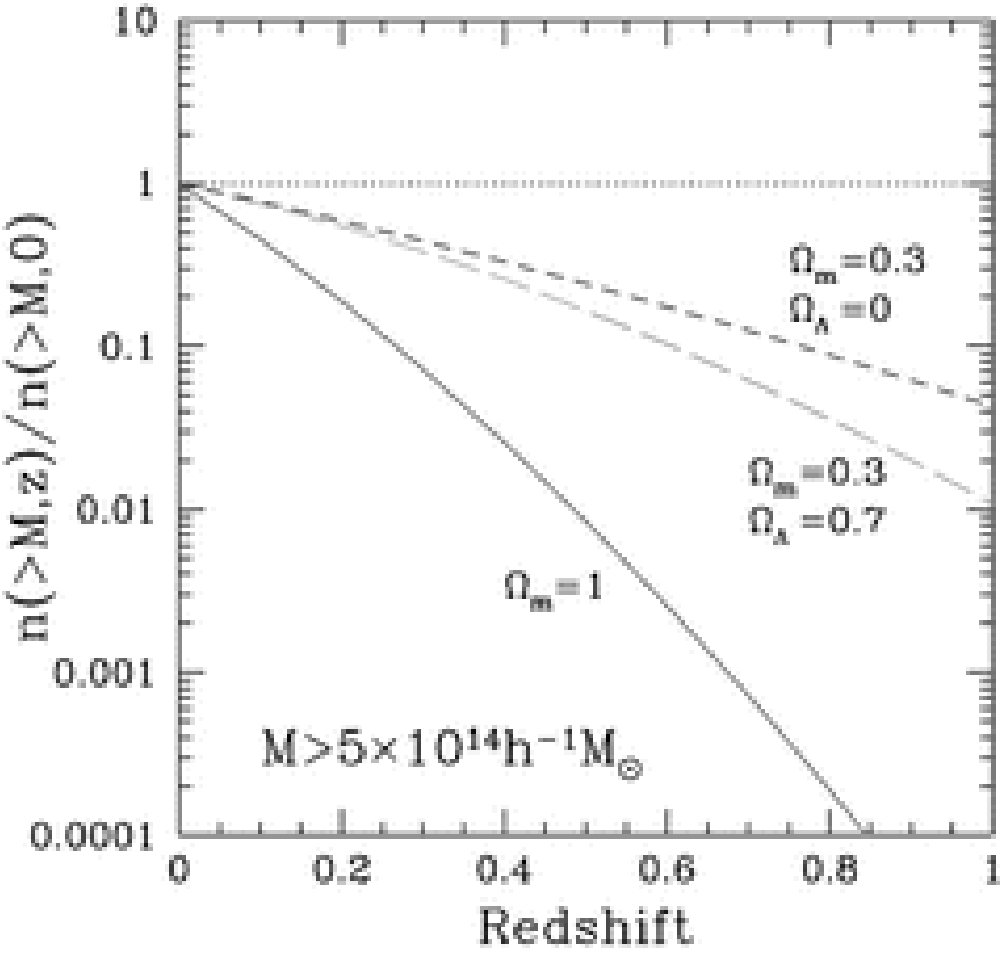
Cluster Evolution

Collapse of rare high density peaks of primordial density distribution produces clusters

- probe high-density tail of the cosmic density field
- number density is highly sensitive to cosmological model, e.g. growth rate of density fluctuations depends on

$$\Omega_m$$

Growth rate of density fluctuations



number of clusters at a certain mass (normalised to the present number)

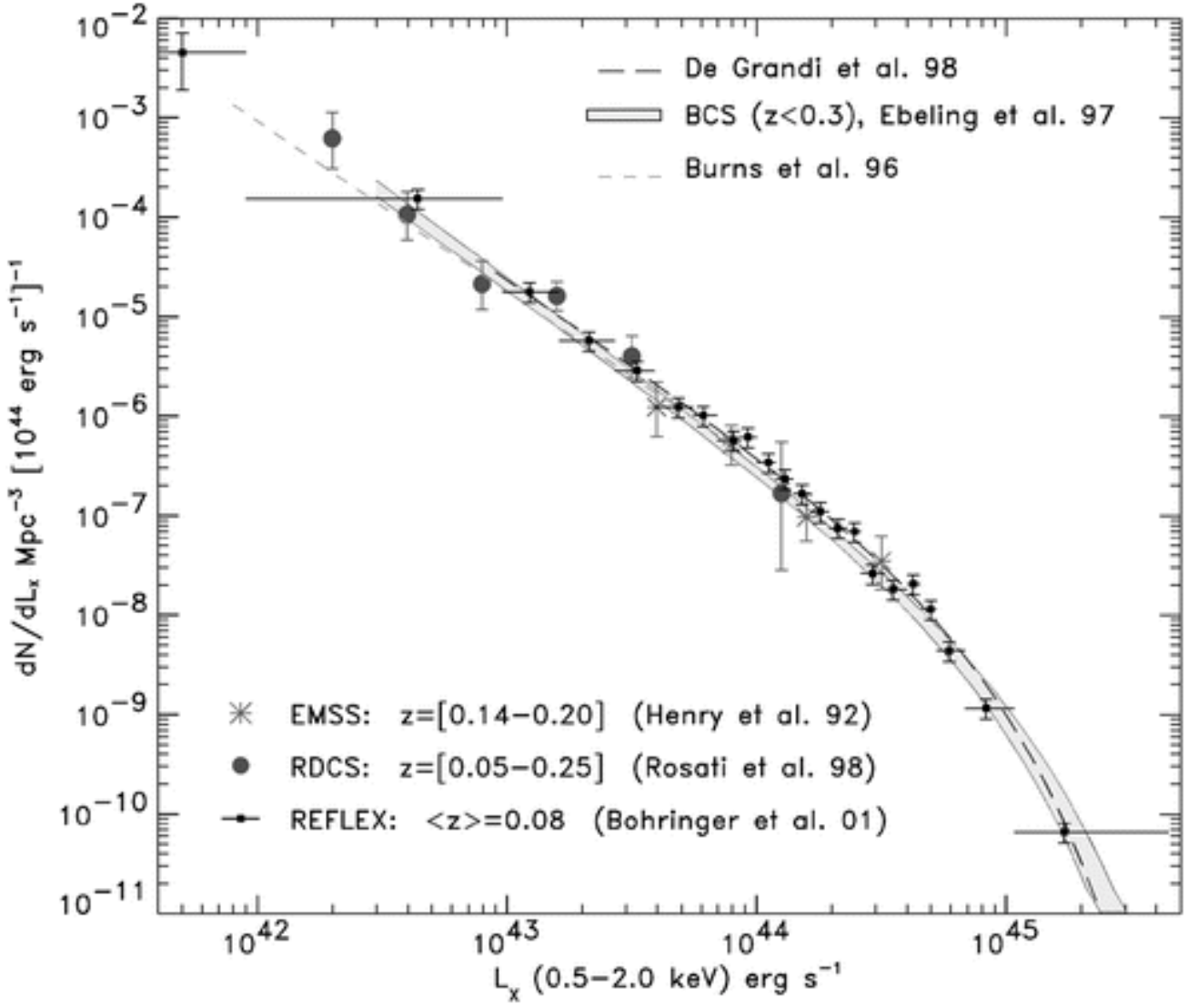
Number density of clusters of given mass versus mass = mass function

