Topology of SDSS LRGs: Genus statistics and non-Gaussianity

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Non-Gaussianity From Large Scale Structures

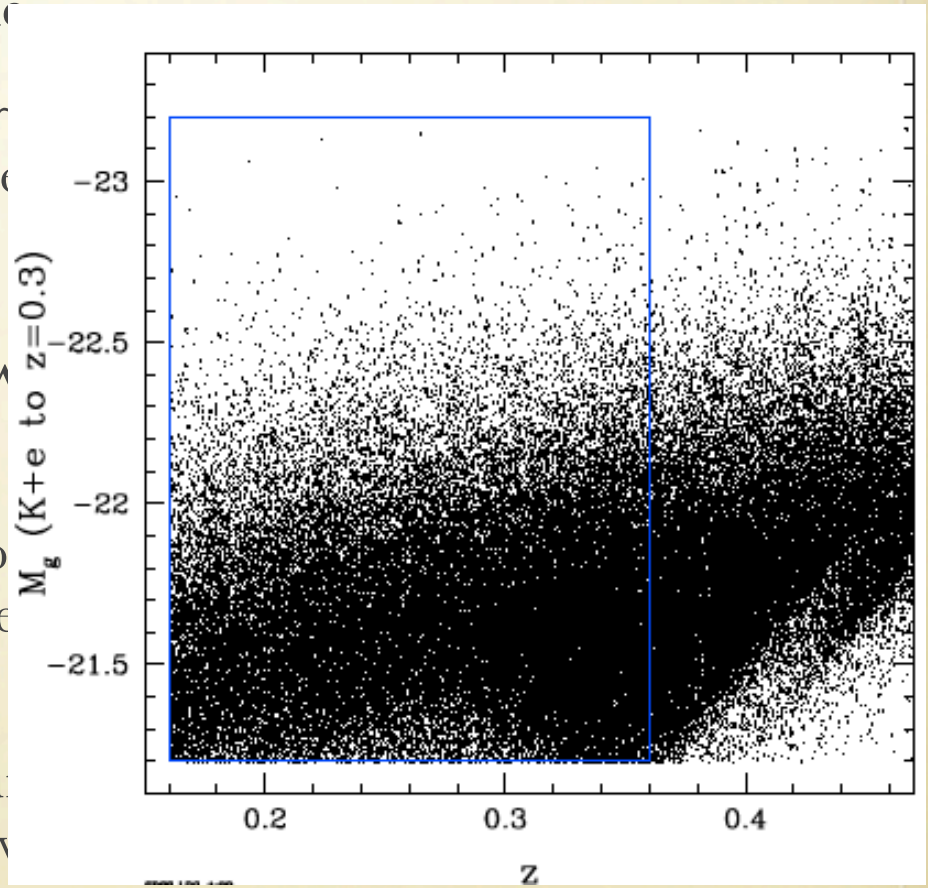
- LSS arose from primordial density fluctuations during inflation (Bardeen, Steinhardt & Turner 1983): the primordial field fluctuation is described statistically by a (*nearly*) *Gaussian* random field.
- Departure from the Gaussianity (Non-Gaussianity, NG) in the observed LSS:
  - NG in the initial density field: primordial NG
  - Non-linear gravitational evolution
  - Galaxy biasing
  - Shot noise, redshift-space distortion, survey mask, etc: *Young-Rae Kim*'s talk

Why study Topology?

- *Intuitive measurement*: the degree of connectivity of the smoothed matter distribution in the Universe.
- *Easy to measure*: Integration of local curvature of a surface is related with its topological ***genus***.
- *Known topology* for the Gaussian fields: a good NG measure.
- *Relatively insensitive* to non-linear gravitational evolution, redshift distortion, and galaxy biasing: topology is independent of monotonic deformation of shape.

