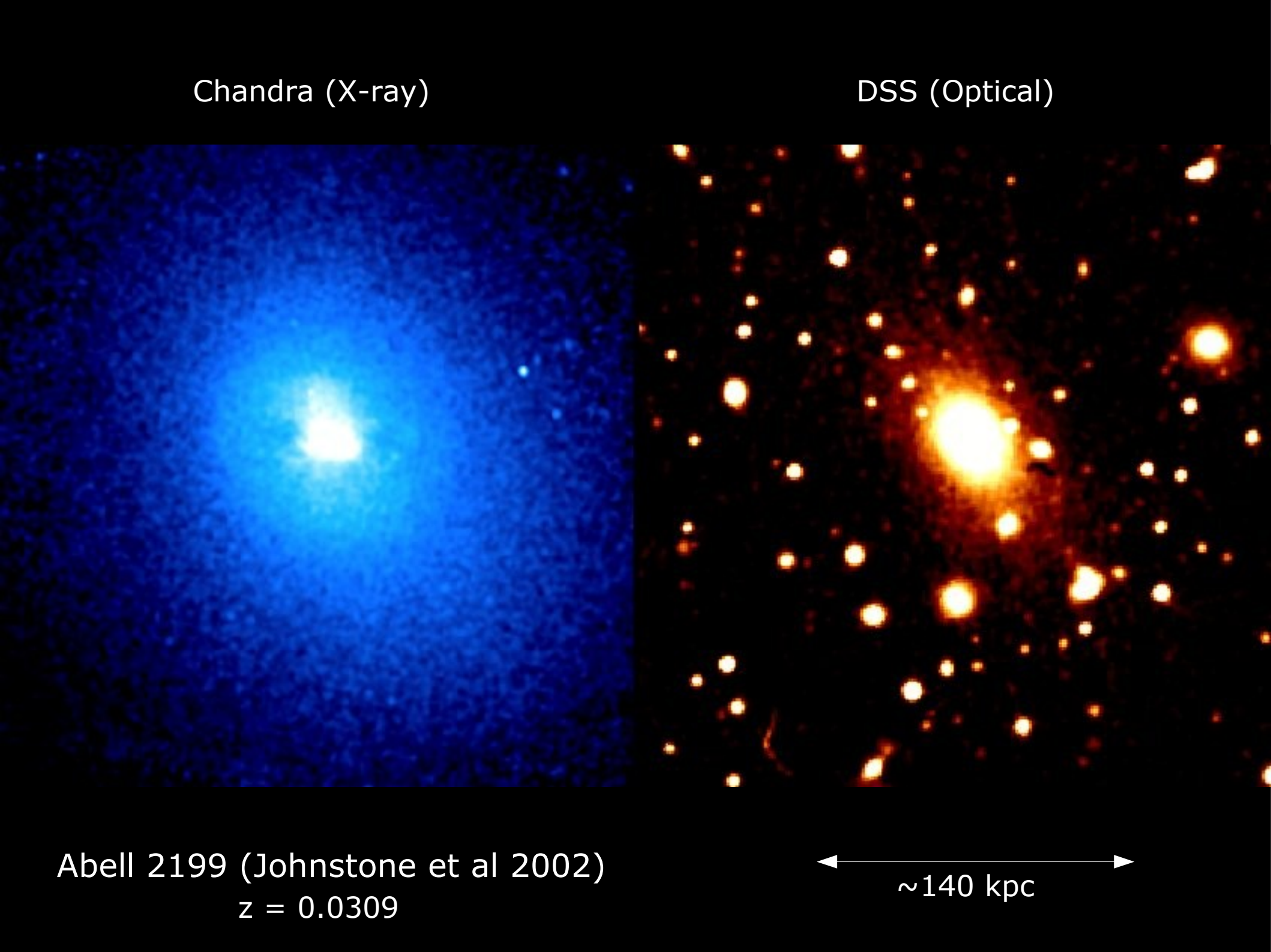
Cool gas in the core of the Centaurus cluster (plus some others)

Jeremy Sanders
Institute of Astronomy
University of Cambridge

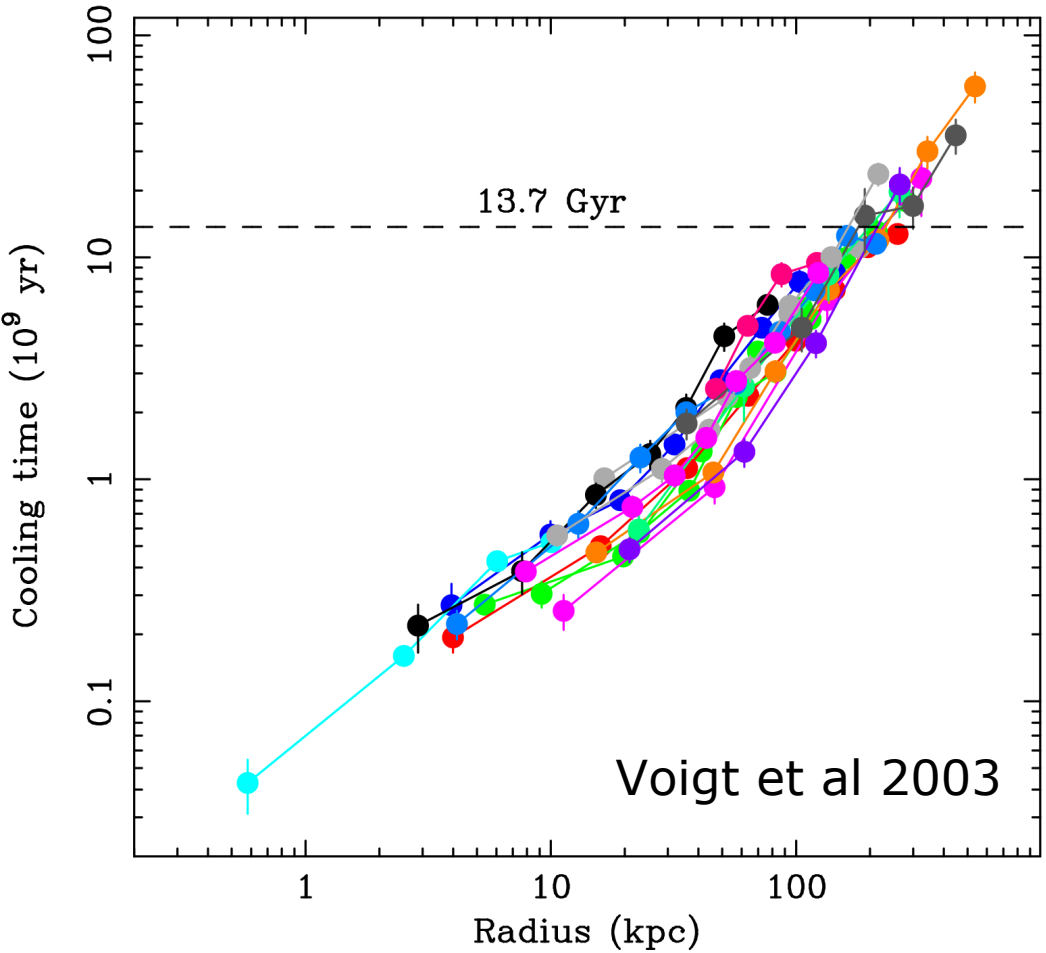
Sanders et al, 2008, MNRAS, 385, 1186
Sanders, Fabian and Taylor, 2009, MNRAS, 393, 71
Sanders et al, in prep

A.C. Fabian, J. Peterson, S.W. Allen, R.G. Morris,
J. Graham, R.M. Johnstone, G.B. Taylor

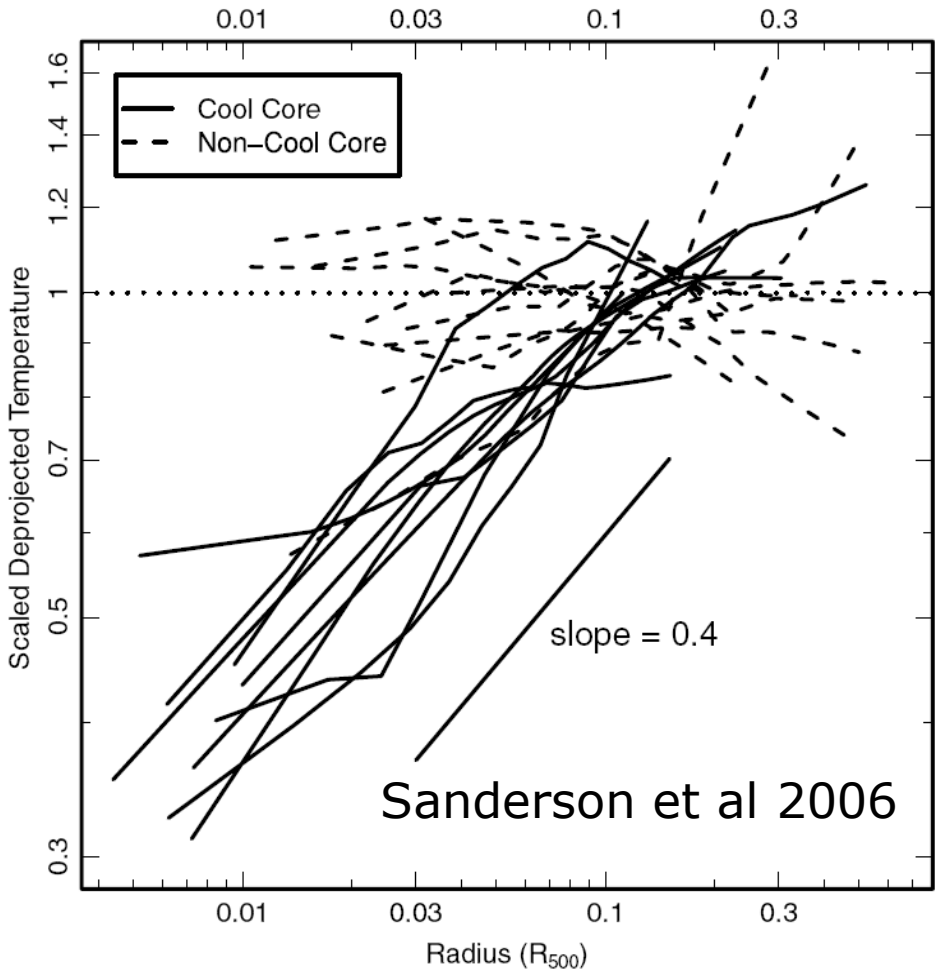

Chandra (X-ray)
DSS (Optical)
Abell 2199 (Johnstone et al 2002)
z = 0.0309
~140 kpc

