Cluster Surveying for Dark Energy Studies

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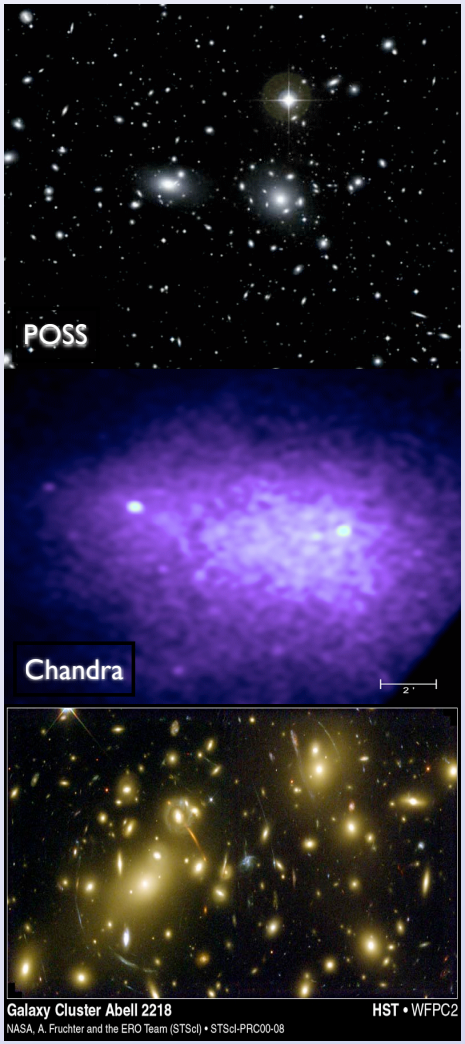
Surveying Needs

- Big surveys to get good statistics
- Control of systematics & self-calibration
- Completeness & purity
- Good - well understood - mass proxies

Galaxy Clusters



Galaxies $M_{gal} \sim 0.02 M_{tot}$ Early type dominated

poor groups 10 - 1000 rich clusters

Gas $M_{gas} \sim 0.10 M_{tot}$ Heated by infall

$T_{gas} \sim (1 - 12) keV$

Dark Matter $M_{tot} \sim 10^{14} - 10^{15} M_{\odot}$

$R \sim 1 Mpc$

Surveying Methods

- Galaxy over-densities in color space
- Halo mass: gravitational lensing
  - Weak shear and/or strong lenses
- Intracluster gas
  - X-ray emission (thermal bremsstrahlung+line emission)
  - Sunyaev-Zel'dovich (SZ) effect

Optical/NIR

- Historic catalogs: Abell (Abell 1958, Abell et al. 1989) & Zwicki (Zwicki et al. 1961)
  - Problem of projection effects
- Modern-day CCD multi-band imaging
  - Detection in real+color space - greatly reduces projection effects
  - Viable cluster catalogs
  - SDSS, Pan-STARRS, DES, EUCLID/JDEM, LSST, Spitzer, WISE

