Testing scaling relations and their scatter

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INTRODUCTION

Galaxy clusters are powerful tools for cosmological investigation once we know their mass. Key point is comparing the observed mass function, N(M|z), with the theoretical one (Press & Schechter 74, Jenkins et al. 01, Sheth & Tormen 99,00).

Measuring the mass(from X-ray, lensing, galaxy velocities) is a long process. Need of mass proxy!

In next few years large cluster surveys will be underway, e.g.

eRosita

South PoleTelescope

Dark Energy Survey

X Mass proxies

X-ray : L_x, T_x…

SZ: Y_{sz}

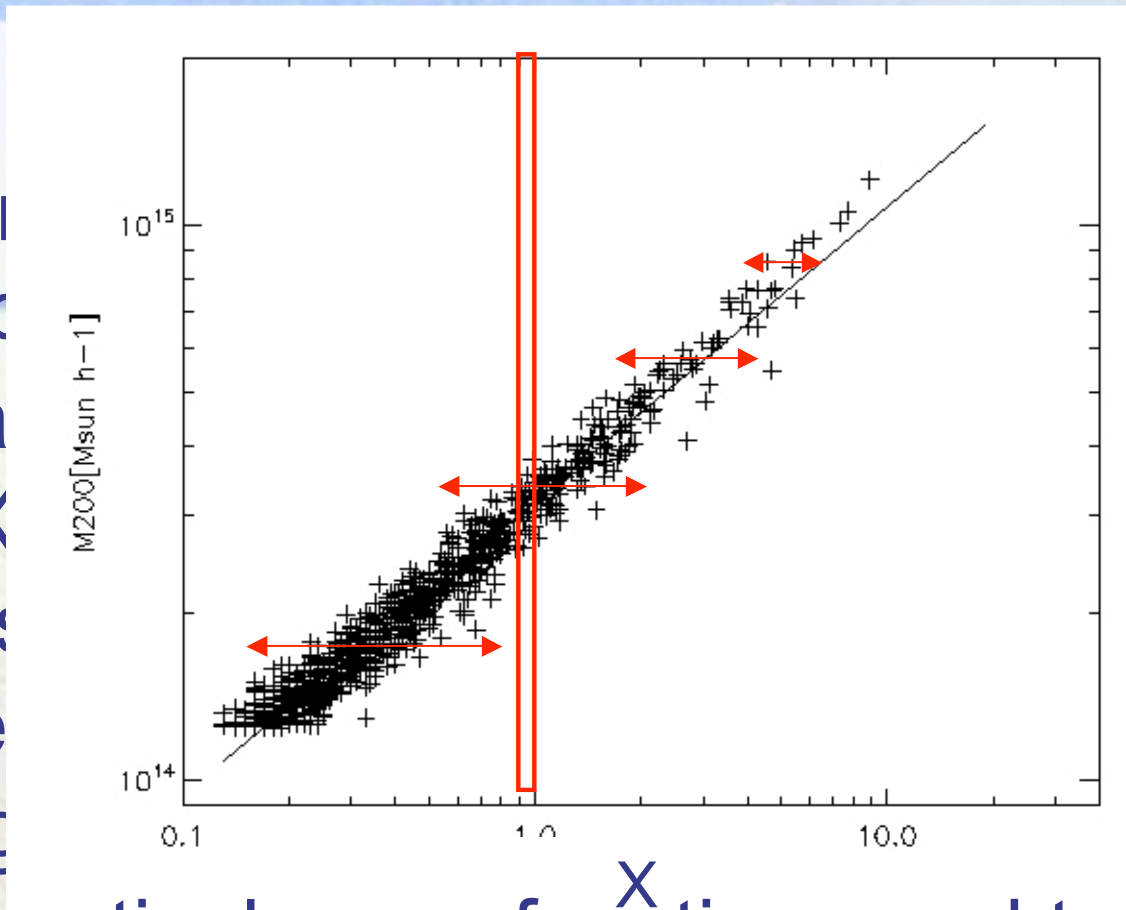
Optical: N_{gal}

INTRODUCTION

- We need NOW to understand the connection between the observable cluster properties, the intrinsic properties and the underlying mass distribution.

Not only the M-X relation itself - intercept and slope - but also the scatter.

•The intri… of
informatio… ion of σ_8.
•Significa… ation of
d(N)/dlnX … ower-
mass clu… es of X
far excee… clusters
scattering…



•The theoretical mass function need to be convolved with this scatter, the high-tail of the model grows with the scatter,at a fixed σ_8. An overestimate of the scatter turns into an underestimate of σ_8.

INTRODUCTION

• 2 approaches for actual and future missions

- small sample (need of control of systematic errors)

- large statistical sample (need of proxies and control on the scatter)

INTRODUCTION

Need to be ready for both visions

1 complicated cluster

•eRosita would not have a spatial resolution as good as Chandra ->more difficult to classify objects by their morphology.

•We need to study the impact of scaling relation scatter by objects which are dynamical unstable

(Rasia,Markevitch,Dolag,Mazzotta,Meneghetti in prep.)

10000 clusters

•Investigate the systematics that could affect the analysis of real data

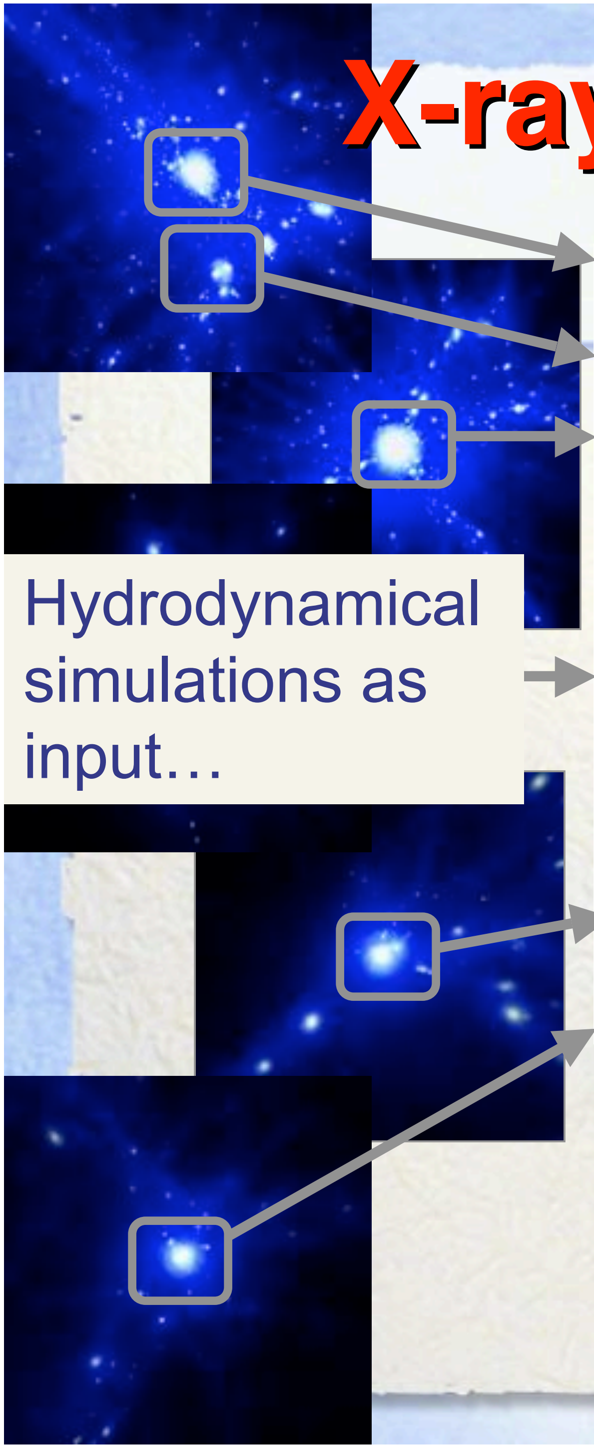
•Provide a concrete theoretical framework for the statistical studies

•This entails the multivariate halo function $P(L_X,T_X,Y_{SZ},T_{MW},c|M)$ and its evolution

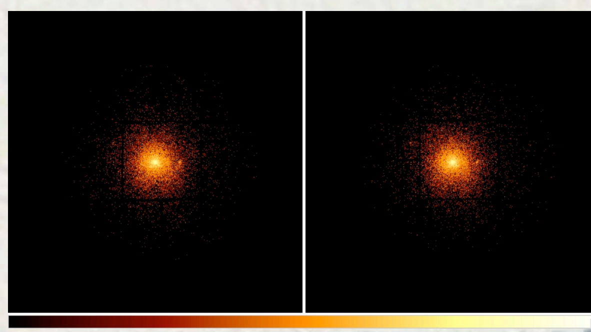
(Rasia, et al. in prep.) (Borgani, Evrard, Gazzola, Mazzotta, Nord, Pearce, Stanek)

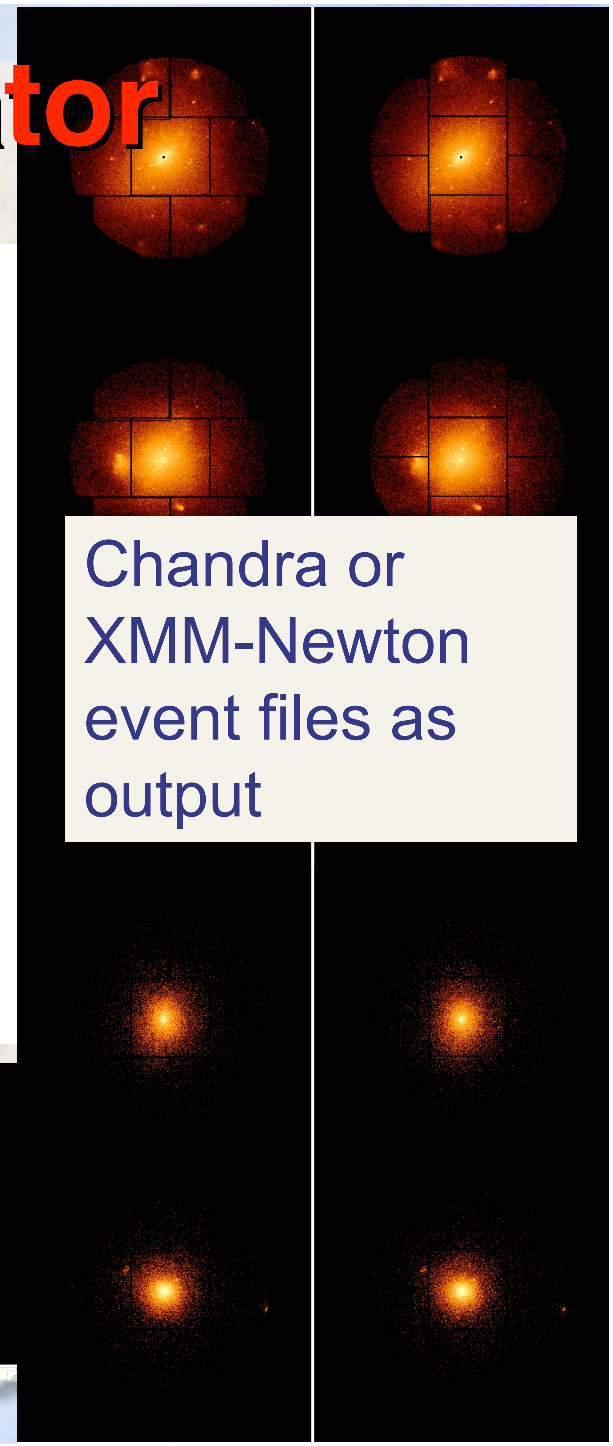
X-ray Map Simulator

Rasia et al. 07 Gardini et al. 04



Hydrodynamical simulations as input…





Chandra or XMM-Newton event files as output

SIMULATIONS...

