MBPROJ: MultiBand X-ray Surface Brightness PROJector applied to the PKS 0745–191 galaxy cluster

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MBPROJ is a method for obtaining accurate profiles of thermodynamic properties of galaxy clusters *without spectral fitting*. It models and fits multiband surface brightness profiles under the assumption of hydrostatic equilibrium. The code allows you to examine cluster profiles with *fine spatial binning* or in the *low count regime*.

- The method is a forward fitting modelling procedure.
- The input parameters are a density profile (non-parametric in radial bins or parametric), mass profile (parametric) and outer pressure.
- Going from the outside to the inside of the model cluster, hydrostatic pressure is calculated. The temperature at a radius is calculated from the pressure and density. From these count rates are calculated (in 0.5–1.2, 1.2–2.5 and 2.5–6 keV bands for PKS0745).
- The model is fit to observed count profiles using a Poisson likelihood.
- Markov Chain Monte Carlo is used to obtain the uncertainties on the model parameters and profiles (using EMCEE; Foreman-Mackey et al. 12).
- Optionally, it can fit the data without assuming hydrostatic equilibrium, fitting a temperature parameter for each annulus.
- PSFs can be taken into account by convolving model profiles.

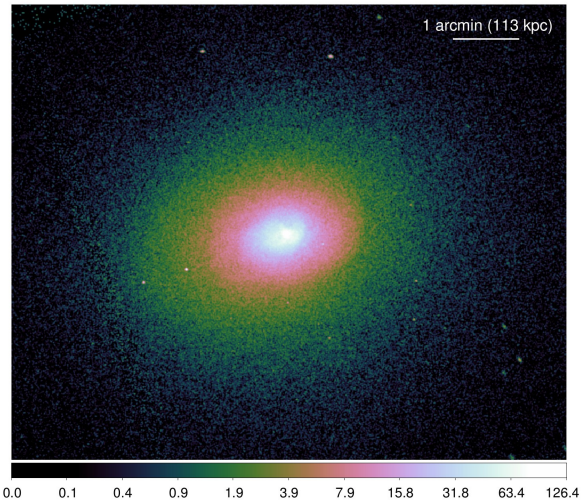

Fig 1: Chandra 135 ks X-ray image of PKS 0745, the X-ray brightest galaxy cluster at $z > 0.1$ ($L_x \sim 2\times10^{45}$ erg s^{-1}).

The MBPROJ results for our Chandra observation of PKS 0745 (Fig 1) agree well with spectral fitting using DSDEPROJ (Sanders & Fabian 07; Russell et al. 08) and PROJCT (Fig 2). Properties can be examined in much narrower bins than spectrally. However, the obtained gravitational acceleration is far too low in the central regions. In particular, the NFW model is a bad fit. This is because the central pressure profile is very flat ($dP/dr = -\rho g$), confirmed spectrally. If only the data beyond 0.5' (60 kpc) are fitted using an NFW model, they agree there with the Suzaku results. The flat pressure is likely due to non-thermal pressure associated with the radio source, gas motions or non-sphericity.