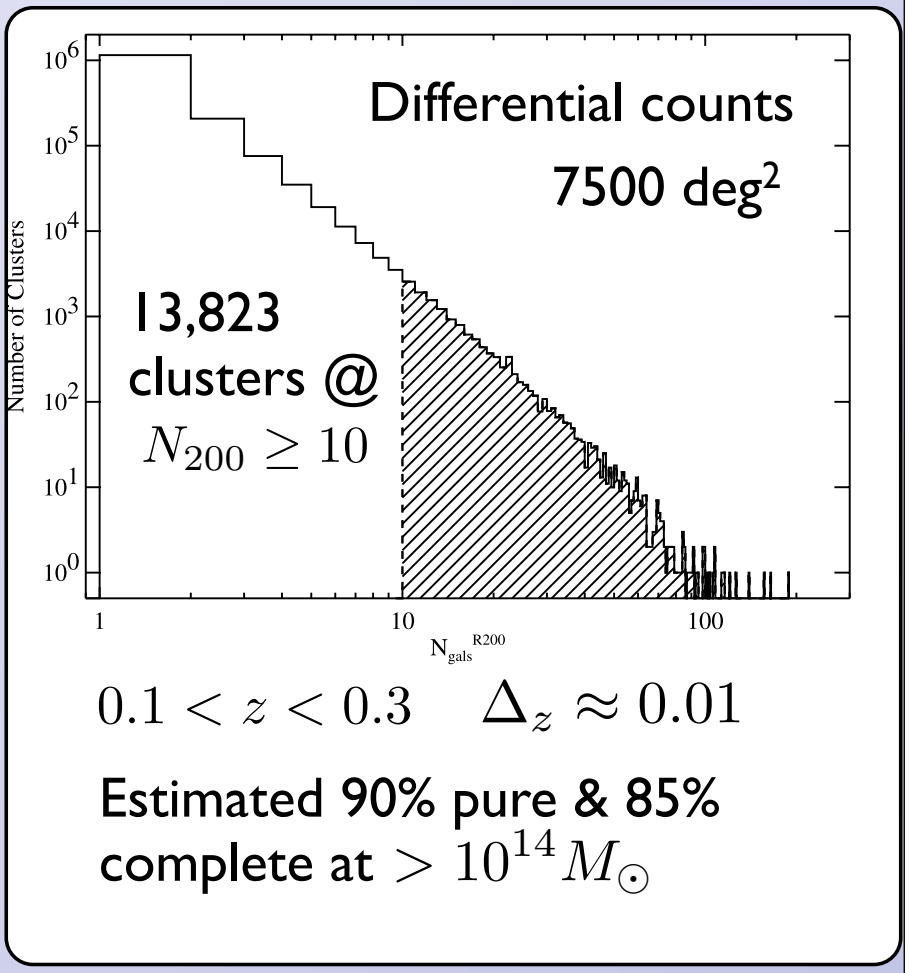
Ex: SDSS MaxBCG

- Select clusters based on their red-sequence galaxy population (Koester et al. 2007, ApJ 660, 221)
- Filter-Likelihood approach:

$$\mathcal{L}(z) = \mathcal{L}_{BCG}(z)\mathcal{L}_R(z)$$

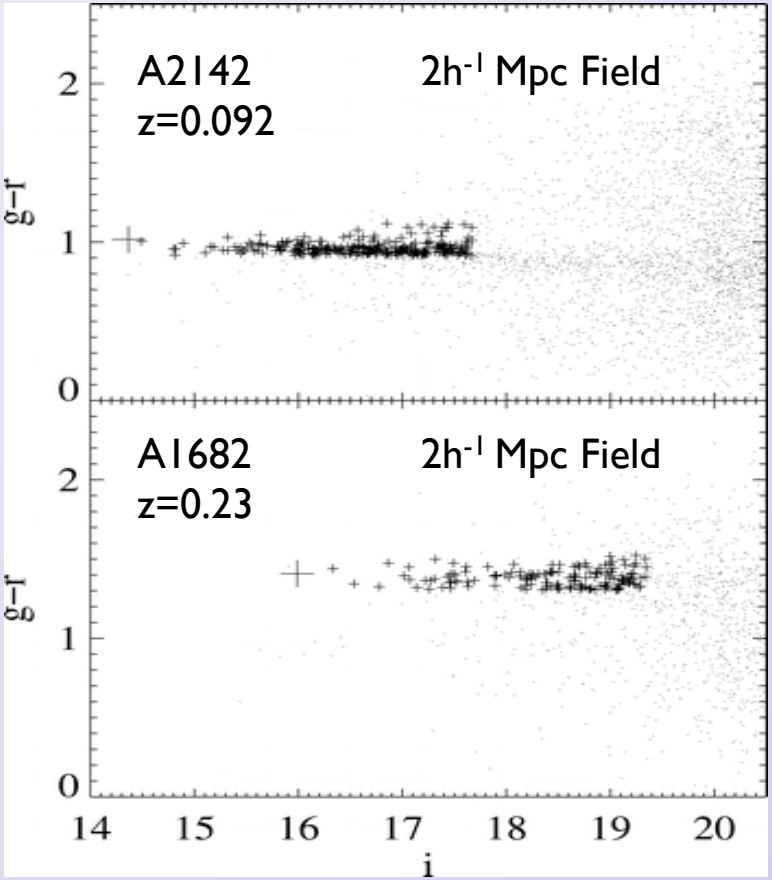
NFW galaxy filter
Sloan g,r,i bands (2 colors, 1 mag)

(See also Dong & Pierpaoli, 2008)

