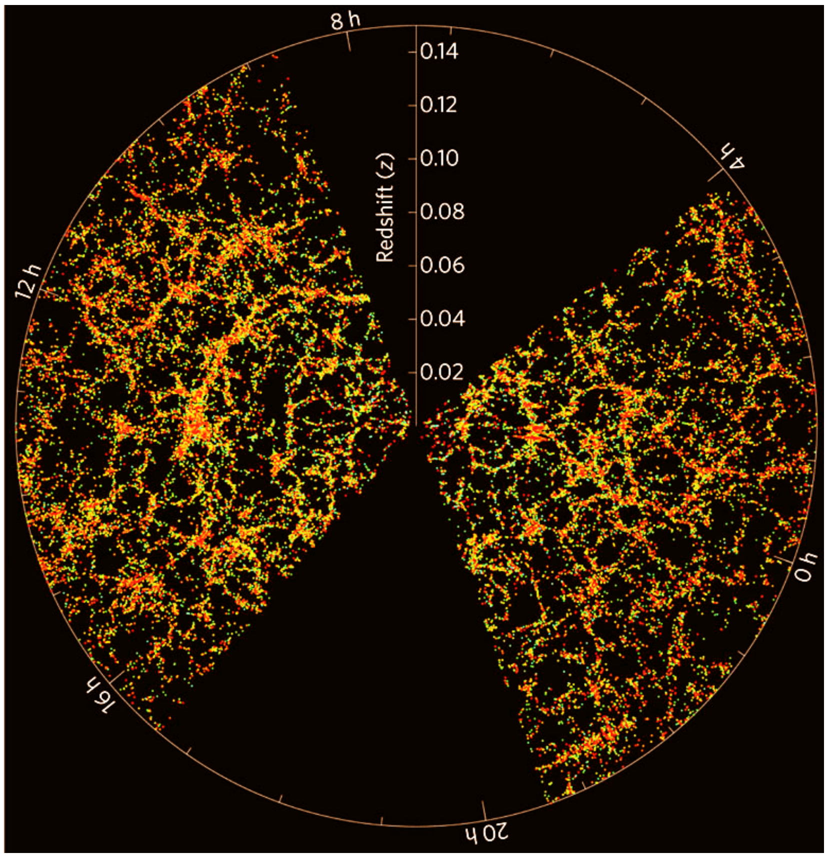
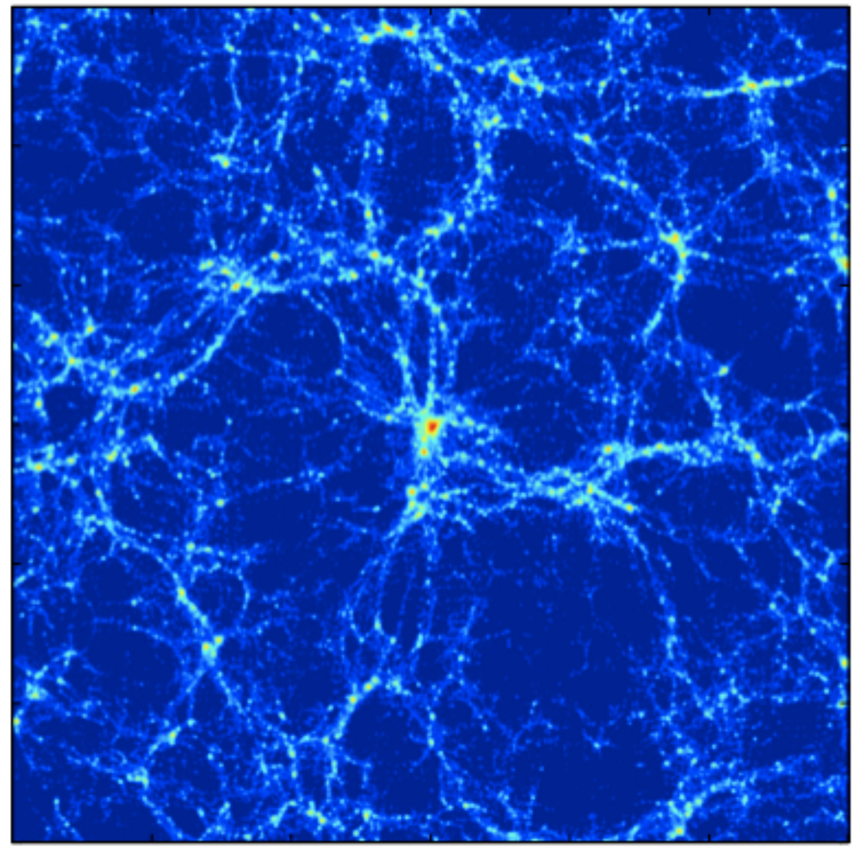
Primordial non-Gaussianity and the large-scale structure of the universe





Argelander-Institut für Astronomie

Cristiano Porciani

universität bonn

Annalisa Pillepich

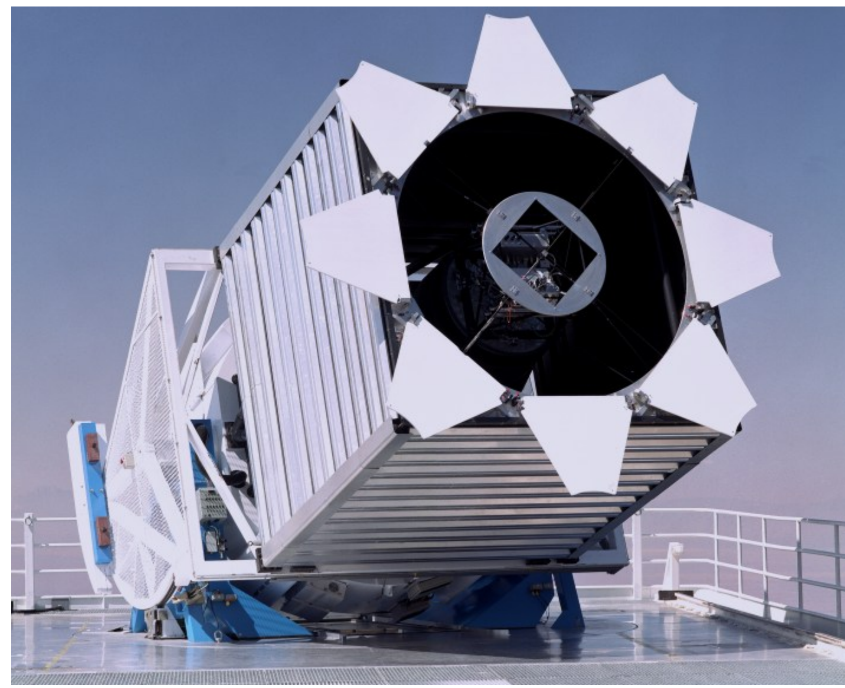
Tommaso Giannantonio

Oliver Hahn

Identity crisis

…you theorists…

…you observers…



The talk of a phenomenologist

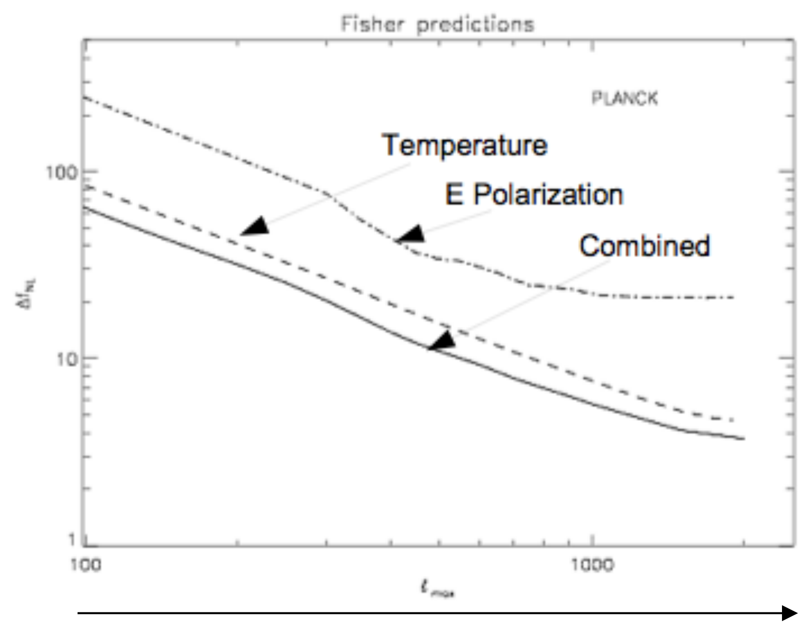
- There are lots of ideas regarding the early universe and the generation of primordial non-Gaussianity (PNG)

- Many experimental efforts are being developed/planned mainly driven by the quest for dark energy

- What will they be able to say about PNG?

