Radio Source / ICM Interactions in Cooling Flow Clusters: Chandra ACIS-S Observation of Abell 262

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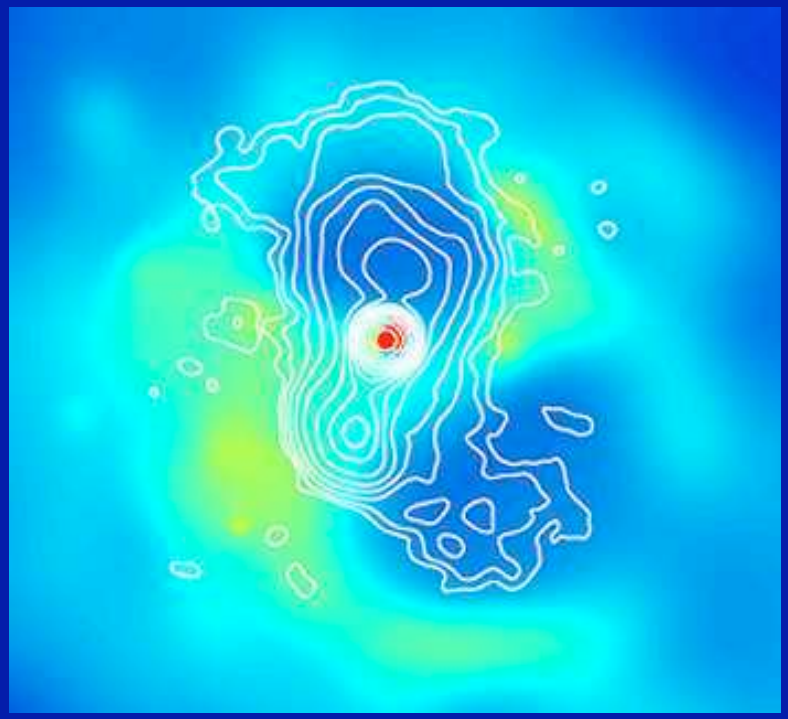
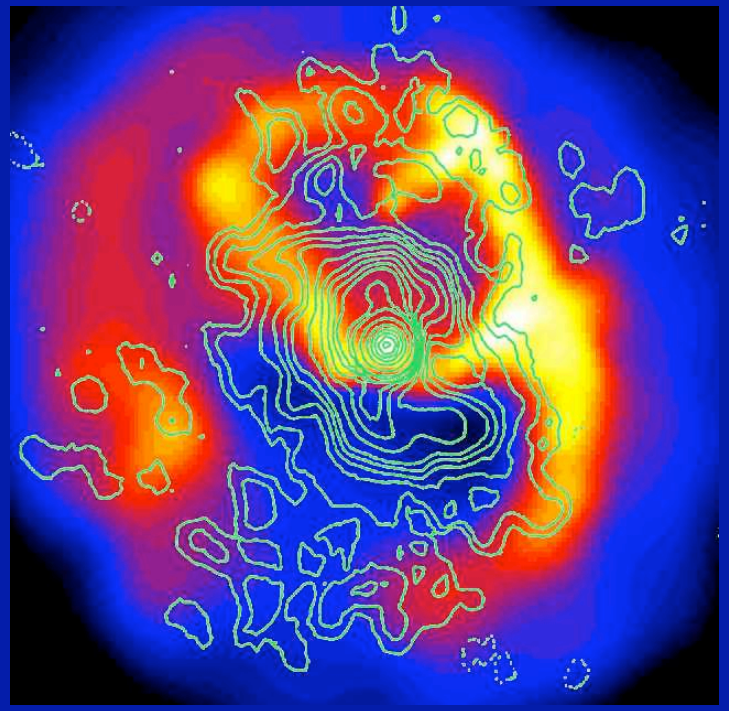
Radio Sources in Clusters

- Radio sources and the X-ray emitting ICM have a profound effect on each other, as seen with Chandra. Radio sources blow bubbles in the ICM and the ICM confines and distorts the radio lobes.
- 70% of cooling flow clusters contain central cD galaxies with associated radio sources, and 20% of non-cooling flow clusters have radio-bright central galaxies. Cooling gas feeds AGN?

