The Baryonic and Dark Matter Content of Distant Galaxy Clusters

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CLJ2010 (29 June 2010)
The ubiquitous role of cluster masses and motivations to push cluster studies well beyond $z=1$

- The cluster mass distribution, *both on sub-Mpc scales and across the cluster population*, is key to test of structure formation models and the properties of the Dark Matter.

- The most distant massive clusters provide a strong leverage:
  - on cosmological models and Dark Energy
  - on the formation of stellar populations in massive galaxies, mass assembly history, ICM enrichment and energy input

- Precision cosmology relies on a few % level mass calibration (scaling relations) *at all redshifts!* can this be achieved at $z>1$ (e.g. with lensing, X-ray observations)?
Chandra contours onto HST(i,z)+VLT(K) image

XMMJ2235 at z=1.39 (Mullis+ 05, Rosati+ 09)

Multi-\lambda photometry: URizJHKF105+F110+F125+F160

from the XDCP survey

Rosati et al. 08
XMMJ2235 at $z=1.39$ (Mullis+ 05, Rosati+ 09) from the XDCP survey

Multi-$\lambda$ photometry: URizJHK$F_{105}F_{110}F_{125}F_{160}$

Chandra contours onto HST(i,z)+VLT(K) image
Spectroscopic campaign on XMM2235

- Spectroscopic members (over 3 Mpc): 34 (22 passive, 12 star forming)
- >150 redshifts in the field

$\sigma_v = (802 \pm 155) \text{ km/s}$

Rosati et al. 09
XMM2235: SF history of stellar population
(Rosati et al. 09, Gobat et al. 08)

- Core early-type galaxies formed at $z_F \sim 5$, in the outskirts $z_F \sim 3$
- Stellar mass of BGG was assembled in a vigorous and rapid (~1 Gyr) phase; SF quenched by $z \sim 3$
- ETG population of XMM 2235 shows a strong radial age gradient ($\approx 2$ Gyr between core galaxies and infalling outskirts population)
- Active SF suppressed in the $R<250$ kpc core, quenched at $M_{gal}>6 \times 10^{10} M_\odot$
**XMM2235: stellar pop and stellar mass assembly epoch**

(Strazzullo et al. 10)

**Color-Magnitude diagram**

- Tight red sequence ($\delta m=0.06$ mag), ~constant out to $z=1.4$ (also Lidman et al. 08)
- Early epoch star formation but also early stellar mass assembly

**H-band (Nicmos) LF**

Kodama&Arimoto models
XMM2235: stellar pop and stellar mass assembly epoch
(Strazzullo et al. 10)

Size (structural) evolution (?)

H-band (Nicmos) LF

- Tight red sequence ($\delta m = 0.06$ mag), $\sim$constant out to $z = 1.4$ (also Lidman et al. 08)
- Early epoch star formation but also early stellar mass assembly
Chandra Observations of XMM2235 (190 ksec)

- Global fit:
- Core fit ($r=7.5''=60$ kpc):

\[ kT = 8.7^{+1.4}_{-1.2} \text{ keV}, \text{ and } Z = 0.32^{+0.19}_{-0.22} Z_\odot \]

\[ kT = 6.9^{+1.5}_{-1.1} \text{ keV}, \text{ and } Z = 0.59^{+0.29}_{-0.37} Z_\odot \]

Rosati et al. 09
Hottest (most massive) cluster to date at \( z > 1 \) with a prominent cool core:

\[ M_{200}(<1.1 \text{ Mpc}) = (7.3 \pm 1.3) \times 10^{14} \text{M}_\odot \]

The ICM is already enriched at local values at \( z=1.4 \) (metal enrichment must be completed by \( z \sim 2.5 \))
Weak-lensing analysis from HST/ACS
(Jee, PR et al. 09)
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- Shear signal detected out to ~1 Mpc (max >8σ), beyond Chandra, with 8150s exp. (i_{775} band)
- X-ray and Weak Lensing based masses at r=1 Mpc agree within 5%!
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Modeling the core mass distribution 
(with the most distant lens)

6 multiple images well reproduced by the SL model (NIE+ext. shear+IS galaxies)
Mass components of XMM2235 (at z=1.4!)

- Strong Lensing
- Chandra X-ray
- Weak Lensing

\( f_{\text{gas}} \approx 7\% \)

\( f_{\text{stars}} \approx 1\% \)

\( \approx 0.14 \, f_{\text{gas}} \)

\( M_{\text{stars}} (r<R_{500}) \)

from K-LF

Rosati et al. 2010
The core mass distribution

- **NFW** (does not reproduce both SL and WL data)

- **NIS** ($r_{\text{core}} = 47$ kpc) fits both multiple images and WL shear
• Accurate mass density profiles of massive clusters can directly test \( \Lambda \)CDM scenario over \( \sim 30-1000 \) kpc scales:
  • Test predictions on DM concentration/slopes as a function of Mass and Redshifts

• SL: unique probe of inner DM profile \( \rightarrow \) can constrain DM properties

• Key: use a variety of complementary probes covering 2-3 decades in scale, degeneracies (inner slope, concentration and M*/L) are mitigated

Remember T. Treu’s talk..
DM and Baryon mass distribution in clusters

Abell 611

Early results point to a clash with $\Lambda$CDM: large mass concentrations, shallow inner slopes, large Einstein radii:
- Formation of clusters at earlier times than expected? non-gauss. fluctuations?
- How baryonic physics shapes the inner DM potential?
- Does $\Lambda$CDM have problems on small scales despite the success on large scales?

