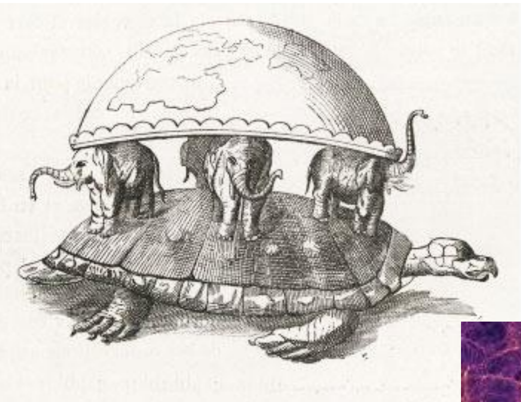
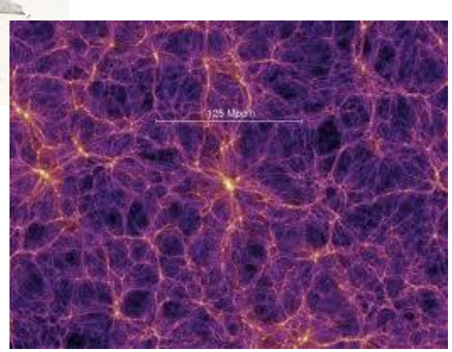
Structure Formation: à la recherche de paramètre perdu





Séminaires de l'IAP

Shant Baghram

IPM-Tehran

13 September 2013

Collaborators:

Hassan Firouzjahi (IPM), Shahram Khosravi (Kharazmi University-IPM),

Mohammad Hossien Namjoo (IPM), Nareg Mirzathuny (Sharif University of technology),

Hosien Moshafi (Institute in Advance Studies in Basic Sciences)

arXiv:1303.4368 __JCAP08(2013)048

arXiv:1305.0813,

arXiv:1308.2874

Content of the talk:

- **6 parameter standard Cosmology model and open Questions**
- Accelerated Expansion of the Universe
- ❖ Modified gravity as a source of accelerated expansion
- Initial Conditions
- ❖ Non-Gaussian, Anisotropic inflationary models and LSS
- Simultaneous effect of MG and NG inflationary models
- Conclusion and further remarks

Cosmology in Background

$$H^2 = \frac{8\pi G}{3}\rho$$

- Cosmology is a Science of measuring two quantities

Alan Sandage, Physics Today 1970 H, q

$$q = -\frac{\ddot{a}a}{\dot{a}^2}$$

- Geometrical tests of Background Cosmology

We are measuring distances in the Universe

Standard candles

Standard Rulers

Photo: Lawrence Berkeley National Lab — Saul Perlmutter

Photo: Belinda Pratten, Australian National University — Brian P. Schmidt

Photo: Scanpix/AFP — Adam G. Riess

The Nobel Prize in Physics 2011 was awarded *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"* with one half to Saul Perlmutter and the other half jointly to Brian P. Schmidt and Adam G. Riess.

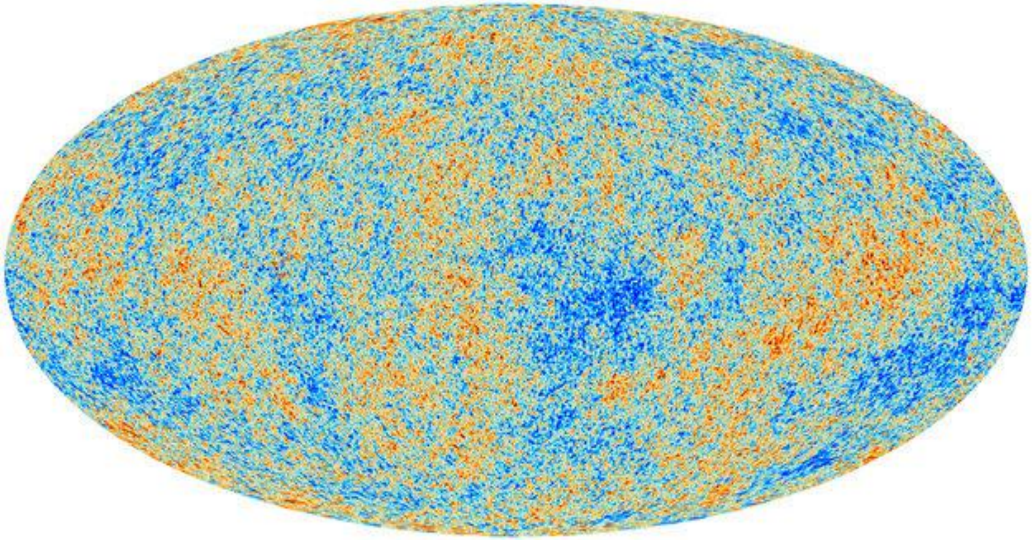
$$d_L = (1+z)\int \frac{dz}{H(z)}$$

Background is boring:
Cosmology with Perturbations

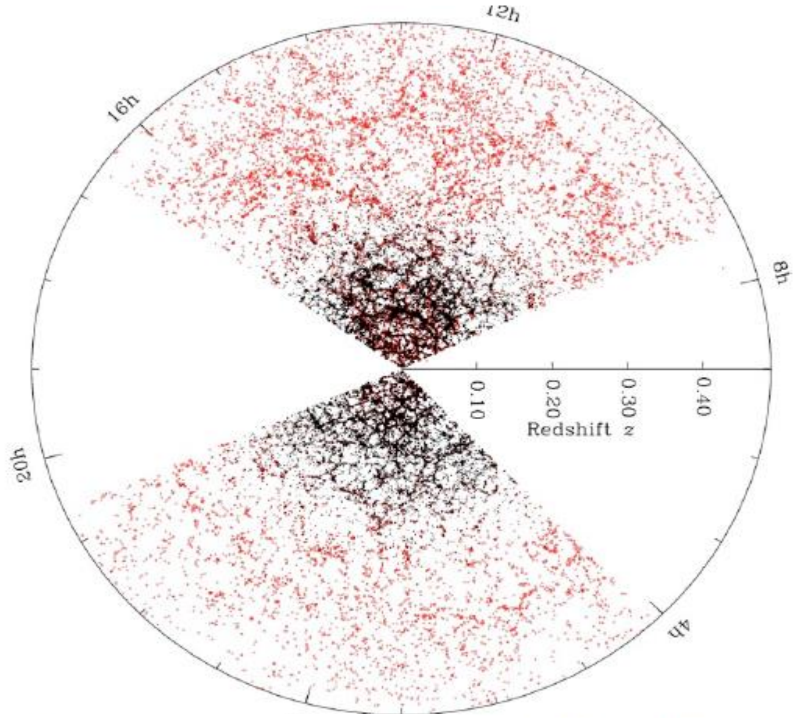
- Precision Cosmology with perturbations

$$\frac{\delta T}{T} \sim 10^{-5}$$

$$\delta_g(R) = \frac{n_g(R) - \bar{n}_g}{\bar{n}_g}$$



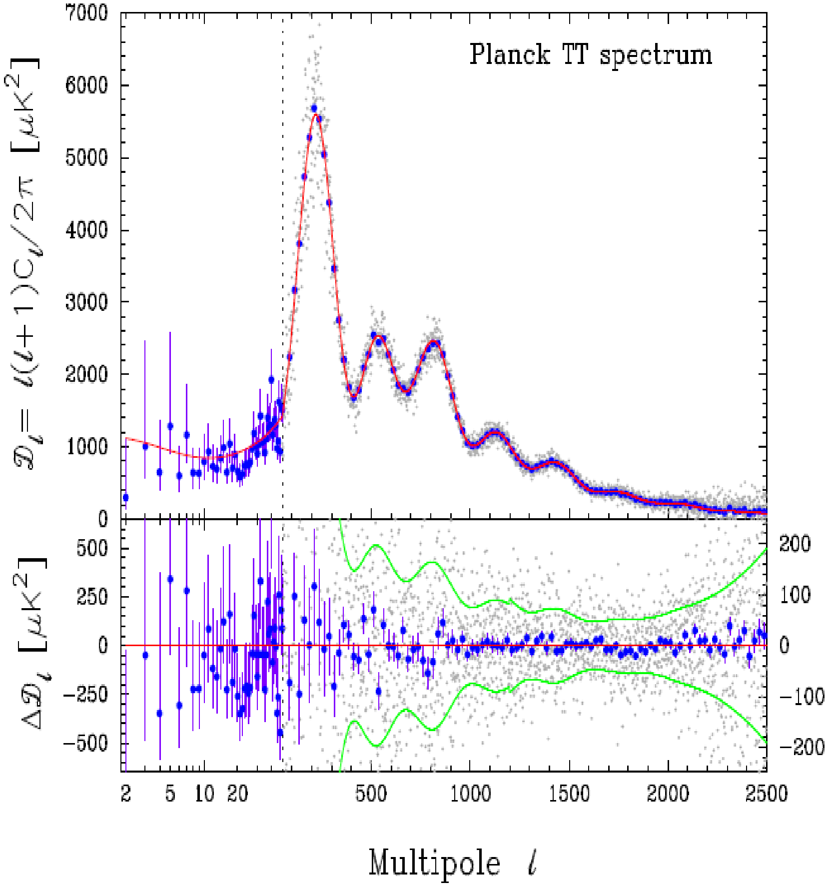
Planck 2013

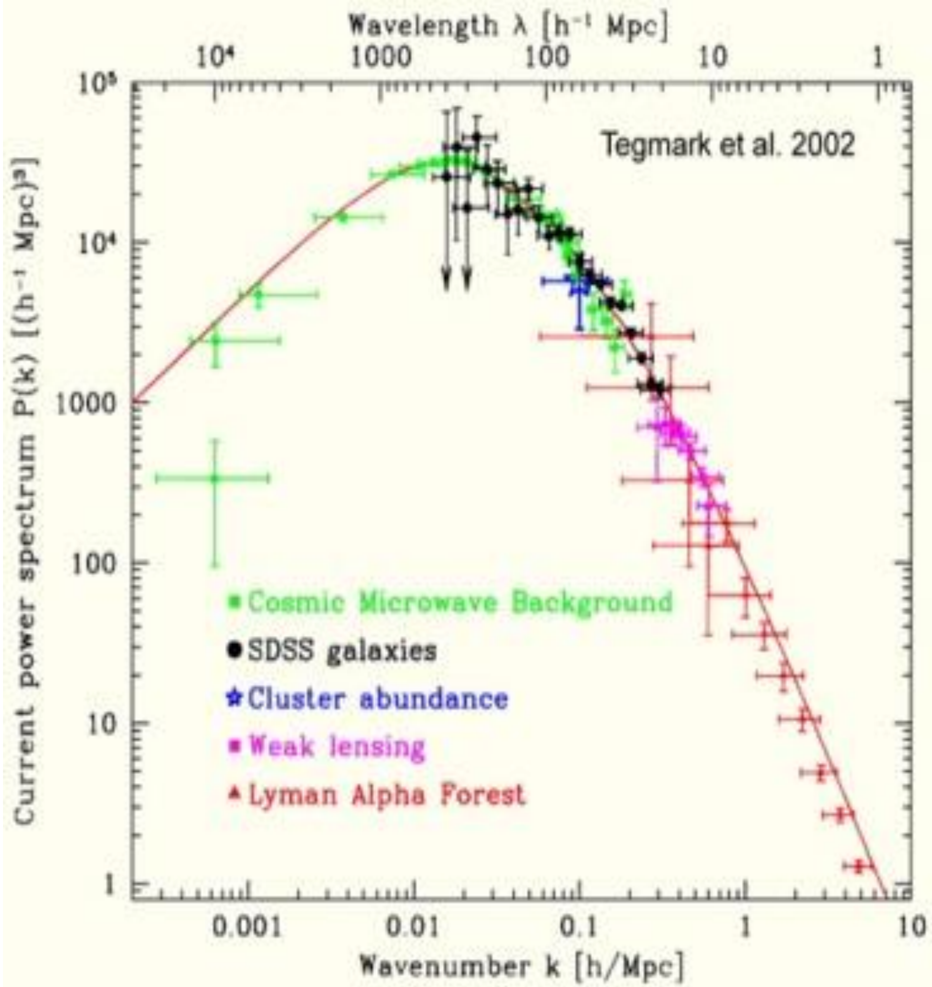


credit: Michael Blanton

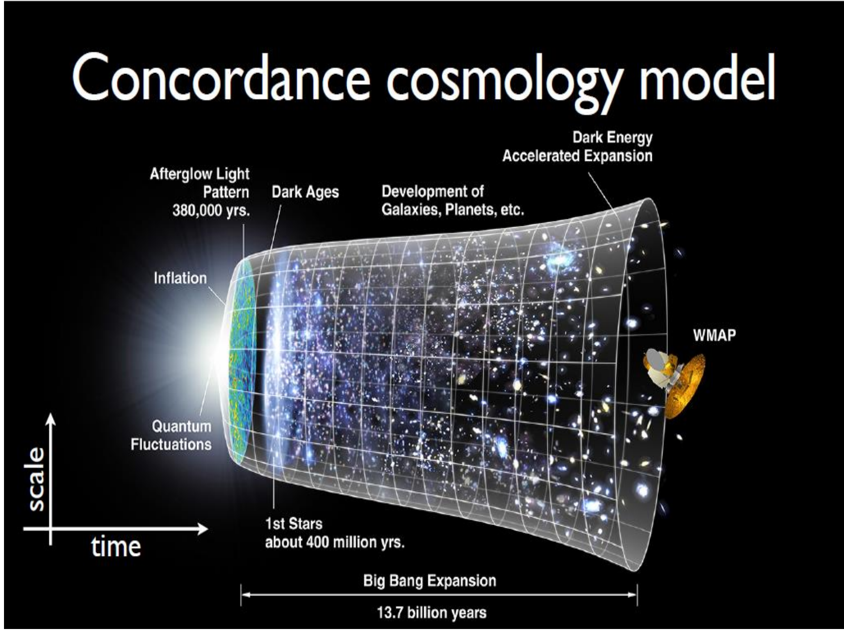
The Tale of two Power Spectrums

- Establishment of standard model of Cosmology





The tale of two standard model



A Universe is made up of

- Baryons 5% (Standard Model of Particles) $\Omega_b h^2$
- Cold Dark Matter 27% $\Omega_c h^2$
- Dark Energy 68% Ω_Λ

Known as ΛCDM A

- with Initial Conditions n_s

Gaussian, isotropic, adiabatic and scale invariant τ

3 Questions for 21th Century

1)Why is the Universe accelerating? (Dark Energy)

2)What is Missing Matter? (Dark Matter)

3)What is the physics of early Universe? (Inflation)

- **Large Scale Structure can address these three questions.**
- **We will need to add free parameters to our known 6**

Content of the talk:

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How to explain the Accelerated Expansion of the Universe?

