The Quest for Cluster Simulations

Klaus Dolag

Max-Planck-Institut für Astrophysik

Intro

Outline / Motivation

- Do we model the ICM accurate enough to do cosmology with galaxy clusters ?

⇒ State of the ICM vs. Cluster properties
see poster by **E. Rasia** on ”x-ray Mass”

⇒ ICM properties vs. model assumptions (e.g. physical processes included)

- Many physical processes are linked together (e.g. thermal conduction, turbulence, magnetic fields)
see poster by **D. Sijacki** on ”Central AGN feedback”

⇒ Can we model their individual effects ?

⇒ Can we overcome numerical issues and start to study such processes (e.g. SPH,Gadget-II-XXL)

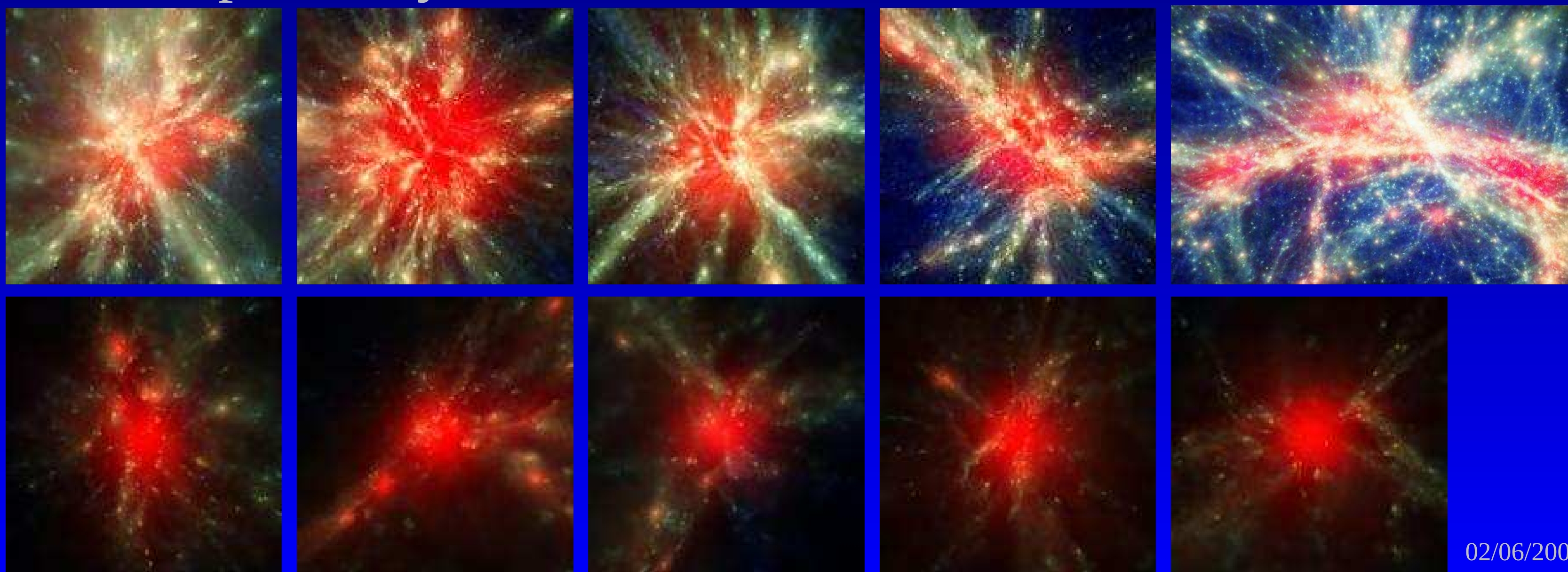
Outline:

- General properties of simulated galaxy clusters
- ”Turbulence” in SPH simulations
- Magnetic Fields in galaxy clusters

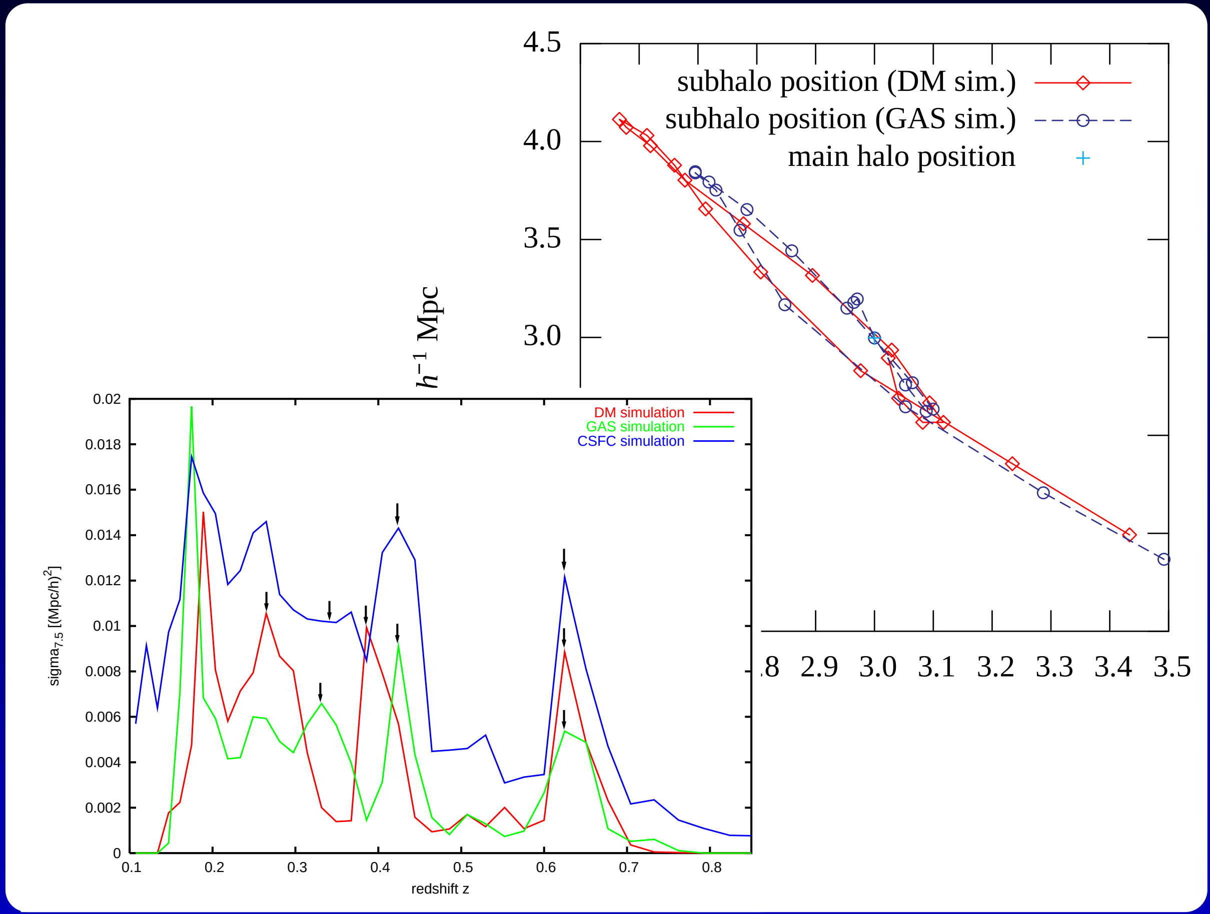
Hutt (High resolution Cluster set)

39 Haloes ($> 0.7 \times 10^{14} M_{sol}$), up to 4×10^{6} Particles in R_{vir} !

- DM-only (**dm**)
- none radiative gas (**gas**)
- cooling+starformation+winds (**csf**)
- no/week/strong winds (**csfnw,csf,csfsw**)
- thermal conduction (**csfc**)
- new scheme to avoid damping of turbulence (**gas_nv**)
- numerical tests (e.g. resolution, grid vs. glass, etc.)
- Metals and chemical enrichment
  ⇒ poster by **Luca Tornatore** on ”chemical enrichment”



The revenge of the ICM

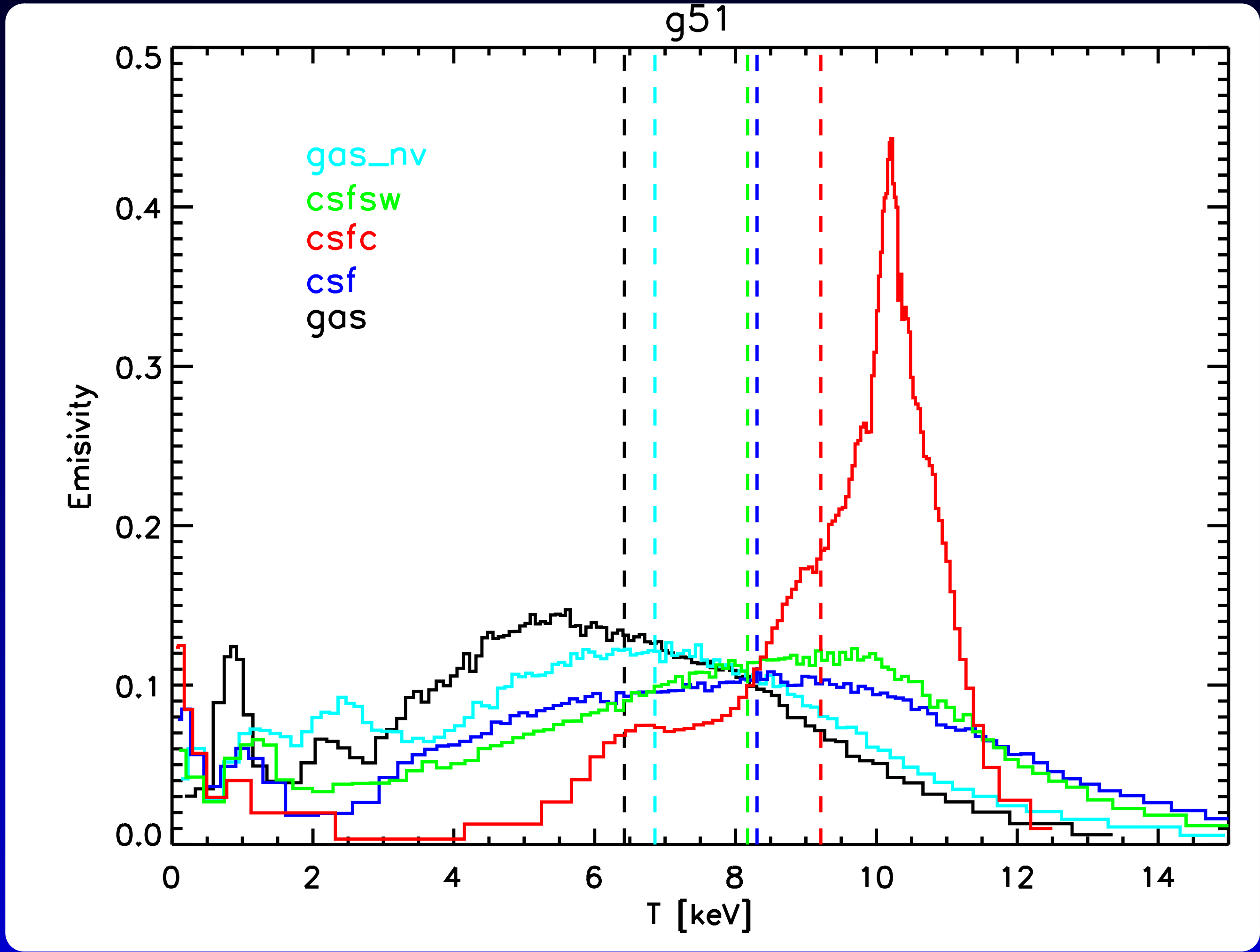


The presence of gas changes dynamics and profiles !

