PRIMORDIAL IMPRINTS IN HALO DISTRIBUTIONS

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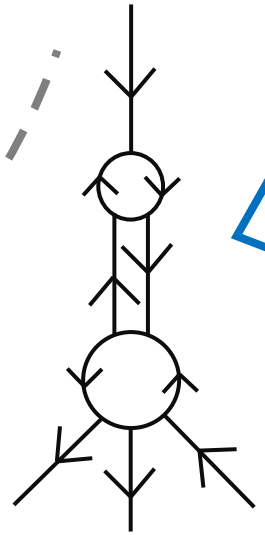
Sep. 10, 2026
TDLI, Shanghai

with Itamar Allali, Xingang Chen and JiJi Fan, In prep.

Outline

- ❑ Prelude: modified power spectrum
- ❑ Common Properties of Primordial Features
- ❑ From Features to Halo Mass Function
- ❑ Possible Probes from UV Light Function (UVLF) and Beyond

The Big(gest) and Small(est) Scales



Insertion of N_{efold}, H_0, H_{inf}, T_{rh}, M_{PL}...

> Mpc

Scales

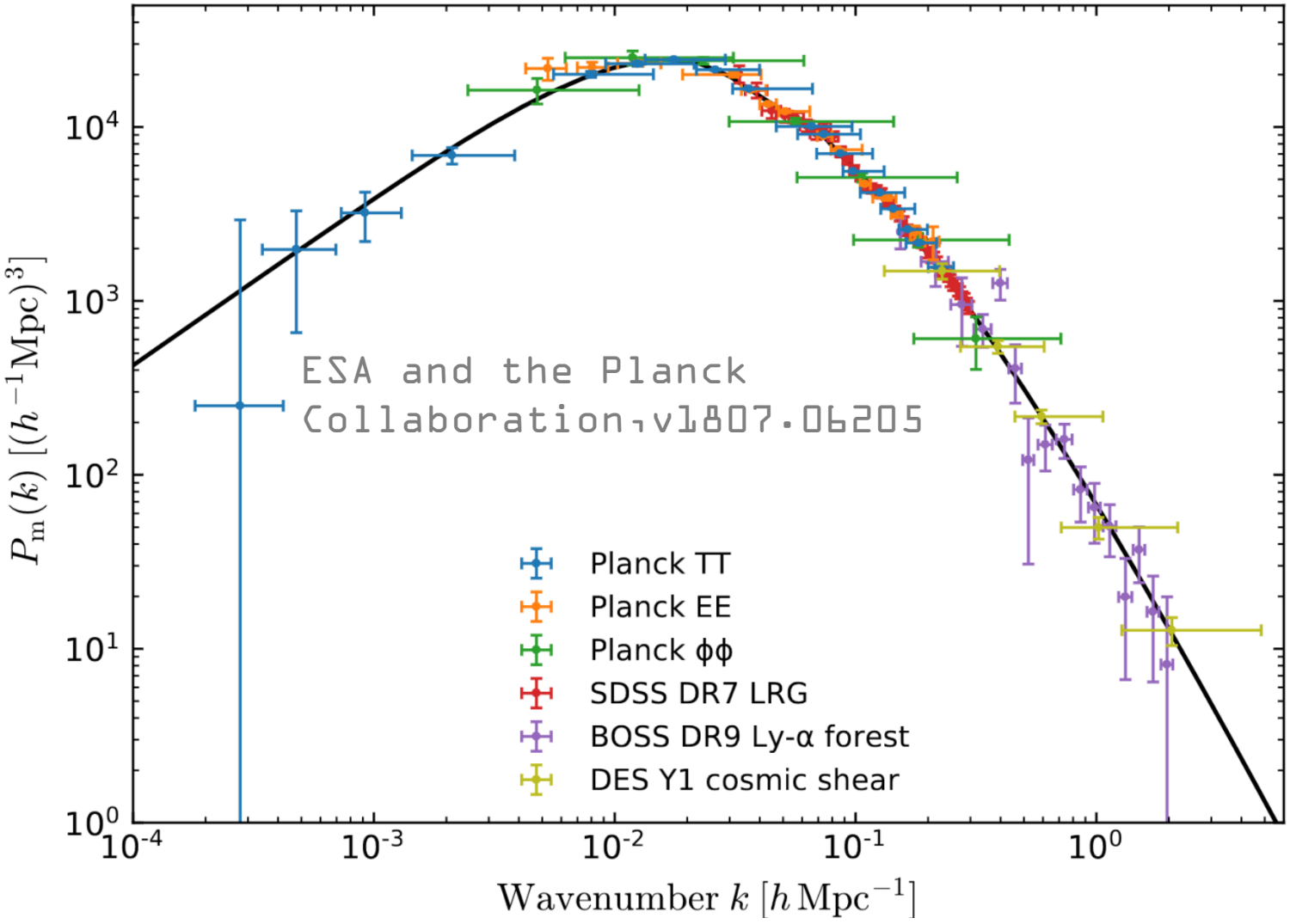
< TeV^{-1}

Inflation

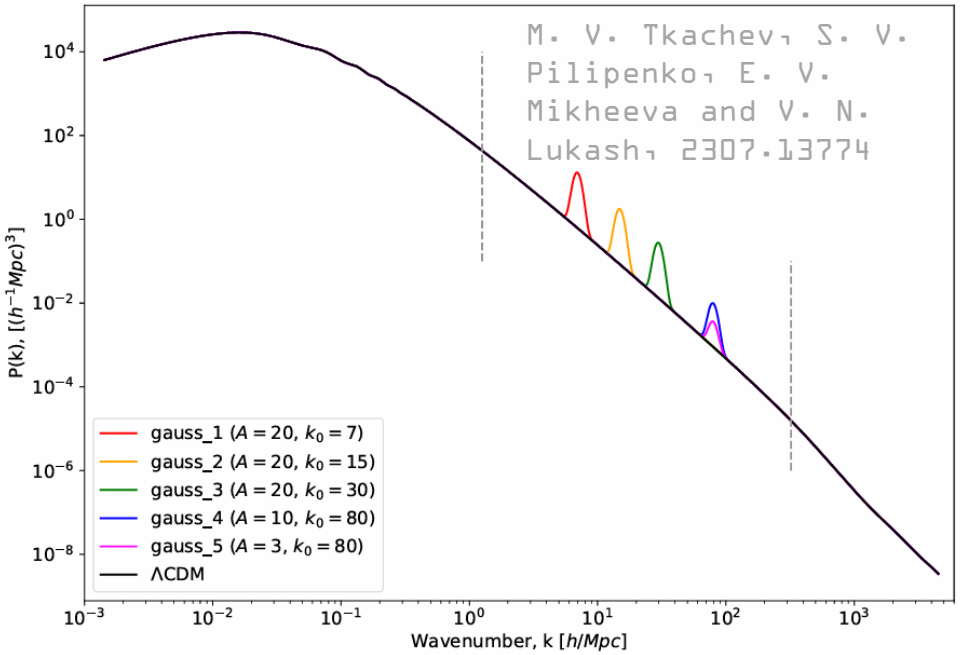
This is never easy...

Linear Matter Power Spectrum (MPS)

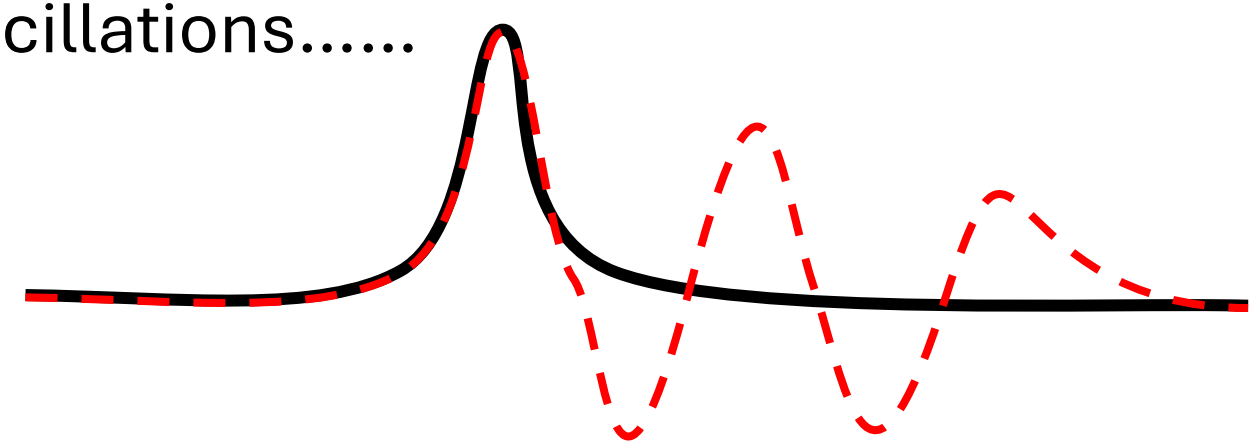
Scale too large, cosmic variance



Scale too small, harder to probe



- If one injects large corrections to MPS, intuitively shall be accompanying oscillations……



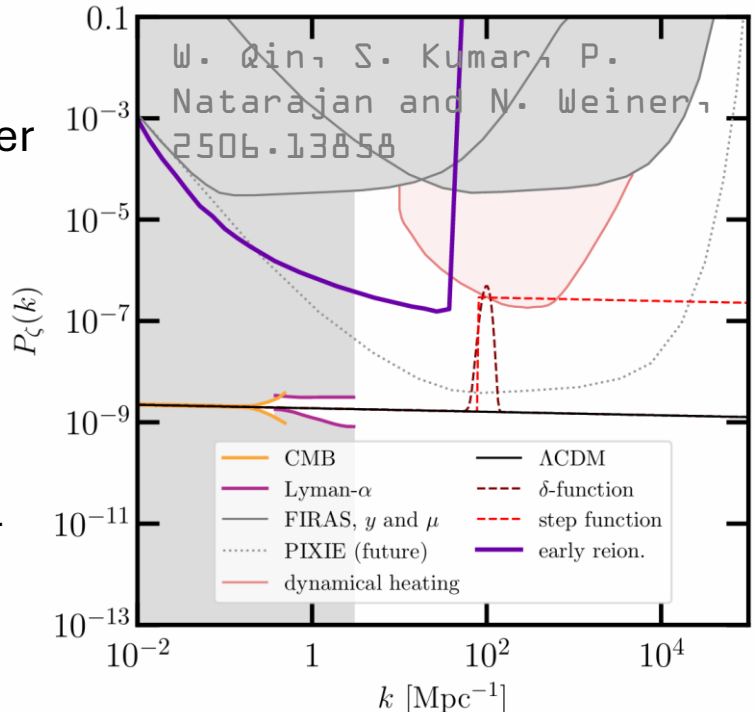
D. Cheung, M. Tadepalli, 2110.02772; X. Chen, J. Fan, LFL, 2303.03406; LFL et al. 2606.11312……

