# ATHENA unrolls AGN radiative and kinetic feedback

- Science case
- Current limits

- Why ATHENA+
- Requirements

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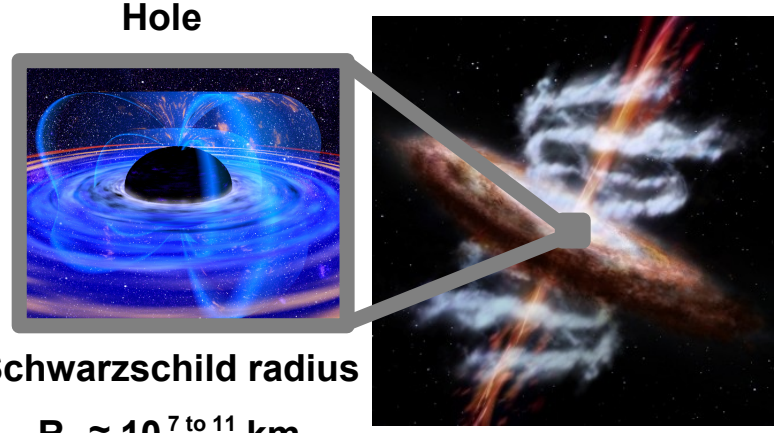
erc
European Research Council
Established by the European Commission

