arXiv:1712.09017, MNRAS Letter, with Xue-Wen Liu & Rong-Gen Cai

https://github.com/hubinitp/CHAM

CHAM: Fast modelling non-linear matter spectrum for the modified gravity

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Shanghai/2018/Jun

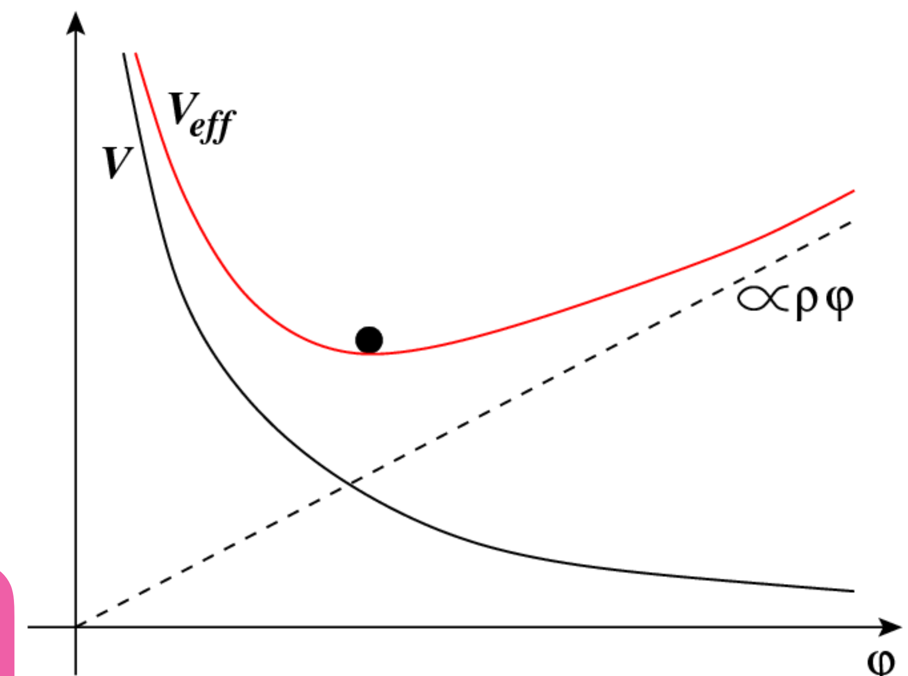
sCreened HAlo Model

“Screening” mechanisms:

The fifth force should act only on large scales and it should be hidden on small scales

Chameleon mechanism

Effective Mass



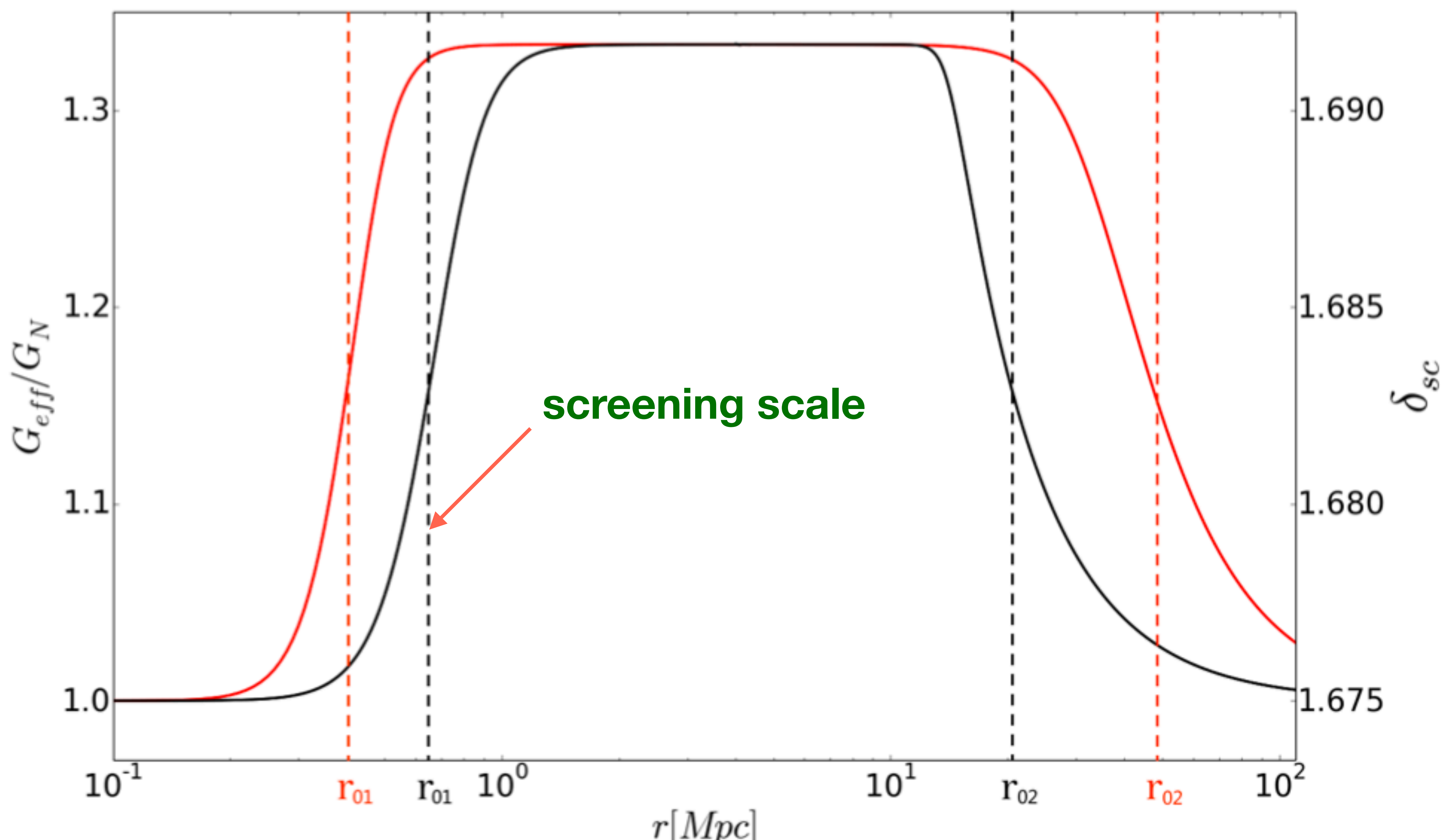
Vainshtein mechanim

Higher order Kinetic interaction

Symmetryon mechanism

Symmetry transition in environment

Phenomenologically, MG effect shows as a **scale dependent** Newton constant



Newtonian Limit

GR Limit

Unified Parametrisation

[Lucas Lombriser 1608.00522]

$$\boxed{\frac{G_{eff}}{G} = A + \sum_i^{N_0} B_i \prod_j^{N_i} b_{ij} \left(\frac{r}{r_{0ij}}\right)^{a_{ij}} \left\{ \left[1 + \left(\frac{r_{0ij}}{r}\right)^{a_{ij}} \right]^{1/b_{ij}} - 1 \right\}},$$

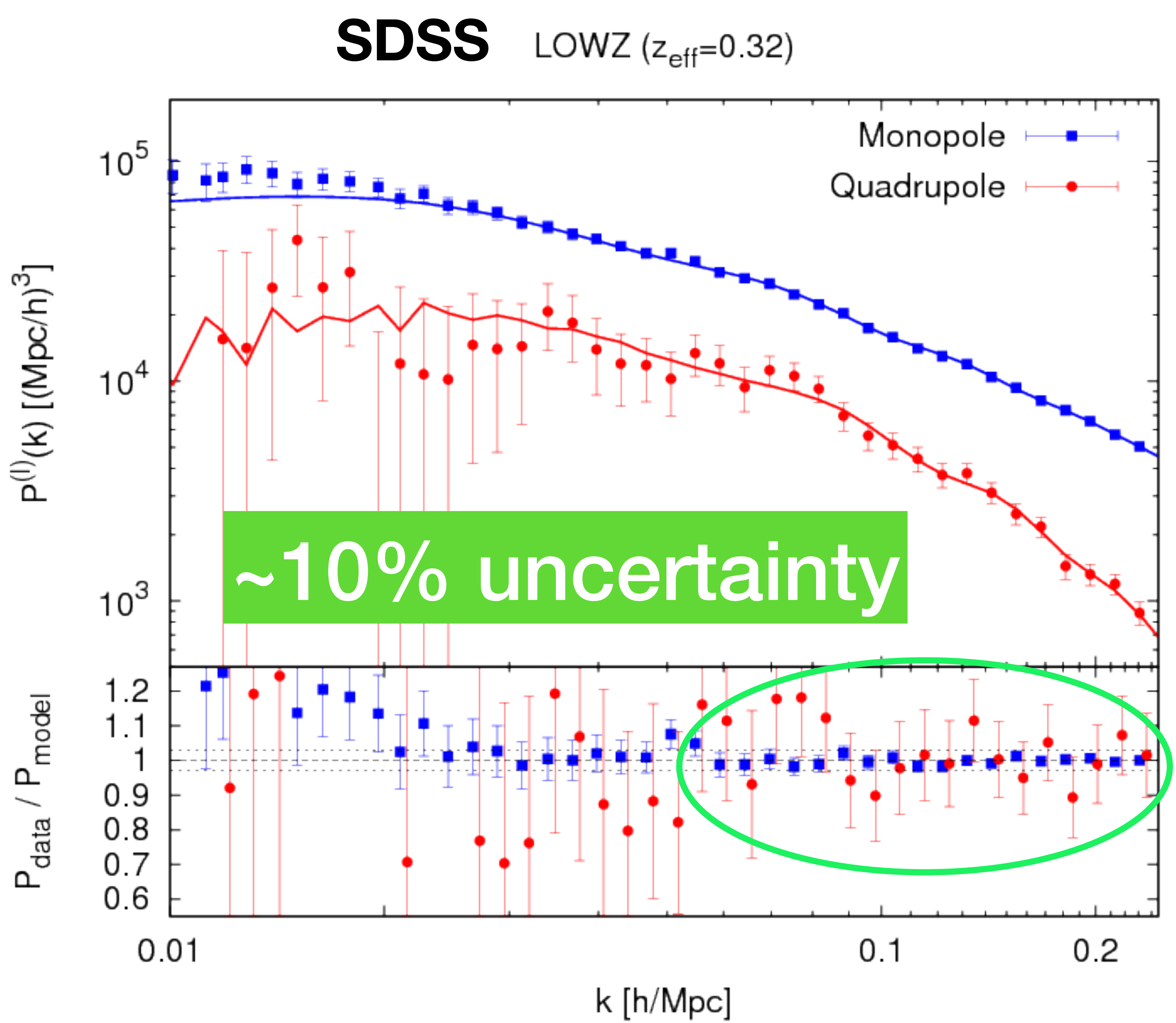
(i) Screening at large field values such as in chameleon [4] or symmetron [6] models: This screening effect operates in regions where the Newtonian gravitational potential exceeds a given threshold, $|\Psi_{\rm N}| > \Lambda_{\rm T}$. The mapping of this mechanism to Eq. (2.12) will be described in Sec. 3.1.

(ii) Screening with first derivatives such as in k-mouflage [5]: This screening effect is activated when the local gravitational acceleration passes a given threshold value, $|\nabla\Psi_{\rm N}| > \Lambda_{\rm T}^2$. The mechanism can be mapped to Eq. (2.12) as described in Sec. 3.2.

(iii) Screening with second derivatives such as in the Vainshtein mechanism [3]: This screening mechanism operates when curvature or local densities become large, $|\nabla^2\Psi_{\rm N}| > \Lambda_{\rm T}^3$. The mapping of this effect onto Eq. (2.12) is presented in Sec. 3.3.

