The DES Cluster Cosmology Program

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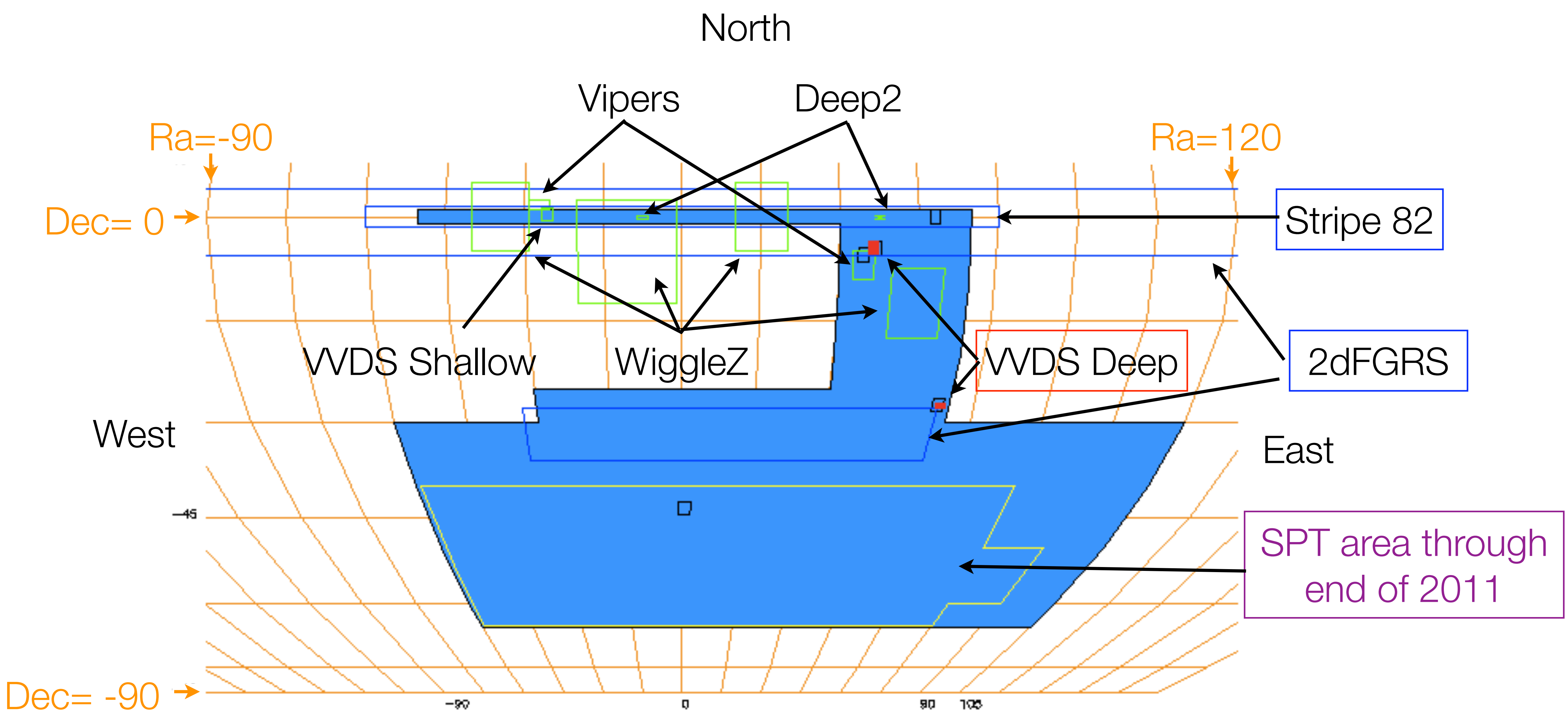
August 10, 2010

DES Footprint: Photo-z Training Areas

DARK ENERGY SURVEY

This plot shows a quadrant of the sky centered on the South Galactic Cap

Think:
5000 sq-degrees to i~24.



Redshift surveys:
Blue i < 20
Green i < 22
Red i < 24

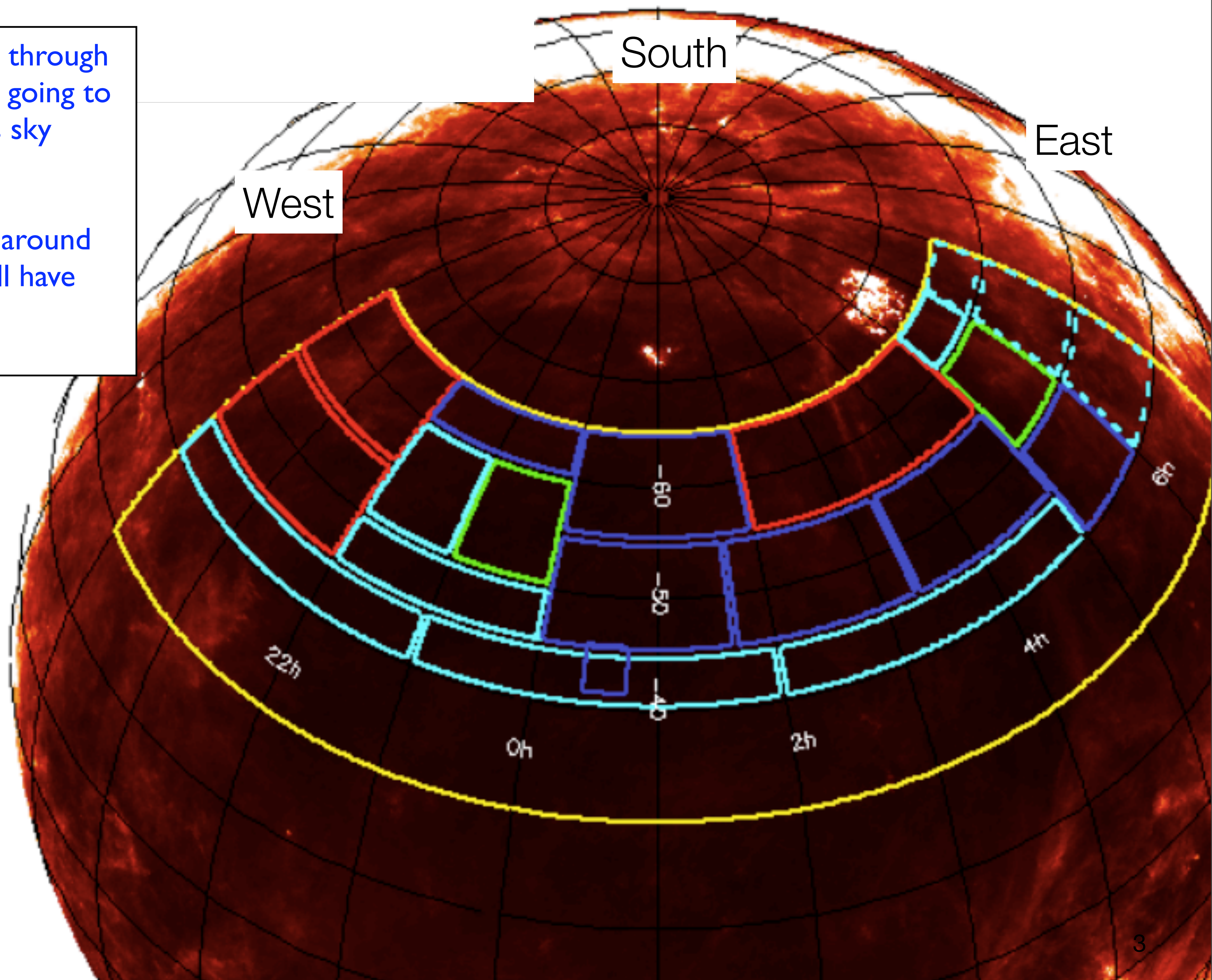
Black boxes are the 5 DES SN Fields

Footprints: The South Pole Telescope

4000 sq deg
2008 fields
2009 fields
2010 fields
2011 fields

The SPT plans on pursuing an SZ survey through the end of 2011. Following that, they are going to put on a CMB polarimeter which covers sky much more slowly.

We can assume that at the end of 2011, around the time the DES starts, that the SPT will have covered 2250 sq-degrees at:
-60 <= RA <= 90 -65 <= Dec < -40



Survey Strategy Simulations I

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- Simulation assumptions
  - astronomical twilight to astronomical twilight
  - no standard stars
  - 30 year weather statistics, used in 5 year blocks
  - Hybrid SN strategy
  - Slew time model
  - Readout+overhead = 20sec
  - Community time model:

Bright	Full moon +- 1 night
Dark	New moon +- 1 night
Gray	2, 3, or 4 nights centered on first quarter

- The New Baseline
  - Add y-band in years 1+2
  - Year 5 increases z depth by 0.25mag

95% of observations taken at airmass 1.17 +- 0.17

An unusual year- bad weather in Jan/Feb. Most scenarios show this gap in the East.

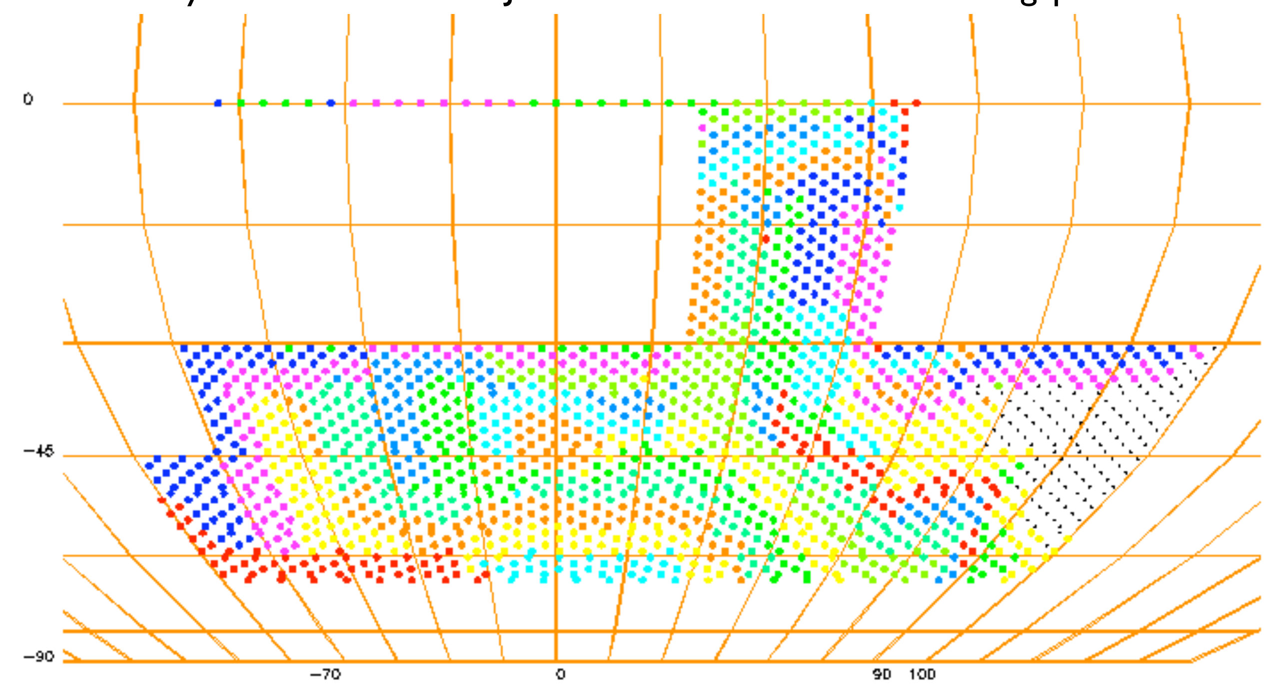


Table 3: Scenario 1 summary

Survey Year	Filters	Exposure time	Tilings	Cumulative exposure g r i z y	10σ galaxy magnitude g r i z y
2012	g r i z y	80	2	160 160 160 160 160	24.2 23.7 23.3 22.5 20.9
2013	g r i z y	80	2	320 320 320 320 320	24.6 24.1 23.7 22.9 21.3
2014	i z	200	2	720 720	24.1 23.2
2015	i z	200	2	1120 1120	24.4 23.6
2016	z	400	2	1920	23.8

Table 4: Hour use summary for 1989-1993

Year	Hrs	On-object	SN photo	SN nonpho	NonPhot	Contingency
1	834	410	37	175	57	0.2%
2	825	464	36	147	53	14%
3	832	371	17	210	90	4%
4	834	405	27	162	52	30%
5	830	387	24	146	54	30%