Cambridge X-Ray Astronomy

# Why AGN feedback is important?

Supermassive Black Hole



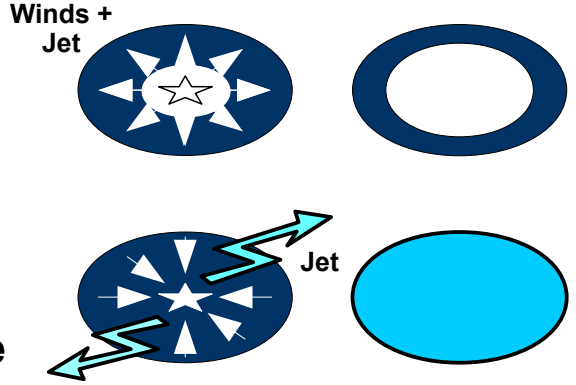
Schwarzschild radius

$R_s \approx 10^{7 \text{ to } 11}$ km

TIME

Small Scale

Large Scale



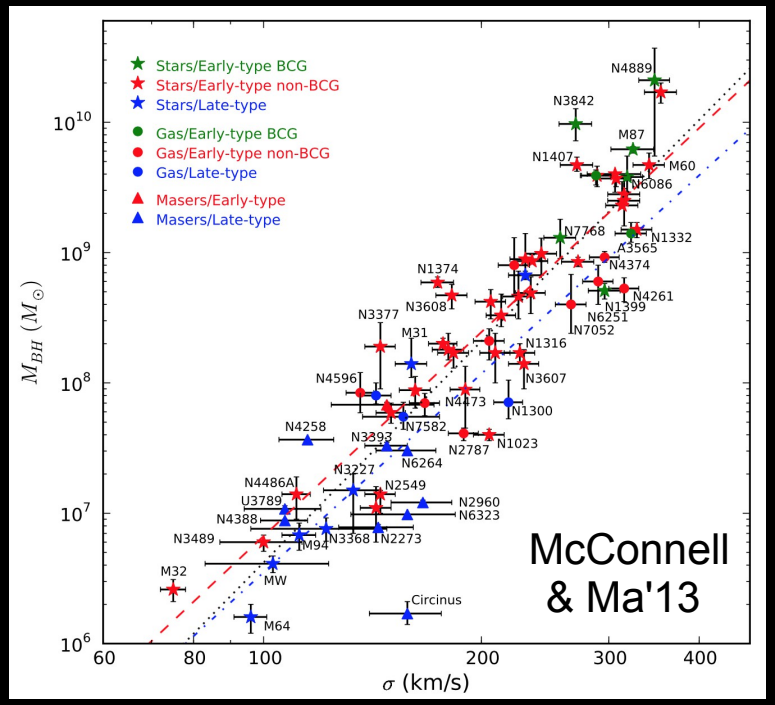

Radiative mode

Suppress star formation

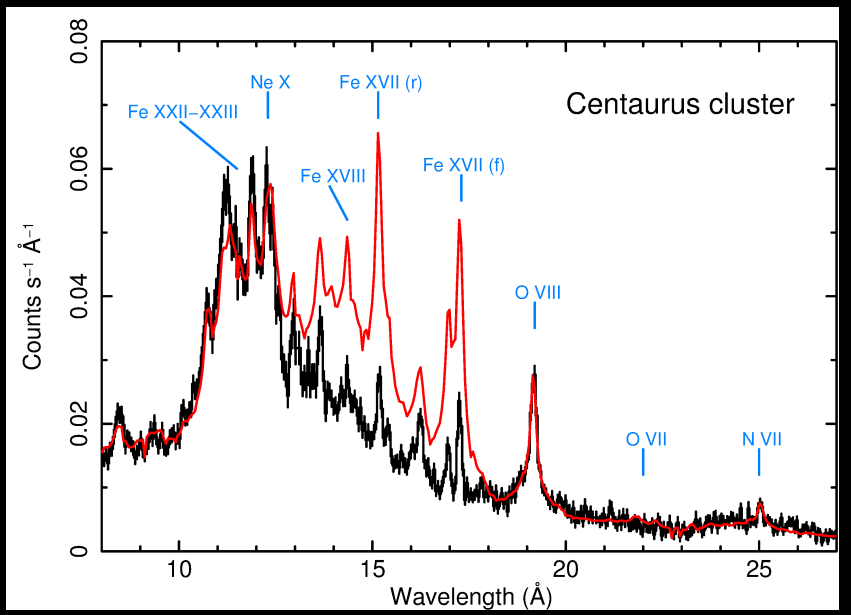
Kinetic mode

Black hole mass

Proxy of Galactic bulge mass

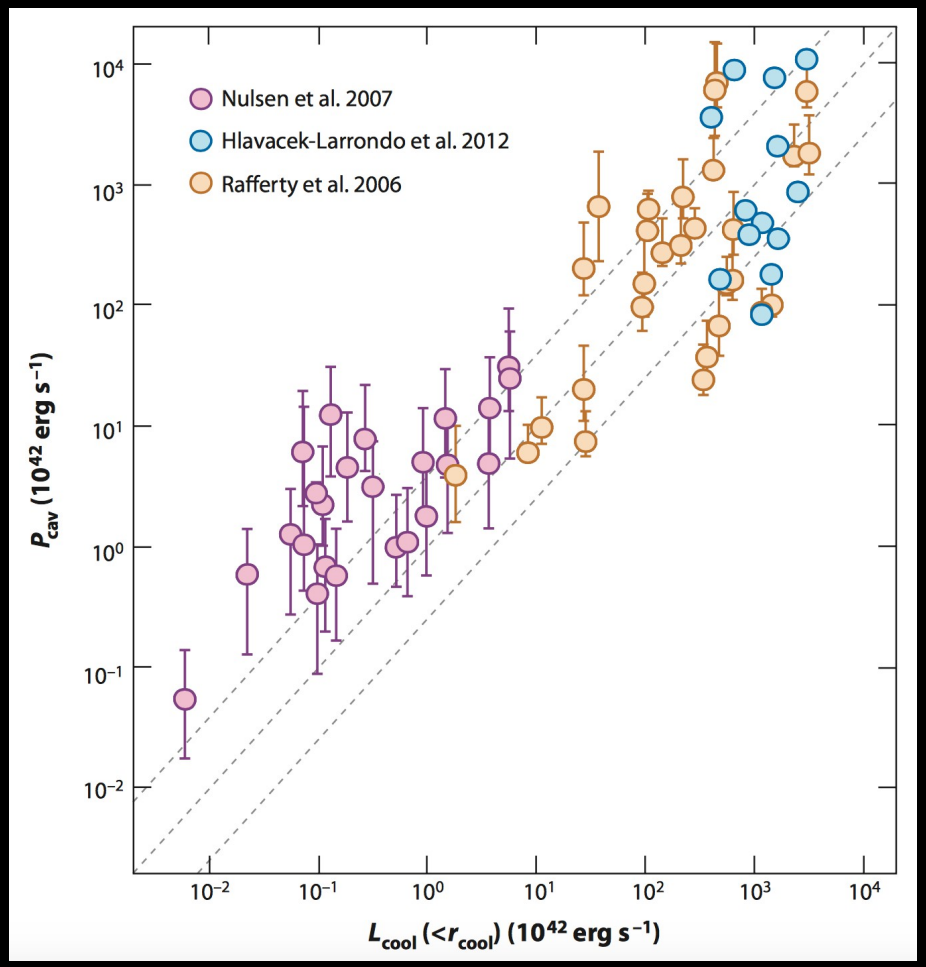



Cool gas missing in clusters of galaxies



# 1. AGN kinetic feedback

Low accretion rates, Radio jets, Clusters




Cavity power VS ICM clusters
(figure by J. Hlavacek-Larrondo)

How does heat get released and distributed?

Dissipation of Turbulence?
Sound waves?

# How to measure turbulence?

1. **Line widths**
   Doppler, direct, mostly upper limits

   Sanders+13
   Pinto+15

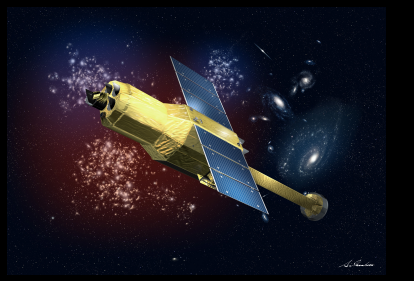
2. **Resonant scattering**
   Line ratios, indirect, mostly lower limits

   Sanders+08
   Werner+09
   de Plaa+12
   Pinto+16
   Ogorzalek+17

3. **Surface brightness fluctuations**
   Imaging, indirect, tighter limits

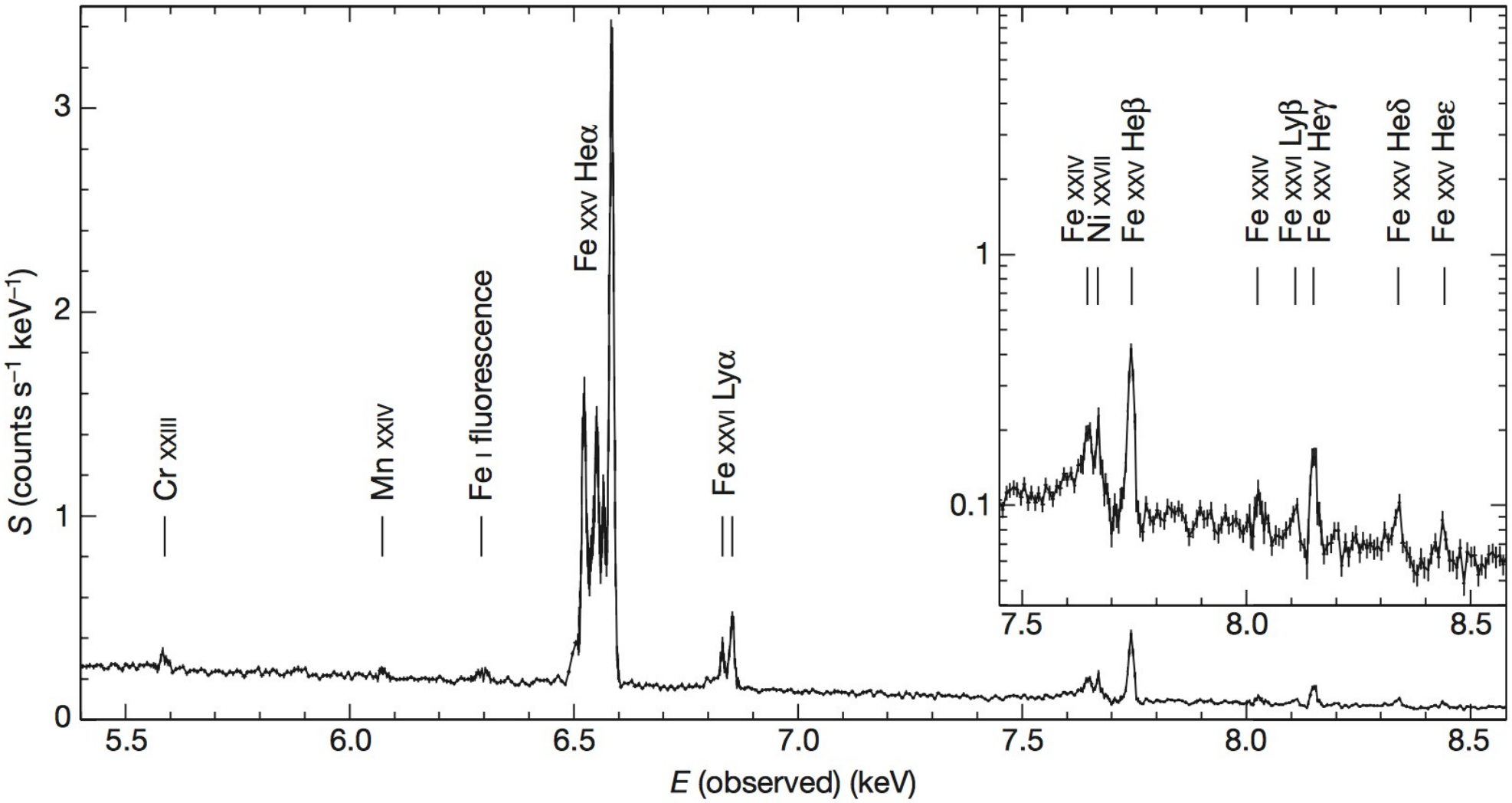
   Sanders+12
   Zhuravleva+14
   Walker+15
   Eckert+2017

