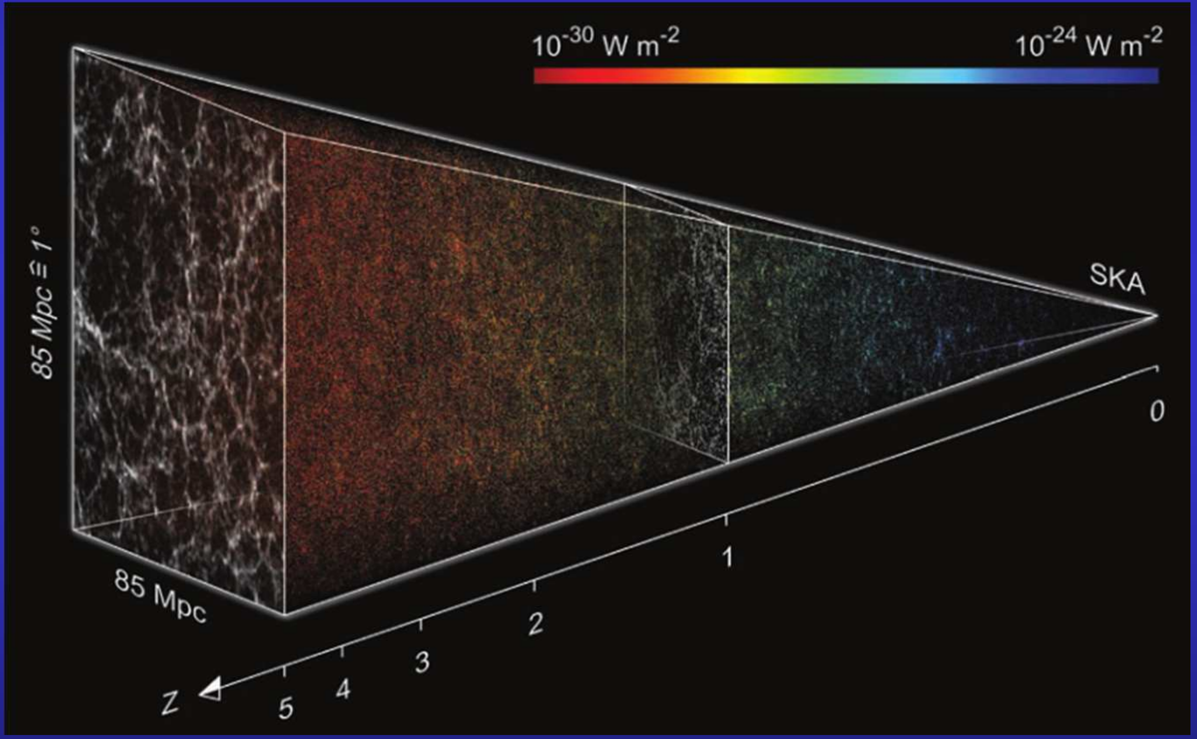
Fun -
damental Cosmology*
with the SKA



Myers et al. 2009

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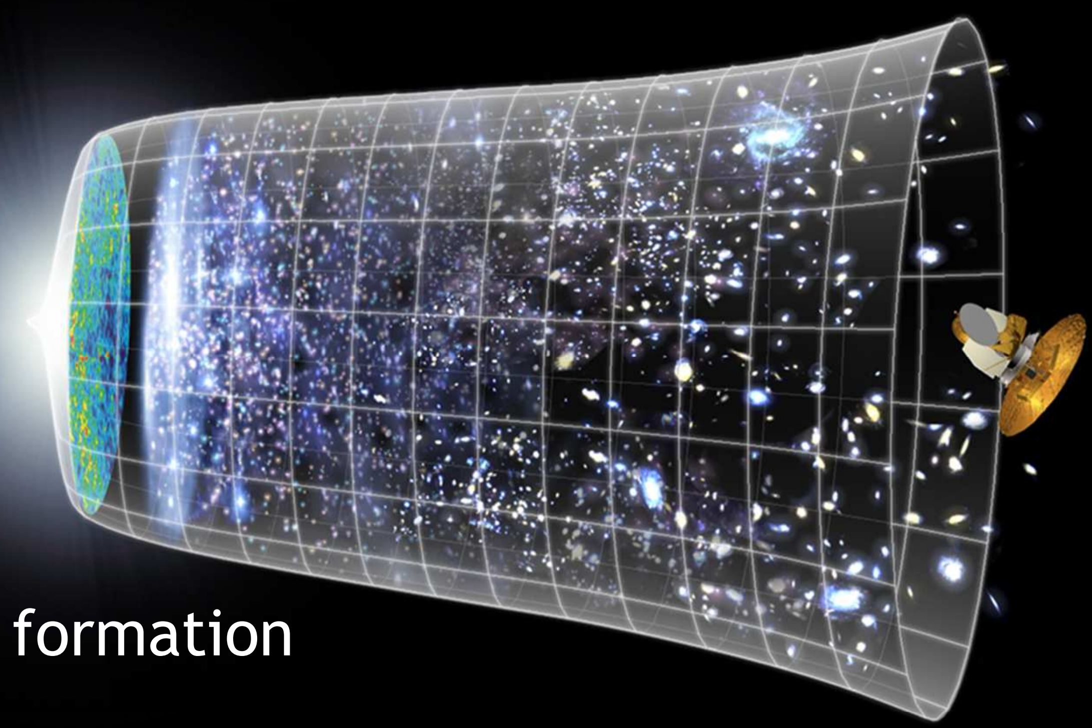
**specifically, neutrino masses and non-Gaussianity*

Information encoded in cosmological perturbations

Inflation

- spectral index, running:
  inflaton potential
- adiabatic vs. isocurvature perturbations:
  additional degrees of freedom
- non-Gaussianities:
  inflaton interactions



Structure formation

- small scale power:
  neutrino masses, sterile neutrinos, warm dark matter (gravitinos etc.)
- linear growth factor:
  modified gravity theories

