TESTING THE EXPANSION HISTORY OF THE UNIVERSE WITH THE GMT

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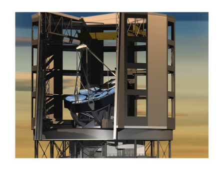
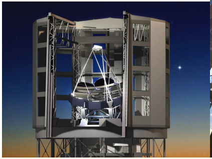
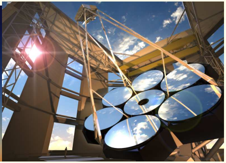
OUTLINE

1. Evolutionary history of the Universe
2. The role of the GMT
3. LSS as a cosmic standard ruler
4. Impact and future applications

BASED ON

- C. Park & Y. Kim (2010), ApJ Letter, 715, L185

STANDARD RULERS

GOALS

- Reconstruct the expansion history of the Universe
- Measure and constrain the basic cosmological parameters ($\Omega_M h, \Omega_\Lambda$, ...)
- Constrain the dark energy equation of state (i.e. w)

STANDARD METHODS → LS GALAXY DISTRIBUTION

- Two-point correlation function (for example Davis & Peebles 1983; Maddox et al. 1991)
- Power spectrum (for example Park et al. 1994; Tegmark et al. 2006; Percival et al. 2007)
- BAO features in CF and PS (Eisenstein et al. 2005)

A NEW APPROACH

- Topology of the LSS (Park & Kim 2010)

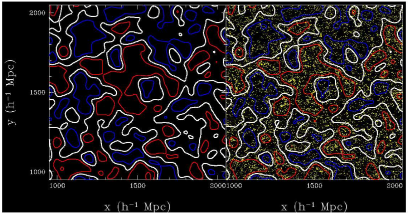
LSS TOPOLOGY AS A COSMIC STANDARD RULER

BASIC PROPERTY

Final-state web is present in embryonic form in the overdensity pattern of the initial fluctuations with NL dynamics just sharpening the image (Bond et al. 1996)

SPONGE TOPOLOGY (LARGE/QUASI-LINEAR SCALES)

All LS structures, including voids, maintain their initial (sponge) topology till the present (Park & Kim 2010)



LEFT Initial density field

RIGHT Matter density field at z=0

WHY LSS TOPOLOGY?

ADVANTAGES

- Less affected by observational systematics (redshift space distortions, galaxy biasing, nonlinear gravitational evolution)
- Intrinsic topology does not change as structure collapse, expand or deform without breaks
- Use the entire shape of the PS, not just the wiggles
- Easy to measure, and direct intuitive meaning

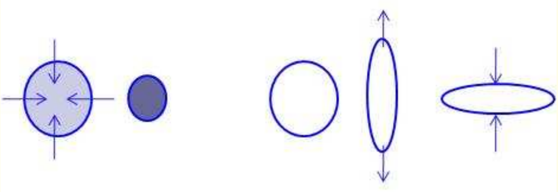


Figure courtesy of Changbom Park

What is the topology study for?

Science

- **Very large linear scales** → Constrain inflationary models
- **Small non-linear scales** → Galaxy formation and cosmological parameters
- **Large linear/quasi-linear scales** → Expansion history of the Universe

Measurements

- **3D** → (1) 3D genus (2) mean curvature (3) Contour surface area (4) Volume fraction
- **2D** → (1) 2D genus (2) Contour length (3) Area fraction
- **1D** → (1) Level crossings (2) Length fraction

GMT SCIENCE CASE

5 AREAS OF STUDY

- LSS of the Universe, distribution & nature of matter and energy
- Dawn of moder Universe, first stars and galaxies
- Formation & evolution of black holes
- Formation of stars & planets
- Impact of astronomical environment on Earth

THE ACCELERATING UNIVERSE

- Key to understanding DE is to study its evolutionary history over the full span of cosmic time
- So far many surveys below $z = 1$
- Need to push the redshift envelope to constrain DE models
- GMT is in a unique position to measure the evolution of DE at early times

GMT SCIENCE CASE

OBSERVATIONAL APPROACHES TO DE

- Baryonic acoustic oscillations
- Supernovae
- Follow-up to LISA sources

KEY ATTRIBUTES OF THE GMT

- Enormous collecting area
- High angular resolution and pupil geometry
- Increased sensitivity out to z=7 and up!
- Wide-field optical spectrograph
- Unique capabilities of the telescope and its instruments
- Spectroscopy of a $3 - 5 \times 10^5$ objects in $5.5 \leq z \leq 6.5$ over 50 sq. deg. to constrain the galaxy PS to $\sim 1\%$
- Strong, independent constraint on DE at the highest redshifts

