Intracluster Medium Mass Map Derivation

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1 Methodology

We derive 2D intracluster medium (ICM) mass maps from *XMM-Newton* data, assuming spherical symmetry and an optically thin, thermal plasma described by the APEC model. The method involves data preprocessing, spectral fitting, gas density derivation, and projection to produce surface mass density maps for subtraction from weak lensing total mass maps, resulting in dark matter mass map.

1.1 Preprocessing

Following standard X-ray analysis procedures [1, 2], we apply:

1. Flare filtering and exclusion of bad pixels using *XMM-Newton Science Analysis System*
2. Point source masking using `edetect_chain`, `mrwavelet`-based detection [3], and vignetting correction via exposure maps;
3. Background subtraction using ESAS blank-sky templates [4].

1.2 Spectral Modeling and Density Estimation

Spectra are extracted in concentric annuli centered on the X-ray emission peak. Each annulus is fit with a `phabs*apec` model. The APEC normalization is given by:

$$K = \frac{10^{-14}}{4\pi D_A^2 (1+z)^2} \int n_e n_H, dV \tag{1}$$

where:

- K: APEC normalization (fit from XSPEC)
- D_A: angular diameter distance (cm),
- z: redshift,
- n_e: electron number density (cm^{-3}),
- n_H: hydrogen number density (cm^{-3}),
- V: emitting volume (cm^3).

Assuming constant density within each shell and , the electron density is calculated by rearranging Equation 1:

$$n_e(r) = \sqrt{\frac{K \cdot 10^{14} \cdot 4\pi D_A^2 (1+z)^2}{(n_e/n_H) V_{\text{shell}}}} \tag{2}$$

1.3 Gas Mass Density and Projection

Assuming a mean molecular weight $\mu \approx 0.6$, the 3D gas mass density as a function of radius r is given by:

$$\rho_{\mathrm{gas}}(r) = \mu m_p n_e(r) \tag{3}$$

where:

- $\rho_{\mathrm{gas}}(r)$: 3D gas mass density at radius r ($\mathrm{g\,cm^{-3}}$),
- μ: mean molecular weight of fully ionized primordial gas (~ 0.6),
- $m_p = 1.67 \times 10^{-24}$ g: proton mass,
- $n_e(r)$: electron number density at radius r ($\mathrm{cm^{-3}}$).

To project the 3D density onto 2D mass map, we integrate along the line of sight using the Abel transform:

$$\Sigma_{\mathrm{gas}}(R_\perp) = 2 \int_{R_\perp}^{\infty} \frac{\rho_{\mathrm{gas}}(r)\, r}{\sqrt{r^2 - R_\perp^2}}\, dr \tag{4}$$

where:

- $\Sigma_{\mathrm{gas}}(R_\perp)$: projected surface gas mass density at projected radius $R_\perp$ ($\mathrm{g\,cm^{-2}}$),
- r: 3D radial distance from the cluster center (cm),
- $R_\perp$: projected 2D radius in the image plane (cm),
- $\rho_{\mathrm{gas}}(r)$: 3D gas mass density as given in Equation 3.

This transformation assumes spherical symmetry, allowing the construction of a 2D gas surface mass density map suitable for comparison with lensing-based total mass reconstructions.

1.4 Map Generation and Error Propagation

We evaluate Equation 4 at each pixel position to construct the 2D surface mass density map . This map is resampled to match the weak lensing total mass map. The dark matter surface mass map is:

$$\Sigma_{\mathrm{DM}}(x, y) = \Sigma_{\mathrm{total}}(x, y) - \Sigma_{\mathrm{gas}}(x, y) \tag{5}$$

References

[1] Snowden, S. L., Kuntz, K. D., Davis, D. S. (2008). *AA*, 478(2), 615–655.

[2] Read, A. M., Ponman, T. J. (2011). *AA*, 409, 395–410.

[3] Lumb, D. H., et al. (2002). *AA*, 389, 93–105.

[4] Ghizzardi, S. (2001). *XMM-SOC-CAL-TN-0022*.