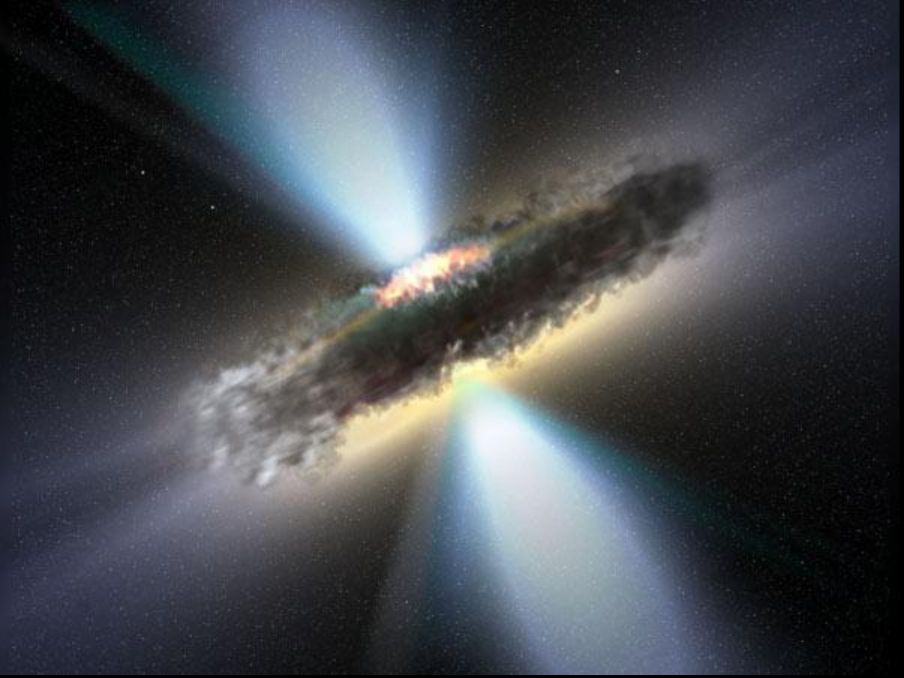
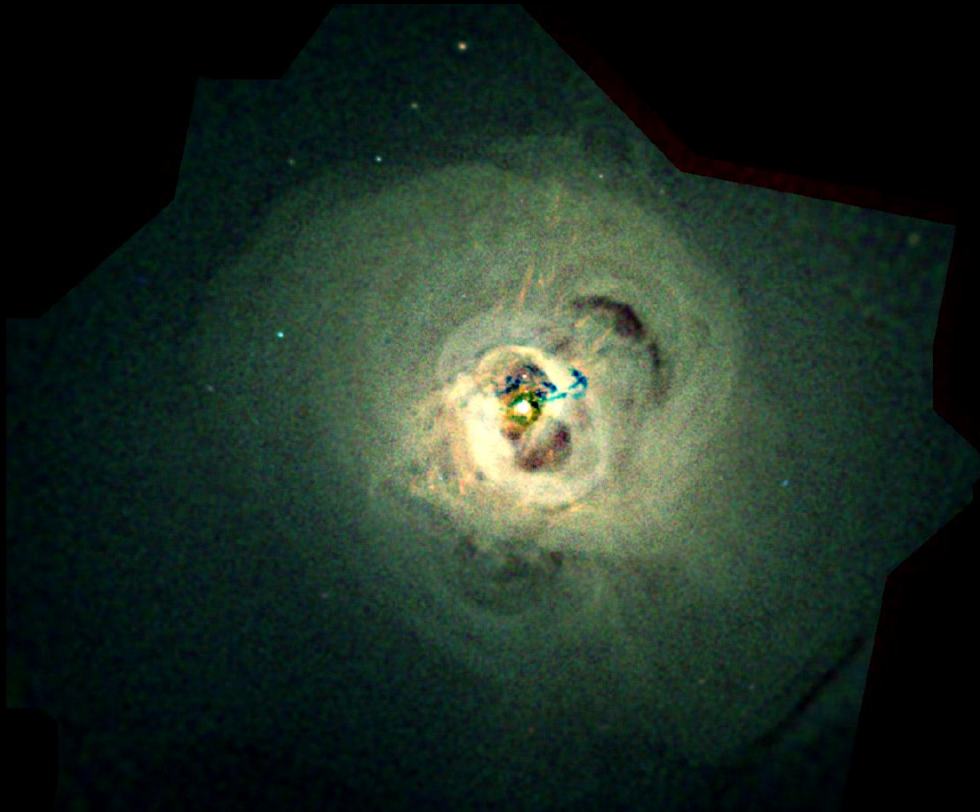
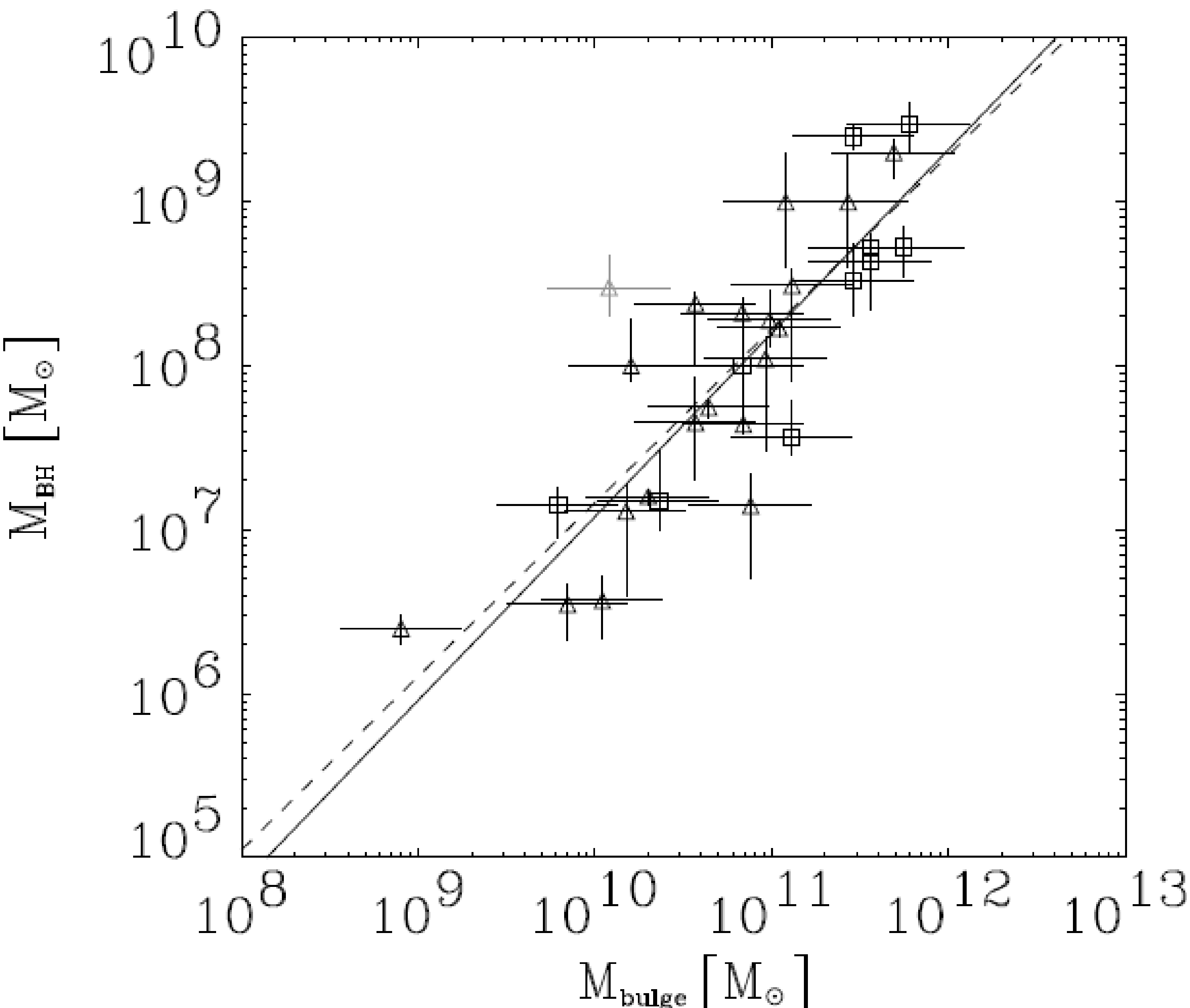


AC Fabian, Cambridge
UK

Cosmic Feedback from AGN





Haring+Rix04

Possible effect of central black hole on galaxy

- Binding energy of galaxy mass M ~$M\sigma^2$
- Mass of BH ~M/1000

- Energy released by BH E_{BH}~$0.1M_{BH}c^2$~$10^{-4}Mc^2$

- Therefore BE/E_{BH}~$10^4(\sigma/c)^2$

- Now σ<c/1000, BE~$0.01E_{BH}$
- So BH can easily affect galaxy growth

Possible effect of central black hole on host galaxy

$$E_{BlackHole} > 30 \times E_{Galaxy}$$

Energy released by growth of Black Hole

Gravitational Binding Energy of Host Galaxy

2 major modes for the interaction:

Kinetic (radio/jet) and Radiative (quasar/wind)

Radiative mode

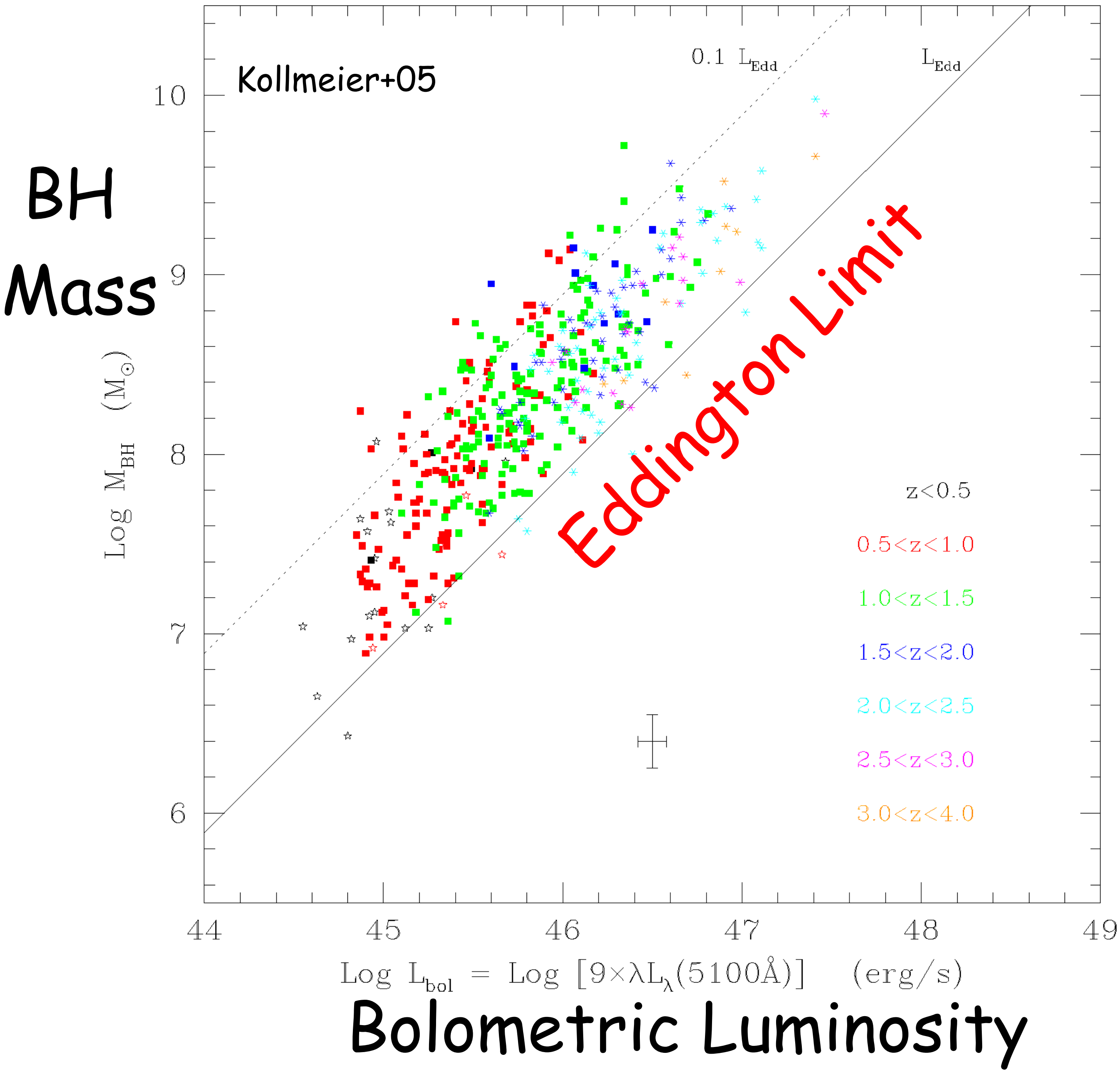
Quasar Feedback

- Energy terminates galaxy growth (Silk & Rees 1998; Blandford 1999; Haehnelt+98)

$M \propto \sigma^5$

- Momentum : wind (Fabian 99)
  radiation pressure (Fabian02)
  (King 2003; Murray +04; Sazanov+05)

$M \propto \sigma^4$



BH
Mass
Bolometric Luminosity
Kollmeier+05
Eddington Limit
0.1 L_Edd
L_Edd
Log M_BH (M_⊙)
Log L_bol = Log [9×λL_λ(5100Å)] (erg/s)
z<0.5
0.5<z<1.0
1.0<z<1.5
1.5<z<2.0
2.0<z<2.5
2.5<z<3.0
3.0<z<4.0
6
7
8
9
10
44
45
46
47
48
49

The Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T}$$

The effective Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T}$$

$$L'_{Edd} = \frac{4\pi G M_{gal} m_p c}{\sigma_d}$$

$$\left(\frac{M_{gal}}{M_{bh}} = \frac{\sigma_d}{\sigma_T} = 500 \right)$$

The effective Eddington limit

$$L_{Edd} = \frac{4\pi G M_{bh} m_p c}{\sigma_T} \qquad L_{Edd}^{'} = \frac{4\pi G M_{gal} m_p c}{\sigma_d}$$