# Hitomi



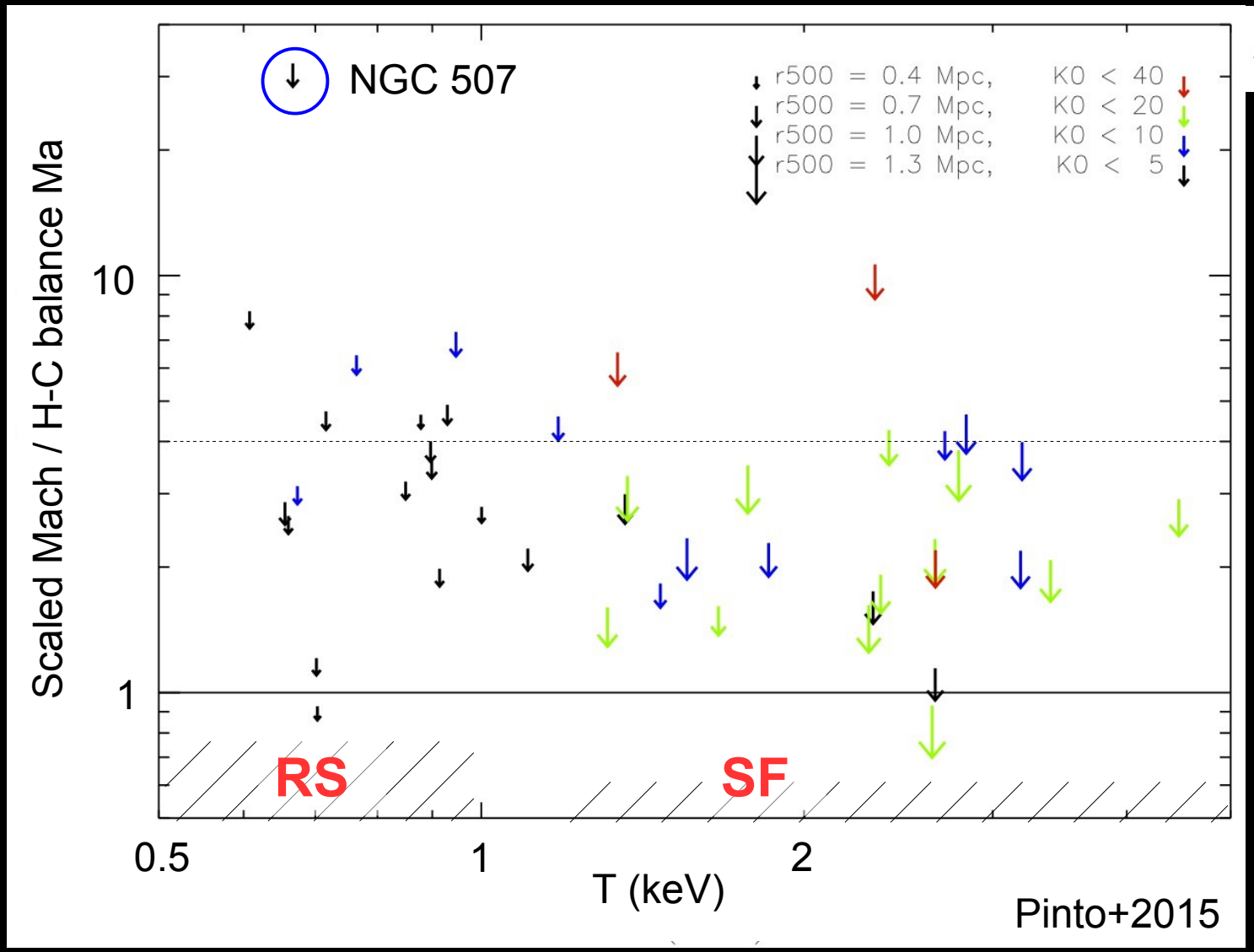
Velocity dispersion of 100-200 km/s, might be enough to balance cooling

Hitomi Collaboration (2016)



# Turbulence VS H-C balance constraints

Combining line widths (arrows), resonant scattering & surface brightness fluctuations (shades)




$$Ma_{REQ} \approx 0.15 \left(\frac{n_e}{10^{-2}\,\mathrm{cm}^{-3}}\right)^{1/3} \left(\frac{c_s}{10^3\,\mathrm{km\,s}^{-1}}\right)^{-1} \left(\frac{l}{10\,\mathrm{kpc}}\right)^{1/3}$$

Some lower limits:
Resonant scattering

(Werner+09
de Plaa+12
Ogorzalek+17)

Surface brightness
Fluctuations

(Zhu+14,Eckert+17)

