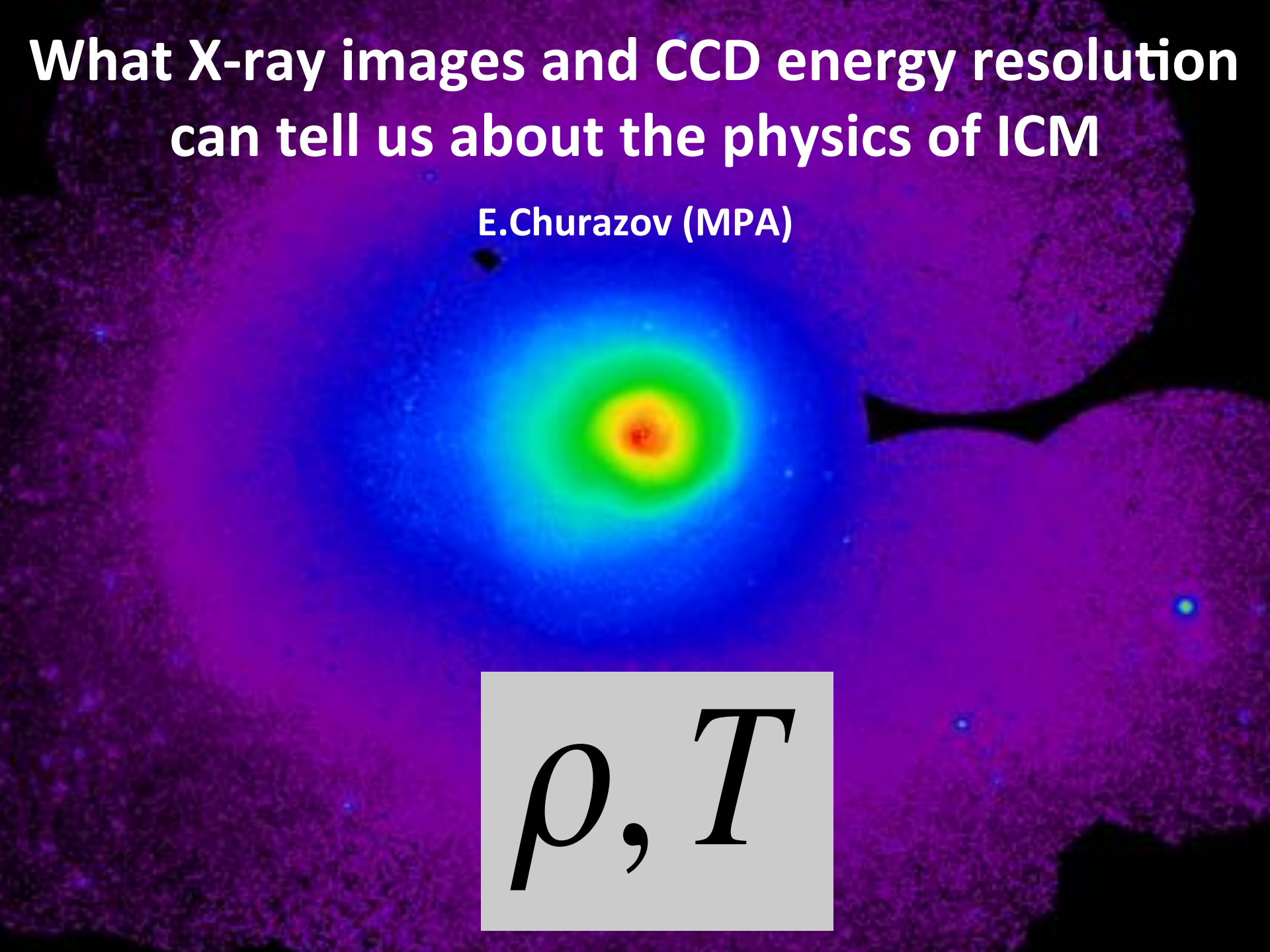
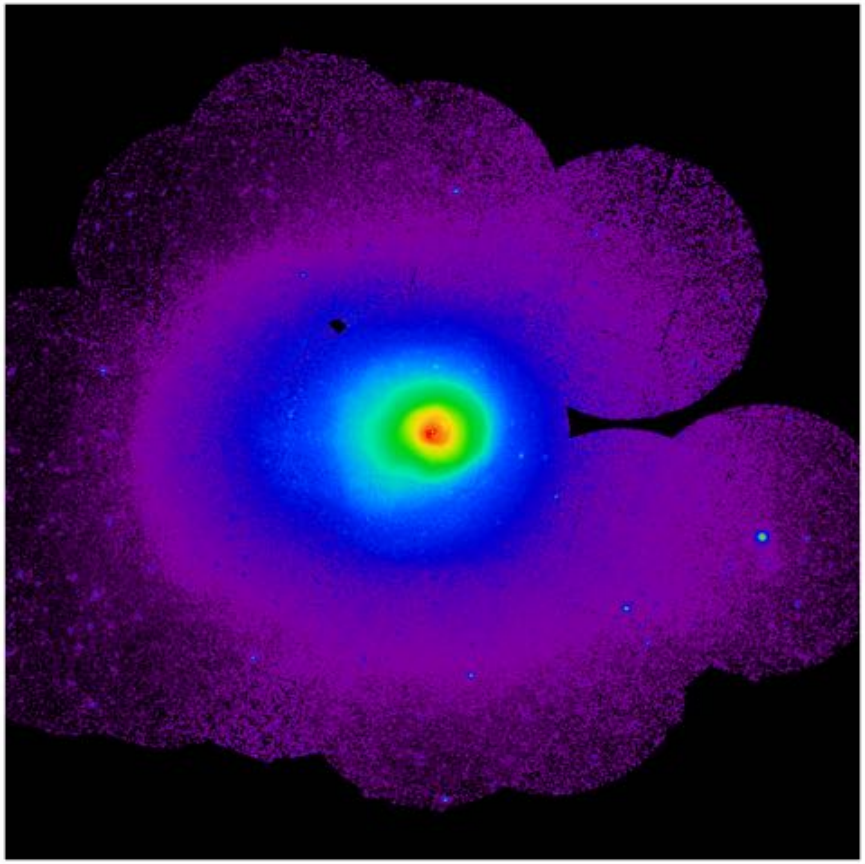
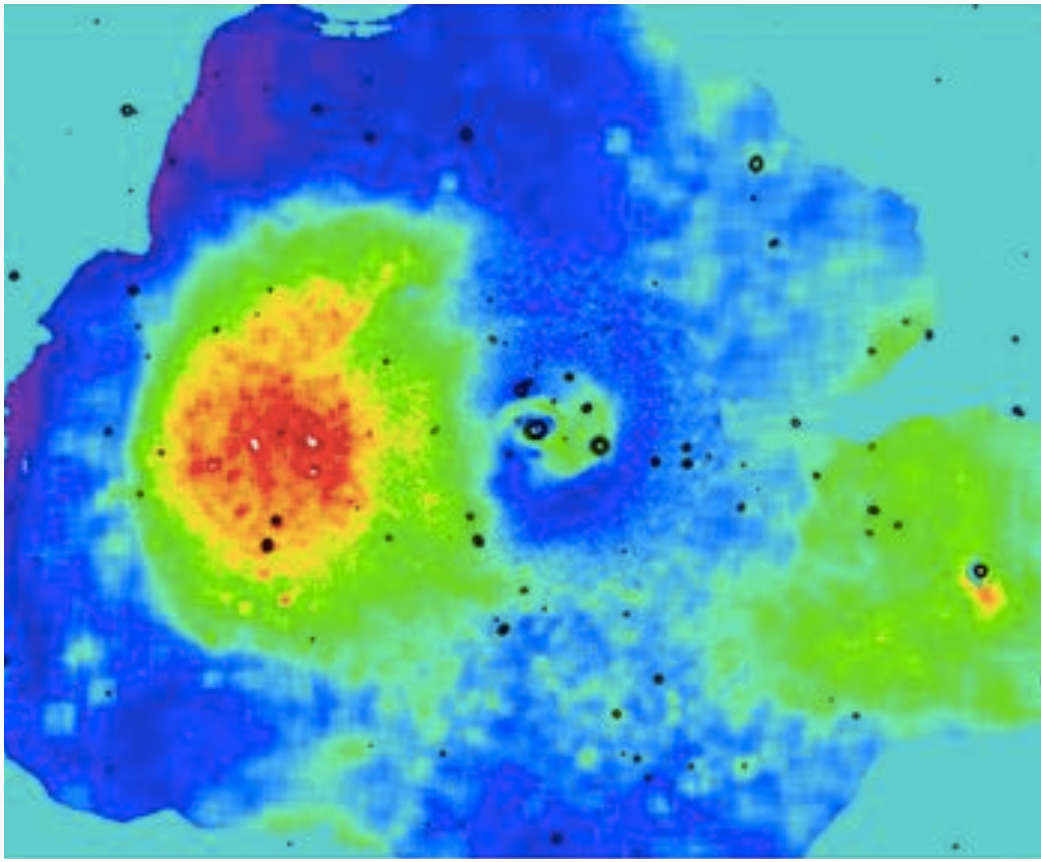
What X-ray images and CCD energy resolution can tell us about the physics of ICM