Data - topology of LRG distribution

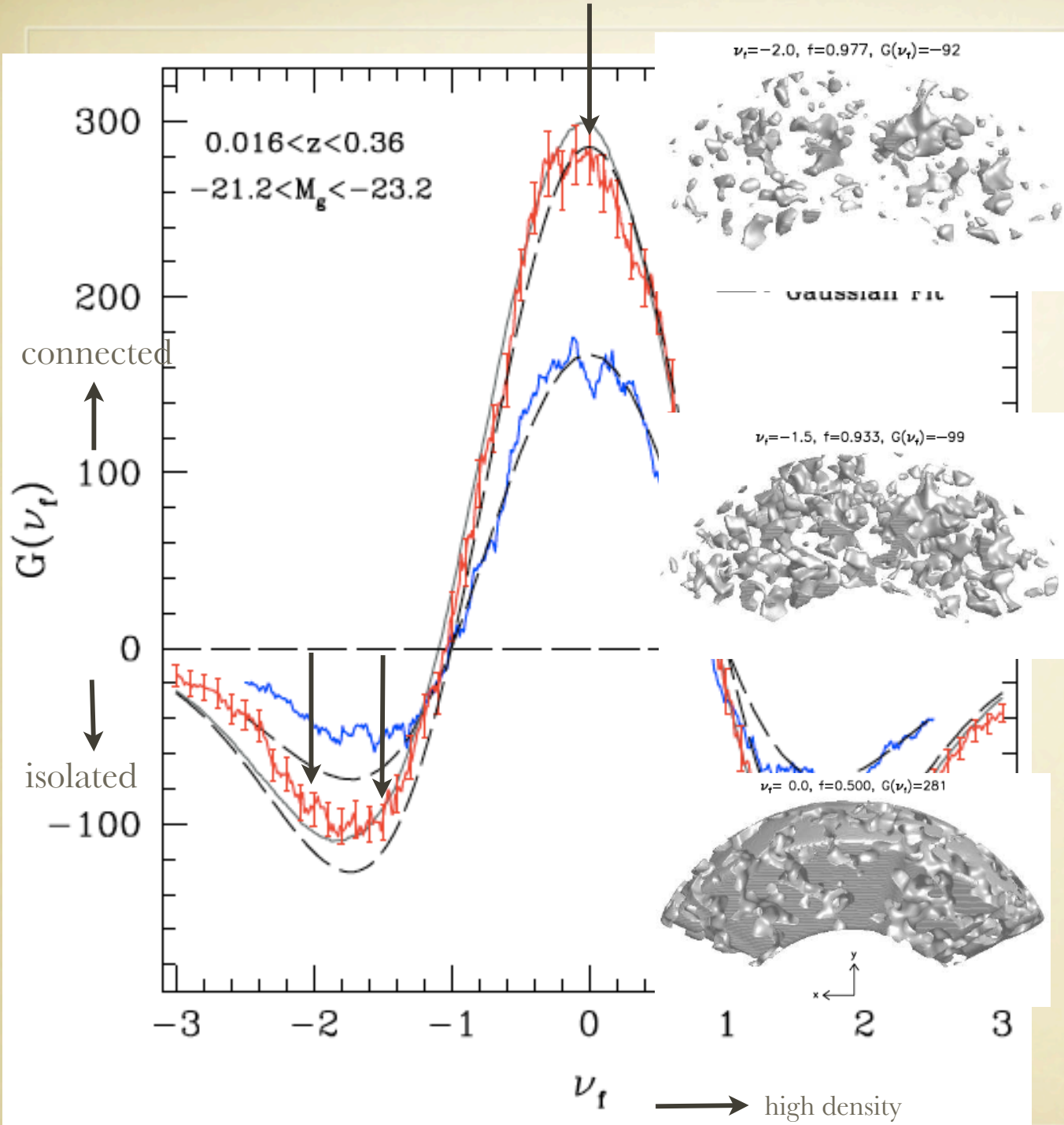
- SDSS DR7 spectroscopic LRG sampl
  - A volume-limited sample covering
    -21.2<M_g<-23.2, ~62k galaxies, m
- Mock LRG sample
  - Horizon Run 3 (initially Gaussian Λ
    particles, 10.815h^{-1}Gpc box): *Juhan*
  - Galaxy formation model: gravitatio
    Park, 2006) and subhalo abundance
    are identified as LRGs)
  - 81 mock samples from 27 all-sky su
    redshift-space, having nearly non-ov
    uncertainties due to cosmic variance.