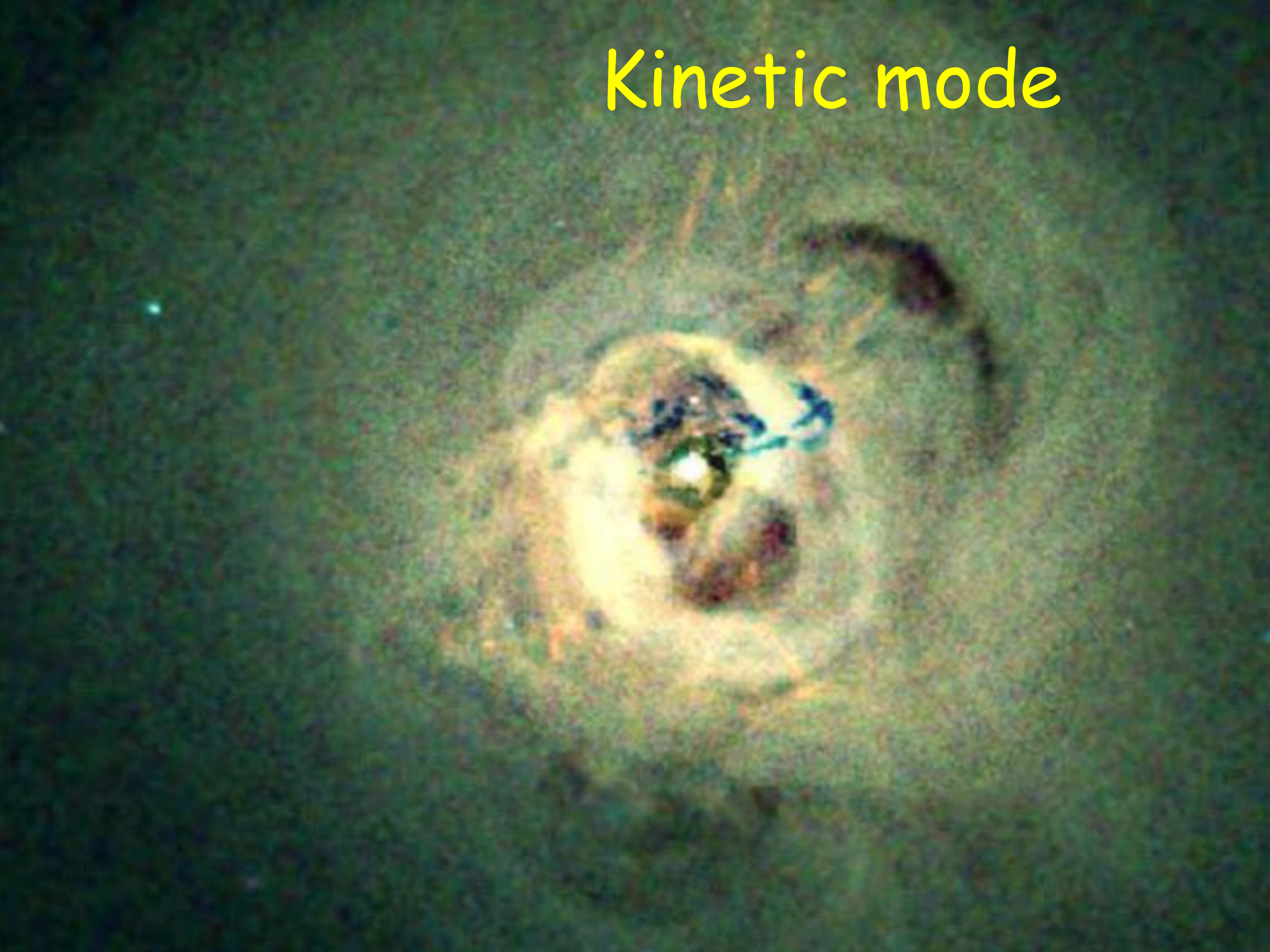
$$\left(\frac{M_{gal}}{M_{bh}} = \frac{\sigma_d}{\sigma_T} = 500 \right)$$

$$M_{bh} = \frac{f\sigma^4}{\pi G^2 m_p} \sigma_T$$

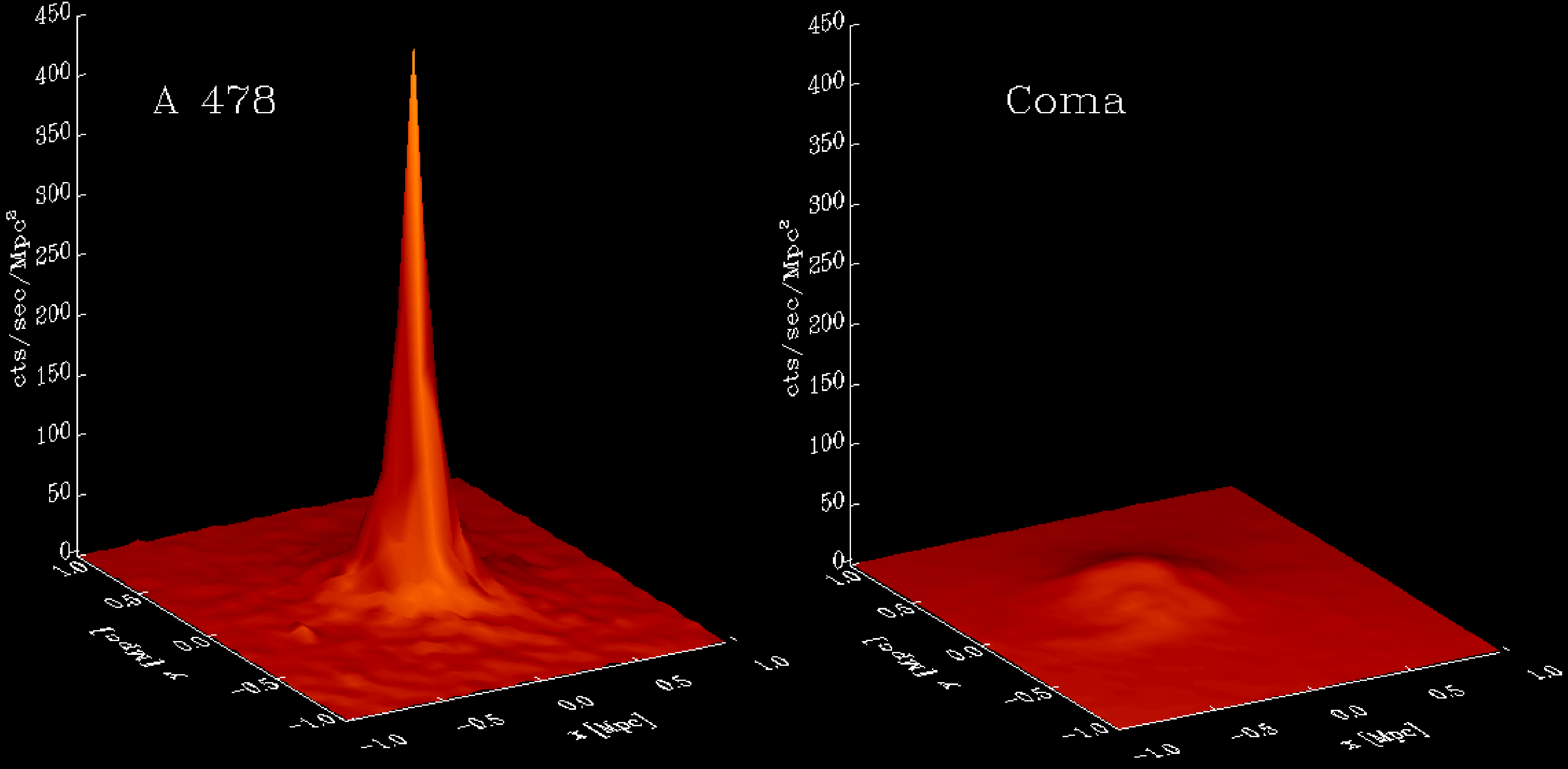
Isothermal galaxy

Radiative feedback difficult to observe directly since necessitates radiation being absorbed