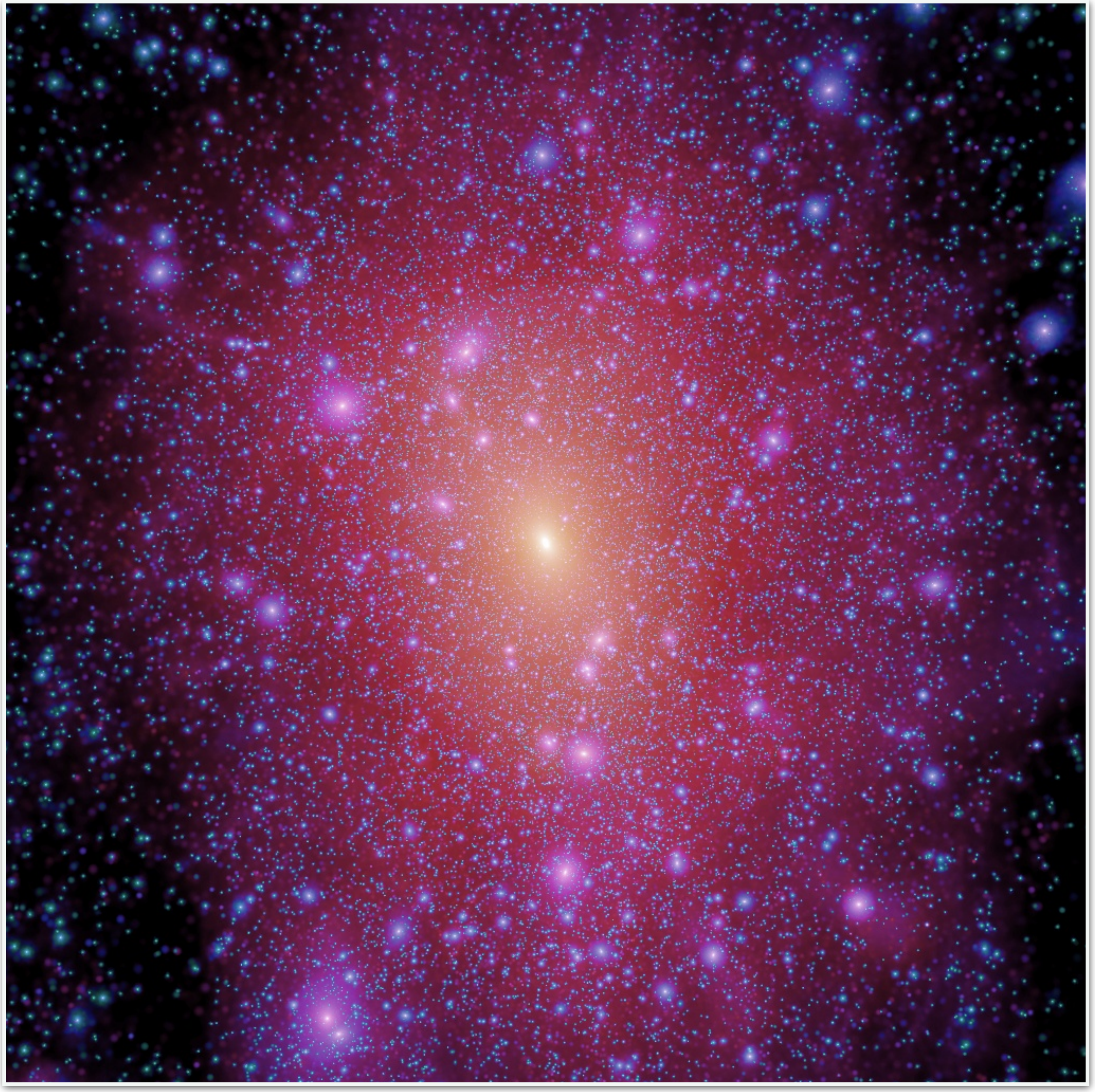
(iv) Linear suppression effects such as the Yukawa suppression or linear shielding mechanism [8]: These effects become important when separations cross the scale set by the linearised mass or sound speed of the field. The mapping to Eq. (2.12) is provided in Sec. 3.4.

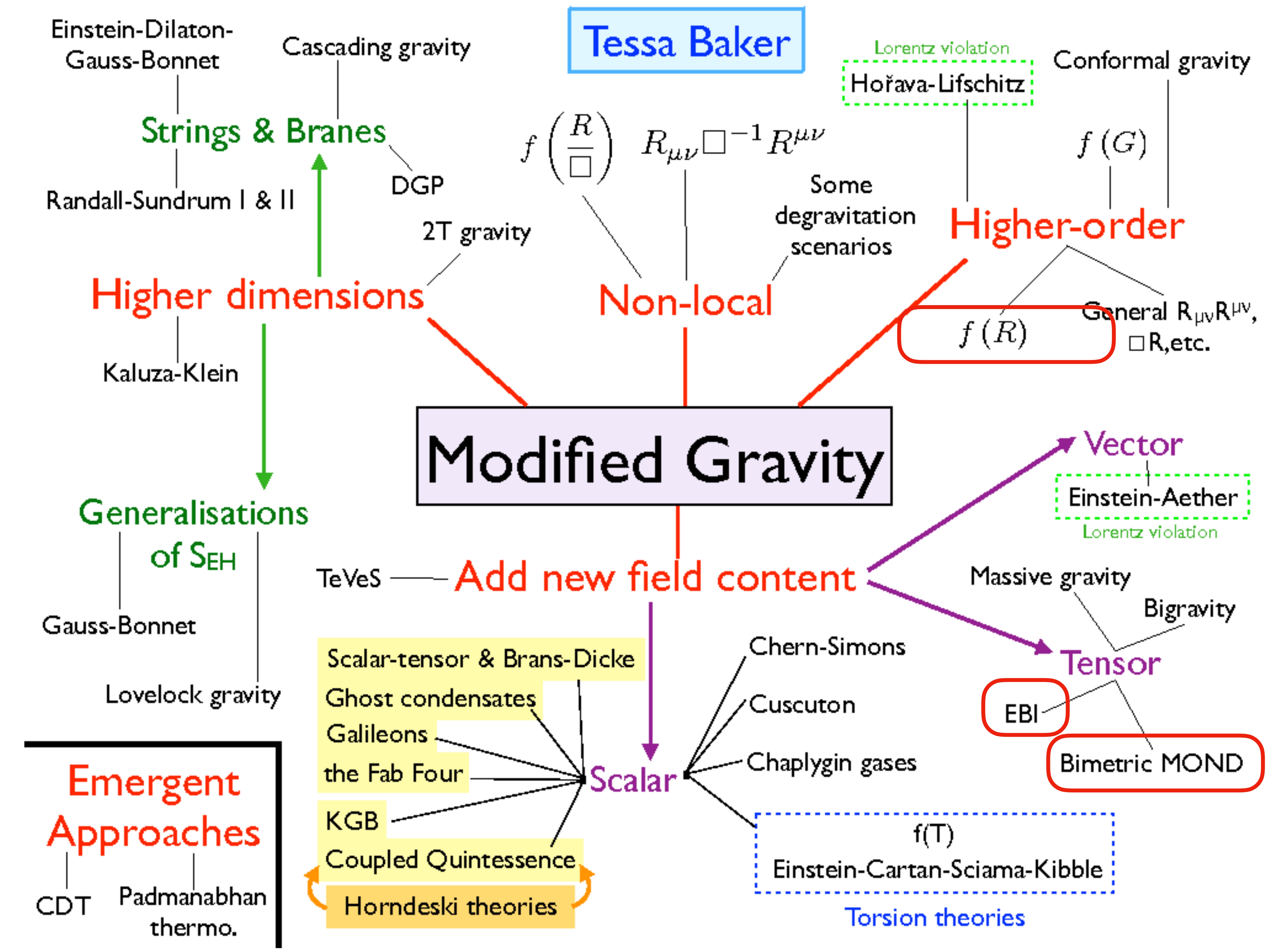
Where we stand for testing GR with LSS?


SDSS
LOWZ (z_{eff}=0.32)
Monopole
Quadrupole
$P^{(l)}(k)$ [(Mpc/h)^3]
10^5
10^4
10^3
~10% uncertainty
P_{data} / P_{model}
1.2
1.1
1
0.9
0.8
0.7
0.6
0.01
0.1
0.2
k [h/Mpc]

N-body simulation of MG is too much expensive: hundreds of CPU, several weeks run

For **ONE** model, **ONE** cosmology





Tessa Baker
Einstein-Dilaton-Gauss-Bonnet
Cascading gravity
Strings & Branes
DGP
Randall-Sundrum I & II
2T gravity
Higher dimensions
Kaluza-Klein
$f\left(\frac{R}{\Box}\right)$
$R_{\mu\nu}\Box^{-1}R^{\mu\nu}$
Some degravitation scenarios
Non-local
Lorentz violation
Hořava-Lifschitz
Conformal gravity
$f(G)$
Higher-order
$f(R)$
General $R_{\mu\nu}R^{\mu\nu}$, $\Box R$,etc.
Modified Gravity
Vector
Einstein-Aether
Lorentz violation
Generalisations of S_{EH}
Gauss-Bonnet
Lovelock gravity
TeVeS
Add new field content
Massive gravity
Bigravity
Tensor
EBI
Bimetric MOND
Scalar-tensor & Brans-Dicke
Ghost condensates
Galileons
the Fab Four
KGB
Coupled Quintessence
Horndeski theories
Scalar
Chern-Simons
Cuscuton
Chaplygin gases
f(T)
Einstein-Cartan-Sciama-Kibble
Torsion theories
Emergent Approaches
CDT
Padmanabhan thermo.

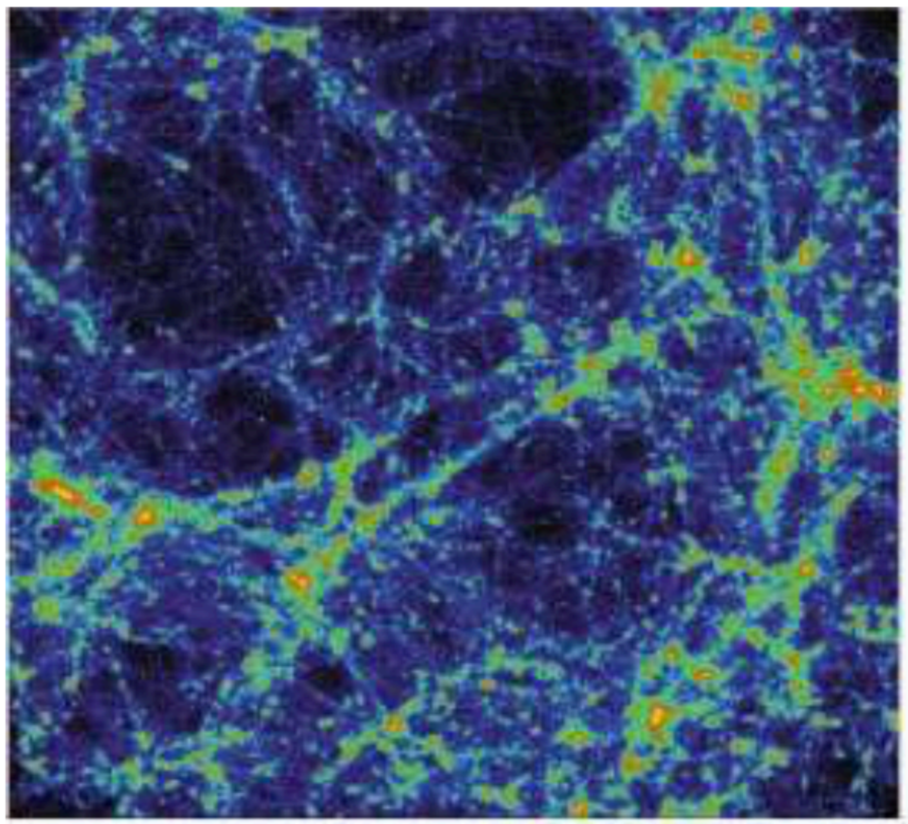
For P(K):

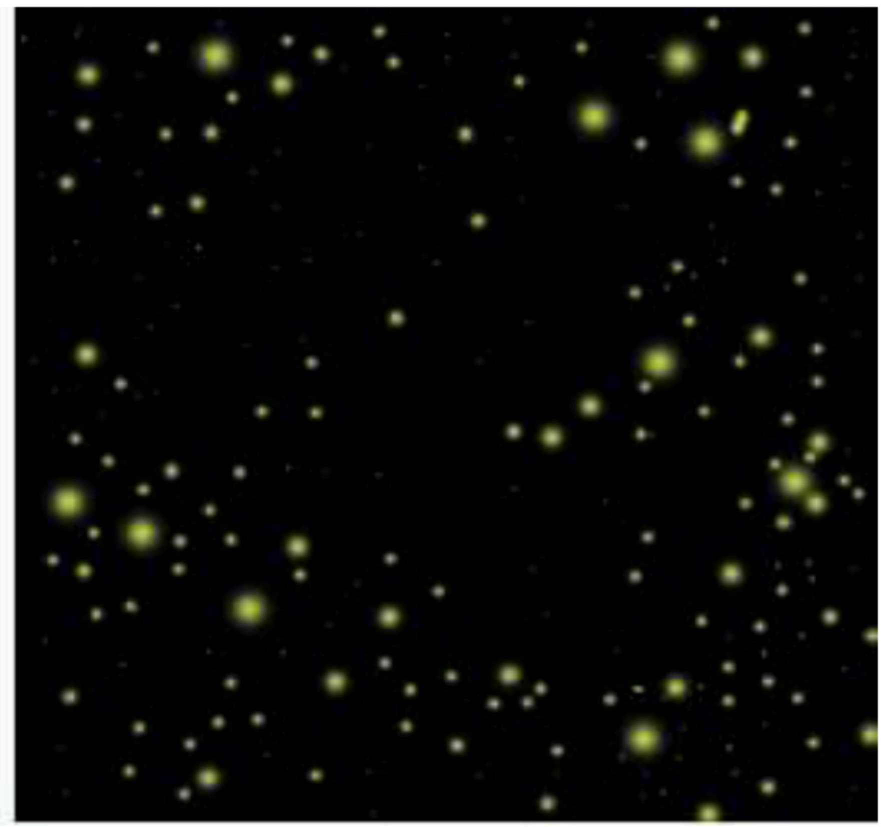
Is there another way beside N-body?