- Recent deep field observations suggest some modification of matter power spectrum might be needed

Parashari and R. Laha, 2305.00999; N. Sabti, J. B. Mu˜noz and M. Kamionkowski, 2305.07049……

- Could be related to other phenomena like primordial black holes

V. De Luca et al. 2512.19666……

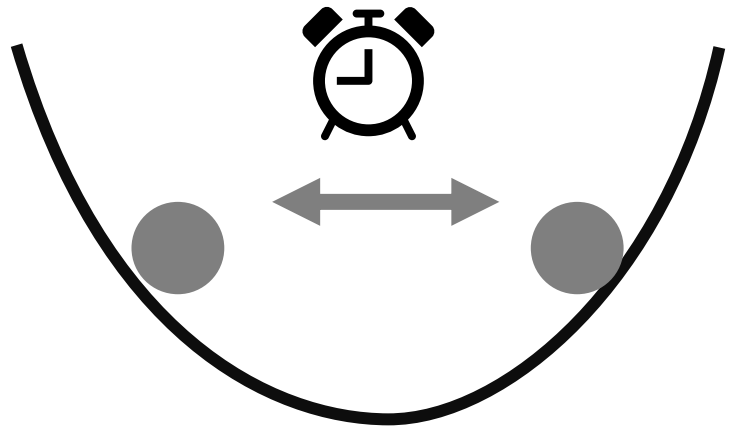


Question: how would these oscillatory feature look like? Would up's and down's cancel?