But this is based on a handful of clusters... small (biased?) samples, cl-cl variance?

CL0024

Umetsu et al. 10

Newman et al. 09
Anatomy of Massive Cluster at $z=1.4$

- XMM2235 is in a surprisingly advanced evolutionary state at $2/3 \ T_U$:  
  - Old stellar pops, almost complete stellar mass assembly, early ICM metal enrichment, prominent cool core  

- The DM profile of massive clusters even at these redshifts can be reconstructed over 10-1000 kpc using HST+VLT data (with SL features)  

- Very robust mass determination (multiple mass probes):  
  - Such massive cluster not expected ($p\approx0.5\%$) in the X-ray survey volume → this stimulated a number of papers exploring also “exotic solutions” (Jimenez&Verde 09, Sartoris et al. 10, Holz&Perlmuter 10, Baldi et al. 10)  

- Good news for mass calibration of future distant cluster surveys  

- The inner mass DM profile is very flat, *inconsistent with NFW*  
  → Tommaso’s talk for $z\sim0.4$ clusters
More SL clusters at $z>1$ are on the way...

...but we also need a comprehensive study of the DM&B mass profiles in low-z clusters
Cluster Lensing And Supernova survey with Hubble
HST multi-cycle Treasury Program (530 orbits) - PI: M.Postman

- Panchromatic (ACS+WFC3 14 filters) imaging of 25 massive intermediate-z galaxy clusters
- Measure DM mass profiles over 10-3000 kpc with unprecedented precision
- “Wide-field” gravitational telescopes on the very high-z Universe
- SNe Ia search at 1<z<2 from parallel fields (doubling SNe at z>1.2)

See also K.Umetsu’s talk

Zitrim, Broadhurst et al. 09
CLASH multiple facilities: DM & Baryonic Mass Distribution from independent probes over the 10 kpc ~ 3 Mpc range

- **CLASH**
  - Multiple facilities
  - DM & Baryonic Mass Distribution
  - From independent probes over the 10 kpc ~ 3 Mpc range

- **VIMOS Large Prog (230 hr)**
  - ~500 members per cluster
  - + arcs redshifts

- **ICM physics & metallicity**

- **DM mass profiles**

- **Cosmological simulations**

- **Strong Lensing**
  - Mass profile in the core

- **High-z galaxies**

- **Stellar masses**

- **High-z gals**

- **Dynamical analysis**

- **WL masses profile**

- **Stellar masses**

- **DM and Baryons in Clusters**

- **DM and Baryons in Clusters**

- **SZ observations**

- **AMiBA**
  - PI: K. Umetsu
  - ICM physics
  - DM&Baryon masses
  - SZ observations

- **XMM**
  - PI: M. Donahue
  - Baryon mass distribution
  - X-ray masses
  - ICM physics & metallicity

- **Chandra**

- **VLT**
  - PI: P. Rosati
  - VIMOS Large Prog (230 hr)
  - ~500 members per cluster
  - + arcs redshifts

- **Subaru (+ ESO-WFI)**
  - PI: K. Umetsu
  - Stellar masses
  - High-z gals
  - Dynamical analysis

- **Spitzer**
  - PI: W. Zheng
  - Stellar masses
  - High-z galaxies

- **HST**
  - Treasury Program (530 orbits)
  - PI: M. Postman

- **K. Umetsu’s talk**
Wide Field X-ray Telescope
The ultimate X-ray survey
(A vast legacy for Cluster Cosmology and Astrophysics)

PI: S.Murray
Senior Advisor: R.Giacconi
Project Scientist: A.Ptak
M.Weisskopf, B.Forman
A.Vikhlinin & WFXT team

EU Team coordinators:
P.Rosati       G.Pareschi
S.Borgani     R.Gilli
P.Tozzi          M.Paolillo

http://wfxt.pha.jhu.edu
http://www.wfxt.eu

(Submitted to the US Decadal Survey 2010)
Science Drivers and Mission Requirements

- $\geq 5 \times 10^5$ clusters to $z \sim 2$
- Precision Cosmology
- Fundamental physics: (DM, DE, theory of gravity)

- Cosmic evolution and cycle of baryons
- Proto-clusters at $z > 2$

- $> 10^7$ AGN to $z > 6$
- First SMBHs, accretion history
- AGN/Galaxy co-evolution

- High sensitivity
- Wide survey area
- Good angular resolution
- Low background

M-class mission cost envelope

S.Borgani's talk

Can be done with a specific X-ray optical design and affordable technological development

A = 1 m$^2$ at 1.5 keV

5” HEW over the entire 1 deg$^2$ FoV

Galactic studies
- SF regions
- hot ISM
- compacts objects
Grasp = (A·Ω) is 2-3 order of mag advance over existing or planned missions

- **dramatic increase survey volume** ($\Phi(M,L_x)$), i.e. large number of sources, over a wide $L_x$/Mass and $z$ range
- **enable physical source characterization** with a large number of high S/N spectra
Wide Field X-ray Telescope

the ultimate X-ray survey

(13 ksec) 1 deg²
Wide Field X-ray Telescope
the ultimate X-ray survey

..first results at CLJ2020..

>10^5 at z>1

The End