- Strong lensing cross section decreases for none radiative gas with strong turbulence (e.g. none thermal pressure)
- Increases strongly for cooling and starformation.

Puchwein, Bartelmann, Dolag & Meneghetti 2005, A&A in press, astro-ph/0504206

State of the ICM

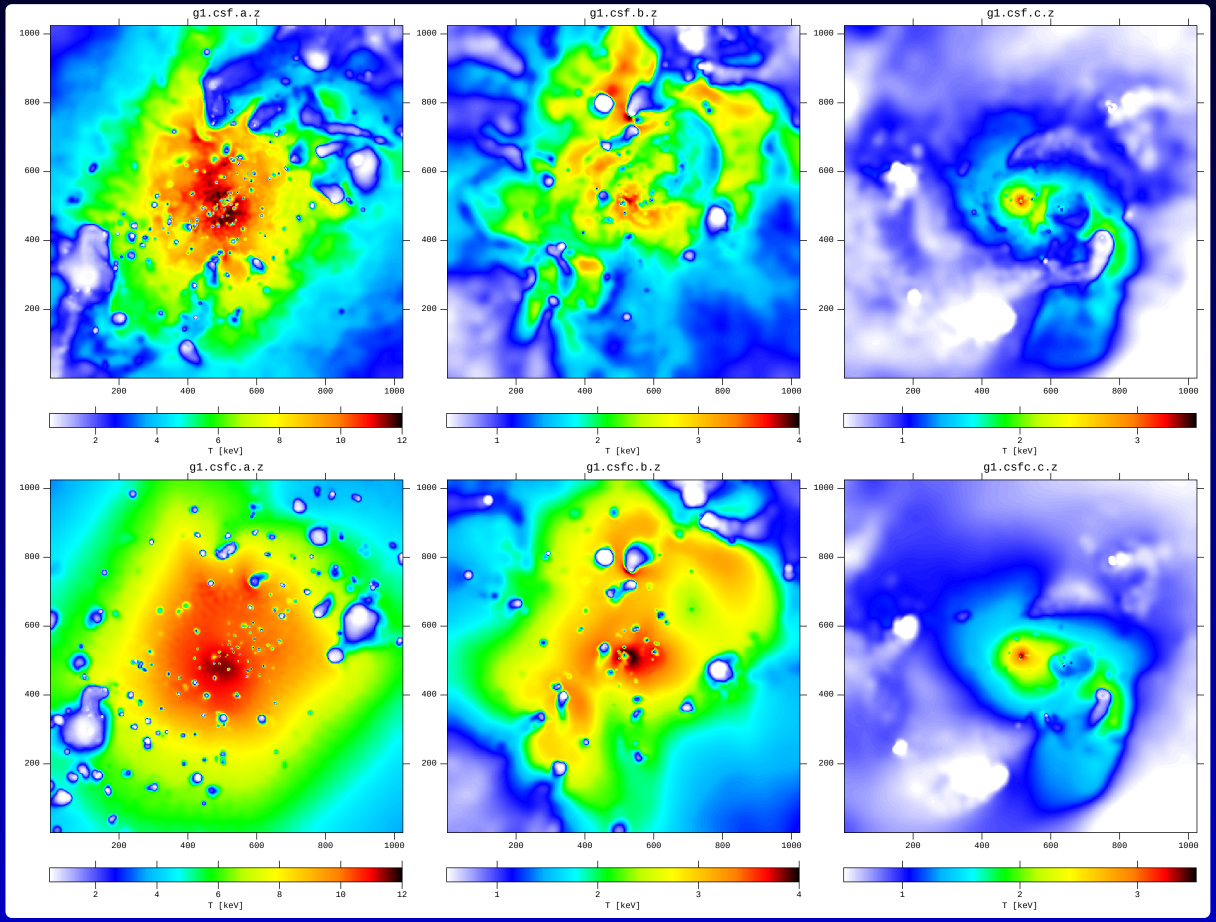


Emission is complex, mixture of dynamic & physical processes !

Shape crucial for interpretation of global quantities !

Dolag et al. (in prep.)

State of the ICM



First cosmological simulations including thermal conduction.

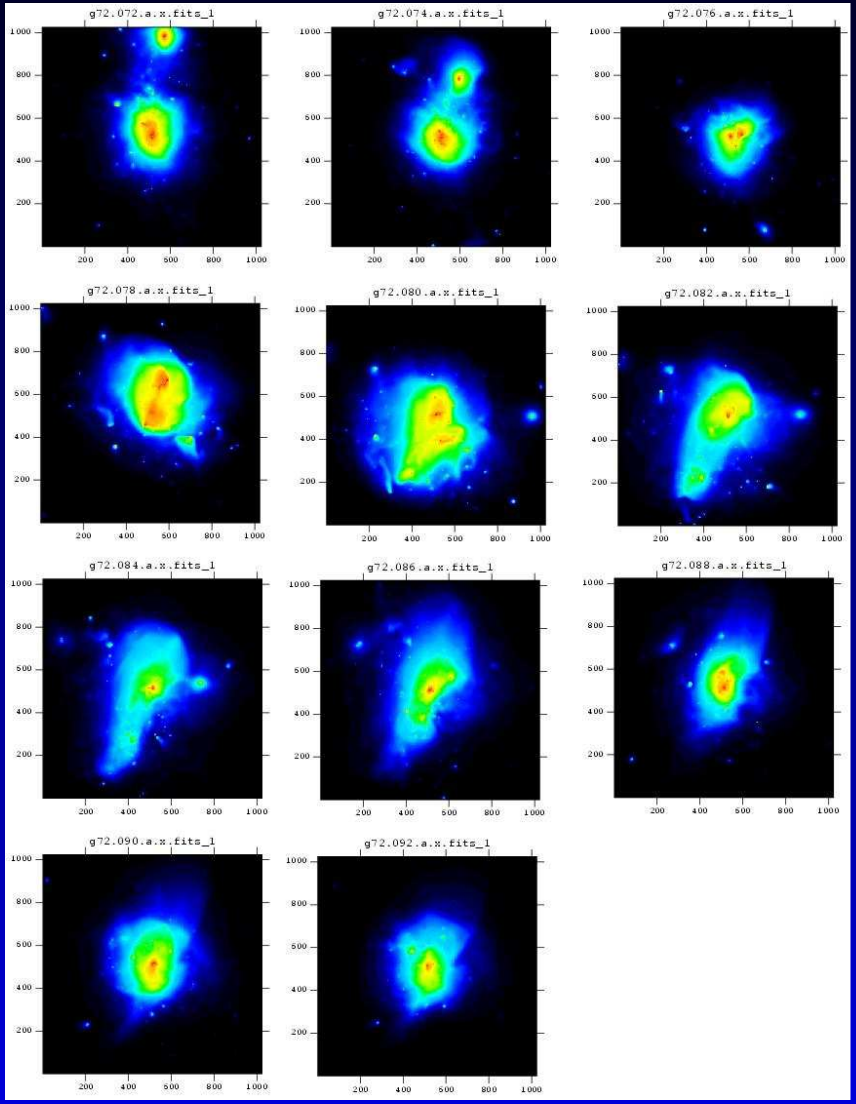
⇒ but no solution for the catastrophic cooling !

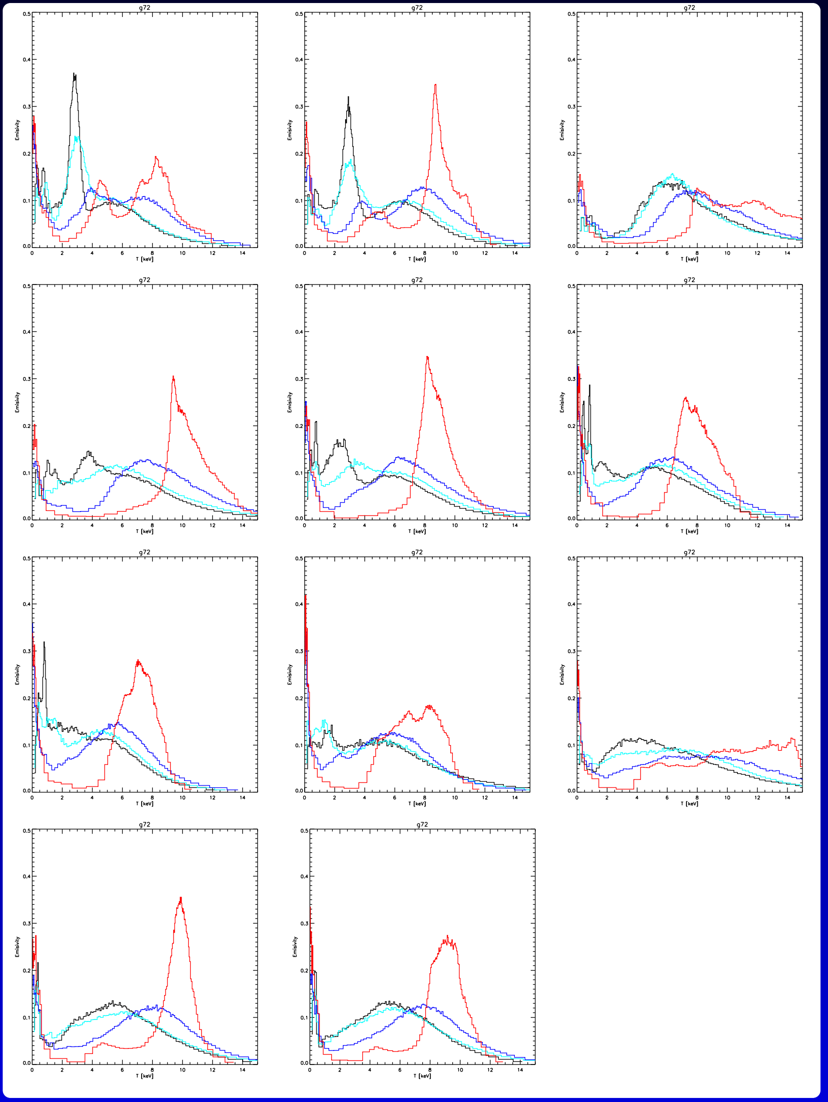
⇒ flat temperature profile for T > (8-10)keV !