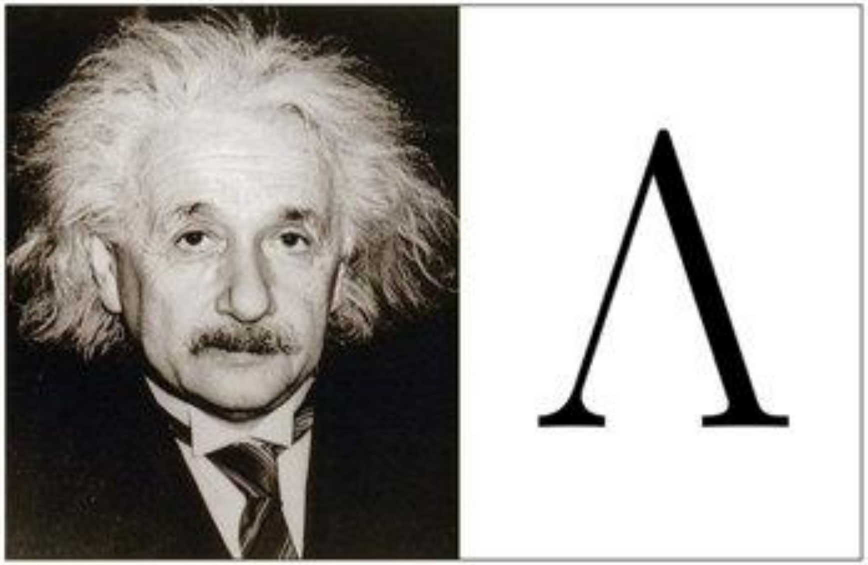
Cosmological Principle +CDM/baryons+ GR

How to explain the Accelerated Expansion of the Universe?

Cosmological Principle +CDM/baryons+ GR

✓ Does the Cosmological Constant cause the acceleration of the Universe?

(Old-new Cosmological constant problem)

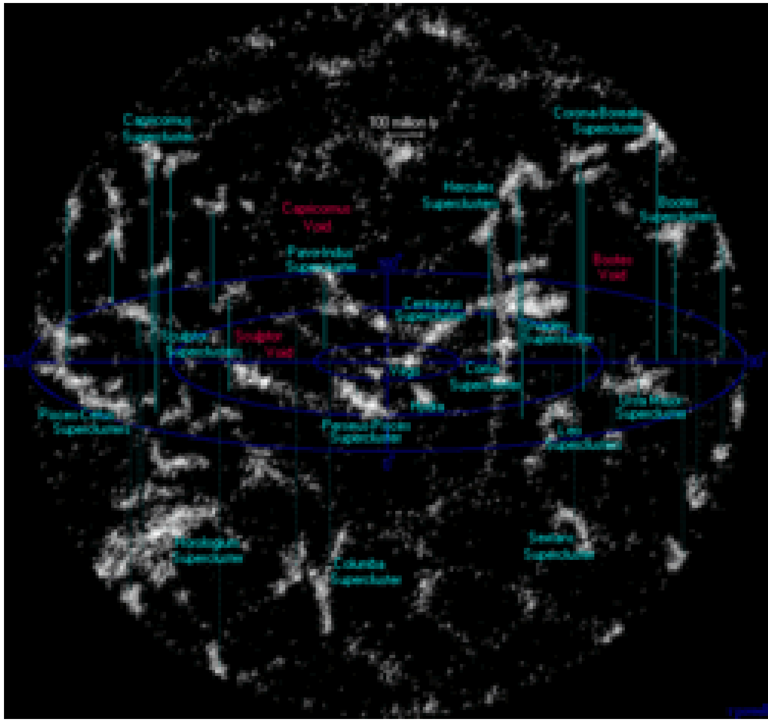


How to explain the Accelerated Expansion of the Universe?

Cosmological Principle +CDM/baryons + GR

✓ Cosmological Principle: Homogenous and Isotropic Universe

✓ Non homogenous Universe



How to explain the Accelerated Expansion of the Universe?

Cosmological Principle +CDM/baryons + GR

✓ Is Dark Energy a dynamical exotic entity

(e.g. quintessence, k-essence,...)?

$$w_{DE} = \frac{p_{DE}}{\rho_{DE}}$$

$$w_{DE} = w_0 + w_a \frac{z}{1+z}$$

$w_0 \sim 0.01$

$w_a \sim 0.1$

Euclid goal

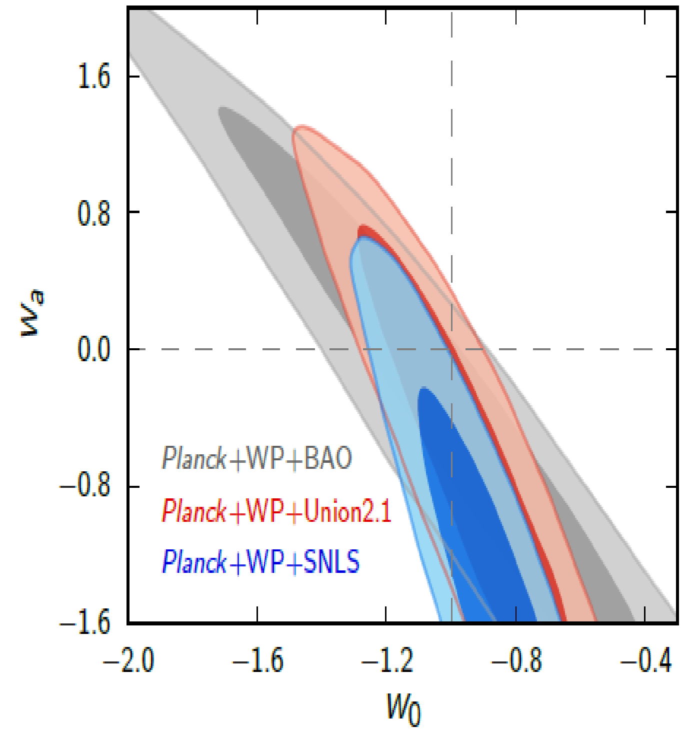


Fig. 36. 2D marginalized posterior distributions for w_0 and w_a, for the data combinations *Planck*+WP+BAO (grey), *Planck*+WP+Union2.1 (red) and *Planck*+WP+SNLS (blue). The contours are 68% and 95%, and dashed grey lines show the cosmological constant solution.

Planck 2013

How to explain the Accelerated Expansion of the Universe?

Cosmological Principle +CDM/baryons + GR

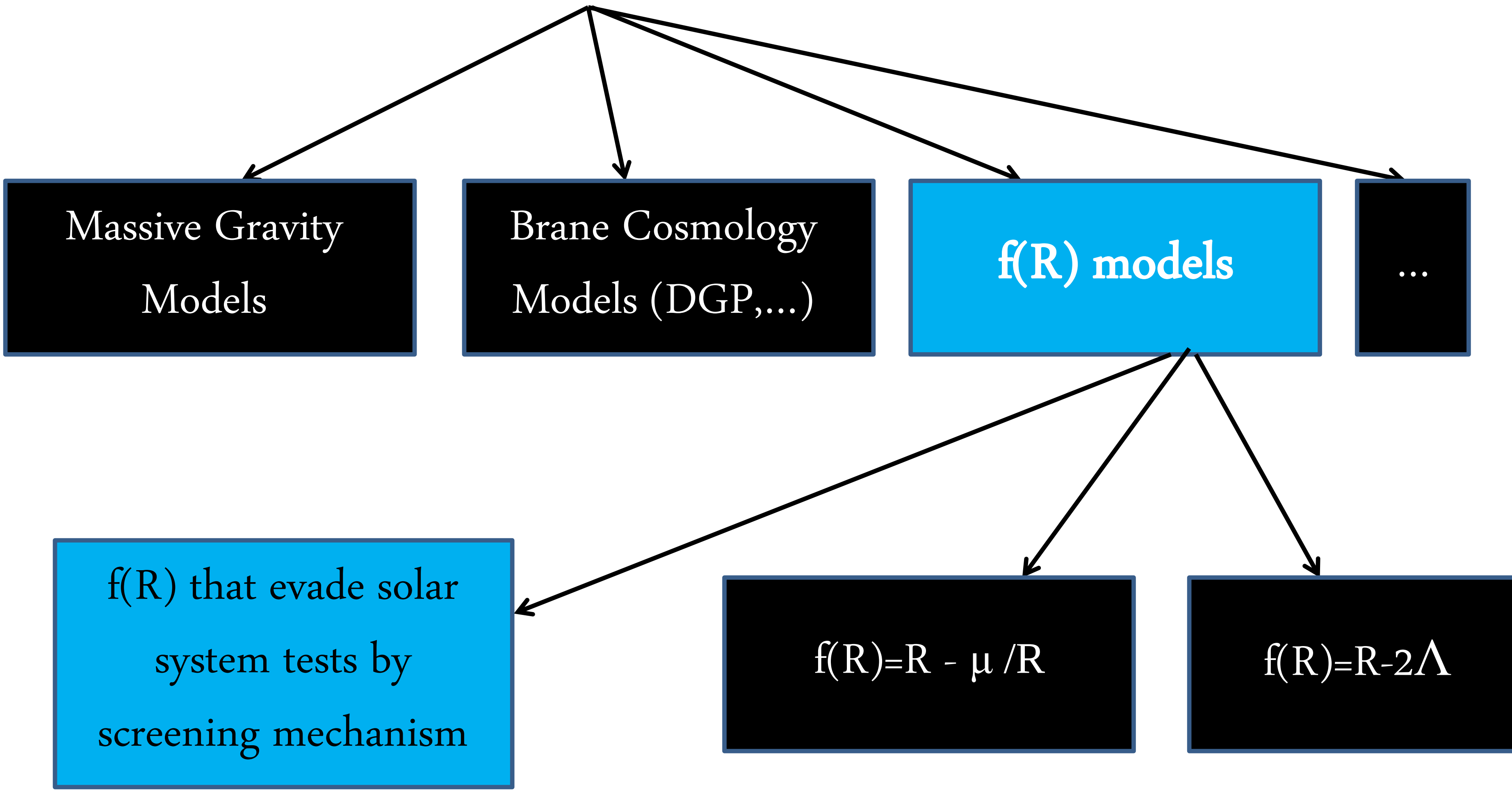
✓ Is GR the correct classical theory of Gravity?

✓ Modification of GR (e.g. f(R) gravities)

What we mean by Modified Gravity?

Model	Dark Matter Problem	Dark Energy Problem
1	CDM	Cosmological Constant
2	MG (e.g. MOND)	Cosmological Constant
3	CDM	MG
4	CDM	Quintessence
5	….	….

Modified Gravity



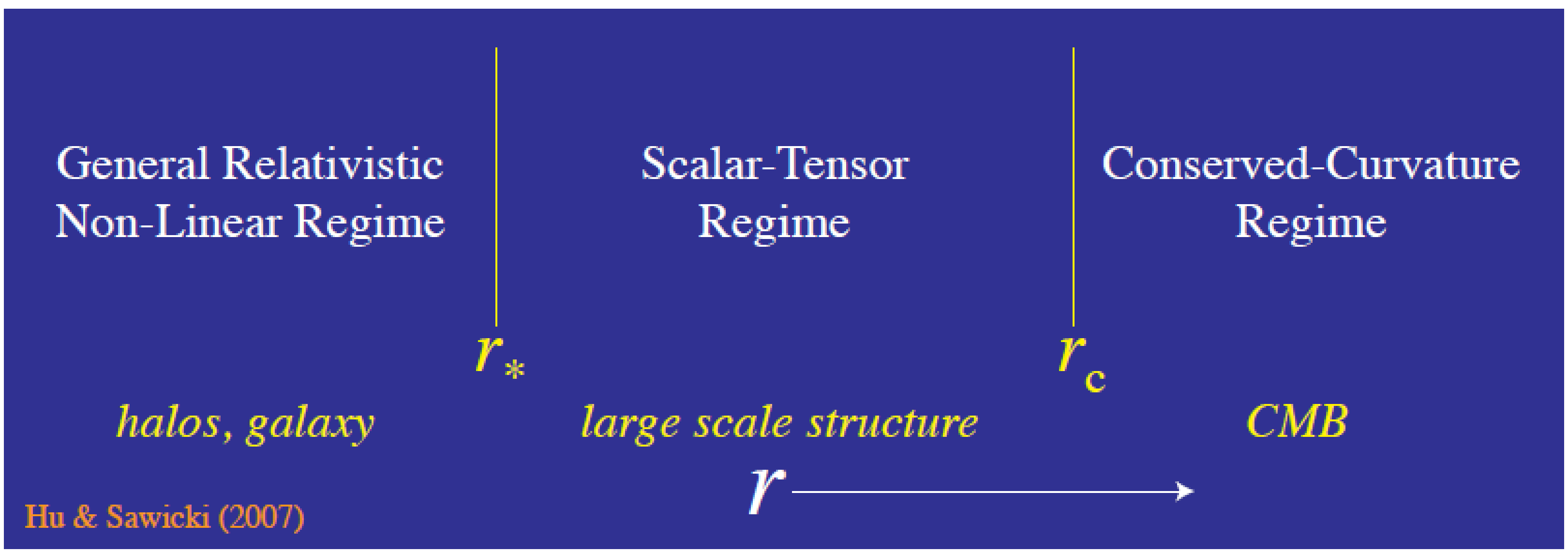
Why f(R) gravity?