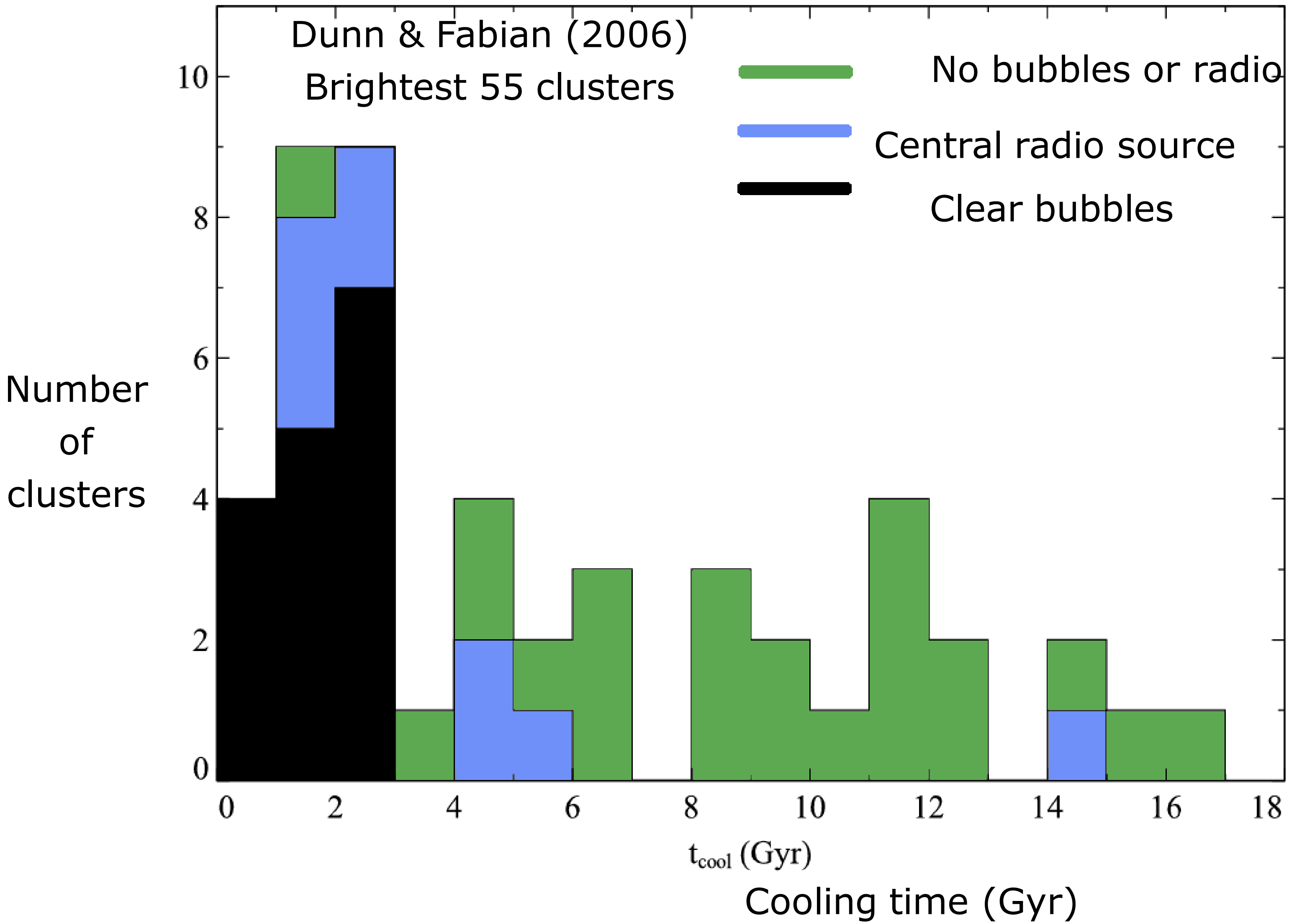
Kinetic mode



X-ray surface brightness of typical clusters of galaxies



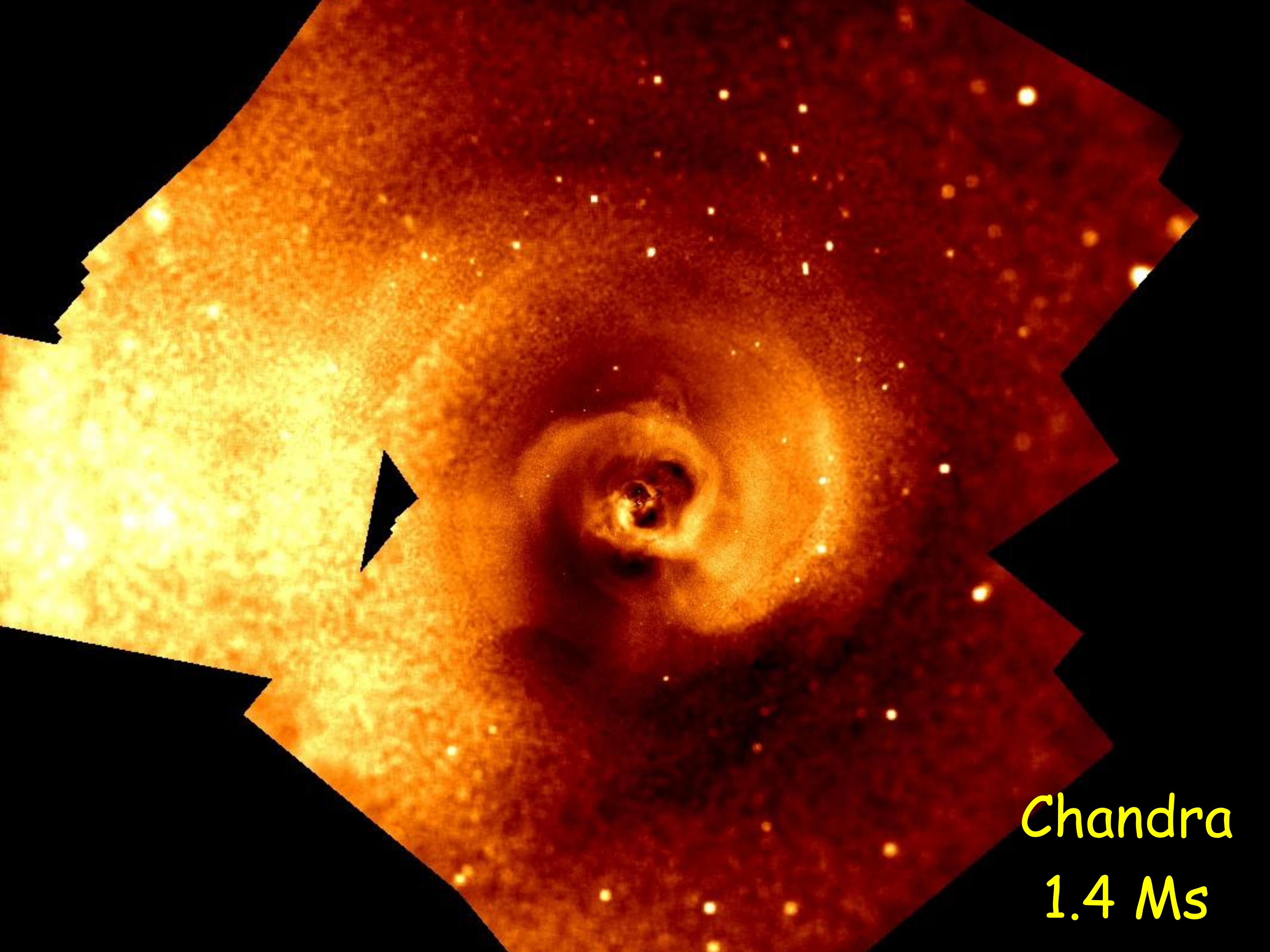
Duty cycle is 70-90%

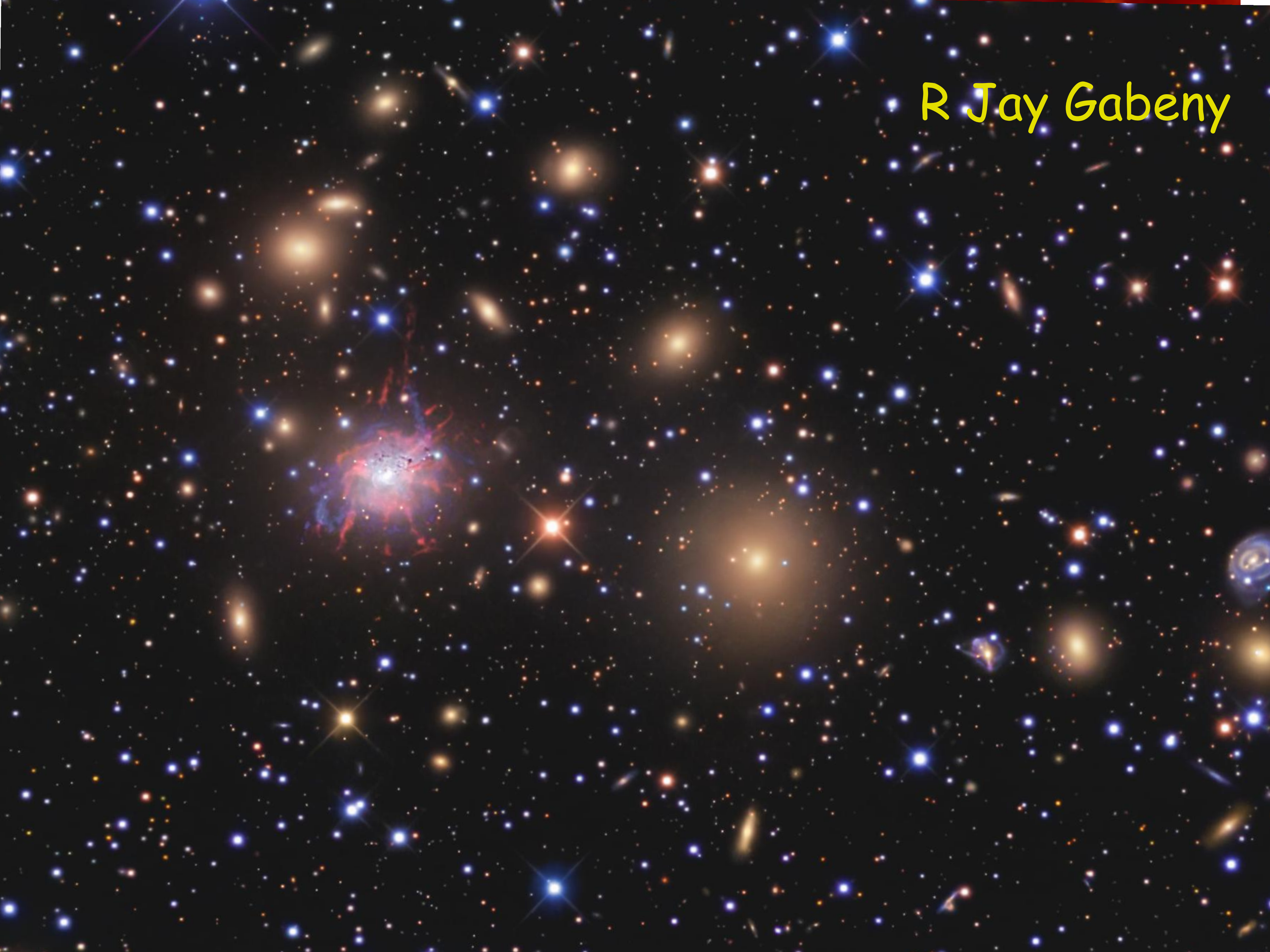


See also Birzan+04, Rafferty+06, Dunn+F07

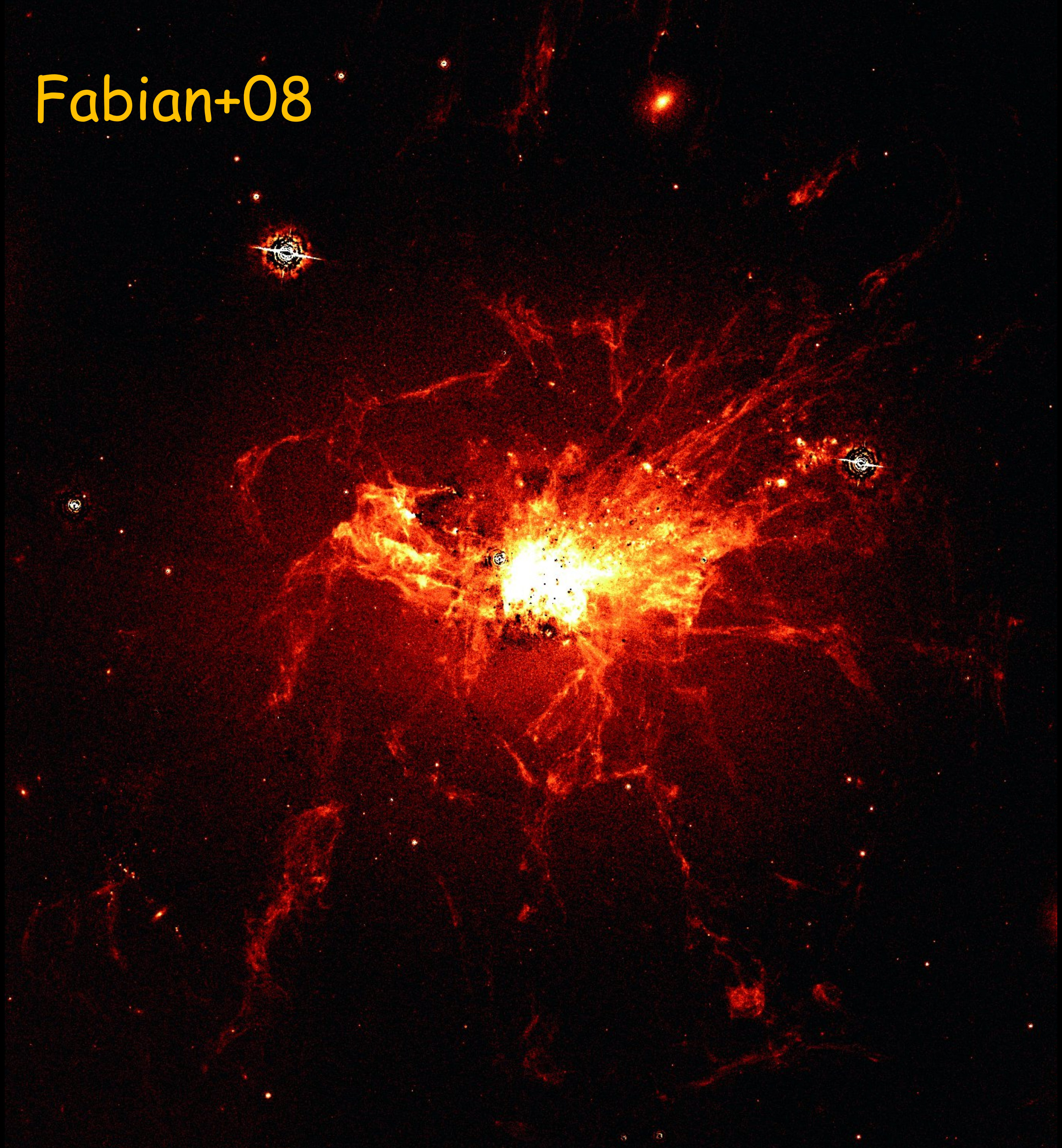
Issues

- Total Energy not an issue.
- How does energy get distributed?
- How close is the heating/cooling balance?
- 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 kT<0.5 keV with radiative cooling time ~10^7yr) prevented from cooling?