Expansion history

- distances from BAO scales:
  dark energy equation of state, curvature

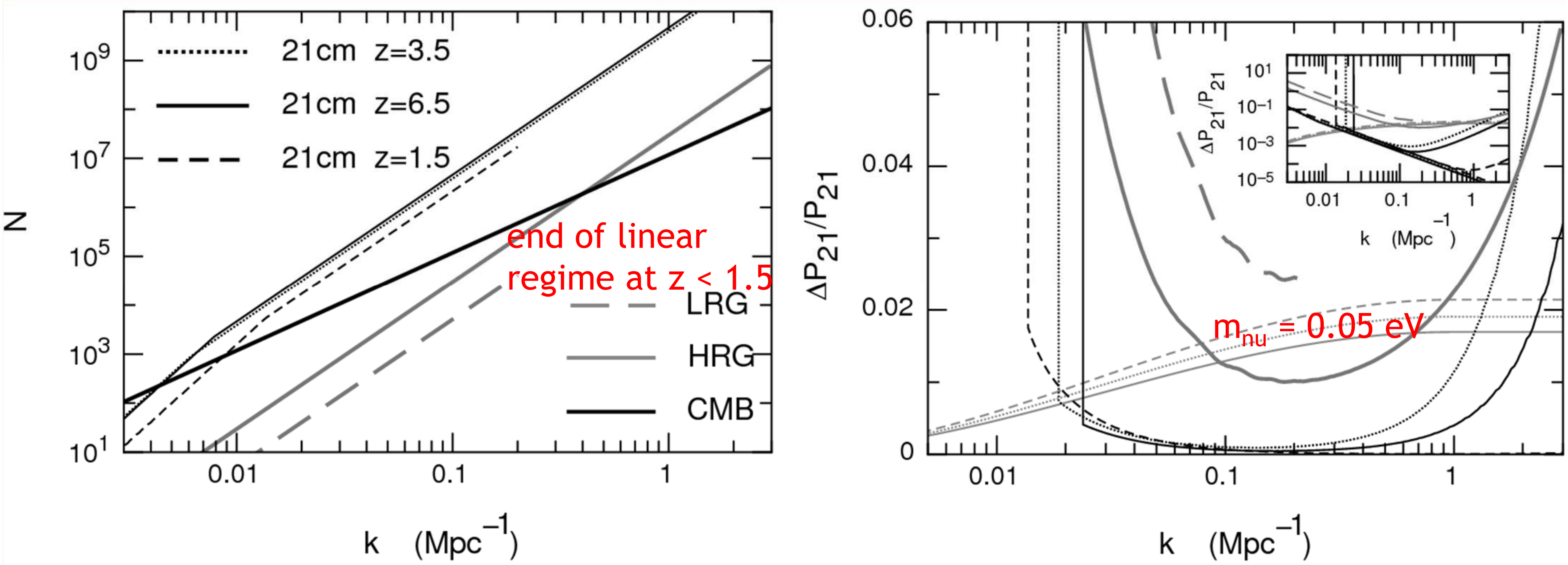
Limitation 1: sampling variance

$$\frac{\delta P}{P} = \frac{1}{N_{\rm modes}^{1/2}}$$

Range in z	Ω(sr)	$N_{\rm modes}$	$\delta P/P$	Surveys
0.0 – 0.2	3.0	3×10^4	6×10^{-3}	SDSS, SKA_0
0.2 – 0.7	3.0	8×10^5	1×10^{-3}	BOSS
0.2 – 2.0	0.06	1×10^5	3×10^{-3}	SKA_1
0.2 – 2.0	6.0	1×10^7	$\mathbf{3 \times 10^{-4}}$	SKA_2, BigBOSS, Euclid
2.0 – 3.0	0.3	6×10^5	1×10^{-3}	HETDEX
2.0 – 6.0	0.01	7×10^4	[a]	SKA_1
2.0 – 6.0	6.0	4×10^7	$\mathbf{2 \times 10^{-4}}$	SKA_2
6.0 – 13.0	0.03	2×10^5	[b]	SKA_0
6.0 – 13.0	0.03	2×10^5	2×10^{-3}	SKA_1
6.0 – 13.0	3.0	2×10^7	$\mathbf{2 \times 10^{-4}}$	SKA_2
13.0 – 30.0	0.03	2×10^5	[b]	SKA_1
13.0 – 30.0	3.0	2×10^7	$\mathbf{2 \times 10^{-4}}$	SKA_2
CMB	11.0[c]	2×10^5		WMAP, Planck

