Outline

- What can clusters do?
- Advantages of using clusters to probe growth of structure
- Systematics
  - WL mass calibration
  - Galaxy colors + photo-z biases
  - Cluster centering
- Modeling uncertainties
What Can Clusters Do?

- Excellent probes of Growth of Structure
- Clusters can falsify DE + GR

Example: Growth predicted by BAO+SN+CMB

Mortonson et al. (2009, 2010)

Cluster predictions:
Mortonson et al. (2011)

WL predictions:
Vanderveld et al. (2012)

$\Lambda\text{CDM}$

quintessence

(68 / 95% CL)

Mortonson et al. (2009, 2010)

cluster predictions: Mortonson et al. (2011)

WL predictions: Vanderveld et al. (2012)
How Does it Work?

• Measure abundance function as function of mass and redshift
• Compare to geometric probes (SN, BAO, etc.)
• Voila!

• If only life were so easy...
Cluster Advantages

- Very massive ("the most massive gravitationally bound structures in the Universe")
- Majority of signal comes from relatively low-mass clusters
- Rich in galaxies and observables
  - Optical galaxy counting + precise photo-zs
  - Spectroscopy
  - WL shear of background galaxies
  - X-ray measurements
  - SZ detections
Cluster Systematics

• #1: Mass Measurements
  • Require 2% mass precision for Stage IV for 0.9% precision in $\sigma_8$
  • Can WL shear-based masses achieve this?
    • Shear biases (easier than cosmic shear)
    • Photo-z biases in background galaxies
  • Spectroscopic cross-correlation helps
• Note that currently ~7% mass calibration is achieved, but 20% offsets between different analyses!
Optical Systematics

- But that’s not all...
- How do you measure galaxy colors?
  - This is not a settled question
  - Bright galaxies/faint galaxies
  - Color gradients
  - Different seeing in different bands
    - Kolmogorov \((\text{FWHM} \sim \lambda^{-0.2})\)
    - Bands taken in dark/bright time will be correlated based on obs. time
  - 1% relative photometry yes...how far down can we push this?
- Extensive LSST sim work
SDSS Relative Colors

\[(g-r) - (r-i), \; 0.1 < z < 0.3\]
SDSS Relative Colors

\[<r-i> - <i-z>, 0.4 < z < 0.6\]
Optical Systematics

- Galactic Reddening
- An incorrect reddening law creates photo-z biases (significant in SDSS!)
- Uncertainties in the amplitude of the reddening correction may wash out faint signals (Cunha+2013)
- Do we require full spectroscopic coverage?
Optical Systematics

- Cluster Centering (optical + SZ clusters)
- WL mass measurements require tangential shear around a center
- Where is the halo center? What about merging systems?
- X-ray data can calibrate systematic
- Can it be controlled at the sub-percent level?
X-Ray

- Hydrostatic mass bias uncertainty
- 0%, 10%, 20%, 40% biases have all been claimed in the literature, via both theory and observations
- Other cross-calibration (Chandra vs XMM) issues are still present
- WL mass calibration helps
- X-ray masses remain the lowest scatter mass proxies (even if biased)
- Key part of any multi-wavelength cluster analysis
Modeling Systematics

• Analyses up to now have used a simple log-normal powerlaw model (w/ covariance) for all scaling relations
• Add in projection effects into model (near term)
• Is the shape of richness-mass relation truly log-normal? How does it evolve with redshift? What astrophysics impact this?
• High resolution X-ray studies