- Help us to understand scaling relation
- Their scatter
- Their covariance matrix

Now:

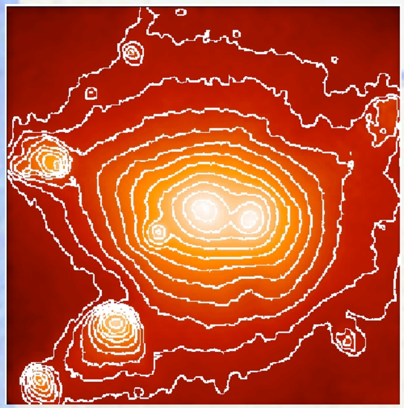
- Good treatment of the physics
- Availability of a big sample of objects

- We need to compare simulations and observation 1:1
- T_{sl} (Mazzotta et al.04) &
- X-MAS(Gardini et al.04, Rasia et al. 07)

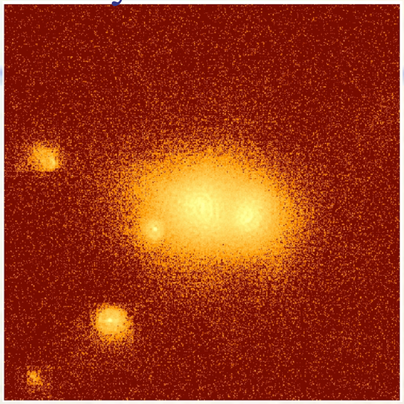
BIG QUESTION: HOW CAN WE(SIMULATOR) HELP THE OBSERVERS

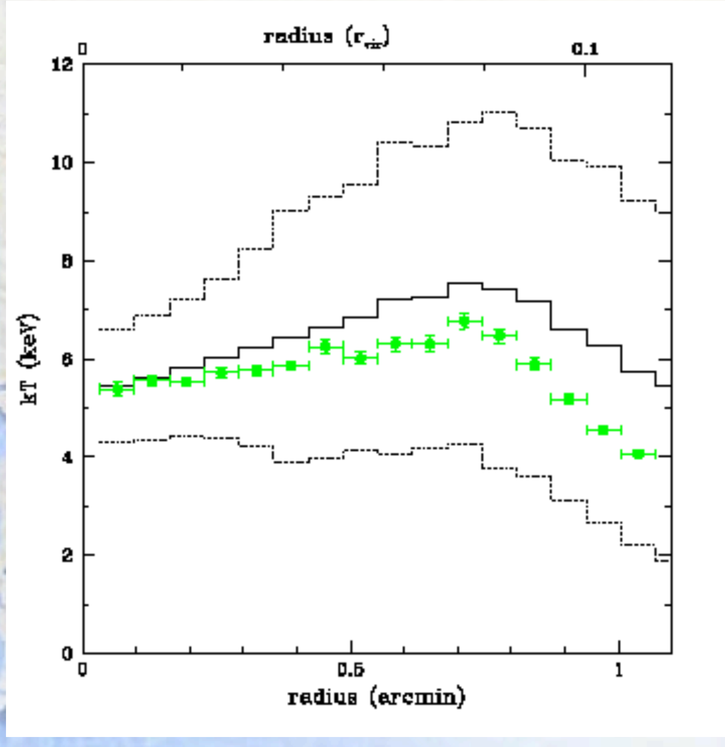
TEMPERATURES

simulation



X-ray observation





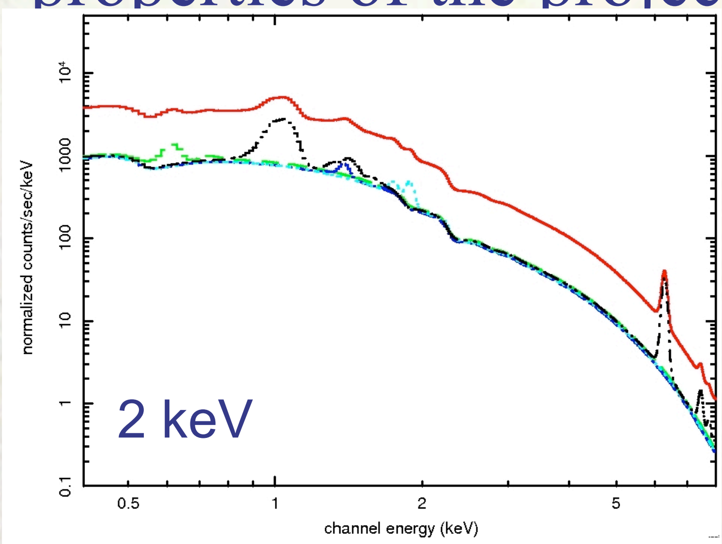
The different degrees of thermal homogeneity have strong implications on the temperature profiles:

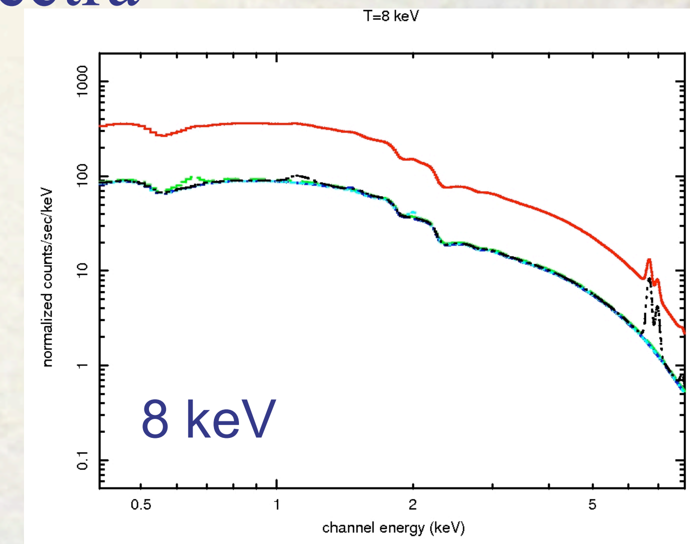
For the perturbed systems, the spectral and emission-weighted temperature profiles are not in good agreement

(Gardini et al. 2004)

SPECTRAL TEMPERATURE

- Measuring a projected temperature is equivalent to finding a thermal model with a temperature, $T_{spec,}$ whose spectral properties are as close as possible to the properties of the projected spectra



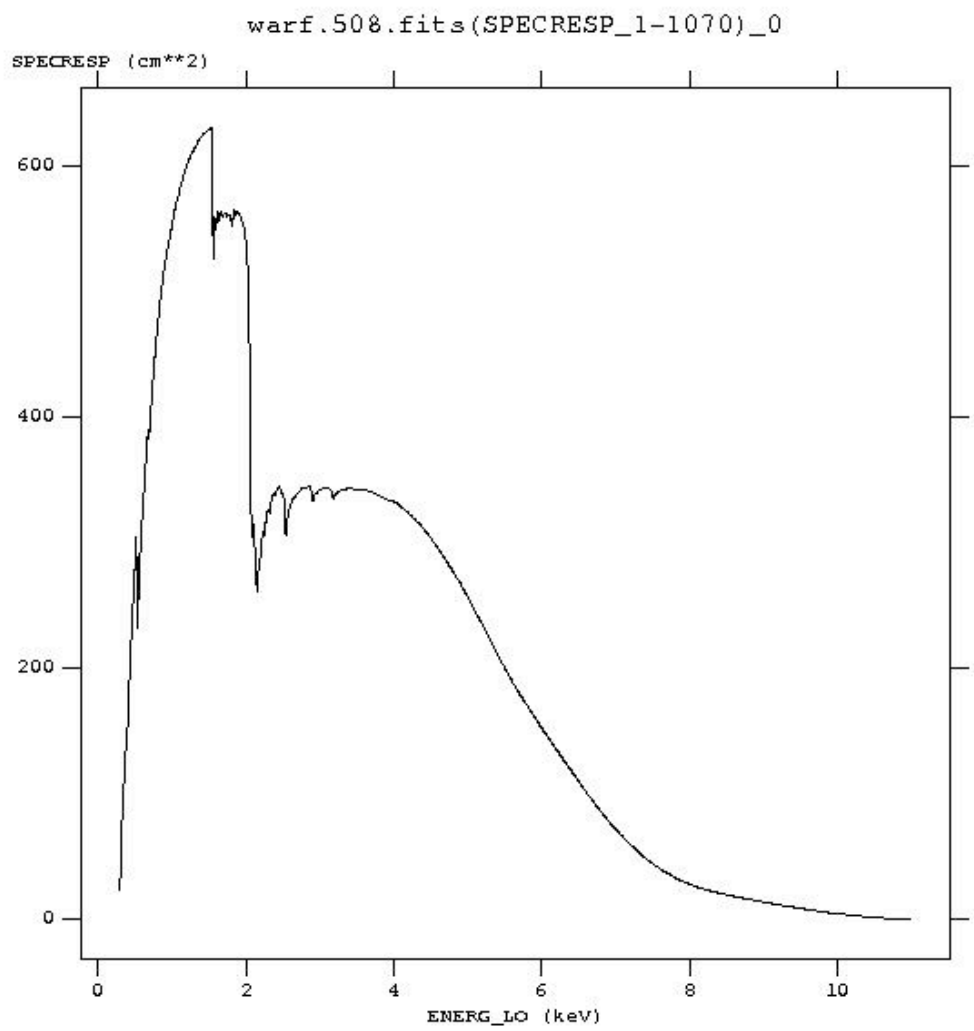


- The sum of two Bremsstrahlung spectra with similar emission but different temperature, T_1 and $T_{2,}$ is no longer a Bremsstrahlung with a given temperature T_3 (unless T_1=T_2)

Mazzotta,Rasia,Moscardini,Tormen (2004)

SPECTRA

1) Mixing plasma of two temp. (same normalization)
2) Fitting with ONE single temperature model
3) The retrieved spectral temperature is NOT the average of the two temperatures
4) The response of the instrument is energy dependent