Currently not targeting any particular anomaly but as a general study…

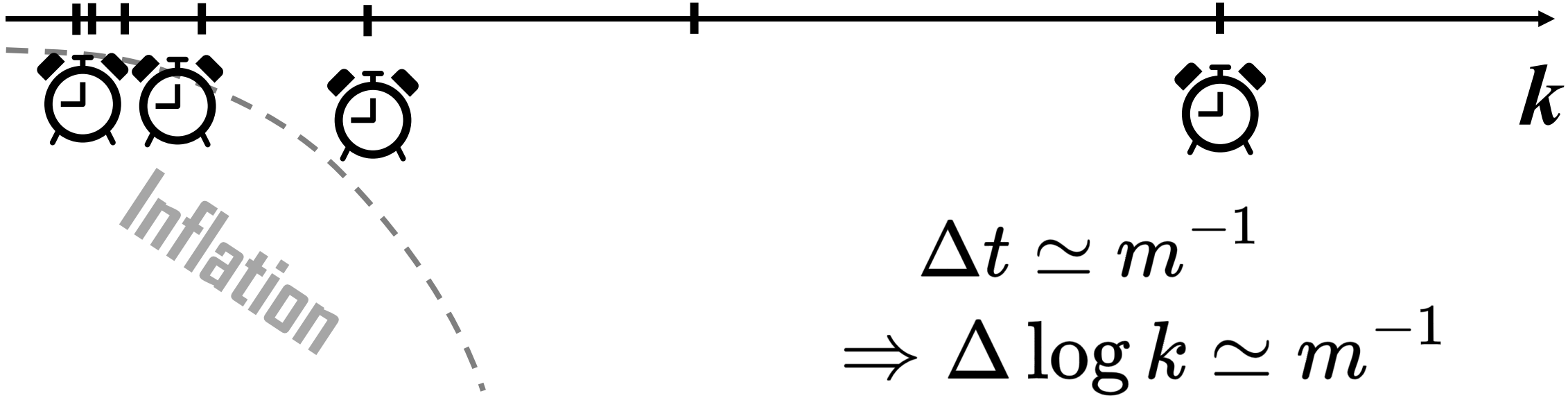
How the Clock Ticks

The simplest (?) clock



$$a \propto e^{Ht}$$

$$k^* \simeq H^{*-1}$$

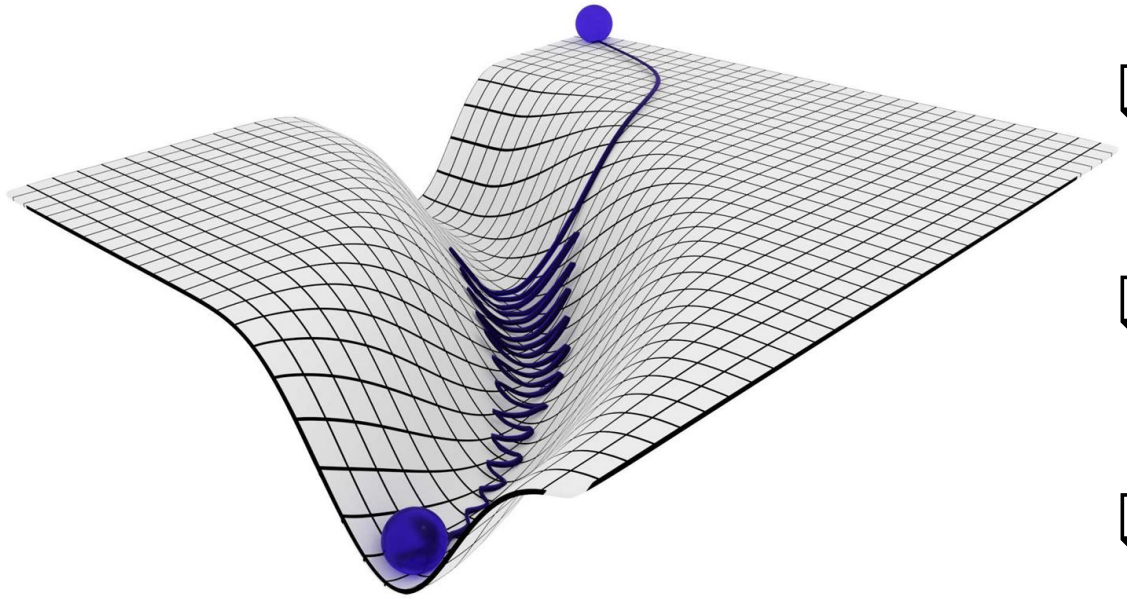


$$\Delta t \simeq m^{-1}$$

$$\Rightarrow \Delta \log k \simeq m^{-1}$$

One Scheme for Primordial Feature

X. Chen, M. H. Namjoo and Y. Wang, 1411.2349

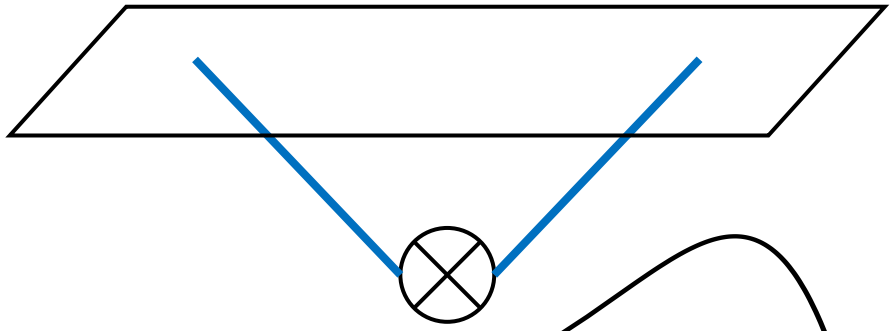


- Could come from the quasi-single field inflation paradigm
- May also give significant non-Gaussianty observables
- A sharp turn in the potential usually indicate heavy modes heavier than inflationary Hubble

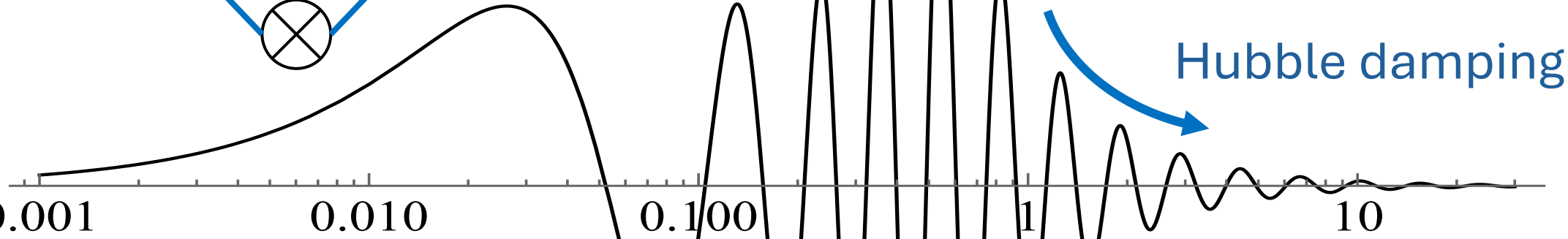
See also: K. Inomata, E. McDonough, W. Hu, 2021; I. Dalianis, G. P. Kodaxis, I. D. Stamou, N. Tetradis, A. Tsigkas-Kouvelis' 2021; R. Kawaguchi, T. Fujita, M. Sasaki, 2023; Shi Pi, M. Sasaki, 2022; A. Bodas, R. Sundrum, 2022; H. An, B. Su, H. Tai, L.T. Wang, C. Yang, 2023……

Clock signal, sensitive to mass

$$\frac{\Delta P_\zeta^{\rm clock}}{P_{\zeta 0}} \simeq C_{\rm clock}\left(\frac{2k}{k_r}\right)^{-3/2}\left[1+\sin\left(\nu \ln\frac{2k}{k_r}+\alpha\right)\right]$$



