AGN Feedback in Clusters

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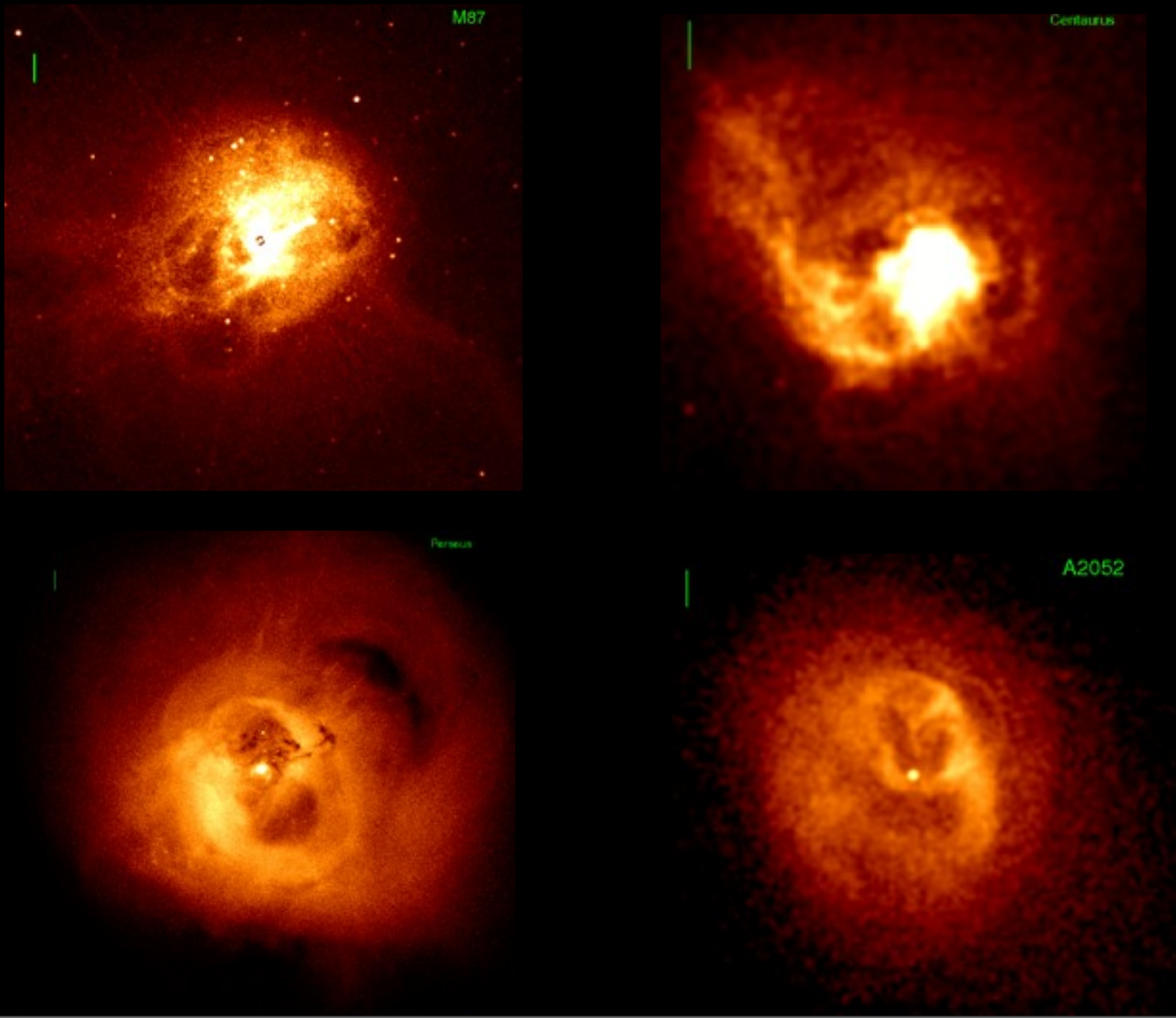
With much help from Jeremy Sanders

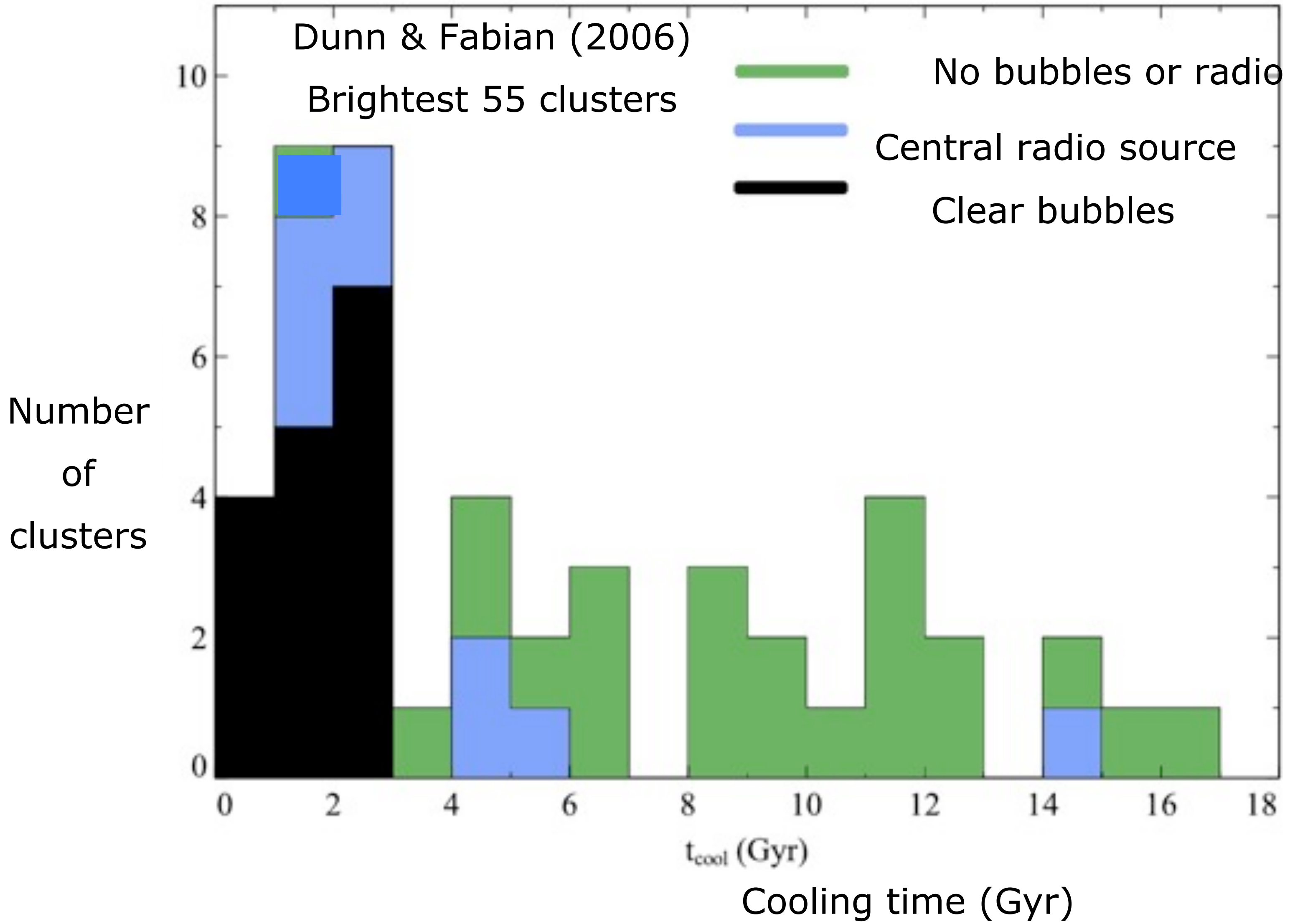
and others


M87
Centaurus
Perseus
A2052

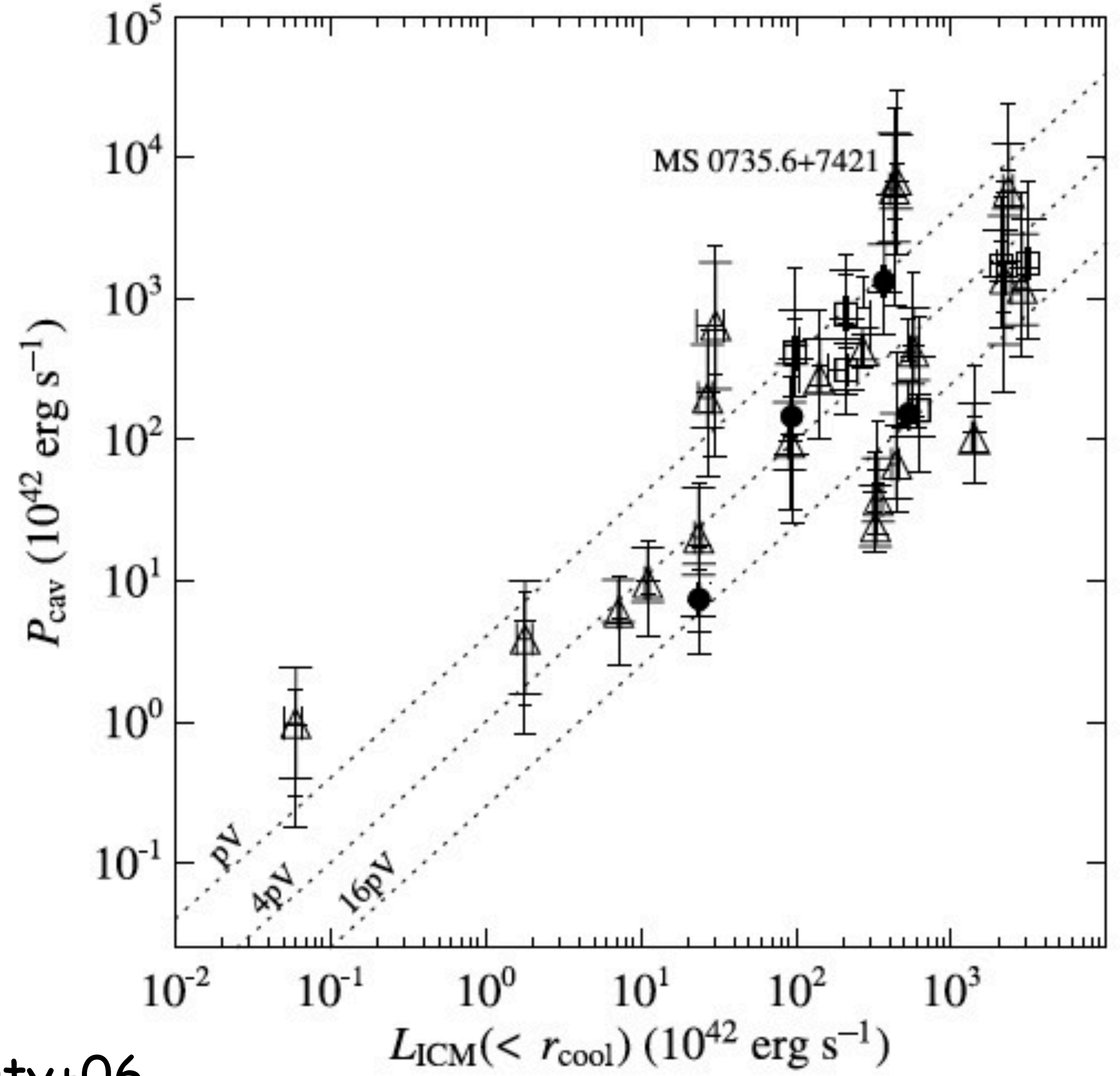
M84

Hydra A

Duty cycle is ~100%



See also Birzan+04, Rafferty+06+08, Dunn+F07



MS 0735.6+7421
pV
4pV
16pV
P_{cav} (10^{42} erg s^{-1})
L_{ICM}($< r_{cool}$) (10^{42} erg s^{-1})

Rafferty+06

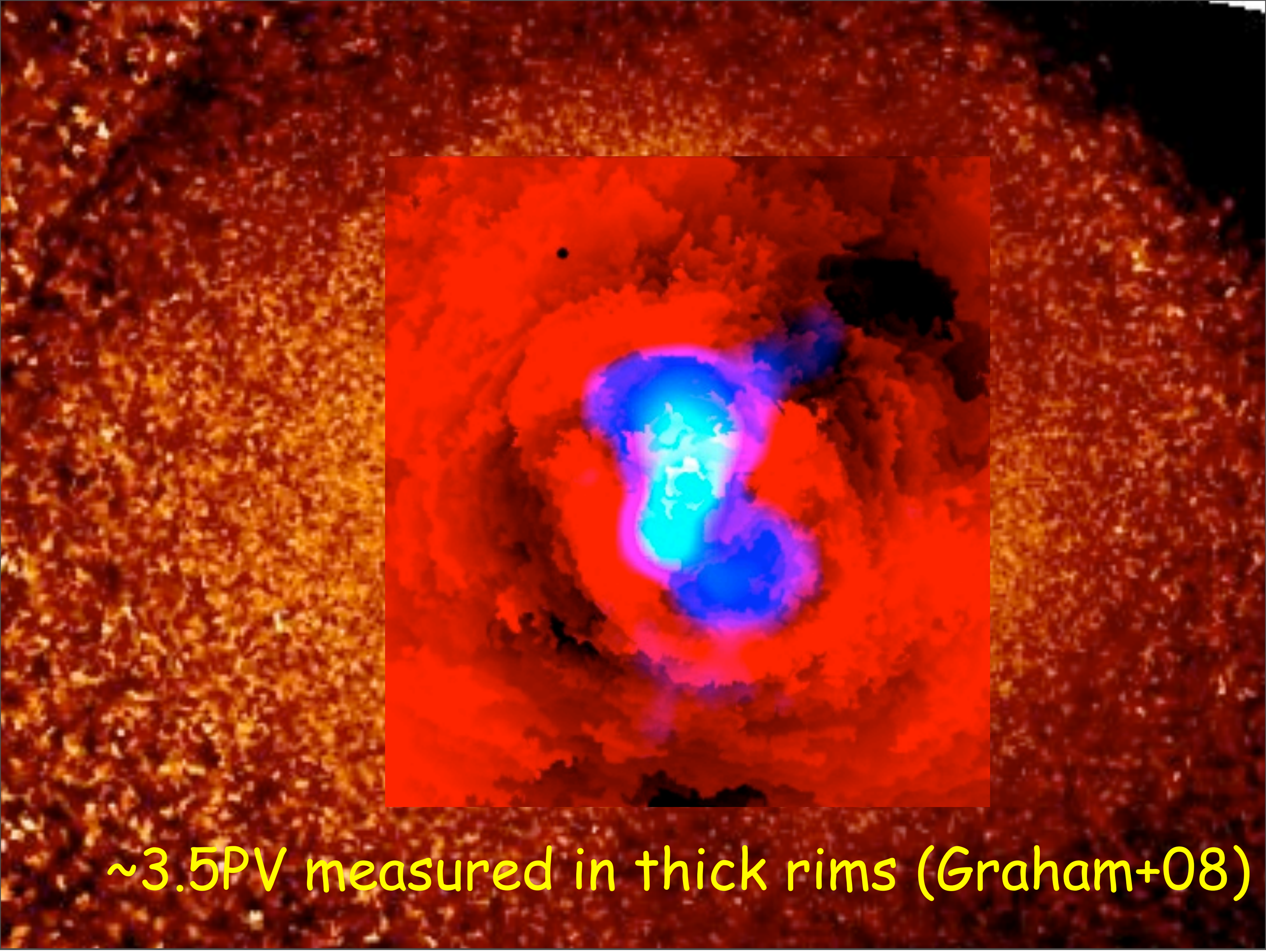
Issues

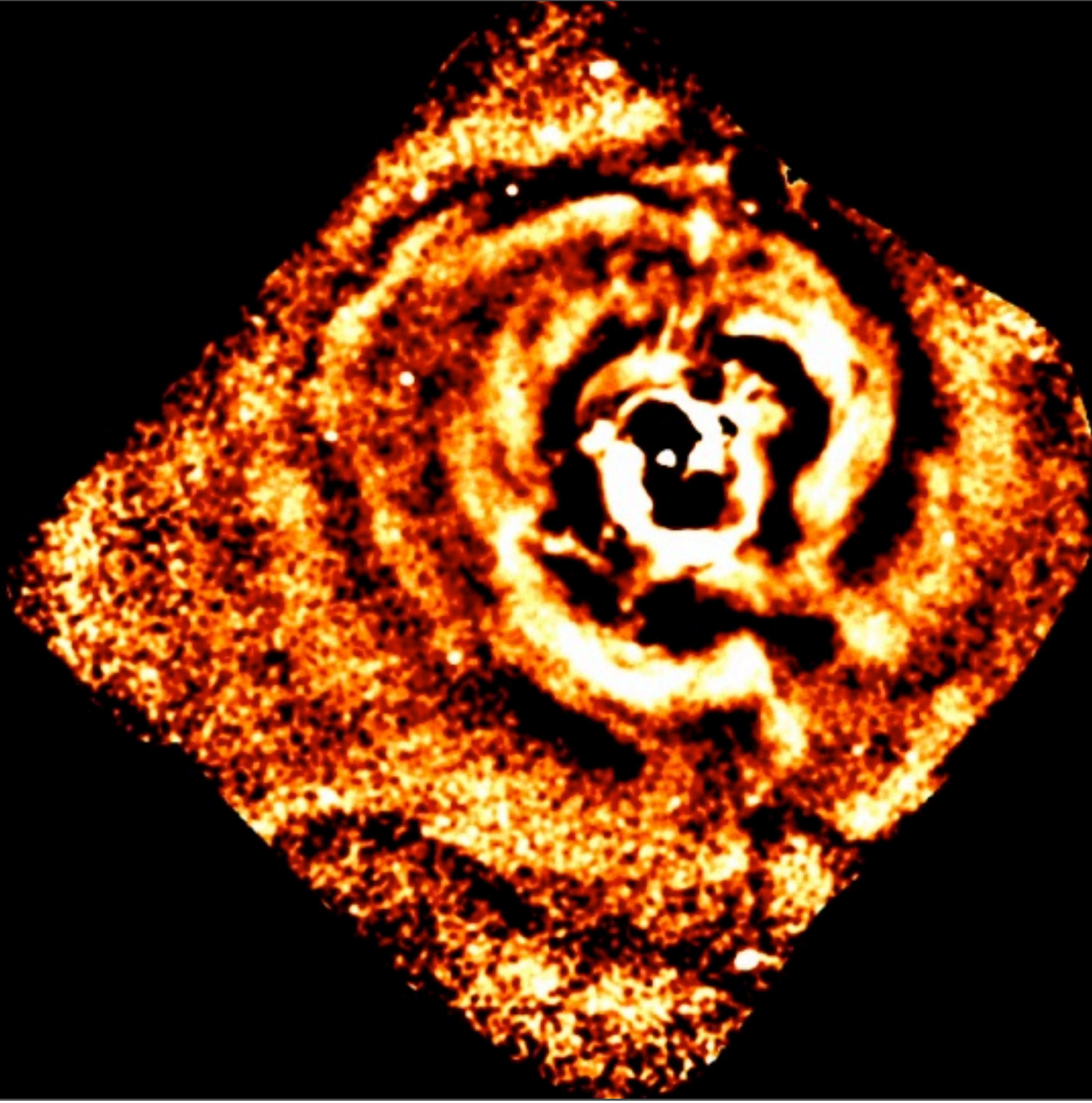
- Total Energy not an issue.
- How does energy get distributed?
- How close is the heating/cooling balance? Feedback too good?
- Observations suggest better than 10% for many Gyr in some objects.
- HOW DOES THE AGN DO THIS?
- Moreover, (how) is coolest X-ray gas