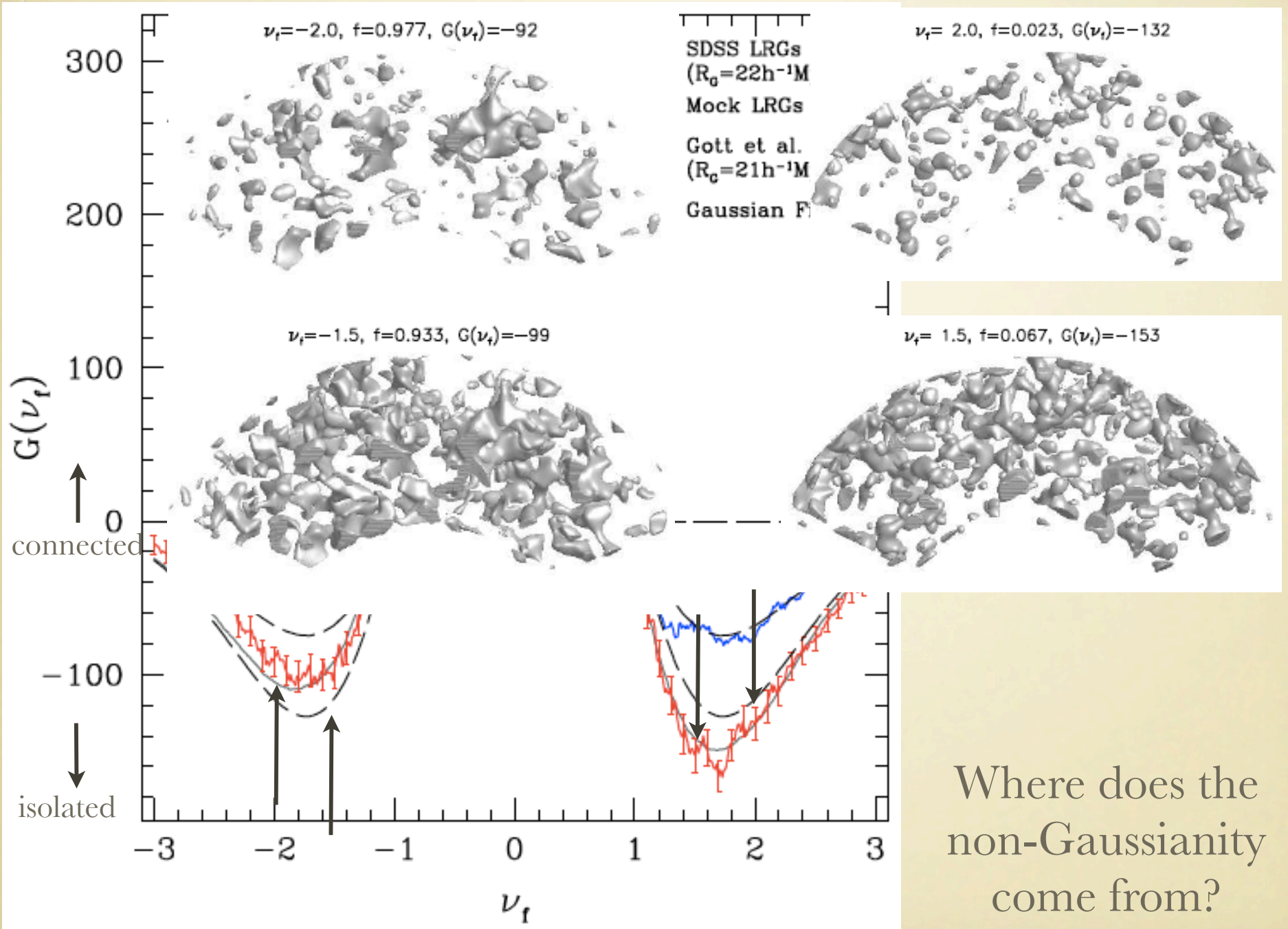
Topology measure: Genus

- A measure of the degree of connectivity of the smoothed galaxy density field.
- G = # of holes in iso-density contour surface - # of isolated regions (Gott et al. 1986, etc.)
- Gaussian field: $$G(\nu)=\frac{1}{(2\pi)^2}\left(\frac{\sigma_1}{\sqrt{3}\,\sigma_0}\right)^3 e^{-\nu^2/2}$$
- Non-Gaussian field: Perturbative formula for genus derived by Matsubara (1994, 2003)

