Feedback From Supermassive Black Holes: A Missing Piece in Galaxy Evolution

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Yale Computational Cosmology Seminar Series

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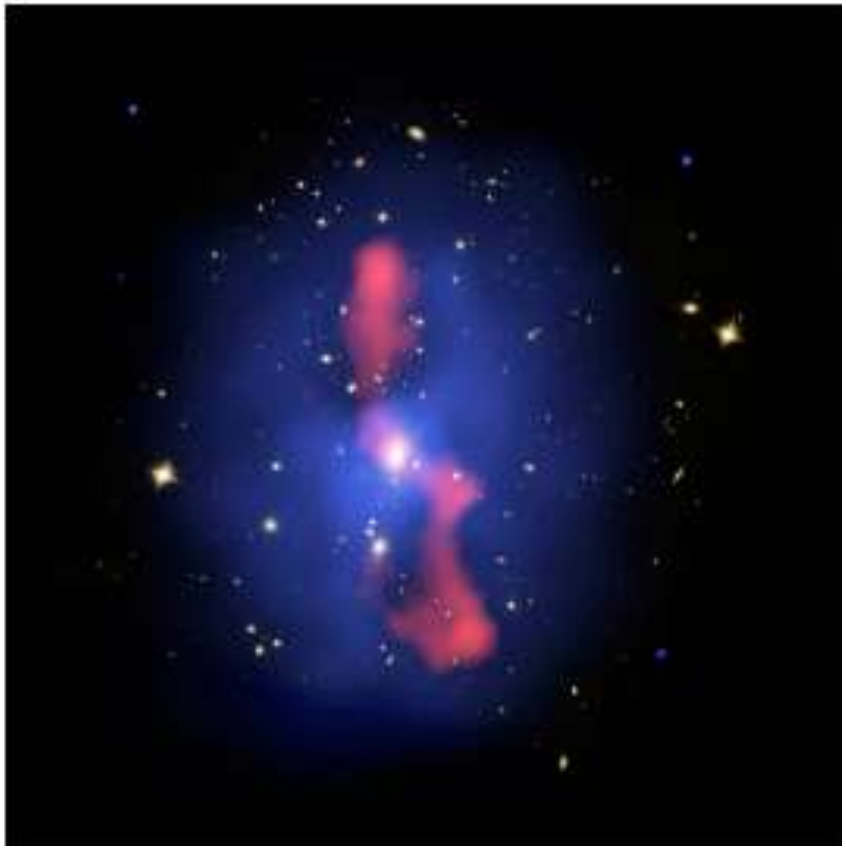
Outline of the Talk

- Active Galactic Nuclei (AGN)
- Feedback from AGN
- Cosmological Impact of AGN Feedback
- Observational Probes of AGN Feedback

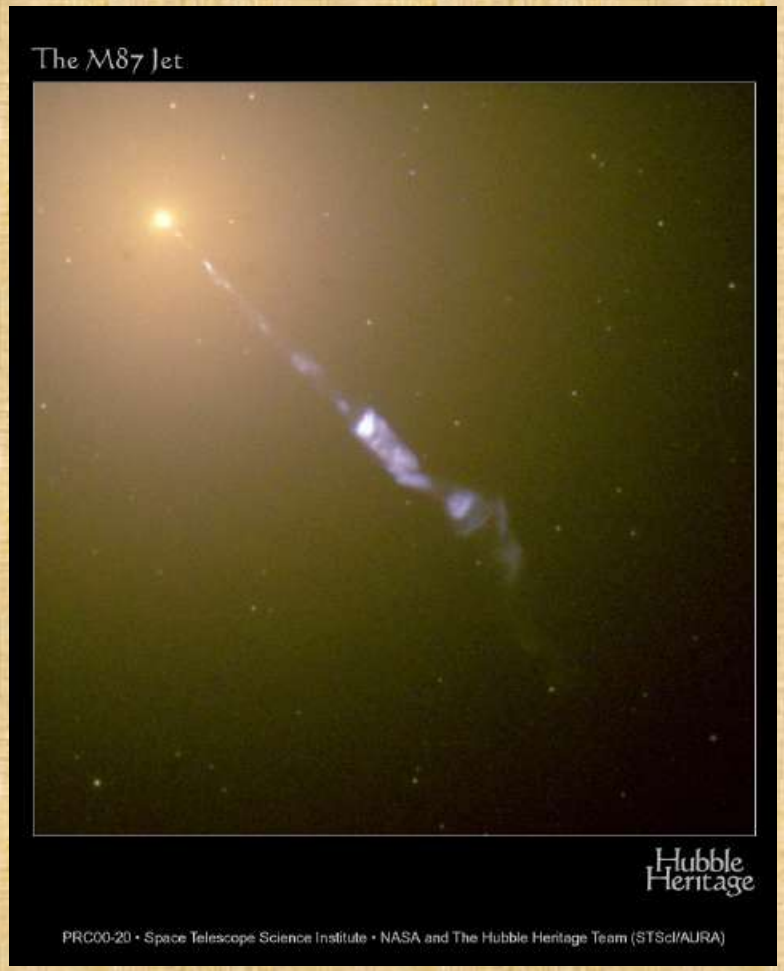
Black Hole Feedback in Galaxy Cluster



HST image of MS0735.6 + 7421 cluster
Chandra X-ray image in blue
VLA radio image in red