E.Churazov (MPA)



Can we measure gas velocities?





We know that the Perseus cluster is not at rest

Direct velocity measurements

Calorimeters
[ASTRO-H]

60 km/s

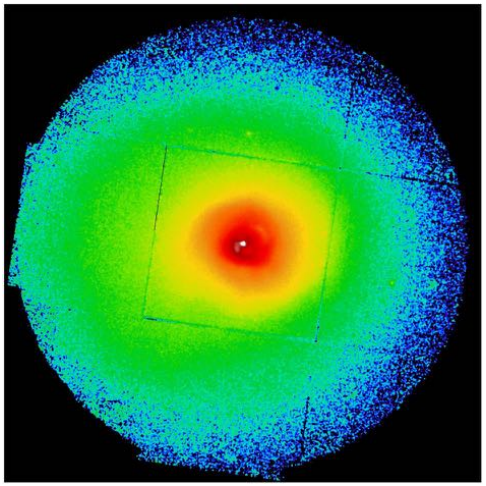
Indirect velocity measurements

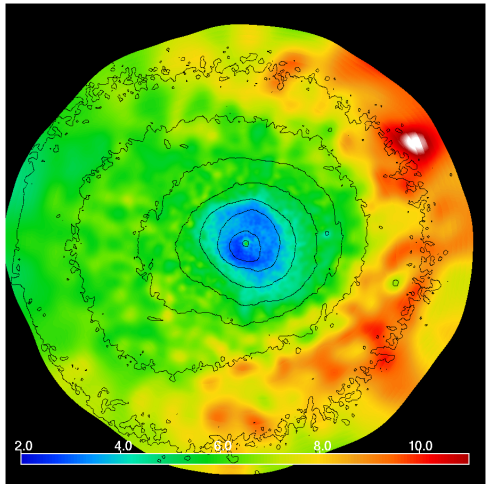
140 km/s

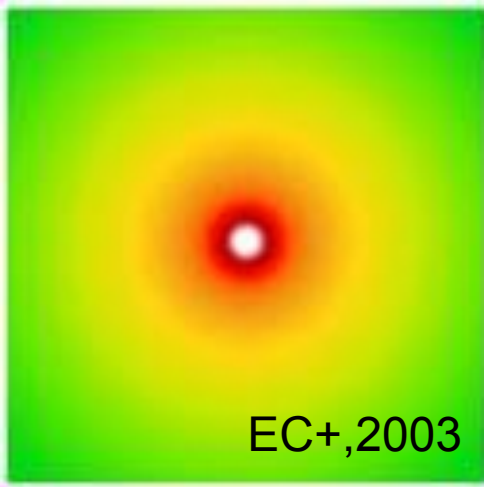
Subsonic motions in the fluid

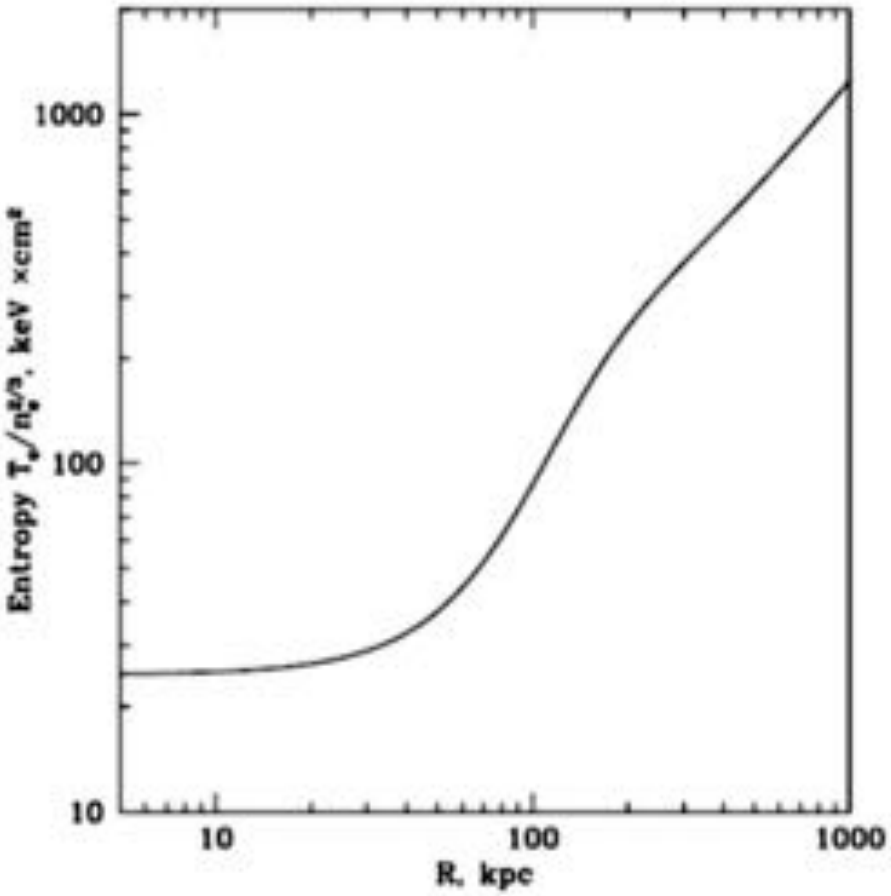
Passive scalar gradients make gas motions visible

