Clusters of galaxies and the cosmic-web

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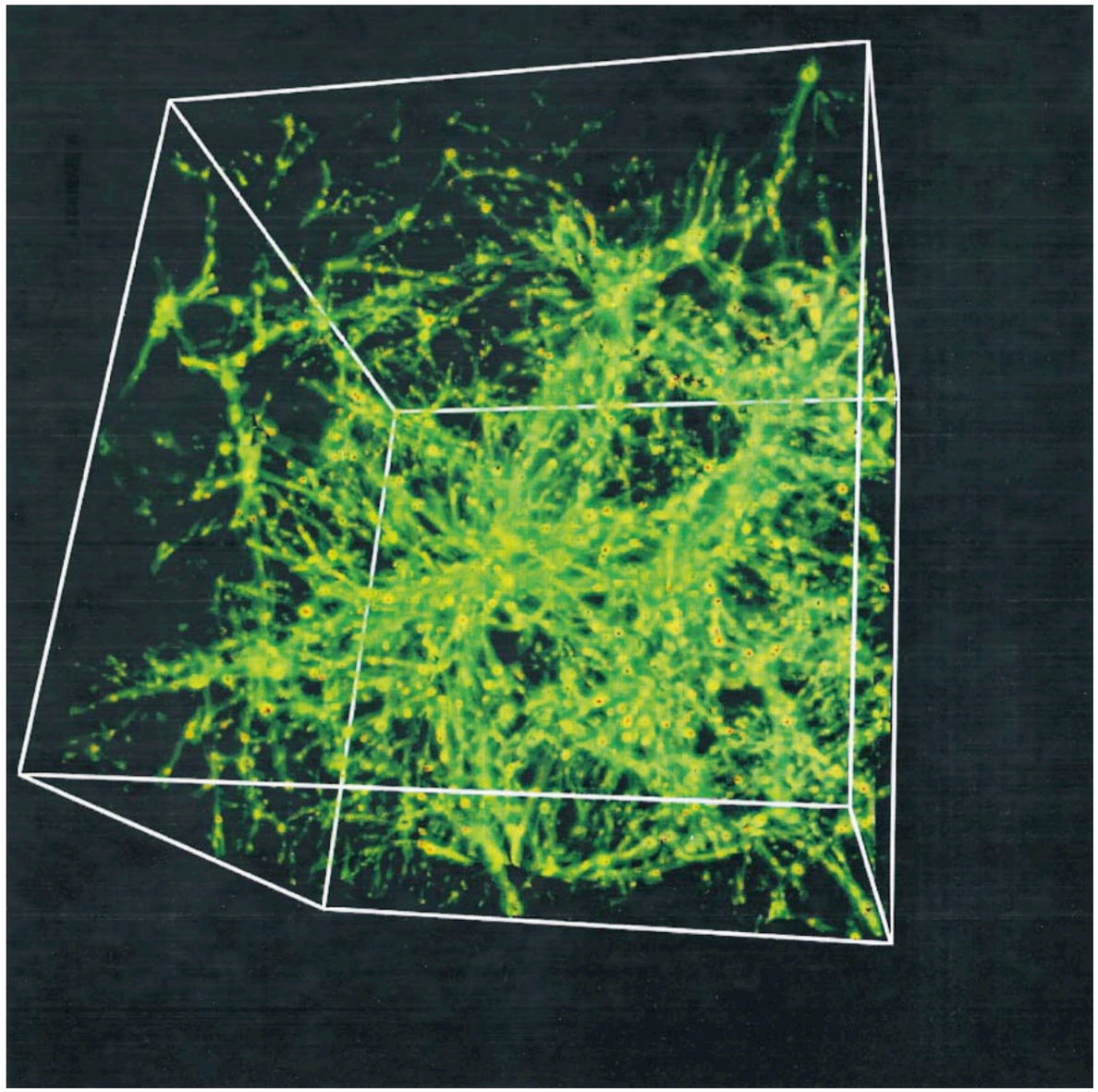
The Warm Hot Intergalactic Medium (WHIM)



- About 30%-40% of baryons at $z \leq 2$ resides in filaments connecting galaxy clusters.

- The temperature of these baryons is 10^5-10^7 K.

- Density 4×10^{-6} to 10^{-4} cm^{-3} corresponding to 15-400 of mean baryonic density (Warm-Hot intergalactic medium; Cen et al. 1999; Dave et al. 2002).

Previous attempts to detect the WHIM in the X-ray band

- **In emission:**

  - with ROSAT: Kull & Böhringer 1999, Zappacosta et al. 2002

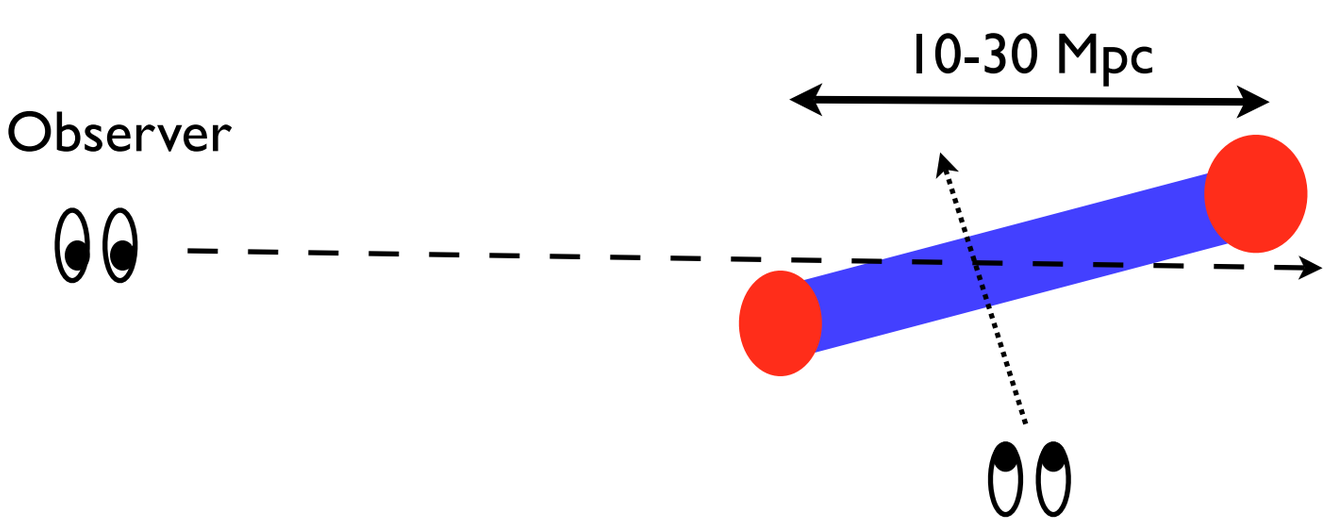
  - with XMM-Newton: Kaastra et al. 2003, Finoguenov et al. 2003