Rawlings 2011

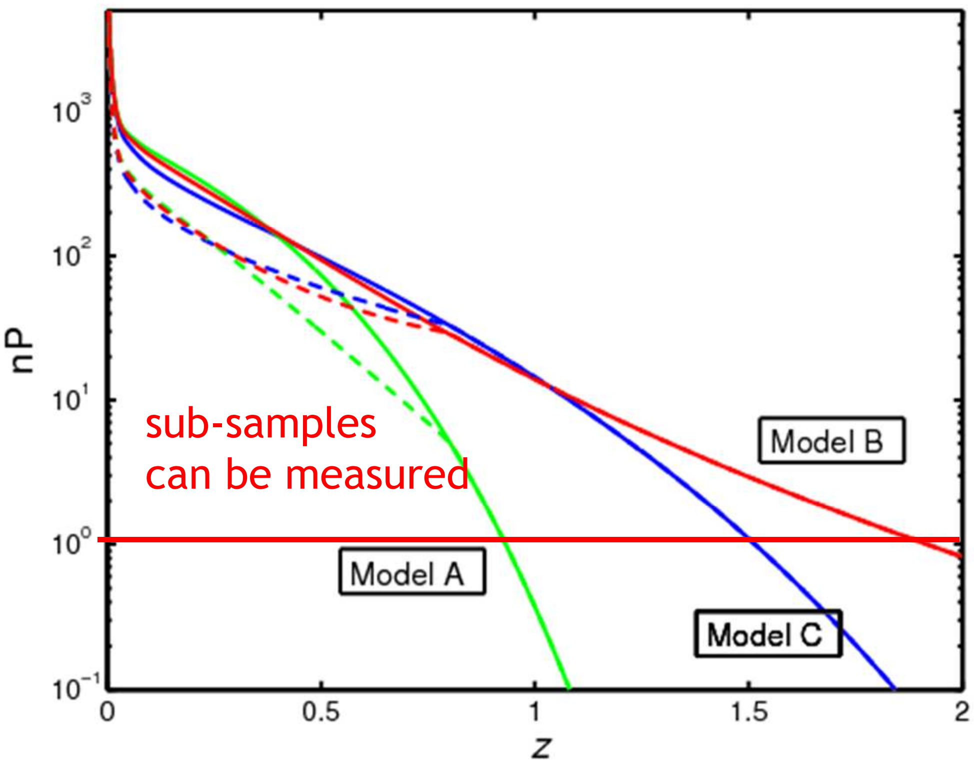
Cosmic variance limited 21cm-cosmology

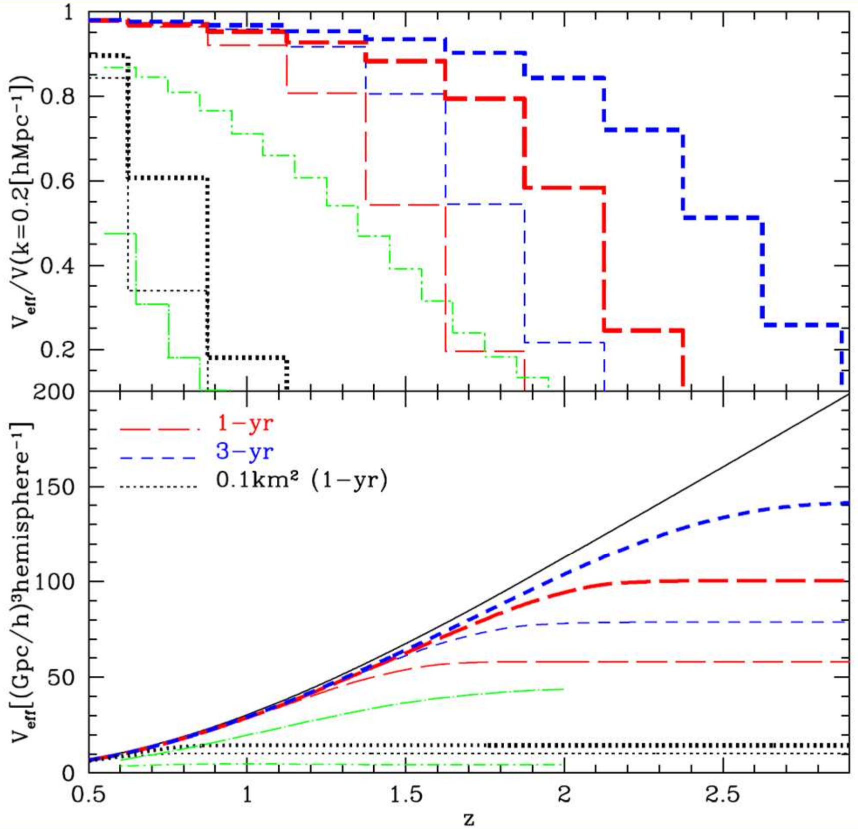


Loeb & Wyithe 2008

Limitation 2: Shot noise

$$\frac{\delta P}{P} = \frac{1 + (b^2 P n)^{-1}}{N_{\rm modes}^{1/2}}$$



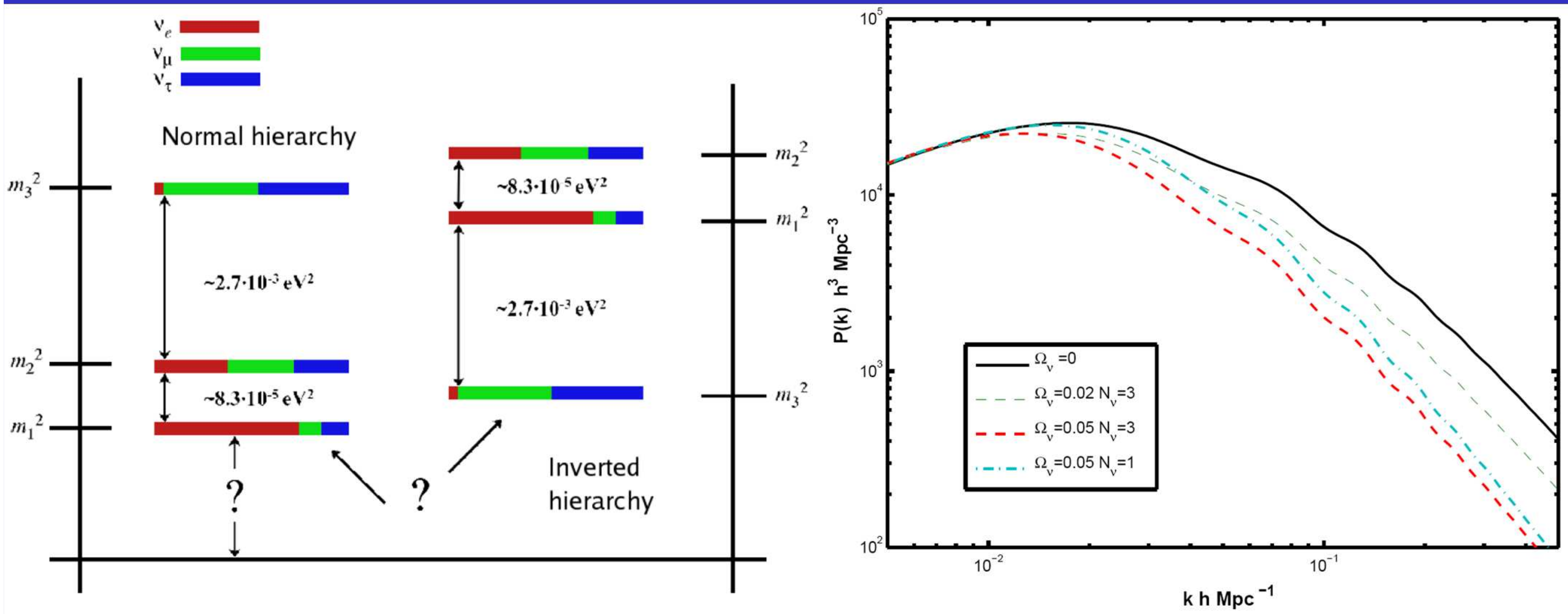


Abdalla et al. 2010

Kim et al. 2010

Neutrino masses

- neutrinos suppress the power spectrum below free-streaming scale (several % at k > 0.1 h/Mpc for ~ 0.1 eV nu)
- cosmological bounds: sum of neutrino masses < 0.3 eV (Thomas et al. 2010)
- neutrino oscillations: at least one neutrino has mass > 0.05 eV
- need z>~ 1, k > 0.2 h/Mpc for analytical treatment of power spec. at % level
- SKA forecasts : Abdalla & Rawlings 2007



Abdalla & Rawlings 2007

Primordial non-Gaussianity

Killing vanilla inflation

- Inflation predicts nearly Gaussian (independent k modes) curvature perturbations.
- Define amplitude f_{nl} for (local type) non-Gaussianity:

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

- Vanilla (single field, slow roll, canonical kinetic term, standard vacuum,…) inflation predicts f_{nl} = 0.015, hence any detection will kill vanilla inflation.