Table 5: Quartile distributions

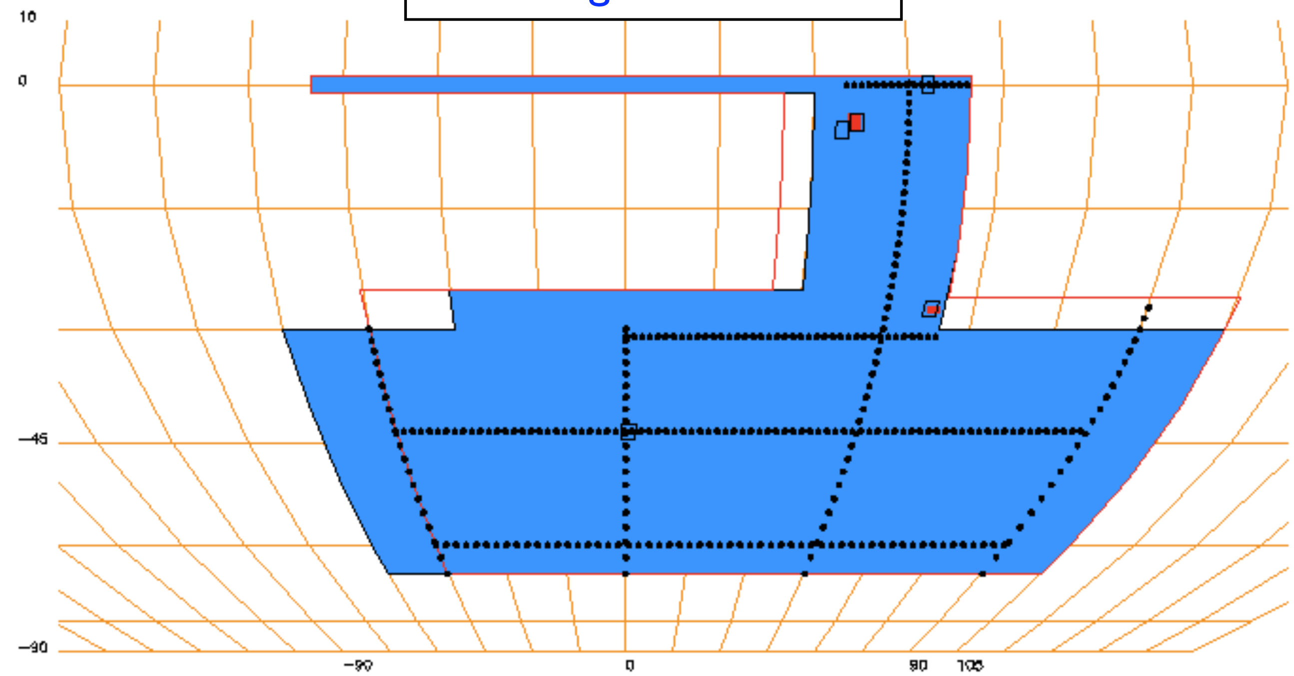
	25%	50%	75%	90%	95%
Slew (degrees)	1.8	2.0	3.1	5.9	23.1
Airmass	1.07	1.16	1.23	1.30	1.34
HA (degrees)	14	35	36	37	38

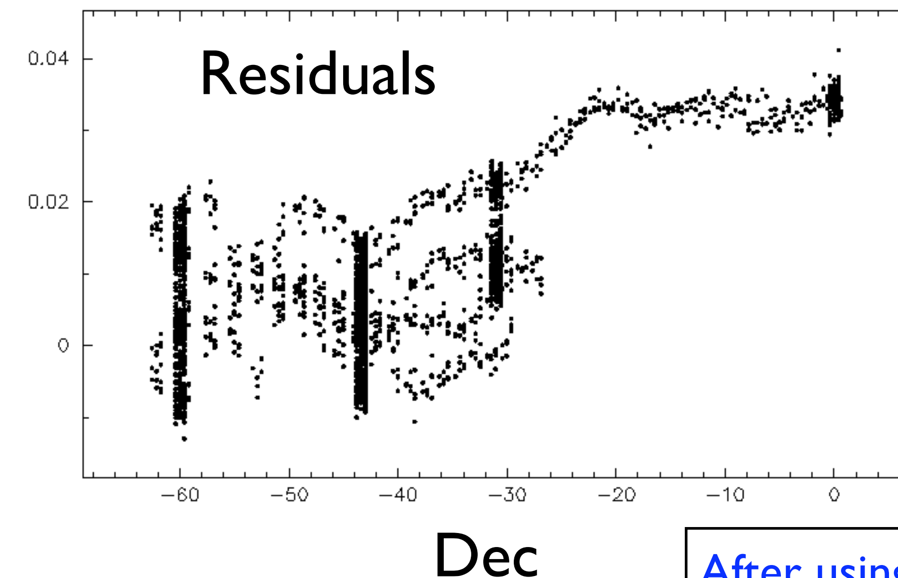
Contingency is photometric time not spent on observations

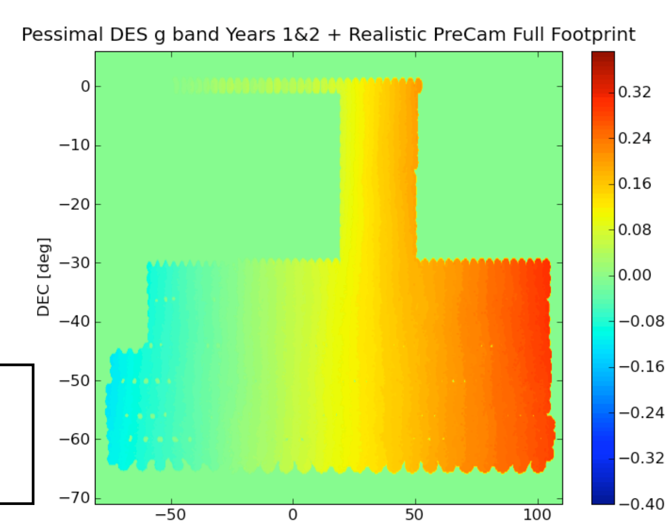
Calibration

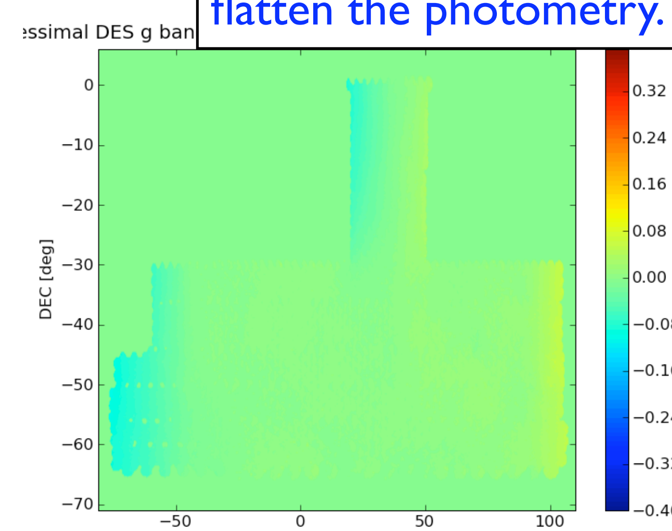
1. PreCam
   - Curtis-Schmidt and 2 DES CCDs
   - this season
   - grid-like footprint, observed in 1 night
   - observed ~10 times to get root(N) increase in photometric precision
2. DES overlapping survey imaging.
   - relative photometry of stars provides both super star flats and tile to tile zeropoints
   - This should be flat.. but
3. In tandem, the PreCam provides a framework to keep the DES photometry from creeping with, for example, RA and season.
4. The plots show various simulations of stars with photometric errors in both the PreCam data and DES data, and how well they work together.

DES footprint in blue
PreCam grid in black









After using PreCam to flatten the photometry.

DES with a 10% flat field gradient aligned along a seasonal variation in zeropoint

How to does one do DES color terms?
In a catalog level operation after Global Absolute Calibration:

DARK ENERGY SURVEY

The issue is that what we care about is the coadded catalog, and the coadded catalog is a form of averaging of fluxes taken through different system responses. So, how do we apply the color terms? It isn't as elegant as the last step:

1. Prerequisites:
   1.1. We work at the coadd catalog level
   1.2. A Mangle mask that tracks only image boundaries must be computed
      1.2.1. This mask incorporates all bandpasses

"Mangle"

2. Then for each homogeneous area in the coadd,
   2.1. Locate:
      1. The single pass images that are inputs
      2. The system response curves of those images, $T_i(\lambda)$
   2.2. For each bandpass, compute the effective bandpass
      2.2.1. As $F_b = \int F_\lambda(\lambda) T_b(\lambda) \lambda^2 d\lambda$ is linear in $T_b(\lambda)$, we can form a weighted effective bandpass: $T_{eff} = \Sigma_i T_i * w_i$.
      2.2.2. The w_i are the weights that went into the coadd, including zeropoint (which includes exposure time).
   2.3. and compute the fiducial to effective bandpass ratio: $T_{fid}/T_{eff}\,(\lambda)$.
   2.4. For a library of spectra *F*, say the Pickles Stellar Atlas, compute "color correction"
      2.4.1. "color correction" is defined as $g_{fid} = g_{eff} + c\,(g\text{-}r)_{eff}$ and we know $g_{fid} - g_{eff} = -2.5*[\mathrm{Int}(F\,\lambda^2 T_f/T_e)]$, so
      2.4.2. finding "c" is actually a lookup table that goes from the observed $(g\text{-}r)_{eff}$ to the computed $g_{fid} - g_{eff}$
   2.5. So, for each object
      2.5.1. get its (g-r), find the right $g_{fid} - g_{eff}$, and add it to g_{eff} .

"Synthetic"

b is a given bandpass,
i is a given image.

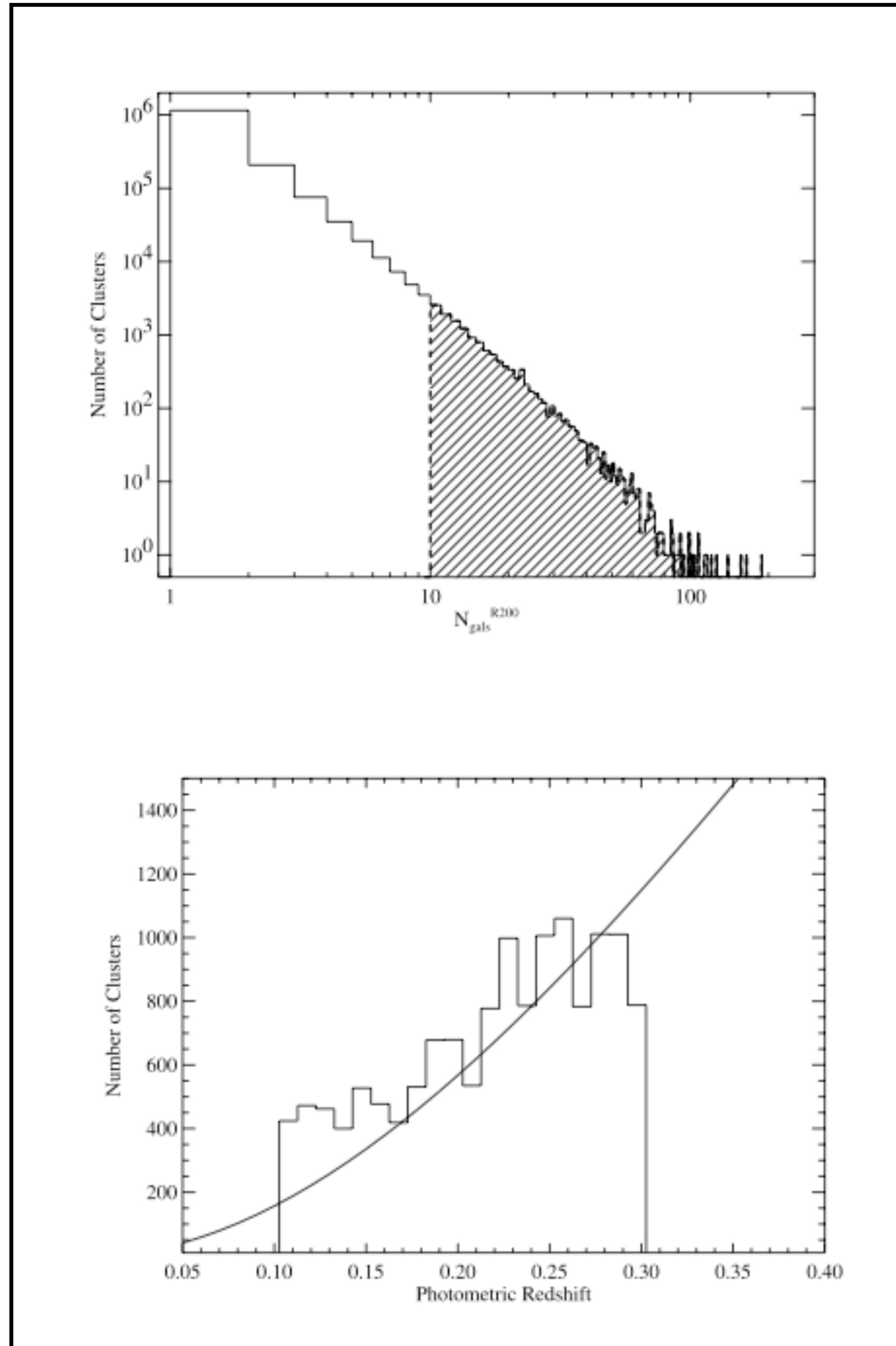
In 2.4 I'll drop the per bandpass notation and switch over to all images in a given filter notation.