- **In absorption:**

  - marginal detections near clusters: Fujimoto et al. 2004, Takei et al. 2007

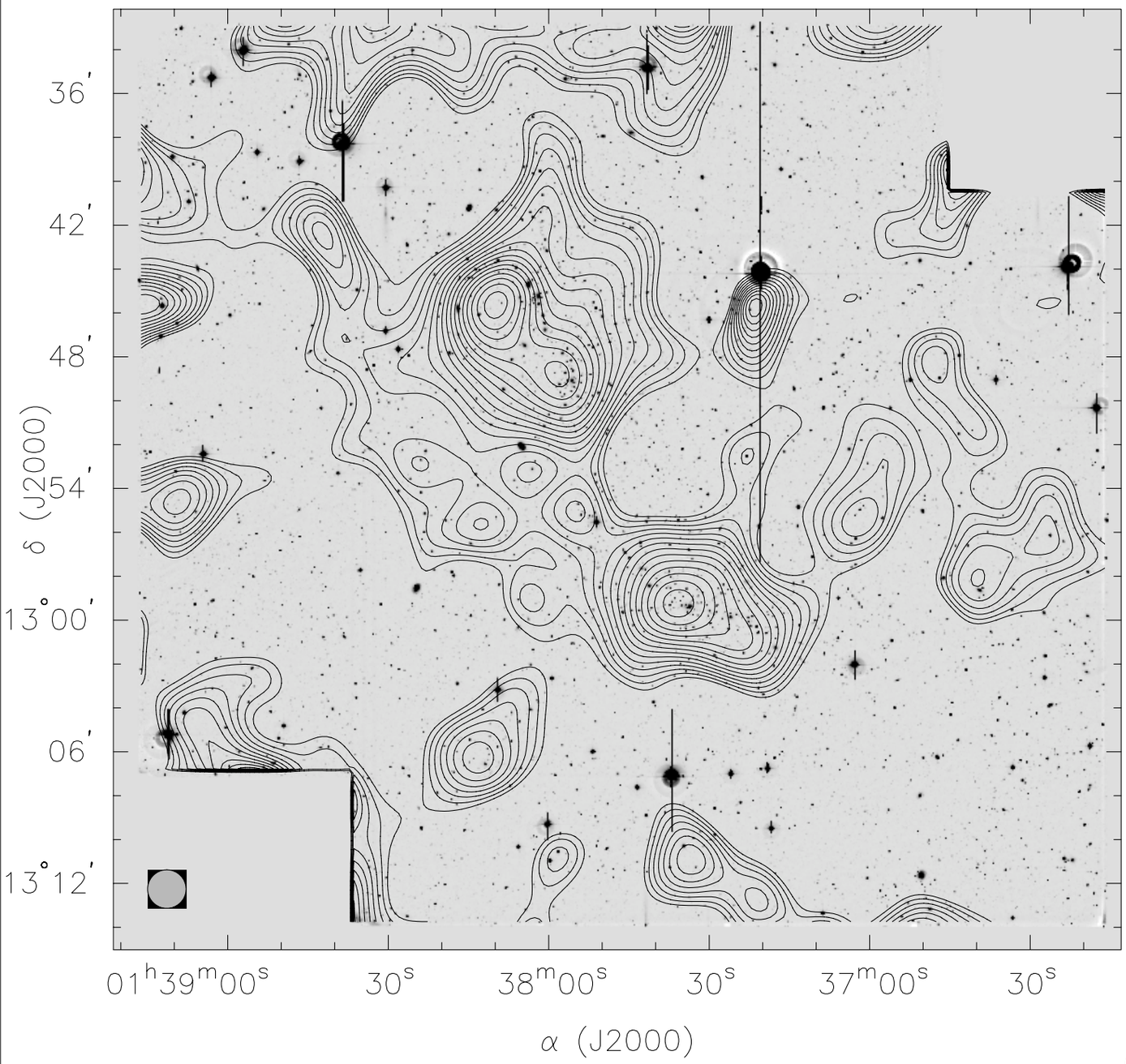
  - blind search: Fang et al. 2002, Mathur et al. 2003, Nicastro et al. 2005 (but Kaastra et al. 2006 & Rasmussen et al. 2007)

Search for WHIM in cluster pairs



- XMM-Newton EPIC allows to probe densities down to 3×10^{-5} cm^{-3}
- XMM-Newton could reveal the densest, hottest parts of WHIM filaments
- Detection of filaments between pairs a differential test - less sensitive to systematics
- Proposed dedicated missions will probe densities of ~1×10^{-5} cm^{-3}