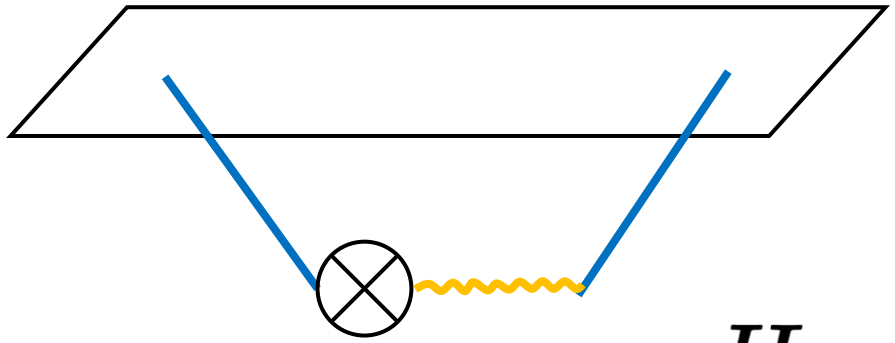
Hubble damping



k/k_0

$$\frac{\Delta P_\zeta^{\rm sharp}}{P_{\zeta 0}} = C_{\rm sharp}\frac{1}{w\sqrt{2\pi}}e^{-\frac{(k-k_p)^2}{2w^2}}\left[1+\sin\left(\frac{2k}{k_0}+\alpha\right)\right]$$