The CMB future

- The Planck satellite has been launched on May 14 2009 and is currently acquiring data
- For PNG of the local type, the expected Cramér-Rao limit is $\Delta f_{NL} \approx 5$ from temperature anisotropies (Komatsu & Spergel 2001)
- This reduces to $\Delta f_{NL} \approx 3$ from the joint analysis of temperature and polarization maps (Yadav, Komatsu & Wandelt 2007)



Smaller angular scales

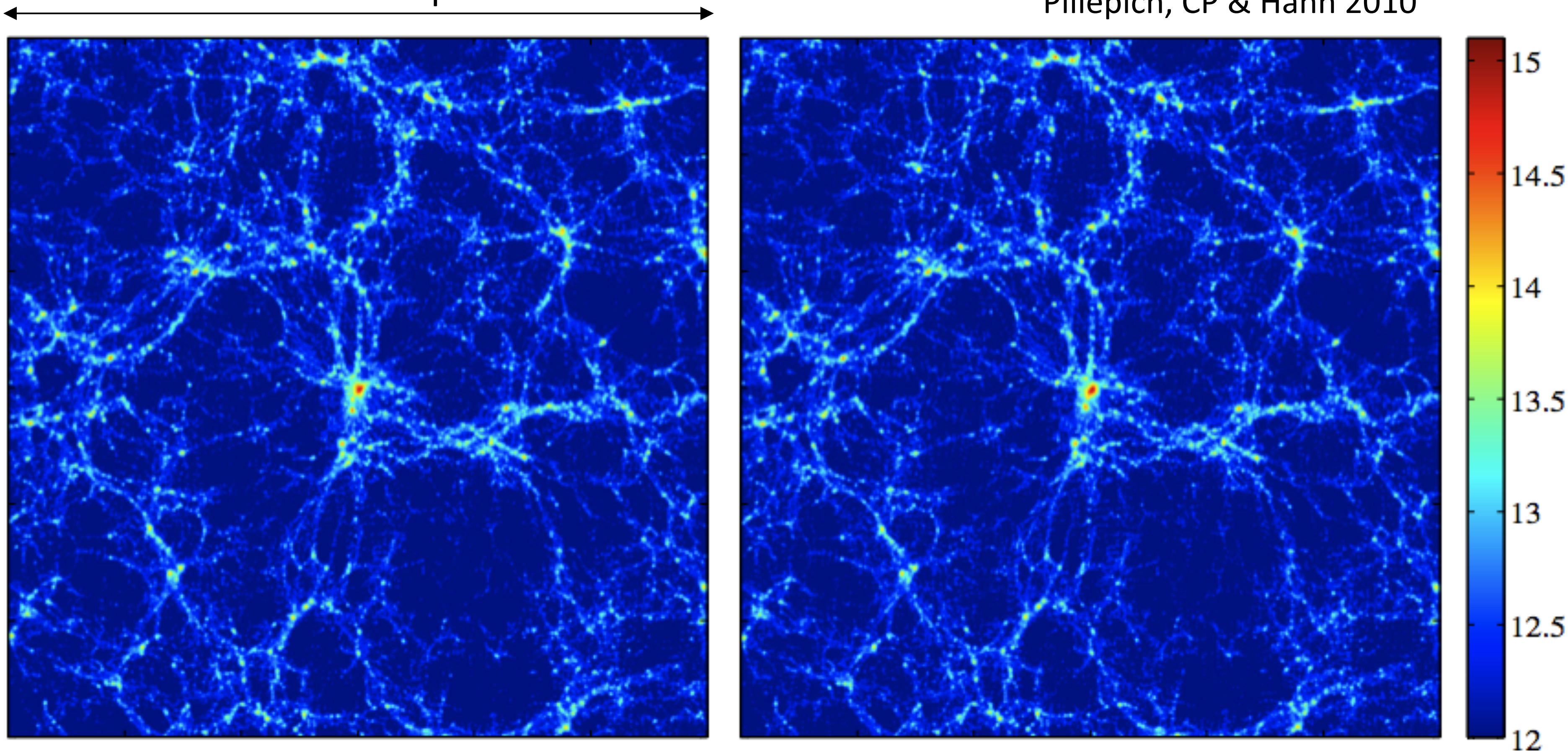
Are there other probes of primordial non-Gaussianity beyond the CMB?

- Abundance of dark-matter halos
- Abundance of voids
- Topology of the LSS
- Clustering of the matter distribution
- Clustering of dark-matter halos

