SZ/X-ray galaxy cluster model and the X-ray follow-up of the Planck clusters

Antoine Chamballu, Imperial College London
James G. Bartlett, APC-Univ. Paris 7
Jean-Baptiste Melin, CEA-SPP, Saclay
Monique Arnaud, CEA-SAp, Saclay
Introduction

Context

- Forthcoming SZ observations:
  - New kind of cluster survey
  - Thousands of newly discovered clusters

⇒ Relation of these SZ surveys to other cluster surveys (e.g. X-ray surveys)?
Introduction

Motivation

• Create an empirical, easily adaptable model for SZ and X-ray emissions, constrained by X-ray observations and WMAP3 cosmology (except $\sigma_8$)
  • Predict SZ survey results and catalog properties
  • Relate SZ and X-ray surveys
  • Motivate, dimension and guide X-ray follow-up of new clusters: X-ray characteristics of SZ samples
    ➢ How many clusters?
    ➢ Exposure time needed?
    ➢ Information/science that can be obtained with a given program?
SZ/X-ray model

Overview

- Use of the Jenkins mass function, observed scaling laws ($L_X - T_X$ relation (Arnaud & Evrard, 1999), $M_{500} - T_X$ relation (Arnaud et al., 2005; Vikhlinin et al., 2006), $r_c - T_X$ relation (Sanderson et al., 2003; Lumb et al., 2004)) and local cluster counts (Henri, 2004).
Using the Jenkins mass function, observed scaling laws ($L_X - T_X$ relation (Arnaud & Evrard, 1999), $M_{500} - T_X$ relation (Arnaud et al., 2005; Vikhlinin et al., 2006), $r_c - T_X$ relation (Sanderson et al., 2003; Lumb et al., 2004)) and local cluster counts (Henri, 2004).

Gas modeled by an isothermal spherical $\beta$-model

$$\rho_{gas} = \frac{\rho_{gas0}}{\left[1 + \left(\frac{r}{r_c}\right)^2\right]^{\frac{3\beta}{2}}}$$
SZ/X-ray model

Overview

• Use of the Jenkins mass function, observed scaling laws ($L_X - T_X$ relation (Arnaud & Evrard, 1999), $M_{500} - T_X$ relation (Arnaud et al., 2005; Vikhlinin et al., 2006), $r_c - T_X$ relation (Sanderson et al., 2003; Lumb et al., 2004)) and local cluster counts (Henri, 2004).

• Gas modeled by an isothermal spherical $\beta$-model

• Mostly self-similar model but deviations are introduced in order to reproduce observed $L_X - T_X$ et $r_c - T_X$ relations:
  • temperature dependant density profile
  • temperature dependant gas fraction (Mohr et al., 1999)
SZ/X-ray model

Overview

• Use of the Jenkins mass function, observed scaling laws ($L_X - T_X$ relation (Arnaud & Evrard, 1999), $M_{500} - T_X$ relation (Arnaud et al., 2005; Vikhlinin et al., 2006), $r_c - T_X$ relation (Sanderson et al., 2003; Lumb et al., 2004)) and local cluster counts (Henri, 2004).

• Gas modeled by an isothermal spherical $\beta$-model

• Mostly self-similar model but deviations are introduced in order to reproduce observed $L_X - T_X$ et $r_c - T_X$ relations:
  • temperature dependant density profile
  • temperature dependant gas fraction (Mohr et al., 1999)

• Special care with various mass definitions (for instance $M_{500}$, $M_{\text{vir}}$, $M_{\text{fof}}$...)

March 17 2008 - Moriond
A. Chamballu, Imperial College London
SZ/X-ray model

Overview

• Use of the Jenkins mass function, observed scaling laws ($L_X-T_X$ relation (Arnaud & Evrard, 1999), $M_{500}-T_X$ relation (Arnaud et al., 2005; Vikhlinin et al., 2006), $r_c-T_X$ relation (Sanderson et al., 2003; Lumb et al., 2004)) and local cluster counts (Henri, 2004).

• Gas modeled by an isothermal spherical $\beta$-model

• Mostly self-similar model but deviations are introduced in order to reproduce observed $L_X-T_X$ et $r_c-T_X$ relations:
  • temperature dependant density profile
  • temperature dependant gas fraction (Mohr et al., 1999)

• Special care with various mass definitions (for instance $M_{500}$, $M_{\text{vir}}$, $M_{\text{fof}}$…)

 thôi Determination of $\sigma_8$, $r_c$, $T^*$, $n_e_0$
SZ/X-ray model

- Fit to the local XTF considering measured $T^*$ (Vikhlinin et al., 2006):
  - $\sigma_8 = 0.78 \pm 0.027$
  - (consistent with WMAP5+BAO+SN value: 0.817±0.026)
• Fit to the local XTF considering measured $T^*$ (Vikhlinin et al., 2006):
  \[ \sigma_8 = 0.78 \pm 0.027 \]  
  (consistent with WMAP5+BAO+SN value: 0.817±0.026)

• Observed local XLF reproduced

• Simple model with few parameters consistent with all local constraints
SZ/X-ray model

Redshift evolution

- ROSAT observations well reproduced with self-similar $M_{500} - T_X$ (Kotov & Vikhlinin, 2006) and $L_X - T_X$ (Pacaud et al., 2007) evolution, e.g.:
  - REFLEX (Böhringer et al., 2004):
    - $f_{X_{\text{det}}} = 3.10^{-12}$ erg s$^{-1}$ cm$^{-2}$
    - area: 4.24 ster
    - 447 clusters (~90% complete)

