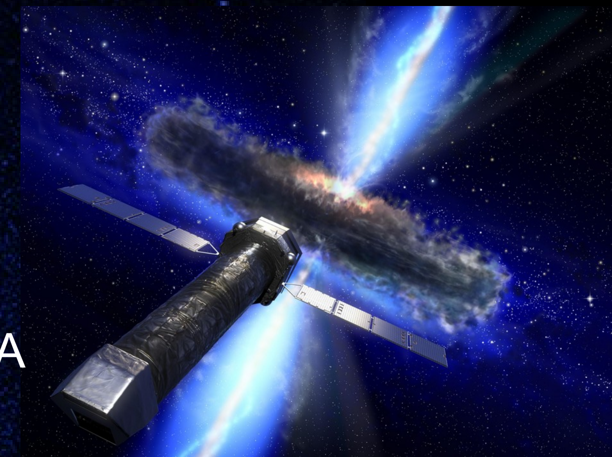
Understanding AGN feedback with *XRISM* & *ATHENA*

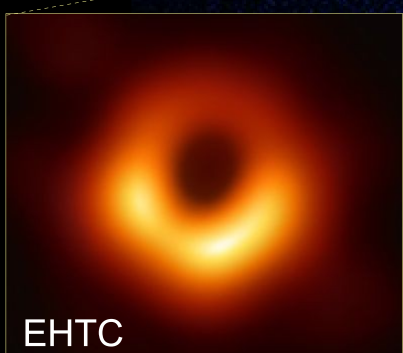


NOW

XRISM

ATHENA

ESA 2050
Voyage



Ciro Pinto

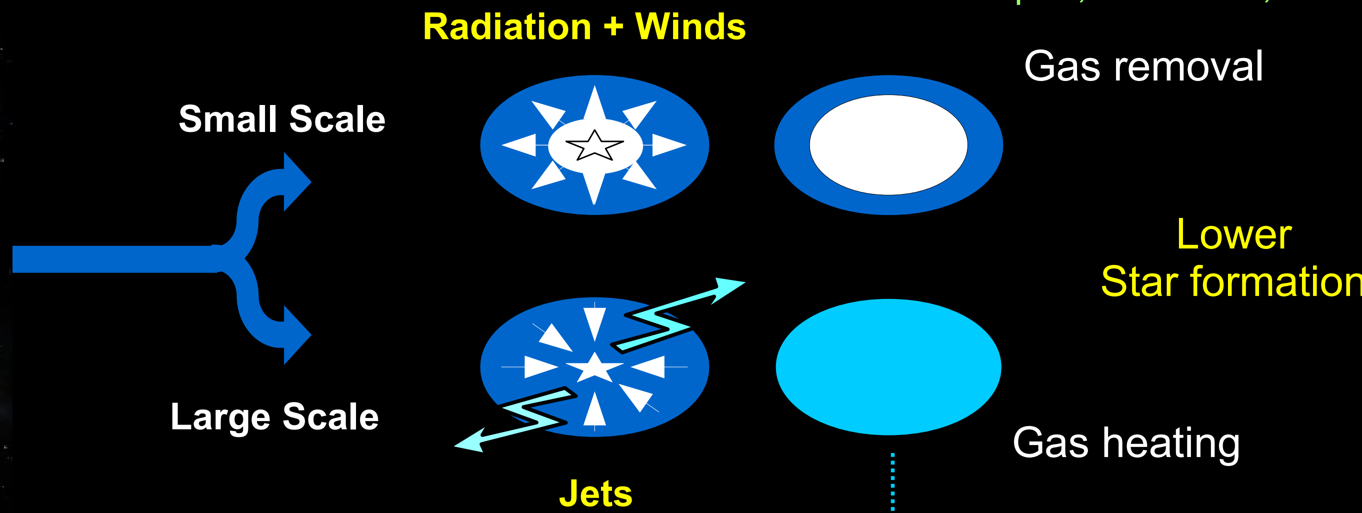
European Space Agency

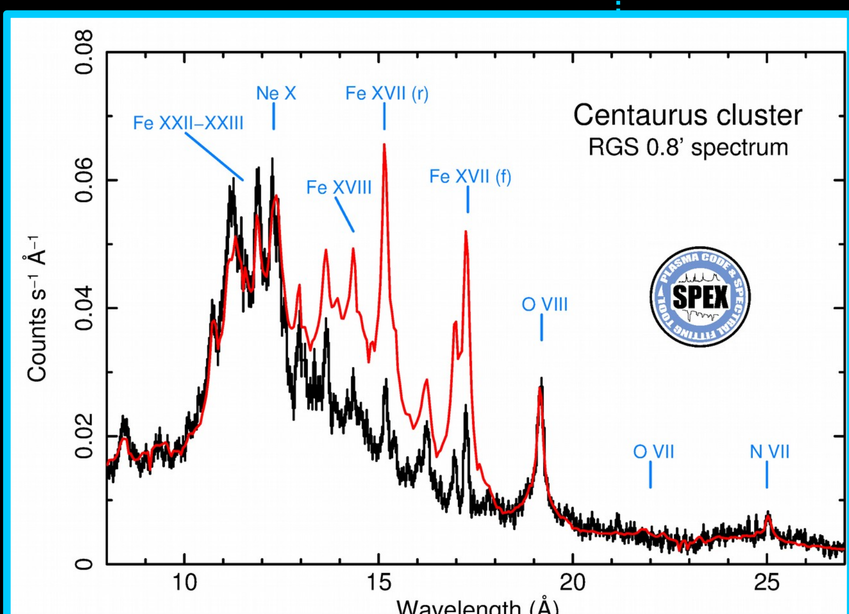
A. Fabian, J. Sanders, C. Bambic, H. Liu, F. Mernier, P. Kosec, J. De Plaa, J. Kaastra, L. Gu, A. Ogorzalek, N. Werner, I. Zhuravleva, J. Ahoranta, A. Simionescu, A. Finoguenov, C. Reynolds, H. Russell, M. McDonald, M. Guainazzi, YY Zhang

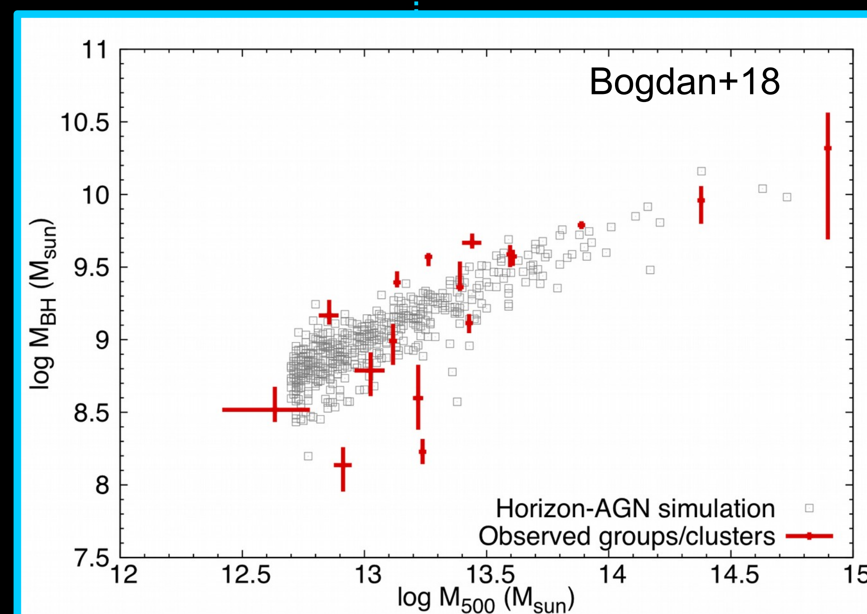
AGN feedback in galaxy clusters

Talks : Ishibashi, Longinotti, Kaastra, Mehdipour, Ricci, ...
Posters : Tombesi, Luminari, Bertola, Marinucci, Brusa, Gaspari, Serafinelli, Nardini ...

Figure by Tombesi+



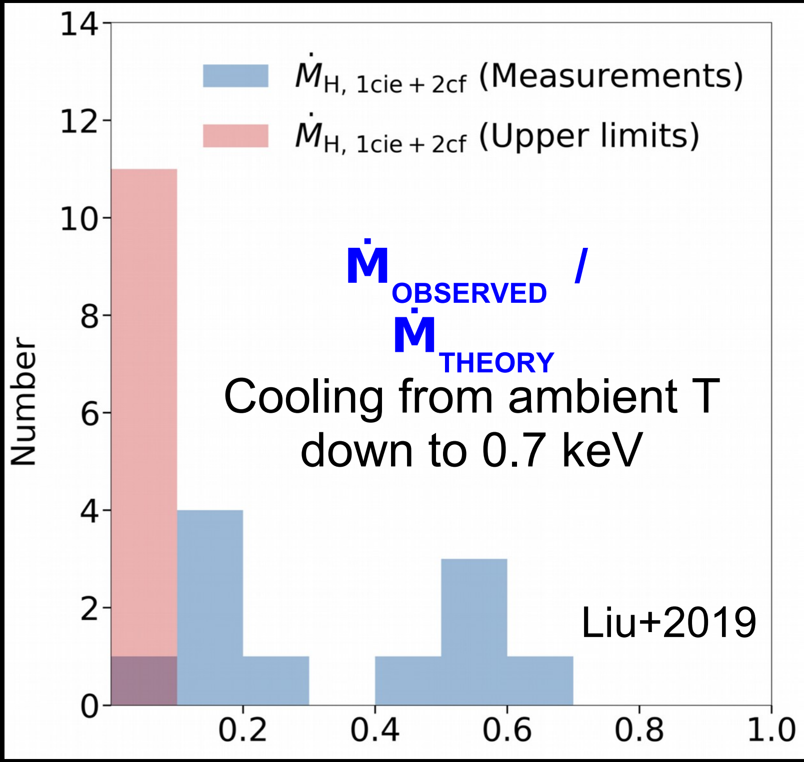


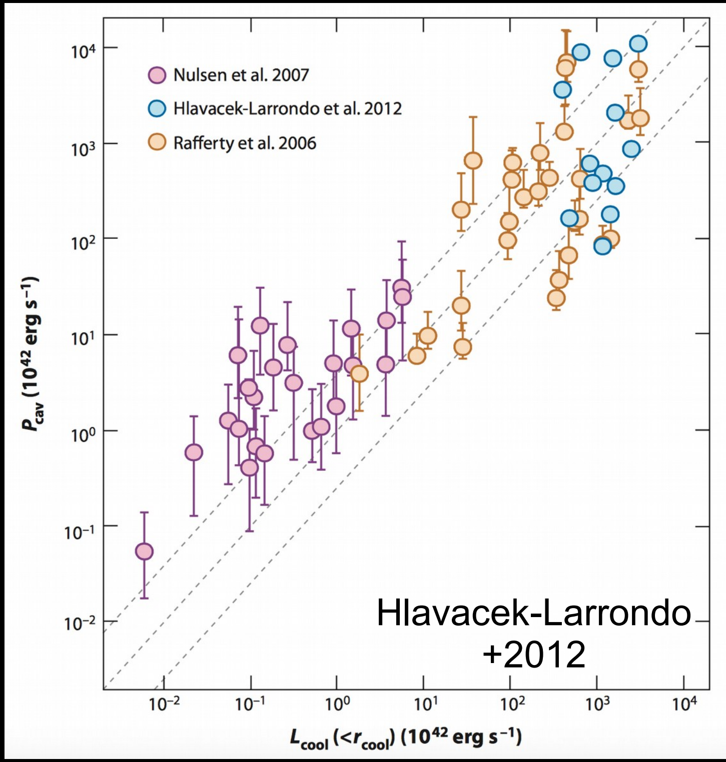


e.g. Kaastra +01-03, Peterson +01-03

How powerful is AGN feedback?