Cooling times and temperatures

Mean radiative cooling time profiles



Temperature profiles



- Mean radiative cooling times in centre of many cluster cores < 10^9 years
- Cluster centres typically cooler than 1/2 to 1/3 of the outer temperature

Cooling in cluster cores

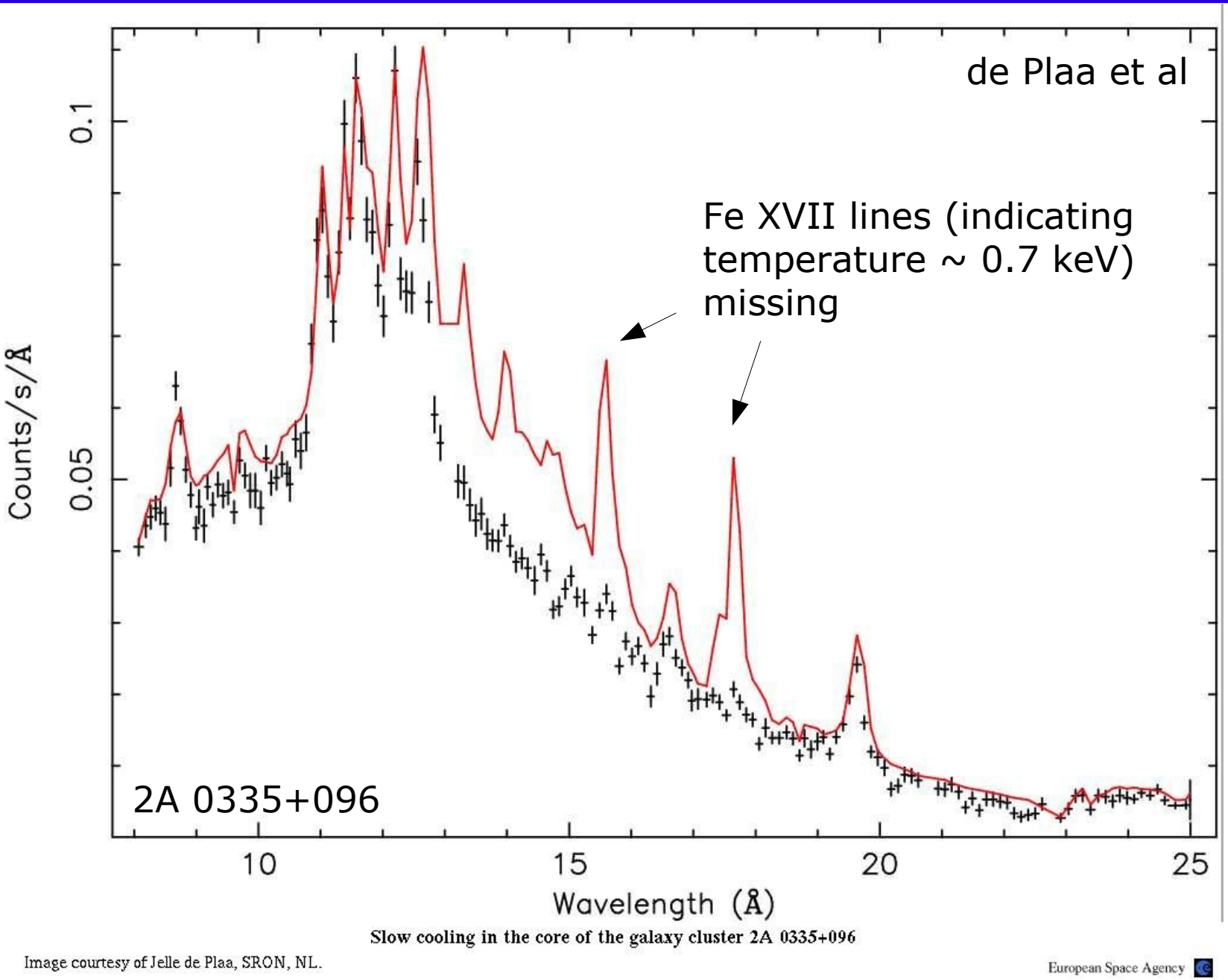
- Suppose there is a luminosity L emitted from within a cooling region r_{cool}
- To offset radiation lost through cooling, if the cluster is in steady state and there is no heating, there should be a deposition rate of

$$\dot{M} \approx \frac{2}{5} \frac{L \mu m}{kT}$$

luminosity of region is:
- radiation of thermal energy
- PdV work done on gas entering r_{cool}

- Measured values from SB profiles gave values of 10-1000s solar masses per year – a "cooling flow"

Lack of cool X-ray emitting gas



Slow cooling in the core of the galaxy cluster 2A 0335+096

Image courtesy of Jelle de Plaa, SRON, NL.

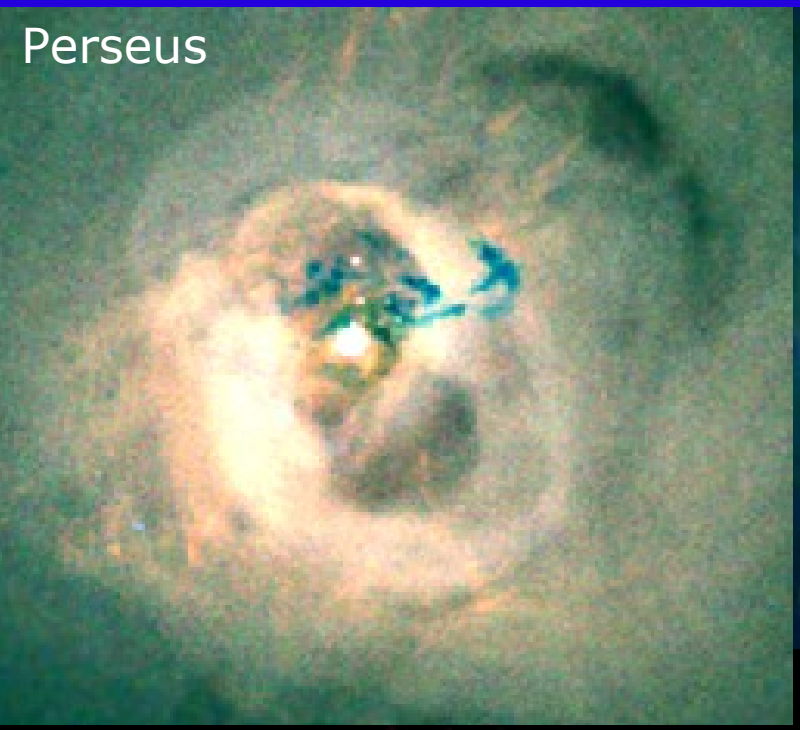
European Space Agency

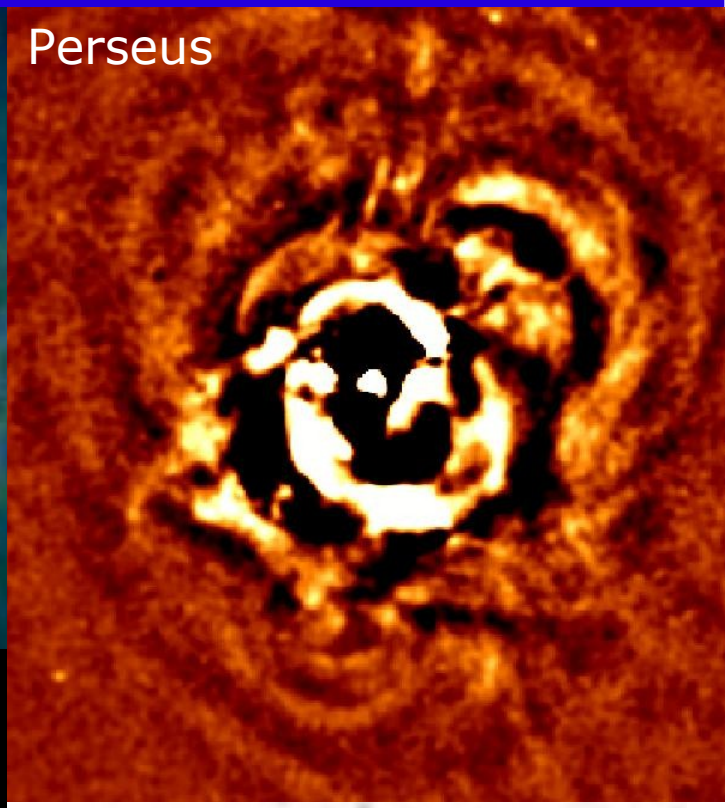
Spectra imply less than 10% of cooling rates expected from luminosity profiles