Chandra Observations of Radio Sources in Clusters



Perseus, Fabian et al. 2000



A2052, Blanton et al. 2001,3

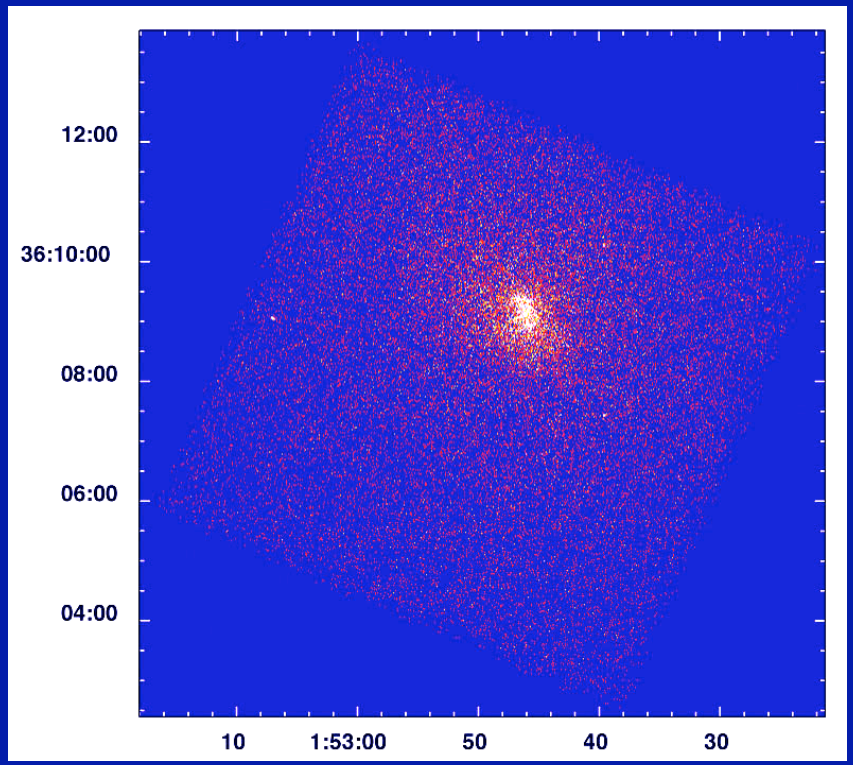
The Cooling Flow Problem

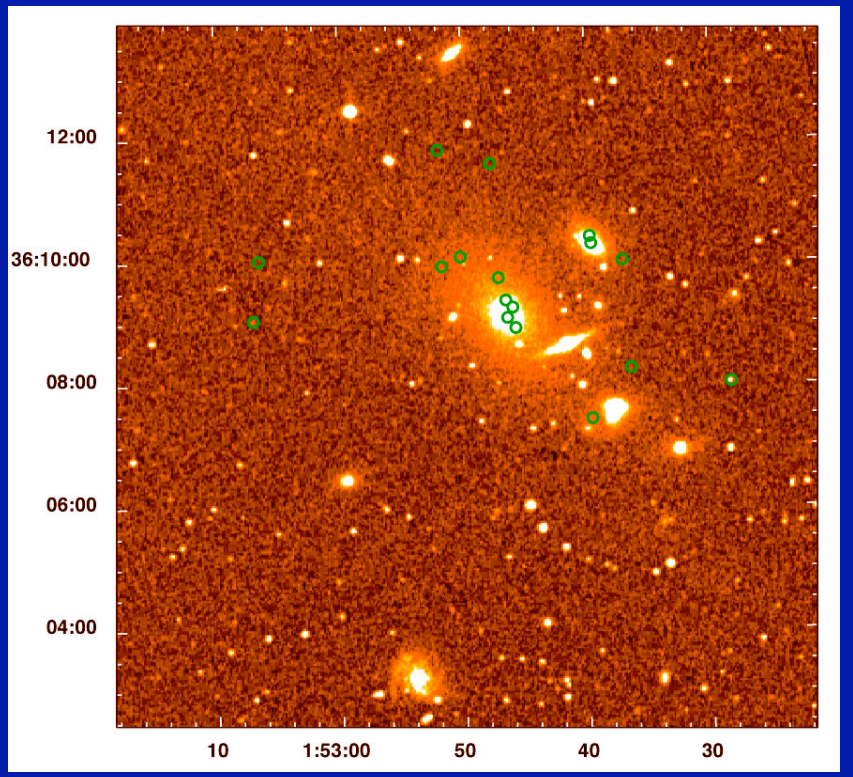
- Where does the cooling gas go?
- Central cD galaxies in cooling flows do emit blue light and exhibit massive star formation, however the star formation accounts for only ~ 1-10% of the expected gas derived from the X-ray predictions (as measured from Einstein, ROSAT, and ASCA).
- Both Chandra and XMM-Newton have revealed an apparent lack of the expected quantities of cooler gas below about kT < 1- 2 keV (~10^7 K).
- Radio sources are possible heaters (but not by strong shocks).