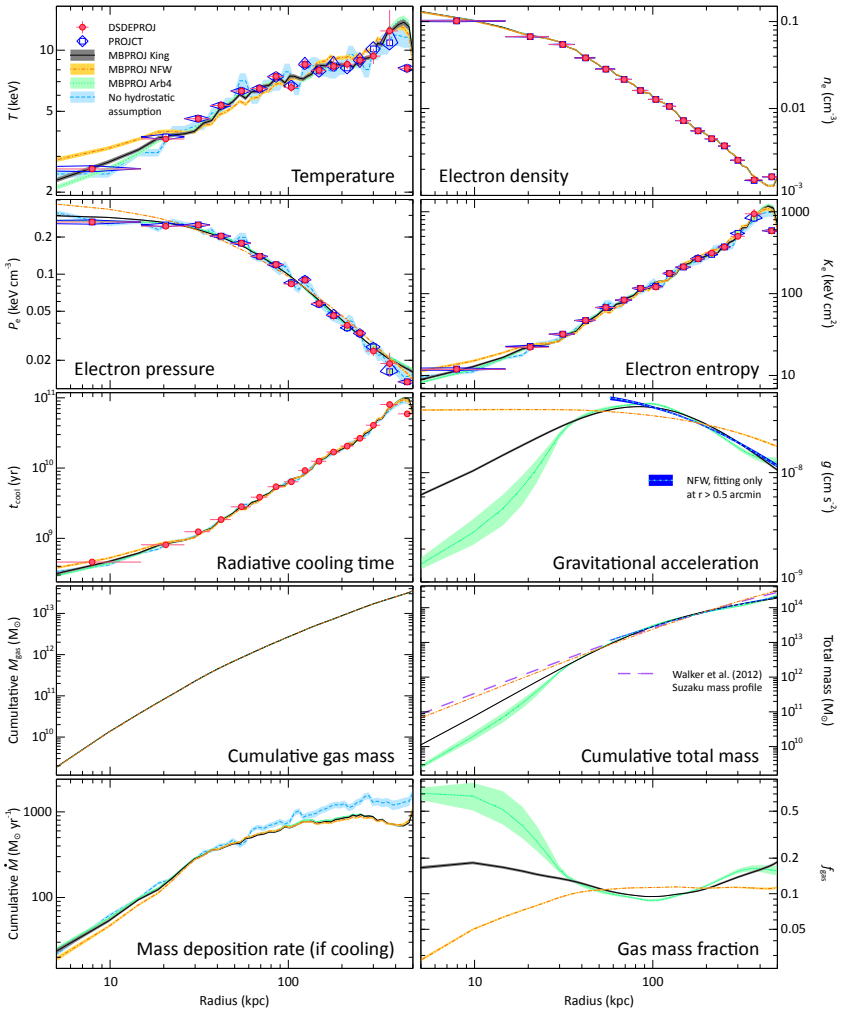

Fig 2: Comparison of PKS 0745 profiles created using spectral methods (DSDEPROJ and PROJCT) with those from MBPROJ using King, NFW and Arb4 mass models. Arb4 has mass parametrised at four radii, interpolating logarithmically at intermediate radii. We also show the MBPROJ results without the assumption of hydrostatic equilibrium, with a temperature parameter for each pair of radial bins. In the gravitational acceleration and mass profile plots we show the results from an NFW model, fitting just the data at large radii. In the total mass plot we show the Suzaku results of Walker et al. (2012), obtained out to the virial radius.

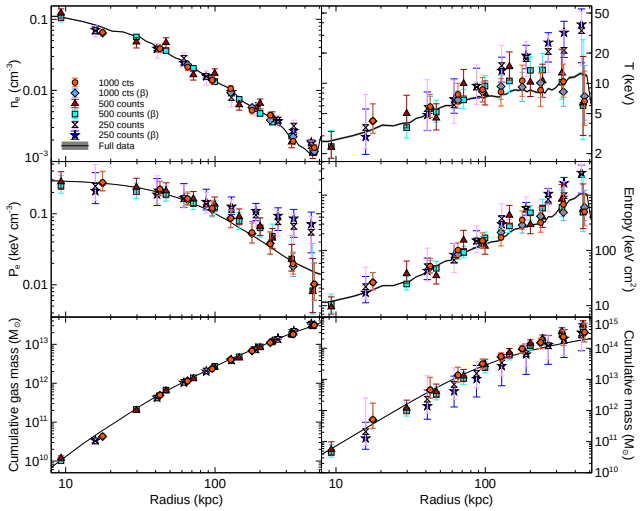

Fig 3: MBPROJ analyses of PKS 0745 data reduced to 1000, 500 and 250 counts. Shown are results from non-parametric density models and those assuming a beta model (β).

Fig 3 shows results where the number of counts has been drastically reduced. Accurate profiles can be produced with only a few 100 to a 1000 counts, in particular for gas mass and density. In cooler clusters MBPROJ will be more effective, as high temperatures are harder to determine. The plot indicates that MBPROJ will be ideal for analysing data from current and future X-ray surveys of galaxy clusters, for example the forthcoming eROSITA survey (Predehl et al. 10; Merloni et al. 12). Runtimes of the Python implementation can be just a few minutes.

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