Mapping out the inflaton Lagrangian

- Different kinds of modifications (i.e., coupling of the inflaton to itself or other fields) produce distinct signatures in higher N-point functions (bispectrum etc.)
- Current discussion uses bispectrum shapes (local, folded, equilateral,...), but more precise language needed (perhaps based on Shellard et al.'s polyspectra)
- Perhaps the best (only?) way to learn about the inner workings of inflation

Measuring primordial non-Gaussianity

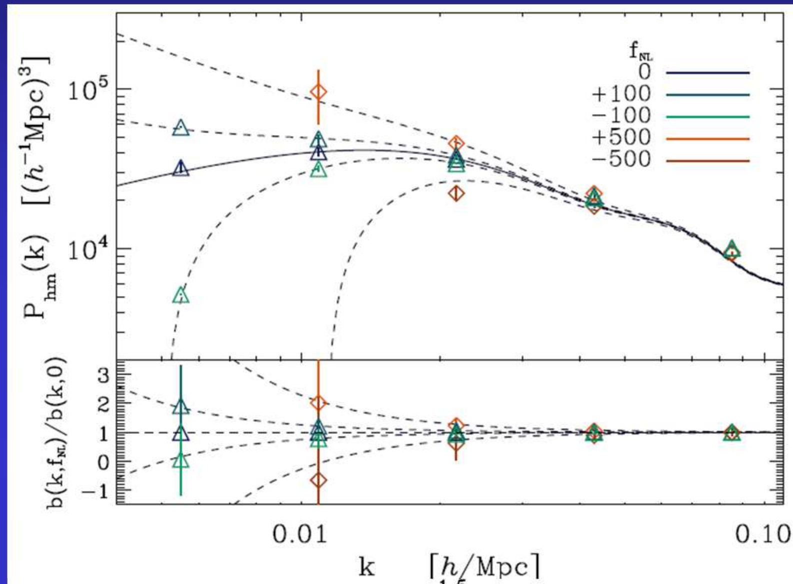
CMB

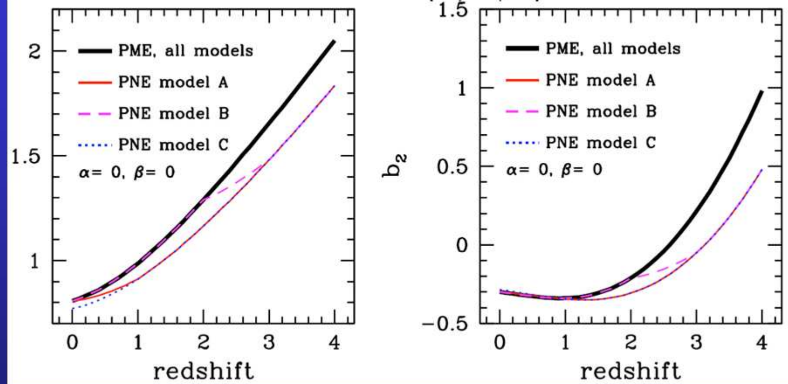
- current best limit from CMB bispectrum (WMAP 7, Komatsu et al. 2010): $f_{nl} = 32 \pm 21$
- Planck expected to give $\Delta f_{nl} \sim 5$

Large-scale structure

- cluster mass function
- galaxy power spectrum: strong scale dependent bias (Dalal et al. 2008)
- this effect is already competitive with CMB ($-29 < f_{nl} < 70$, Slosar et al. 2008; $25 < f_{nl} < 117$, Xia et al. 2010)
  - strongest on large scales, need large volume
  - need strongly biased tracer, or combine 2 tracers to eliminate sampling variance (Seljak 2009), e.g. optical and HI ?
- galaxy bispectrum: potentially strongest constraints for non-local PNG