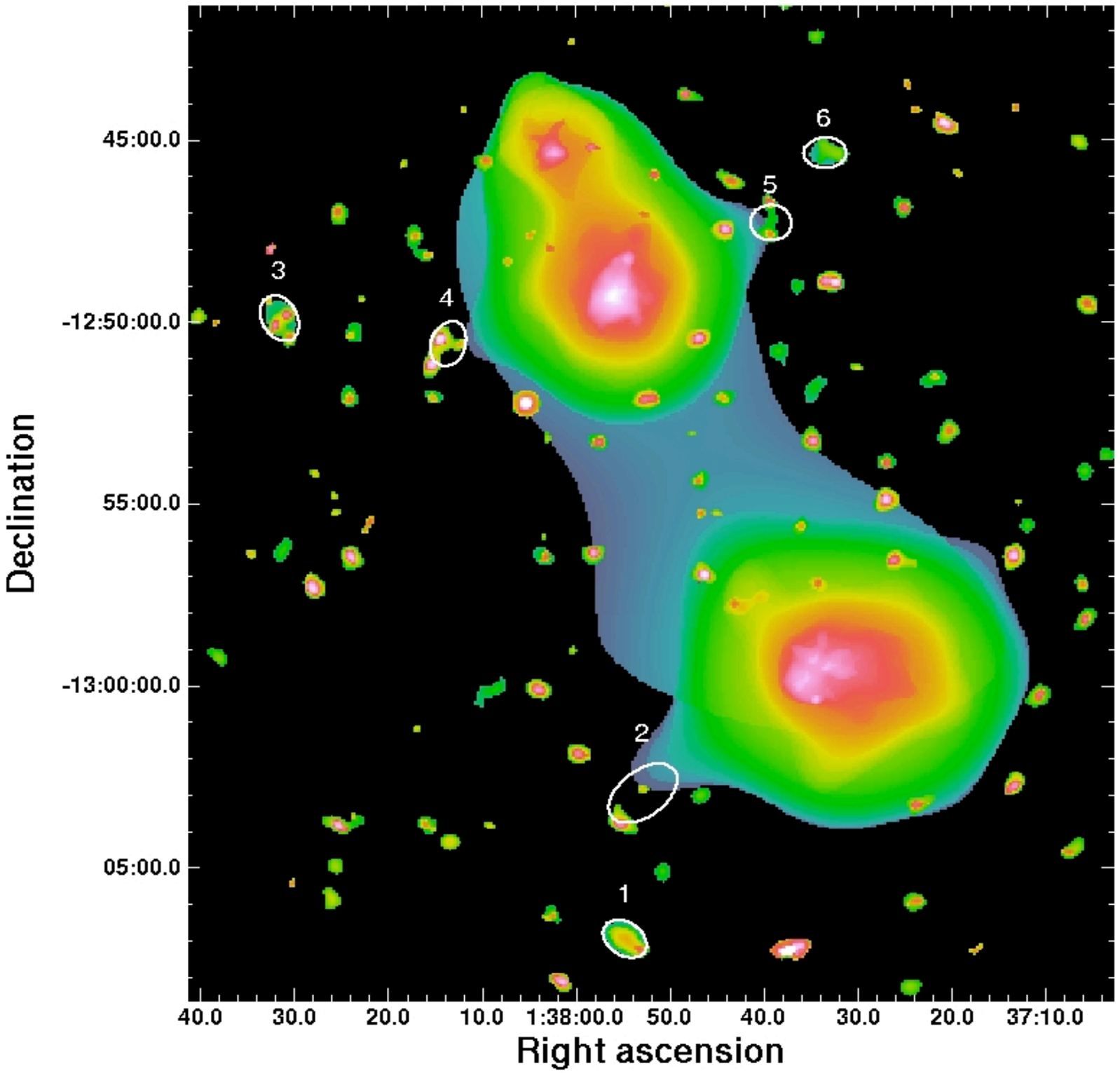
The pair of clusters Abell 222/223



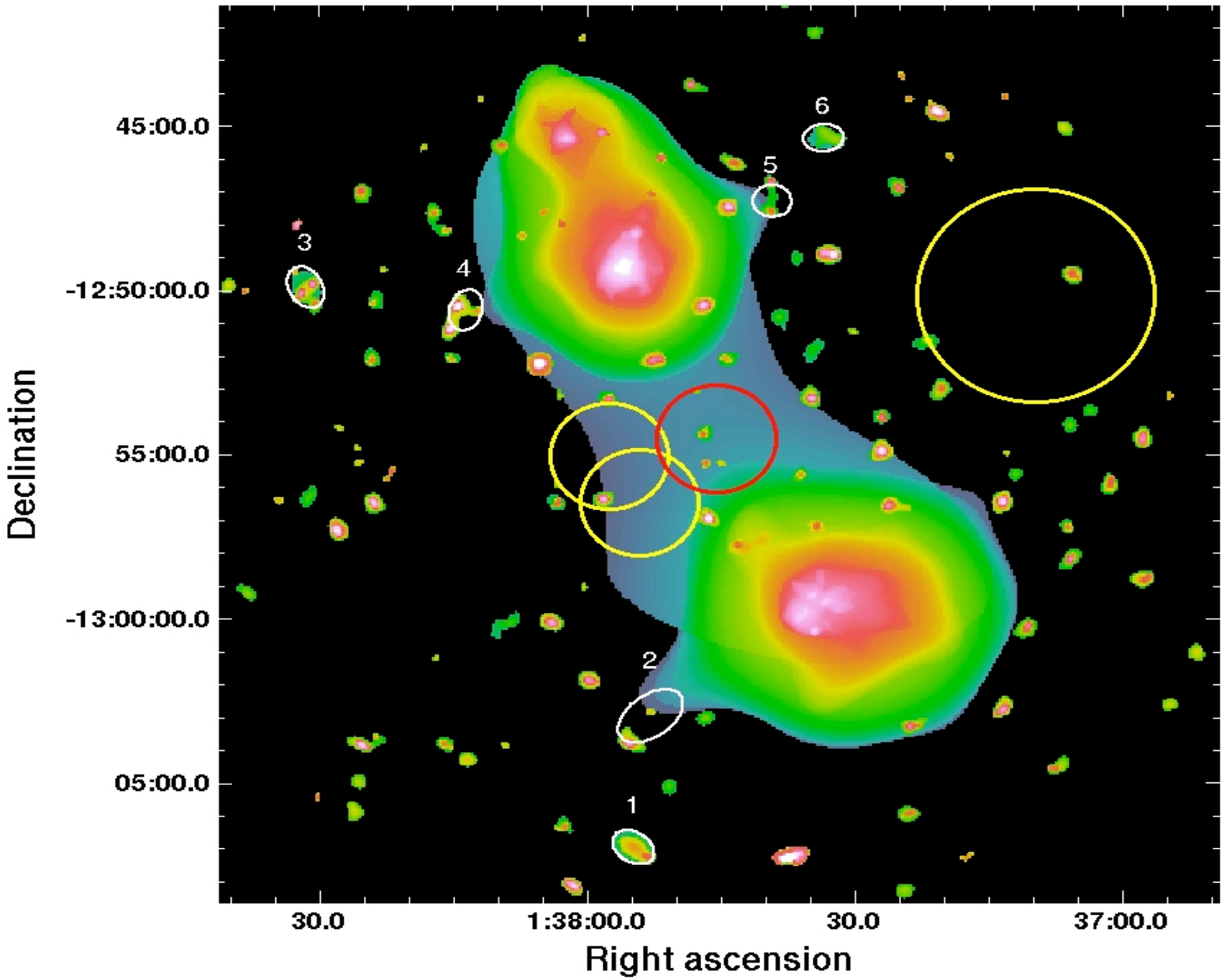
- z ~ 0.21
- separation on the sky ~14' (2.8 Mpc)
- line of sight distance 15 Mpc
- filament detected by weak lensing
- over-density of colour selected galaxies (7 sigma)

Weak lensing map (Dietrich et al. 2005)