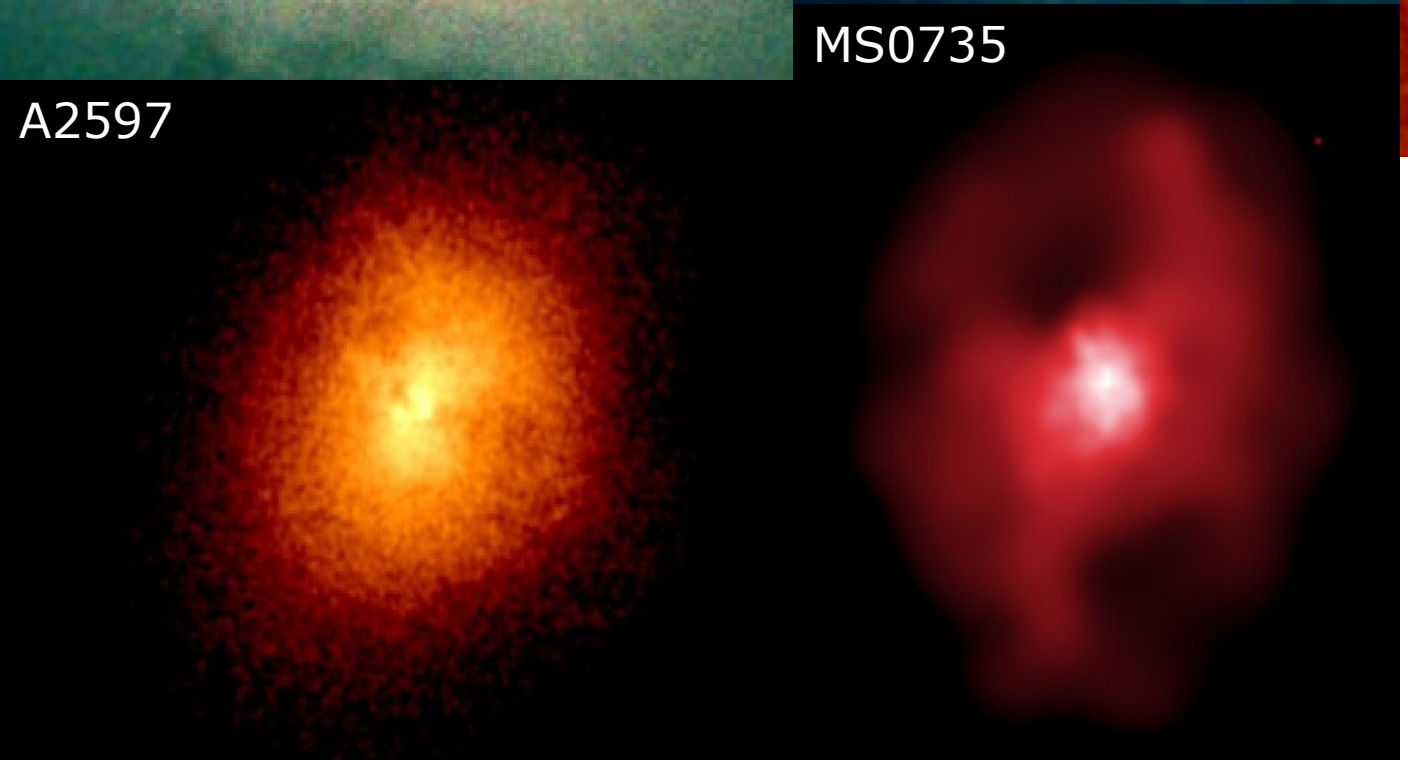
Only significant gas down to 1/2 to 1/3 of outer temperature

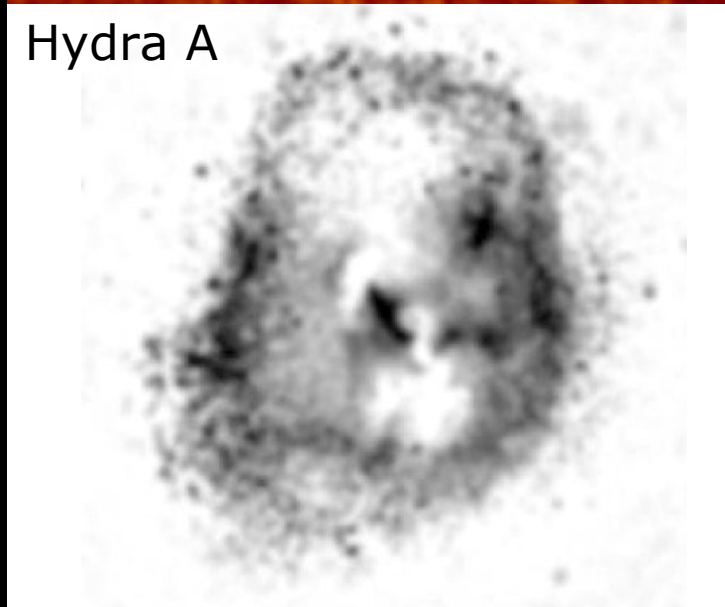
see also Peterson et al 01, 03, Kaastra et al 01, 03, Tamura et al 01,...