Chandra
1.4 Ms

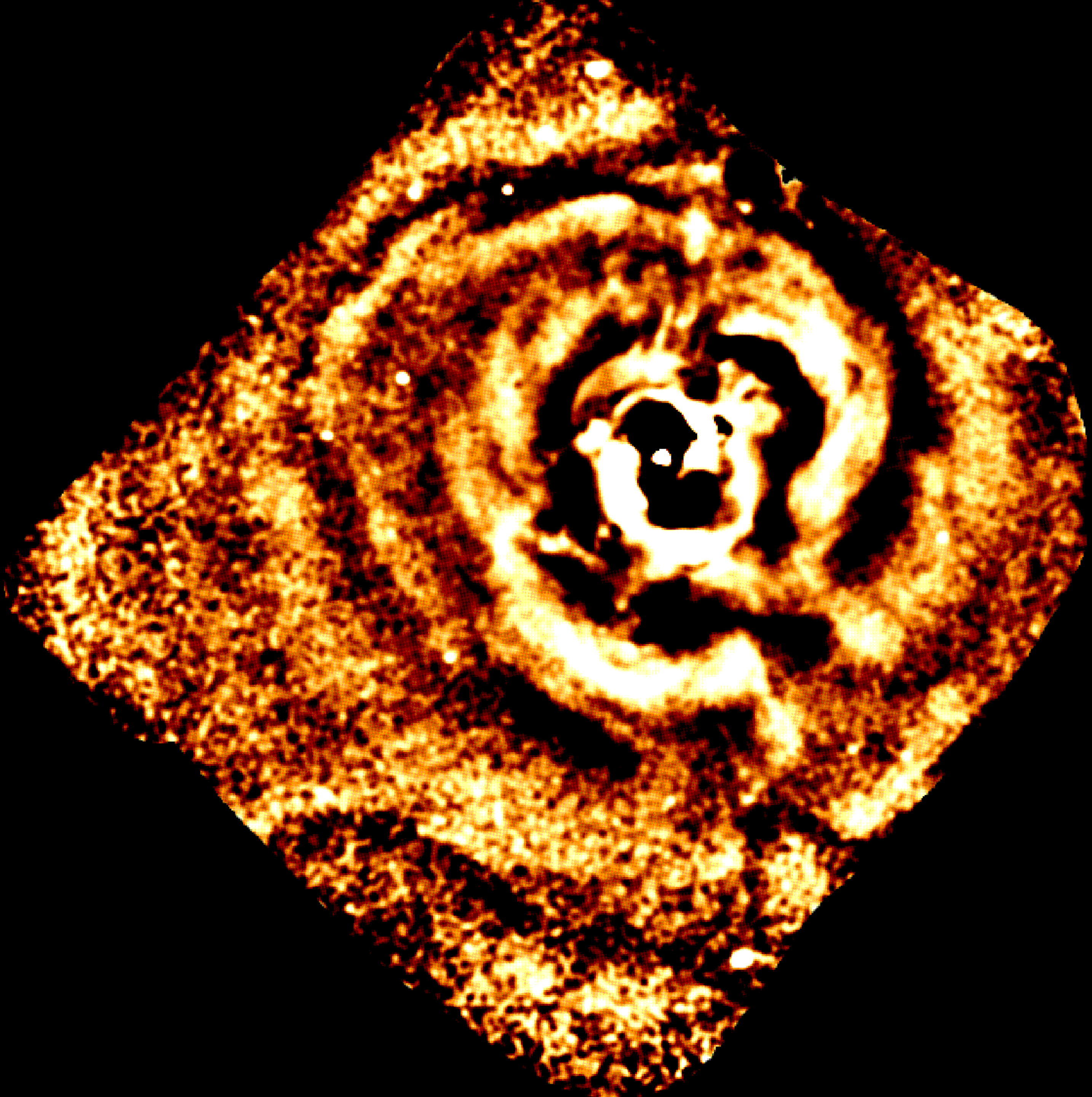

R Jay Gabeny

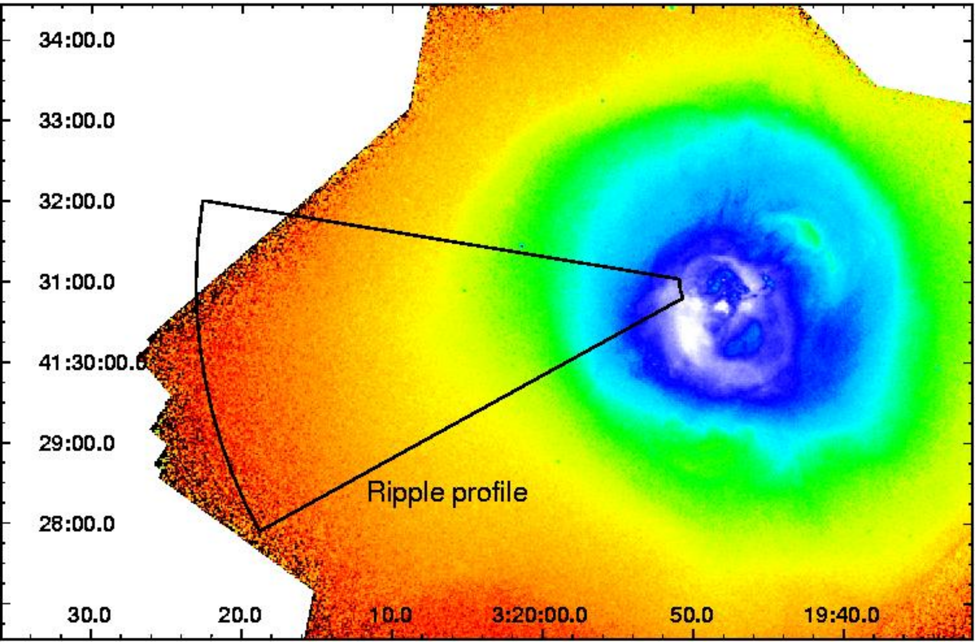
Optical Fabian+08

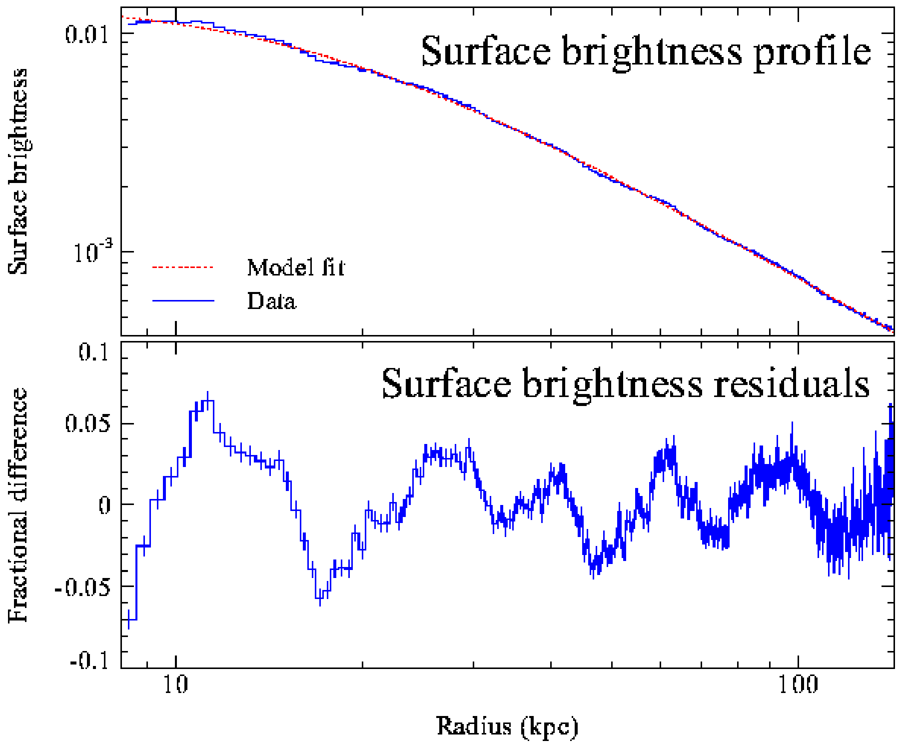


Perseus


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

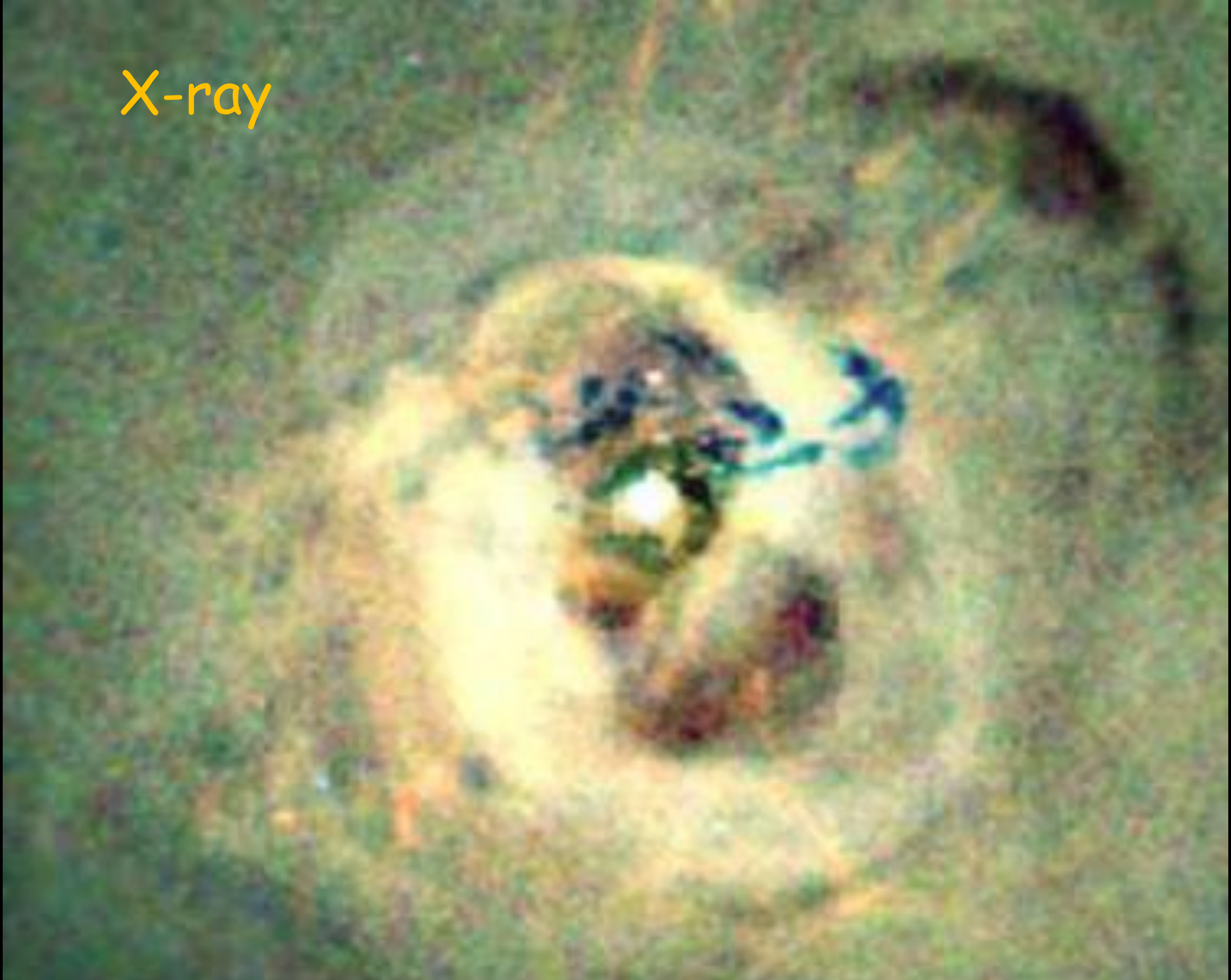




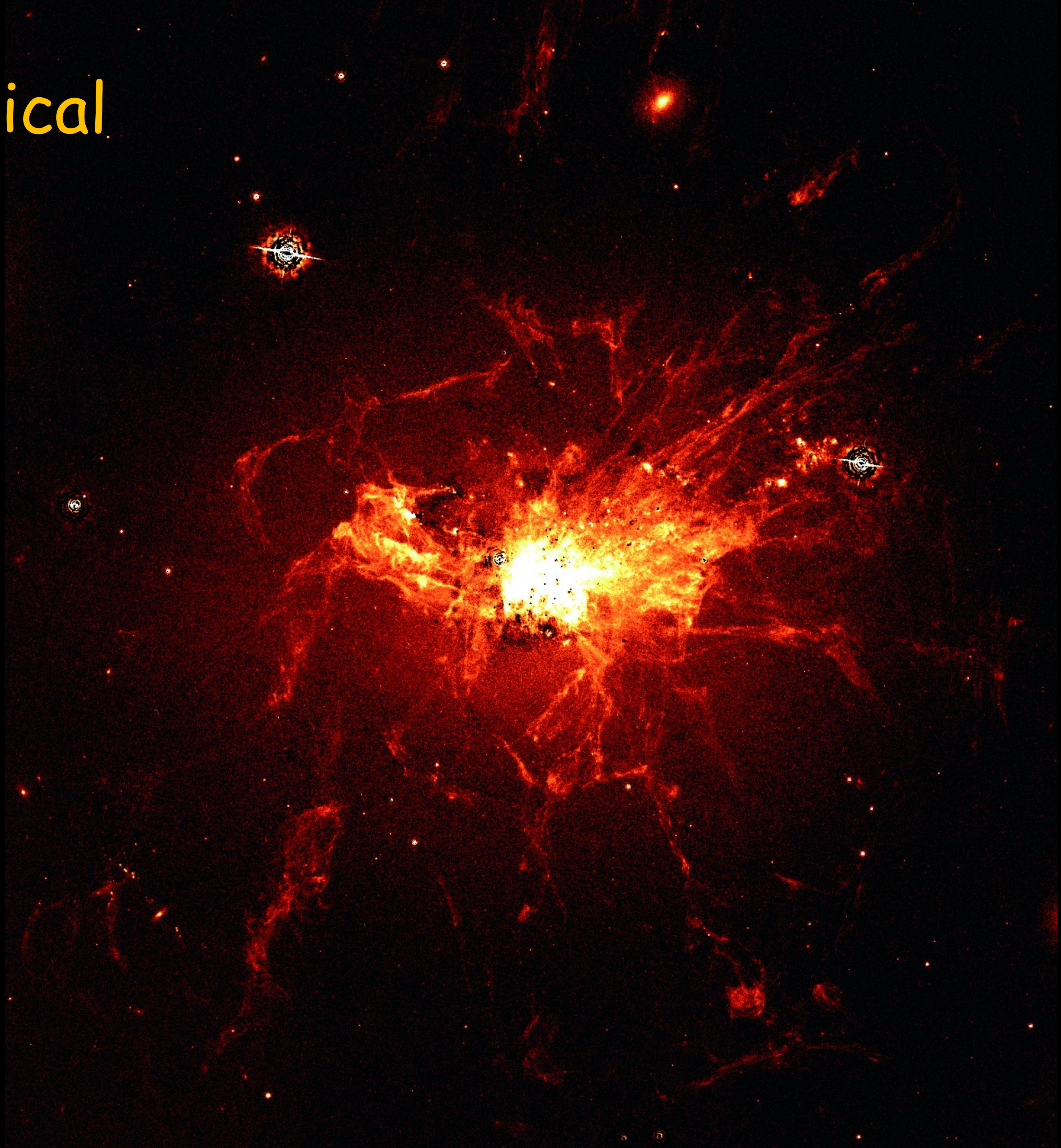


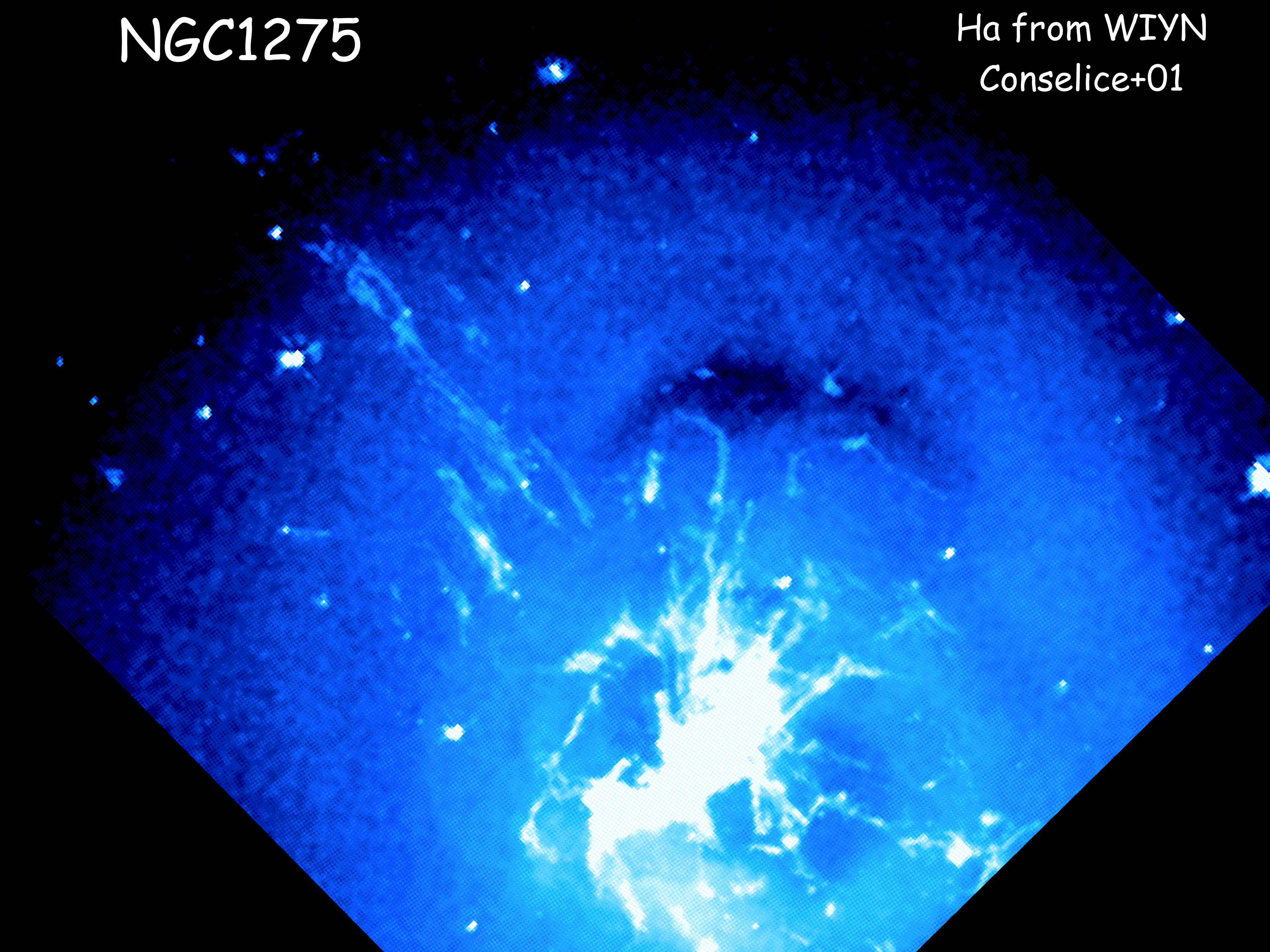
Power in ripples (sound waves) ~ X-ray luminosity within 70 kpc