To be concrete, I'll work with the g-band and g-r colors.

Uber Mangled Syn

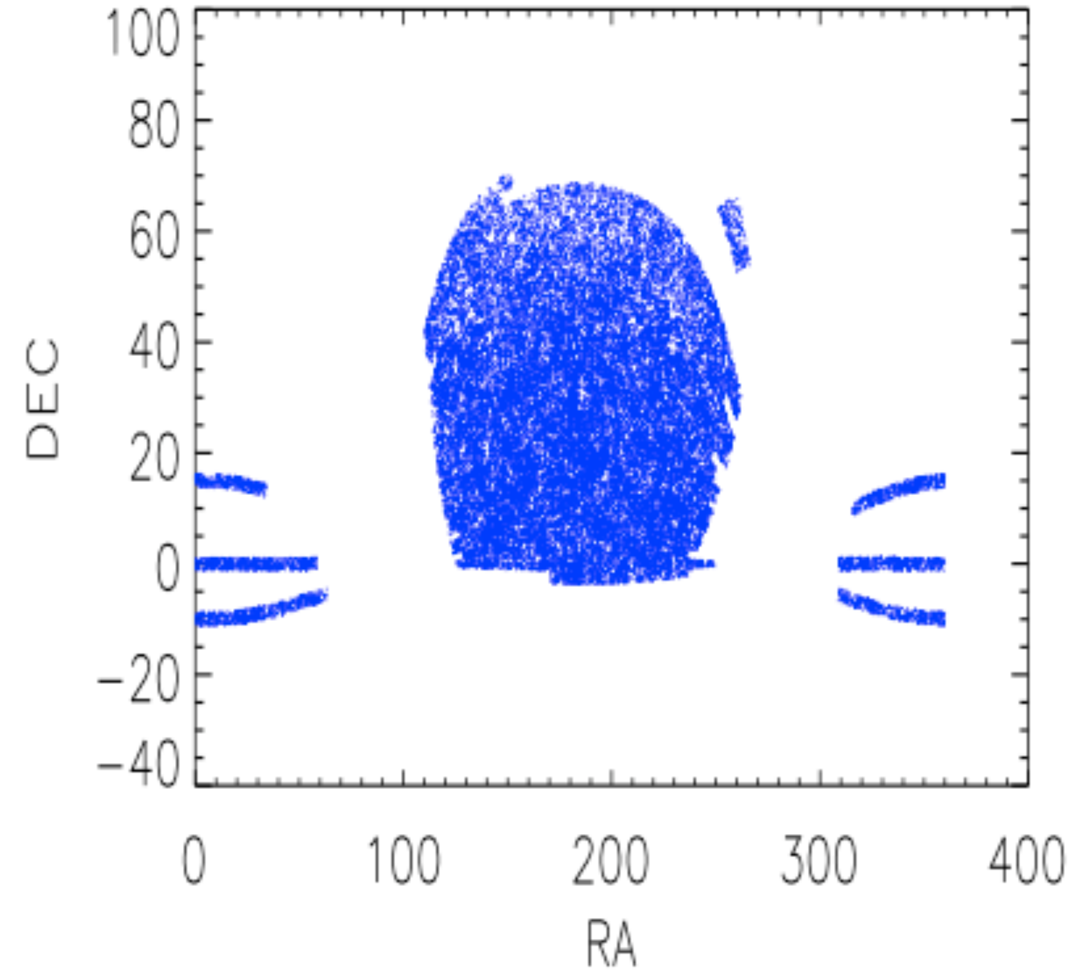
maxBcg

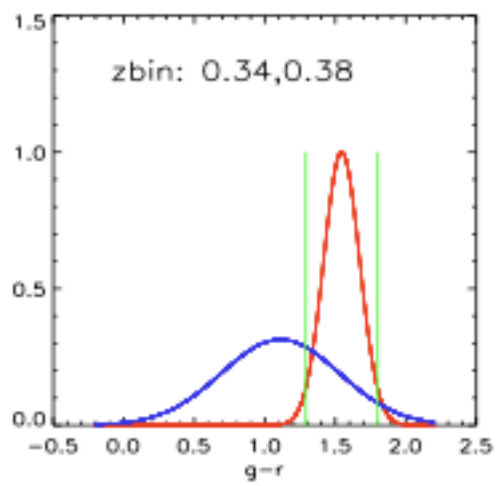
1. The maxBCG catalog of Koester et al (2007 a&B) came from the Sloan Digital Sky Survey collaboration.
2. 13,823 clusters down to N = 10
   - DR4 based, 7500 sq-degrees
3. A red sequence finder that uses colors instead of photometric redshifts
4. Its great value now comes from being well studied.
5. This catalog started the DES Cluster cosmology experience in the sense that it provided a platform upon which to learn the techniques needed to do a purely optical cluster cosmology program.
6. It is one of many cluster finders in the DES.



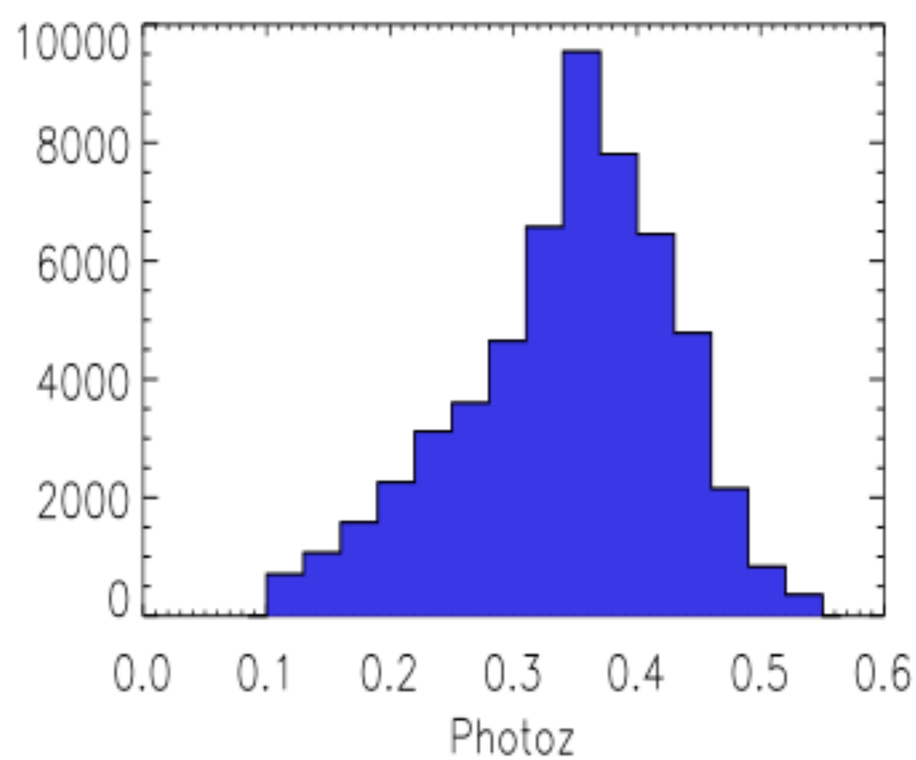
GMMBCG

1. A cluster catalog of 55,880 rich clusters from SDSS DR7
2. Algorithm
   - Select potential BCG from universe of reddish galaxies with photo-z
   - Run gaussian mixture model to determine number and positions of gaussians necessary to describe population in g-r or r-i space (down to 0.4L*)
   - Measure properties of fit red sequence





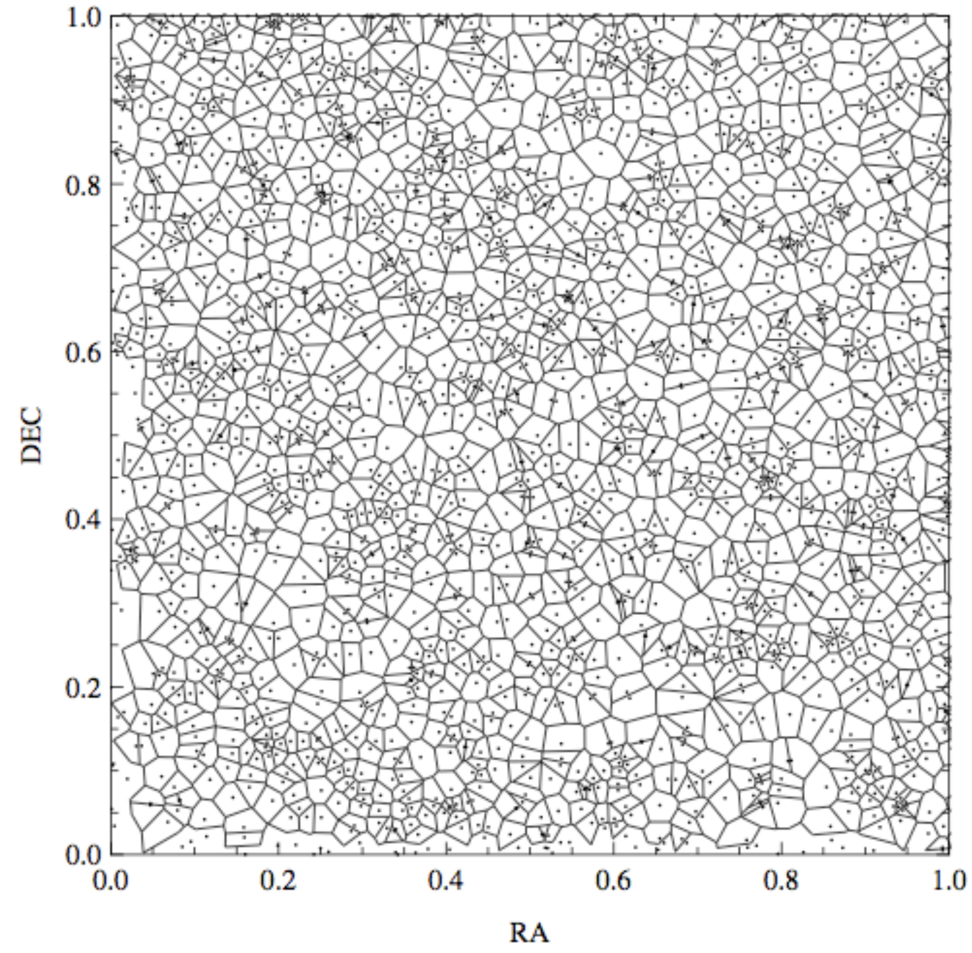
3. Advantages over maxBcg
   - the catalog covers the entire SDSS-II
   - z coverage to z ~ 0.5