AGN heating

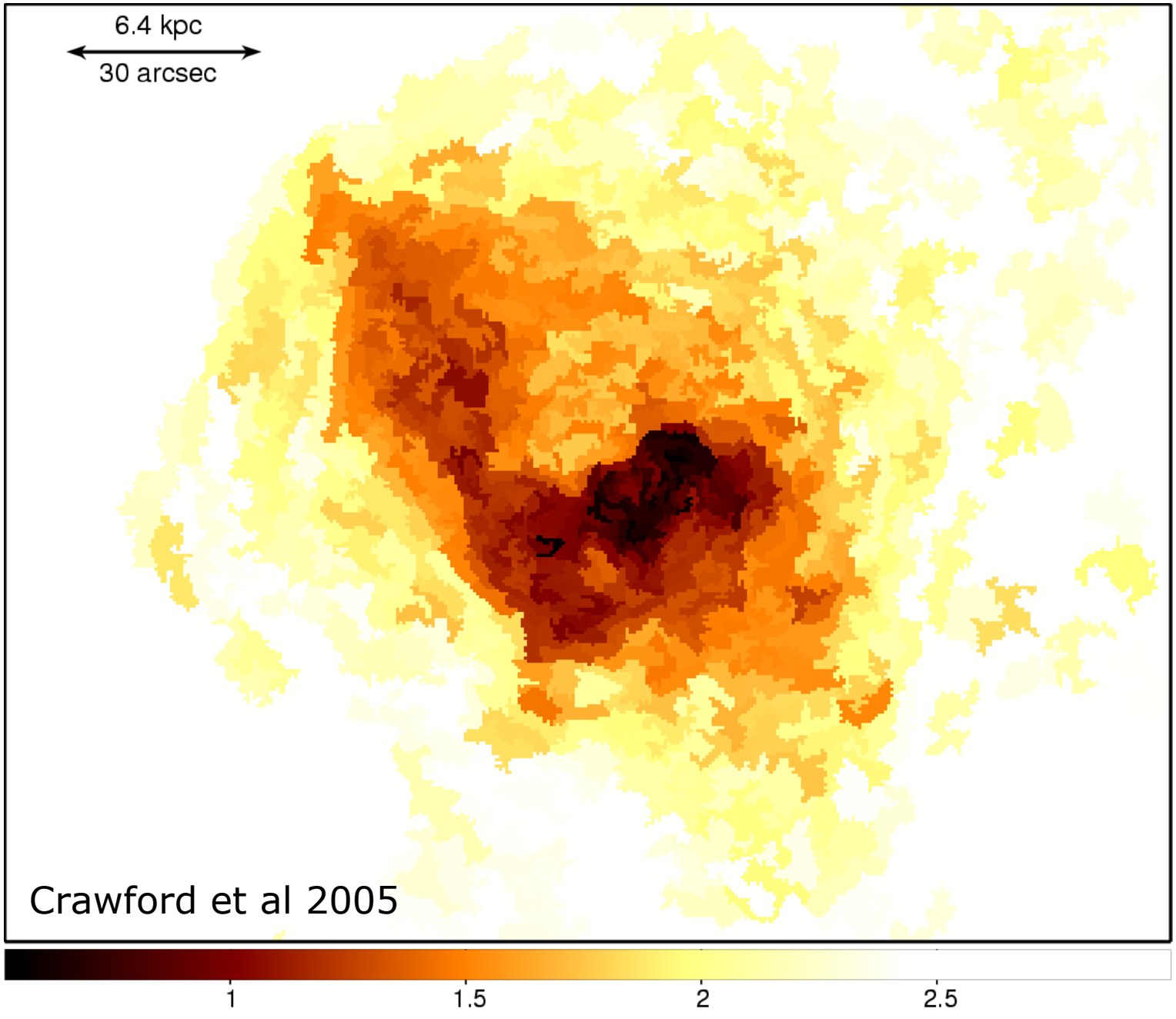




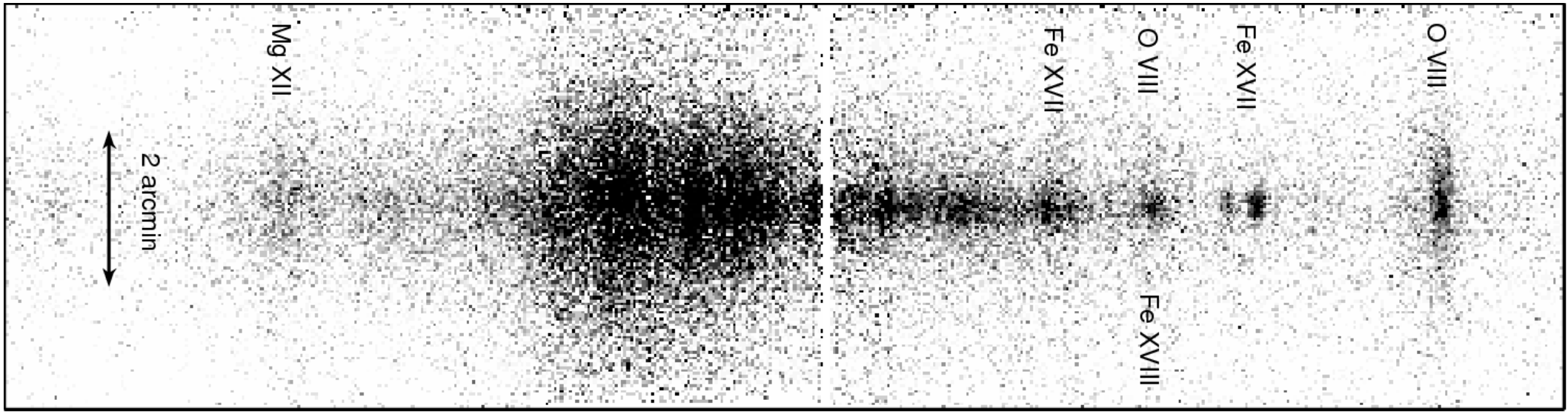




Centaurus temperature map



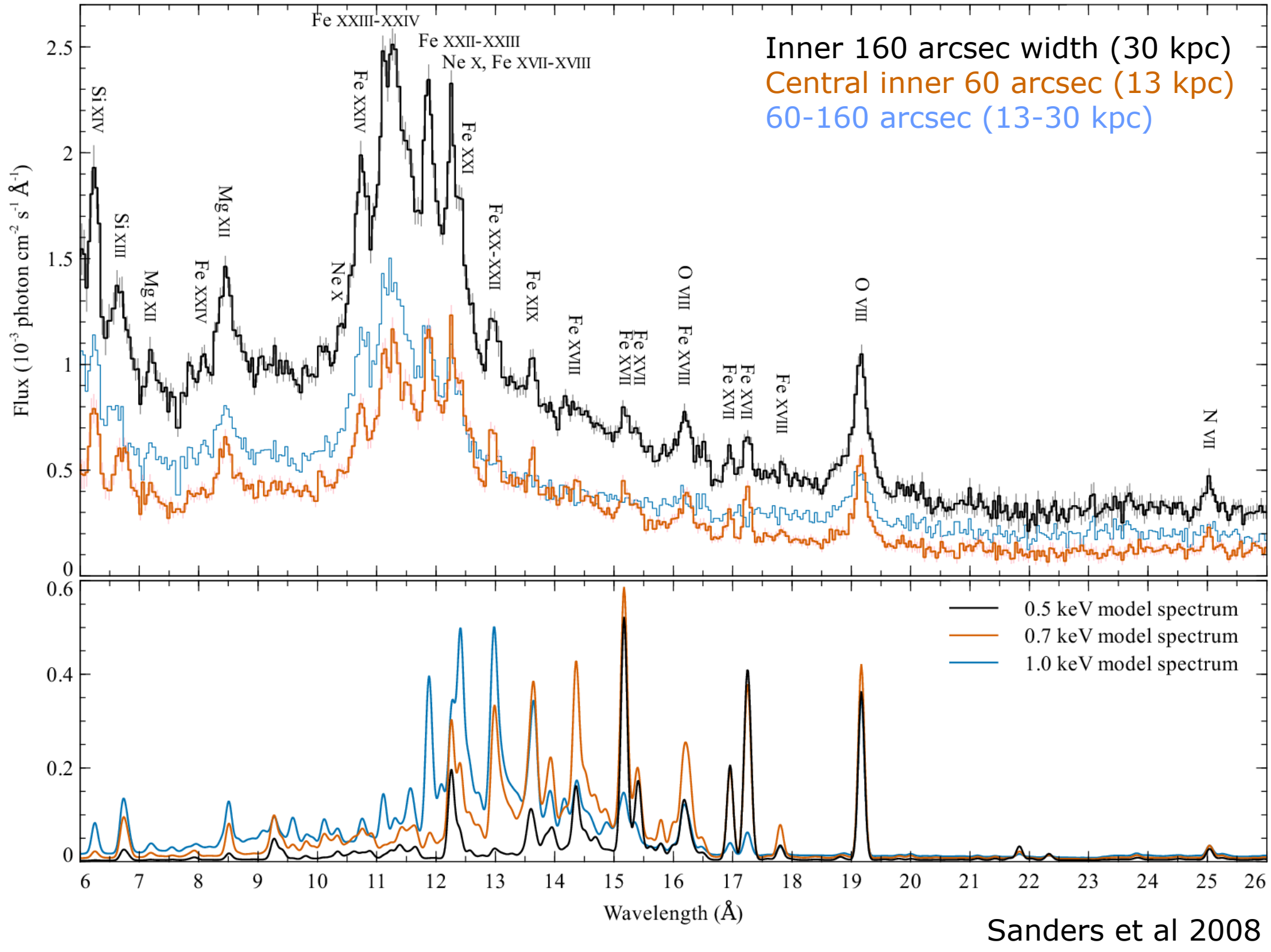
Centaurus cross dispersion image



wavelength

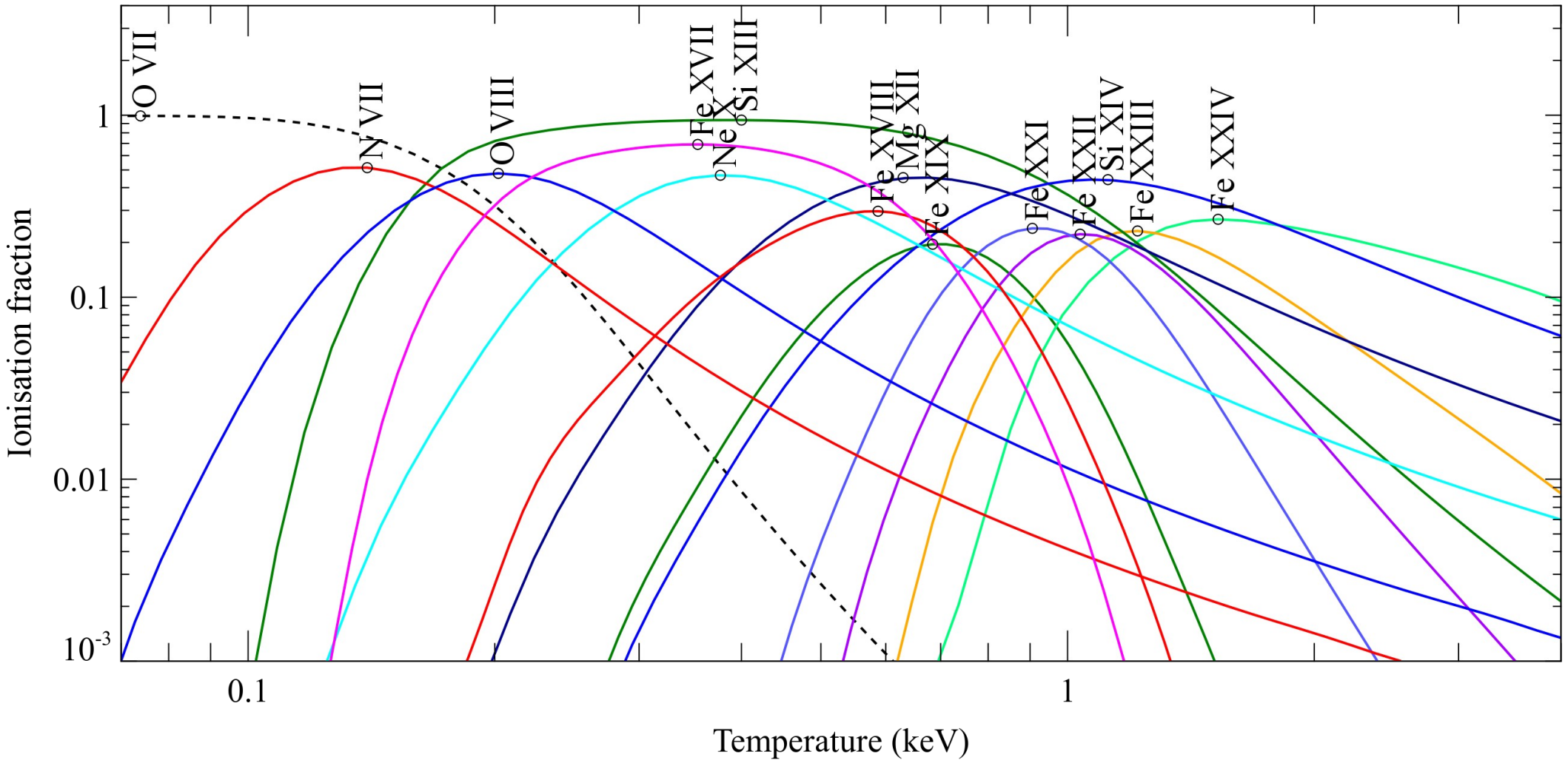
1D image