McNamara & Nulsen 2007

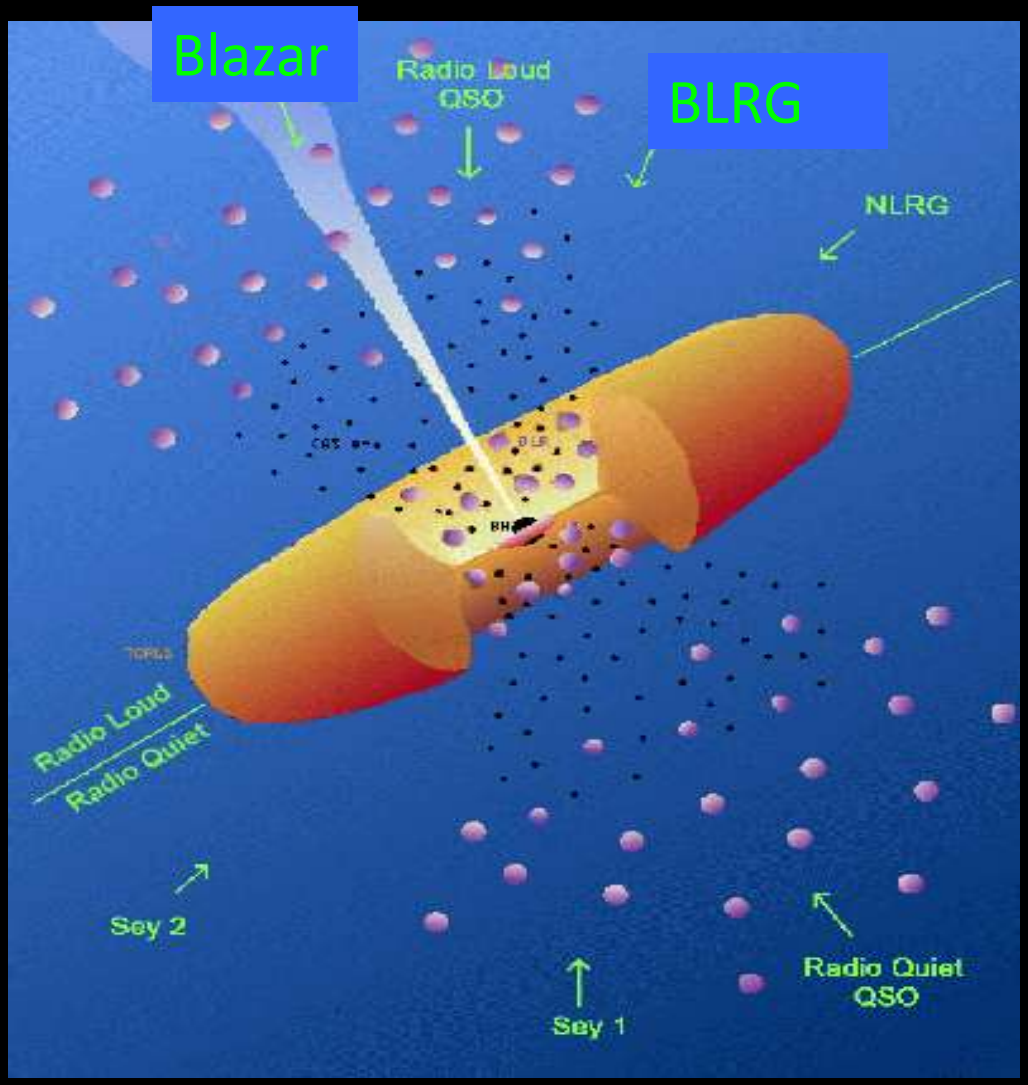
Definition



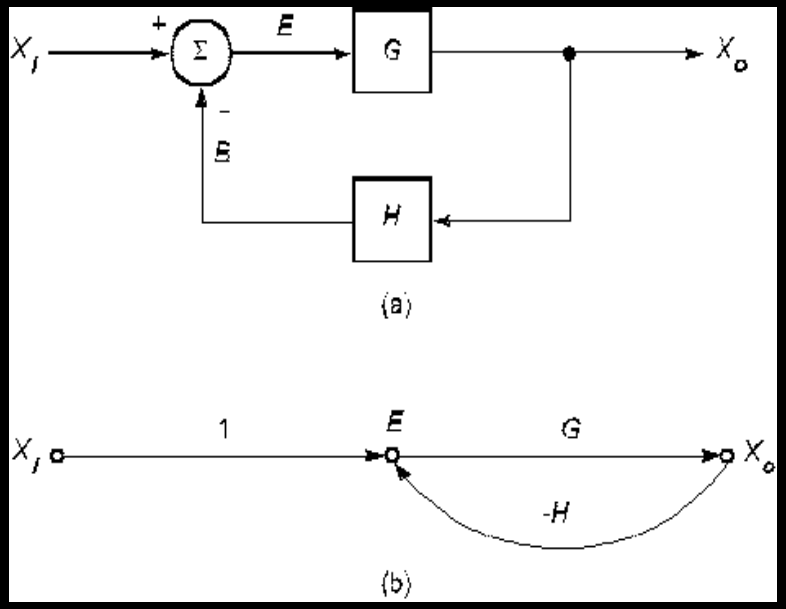
"An active galactic nucleus (AGN) is a compact region at the centre of a galaxy which has a much higher than normal luminosity over some or all of the electromagnetic spectrum. The radiation from AGN is believed to be a result of accretion on to a super-massive black hole at the centre of the host galaxy."

-Wikipedia

AGN : Unified Picture



Courtesy:
C.M. Urry & P. Padovani



- Σ => Input Voltage
- H acts as a feedback loop
- A part of the output is fed into the input

FEEDBACK LOOP

Gas particles fed into the system

Black Hole AGN system

Outflows from the AGN

Through materials (Mechanical) and energy (thermal) outflow impacts it environments