but: mass is difficult to measure for large samples and for distant clusters

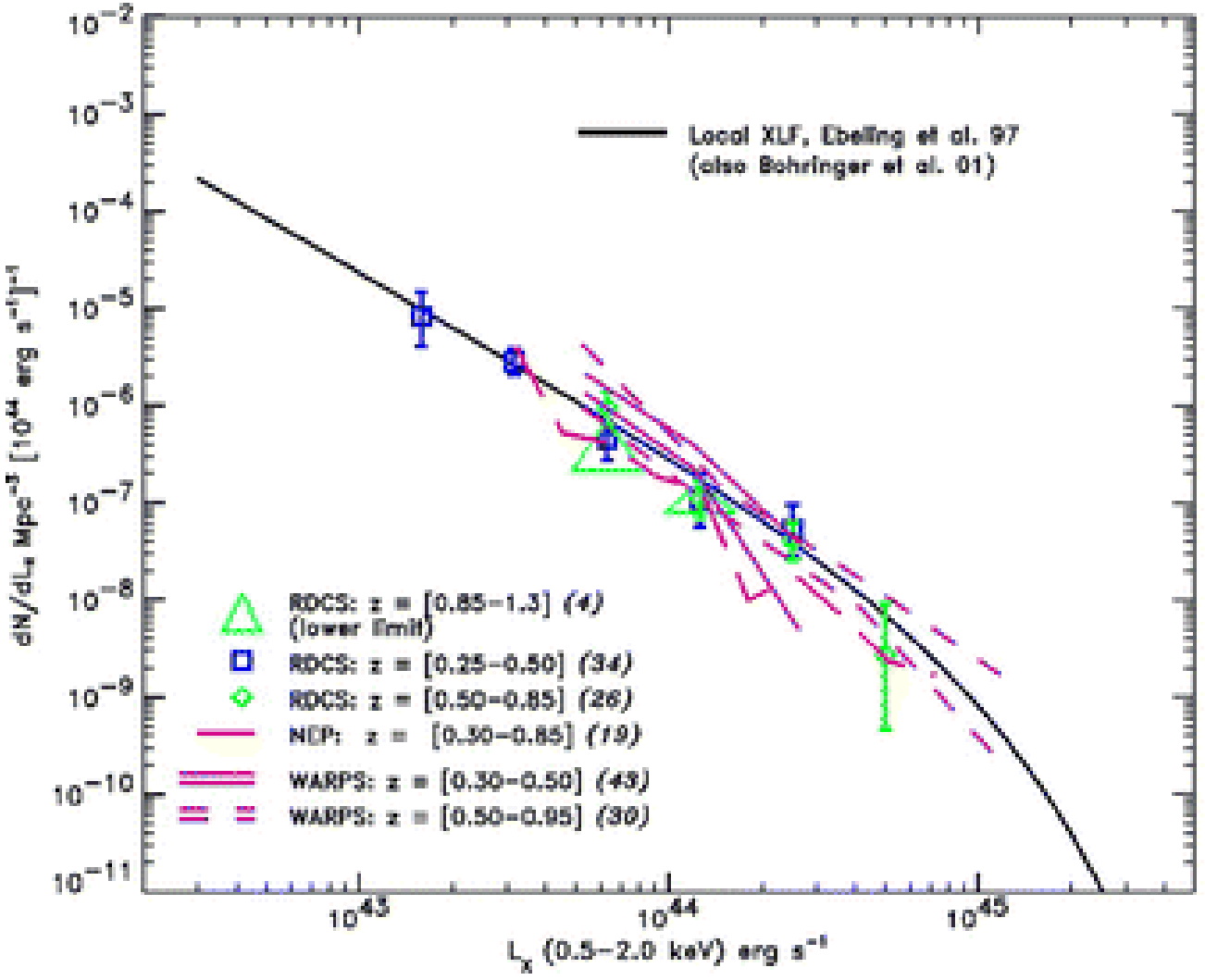
⟶ temperature function

⟶ X-ray luminosity function

Luminosity function

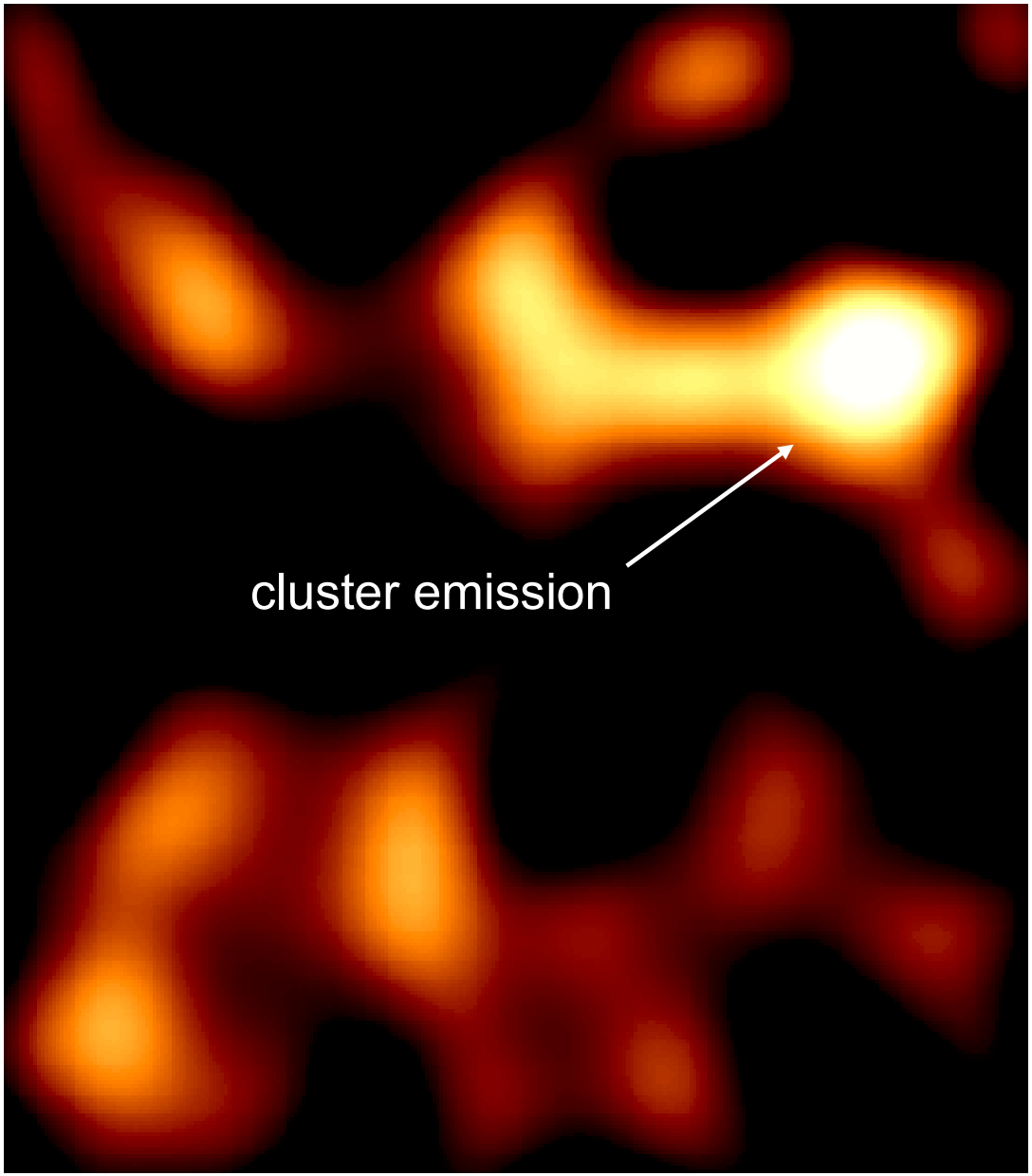


Luminosity functions of distant clusters



Careful !

- selection effects
- source confusion



RBS380

Fainter than expected, most of the emission comes from an AGN
→ (source confusion!)

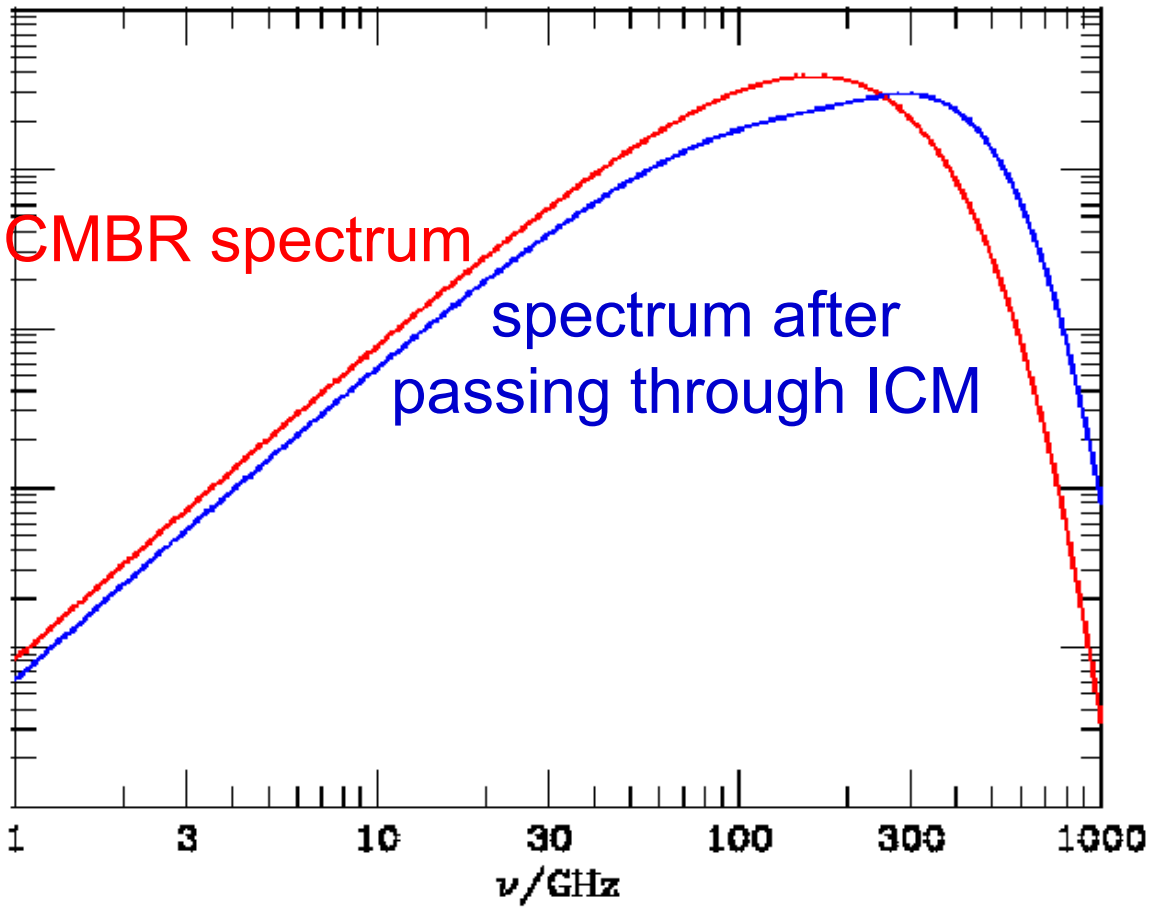
High resolution X-ray images are important for cosmological applications

Gil-Merino & Schindler, in press

Result from luminosity/temperature functions

$$\Omega_m \approx 0.3 \pm 0.1$$

Distance determination with the Sunyeav – Zel‘dovich effect



Photons of the CMBR are scattered at the hot ICM

spectrum is shifted to slightly higher energies

depending on energy a decrement or an increment of the intensity is observed

Distance determination with the Sunyaev – Zel'dovich effect

- SZ De- or Increment ~ density
- X-ray emission ~ density^2

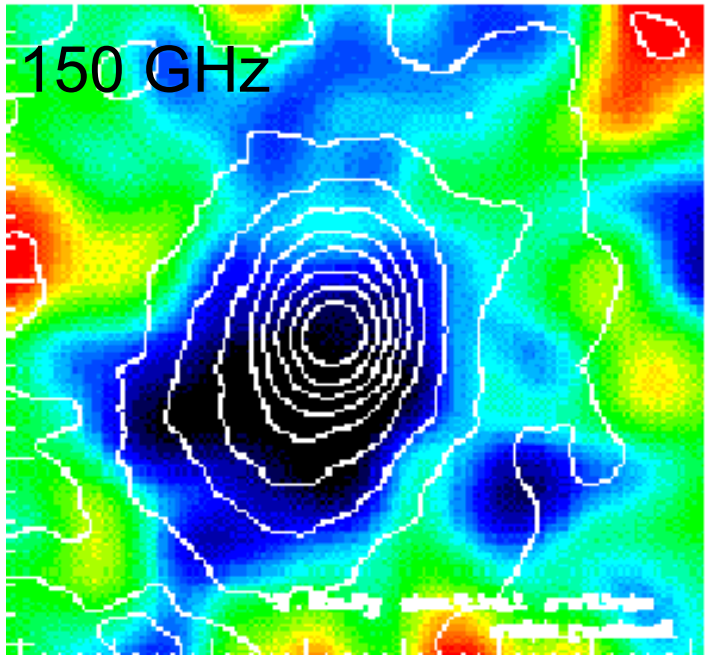
→ physical size – angular size

→ direct distance determination

→ Hubble constant

RXJ1347

- Contours: X-ray
- Colours: SZ



Komatsu et al. 2001

Problem: deviation from spherical symmetry

physical size

→ along line of sight

angular size

→ perpendicular to l.o.s.

Many clusters have to be observed

→

Carlstrom et al. 2001:

$H_0 = 60 \pm 10$ km/s/Mpc

Interaction of Galaxies with ICM ...