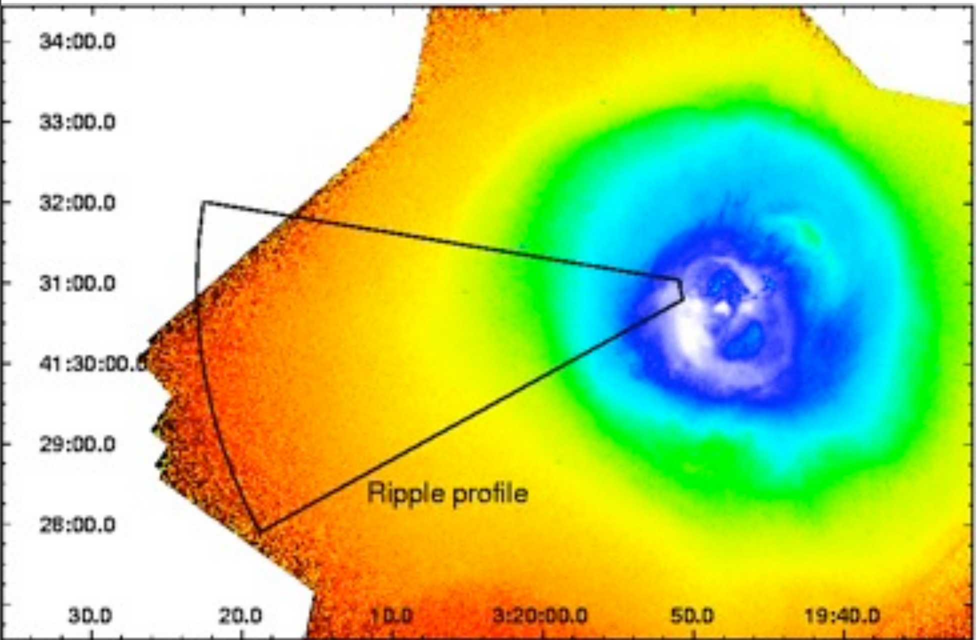
  (ie $T<5.10^6$K with radiative cooling time $\sim 10^7$yr) prevented from cooling?

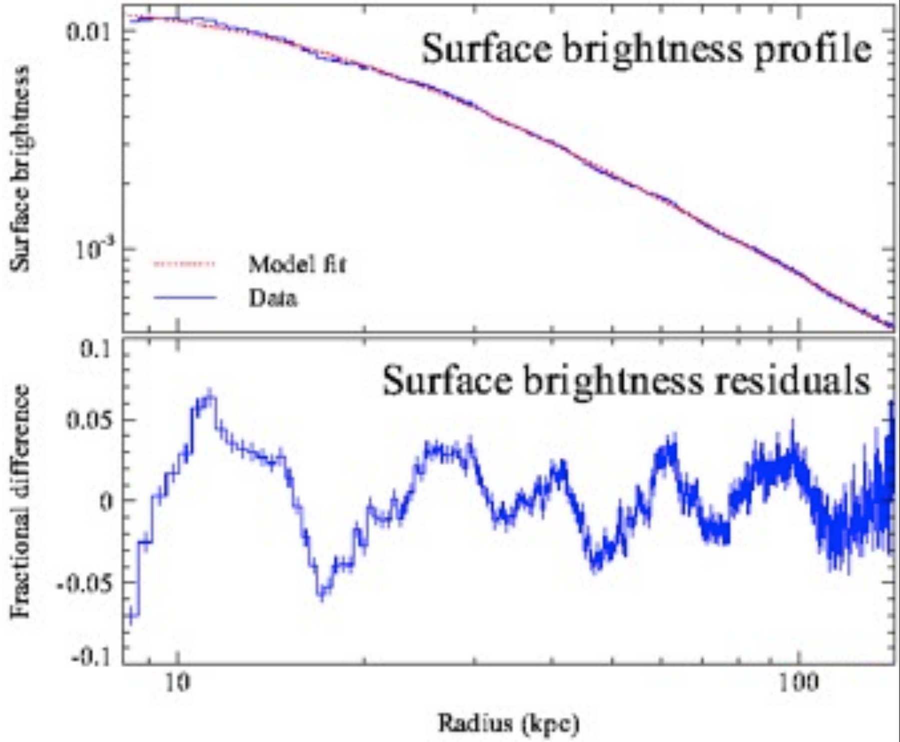
- Much of the Feedback is maintenance
- Continuous and "gentle"
- Some outbursts occur (MS07, Cyg A etc), but this does not necessarily disrupt core


Bubbling
long lived


~3.5PV measured in thick rims (Graham+08)

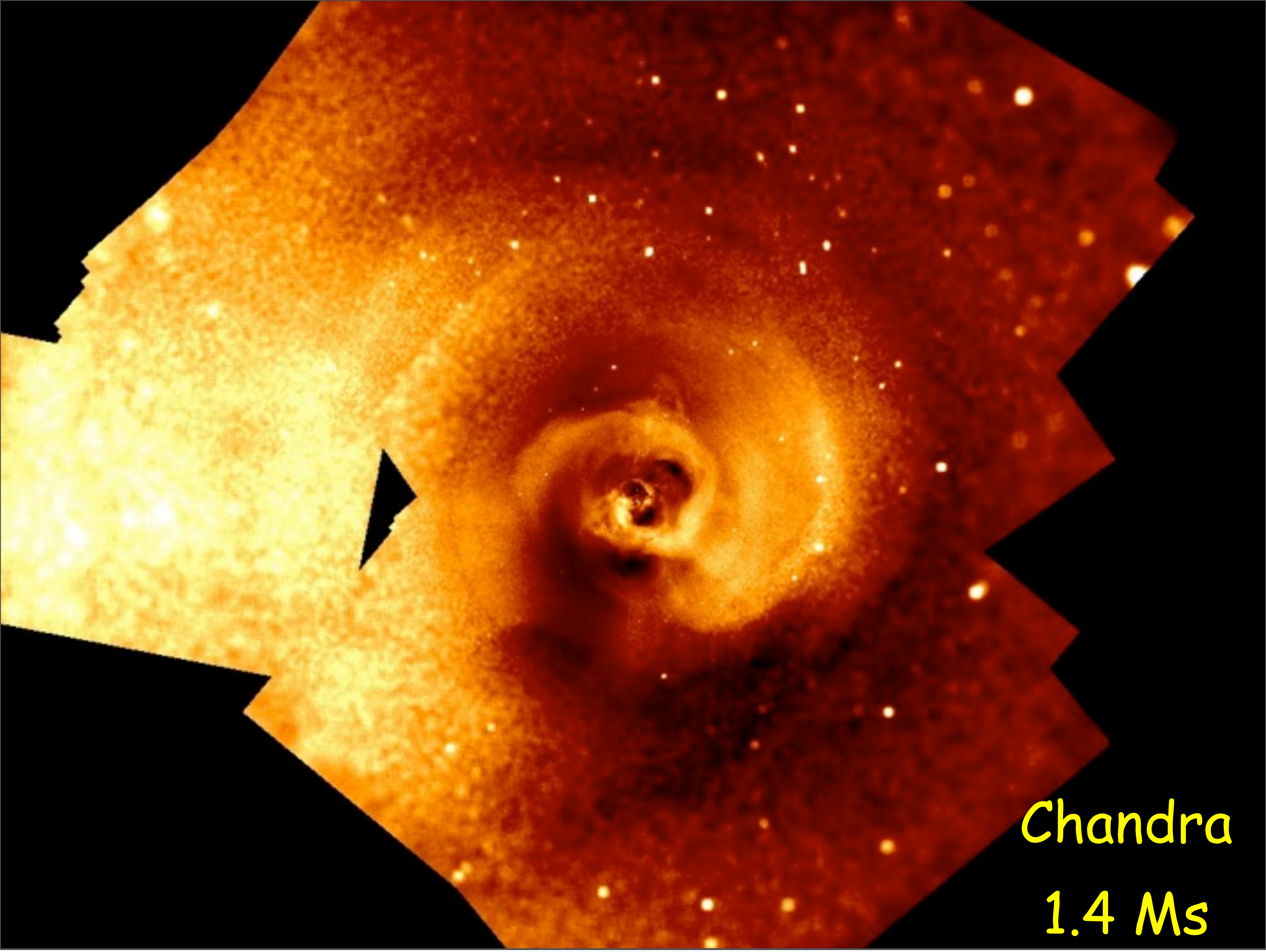


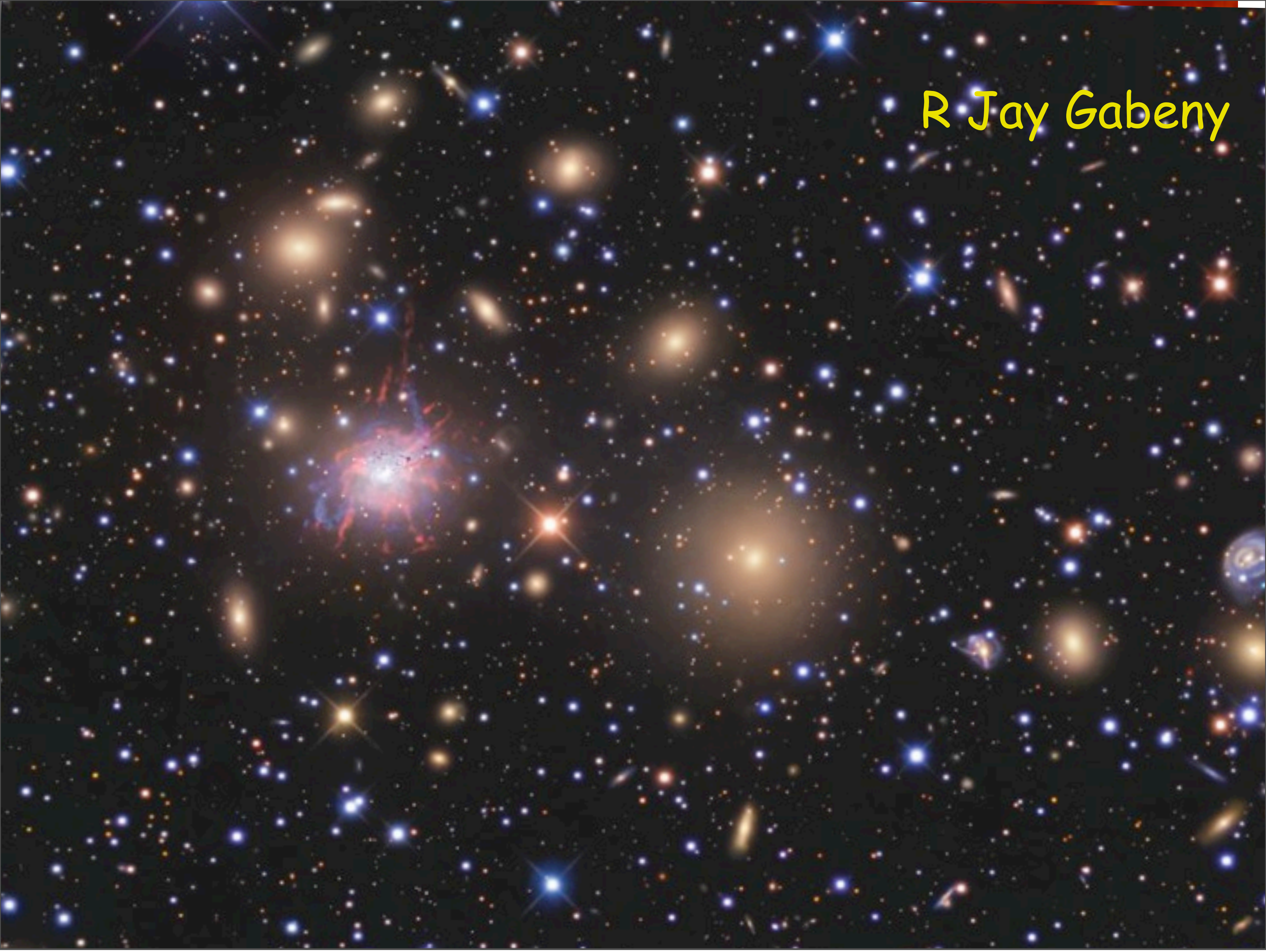


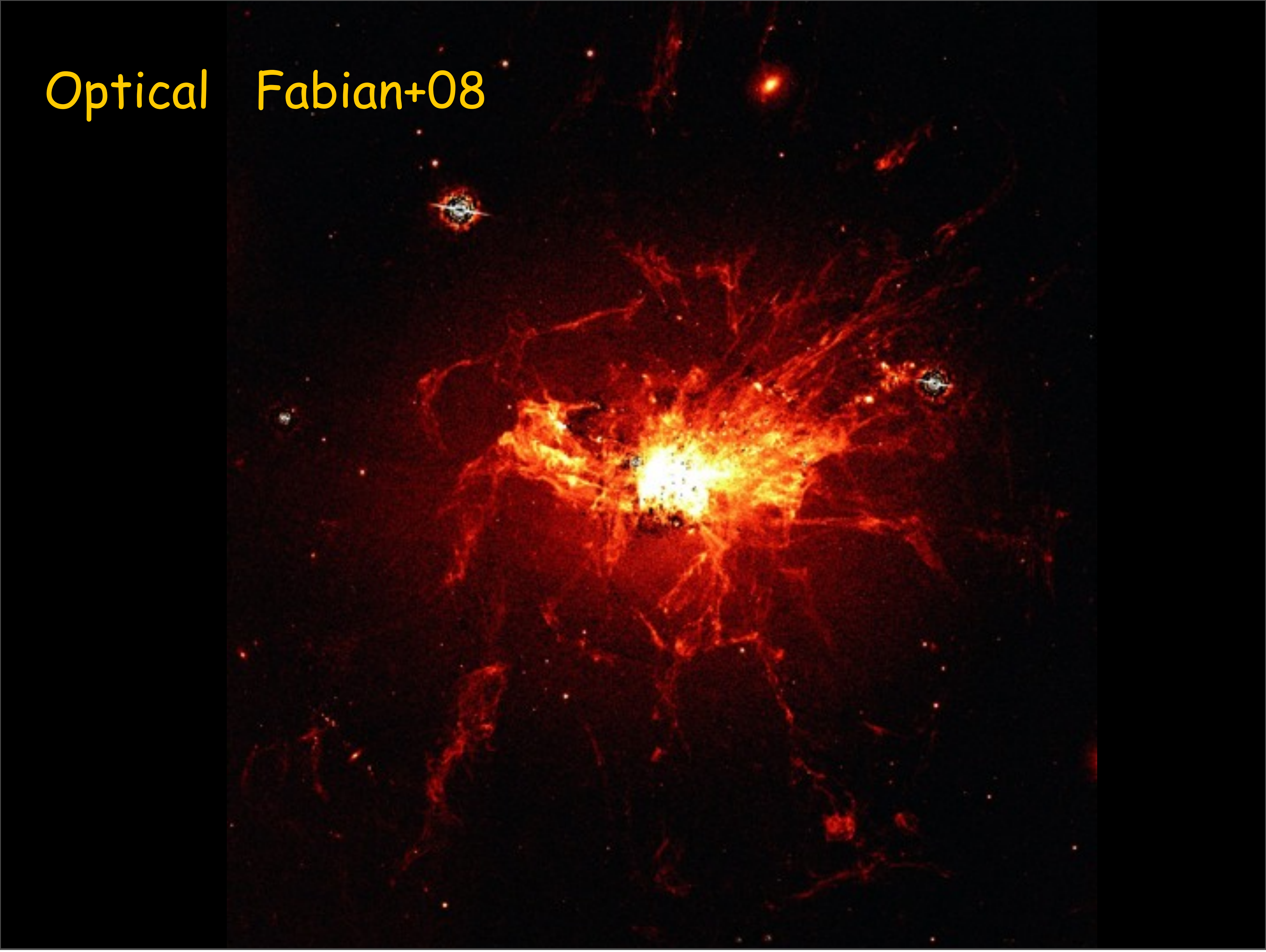


Power in ripples (sound waves) ~ X-ray luminosity within 70 kpc

Also seen in Centaurus, Virgo...