Redistributes the gas particles

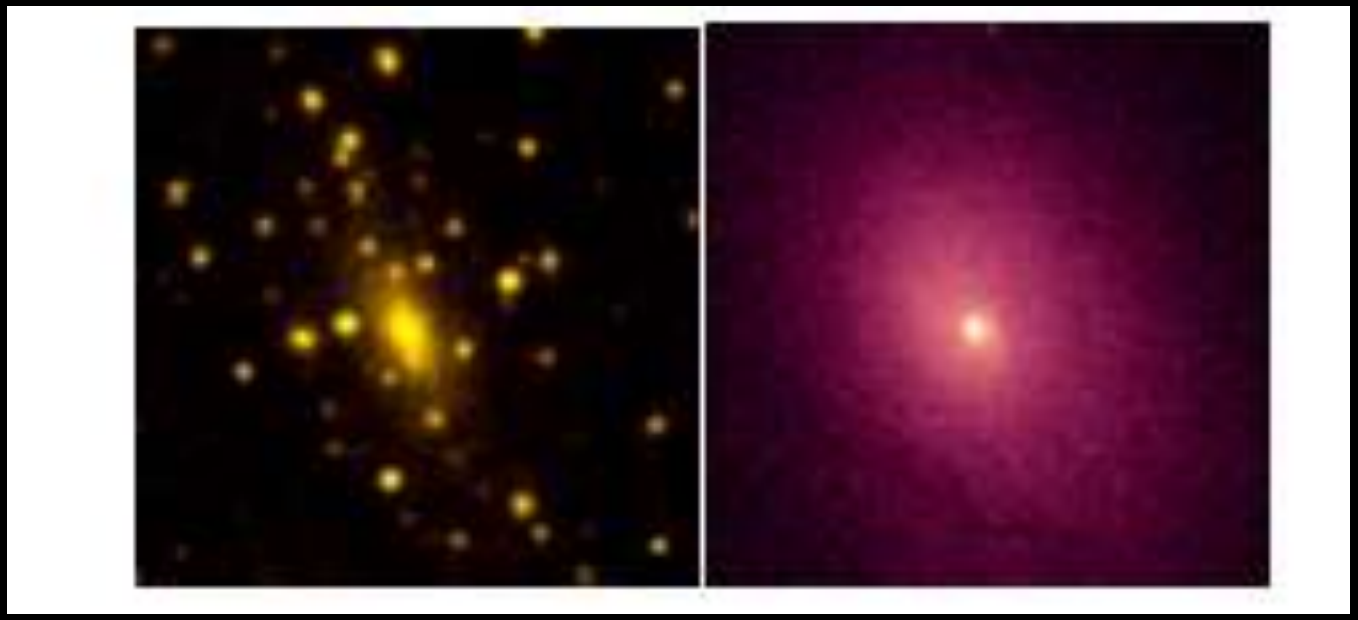
Accretes particles from its environment

Cosmological Impact of AGN Feedback

(see Daisuke Nagai's talk)

Galaxy Cluster Facts

- Cluster Temperature: **1-10 kev (10^7-10^8K)**
- Electron density: **10^{-2}-10^{-4}/cm^3**
- Mass : **$10^{14}M_{sun}$-$10^{15}M$**
- X-ray Luminosity : **10^{43} ergs/s-10^{46} ergs/s**
- Virial Radius : ~ **1Mpc**



Peterson & Fabian 2006

Cluster Scaling Relations

$$L_X \sim n_e^2 T^{1/2} R_v^3$$

- X-ray emission in clusters : Thermal Bremsstrahlung mainly
- Bremsstrahlung : radiation from the acceleration of a charged particle (see Rybicki & Lightman)

- Gas in clusters are heated: Gravitational infall into the cluster potential well

$$\frac{GM}{R_v} \sim T$$

$$R_v^2 \sim T$$

Virial Theorem

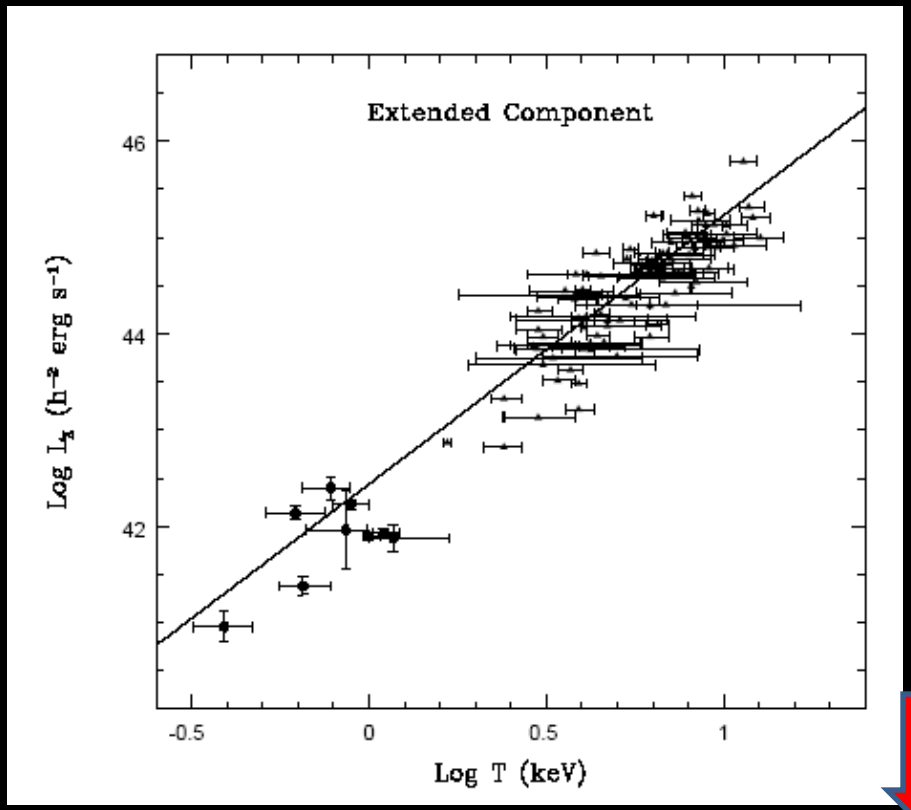
Self Similar (Gravity only) model predicts

$$L_X \sim T^2$$

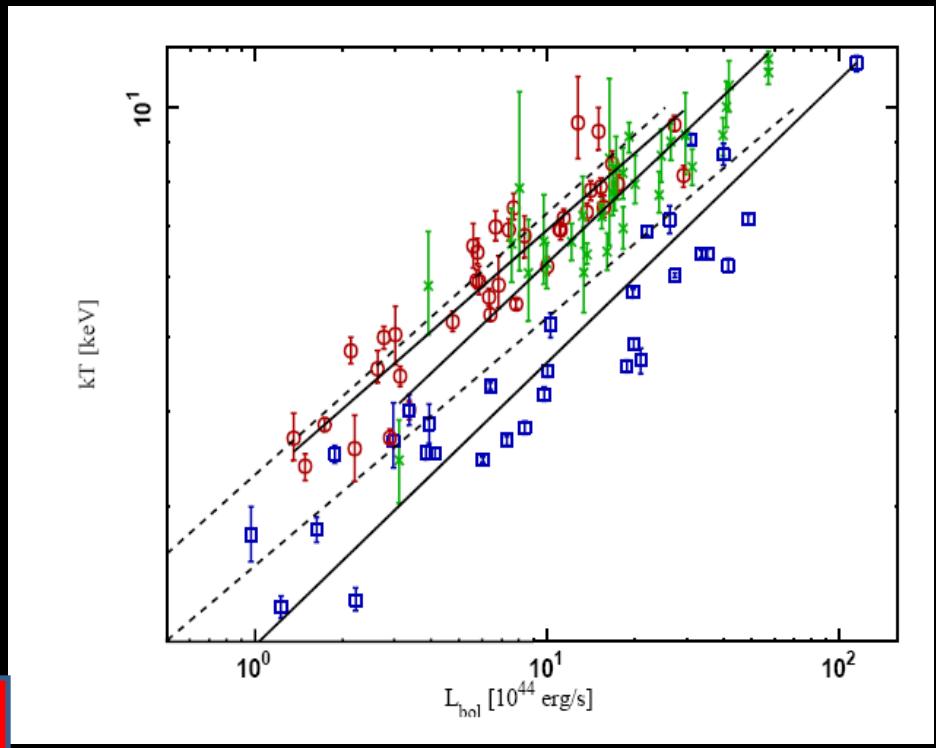
See Laurie Shaw's talk

Lx-T Relation in Clusters

Mulchaey & Zabludoff 98



Andersson et al. 2009



$$LogL_X = (42.44 \pm 0.11) + Logh^{-2} + (2.79 \pm 0.14) LogT$$

- **But observations show $L_x \sim T^3$**
- **Hallmarks of non-gravitational heating**