Case Study: Abell 262

- Abell Richness Class 0
- z = 0.0163 (1 arcsec = 0.33 kpc)
- $L_{x,bol}$ = 4 x 10^{43} erg/s (ROSAT; Peres et al. 1998)
- <kT> = 2.2 keV
- $\dot{M} = 27^{+4}_{-3}$ (ROSAT) 52^{+42}_{-51} (ASCA) $M_{\odot}$/yr
- Central radio source 0149+35 with $\log P_{1.4}$ = 22.6 W/Hz (double-lobed FR I)
- Observed for 28 ksec with Chandra ACIS-S

Abell 262: X-ray and Optical

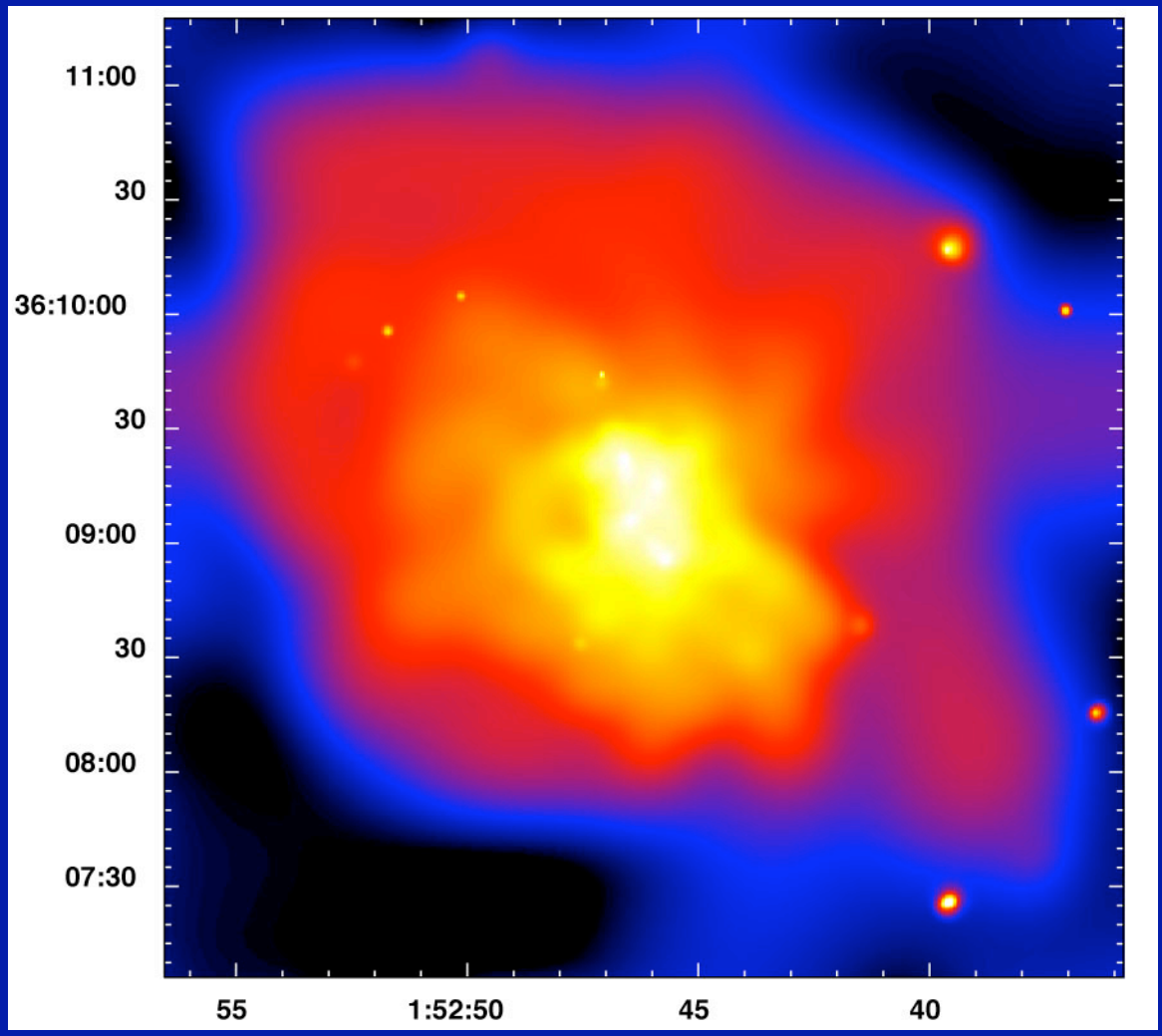