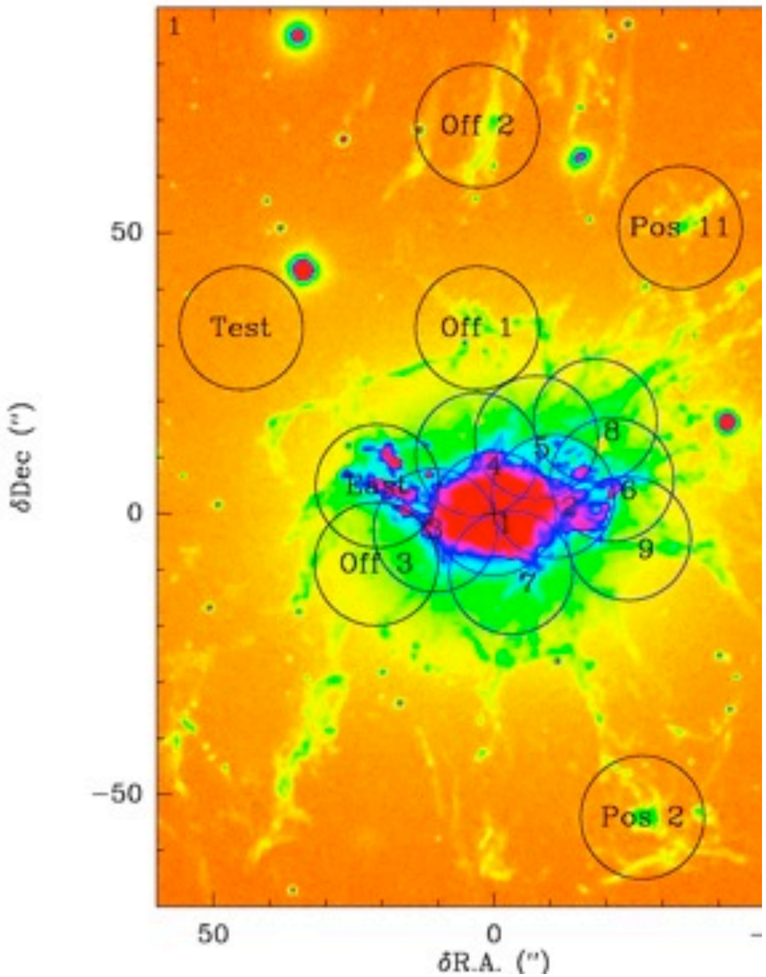

Chandra
1.4 Ms


R Jay Gabeny


Optical Fabian+08

Salome+08 CO measurements

Salomé, P. et al.: Cold gas in the Perseus cluster core: Excitation of molecular gas i



8 Salomé, P. et al.: Cold gas in the Perseus cluster core: Excitation of molecular gas in filaments

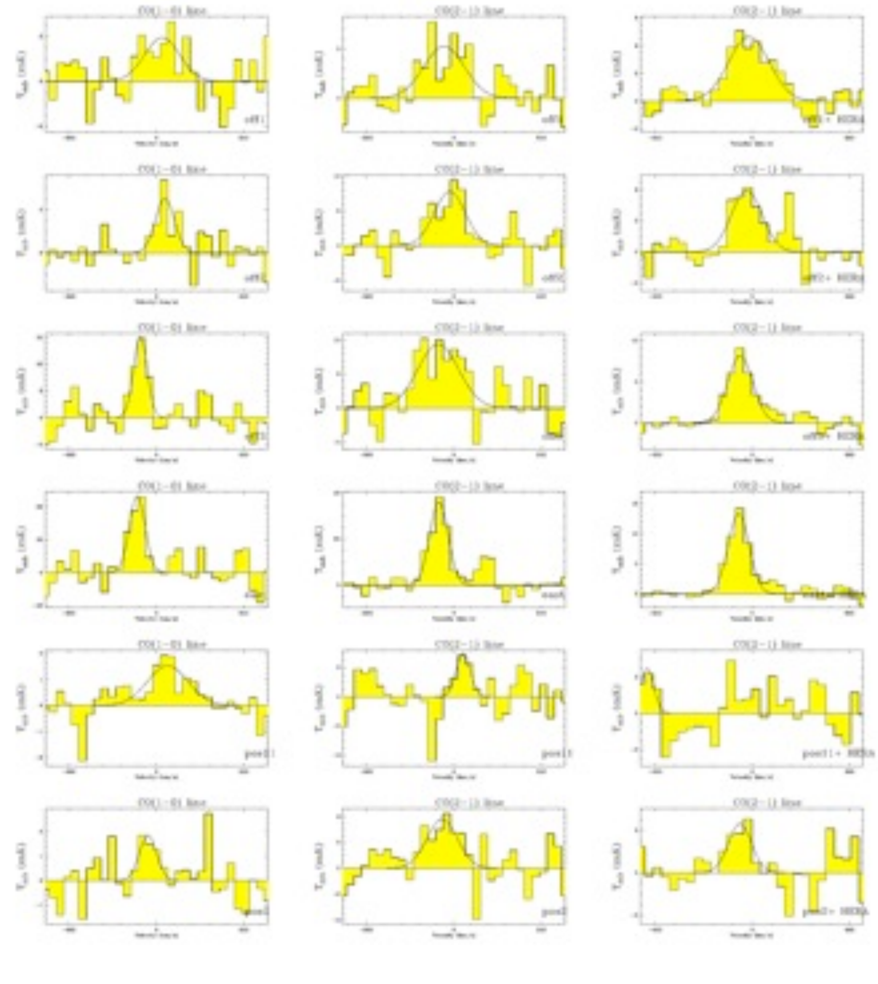
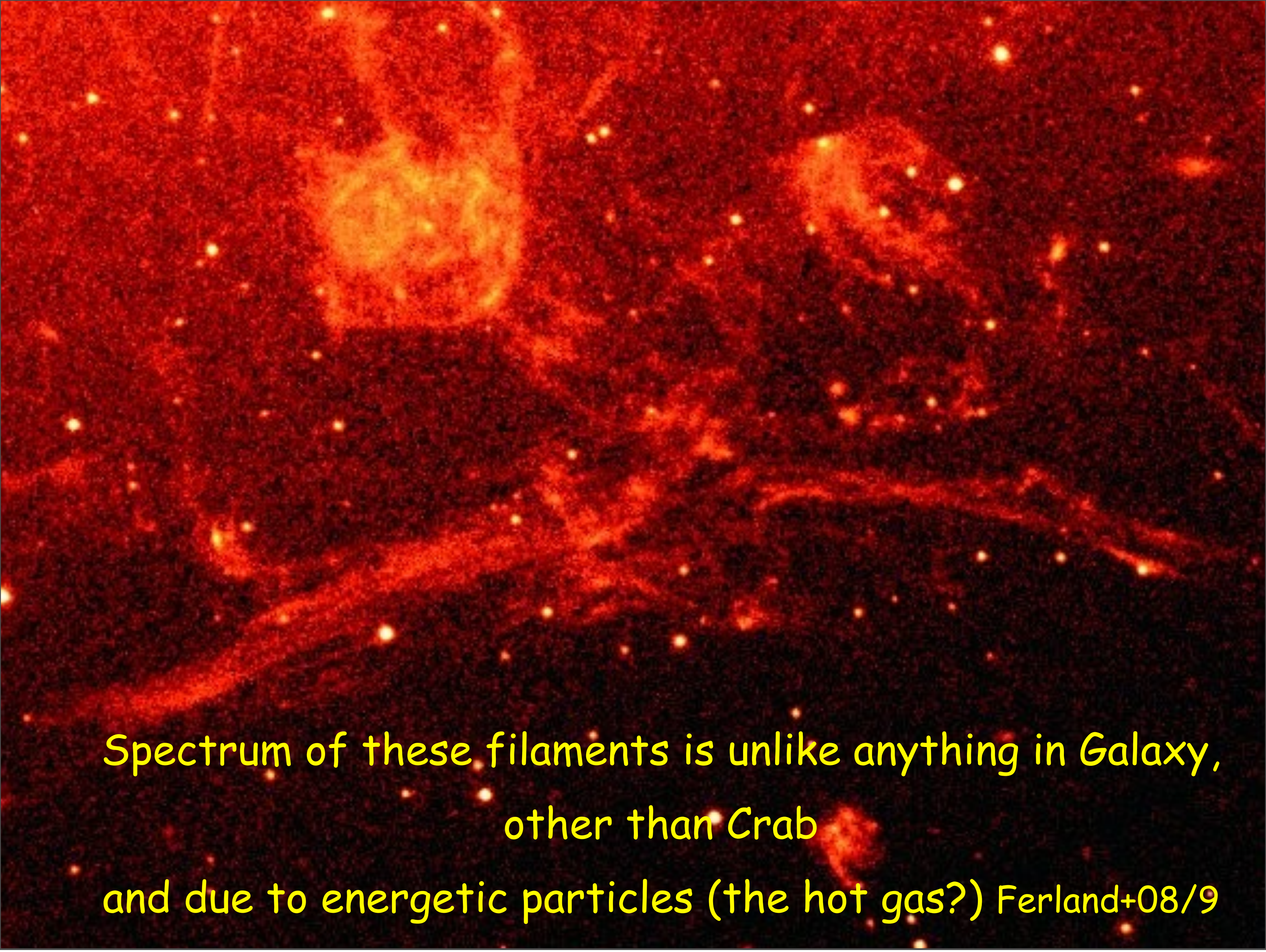
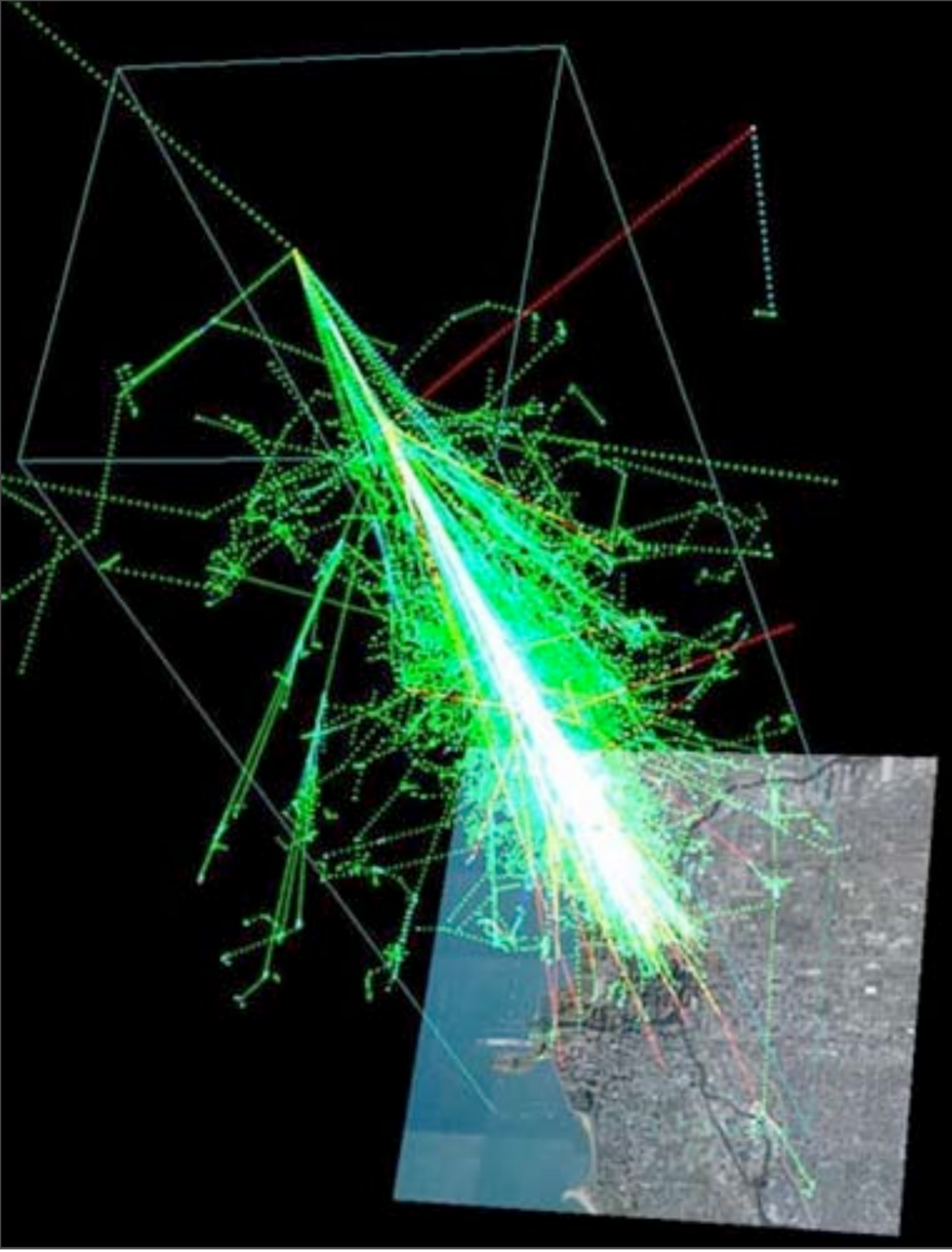


Fig. 2. CO(1–0) and CO(2–1) spectra obtained at all the positions observed as indicated at lower right in each diagram. The channel width is 42 km/s. On the left hand side are the CO(1–0) lines detected with the a100 and b100 receivers. In the middle are the results obtained for the CO(2–1) line with the A230 and B230 receivers. On the right hand side are the CO(2–1) lines computed with both A230 and B230 merged with previous HERA data and smoothed to the 3mm beam size.

Almost 10^{11} Msun of cold gas in Perseus


Spectrum of these filaments is unlike anything in Galaxy,
other than Crab
and due to energetic particles (the hot gas?) Ferland+08/9



Ferland+08/09

- Energetic particles produce
- Ionized gas
  - Heating
- Neutral gas
  - Shower of suprathermal electrons
  - Secondary excitation and ionization
  - less heating

Properties of filaments

- Magnetic Fields B~70uG
- Diameter~70pc, length many kpc
- Mass usually dominated by molecular gas
- Hot ICM particles penetrate cold gas, providing secondary ionization

- Filament mass growing at

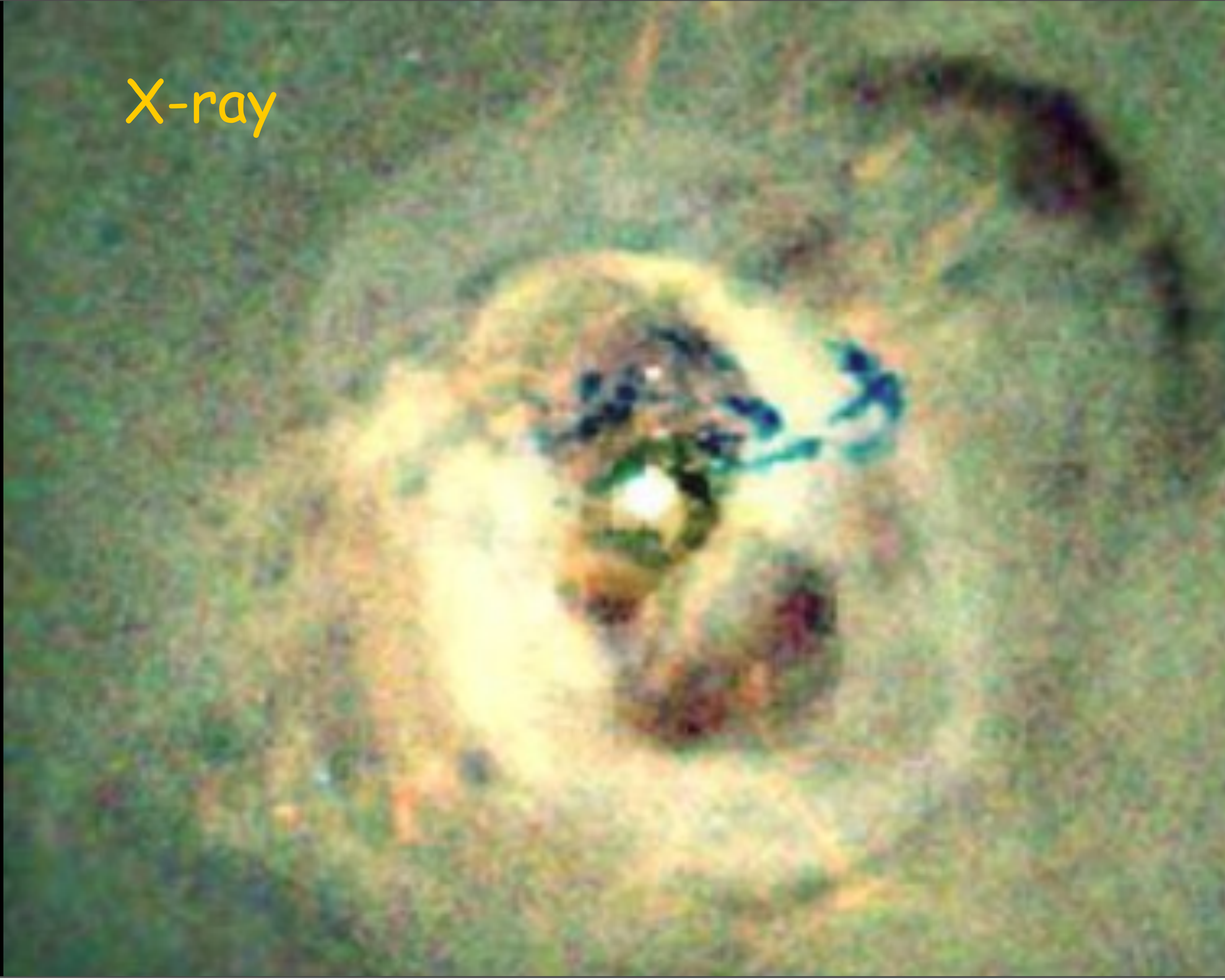
  10-100 Msun yr

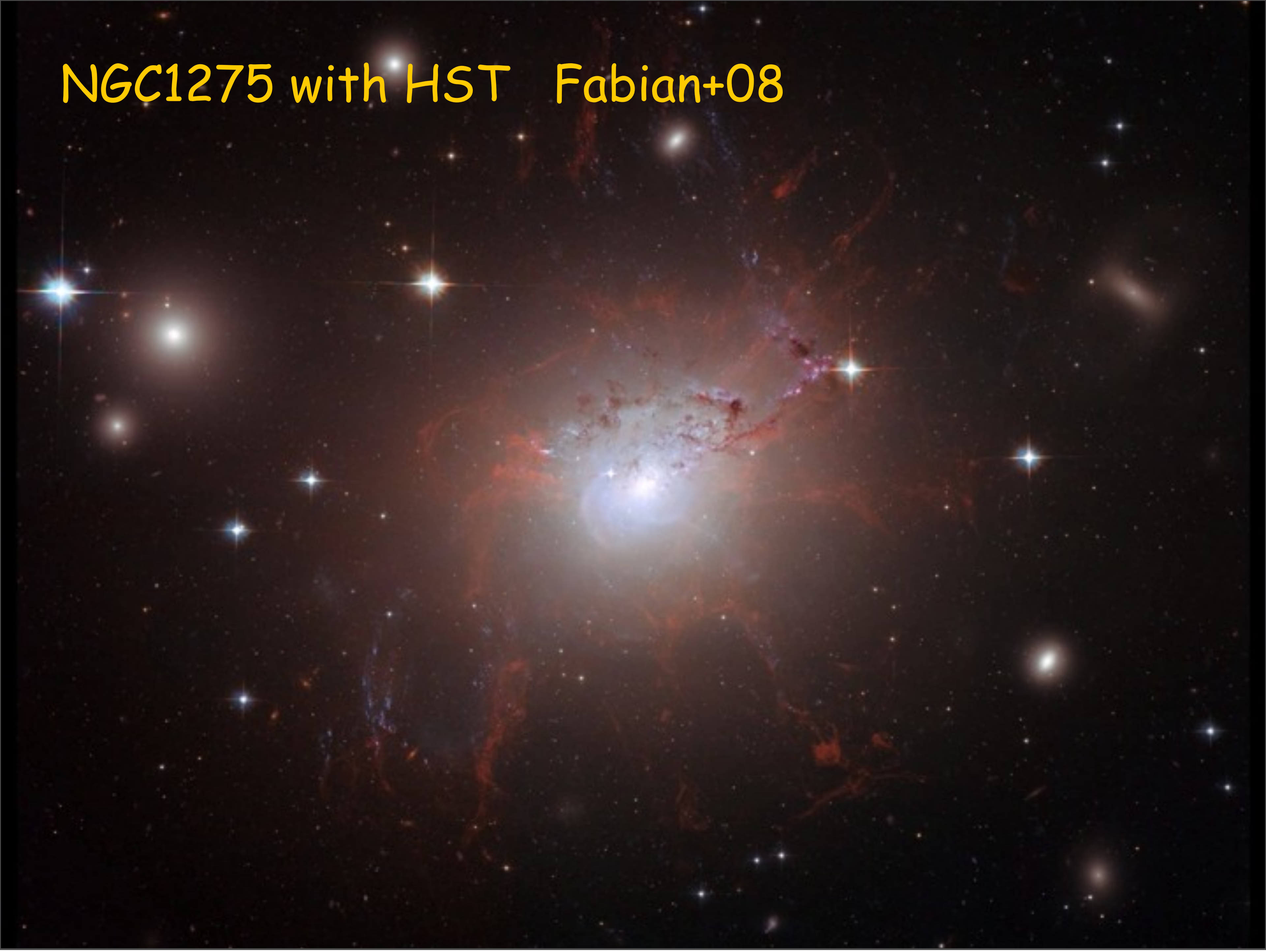
(Fabian+11)

