Off-Centre Abundance Peaks In Clusters of Galaxies

Jeremy S. Sanders and A.C. Fabian

jss@ast.cam.ac.uk

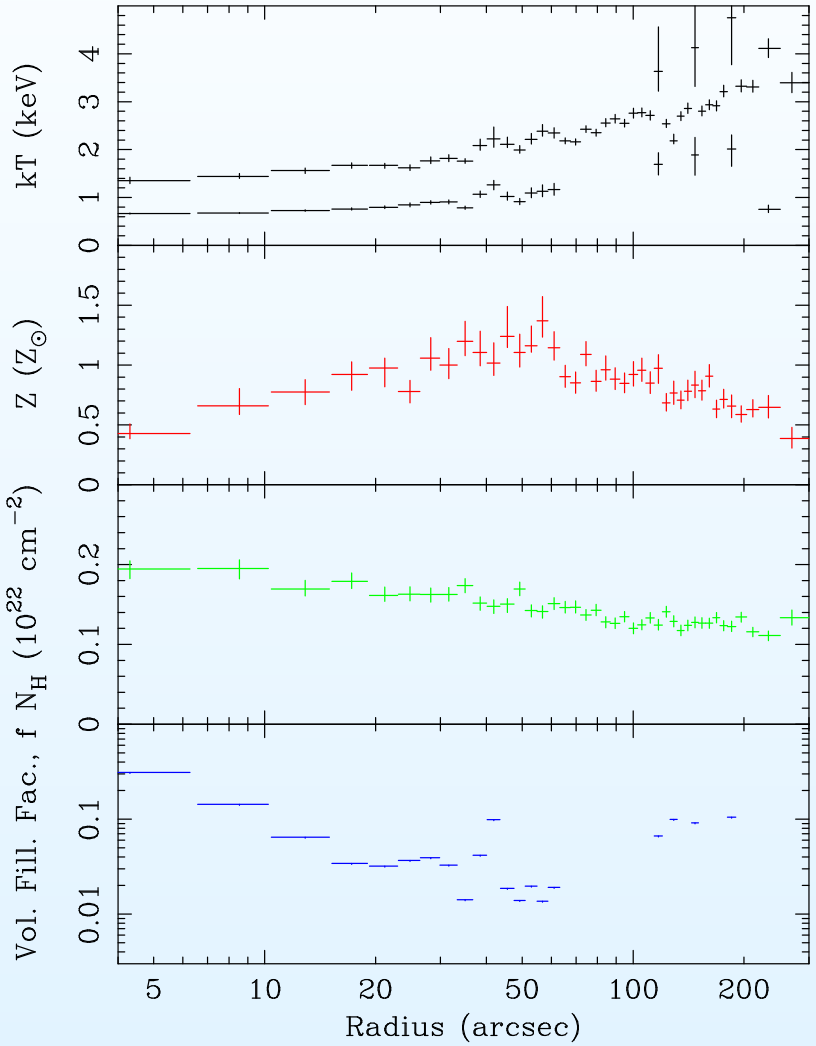
Institute of Astronomy, University of Cambridge, UK

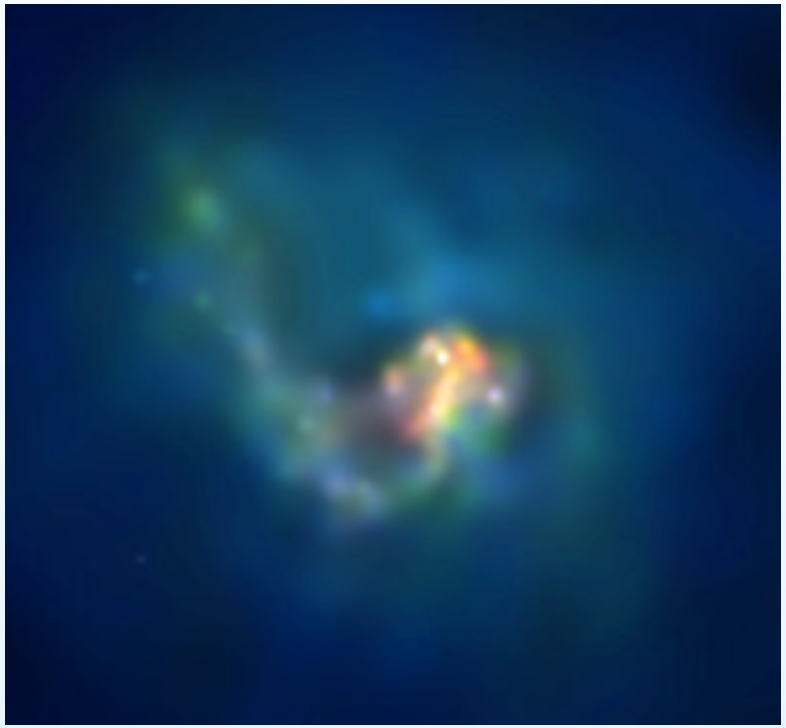
Introduction

- Abundance gradients have been known for some time in clusters of galaxies (e.g. Fukazawa et al. 1994).
- However, analysis of *Chandra* observations show that a number of different clusters show off-centred abundance profiles.
- Examples include:
  - Centaurus (Sanders & Fabian 2002)
  - Perseus (Schmidt, Fabian & Sanders 2002; Churazov et al 2003)
  - Abell 2199 (Johnstone et al 2002)
  - NGC 4636 (Jones et al 2002)

Centaurus Cluster — Sanders & Fabian (2002)