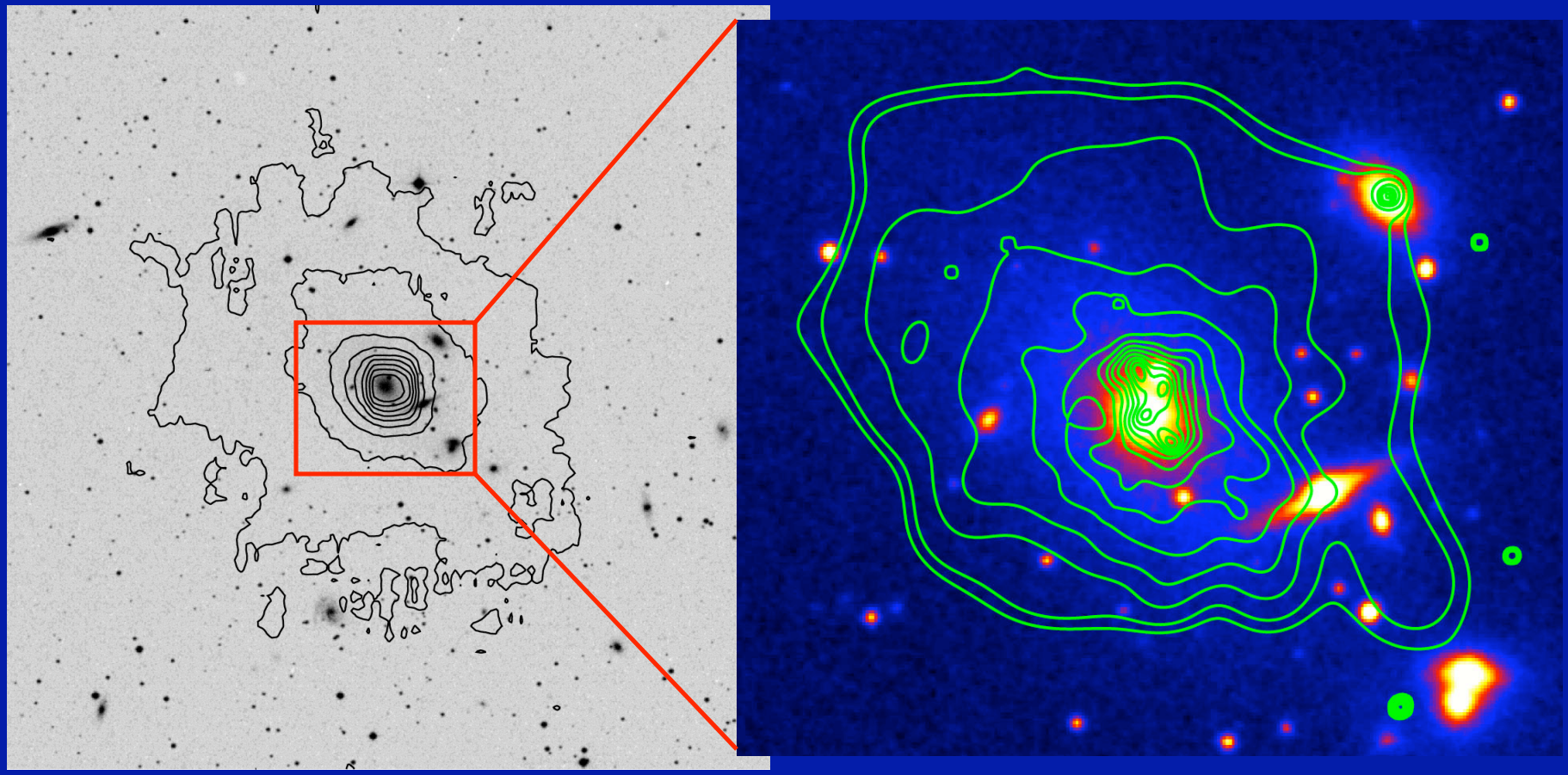
Chandra ACIS-S3, 28 ksec

DSS

A 262, Adaptively Smoothed



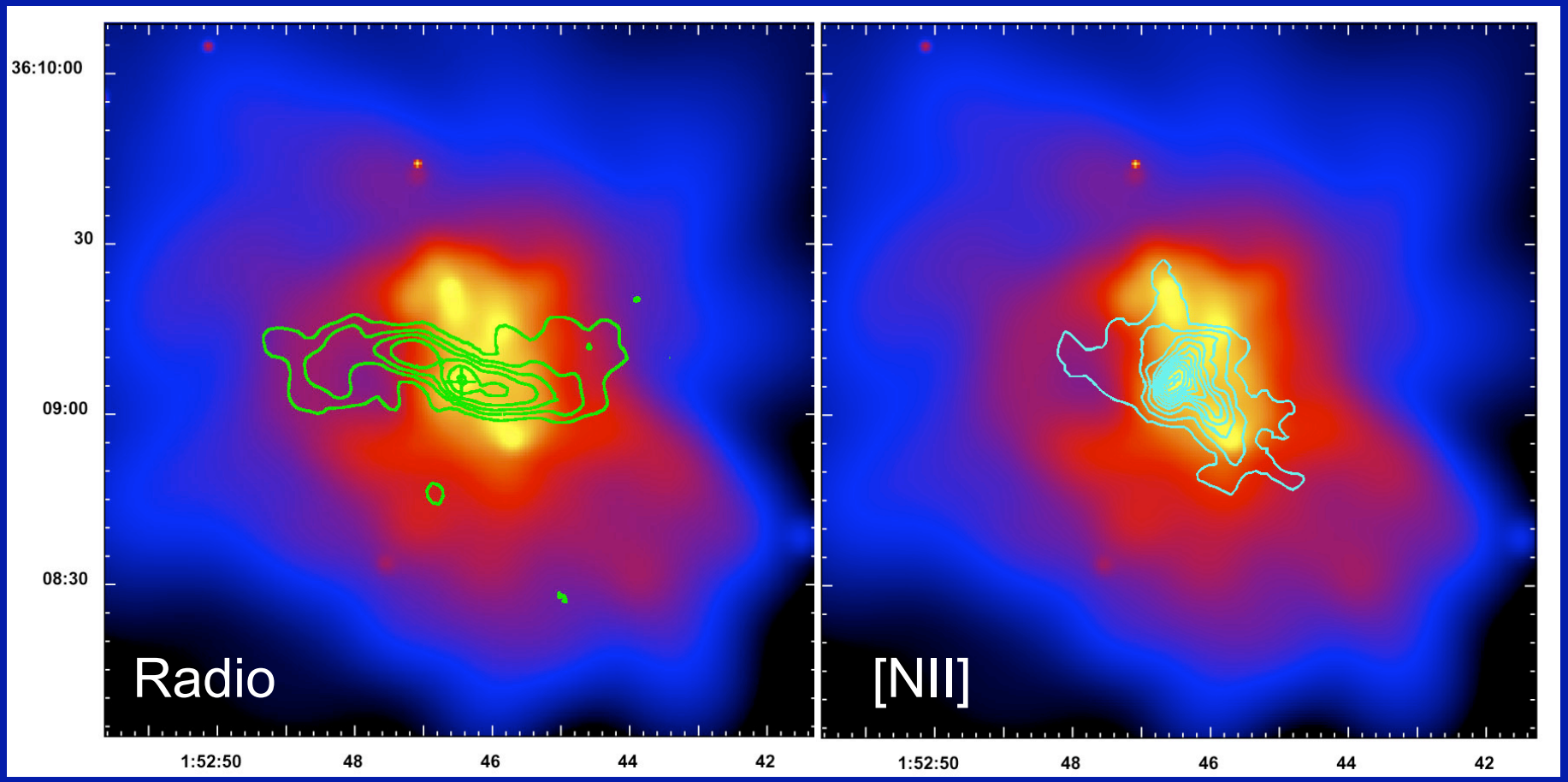
Old and New



ROSAT HRI
Neill et al. (2001)