In other words

- Innermost hot gas cools radiatively through X-ray emission to $\sim 10^7$K, then plunges to $<10^4$K by mixing with cold filaments

(cf Fabian+01,02, Soker04)

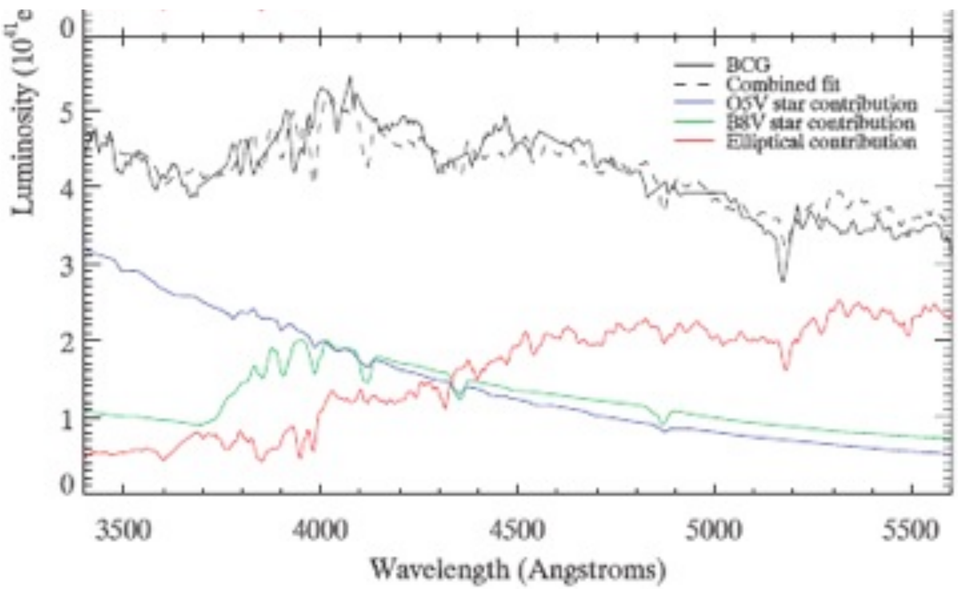

X-ray

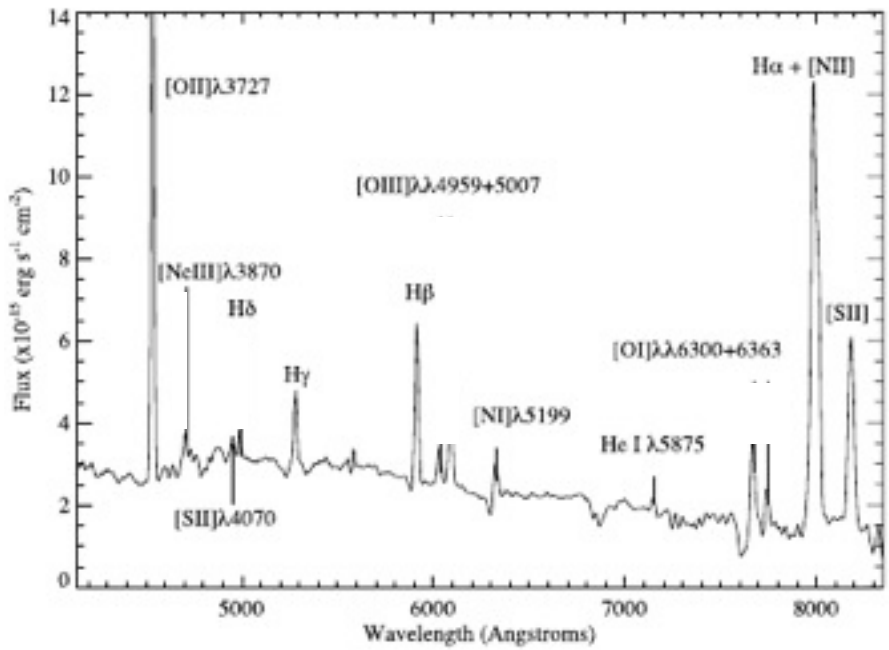

NGC1275 with HST Fabian+08

Perseus SFR~20 Msunpyr Canning+10

RXCJ1504 Ogrean+10 z=0.2

SFR~140 Msunpyr





 +10 MACS J1931 z=0.35

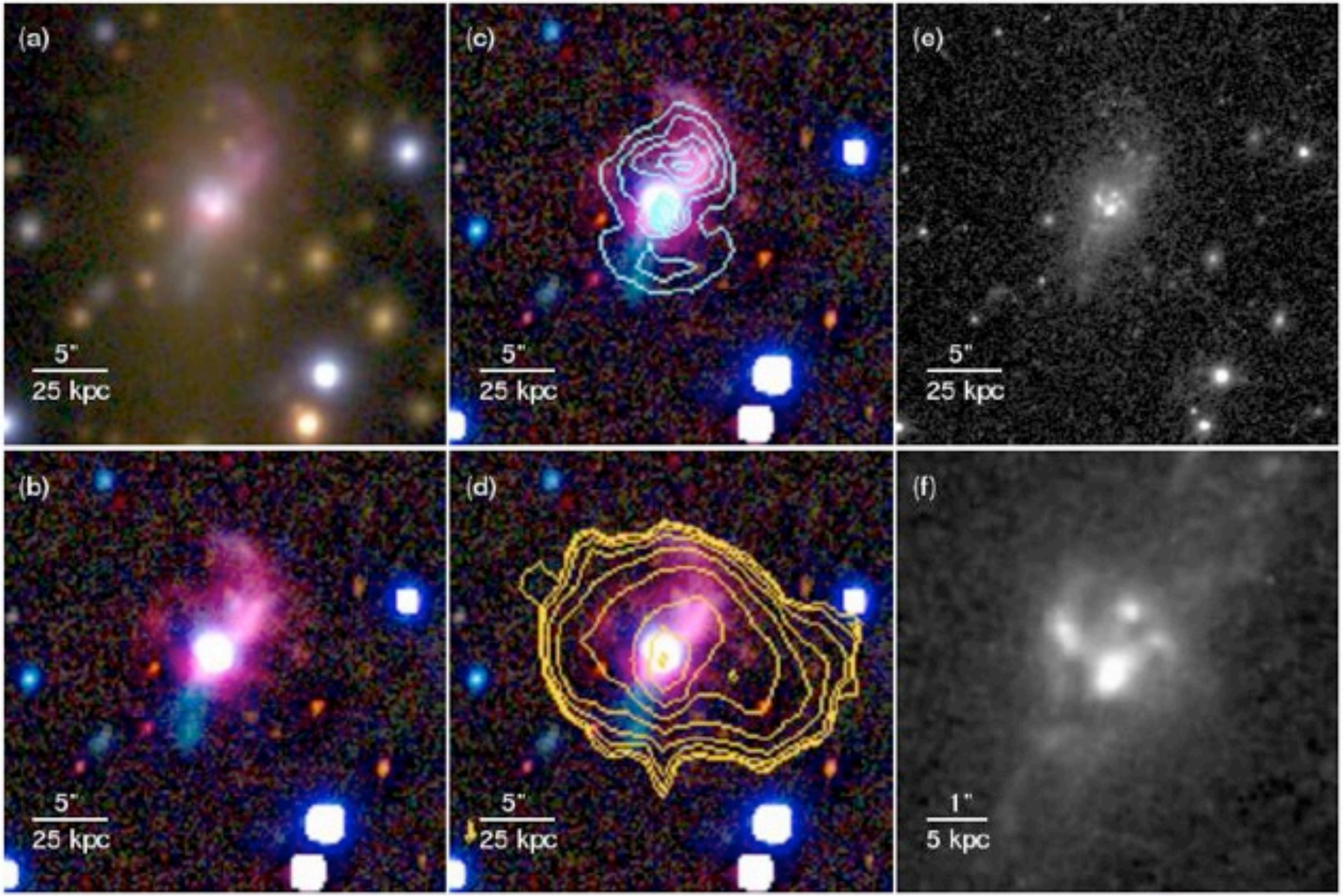
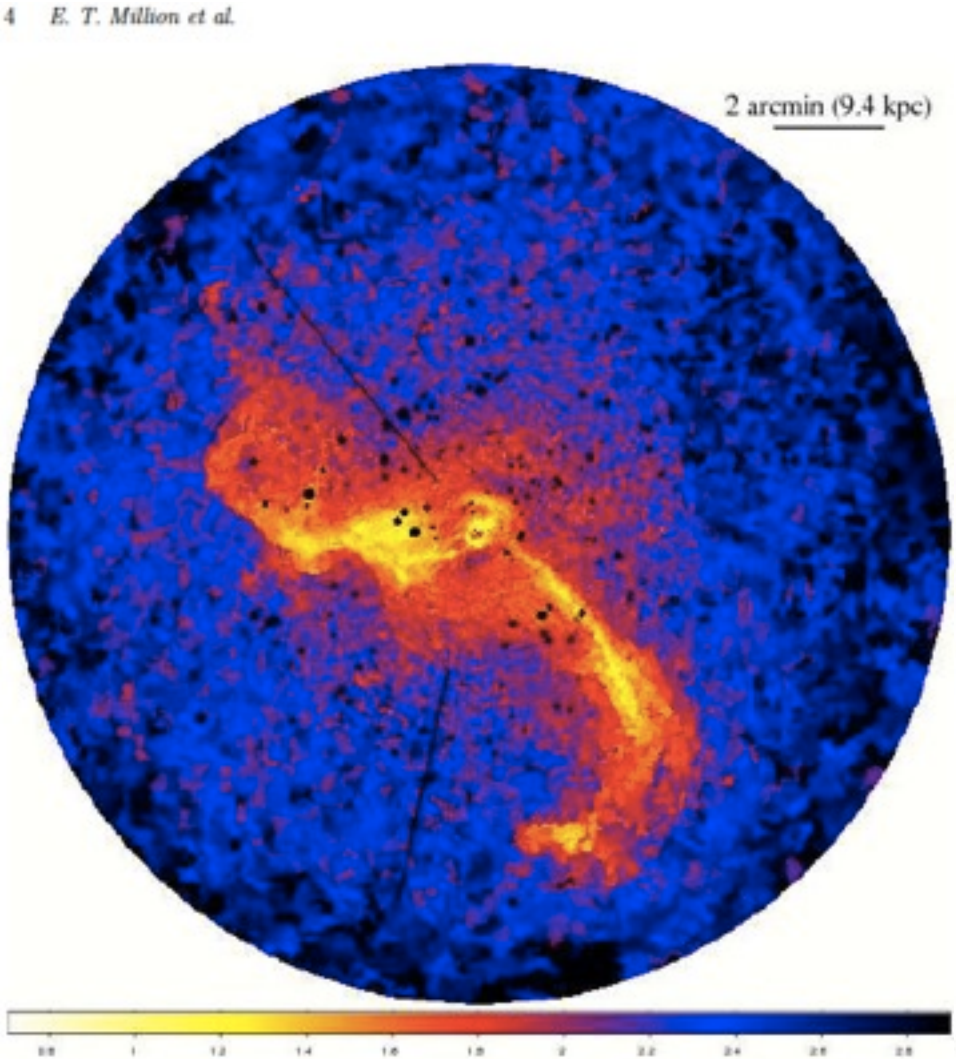
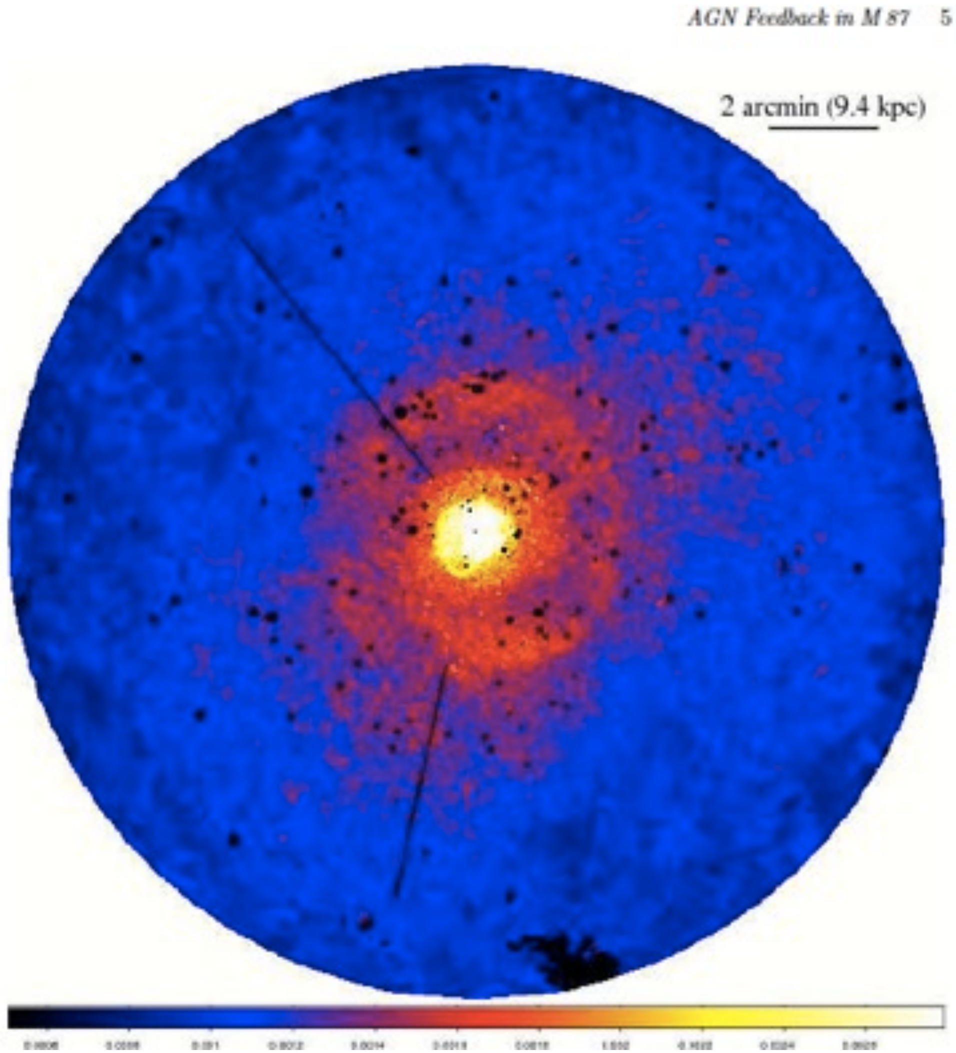


Figure 12. Optical structure of the BCG of MACS J1931.8-2634. (a): SuprimeCam *BRz* image of the central 30 arcsec × 30 arcsec. (b): For this image, the