Modified gravity Theories and where the scale dependence come?

$$S = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\, f(R) + S_m(g_{\mu\nu}, \Psi_m)$$

$$F = \frac{\partial f(R)}{\partial R}$$

$$M^2 = \frac{F}{3F_{,R}}$$



Large Scale Structure Formation : GR vs MG

✓ Distribution of luminous matter

(Correlation functions-Power spectrum, cluster count)

✓ BAO

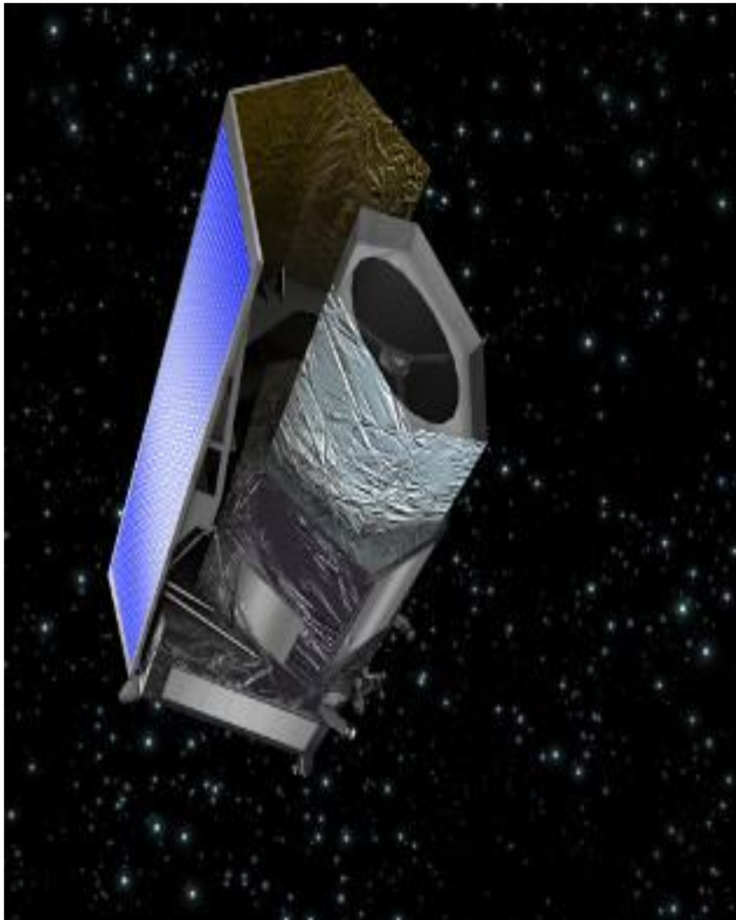
✓ Weak Gravitational Lensing

✓ SNIa: distance measurements

✓ CMB lensing

✓ 21 cm

✓ ISW …



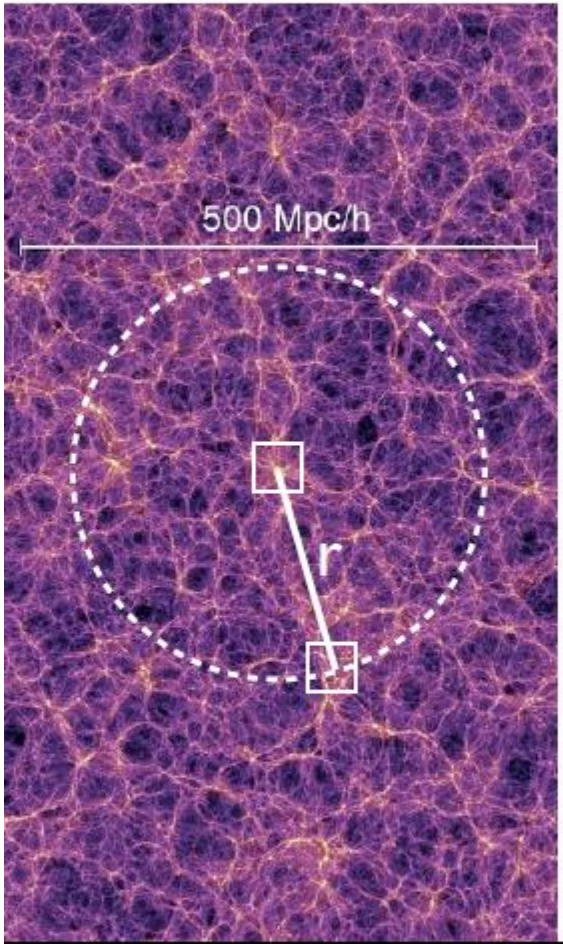
Statistical Properties of our Universe

- We need to define the two point correlation function as:

$$\xi(\vec{r}) = \langle \delta(\vec{x})\delta(\vec{x}+\vec{r}) \rangle$$

where the correlation function is the excess of particles from randomness.

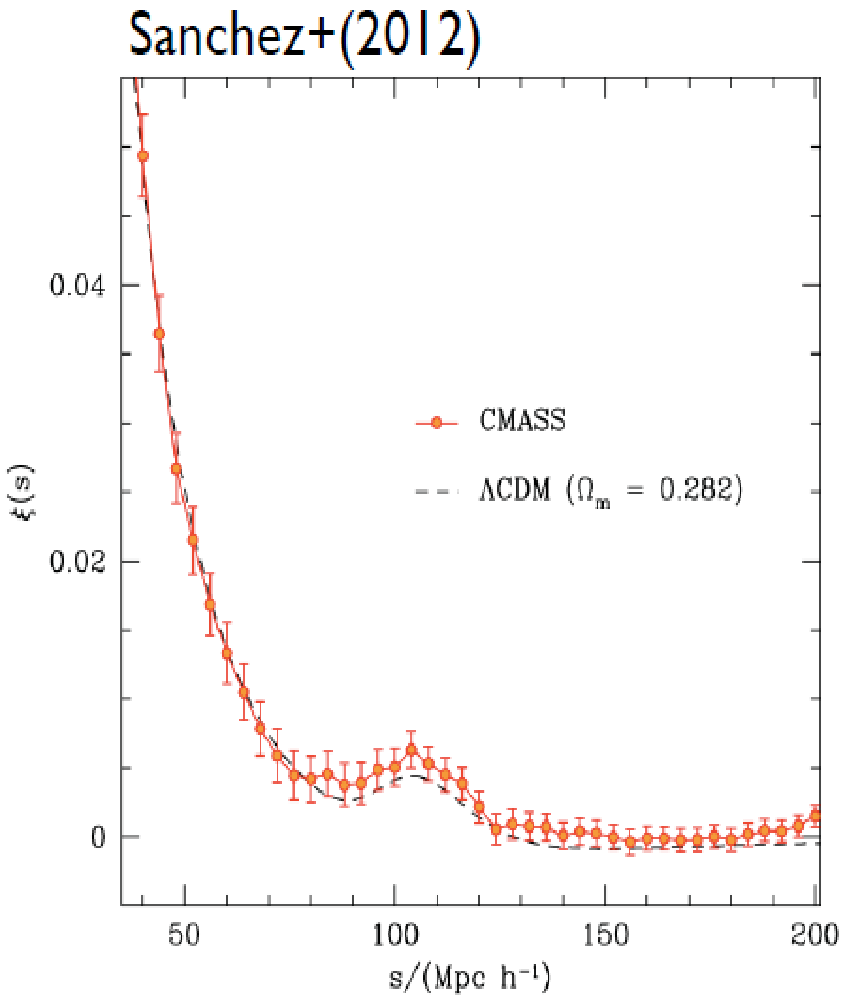
$$\delta(x) = \frac{\rho(x) - \rho_b}{\rho_b}$$

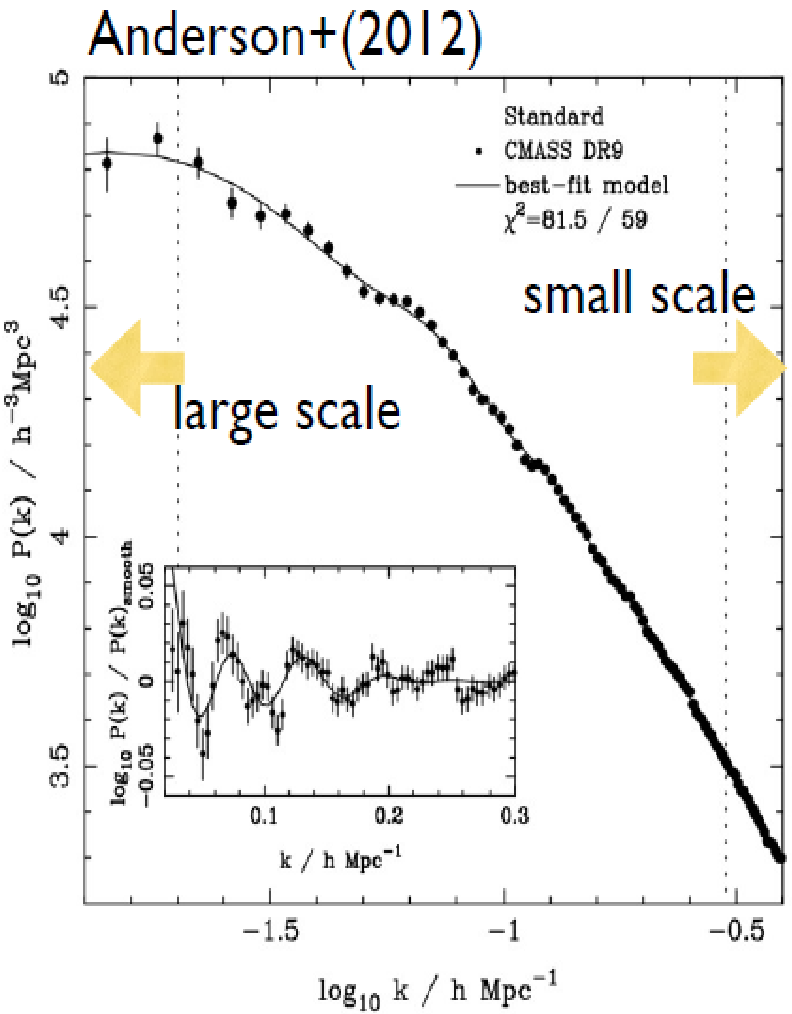


Where power-spectrum is the Fourier transform of correlation function as:

$$\langle \delta(\vec{k})\delta(\vec{k}') \rangle = (2\pi)^3 P(k)\delta^D(\vec{k}+\vec{k}')$$

Correlation function and Power Spectrum of matter





What is the matter Power-Spectrum?

- The matter power spectrum $P(k,z)$ in present time can be found by knowing:

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1)Primordial power spectrum:

encoded in spectral index and the amplitude of perturbations A, n_s

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3)The Evolution of density contrast due to expansion of universe $D(z)$

$$P(k,z) = Ak^{n_s}T^2(k)D^2(z)$$

$$\delta(z) = D(z)\delta_0$$

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$$P(k,z) = Ak^{n_s} T^2(k) D^2(z)$$

Growth function

$$\delta(z) = D(z)\delta_0$$

How do we find the growth rate D(z) ?

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$$ds^2 = -dt^2 + a^2(t)\delta_{ij}dx^i dx^j$$

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Linear Perturbation theory:

$$\delta G_{\mu\nu} = 8\pi G \delta T_{\mu\nu}$$

1)The perturbed metric : 10 degrees of freedom and the gauge

$$g_{00}(\vec{x},t) = -1 - 2\Psi(\vec{x},t)$$
$$g_{0i}(\vec{x},t) = 0$$
$$g_{ij}(\vec{x},t) = a^2\delta_{ij}(1 + 2\Phi(\vec{x},t))$$

$$\ddot{\vec{x}} = -\vec{\nabla}\Psi$$
$$\nabla^2\Phi = -4\pi G a^2 \delta\rho$$

How do we find the growth rate D(z) ?

$$G_{\mu\nu} = 8\pi G T_{\mu\nu} \qquad ds^2 = -dt^2 + a^2(t)\delta_{ij}dx^i dx^j$$

Linear Perturbation theory: $\delta G_{\mu\nu} = 8\pi G \delta T_{\mu\nu}$

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$$\ddot{\vec{x}} = -\vec{\nabla}\Psi$$
$$\nabla^2\Phi = -4\pi G a^2 \delta\rho$$

2)Energy-momentum tensor of perturbations

$$T_{\mu\nu} = (\rho + p)u_\mu u_\nu + p g_{\mu\nu} + q_\mu u_\nu + q_\nu u_\mu + \pi_{\mu\nu}$$

$$\delta T_0^0 = -\delta\rho$$
$$\delta T_i^0 = -\delta T_0^i = (1+\omega)\rho v^i$$
$$\delta T_i^i = c_s^2 \delta\rho$$

What are the players of linear Perturbation theory?

- Geometry terms

$$\Psi(t,\vec{x})$$

$$\Phi(t,\vec{x})$$

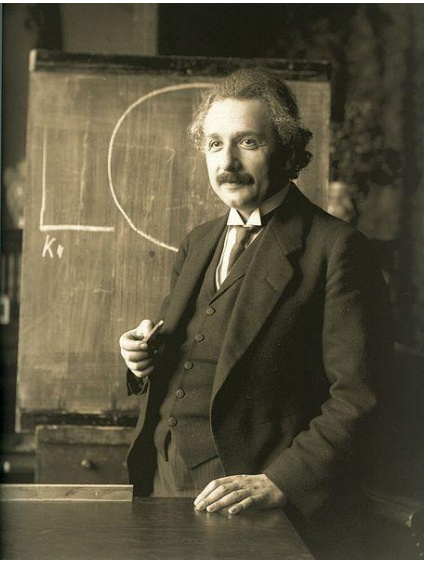
- Energy momentum terms

$$\delta(t,\vec{x})$$

$$\theta = \nabla . v$$

gauge issue: gauge-invariant quantities

Equations you have to Solve!

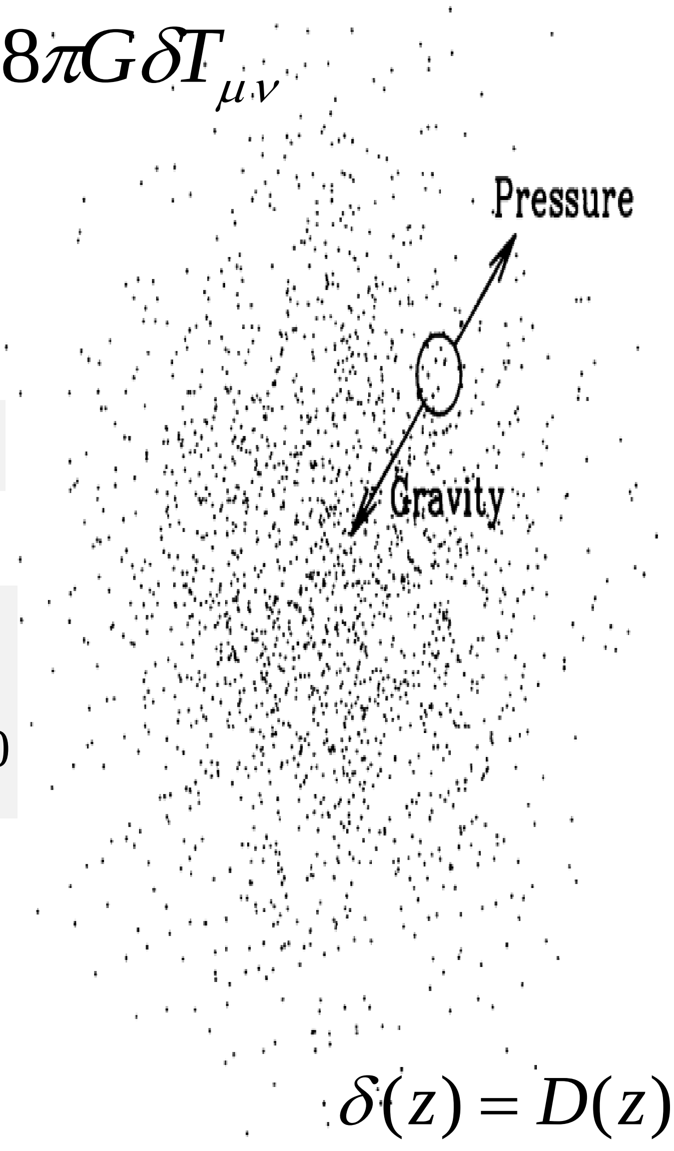


$$T^{\nu}_{\mu\nu;} = 0 \qquad \delta G_{\mu\nu} = 8\pi G \delta T_{\mu\nu}$$

$$\ddot{\delta} + [pressure - garvity]\delta = 0$$

$$\ddot{\delta} + 2H\dot{\delta} = 4\pi G\rho + c_s^2\nabla^2\delta$$

$$\ddot{\delta}_k + 2H\dot{\delta}_k + \delta_k[\frac{c_s^2 k^2}{a^2} - 4\pi G\rho\delta_k] = 0$$



background **Law of gravity**

$$\delta(z) = D(z)\delta_0$$

Growth function: MG vs GR

GR $$\ddot{\delta}_m + 2H\dot{\delta}_m - 4\pi G\rho\delta_m = 0$$ $$\delta(z) = D(z)\delta_0$$