Chandra ACIS-S

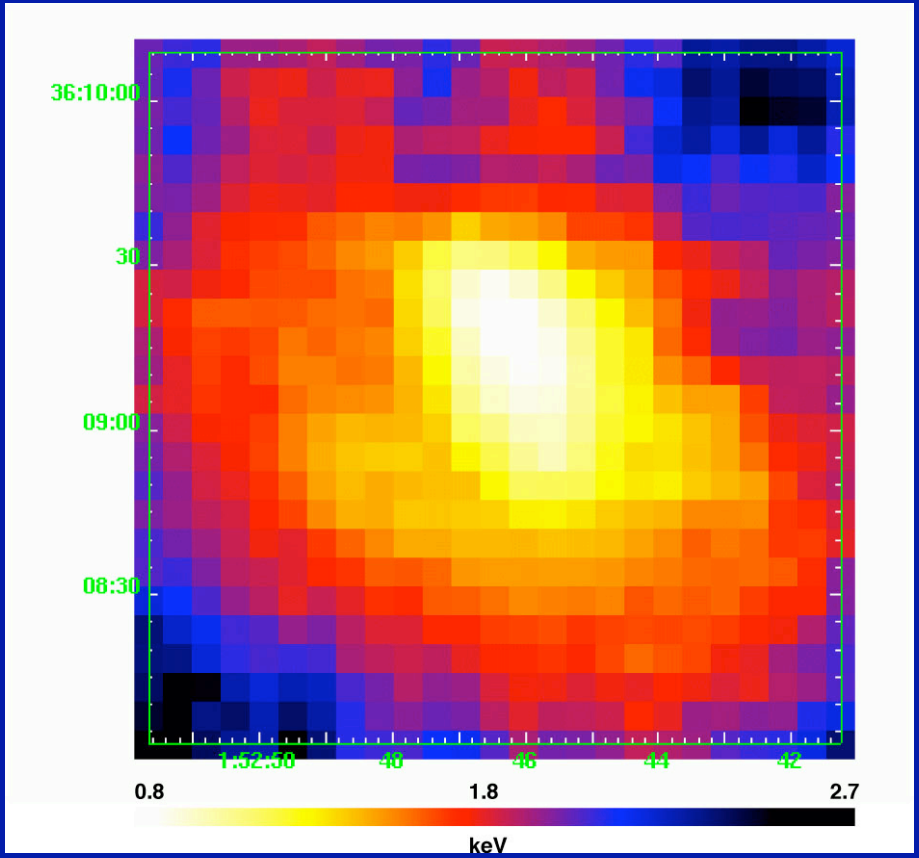
Connection with other Wavelengths



Radio contours (Parma et al. 1986).
anti-correlation btwn radio and X-ray

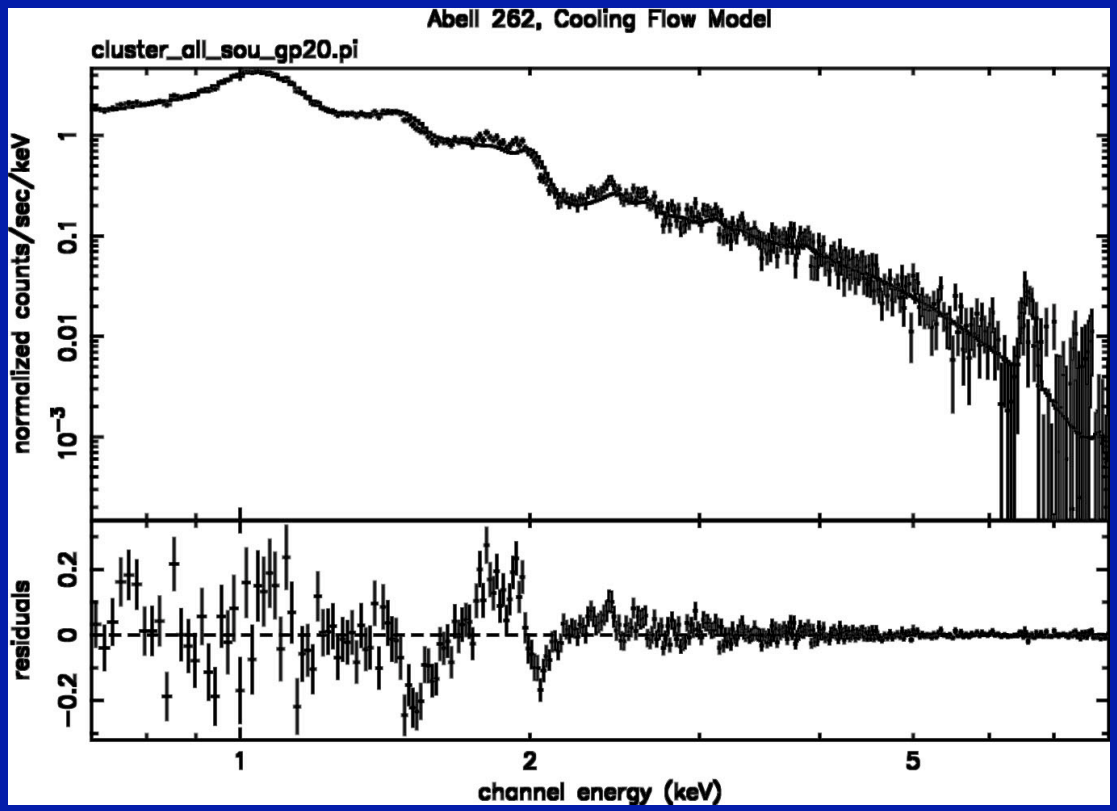
[NII] contours (Plana et al. 1998).
thermal, cool (~10^4 K), gas,
correlated with X-ray