... has effects on galaxies and on the ICM

... has effects on several ICM quantities

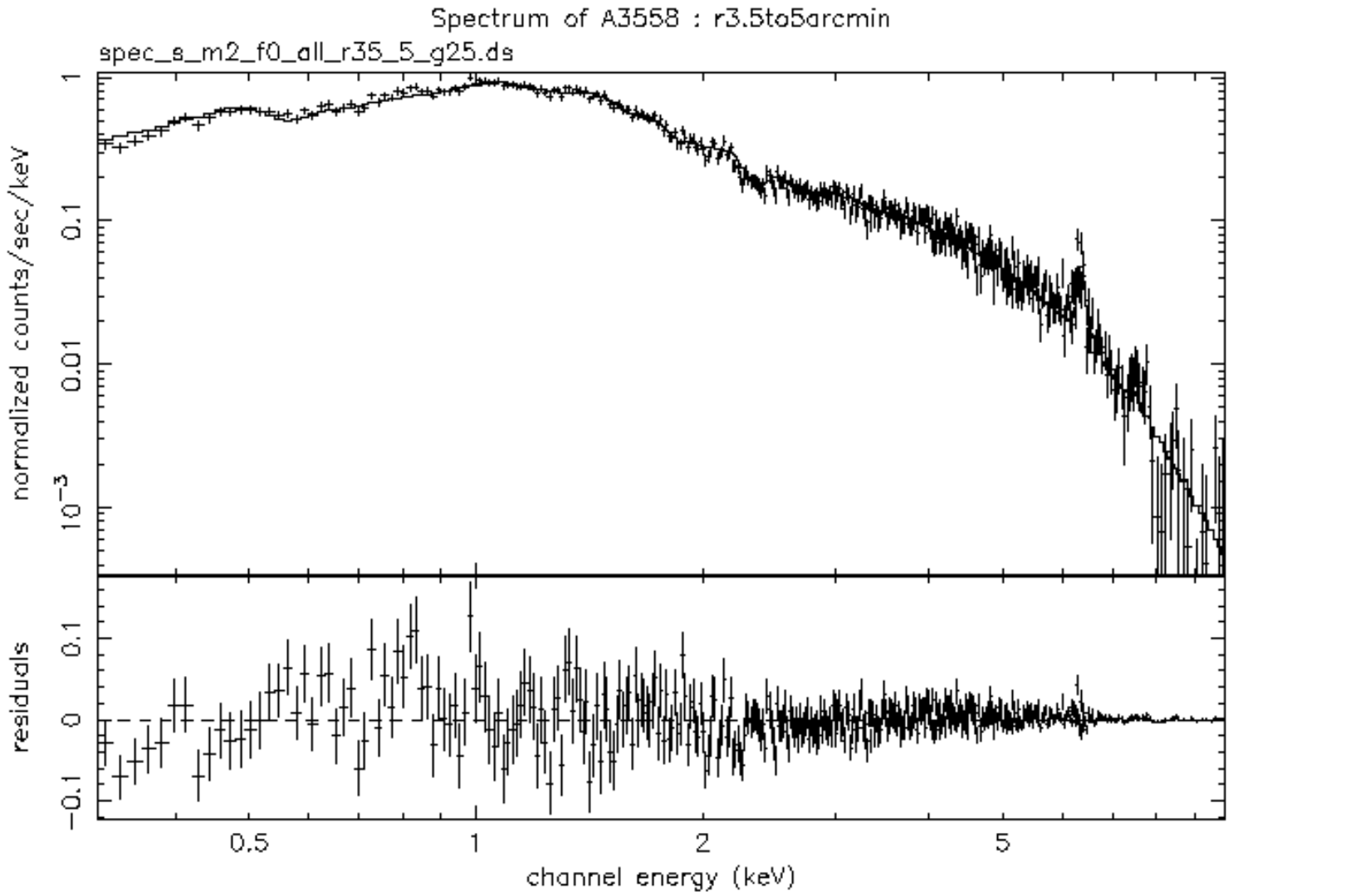
- energy
- entropy
- metallicity
- ...

Interaction of Galaxies with ICM

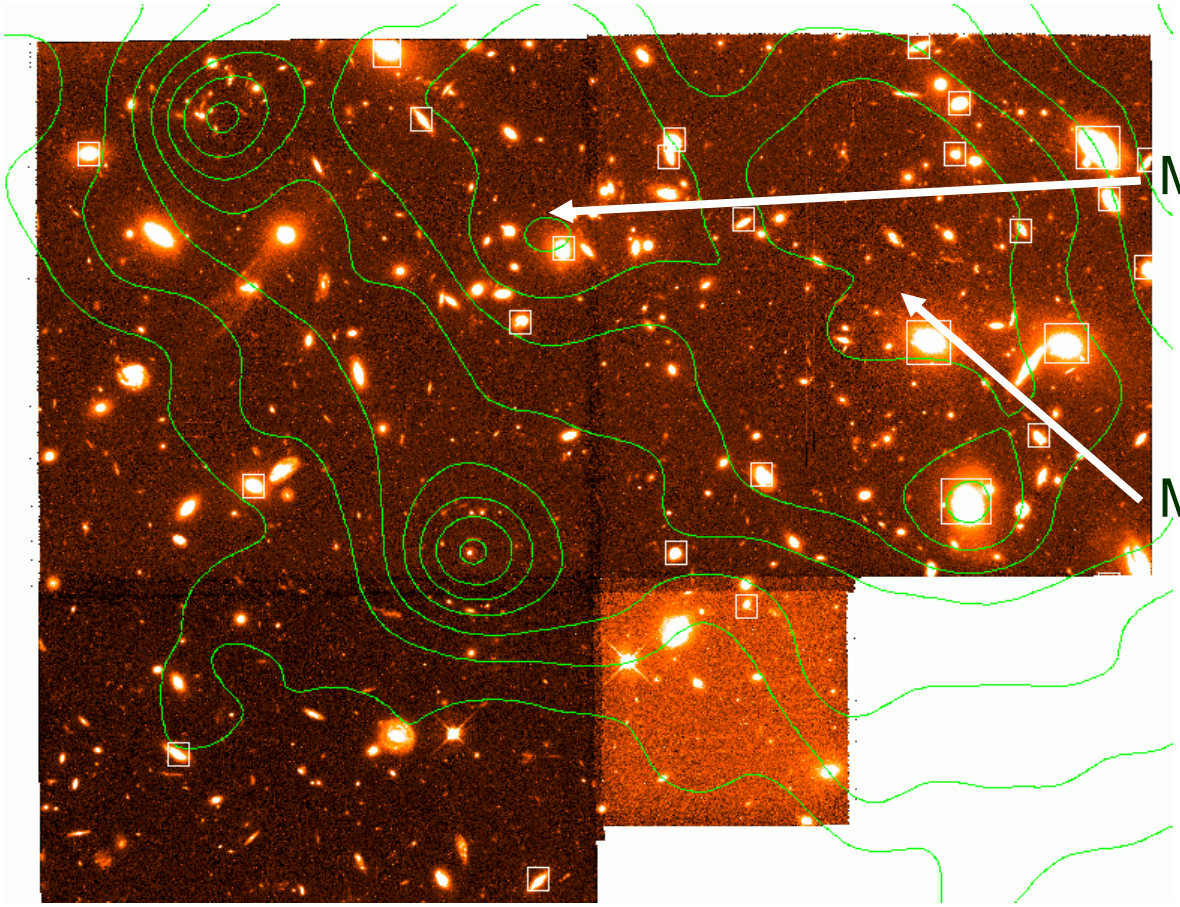
Best tracer is metallicity:

- Distribution, not only radial gradients!!!
- Evolution (out to z=1)
- Element ratios

XMM spectrum of A3558

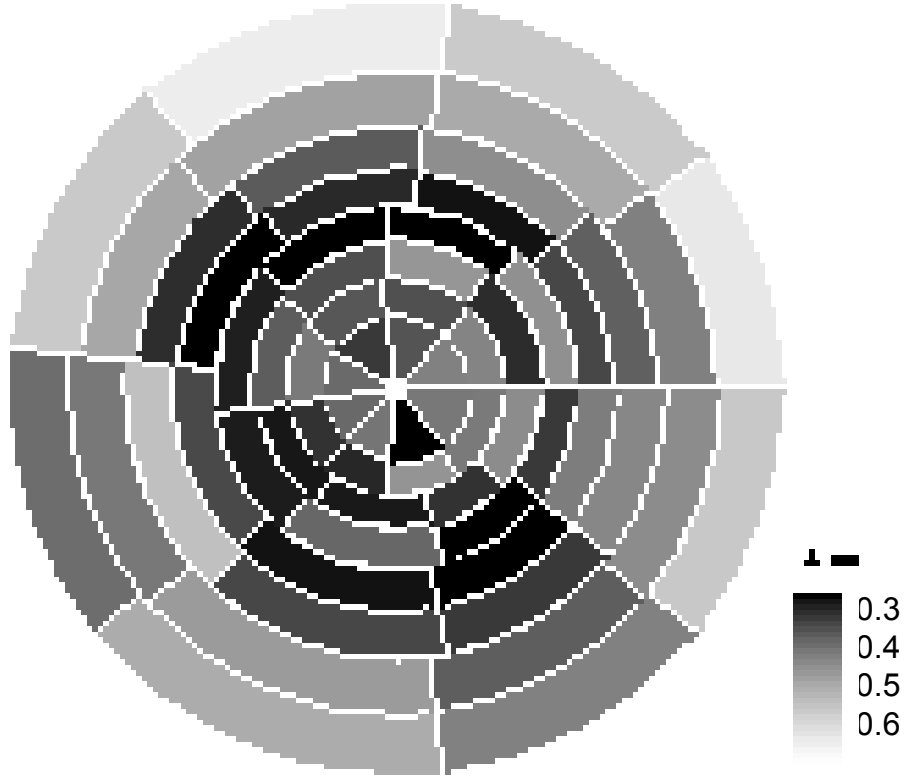


CL0939+4713 (XMM, HST)



De Filippis, Schindler, Castillo-Morales 2003

Perseus cluster



Metallicity (solar)

Schmidt et al. astro-ph/0207290

Interaction of Galaxies with ICM

Best tracer is metallicity:

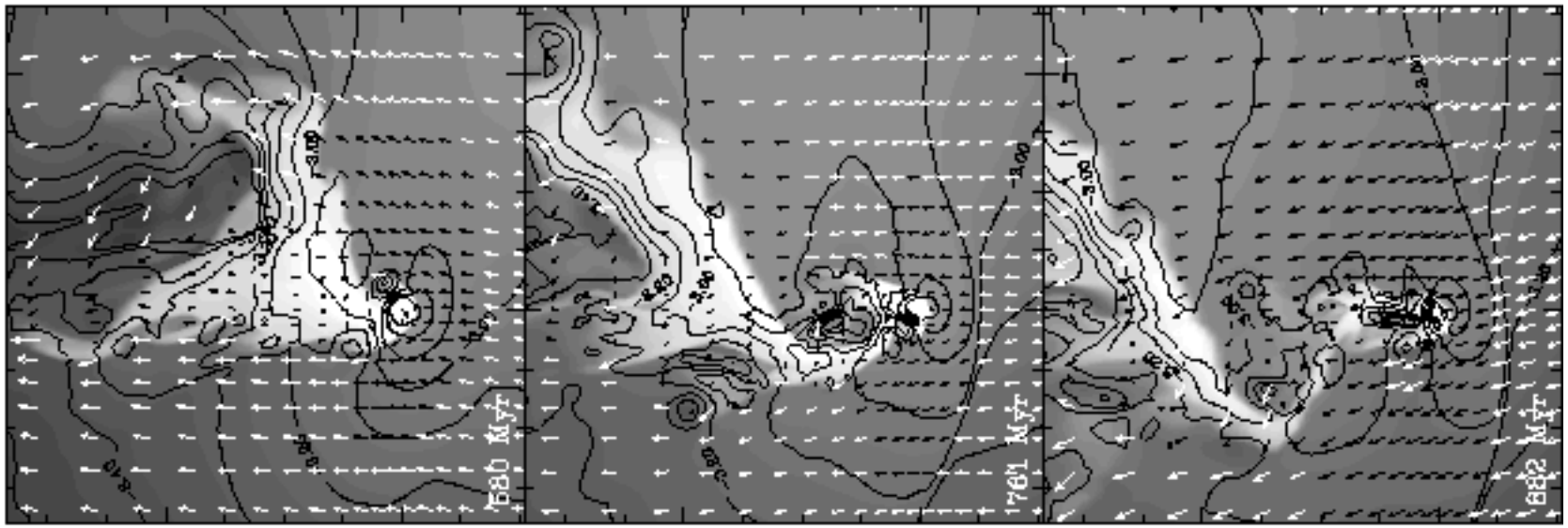
- Distribution, not only radial gradients!!!
- Evolution (out to z=1)
- Element ratios

Enrichment processes

- Ram-pressure stripping (Gunn & Gott ´72)
- Galactic winds (De Young ´78)
- Galaxy – galaxy interaction
- Jets from AGNs

Ram-pressure stripping

- Galaxy is moving through the ICM



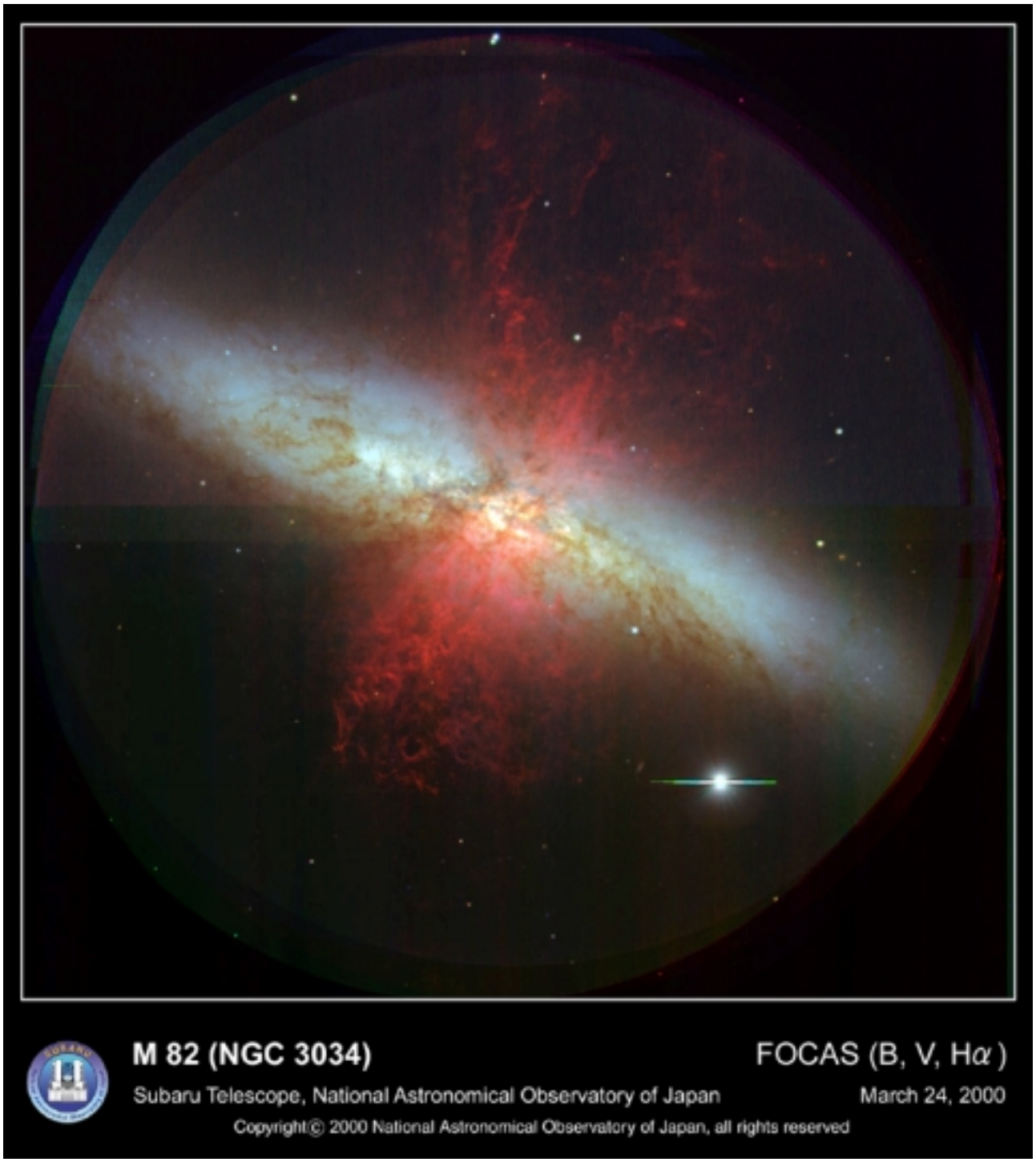
grey scale: density

contours: pressure

Toniazzo & Schindler 2001

Enrichment processes

- Ram-pressure stripping (Gunn & Gott ´72)
- Galactic winds (De Young ´78)
- Galaxy – galaxy interaction
- Jets from AGNs

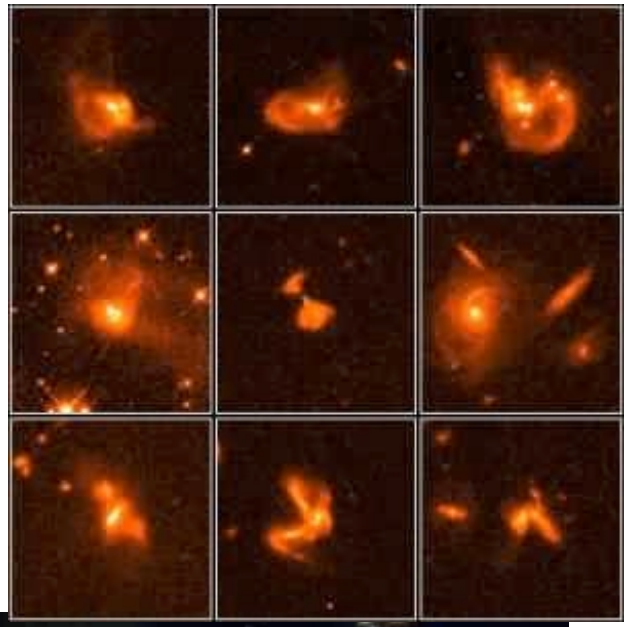


Galactic Winds

Enrichment processes

- Ram-pressure stripping (Gunn & Gott ´72)
- Galactic winds (De Young ´78)
- Galaxy – galaxy interaction
- Jets from AGNs