Jubelgas, Springel & Dolag 2004, MNRAS, 351, 423;

Dolag, Jubelgas, Springel, Borgani & Rasia 2004, ApJ 606L, 97

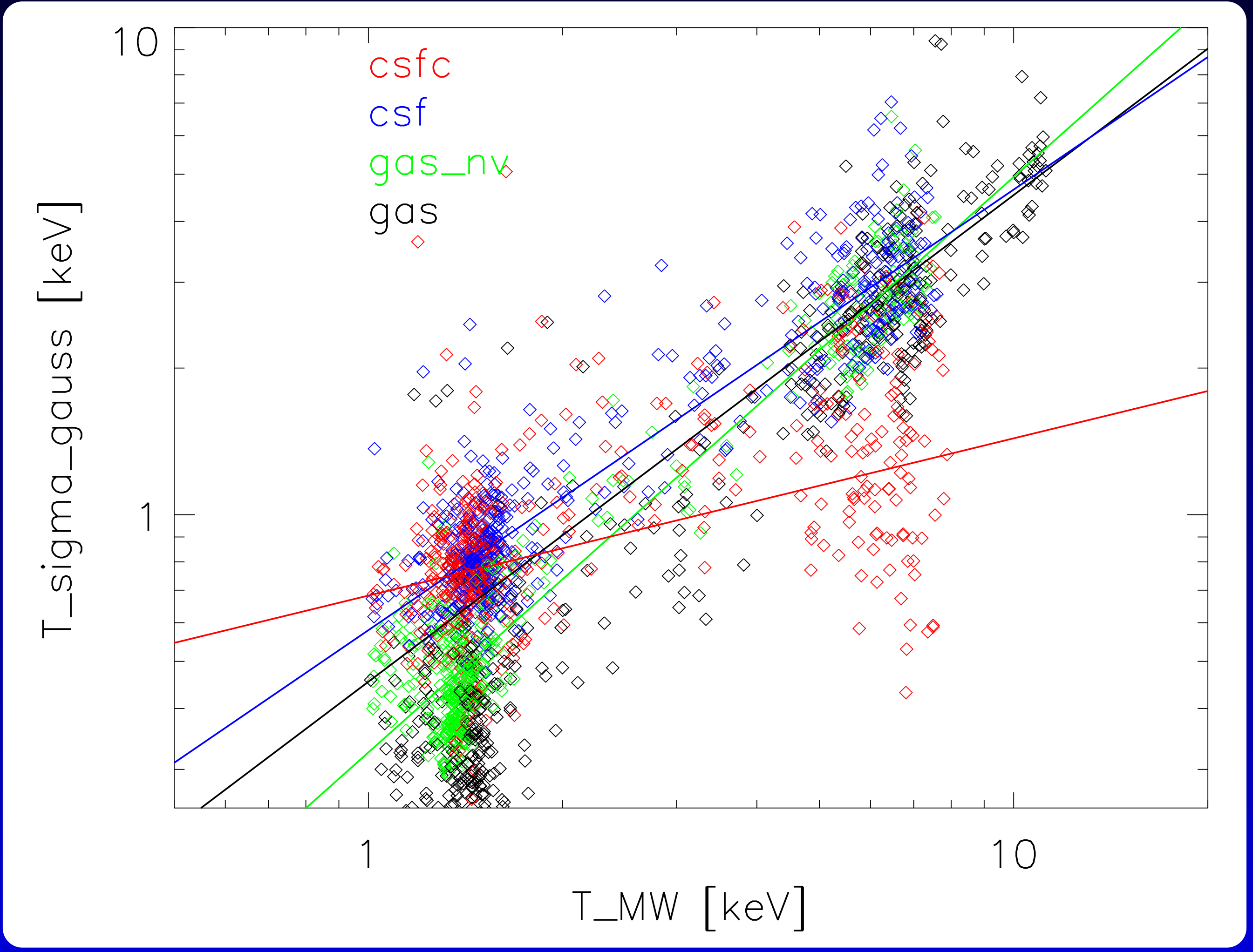
State of the ICM





Deviation from gaussianity contain information about dynamics !

State of the ICM

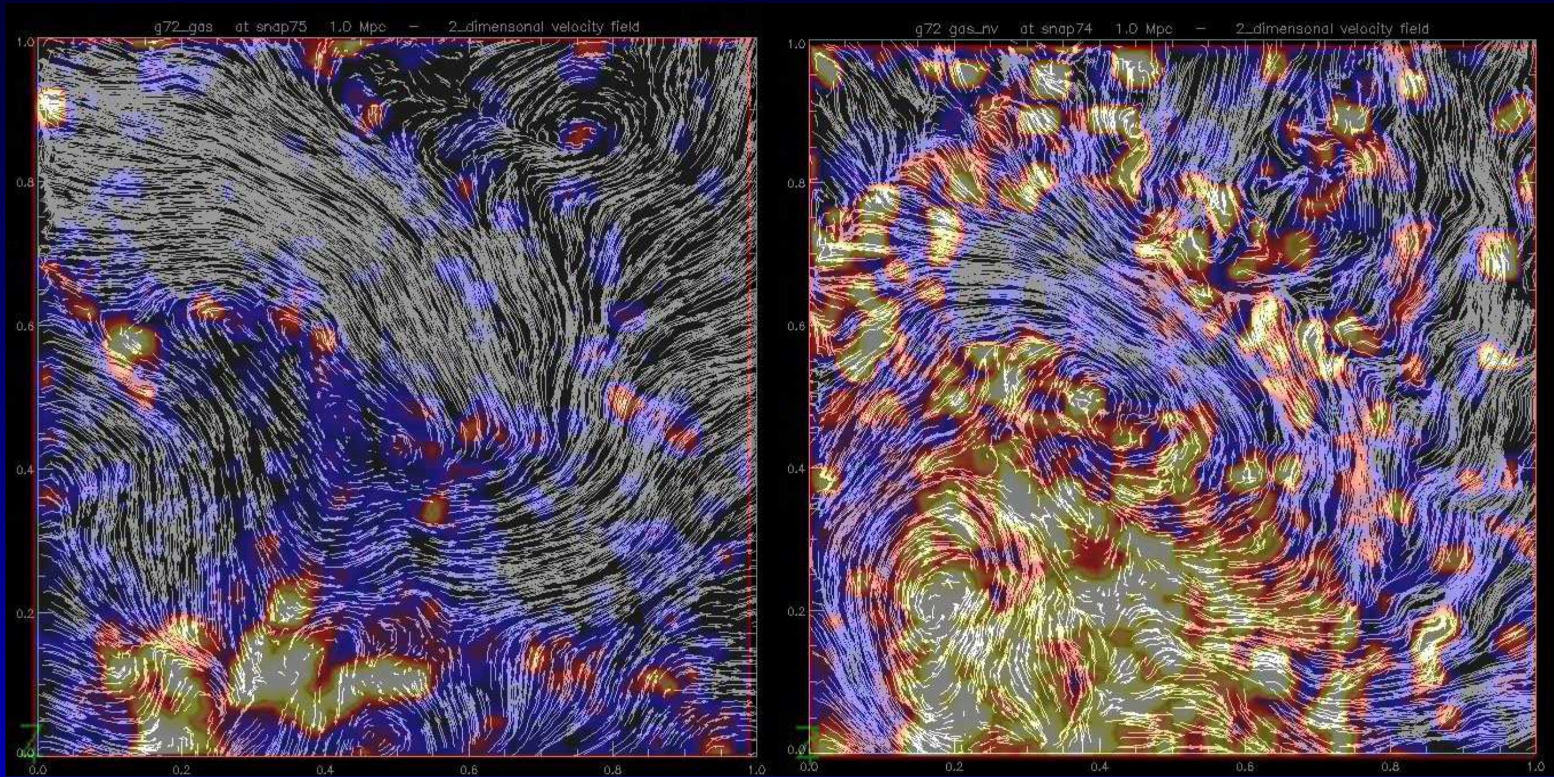


Mass weighted temperature vs. with of the gaussian fit !

⇒ Correlated, but physics, e.g. thermal conduction !

Turbulence in the ICM

Old viscosity scheme **New viscosity scheme**



Artificial viscosity completely switched of outside of shocks !

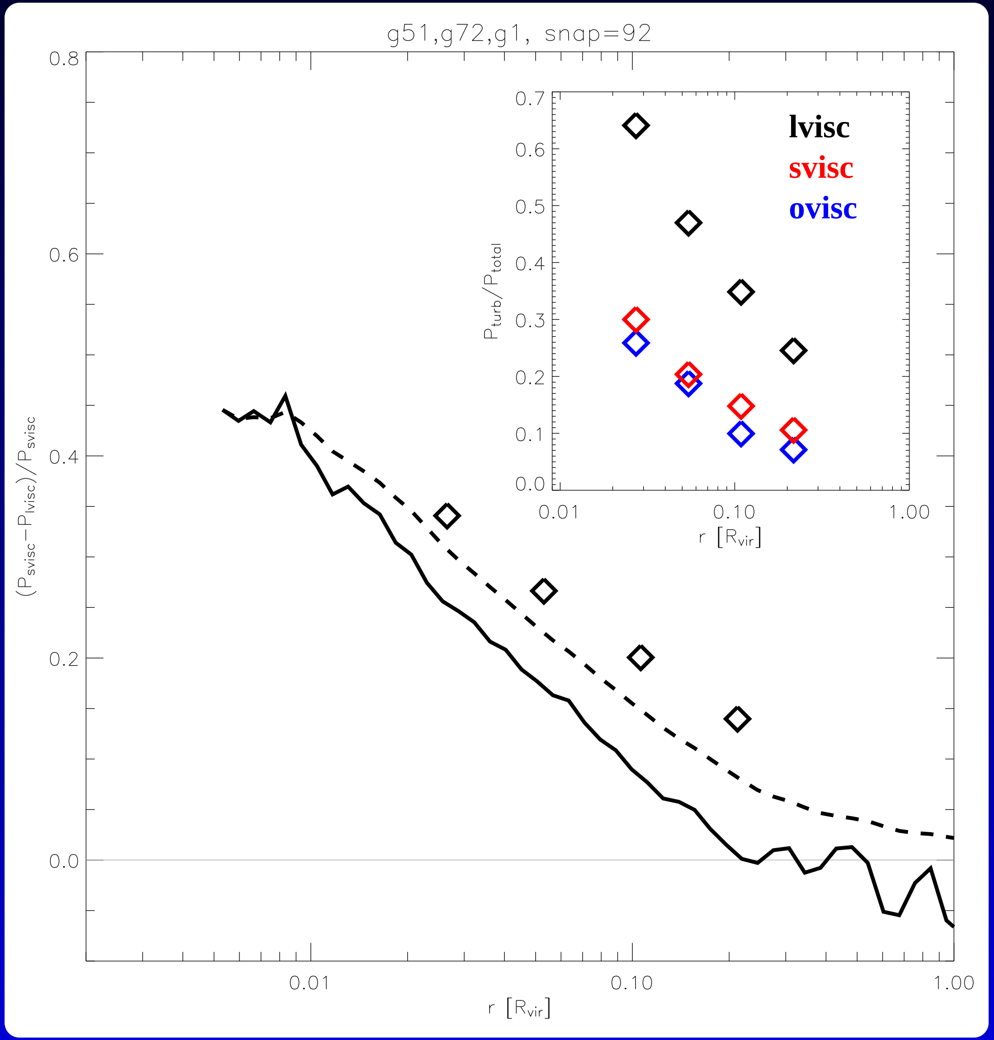
- Instabilities less damped (e.g. Kelvin-Helmholtz).