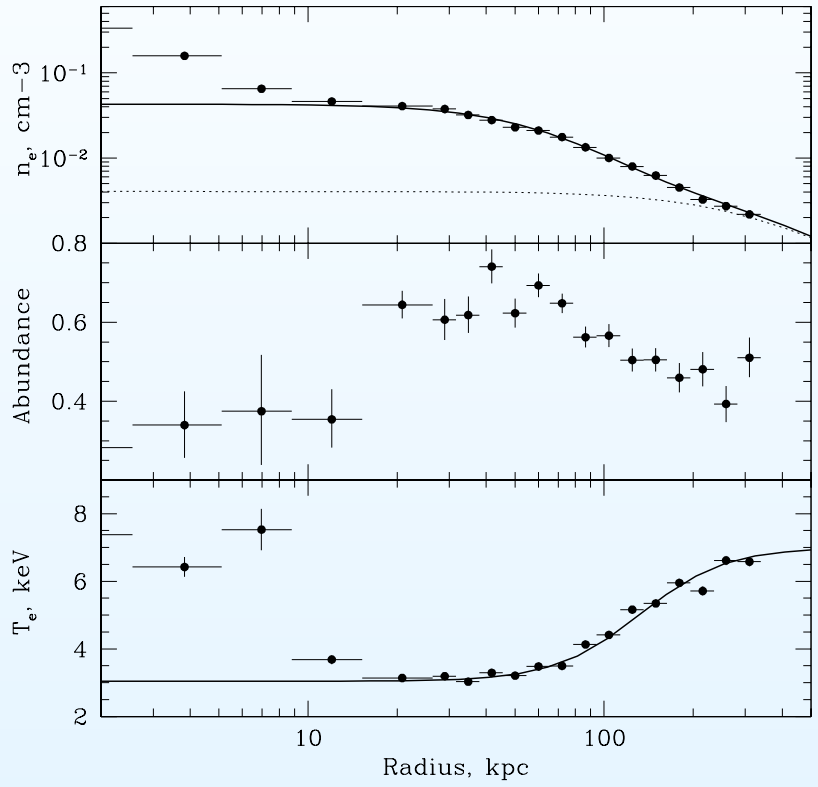
Profile and inner 100 arcsec (∼23 kpc) diameter image.