The large-scale structure

$250\ h^{-1}$ Mpc

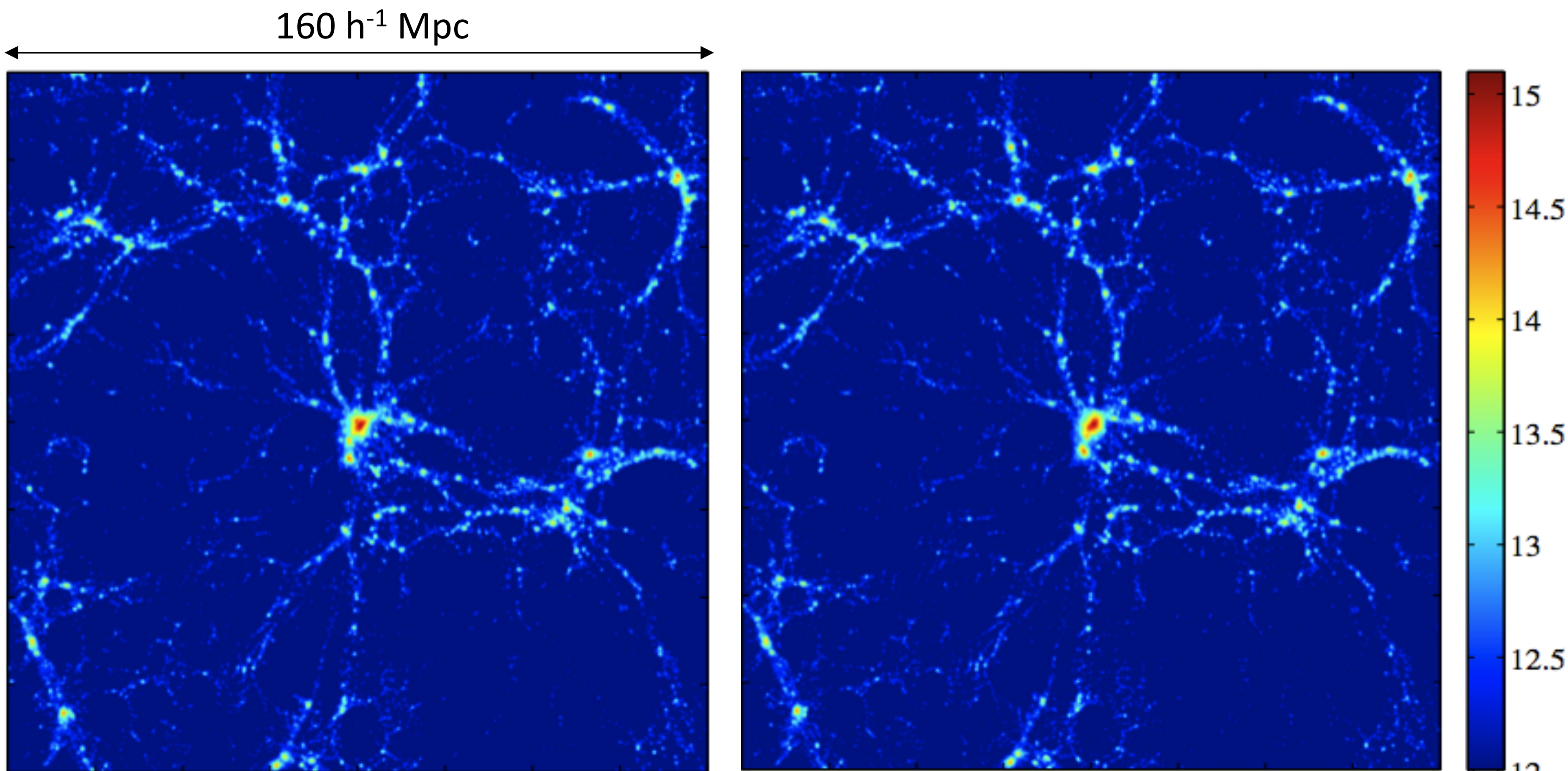
Pillepich, CP & Hahn 2010



$f_{NL} = 0$

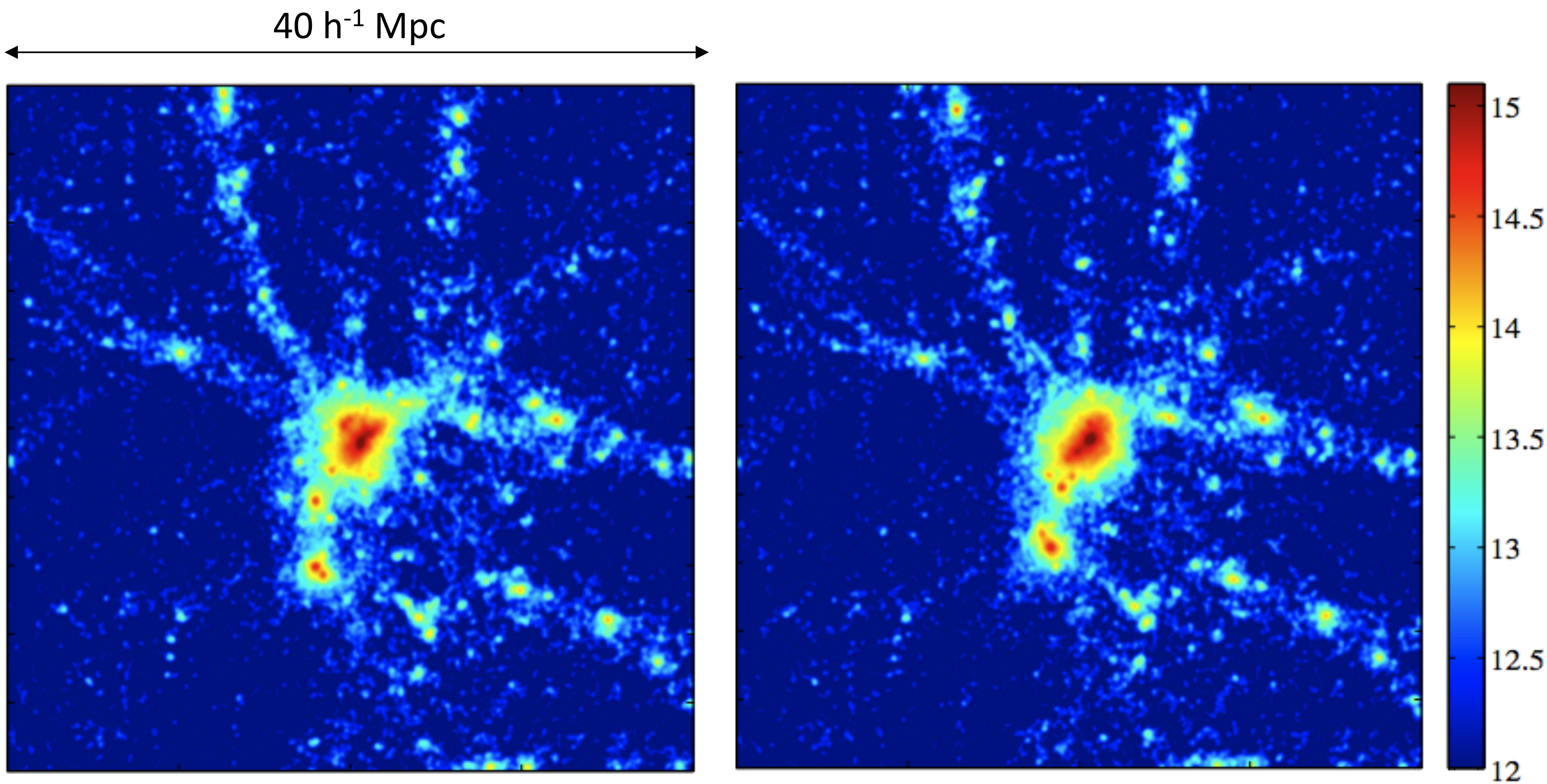
$f_{NL} = 750$

Zooming in



$f_{NL} = 0$ $f_{NL} = 750$

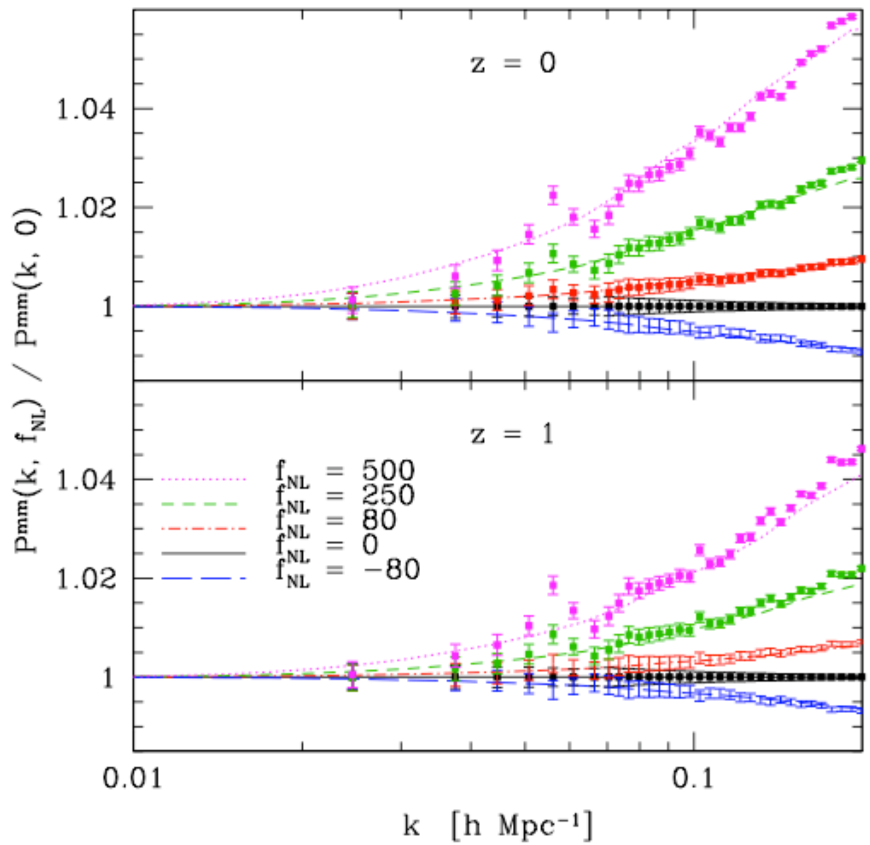
A massive galaxy cluster



$f_{NL} = 0$ $\quad$ $f_{NL} = 750$

Matter power spectrum (large scales)

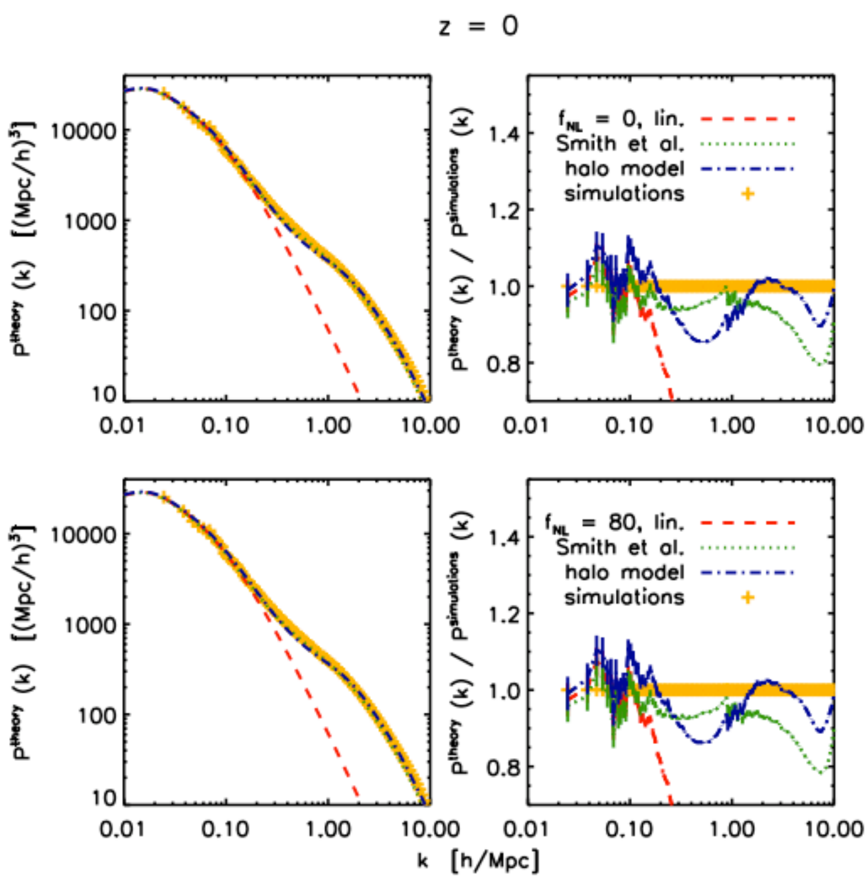
Giannantonio & Porciani 2010



Good agreement with perturbation theory on large scales

Taruya, Koyama & Matsubara 2008
Bartolo et al. 2010 (TRG, see S. Matarrese talk)

Matter power spectrum (small scales)



Halo model can predict it to 10-15% accuracy

Giannantonio, CP et al. 2011
Fedeli & Moscardini 2010

Halo mass function

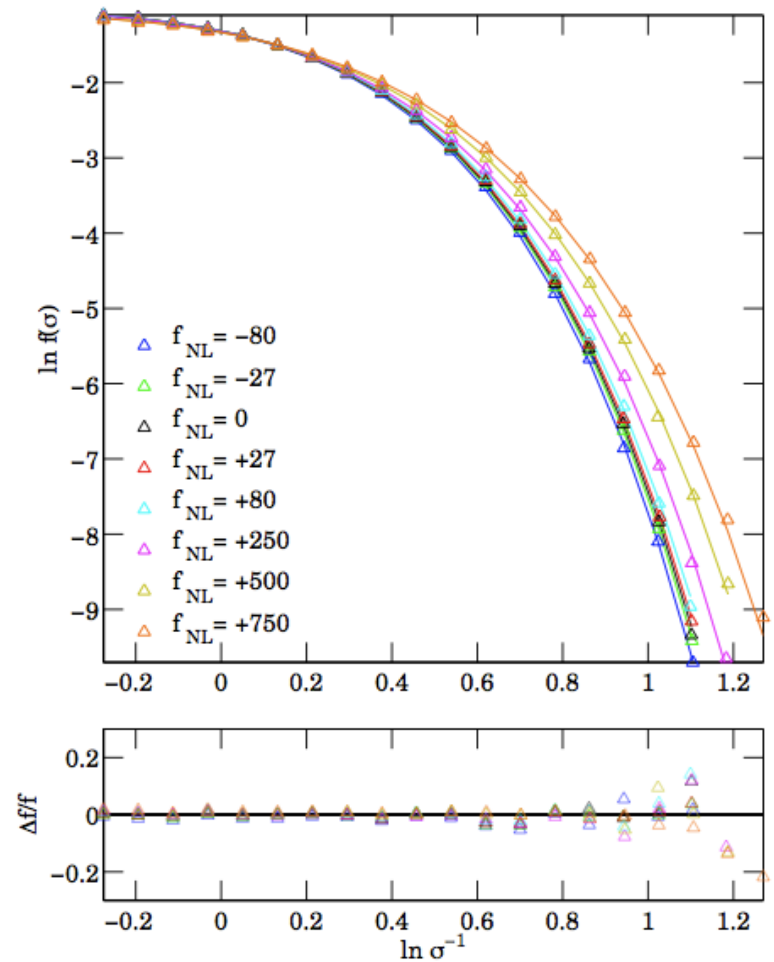
- A positive local f_{NL} enhances the formation of most massive halos at the expenses of the less massive ones