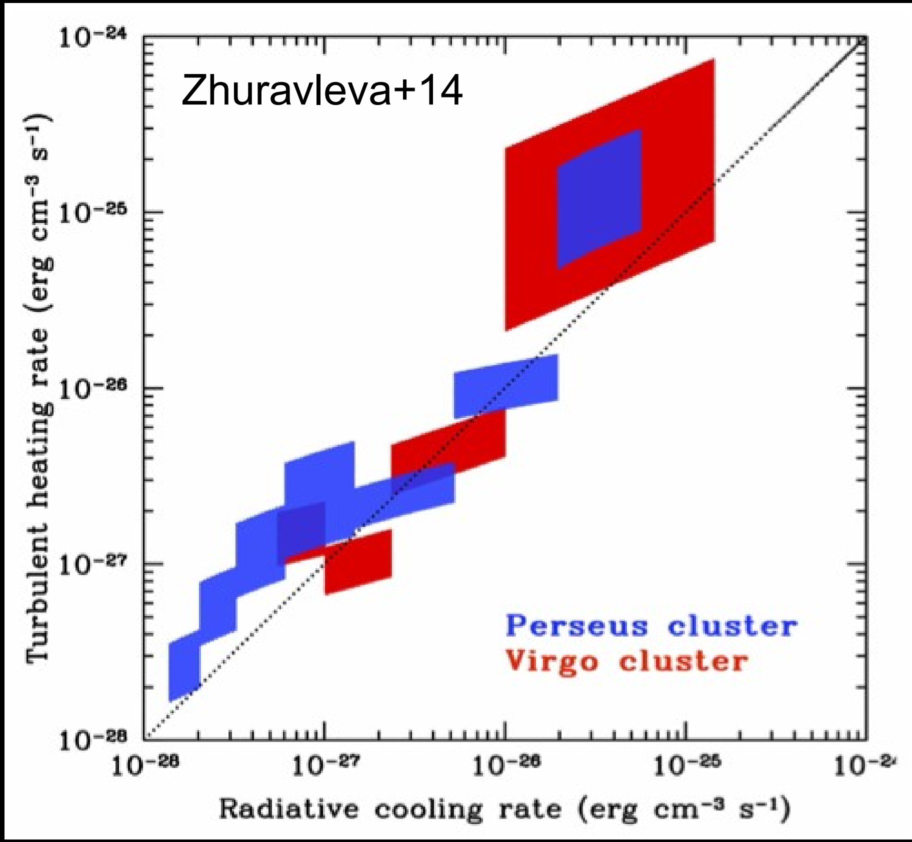
McNamara & Nulsen 2007





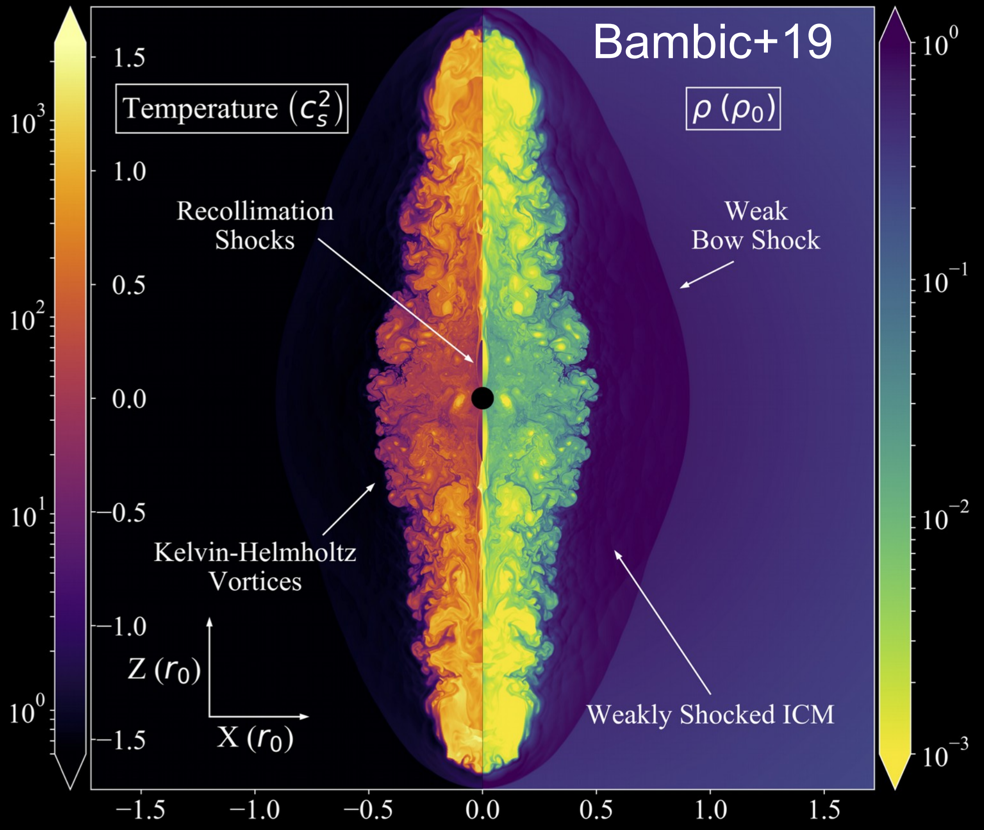
How is the energy released & propagated?

Dissipation of Turbulence?



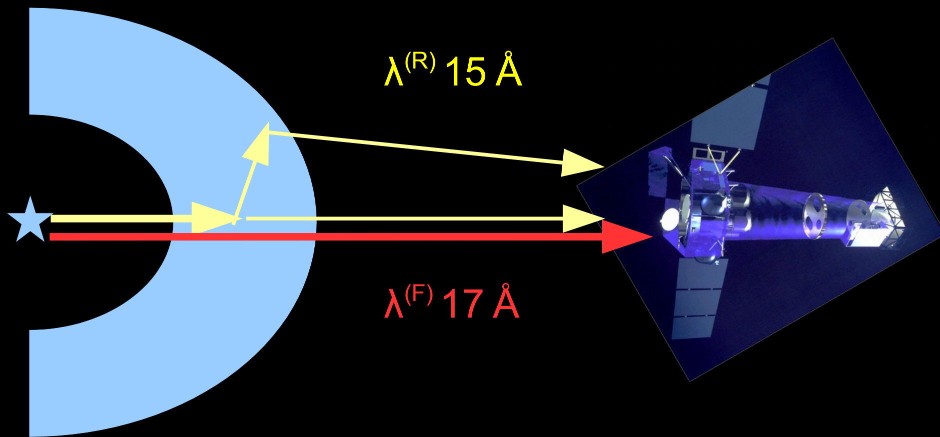
(if X-ray S.B. fluctuations are turbulence)

Dissipation of Sound waves?



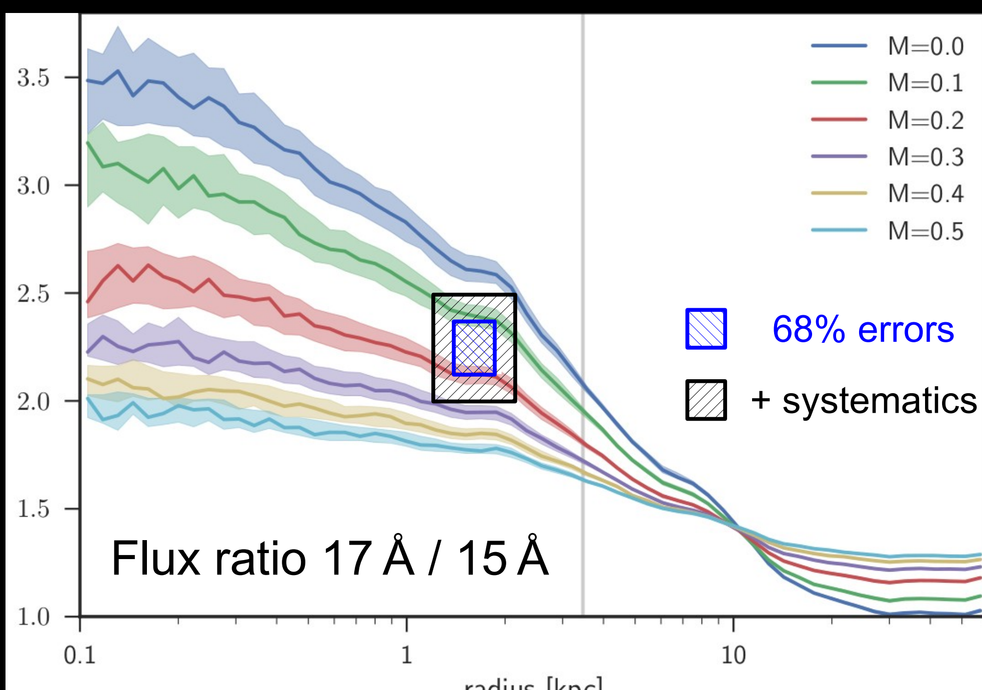
(displacement velocity amplitude ≈ 200 km/s)

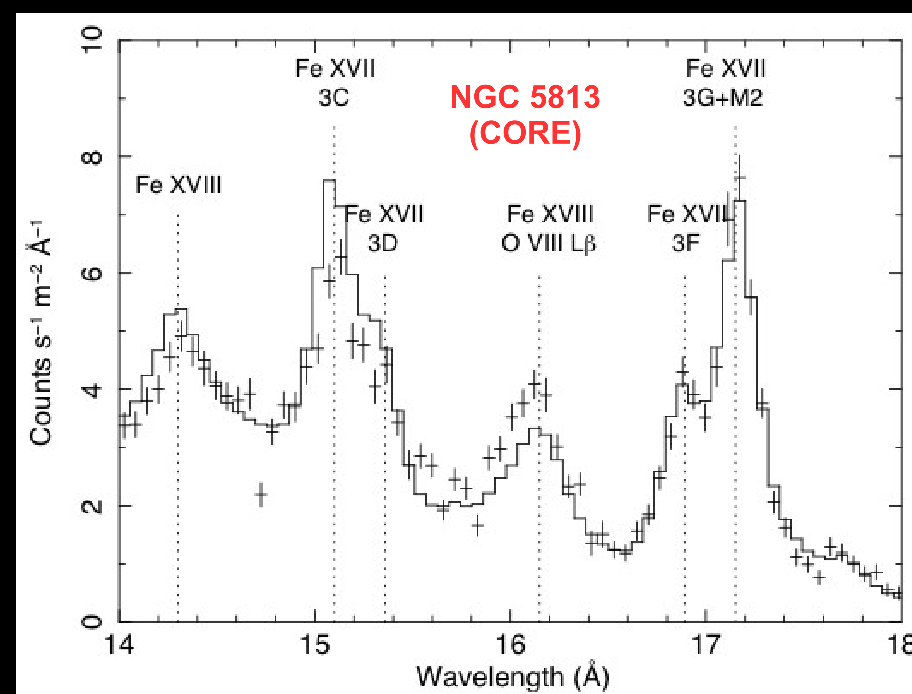
RGS constraints on Velocity Broadening
Resonant scattering