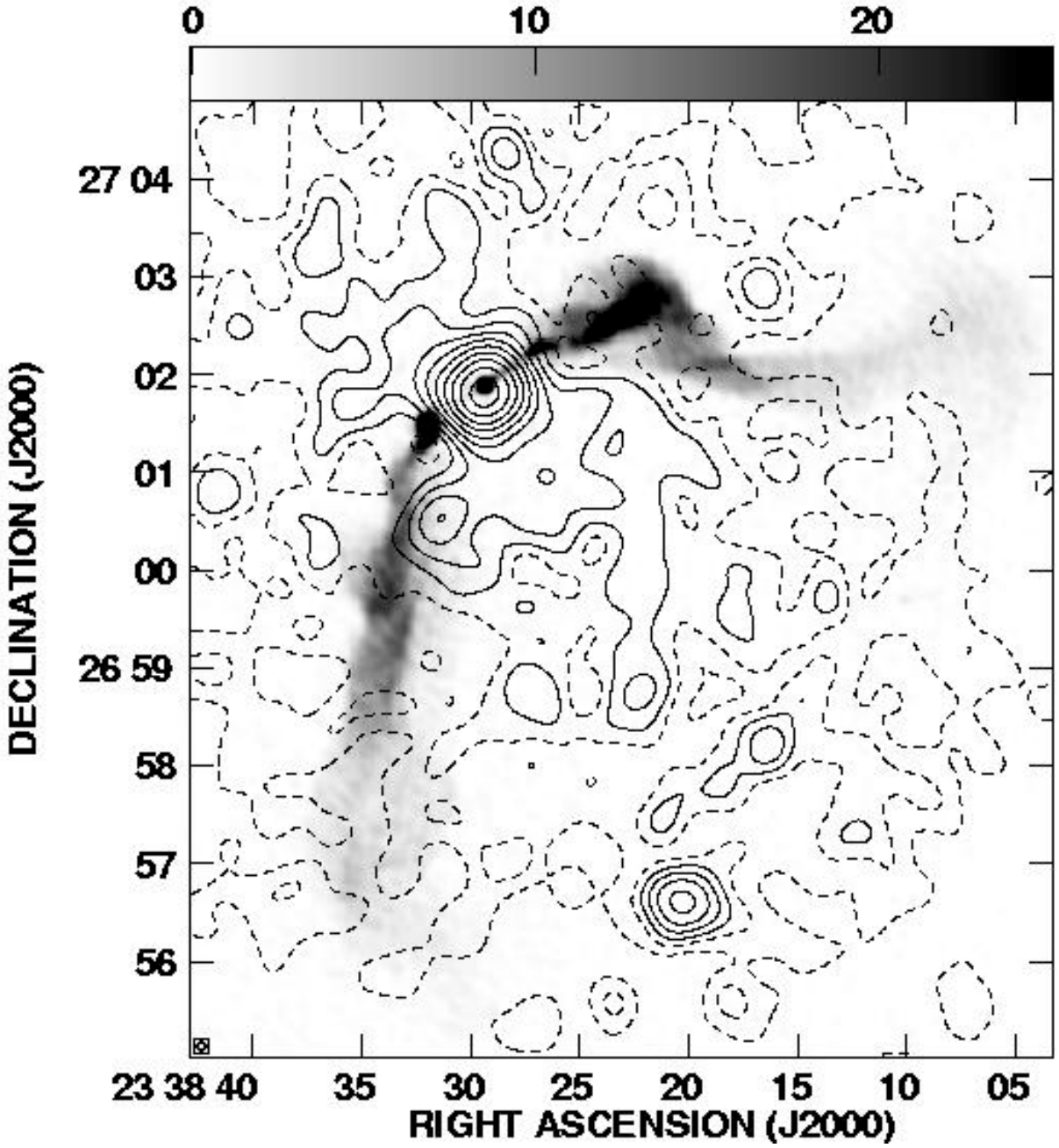
Galaxy – galaxy interaction



Enrichment processes

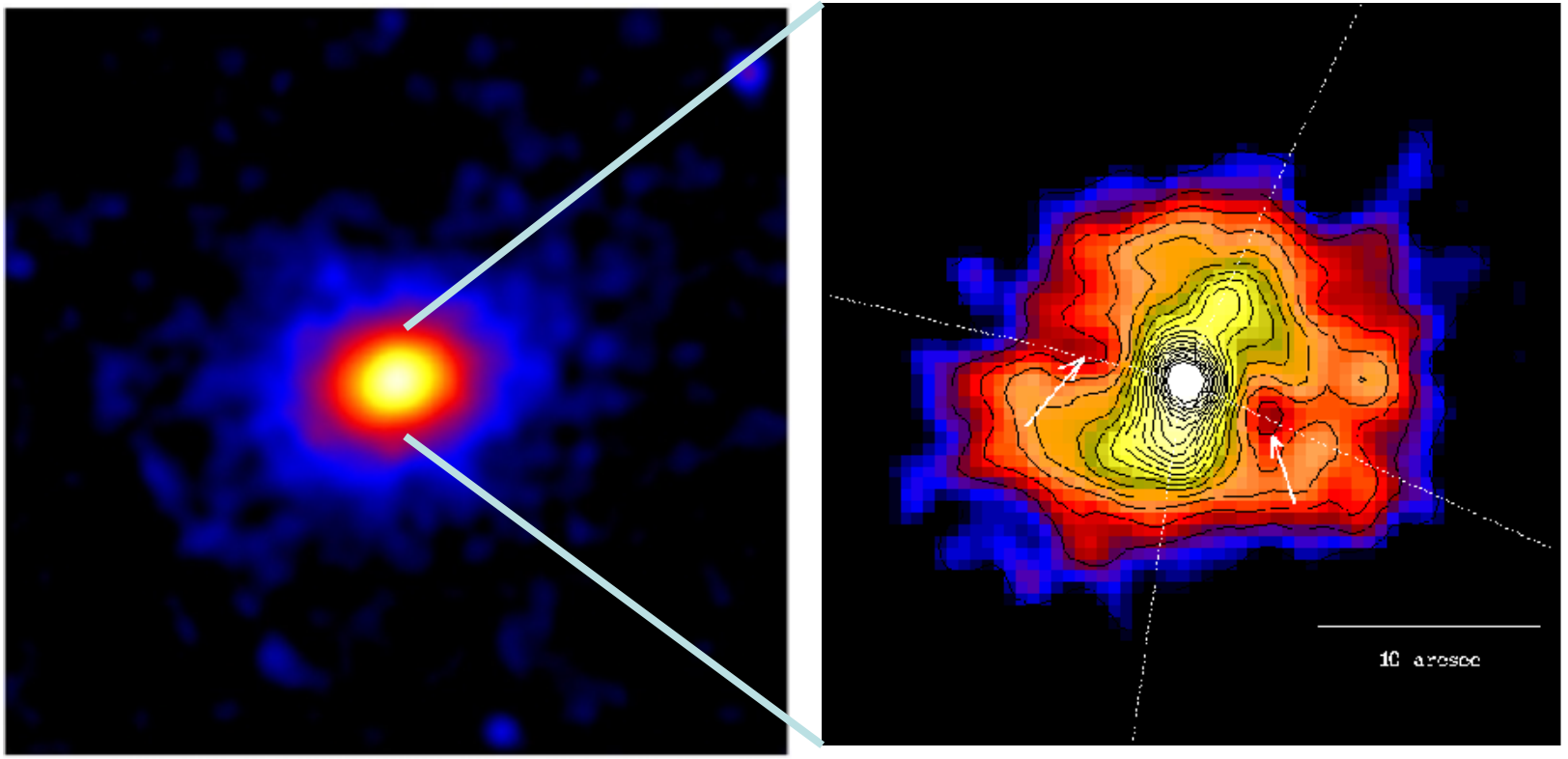
- Ram-pressure stripping (Gunn & Gott ´72)
- Galactic winds (De Young ´78)
- Galaxy – galaxy interaction
- Jets from AGNs

A2634


0
10
20
27 04
03
02
01
00
26 59
58
57
56
DECLINATION (J2000)
23 38 40
35
30
25
20
15
10
05
RIGHT ASCENSION (J2000)

RBS797 (z = 0.35, $T = 7.7^{+1.2}_{-1.0}$ keV)
CHANDRA (0.5 – 7 keV)

Schindler et al. 2001



total cluster emission

central part of the cluster

pressure of relativistic particles pushes away the ICM

so far: controversial results on the efficiency of the processes

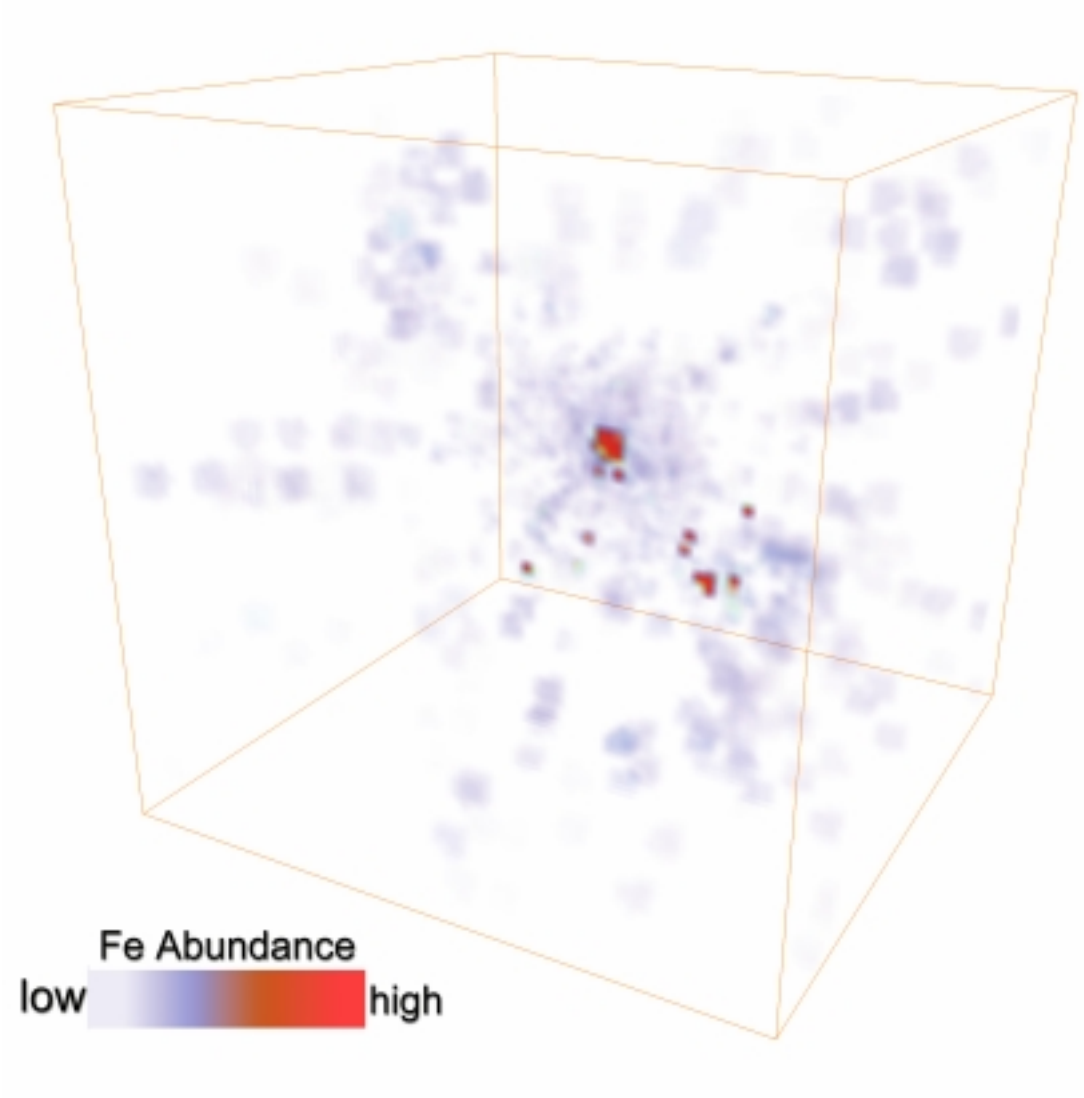
Comprehensive models

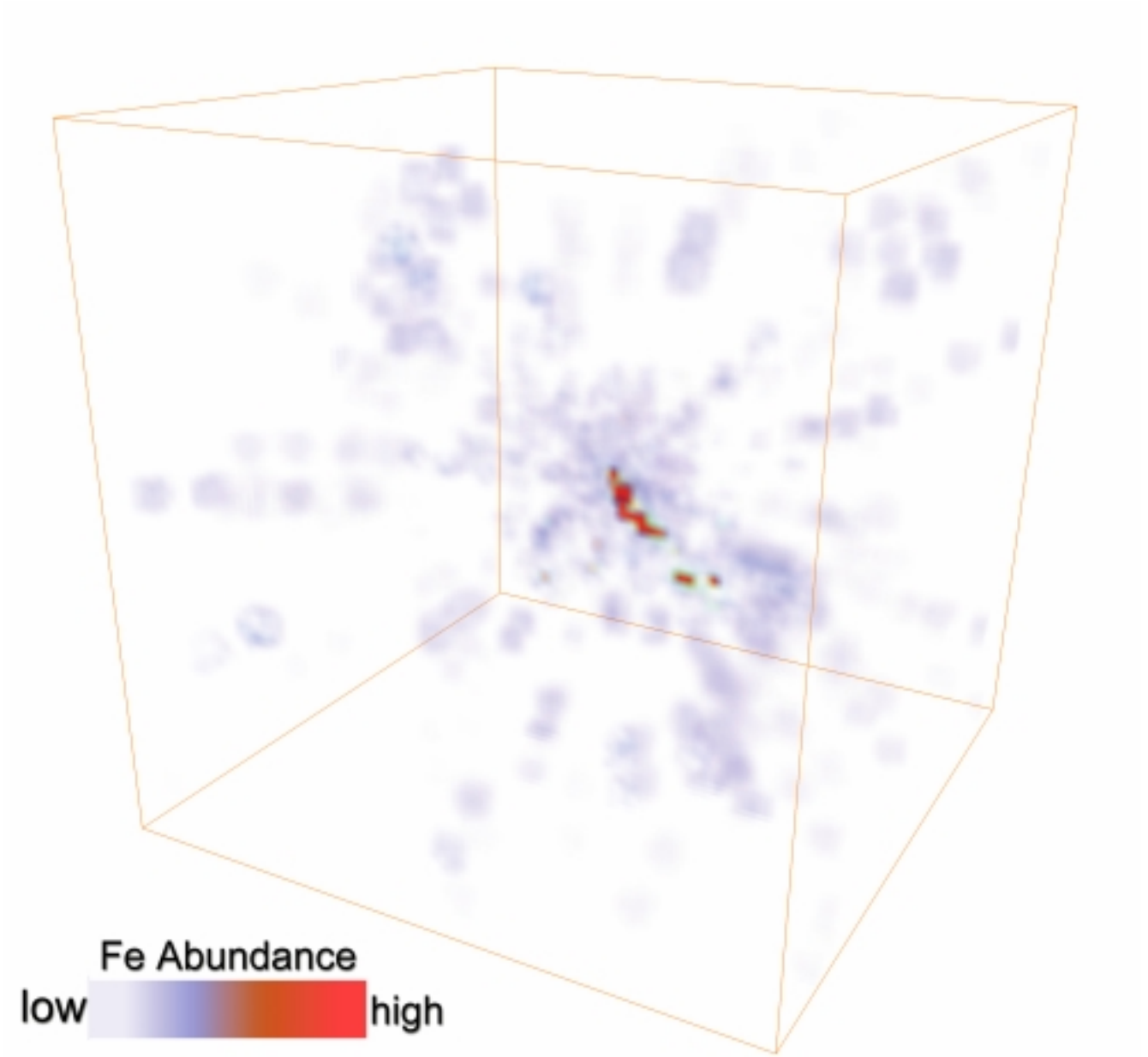
- Hydrodynamic simulations
- N-body simulations
- + Inclusion of all enrichment processes