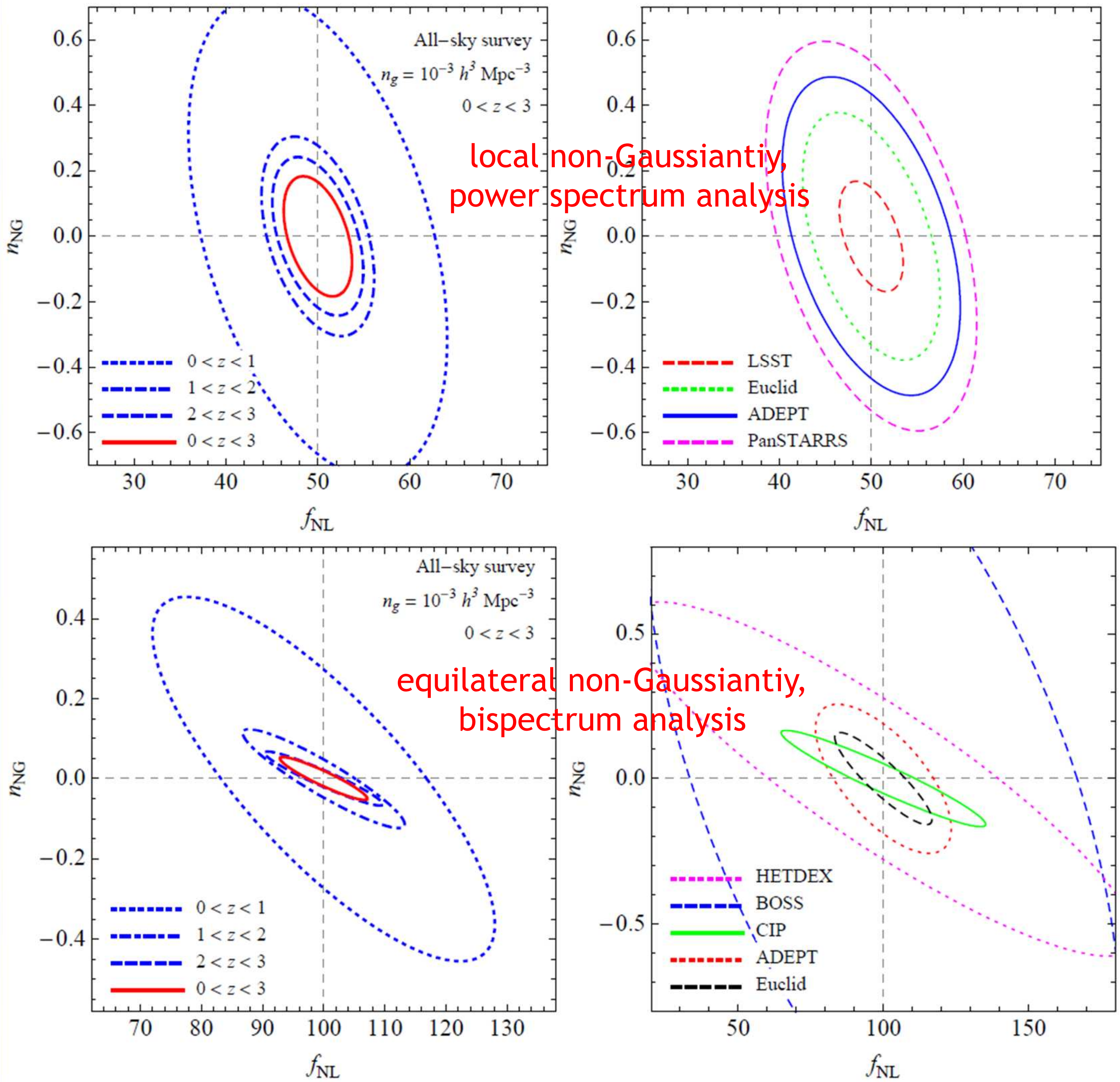
Dalal et al. 2008





Marin et al. 2010

AG Tagung 2011



Sefusatti et al. 2009

Challenges for theory and simulations

Modelling HI evolution

- so far mostly from semi-analytic models (e.g., Kim et al. 2010)
- hydro + N-body simulations: careful treatment of self shielding and subgrid physics needed (Duffy et al. 2011)
- need large computational volumes to predict large-scale HI bias

Non-Gaussianity from LSS surveys

- define observables and estimators for general classes of non-Gaussianity (Fergusson, Regan, Shellard; …)
- connect with effective field theories for inflation (Senatore, Zaldarriaga, Baumann, Green; …)