Temperature Structure



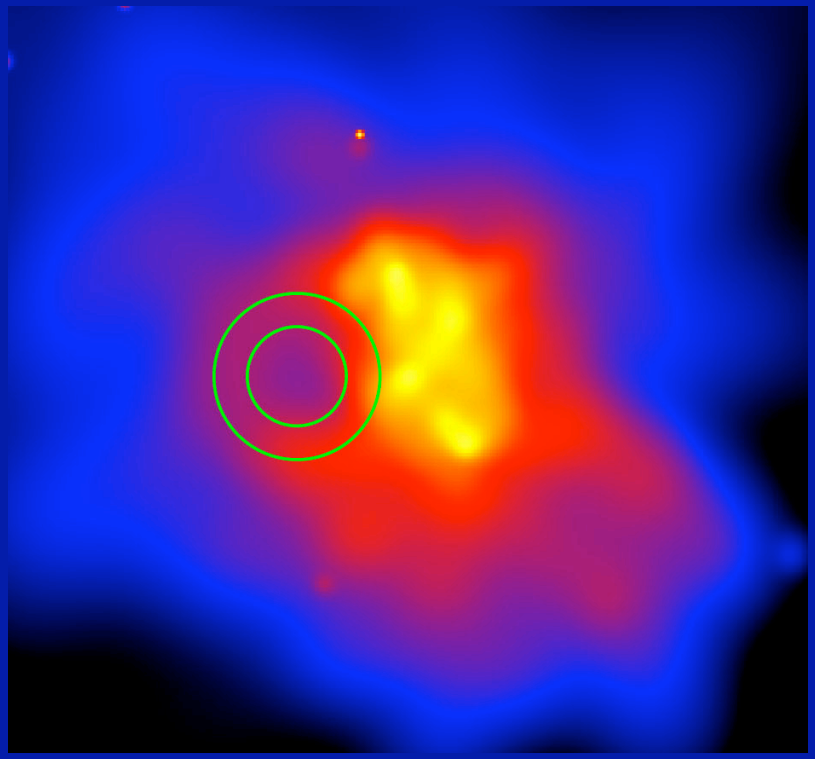
- Cluster is cool in the center - evidence of cooling, if not flow.
- Lowest projected kT is about 0.8 keV.
- Gas around radio source is cool, not hot.
- No evidence that radio source is shocking the ICM.
- Cooling time in region around E radio lobe is 3 x 10^8 yr.

Total Spectrum



- Cooling flow model with Galactic N_H
- $\dot{M} = 40^{+4}_{-4}$ $M_\odot$/yr
- kT_{low}= 1.1 keV
- kT_{high}= 2.5 keV
- If we fix kT_{low}= 0.001 keV, $\dot{M} = 10^{+1}_{-1}$ $M_\odot$/yr
- No evidence for excess absorption

Pressure in Shell



- Pressure in shell around radio source is 1.2×10^{-10} dyn/cm^2
- X-ray pressure is an order of magnitude higher than radio equipartition pressure (Heckman et al. 1989)
- Additional pressure from very hot, diffuse gas?

Can the radio source offset cooling?