(Peterson & Fabian 2006)

The Cooling Flow Problem

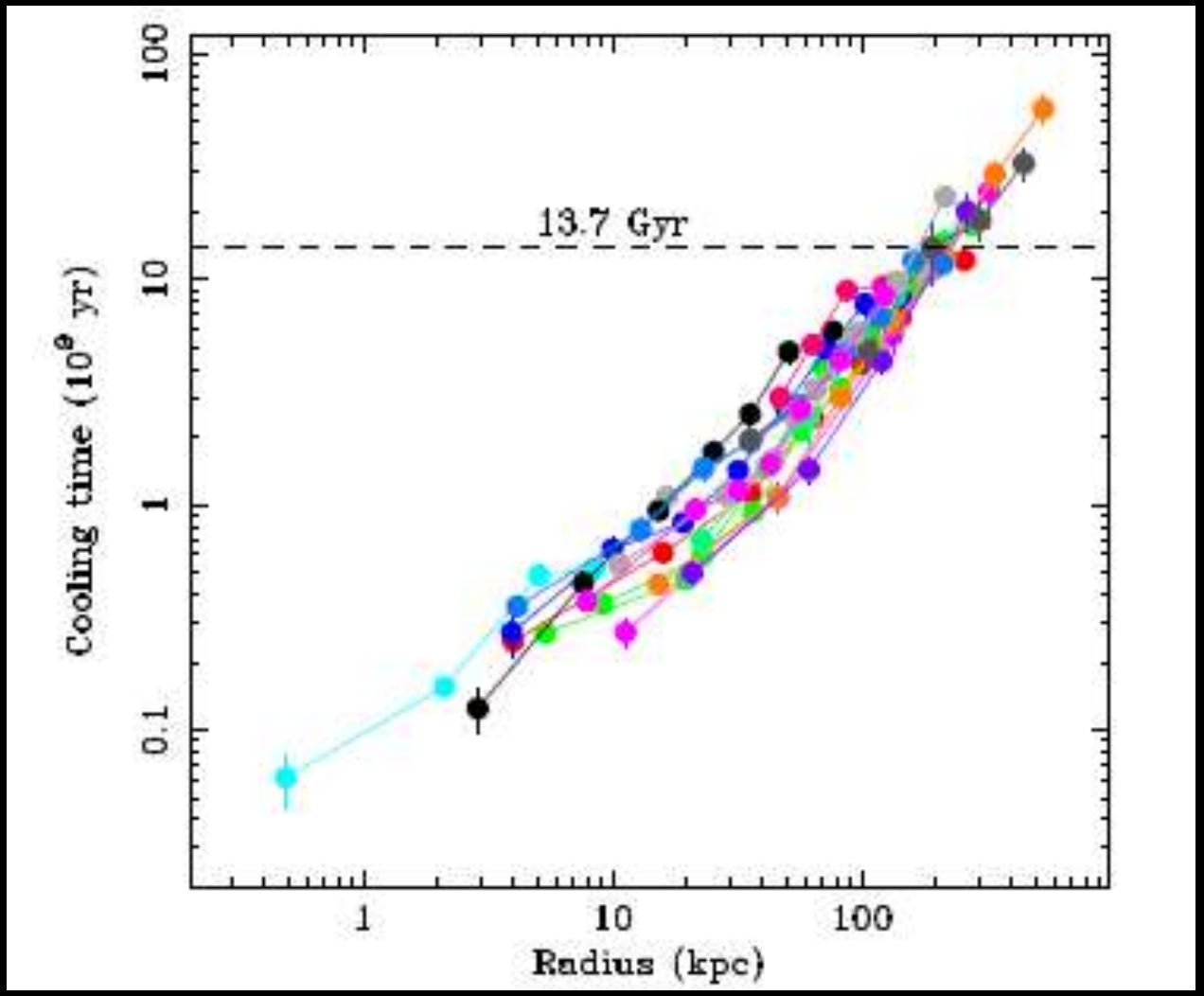
See Peterson & Fabian 2006 for a review

Refer to Daisuke Nagai's talk

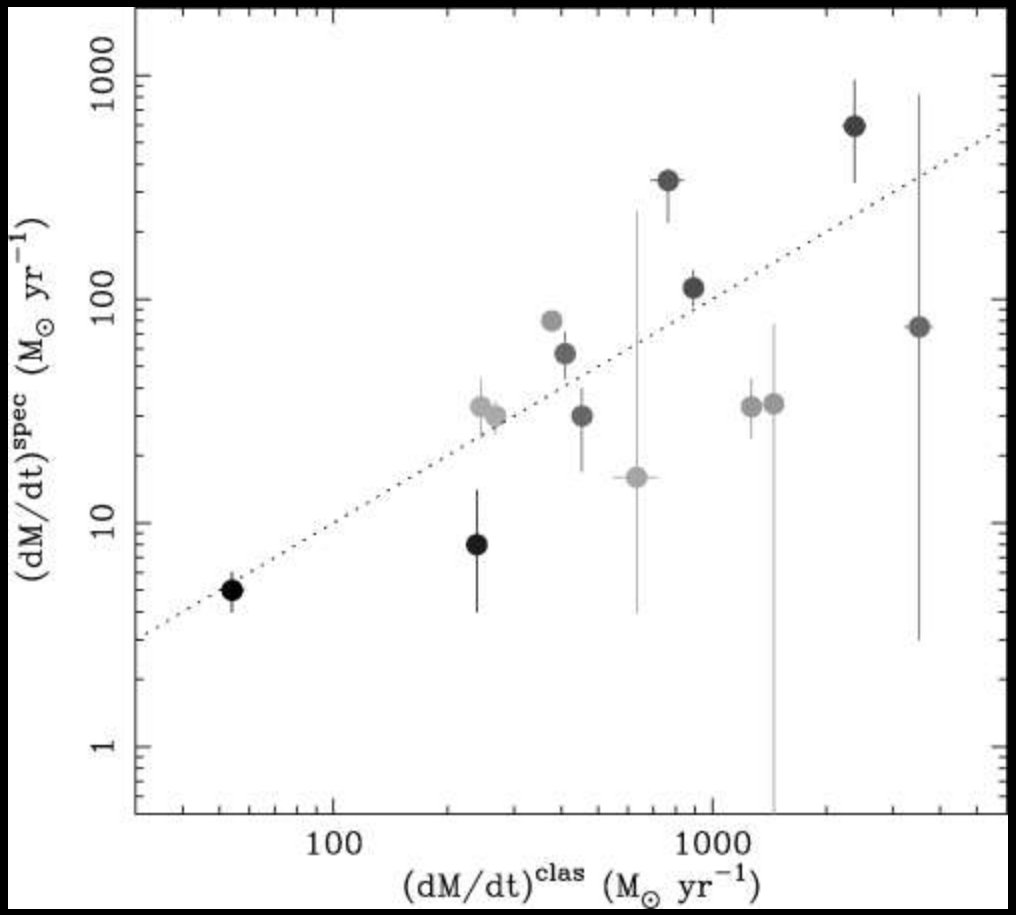
- X-ray surface brightness peaks at cluster centers (since the density of gas at the center of the cluster is maximum)
- Gas undergoes radiative cooling
- The cooling time (t_{cool}) ~ E/(dE/dt) ; E is the energy of the gas