EC
XMM Workshop
El Escorial
2005









- 1 part green crème de menthe
- 1 part Irish cream liqueur
- 1 part Grand Marnier orange liqueur

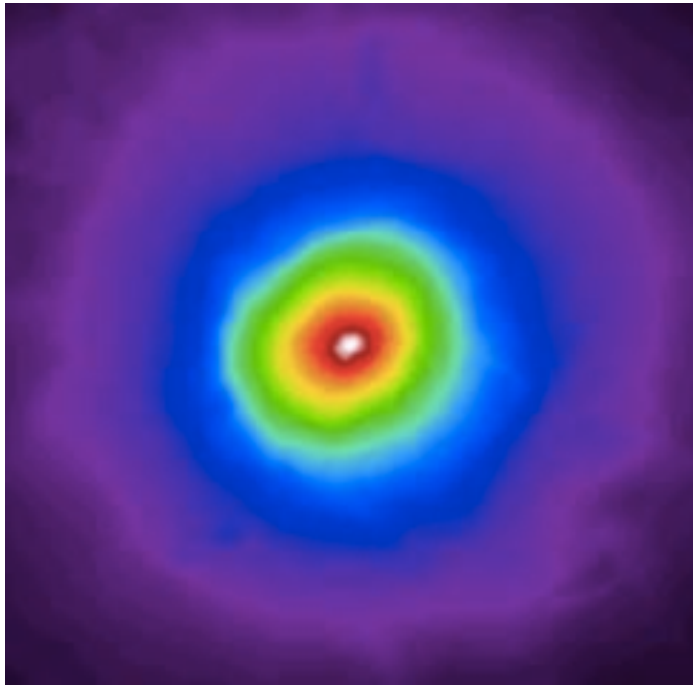
Increasing velocity

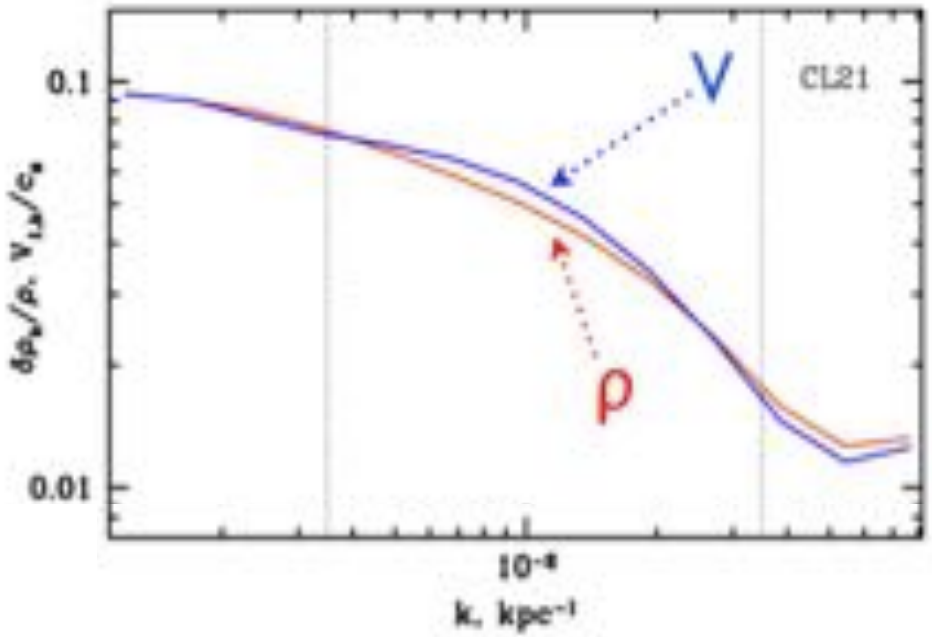
$$\frac{\mathrm{v}_r}{c_s} \approx \eta \frac{\delta\rho}{\rho}$$

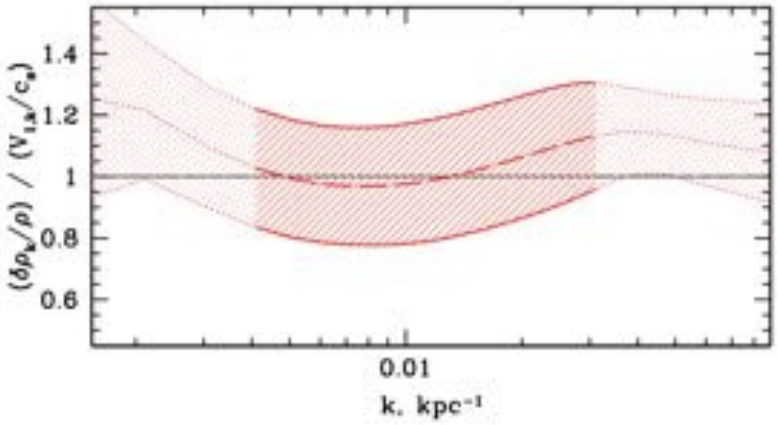
$$\frac{\mathrm{v}_k}{c_s} \approx \eta \frac{\delta\rho_k}{\rho}$$

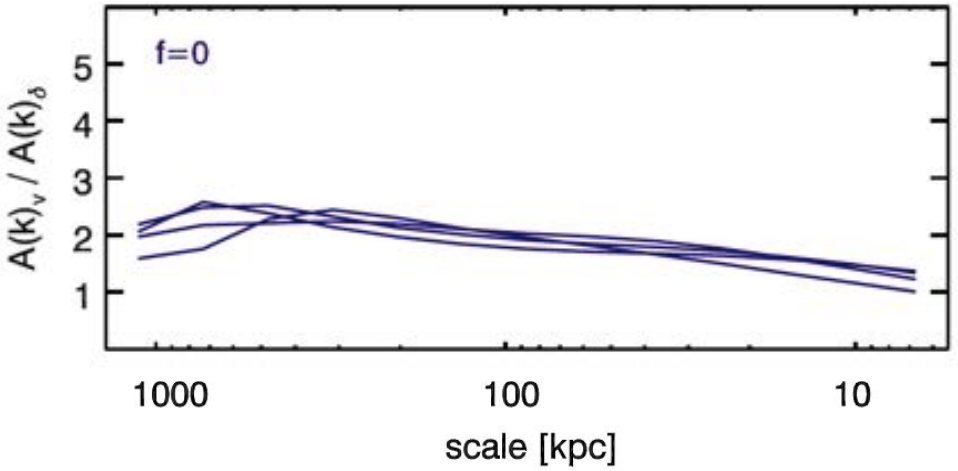
$$\eta \approx \sqrt{\frac{H_P}{H_s}} \approx 1$$