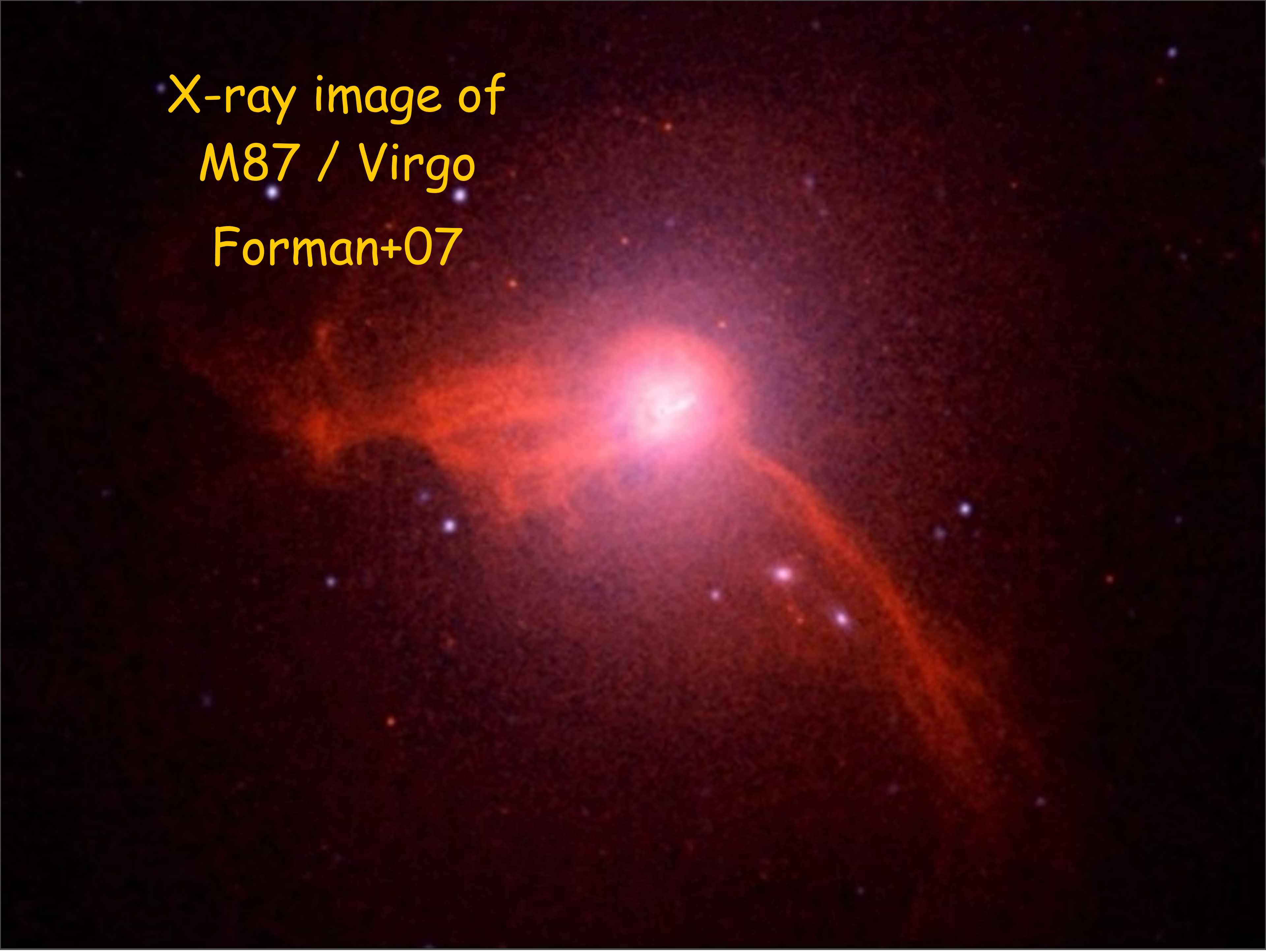
SFR~170 Msunpyr

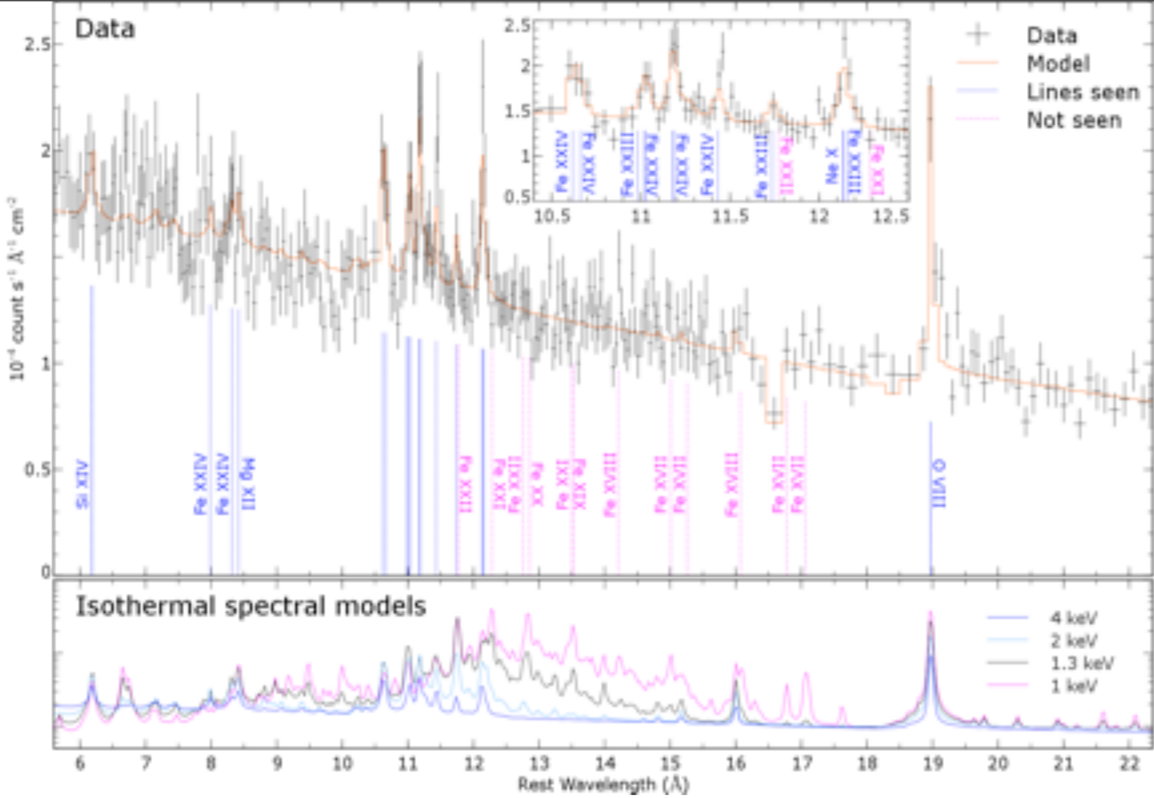




Temperature

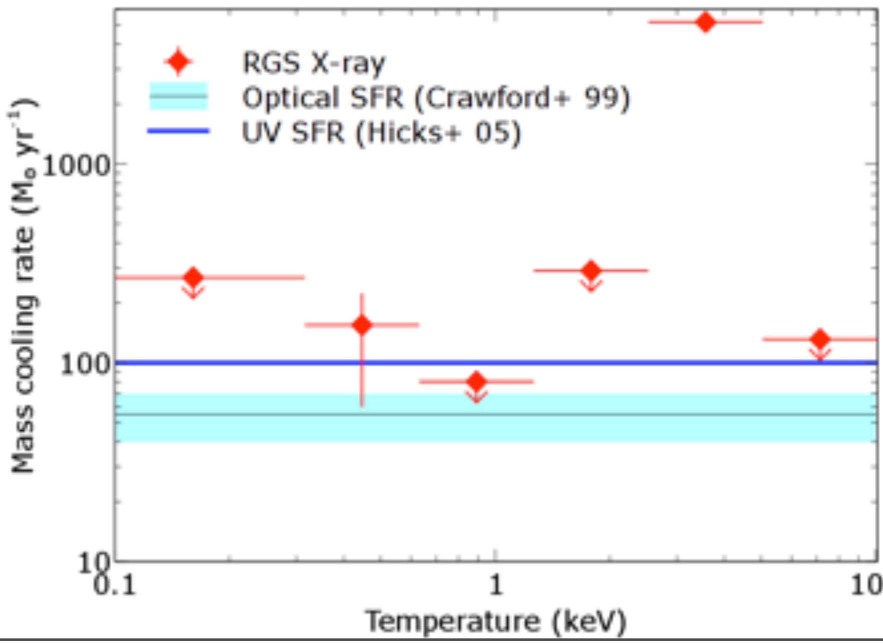
Pressure

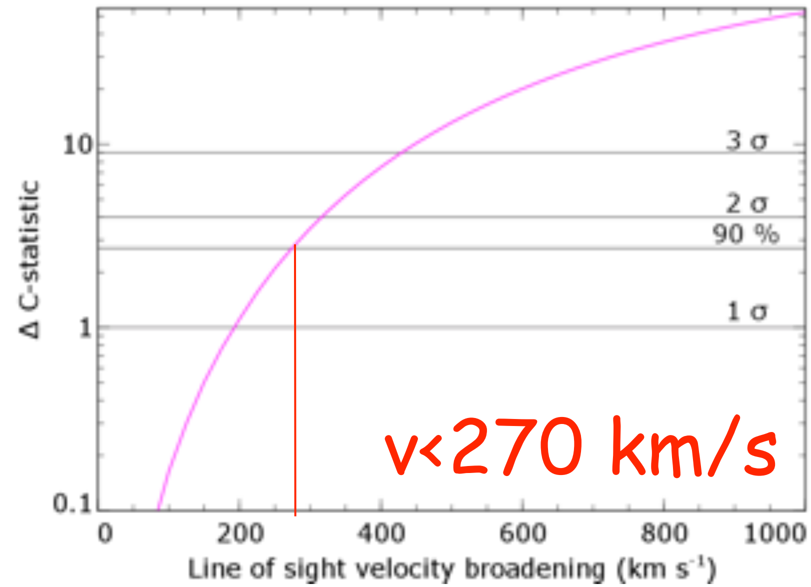

X-ray image of
M87 / Virgo
Forman+07



A1835

Sanders+09

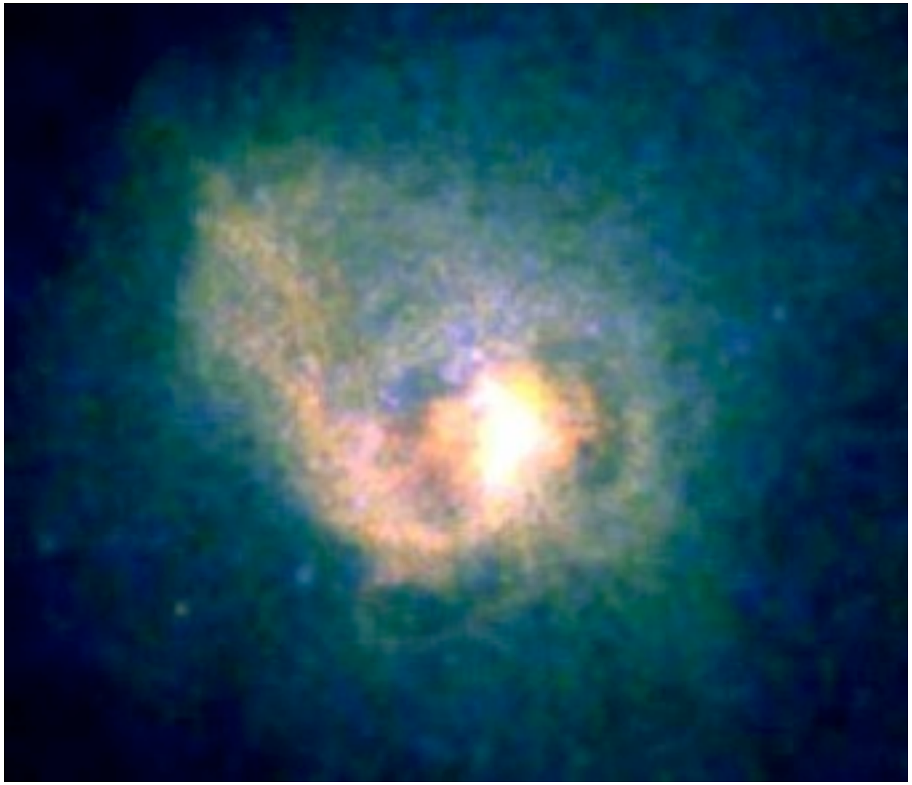


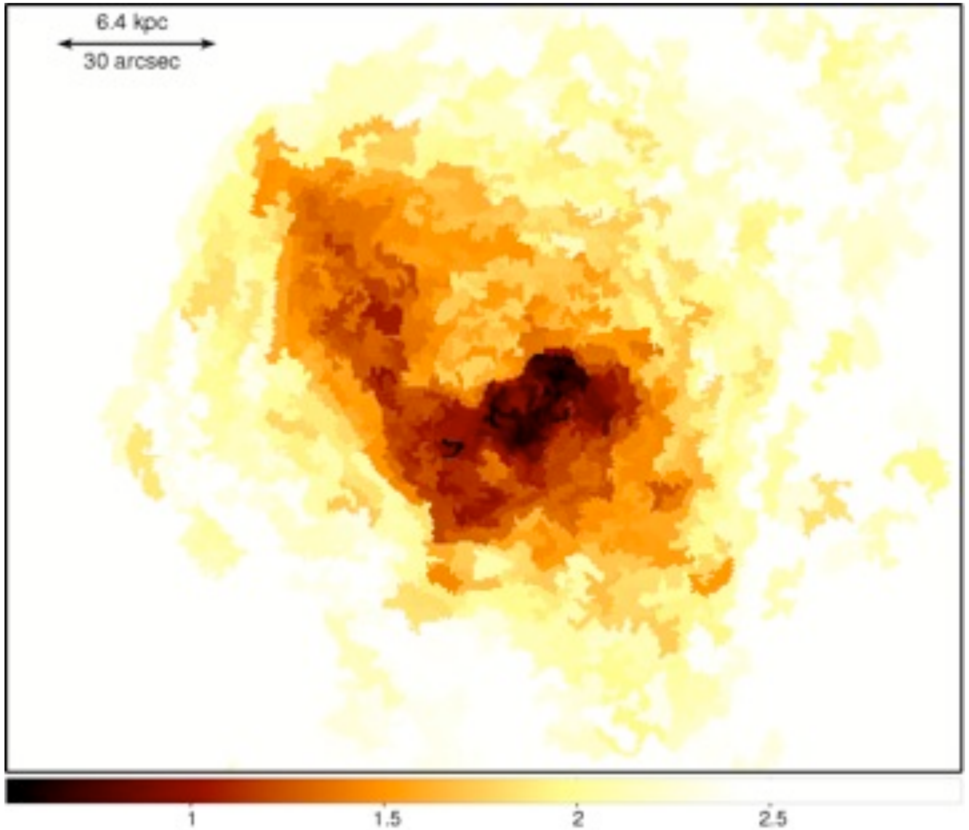


v<270 km/s

Cool X-ray gas in Centaurus

200 ks Chandra observation



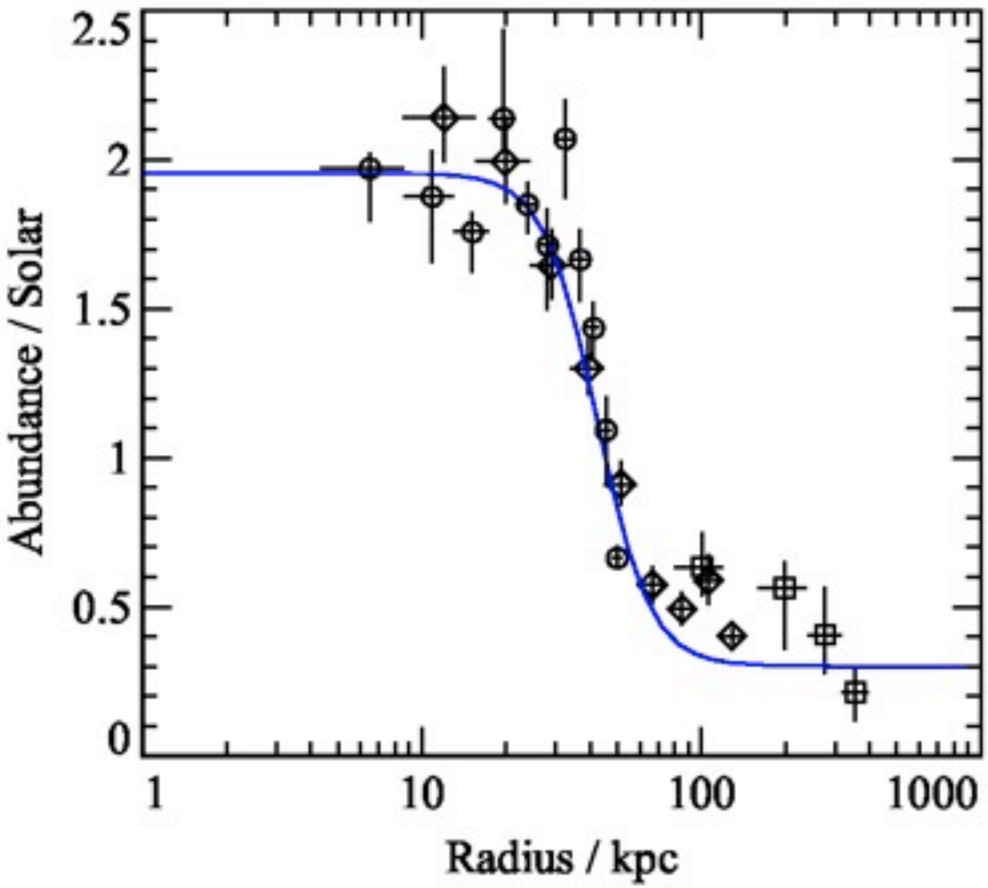


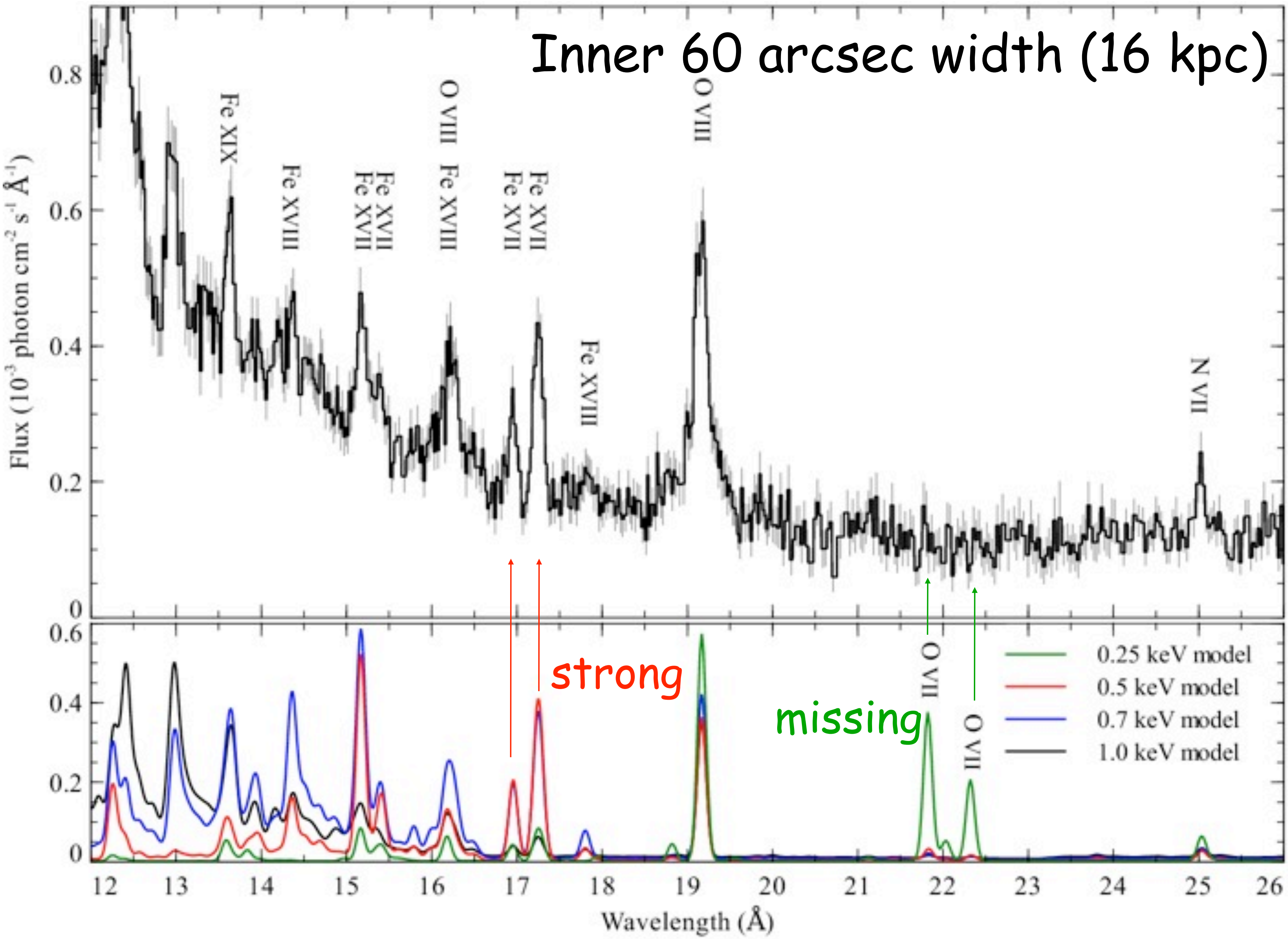
Temperature (keV)