$$t_{cool} \propto \frac{T^{\alpha}}{n_e}$$

- Cooling is maximum at cluster centers
- Cooling of gas creates a pressure gradient
- A mass inflow is expected toward the cluster center



Voigt & Fabian 2004



Voigt & Fabian 2004

- From Classical cooling models the calculated mass deposition rates are hundreds of Solar Masses per year
- With X-ray spectroscopy the mass deposition rate was observed to be Tens of M_{sun}/yr.
- Lack of expected cooling flow

Something compensates the cooling at the cluster center

Cosmic Downsizing

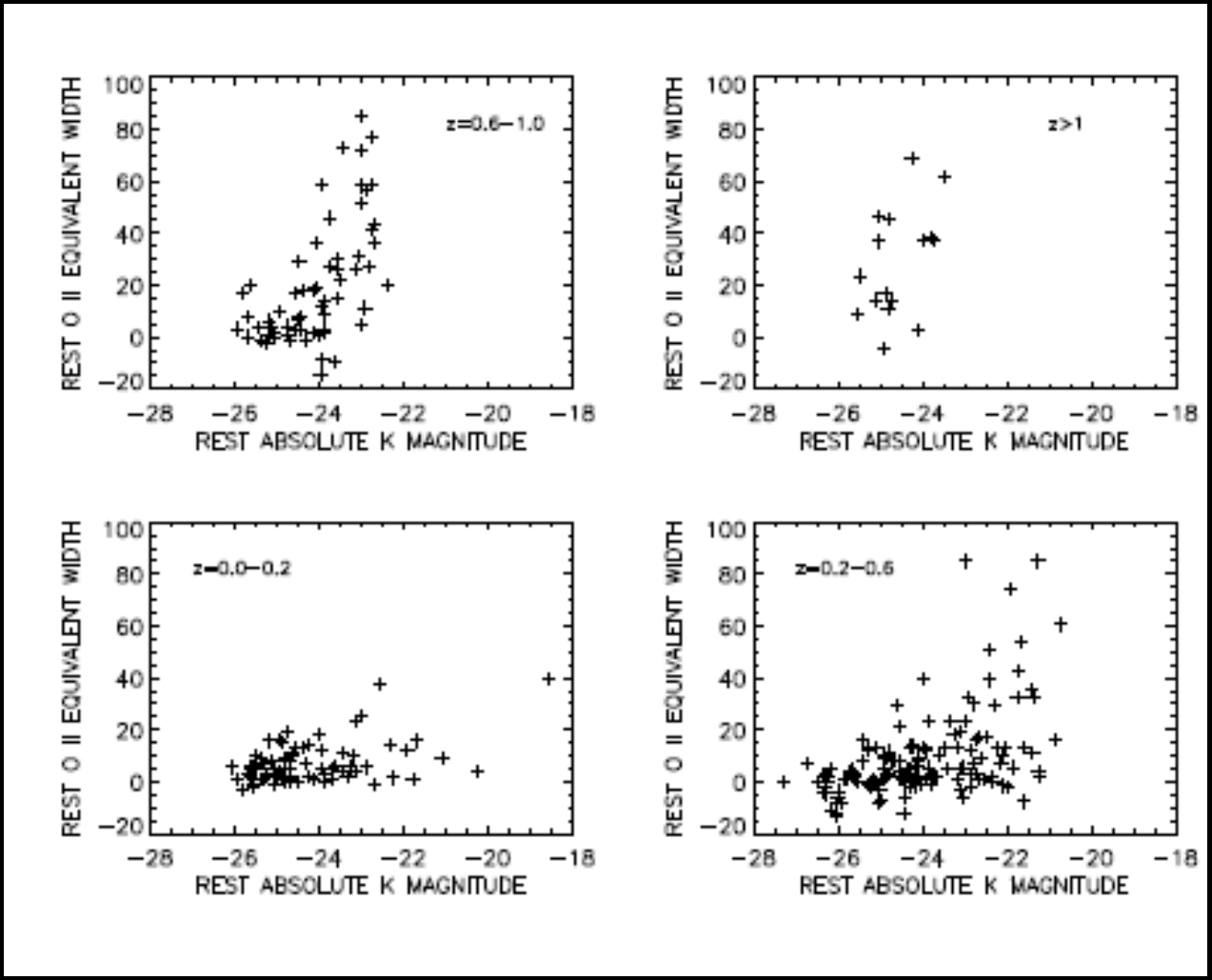
- **Structures form hierarchically in CDM**

⇒Larger structures form by accretion and merging of smaller structures

- **Baryons fall into the dark matter potential and undergoes radiative cooling**
- **Larger the structure; longer it takes gas to cool**

⇒Galaxy formation is even more hierarchical

- **Observations show that at redshift 2.0 star formation is shut down in massive galaxies but the smaller ones are still forming stars**
- **Anti-hierarchical nature of galaxy formation : Cosmic downsizing** Cowie et al. 1996



