMBH growth!
- the discovery of multiple velocity components also suggests the likelihood of internal shocks in the wind, with implications for both the total radiative and mechanical output.