Shows feedback (cavities) and cool gas (~0.7 keV) in CCD spectra

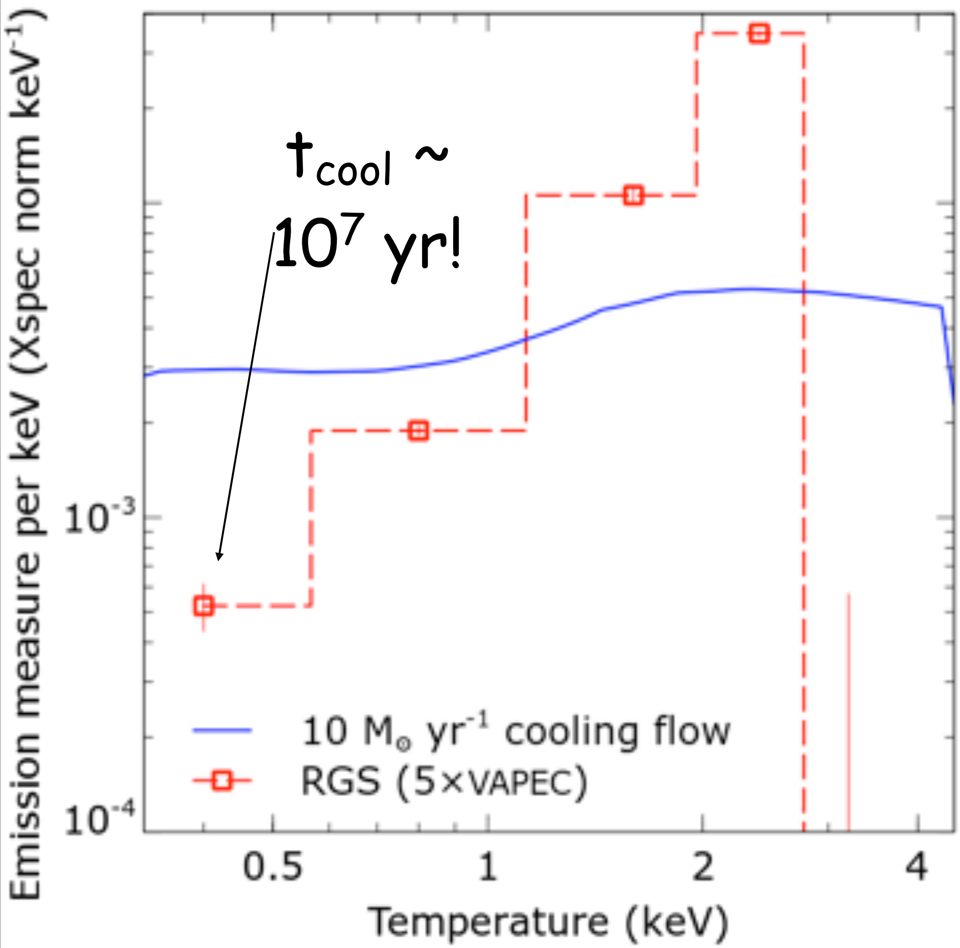
How much gas is there at low X-ray temperatures?

Cen cluster: Abundance profile implies little diffusion/mixing

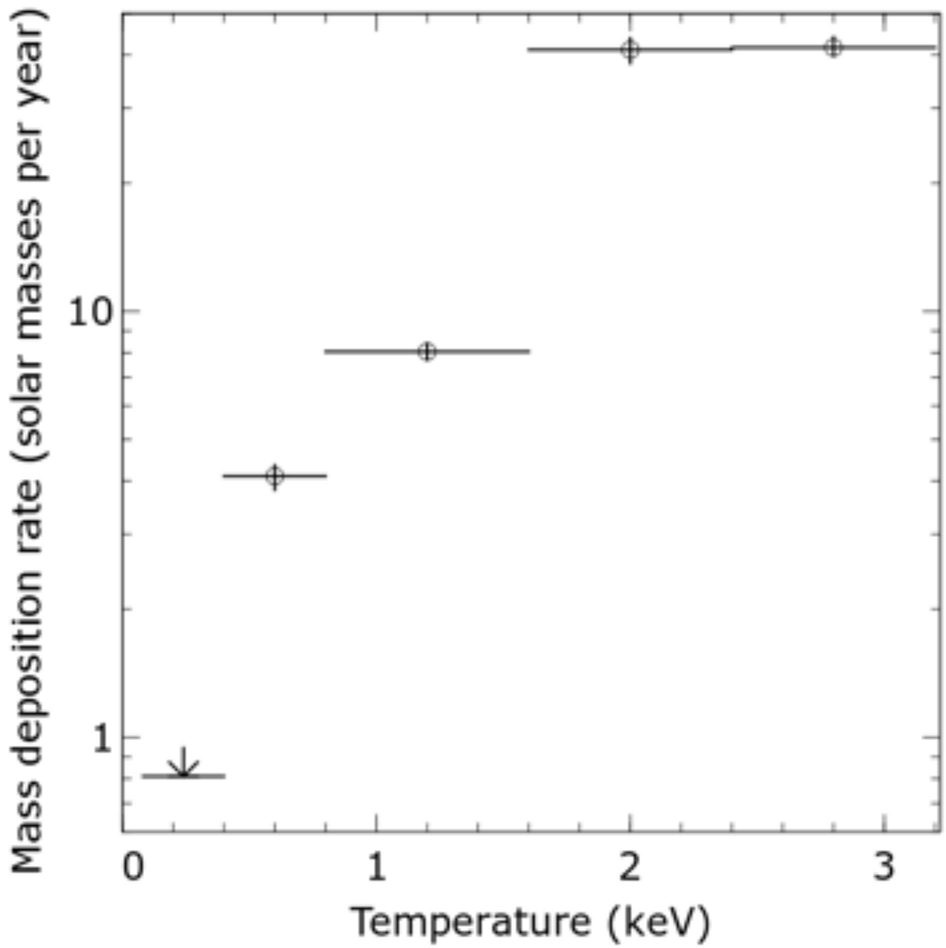



Inner 60 arcsec width (16 kpc)
Fe XIX
Fe XVIII
Fe XVII
Fe XVII
O VIII
Fe XVIII
Fe XVII
Fe XVII
Fe XVIII
O VIII
N VII
strong
missing
O VII
O VII
0.25 keV model
0.5 keV model
0.7 keV model
1.0 keV model
Flux (10^{-3} photon cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)

Spectral fitting limits on gas kT

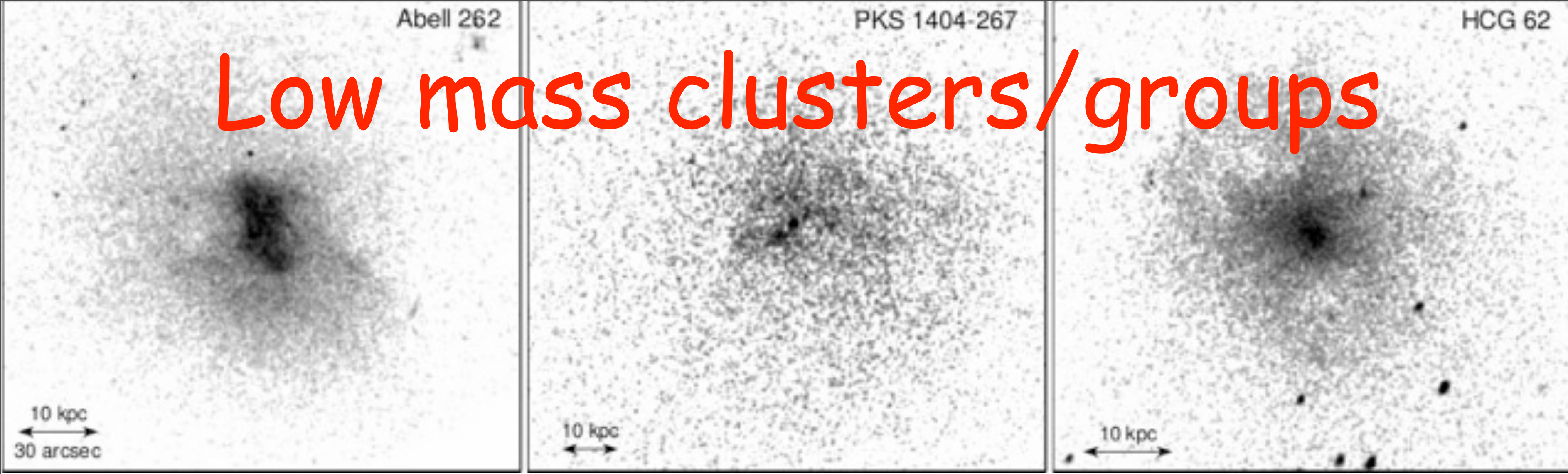


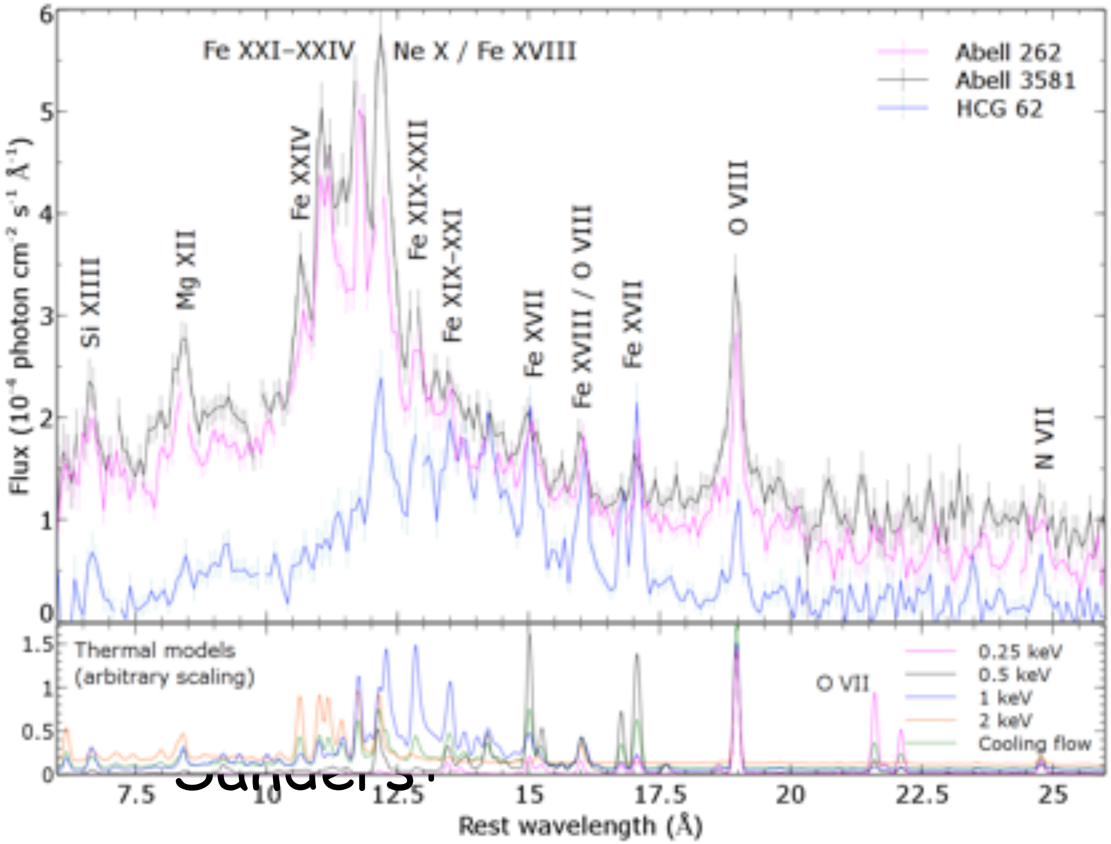
Multi temperature model



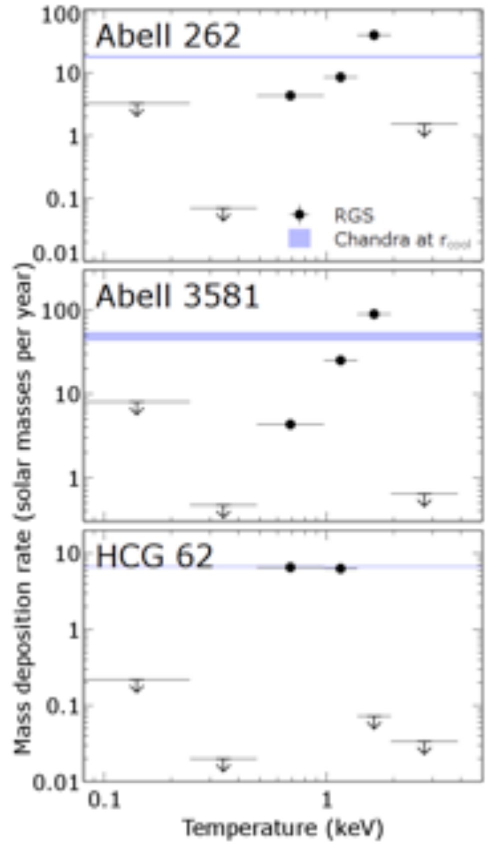
Cooling flow model

Low mass clusters/groups





Sanders:

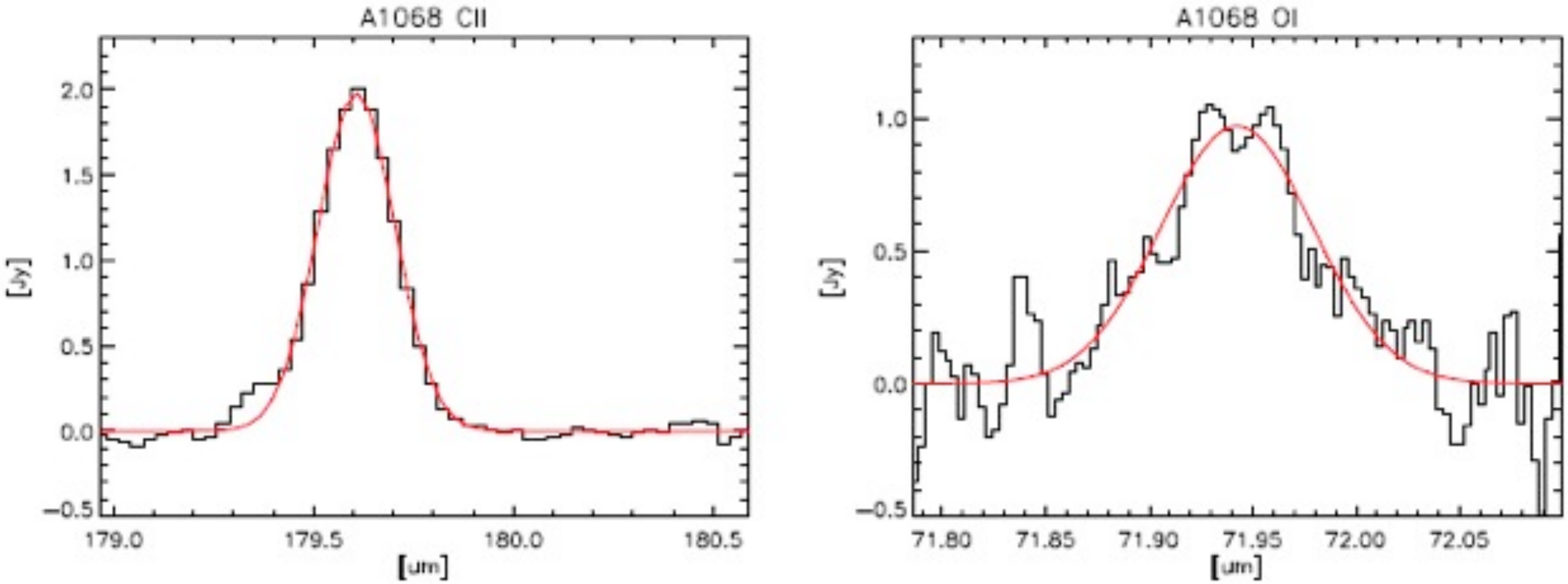


April 28, 2010

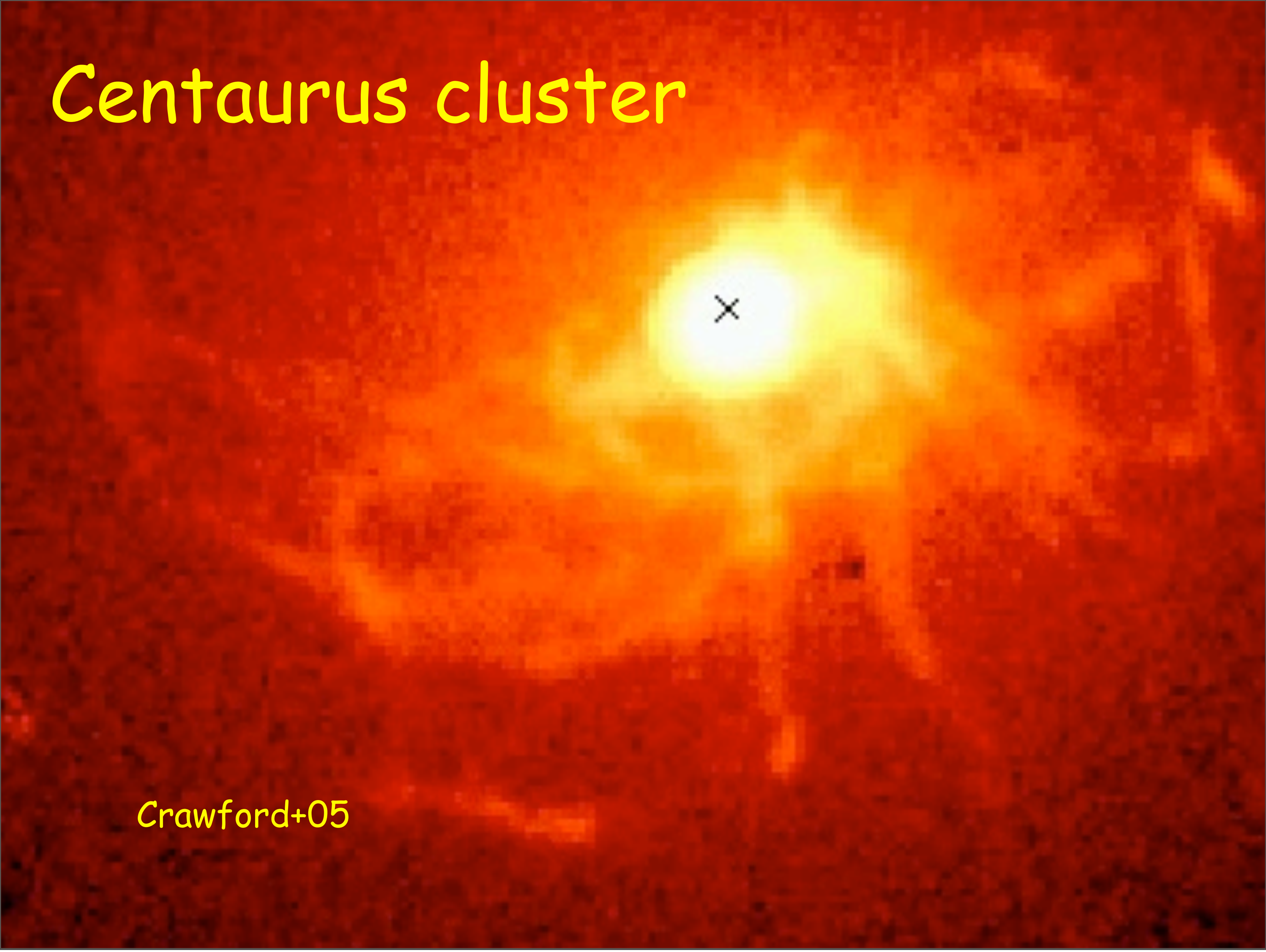
LETTER TO THE EDITOR

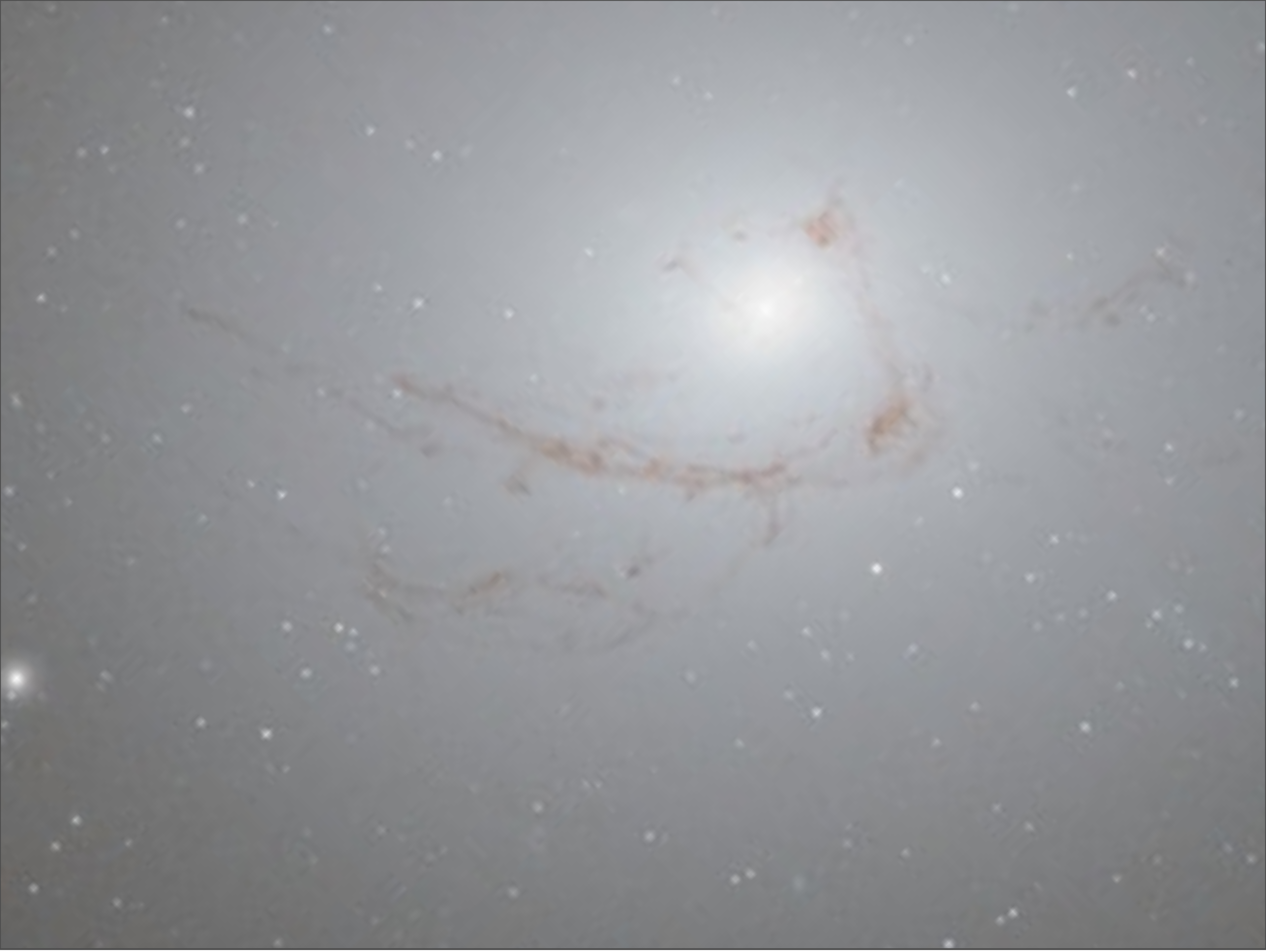
Herschel observations of FIR emission lines in brightest cluster galaxies ⋆

A. C. Edge[1], J. B. R. Oonk[2], R. Mittal[3], S. W. Allen[4], S. A. Baum[3], H. Böhringer[5], J. N. Bregman[6], M. N. Bremer[7], F. Combes[8], C. S. Crawford[9], M. Donahue[10], E. Egami[11], A. C. Fabian[9], G. J. Ferland[12], S. L. Hamer[1], N. A. Hatch[13], W. Jaffe[2], R. M. Johnstone[9], B. R. McNamara[14], C. P. O'Dea[15], P. Popesso[5], A. C. Quillen[16], P. Salomé[8], C. L. Sarazin[17], G. M. Voit[10], R. J. Wilman[18], and M. W. Wise[19]



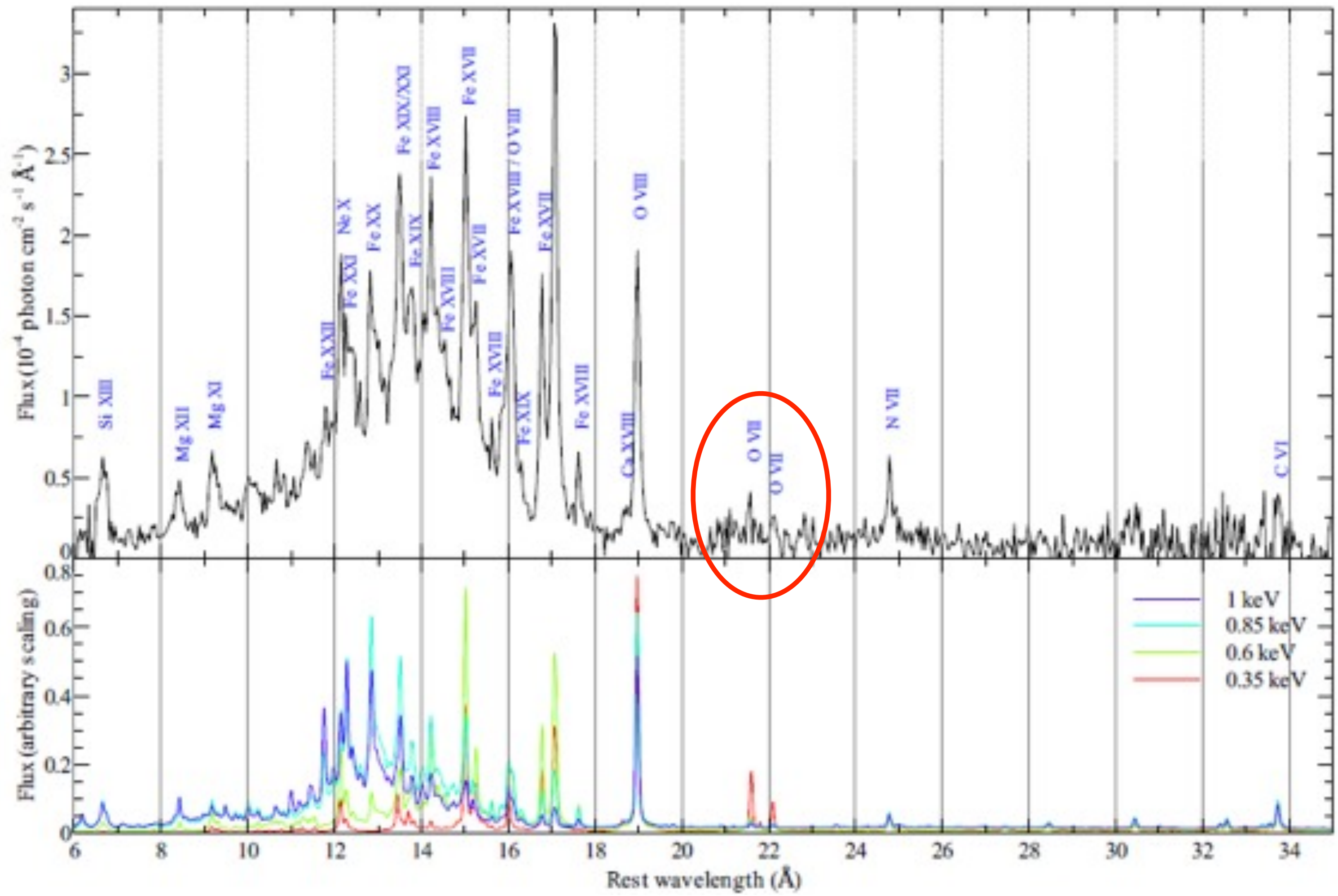
$L(CII) \sim 5\times10^{42}$ erg/s $\sim 6 \times L(H\alpha)$