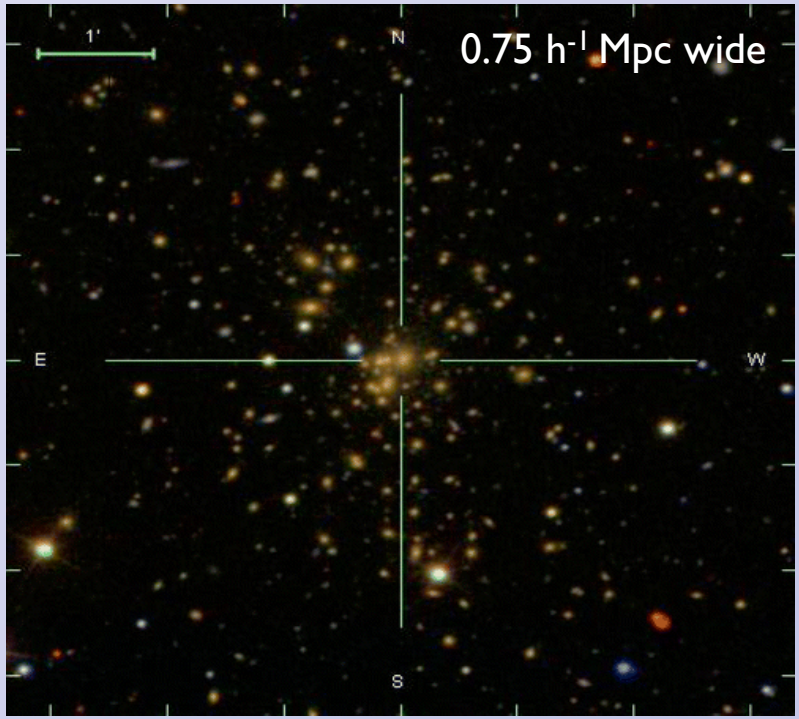


SDSS MaxBCG

Koester et al. (2007), ApJ 660, 221: *0.1<z<0.3*



A1689 z=0.18



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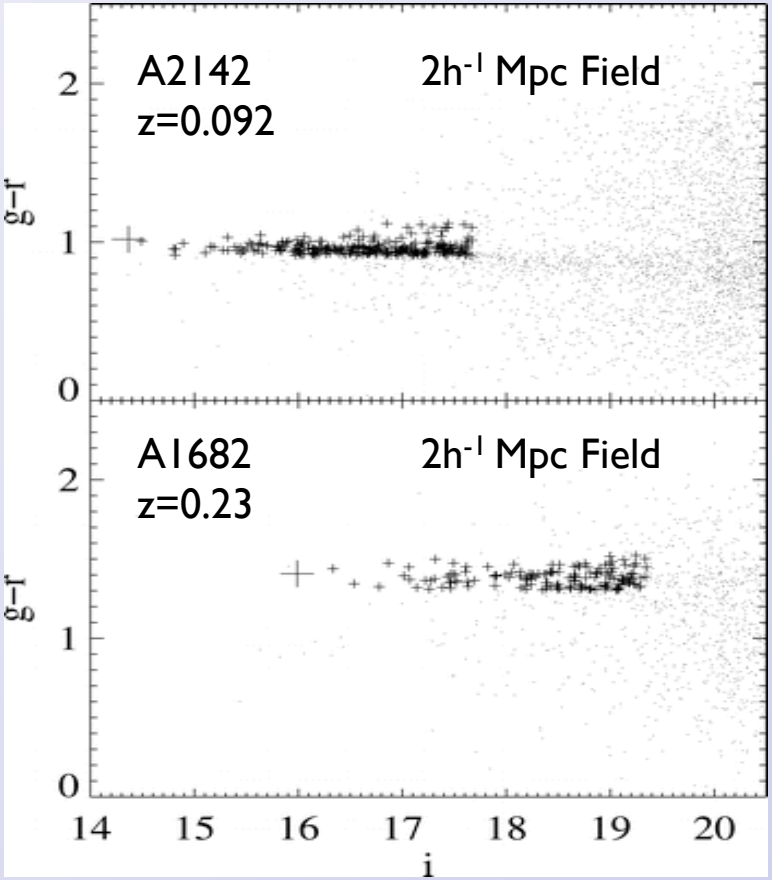
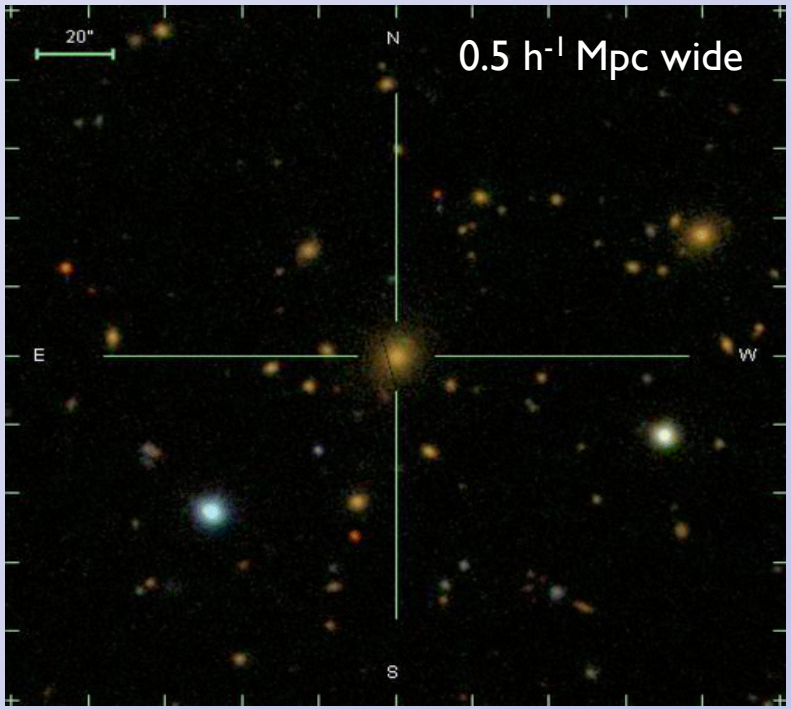