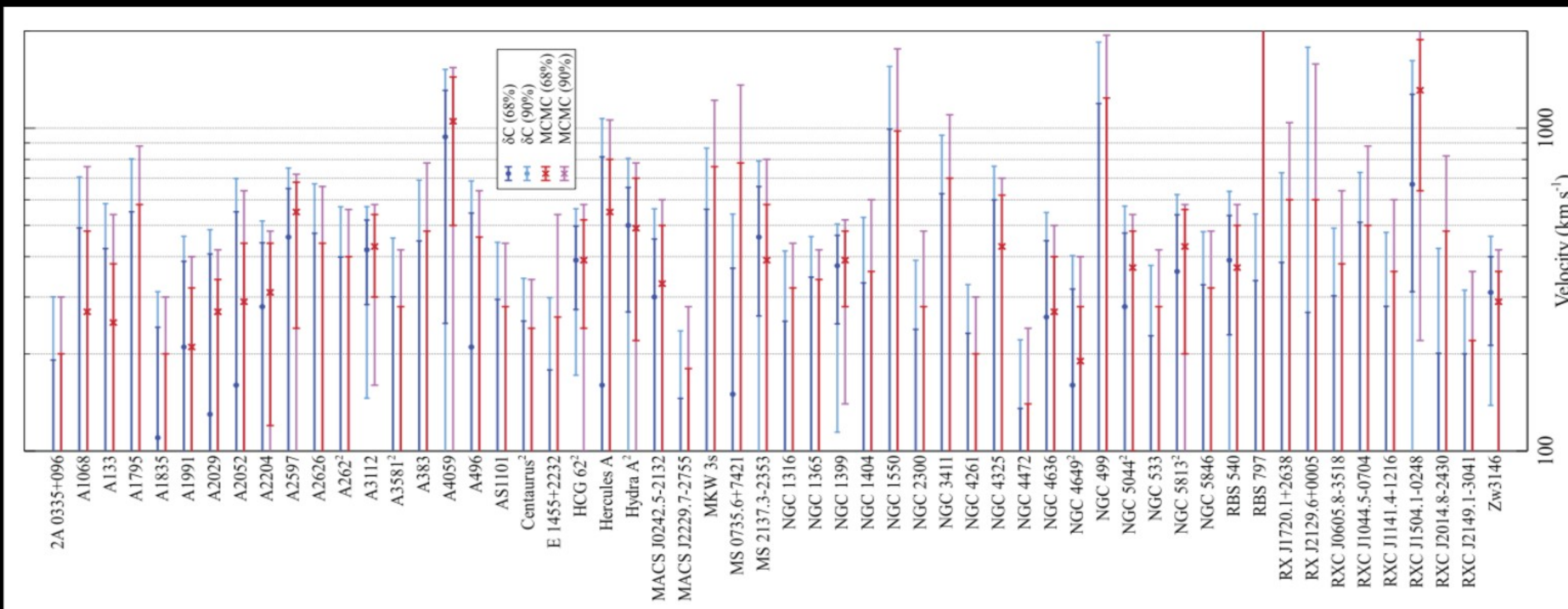
Need accurate atomic databases:
AtomDB, SPEX, Chianti, ...

Xu+02
Werner+09
de Plaa+12
Ahoranta+16
Pinto+16b
Ogorzalek+18



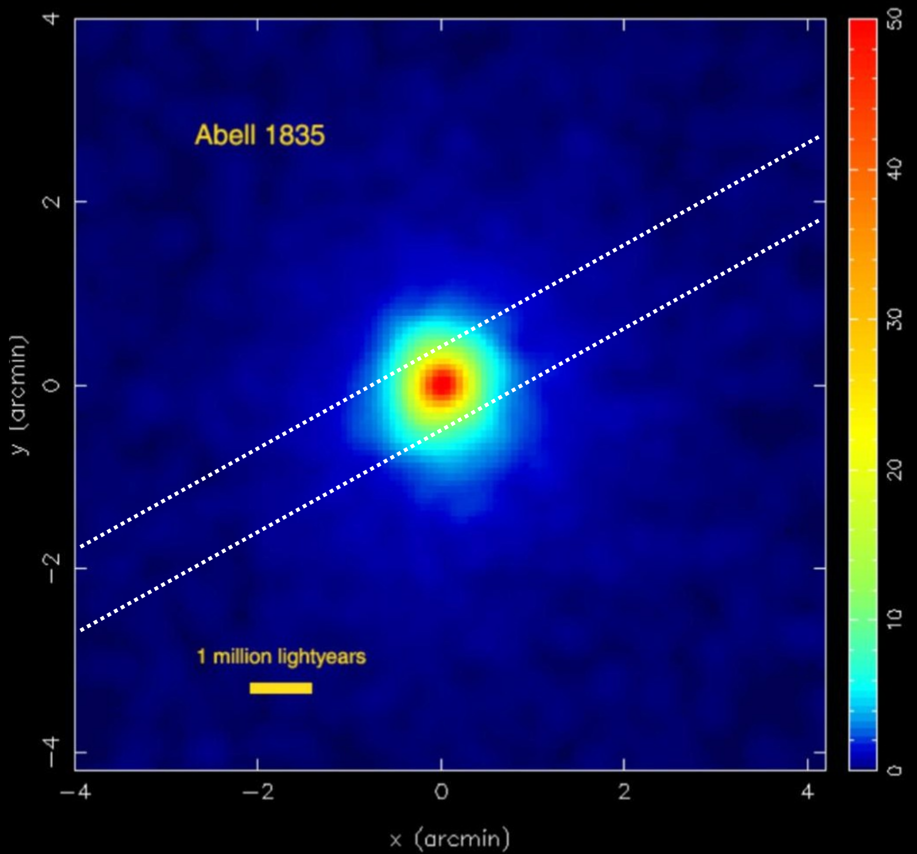


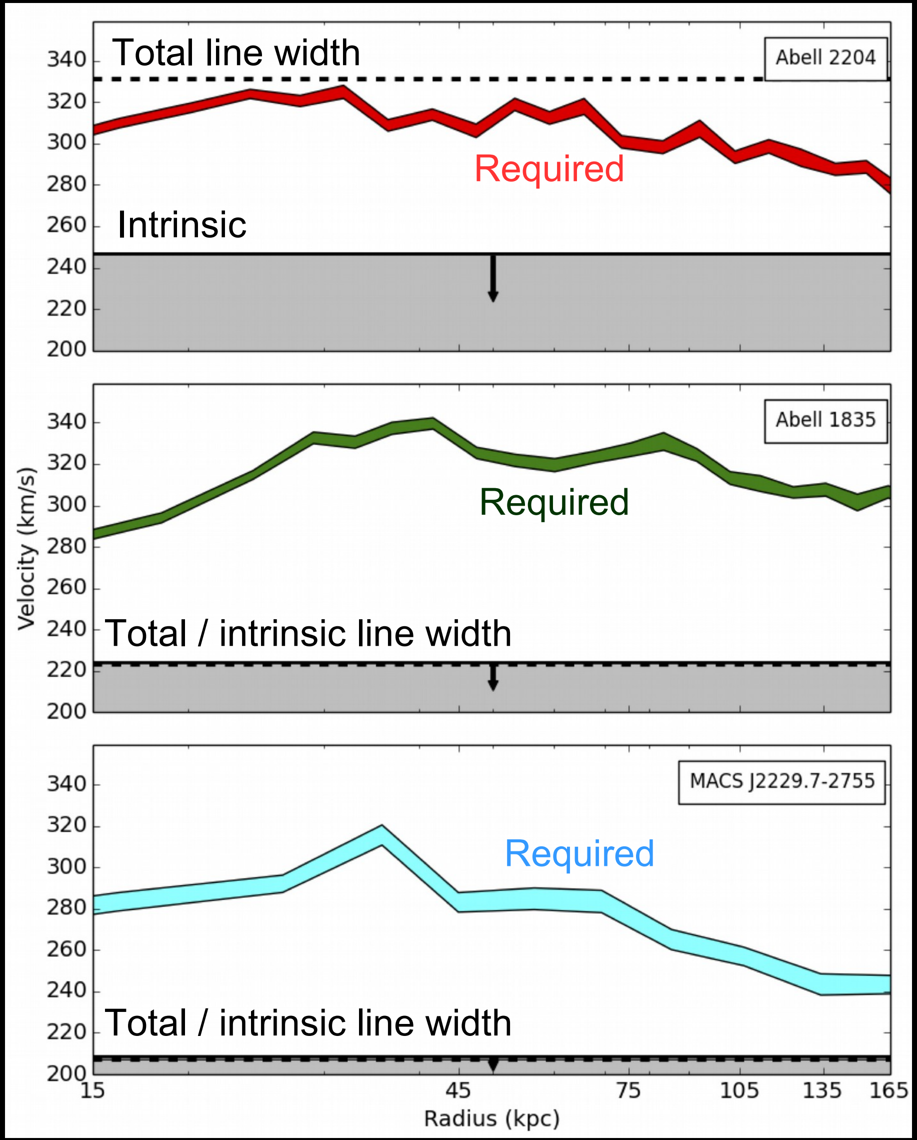
RGS constraints on Velocity Broadening
Lines widths



Sanders & Fabian 2013
see also Pinto + 2015

Propagation problem





$$L_{Cool} = L_{Turb}$$

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

Required : $\sigma_{km/s} \sim (r_{kpc} \, T_{keV} / t_{yr})^{1/3}$

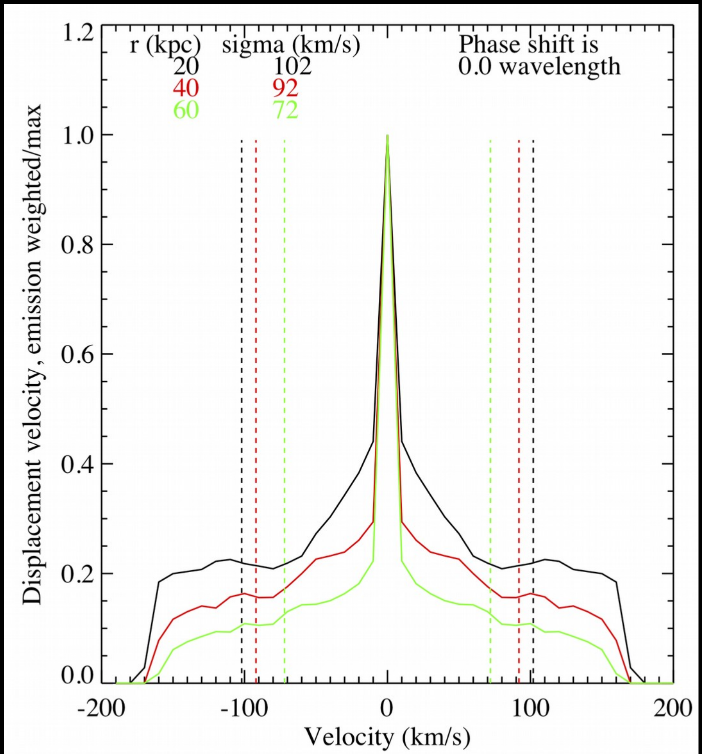
Bambic et al. (2018), Pinto et al. (2018b)