Cowie et al. 1996

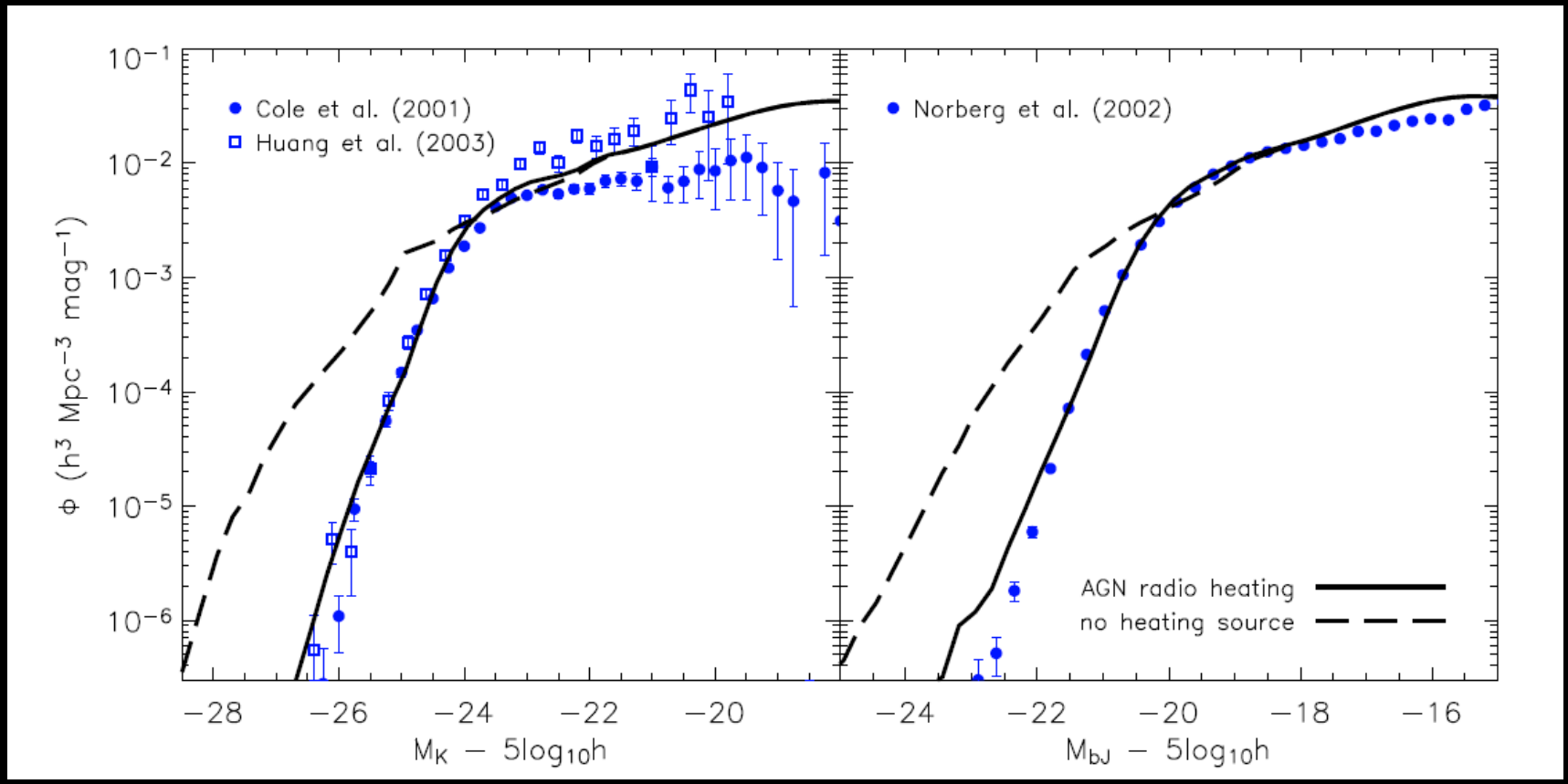
- Star-formation rate (O[II] equivalent width is plotted as a function of stellar mass of the galaxy.
- Massive galaxies are forming stars at higher redshift

Implication of downsizing of galaxy population

The Missing Piece (Feedback from AGN)

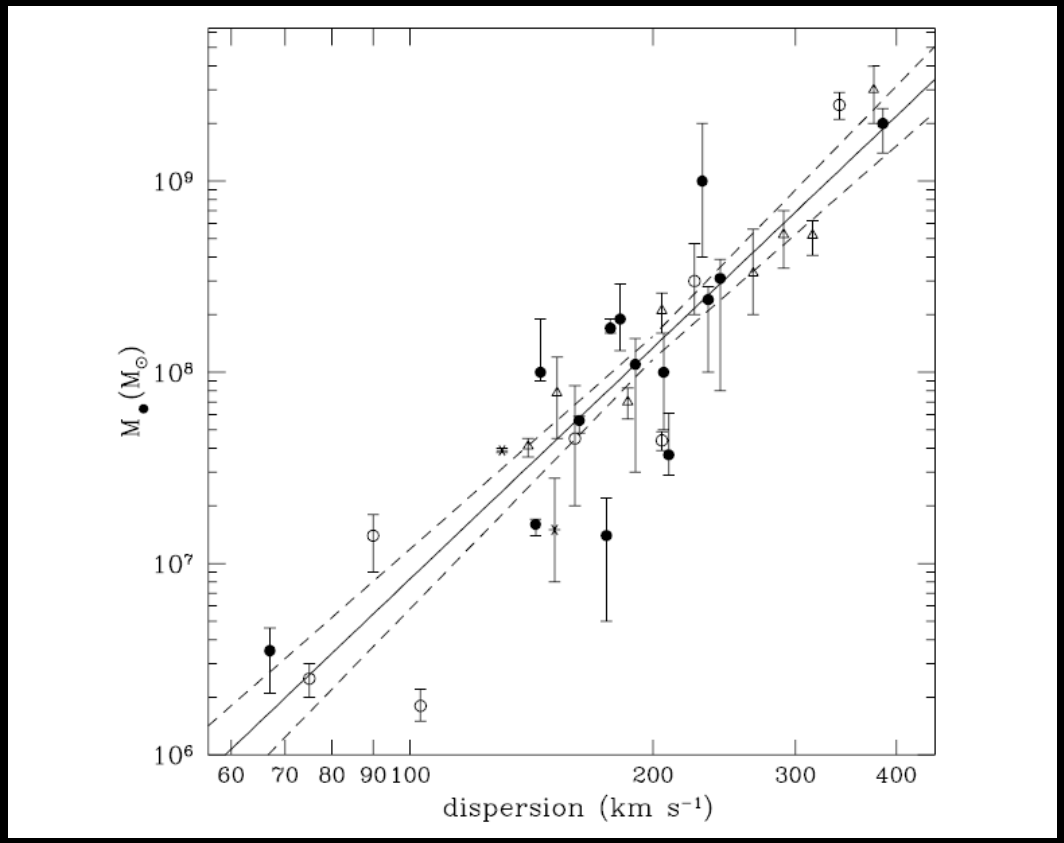
(e.g. Binney & Tabor 1995)