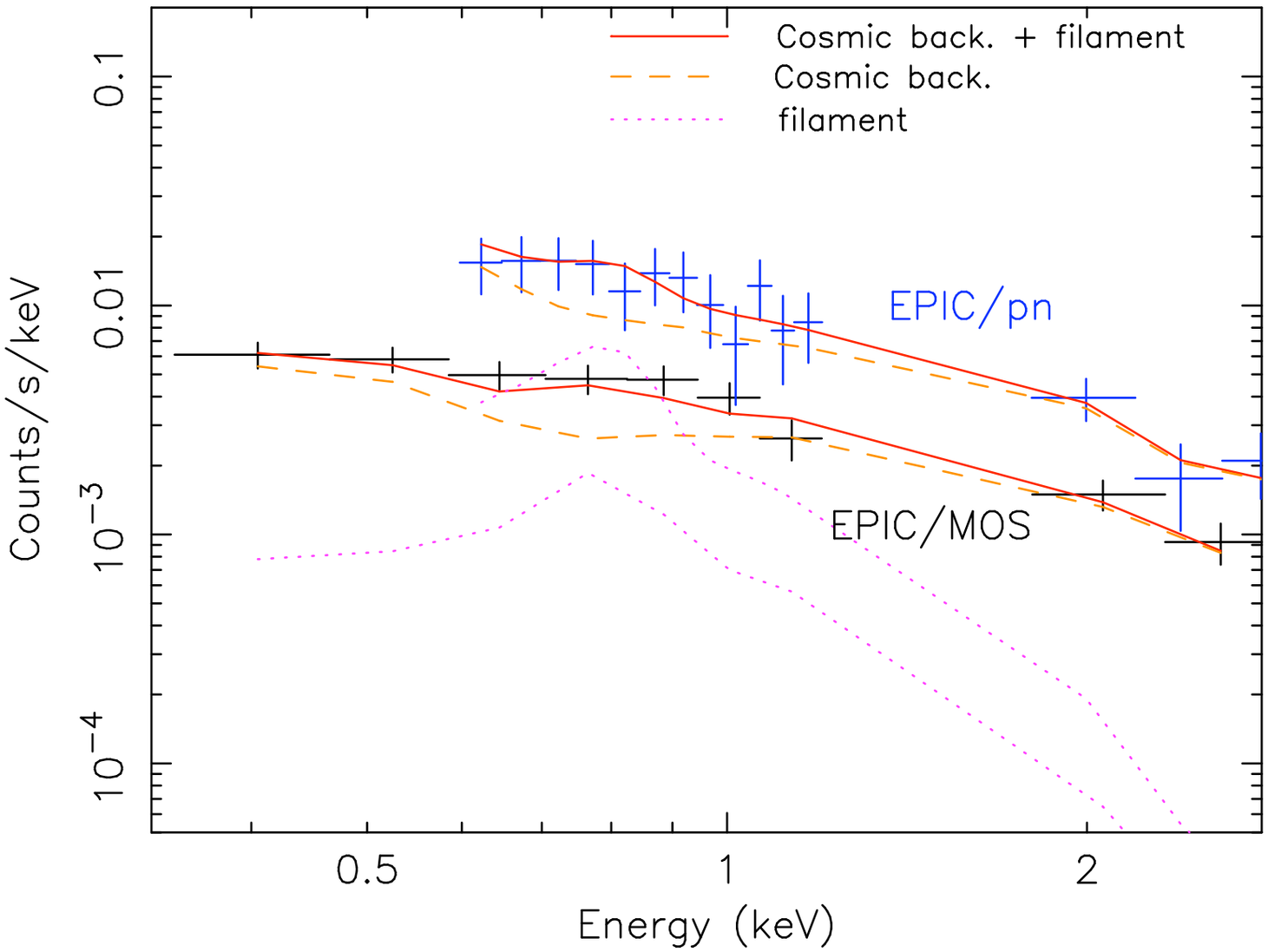
XMM-Newton image of A222/223



Spectrum of the filament



Spectrum of the filament



$kT = 0.91 \pm 0.25$ keV

$Z = 0.2$ Solar

$EM = (1.72 \pm 0.67) \times 10^{65}$ cm^{-3}

$l = 15$ Mpc

$n = (3.4 \pm 1.3) \times 10^{-5}\ l^{-1/2}$ cm^{-3}