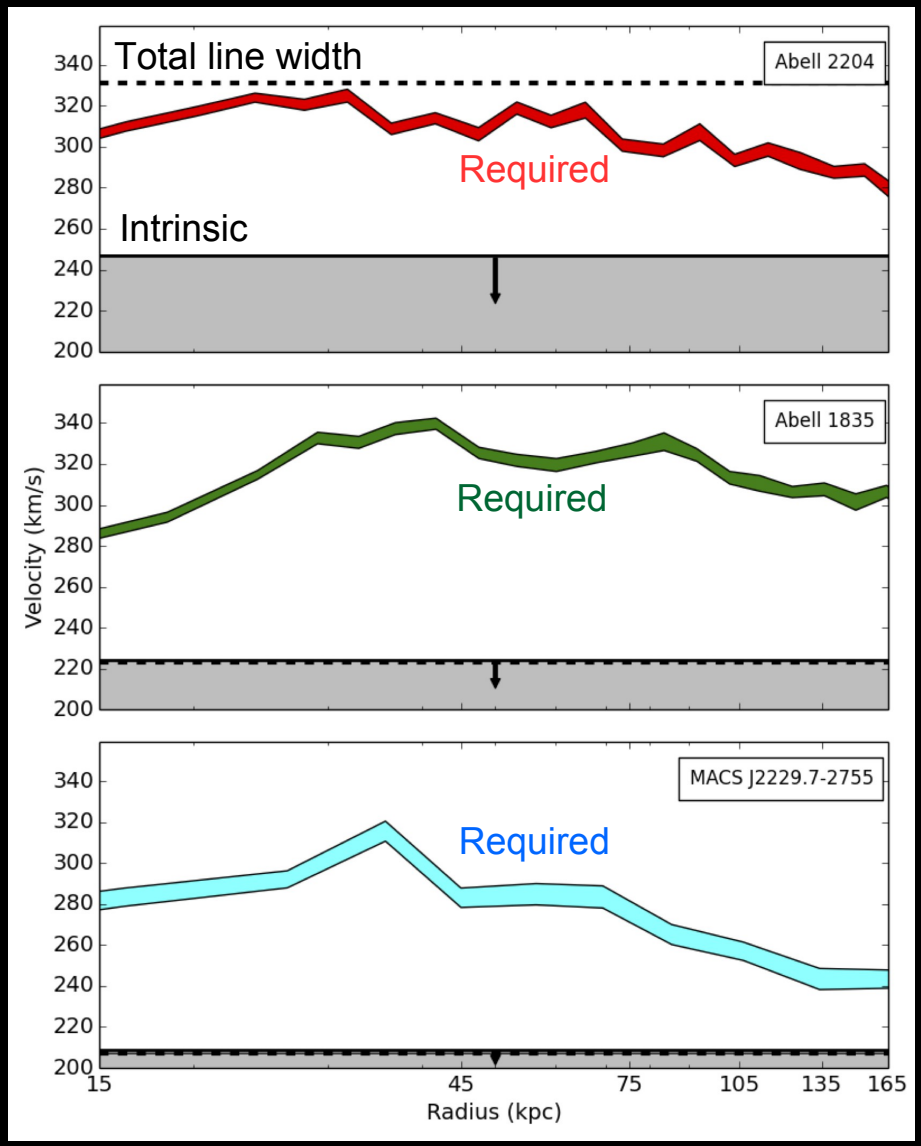
# Heating Transfer Problem

Is turbulence high enough to propagate throughout the cool core?

Assuming : $L_{Cool} = L_{Turb}$

$\rightarrow E_{thermal} / t_{cool} = E_{turb} / t_{turb}$

$\sigma_{km/s} = 5.39 \times 10^4 ( r_{kpc} T_{keV} / t_{yr} )^{1/3}$




Bambic, Pinto et al. (2018)

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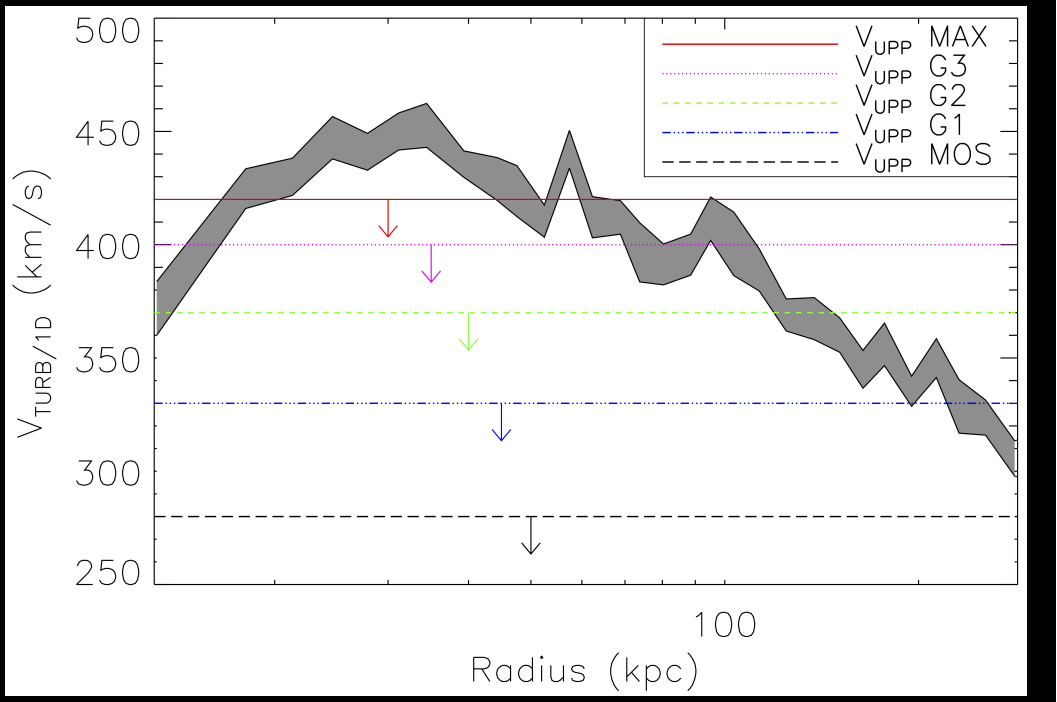


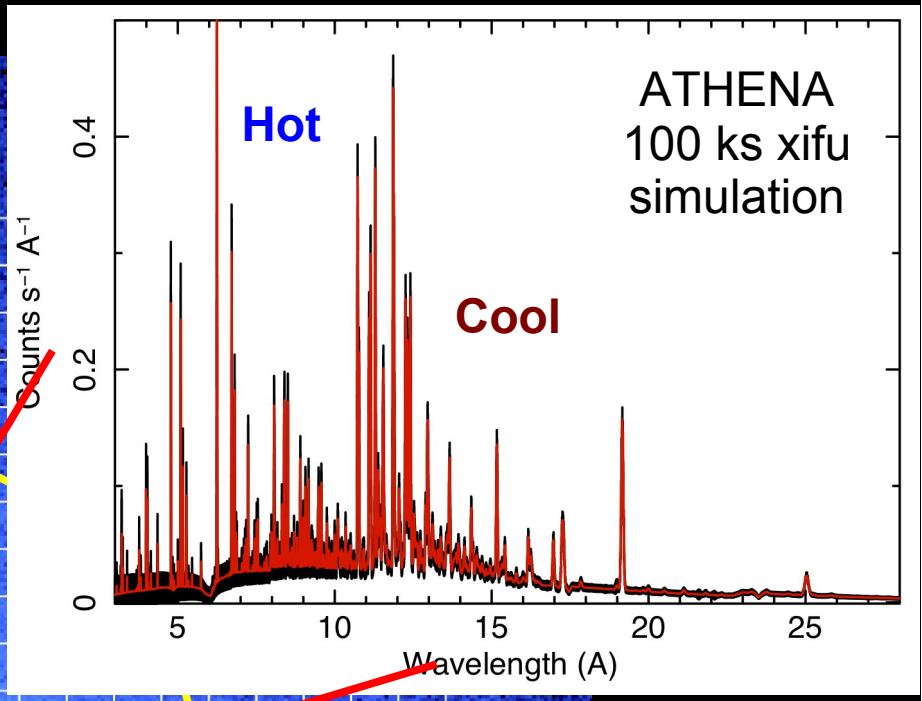

Phoenix cluster - Pinto et al. (2018)

$\sigma_{km/s} = 5.39 \times 10^4 ( r_{kpc} T_{keV} / t_{yr} )^{1/3}$

150-600 $M_{sun}$ $yr^{-1}$ cooling below 2 keV

$2 \cdot 10^{10}$ $M_{sun}$ of molecular gas (half at the peripheries of radio bubbles, Russell+17)