SIMULATION TEMPERATURE MAPS

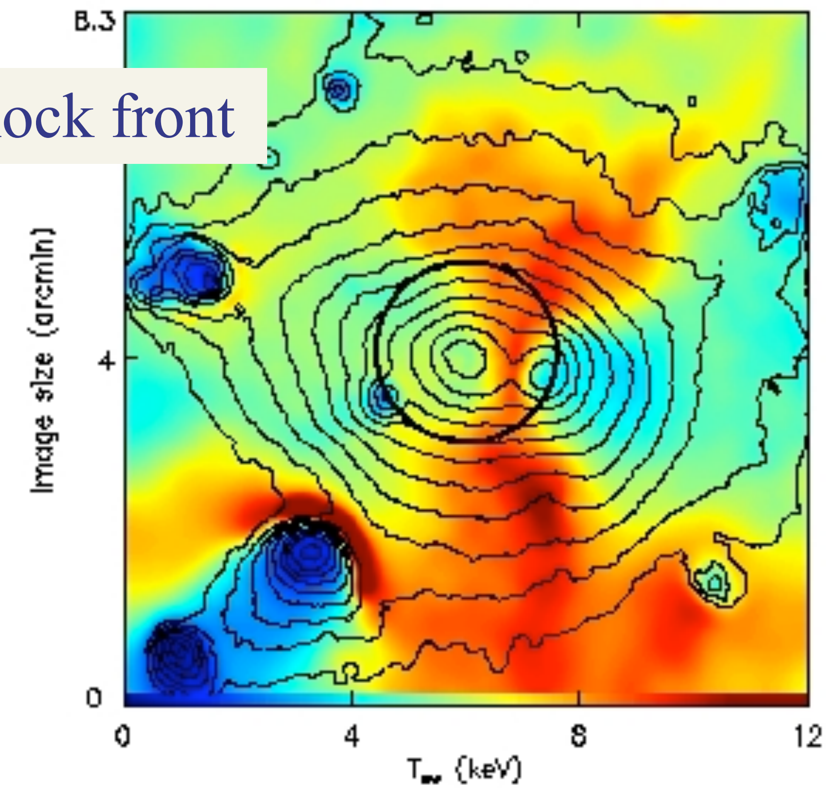
Emission-Weighted

$$T_{ew} \equiv \frac{\int \Lambda(T) n^2 T dV}{\int \Lambda(T) n^2 dV}$$

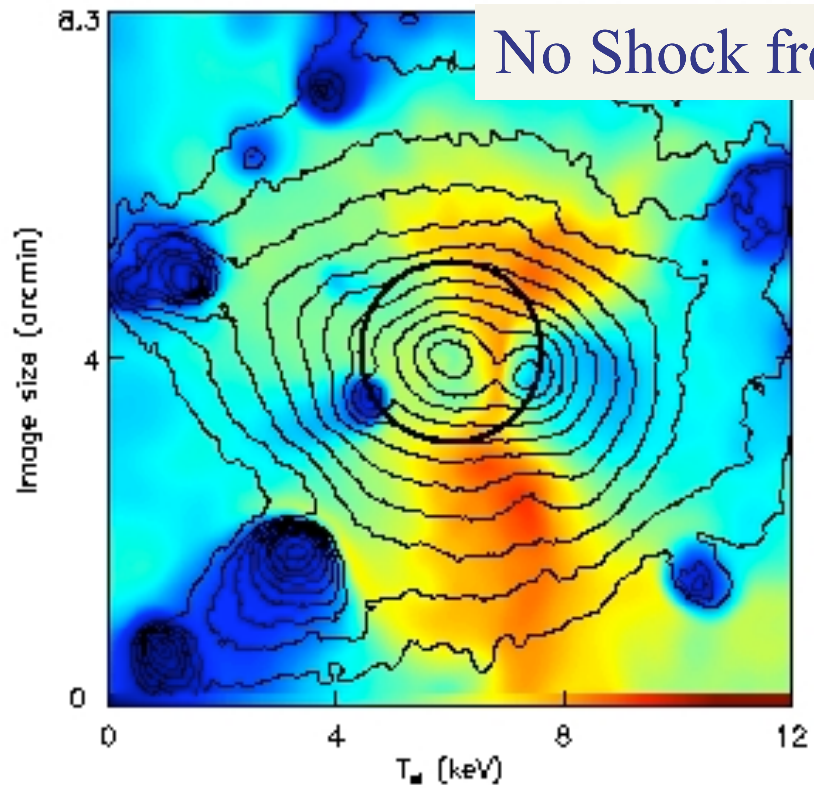
Spectroscopic-Like

$$T_{sl} \equiv \frac{\int n^2 T^{1/4} dV}{\int n^2 T^{-3/4} dV}$$

Shock front

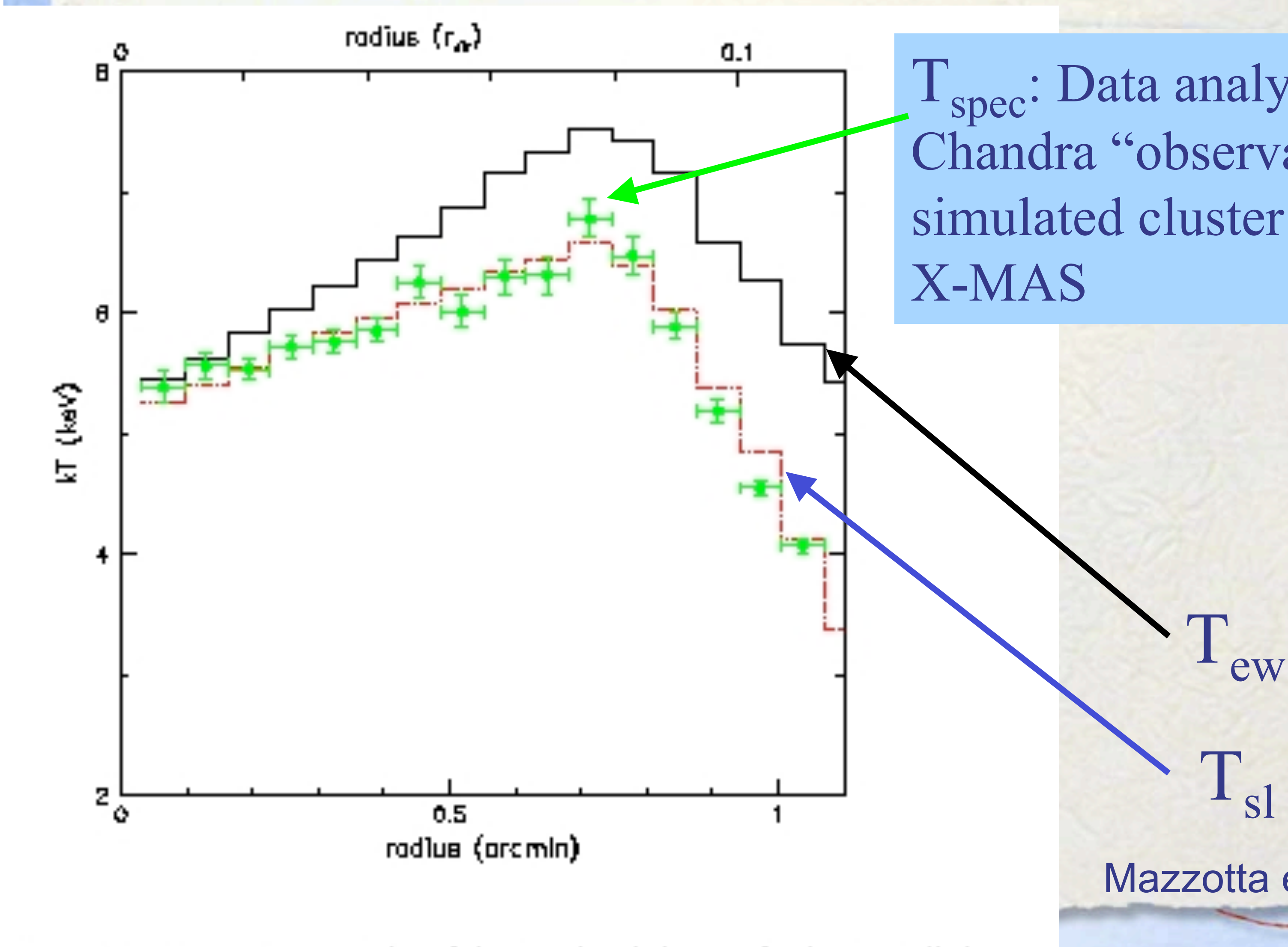


No Shock front



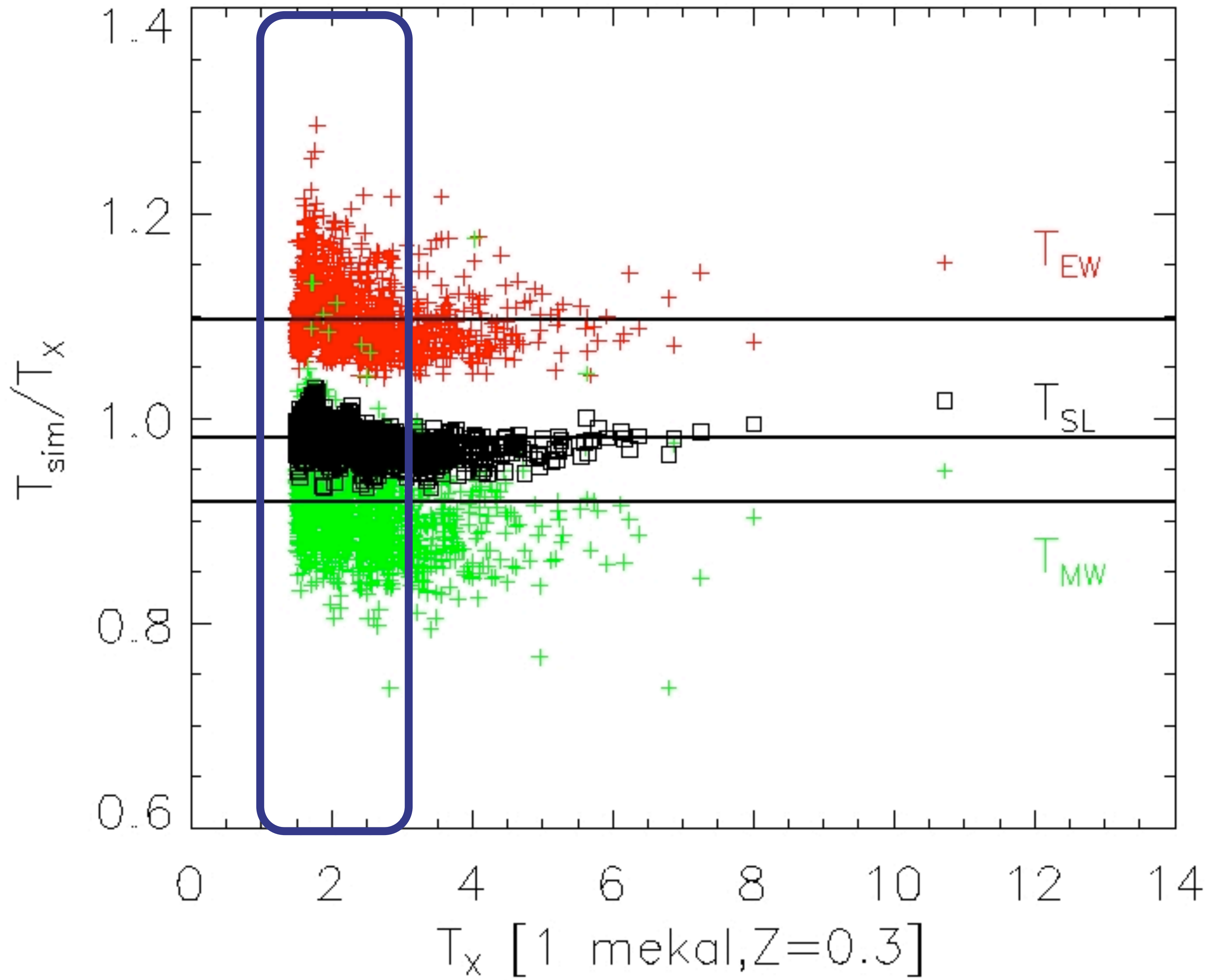
Mazzotta, Rasia, Moscardini, Tormen (2004)

TEMPERATURE PROFILES



T_{spec}: Data analysis of the Chandra "observation" of the simulated cluster obtained with X-MAS

Mazzotta et al,2004



RE

s

fit

rature

e

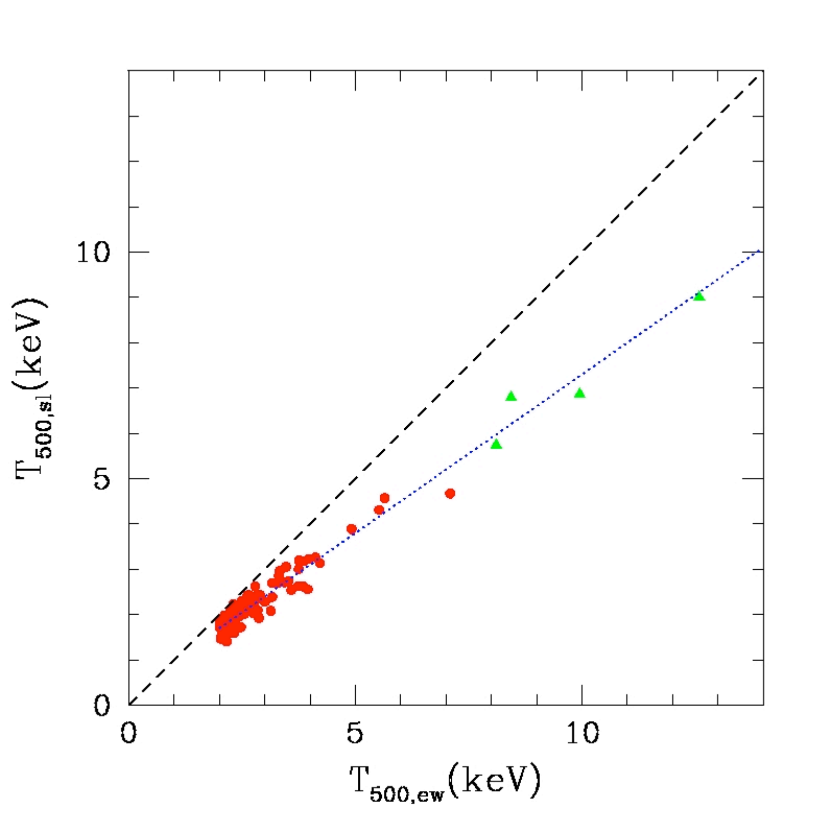
TAKE-HOME MESSAGE #1

- WE NEED TO MAKE SIMULATION CLOSER AS POSSIBLE TO OBSERVATIONS (X-MAS) OR TO ANALYSE THEM USING COMPARABLE QUANTITIES (T-SL).

COSMOLOGICAL IMPLICATIONS

Simple theoretical arguments supported by hydro N-body simulations suggest the existence for virialized gravitational systems with a tight relation between M and T:

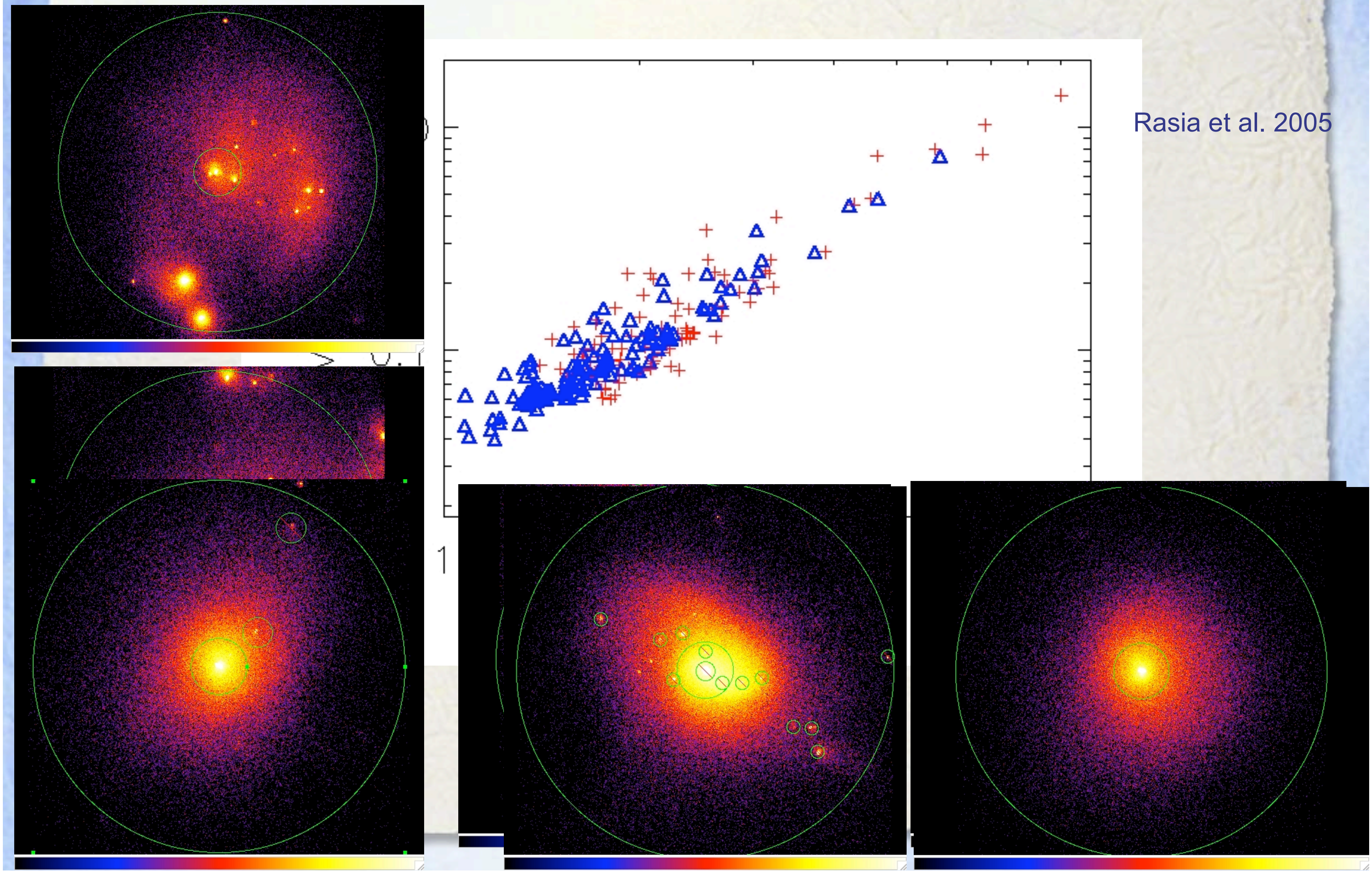
$M_{500}=M_0(kT_{500}/1\mathrm{keV})^a$



$$T_{SL}=(0.70\pm0.01)T_{EW}+(0.29\pm0.05)$$

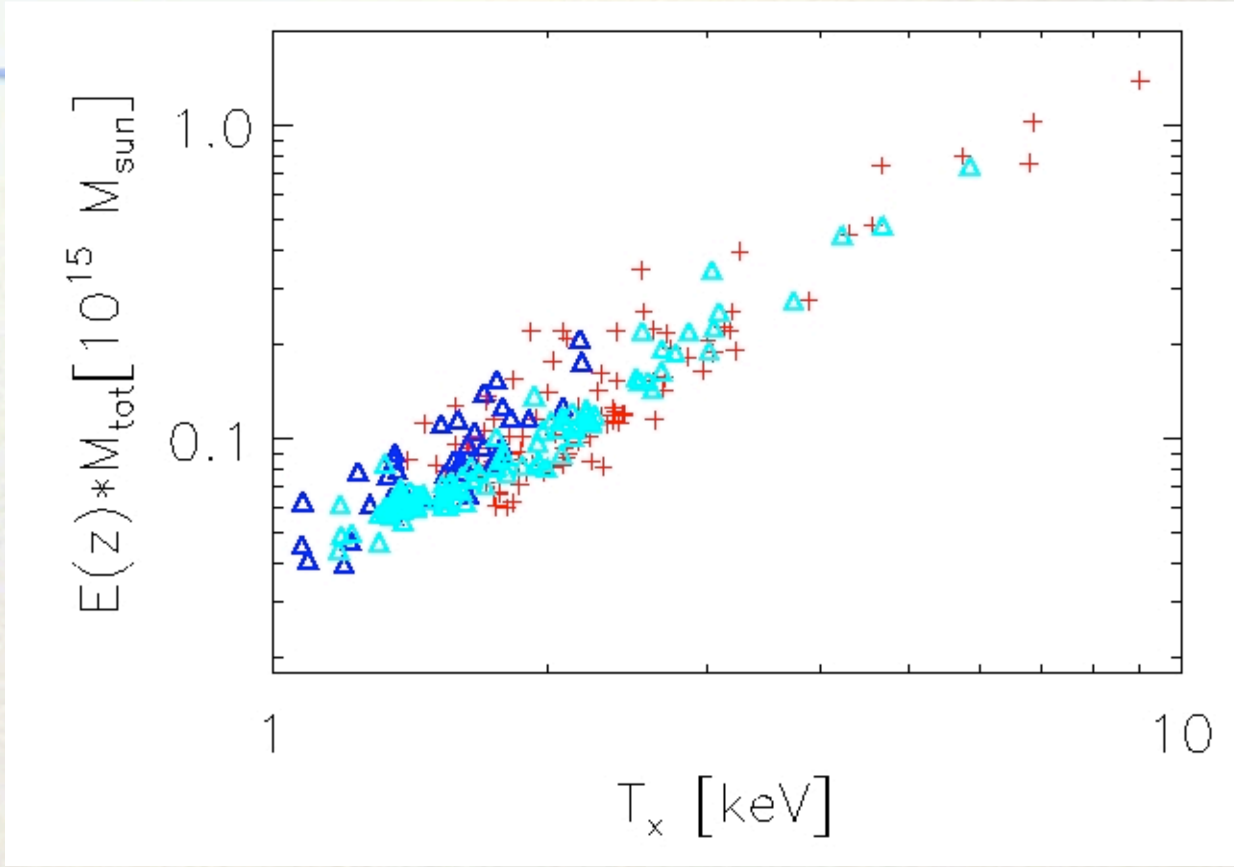
Rasia et al .2005, Kawahara et al. 2007

MASS - TEMPERATURE



Rasia et al. 2005

MASS-TEMPERATURE

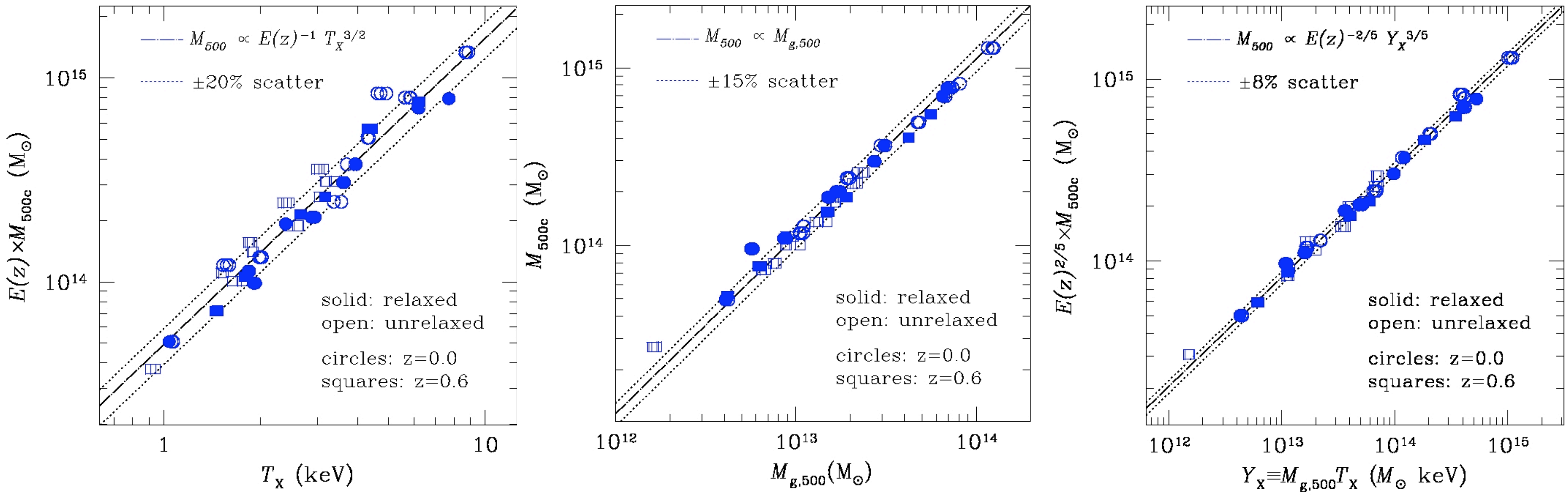


CONSIDERING REGULAR CLUSTER REDUCED A LOT THE SCATTER

TAKE_HOME MESSAGE #2

- NOT ONLY MAKE THE SIMULATIONS CLOSER TO OBSERVATION BUT ALSO USING THE SAME ANALYSIS PROCEDURE.
- IF WE HAVE ENOUGH PHOTON WE CAN MASK THE IMAGES AND SUBSAMPLE INTO REGULAR AND NOT-REGULAR CLUSTERS

SCALING RELATIONS



by Kravtsov et al 06

M_{tot} =

$10^{14.41}$ $(T_X/3\ \text{keV})^{1.521}$

$10^{14.35}$ $(M_{gas}/2\ 10^{13})^{0.921}$

$10^{14.27}$ $(Y_X/4\ 10^{13})^{0.581}$

$Y_x = M_{gas}\ T_X$

all clusters

$[710^{13}210^{15}]M_{sun}/h$

all z (=0,0.6)

All quantities at R_{500}

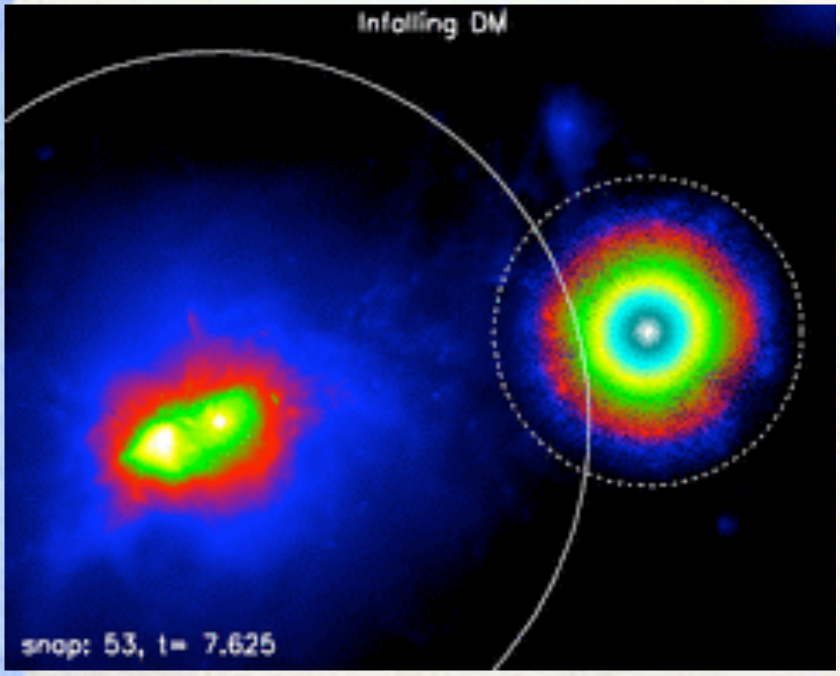
excluding 0.15 R_{500}

ONE SPECIAL SIMULATED CLUSTER

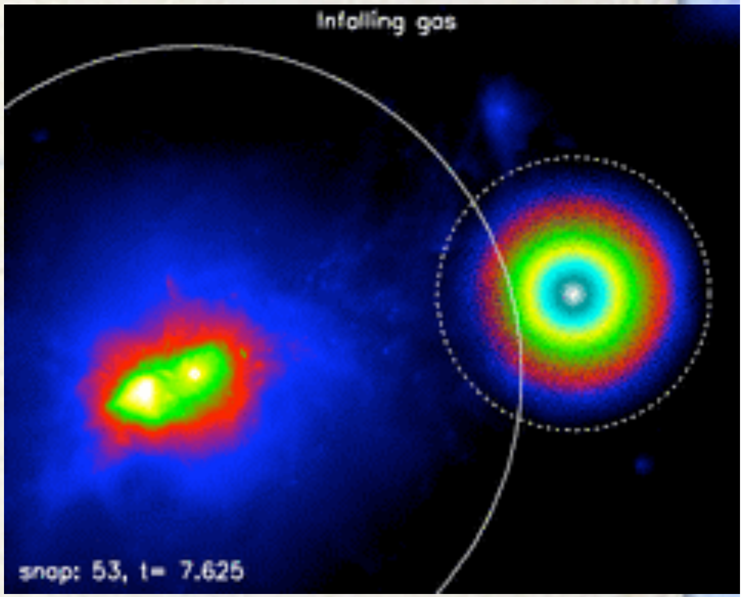
- Physics: radiative cooling,uniform time-dependent UV background, star formation from multi-phase interstellar medium, galactic winds powered by SN
- Mass resolution: DM particle = 1.74 10^8 M_{sun}/h GAS particle =2.6 10^7 M_{sun}/h
- Physical resolution: softening 2.5 kpc/h
- Total mass at R_{200}: M_{200}= 2 10^{15} M_{sun}/h
- Active dynamic history and strong merging (Mach number 2.5)