- **AGN feedback serves as non-Gravitational heating mechanism in clusters**
  - **Gas is blown out from the center of the cluster**
  - **Steepening the L_X-T relation**
- **Lack of cooling flow**
  - **AGN heating compensates the cooling or in other words decreases the cooling rate**
- **Cosmic Downsizing**
  - **Feedback from AGNs doesn't allow gas to cool**
  - **Shuts up star formation**
  - **AGN luminosity function peaks between redshifts 2 and 3**



Croton et al. 2006

Producing the observed galaxy luminosity function from numerical simulations



$$\log(M_\bullet/M_\odot) = \alpha + \beta \log(\sigma/\sigma_0)$$

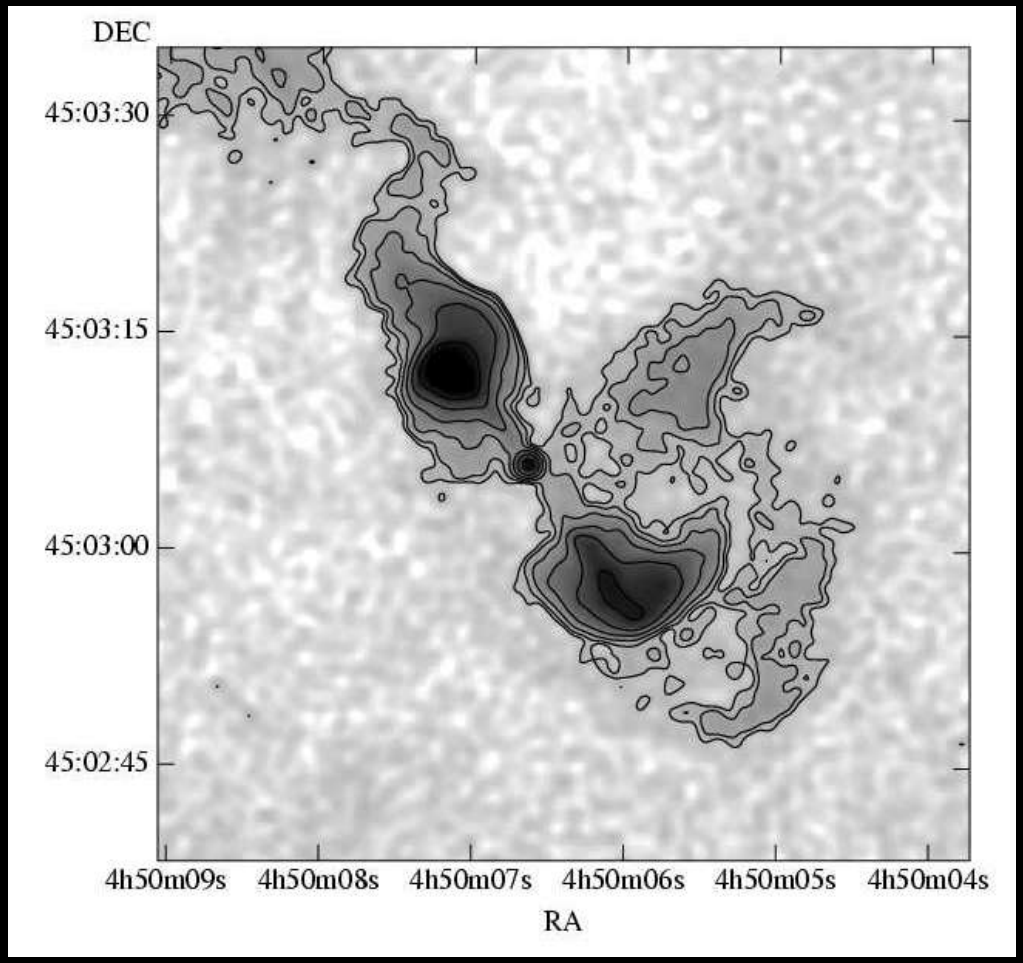
$\beta = 4.02 \pm 0.32$, $\alpha = 8.13 \pm 0.06$,

Tremaine et al. 2002

- Correlation between black-hole masses and dispersions for the galaxies.
- The dashed lines show the 1σ limits on the best-fit correlation

Observational Probes of AGN Feedback

Radio Observations



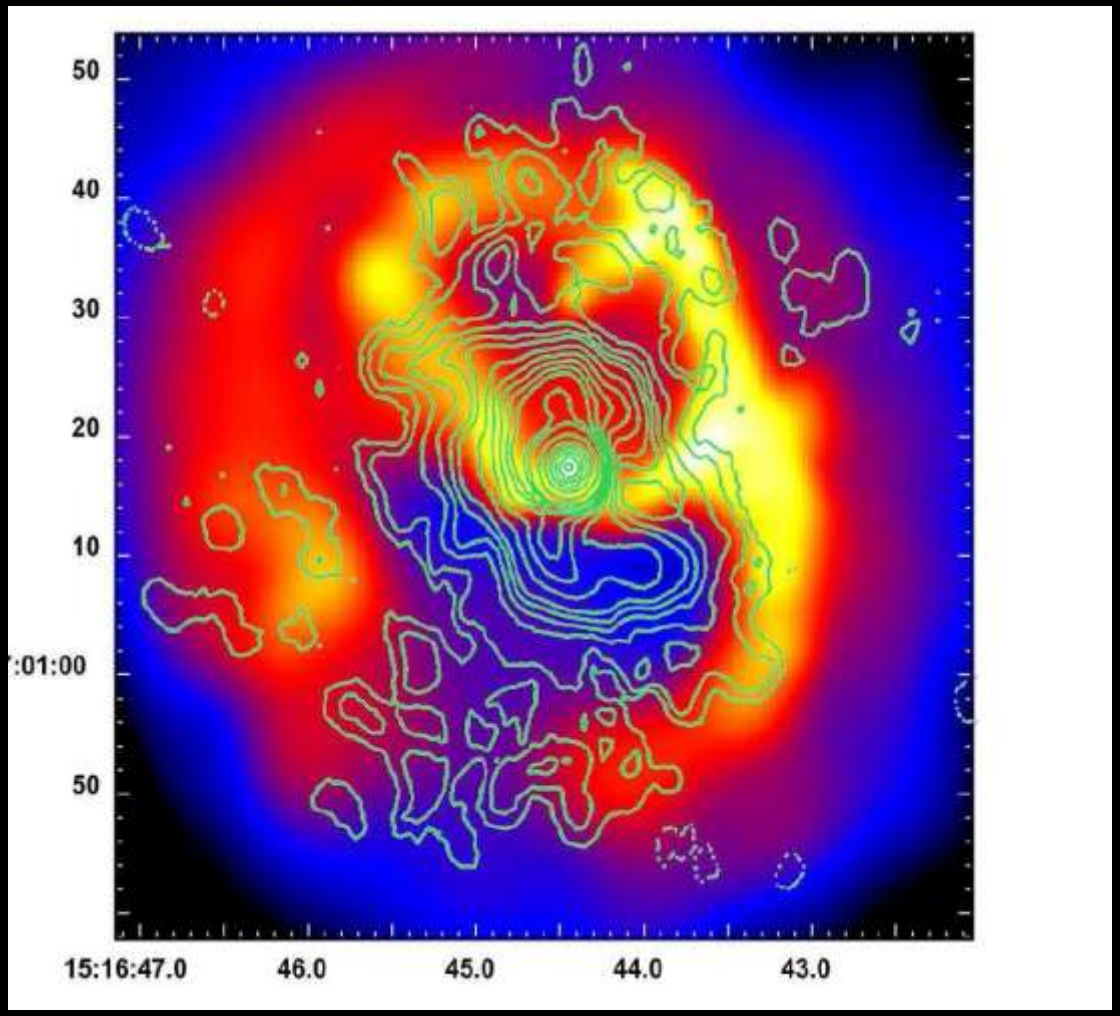
The 5GHz radio emission from 3C129.1 (Taylor et al. 2001)