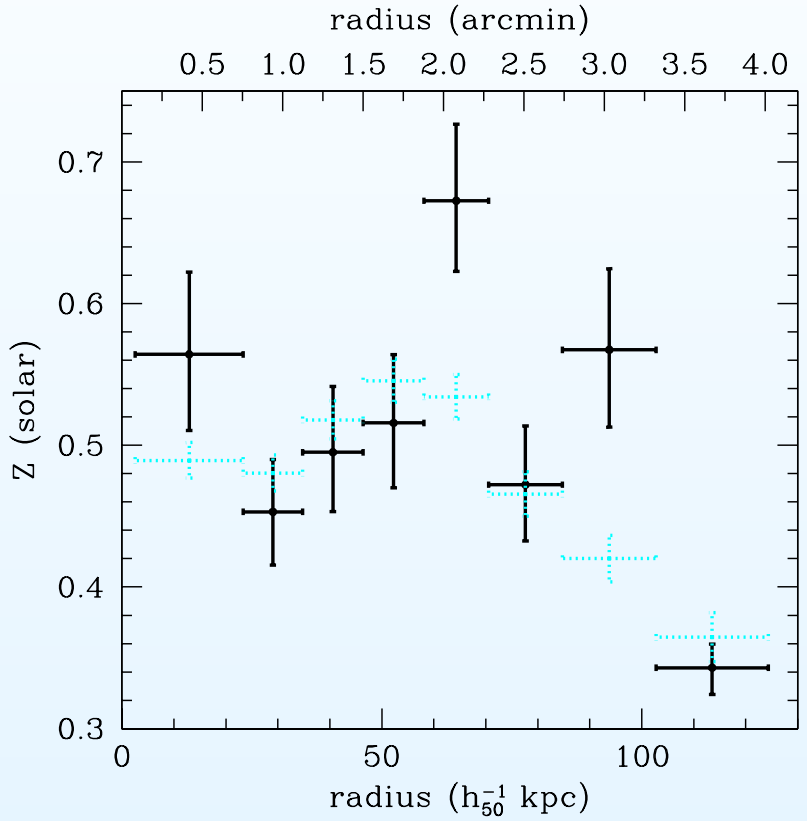




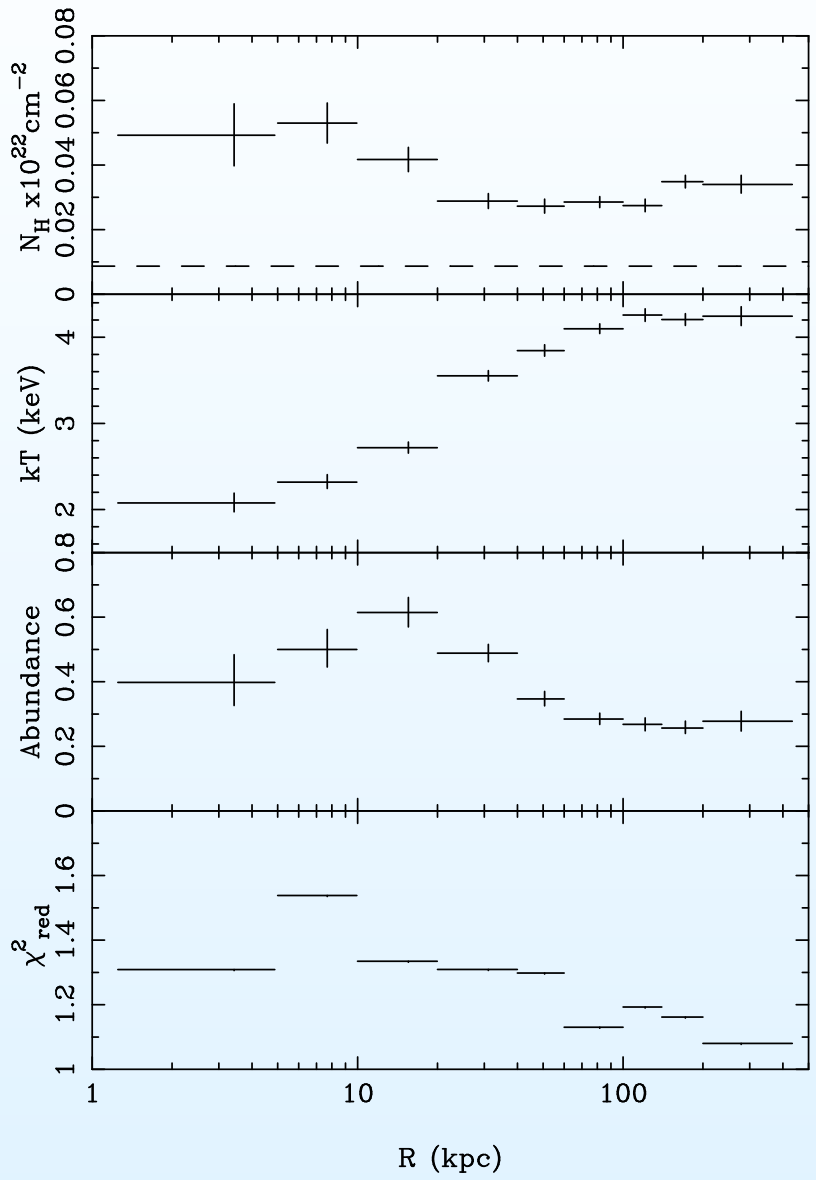
Perseus Cluster

Deprojected profiles — Churazov et al (2003), Schmidt et al (2002)

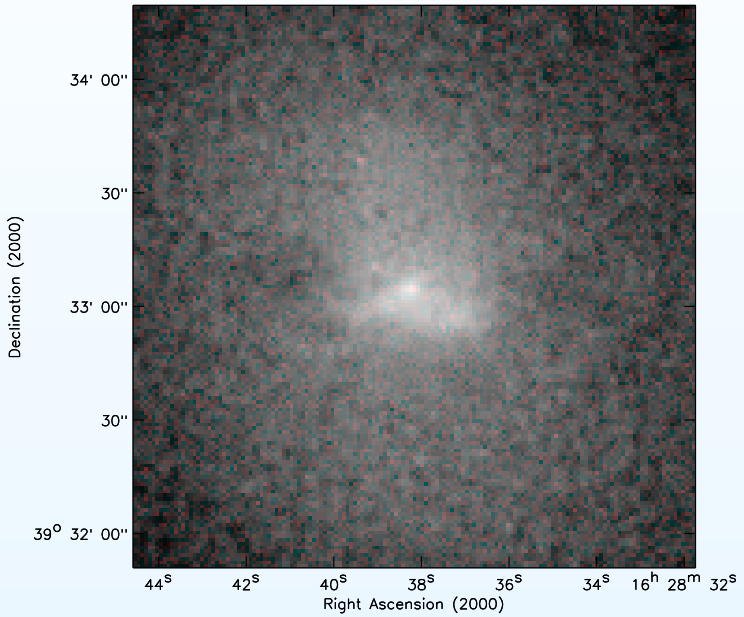




Abell 2199 — Johnstone et al (2002)



Deprojected profiles



Possible reasons

- Physical effect — abundance really declines to the centre of the cluster. Have to explain with enrichment models.
- Resonant scattering — certain emission lines from higher density regions are resonantly scattered away from us (e.g. Gilfanov et al 1987).
- Small scale metallicity variations — see poster by G. Morris (Morris & Fabian 2003).
- More than one temperature component at each radius (also known as Fe Bias, Buote 2000). Underestimate abundance due to inappropriate model (wider Fe-L structure).

Here we investigate the effect of different types of spectral model on the abundance profile, allowing for projection.