- Modified Press-Schechter
  (Matarrese, Verde & Jimenez 2000; Lo Verde et al. 2008; Lam & Sheth 2010)

- Excursion set + path integral
  (Maggiore & Riotto 2010)

- Fitting formulae
  (Pillepich, Porciani & Hahn 2010)

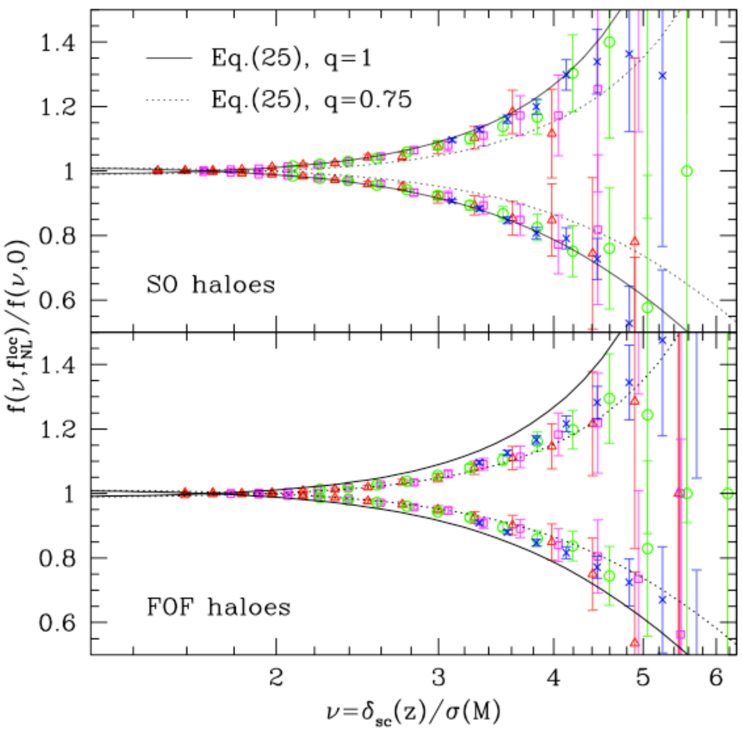
Pillepich, CP & Hahn 2010



Halo mass function

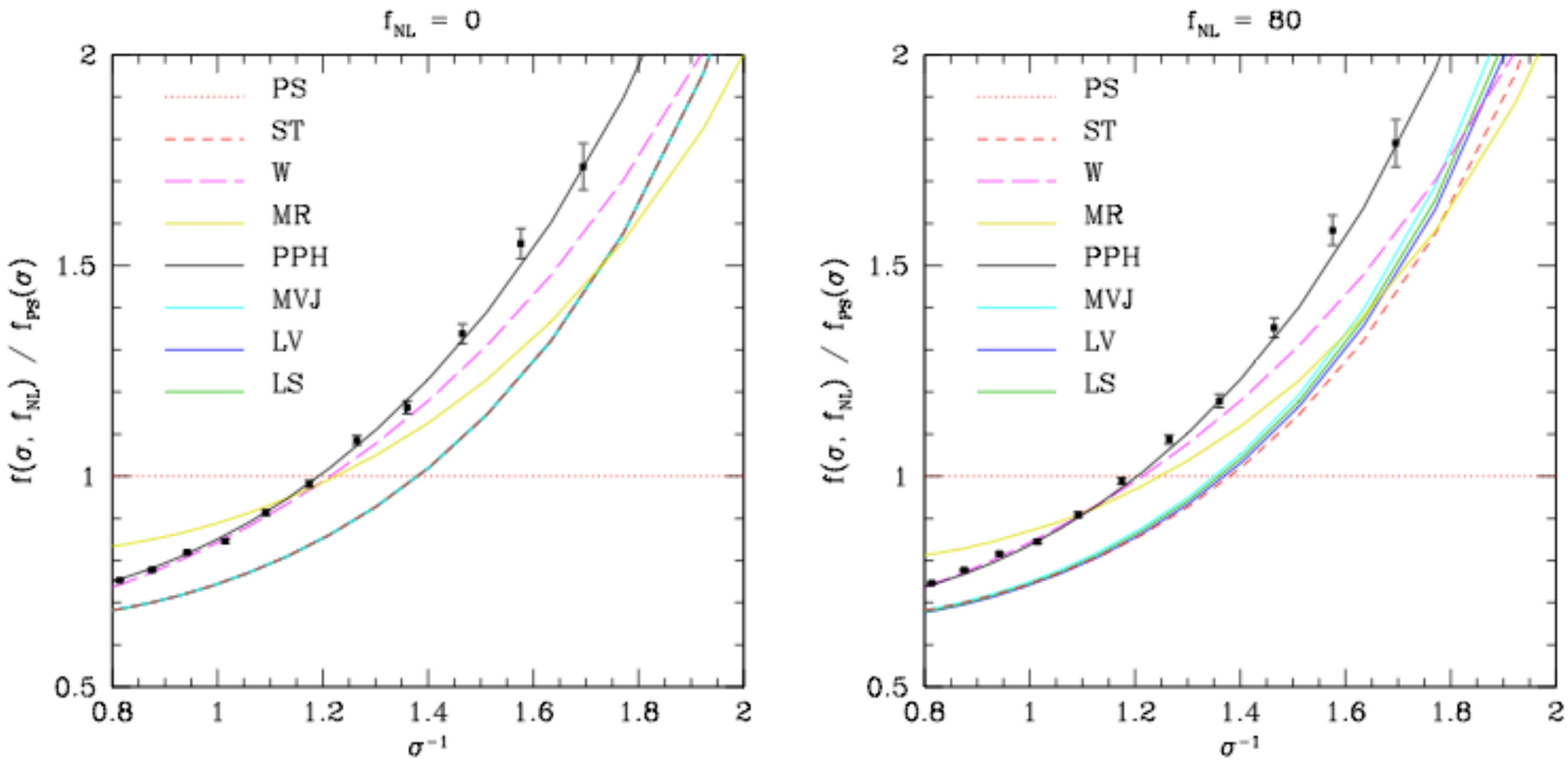
- Models have been tested against N-body simulations (Grossi et al. 2007, 2009, Desjacques et al. 2009, Pillepich et al. 2010, Giannantonio & Porciani 2010, Wagner et al. 2010)
- Good agreement for the ratio between the mass functions in Gaussian and non-Gaussian models
- Model parameters need to be fine tuned depending on the adopted definition of dark-matter halo. What is q for galaxies?

Desjacques & Seljak 2010



Halo mass function

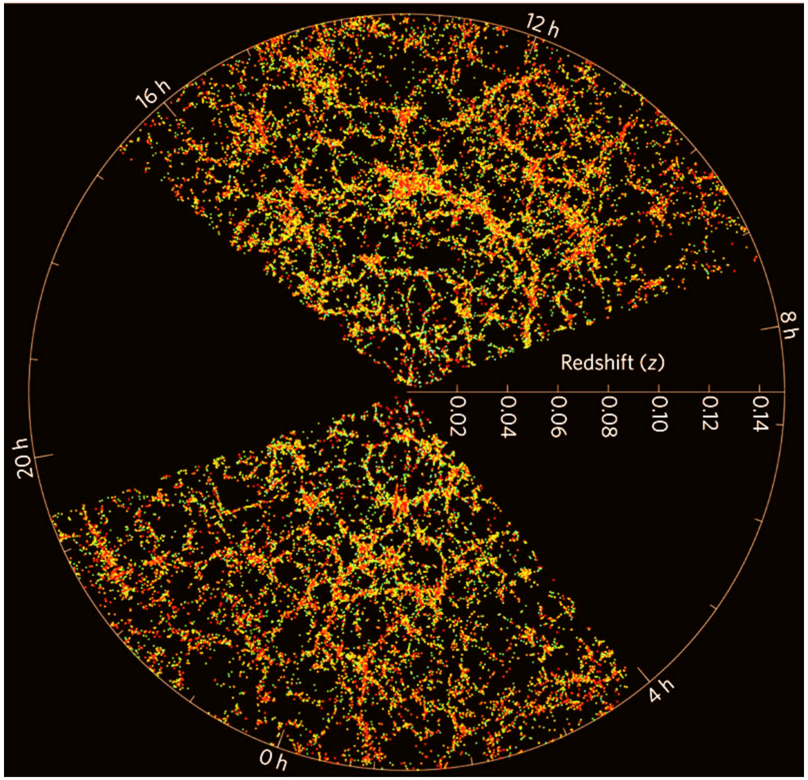
But you need to make sure that also your Gaussian mass function is accurate!



Giannantonio & Porciani 2010

Non-Gaussianity from galaxy clustering?