FASTER but LESS ACCURITE

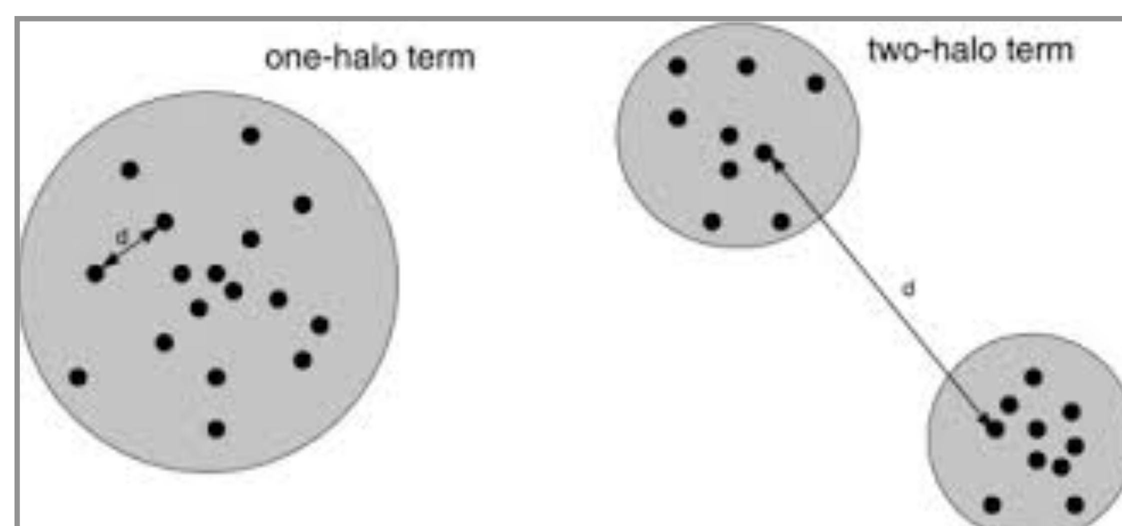
Halo Model

discretise the continuous matter distribution into halo (bounded state)





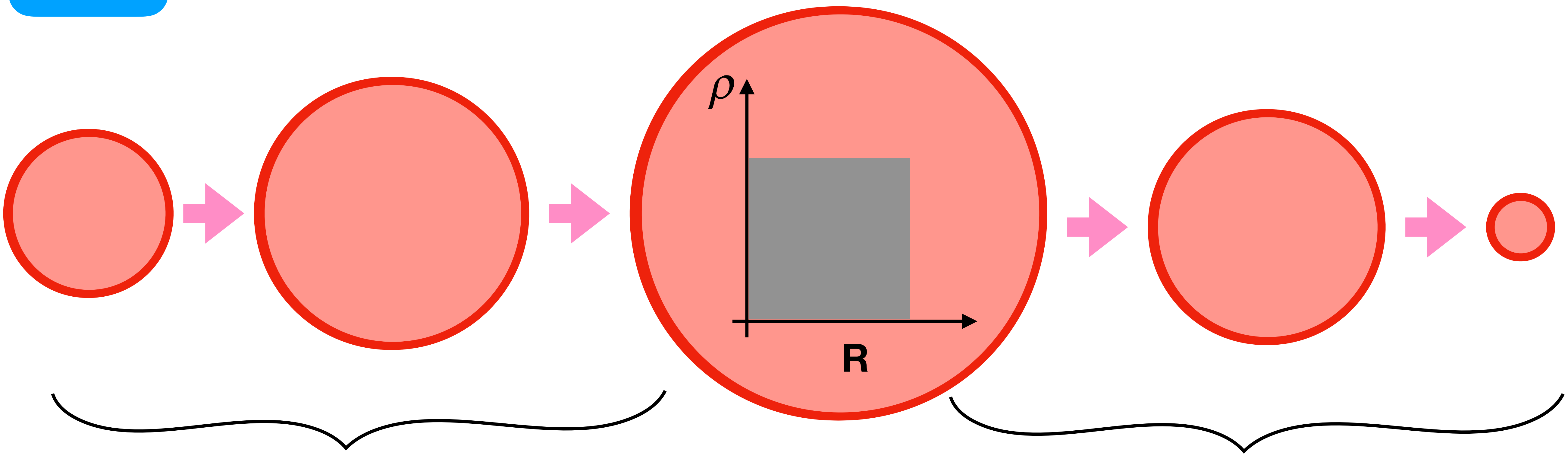
$$\boxed{P_m(k) \sim P_{2halo}(k) + P_{1halo}(k)}$$



[Cooray & Sheth astro-ph/0206508v1]

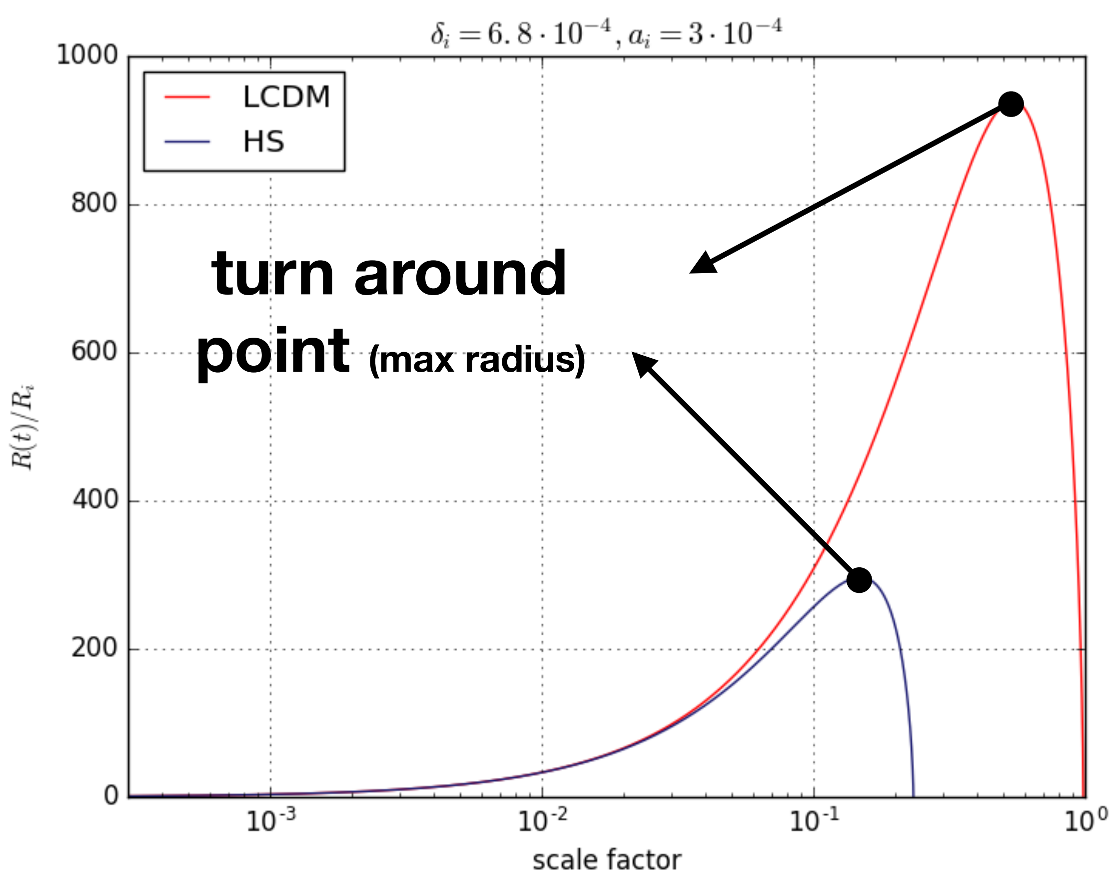
Step-1:

Halo formation — Spherical Collapse



expand with background

decouple from background expansion



$$\frac{1}{2}\left(\frac{dr}{dt}\right)^2 - \frac{GM}{r} = \varepsilon$$

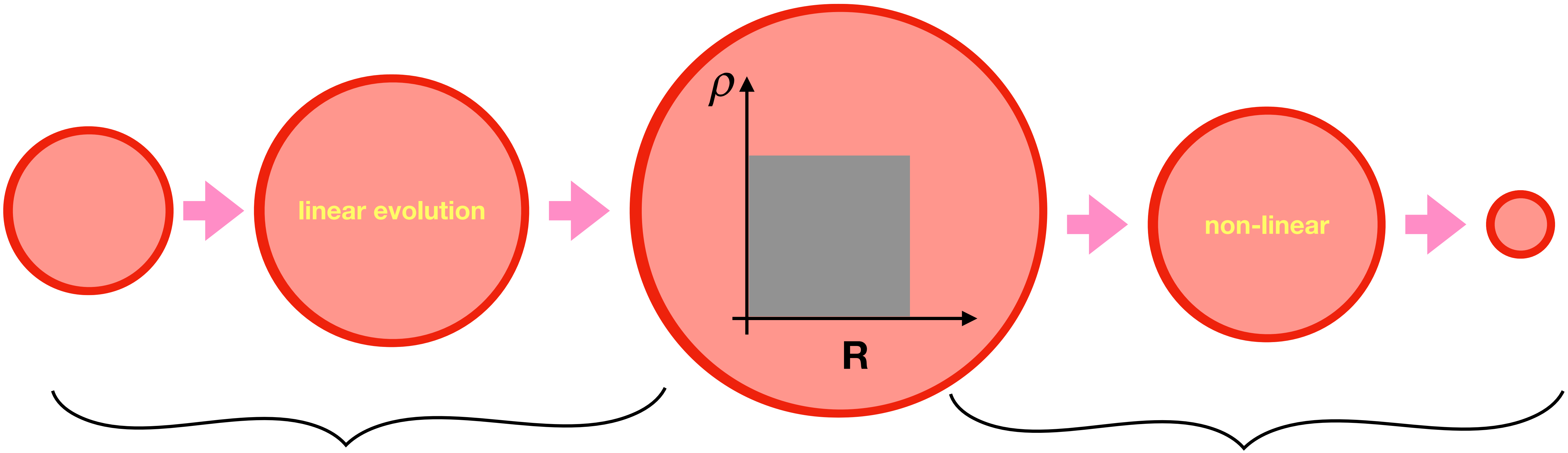
assuming initially, shell is co-moving

$$\dot{r} = Hr$$

One can prove that, in EdS universe,
for arbitrary over density regime, it will always collapse!
early collapse ~ higher density; later collapse ~ lower density

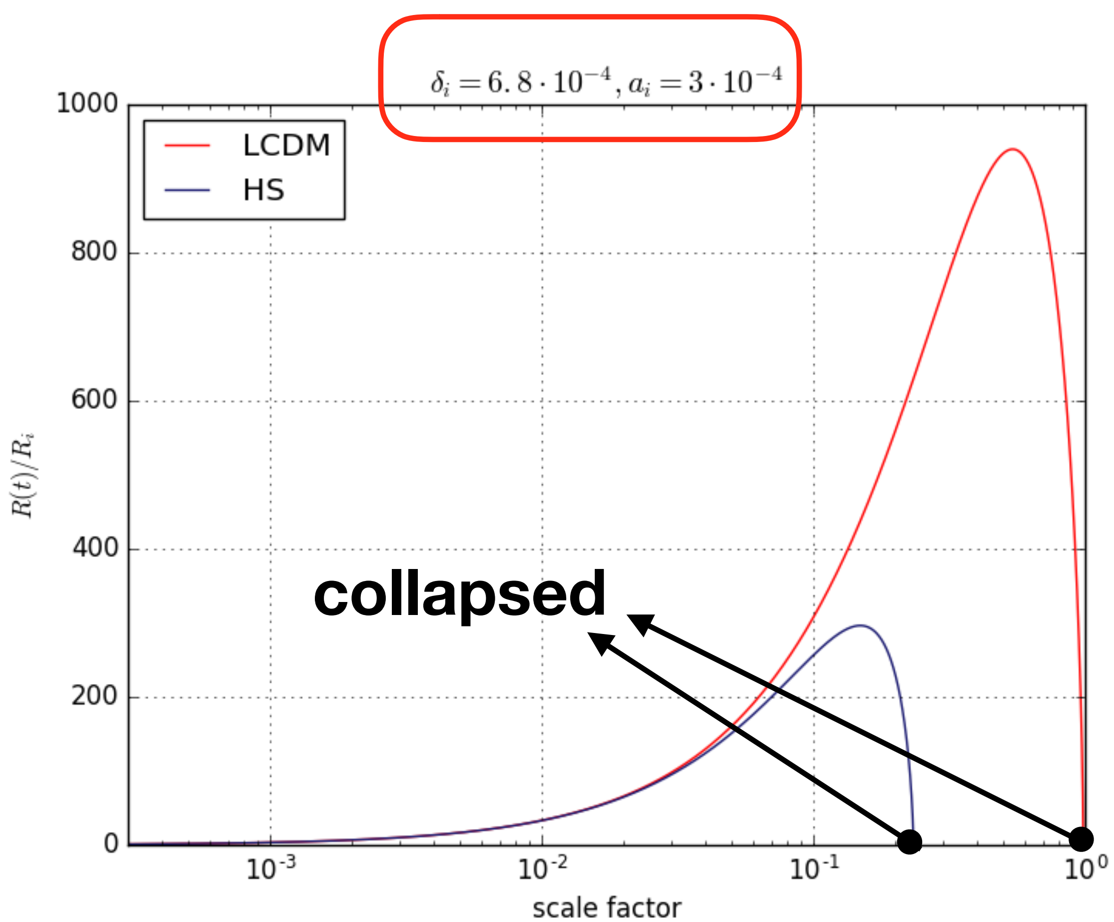
$$\varepsilon = -\frac{1}{2} H_i^{\,2} r_i^{\,2} \delta_i < 0$$