# Centaurus cluster




5σ region

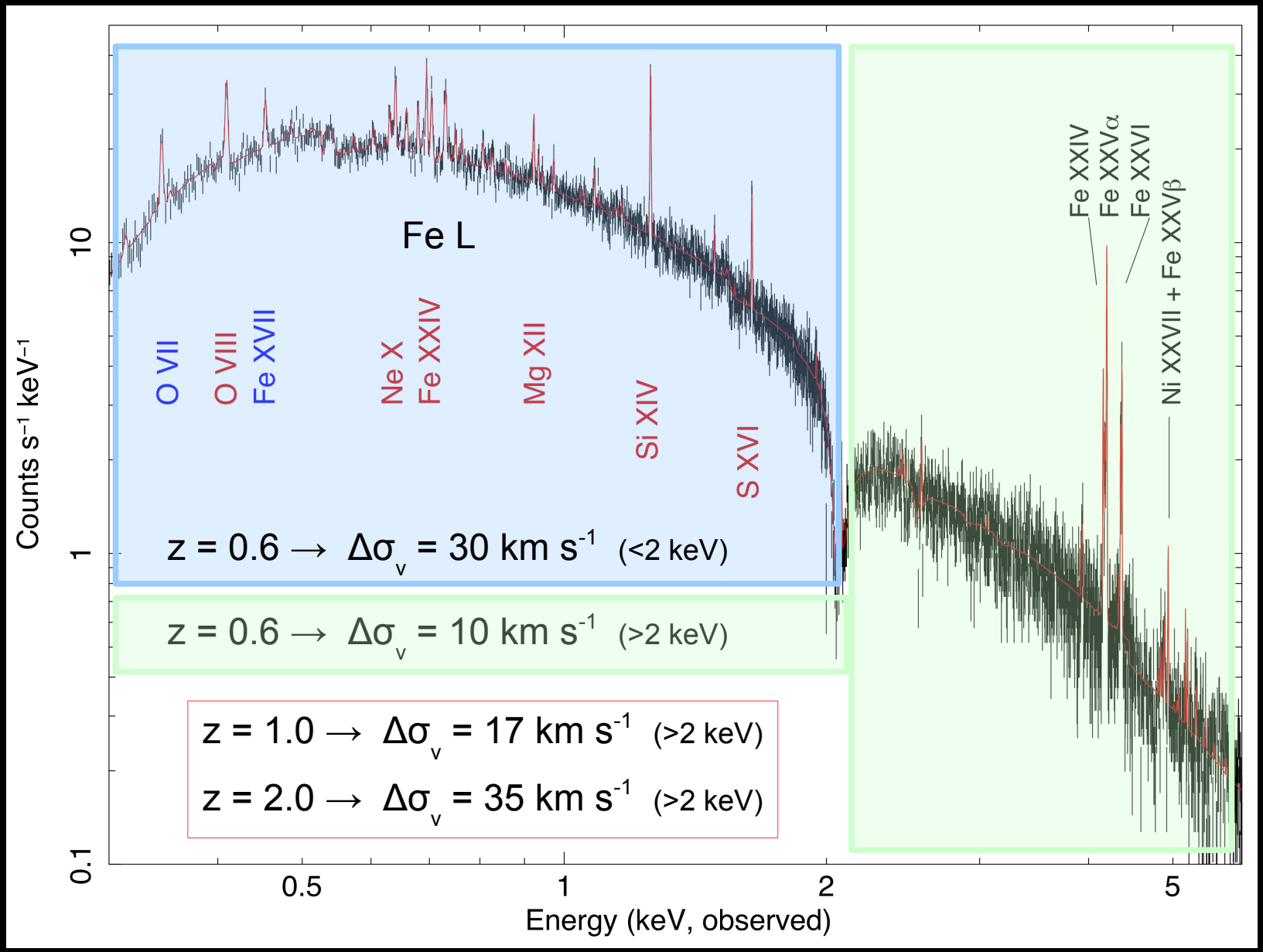
12" → PSF = 5" ?

5' x 5' grid

5 kpc

# Phoenix cluster

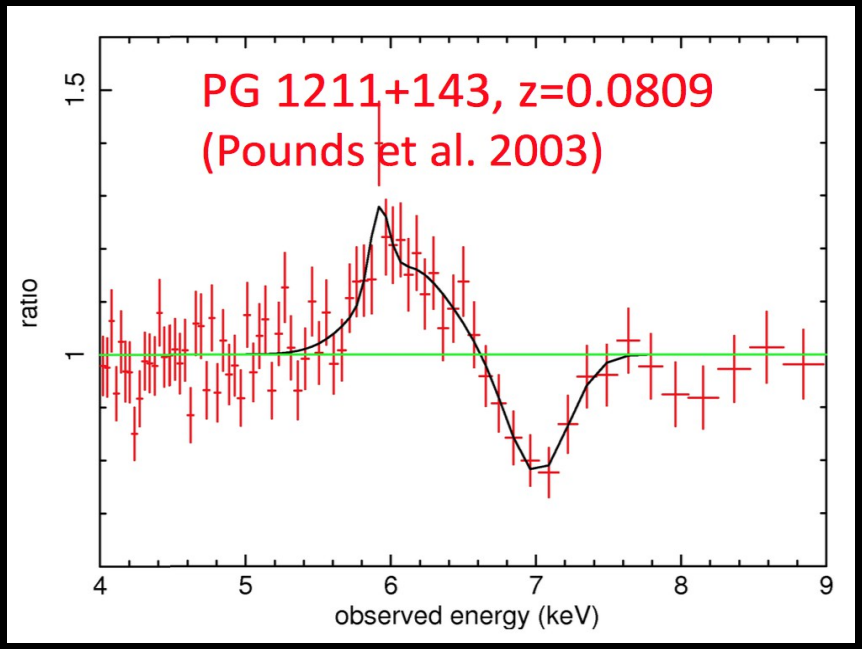
(z=0.6, 10 ks XIFU sim, $\sigma_v$ = 300 km s$^{-1}$)