- We choose Hu-Sawicki model $$f(R) = R - \mu R_c \frac{(R/R_c)^2}{1+(R/R_c)^2}$$
- We choose the free parameter of the model: $$f_0 = \frac{\partial f(R)}{\partial R}\Big|_{R=R_0} - 1$$

$$\ddot{\delta}_m + 2H(z)\dot{\delta}_m - 4\pi G_{eff}(k,z)\rho_m\delta_m = 0$$

$$f_{growth} = \frac{d\ln\delta}{d\ln a}$$

Scale dependent Growth rate

$$\frac{df_{growth}(k,z)}{dz} - \frac{f_{growth}{}^{2}(k,z)}{1+z} + \left(\frac{dH/dz}{H} - \frac{2}{1+z}\right) f_{growth}(k,z) + \frac{3}{2} H_0^2 \Omega_m^0 \frac{(1+z)^2}{H^2} \frac{G_{eff}(k,z)}{G} = 0$$

$$H^2 = \left(\frac{1}{a}\frac{\mathrm{d}a}{\mathrm{d}t}\right)^2 = H_0^2 \left[\Omega_{m_0} a^{-3} + \left(1-\Omega_{m_0}\right) \exp\left(-3\int_1^a \frac{1+w(a')}{a'} \mathrm{d}a\right)\right].$$

Scale dependent Growth rate

$$f_0 = \frac{\partial f(R)}{\partial R}|_{R=R_0} - 1$$

$$\frac{df_{growth}(k,z)}{dz} - \frac{f_{growth}^{\;2}(k,z)}{1+z} + \left(\frac{dH/dz}{H} - \frac{2}{1+z}\right) f_{growth}(k,z) + \frac{3}{2} H_0^2 \Omega_m^0 \frac{(1+z)^2}{H^2} \frac{G_{eff}(k,z)}{G} = 0$$

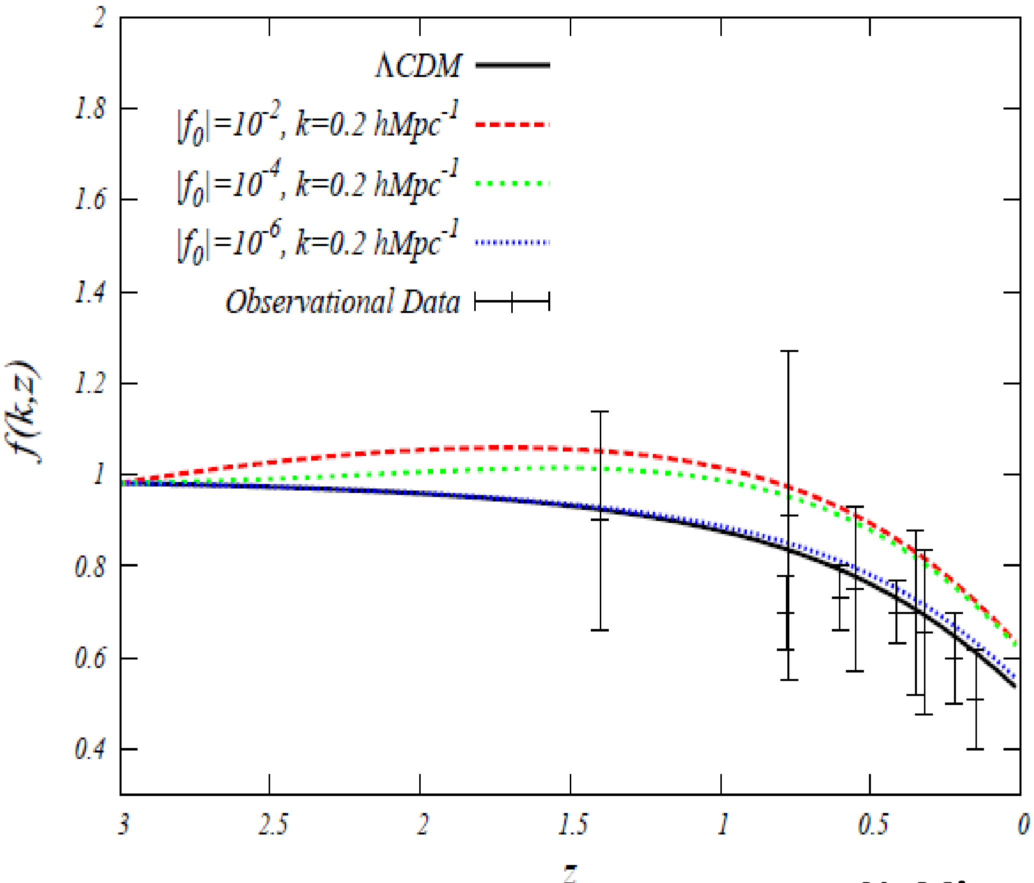


TABLE I: Growth rate f_{obs} observational constraints

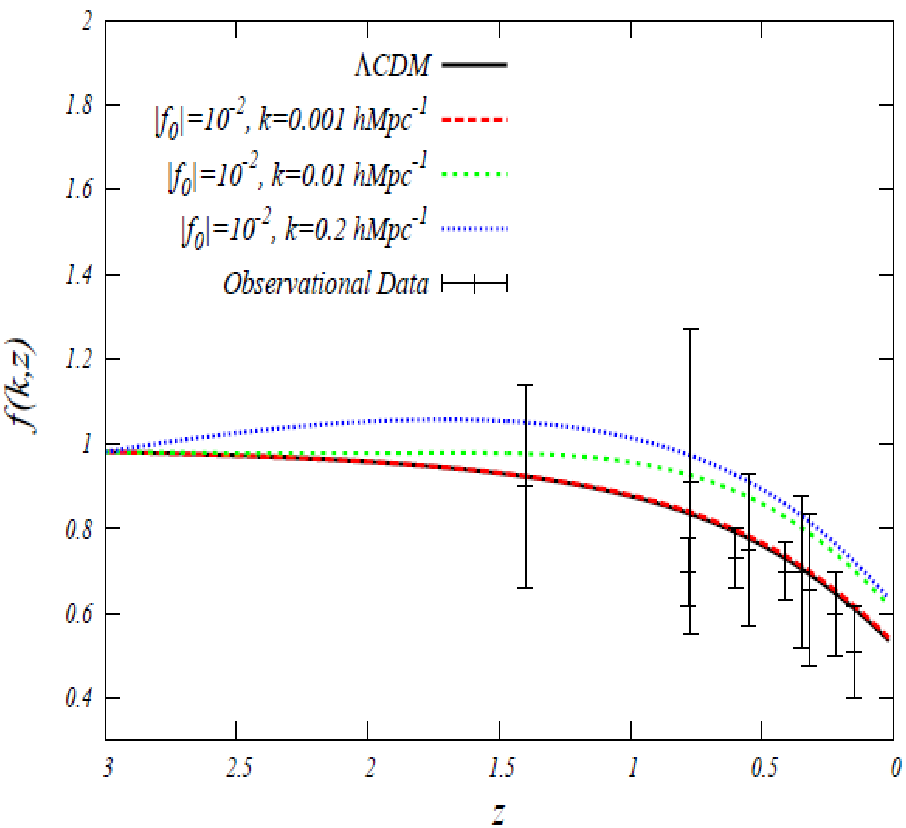
z	f_{obs}	σ	Survay	Ref.
0.15	0.51	0.11	2dF	[44–46]
0.22	0.60	0.10	WiggleZ	[24]
0.32	0.654	0.18	SDSS	[47]
0.35	0.70	0.18	SDSS	[48]
0.41	0.70	0.07	SDSS	[24]
0.55	0.75	0.18	2dF-SDSS	[49]
0.60	0.73	0.07	SDSS	[24]
0.77	0.91	0.36	VIMOS-VLT	[50]
0.78	0.70	0.08	SDSS	[24]
1.4	0.90	0.24	2dF-SDSS	[51]
3.0	1.46	0.29	SDSS	[52]

N. Mirzathuny, Sh. Khosravi, SB and H.Moshafi

arXiv:1308.2874

Scale dependent Growth rate

$$\frac{df_{growth}(k,z)}{dz}-\frac{f_{growth}^{\,2}(k,z)}{1+z}+\left(\frac{dH/dz}{H}-\frac{2}{1+z}\right)f_{growth}(k,z)+\frac{3}{2}H_0^2\Omega_m^0\frac{(1+z)^2}{H^2}\frac{G_{eff}(k,z)}{G}=0$$



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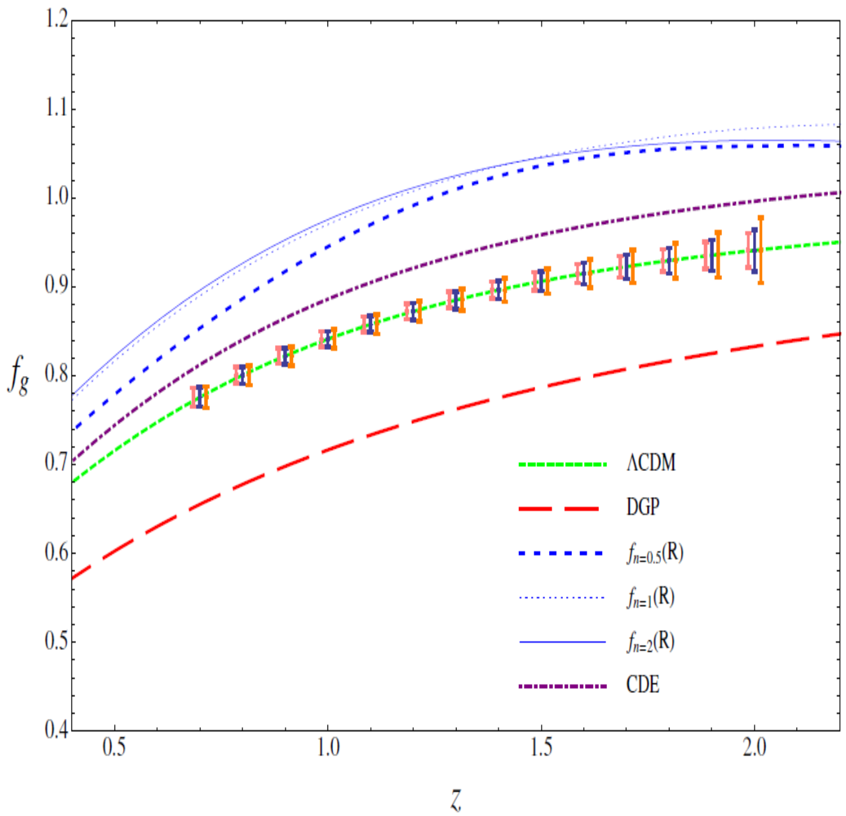
N. Mirzathuny, Sh. Khosravi, SB and H.Moshafi [arXiv:1308.2874]

Scale dependent Growth rate by Euclid

$$\frac{df_{growth}(k,z)}{dz}-\frac{f_{growth}{}^2(k,z)}{1+z}+\left(\frac{dH/dz}{H}-\frac{2}{1+z}\right)f_{growth}(k,z)+\frac{3}{2}H_0^2\Omega_m^0\frac{(1+z)^2}{H^2}\frac{G_{eff}(k,z)}{G}=0$$



Living Rev. Relativity, **16**, (2013), 6
http://www.livingreviews.org/lrr-2013-6
doi:10.12942/lrr-2013-6

LIVING REVIEWS *in relativity*

Cosmology and Fundamental Physics with the Euclid Satellite

Discussion

- ✓ Modified gravity theories introduce a scale dependence in growth of the structures.

- ✓ What other cosmological effects can introduce a scale dependence growth?

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3 Questions for 21 Centaury

1)Why is the Universe accelerating? (Dark Energy)

2)What is Missing Matter? (Dark Matter)

3)What is the physics of early Universe? (Inflation)

Non Gaussianity + Anisotropy can introduce a scale dependence behavior in the growth of the structures through bias.

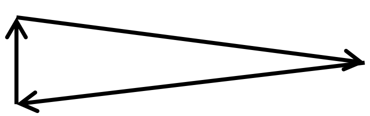
Deviation from a single field Inflationary models?

✓ Non-Gaussianity

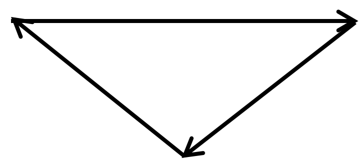
Multi-fields, non Bunch Davis vacuum, entropic perturbations,...

$$\langle \Phi_{k_1} \Phi_{k_2} \Phi_{k_3} \rangle = (2\pi)^3 \delta^D (\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_3) B(k_1, k_2, k_3)$$

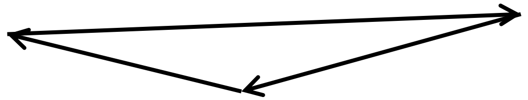
$$B_\Phi(k_1, k_2, k_3) = f_{NL} \frac{1}{k_1^2 k_2^2 k_3^2} F\left(r_2 = \frac{k_2}{k_1}, r_3 = \frac{k_3}{k_1} \right)$$



$f_{NL}^{loc} = 2.7 \pm 5.8$



$f_{NL}^{equi} = -42 \pm 75$



$f_{NL}^{ortho} = -25 \pm 39$

Planck Results

Is there a room for Non Gaussianity (NG)?

✓Anisotropy introduce a NG

Mohammad Hossein Namjoo, Shant Baghram, Hassan Firouzjahi: arXiv:1305.0813

✓LSS observations to detect NG in sub-CMB scales.

✓Scale dependence of NG

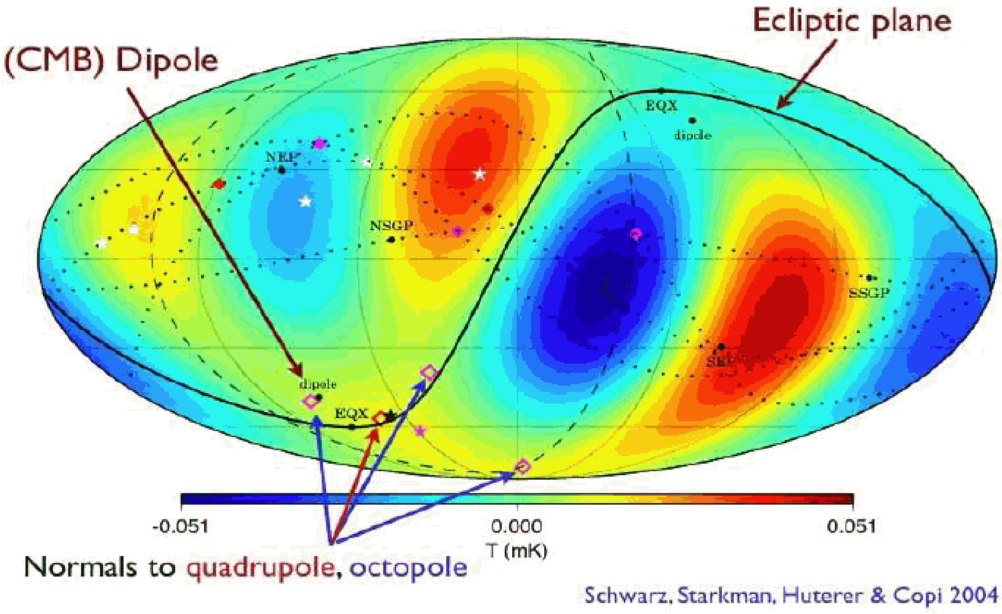
✓Non-trivial NG shapes

Table 10. Separable template-fitting estimates of primordial $f_{\rm NL}$ for local, equilateral, orthogonal shapes, as obtained from SMICA foreground cleaned maps, after marginalizing over the Poissonian point-source bispectrum contribution and subtracting the ISW-lensing bias. Uncertainties are 1σ.