- It would be important to cross-check CMB results against probes with different systematics
- What about the large-scale structure? e.g. the galaxy bispectrum?
- Unfortunately the non-linear growth of perturbations superimposes a much stronger non-Gaussian signal onto the primordial one that is then difficult to disentangle and recover

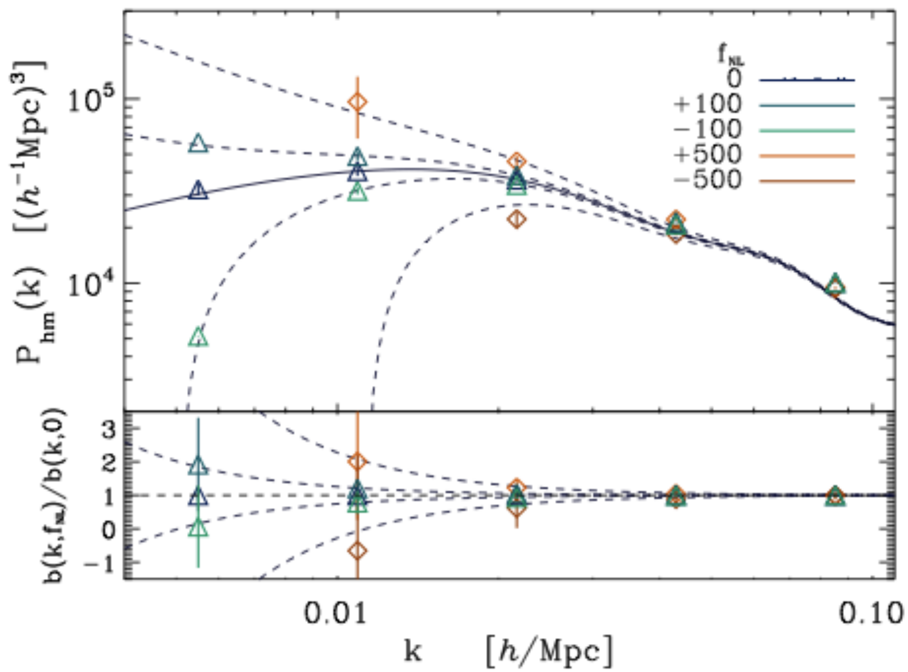


(Verde et al. 2000, Scoccimarro et al. 2004, Sefusatti & Komatsu 2007).

Back to life in 2008

- The large-scale clustering of collapsed objects (galaxies, galaxy clusters) as measured by the power spectrum depends linearly on f_{NL}!!!
- An approximated model based on linear theory captures all the relevant physics (Dalal et al. 2008, Matarrese & Verde 2008, Slosar et al. 2008, Afshordi & Tolley 2008, McDonald 2008)

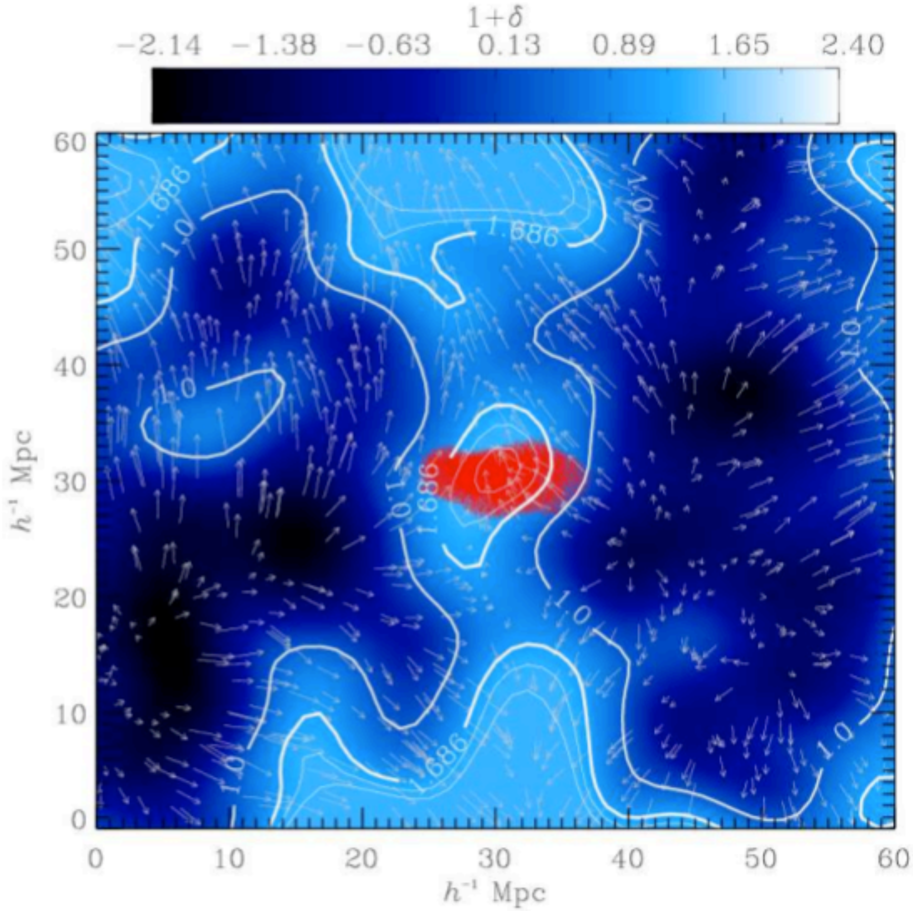
Dalal et al. 2008



Do halos form at linear density peaks?

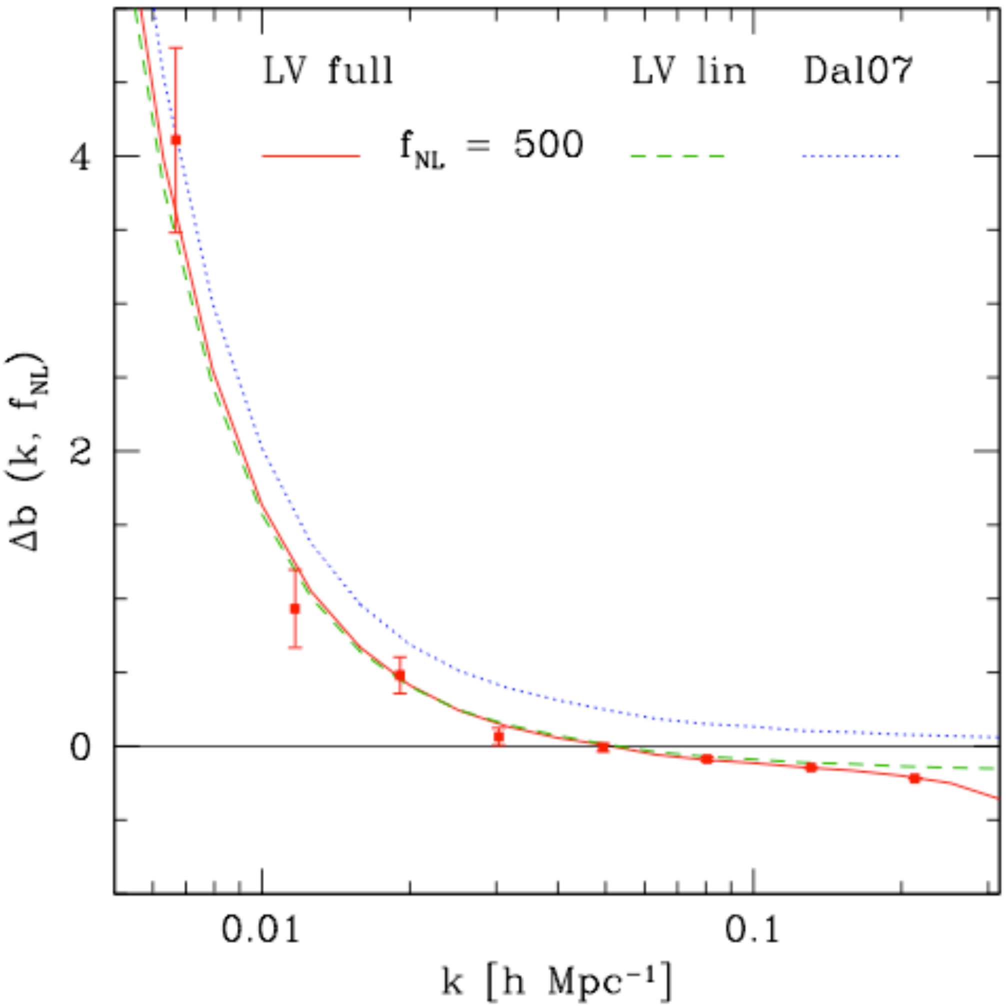
Ludlow & Porciani 2010a
(do they form at peaks?)

Ludlow & Porciani 2010b
(do they collapse according to the ellipsoidal model?
Do all peaks above threshold make halos?)



Scale-dependent bias

(to 1-loop in PT)



Giannantonio & Porciani 2010

Scale-dependent bias

Giannantonio & Porciani 2010

$$b_{eff}(k, f_{NL}) = \frac{P_{hm}(k, f_{NL})}{P_{mm}(k, f_{NL})}$$

$$\Delta b(k, f_{NL}) = b_{eff}(k, f_{NL}) - b_{eff}(k, 0)$$

$$\Delta b(k, f_{NL}) = b_{10}(f_{NL}) - b_{10}(0) + 2\frac{f_{NL}}{\alpha(k)}\delta_c[b_{10}(f_{NL}) - 1]$$

$$\alpha(k) = \frac{2c^2k^2T(k)D(z)}{3\Omega_m H_0^2}\frac{g(0)}{g(\infty)}$$

For other shapes of PNG see Schmidt & Kamionkowski (2010) and F. Schmidt talk.