Relation between density and velocity perturbations in stratified atmospheres





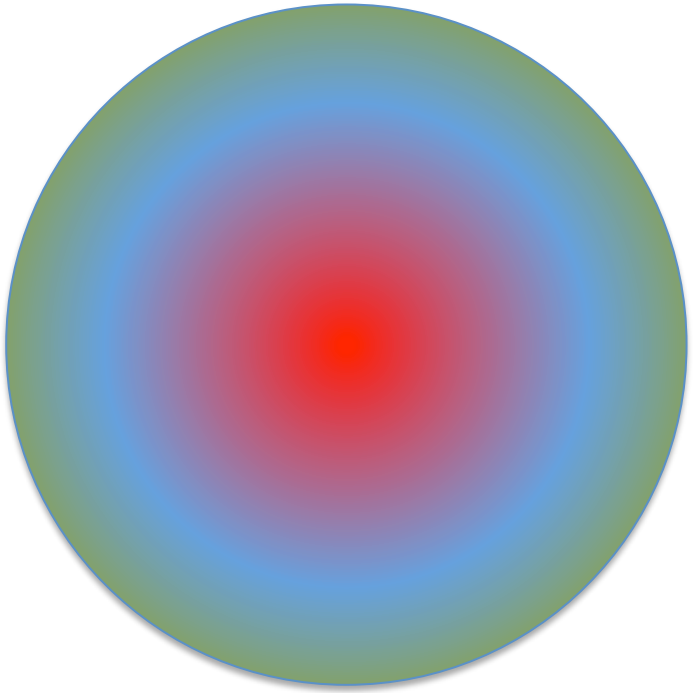




Zhuravleva+,14a

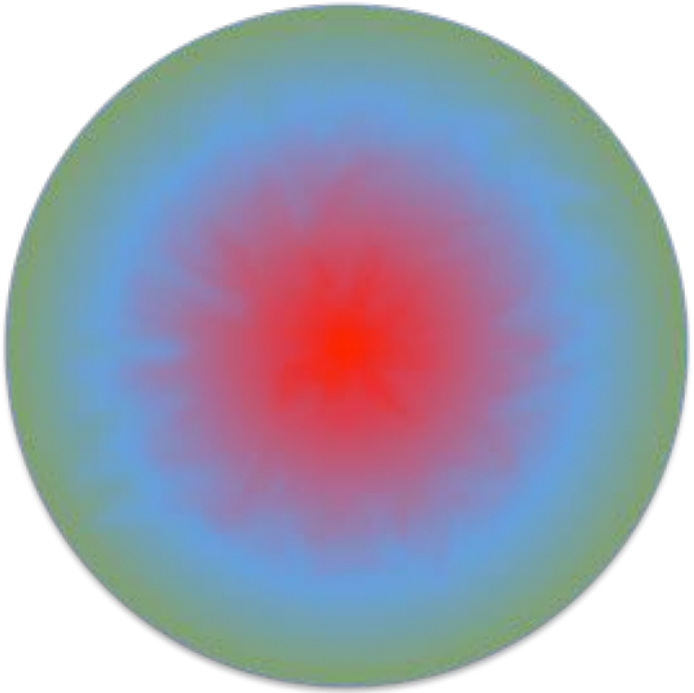
Gaspari+,14

Fully relaxed cluster



V=0

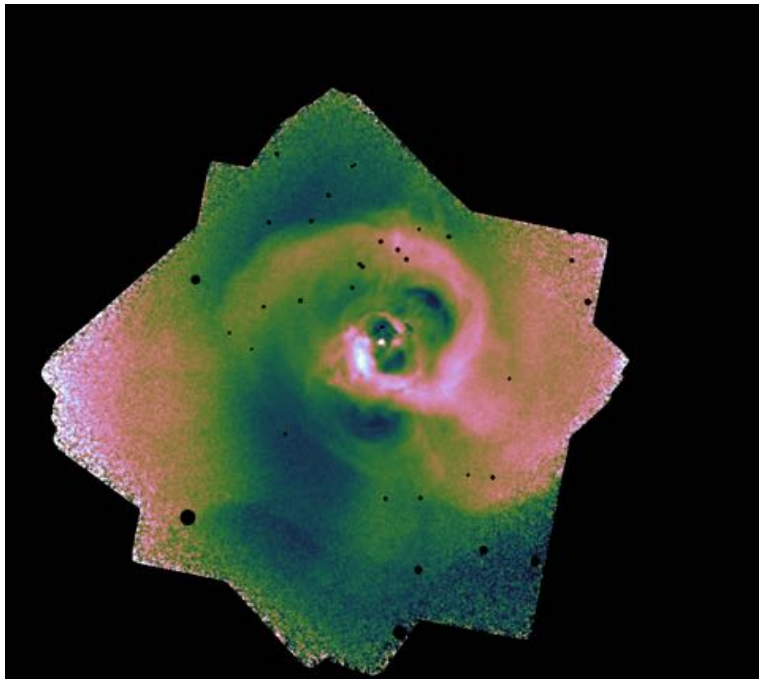
Slightly disturbed cluster

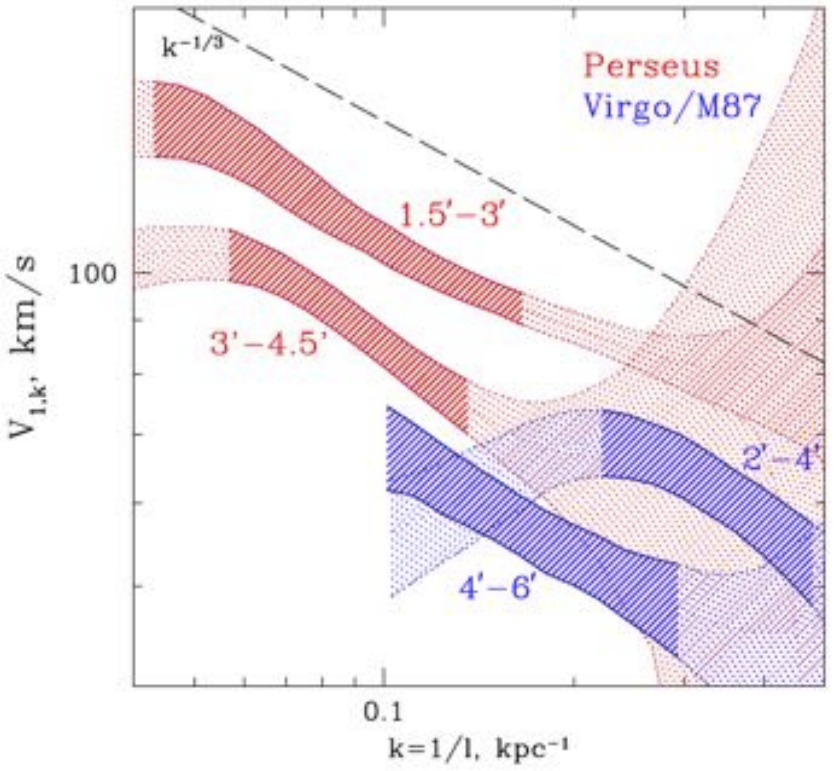


V≠0

Disturbed image => V≠0. We can link V and δn/n.