⇒ Inset of turbulence

⇒ Enlarged energy-fraction in gas velocity

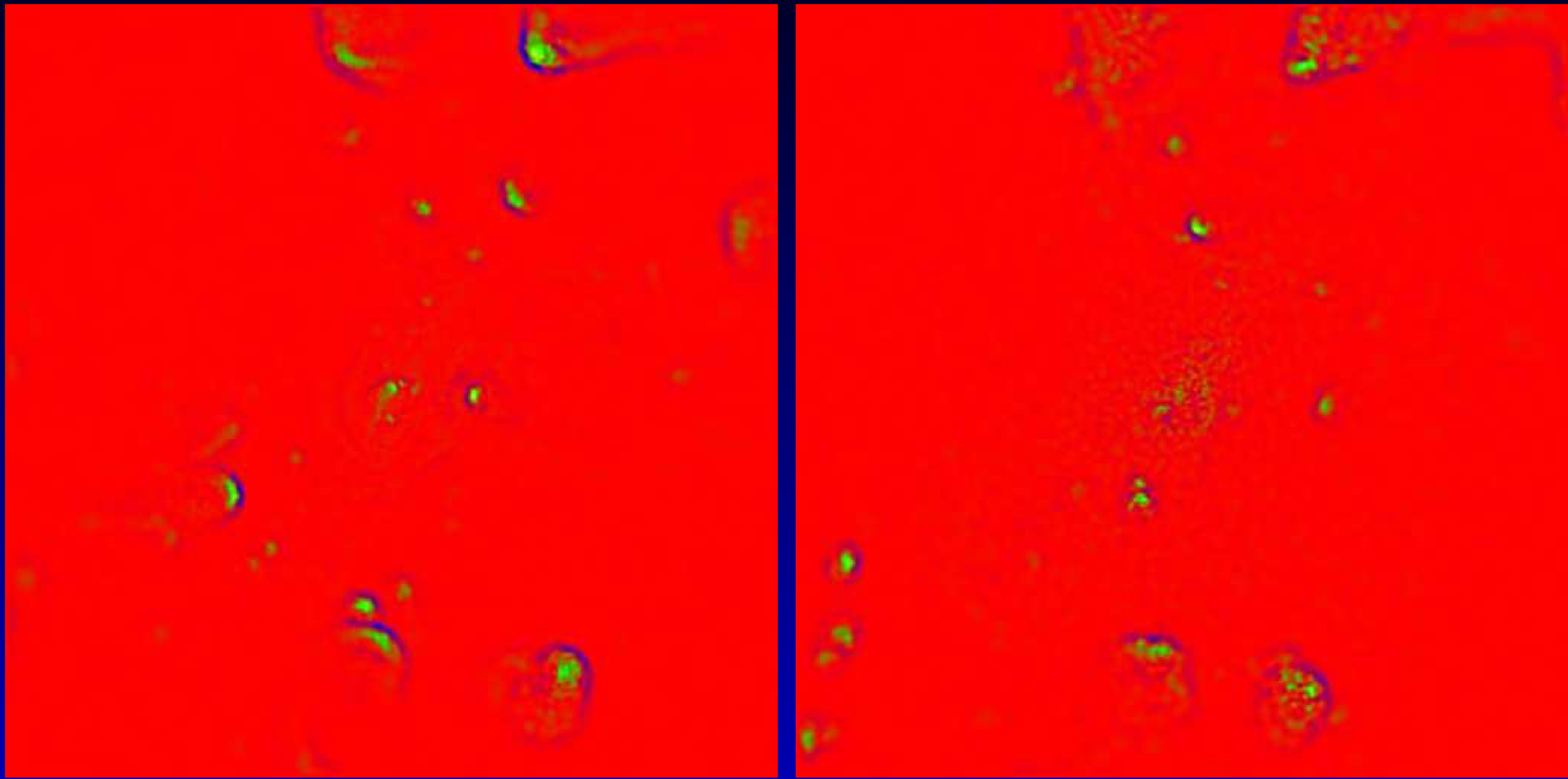
Dolag, Vazza, Brunetti, Tormen & Springel (in prep.)

Turbulence in the ICM



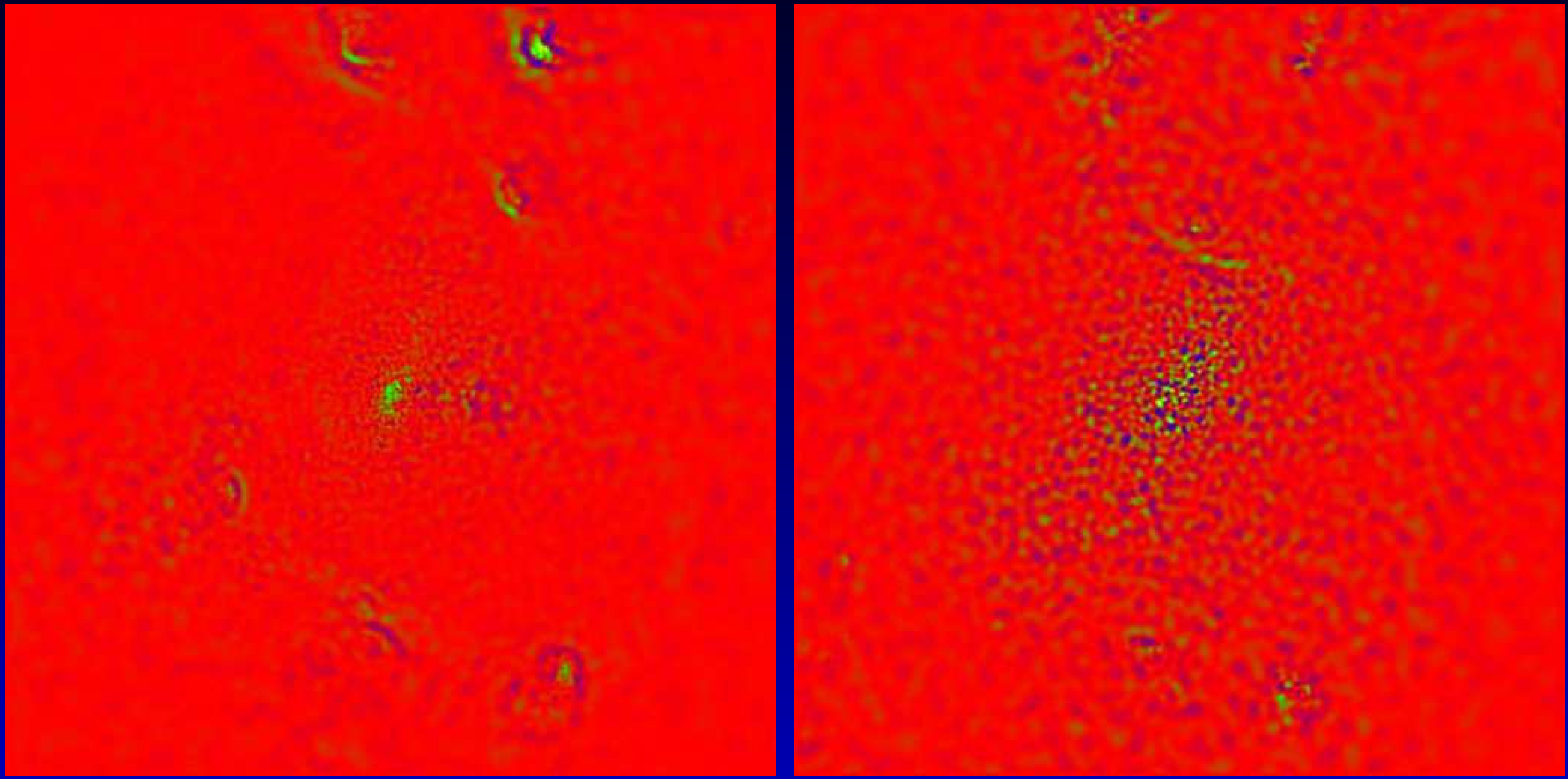
Turbulence can leave to significant pressure support !