A non-local biasing scheme

- Using the peak-background split, we have shown that, in general (Giannantonio & Porciani 2010):

$$\delta_h(x) = F[\delta_m(x),\ \phi(x),\ [\nabla\phi(x)]^2]$$

- Since the potential and the density field are linked by the Poisson equation, this generates a non-local biasing scheme in terms of the mass density

- When $f_{NL} \neq 0$, this is not compatible with the standard local, deterministic biasing scheme by Fry & Gaztañaga (1993)

The bias expansion

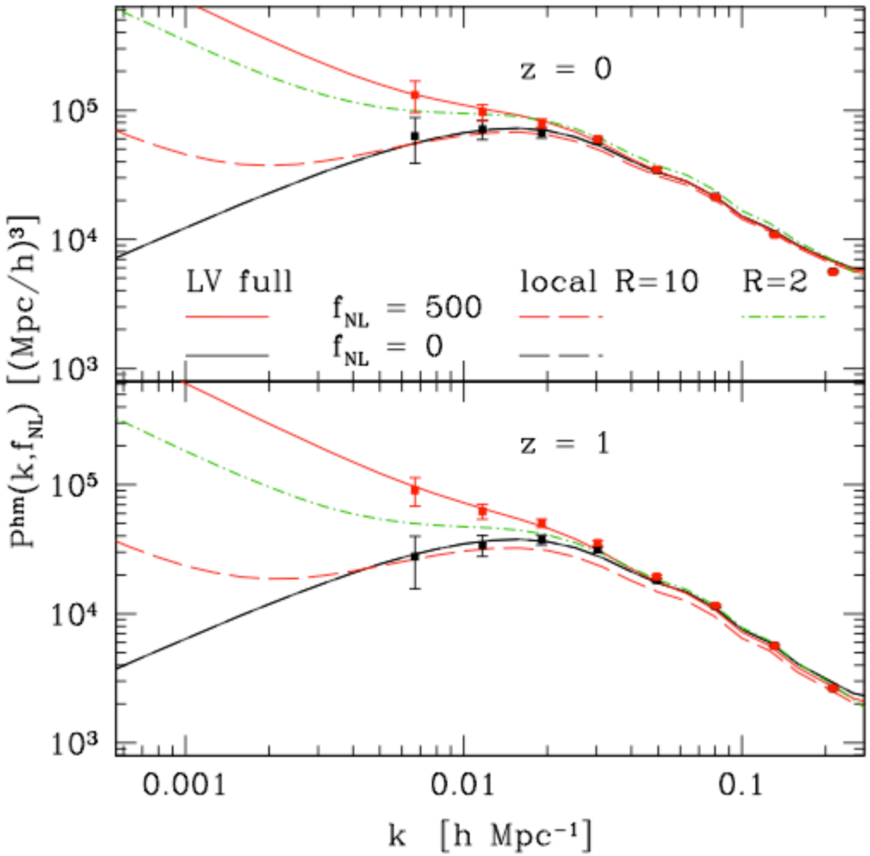
For galaxy and cluster sized halos, we can expand the halo overdensity as:

$$\delta_h(\mathbf{x}) = b_0 + b_{10}\,\delta + b_{01}\,\varphi + \frac{1}{2!}\left(b_{20}\,\delta^2 + 2\,b_{11}\,\delta\varphi + b_{02}\,\varphi^2\right) + \frac{1}{3!}\left(b_{30}\,\delta^3 + 3\,b_{21}\,\delta^2\varphi + 3\,b_{12}\,\delta\varphi^2 + b_{03}\,\varphi^3\right),$$

This term generates the leading order scale-dependence in the bias

and we provide explicit expressions for the bias coefficients as a function of f_{NL} and g_{NL}. (see also talk by K. Smith)
All terms including the Gaussian potential vanish when f_{NL}=0 and the bias reduces to the model by Fry & Gaztañaga (1993).

Halo-matter cross spectrum



Solid lines: perturbative calculations (up to second next to leading order) by Giannantonio & Porciani 2010.

Points with errorbars: N-body simulations by Pillepich, Porciani & Hahn 2010.

The model is not a fit to the data!

Competitive with CMB!

- Fitting the best datasets for galaxy clustering with this model, gives:

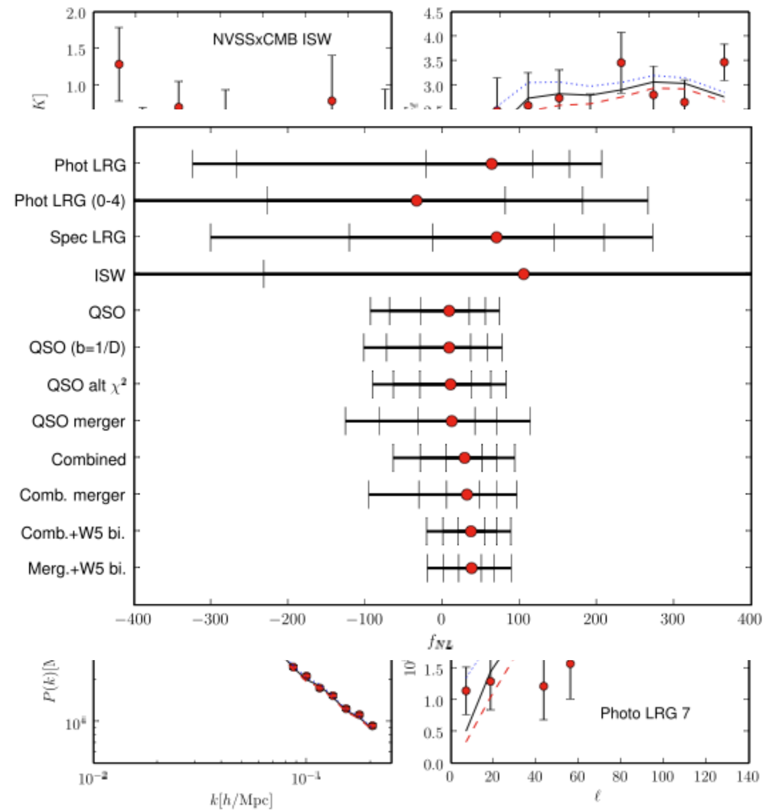
  $-29 < f_{NL} < 70$ at 95% CL

- This is competitive with the WMAP 5yr results!

- Combined CMB+LSS:

  $0 < f_{NL} < 69$

Slosar et al. 2008



For a more recent analysis see Xia et al. 2011 and S. Matarrese talk

Generalisation to other shapes

- Local:
  $\Delta b \sim 1/k^2$ as k-> 0

  Schmidt & Kamionkowski 2010
  Wagner et al. 2010

- Orthogonal:
  $\Delta b \sim 1/k$

- Equilateral:
  $\Delta b \sim$ constant

From theory to observations

Observable	Experiment	Systematics
Matter power spectrum	Weak lensing surveys	Dynamic non-linearities, intrinsic alignments, effect of baryons
Galaxy power spectrum or bispectrum	Galaxy redshift/ photometric surveys	Galaxy biasing, non-linearities, shot noise, redshift-space distortions
Cluster abundance	X-ray, SZ surveys	Mapping observables to masses, accurate models for the mass function, effect of baryons
Void abundance	Galaxy redshift surveys	Galaxy biasing, definitions
Topology of LSS	Galaxy redshift surveys	Galaxy biasing, definitions

eROSITA

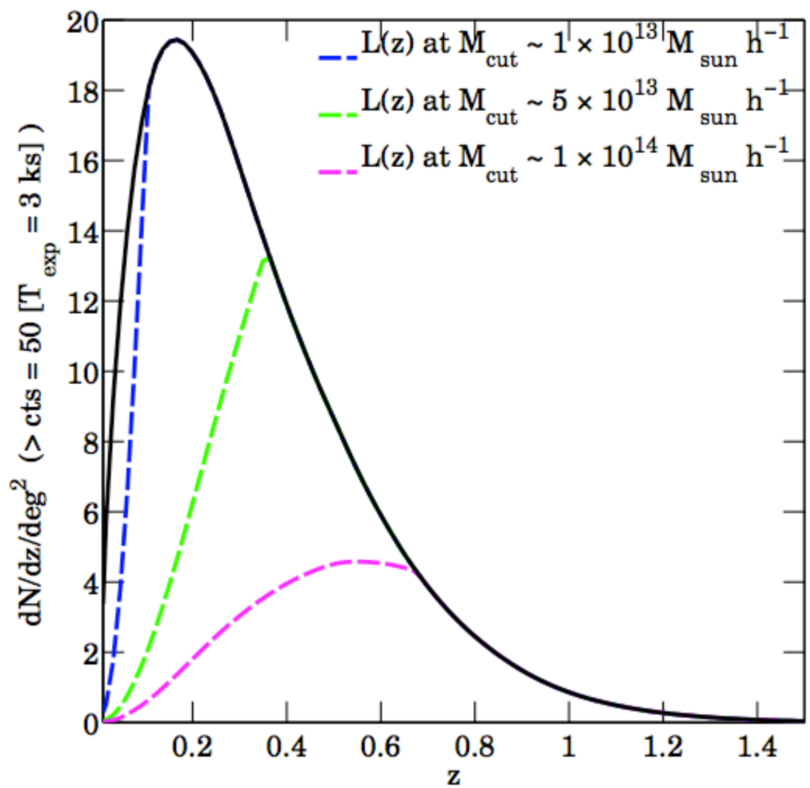
extended Roentgen Survey with an Imaging Telescope Array