New MaxBCG z=0.23



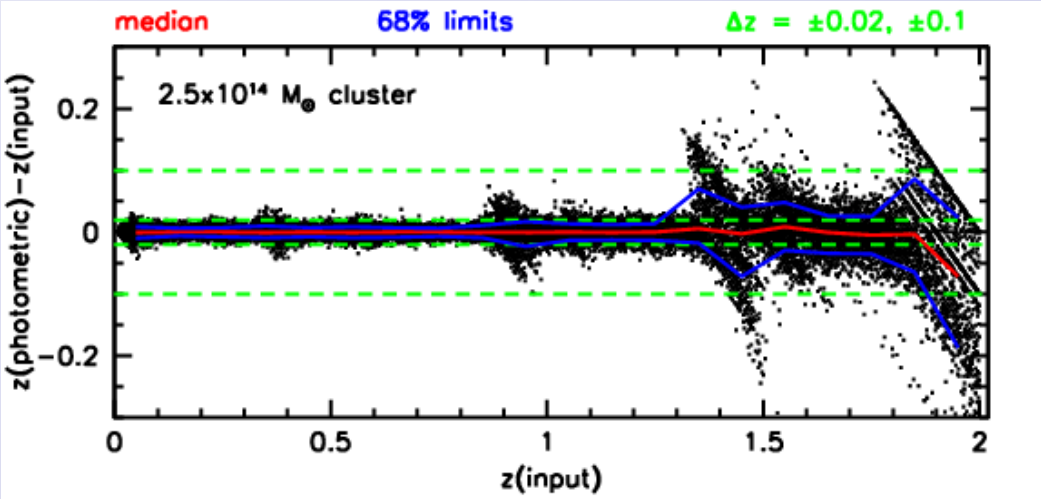
Upcoming Optical/NIR Surveys

- Dark Energy Survey (DES)
  - *griz, ~23-24mag (10σ), ~5000 sq. deg.*
- Pan-STARRS
  - PS1: grizY, ~23.5-24mag (5σ, 1year) over 3π
  - PS4:
    - *grizY, ~24mag (5σ, single visit),*
    - *~26mag stacks over 3π*
- Large Synoptic Survey Telescope (LSST)
  - *ugrizY, ~24.7mag (5σ, single visit)*
  - *~27.6mag (10 years), 20,000 sq. degs.*

Dark Energy Survey

- 4 Sloan filter bands griz
- ~5000 sq. degs. in the South (SPT follow-up)

Filter	g	r	i	z
mag (10σ)	22.8	23.4	24	23.6



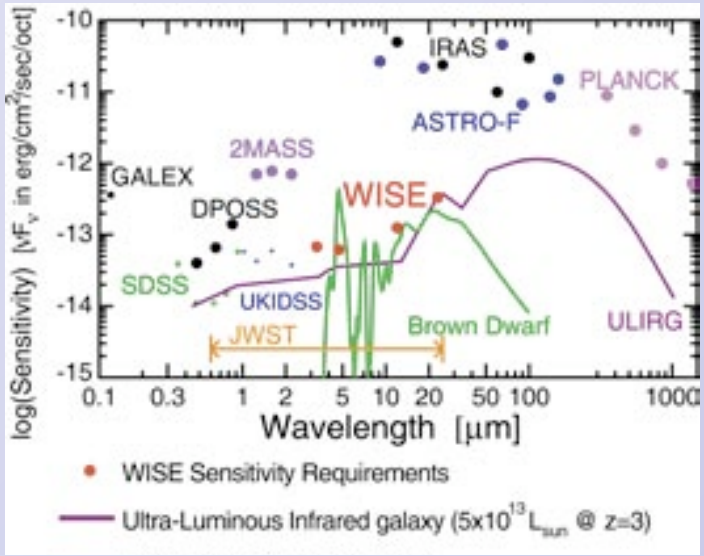
Cluster photo-z's (Mock catalog)

Cluster catalog:

$$M \geq 2 \times 10^{14} M_{\odot}$$
$$z \leq 1.3$$

Optical/NIR Space Surveys

- WISE: MIDEX Explorer 2009
  - 3.3, 4.7, 12, 23 microns

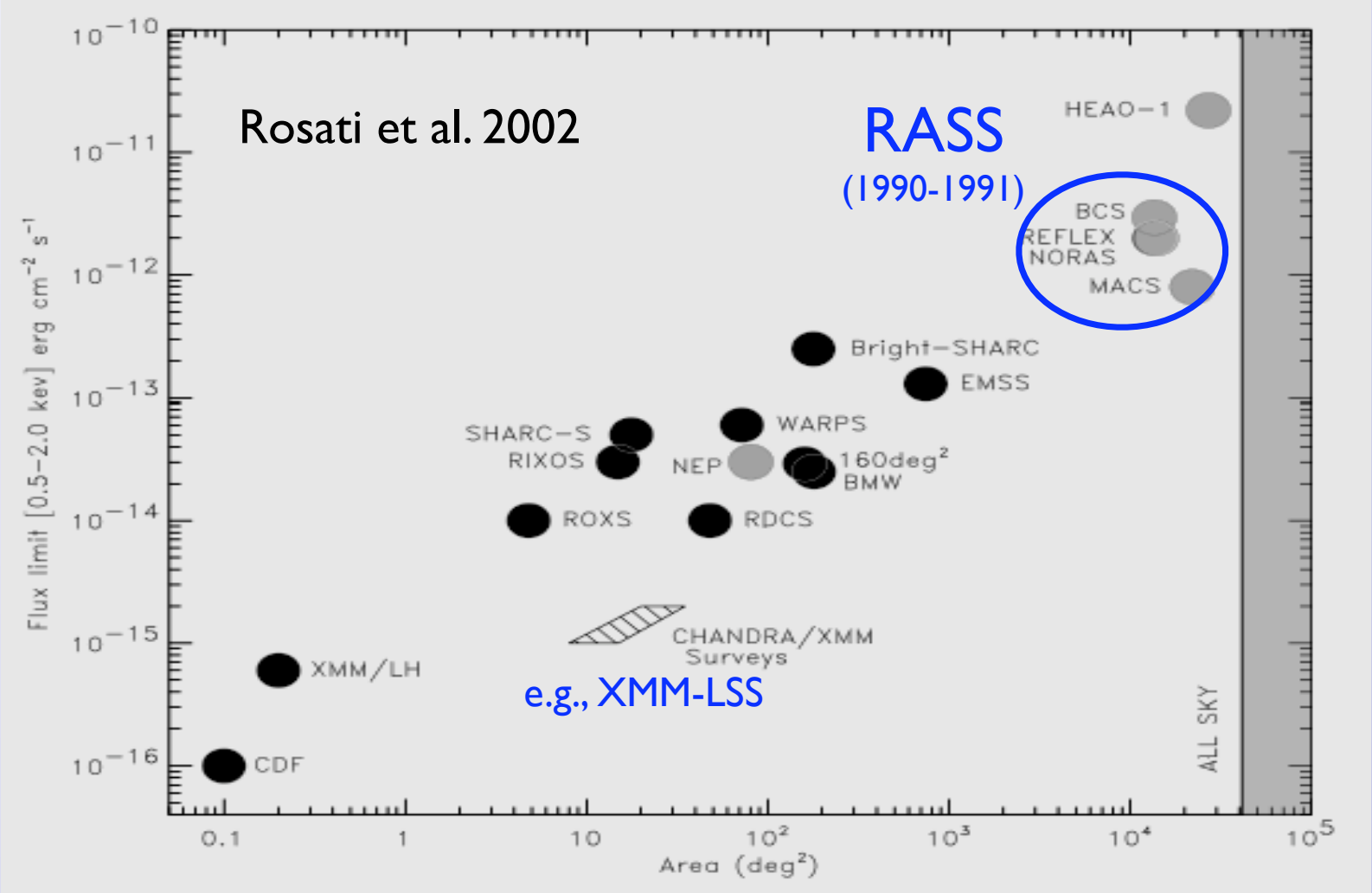


- EUCLID/JDEM
  - ~10,000 sq. deg. to ~26mag into NIR

X-ray Surveys

- Most productive to date for cosmological applications
- Long history and accumulated experience
- Requires important resources - satellite
- Today: Chandra & XMM-Newton
  - Not survey telescopes
  - Surveys (serendipitous or other): $\leq 500\ \mathrm{deg}^2$

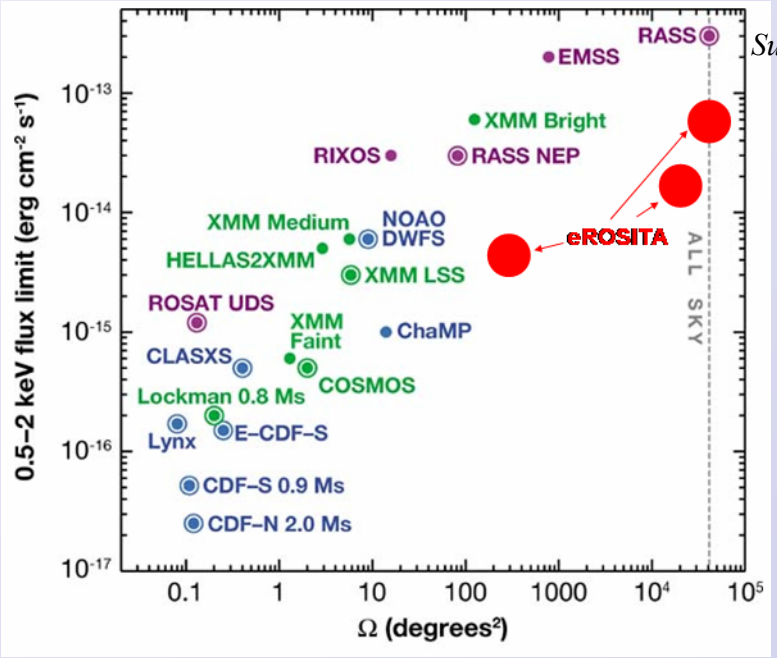
Cluster X-ray Surveys



eROSITA

http://www.mpe.mpg.de/projects.html#erosita

X-ray satellite: Nov 2011 launch (?)



