The Abdus Salam
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Summer School on Cosmology

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Clusters of Galaxies - Lecture 4

J. Mohr
LMU, Munich

ICTP Summer School on Cosmology, Trieste, July 2012

Future Prospects

The recent successes in galaxy cluster cosmological studies set the stage for the next generation of experiments. These experiments focus both on scaling up the number the clusters and on better control of systematics- particularly on better mass calibration.

Joe Mohr
Ludwig-Maximilians University, Munich
Max Planck Institute for Extraterrestrial Physics, Garching

Outline

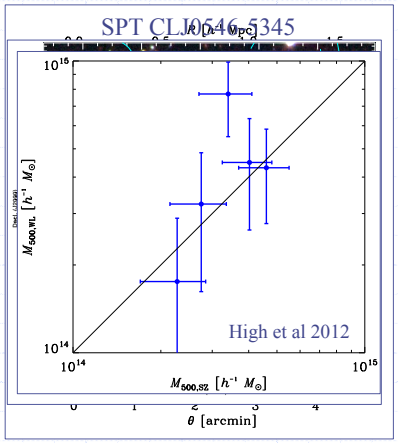
- Halo abundance as cosmological constraints
- Galaxy clusters and galaxy cluster surveys
- Cosmological constraints from cluster surveys
- Future Prospects

Overview: Future Prospects

- The cluster mass calibration challenge
- There are several future missions that will include cluster cosmology as an important driver:
  - Deep multiband optical surveys
    - The Dark Energy Survey
    - HyperSuprimeCam Survey
  - eROSITA all sky X-ray survey
  - EUCLID space based imaging survey
- These large contiguous surveys offer the possibility to use the clustering of the cluster population- attacking many of the problems Will has just been discussing

Weak Lensing Cluster Masses

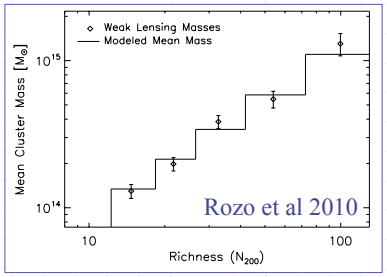
- The cluster survey teams have turned to weak lensing mass calibration
- Within SPT we are pursuing Magellan Megacam observations of a sample of 18 z~0.3-0.4 clusters together with HST+VLT observations of a sample of 14 z~0.6-1.15 clusters
  - Only first results available



Stacked Weak Lensing Masses

- Weak lensing masses are not precise because: (1) shape noise is high on a per galaxy basis, (2) there are limited numbers of background source galaxies to constrain the shear and (3) variations in the large scale structure correlated with the cluster and projected along the line of sight
  (see Henk's talk later this week, Gruen et al 2011 and e.g. Schneider 2005)
- By combining weak lensing from a large number of clusters with a similar observable (i.e. L_x, ξ or B_{gc}), it is possible to beat down these statistical and systematic noise sources

State of the art stacked weak lensing calibration in SDSS

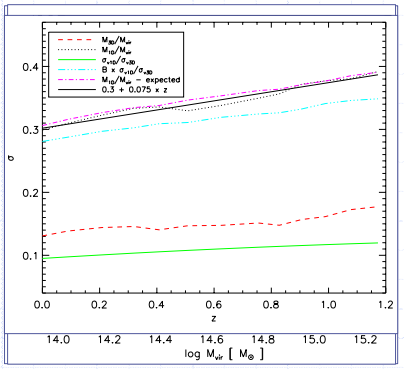


N_{clus}=5651, 2269, 1021, 353, 55 (low to high)

Velocity Dispersions for Mass Calibration

- Velocity dispersions offer noisy single cluster mass constraints, but like weak lensing they can be combined to a robust overall calibration (Evrard et al 2008; White et al 2010; Saro et al 2012)
- Subhalo kinematics can be studied in simulations
- Key issues are importance of selection (i.e. red sequence) and quantifying velocity bias
  - Current literature survey- ~5% disagreement on velocity bias