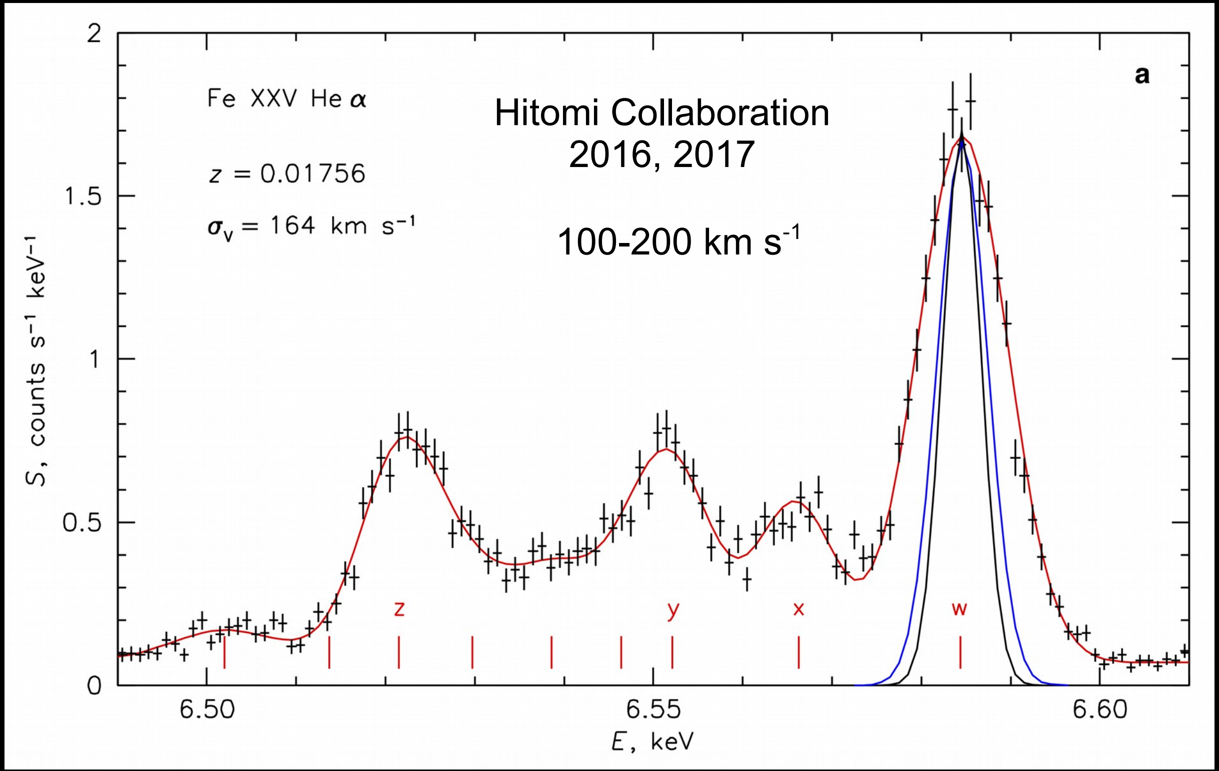
XMM-*Newton* & *Hitomi*

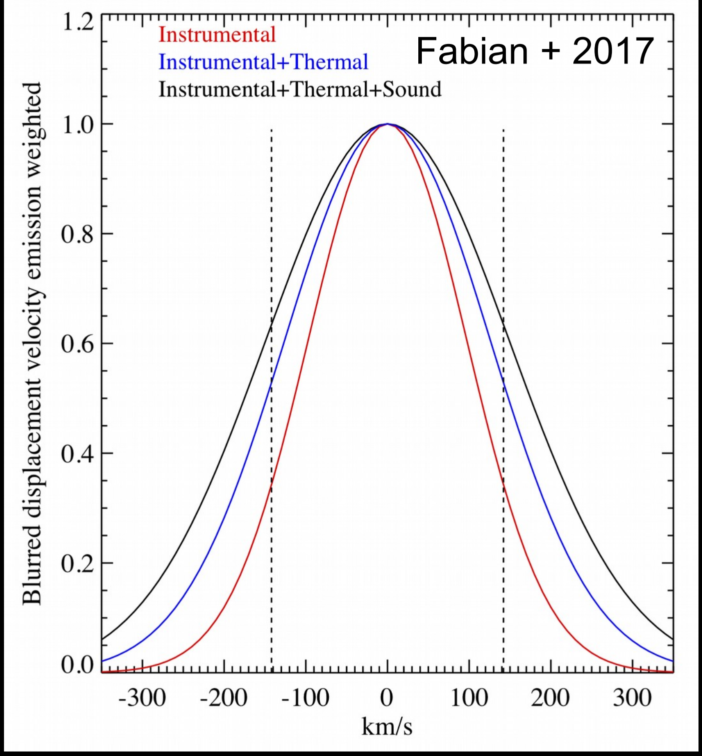
Turbulence alone is too low to propagate heat through the cluster core

Again, need for very accurate atomic databases!

Sloshing contributes too (Walker+, also Sanders' talk)

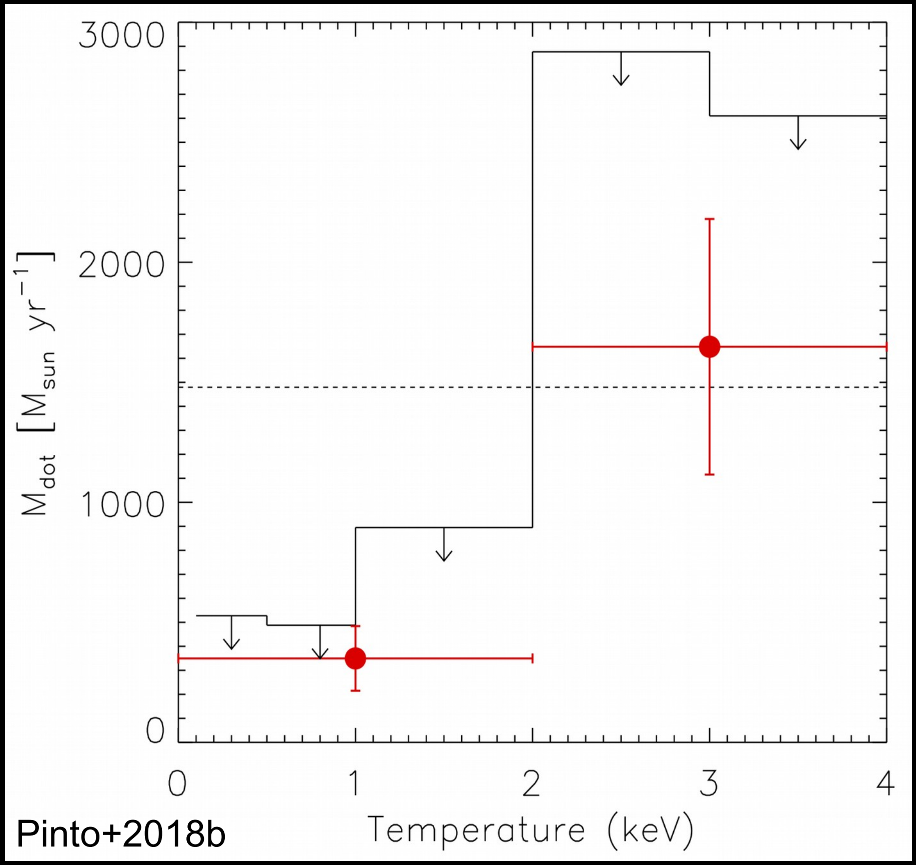




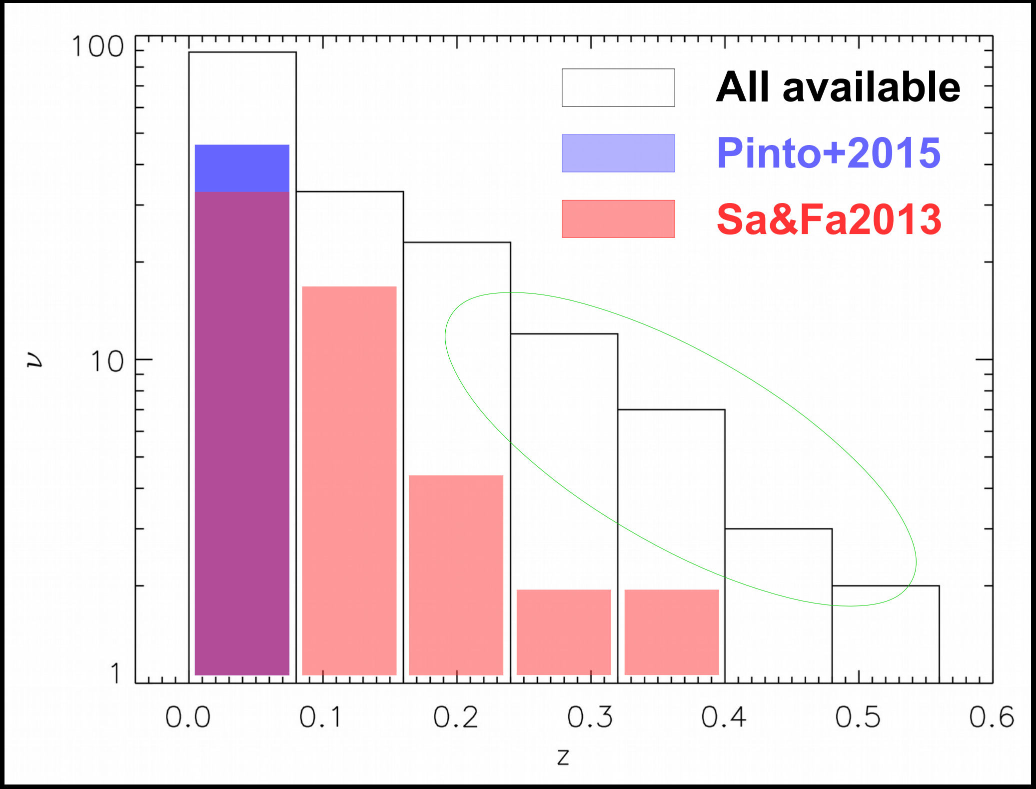


How about high redshifts clusters?

Cooling rates



More can be done with RGS!

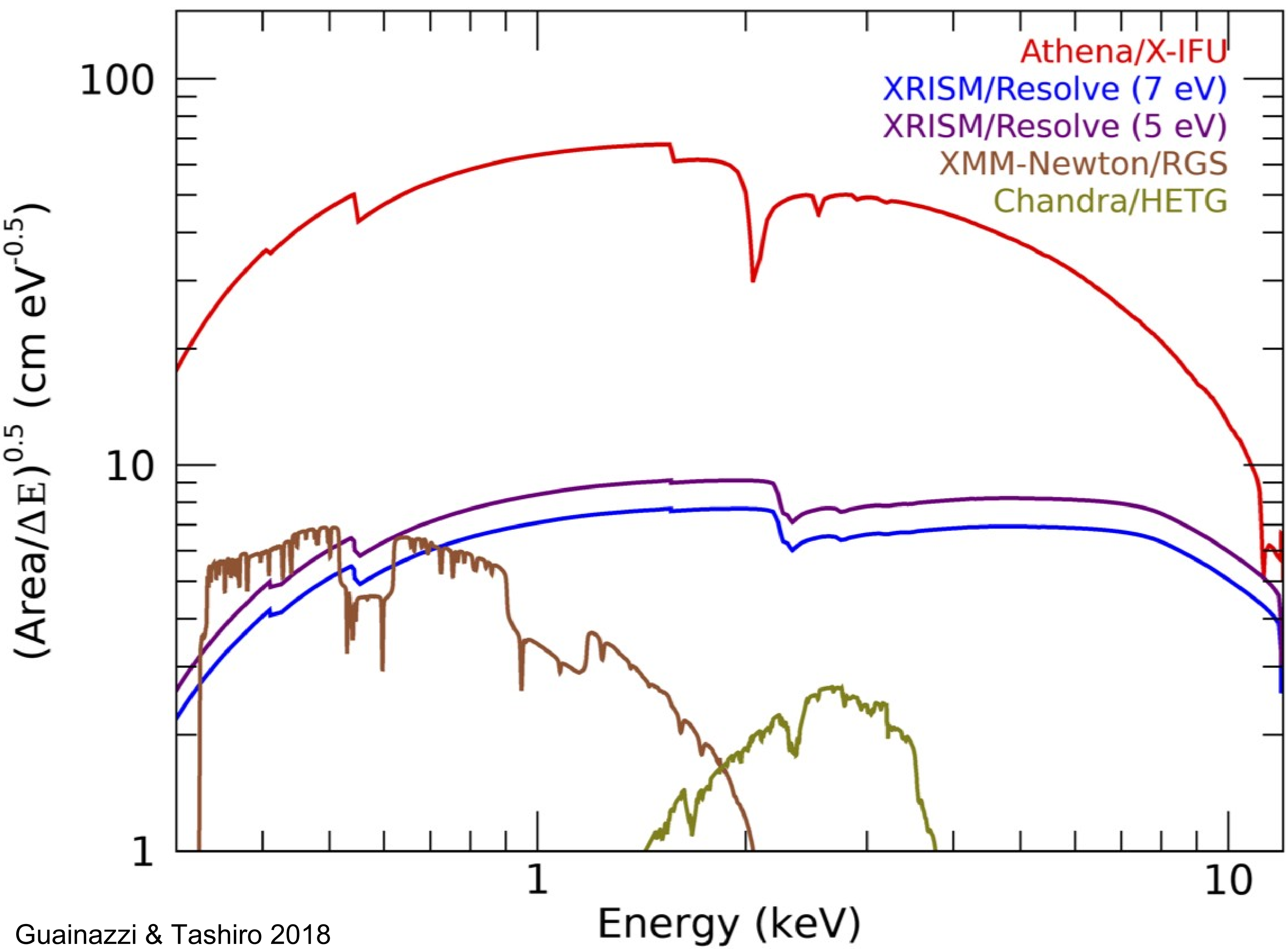


High cooling and star formation rates!