BASIC PROPERTIES

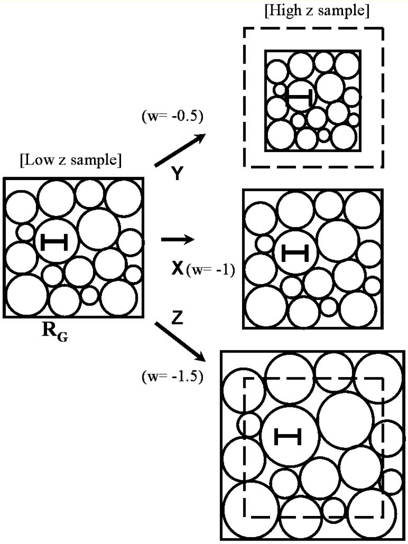
KEY TOPOLOGICAL FEATURES

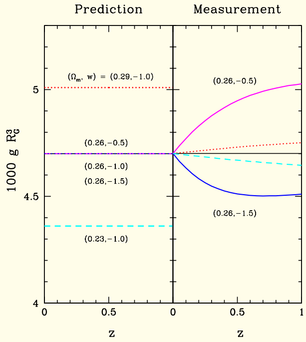
- LS structures in the quasi-linear regime (large scales) preserve their initial topology at all redshifts $\rightarrow$ cosmic 'sponge' is conserved in comoving space
- The topological quantity considered vs smoothing length relation is scale-dependent

MAIN IDEA

- X = reference cosmology
- Y = different cosmology
- Two effects to consider (1) Unit box (2) Smoothing
- Conserved quantity with wrong cosmology Y will contain less or more LSS than the true cosmology X per unit box, and the applied smoothing will be also different

THE BASIC IDEA → PARK & KIM (2010)

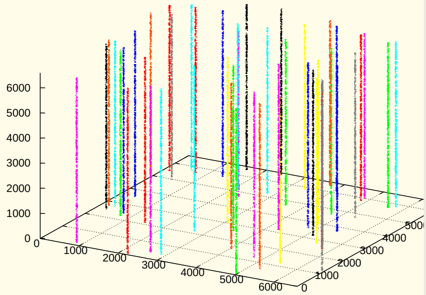




BASIC PROCEDURE

1. Consider a density realization in a reference cosmology – i.e. $\Omega_{\rm M}$, Ω_{Λ}, H_0 and $P^{\rm 3D}(k)$ – with known positions of particles.
2. Convert galaxy redshifts into comoving distances, assuming the reference cosmology
3. Bin and smooth the data in comoving space
4. Divide data in redshift intervals
5. Compute the conserved statistics in different redshift intervals
6. Select the cosmology which gives the same results for different redshift bins

Pencil beam surveys



The Horizon Run

- 6592 Mpc/h comoving size box
- Mean density of halos $3.05 \times 10^{-4} (h/Mpc)^3$
- Mimimum halo mass $1.33 \times 10^{13} M_\odot / h$
- 87,458,296 halos
- $\Omega_\mathrm{M} = 0.26$
  $\Omega_\Lambda = 0.74$
  $h = 0.72$
  $\Omega_\mathrm{b} = 0.044$

IMPORTANCE

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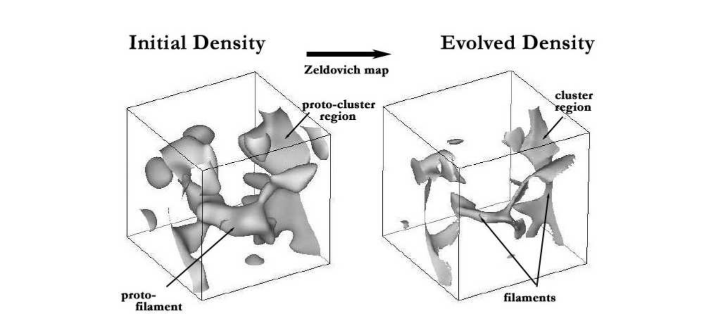
- Pattern of LSS is conserved in time and scale-dependent
- LSS topology is insensitive to linear and nonlinear systematics
- LSS topology has a direct and intuitive meaning
- Use LSS topology to constrain cosmological parameters and the DE EOS



Impact and the Future

Impact/Relevance

- Technique competitive with the standard BAO method, but less affected by observational artifacts
- Stringent constraints on DE EOS and on cosmological parameters
- Wide range of applications

Possible applications and studies

- Wiggle-Z, HETDEX, BOSS, GMT
- Effects on non-linearities
- Study of the reionization history

THANK YOU!

Kamsahamnida!

Komawoyo [very informal]