Saro et al 2012

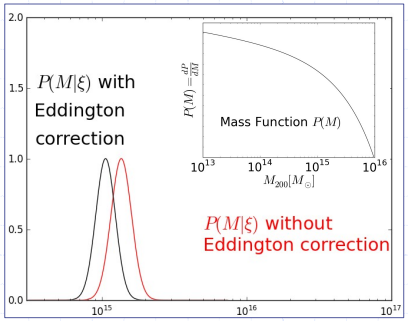


$$M_{dyn} = \left(\frac{\sigma_v}{938 km/s}\right)^{2.91} h_{70}^{-1}(z) 10^{15} M_\odot$$

Calibrating Scatter is Important

- The most straightforward way to think about scatter calibration is by examining relationship of observable to a low scatter mass proxy (Vikhlinin et al 2009)
- Alternatively one parametrizes it and fits for it along with other nuisance parameters
- Mass scatter from Literature
  - B_{gc}: 73%+/-18% (Gladders et al 2007)
  - N_{200}: 47%+/-10% (Rozo et al 2010)
  - L_x: 25% (Vikhlinin et al 2009)
  - ξ: 18%+/-12% (Benson et al 2011)
  - Y_x: <10% (Kravtsov et al 2007)

Bazin et al 2012



$$P(M|\xi,\theta) \propto P(\xi|M,\theta) P(M)$$

Eddington bias (Mortonson et al 2010)

$$\ln M_m = \ln M_{obs} + \gamma \sigma^2_{\ln M}$$

Multi-λ Cluster Studies

- There are many upcoming opportunities given the multi-wavelength survey datasets being acquired over large regions of the sky
- Multiband Optical/NIR:
  - SDSS, PS1, ESO/VST surveys – similar depths to ~22 mag
  - ESO/KIDS to 24+, DES to 24+, HSC to ~25
  - LSST will go even deeper
  - VISTA NIR surveys underway, WISE already released
- X-ray All Sky Survey: eROSITA (30X deeper than RASS)
- Space based imaging: EUCLID
  - Deep optical for lensing, deep NIR YJH to 24 mag
- Large spectroscopic survey beyond SDSS & BOSS pushing forward

The Dark Energy Survey

- 5000 deg^2 *grizY* to ~24
- 30 deg^2 deep, repeat observations
- First light September 1, 2012
- Multi-λ cluster cosmology
  - Optical cluster finding
  - Weak lensing masses for SPT clusters
- Also:
  - Weak Lensing/Cosmic Shear
  - Baryon Acoustic Oscillations
  - SNe Ia Distances

Blanco 4m on Cerro Tololo, Chile

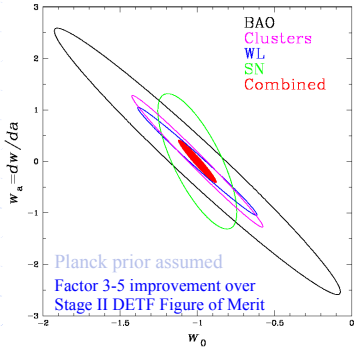
Image credit: Roger Smith/NOAO/AURA/NSF

DES Science Summary

Four Probes of Dark Energy

- Galaxy Clusters
  - ~100,000 clusters to z>1
  - Synergy with SPT – weak lensing masses
  - Sensitive to growth of structure and geometry
- Weak Lensing
  - Shape measurements of 200 million galaxies
  - Sensitive to growth of structure and geometry
- Large-scale Structure (BAO)
  - 300 million galaxies to z = 1 and beyond
  - Sensitive to geometry
- Supernovae
  - 30 sq deg time-domain survey
  - ~4000 well-sampled SNe Ia to z ~1
  - Sensitive to geometry

Forecast Constraints on DE Equation of State



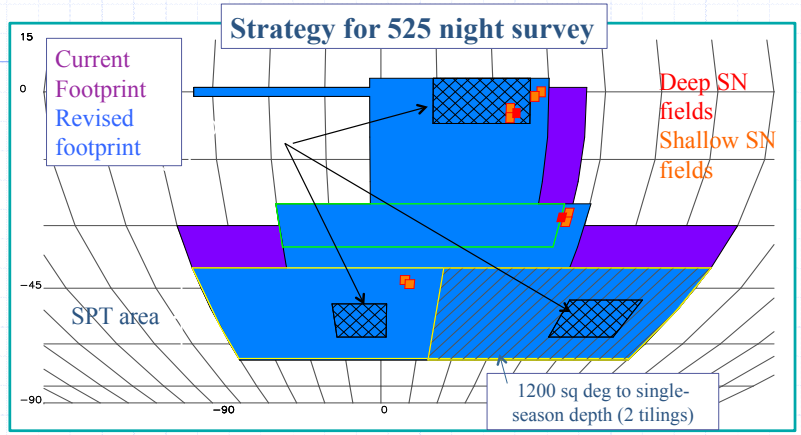
Updates forecasts coming soon.