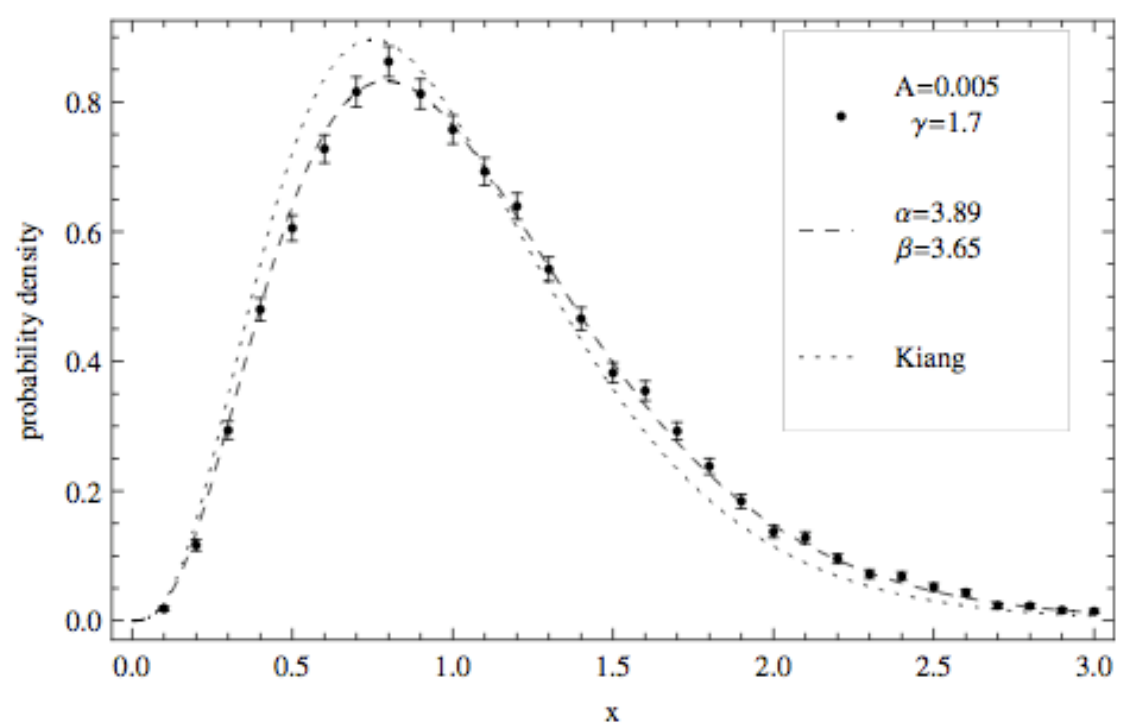


Jiangang Hao et al 2010

Voronoi Tesselation

1. A VTT cluster finding algorithm on the 200-sq degree SDSS coadd (i~24)
2. Algorithm
   - Tesselate a photo-z slice
   - Use the cumulative cell size distribution to set connected cell threshold
   - Connected cells are a cluster
   - Rerun tessellation on centers but across photo-z slices for final centers and membership lists
3. Cumulative cell size distribution
   - for a Poisson distribution this is well fit by Kiang's conjecture $$p(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} x^{\alpha-1} \exp^{-\beta x}$$ $$\alpha = \beta = 2n.$$
   - for power law galaxy angular correlation function it turns out that the distribution is well fit by the Kiang form but with $\alpha = 0.26 + \beta$
   - where α or β depends on the measured 2 pt function.
4. Advantages: color and shape agnostic



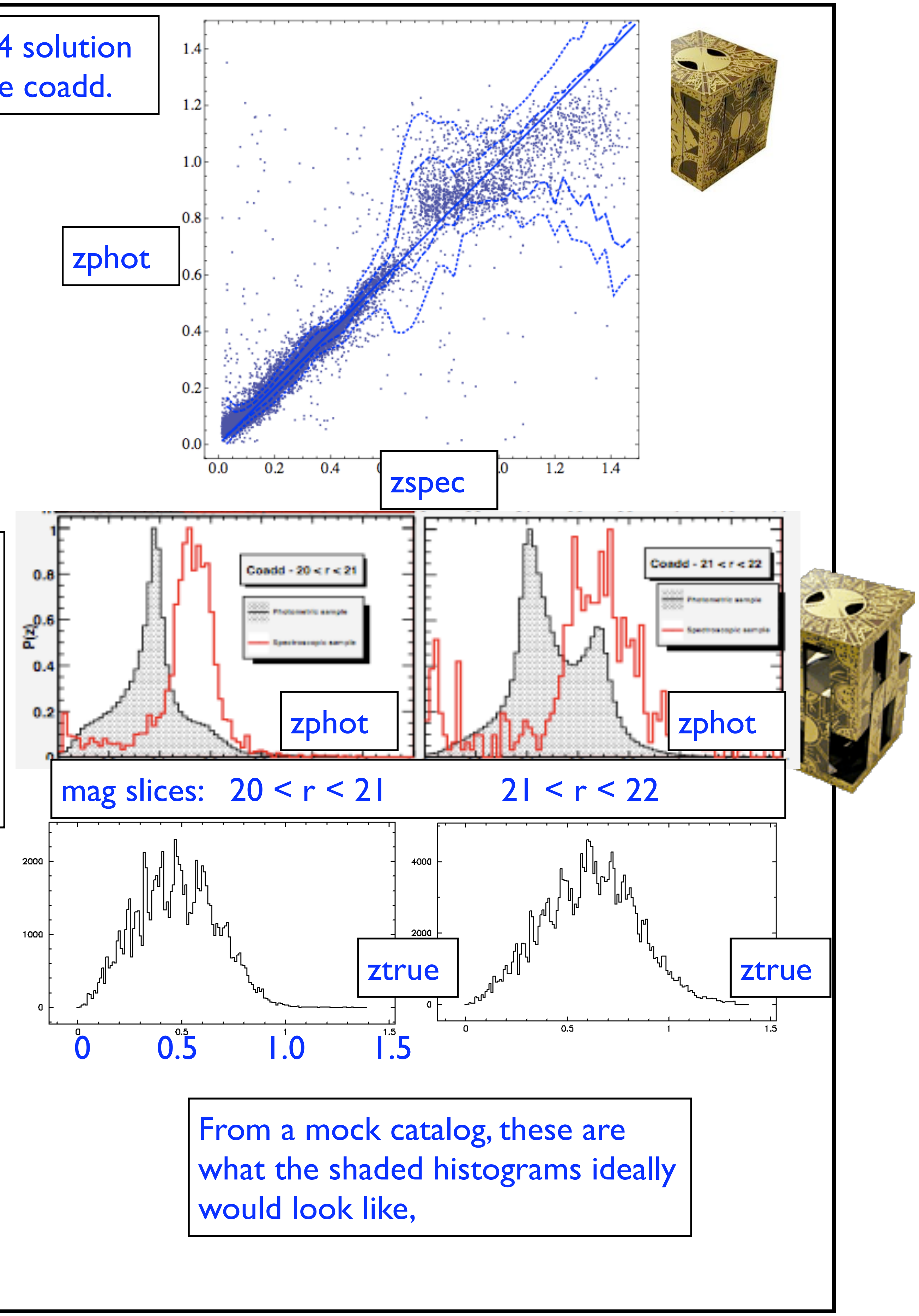


Marcelle Soares-Santos et al 2010

Photometric redshifts

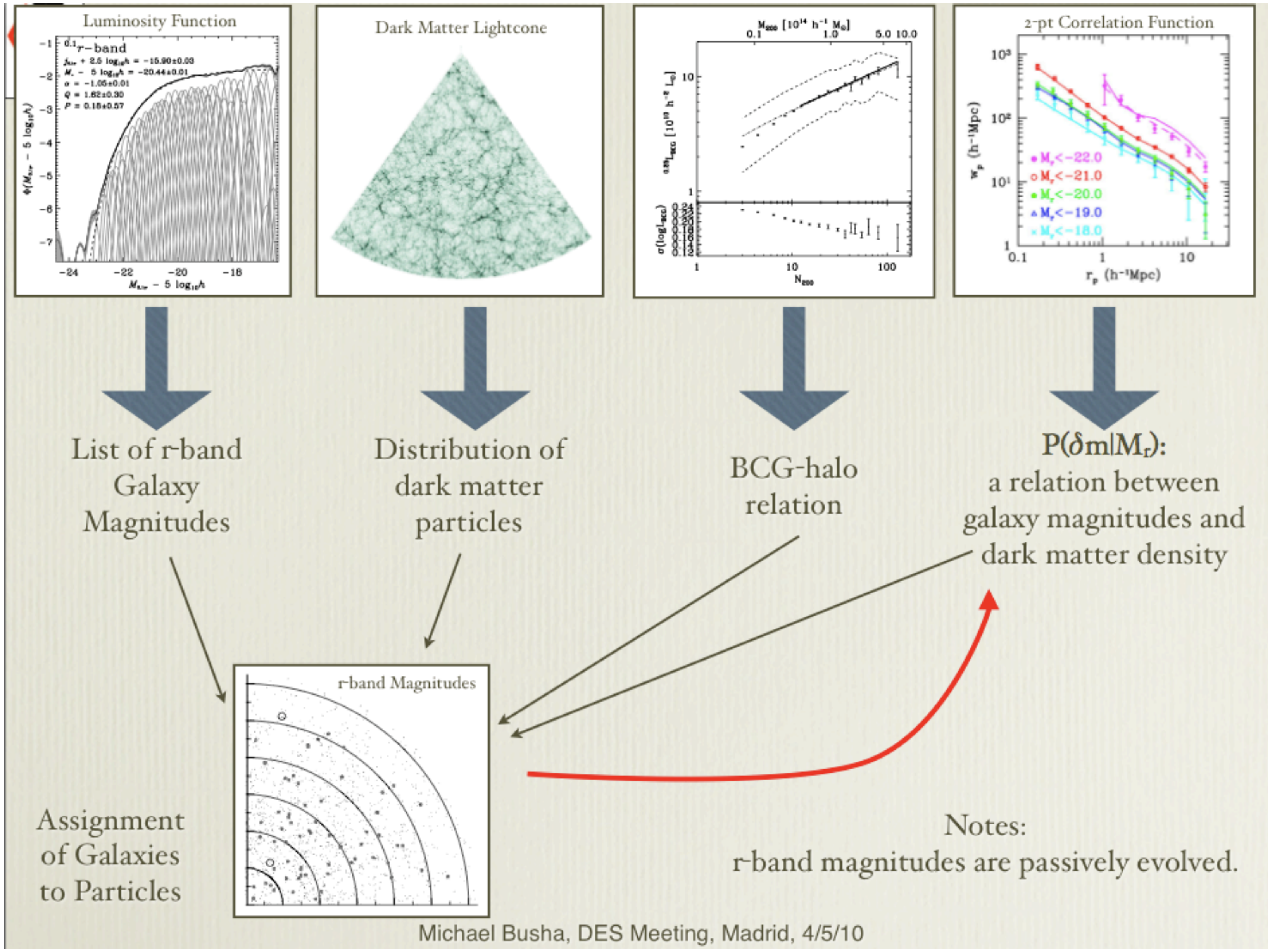
1. Most recent cluster finders, alas, use photometric redshift catalogs as the base for cluster finding. The only problem with this is using photozs.
2. Our case in point is the the SDSS Coadd, where we have 7(!) training samples:
   - SDSS DR7
   - CNOC2
   - DEEP2
   - SDSS-3/BOSS
   - WiggleZ
   - 2SLAQ
   - VVDS
3. The solution looks good, but the training samples do not cover all of the magnitude and color space. Biases show in the magnitude sliced z histograms
   - one solution- only use photo-zs for objects which there are good training sets - Cunha et al 2009
   - BCG photo-zs have the advantage that the target population is the training population. (GMMBCG)
   - Or, go back to pure color methods (maxBCG)

Red is training sample in the mag slice. Shaded is the photo-z catalog in the slice.
The way to read this is that the galaxies of this color slice exhibit degenerate with one or two redshifts.



Ribamar Reis et al in preparation

ADDGals



In order to make progress on connecting clusters of galaxies found in imaging surveys to the underlying dark matter halos we need simulations. Thus ADDGals on cosmological n-body simulations.

Risa Weschler was on the first DES proposal in 2004. ADDGals mocks are central to our work.

Michael Busha has our mock catalogs are up to version v2.13. Sarah Hansen recently worked up a mock catalog valdiation pipeline... because errors creep in.