Step induced, clock independent



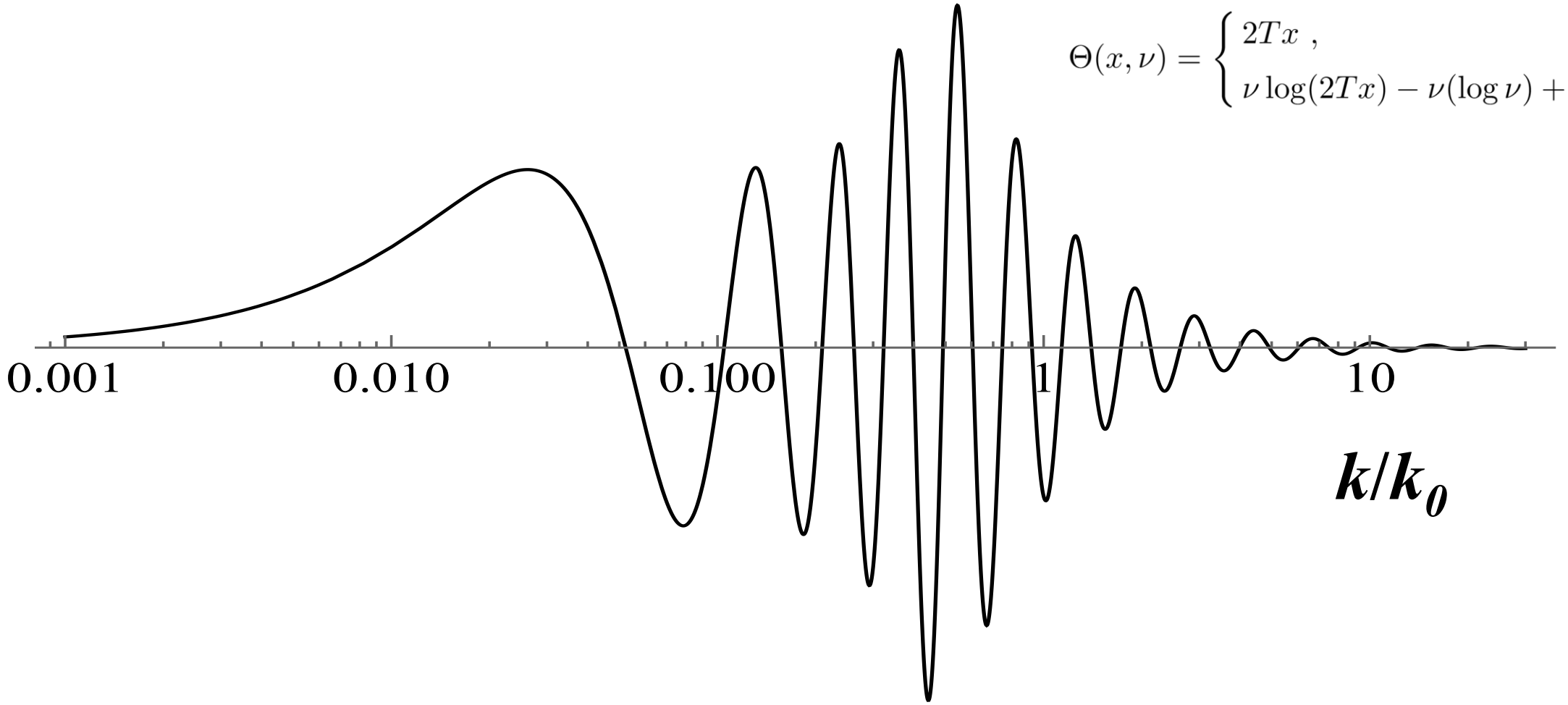
$$m \simeq \nu H$$

New Template Proposed

$$\text{const} \times Y(x) \sin[\Theta(x,\nu) + \phi]$$

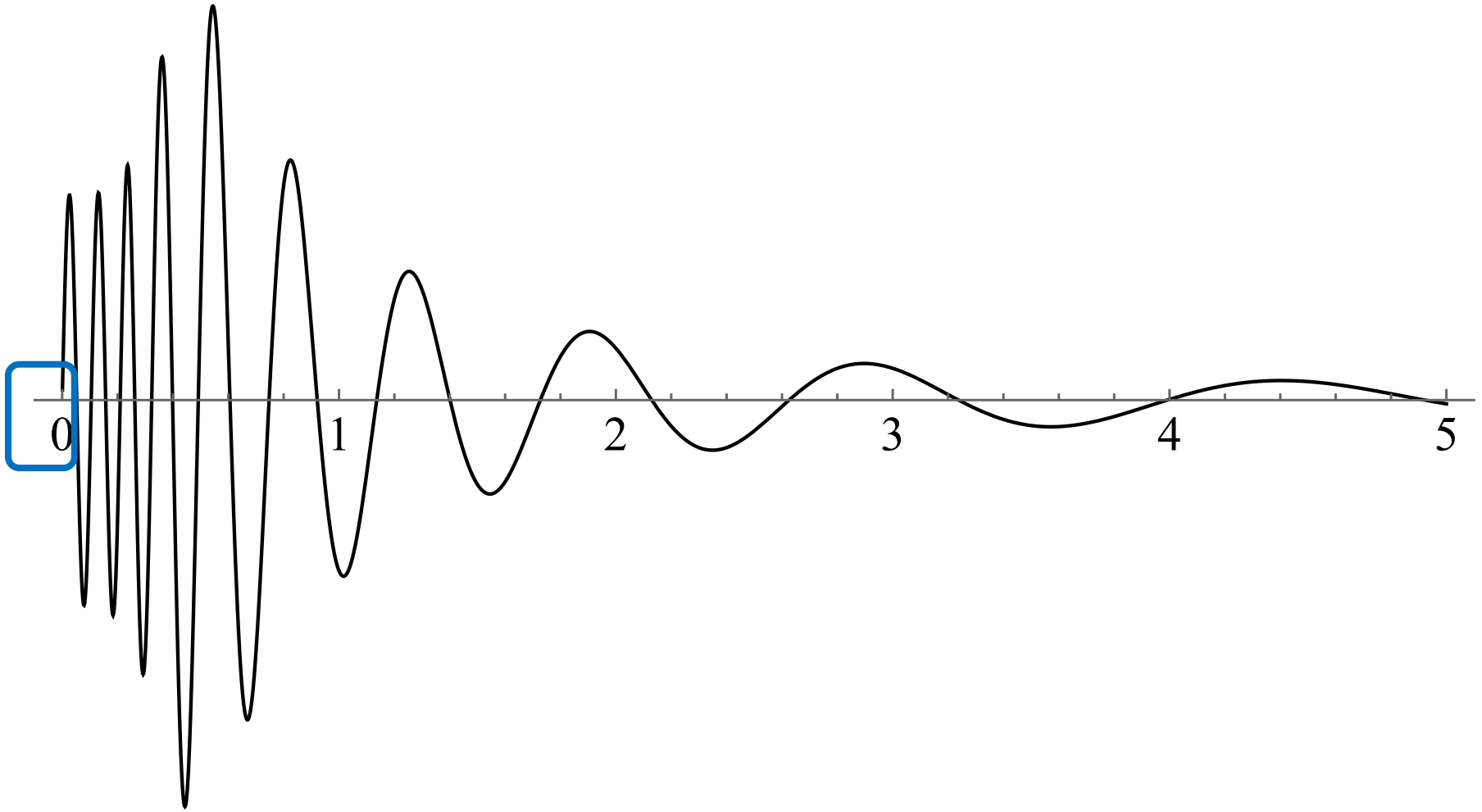
$$x \equiv k/k_0 \ , \ Y(x) \equiv \frac{(x/2)^{-3/2} + (x/2)^{-s}/5}{1 + (x/2)^{-s}/2}$$

$$\Theta(x,\nu) = \begin{cases} 2Tx \ , & 2Tx \le \nu \\ \nu \log(2Tx) - \nu(\log \nu) + \nu \ , & 2Tx > \nu \end{cases}$$