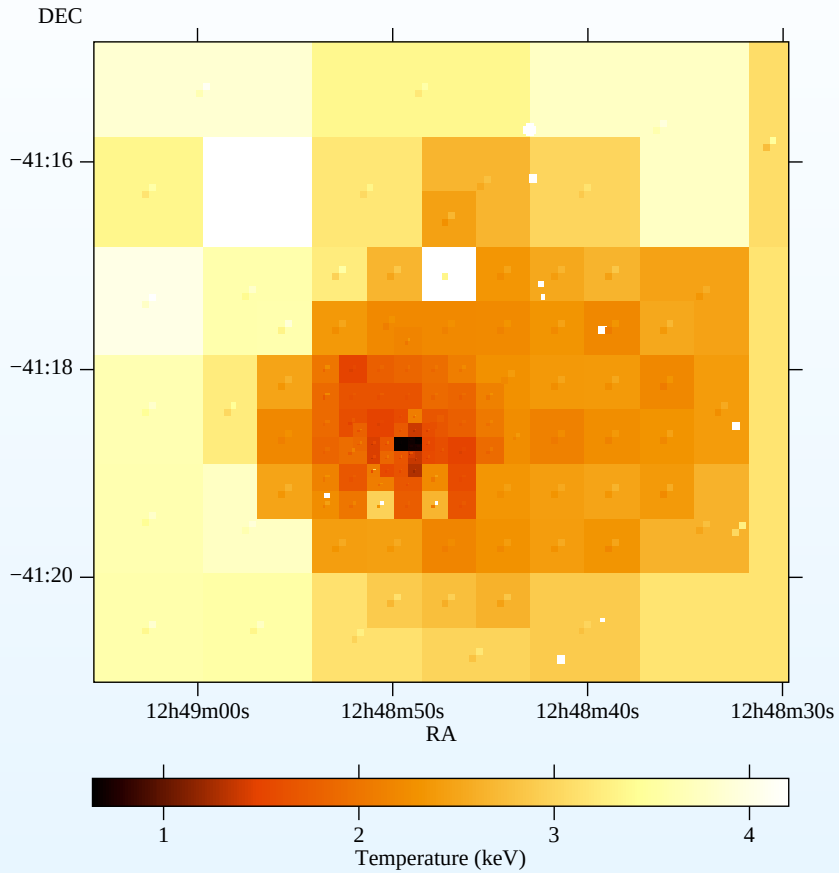
Centaurus: New analysis of Chandra data

- Data reprocessed with latest calibration files.
- RMFs and ARFs weighted over regions, CORRARF applied to ARFs (ACISABS correction, Chartas & Getman).
- Spectra extracted from annuli covering western half of Centaurus.
- Data fitted with PROJCT XSPEC model to account for projection effects.
- Galactic absorption and redshift allowed to vary.
- Individual abundances allowed to vary, as this greatly improves the quality of the fit ($\Delta\chi^2 \sim 500$) (O, Fe, Ni, Ne, Si, S, Ar, Mg).

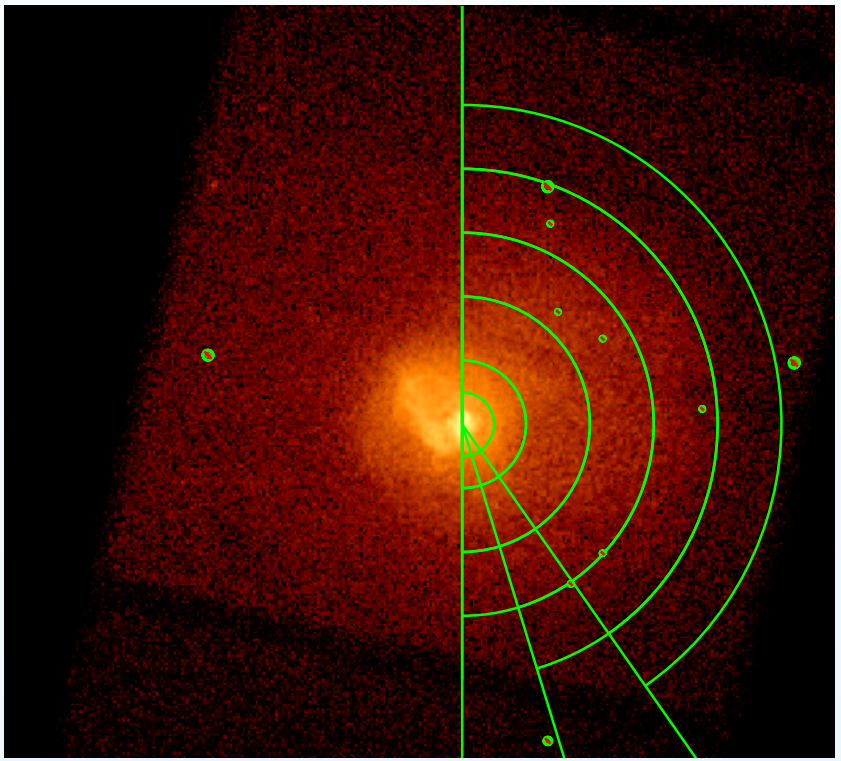
The models we fitted include

- Single temperature VMEKAL
- Two-temperature VMEKAL (abundances linked, $T_l = T_u/2$)
- VMCFLOW and VMEKAL (abundances linked)