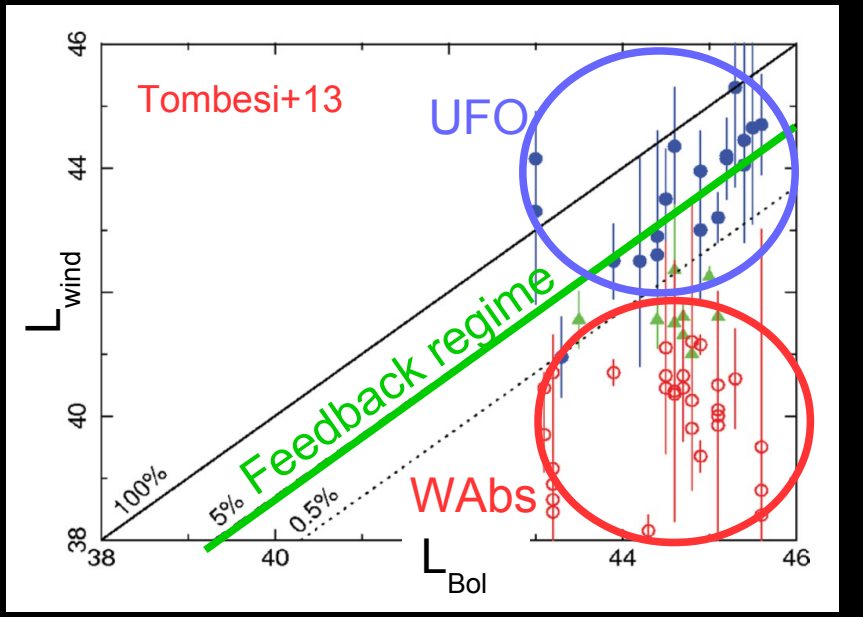



Pinto et al. (2018b)

# 2. AGN Radiative feedback

Moderate to high accretion rates, Radiation & winds, Bulges



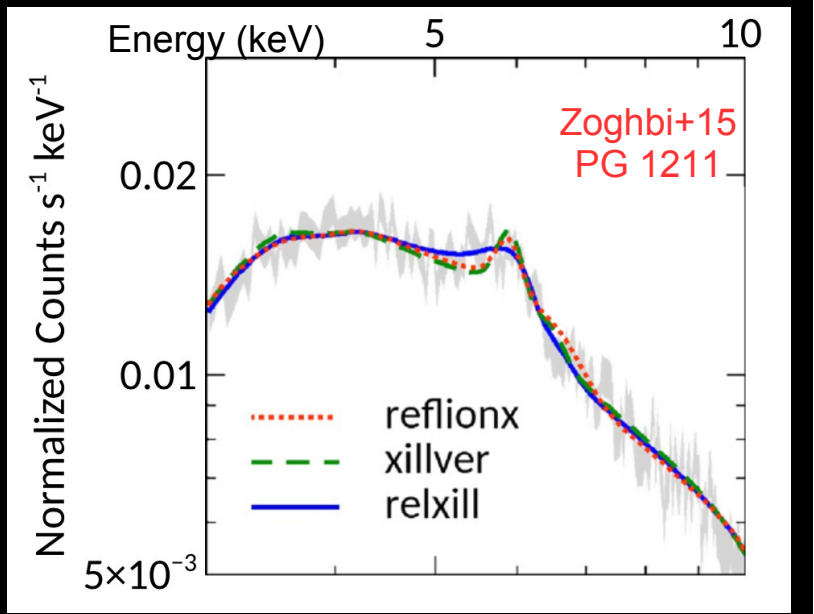




UFOs not always detected
and seem to vary

1) Variation in the column ?

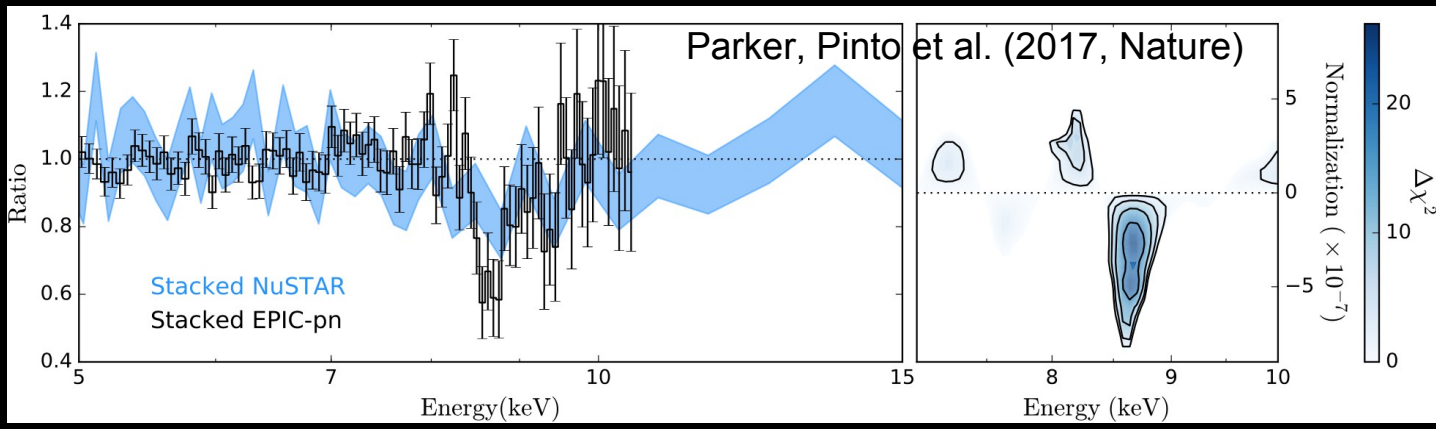
2) Variation in the ionization ?

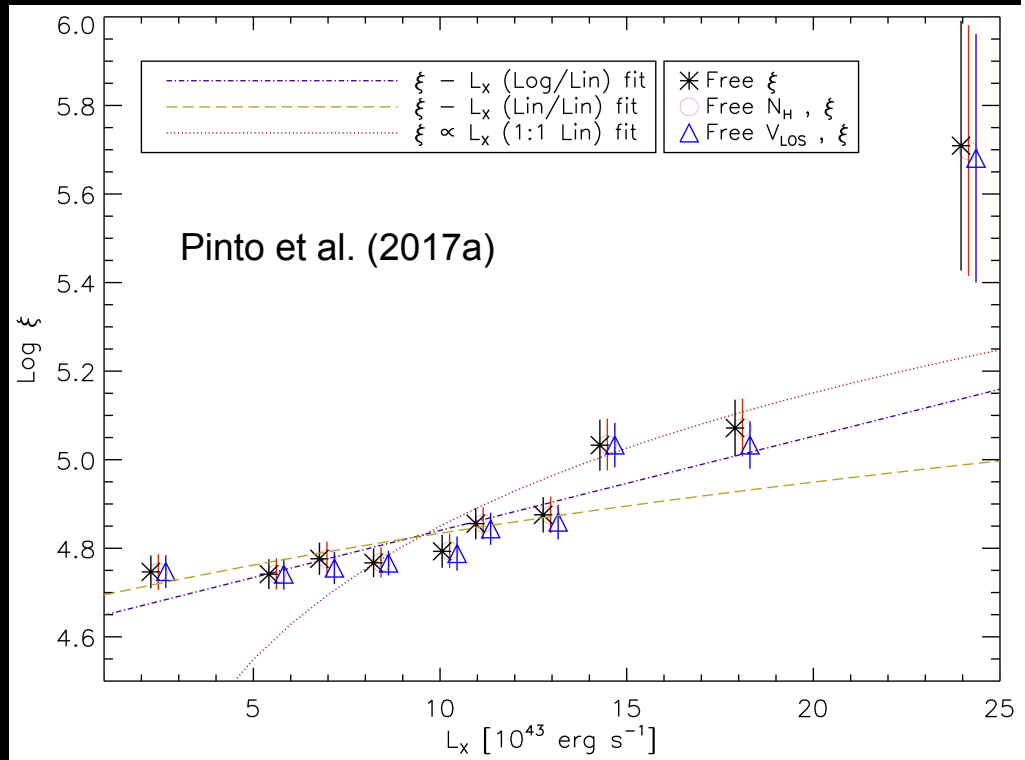
3) False detection ?