Getting gas velocity power spectrum from images

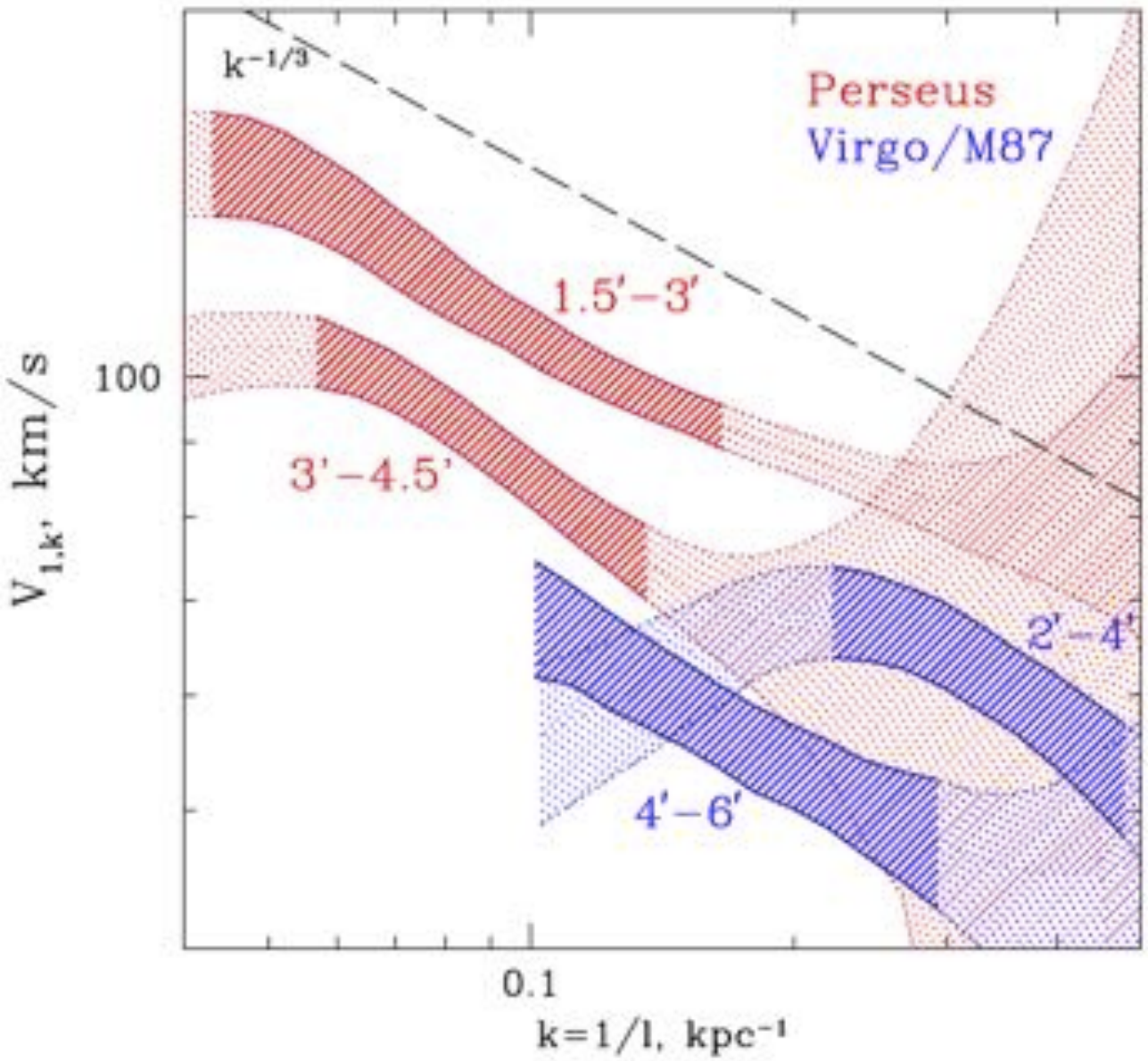




Zhuravleva+,14b

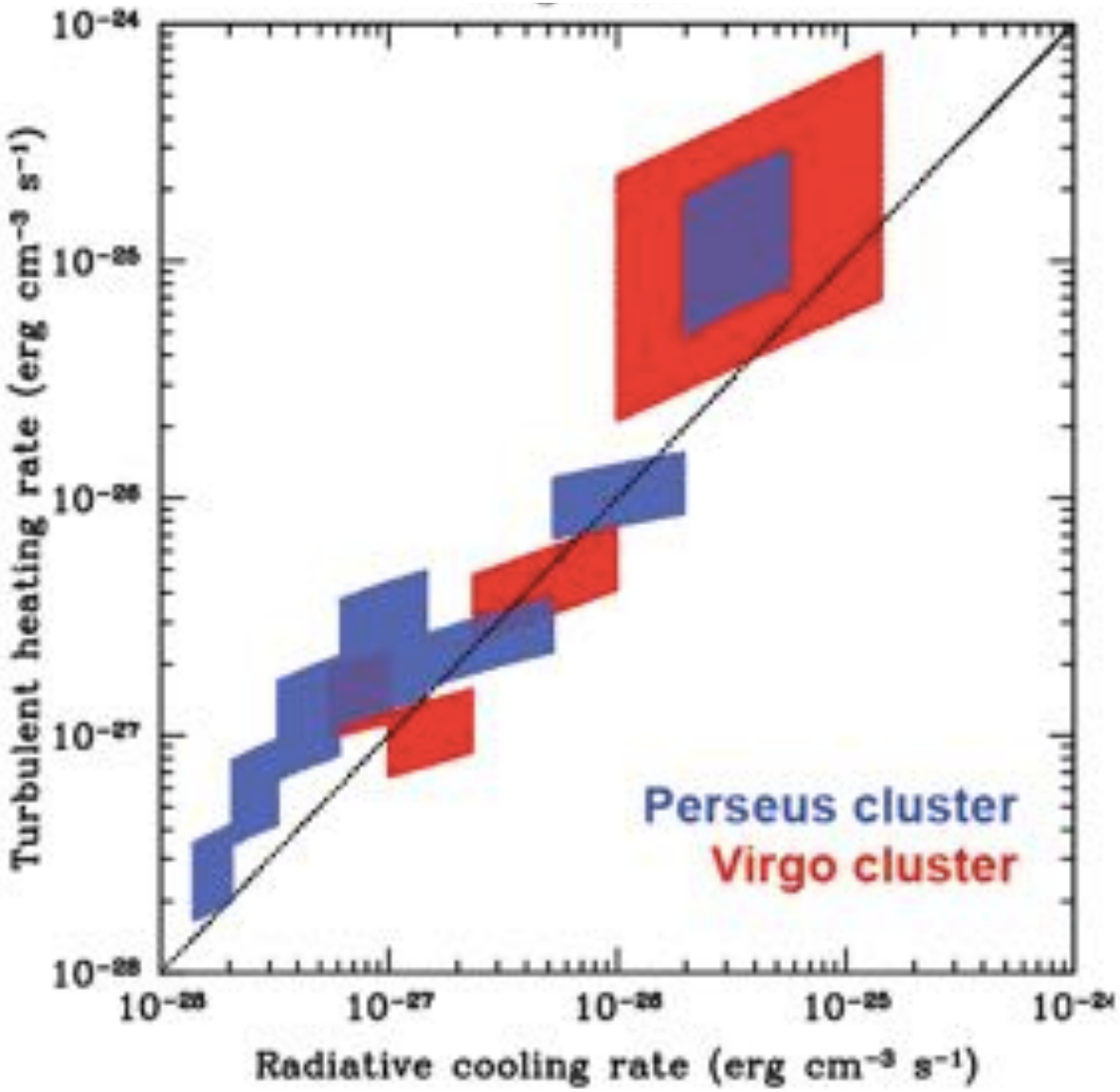
$$\frac{\delta I}{I} \Rightarrow P_{2D}(k) = C \times P_{3D}(k) \Rightarrow \frac{\delta \rho}{\rho} \Rightarrow \frac{\mathrm{v}}{c_s}$$

Velocity power spectra in Perseus and M87



Heating rate