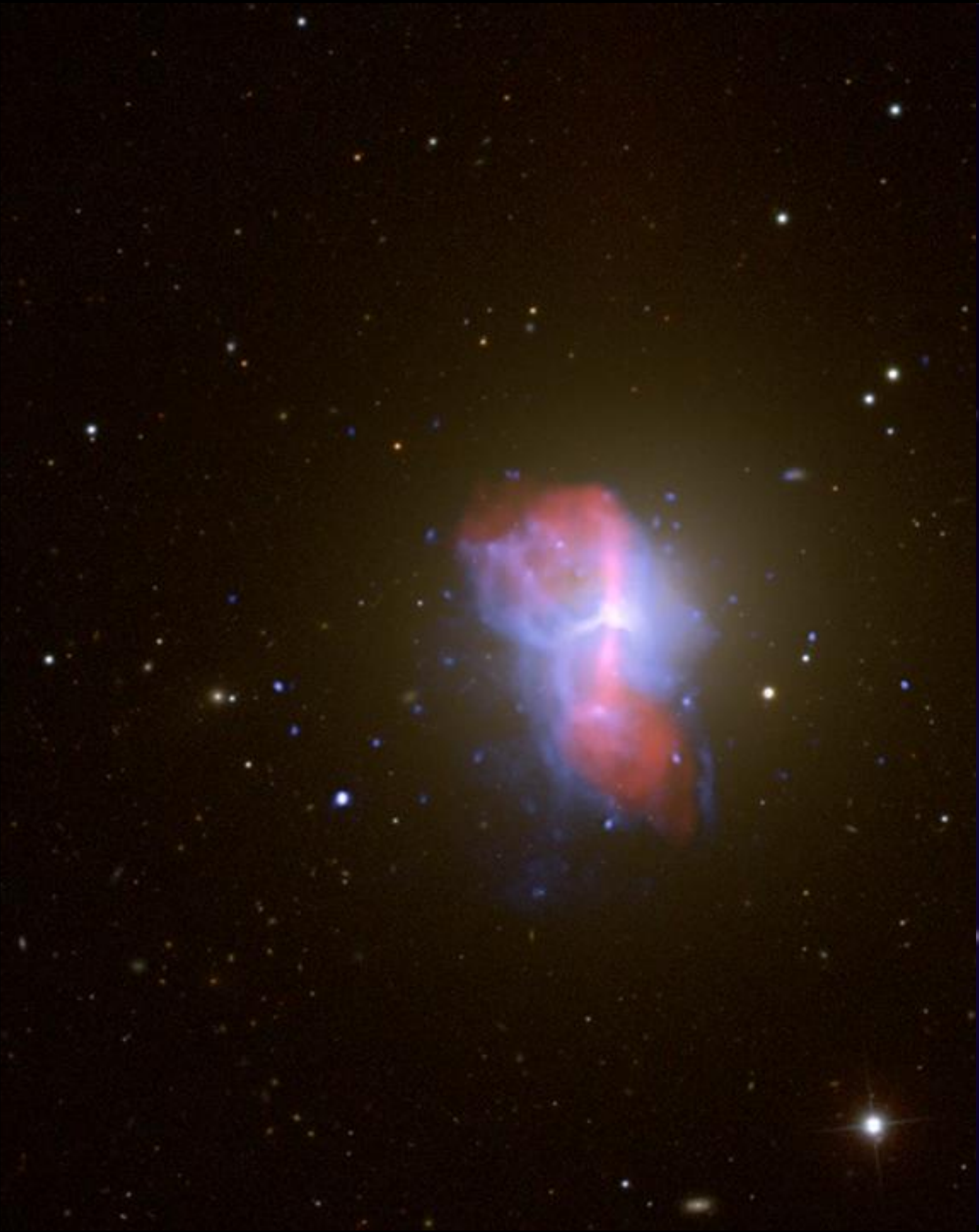
Also seen in Centaurus, Virgo…


X-ray

Optical

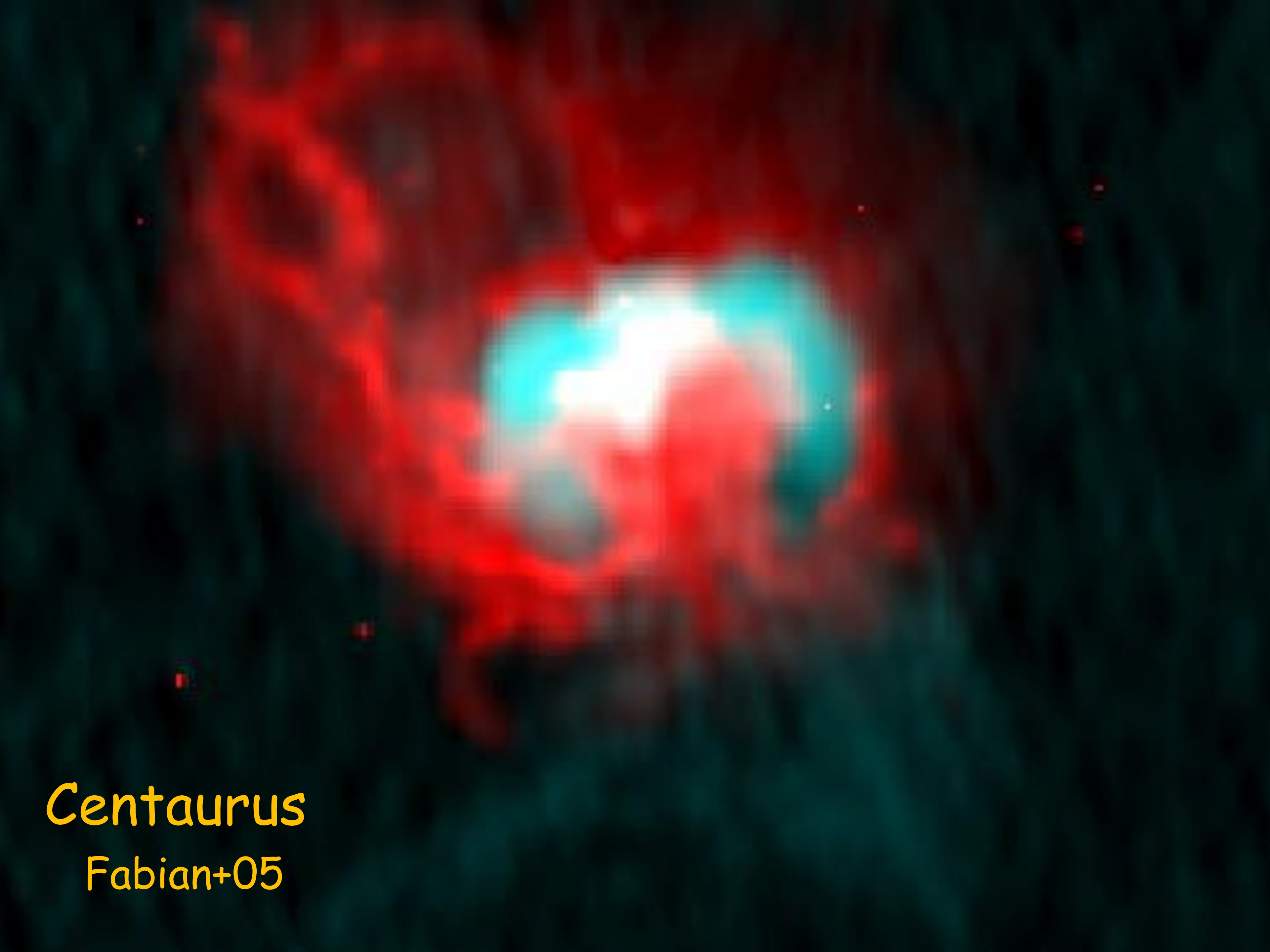



NGC1275
Ha from WIYN
Conselice+01



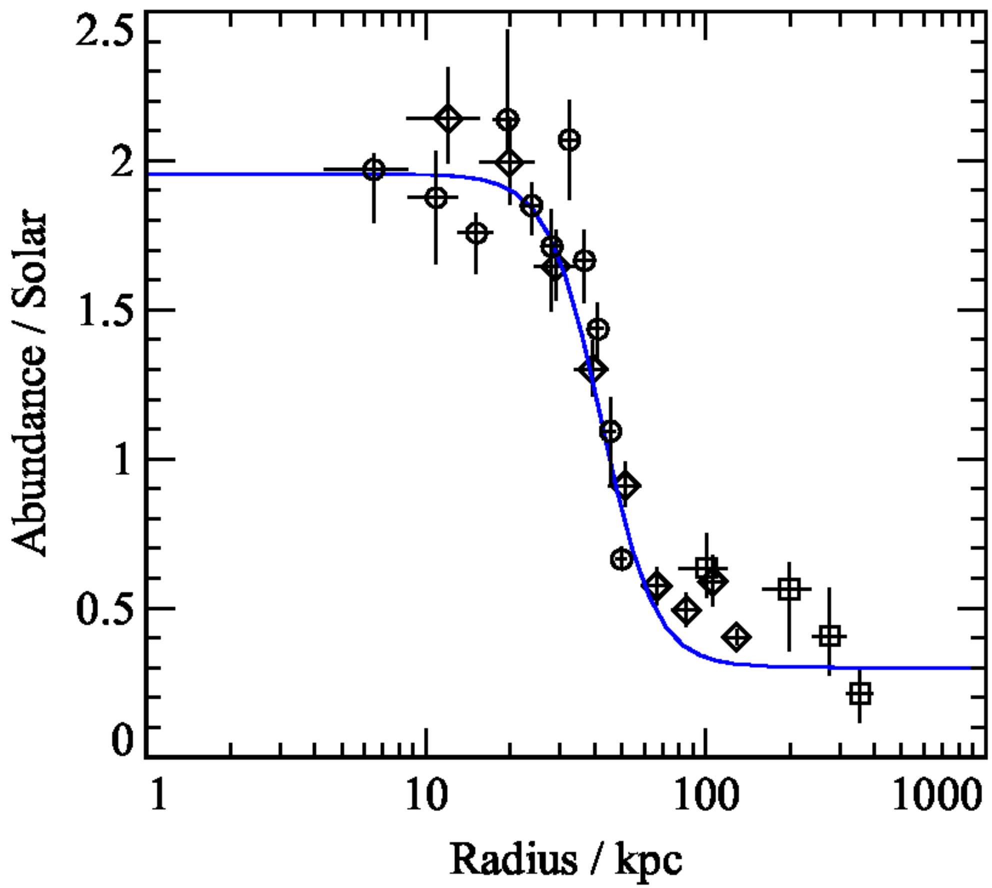
M84

Hydra A


Centaurus
Fabian+05

Cen cluster: Abundance profile implies little diffusion/mixing

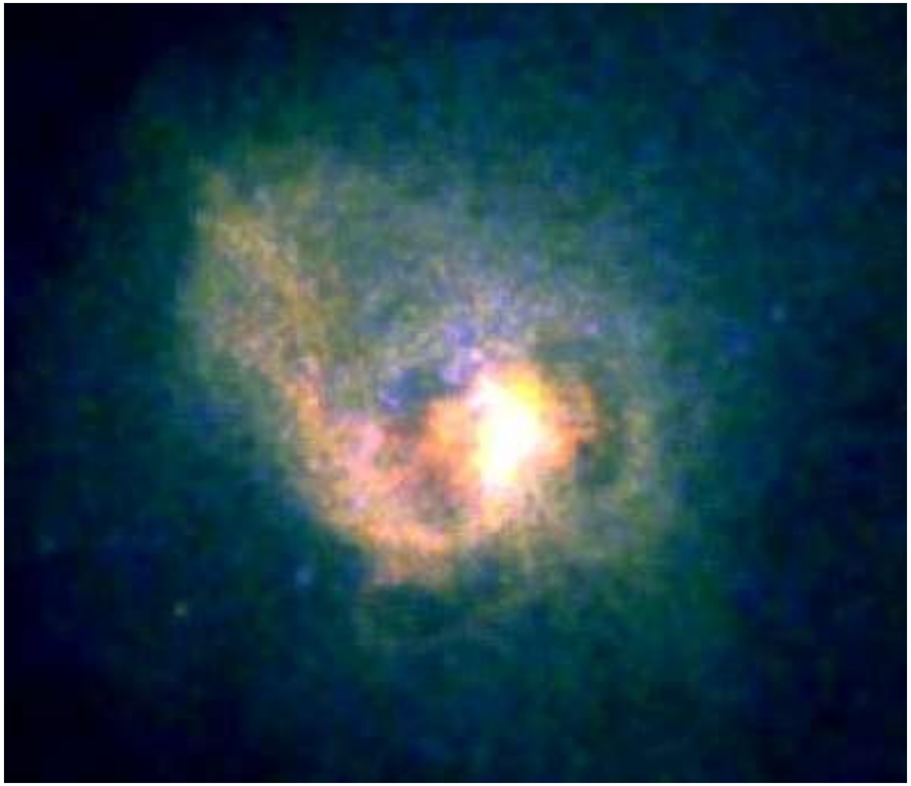
Graham+06 (following method of Rebusco+05)

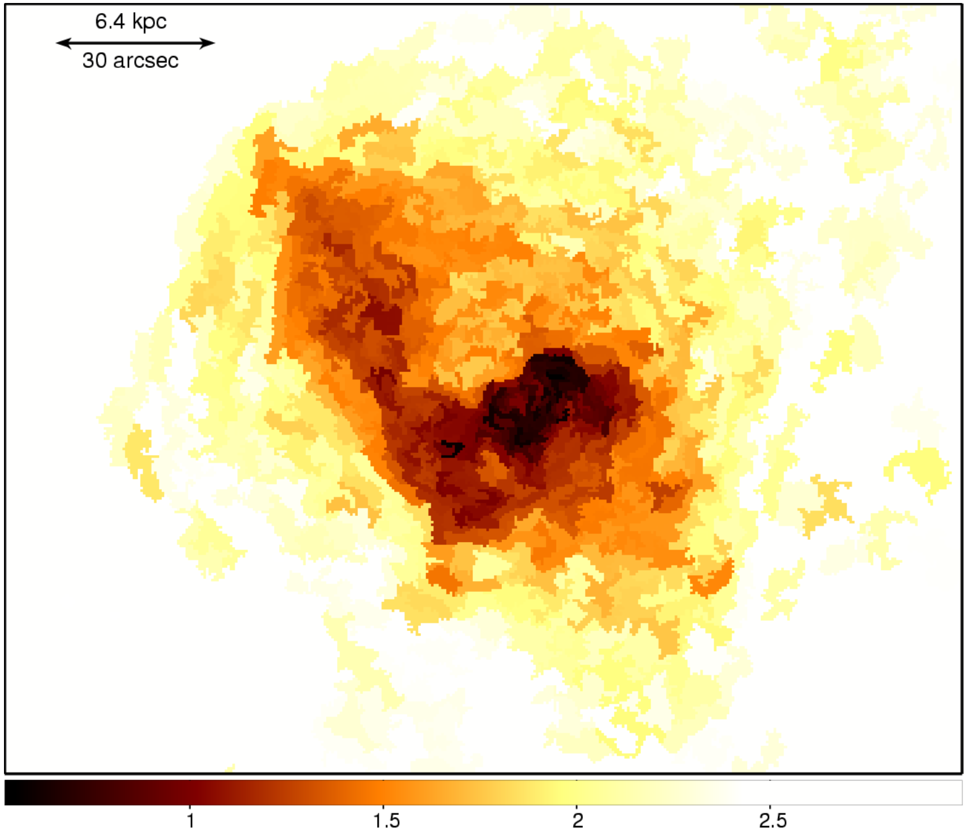


Cool X-ray gas in Centaurus

200 ks Chandra observation

Crawford et al 2005

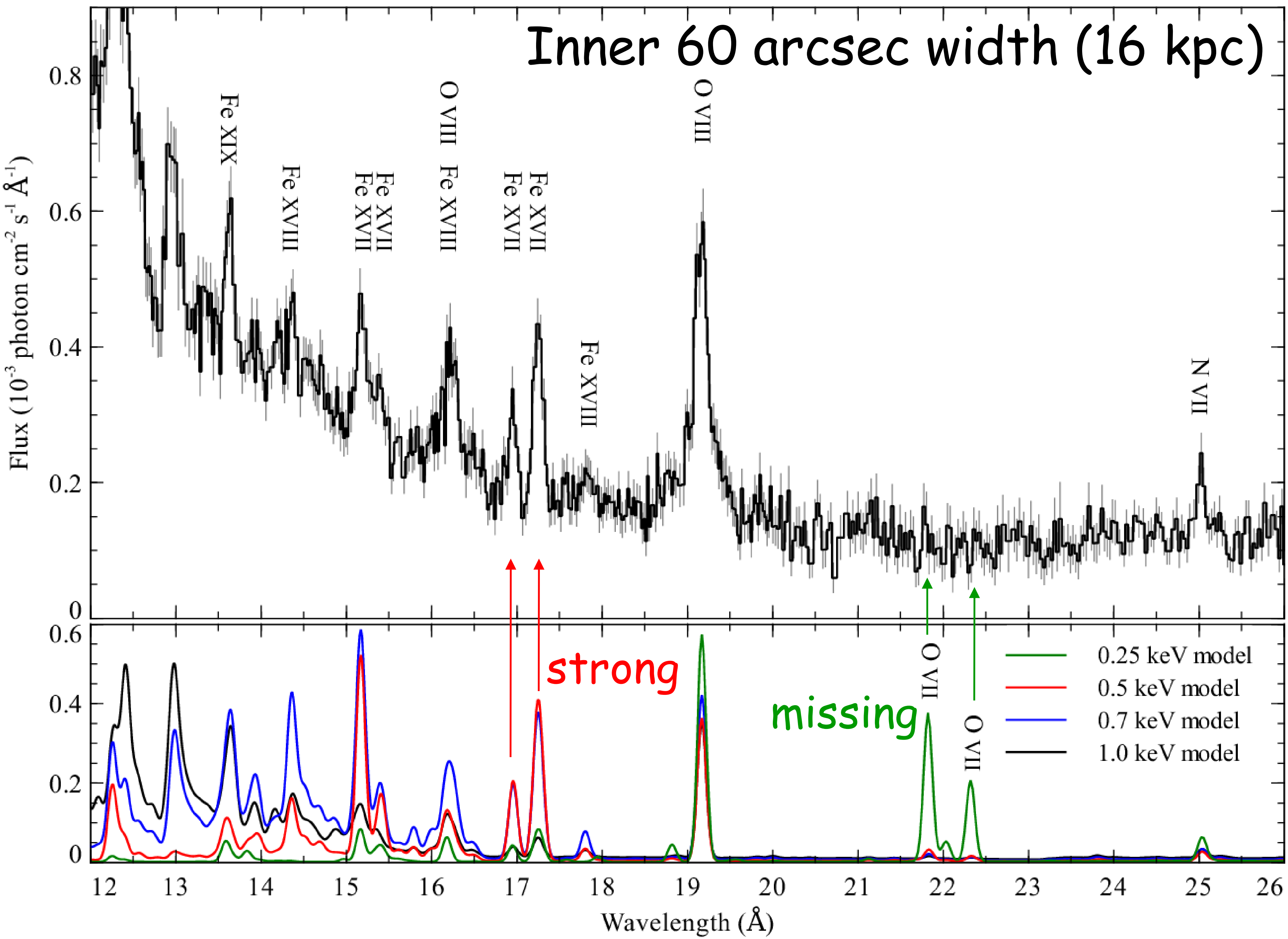




Temperature (keV)

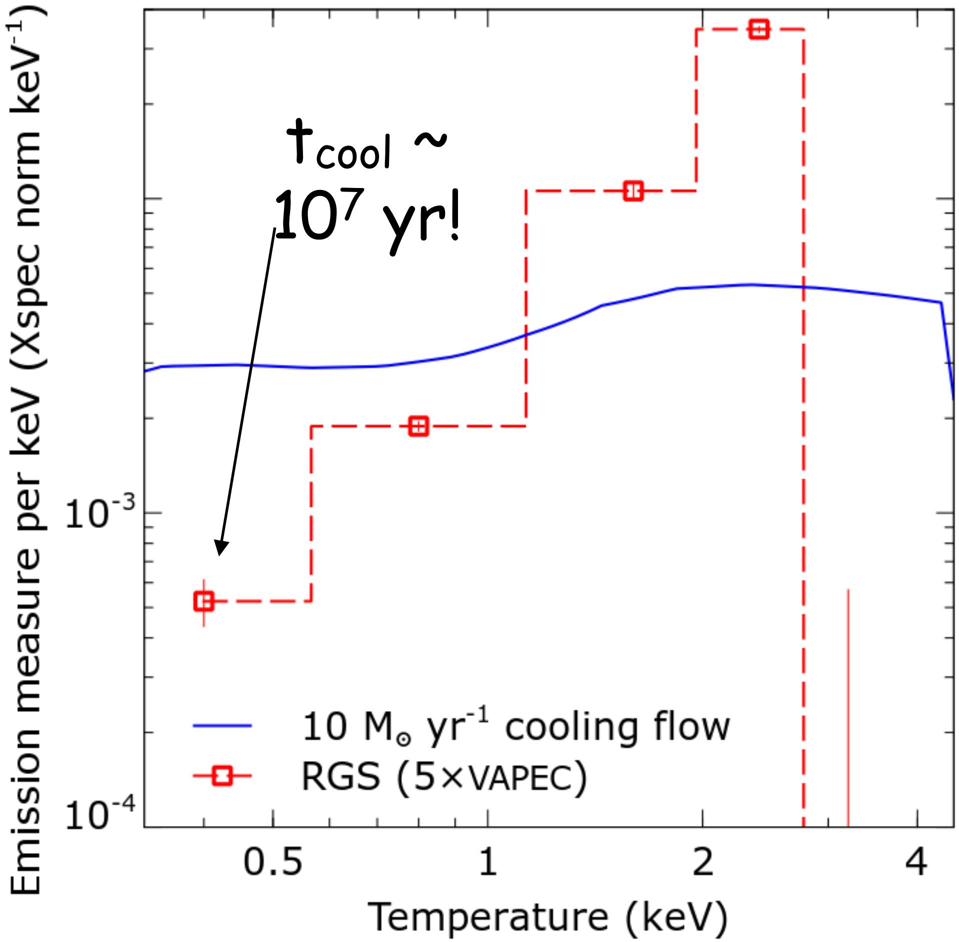
Shows feedback (cavities) and cool gas (~0.7 keV) in CCD spectra