Cluster Comparison

1. We have at least 8 cluster finders in the DES. Evaluating them turns out to be the problem of evaluating the selection function.

maxBcg	Koester
GMMBCG	Hao
VTT2+1	Soares-Santos
VTT red sequence	Barkhouse
C4	Baruah
FoF	Farrens
Matched Filter	Ogando
WAZP	Benoist

2. Decouple photo-z, richness, and members list from the cluster finder.
   - we run standard richness/members finder
   - use rank instead of richness/mass

3. Run finders on the mocks, compare clusters with halos
   - membership matching of halos and clusters

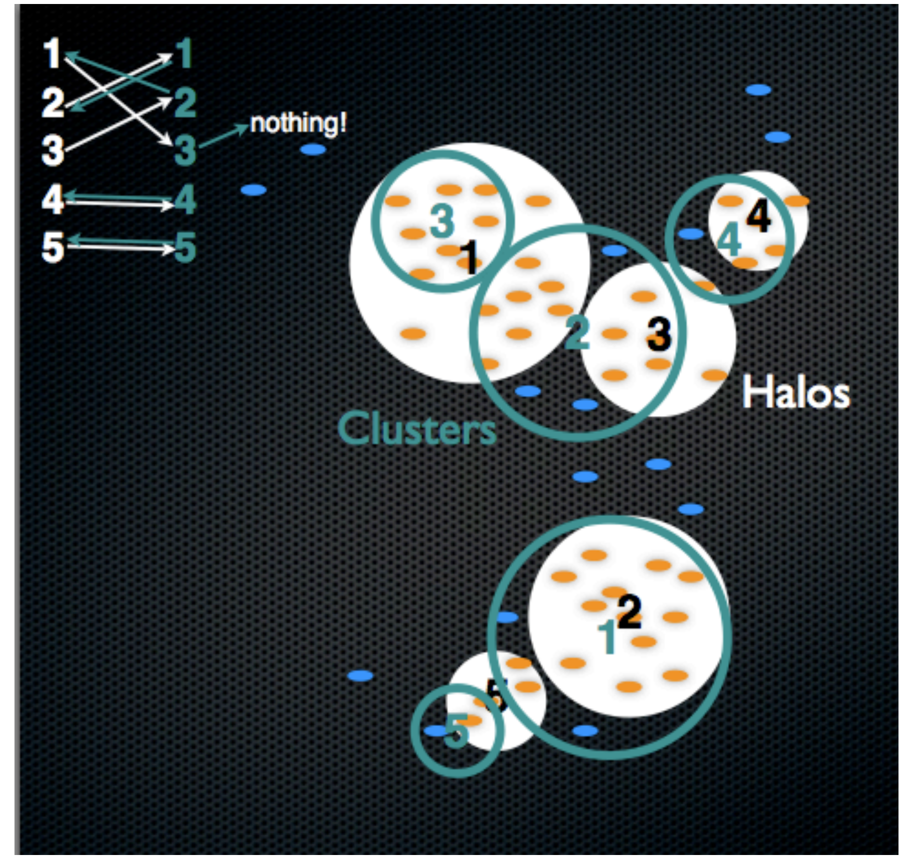
   proximity matching- inside a space/z cylinder

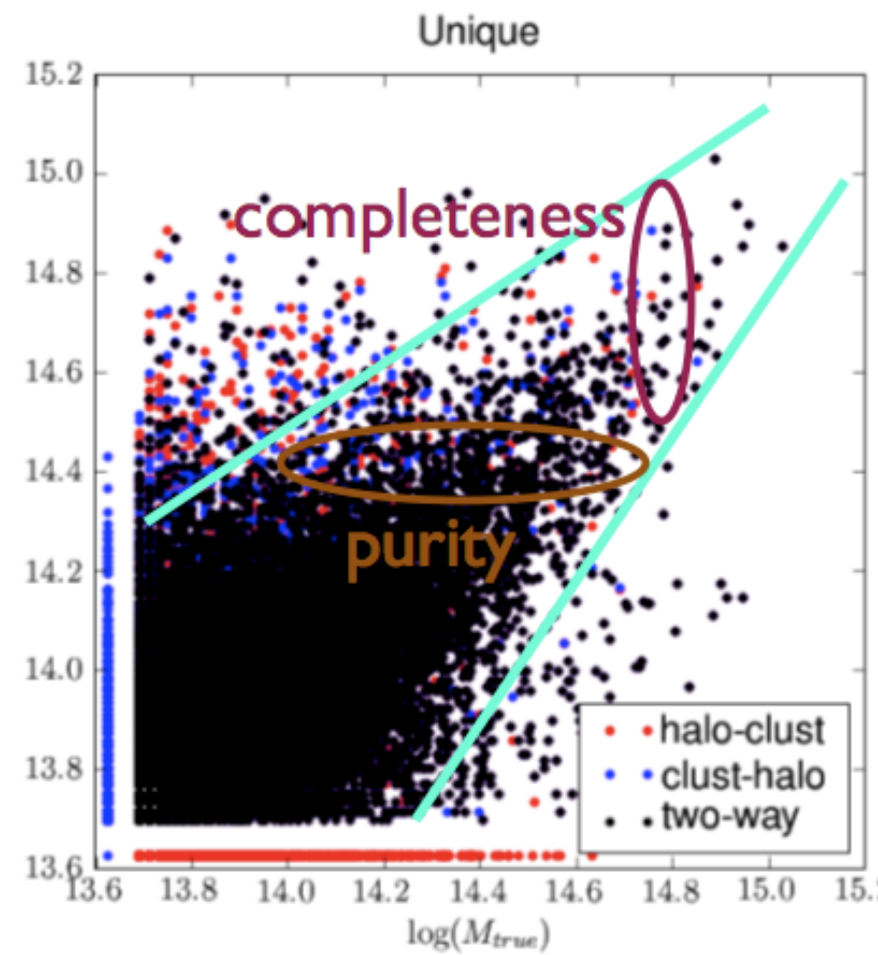
   membership matching- match halo and cluster membership lists. Two-way matching demands the halo matches to the cluster and the cluster to the halo.

4. Calculate purity and completeness

$$N_{clust}(M_{obs}, z) = \int N_{halo}(M_{true}, z) P(M_{obs}|M_{true}) \frac{c(M_{true}, z)}{p(M_{obs}, z)} dM_{obs}$$

observable cosmology scatter selection function

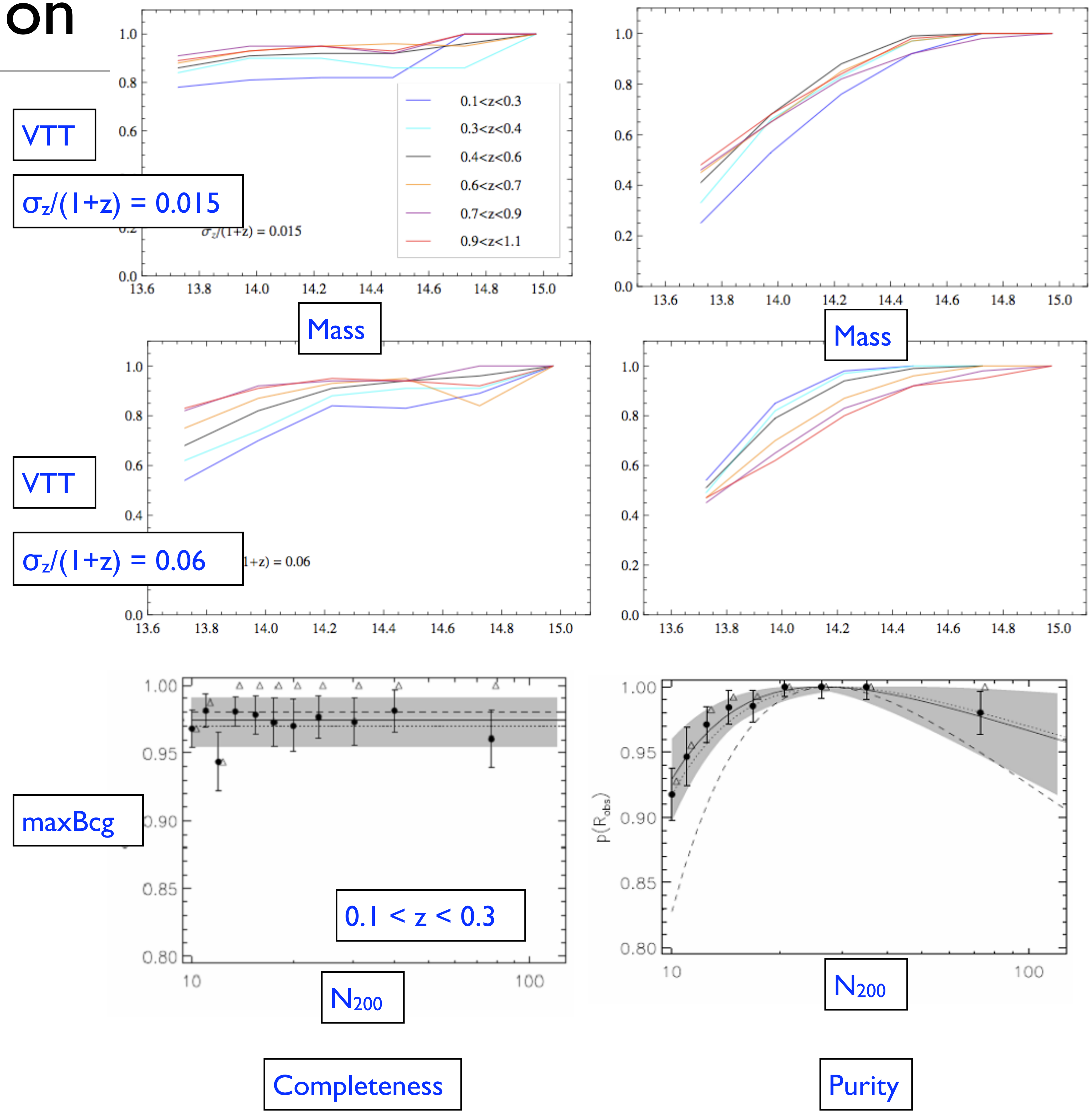




Brian Gerke, SLAC

Selection Function

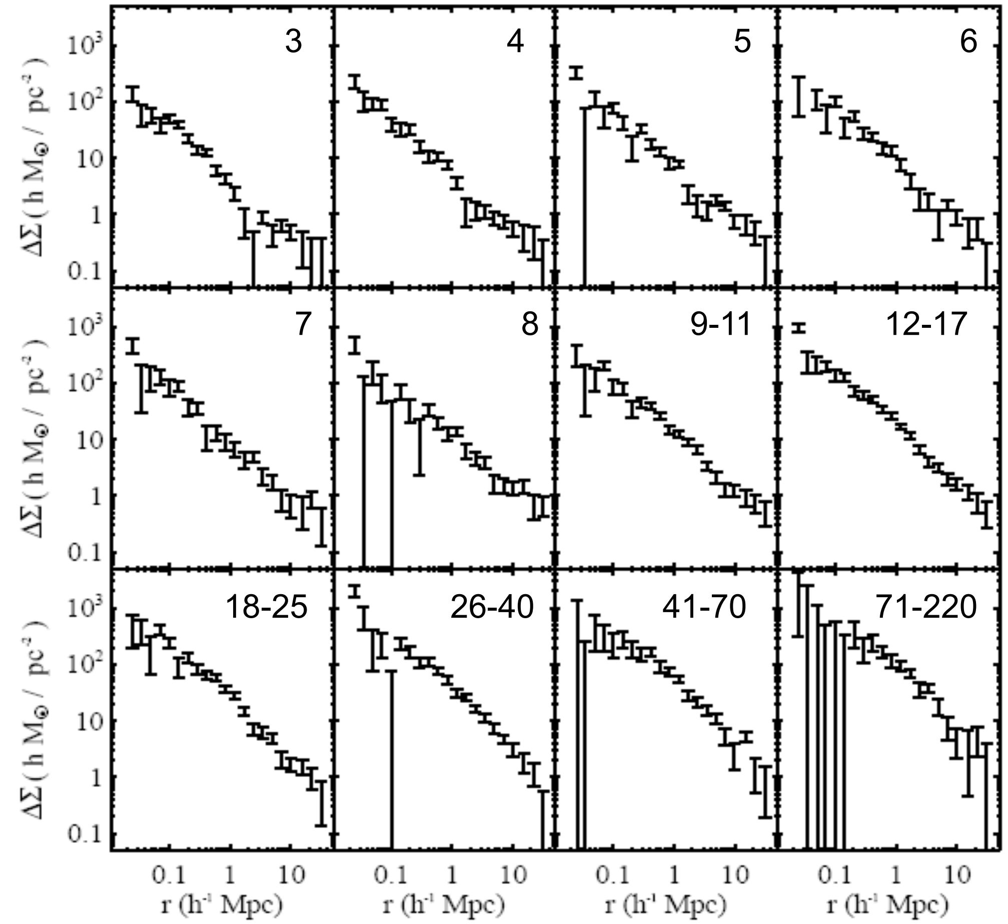
1. Unique, two way matches.
2. VTT has ~90% completeness at z>0.4 if very good photo-zs available.
   - this is probably close to a red sequence finder
3. Purity is a formal lower limit-
   - VTT uses all galaxies available
   - ADDGals doesn't use halo catalog to put in galaxies
   - there is a lower mass cut to the halo catalog, but the galaxies of halos less then this are emplaced.
4. Compare with the red sequence finder maxBCG (Rozo et al 2007).