$f_{\rm NL}$		
Local	Equilateral	Orthogonal
2.7 ± 5.8	-42 ± 75	-25 ± 39

Planck (2013)

CMB and Anisotropy



- CMB anomalies

1)Cold Spot

2) hemispherical asymmetry

3) alignment of quadrupole and octopole

4) Power deficiency in low multipoles

- Measure problem
- ...

Intrinsic Anisotropy of CMB

✓ Geometric origin, vector fields, long mode modulation

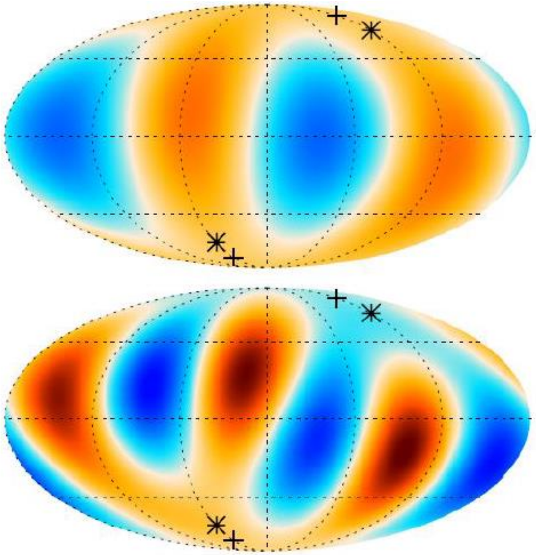
$$\mathcal{P}_{\mathcal{R}}^{1/2}(k,\mathrm{x}) = \mathcal{P}_{\mathcal{R}}^{1/2^{iso}}(k)(1 + A(k)\hat{\mathrm{p}}.\mathrm{x}/x_n)$$

$$P_R^{1/2}(k,x) = P_R^{1/2^{iso}}(k,x)\left(1 + A_{LM}(k)Y_{LM}(\hat{n})\right)$$

Data set	FWHM [°]	A	(l,b) [°]	$\Delta \ln \mathcal{L}$	Significance
Commander	5	$0.078^{+0.020}_{-0.021}$	$(227, -15) \pm 19$	8.8	3.5σ
NILC	5	$0.069^{+0.020}_{-0.021}$	$(226, -16) \pm 22$	7.1	3.0σ
SEVEM	5	$0.066^{+0.021}_{-0.021}$	$(227, -16) \pm 24$	6.7	2.9σ
SMICA	5	$0.065^{+0.021}_{-0.021}$	$(226, -17) \pm 24$	6.6	2.9σ
WMAP5 ILC	4.5	0.072 ± 0.022	$(224, -22) \pm 24$	7.3	3.3σ

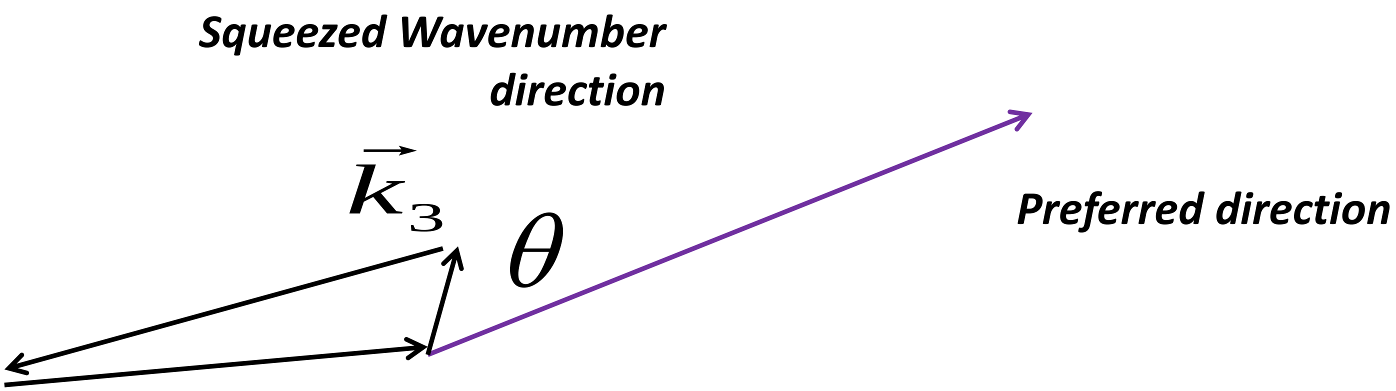
Planck 2013

Anisotropic- Non Gaussian Bias



- Anisotropic Inflationary model:

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{f^2(\phi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\phi)\right],$$



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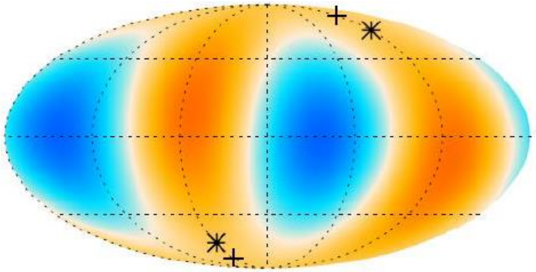
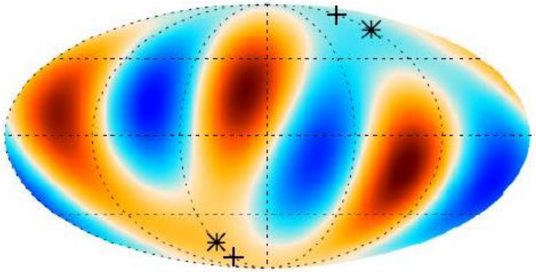
Anisotropic- Non Gaussian Bias





- Anisotropic Inflationary model:

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{f^2(\phi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\phi)\right],$$

- The direction dependent bispectrum

$$B_\zeta(\vec{k}_1,\vec{k}_2,\vec{k}_3) = 288IN(k_1)N(k_2)N(k_3)\left(C(\vec{k}_1,\vec{k}_2)P_0(k_1)P_0(k_2) + 2\text{perm.}\right).$$

$$N(k) - N_{CMB} = \ln\left(\frac{k}{k_{CMB}}\right), \qquad C(\vec{k}_1,\vec{k}_2) \equiv \left(1 - (\hat{k}_1.\hat{n})^2 - (\hat{k}_2.\hat{n})^2 + (\hat{k}_1.\hat{n})(\hat{k}_2.\hat{n})(\hat{k}_1.\hat{k}_2)\right),$$

- Where the free parameter g_* shows itself in:

$$P_\zeta(\vec{k}) = P_0\left(1 + g_*(\hat{k}.\hat{n})^2\right),$$

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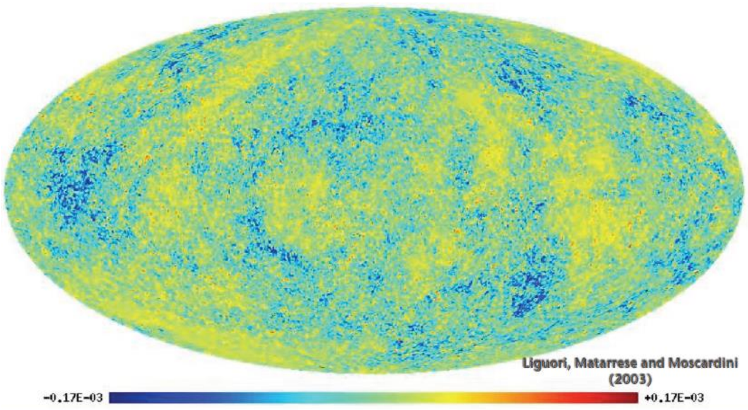
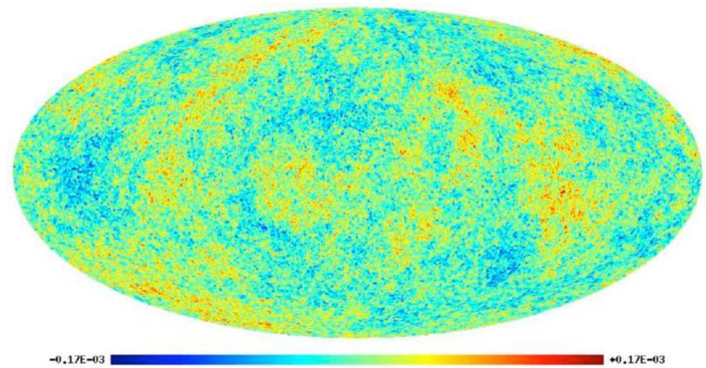
Where we can find the signature of Early Universe?

Where we can find the signature of Early Universe?

- CMB



$$f_{Nl} = 3000$$



$$f_{NL} = 0$$

Komatsu, Spergel 2001

Finger Print of Inflationary Physics in LSS

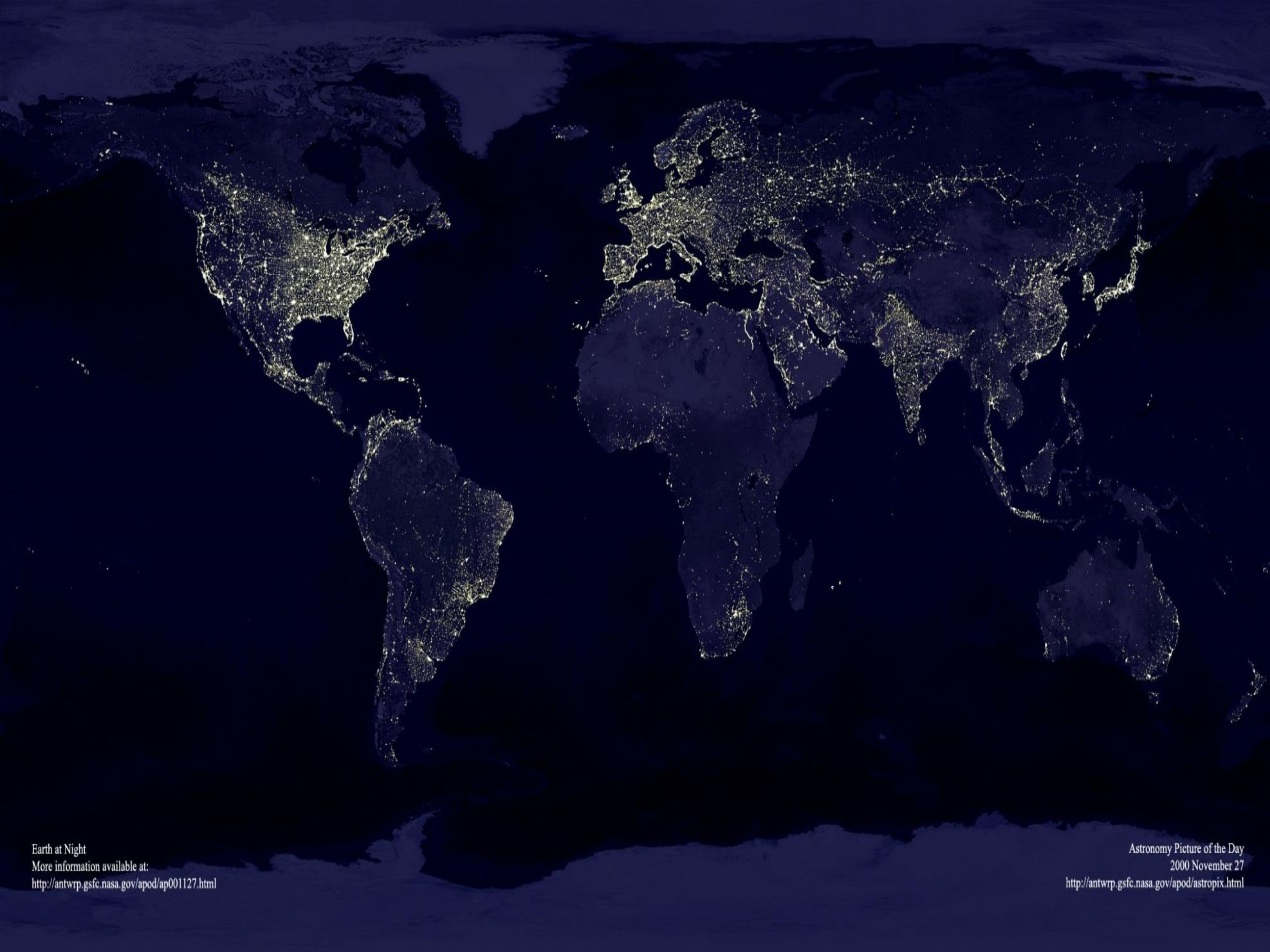
1) Galaxy Power Spectrum

2) The Bispectrum of galaxy distributions

3) Number of rare objects in Universe

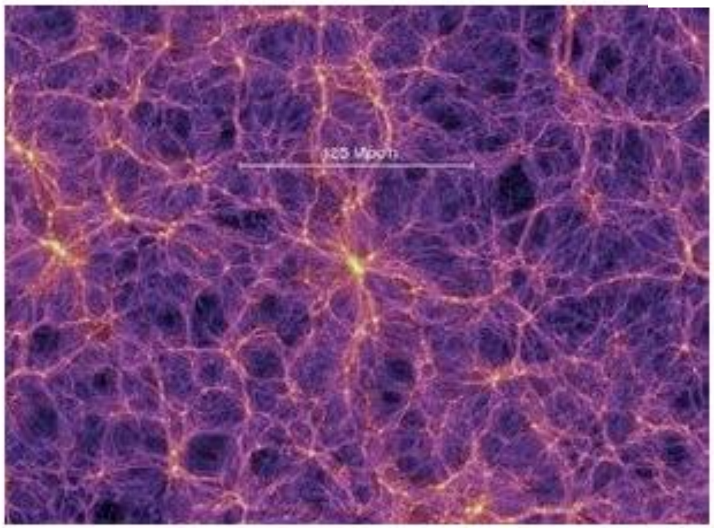
4)The Bias parameter (Non linear Structure formation)

Dalal et al. 2008; Desjacques, Seljak & Iliev 2009; Slosar et al. 2008; Matarrese & Verde 2008; Nishimichi et al. 2009