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

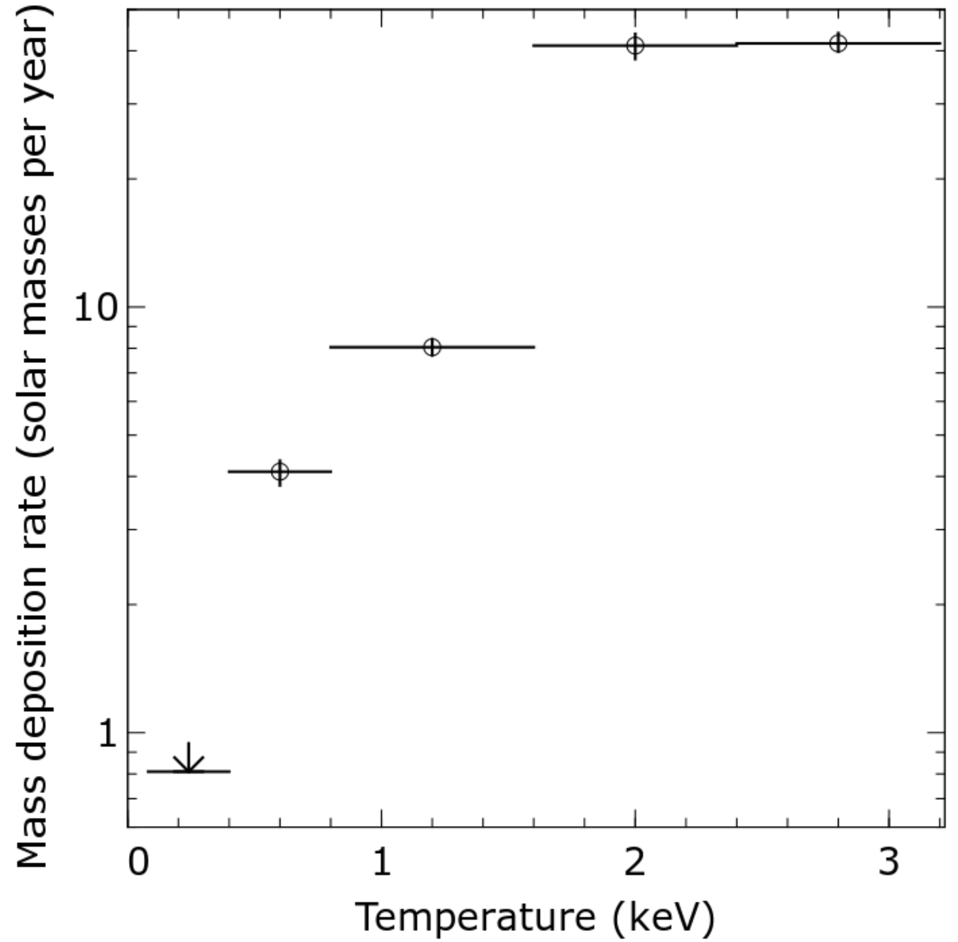


Inner 60 arcsec width (16 kpc)
Flux (10^-3 photon cm^-2 s^-1 Å^-1)
Fe XIX
Fe XVIII
Fe XVII
Fe XVII
O VIII
Fe XVIII
Fe XVII
Fe XVII
Fe XVIII
O VIII
N VII
strong
missing
O VII
O VII
0.25 keV model
0.5 keV model
0.7 keV model
1.0 keV model
Wavelength (Å)

Spectral fitting limits on gas kT

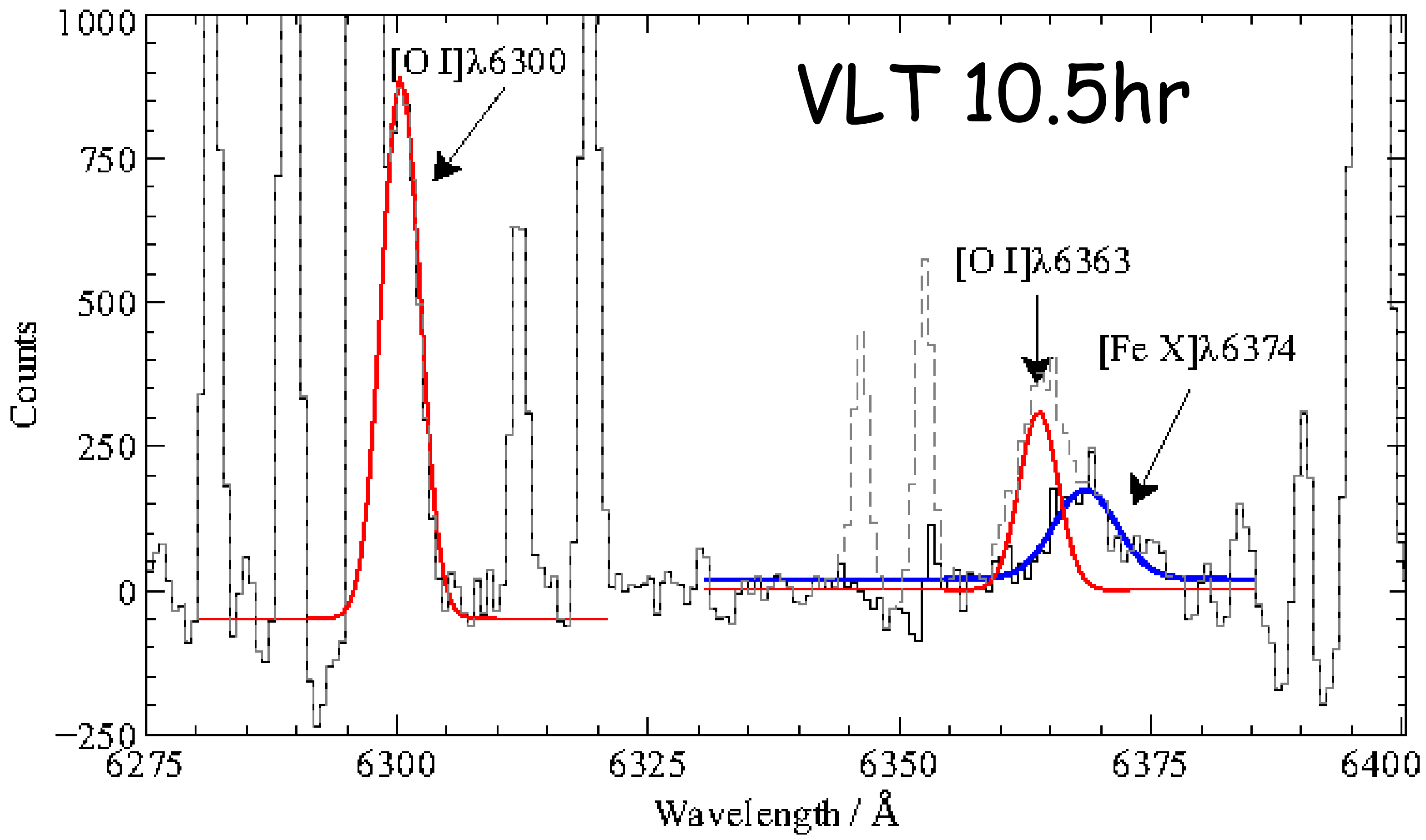


Multi temperature model



Cooling flow model

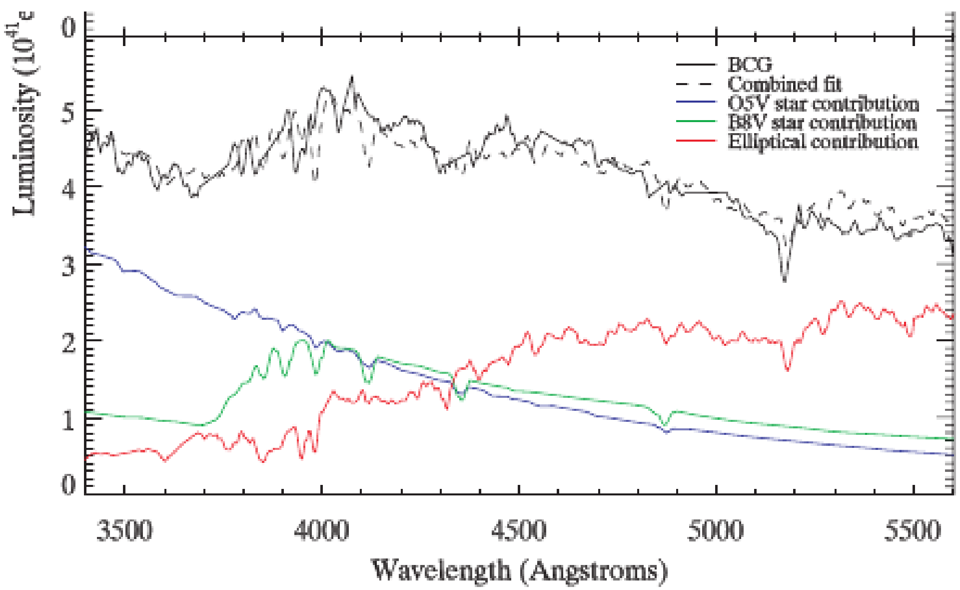
Coronal line emission [FeX] from 10^6K gas in Centaurus Canning+10