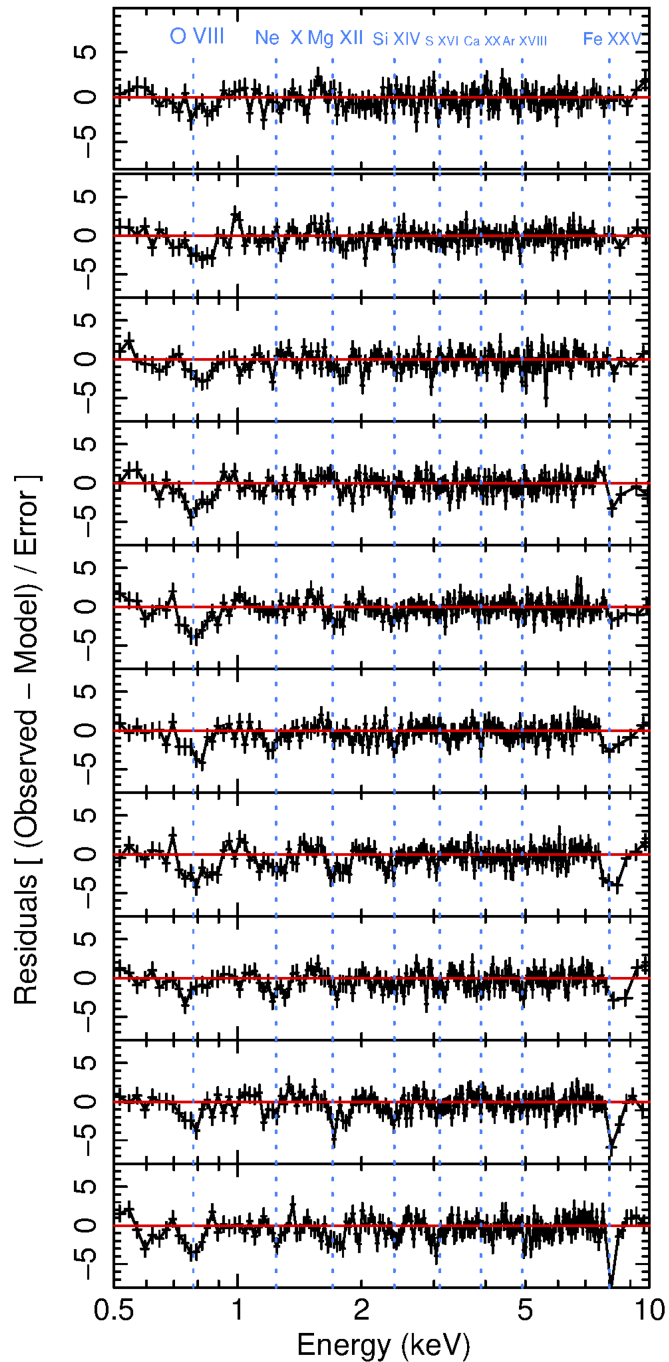


# High-Eddington NLS1 IRAS 13224-3809

V = 0.2c (Fe XXVI) / 0.25c (Fe XXV)



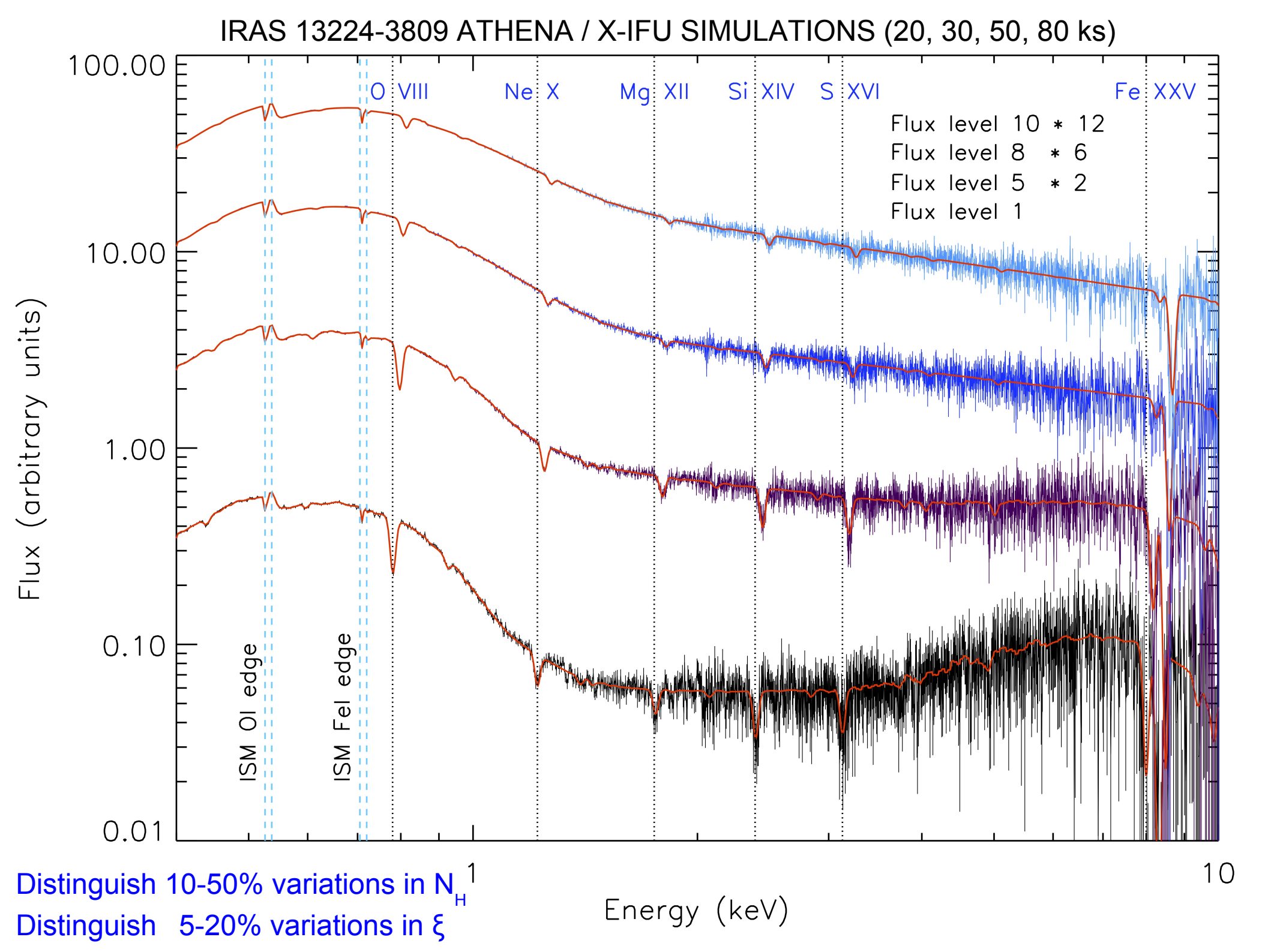
# How much energy is lost in the winds? Do they provide feedback?