Turbulence in the ICM



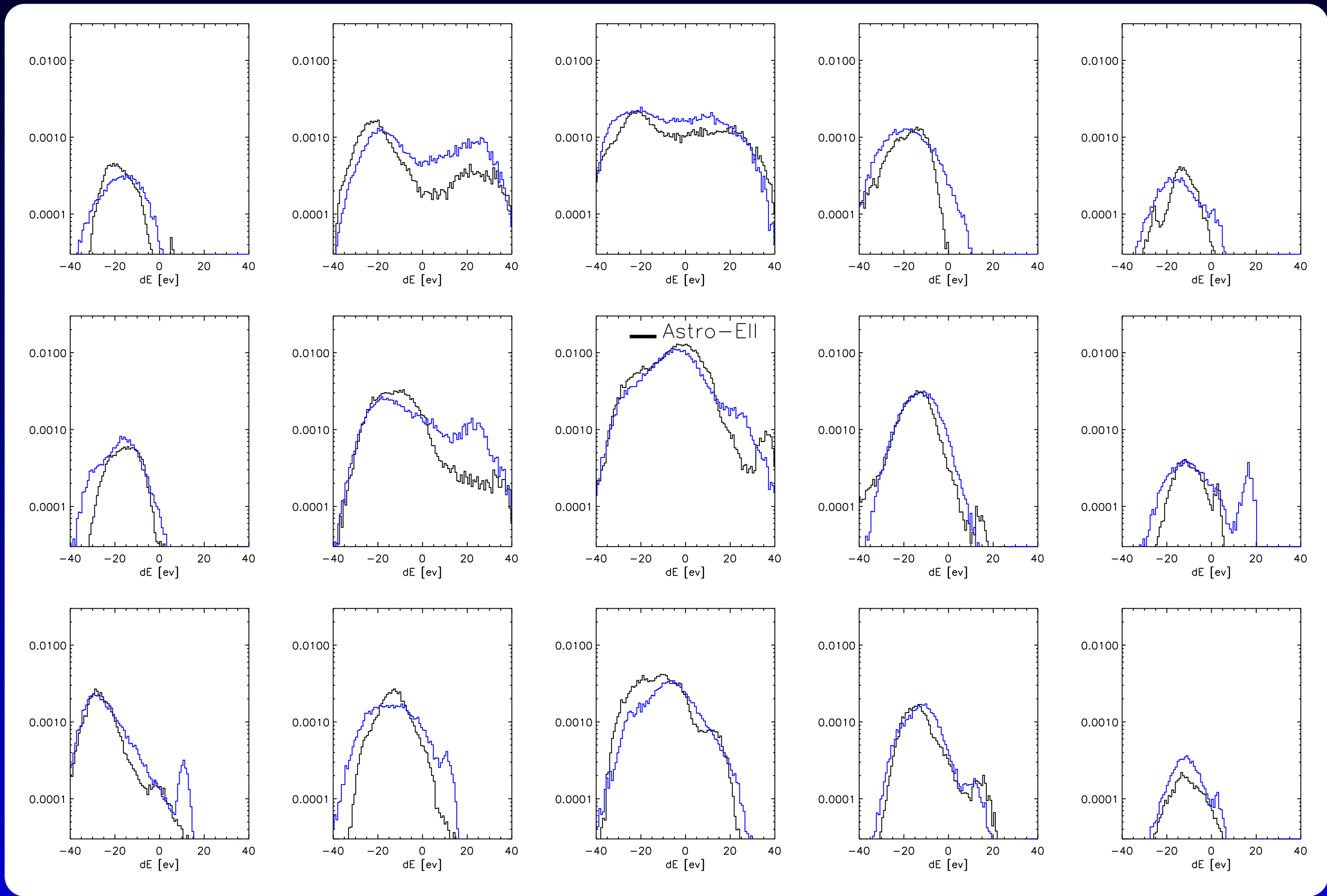
Unsharpened masked: image - smoothed(image,200kpc)
2Mpc x 2Mpc x-ray emission of *g1* comparing the two viscosity schemes.

Turbulence in the ICM



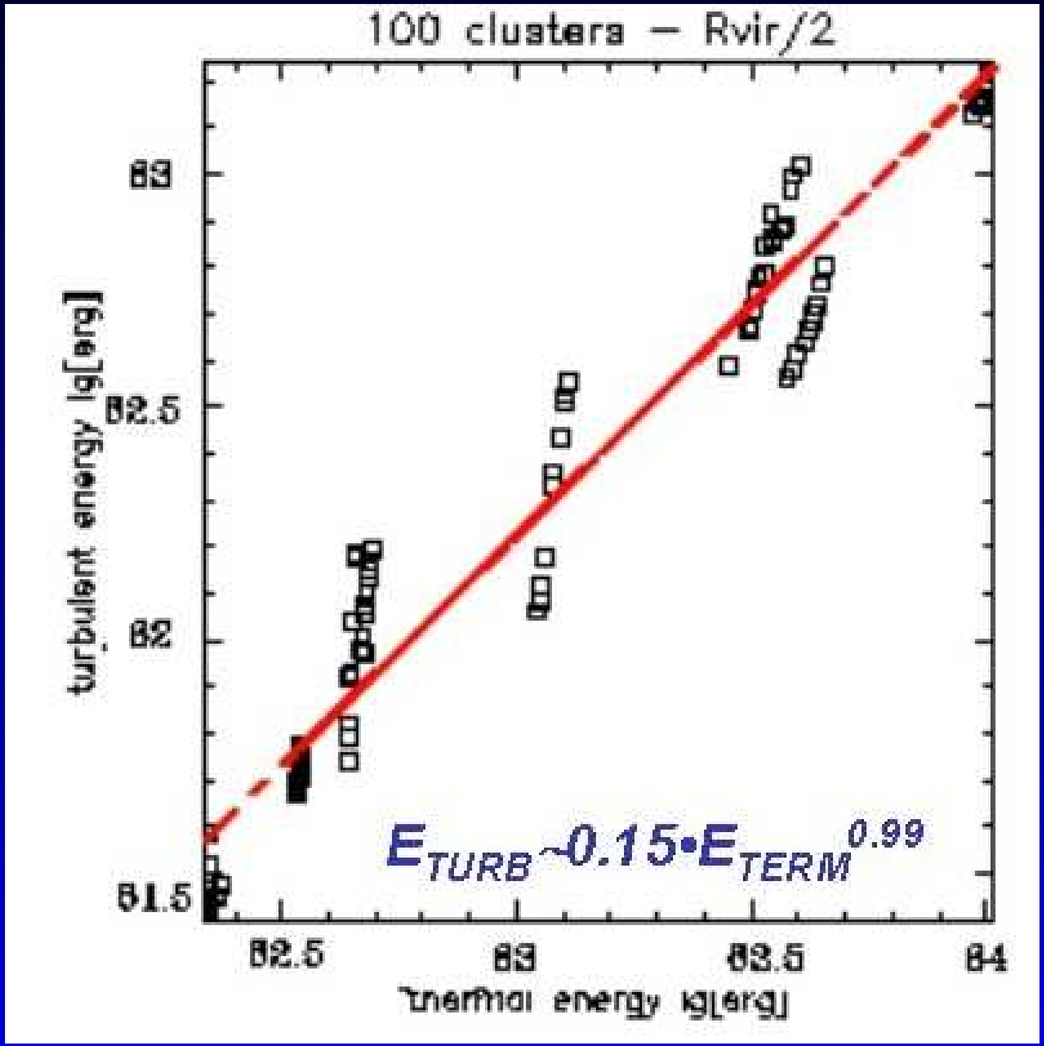
Unsharpened masked: image - smoothed(image,200kpc)
2Mpc x 2Mpc pressure map (e.g. SZ) of *g1* comparing the two viscosity schemes.

Turbulence in the ICM



Due to large contribution of bulk motions and beam smearing, the imprint of “true“ turbulence will be hard to detect, even resolution like Astro-E2 !

Turbulence in the ICM

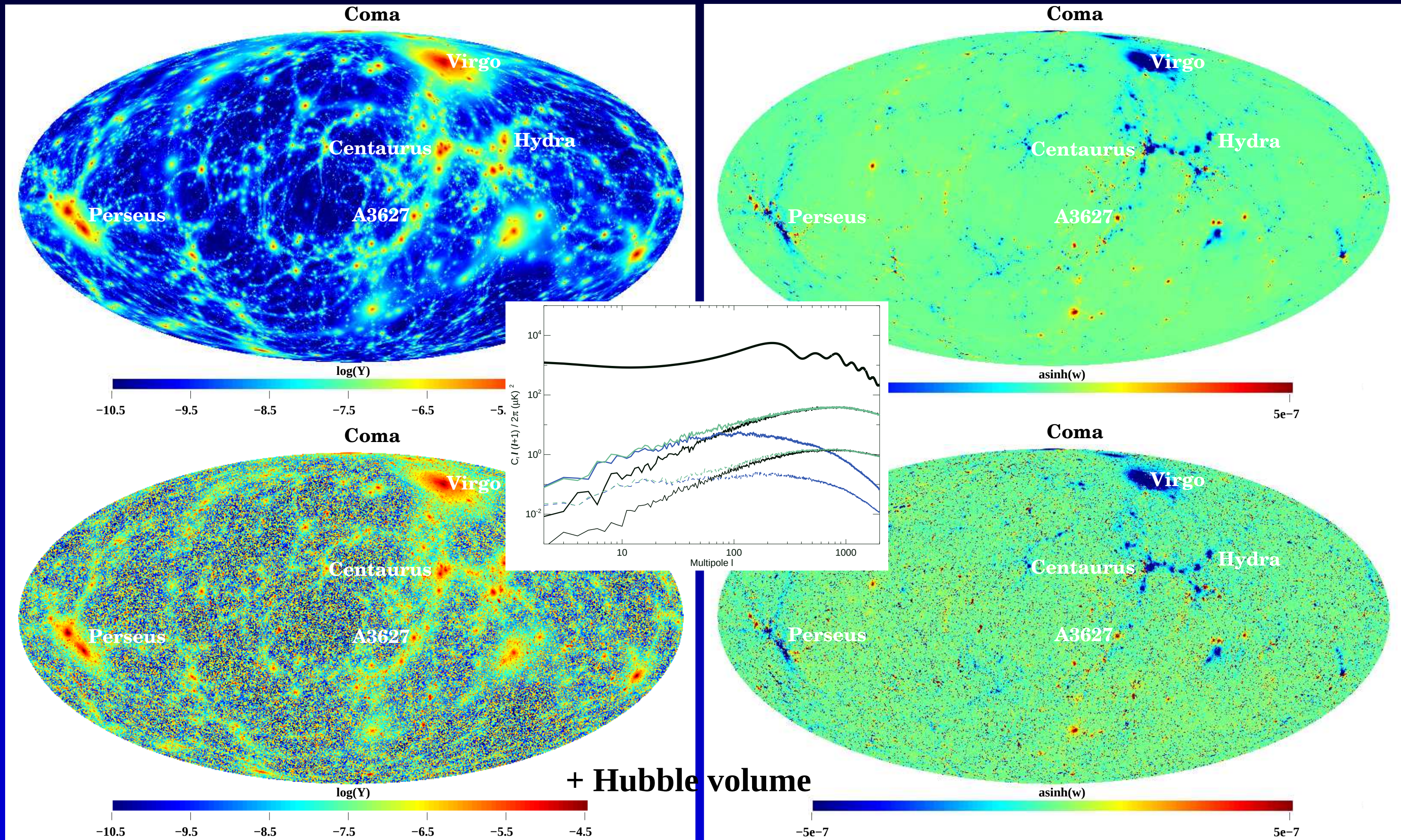


Turbulent energy content in galaxy clusters as function of mass.