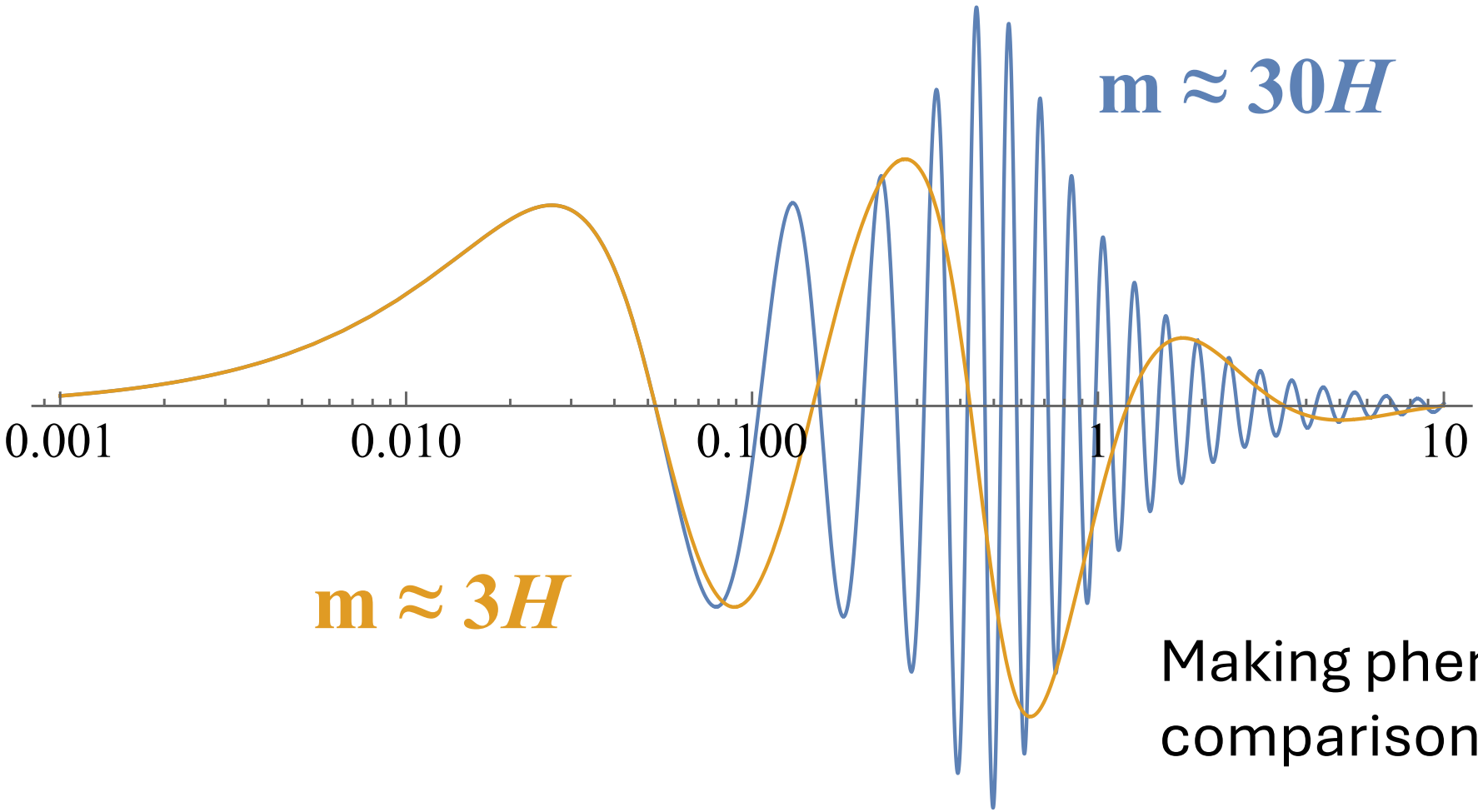


Linear Scale View

All we know (clearly) is here

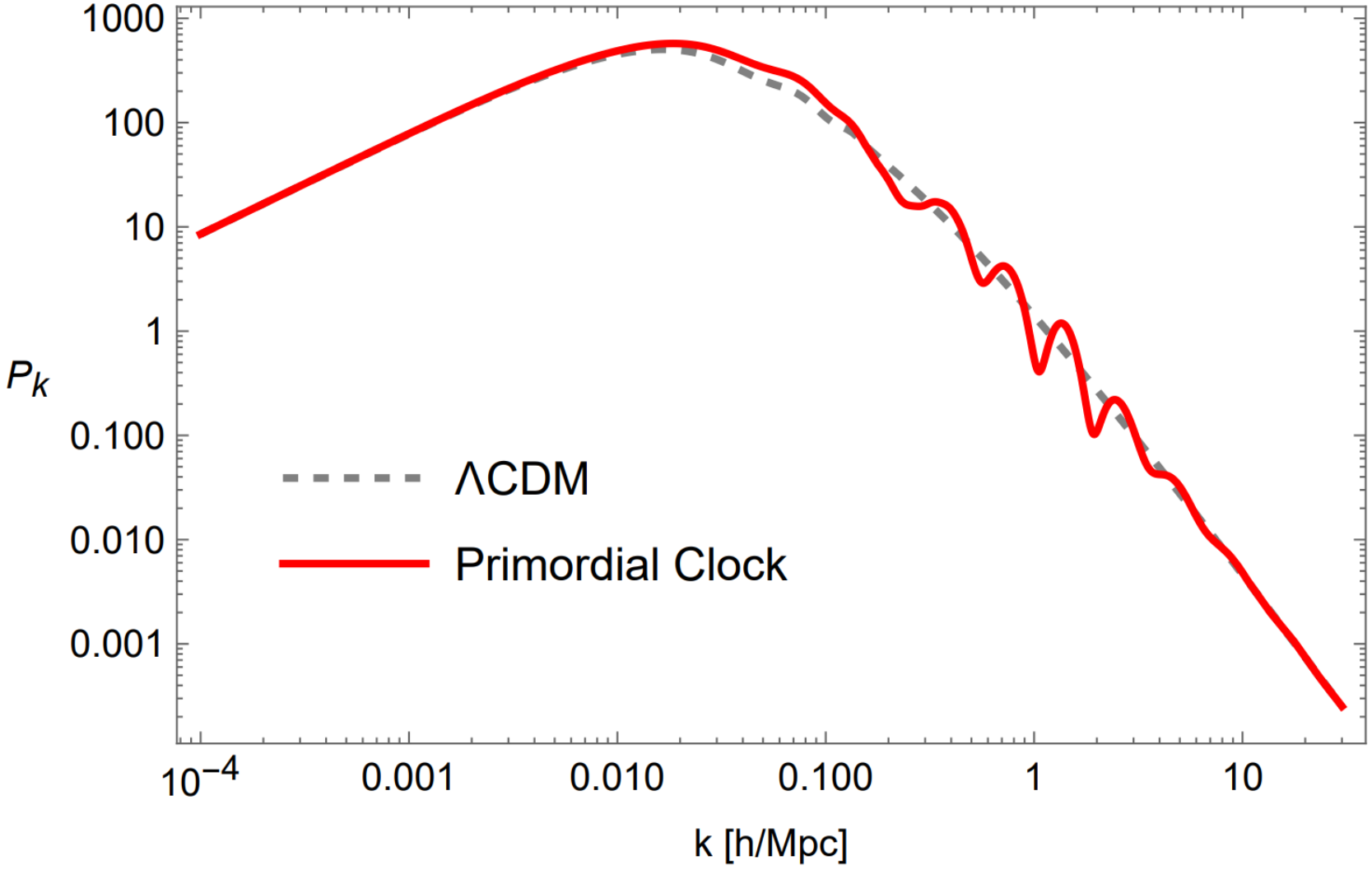