~508 clusters (90% ⇒ 457)
ROSAT observations well reproduced with self-similar $M_{500} - T_X$ (Kotov & Vikhlinin, 2006) and $L_X - T_X$ (Pacaud et al., 2007) evolution, e.g.:

- REFLEX (Böhringer et al., 2004):
  - $f_{X\,\text{det}} = 3.10^{-12}$ erg s$^{-1}$ cm$^{-2}$
  - area: 4.24 ster
  - 447 clusters ($\sim$90% complete)

- 400 square degrees (Burenin et al., 2006):
  - $f_{X\,\text{det}} \geq 1.3 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
  - 242 clusters

- High-z XLF (Mullis et al., 2004) reproduced in the self-similar case
Application:

Planck/X-ray
The Planck cluster catalog

Properties

Sources of (important) uncertainty:
- $\sigma_8$
- $Y-M$

Resolved clusters $\Rightarrow$ “Interesting” Selection effects

$N_{tot} \approx 2350$

Pt-source approx

Matched filters

$|b| > 15$ deg

Fid. model

3$\sigma$ threshold

~200 clusters at $z > 0.6$

~10 clusters at $z > 1$
The Planck cluster catalog

Properties

• REFLEX (south) and NORAS (north) surveys (Böhringer et al. 2000, 2004):
  • ~30000 deg$^2$
  • ~950 clusters
• Planck:
  • bigger volume (more clusters)
  • efficient high redshift detection
  • many massive high-z clusters; only a few small low-z ones

Planck $|b|>15$ deg

Fiducial Model
The Planck cluster catalog

- Ideal for cosmological studies:
  - insensitive to non-gravitational processes
  - very sensitive to cosmology
- Detailed X-ray follow-up studies:
  - Calibration of the $Y-M$ relation
  - Gas fraction measurements ($f_{\text{gas}}(z)$)
  - Scaling relations (and their evolution) between $M, M_{\text{gas}}, T_X, L_X, Y$
  - Mass profiles

Dimensioning X-ray follow-up?
XMM follow-up

Known high-z clusters

- Very few hot, high-z clusters known
  - 42 clusters
  - $T > 5\text{keV}$
  - 6 w/ $z > 0.5$

Potential to highly improve sample and thus, cosmological constraints
XMM follow-up

- Relevant examples of observations with XMM
  - MS1054-0321 (Gioia et al., 2004)
    - $z = 0.847 \pm 0.05$; $T_X = 7.2 \pm 0.7$ keV;
    - $f_X [0,5-2] = 1.9 \pm 0.09 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
  - Exposure time: 25 ks
XMM follow-up

- Relevant examples of observations with XMM
  - MS1054-0321 (Gioia et al., 2004)
    - $z = 0.847 \pm 0.05$; $T_X = 7.2 \pm 0.7$ keV;
    - $f_X [0.5-2] = 1.9 \pm 0.09 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
    - Exposure time: 25 ks
  - ClJ1226.9+3332 (Maughan et al., 2007)
    - $z = 0.89$; $T_X = 10.4 \pm 0.6$ keV;
    - $M_{500} = 5.2 \pm 1.0 \times 10^{14}$ $M_\odot$;
    - $f_X [0.5-2] = 3.10 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
    - Exposure time: 70 ks
• Relevant examples of observations with XMM
  • MS1054-0321 (Gioia et al., 2004)
    • $z = 0.847 \pm 0.05$; $T_X = 7.2 \pm 0.7$ keV;
      $f_X [0.5-2] = 1.9 \pm 0.09 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
    • Exposure time: 25 ks
  • ClJ1226.9+3332 (Maughan et al., 2007)
    • $z = 0.89$; $T_X = 10.4 \pm 0.6$ keV;
      $M_{500} = 5.2 \pm 1.0 \times 10^{14} M_\odot$;
      $f_X [0.5-2] = 3.10 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$
    • Exposure time: 70 ks

Temperatures with 10% errors and temperature profiles obtained with observations of 25-50 ks per cluster with fluxes of a few $10^{-13}$ erg s$^{-1}$ cm$^{-2}$
Clusters detected by Planck (matched filters) but not by ROSAT ($f_X[0.1-2.4] > 10^{-12}$ erg s$^{-1}$ cm$^{-2}$)

- ~200 clusters with $z > 0.6$ and $T > 6$ keV
- All clusters have fluxes in the [0.5-2]keV band greater than $10^{-13}$ erg s$^{-1}$ cm$^{-2}$

A ~5 Ms (Very Large Project) would allow us to get $T_X \pm 10\%$ and mass estimations for most of these clusters

A. Chamballu, Imperial College London
SZ/X-ray model - Planck clusters

Summary/Conclusions

• SZ experiments will soon discover many new clusters; other types of observations are needed to bring more information (redshift, mass, gas fraction…)
• Our model relates SZ and X-ray observables; consistent with current (local and high-z) X-ray constraints
• SZ survey predictions; X-ray characteristics can then be determined in order to define follow-up strategy
• As an example:
  • A ~5 Ms large program with XMM could give $T_X \pm 10\%$ and some temperature profiles ($\Rightarrow$ masses) of at most 200 Planck clusters with $T_X > 6$ keV and $z > 0.6$ (Bartlett, Chamballu, Arnaud & Melin, in preparation)

 País ~10/50-fold increase in cluster sample