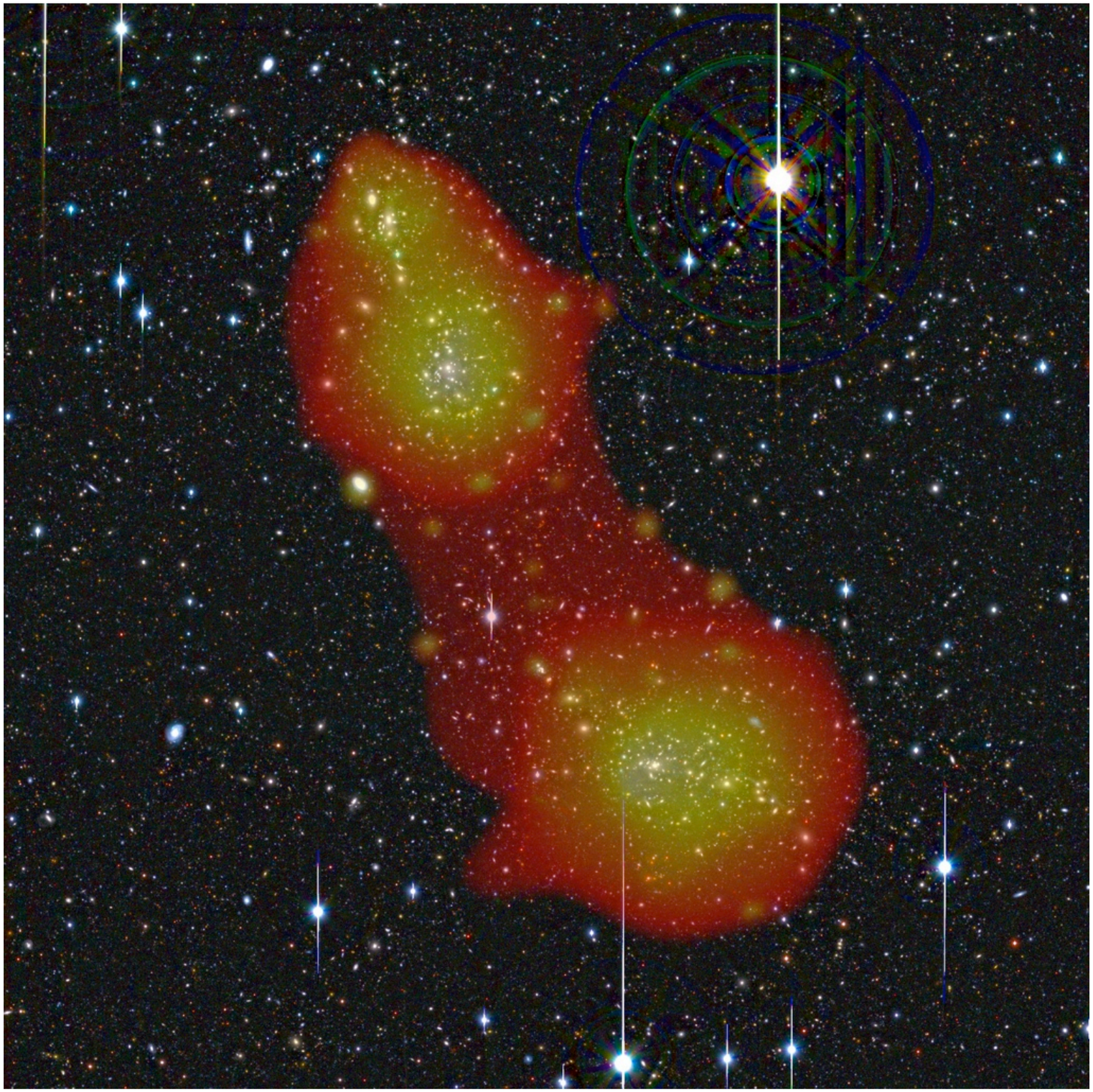
$\rho/\langle\rho\rangle \sim 150$

$kT\ /\ n^{2/3} \sim 870$ keV cm^2 $l^{1/3}$

$M_{\rm gas} \approx\ 1.8 \times 10^{13}\ M_\odot$

$M_{\rm tot} \approx 1.1 \times 10^{14}\ M_\odot$

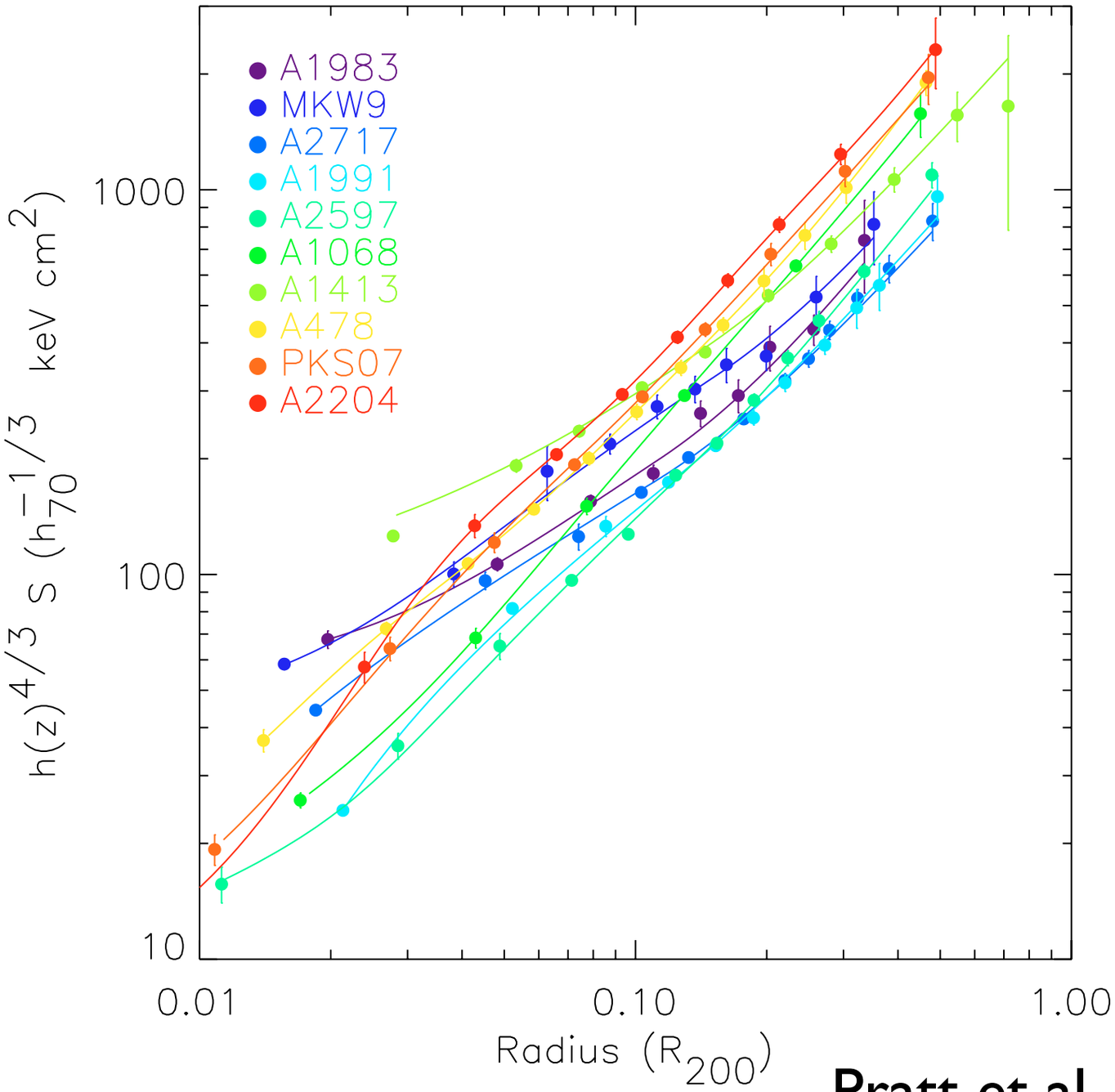
What's the connecting bridge?



Cluster outskirts?