Sanders et al 2008

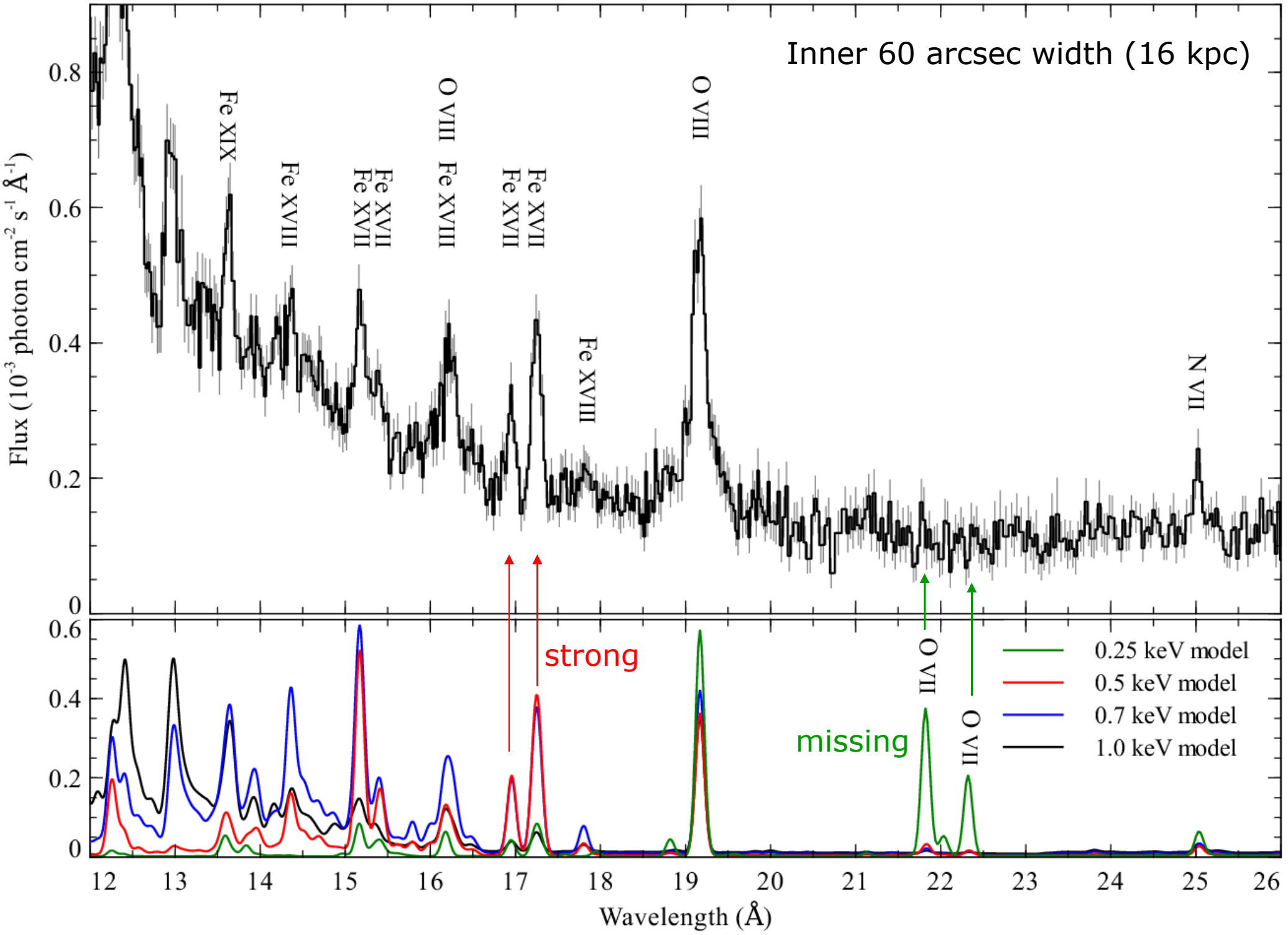


Sanders et al 2008

Ionisation equilibrium

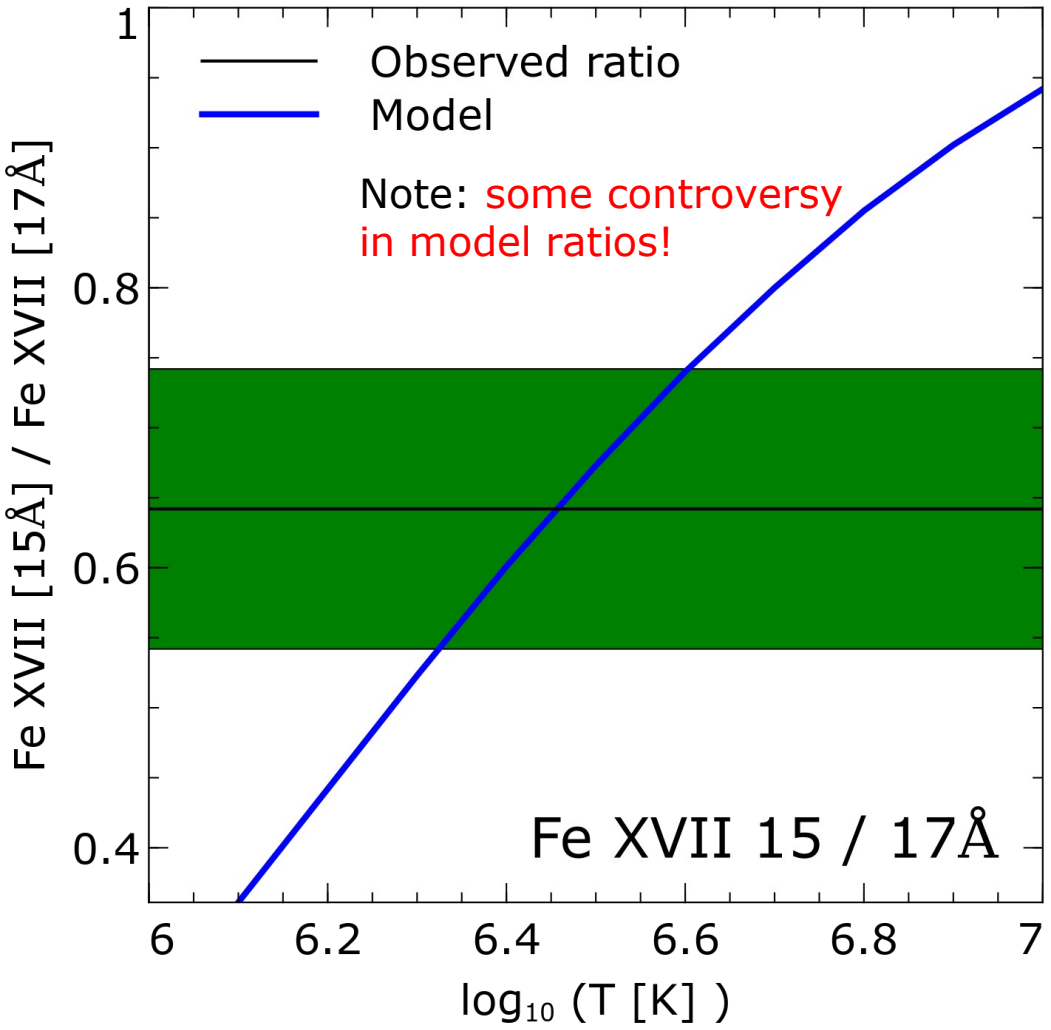


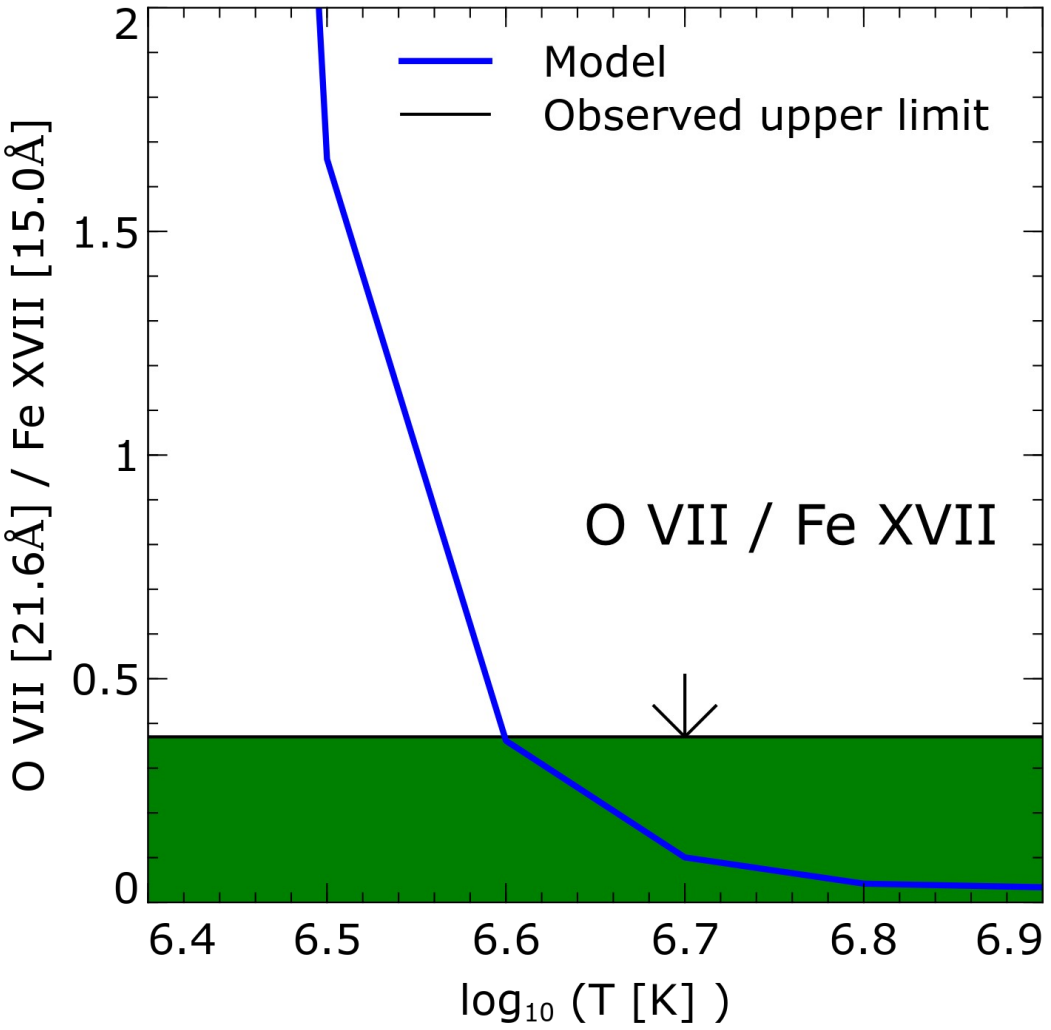
Data from Mazzotta et al 1998


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)