Centaurus: Regions

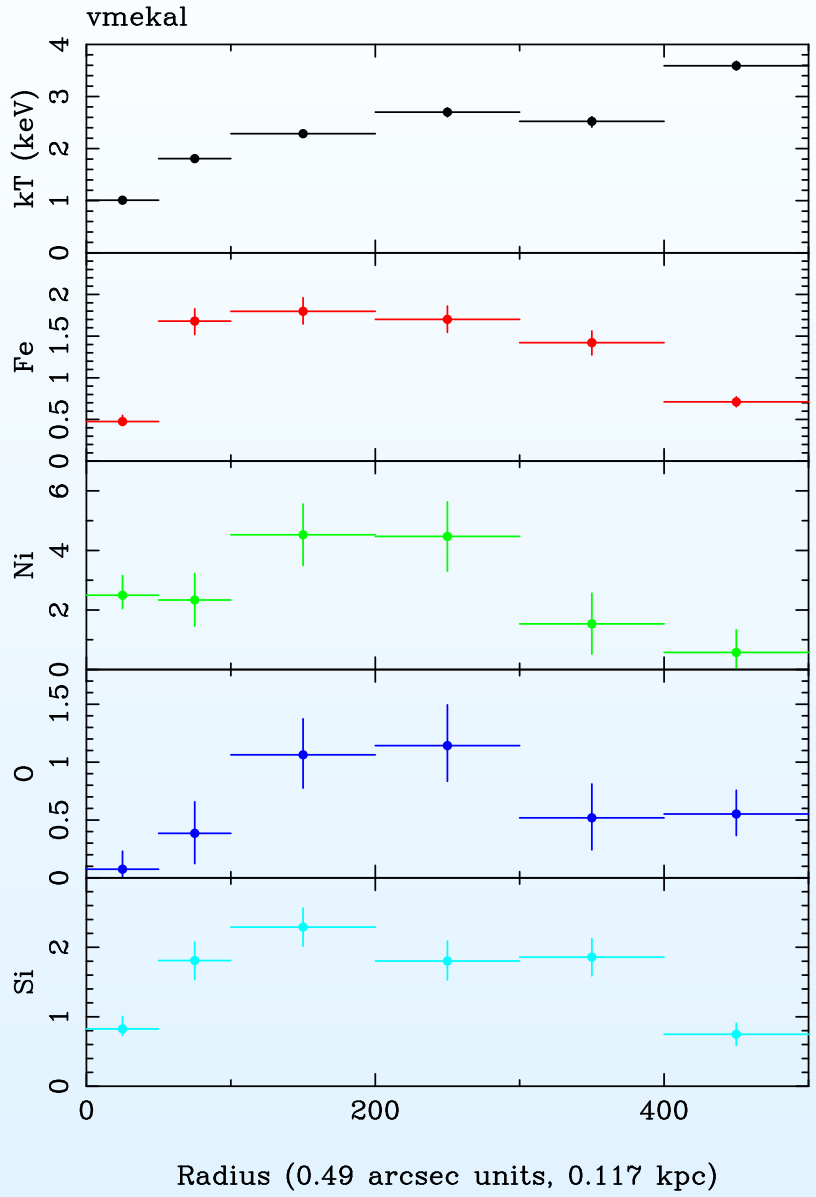


Sanders & Fabian (2002)

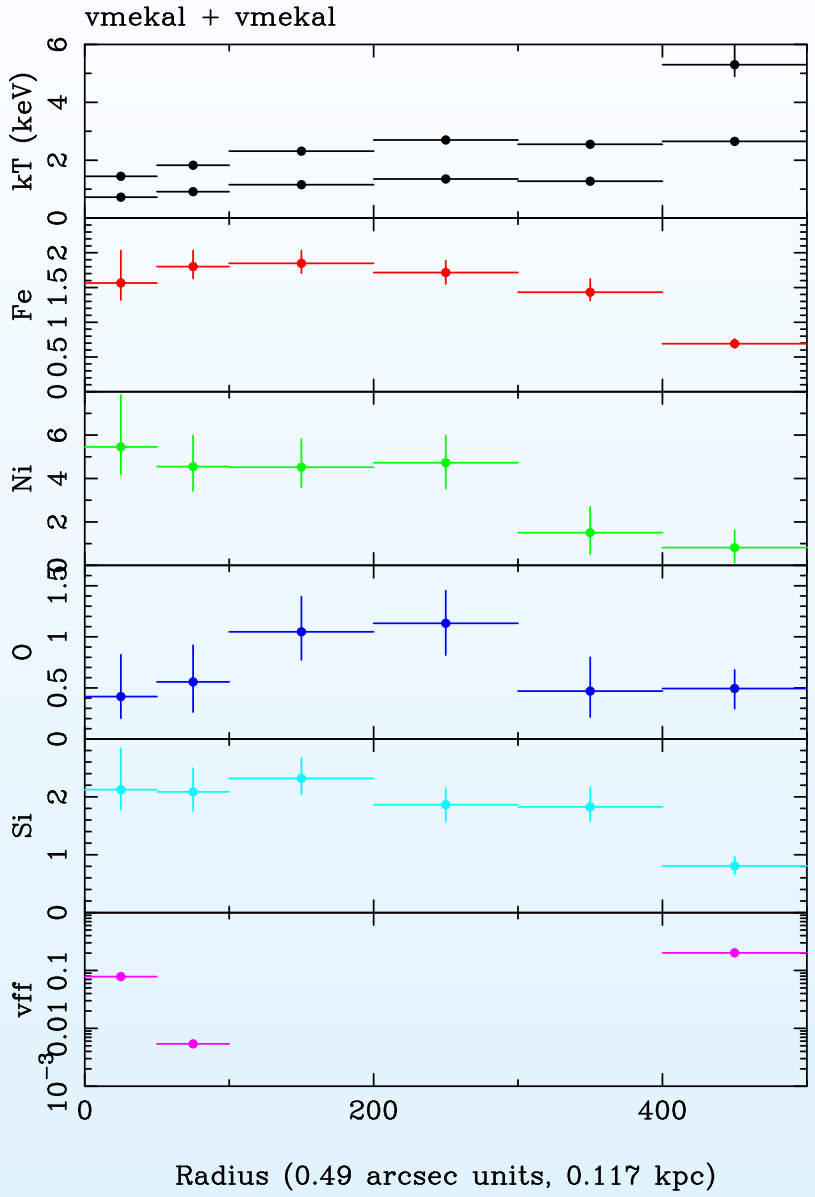


0 to 245 arcsec radius (0 to 58 kpc)