DES Science Working Groups

Chair: Ofer Lahav

Large Scale Structure	(Gaztanaga & Percival)
Weak Lensing	(Bridle and Jain)
Clusters	(Mohr and Miller)
SNe Ia	(Sako and Nichol)
Photo-z	(Castander and Lin)
Simulations	(Evrard and Kravtsov)
Galaxy Evolution	(Thomas and Wechsler)
QSO	(Martini and McMahon)
Strong Lensing	(Buckley-Geer and Makler)
Milky Way	(Santiago and Yanny)
Theory and Combined Probes	(Dodelson and Weller)
+ Spectroscopic Task Force	(Abdalla and Sako)

Survey Plans for First Season



1st Season: Proposed 20 first-half nights for SV and 67.5 nights for 2012B
Active consideration of equatorial survey -10<δ<10 to support Big-BOSS
Desire to cover full south galactic cap

Expected Photometric Depths/Seeing

- Survey strategy: expose for 800s in g/r, 1000s in i/z

Table 2. Expected Cumulative Wide-Area Survey Depths and Median Delivered PSF

filter	exp (sec)	mean PSF 5σ m_{lim}	mean galaxy 10σ m_{lim}	90%-tile bright m_{lim}	95%-tile bright m_{lim}	median PSF(arcsec)
g	800	26.5	25.2 ± 0.12	25.03	24.99	0.83 ± 0.05
r	800	26.0	24.8 ± 0.11	24.61	24.58	0.79 ± 0.05
i	1000	25.3	24.0 ± 0.10	23.90	23.86	0.79 ± 0.05
z	1000	24.7	23.4 ± 0.08	23.34	23.30	0.78 ± 0.04
y	500	23.0	21.7 ± 0.08	21.61	21.56	0.77 ± 0.04

$n_{eff} = 11.2/\square'$ for weak lensing; survey area = 4944 deg^2; $N_{gals} = 200 \times 10^6$.
PSF $\equiv$ 1.0*FWHM aperture mag; galaxy mag $\equiv$ 1.6*FWHM aperture mag
σ are the distribution across the full survey area

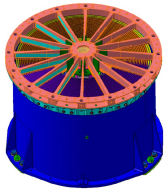
- Characteristic 10σ galaxy depth is ~24

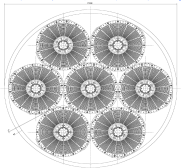
DES Overview

- DES Science Verification data will be released immediately after it is acquired (currently mid Nov this year), surveys continues 5 yrs
- DES fully calibrated catalogs will be released at midpoint of survey and one year after the end of the survey
  - Raw and detrended data available one year after acquisition
- A broad range of science is possible… think of SDSS science but over a redshift range extending beyond z=1
  - Timing may be appropriate for starting graduate students

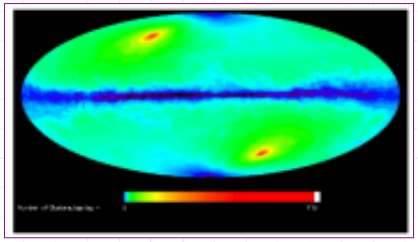
e-ROSITA All Sky X-ray Survey

PI Peter Predehl (MPE)





- Collecting area of 2 XMM's with 1 deg diameter FOV
- Good angular resolution – <30" averaged over field
  (similar to ROSAT PSPC pointed data within inner ring)
- Four year nominal mission
- Characteristic flux limit is ~2x10^{-14} erg/s/cm^2
  (~30X deeper than ROSAT All Sky Survey w/ CCD spectroscopy)



