Advantages of X-ray Clusters

Can be well modeled
X-rays are optically thin thermal radiation from material nearly in collisional equilibrium
Not as simple as the microwave background
Simpler than supernovae, galaxies or AGN

Fewer projection effects with X-ray selection
X-rays are more peaked than galaxy distribution
Fewer foreground/background objects
Confining hot gas requires a real object of high mass

Close relation of X-ray observable to cluster mass
X-ray bright so seen to cosmological distances
Comparison of dark matter and x-ray cluster and group distribution

every bound system visible in the numerical simulation is detected in the x-ray band - bright regions are massive clusters, dimmer regions groups,
Dark Universe Observatory

Sensitivity to Dark Energy equation of state

Volume element

Comoving distance

\(-d\ln f/dw\)

\(-d\ln r/dw\)

\(d\ln H/dw\)

Huterer & Turner
Volume Element as a function of $w$

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**Volume Element**

$\frac{dV}{d\Omega} (\text{arbitrary units})$

Redshift

$\Omega_{m}=0.3; \Omega_{x}=0.7$

$w=-1$

$w=-0.7$

$E-deS:w=0$

Dark Energy $\rightarrow$ More volume at moderate redshift
Cluster Evolution and Cosmology

- The observables are the x-ray luminosity, temperature correlation function and their evolution with z
- x-ray properties directly connect to mass (Allen 2002)

**X-ray properties of clusters trace mass**

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**Mass temperature relation**

Horner et al 2001

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Borgani and Guzzo 2001

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*Figure 7.4: X-ray Mass-Temperature Relation. Solid circles are clusters with kT.*

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*Figure 450x240 to 724x534*
Instrument Heritage

ABRIXAS and XMM

- DUO has a high degree of heritage
- 7 X-ray mirrors, focal length 1.6m
- Total field of view 3.3 sq. degs.
- Effective resolution 45 arcs.
- 7 PN-CCDs, 0.3 – 10 keV
The optical system

12 outer shell coated with nickel, the others with gold

all 27 shells coated with gold

Telescope $A_{\text{eff}}$ [cm$^{-2}$] (1 telescope)

10°
New pn-CCD detector performance

Number of Events

0.28 keV

New pn-CCD

ADU
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Ball RS300 Spacecraft

- Telescope
- Winston Cone
- Contamination Cover
- Star Tracker
- Single-Axis Driven Solar Array
- Spacecraft Bus

On Orbit

Stowed in 63” Taurus Fairing
Observing Strategy (eff. > 60%)

DUO Wide Survey: 6000 deg²

- Within SDSS Northern Galactic Cap
- 8000 clusters with $M > 2 \times 10^{14} M_\odot$ (kT > 3.5 keV) complete to $z=0.7$
- Redshifts already available

DUO Deep Survey: 176 deg²

- 1800 clusters, about 200 at $z>1.0$
- Southern Sky (ping-pong operation)
- Synergy with large SZ-Surveys
- Optical follow-up from VLT

Operations: Scan both regions in 2 years
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Rosati, Borgani & Norman
ARAA 40, 539,
Redshift distributions

$N(>z) \propto 10^6$

$N(>z) \propto 10^5$

$N(>z) \propto 10^4$

$N(>z) \propto 10^3$

$N(>z) \propto 10^2$

$N(>z) \propto 10$

$N(>z) \propto 1$

$1+z$ vs. $N(>z)$ for AGN, Clusters, SDSS LRG’s.
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One Square Degree of Deep Survey

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Discrimination of Clusters vs. Active Galactic Nuclei
Measurements of Dark Energy with DUO
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**P(k)**

**Neutrinos**

![Graph showing the power spectrum P(k) and other cosmological parameters.](Image)
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- Dark Energy: 73%
- Cold Dark Matter: 25%
- Atoms: 4%

Dark Matter
Hot Gas