... but limited to z < 1 ...

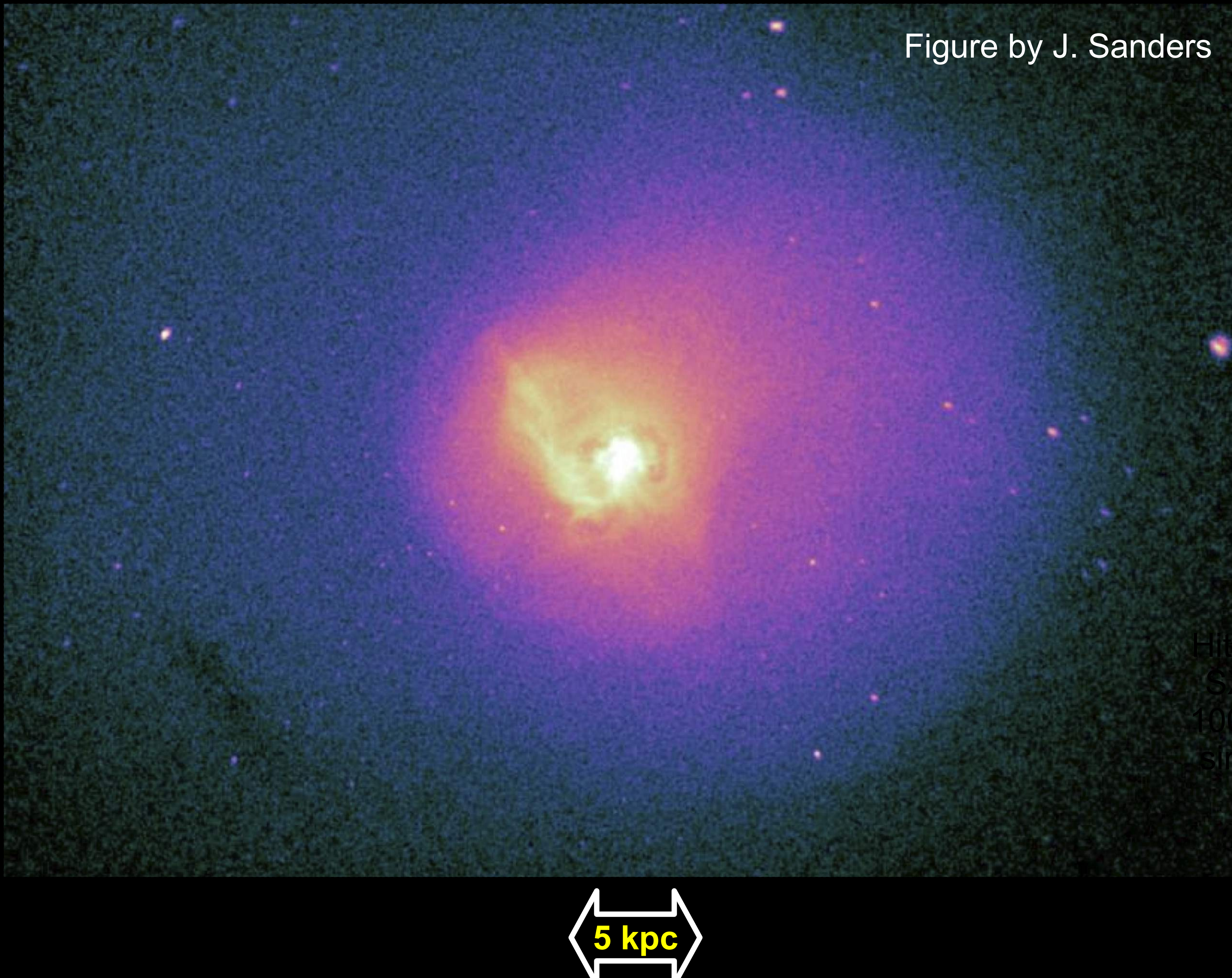
Feedback "young" or other "mode" e.g. Compton Cooling?