Line ratios — constraints on kT

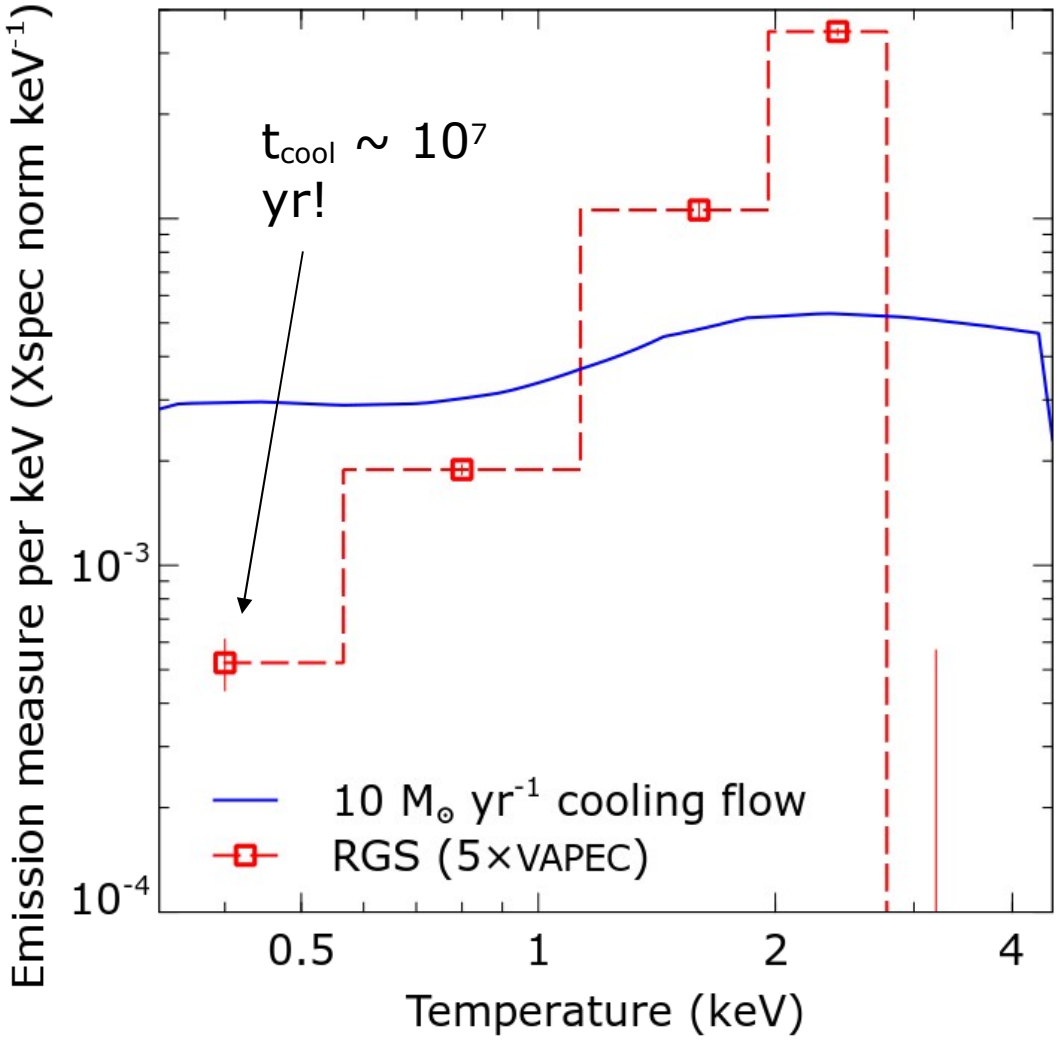
Ratio of flux of emission lines and compared to CHIANTI model





Implies average temperature of gas 3.5 to 5.2 × 10^6 K

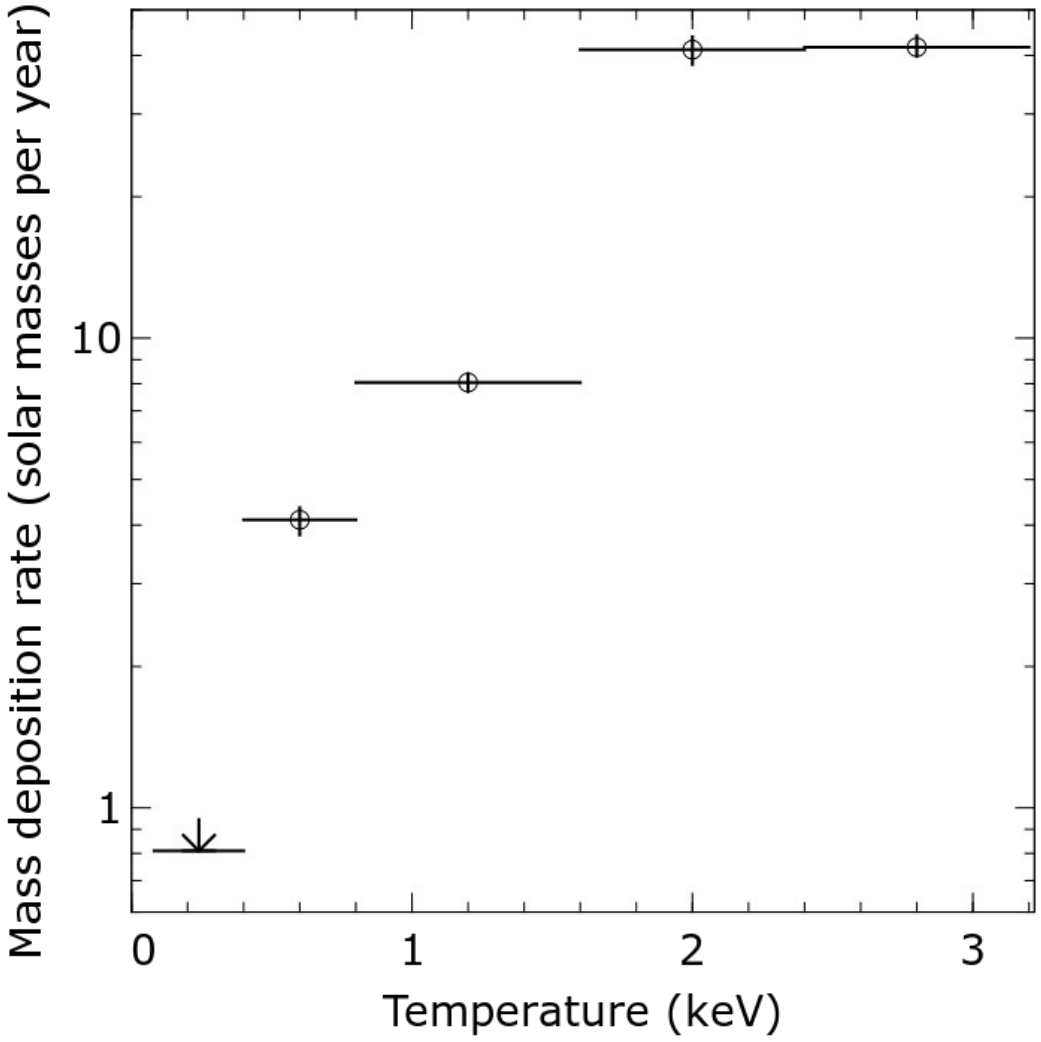
Spectral fitting limits on gas kT



Multi temperature model

(components fixed in temperature but varying in emission measure)

- Factor of 10 in temperature

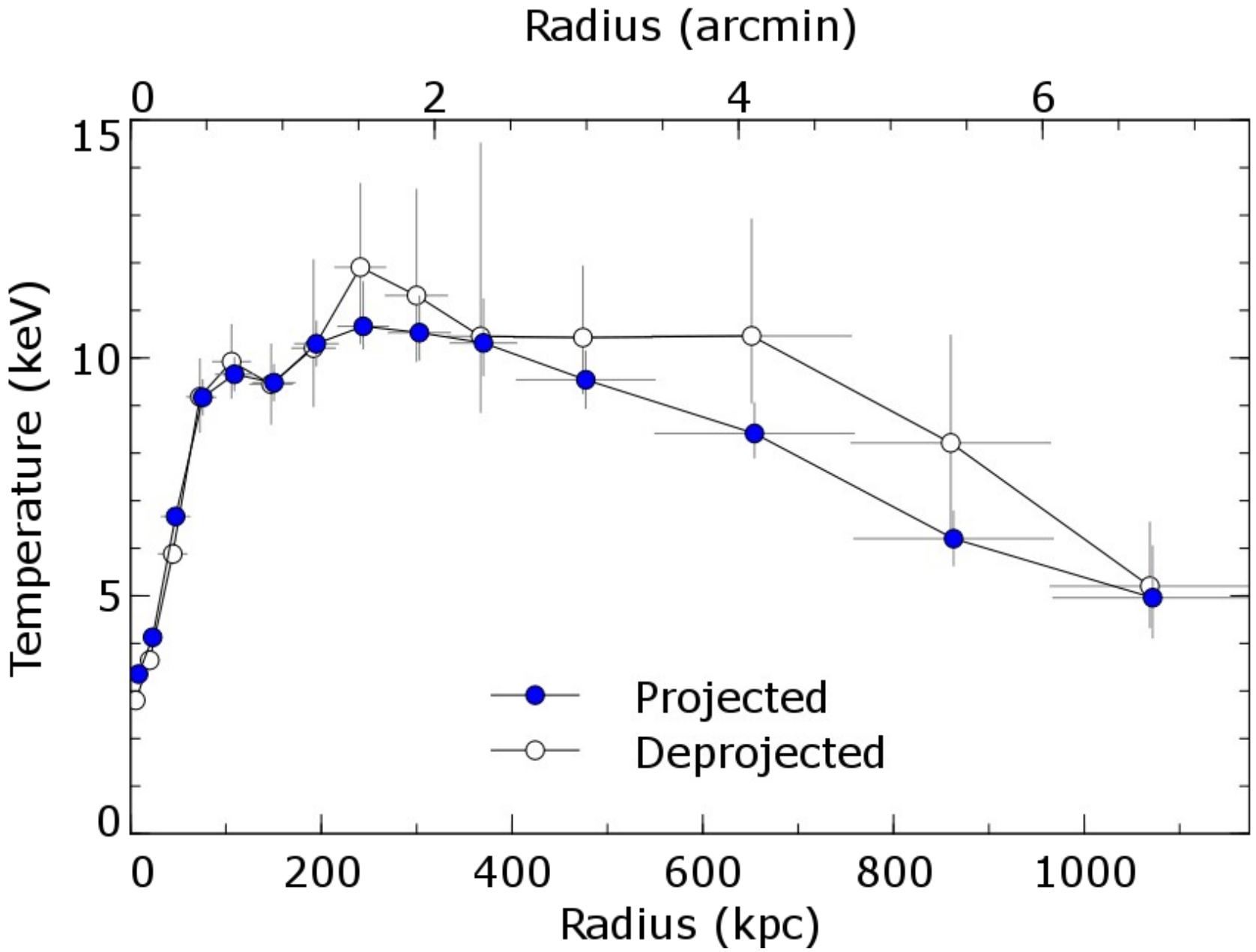


Cooling flow model

(mass deposition in absence of heating)