Innsbruck, Edinburgh, Potsdam

(test runs)

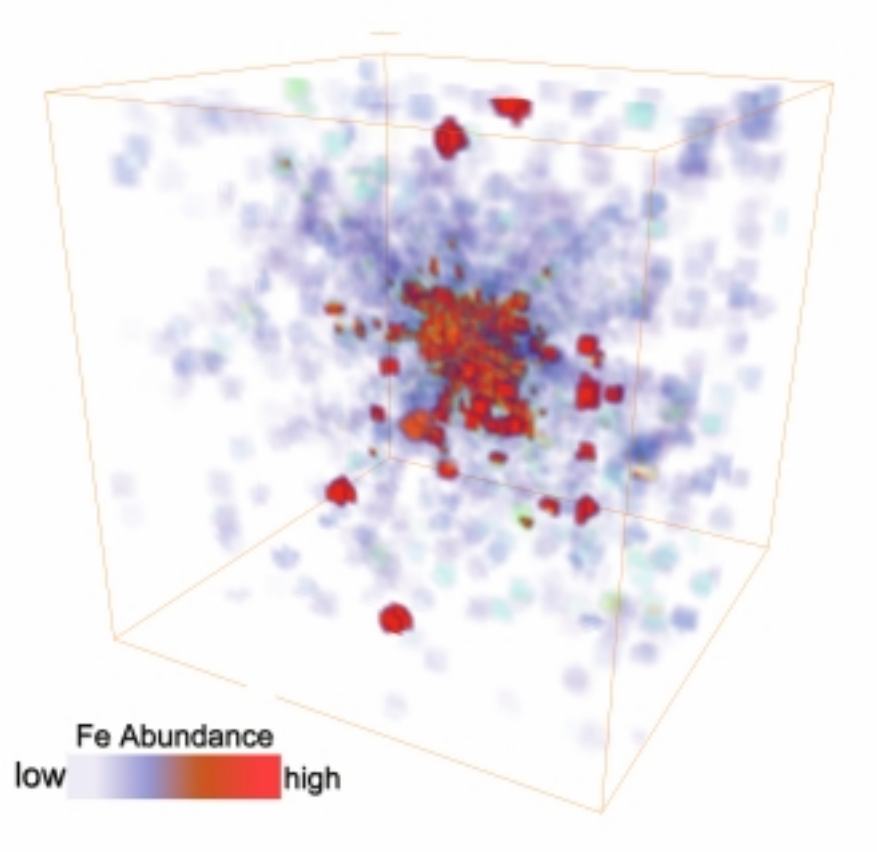
Metallicity Distribution

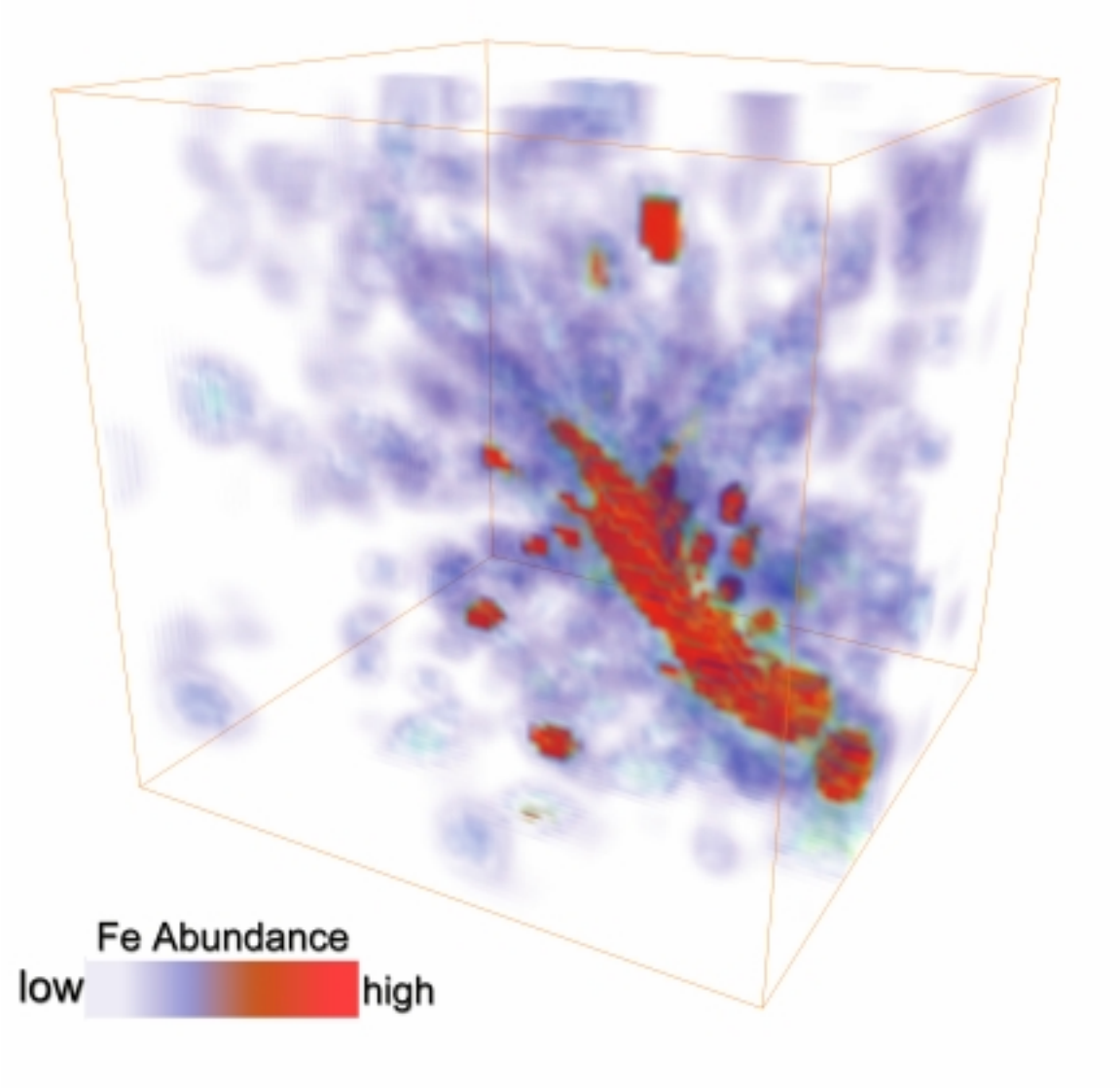




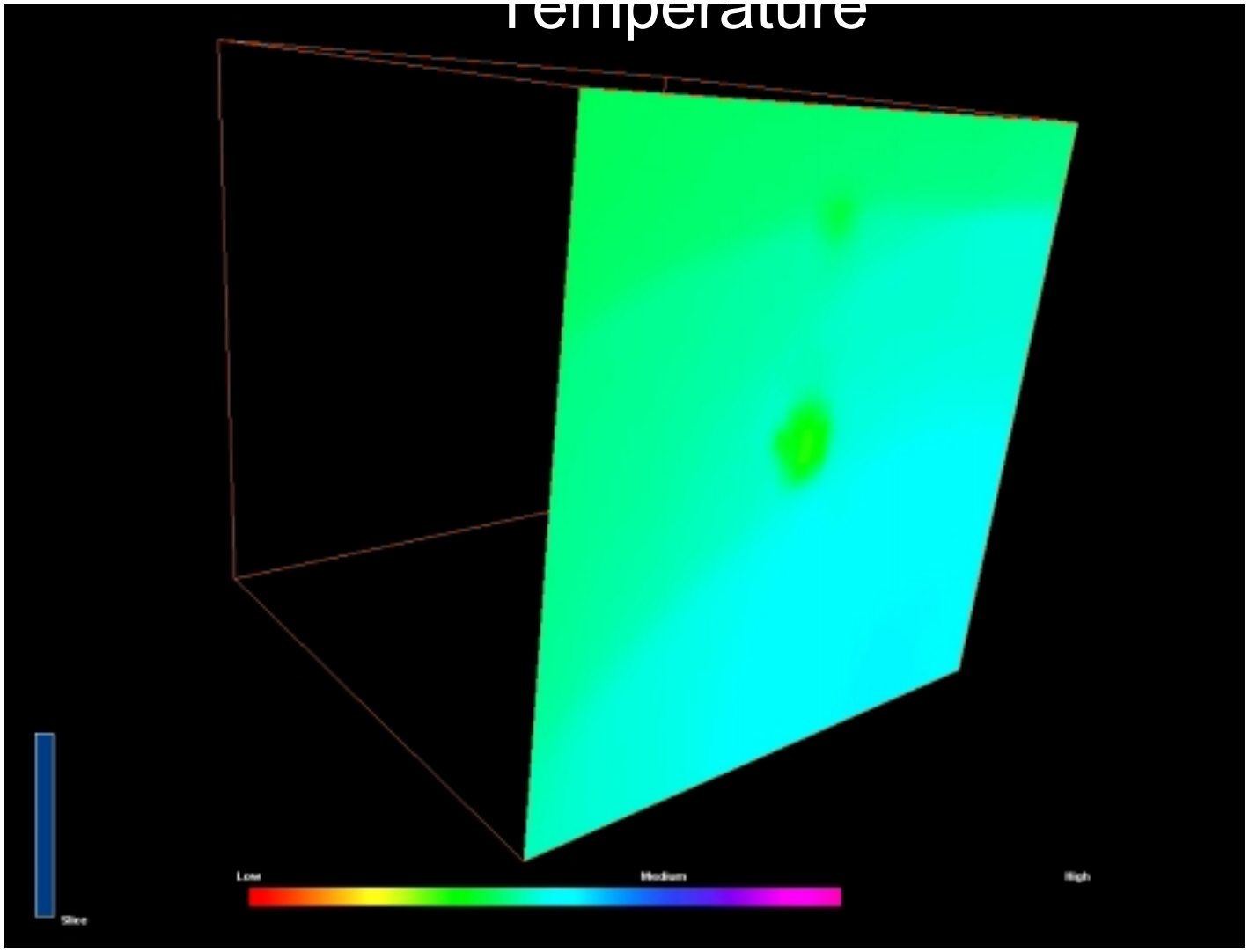
Movies are available at http://astro.uibk.ac.at/astroneu/hydroskiteam/index.htm