VIDEOS

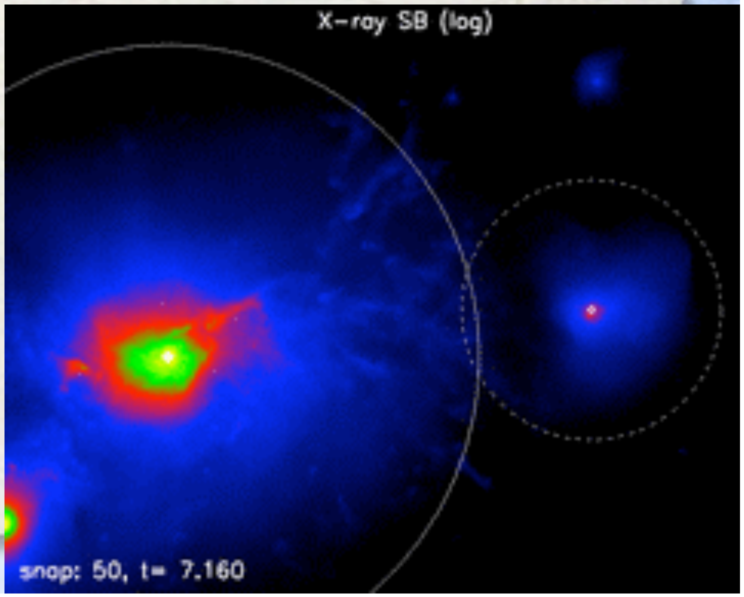
DM



GAS



galaxies



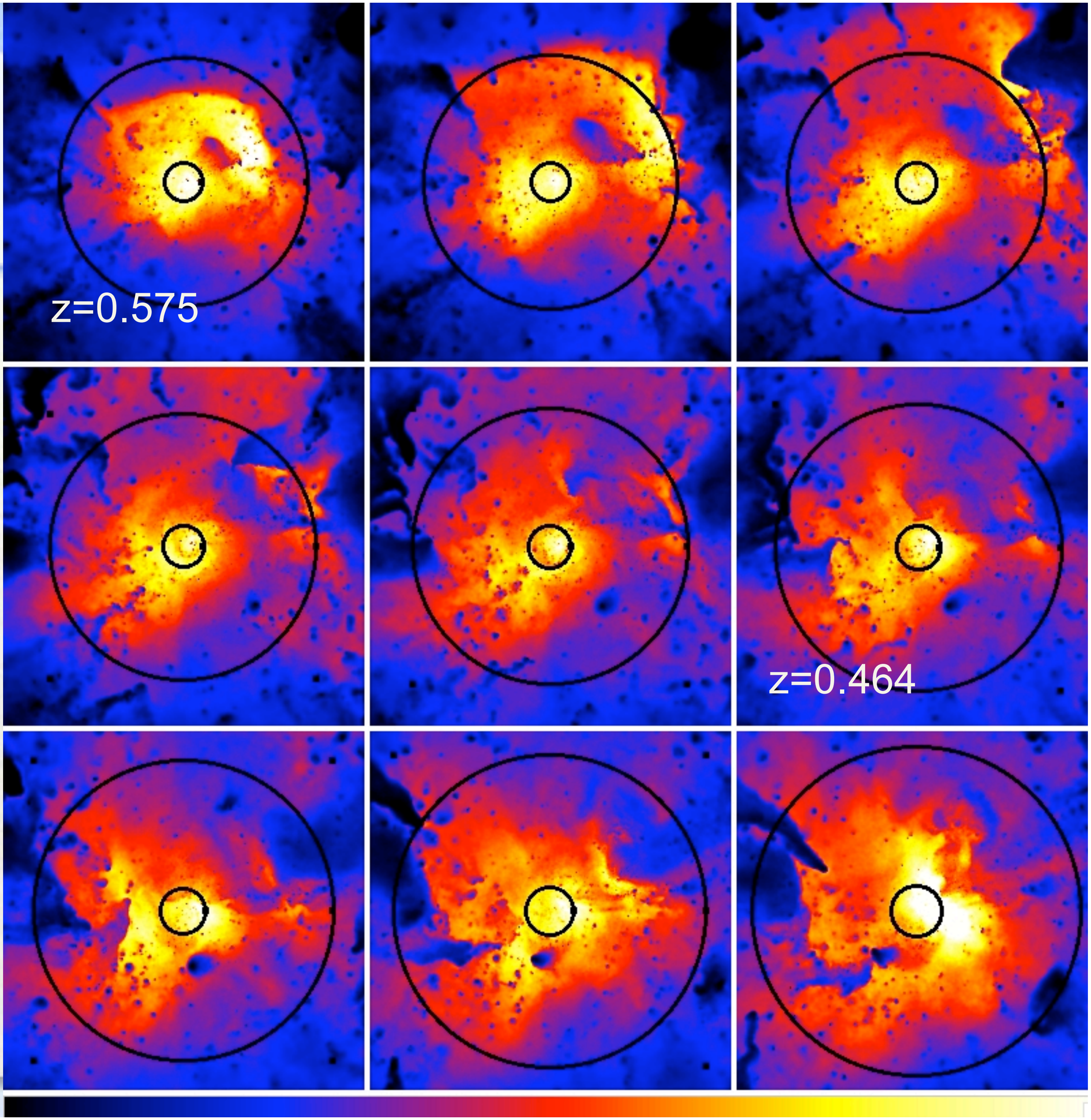
Courtesy of Klaus Dolag

SCALING RELATION

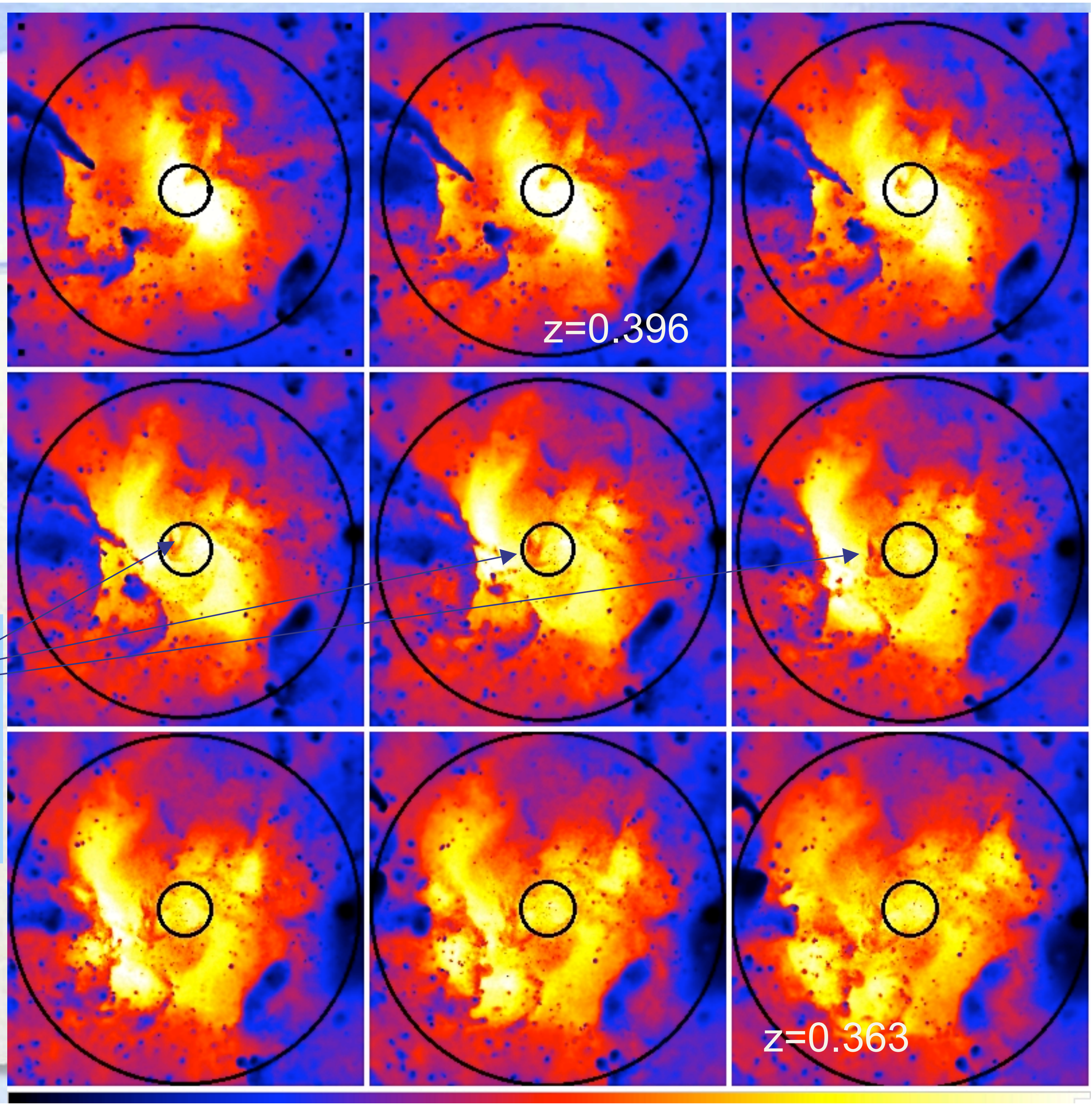
- SIMULATION
- All the quantities (T_{sl}, M_{gas}, Y_X=T_{sl} M_{gas})computed inside R_{500} (excluding 0.15 R_{500}) with R_{500} determined from the simulation itself

- OBSERVATION
- Cluster processed through XMAS2 to obtained X-ray images
- Mask blobs
- All the quantities from X-ray measurements computed in R_{500} (excluding the core) estimated from X-ray.

T maps

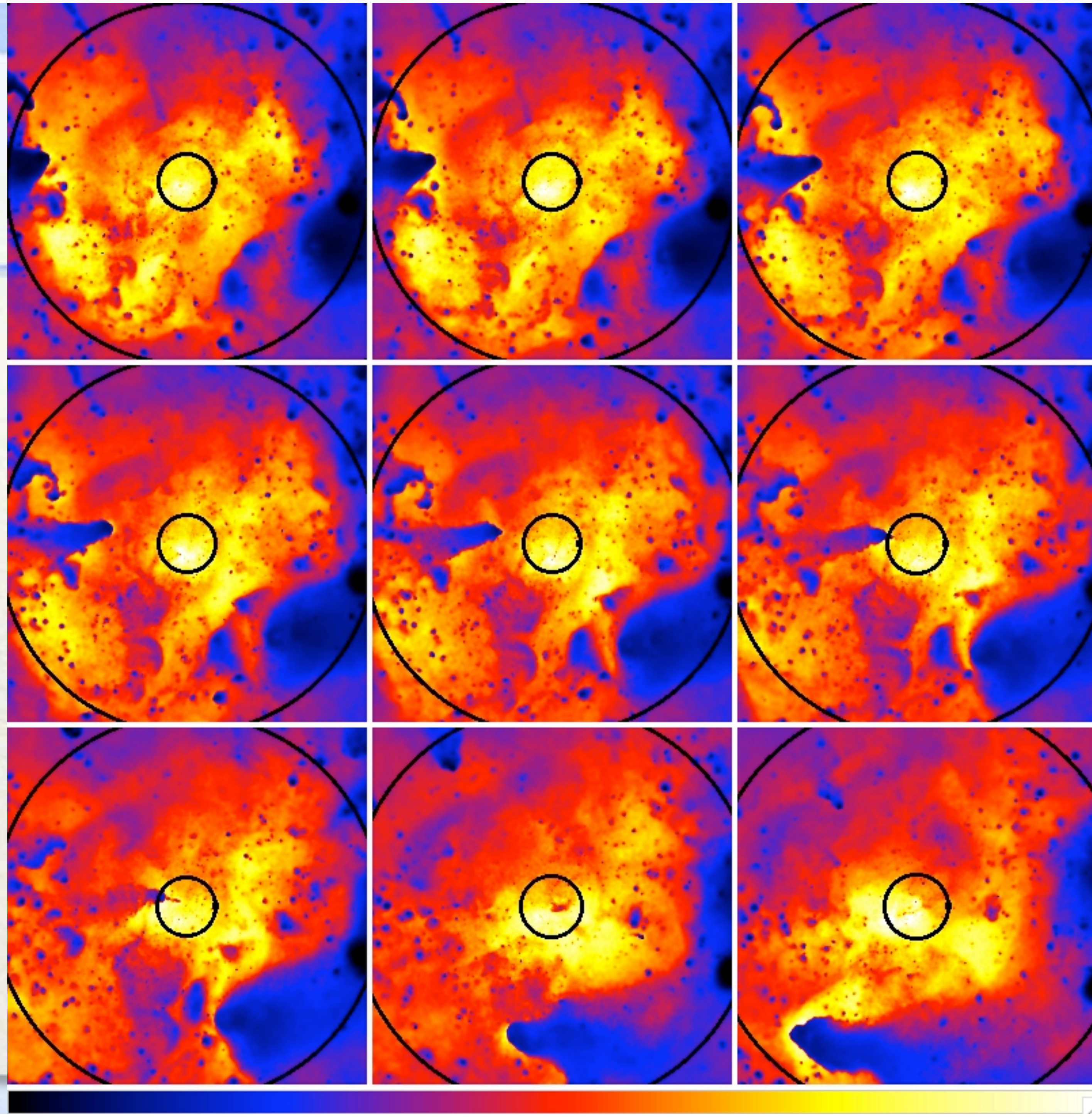


T maps

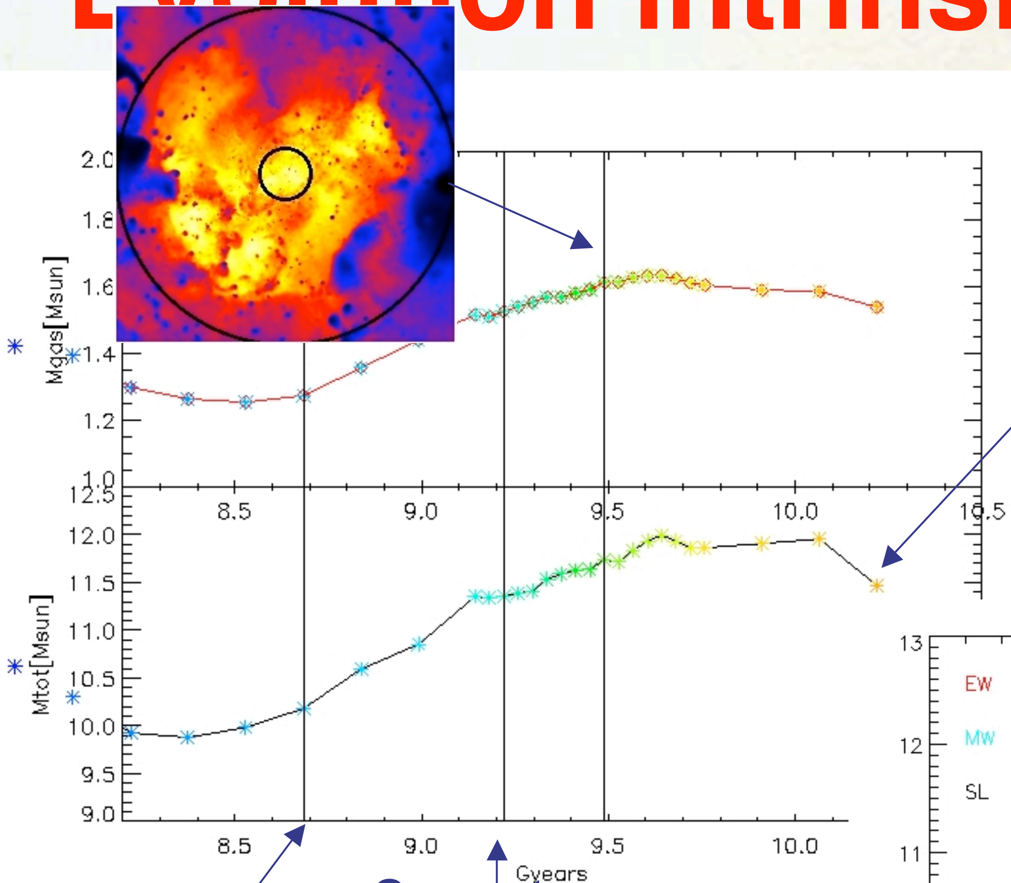


Mushroom Structure (Markevitch & Vikhlinin 07)