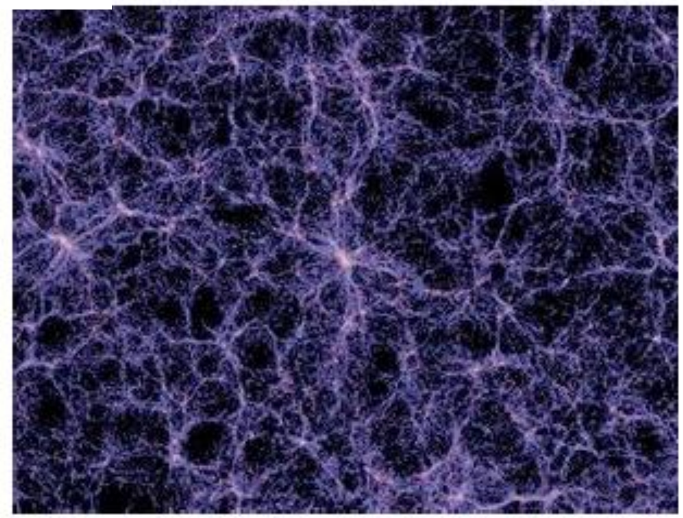

Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

Bias

What we observe in the Universe is the luminous matter



matter density: δ_m

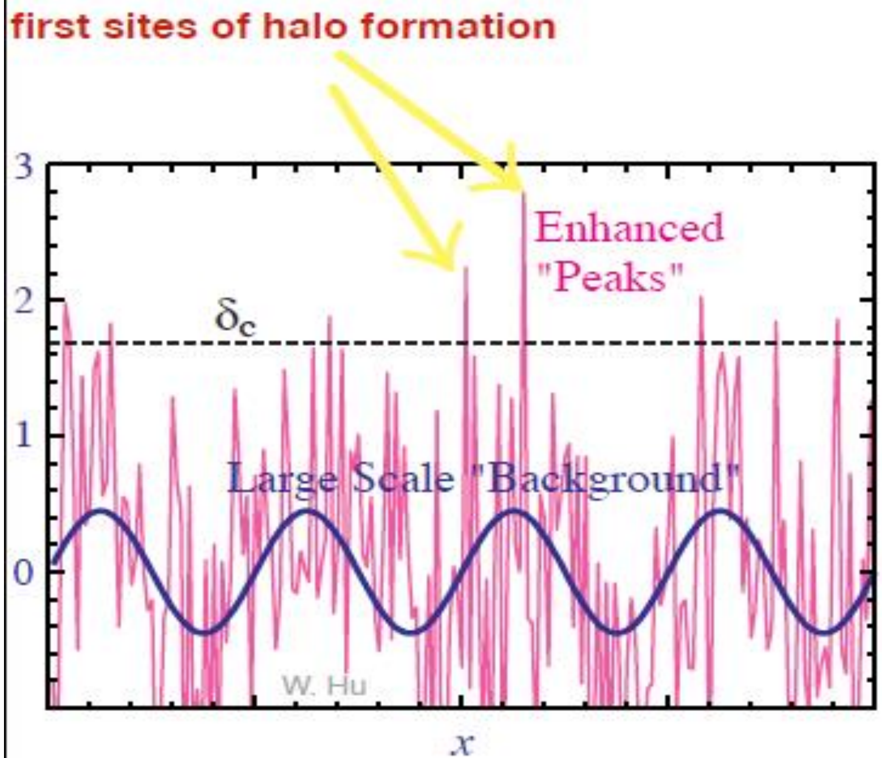


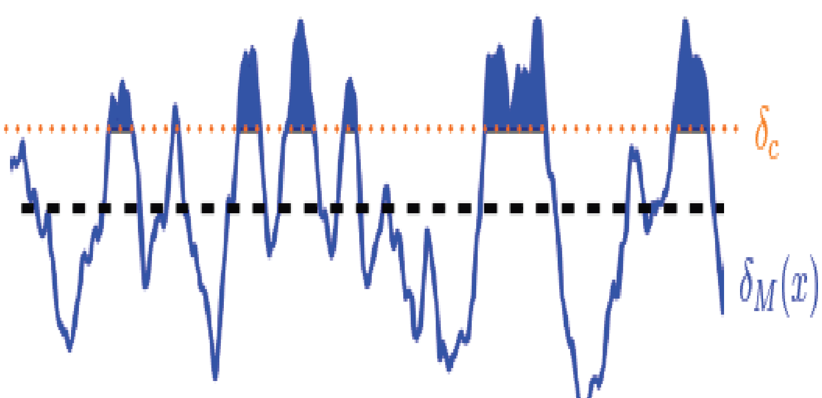
galaxy density: δ_g

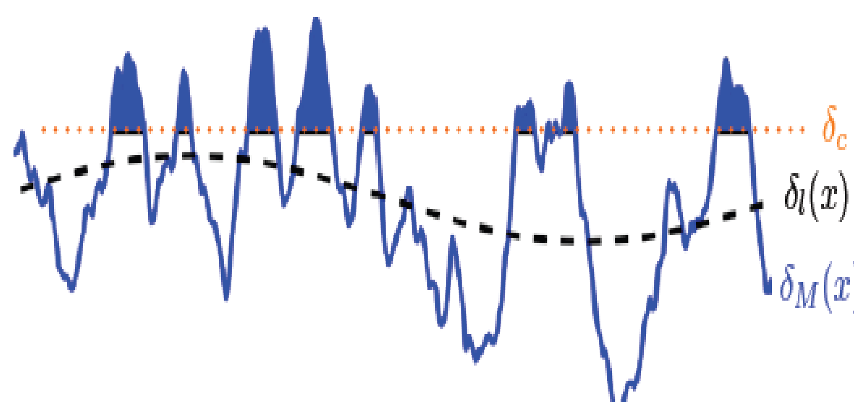
$$\delta_g = \delta_h = b(X_{cosmology}, x_{local})\delta_m$$

$$P_g = b^2 P_m$$

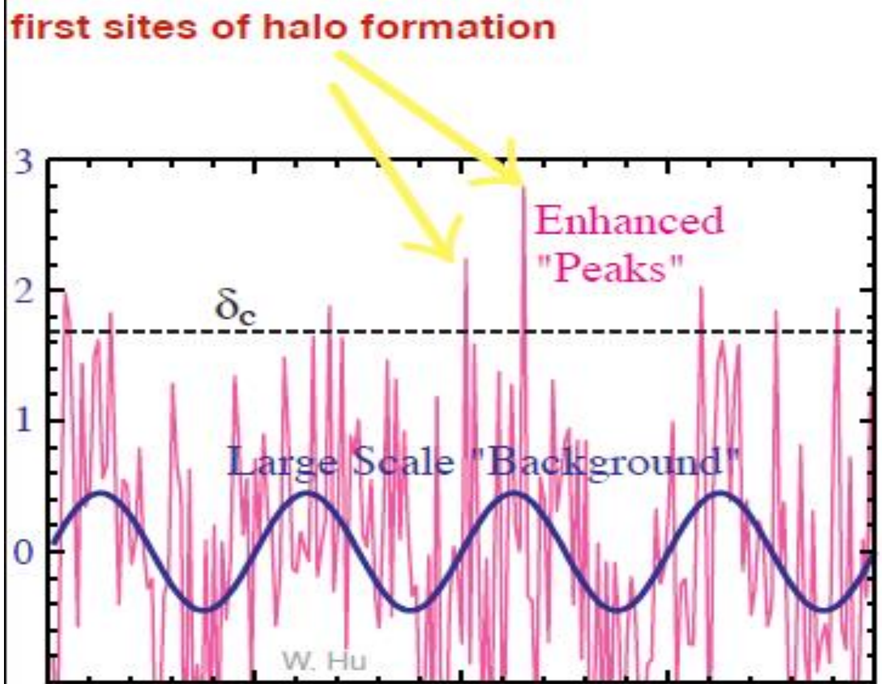
halo formation in peaks





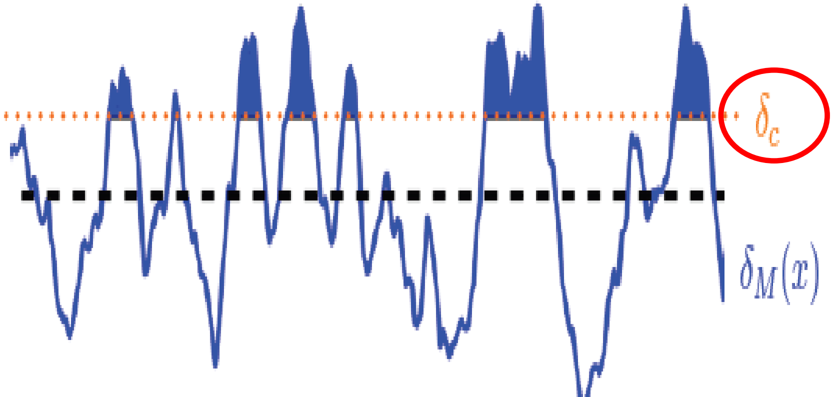


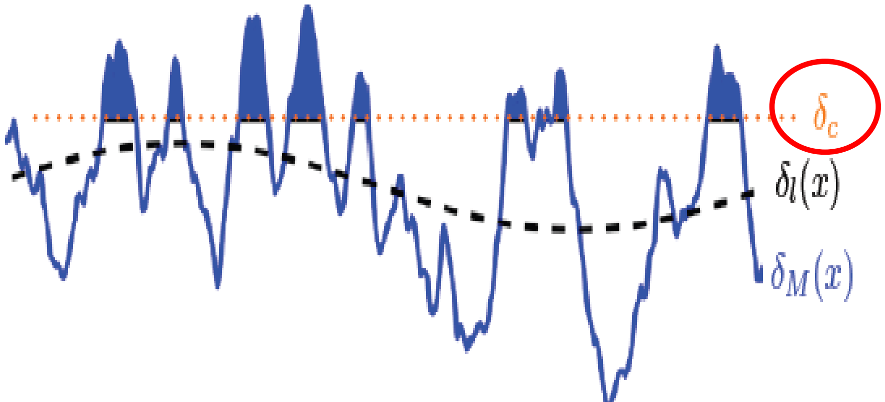
halo formation in peaks



$$\Pi_{PDF}(\delta) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\delta^2 / 2\sigma^2}$$

$$\nu(x) = \frac{\delta(x)}{\sigma_R(M)}$$





How to find bias for a general NG density field

- Intrinsic halo bias via background model $\delta_b \equiv \delta_l$ and mass function modification $n(M)$
- Taylor expand number density $n_M \equiv dn/d\ln M$

$$n_M + \frac{dn_M}{d\nu}\frac{d\nu}{d\delta_b}\delta_b \ldots = n_M\left[1 + \frac{(\nu^2 - 1)}{\sigma\nu}\right]$$

- Combine the enhancement with the original unbiased expectation

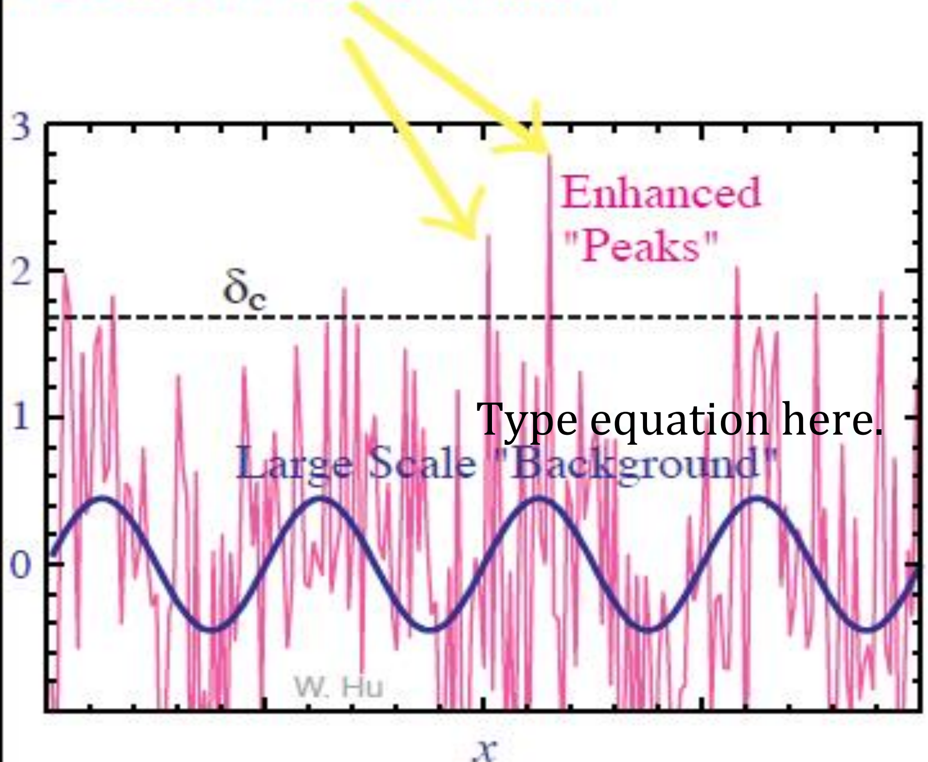
$$\delta_h = \frac{\delta n_M}{n_M} = b(M)\delta$$

- For Press-Schechter

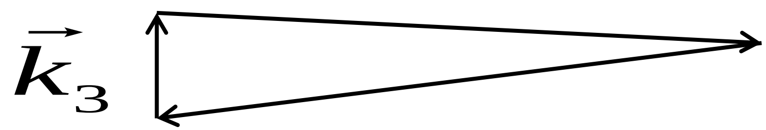
$$b(M) = 1 + \frac{\nu^2 - 1}{\delta_c}$$

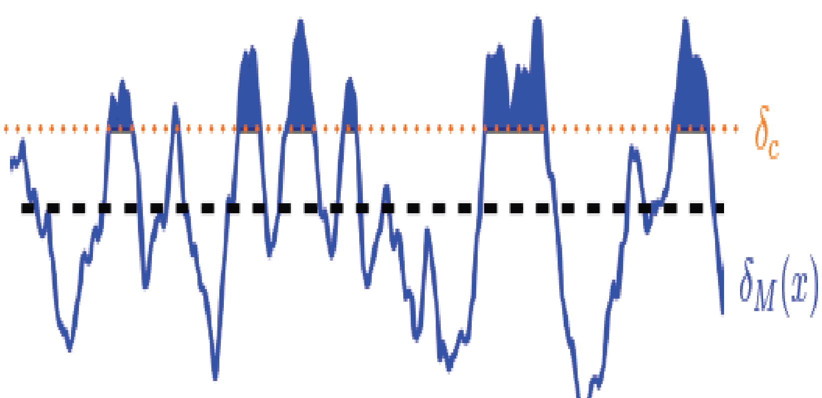
What does Non Gaussianity do to bias!!!