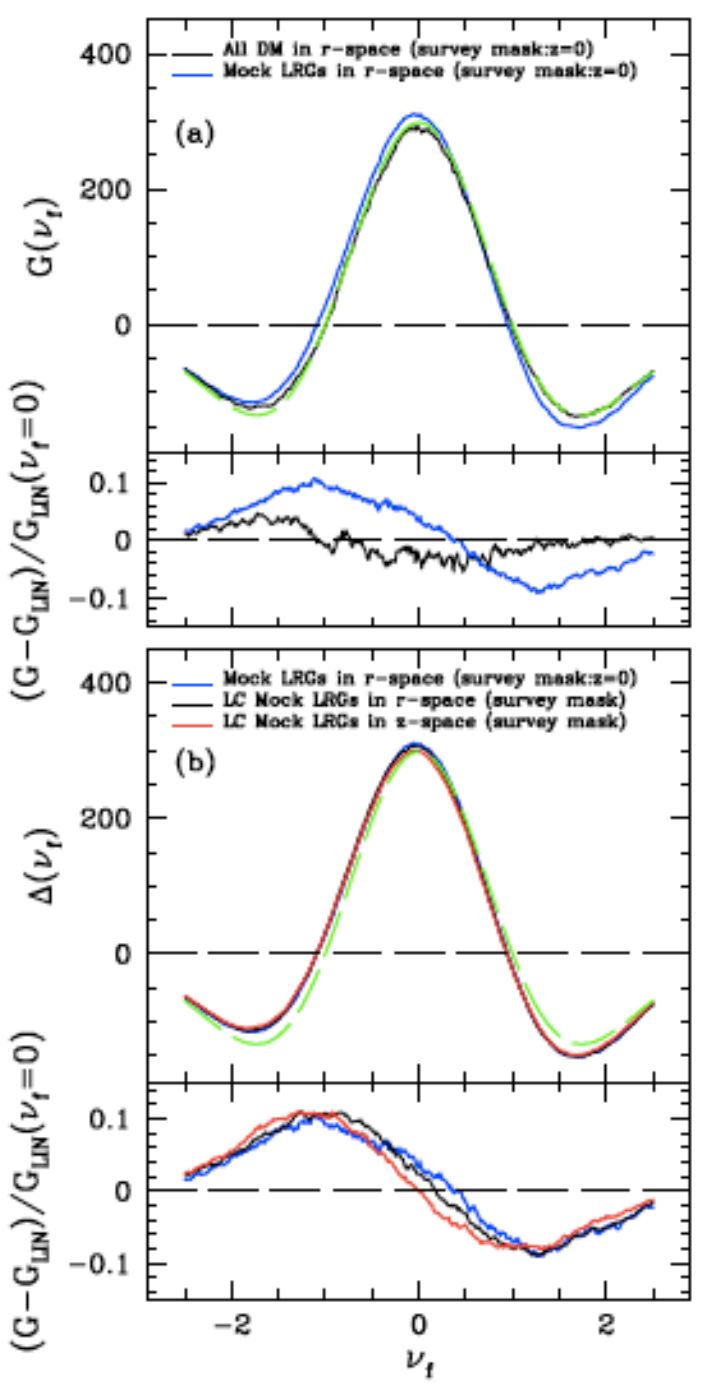
$$G(\nu)=\frac{1}{(2\pi)^2}\left(\frac{\sigma_1}{\sqrt{3}\,\sigma_0}\right)^3 e^{-\nu^2/2}\left(1-\nu^2+\left[\left(S^{(1)}-S^{(0)}\right)\left(\nu^3-3\nu\right)+\left(S^{(2)}-S^{(0)}\right)\nu\right]\sigma_0\right)$$



initially Gaussian ΛCDM model + galaxy formation model successfully reproduce the observed topology of LRGs at $22h^{-1}$Mpc scales except for the void abundance in very low density regions filling ~3.5% of survey volume.