Halo formation — Spherical Collapse



expand with background

decouple from background expansion



linear grow in MD $\delta_m \sim a$

$\delta_{Lin}(col) \sim 1.68$ **LCDM**

$\delta_{Lin}(col) > 1.68$ **gravity enhanced** $G_{eff} > G_N$

$\delta_{Lin}(col) < 1.68$ **gravity suppressed** $G_{eff} < G_N$

Compton Wavelength Scale

Poisson

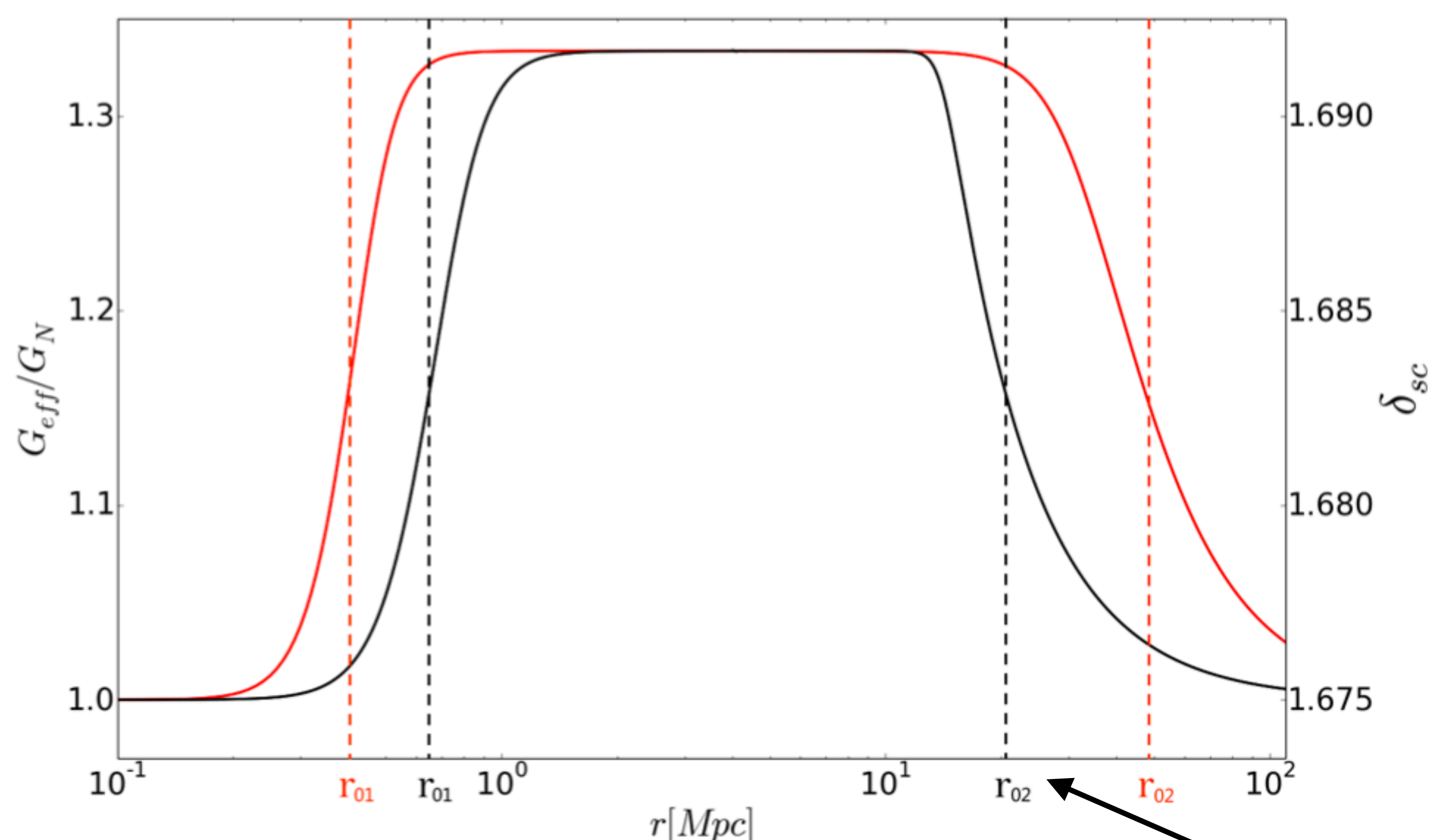
$$k^2\Psi(\mathbf{k}) = -4\pi G\left(\frac{4}{3} - \frac{1}{3}\frac{\mu^2 a^2}{k^2+\mu^2 a^2}\right) a^2\delta\rho_{\rm m}(\mathbf{k})\,,$$

$\mu^{-1} \longrightarrow$ **Compton wavelength**

$k^2 >> \mu^2 a^2$ **below Compton wavelength** **G_{eff} is enhanced by a factor 1/3**

$k^2 << \mu^2 a^2$ **above Compton wavelength** **Restore LCDM limit**

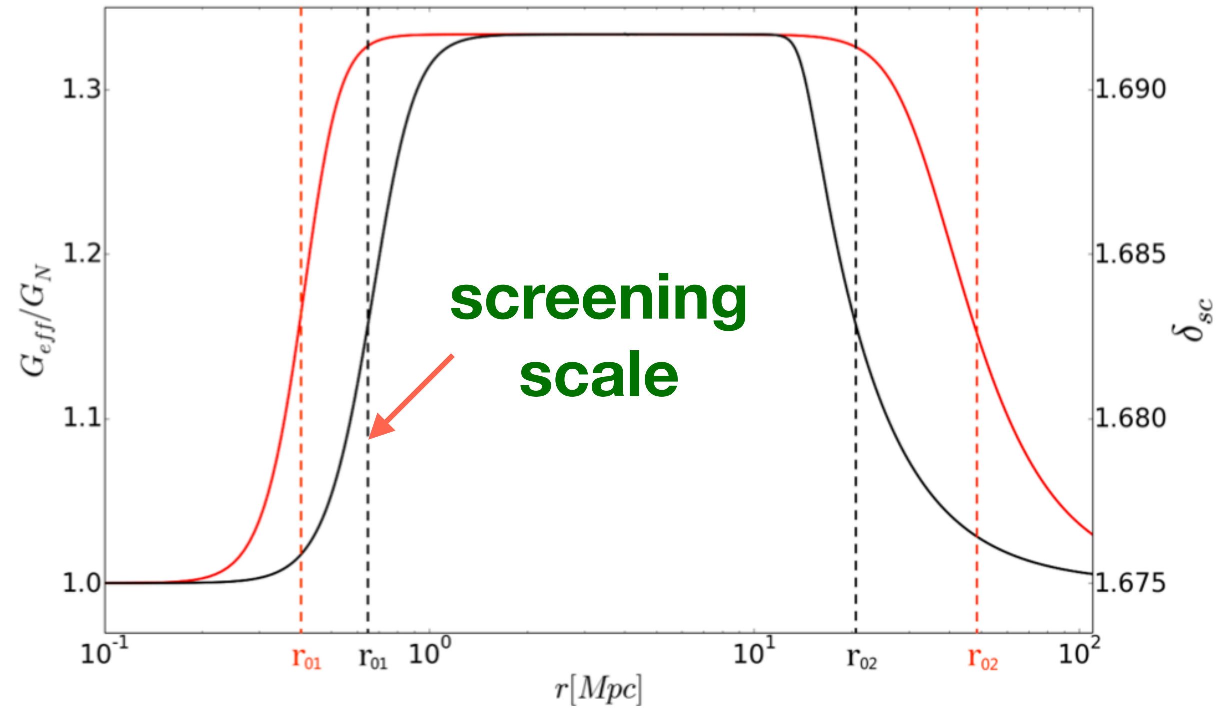
$$|f_{R0}| \sim \frac{\mu^{-1}}{H_0^{-1}}$$



Compton scale

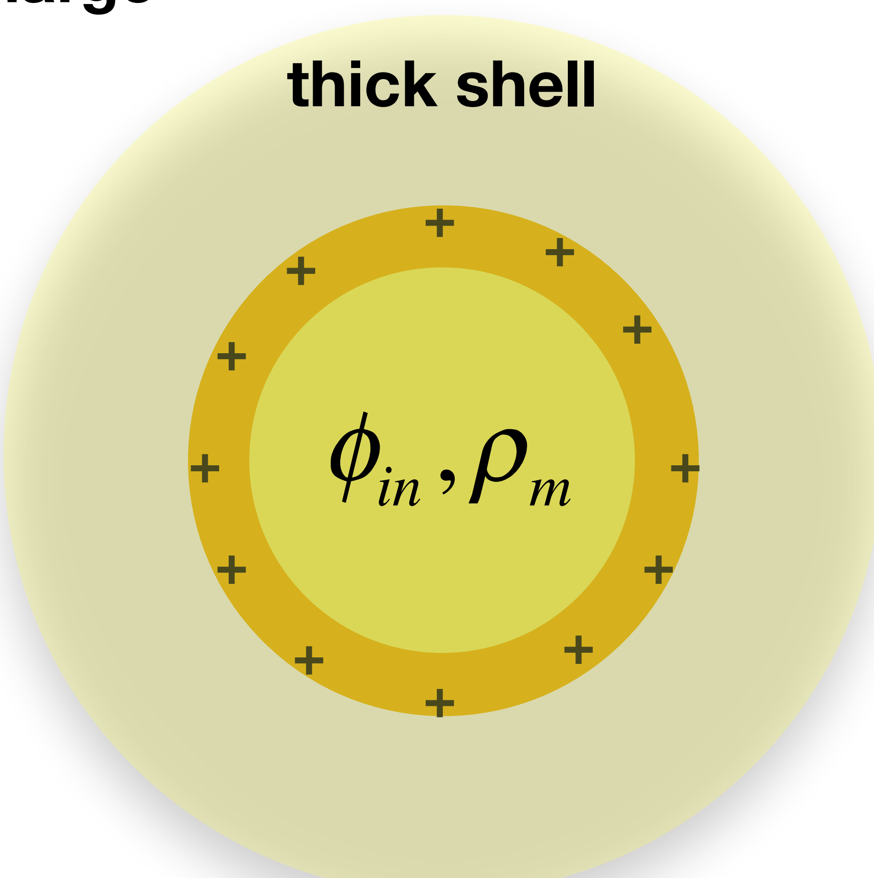
Chameleon Mechanism

Screening Scale



$$\xi M$$

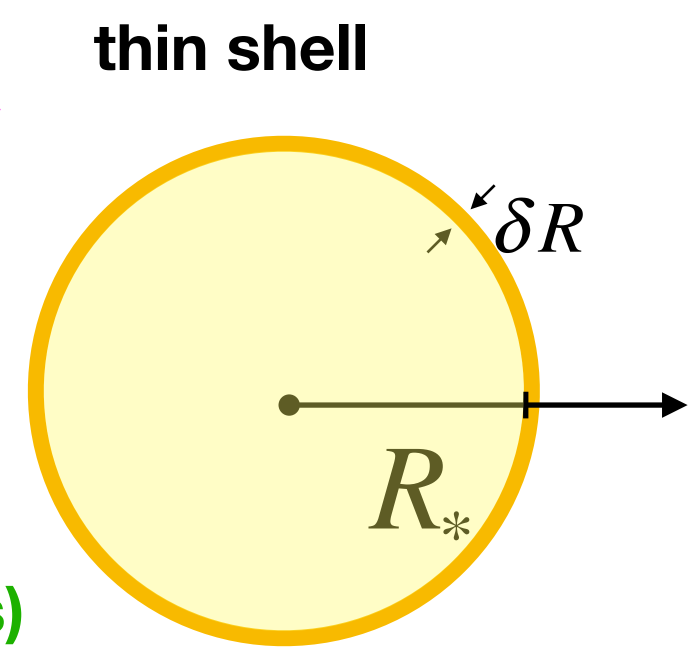
Charge



Scalar charge is only distributed on the surface! **R^2**

V.S.

