Large Scale Structure

Laura Parker
The History of the Universe
(in one slide!)

- **Big Bang**
- CMB
- Neutral HI
- First stars and galaxies optical and IR
- Today
Large Scale Structure

✦ Powerful probe of cosmology:
  ✦ early density fluctuations evolve into the galaxies we see
  ✦ weak lensing, SNe, BAO, redshift space distortions, clusters

✦ Clusters

✦ Gravity beyond GR

✦ Early Universe
  (see talk by Simon Foreman)
Growth of structure

Distribution of structure depends on amount of dark matter and dark energy (and properties of dark energy)

Tracers: weak lensing, clusters, redshift space distortions
Clusters

- Interesting for galaxy evolution (Ivana Damjinov)
- Cluster abundance $\rightarrow \sigma_8$
- Evolution in abundance $\rightarrow \Omega_m, w, \Omega_\Lambda$

**Challenges:** selection (purity/completeness), enough spec. z's at higher redshift, uncertainty in converting observables to mass (Lx, SZ, dynamics)

hard to reach precision of CMB and BAOs measurements
Redshift Space Distortions

\[ v_{obs} = Hr + v_{pec} \]

- “Fingers of God”
- Overdensity due to infall
- Due to cluster velocity dispersion

- “contaminate” other measurements relying on redshifts
- Strength of distortions is a probe of growth of structure
Weak Lensing Tomography

Constrains growth of structure directly
Use to distinguish cosmological constant from dynamic DE

Measure the correlation of galaxy shapes in redshift slices
Requirements: high quality deep and wide imaging, high quality redshifts, shear measurements from multiple telescopes help constrain systematics
Clustering: Baryon Acoustic Oscillations

- As the universe expands the scale of fluctuations from the early universe grows and is imprinted on the galaxy population.
- Should see peak in clustering on this scale (evolves with redshift) - sensitive to cosmology.

Illustration Credit: Zosia Rostomian (LBNL), SDSS-III, BOSS

Anderson et al. 2012

\[ \alpha = 1.016 \pm 0.017 \]
\[ \chi^2 = 30.53/39 \text{ dof} \]
Standard Candles - SNe

- Very luminous standardizable candles
- Large samples can constrain expansion history

- LSST will find enormous numbers
- WFIRST will have advantage of stability in photometry
- Systematics controlled by combining LSST+WFIRST++
- High resolution spectroscopy of host galaxies would help control systematics
Constraining Dark Energy

\[ P = w \rho \]

\[ w = w_0 + w_a (1 - a) \]

\[ a = 1/(a+z) \]

C11 & JLA: SNe

Betoule et al. 2014
Large Scale Structure Probes
Spec-z versus Photo-z

• Spec-z’s needed for calibration of photo-z’s
• Photo-z’s benefit from adding more wavebands (both at blue and red end)
• Spec-z’s are critical for studies of clusters, SNe purity

• Follow-up of large imaging surveys requires highly-multiplexed, wide-wavelength-coverage spectroscopy with moderate resolution
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Large Scale Structure Probes

Spec-z versus Photo-z

Sloan Digital Sky Survey

Courtesy: Peter Capak and Shoubaneh Hemmati
Upcoming*

* incredibly biased optical/near-IR view, also see talks to come on: CHIME, SKA, CCAT, CMB experiments
LSS studies: Exciting Opportunities for Canada

✦ Involved in many of the international projects

✦ Possible unique contributions

✦ CASTOR - blue filters significantly improve photometric redshifts, space-based resolution helps with object selection and de-blending (LSST), g-band lensing

✦ MSE - large aperture telescope necessary for spec z’s of faint targets, hugely multiplexed. Ideal for precise distances for BAOs at high z, z-space distortions, studies of clusters
Summary

• The study of LSS places important constraints on cosmology

• Each technique has its own systematics and we need to combine measurements from multiple probes and projects

• Many exciting projects on the horizon and the possibility for Canada to make important contributions