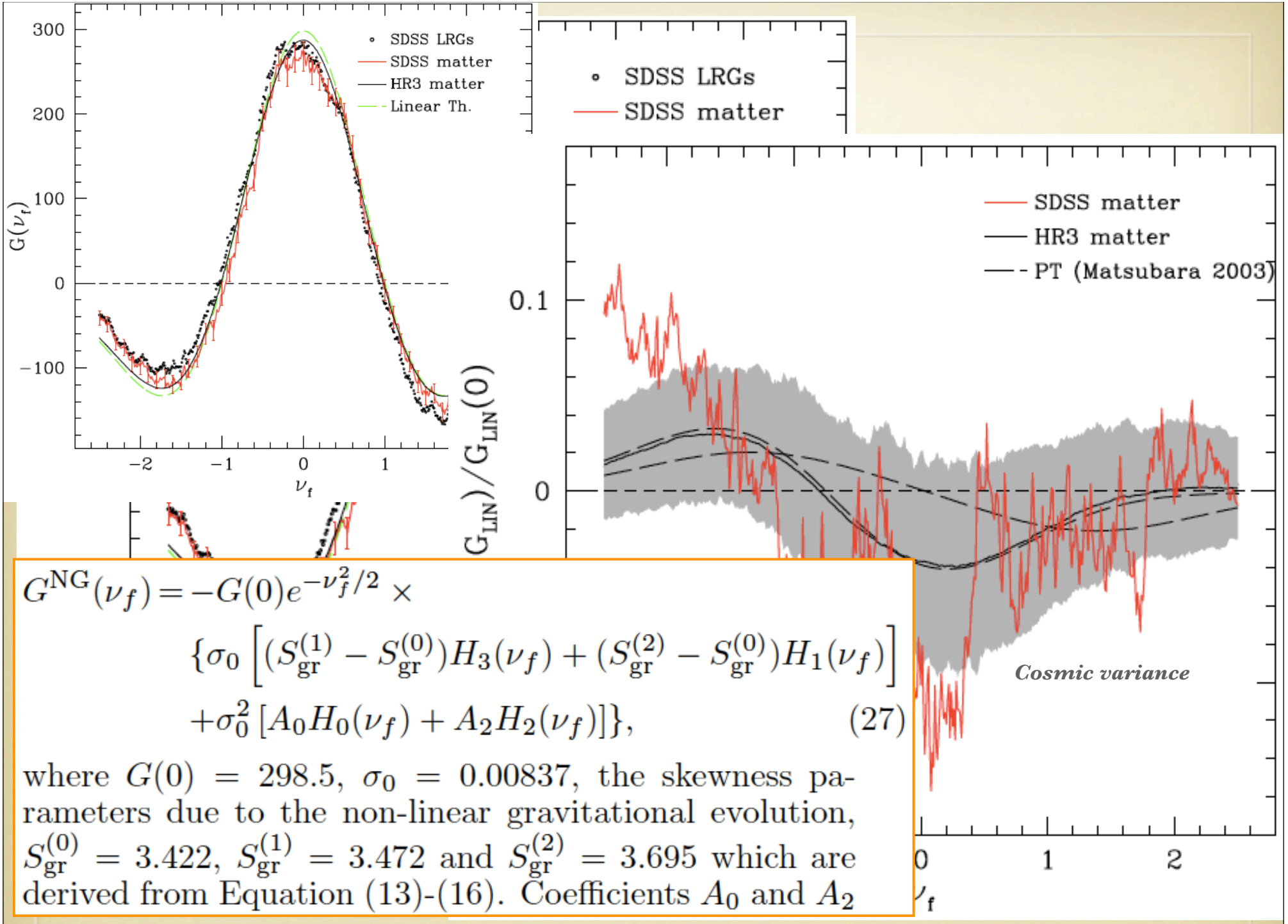


Where does the non-Gaussianity come from?