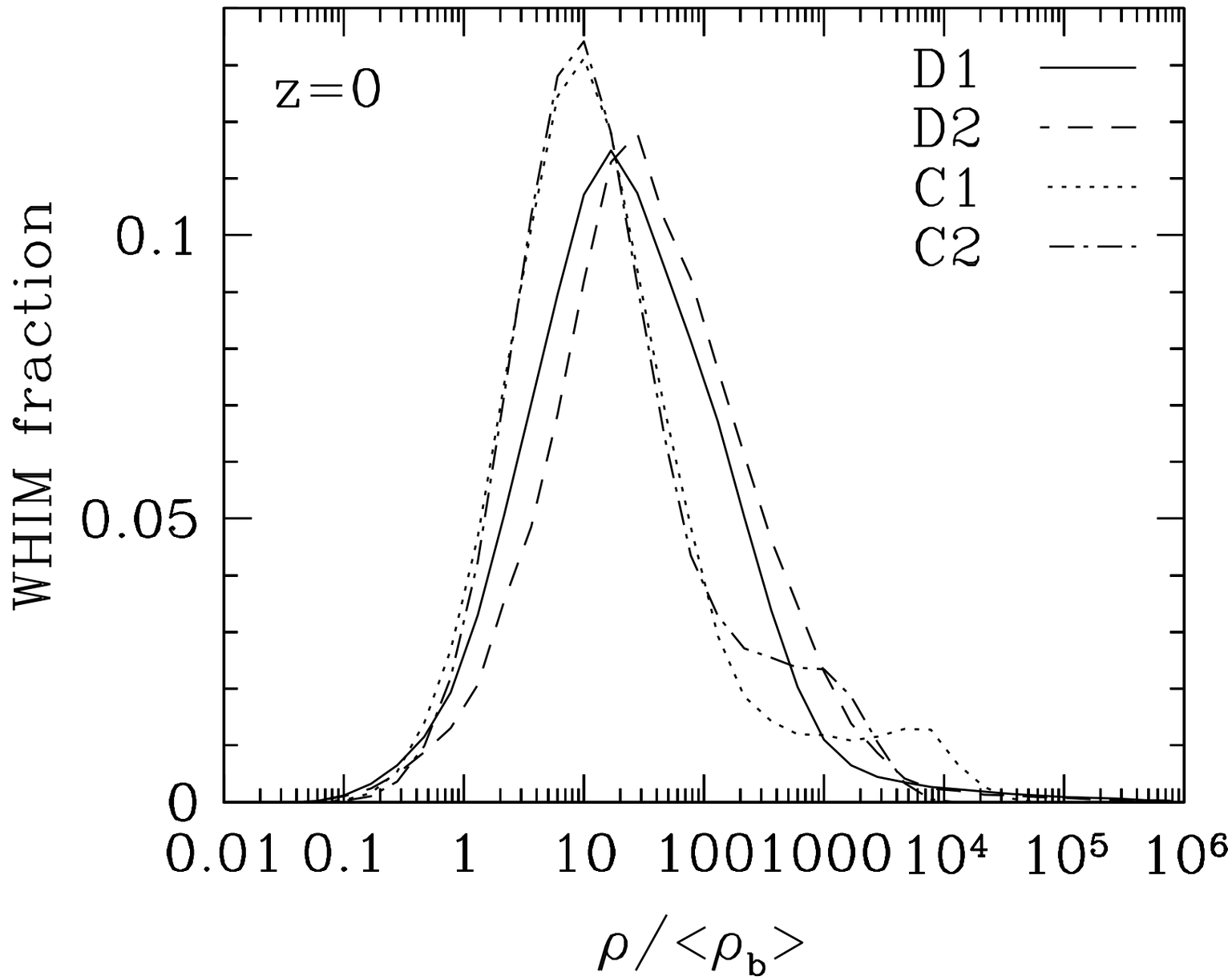
For $l = 2.5$ Mpc

$kT / n^{2/3} \sim 420$ keV cm^2



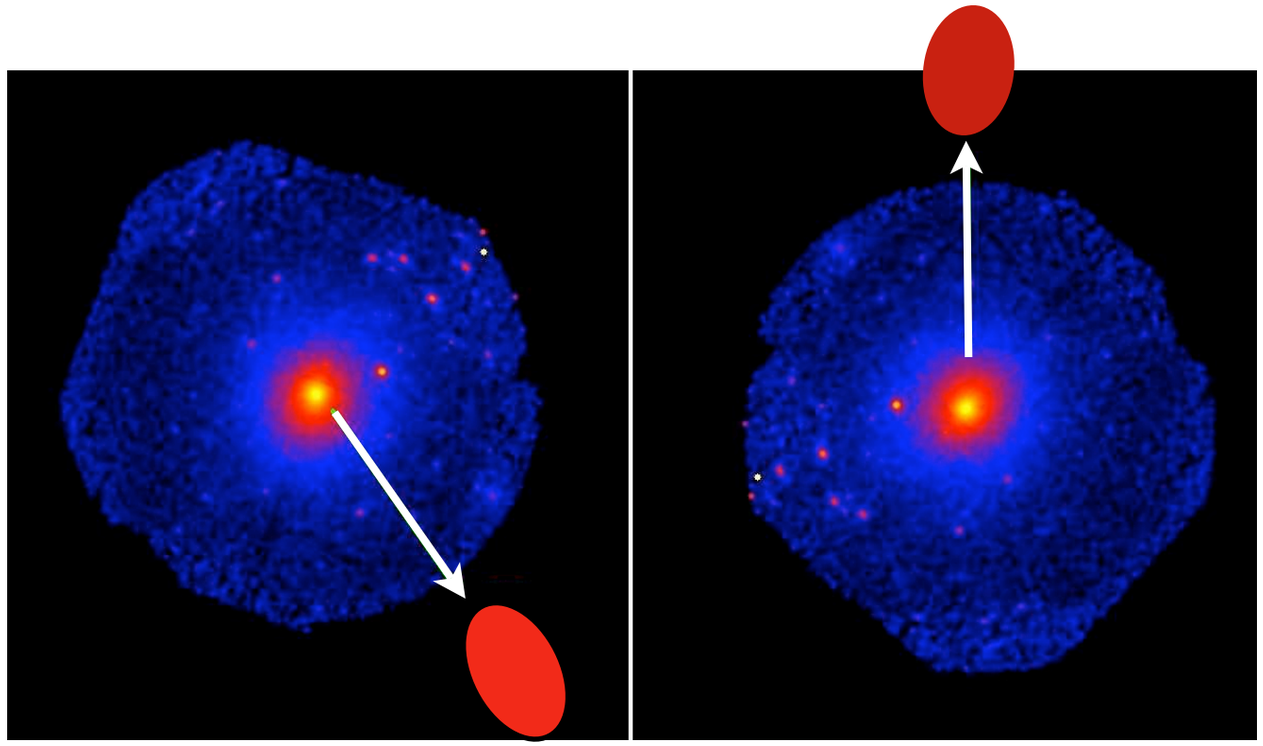
Pratt et al. 2006

Do we detect the missing baryons?