~10^5 X-ray selected galaxy clusters

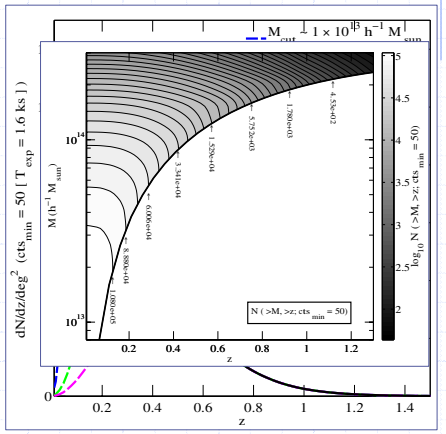
DES and PS1 Surveys Enable:
* Cluster confirmation
* Cluster photo-z's
* Weak lensing mass constraints

- Launch 2014 -

eROSITA Cluster Sample

- A 50 count limit with characteristic exposures one expects 137,000 systems
- Rough estimates:
  - 7000 with 10^3 counts
  - 700 with 10^4 counts
  - 1000 at z>1
- Uniform selection possible over full sky. A variety of analyses are possible- including cluster power spectrum
- Optical confirmation/redshift estimation a sizeable task

Pillepich et al 2011

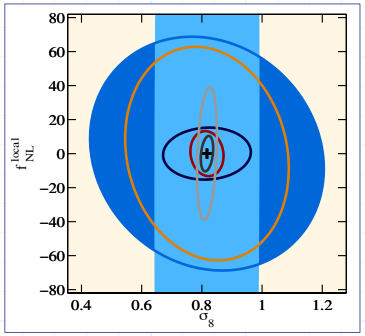


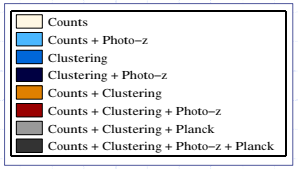
Forecasts

- Examine model in h, Ω_b, n_s, Ω_m, σ_8, f_{NL} plus L-M relation nuisance params
- Examine constraints using different reservoirs of information
- f_{NL} constraints at level of σ_{fNL}<10

See also Sartoris et al 2012, which examines dark energy constraints and their dependence on how well one knows the mass-obs relation.

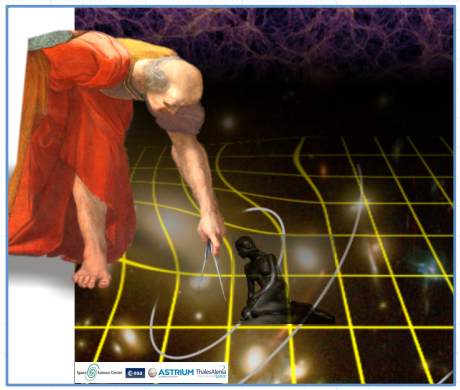
Pillepich et al 2011





EUCLID Space Imaging Mission

- Goal: determine the underlying cause of the cosmic acceleration using cosmic shear and galaxy clustering
  - Offers tremendous dataset for calibration of galaxy cluster masses from eROSITA and other missions
- Will (1) image 15000 deg^2 with Hubble Space Telescope quality imaging, (2) deeply image the sky in the NIR, (3) measure redshifts of 50 million galaxies for cluster studies



see Laureijs et al 2011, Amendola et al 2012

EUCLID Cluster Science

- The EUCLID data will be coupled with deep, multiband ground based data to enable photometric redshift estimates for the EUCLID sample of galaxies
  - This includes DES, HSC, KIDS, PS2 and ultimately LSST
- Primary goal of the Cluster SWG in EUCLID is to use the combination of optical cluster finding and shear to extract a large cluster sample with well understood completeness and contamination
  - This cluster catalog would enable cluster mass function studies, cluster power spectrum studies, cross correlation studies, etc
  - Uniqueness: Calibration of the mass-obs relation enabled by EUCLID HST-like dataset, deep NIR data enables large cluster samples at z>1
- Legacy value: precise mass calibration for all existing X-ray/SZE cluster samples

Summary

- Cluster mass measurements:
  - Current limits on precision cosmology in X-ray/SZE are mass-observable calibration limited
  - Work underway using weak lensing (more on this from Henk)
  - Dispersions provide complementary information
  - Low scatter X-ray observables important, too
- We are entering a period of large, multi-wavelength imaging and spectroscopic surveys
  - "Optical followup" of X-ray/SZE selected cluster samples will be simple query!
  - Low scatter X-ray mass proxies available for ~10^4 clusters
  - Stacked weak lensing on large samples extending to z~1 will be possible
  - Cluster cosmology is just one of many exciting areas

Come join the fun!

References

- *Articles from the current literature*