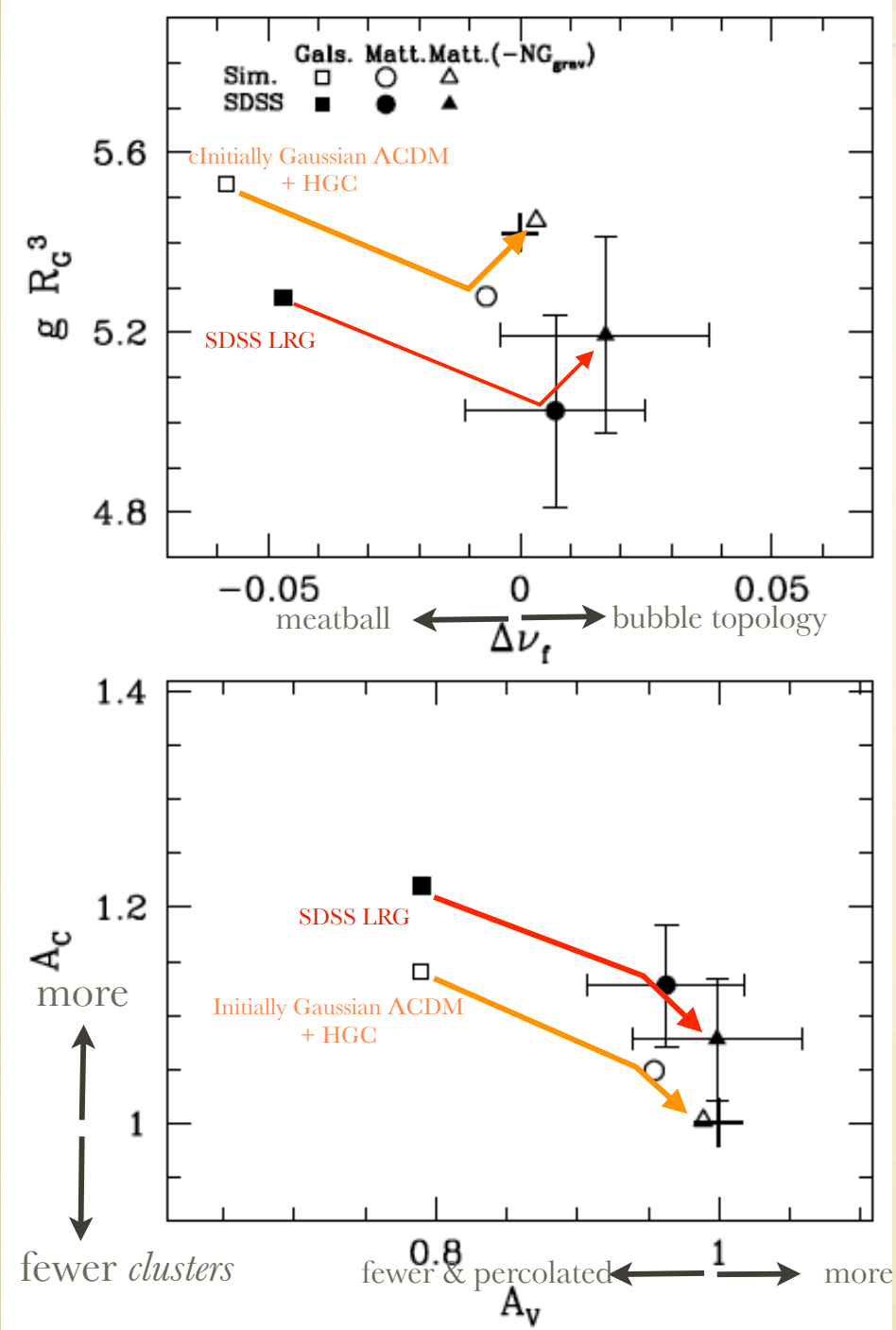
Correction for systematic effects

- The goal is to estimate genus curve of the observed underlying matter density field: (possible) primordial NG + NG due to gravitational evolution.
- To remove all the non-linear systematics in the observed genus curve due to (sampling variance + Halo biasing + light cone effect + redshift distortion + survey mask).
- Most of the systematics comes from both the nonlinearity and stochasticity of halo biasing.



$$G^{\rm NG}(\nu_f) = -G(0)e^{-\nu_f^2/2} \times \{\sigma_0 \left[(S_{\rm gr}^{(1)} - S_{\rm gr}^{(0)})H_3(\nu_f) + (S_{\rm gr}^{(2)} - S_{\rm gr}^{(0)})H_1(\nu_f)\right] + \sigma_0^2 \left[A_0 H_0(\nu_f) + A_2 H_2(\nu_f)\right]\}, \quad (27)$$

where $G(0) = 298.5$, $\sigma_0 = 0.00837$, the skewness parameters due to the non-linear gravitational evolution, $S_{\rm gr}^{(0)} = 3.422$, $S_{\rm gr}^{(1)} = 3.472$ and $S_{\rm gr}^{(2)} = 3.695$ which are derived from Equation (13)-(16). Coefficients A_0 and A_2



Genus Statistics

- + : for random phase curve
- ●, ○: Matter density - a smaller overall amplitude of the genus curve (simpler structures), bubble shifted, more voids & fewer clusters compared to that of galaxy (halo) density.
- △: real space genus curve of the dark matter distribution at initial epoch of the simulation, ▲: initial matter density field from LRG (only contribution of the primordial non-Gaussianity).
- ***Cosmic variance*** is the primary limitation in constraining primordial non-Gaussianity via topology-based methods.