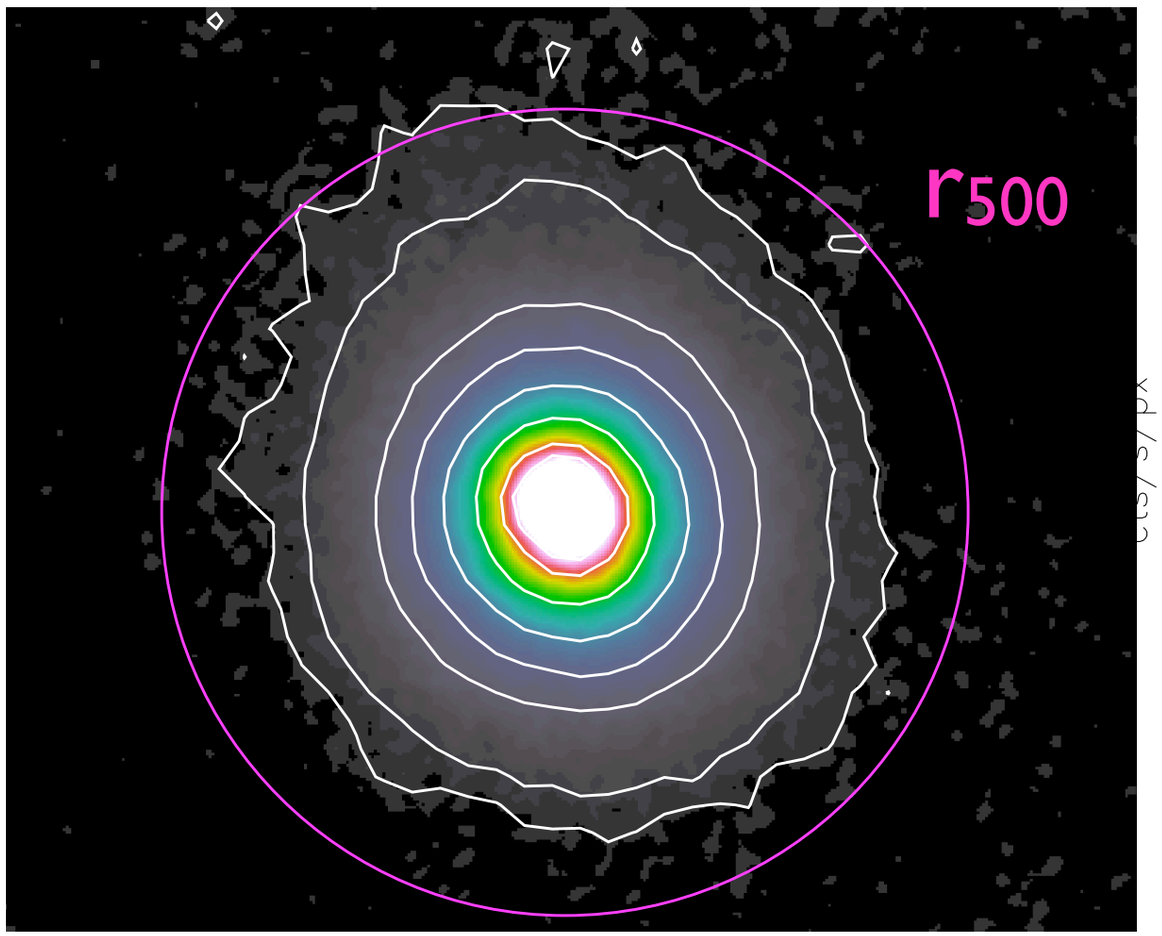


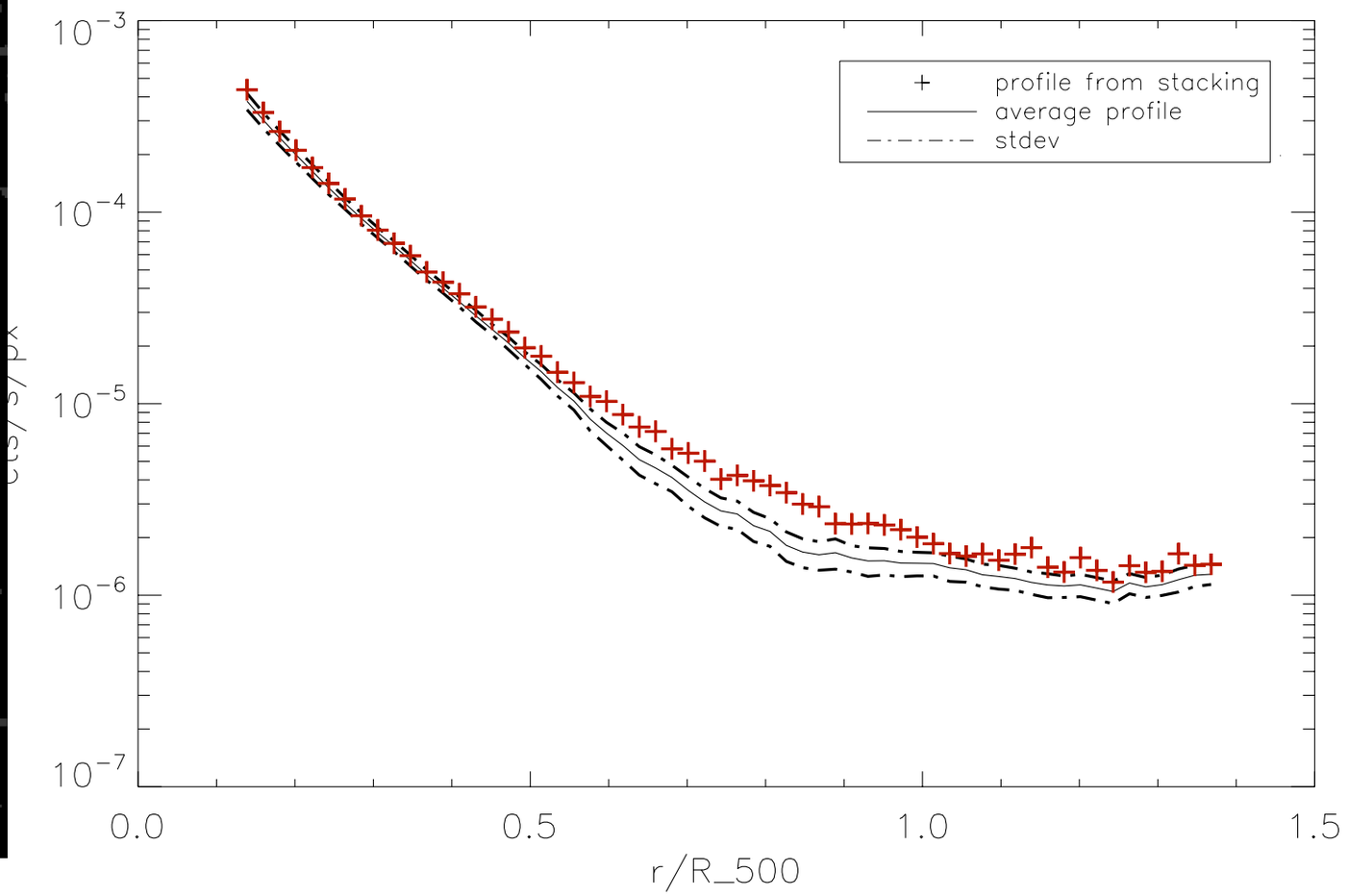
Search for the cosmic-web in superclusters

- XMM data of 46 clusters within 39 superclusters (1.1 Ms)
- images rotated so that the nearest X-ray detected neighbour at same pos. angle
- images scaled: each cluster same fraction of r_{500} per pixel
- all cluster images stacked into single image
- see poster by Oliwia Madej H. 21