gravity charge (mass) is distributed in the whole volume! **R^3**



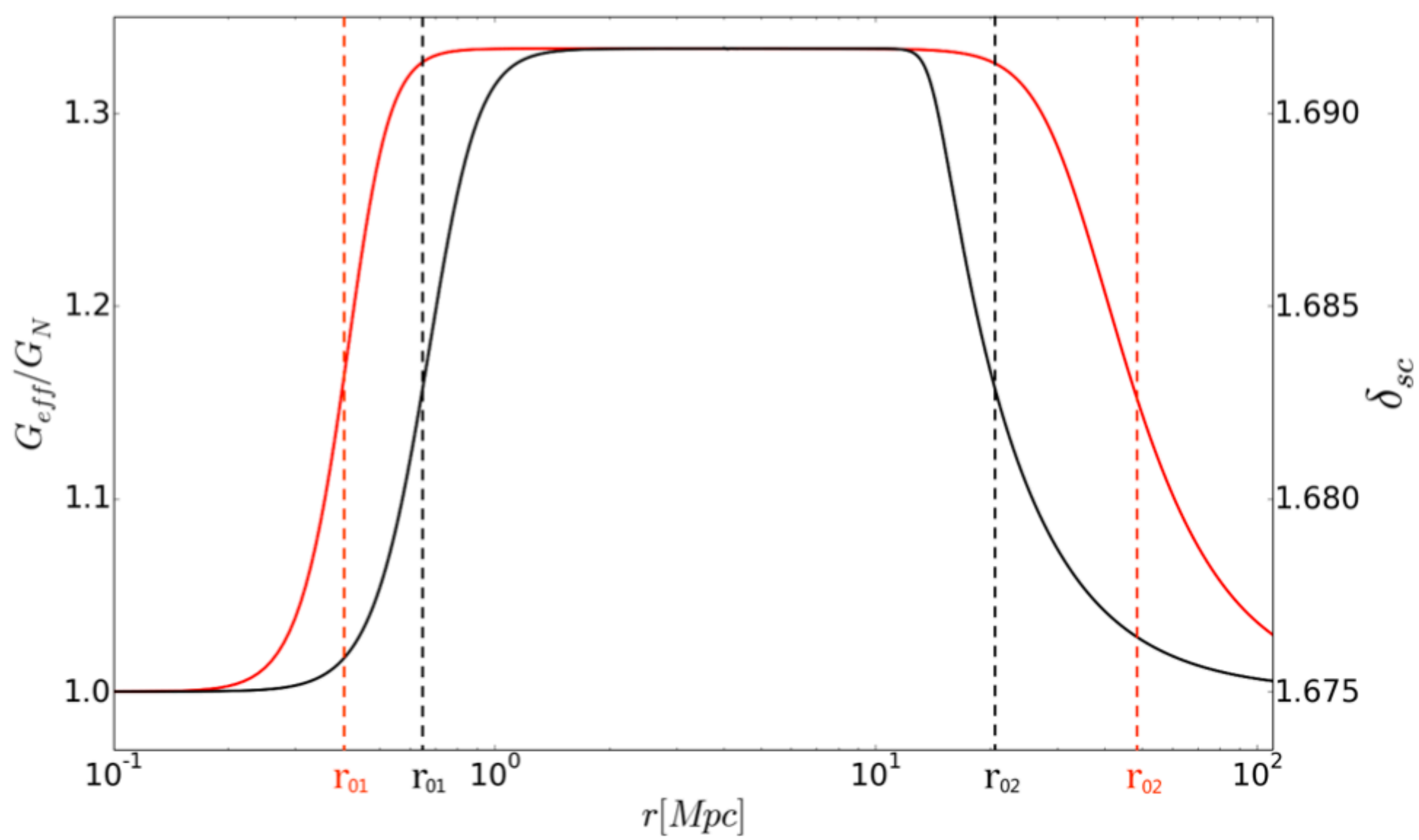
$$\phi_\infty$$

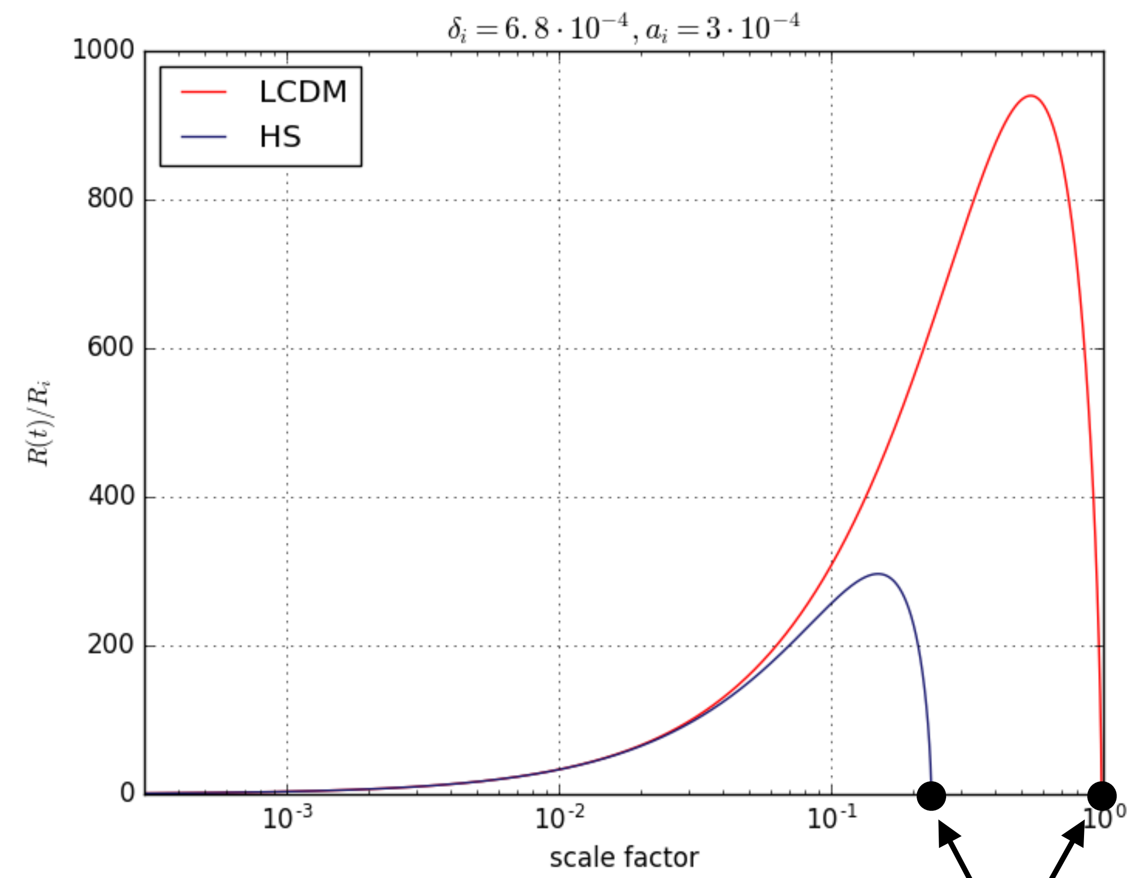
$$\frac{\delta R}{R_*} \sim \frac{\phi_{in} - \phi_\infty}{\Psi}$$

$$\phi(r > R_*) \sim \frac{\delta R}{R_*} \frac{M}{r}$$

The 5th force is screened in the high density regime!

Critical density threshold in f(R) gravity





We think DM halo is stable formed at this point

NON-LINEAR density at this point approaches singular at this point,
$\delta_{non-linear}$ is NOT GOOD indicator of halo!

LINEAR density at this point δ_c is regular, hence a GOOD proxy!

$\delta_{lin} > \delta_c$ **formed!**

$\delta_{lin} < \delta_c$ **not yet!**

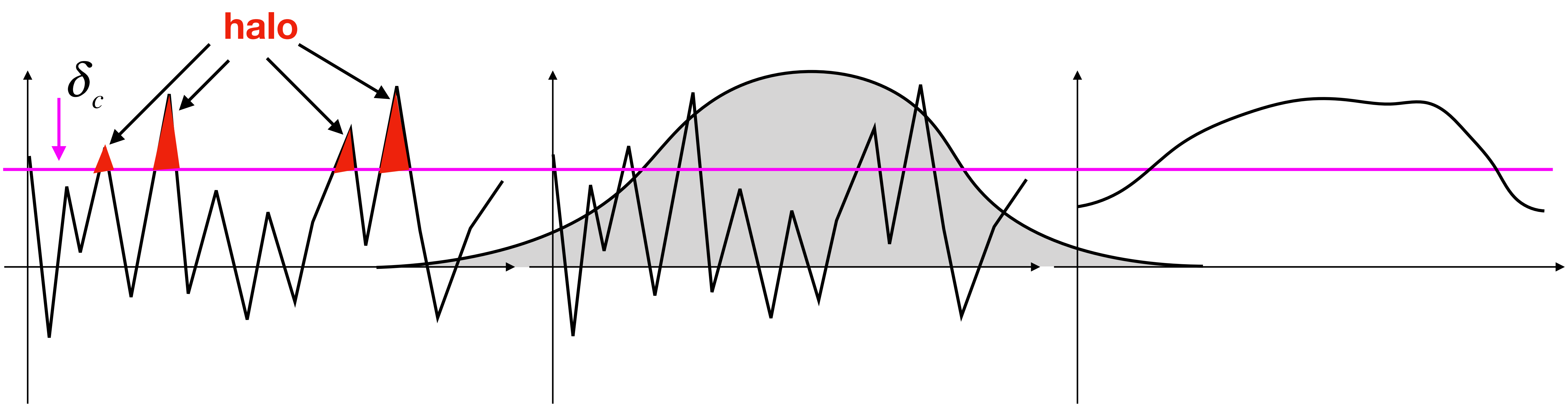
UP to now, we answered how a single spherical halo form.

Next question, how the halo distributed in the large scales?

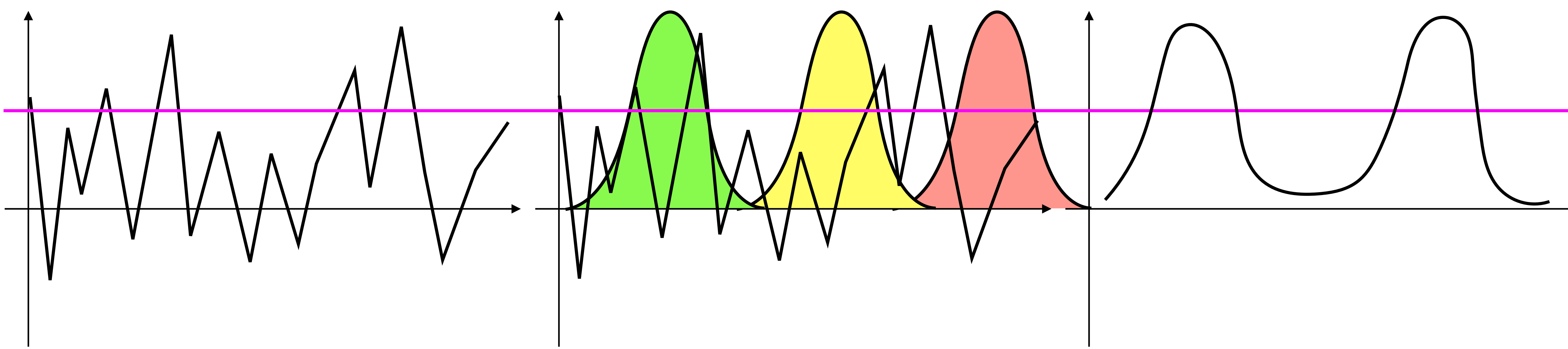
smoothed density field on scale R_W

peak-background split

$$\delta(\vec{x}; R_\mathrm{W}) \equiv \int \mathrm{d}^3x' \; W(|\vec{x}' - \vec{x}|; R_\mathrm{W})\delta(\vec{x}')$$



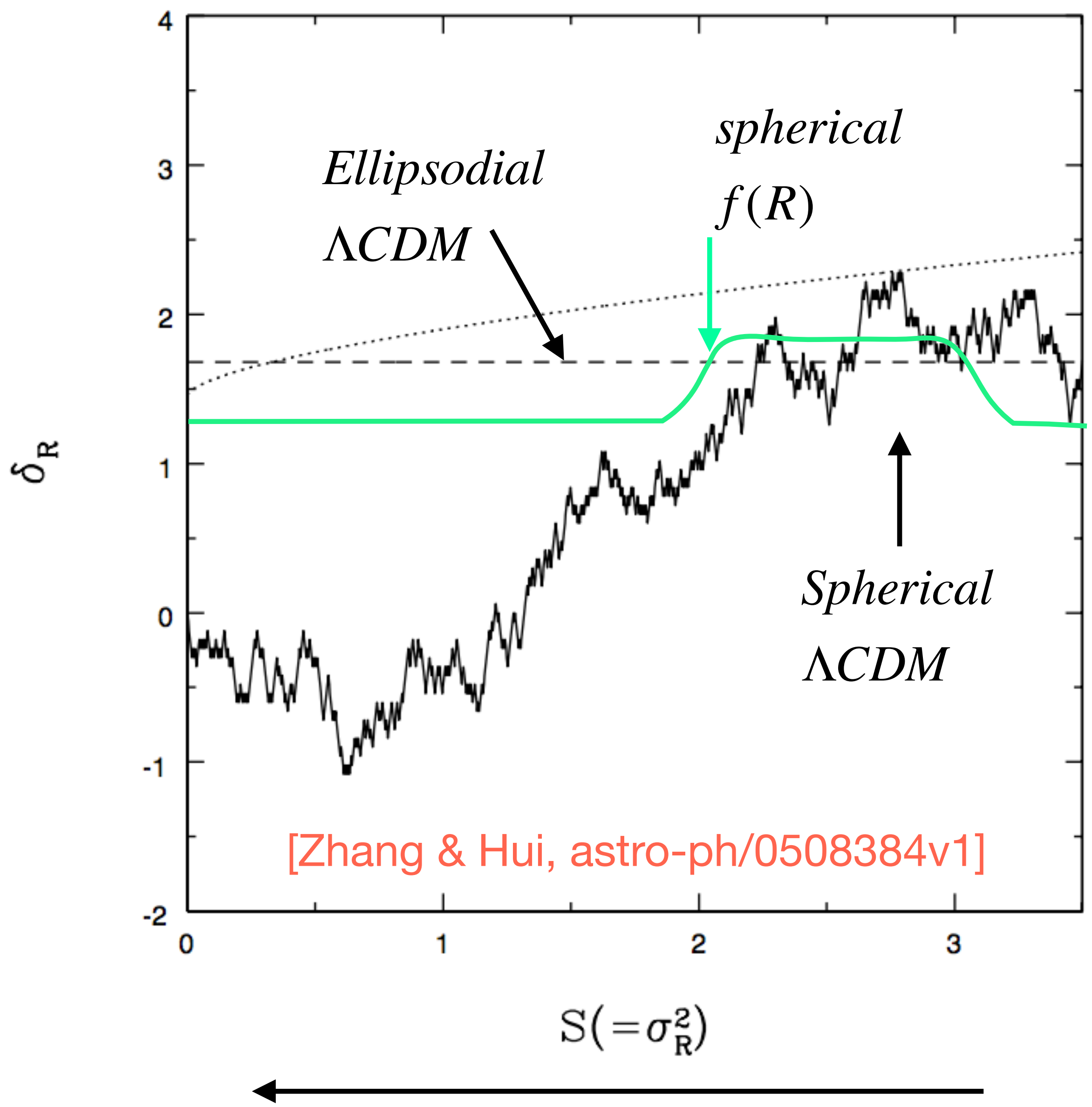
cloud-in-cloud problem



Step-2:

Scale dependent threshold

[Zhang & Hui, astro-ph/0508384v1]



large scale

$$P(\delta,S)=P_0(\delta,S)-\int_0^S dS' f(S')P_0(\delta-B(S'),S-S')$$

$$f(S)=-P(B(S),S)\frac{dB}{dS}-\int_{-\infty}^{B(S)}\frac{\partial P(\delta,S)}{\partial S}d\delta$$

$f(S)dS$: probability of first up-crossing @S

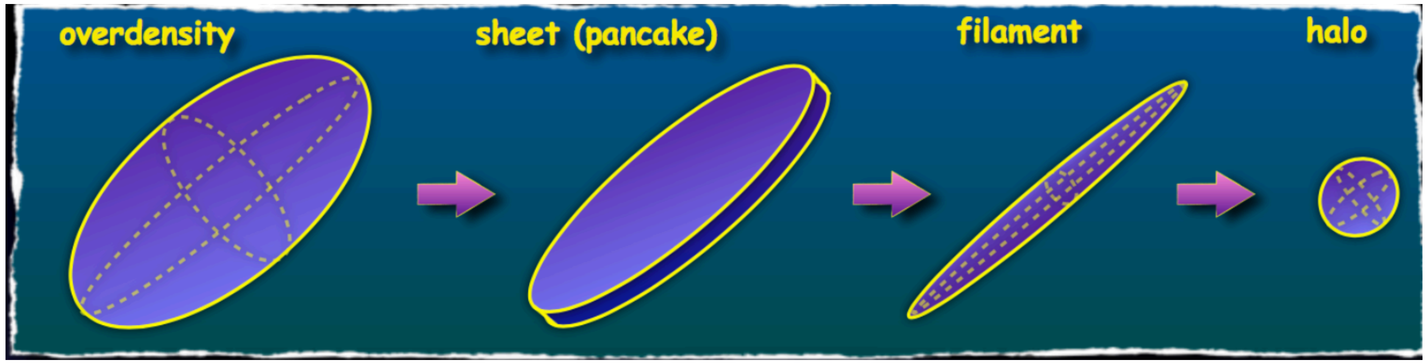
$P(\delta,S)d\delta$: probability of cross btw δ and $\delta+d\delta$ without cross δ_c before S.

conservation: $$\boxed{1=\int_0^S f(S')dS'+\int_{-\infty}^{B(S)}P(\delta,S)d\delta}$$

$$\sigma_R^2 = < \delta^2_{\text{linear}}(\vec{x},R) >$$

Ellipsoidal Collapse

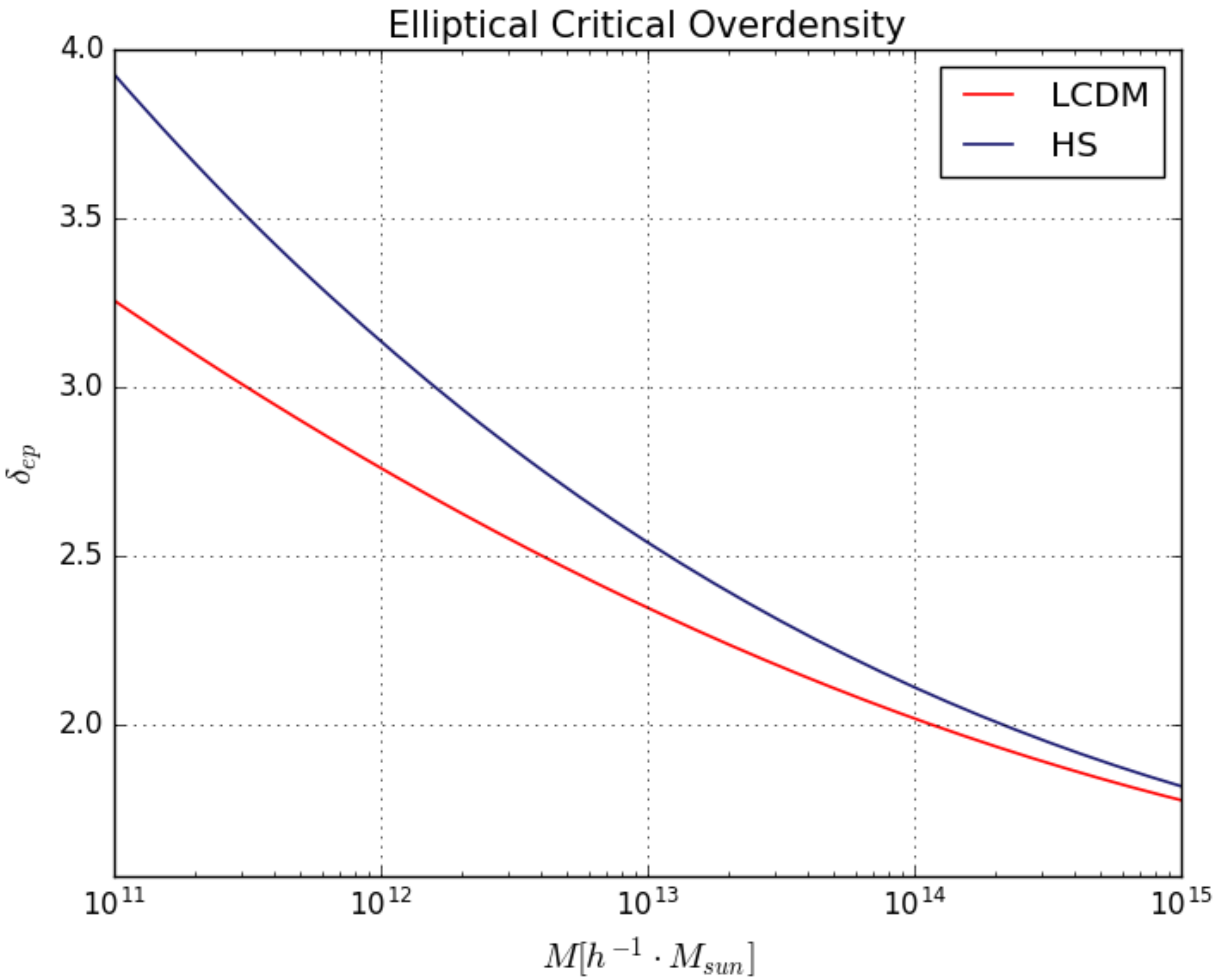
[Sheth, Mo, Tormen, 1999]



Ansatz:

$$\delta_{sc}^{LCDM} \Rightarrow \delta_{sc}^{MG}$$

$$B_{\rm GIF}(\sigma, z) = \sqrt{a}\,\delta_{\rm sc}(z)\left(1 + b\left[\frac{\sigma^2}{a\,\sigma_*^2(z)}\right]^c\right)$$



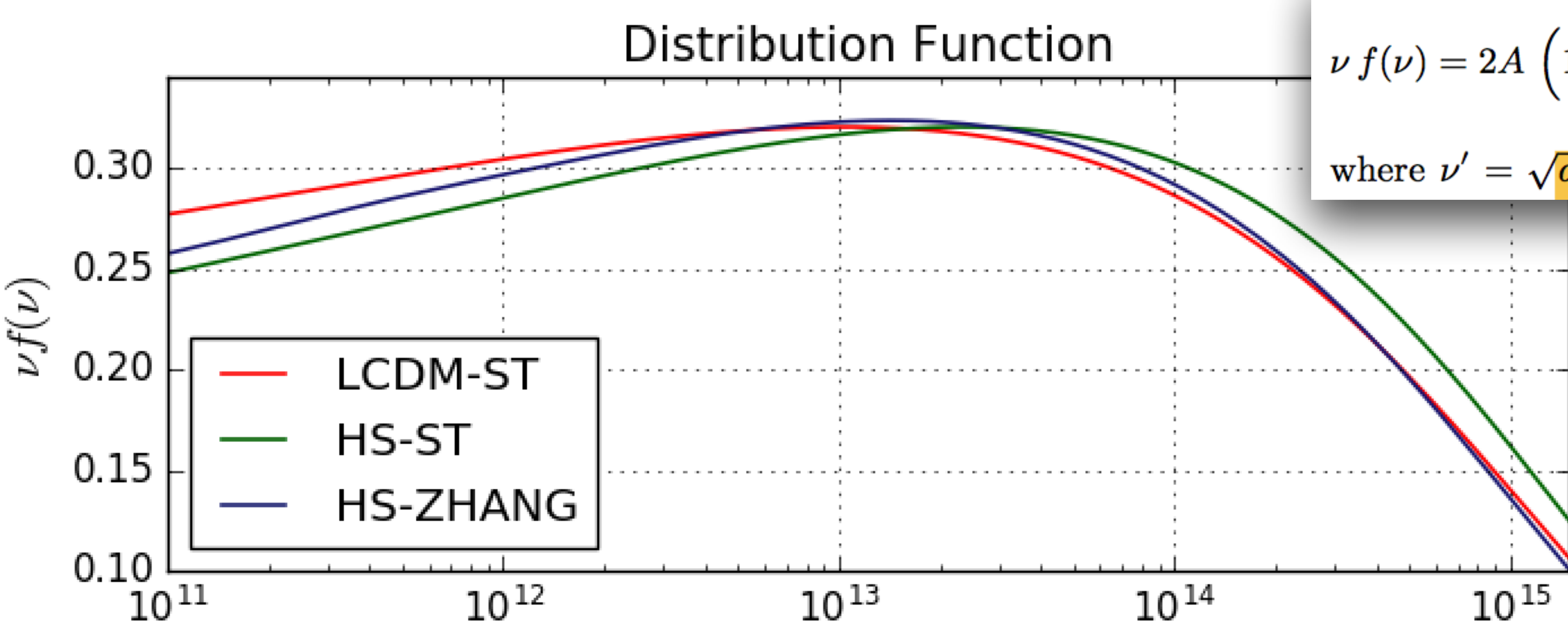
Step-3:

Halo Mass Function

[Sheth-Tormen, 1999]

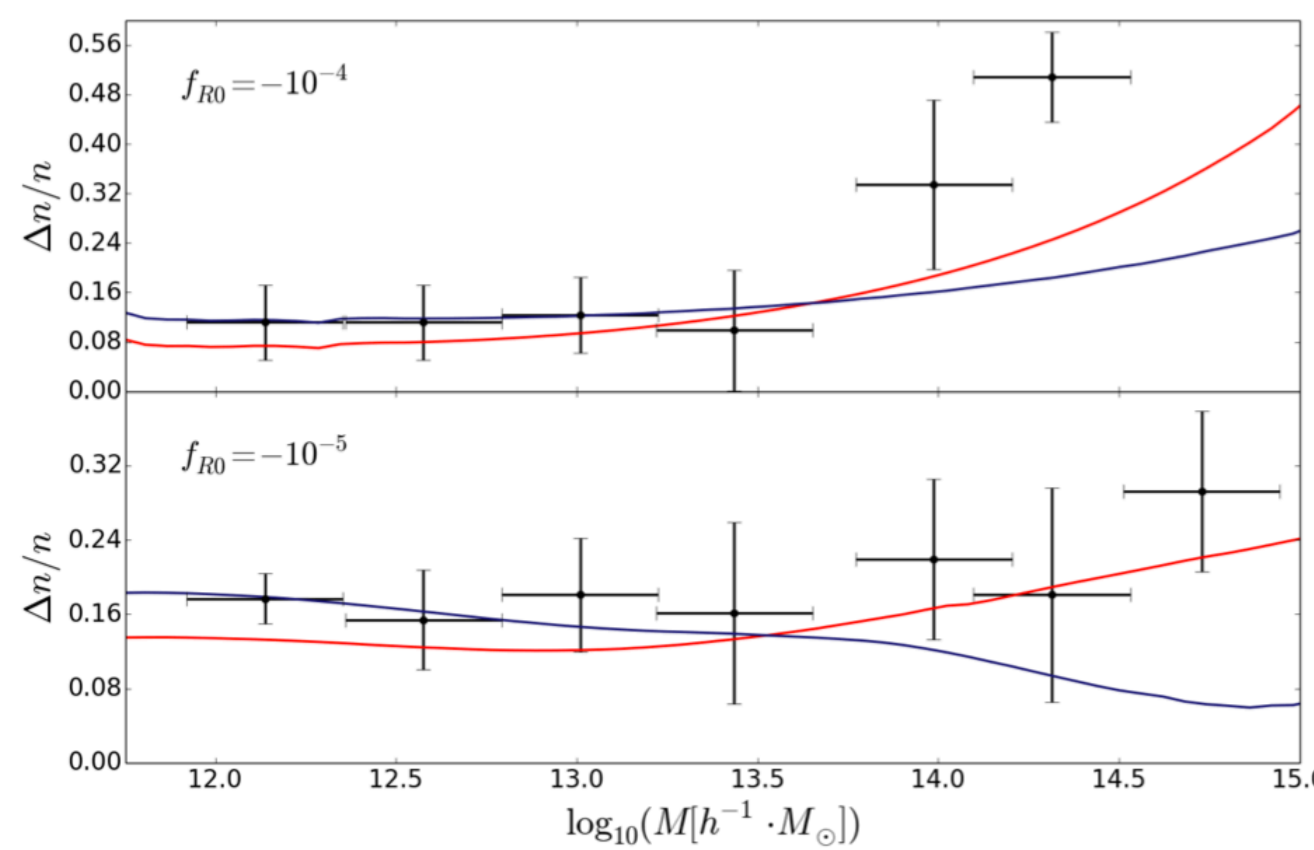
$$\nu f(\nu) = 2A\left(1+\frac{1}{\nu'^{2q}}\right)\left(\frac{\nu'^2}{2\pi}\right)^{1/2}\exp\left(-\frac{\nu'^2}{2}\right),$$