- Primary instrument onboard the Russian Spectrum-Roentgen-Gamma satellite (SRG)
- German-Russian mission. Launched from Baikonur in 2012 (leased by Kazakhstan to Russia)
- L2 orbit
- First all-sky imaging survey in the medium energy X-ray band up to 10 keV with unprecedented spectra and angular resolution
- 7 Wolter-1 mirror modules (containing 54 shells each), special detectors

eROSITA science goals

- Detect the hot intergalactic medium of 10^5 galaxy clusters and groups for studies of structure formation and cosmology
- Detect all obscured accreting black holes in nearby galaxies
- Study galactic X-ray sources

Pillepich, CP & Reiprich 2011



Forecasted marginal constraints

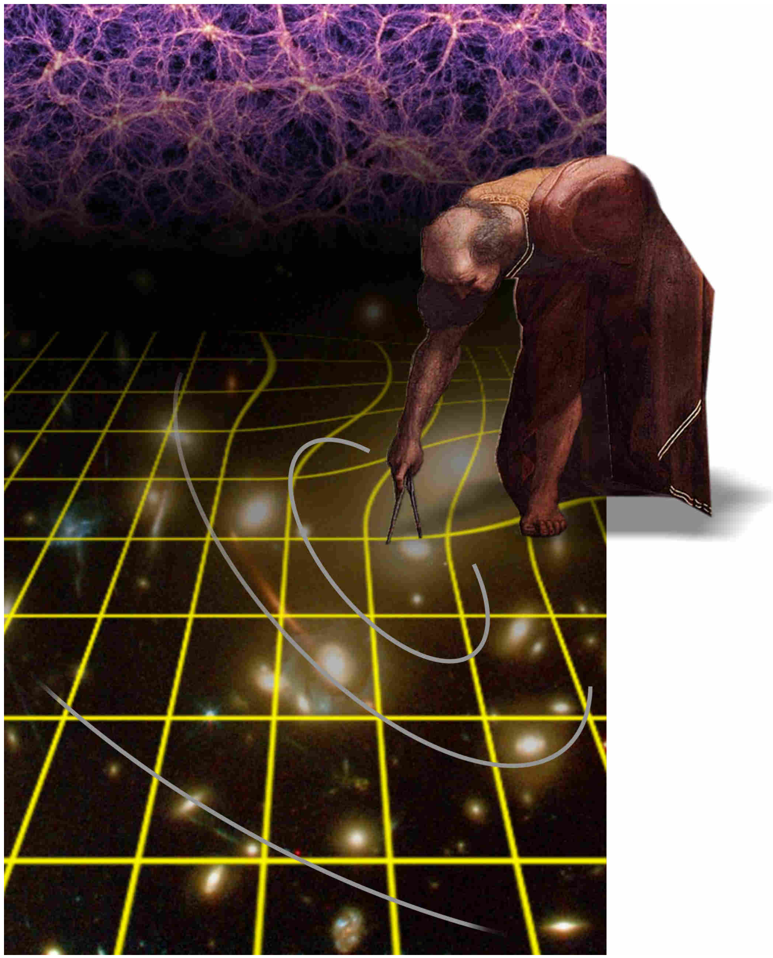
(Fisher matrix with many cosmo + nuisance ICM parameters)

Pillepich, CP & Reiprich 2011

	f_{NL}	n_s	σ_8
I: Counts	7600	2.3	1.6
II: Counts +photoz	248	0.402	0.084
III: Angular Clustering	22	0.378	0.136
IV: Tomography	6.6	0.185	0.135
I + III	21	0.288	0.071
II+IV	6.1	0.071	0.034
I+III+Planck C_l	18	0.022	0.006
II + IV + Planck C_l	5.1	0.006	0.002

PNG of the local type

The EUCLID mission

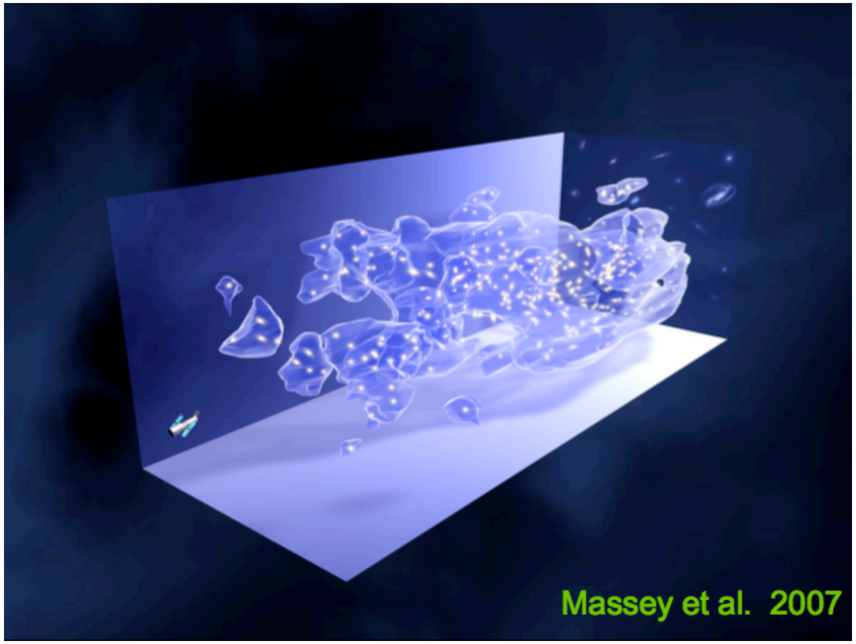


- M-class mission within the Cosmic Vision program of the European Space Agency
- “High-precision survey mission to map the geometry of the dark universe”
- Now in the competitive Definition Phase, launch expected in 2018
- >200 people, 30 Institutions, 7 countries

The EUCLID concept

The EUCLID mission is being optimized for two complementary cosmological probes

- Weak gravitational lensing
- Baryonic acoustic oscillations
- Full extragalactic sky survey with 1.2m telescope at L2
- Additional probes: galaxy clusters, redshift-space distortions, integrated Sachs-Wolfe effect
- Legacy science for a wide range of areas in astronomy



EUCLID imaging surveys

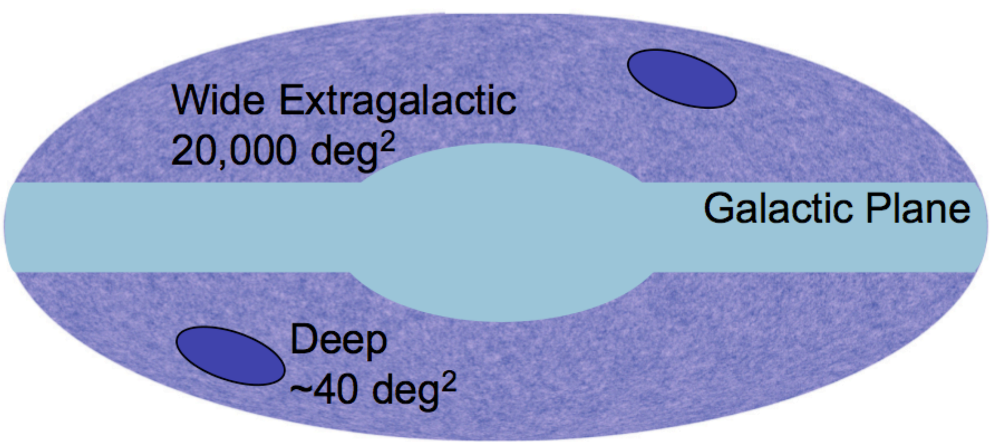
Wide survey (20,000 deg^2)

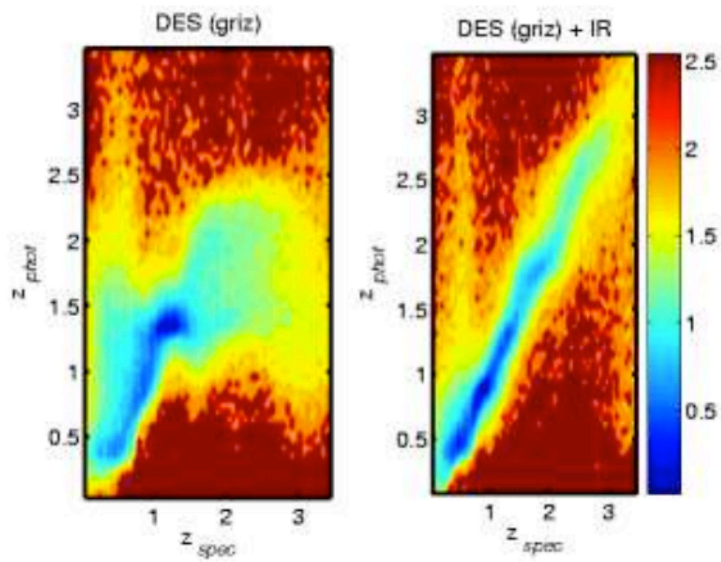
- Galaxy shape measurements in the visible band to $RIZ_{AB} < 24.5$ (10σ) yielding 30-40 resolved galaxies/$arcmin^2$ with a median redshift of 0.9