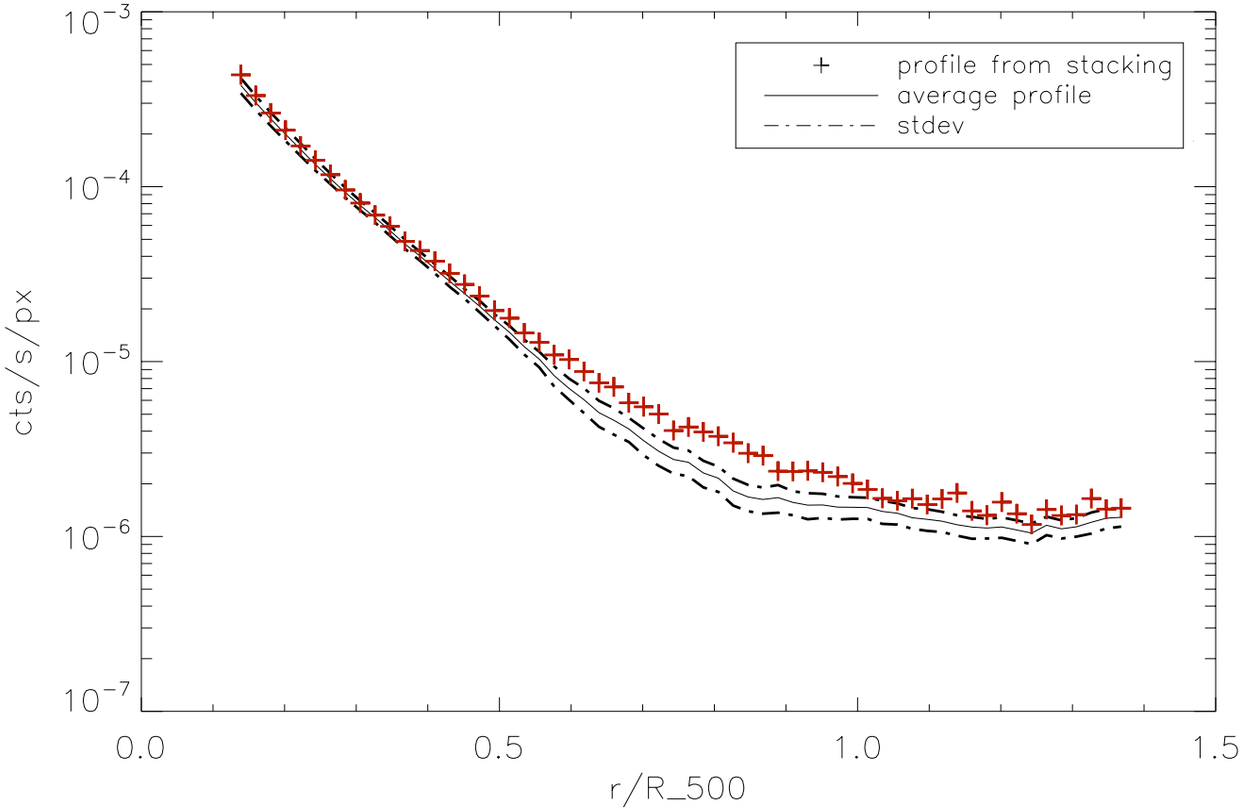
Search for the cosmic-web in superclusters



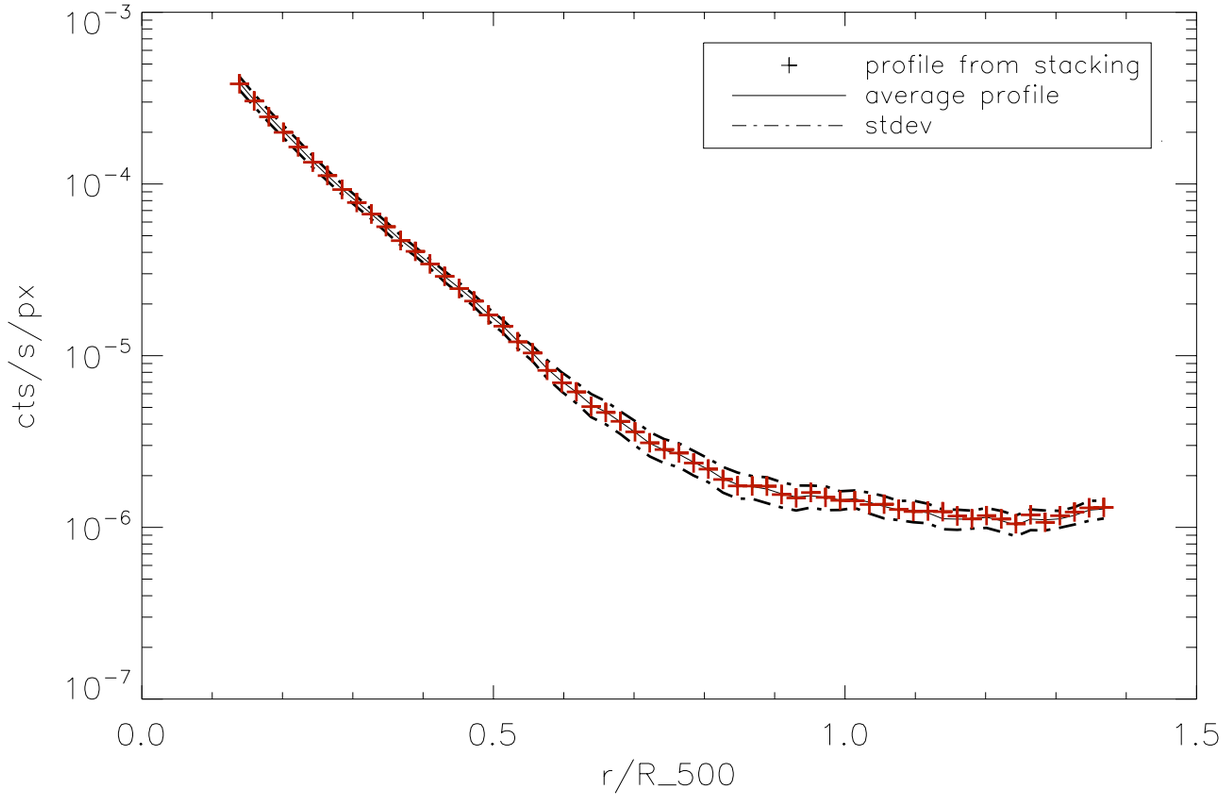


Madej et al. in prep.

Search for the cosmic-web in superclusters



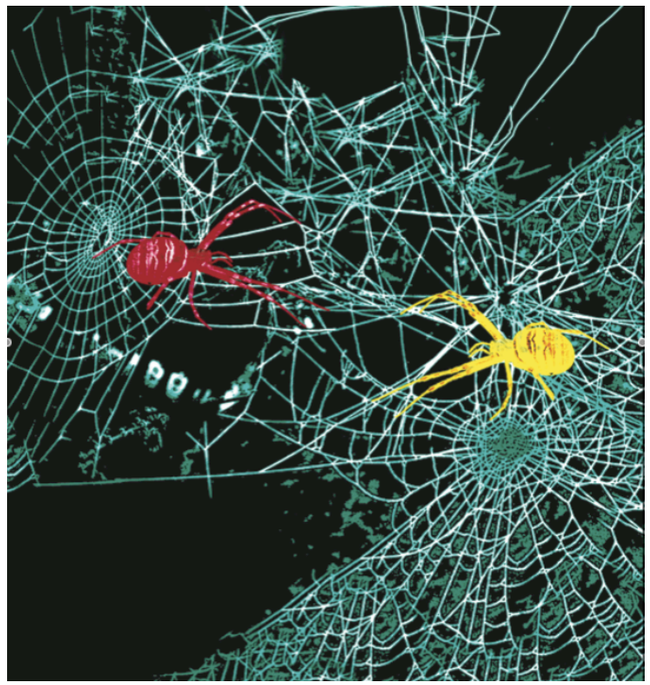
Profile to the North



Profile to the South

Conclusions

- we detect hot gas in the cosmic-web filament between the clusters A 222 and A 223



- the density of the gas is $n = (3.4 \pm 1.3) \times 10^{-5}\ l^{-1/2}\ \mathrm{cm}^{-3}$ and the temperature $kT = 0.91 \pm 0.25$ keV

- we detect the densest and hottest parts of the warm-hot intergalactic medium

- clusters have shallower density profiles toward filaments connecting them with closest massive neighbour