Metallicity Distribution (zoom)

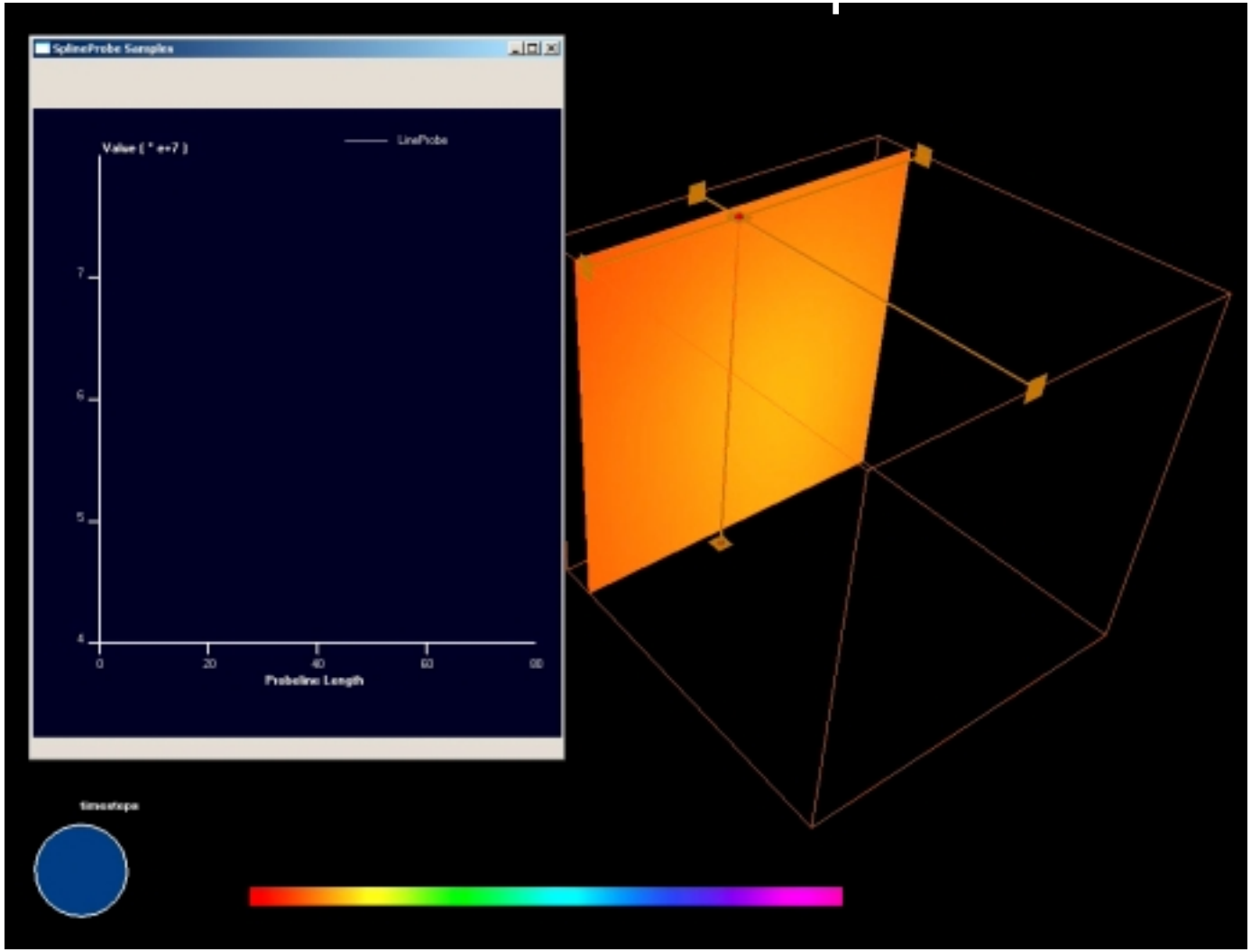




Movies are available at http://astro.uibk.ac.at/astroneu/hydroskiteam/index.htm



Movies are available at http://astro.uibk.ac.at/astroneu/hydroskiteam/index.htm



Movies are available at http://astro.uibk.ac.at/astroneu/hydroskiteam/index.htm

Summary of Interaction Processes

Interaction of ISM/ICM not very clear yet

- Many possible processes
- Enrichment efficiency of the processes and time variation not clear yet
- Controversial results of simulations

We are just at the beginning !!!

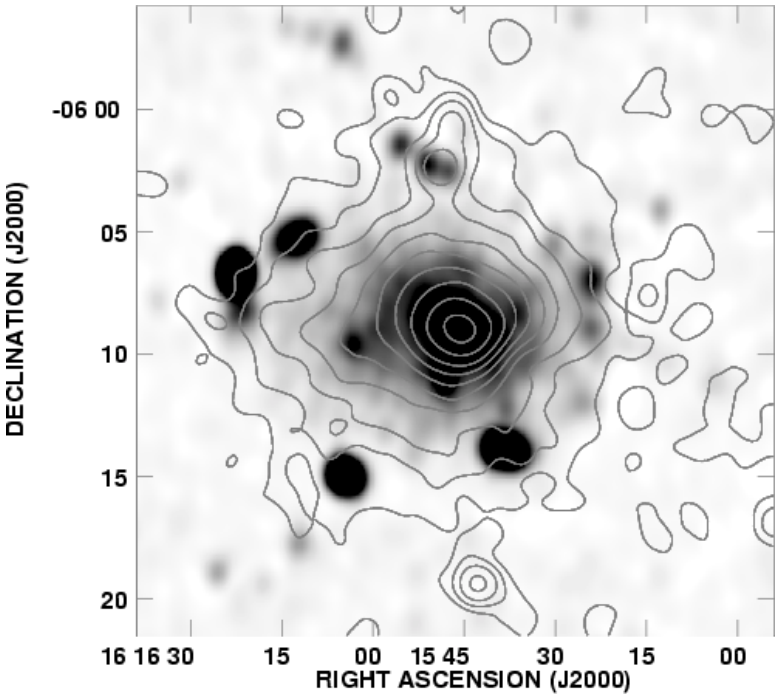
Magnetic fields in clusters

- Radio emission has been found in many galaxies clusters

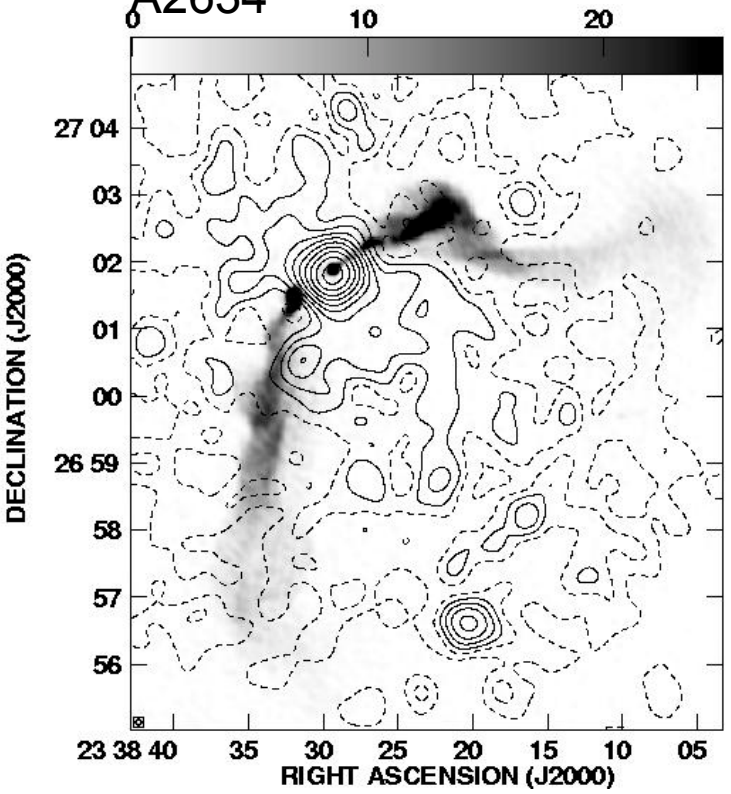
Diffuse emission
(Radio haloes, relics)

Emission associated with galaxies

A2163 Feretti et al. 2001



A2634



How can we measure magnetic fields ?