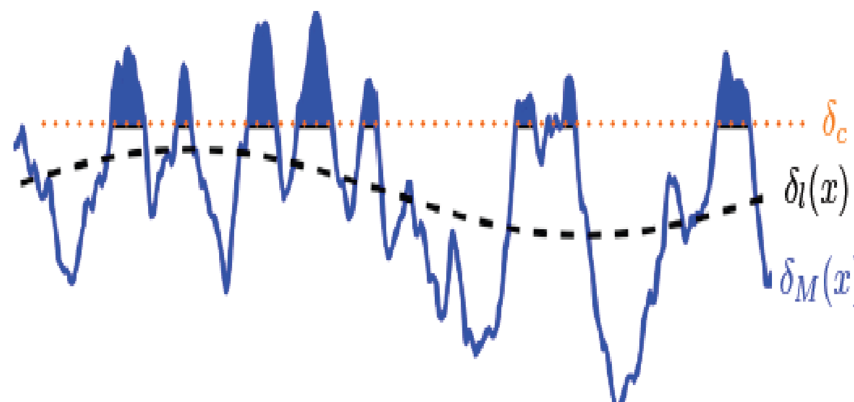
first sites of halo formation



first sites of snowfall







Bias in Peak Background splitting

- There is an intrinsic bias known as halo bias: $\delta_h = b(k,z)\delta_m$
- We can split the perturbations to large-scale and small scale

$$\rho = \bar{\rho}(1+\delta_s+\delta_l)$$

- And the halo number contrast is obtained as:

Long wavelength mode

$$1+\delta_h^L = \frac{\partial_m \int_\infty^{\delta_c} \Pi(\delta_s, \sigma_m^2, \delta_c; \delta_l, \sigma_l^2)\, d\delta_s}{\partial_m \int_\infty^{\delta_c} \Pi_0(\delta_s, \sigma_m^2, \delta_c)\, d\delta_s}$$

R.Scoccimarro et al .Phys. Rev. D 85, 083002 (2012)

The effect of NG on PDF

- The PDF and Cumulates are effected by NG potential

NG field

$$\Pi(\delta_s,\sigma_m^2,\delta_c;\delta_l,0)\rightarrow \Pi[\delta_s,\sigma^2(\phi),c_p(\phi),\delta_c;\delta_l(\phi),0],$$

PDF depend on higher cumulatses and als0othey depend to NG field.

- The first term of **Taylor Expansion**, is the linear bias :

$$p=1:\quad b_{1L}=\frac{\partial_m\int(\partial\Pi/\partial\delta_l)_0}{\partial_m\int\Pi_0}=\left[\frac{\partial}{\partial\delta_l}\ln\left(\frac{dn(\delta_l)}{d\ln m}\right)\right],$$

How Non-Gaussianity effect this:

- The PDF and Cumulates are effected by NG potential

$$\Pi(\delta_s, \sigma_m^2, \delta_c; \delta_l, 0) \to \Pi[\delta_s, \sigma^2(\phi), c_p(\phi), \delta_c; \delta_l(\phi), 0],$$

- The Scale dependence bias Shows UP in second term of

Taylor Expansion, introduced by bispectrum

$$\boxed{p = 2: \quad b_{2L} = \frac{\partial_m [I_{21} \int \partial \Pi_0 / \partial \sigma_m^2]}{M(k) \partial_m \int \Pi_0},}$$

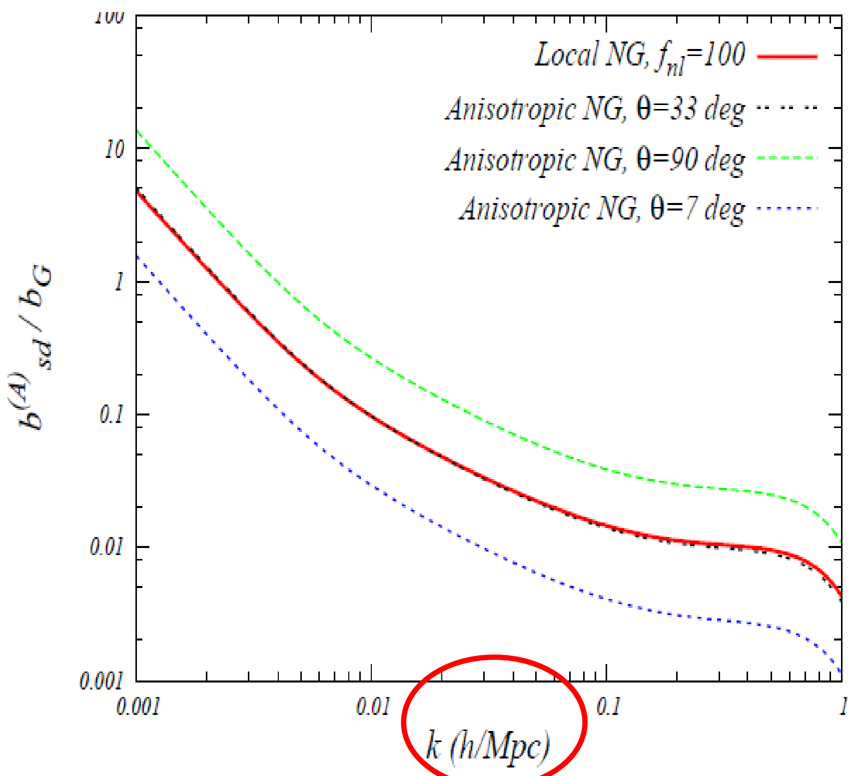
$$\boxed{I_{21}(k, m) = \frac{1}{P_\phi(k)} \int B_{\hat{\delta}\hat{\delta}\phi}(q, k - q, -k) d^3 q,}$$

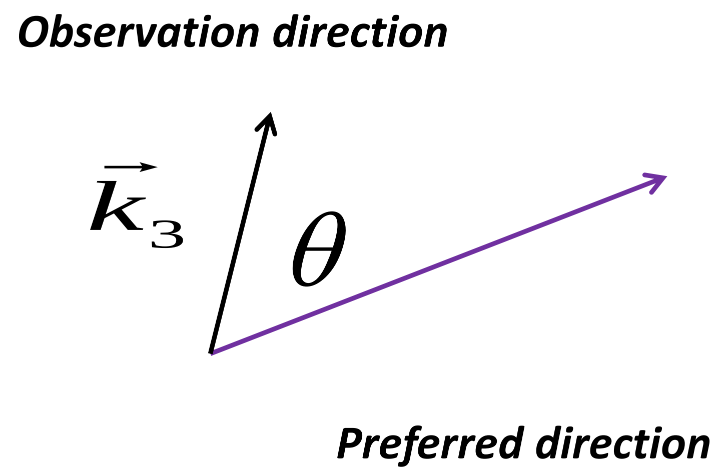
Can we see the anisotropic NG effects in LSS?

$$b_{NG} \approx \frac{2 f_{NL}(b_L - 1)\delta_c}{M(k,z)} \hat{C}(k_3, \hat{n})$$

$$M(k,z) = \frac{2}{5} \frac{k^2 T(k) D(z)}{H_0^2 \Omega_m^0}$$

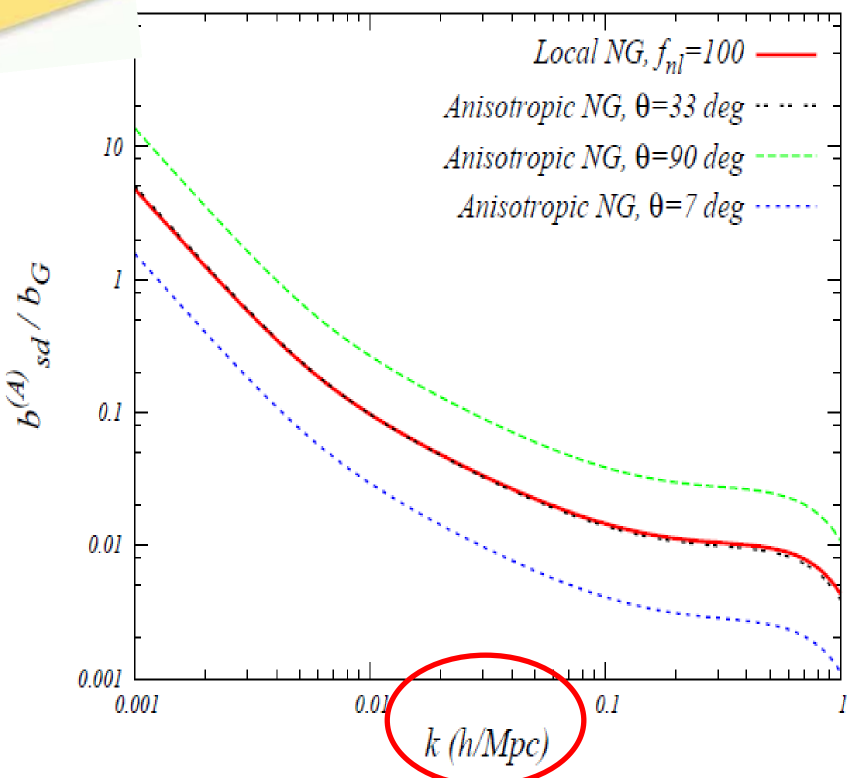
$$B_\zeta(\vec{k}_1, \vec{k}_2, \vec{k}_3) = 288 I N(k_1) N(k_2) N(k_3) \left(C(\vec{k}_1, \vec{k}_2) P_0(k_1) P_0(k_2) + 2\text{perm.} \right) .$$

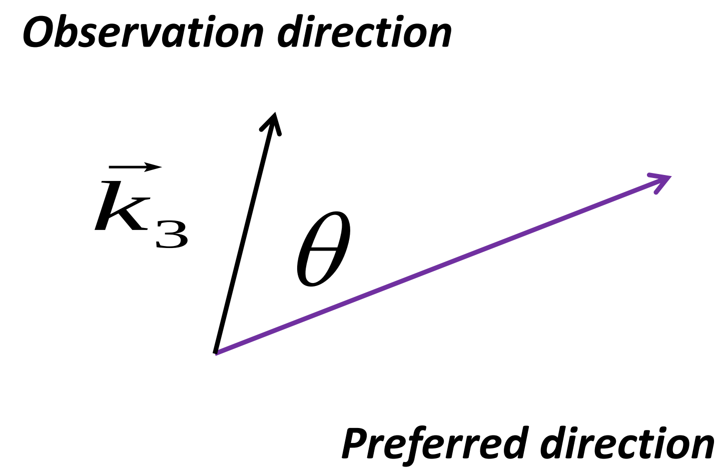




Can we see the anisotropic NG effects in LSS?

Non Gaussianity + Anisotropy can introduce a scale dependence behavior in the growth of the structures through bias





Content of the talk:

- 6 parameter standard Cosmology model and open Questions
- Accelerated Expansion of the Universe
- ❖ Modified gravity as a source of accelerated expansion
- Initial Conditions
- ❖ Non-Gaussian, Anisotropic inflationary models and LSS
- **Simultaneous effect of MG and NG inflationary models**
- Conclusion and further remarks

Redshift Space distortion

- The peculiar velocity dependents on mass distribution

$$\vec{v} = iHf\delta_k \frac{\vec{k}}{k^2}$$

- Where f is the growth rate and bias parameter appears in:

$$\vec{v} = iH\frac{f}{b}\delta_g \frac{\vec{k}}{k^2}$$

$$\boxed{\beta = \frac{f}{b}}$$

Redshift Space distortion

$$\beta = \frac{f}{b}$$

The galaxy distances are mainly measured by they redshift.

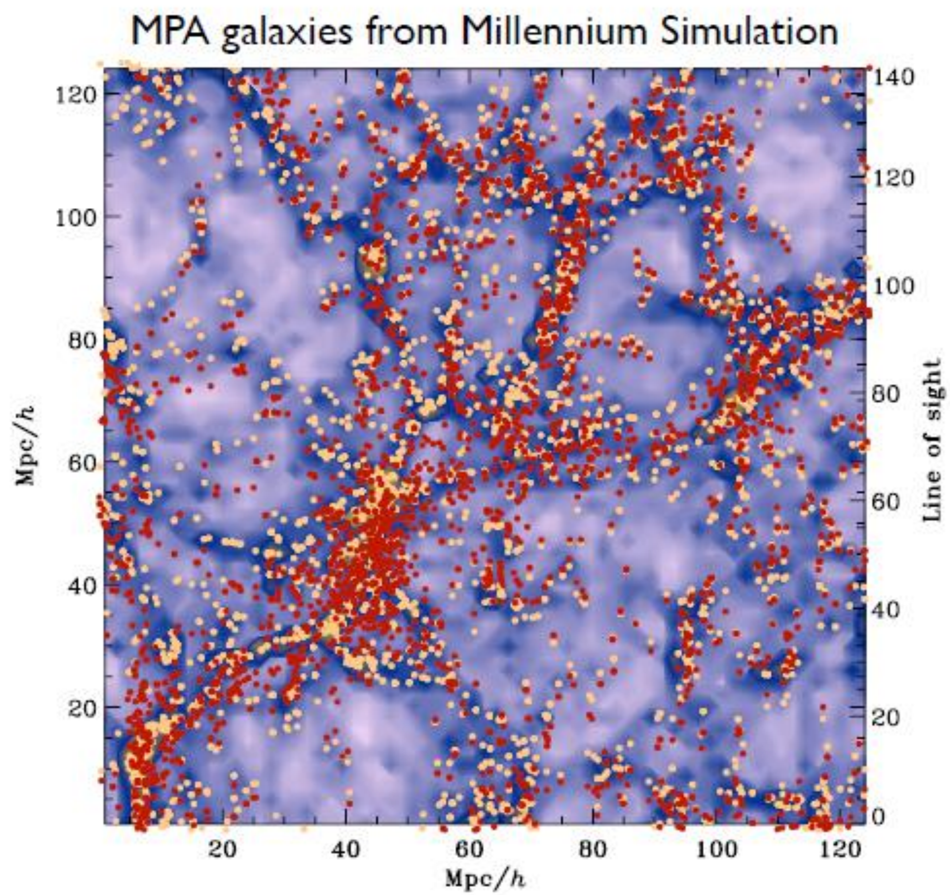
And the redshift include the

Peculiar Velocity of galaxies.