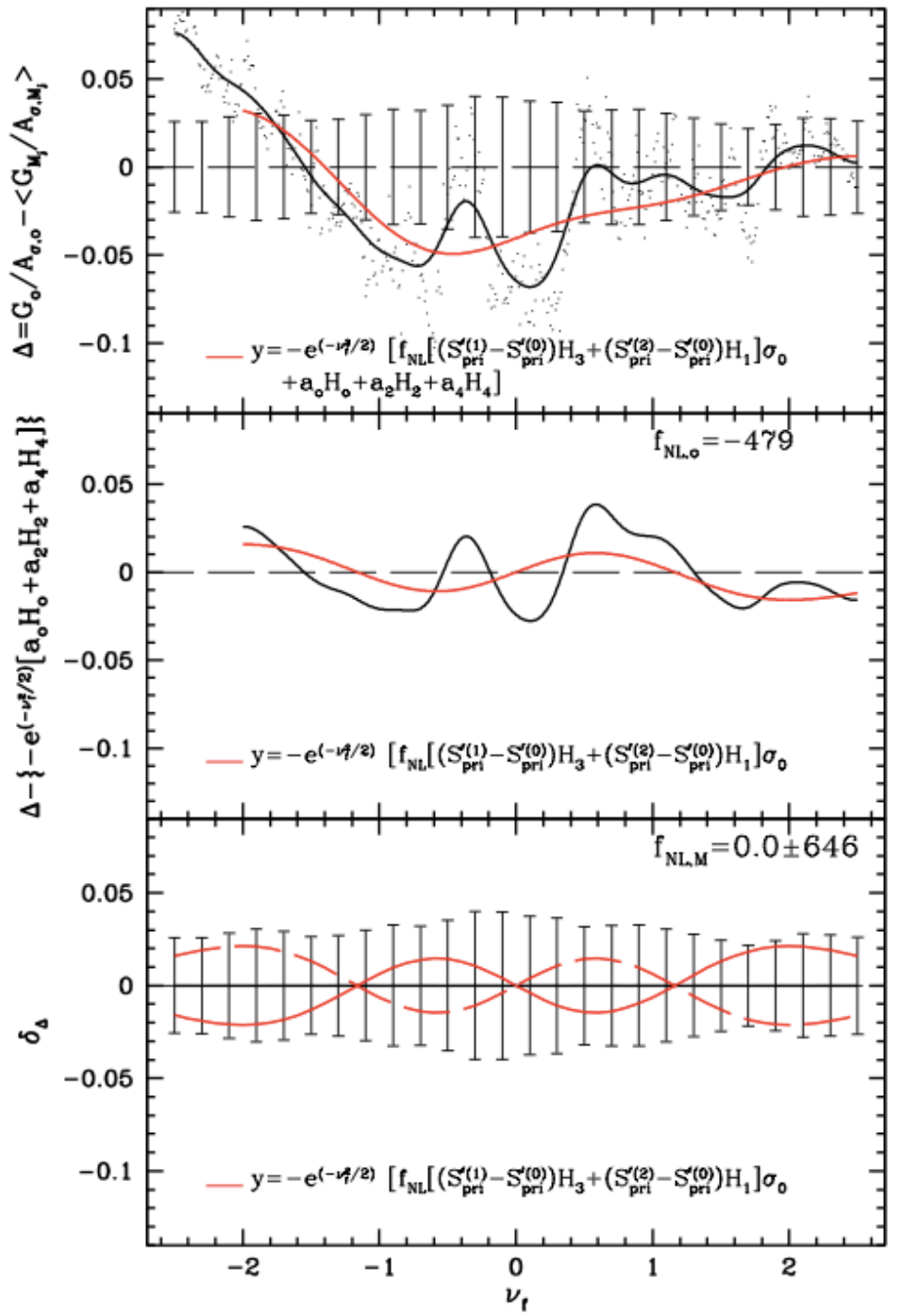
Measuring Primordial Non-Gaussianity

- f_{NL}: standard parameterization of the primordial non-Gaussianity when the local type non-Gaussianity is assumed - amplitude of a quadratic correction to the potential, ϕ,

$$\Phi = \phi + f_{NL}(\phi^2 - \langle\phi^2\rangle)$$

  - Typical value of f_{NL} for standard slow roll inflation is of order 10^{-2}

- For CMB, $-10 < f_{NL} < 74$ (WMAP 7, 95% confindence, Komatsu et al. 2011)
- For LSS, $-29 < f_{NL}$ f<70 (95% conf. combination of galaxy & quasar clustering measurements, Slosar et al. 2008)
- For LSS of SDSS photometric LRG, $-268 < f_{NL}$ f<164 (Slosar et al. 2008), $-81 < f_{NL} < 351$ (Xia et al. 2011), $-168 < f_{NL}$ f<364 (Ross et al. 2012; SDSS DR9 CMASS sample)