Radio galaxies produce polarised radiation

Plane of polarisation is rotated during passage through magnetised plasma (= birefringent medium)

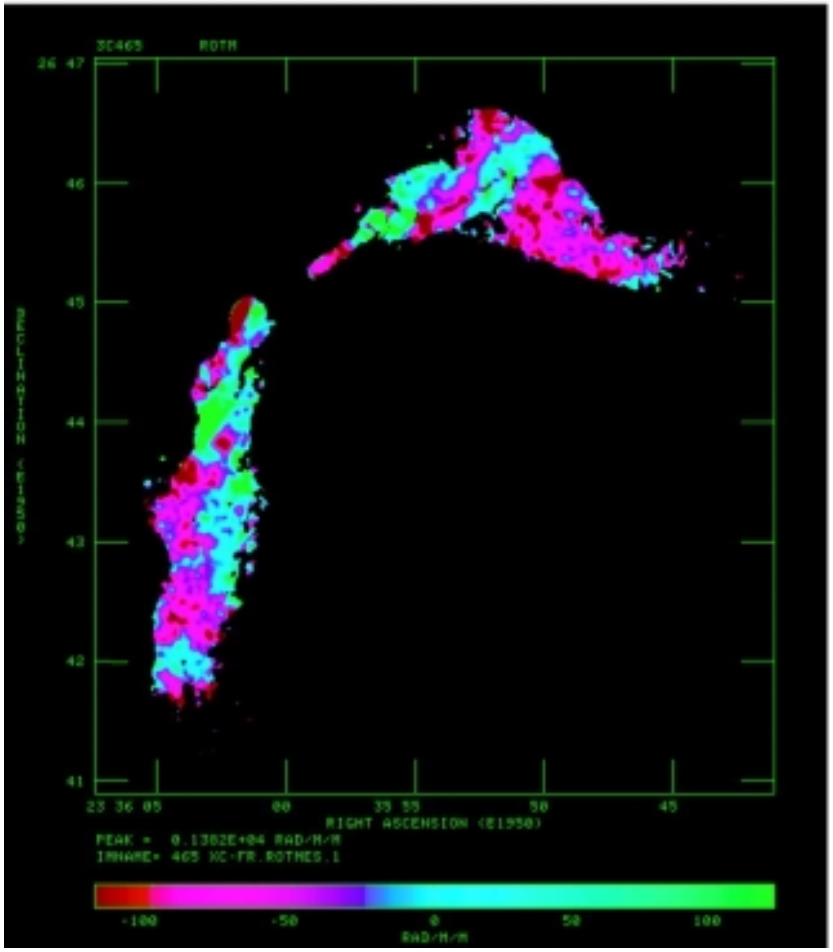
$$\Phi = RM \ \lambda^2$$

angle — rotation measure — wavelength

$$RM \propto \int \rho_e \ B_{II} \ dl$$

rotation measure — electron density — magnetic field — path length

Rotation Measure



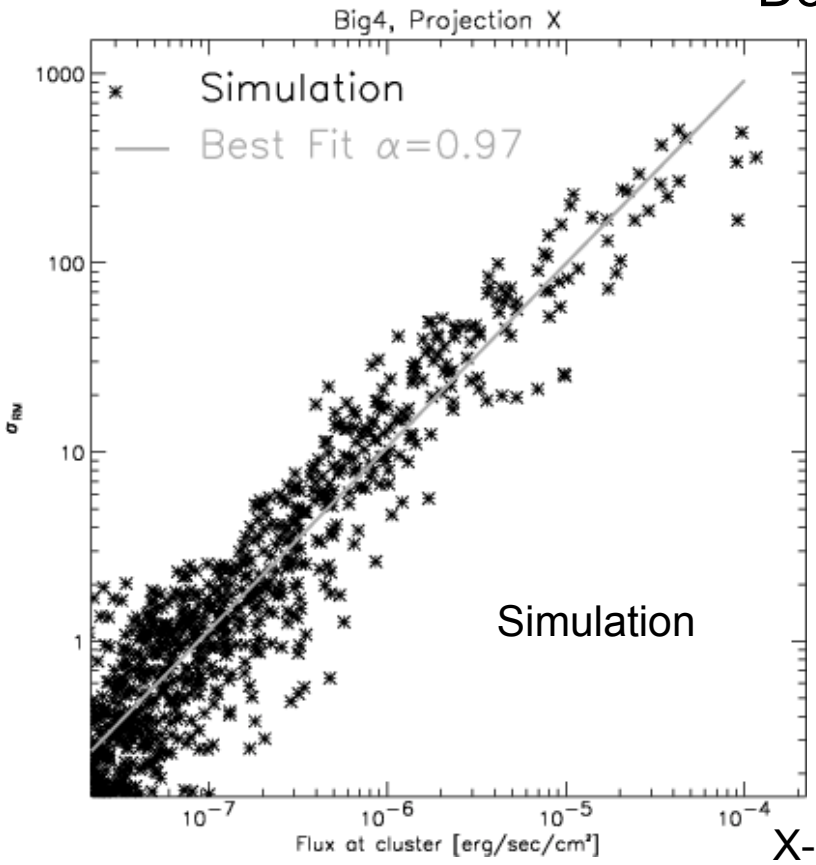
Eilek & Owen 2002 A2634

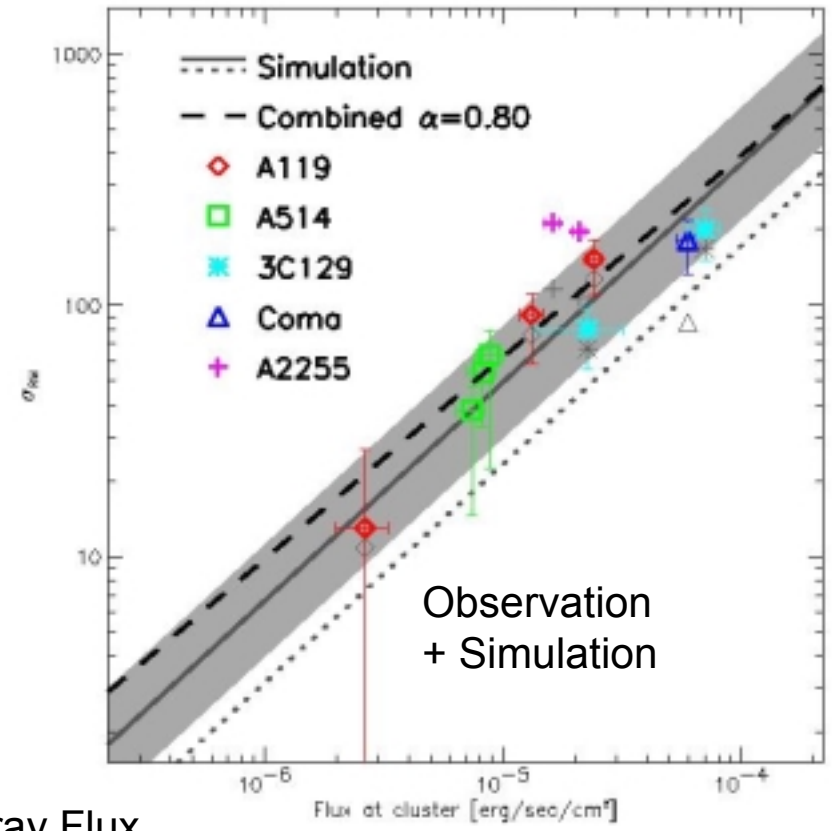
Observations of the RM of sources in or behind a cluster determine

- strength of the magnetic field (few μG)
- distribution of the magnetic field

Dolag, Schindler, Govoni, Feretti et al. ´01

Rotation Measure





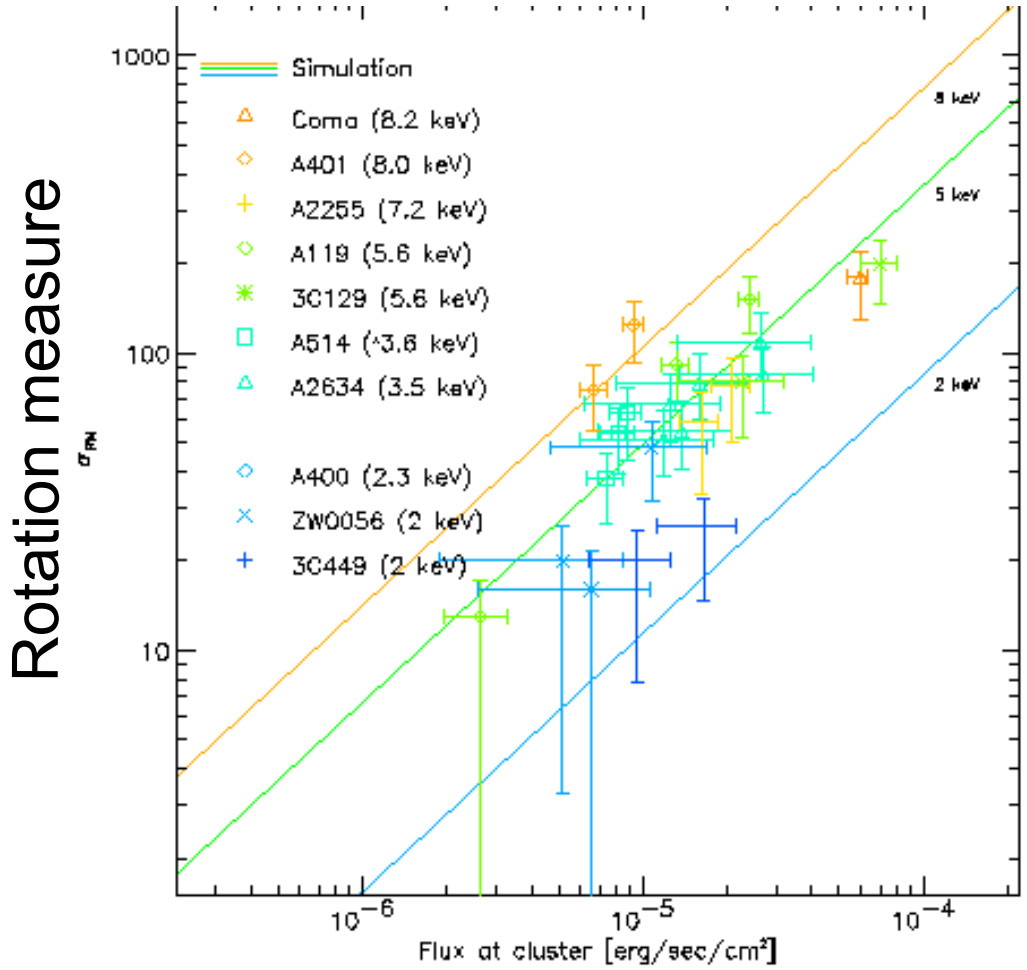
X-ray Flux

Magnetic field is not constant

Rotation Measure ~ X-ray flux

Magnetic field ~ gas density$^{0.9}$

Clusters with different temperature



Next step: determination of dependence on temperature

Radio haloes and relics

Why do not all clusters have radio haloes/relics?

- Only 16 clusters with radios haloes of 1Mpc
- Of the most luminous clusters on ~30% have radio haloes

- ➢ Combination of large size and short lifetimes
- ➢ Correlation between radio halo power and X-ray luminosity
- ➢ Only clusters with merger features have radio haloes

Radio haloes and relics

→ Conclusion:

- radio haloes/relics are linked to major mergers
- particles are (re-)accelerated to relativistic energies in shock waves emerging from mergers

Cooling Flows ?

Standard model:

- gas cools preferably in the centre because X-ray emission ~ density^2
- decrease of pressure in the centre
- gas flows into the centre from outer regions
- even higher density in the centre
- even more X-ray emission in the centre

cooling catastrophe

Cooling Flows ?

- Gas of different temperature should be present (multiphase)

- but: high resolution spectroscopy with XMM showed no signs of gas with temperatures below 1 keV

Summary

- Insight into physical processes (cooling, heating, interaction, magnetic field, particle acceleration,...)
- Clusters of galaxies are very versatile and powerful diagnostic tools for cosmology

Summary

Combination of -

- different methods
- different wavelength
- new generation of telescopes (XMM, CHANDRA, VLT...)
- numerical simulations

→ High-precision cosmology