Vazza, Tormen, Brunetti & Dolag (in prep.)

Coruscant

Constrained Local Universe including Magnetic Fields

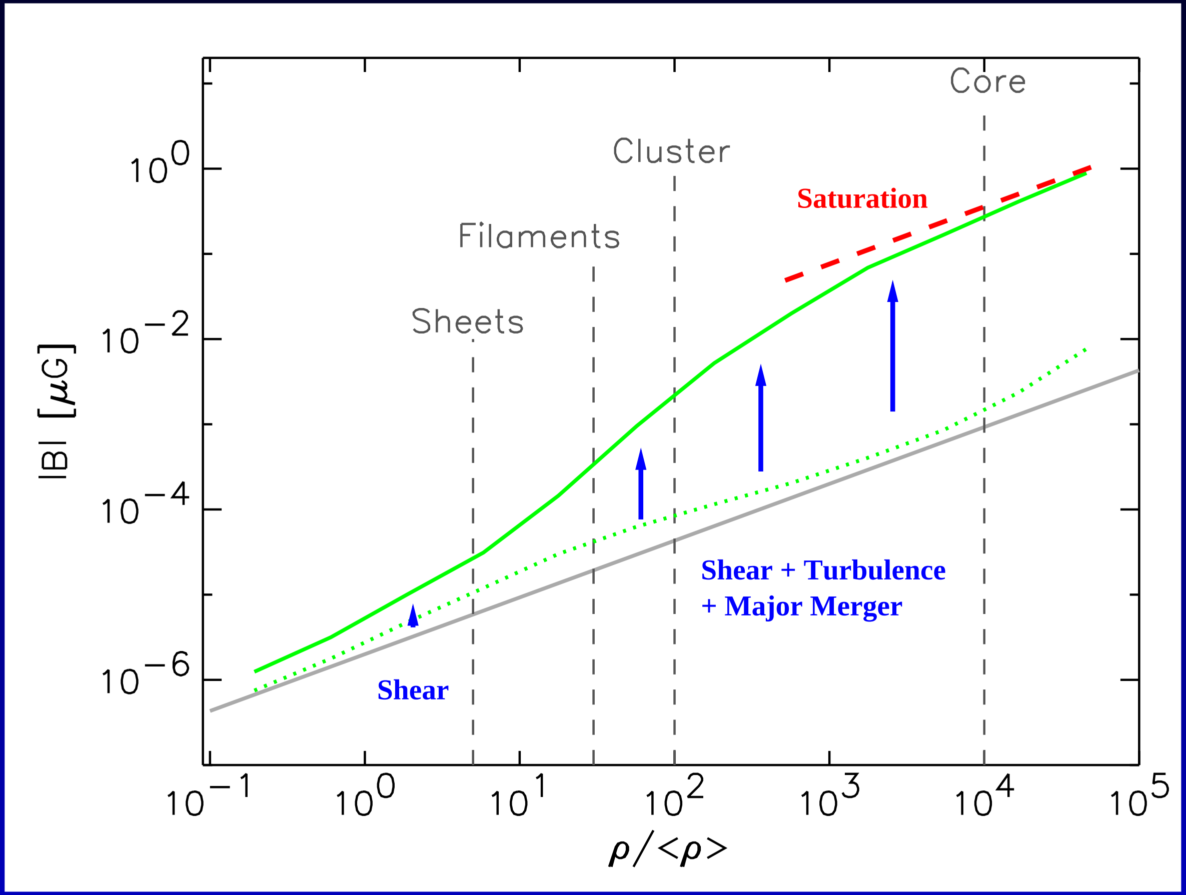


$2 \times$ 50.000.000 particles, $m_{gas} = 4.8 \times 10^8 M_{Sol}/h$

Mathis et al 2002 (DM-Only), Dolag et al 2004 (Gas + MHD)

SZ Maps: Dolag et al. 2005, submitted, astro-ph/0505258

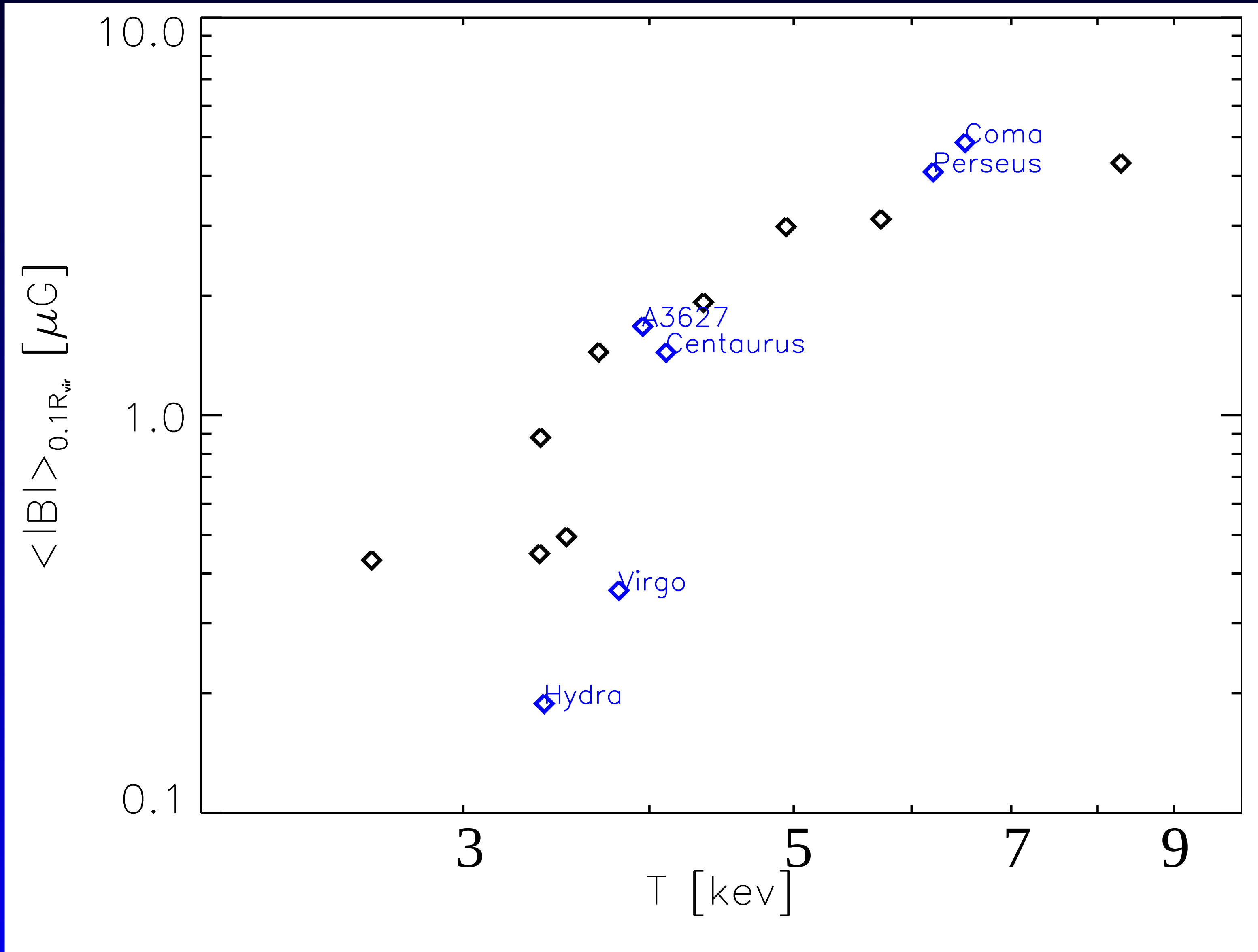
Coruscant with MHD



Magnetic fields powered by compression and anisotropic collaps (see also Bruni et al. 2003), sheer flows (see also Birk et al. 1999) and merger events (see also Roettiger et al. 1999).

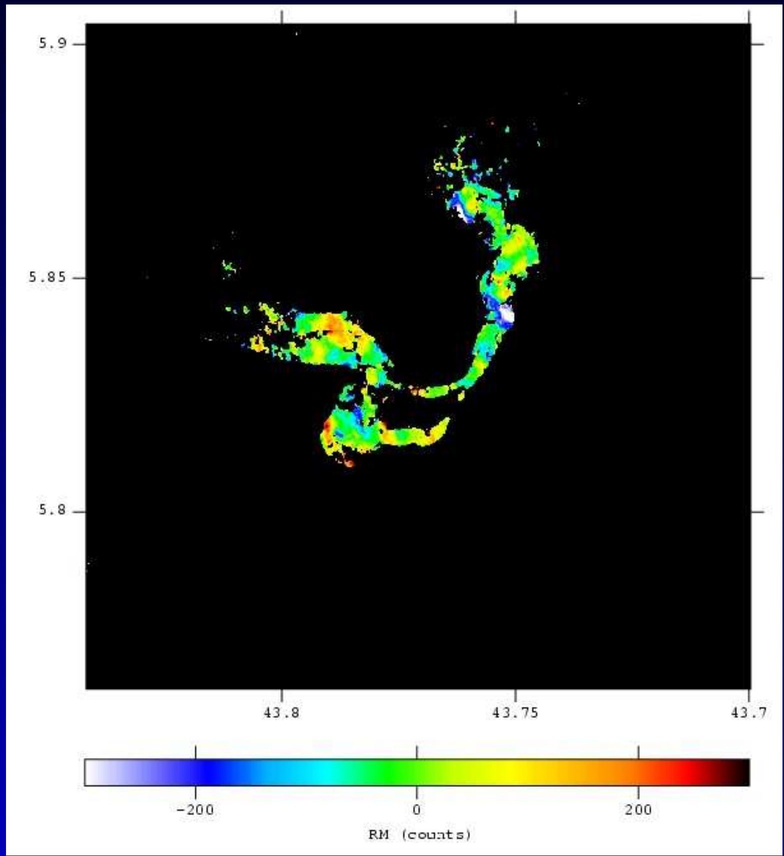
Full ideal MHD (Phillips & Monaghan 1985, Dolag et al. 1999,2002), Brove et al. 2001/2004), Price & Monaghan 2004) assuming a seed field at "high" z.