T maps

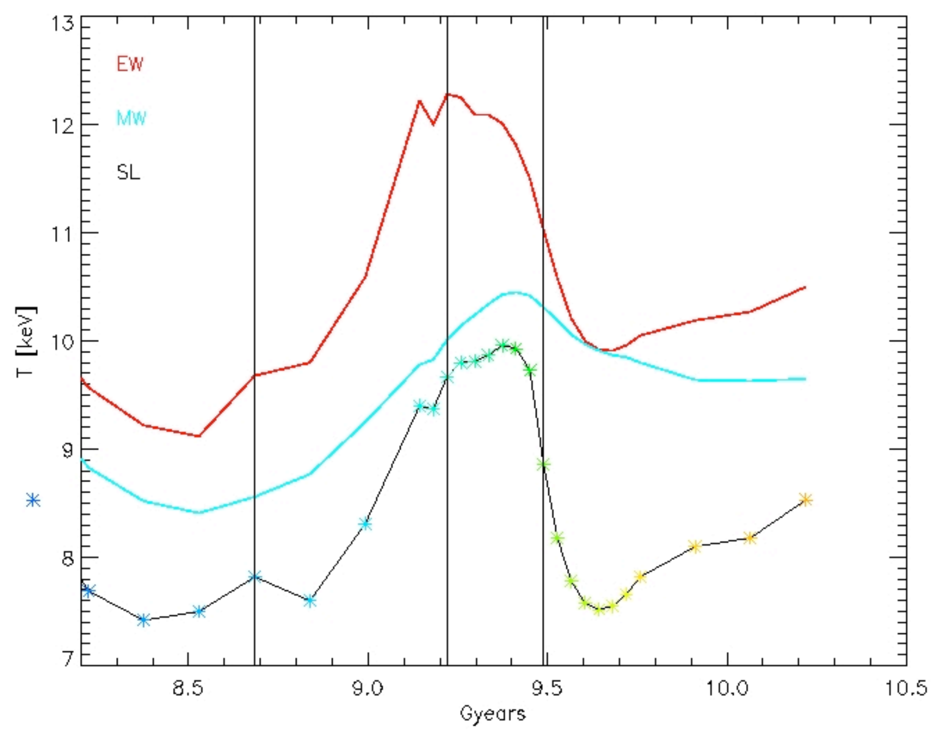


Evolution intrinsic properties



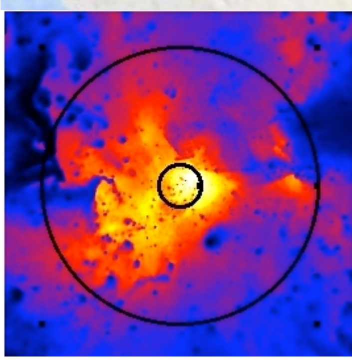
DM bullet-like+ cold blob Exiting R_{500}

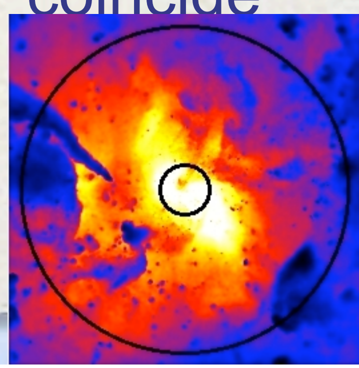
2nd cold blob



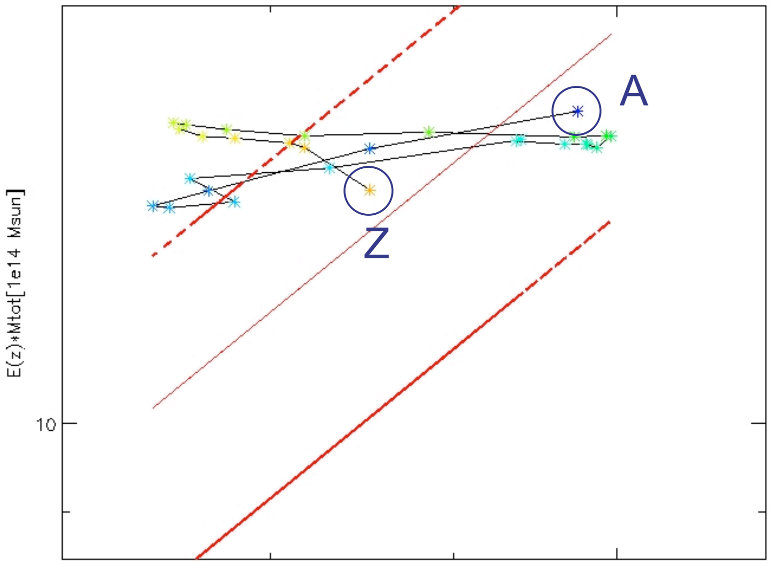
Merger begins

2 centers coincide



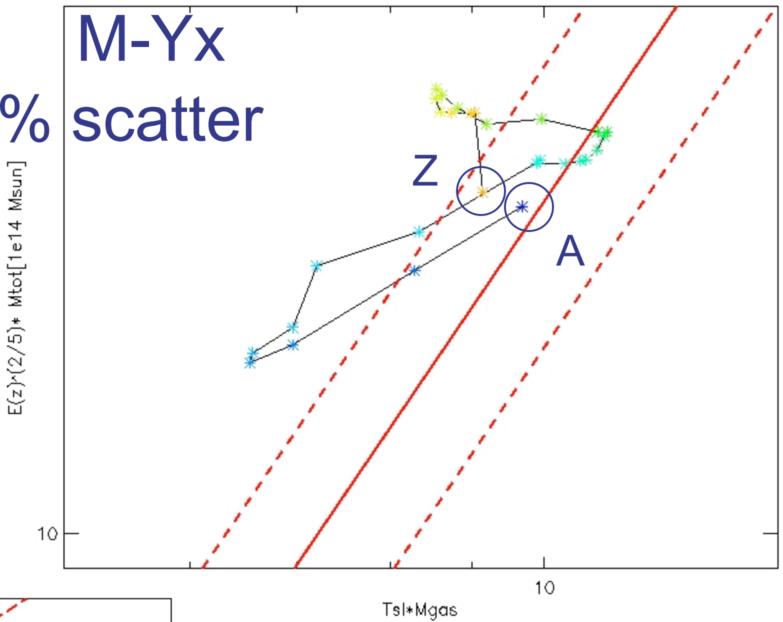


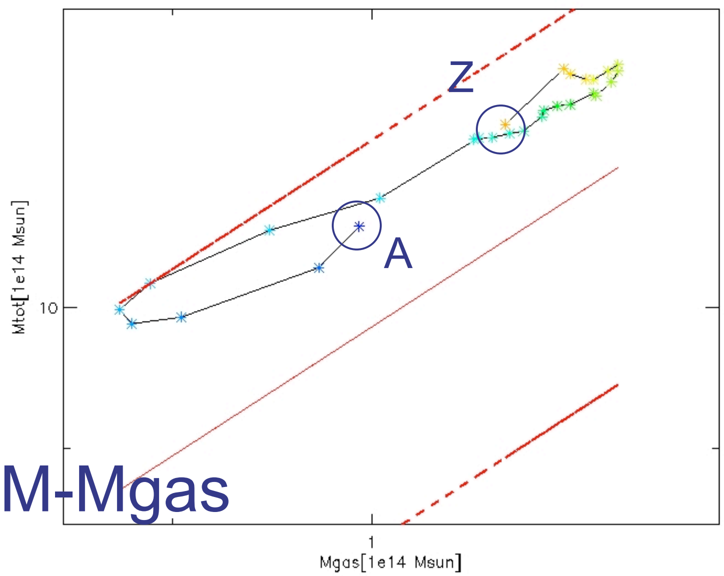
SCALING RELATION FROM SIMULATIONS



M-TsI

Yx 8% scatter





Mgas 11% scatter

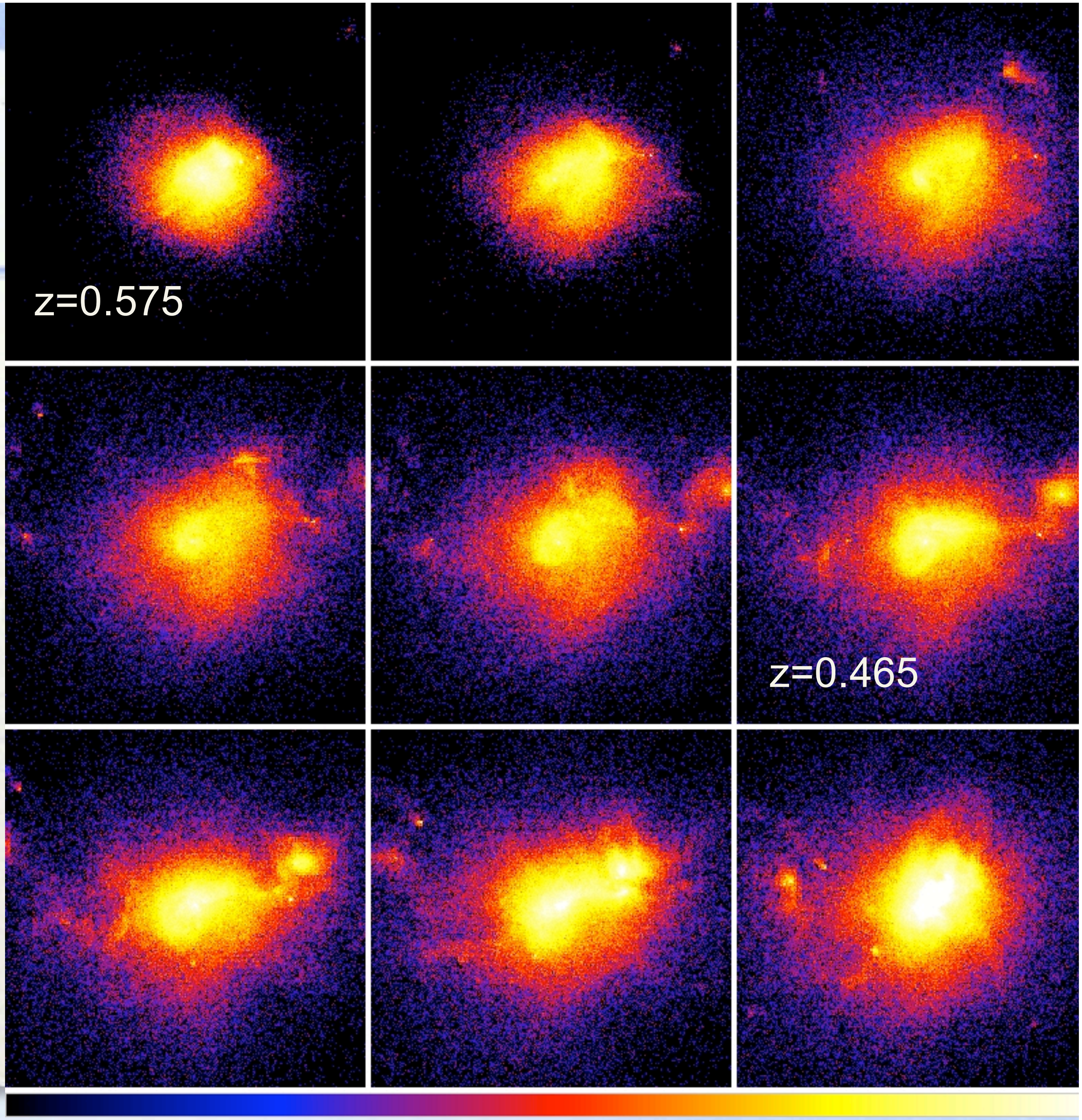
Red lines are the relations proposed by Kravtsov et al 06 + their scatter