Stacked Weak Lensing

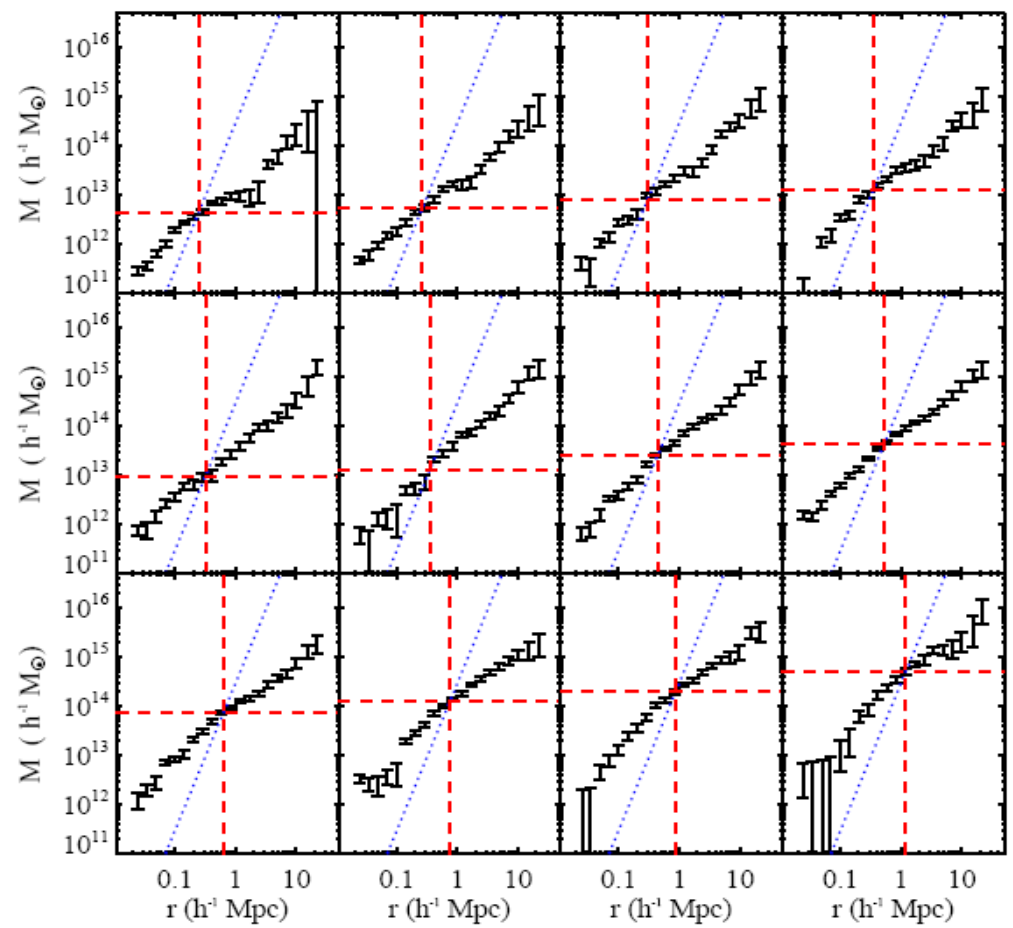
1. The cluster-mass correlation function can be measured with high precision in bins of N_{200} for the maxBCG catalog (Sheldon et al 2007)
   - note the profile for N200 = 3 is as good as for N200 = 18-25. or 41-71.

$$\Sigma_{crit}\gamma_t = \bar{\Sigma}(< R) - \bar{\Sigma}(R) = \Delta\Sigma(R)$$



2. Lensing signals can be deprojected to obtain 3D mass (Johnston et al 2007a)
   - developed and tested on n-body simulations
   - works precisely on stacked halos: spherical symmetry imposed by isotropy and statistics
   - cluster selection may be biased towards objects aligned along line of sight.

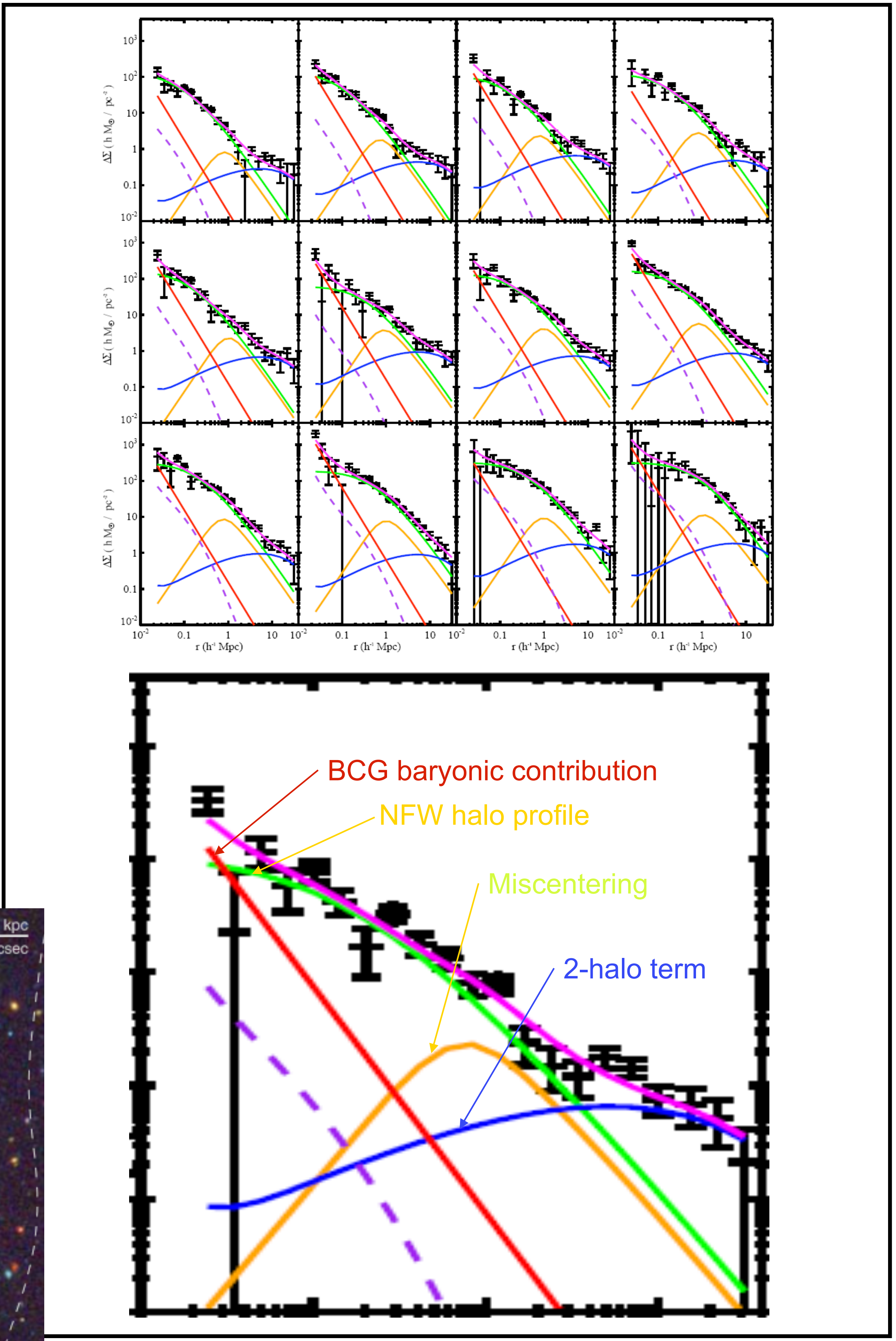
3. Inverted mass profiles M(r) can then be constructed. (Johnston et al 2007b)
   - An integral of the data, smoothing and correlating data points
   - r_{200} is radius at which $\rho(<R) = 200\ \rho_{crit}$
   - These profiles are total mass, not cluster mass.



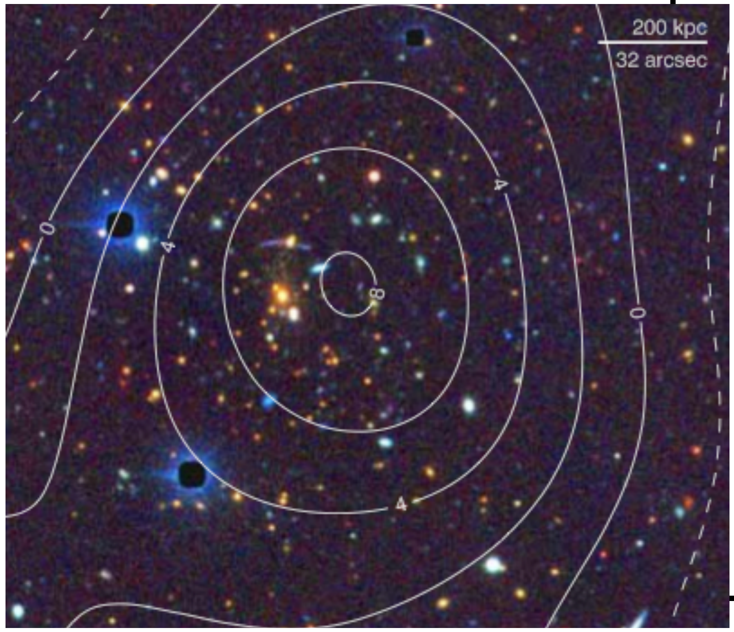
Courtesy of Tim Mckay

Mass Model

1. The total mass profile must be modeled to measure the halo mass. (Johnston et al 2007b)
2. There are four components to the mass distribution
   - NFW for the stacked cluster
   - The BCG baryonic signal
   - Miscentering: ~70% correct, ~30% poorly centered, modeled as a gaussian distribution
   - Cluster clustering: the two halo term
3. Dominant uncertainty is likely the miscentering term (not the photo-zs!)



Some fraction is just picking the wrong BCG (~0.5-1Mpc). Some other fraction is physics: what observable marks the center of a DM halo? The BCG? The SZ peak? A strong lens? This picture is of SPT-CL J2331-5051 (High et al 2010), showing SZ contours, the BCG, and a strong lens, the latter two of which are offset from the SPT center by 100kpc.