Centaurus: Fit results

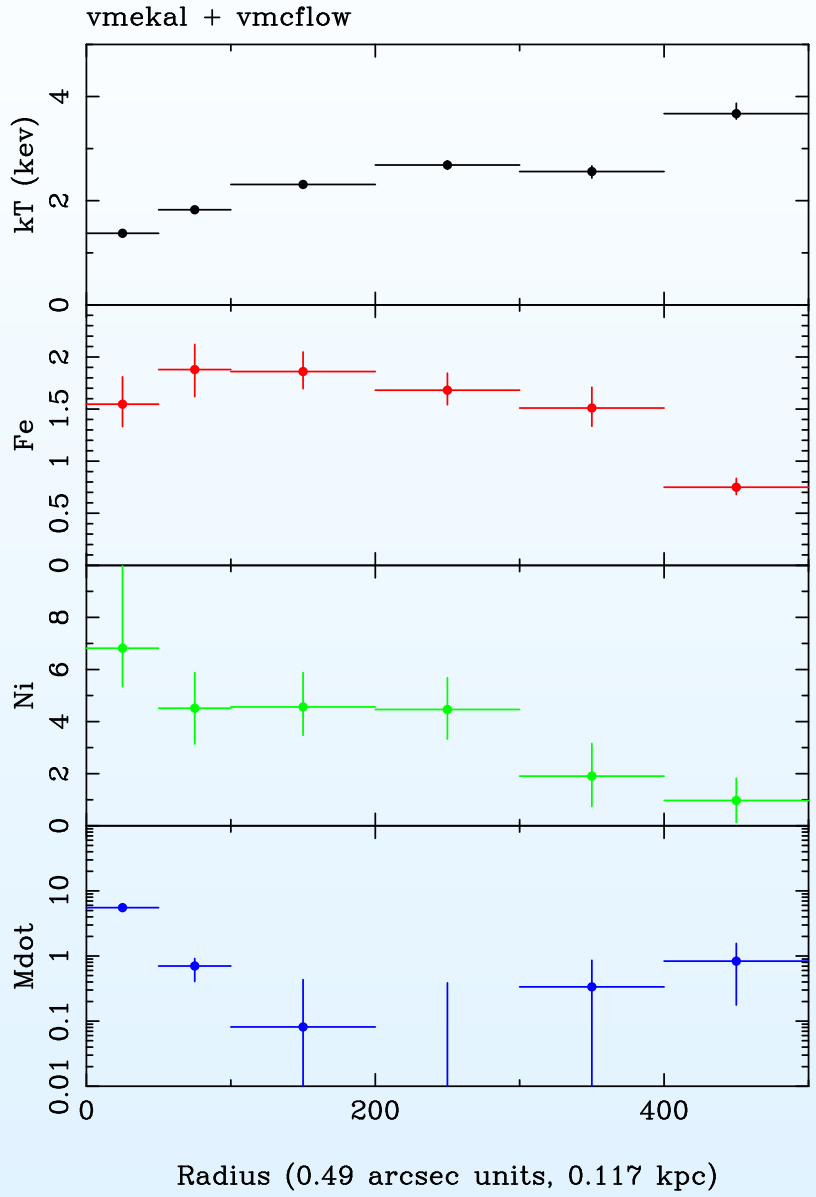


$\chi^2_\nu = 2219/1505 \sim 1.47$



$\chi^2_\nu = 1992/1499 \sim 1.33$

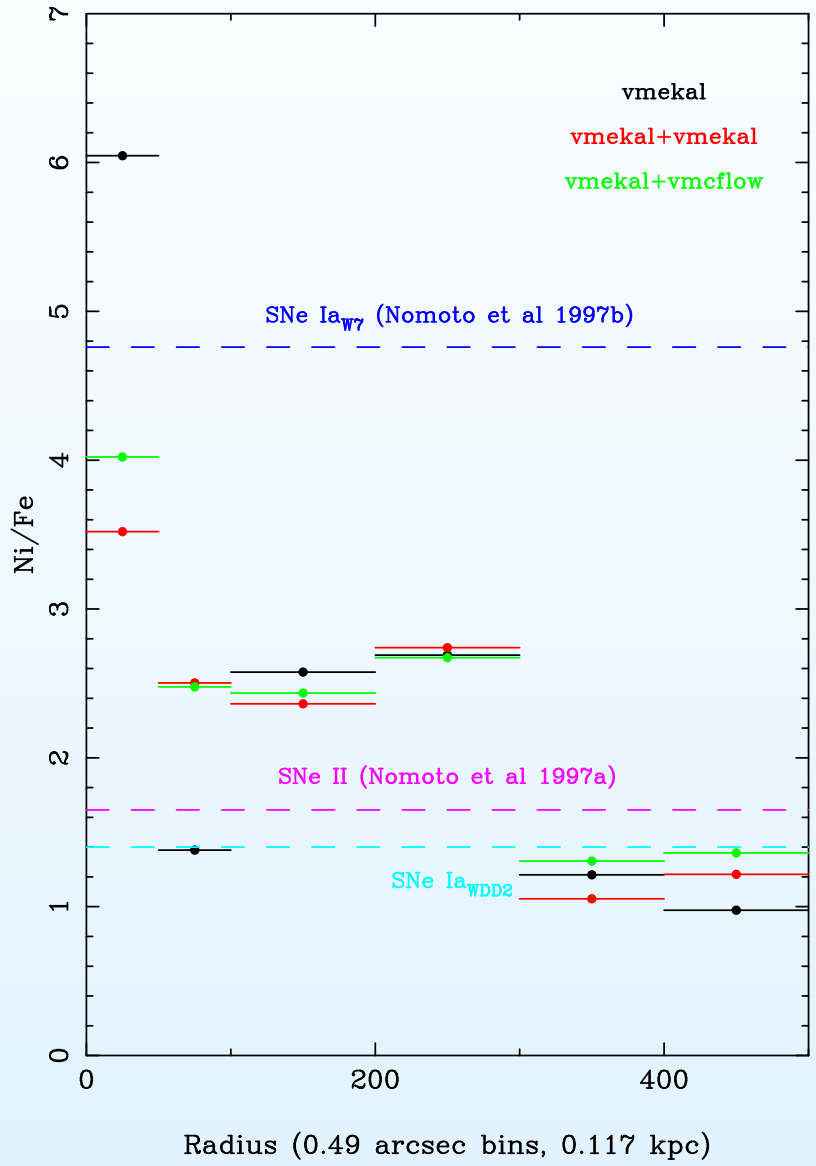
Centaurus: Discussion I



$\chi^2_\nu = 2013/1500 \sim 1.34$

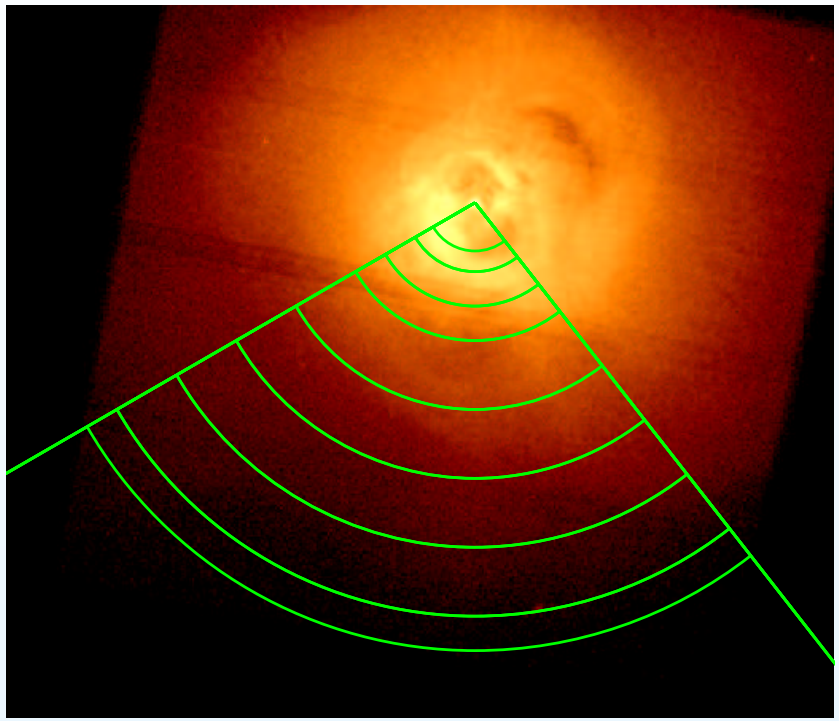
- Fe declines to 0.5 solar in the centre of the cluster with 1T fits, from peak of 1.8 solar.
- With 2T fit the Ni and Fe profiles are approx. flat within 35 kpc.
- The 2T volume-filling-fraction rises to 8% within the inner 6 kpc.
- Factor ~ 5 between innermost temperature and outermost (2T fits).