SCALING RELATION

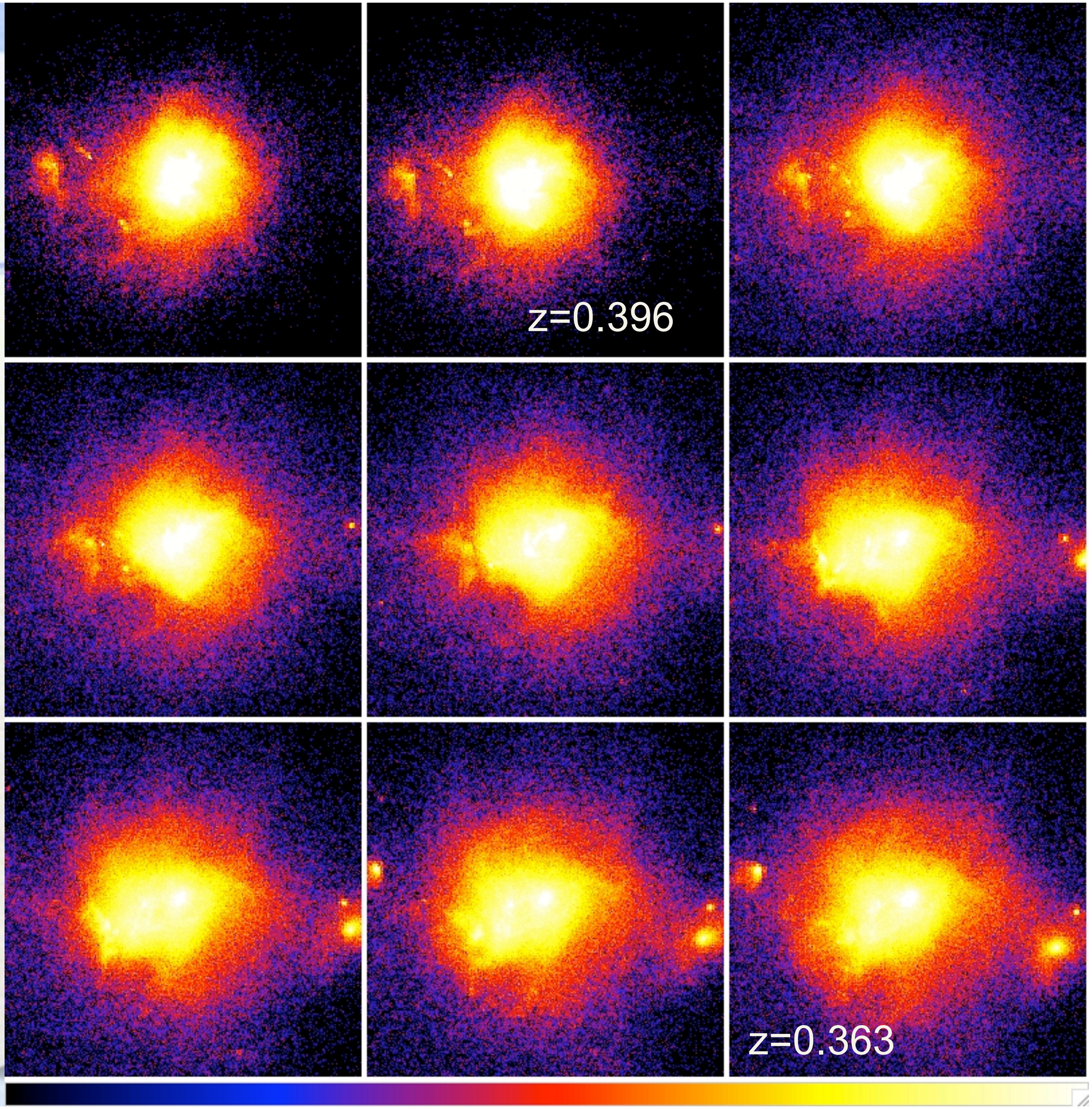
- SIMULATION
- All the quantities (T_{sl}, M_{gas}, Y_X=T_{sl} M_{gas})computed inside R_{500} (excluding 0.15 R_{500}) with R_{500} determined from the simulation itself

- OBSERVATION
- Cluster processed through XMAS2 to obtained X-ray images
- Mask blobs
- All the quantities from X-ray measurements computed in R_{500} (excluding the core) estimated from X-ray.

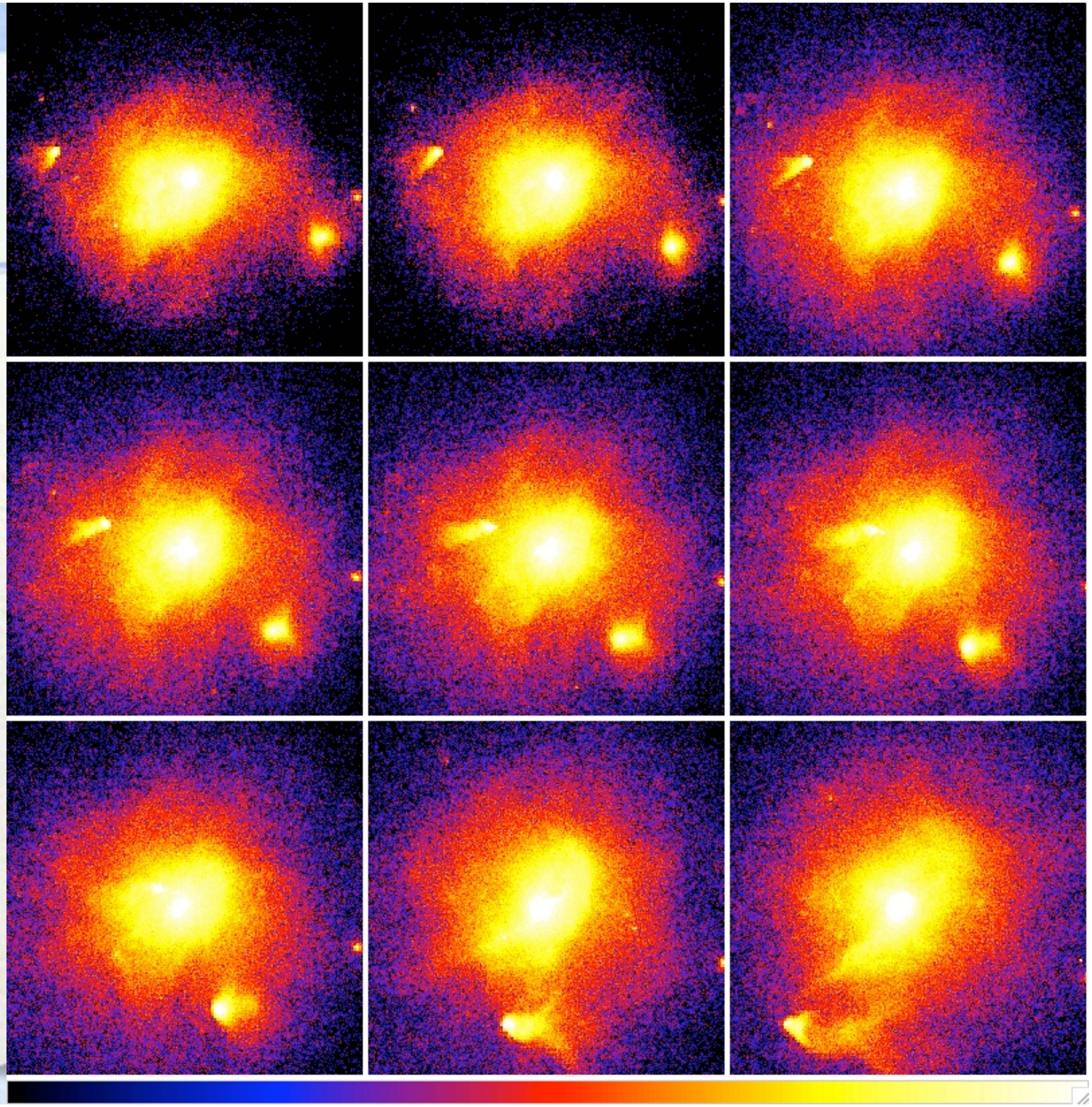
X-ray images



X-ray images



X-ray images

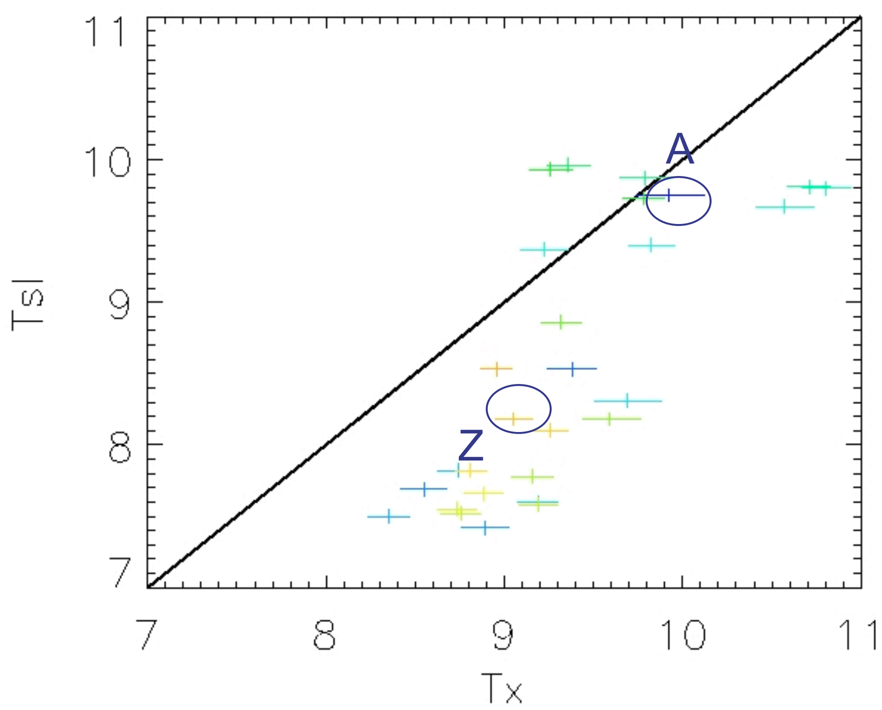


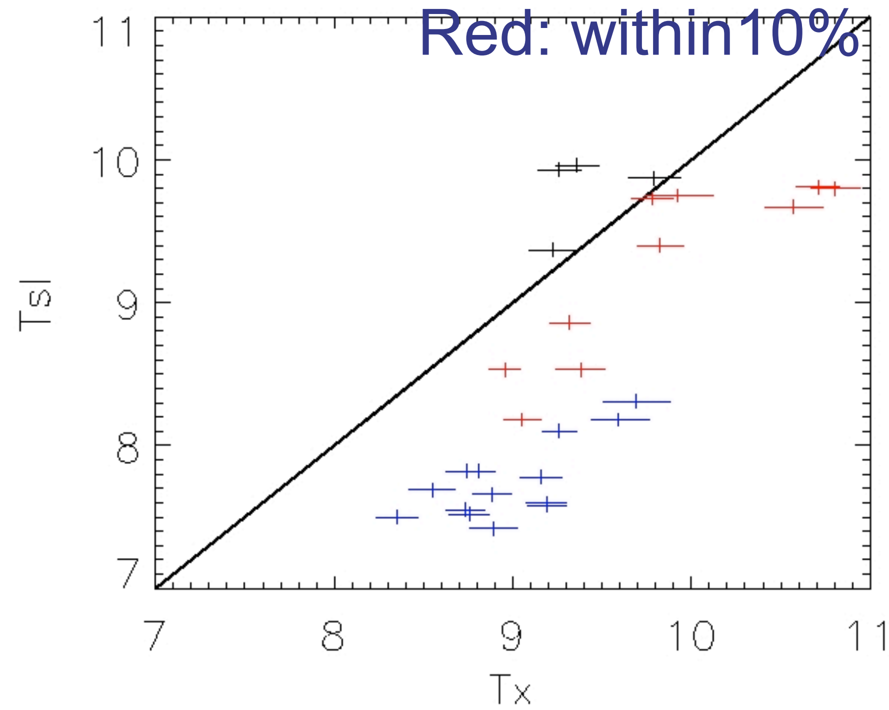
TEMPERATURE

- Mask blobs
- Spectra: [0.5 7] keV, fitting with one single-temperature mekal model (free parameters: T, Z and K)
- First measure at R_{500} computed directly from simulation

TEMPERATURE COMPARISON

1) X-ray temperature at $R_{500,sim}$ centered in the X-ray flux
2) The X-ray temperature is greater due to the ***masking of all blobs*** (which usually are colder the the medium)





Blu: between 10-20% off

S-B AND GAS DENSITY

- Surface brightness profile: [0.5 2] keV images
- Gas density fitting formulae:

$$n^2\{(r/rc)^a[1+(r/r_{c1})^2]^{(a/2-3b1)}[1+(r/rs)^g]^{e/g}\}$$
$$+ m^2\{[1+(r/r_{c2})^2\ ]^{3b2/2}\ \}$$

(Vikhlinin et al. 05)

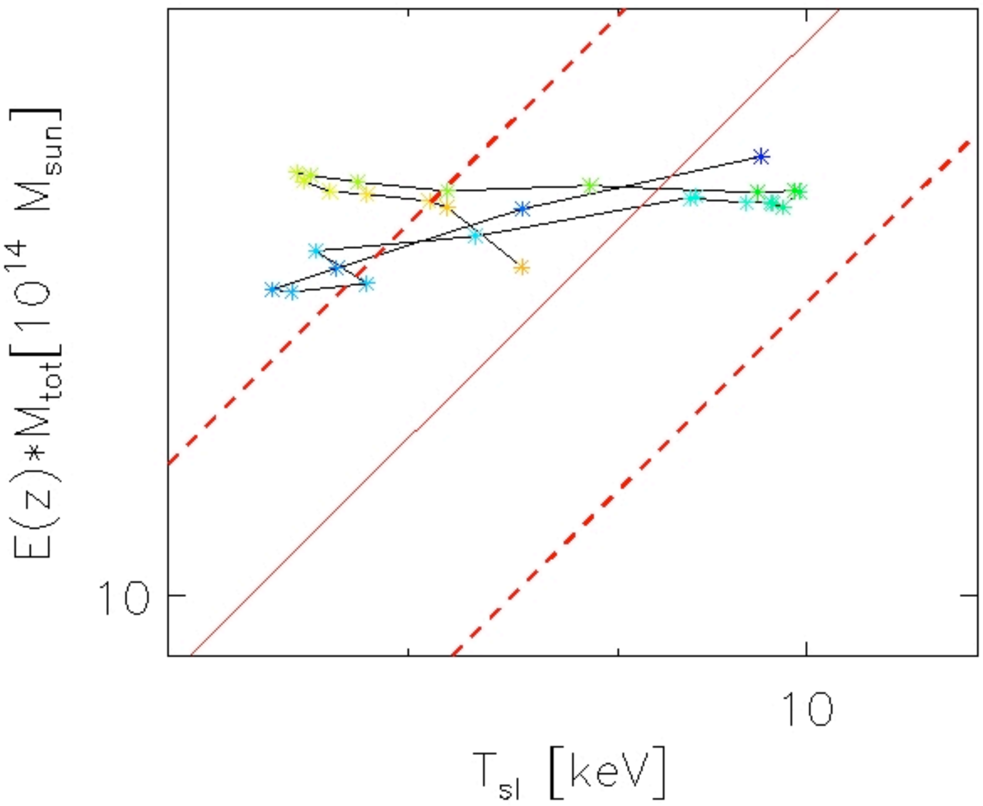
- With the gas mass profile we calculate R_{500} as the radius that satisfy at