Centaurus cluster
Crawford+05

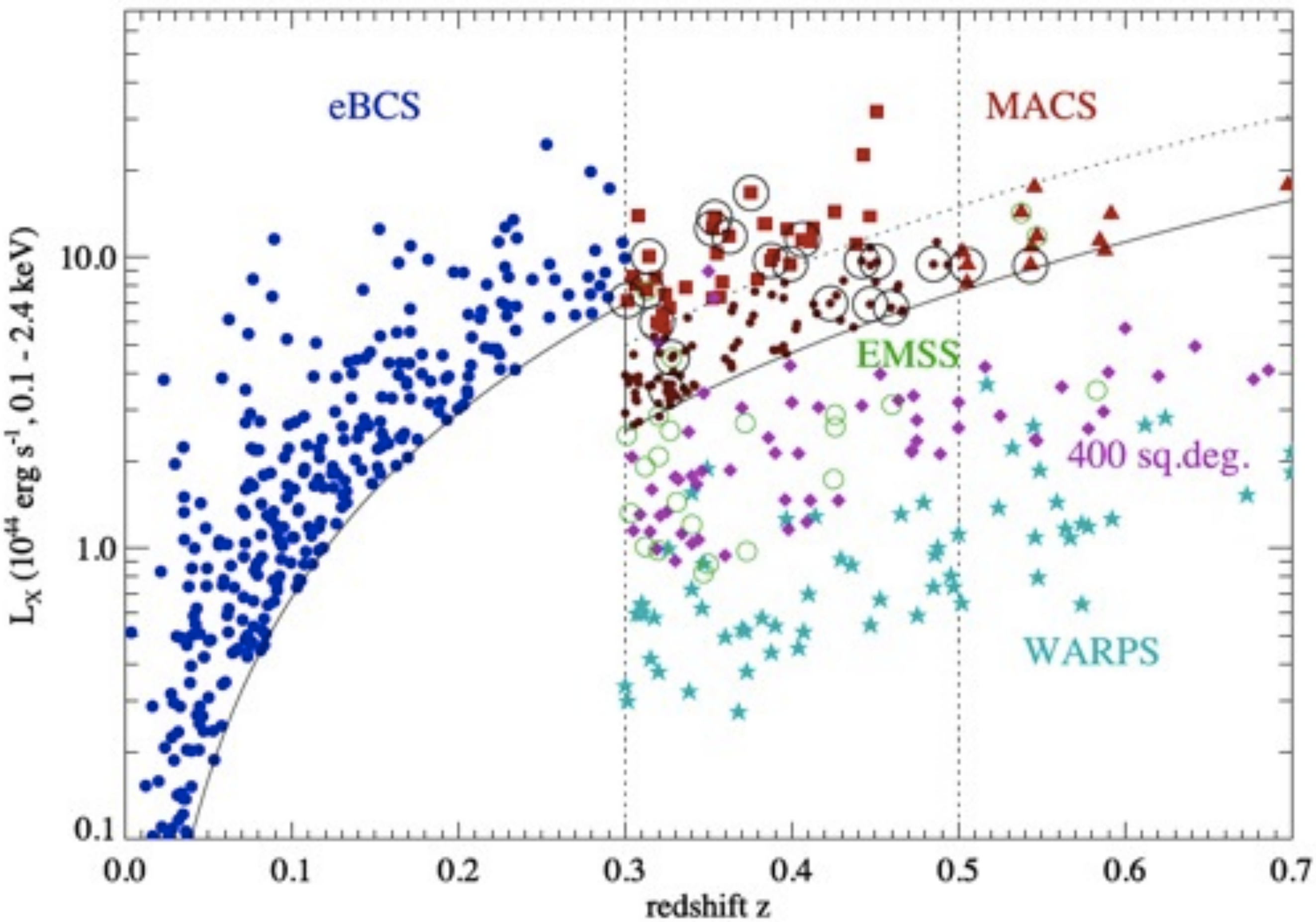


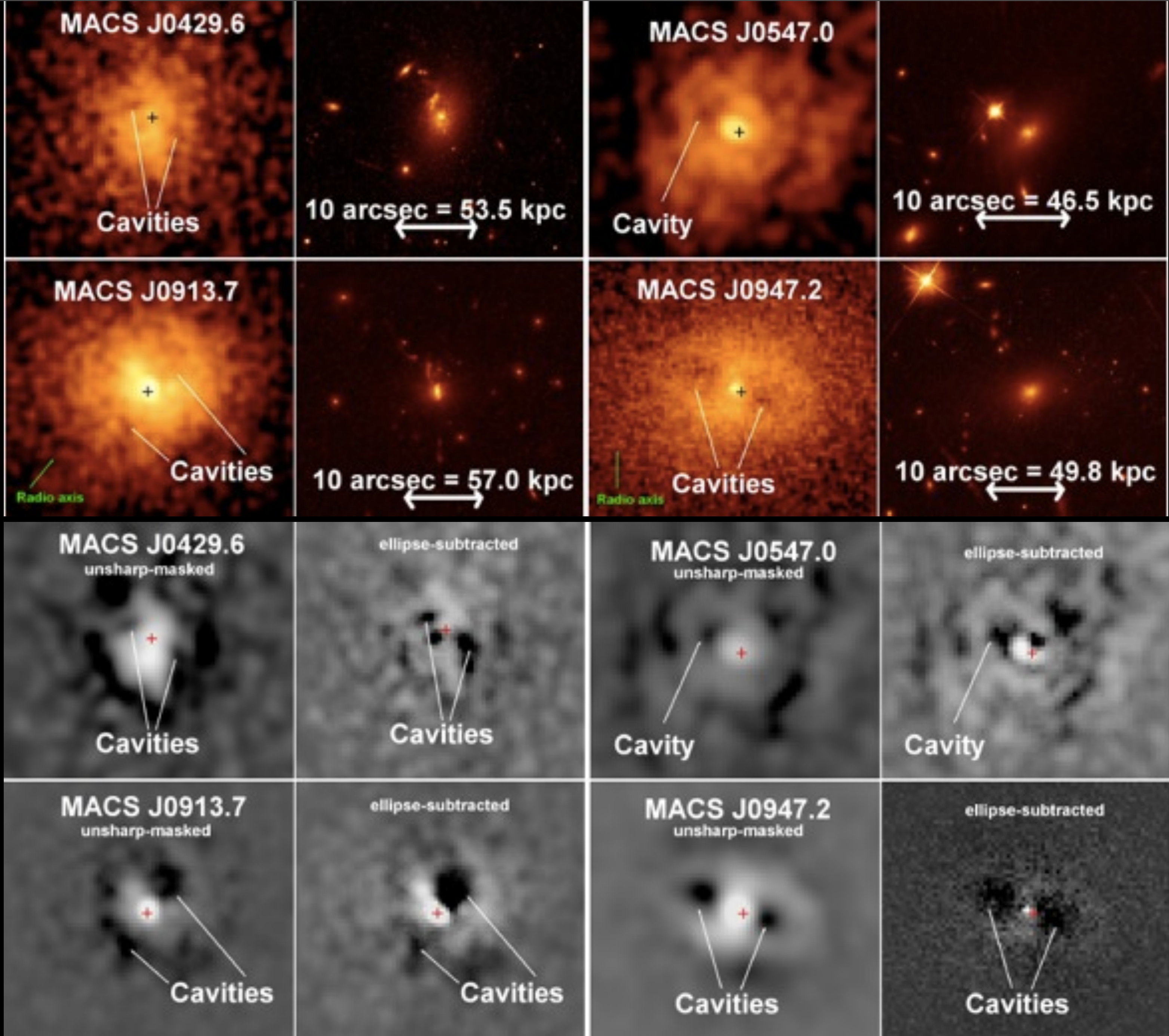
1.2Ms stack of XMM RGS spectra

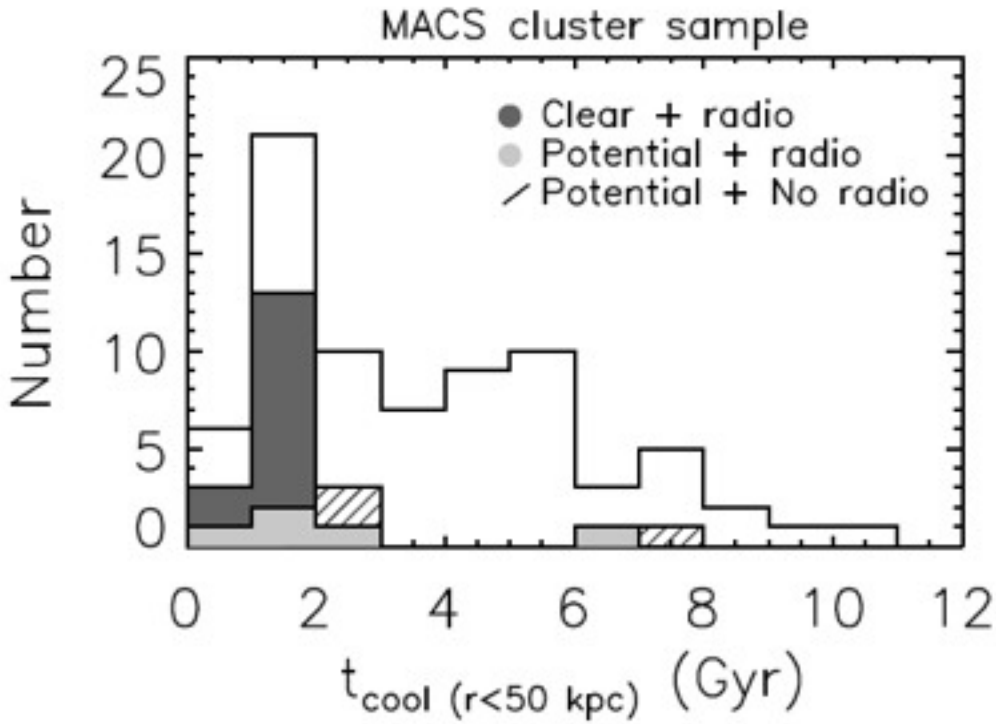
Sanders+Fabian+10

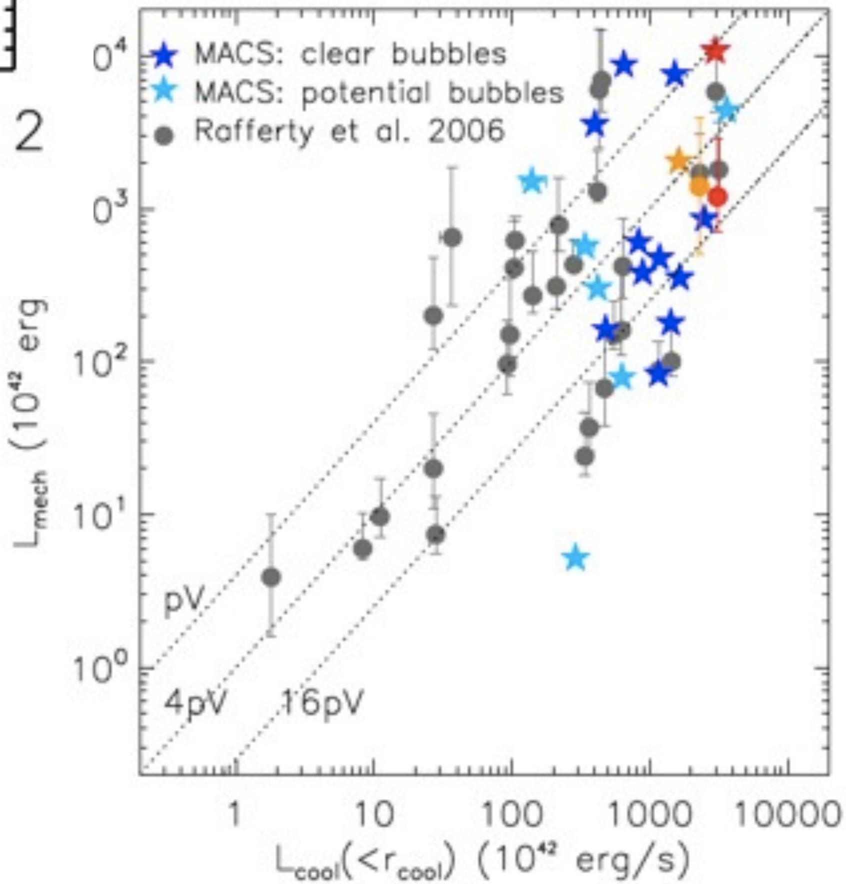


Feedback at z>0.3 Hlavacek-Larrondo+11

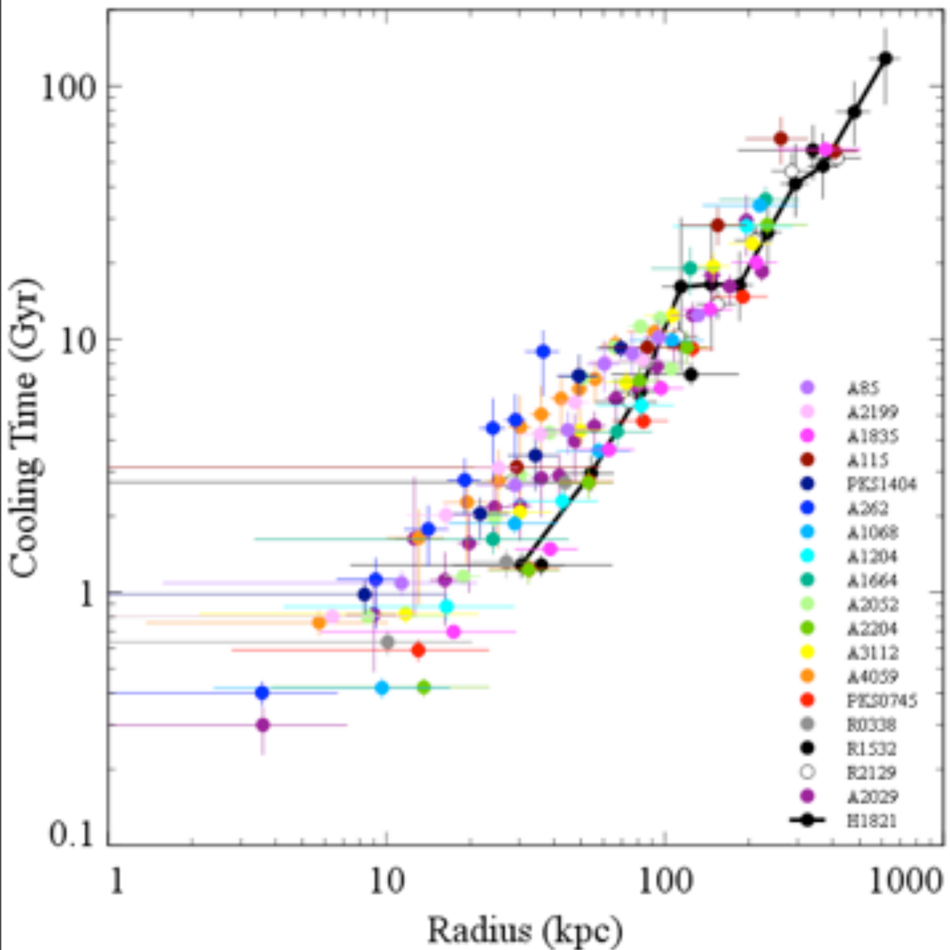


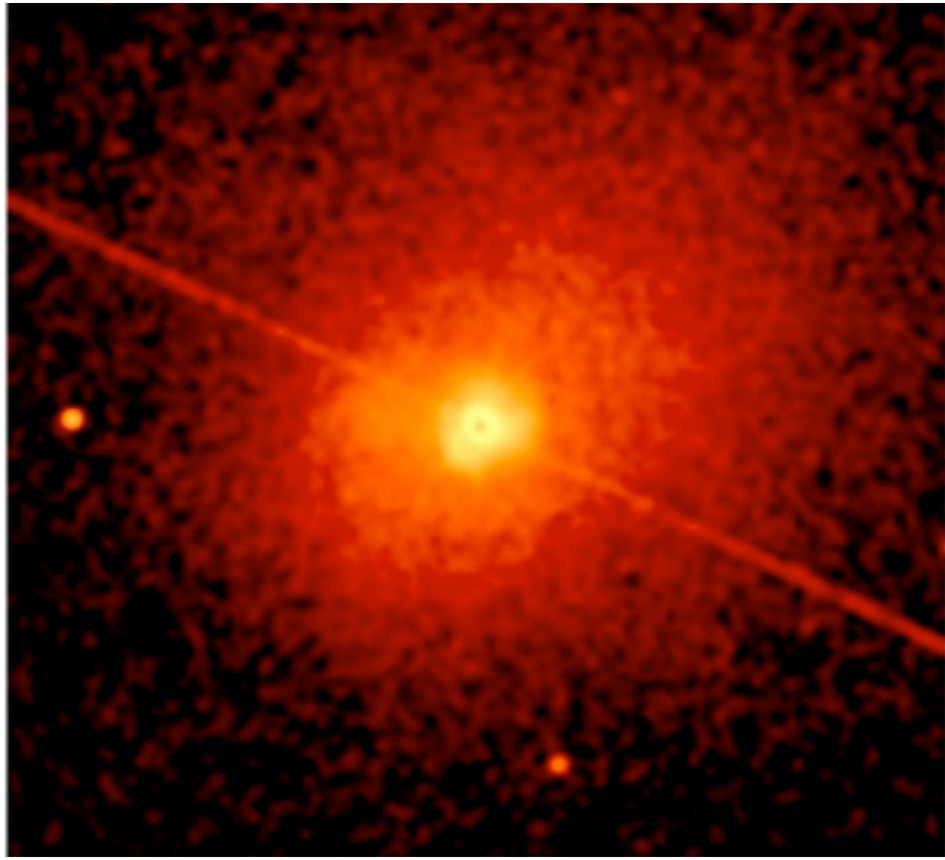

MACS J0429.6
Cavities
10 arcsec = 53.5 kpc
MACS J0547.0
Cavity
10 arcsec = 46.5 kpc
MACS J0913.7
Cavities
Radio axis
10 arcsec = 57.0 kpc
MACS J0947.2
Cavities
Radio axis
10 arcsec = 49.8 kpc
MACS J0429.6
unsharp-masked
Cavities
ellipse-subtracted
Cavities
MACS J0547.0
unsharp-masked
Cavity
ellipse-subtracted
Cavity
MACS J0913.7
unsharp-masked
Cavities
ellipse-subtracted
Cavities
MACS J0947.2
unsharp-masked
Cavities
ellipse-subtracted
Cavities


MACS cluster sample
Clear + radio
Potential + radio
Potential + No radio
Number
$t_{cool\ (r<50\ kpc)}$ (Gyr)


MACS: clear bubbles
MACS: potential bubbles
Rafferty et al. 2006
pV
4pV
16pV
L_{mech} (10^{42} erg
$L_{cool}(<r_{cool})$ (10^{42} erg/s)

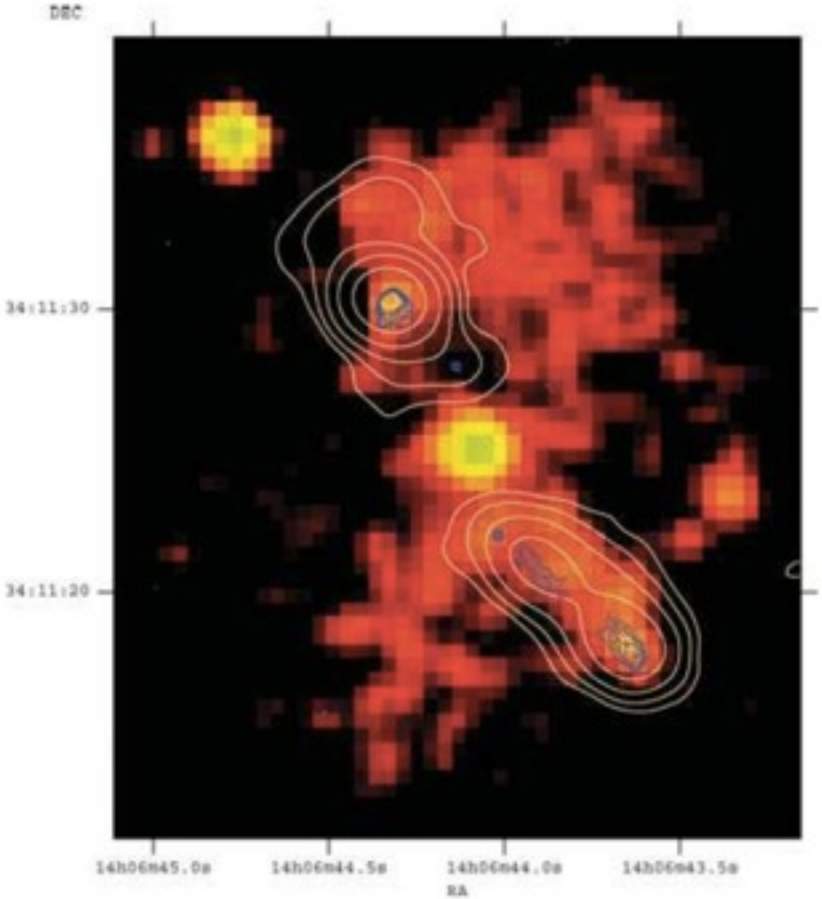
H1821+643 z=0.3 Russell+10

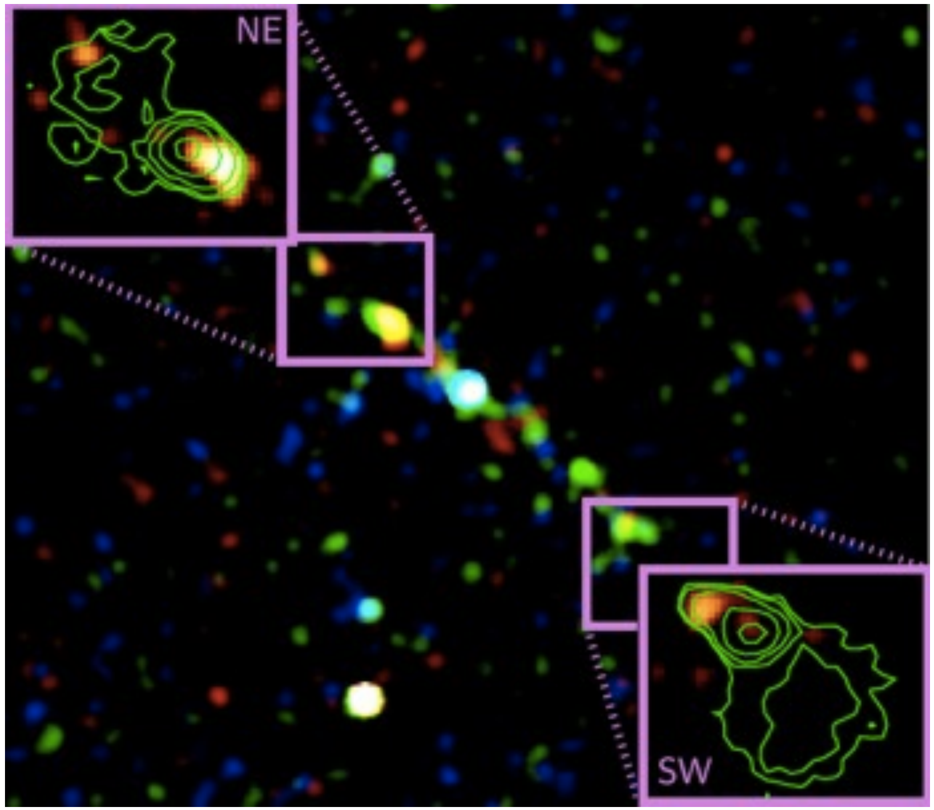




3C186 Siemiginowska+10 z=1.07

3C294 (z=1.785) and 4C23.56 (z=2.5)



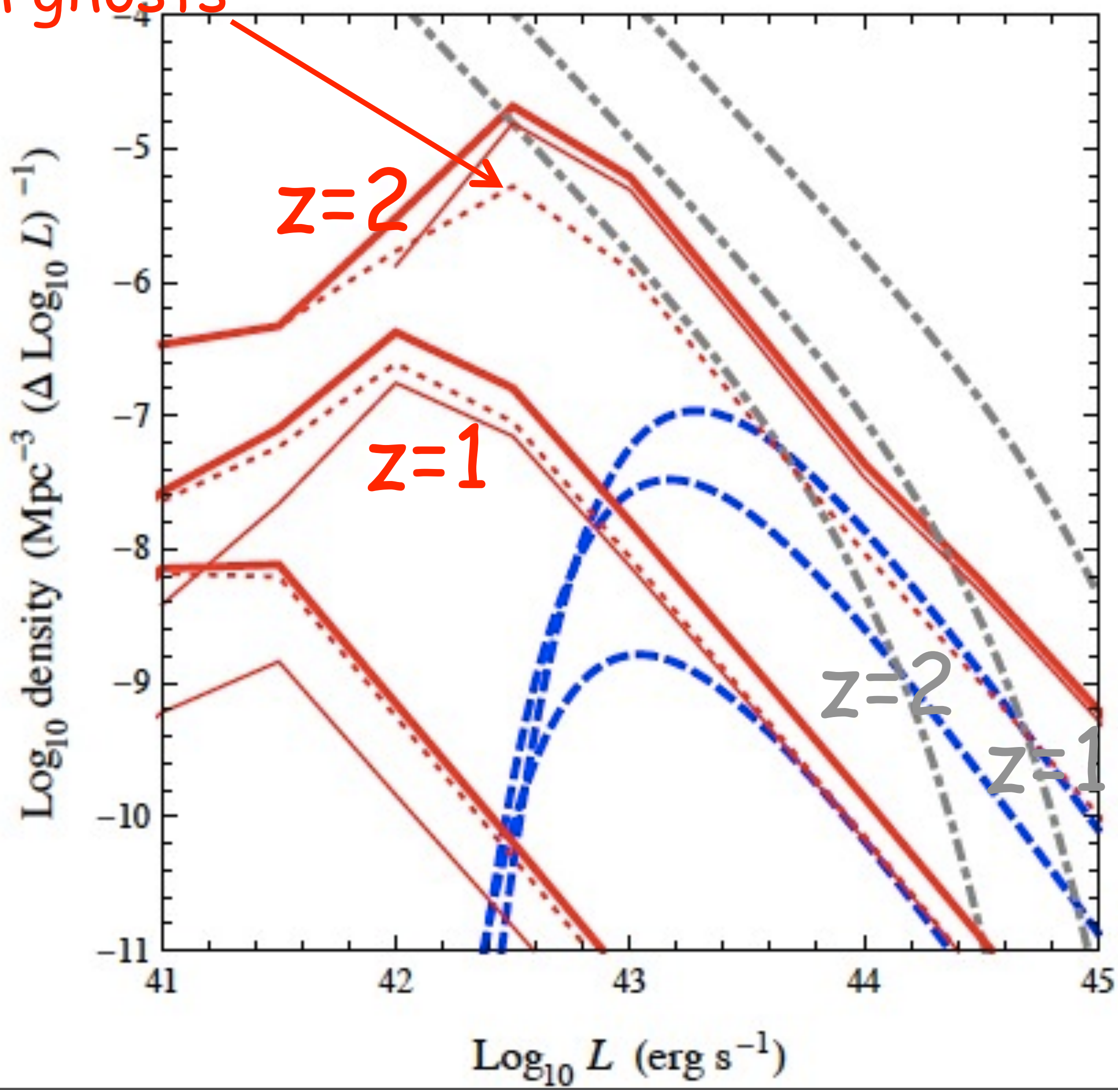


Fabian+03, Erlund+06

Blundell, Fabian11

Giant Radio sources (red)

Clusters (grey)



Mocz+11

For examples

See

Fabian+09

Summary

- Kinetic mode feedback operates in most massive galaxies, those with hot atmospheres, maintaining stellar mass. Parts of feedback loop observed (bubbles, sound waves, warm, cool and cold gas)
- Inner parts of hot atmosphere cooling radiatively and by mixing into cold gas

- e-ROSITA will find many more clusters including cool cores and open up study of feedback evolution
- Central quasars in clusters will complicate identifications
- ICCMB produces extended X-ray emission from giant radio galaxies; such objects can be more numerous than clusters above z~1.5