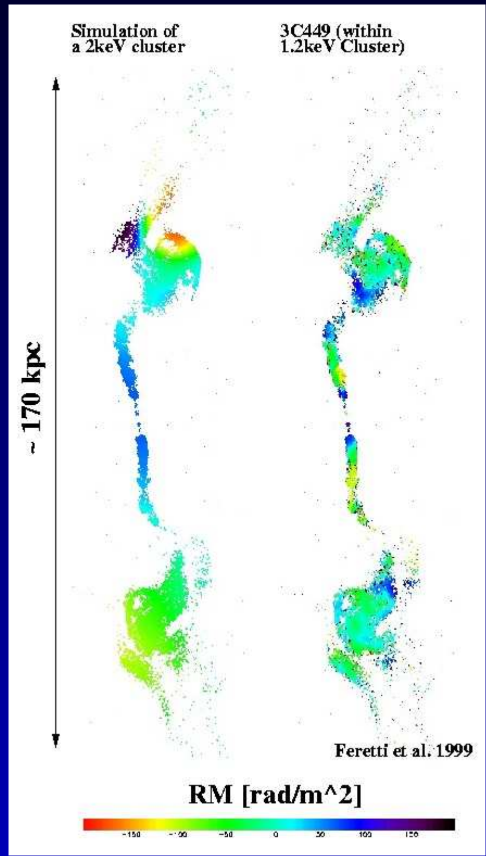
Coruscant with MHD



Magnetic Field - Temperature relation

Coruscant with MHD

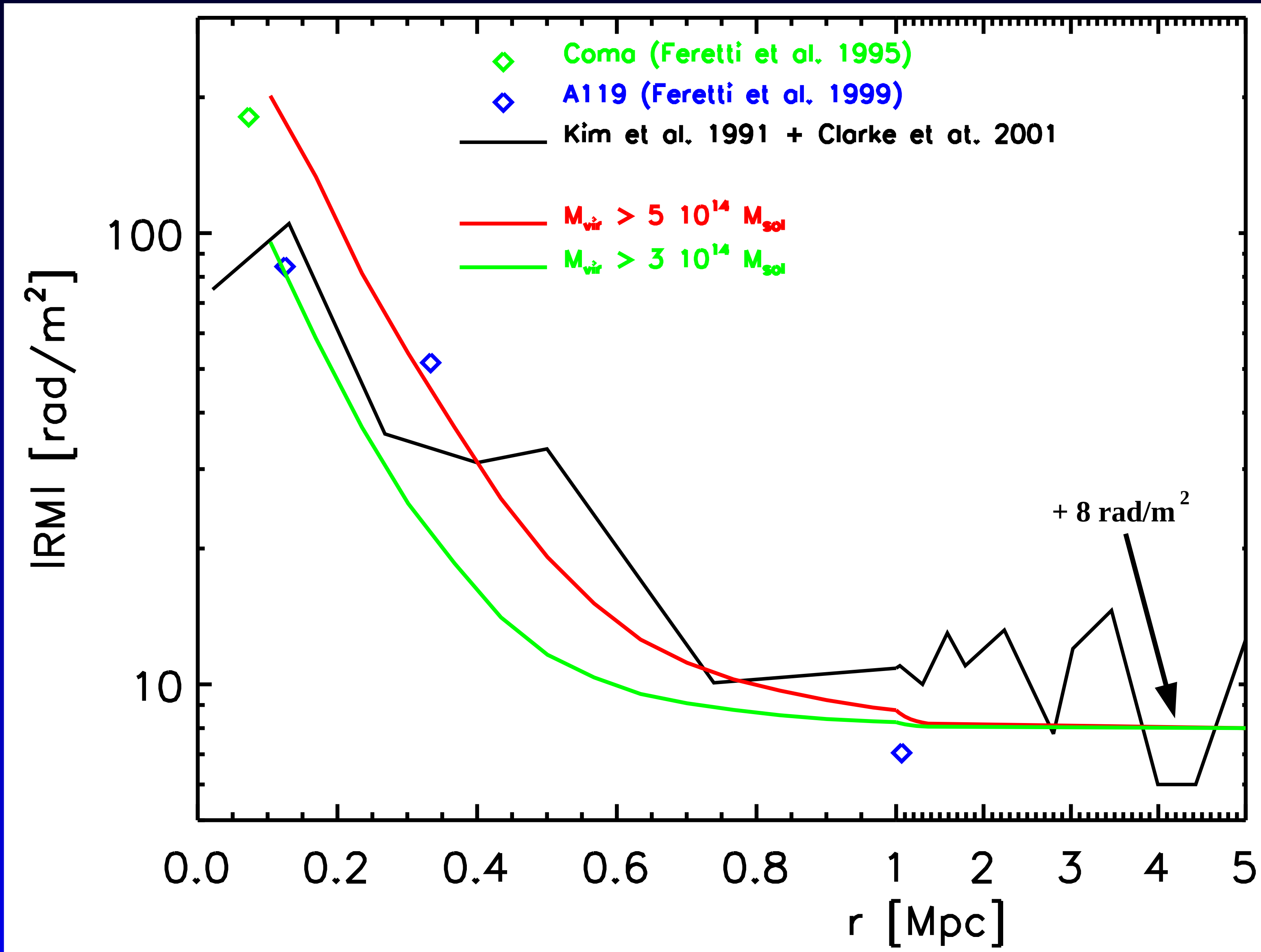




$$RM \propto \int n_e \, B_{\|} \, \mathrm{d}x$$

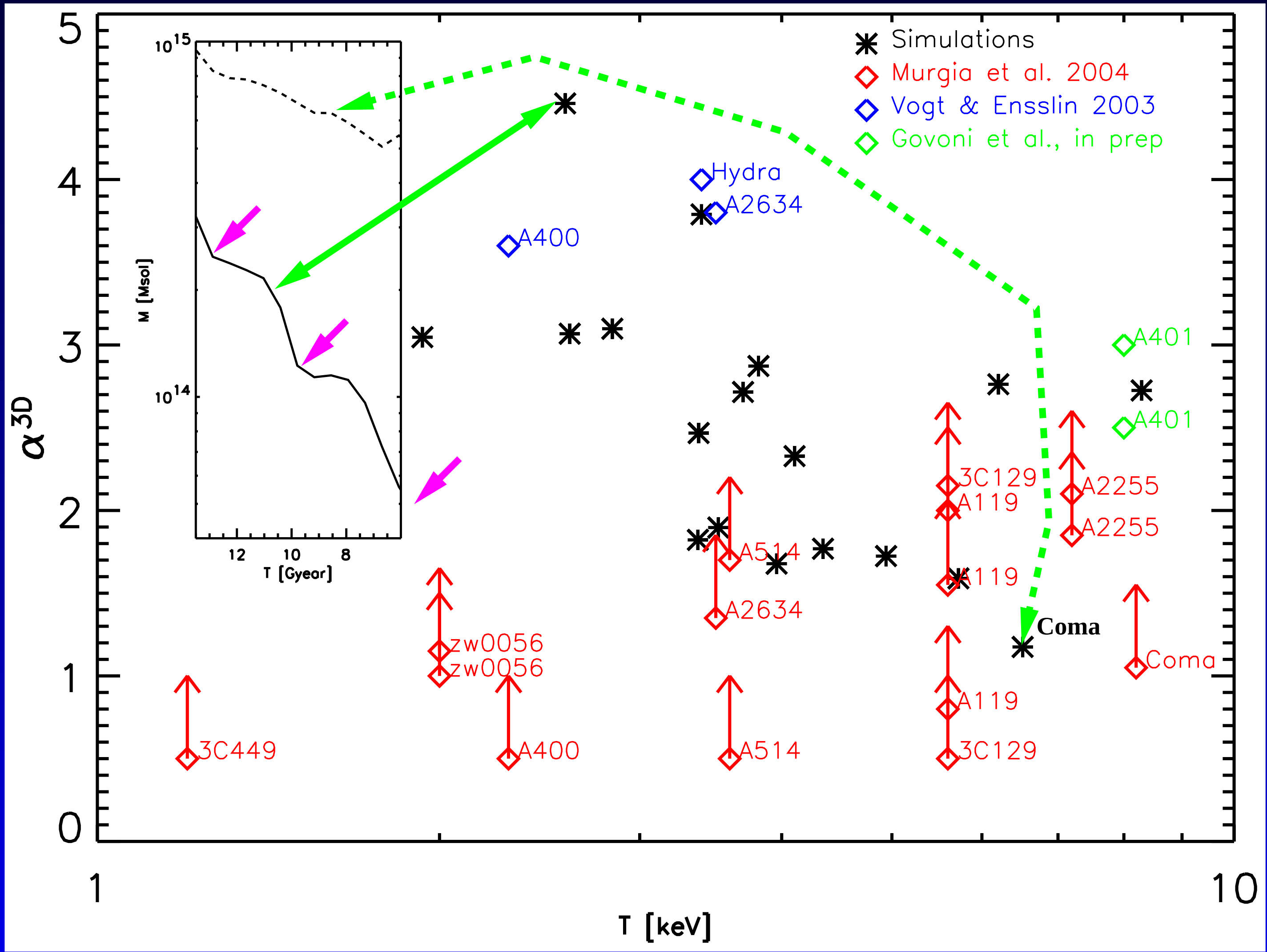
RM map of central radio galaxy in A400 (2.3keV) on the left side and 3C449 in a 1.2keV cluster on the right.
$\Rightarrow$ scaling of RM (e.g. $\vec{B}$) with T, ρ, r ... ?

Coruscant with MHD



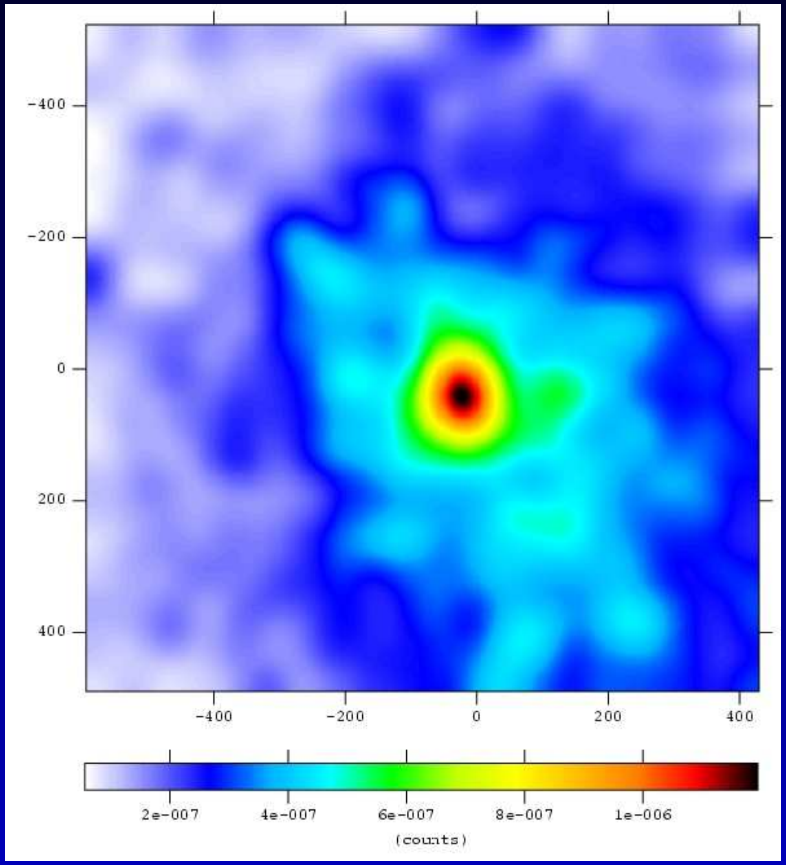
Comparison of radial RM profile.