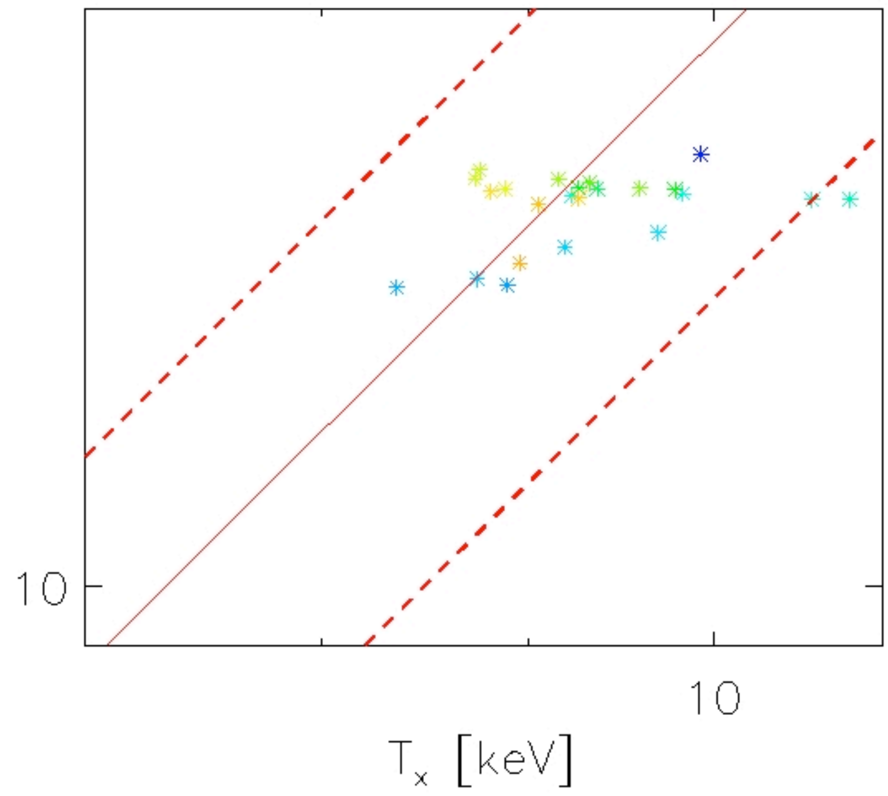
$4\ \pi/3\ 500\ \rho_c(z)\ r^3_{500} = 10^{14.27}\ E(z)^{\ 2/5}\ [Y_X(R_{500})]^{0.581}$
(Kravtsov et al. 06)

MASS - TEMPERATURE

SIMULATIONS

OBSERVATIONS



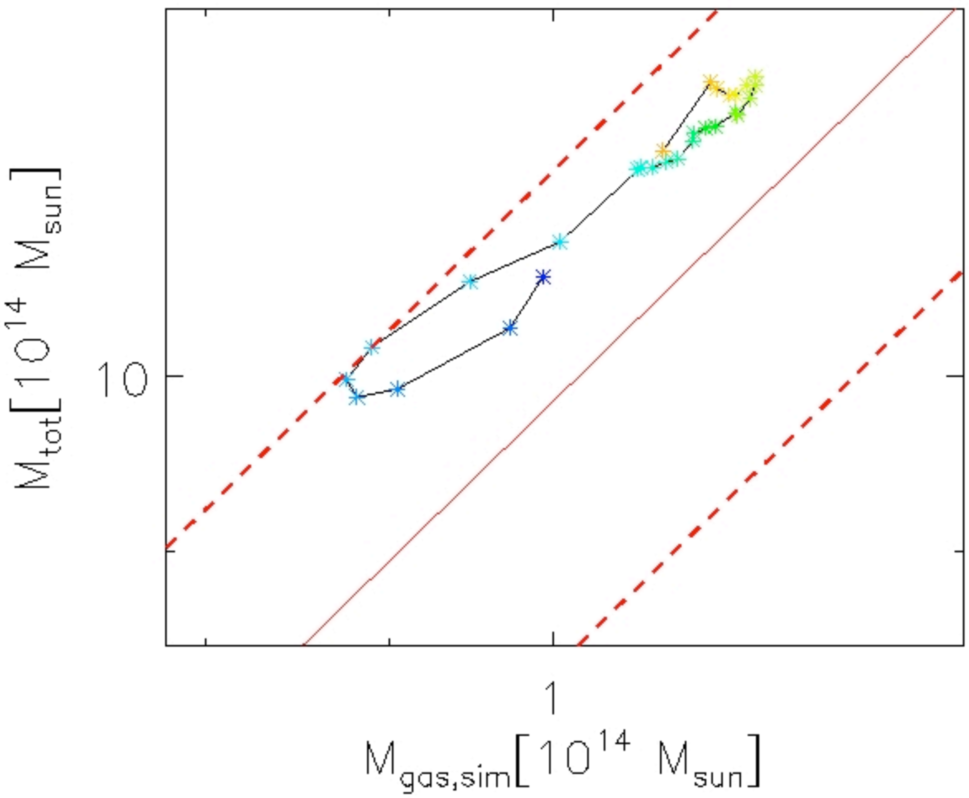


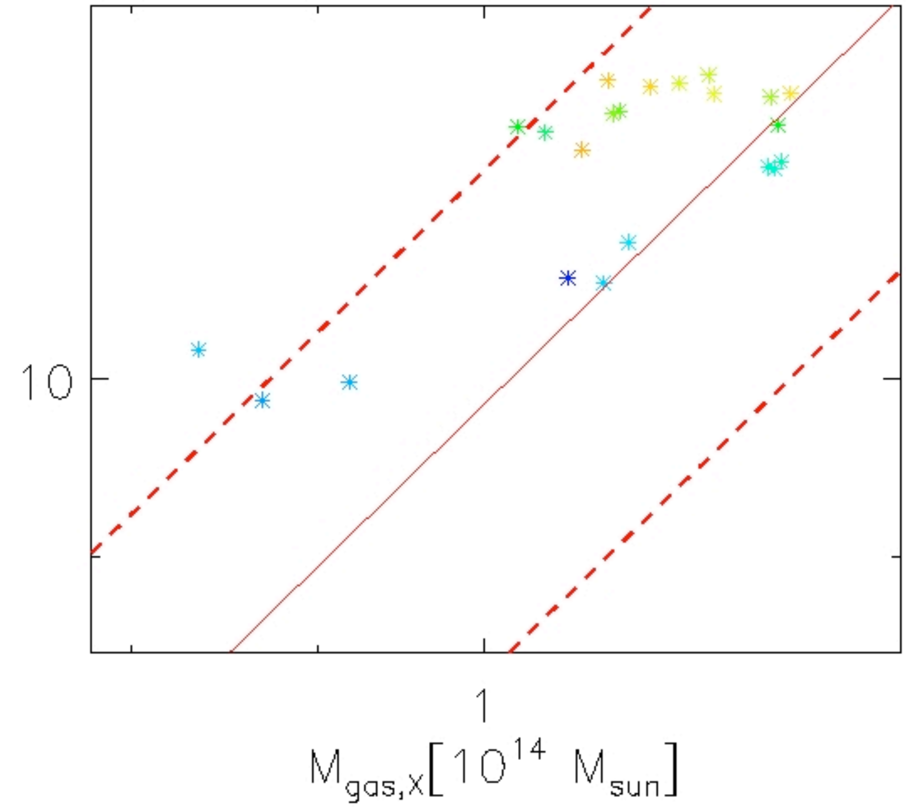
The overall behavior of the M-T is changed substantially. Points are closer to the relation by Kravtsov et al. and within 10% of scatter

MASS - GAS MASS

SIMULATIONS

OBSERVATIONS



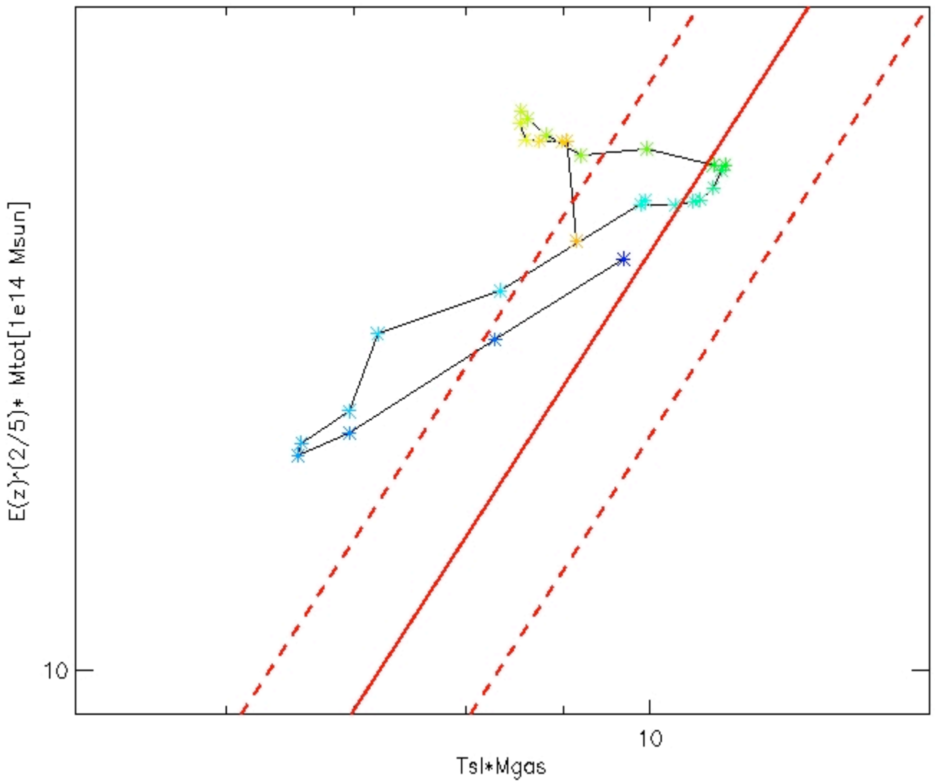


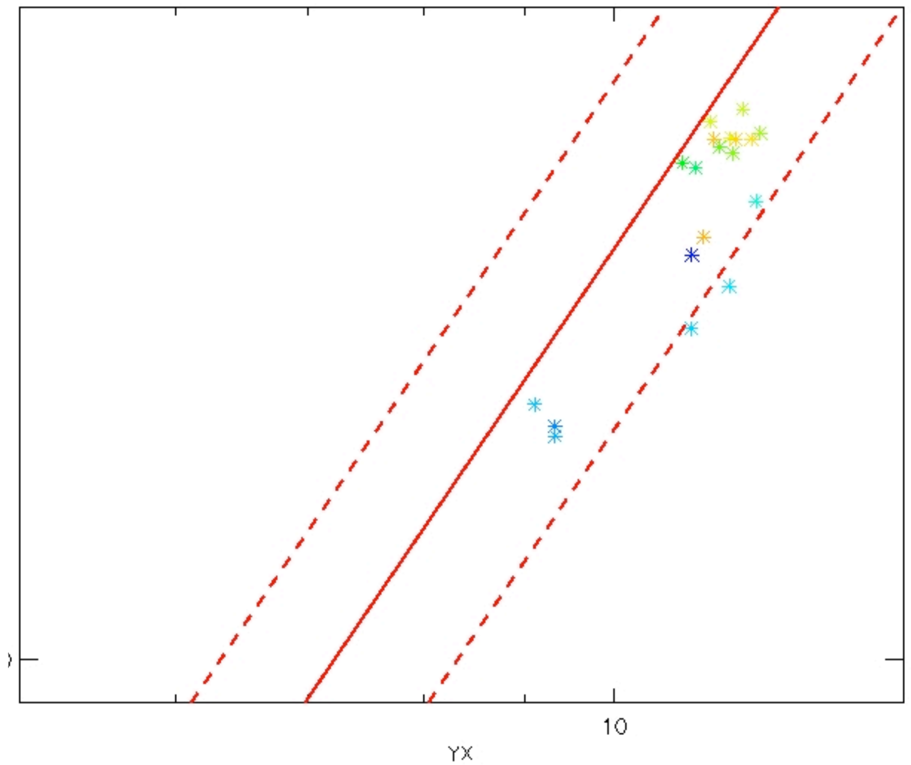
There is a larger spread in the gas mass computed with the X-ray technique, at the same time more points approach to the best-fit by Kravtsov

MASS - YX PARAMETER

SIMULATIONS

OBSERVATIONS





The observed Yx parameter is in agreement with Kravtsov relation.
The “observed scatter” is substantially reduced

TAKE-HOME MESSAGE #3

- We tested the robustness of the scaling relation and we find that they are satisfied also in the case of a strong merger
- The X-ray Temperature is good proxy for mass when an accurate masking is done
- The Y_X parameter is very robust again merger due to the opposite effect that M_{gas} and T_X are experiencing