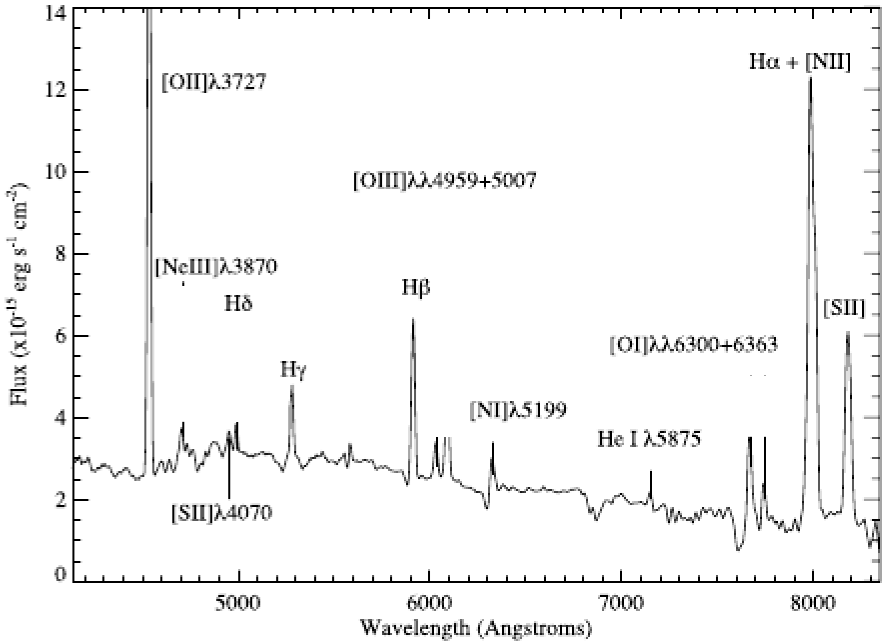


Perseus SFR~20 Msunpyr   Canning+10

RXCJ1504 Ogrean+10 z=0.2

SFR~140 Msunpyr





14 S. Ehlert et al. +10 MACS J1931 z=0.35

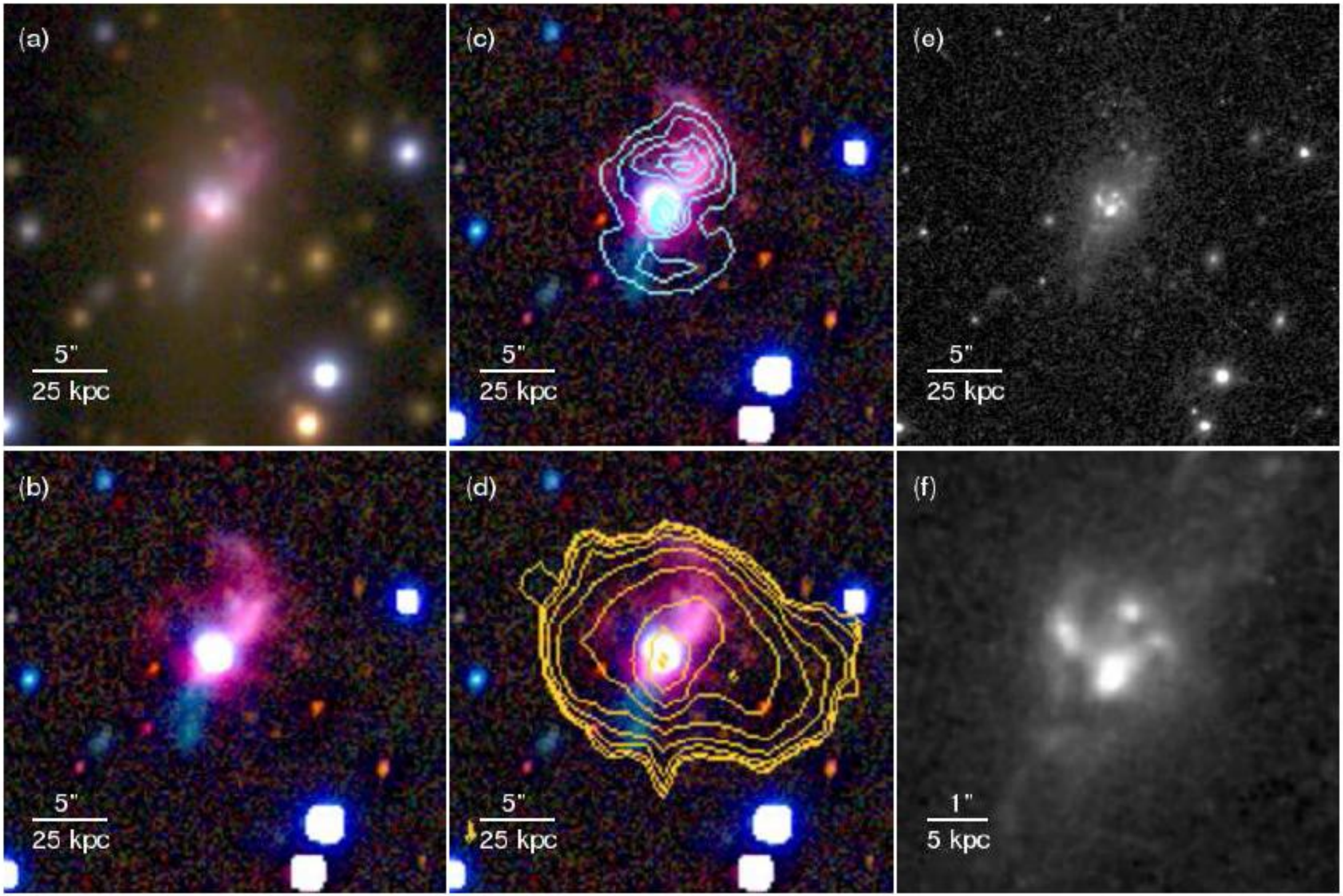


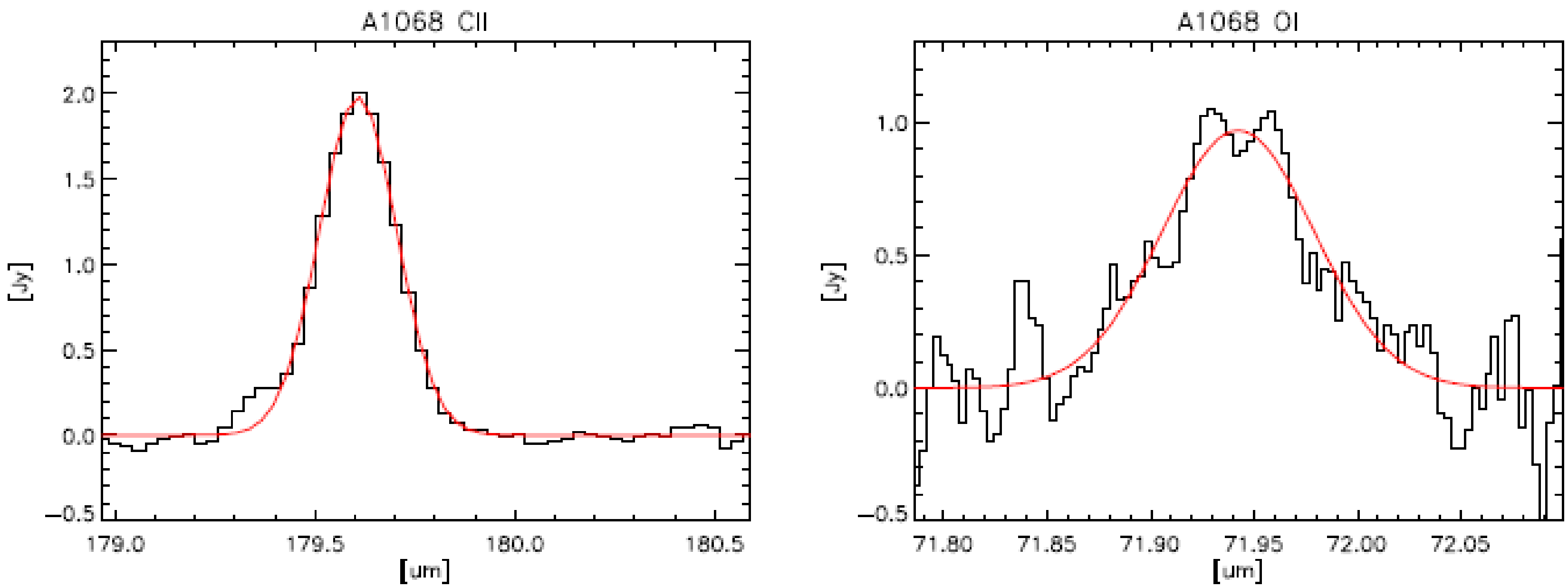
Figure 12. Optical structure of the BCG of MACS J1931.8-2634. (a): SuprimeCam *BRz* image of the central 30 arcsec × 30 arcsec. (b): For this image, the

SFR~170 Msunpyr

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]

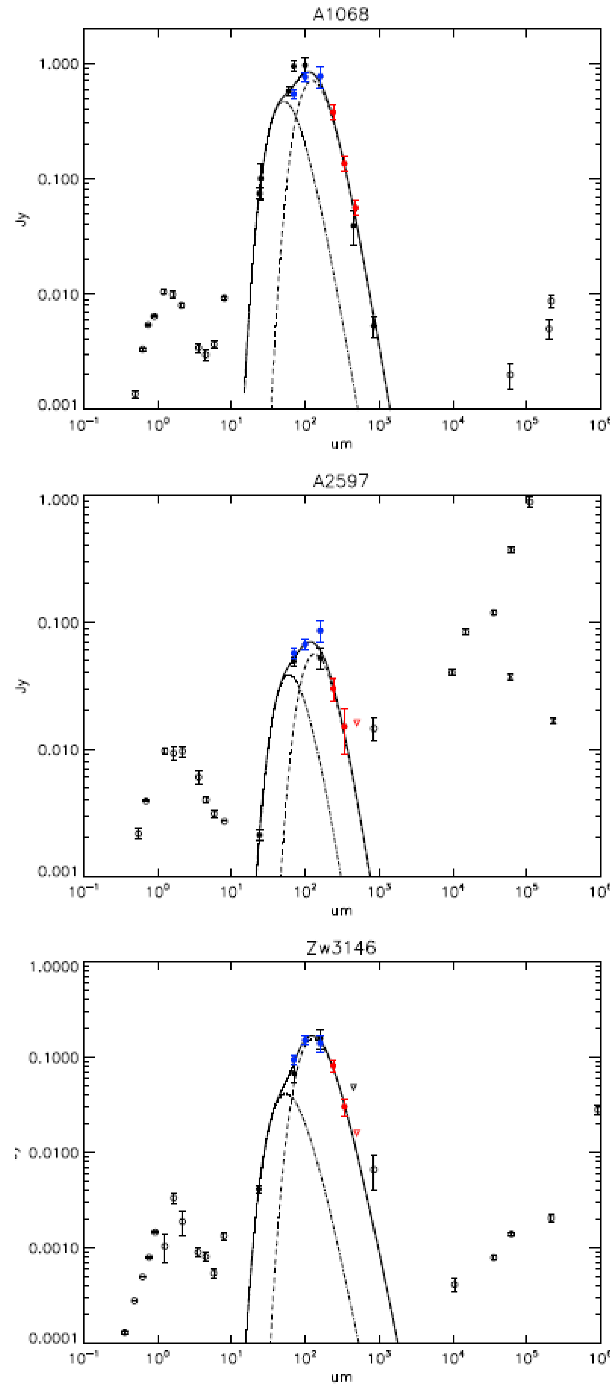


L(CII)~5x10^{42} erg/s ~6 x L(Hα)

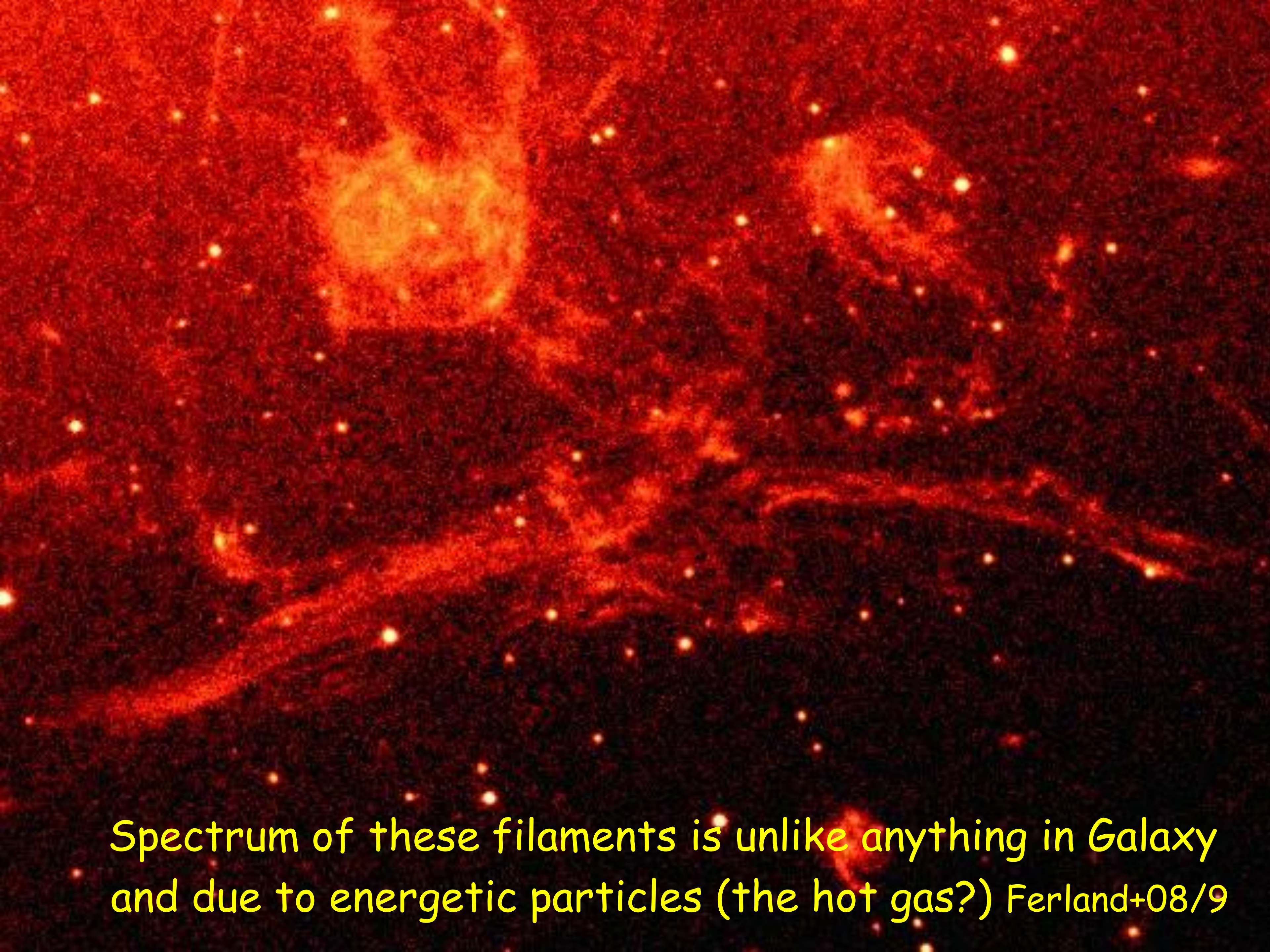
Dust

Herschel points

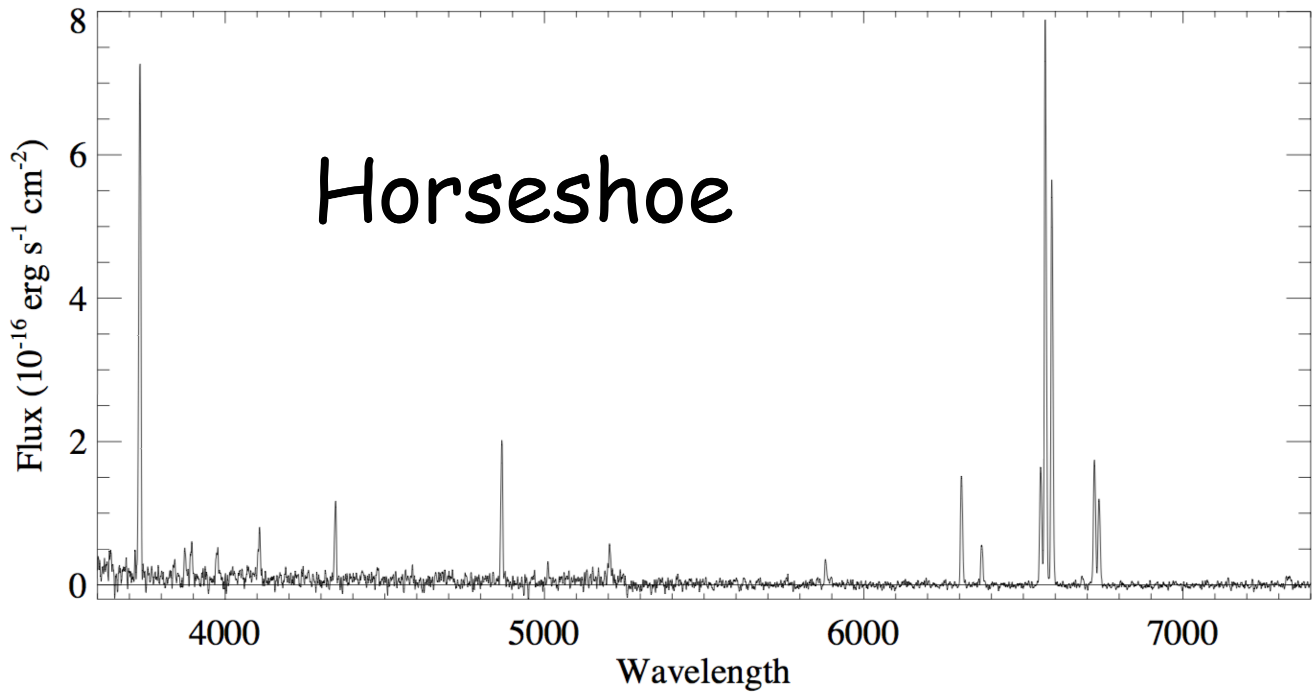
Cluster	A1068	A2597	Zw3146
Dust Temperatures	24±4K	21±6K	23±5K
	57^{+12}_{-4}K	48^{+17}_{-5}K	53^{+22}_{-6}K
Cold Dust Mass	5.1×10^{8} $M_\odot$	2.3×10^{7} $M_\odot$	5.4×10^{8} $M_\odot$
Warm Dust Mass	3.9×10^{6} $M_\odot$	2.9×10^{5} $M_\odot$	1.9×10^{6} $M_\odot$
Total FIR Luminosity	3.5×10^{11} $L_\odot$	8.8×10^{9} $L_\odot$	2.5×10^{11} $L_\odot$
Star Formation Rate	60±20 $M_\odot$ yr^{-1}	2±1 $M_\odot$ yr^{-1}	44±14 $M_\odot$ yr^{-1}
SFR *Spitzer*	188 $M_\odot$ yr^{-1}	4 $M_\odot$ yr^{-1}	70±14 $M_\odot$ yr^{-1}
SFR *optical/UV*	20–70 $M_\odot$ yr^{-1}	10–15 $M_\odot$ yr^{-1}	47±5 $M_\odot$ yr^{-1}
CO gas mass	4.1×10^{10} $M_\odot$	2.0×10^{9} $M_\odot$	7.7×10^{10} $M_\odot$
Hα Slit Luminosity	8×10^{41} erg s^{-1}	3×10^{41} erg s^{-1}	3×10^{42} erg s^{-1}