$$E(k) = K_0 \varepsilon^{2/3} k^{-5/3}$$



$$\text{Cooling} = n^2 \Lambda(T)$$

$$\text{Heating} = C \rho V_{1,k}^3 k$$

Zhuravleva+,14b

Can we prove that we see turbulent cascade?

No

Can we prove that we see entropy variations?
(isobaric fluctuations)

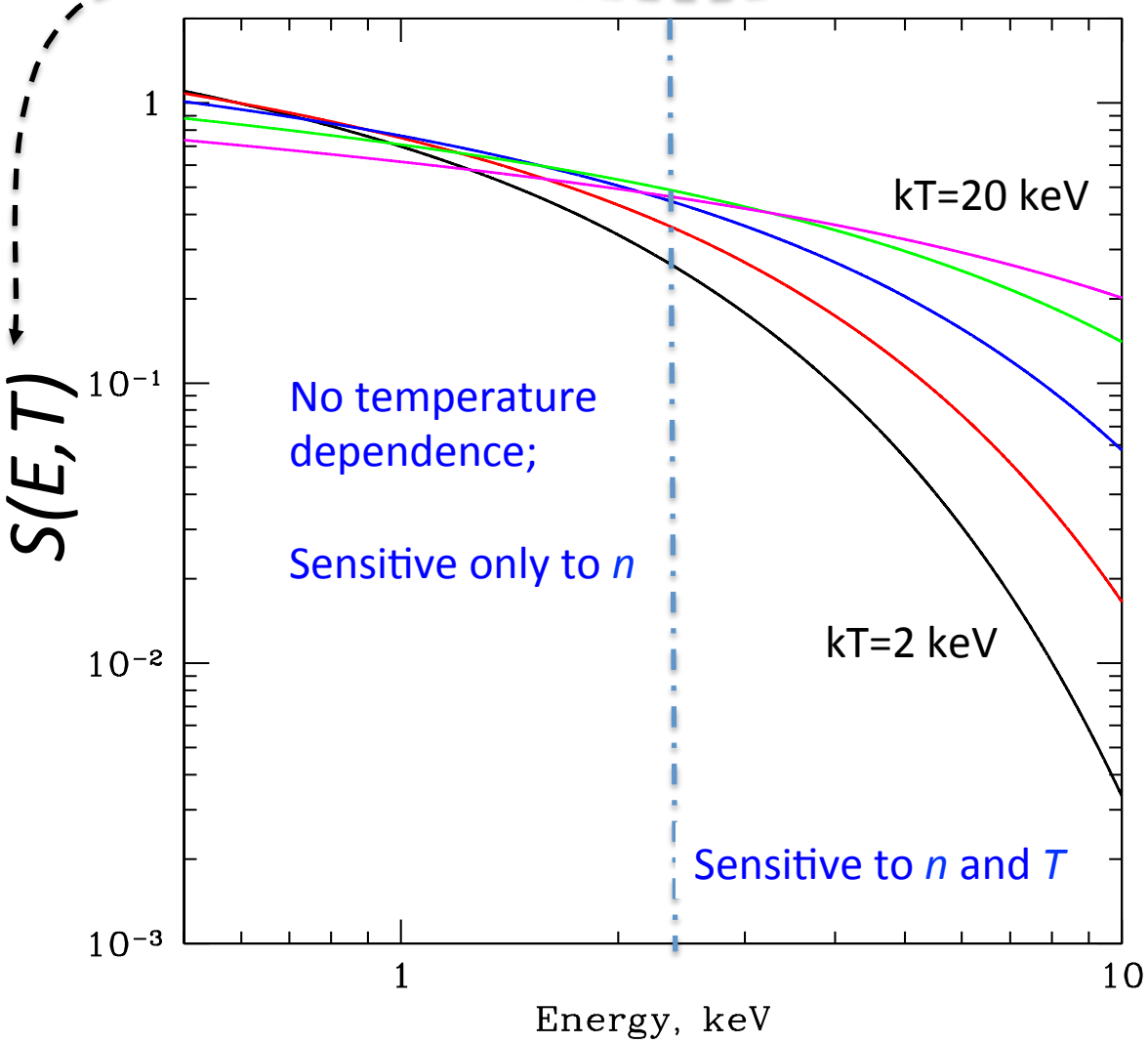
Yes, by arithmetic manipulations with X-ray images