Key parameter : $L_{wind} / L_{bol}$

$$\approx (L_X / L_{bol}) \cdot (v_{out}^{\,3} / \xi) \cdot \Omega\, C_V$$

$$\approx 5\%$$

$$\dot{M}_{out} \approx 0.4\ \dot{M}_{Edd}$$


IRAS 13224-3809 ATHENA / X-IFU SIMULATIONS (20, 30, 50, 80 ks)
100.00
10.00
1.00
0.10
0.01
Flux (arbitrary units)
O VIII
Ne X
Mg XII
Si XIV
S XVI
Fe XXV
Flux level 10 * 12
Flux level 8 * 6
Flux level 5 * 2
Flux level 1
ISM OI edge
ISM FeI edge
1
10
Energy (keV)
Distinguish 10-50% variations in N_H
Distinguish 5-20% variations in ξ

# Take away message

- Current X-ray telescopes are close to their limits
- Provide hints on the role of AGN feedback in clusters and galaxies

- XRISM (Hitomi reprise) will open up a new window on bright, nearby sources (but limited grasp & spatial resolution)

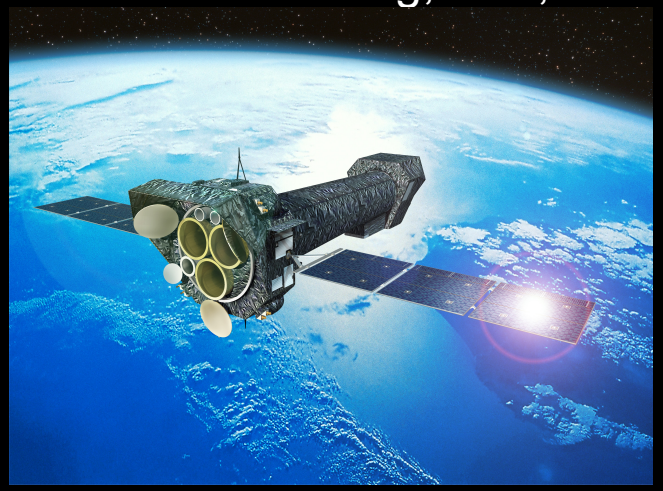
- ATHENA is designed to spatially-resolve nearby objects and observe fainter and distant clusters and AGN.

- The high-energy band is crucial for dynamical measurements.

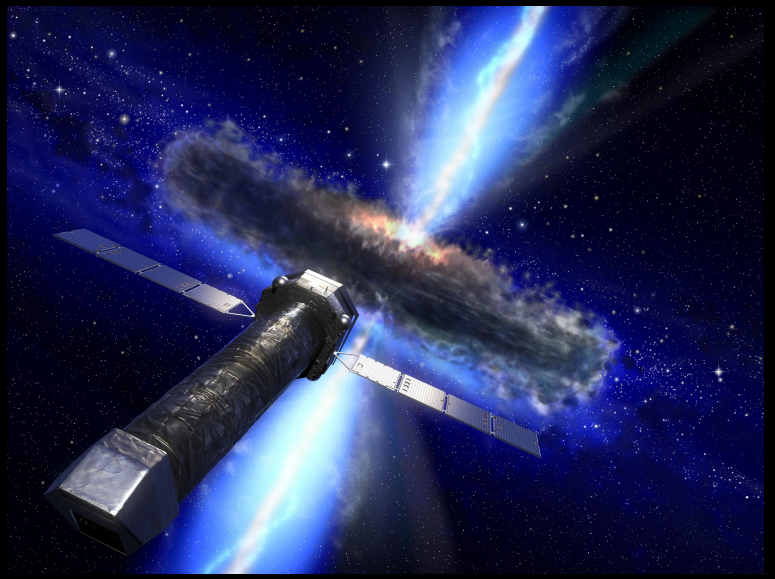
- Current goals on spectral and spatial resolution are a must!

# Lunapark

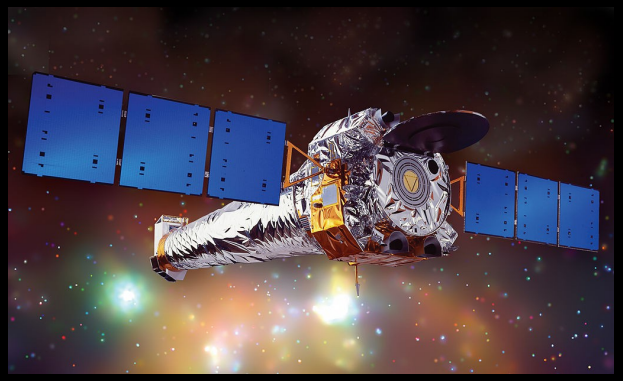
**XMM-Newton**
1D Line broadening, shift, RS



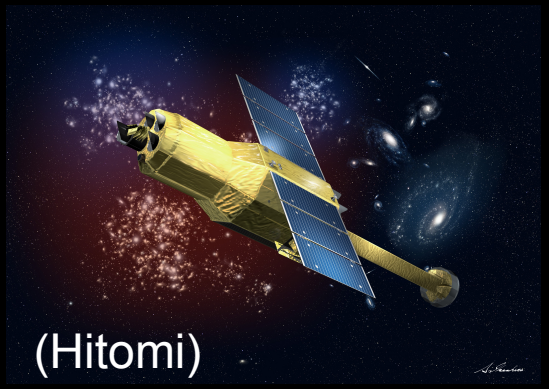
**ATHENA (2030+)**



**Chandra**
Shocks, fluctuations



**XRISM (2021+)**
2D Line broadening, shift, RS



# Centaurus cluster (100 ks XIFU)

## Stat. uncertainty on velocity widths