- CF gives a $\dot{M} \sim 6.3\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ within inner 20 kpc (W of cluster).

Centaurus: Discussion II



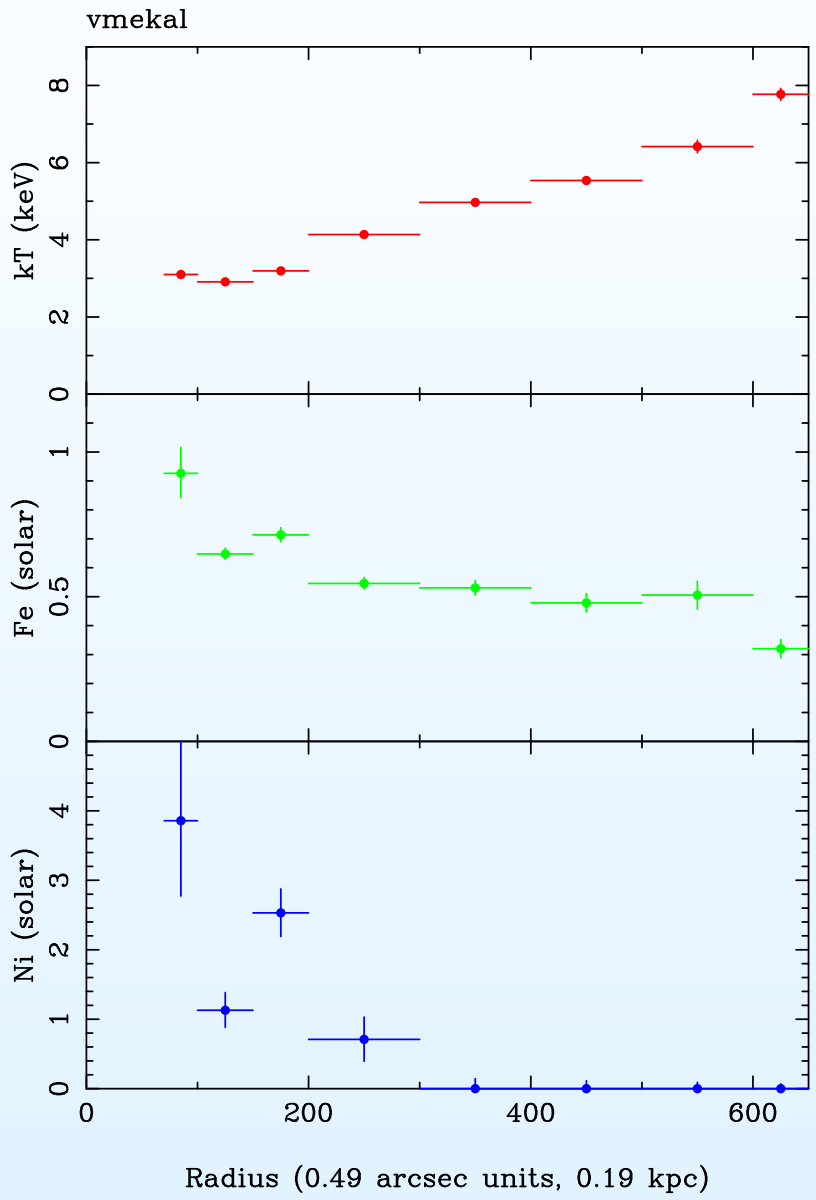
- Ni/Fe abundance ratio increases from $\sim$1 to 3-5 at the centre of the cluster.
- Central value similar to that expected from a fast flame speed SNe Ia at the centre (Nomoto et al 1997b).
- Outer abundance consistent with SNe II or DD SNe Ia.
- O/Fe abundance declines from 0.8 to 0-0.3 at the centre (0.02-0.04 SNe Ia, 3.8 SN II).
- Require more then 1 temperature component at each radius in order to stop abundance decline in Centaurus.