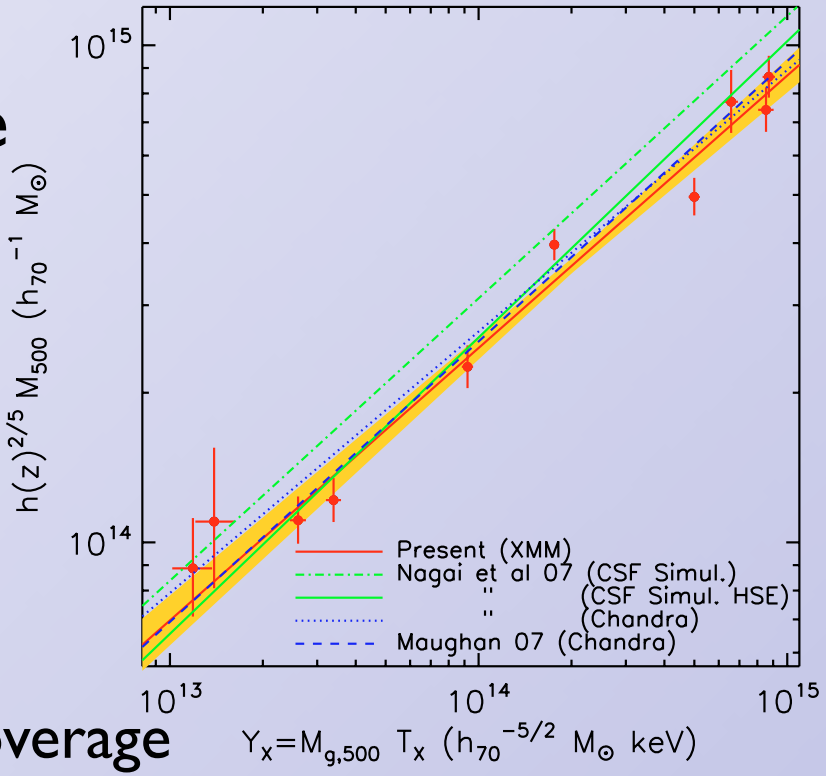
Summary of ROSITA Surveys:

Survey	All-Sky Survey	Wide Survey	Deep Survey
Solid Angle	42000	20000	200
Exposure time	1 yr	2.5 yrs	0.5 yrs
0.5-2 keV $S_{min\ AGN}$	5.7×10^{-14}	1.5×10^{-14}	4×10^{-15}
2-10 keV $S_{min\ AGN}$	1.0×10^{-12}	2.1×10^{-13}	2.4×10^{-14}
0.5-5 keV S_{min} Clusters	1.6×10^{-13}	3.3×10^{-14}	8×10^{-15}
0.5-2 keV AGN	240000	800000	740000
2-10 keV AGN	12600	84000	44000
Clusters	32000	72000	6500

SZ Cluster Surveys

- New, but untried technique
- Potentially powerful
  - Tight mass proxy
  - Flat selection in redshift
- Ground/Space
  - Large telescope/frequency coverage