Future high-resolution X-ray spectrometers

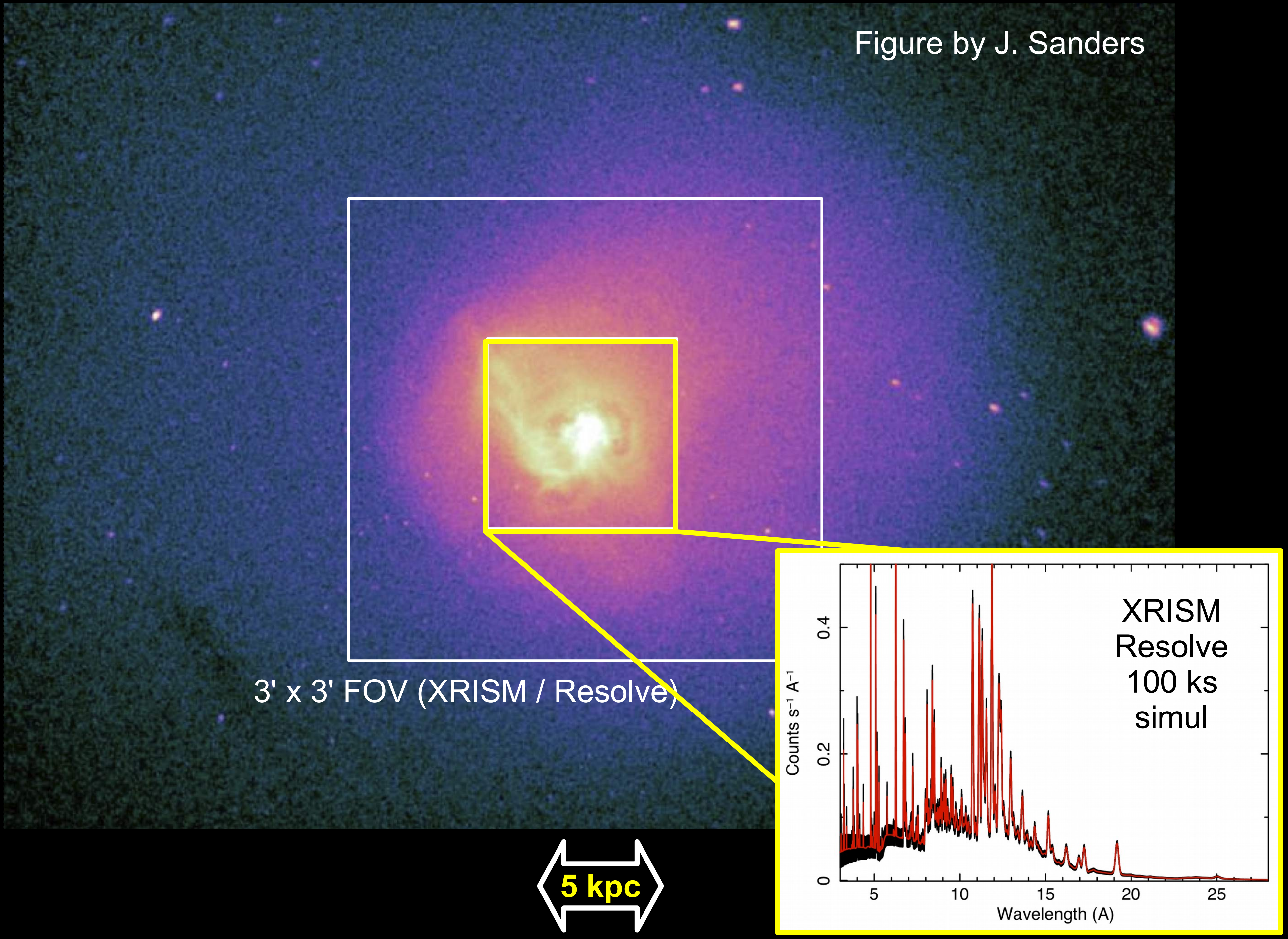


Guainazzi & Tashiro 2018

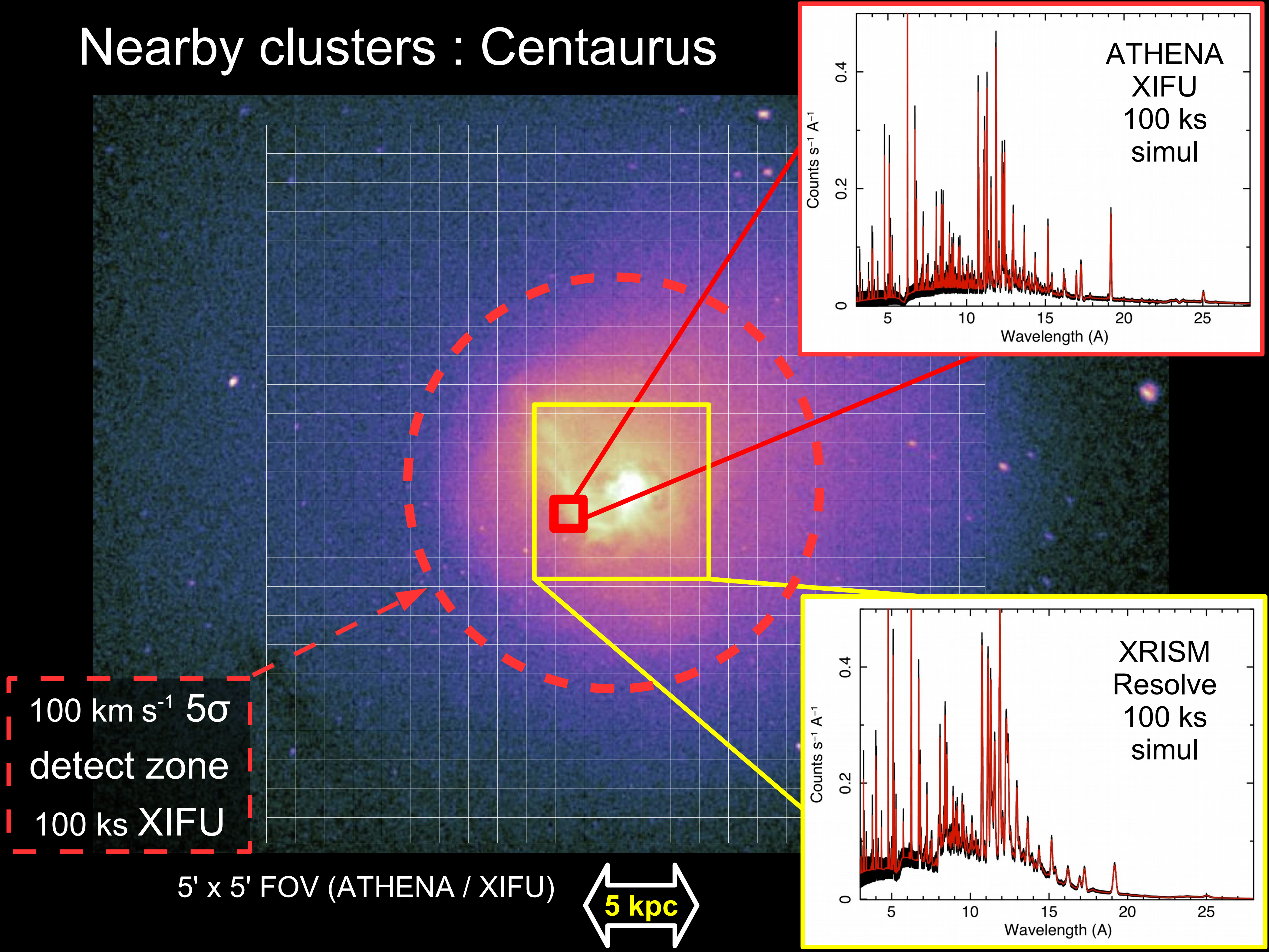
Nearby clusters : Centaurus



Nearby clusters : Centaurus

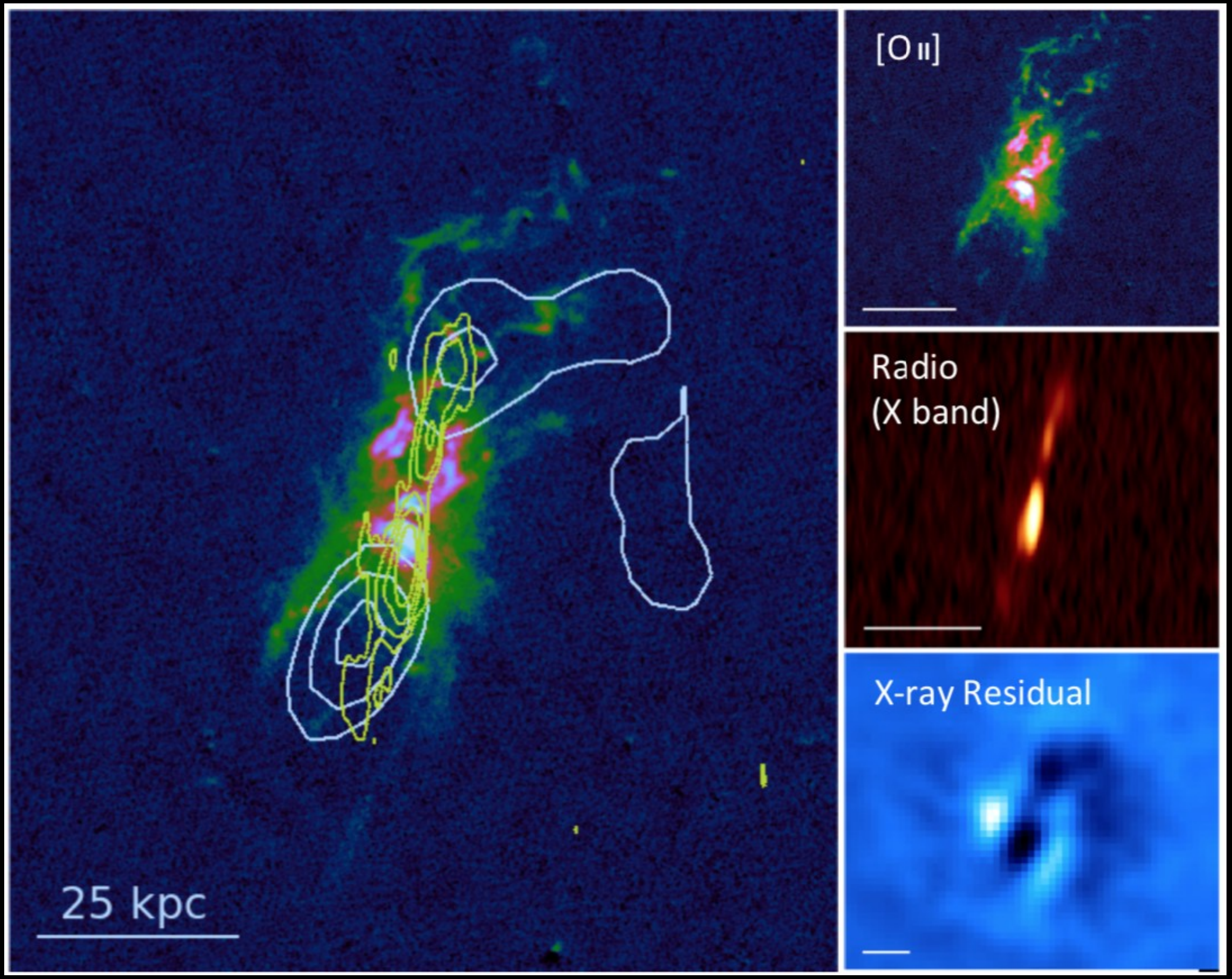


Nearby clusters : Centaurus



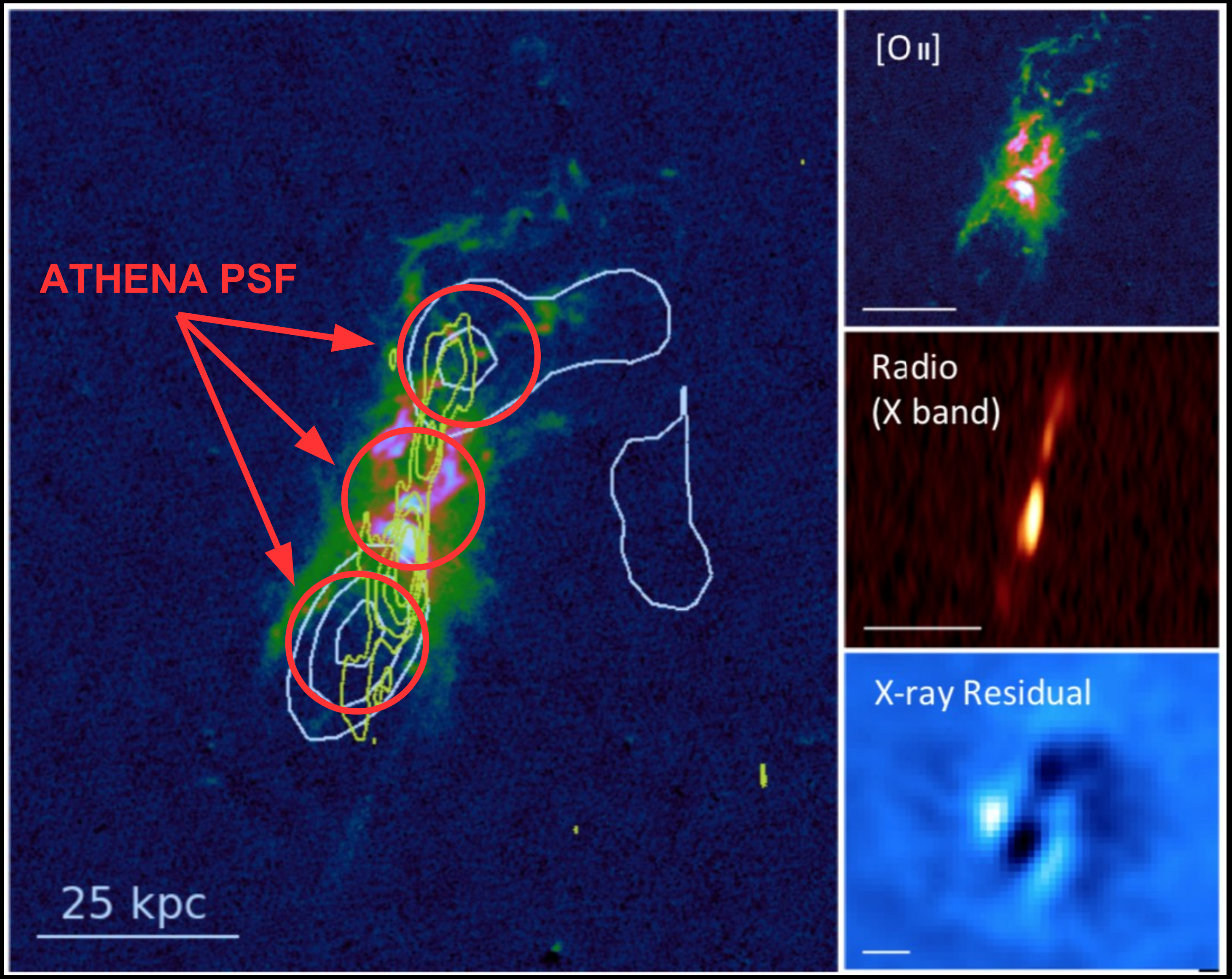
Distant clusters : Phoenix

Figure by M. McDonald



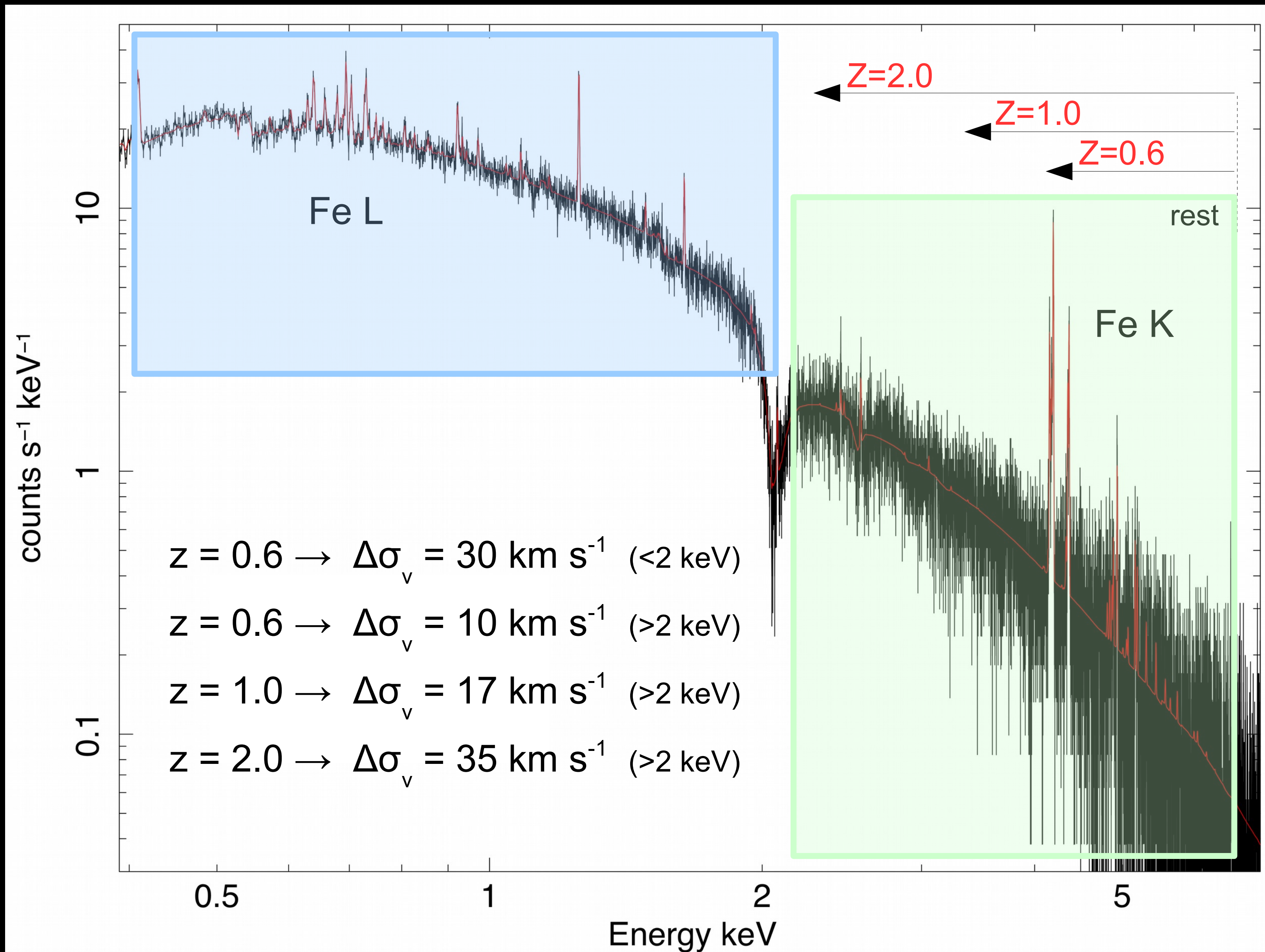
Distant clusters : Phoenix

Figure by M. McDonald

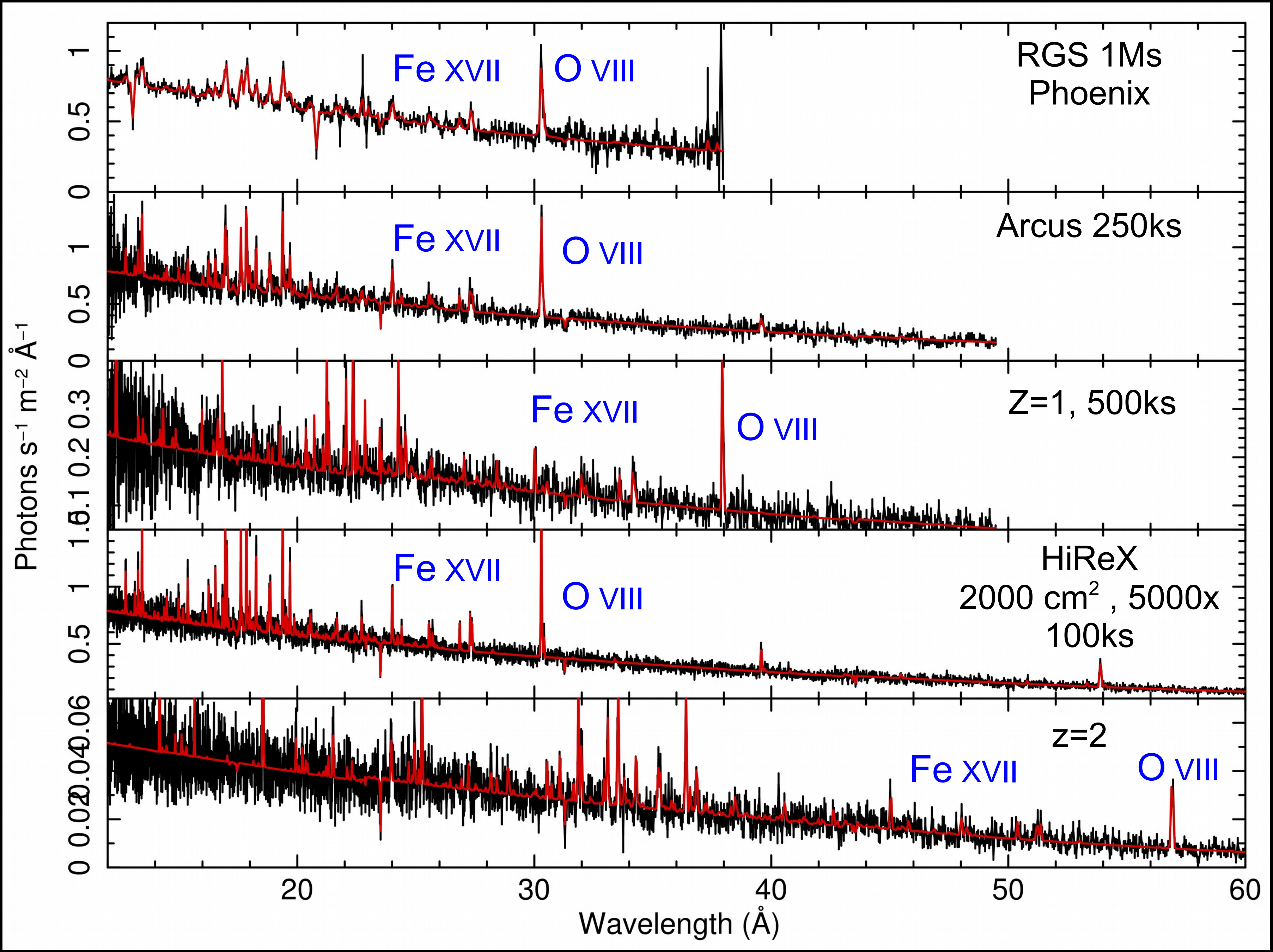


Distant clusters : Phoenix core

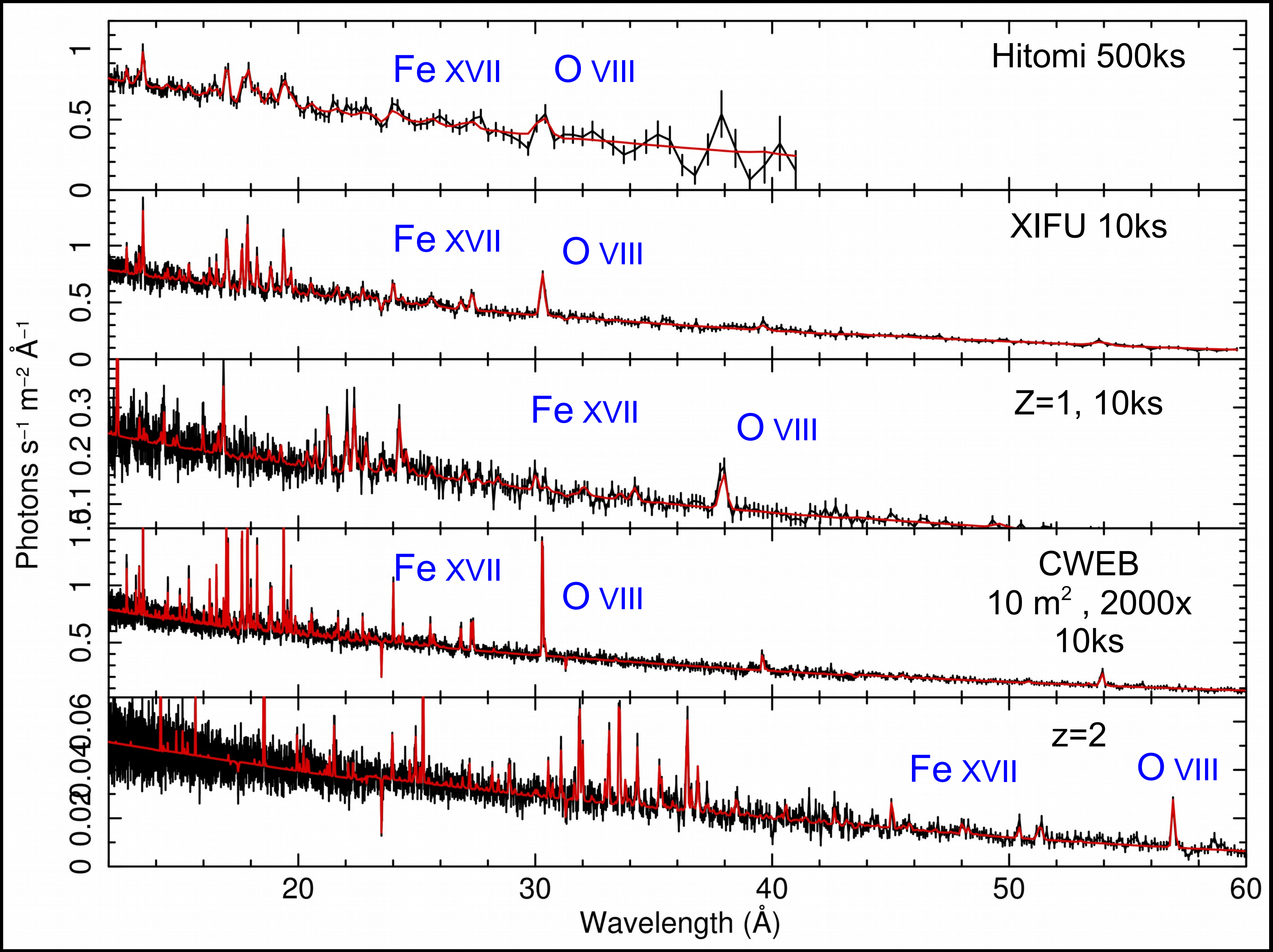
(±50 kpc, z=0.6, 10 ks XIFU sim, σ_v = 300 km s^{-1})



Towards ESA Voyage 2050 : Gratings



Towards ESA Voyage 2050 : Calorimeters



High-res X-ray spectroscopy is the key to understand AGN feedback in galaxy clusters

Constraints on ICM cooling – heating balance

- Current issues: spatial resolution, distance, AtomDB
- XRISM will measure bulk velocities in nearby clusters