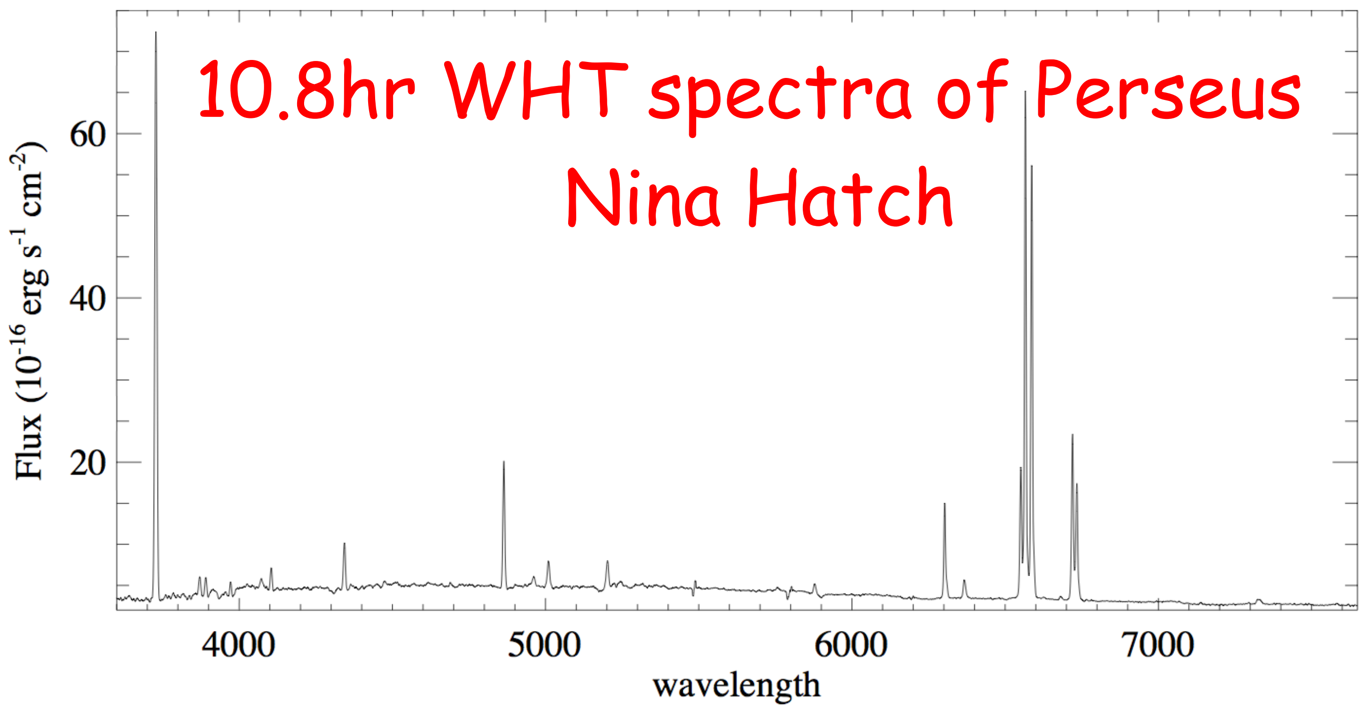


Edge+10



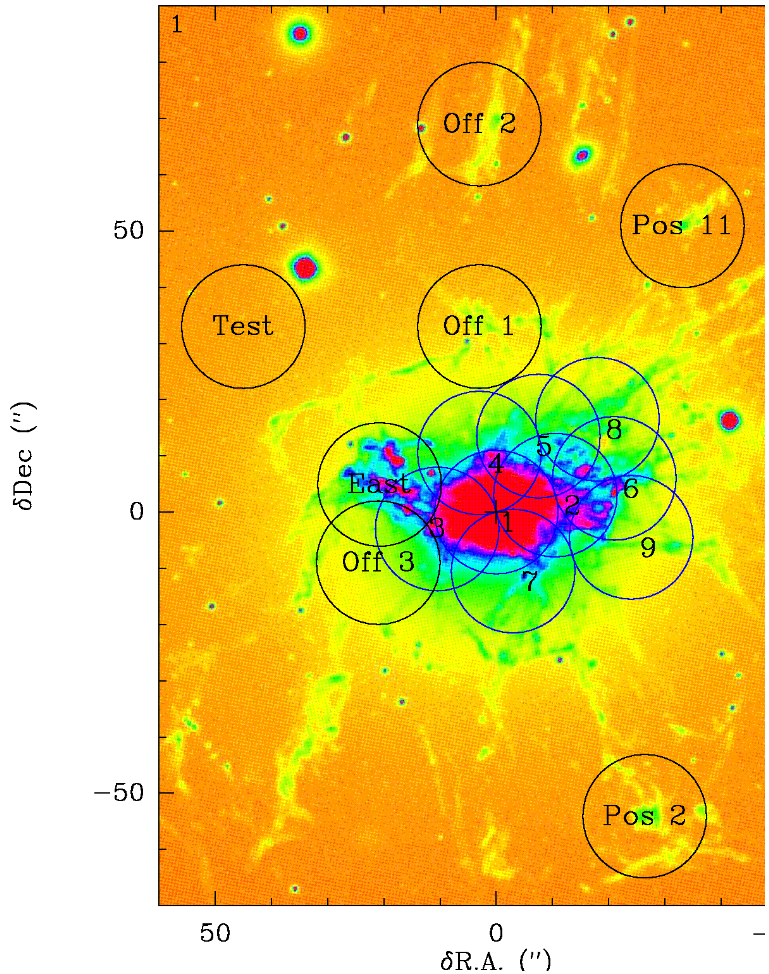
Spectrum of these filaments is unlike anything in Galaxy and due to energetic particles (the hot gas?) Ferland+08/9


Horseshoe
Flux (10^-16 erg s^-1 cm^-2)
Wavelength
0
2
4
6
8
4000
5000
6000
7000


10.8hr WHT spectra of Perseus
Nina Hatch
Flux (10^-16 erg s^-1 cm^-2)
wavelength
20
40
60
4000
5000
6000
7000

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

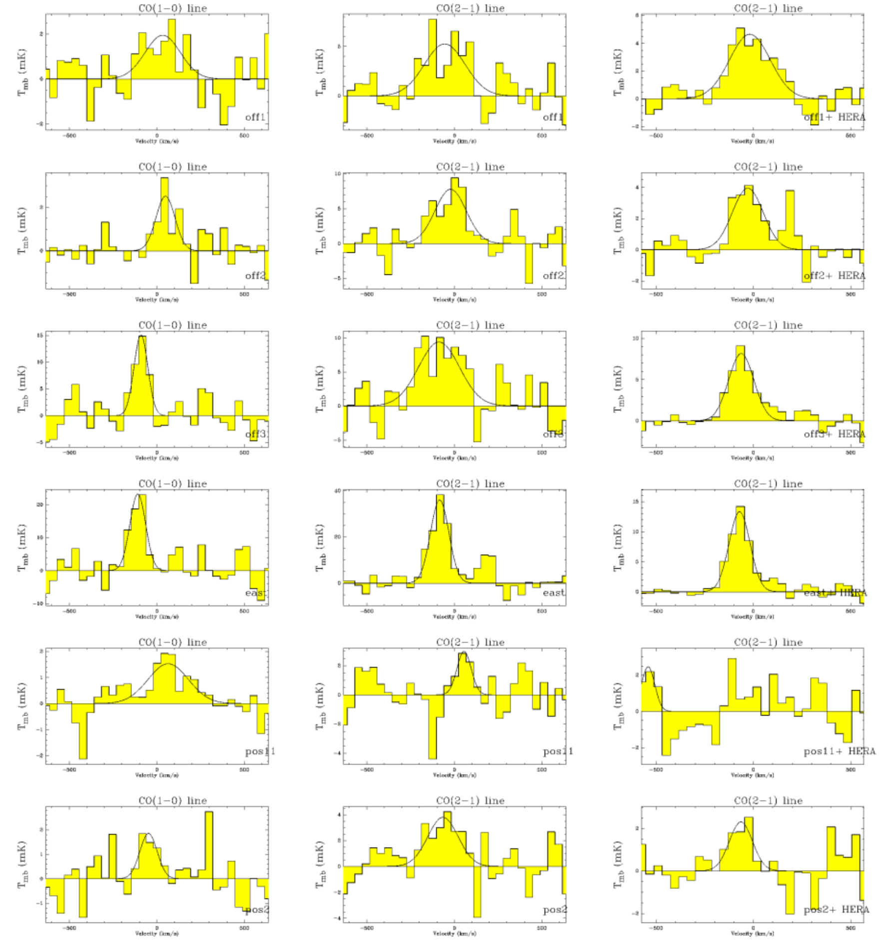


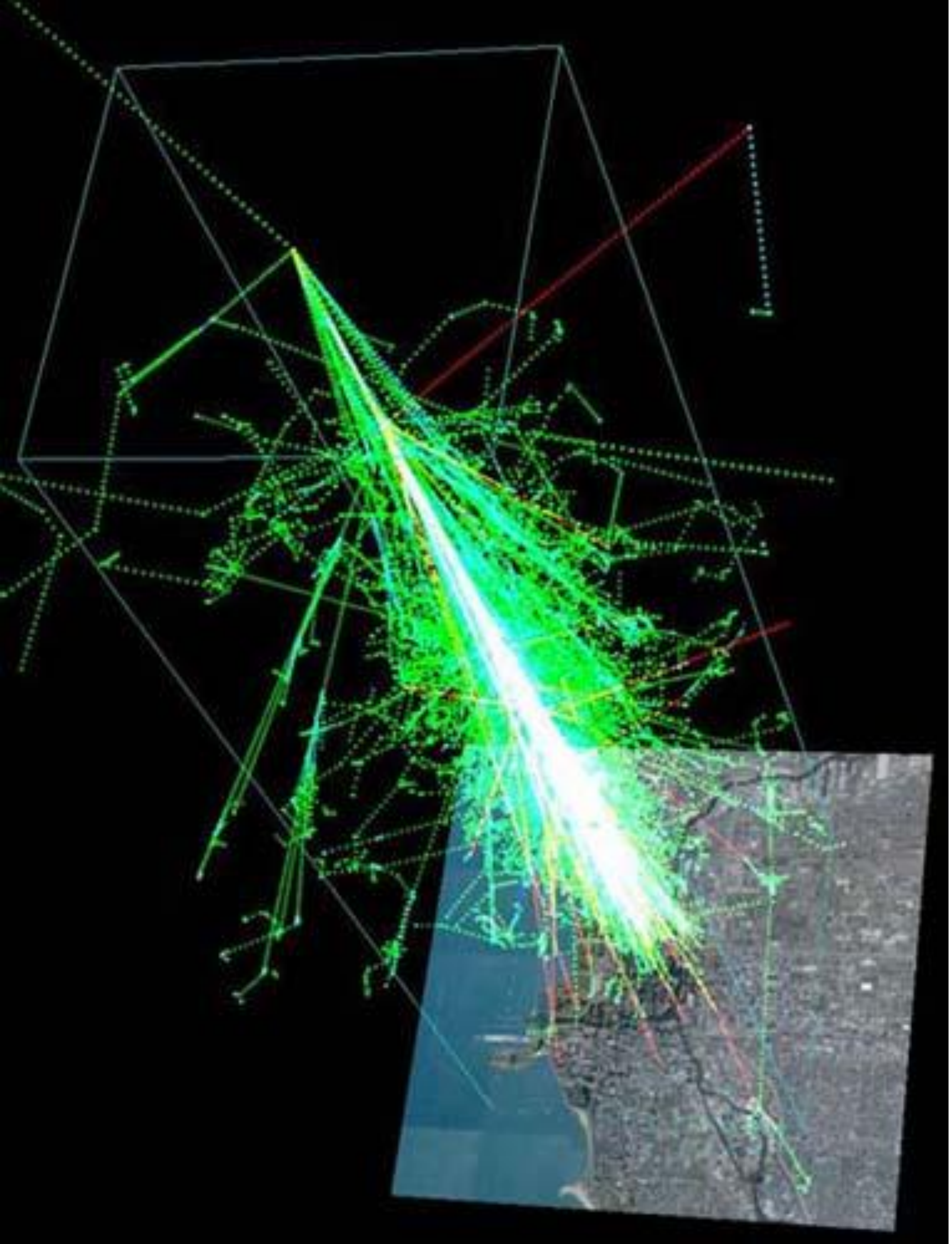
Fig. 2. CO(1–0) and CO(2–1) spectra obtained at all the positions observed as indicated at lower right in each diagram. The channel width is 42 km/s. On the left hand side are the CO(1–0) lines detected with the a100 and b100 receivers. In the middle are the results obtained for the CO(2–1) line with 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

What heats and ionises the cold gas?

Energetic particles

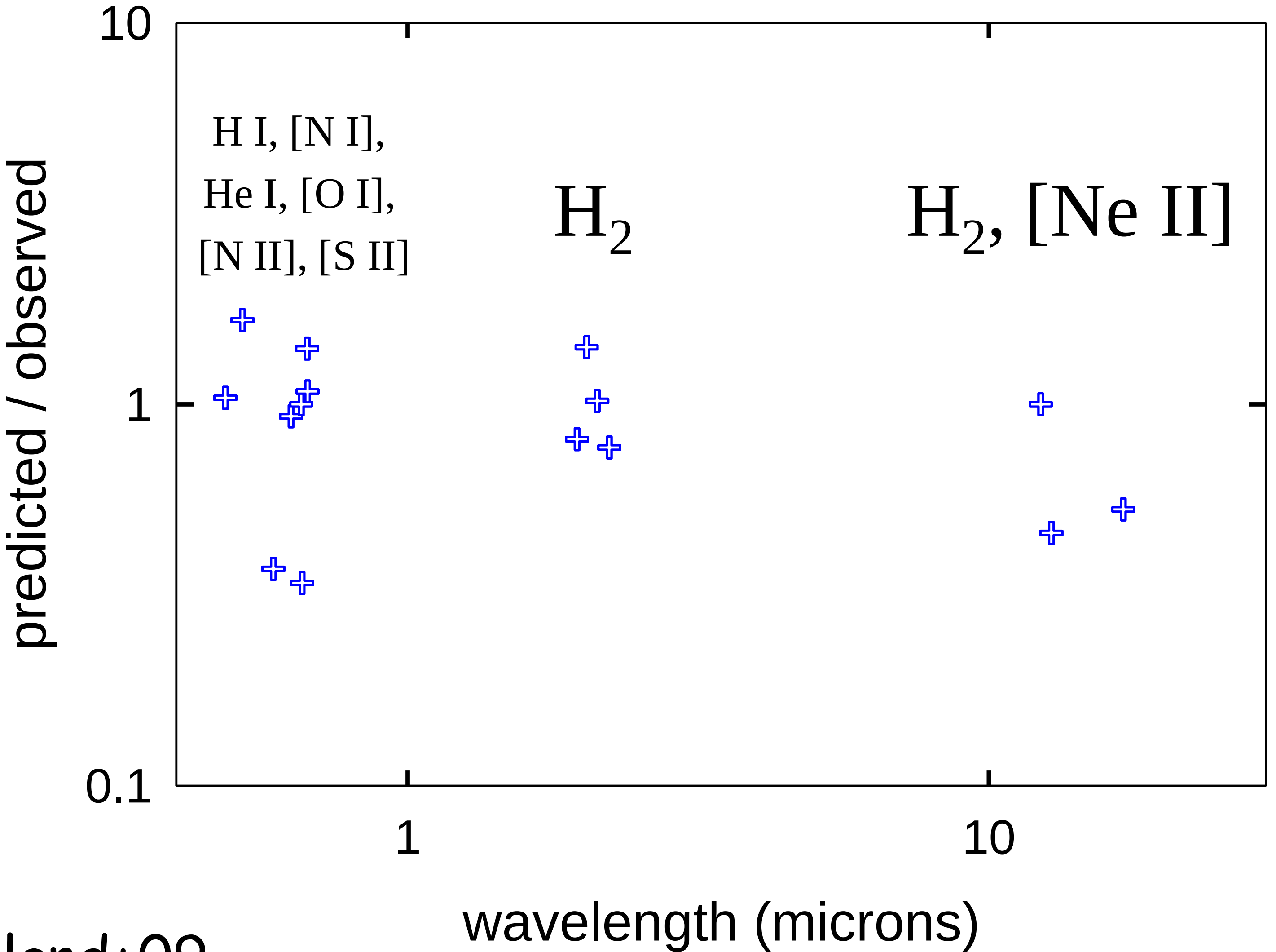
(not photons)



Ferland+08/09

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

Observed / predicted spectrum



Ferland+09

Properties of filaments

- Densities~$10^3 cm^{-3}$ or more
- Pressure nT~$10^{6.5} cm^{-3}$K
- Magnetic Fields B~70uG
- Diameter~70pc, length many kpc
- Mass usually dominated by molecular gas

- Saturated conduction
- Hot ICM particles penetrate cold gas, providing secondary ionization
- Rate about right

  (obs flux~0.01 erg$cm^{-2}s^{-1}$~20% sat.cond.flux)

- Filament mass growing at

  10-100 Msun yr^{-1}

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

(cf Fabian+01,02, Soker04)

Summary

- Radiative mode operating on dusty gas may control maximum growth of most galaxies
- Kinetic mode operates in most massive galaxies, maintaining stellar mass. Parts of feedback loop observed (bubbles, sound waves, warm, cool and cold gas)