where $\nu' = \sqrt{a}\,\nu$, $a = 0.707$, $q = 0.3$ and $A \approx 0.322$



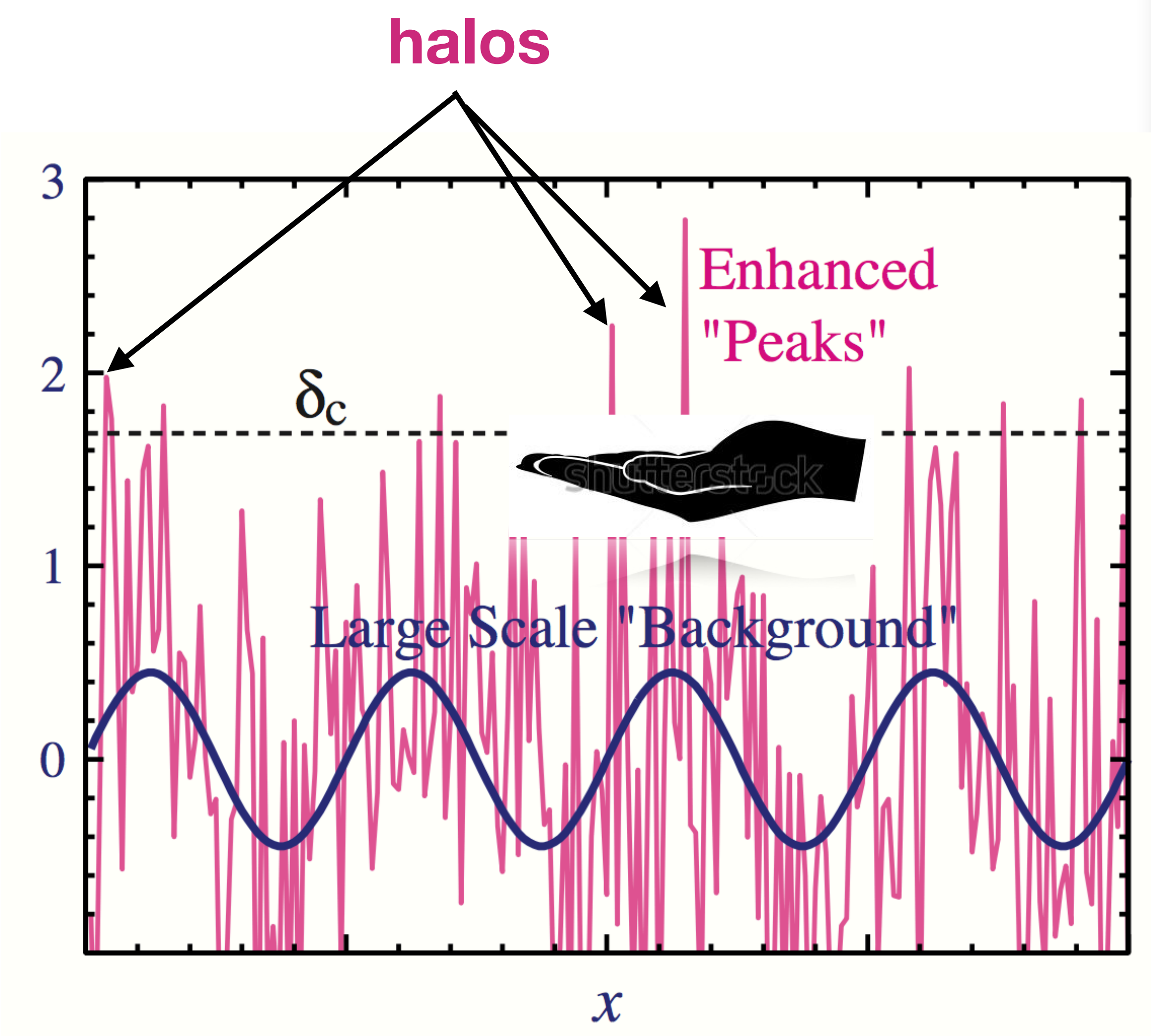
$$n_{\ln M_{\rm vir}} \equiv \frac{{\rm d}n}{{\rm d}\ln M_{\rm vir}} = \frac{\bar{\rho}_{\rm m}}{M_{\rm vir}} f(\nu)\frac{{\rm d}\nu}{{\rm d}\ln M_{\rm vir}}$$

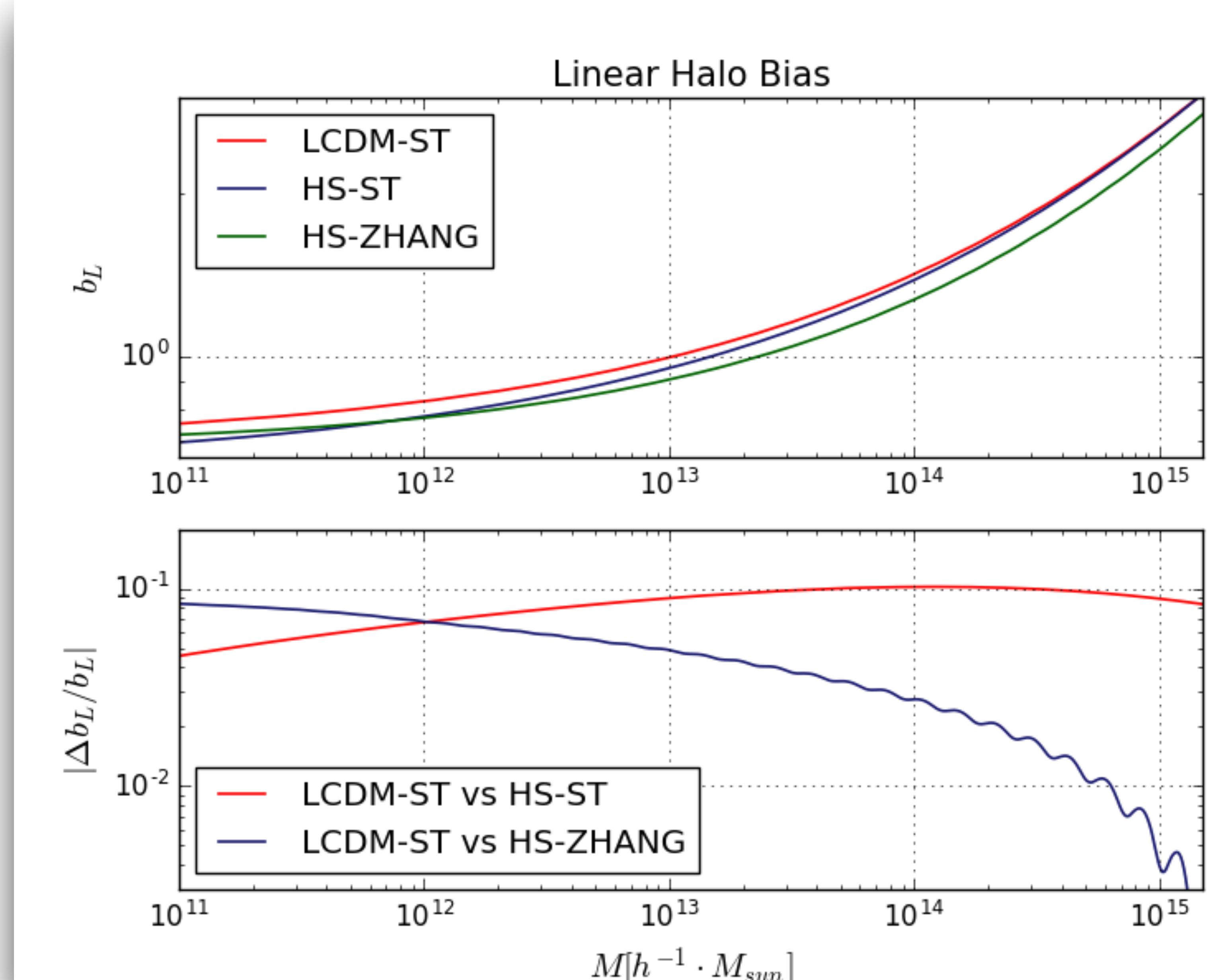
~20%!



Step-4: **Halo mass function gives the mean number density in the range of** $(M \sim M + dM)$

Linear Halo bias $\delta_m = (1+b) \bullet \delta_h$





In denser regime, δ_c **is easier to reach**

$$\delta_c^{eff} \sim \delta_c - \delta_0$$

1~10%!

$$n(m, \delta_c^{eff}) \sim n(m, \delta_c) - \frac{\partial n}{\partial \delta_c} \bullet \delta_0 + \cdots$$

$$b_L \delta_0 = \frac{n(m, \delta_c^{eff})}{n(m, \delta_c)} - 1 = \boxed{\frac{\partial \log n}{\partial \delta_c}} \bullet \delta_0$$

Step-5:

Halo concentration

$$c_v = \frac{r}{r_s}$$

$$\rho_s = \frac{1}{3}\bar{\rho}_m \Delta_{vir} c_{vir}^3 \left[\ln(1+c_{vir}) - \frac{c_{vir}}{c_{vir}+1}\right]^{-1},$$

$$r_s = \frac{1}{c_{vir}}\left(\frac{3M_{vir}}{4\pi\bar{\rho}_m\Delta_{vir}}\right)^{1/3},$$

Halo density profile

(NFW profile)

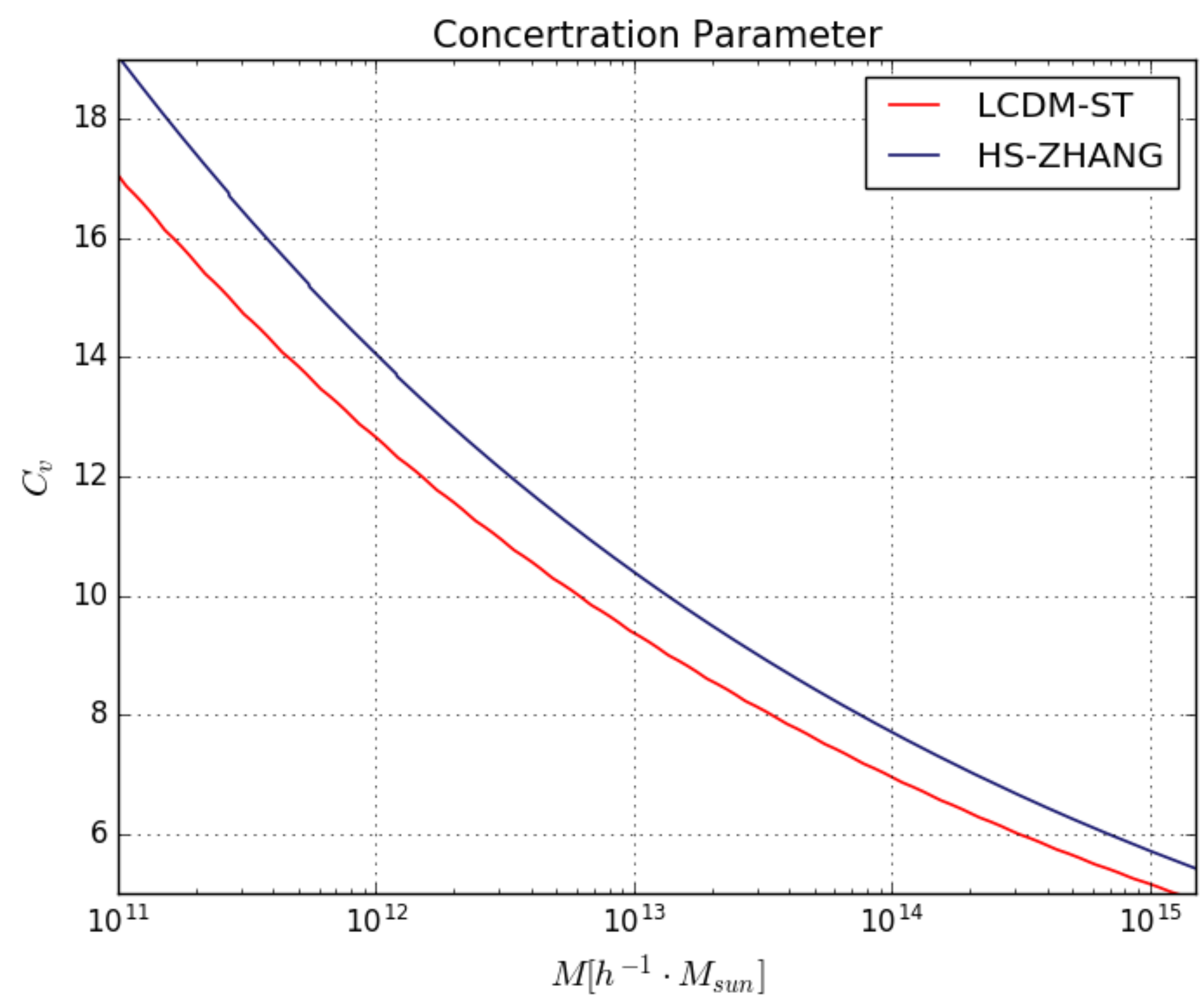
$$\delta\rho_m(r) = \frac{\rho_s}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2} \xrightarrow[\text{transform}]{\text{Fourier}} y(k,M)$$

$$c_v(M_v) = 9\left|\frac{M_*}{M_v}\right|^{0.13} \qquad \sigma(M_*) = \delta_c$$