Arnaud, Pointecouteau & Pratt 2007

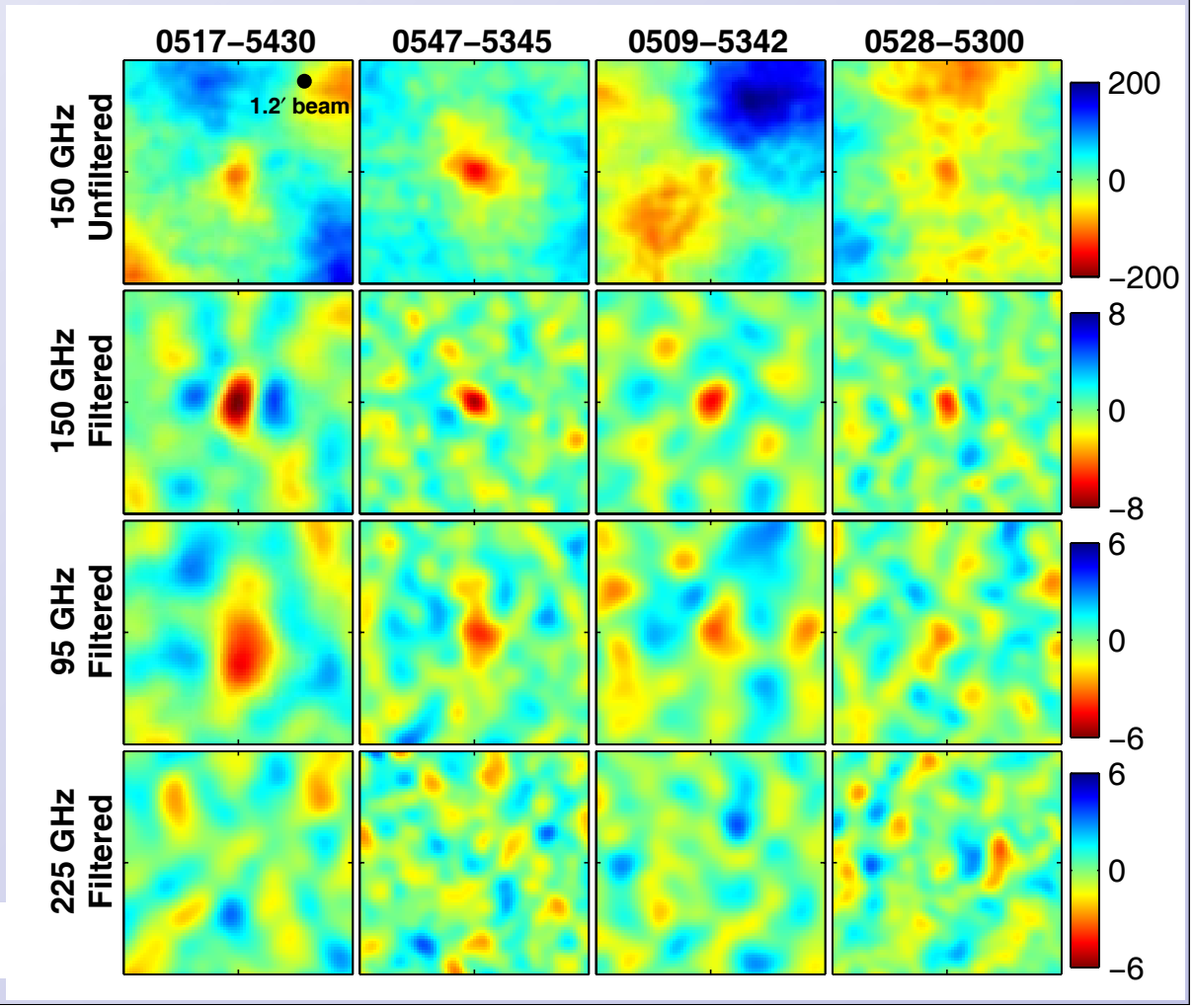


SZ Cluster Surveys

- Interferometers
  - <90GHz, ~arcmin res, ~10 sq. degs. to ~fewμK sensitivity, NORTH
  - AMI, AMIBA, SZA
- Bolometer cameras
  - ~arcmin res, 100-4000 sq. degs. to ~fewμK, SOUTH
  - ACT: deepest
  - APEX: renouncing large surveys - pointed campaigns
  - SPT: widest
- Planck: ~5 arcmin res, all-sky

South Pole Telescope

- Deployed SP 2006-2007 season
- First Austral Winter observations: 2007
- 40 sq. deg. yielded first SZ-detected clusters!!