- Near-infrared photometry yielding photometric redshift errors of 0.03-0.05 (1+z) with ground-based complements (DES, PanStarrs)

Deep survey (40 deg^2):

- 2 mag deeper for both visible and NIR data

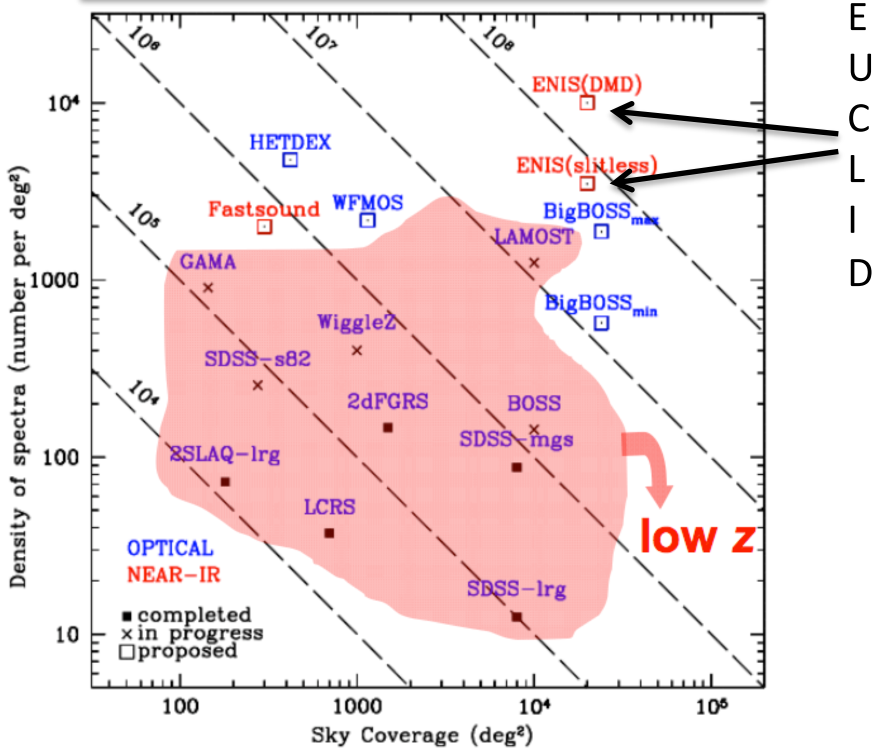




EUCLID spectroscopic survey

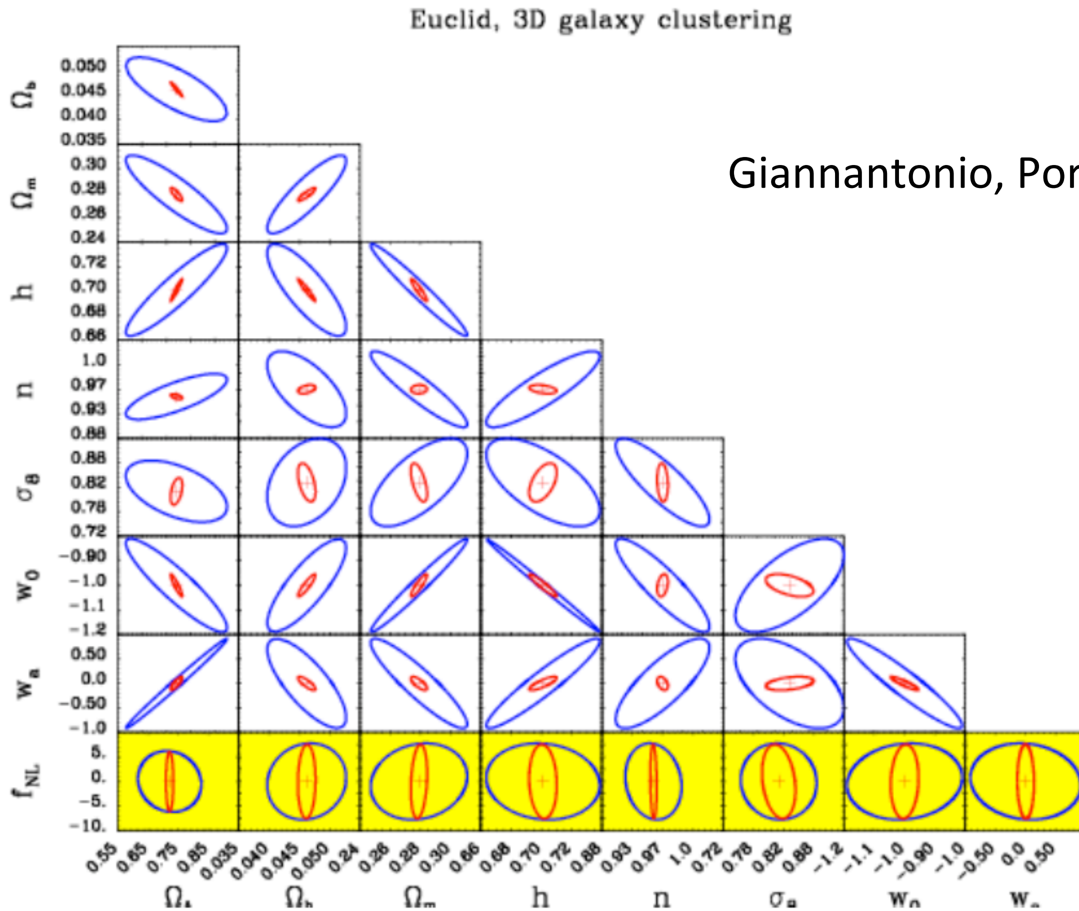
- 20,000 deg^2 in 5 yr
- Slitless spectroscopy with spectral resolution R=500 (1-2 μm) in the near infrared
- $F_{H\alpha}>4x10^{-16}$ erg s^{-1} cm^{-2} (star-forming galaxies)
- $\sigma_z<0.001(1+z)$
- Spectroscopic completeness >0.35 for a total of 70 million galaxy redshifts

Current and future redshift surveys



Impact of EUCLID on PNG

Giannantonio, Porciani et al. 2011



PNG of the local type

Impact of EUCLID on PNG

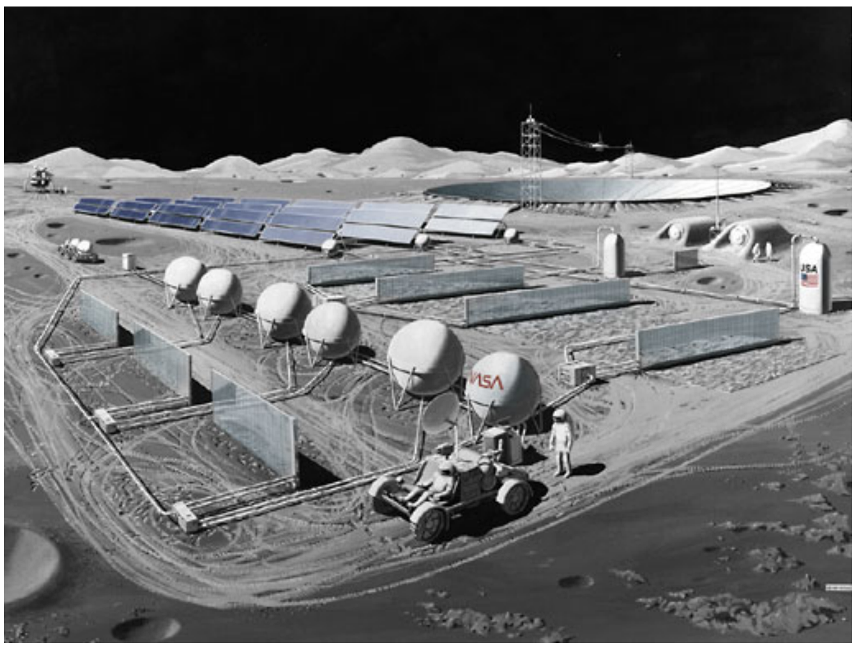
Giannantonio, Porciani et al. 2011 (preliminary)

Probe	Δf_{NL} Local		Δf_{NL} equilateral		Δf_{NL} orthogonal	
	EUCLID	+ Planck	EUCLID	+ Planck	EUCLID	+ Planck
Weak lensing	39	19	18	9.2	5.2	2.7
2D clustering	1.9	1.8	140	29	35	6.9
3D clustering	2.9	2.8	190	34	40	8.8
Combined	1.4	1.3	6.9	4.4	2.1	1.2

For the simplest scale-dependent models (in the local case): Δn_{fnl}=0.05
(Interesting!!!! See C. Byrnes and S. Shandera talks)

1. This is only from 2-point statistics!!!
2. Fiducial model assumes f_{NL}=0 (slightly worse forecasts for the alternative case)
3. In the non-local cases signal comes mainly from lensing, we need to test the halo model is accurate enough against N-body simulations.

Next frontier: the dark side of the Moon!



Credit: NASA

- Constraints from the 21-cm background in the dark ages (bispectrum)
- Tomography of HI distribution between $30<z<100$ would give: $\Delta f_{NL} << 1$
- This would require better modeling of GR and second order effects

Pillepich, CP & Matarrese (2007)
Cooray (2007)

Conclusions

- Primordial non-Gaussianity is fertile land for both theorists and observers
- Near future missions will be able to constrain f_{NL} with a statistical error of ~3 and n_{fNL} to 0.05
- To make this possible we have to work hard on the systematics, especially modeling galaxy biasing and dynamical non-linearities