$$n(r)dV_r = n(z)dV_z$$

$$\delta_z = \delta_r - 2\frac{\Delta u}{r} - \frac{du}{dr}$$

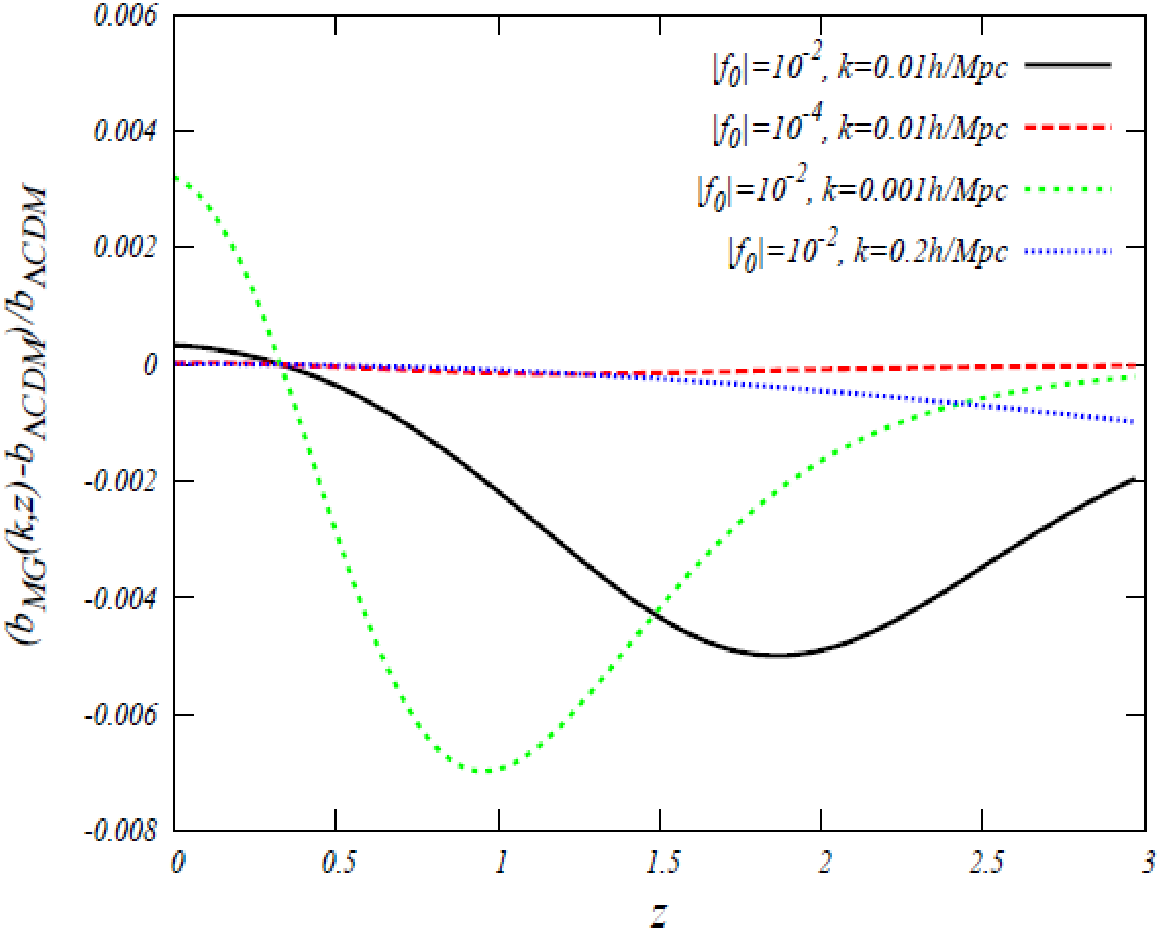
$$P_s(k) = P_r(k)(1+\beta\mu^2)^2$$



Simultaneous effect of MG and NG

$$b_{NG} \approx \frac{2 f_{NL}(b_L - 1)\delta_c}{M_{MG}(k,z)}$$

$$M_{MG}(k,z) = \frac{2}{5}\frac{G_{eff}}{G}\frac{k^2 T(k) D_{MG}(z,k)}{H_0^2 \Omega_m^0}$$



Simultaneous effect of MG and NG (Redshift Space distortion)

$$f'(k,z) - \frac{f^2(k,z)}{1+z} + \left(\frac{H'}{H} - \frac{2}{1+z}\right) f(k,z) + \frac{3}{2} H_0^2 \Omega_m^0 \frac{(1+z)^2}{H^2} \frac{G_{eff}(k,z)}{G} = 0$$

First part of the talk

$$\beta = \frac{f(k,z)}{b(k,z)}$$

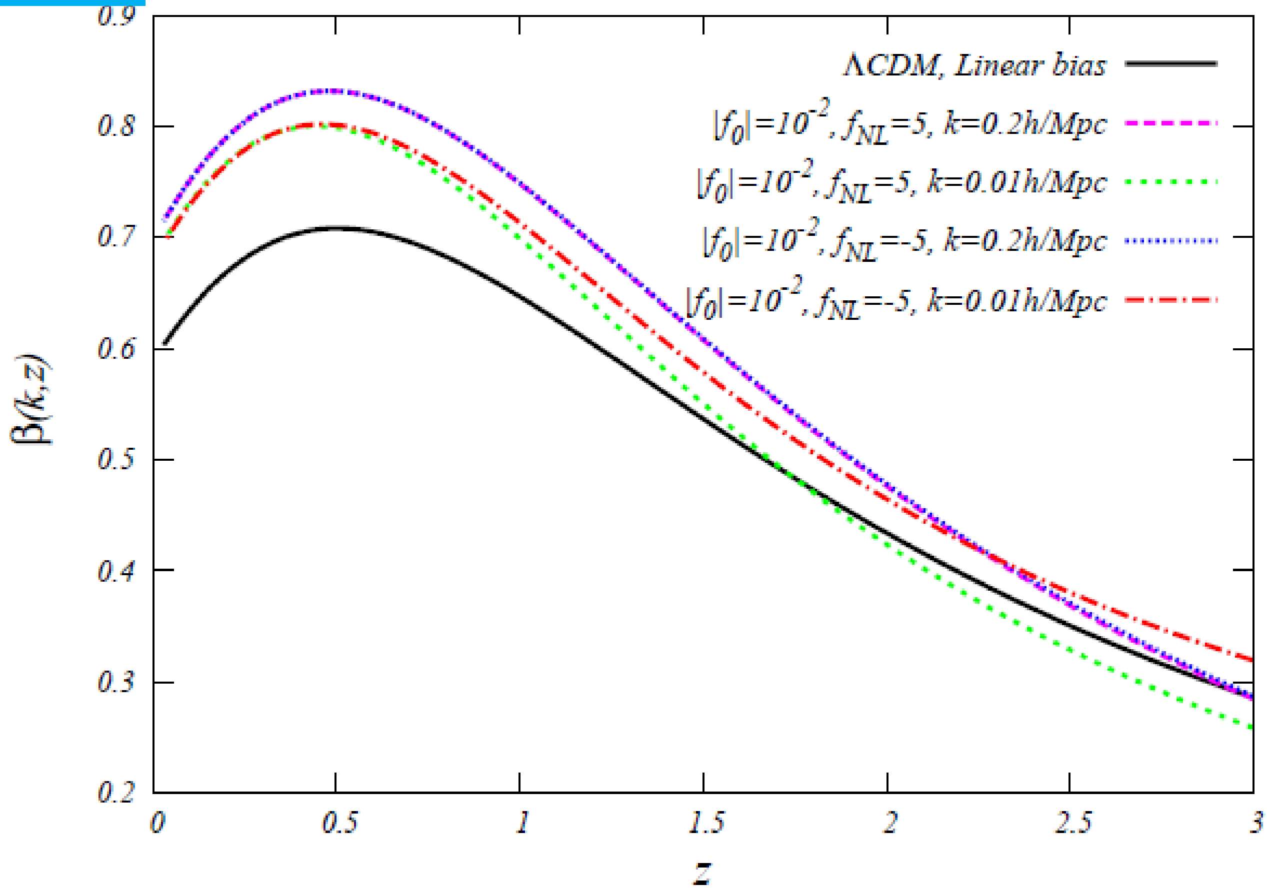
$$b_{NG} \approx \frac{2 f_{NL} (b_L - 1)\delta_c}{M_{MG}(k,z)}$$

Second part of the talk

$$M_{MG}(k,z) = \frac{2}{5} \frac{G_{eff}}{G} \frac{k^2 T(k) D_{MG}(z}{H_0^2 \Omega_m^0}$$

Simultaneous effect of MG and NG (Redshift Space distortion)

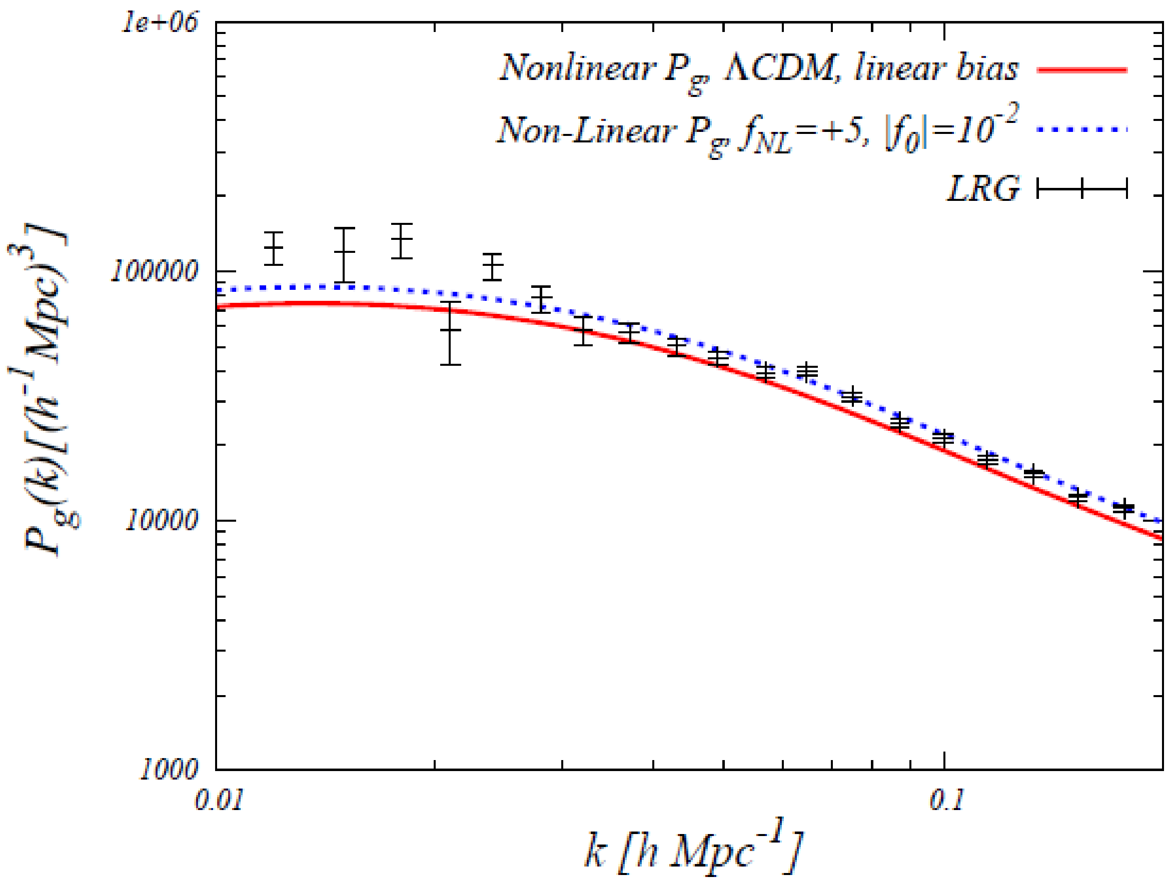
$$\beta = \frac{f(k,z)}{b(k,z)}$$



Galaxy Power Spectrum

Luminous Red galaxies of SDSS as a test For galaxy power Spectrum

$$P_g^{(z)}(k,z) = b^2 P_m^{(r)}(k,z)\left[1+\frac{2}{3}\beta+\frac{1}{5}\beta^2\right]$$



Galaxy growth rate

- Complementary observation : Galaxy growth rate

$$f_g(k,z) = \frac{d\ln(b\delta_m)}{d\ln a} = f_m(k,z) + \frac{d\ln b(k,z)}{d\ln a} = f_m - (1+z)\frac{b'(k,z)}{b(k,z)}$$

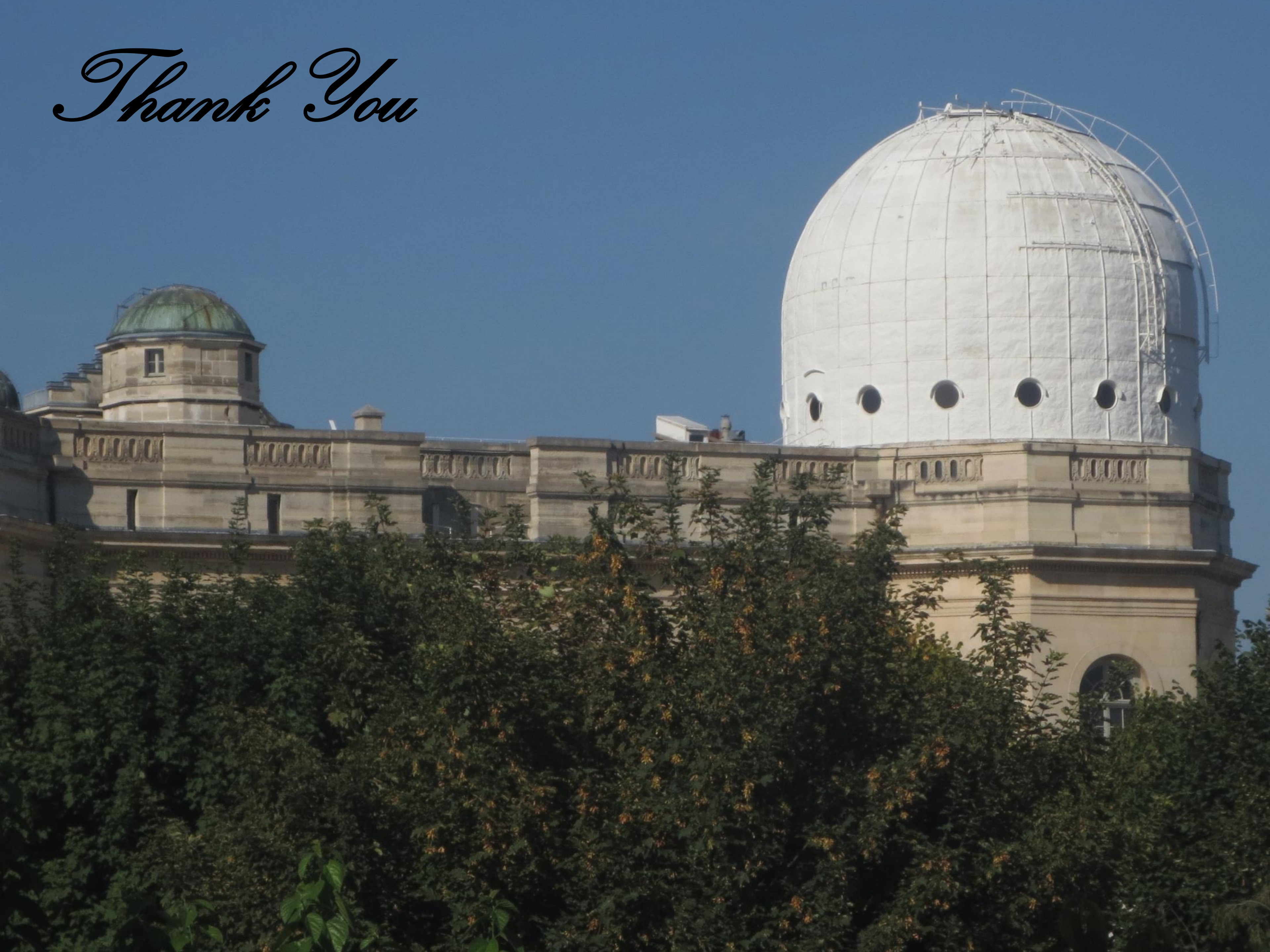
- The redshift space distortion parameter is an observable,

We need N-body simulations for MG theories to determine the bias parameter.

$$\beta(k,z) = \frac{f(k,z)}{b(k,z)}$$

Conclusion and future prospects

- Anisotropic inflationary: candidate to address the CMB anomalies.
- Anisotropic initial conditions introduce a scale dependent, direction dependent bias parameter.
- There is a degeneracy between Modified gravity theories and anisotropic NG initial conditions because of redshift space distortion parameter.
- We need complementary observations to break the degeneracy.
- We need N-body simulations for MG theories
- We need Euclid-like Observations for more statistics


Thank You