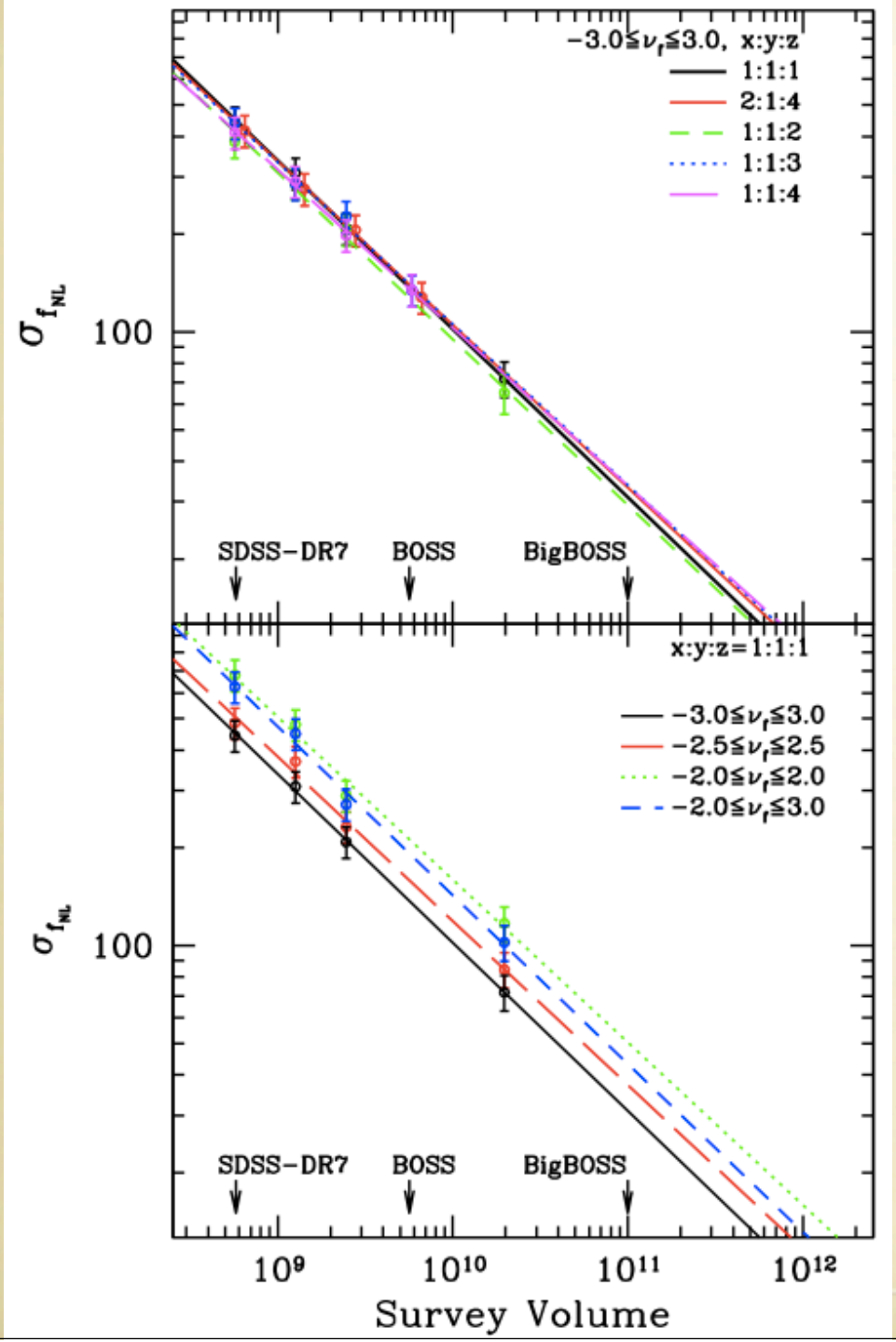
Non-Gaussianity Measurement via Topology-based Method

$$\Delta = G_o/A_{\sigma,o} - \frac{\sum_{i=1}^{N} G_{M_j}/A_{\sigma,M_j}}{N}$$

$$\Delta(\nu) = -e^{-\nu^2/2} \times$$
$$\{f_{NL}\left[(S'^{(1)}_{pri} - S'^{(0)}_{pri})H_3(\nu_f) + (S'^{(2)}_{pri} - S'^{(0)}_{pri})H_1(\nu_f)\right]\sigma_{m,0}$$
$$+a_0H_0(\nu) + a_2H_2(\nu) + a_4H_4(\nu)\}. \quad (28)$$

Δ: the perturbation predictions without any corrections of systematics (ref. Hikage et al. 2006, 2008)

The descripancy: the different biasing schemes of galaxy formation in between the simulation and the real universe, and cosmic variance.



Measurement error of F_{NL} Due to the cosmic variance

- The volume of the SDSS DR9 sample (Ross et al. 2012) will approximately 3.2 times as large as that of the DR7 LRG sample and thus approximately halves the statistical uncertainty: from ~550 (when -3<ν<3) to ~*270*: for the Ross et al. 2012, -82<f_{NL}<245 (68% conf) → isn't is too optimistic?

Summary

- Our initially Gaussian ΛCDM model + galaxy formation model successfully reproduce the observed topology of LRGs at $22h^{-1}$Mpc scales except for the void abundance in very low density regions filling 3.5% of the survey volume.
- Accurate measurement of the genus: SDSS DR7 LRG ~3.5%1
- Accurate estimation of systematic effects on the genus.
- Constraint on local-type f_{NL} from SDSS DR7 LRG with Δf_{NL} ~550 (68% conf.): the uncertainty limit will be Δf_{NL} ~130 for the final BOSS LRG sample.
- Cosmic variance is the crucial limitation in constraining primordial non-Gaussianity via topology-based methods.
- We obtain realistic uncertainties by using the largest simulation. Our topology-based results suggest that tighter constraints on non-Gaussianity from LSS previously quoted in the literature may be too optimistic and thus severely underestimating the contribution of cosmic variance is needed.