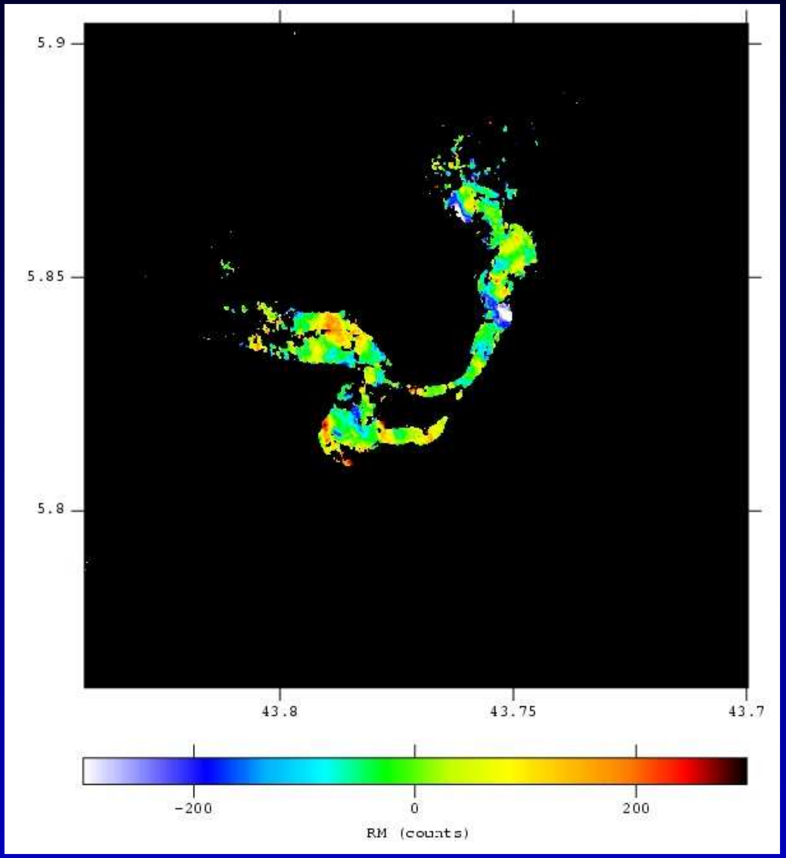
Magnetic power spectrum



Slope of the (3D) magnetic field power spectra $(k^2 B(k)^2)$!

Magnetic power spectrum





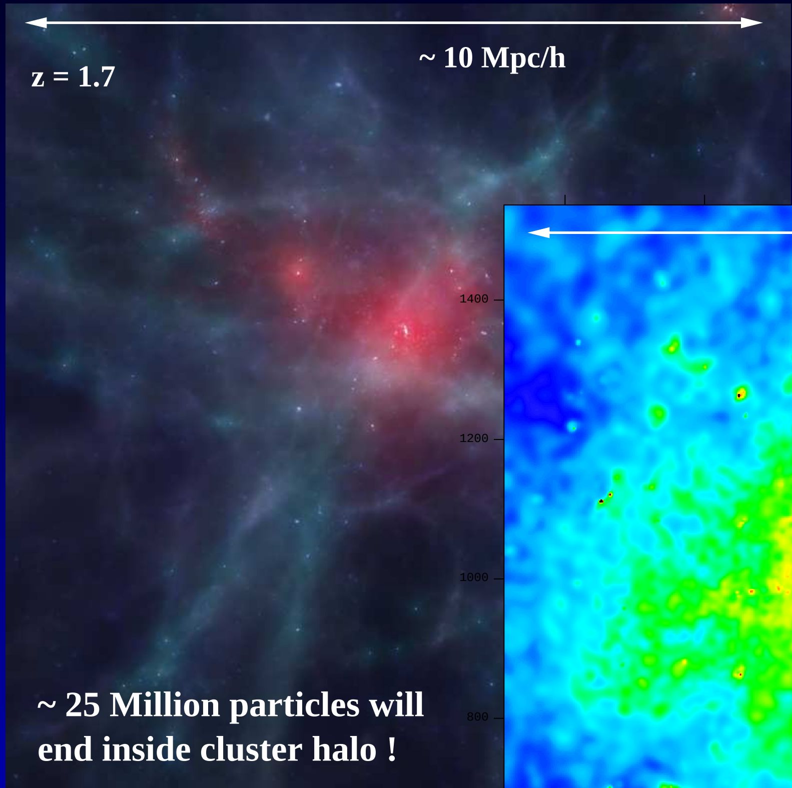
Example A400, Slope observed to be high !

$\Rightarrow$ Signature of Merger or Turbulence ?

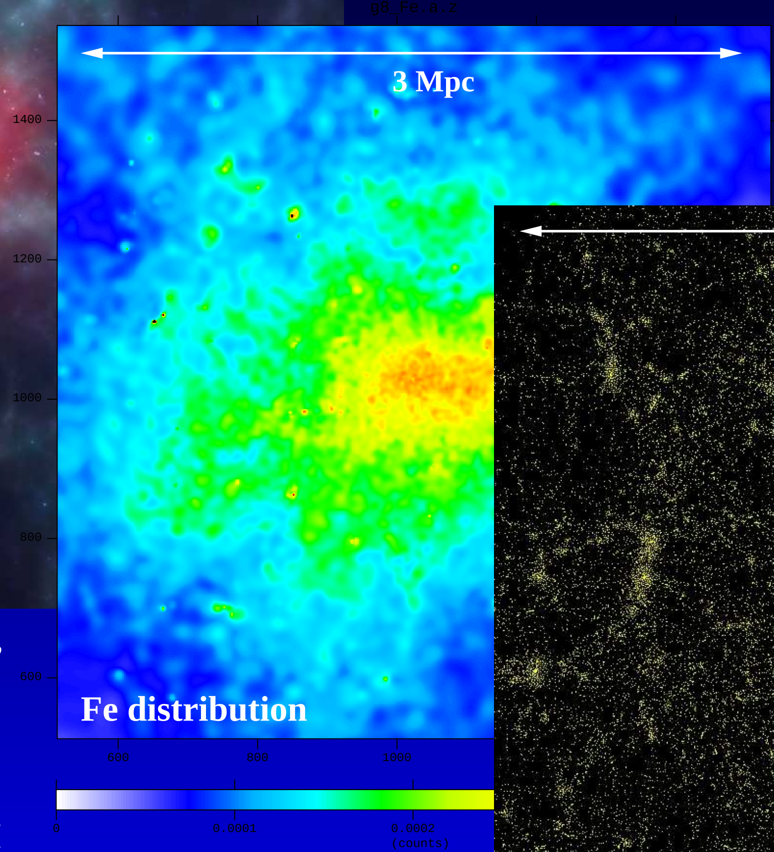
Conclusions

- Many physical processes need to be included and understood in detail to better predict the state of the ICM. This includes turbulence, conduction, viscosity, magnetic field, relativistic component(s), feedback and more.
- Thermal conduction even with $\kappa = 1/3$ does not suppress the catastrophic cooling, does not change global quantities (e.g. mass weighted temperature) but can give rise to dramatic changes in the overall thermal structure.
- Cluster assembly can provide large amount of turbulence which could strongly affect cluster properties.
- Cluster formation leaves its imprint in magnetic field.
- High precision cosmology with galaxy clusters is still ´´Far Far Away´´ !

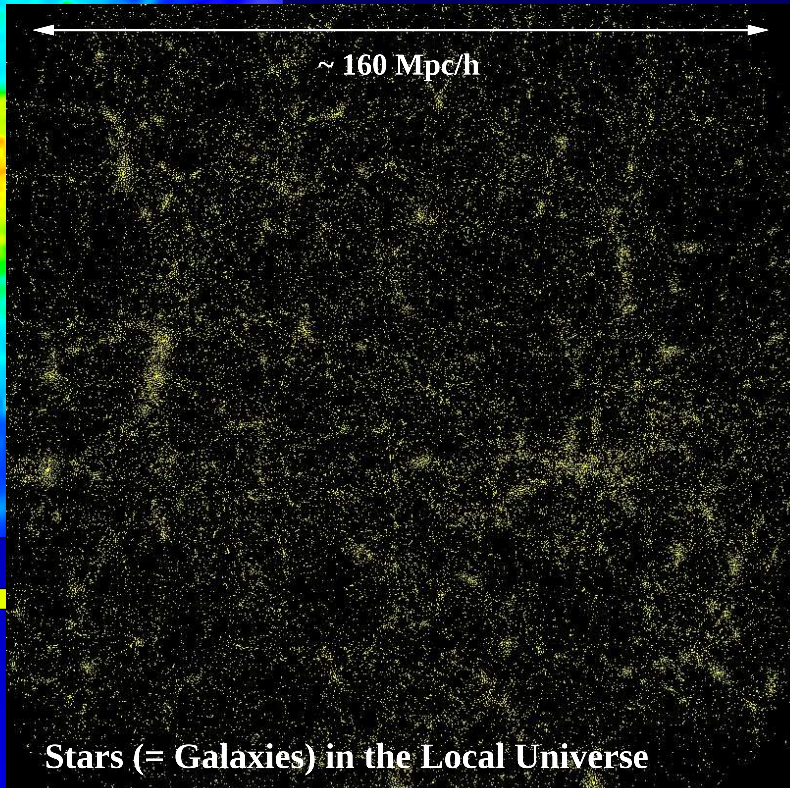
Outlook



Ultra high resolution (12keV) cluster (Luke)
m_{gas}= 2.8 x 10^8 Msol/h !



50 Million gas particles !



Runs using 'metal extension'

- **follows C,N,O,Mg,Si,Fe**
- **metal cooling**
- **following SN I and SN II**
- **distribute metals into ICM**
- **explicit follows stellar population (no IRA !)**
- **includes mass transfer back into ICM by stellar winds**
- **allows various IMFs, even time evolving**

Following evolution of stelar population and chem. enrichment.

(Gadget2 extension by Tornatore et al. 2004/2005)