"Xarithmetic", EC+,2016

Thermal bremsstrahlung spectrum (with Gaunt factor)

$$F(E) = n^2 S(E,T)$$

$$\frac{\delta T}{T} = \alpha \frac{\delta n}{n}$$



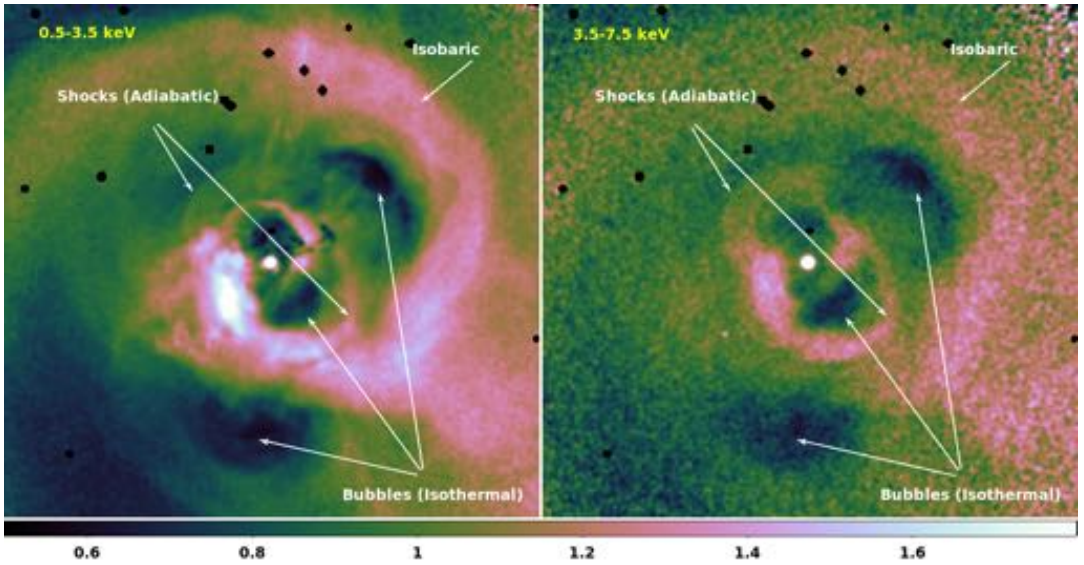
Arithmetic with X-ray images
"Xarithmetic"

$$\frac{\delta T}{T} = \alpha \frac{\delta n}{n}$$

$$A_s(x,y) = \frac{I_s - I_{s,0}}{I_{s,0}}$$

$$A_h(x,y) = \frac{I_h - I_{h,0}}{I_{h,0}}$$

$$B(x,y) = C_1 A_s + C_2 A_h$$

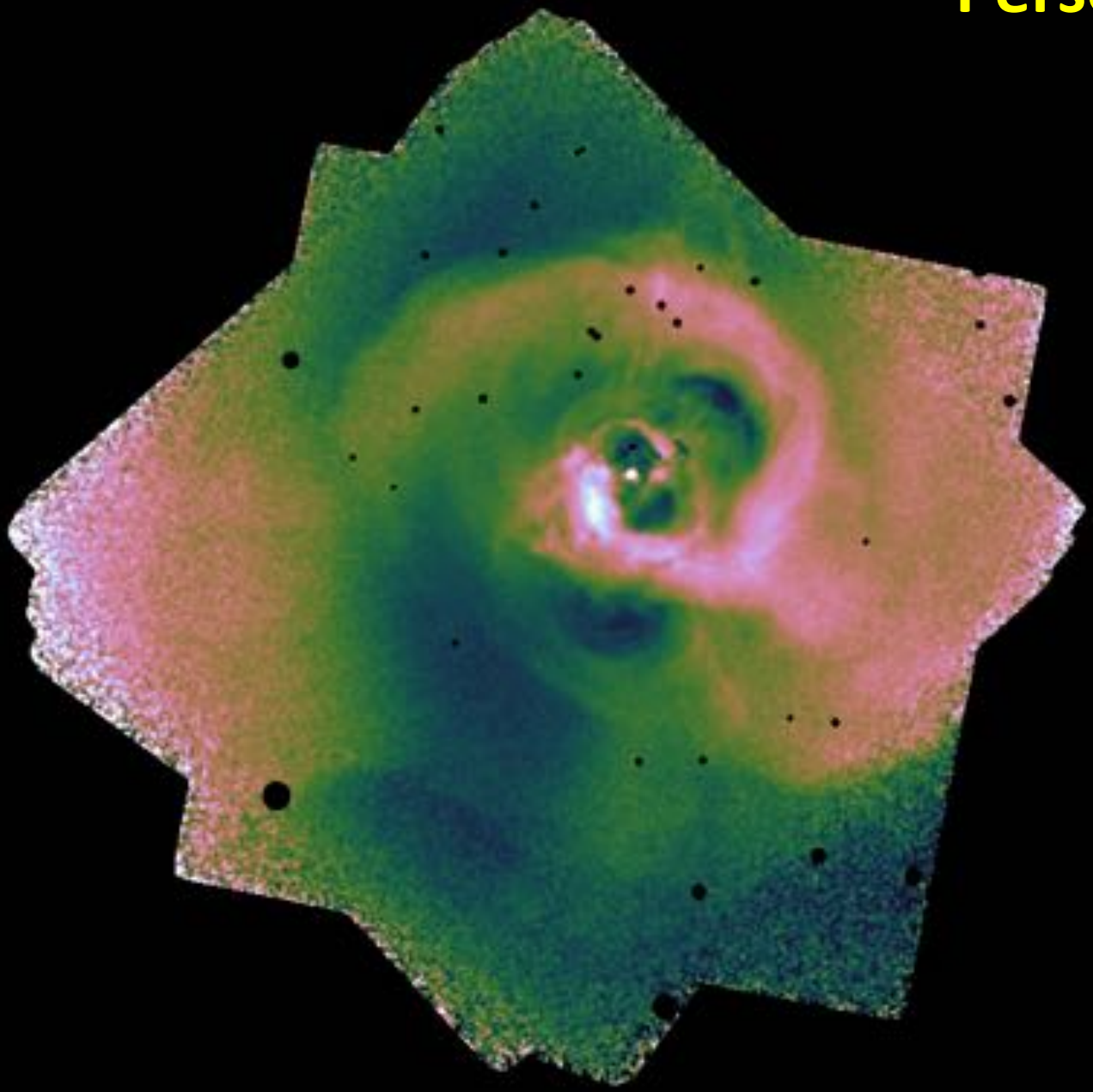


For any given type of perturbations (isothermal, isobaric, adiabatic) we know relative amplitudes of perturbations in A_s and A_h. We can choose C_1 and C_2 to eliminate them.