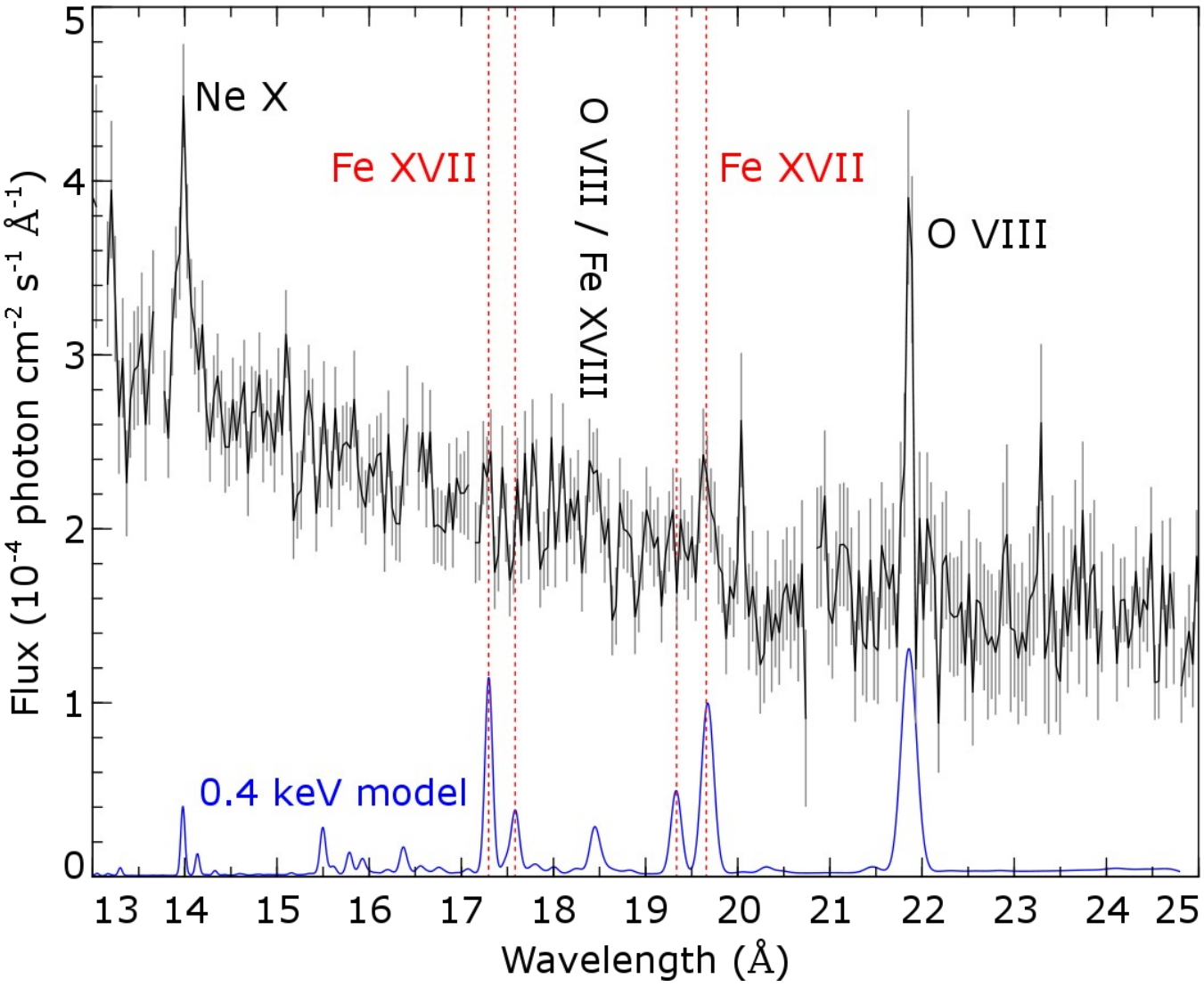
- > factor of 10 in mass deposition

Abell 2204



Chandra temperature profile (Sanders, Fabian & Taylor 2009) z=0.15

Abell 2204: RGS spectrum



We detect a FeXVII line (at >3σ, and weakly a second line)

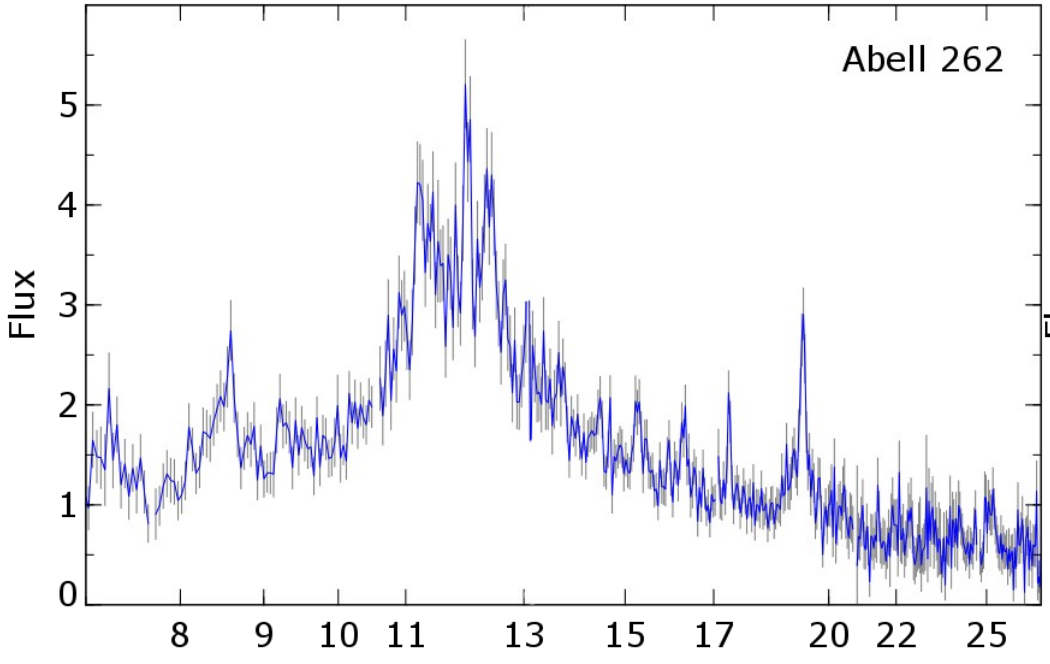
This implies gas around 0.7 keV (~8 MK), consistent with 120 M_{sun} yr^{-1}

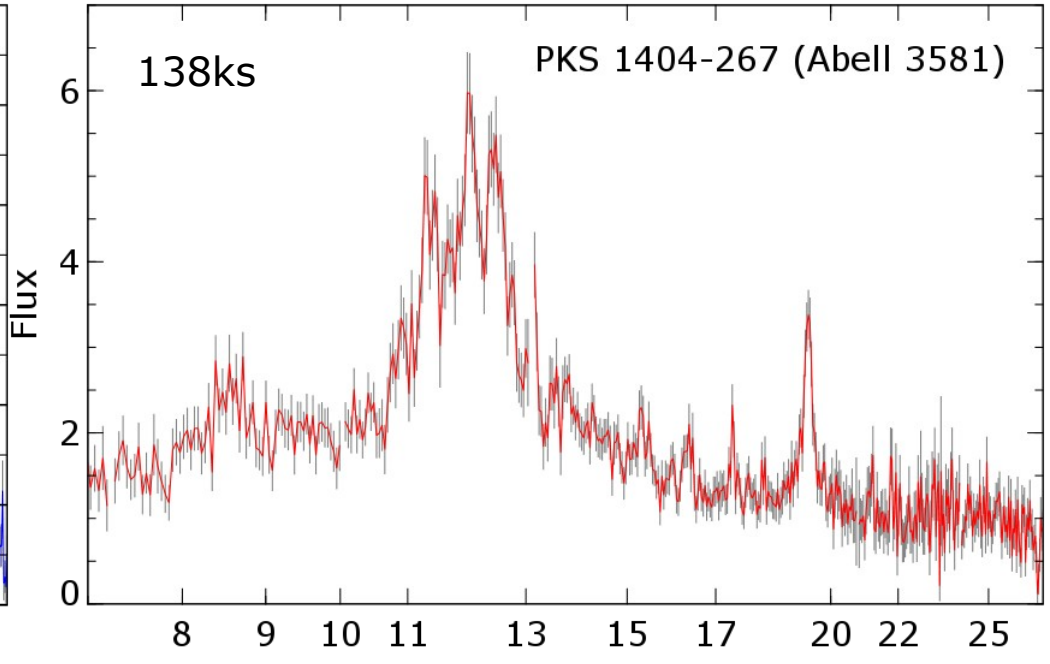
This gas is in a cluster which has upper temperatures of 10 or 12 keV