Stacked Velocity Dispersions

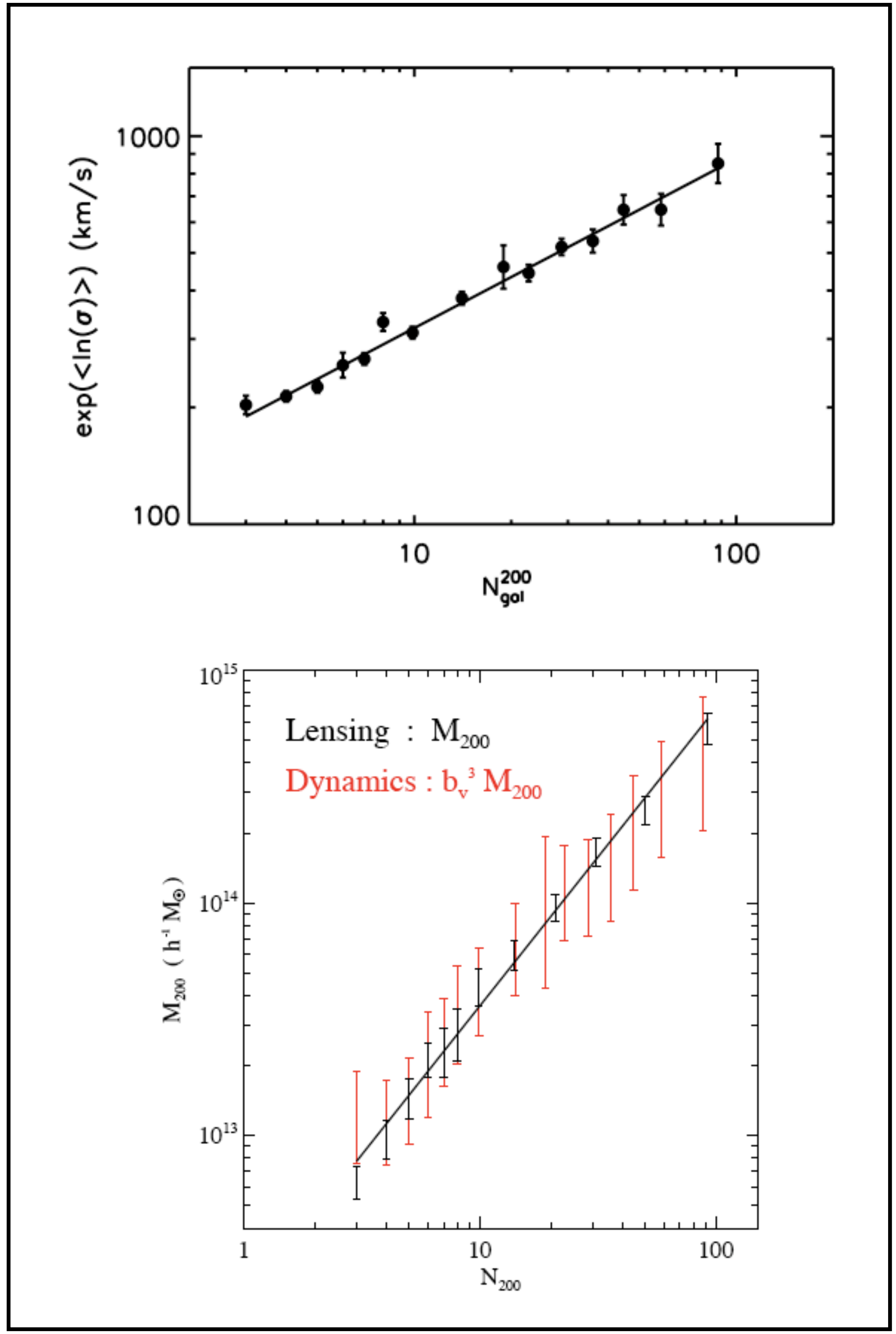
1. The BCG- galaxy velocity correlation function can be measured on maxBcg clusters in bins of N_{200} using SDSS redshifts. (Becker et al 2007)

2. The non-Gaussianity of the stacked velocity dispersions can be used to measure the scatter in velocity dispersion at fixed richness.

3. The σ can be converted to mass using the Evrard et al (2007) relation between halo mass and σ.

4. Miscentering (choosing the wrong BCG and/or the peculiar velocity of the BCG wrt the halo) produces a velocity bias. The error bars reflect the uncertainty in this correction.

5. The masses measured this way agree remarkably well with that from WL.
   - There a other ways to check calibration: T_x from the XMM survey of Kath Romer et al, for example. SPT SZ measures. eRosita when it flies.

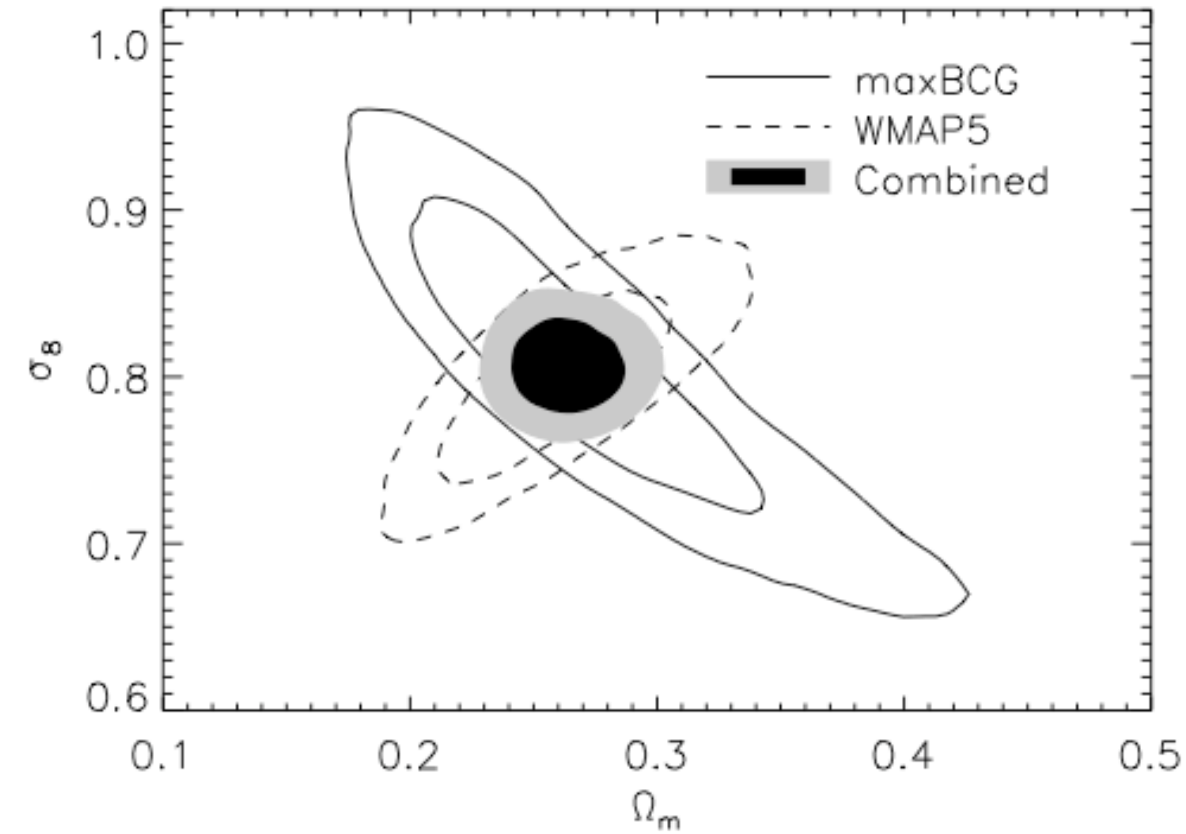


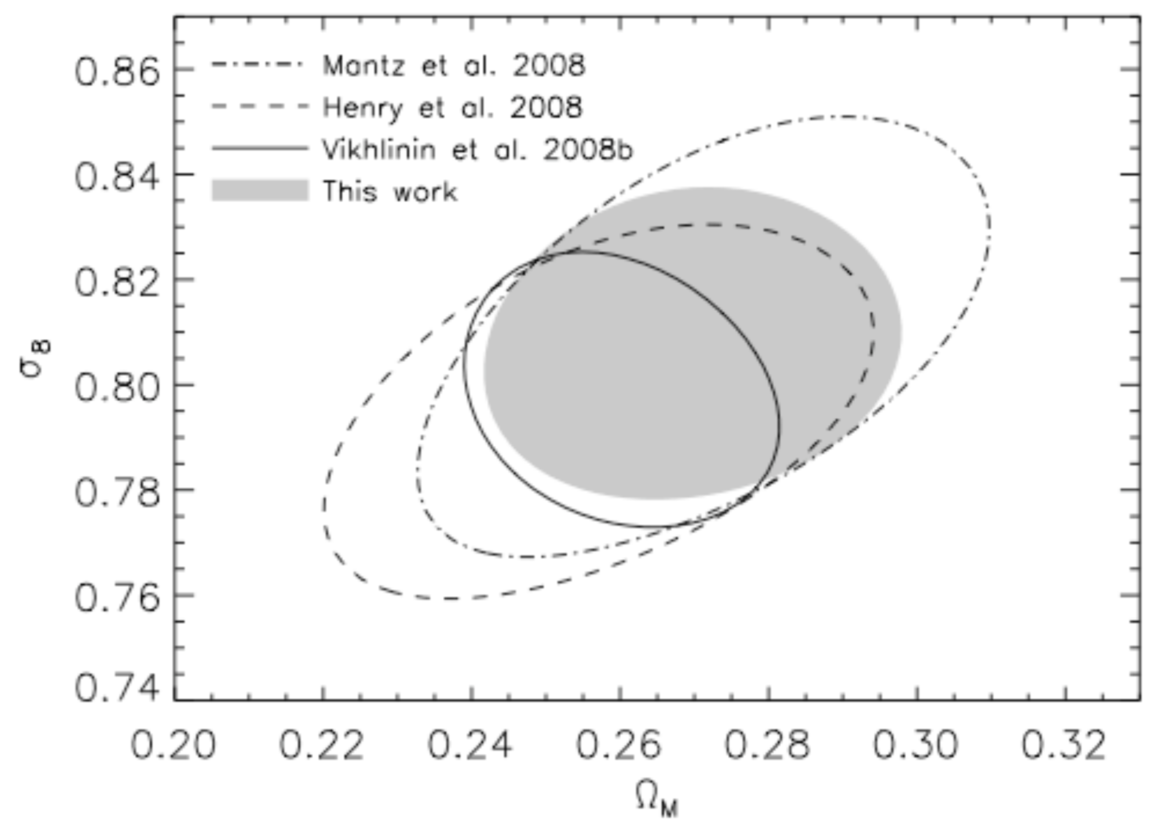
b_v is the velocity bias $\sigma_{gals}/\sigma_{dm}$

The σ_8-Ω_m Plane

1. Rozo et al 2009 ran a cosmological constraints from the maxBCG catalog.
2. The likelihood fit cosmology jointly for the cluster number counts and the cluster-mass correlation function.
3. Assuming a flat ΛCDM cosmology, the analysis gave $\sigma_8(\Omega_m/0.25)^{0.41} = 0.832 \pm 0.033$
4. The errors were dominated by systematics, and the two biggest contributers were the absolute mass scale of the weak lensing masses of the maxBCG clusters, and uncertainty in the scatter of the richness-mass relation.
5. There is agreement between the x-ray and optical cluster measurements of σ_8, despite the quite different systematics.

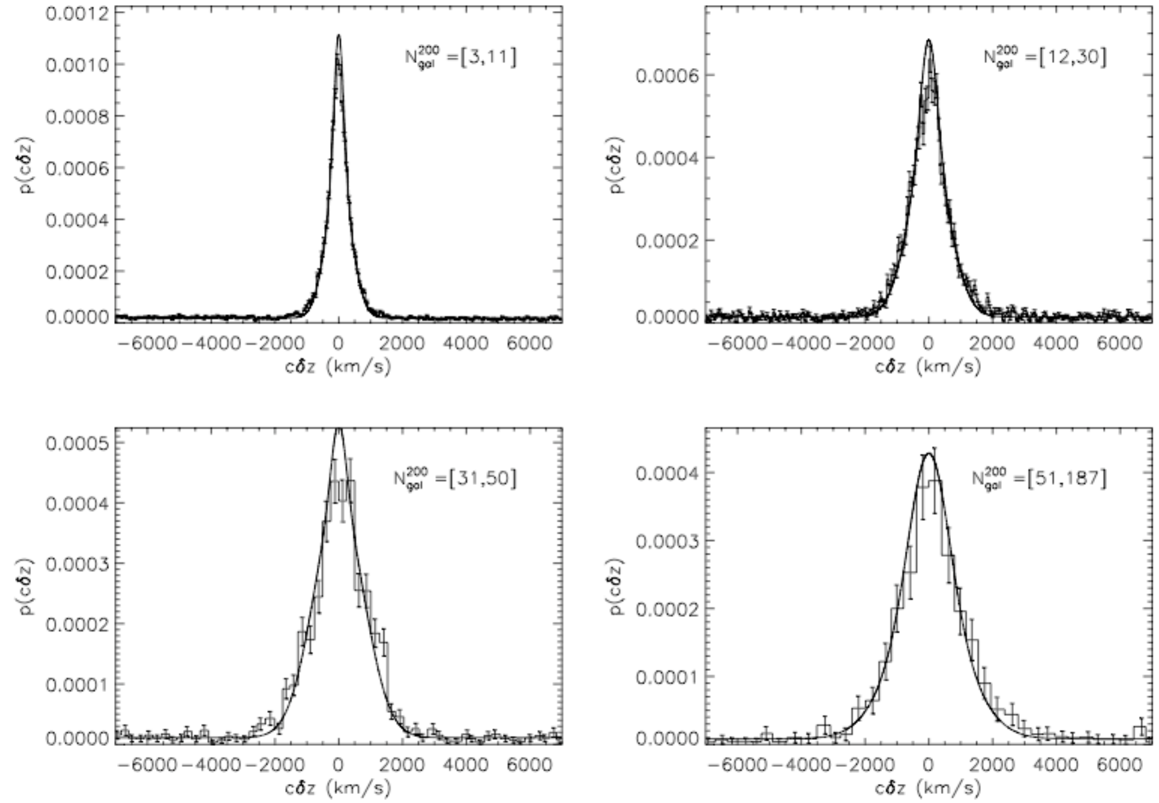
For the current DES mainline likelihood thinking, watch Carlos' talk