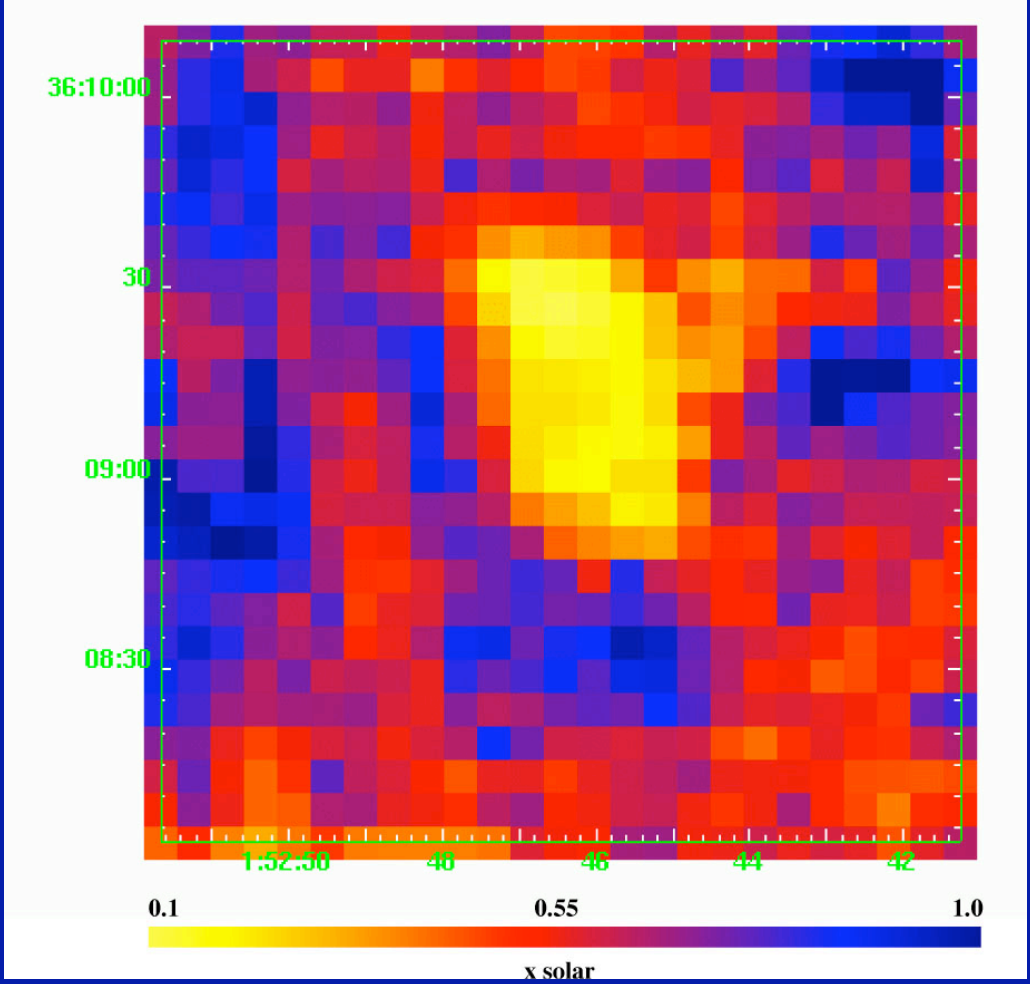
- Assuming X-ray shell and radio bubble are in pressure equilibrium, the total energy output of the radio source, including the work done on compressing the gas is $E \sim 5/2\ PV = 1.3 \times 10^{57}$ ergs.
- With a repetition rate of ~ 1×10^{8} yr, E/t for the radio source = 4.1×10^{41} erg/s
- $$L_{cool} = \frac{5}{2}\frac{\dot{M}}{\mu m} kT$$

  with kT = 2.1 keV,

  $\dot{M} = 10$ $M_{\odot}$/yr

  $L_{cool} = 5.3 \times 10^{42}$ erg/s
- The radio source cannot, on its own, offset the cooling, unless this outburst is less powerful than average.

Abell 262: Conclusions

- See cooling, or at least cool, gas.
- Don't see flow.
- Chandra's spatial and spectral resolution reveals complex ICM structure and correspondence with X-ray, radio, and optical line emission.
- The radio source blows bubbles in the ICM. The bubble rims are cool, and aren't being shocked. Radio sources can transport energy through buoyant bubbles, but maybe not enough to offset cooling.
- The X-ray pressure is 10x higher than the radio equipartition pressure. Additional contribution from diffuse, hot (10 - 20 keV) gas (Constellation X?)?

Abundance Map