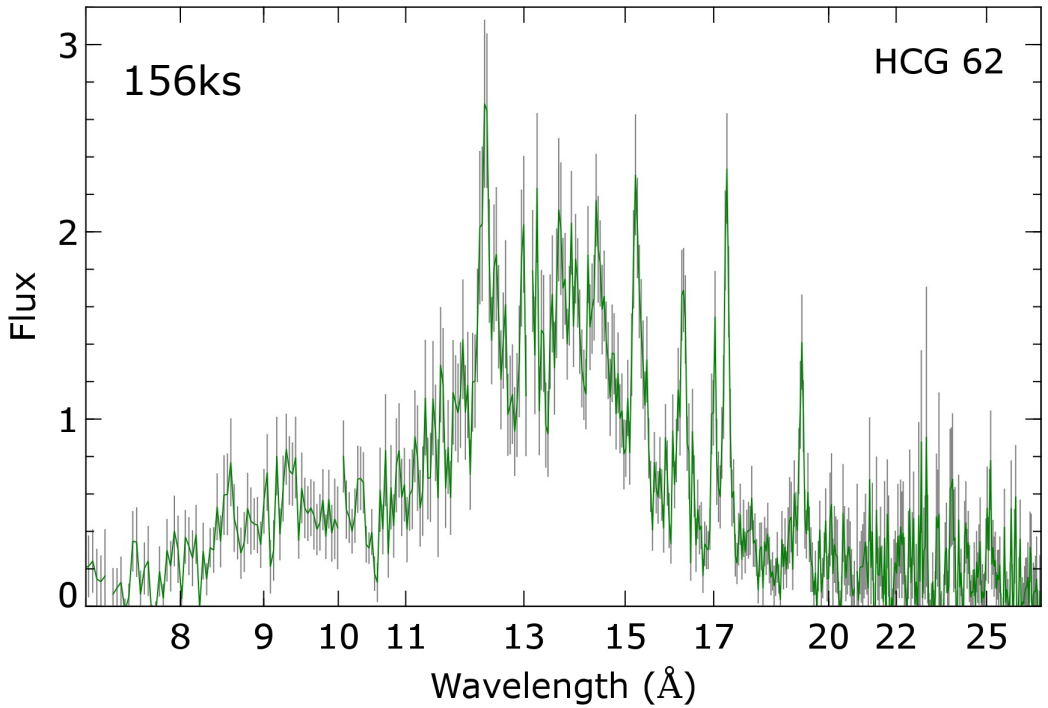
Large range in temperature in this cluster (~15)

114 ks of *XMM-Newton* RGS data (Sanders, Fabian & Taylor 2009)

Current RGS sample







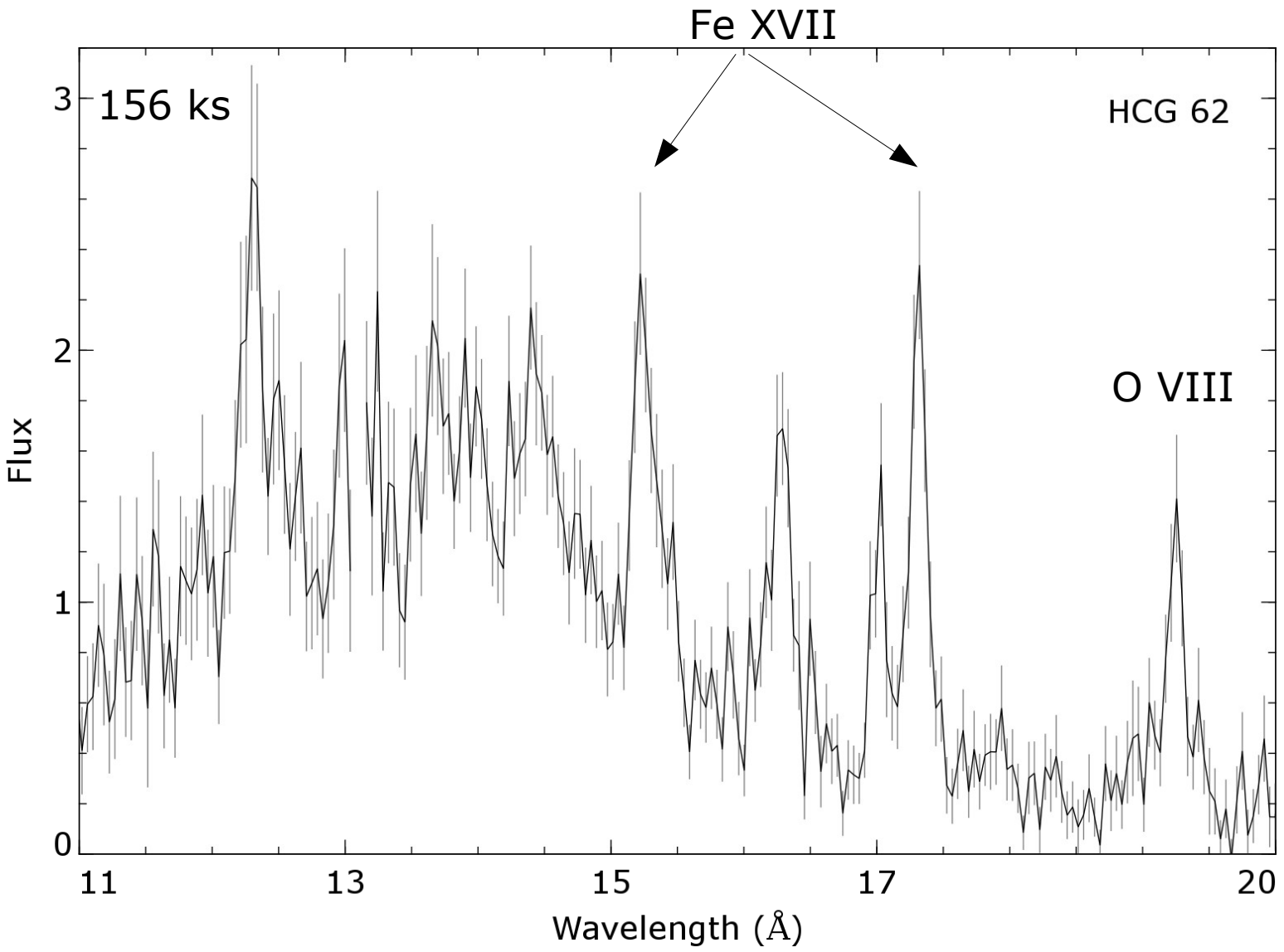
HCG 62

HCG 62 is a compact group of galaxies

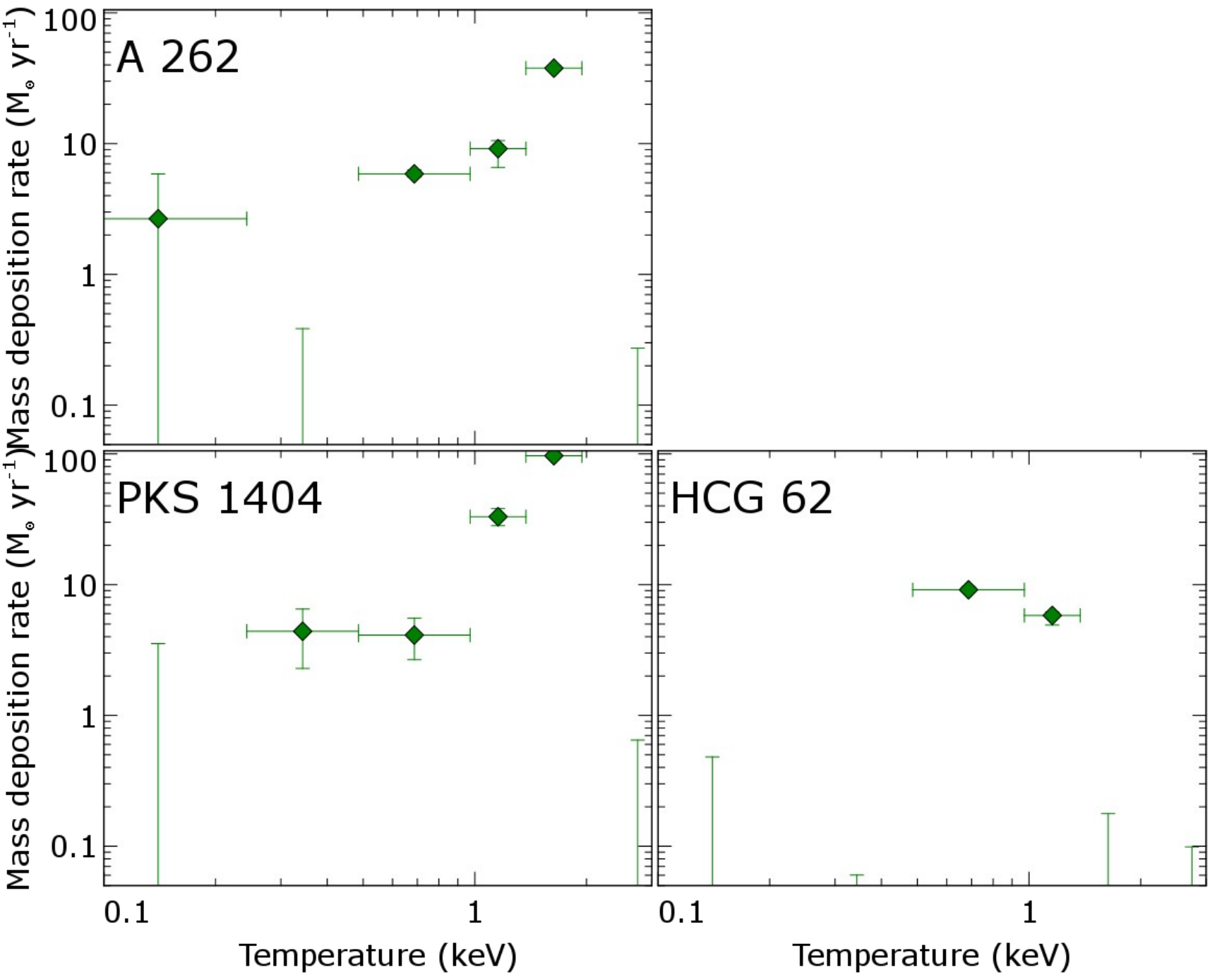
Four bright member galaxies

Temperature varies in spatially resolved studies from 1.5 to 0.7 keV (Morita et al 2006)

High abundance arc (Gu et al 2007)



Temperature distributions



Conclusions

- The behaviour of cool cores observed by RGS is quite varied
  - Wide range in temperature, >10, in Centaurus, A2204, PKS1404, A262 (also Perseus and 2A0335+096, not shown)
  - Narrow range in HCG 62
- Implies there is always close feedback
- It is important to study a wide range of clusters/groups with deep observations with XMM
- New high resolution X-ray telescopes, e.g. Astro-H, IXO very important!