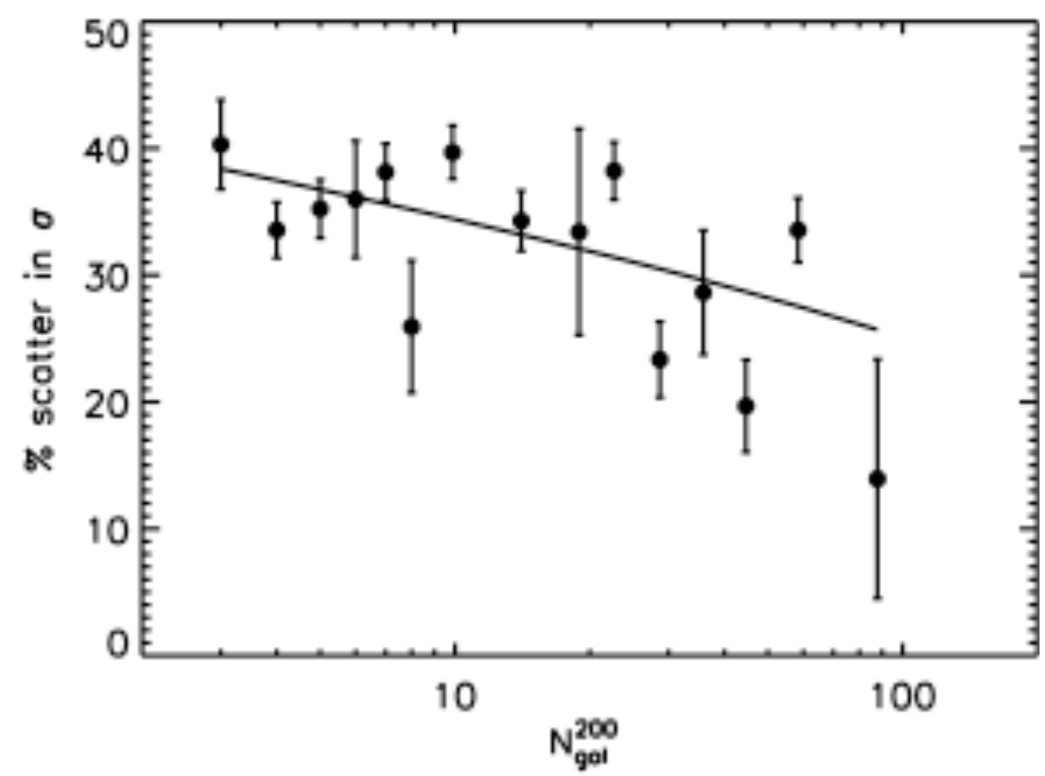




Scatter in Mass-Observable

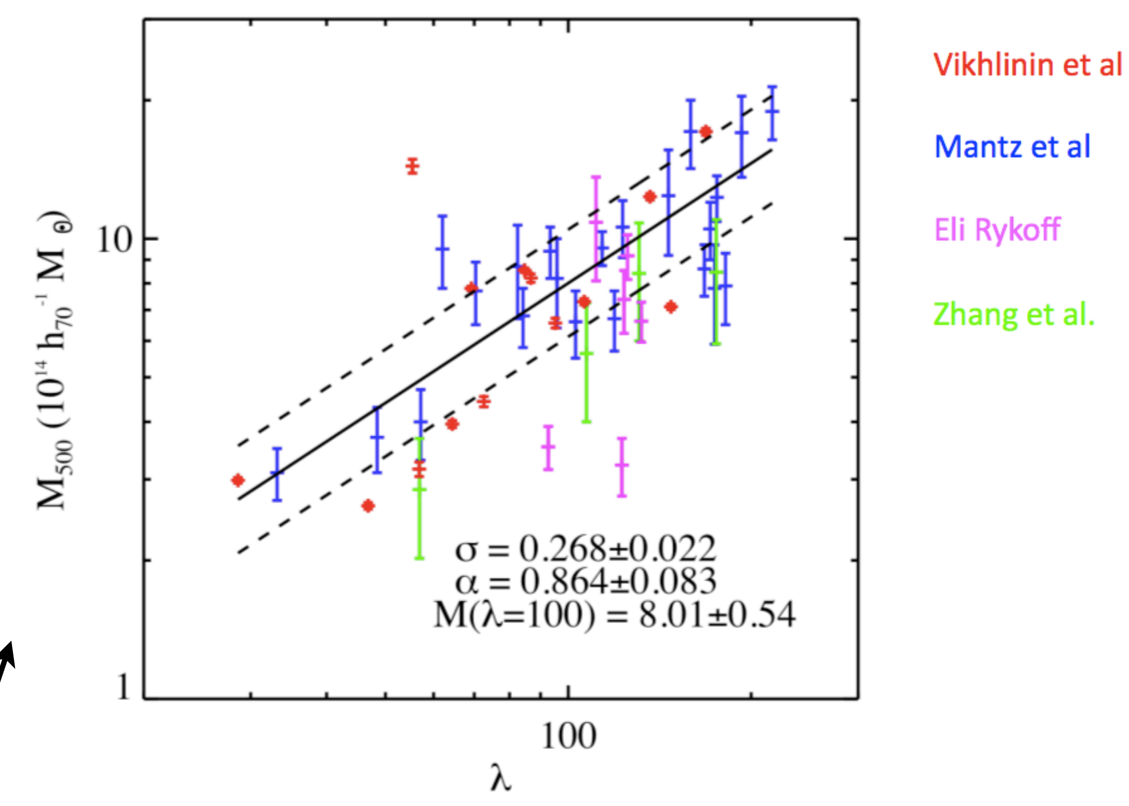
1. Rozo et all defined scatter as the standard deviation of ln N_{200} at fixed M, and assumed it log normal:
   - $\sigma^2_{N200\,|M} = 0.45 \pm 0.10$
   - this was constrained from Lx-N (Rozo et al 2008)
2. Becker et al (2007) measure Std(lnσ) from the non-Gaussianity of the stacked velocity dispersions
   - assuming that the underlying σ-M relation was Gaussian and the non-Gaussianity came from N_{200} -M having scatter.
3. There are observational ways at getting at this.
   - stacked velocity dispersion
   - My from x-ray
   - My from SZ measurements
4. Thus interest in non-DES followup
   - and in ways of optimizing that against cost: Hu, Wechsler, Rozo 2010.
   - leave correlation function and mass function shape to help constrain cosmology

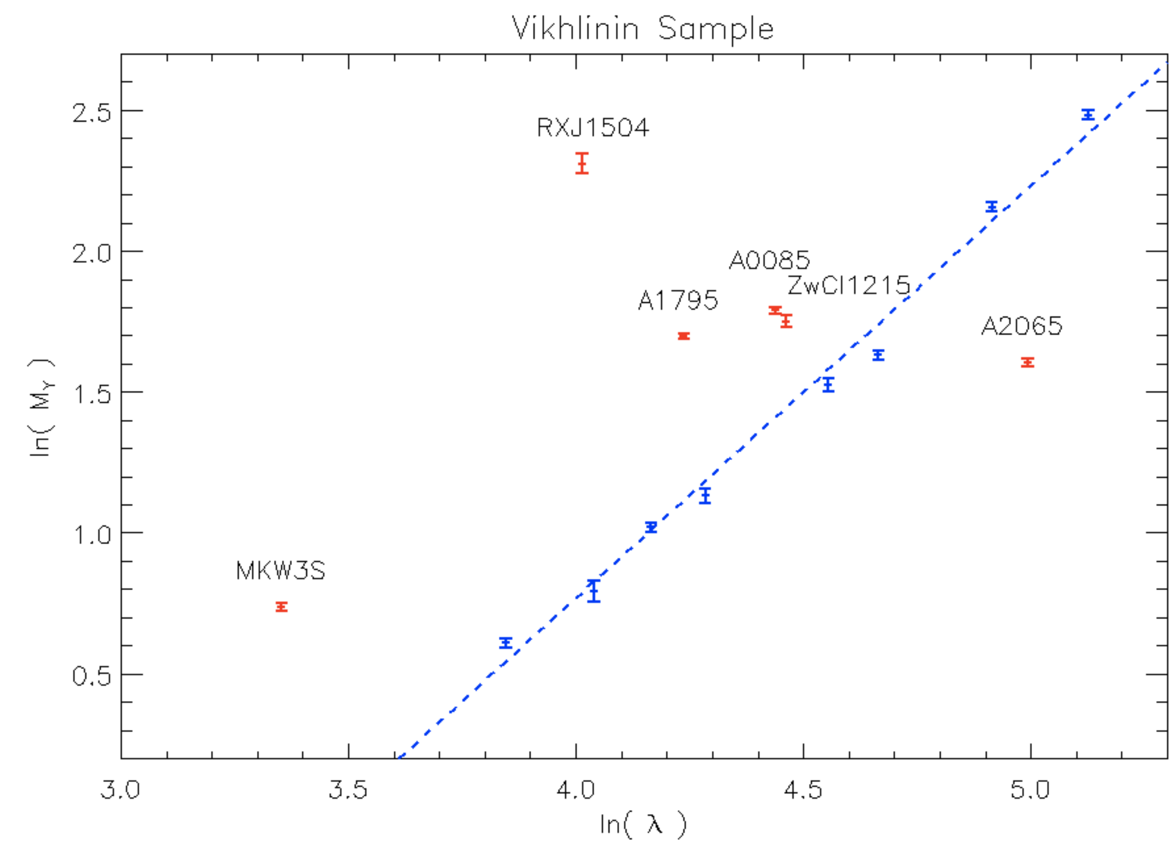




Lambda Postburner

1. One can always improve a richness estimate, and run this on the centers and zs provided by cluster finders.
2. Lambda is a improvement over the "improved richness estimator" of Rozo et al 2008, again optimized using the scatter in the Rosat Lx-N relation.
   - ie., optimized for 0.1 < z< 0.3
3. Lambda (new_20_100)
   - NFW radial profile weighting
   - red sequence weighting
   - 0.2 L* (only tophat left)
4. We compared it with a set of good M_{500} measured in the x-ray.
   - use x-ray centers, and spectroscopic z
   - $\sigma = 0.27 \pm 0.022$
   - scatter is getting smaller!
5. At z < 0.1, the Vikhlinin hydrostatic equilibrium masses, control sample, the scatter is very small, and looks like physics.





Dave Johnston, Eli Rykoff, Eduardo Rozo

Blind Cosmology Challange

1. We adopt the high energy physics model of
   - learning how to do the analysis on simulations before the data
   - optimizing the analysis on data sets/simulations for which the answer is known but hidden
2. Stages
   - Initially one semi-blind cosmology (somewhere within LCDM+WMAP5 priors).
   - Next year, 2 or 3 cosmologies, cosmology kept hidden (Evrard and Kravtsov)
     1. Gadget-2 N-body runs on Teragrid
     2. 4 runs/cosmology at 1.0 to 6.0 Gpc/h volumes
     3. radially segmented light-cones, => z-dependent mass limits similar to apparent magnitude limit
   - Longer run, ~10 cosmologies
     1. other sources for N-bodies?: MICE, LANL, Las Damas...
     2. non-dark energy models?
3. Data sets:
   - light cones run through FOF and SUBFIND halo finders
   - ADDGals produces galaxy catalogs consistent with light cones (Wechsler and Busha)
     1. full survey area, $z < \sim 4$, $m_i < 24$, 1 and 5 year survey photometric errors
   - light ray tracing code run on light cone to produce shears on galaxies (Becker)
   - survey mask added to galaxy catalogs
4. Science working groups
   - Large Scale Structure
   - Weak Lensing
   - and of course, Clusters will run to measure the cosmology

We want these, the true blind analyses, to be done before first light next October.

Which mean the members of these have real work to do!