Cluster	Bubble Radius (Kpc)
3 C129.1	0.60 ± 0.16
A496	5.50 ± 0.53
A1644	1.98 ± 0.34
A1651	1.40 ± 0.49

Dunn & Fabian 2006 analyzed 55 clusters by Correlating the X-ray and radio profiles of these clusters

X-ray Observations

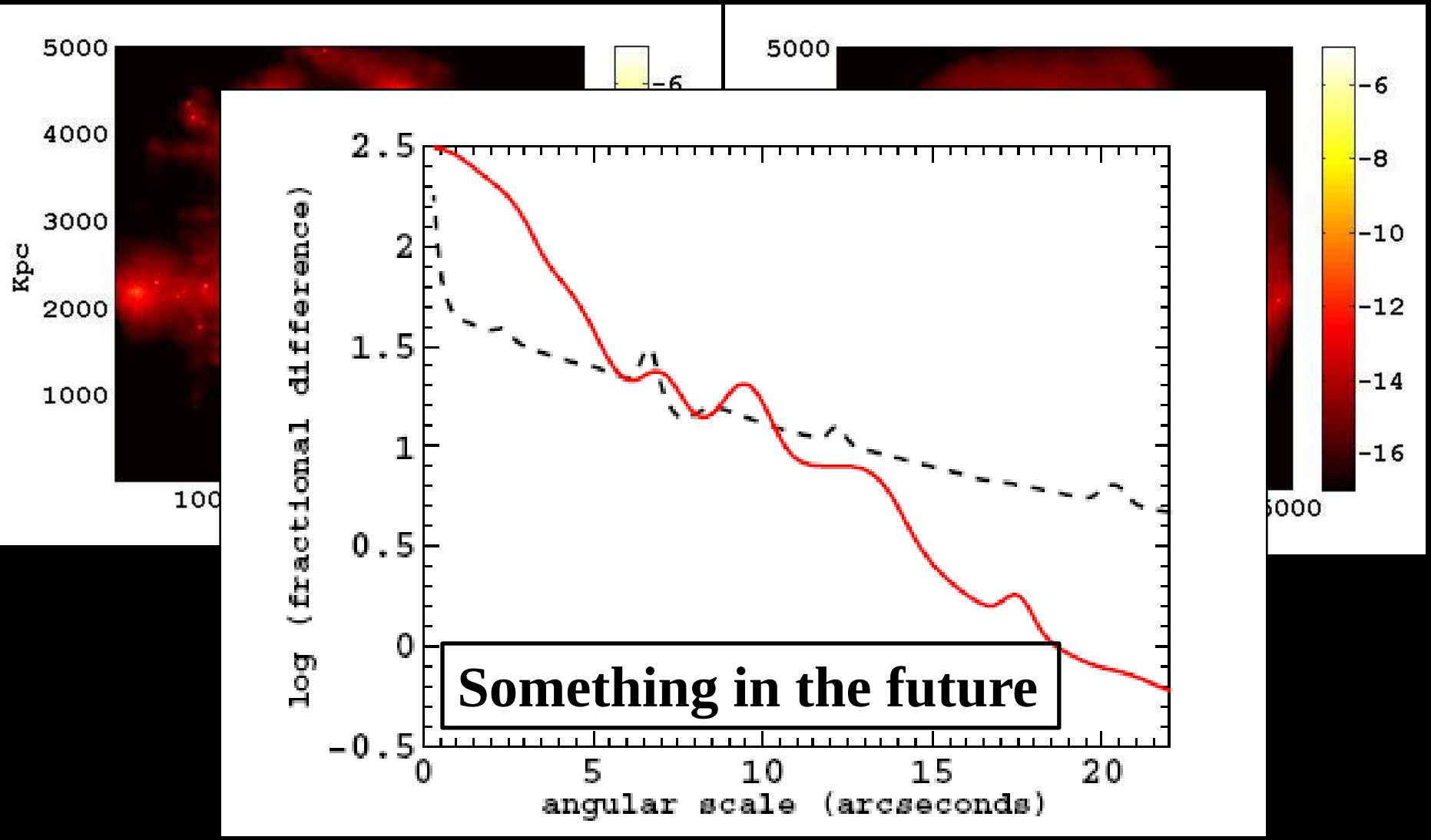
(see Kevin Schawinski's talk)



- Smoothed Chandra image of the central region of Abell 2052 with radio contours (Burns 1990) superposed.
- The radio source has swept out "holes" or "bubbles" in the X-ray emitting gas, creating bright shells of compressed X-ray gas surrounding the holes.

Blanton et al. 2003

Sunyaev-Zeldovich Observations



Chatterjee et al. 2008

THE END
THANK YOU

Feedback From Supermassive Black Holes: Theoretical Overview

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10/16/2009

Stay Tuned