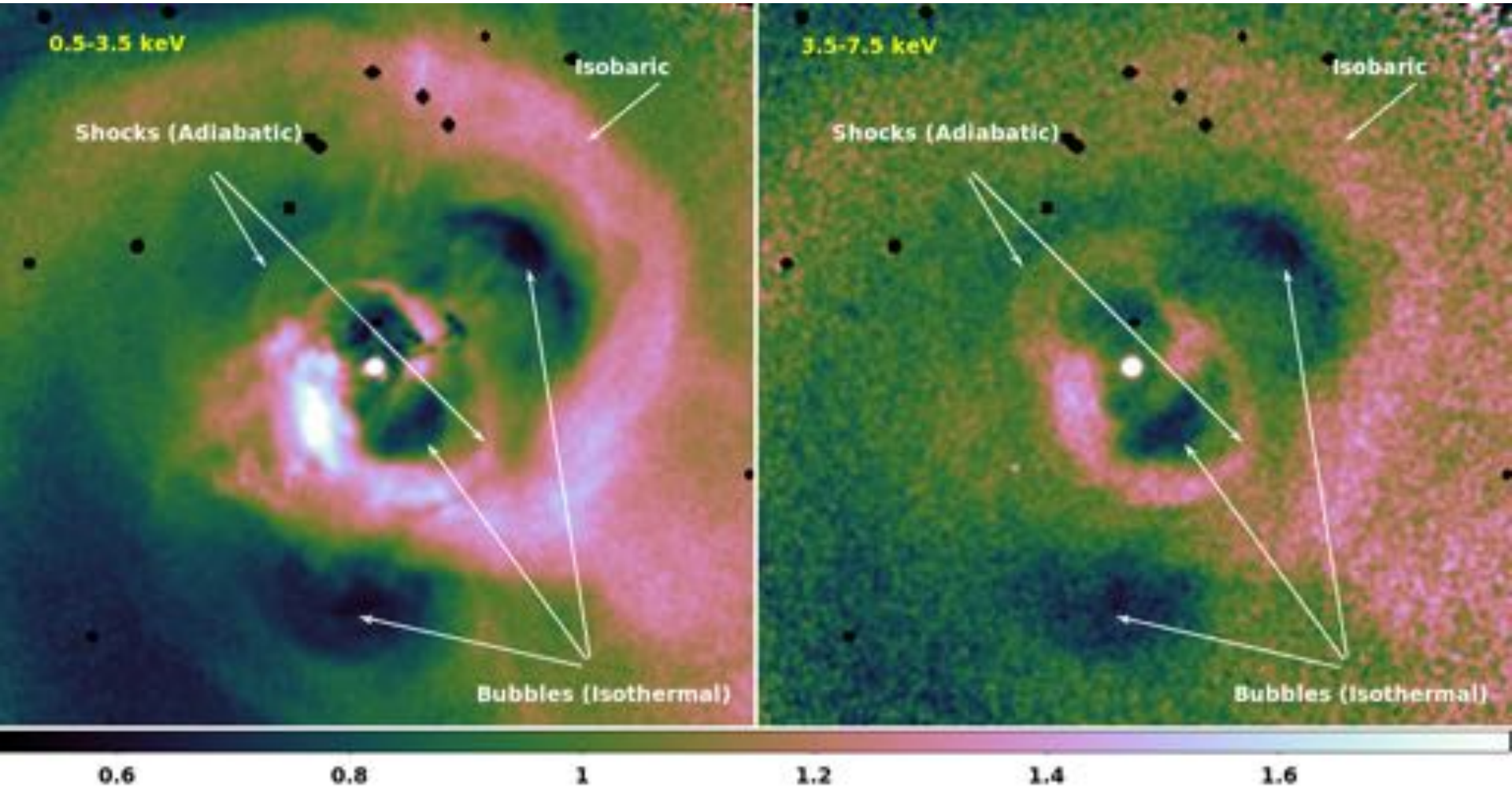
See also Forman+, 2007

EC+, 2016

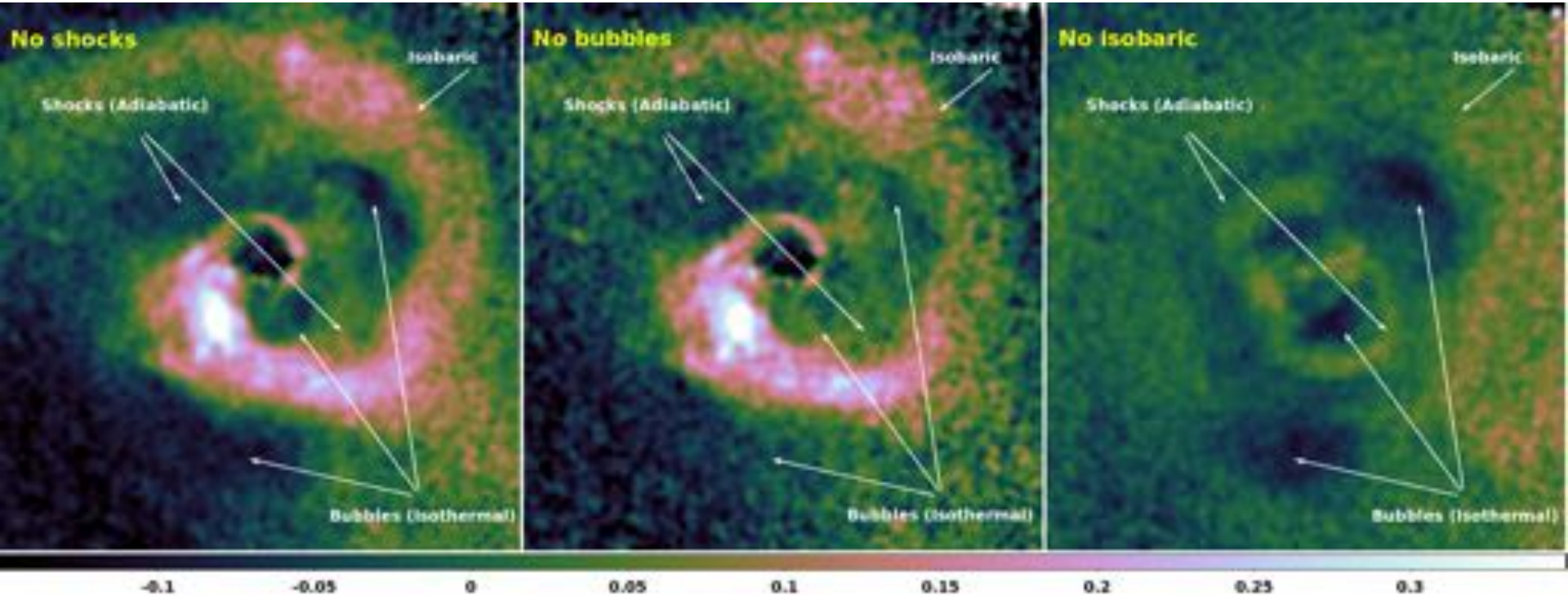
Perseus



Soft and hard band images



Manipulated images



Isobaric (entropy) perturbations dominate

Conclusions

We can measure velocity power spectra from images

In a statistical sense

Nowhere near +/- 10 km/s

If we assume that we do see turbulent cascade => enough heating

We can measure effective equation of state of perturbations with two images

XMM+10 wish list: add background to the standard pipeline products