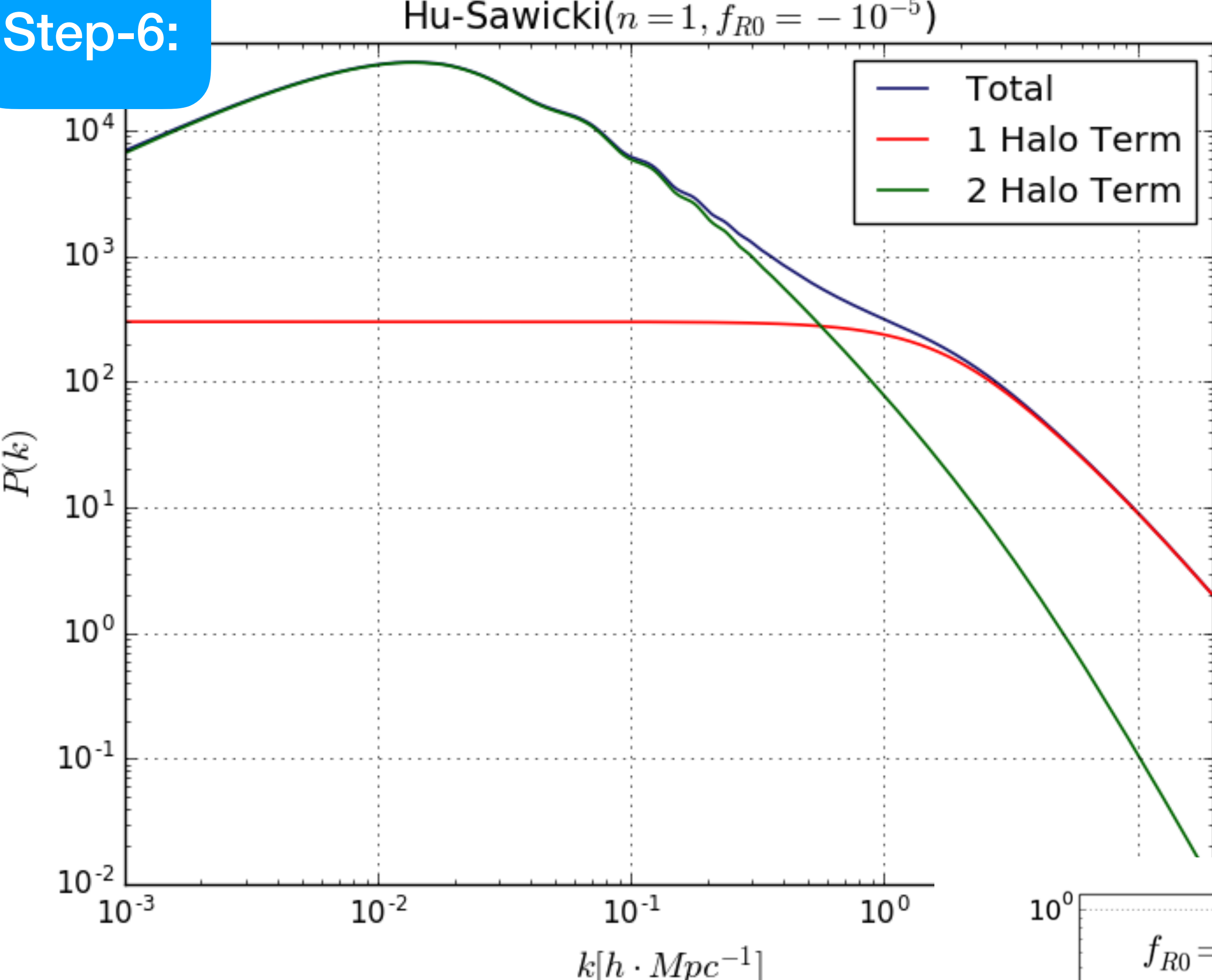
Virial Mass

$$\sigma^2(R) = \langle\delta^2(\vec{x};R)\rangle = \int \mathrm{d}\ln k\ \Delta^2(k)|W(k;R)|^2.$$

~10%!



Step-6:

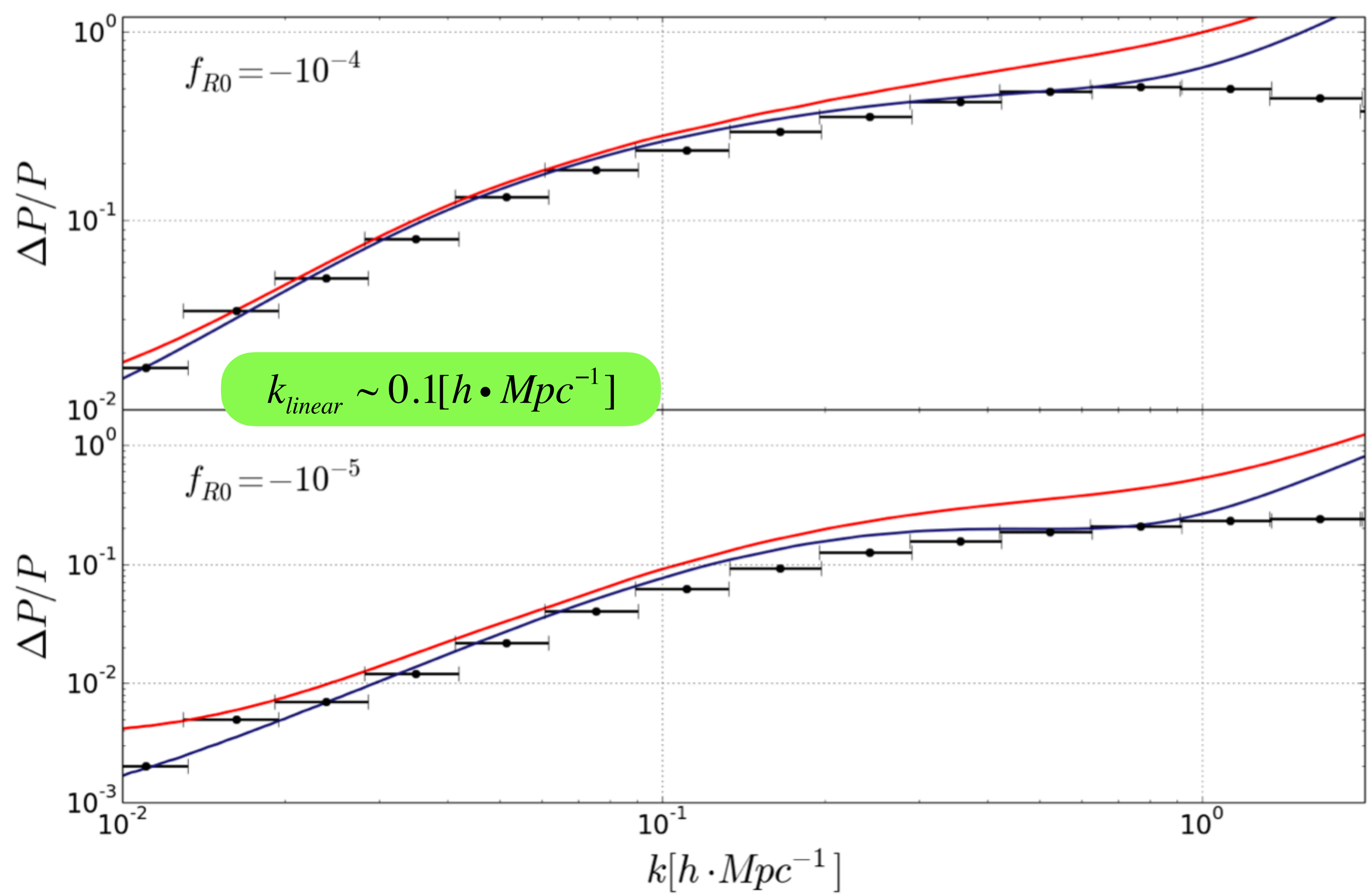


Matter Power spectrum

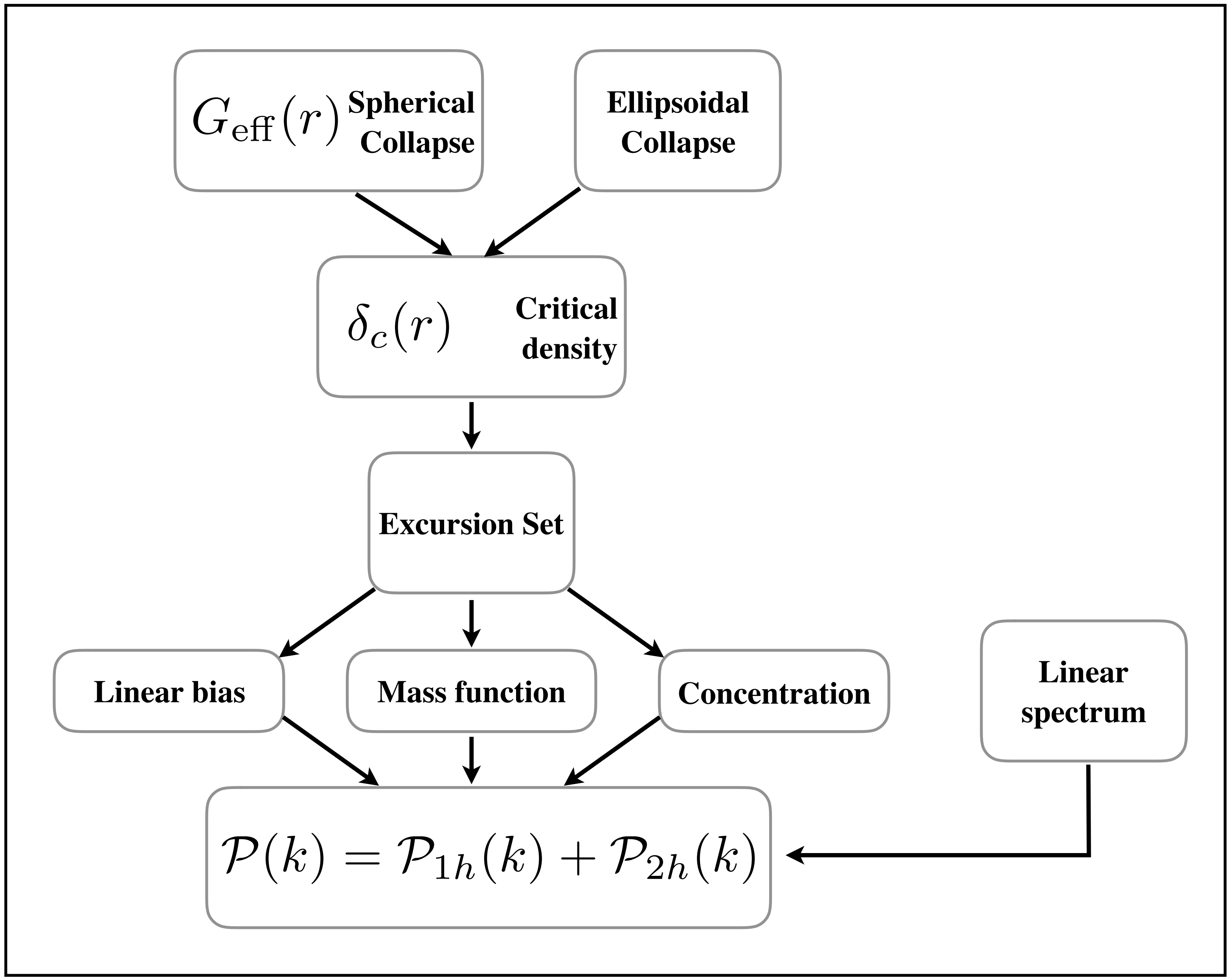
$$P_{\rm mm}(k) \simeq I^2(k)P_{\rm L}(k) + P^{1h}(k),$$

$$P^{1h}(k) = \int {\rm d}\ln M_{\rm vir} n_{\ln M_{\rm vir}} \frac{M_{\rm vir}^2}{\bar{\rho}_{\rm m}^2} |y(k, M_{\rm vir})|^2$$

$$I(k) \simeq \int {\rm d}\ln M_{\rm vir} n_{\ln M_{\rm vir}} \frac{M_{\rm vir}}{\bar{\rho}_{\rm m}} y(k, M_{\rm vir}) b_{\rm L}(M_{\rm vir}),$$



10 times data can be used!



- For the non-linear perturbation, halo model could give a reasonable estimation of the non-linear P(k) up to k~1 [h/Mpc] for Hu-Sawicki f(R) F4/F5 model.

Thanks!