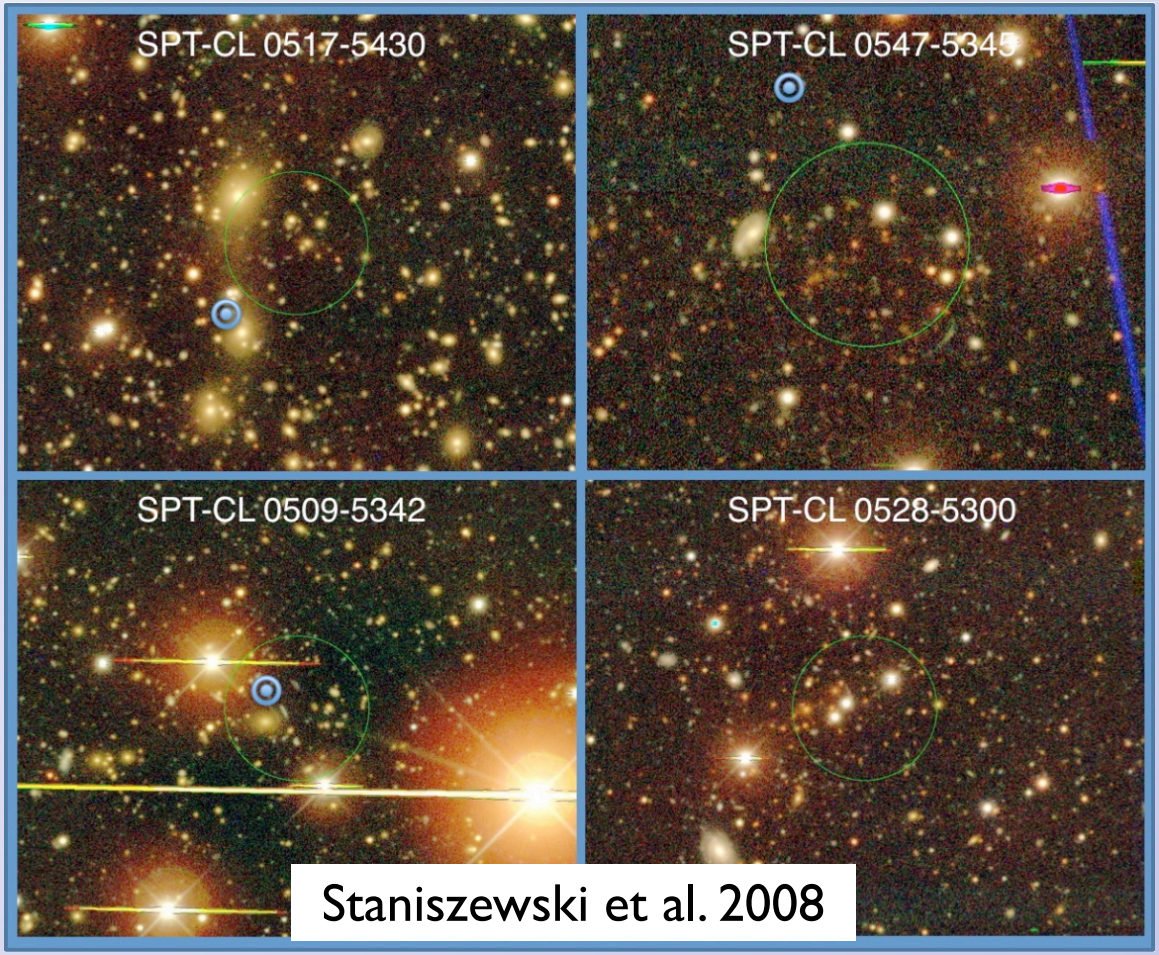


Staniszewski et al. 2008

First SPT Clusters

$z \approx 0.35$

$z \approx 0.4$



Staniszewski et al. 2008

$z \approx 0.8$

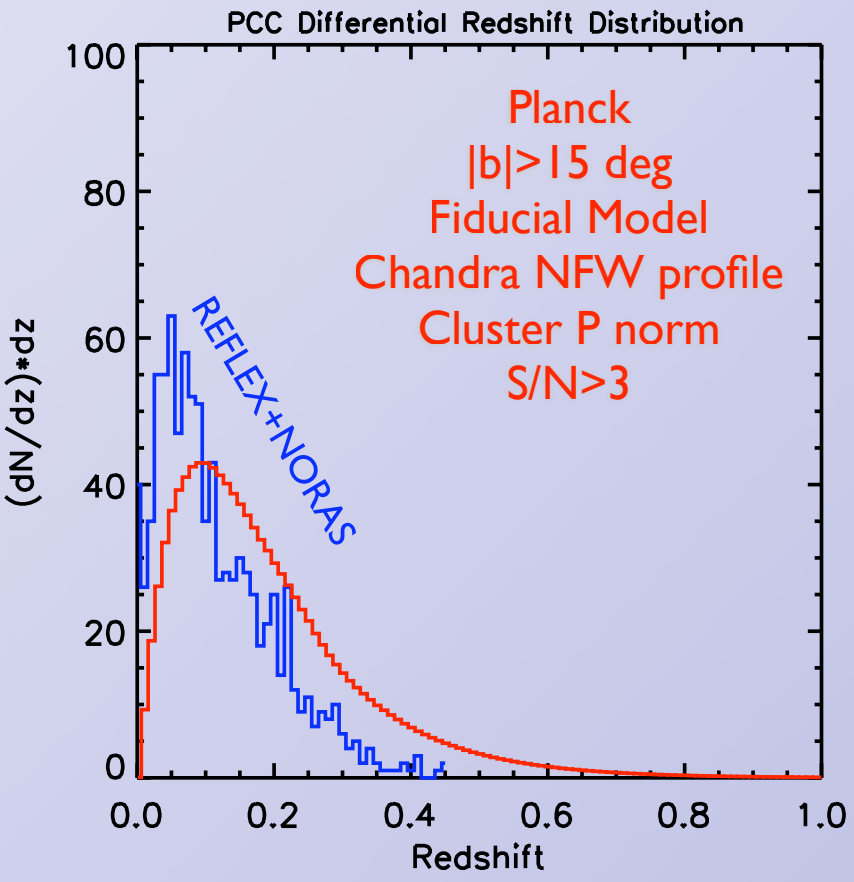
$z > 0.8?$

Blanco Cosmology Survey (BCS): gri images

Planck Survey

Planck is the next all-sky cluster survey First one since ROSAT (1992)!

Chamballu et al. (2008)



Cluster Surveys: X-ray