- ATHENA will resolve velocity & cooling structure at z ~ 1 and measured bulk properties up to z > 2
- Lynx , CWEB & HiReX : Cool – Heat balance at z > 2

2009

Thank you so much X-ray fellows!

2019

Bonus slides

Mach Number Required for Cooling – Heating Balance

$c_s = \sqrt{(\gamma kT / \mu m_p)}$ Sound speed

$\varepsilon_{turb} / \varepsilon_{therm} = (V^2_{los} / kT) \mu m_p$ % of energy in turbulence:

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

Mach number required to balance cooling

$$\sigma_{\mathrm{km/s}} = 5.39 \times 10^4 \left(\frac{r_{\mathrm{kpc}}\,\mathrm{T}_{\mathrm{keV}}}{t_{\mathrm{yr}}}\right)^{1/3}$$

Turbulence required to balance cooling

Mach Number Required for Cooling – Heating Balance

$L_{cool} = L_{turb}$

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

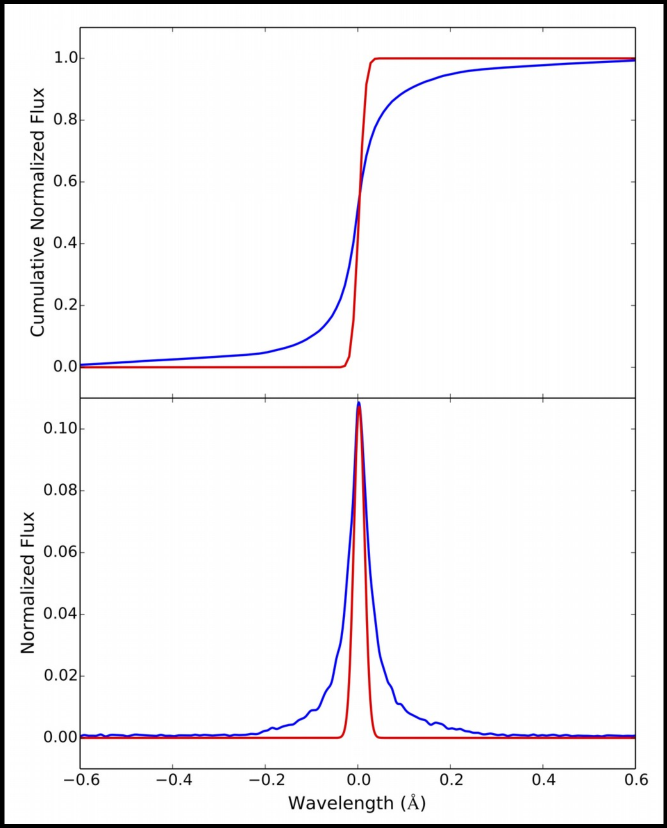
$\sigma_{turb} = r / t_{turb}$

$E_{turb} = 3/2\ M_{gas}\ \sigma_{turb}^{2}$
$E_{ther} = 3/2\ N\ k_B T = 3/2\ M_{gas} / (\ \mu\ m_p\ )\ k_B T$