Perseus: 200 ks observation

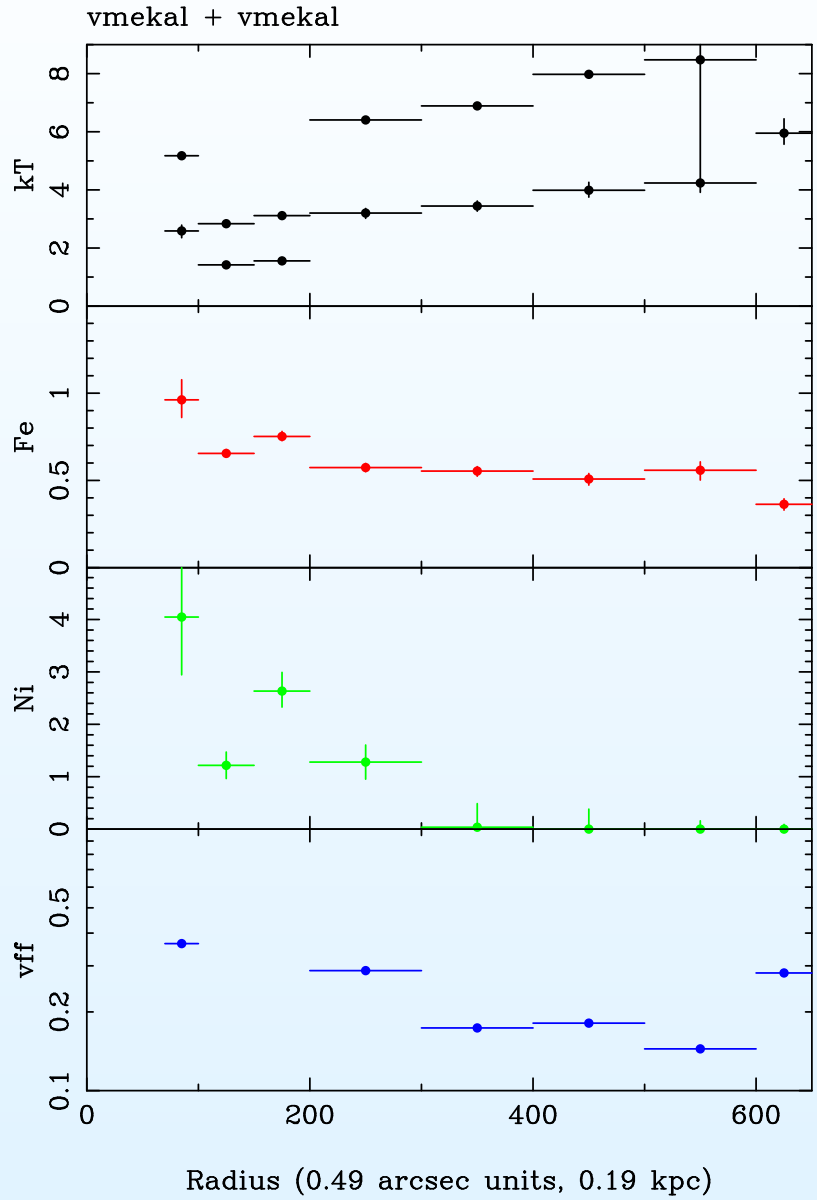


- Fit spectra from annuli between 34 and 319 arcsec (13 to 118 kpc).
- 1T and 2T. Separate Fe, Ni, Mg, S abundances. Fit between 0.7 and 7 keV (missing 1.6-2.3 keV).
- $1 - 6 \times 10^5$ counts in each annulus between 0.5 and 7 keV.

Perseus: Fit results



$\chi^2_\nu = 5649/2995 \sim 1.89$



$\chi^2_\nu = 4571/2963 \sim 1.54$

Conclusions

- In the case of Centaurus there is no evidence of a abundance drop if we allow for projection and multiple temperature components (at least in the W of the cluster).
- Centaurus is an excellent target to study abundances gradients and look for multiple temperature components.
- High Ni/Fe ratios indicate that the metal content near the centres of Centaurus and Perseus is SNe Ia dominated (see also e.g. Dupke & Arnaud 2001).