$\rightarrow t_{turb} = \mu\ m_p\ \sigma_{turb}^{2}\ t_{cool} / (\ k_B T\ )$

$\rightarrow \sigma_{turb}^{3} = r\ k_B T / (\ \mu\ m_p\ t_{cool}\ )$

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

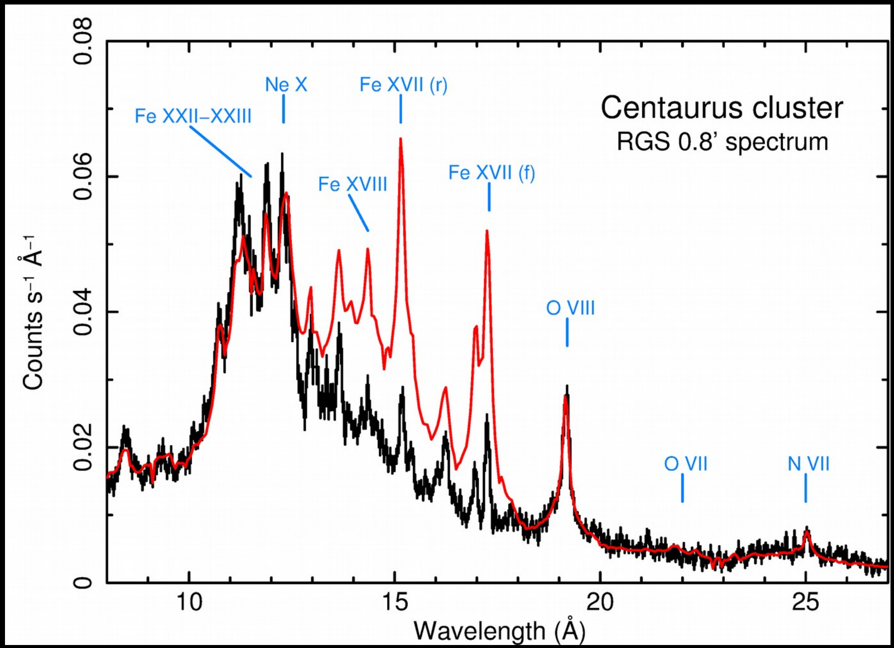


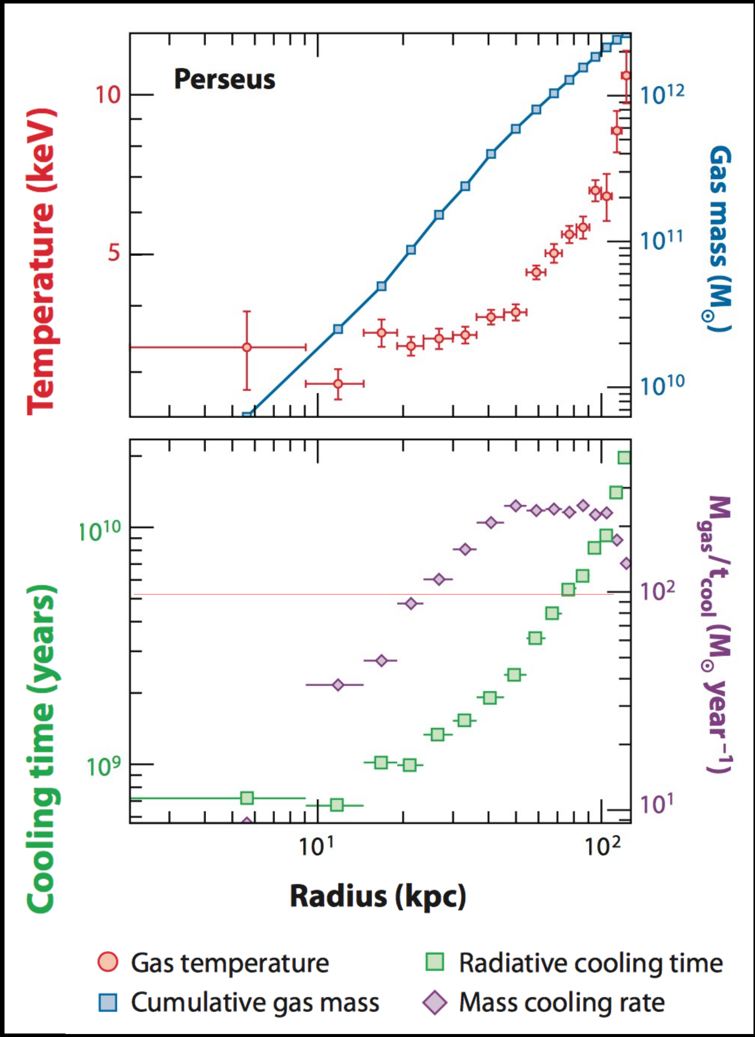
Weak cooling flows in galaxy clusters

Cooling time shorter than cluster age

→ 100-1000 M_{sun} yr^{-1} in cores of clusters

10s M_{sun} yr^{-1} actually observed



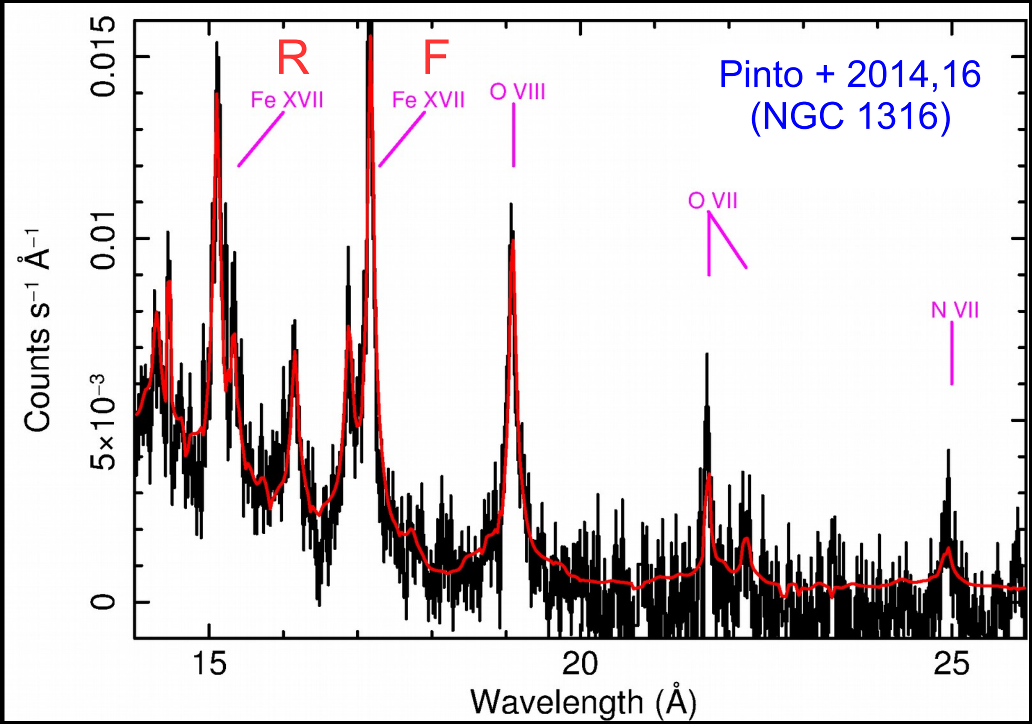


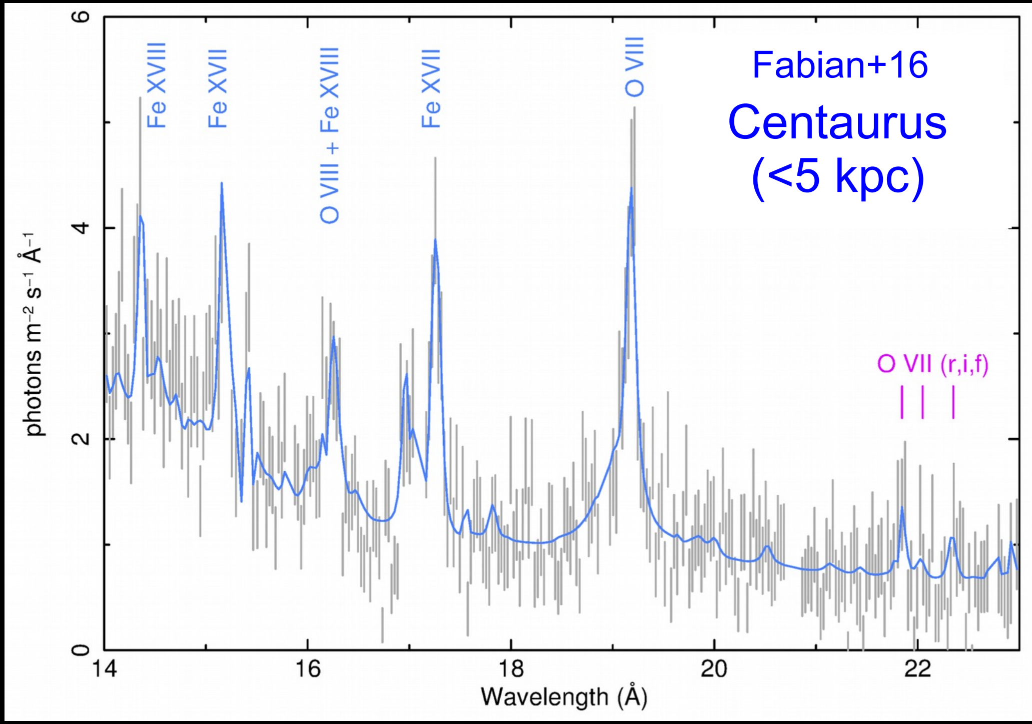
Fabian 2012 (figure by J. Sanders)

$t_{cool} \sim f(T^{1/2}, n^{-1})$

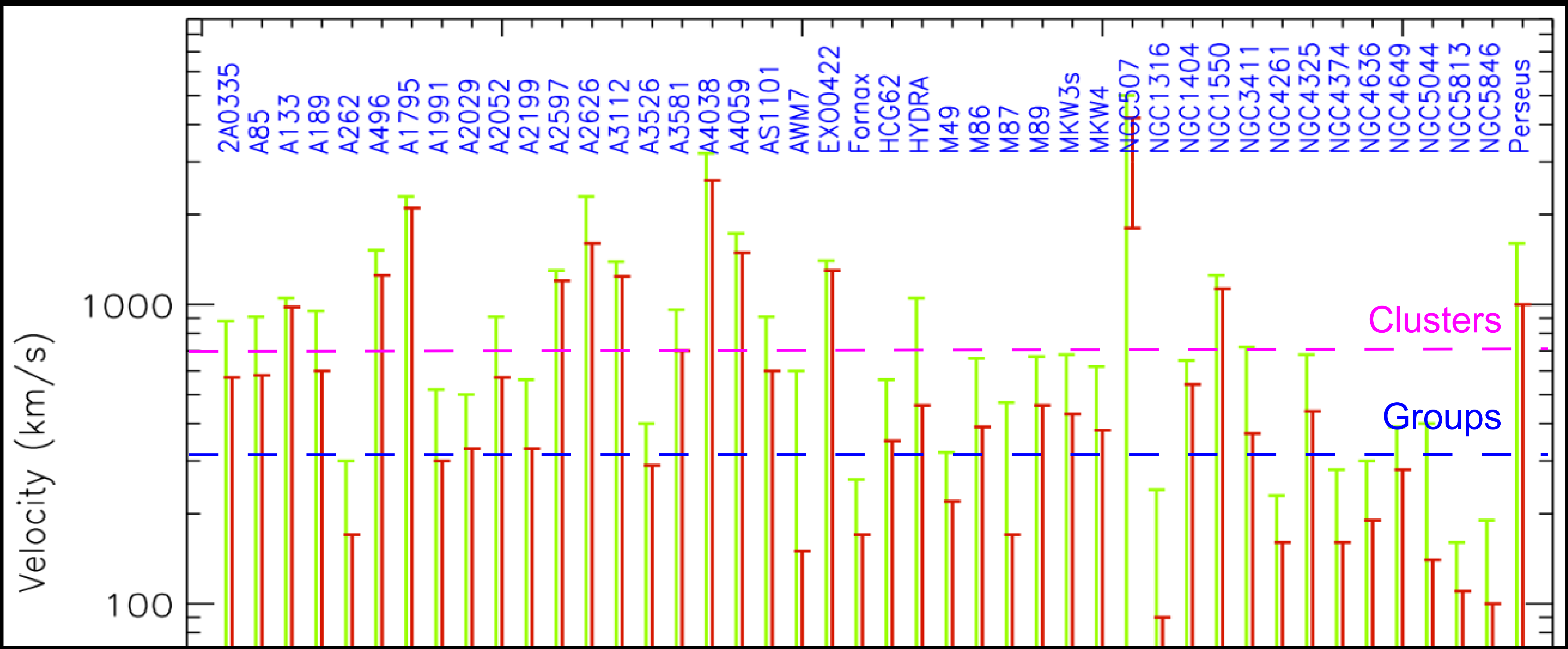
The coolest X-ray emitting gas

- O VII ... cooling below 2 mln K
- O VII = 4-8 times fainter than *cflow* models of galaxy gourps
- Even fainter in clusters of galaxies





RGS constraints on Turbulence
Lines widths



Pinto et al. 2015

Centaurus cluster (100 ks XIFU)
Stat. uncertainty on velocity widths