Identical Behavior at Large Scales



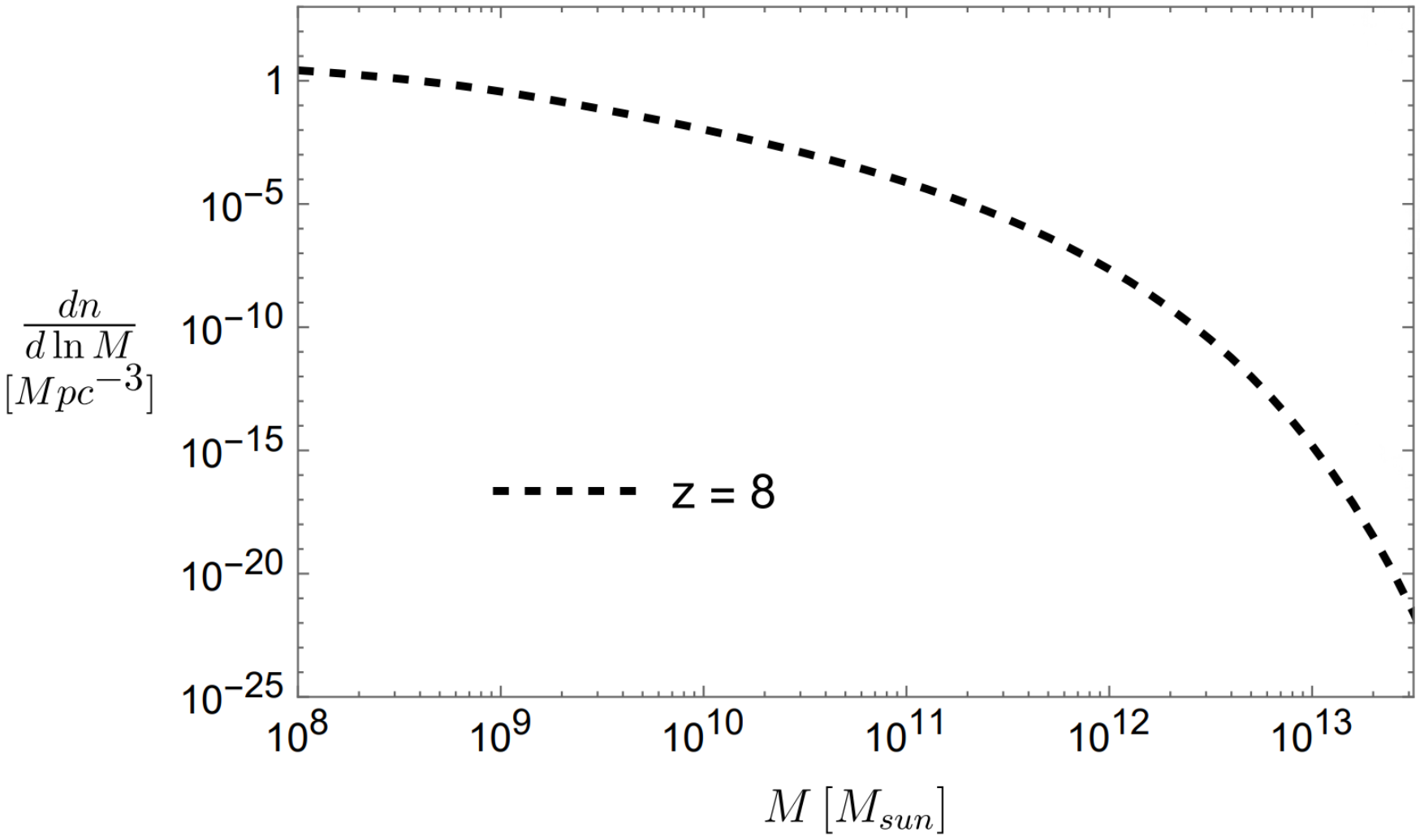
Making phenomenological comparison much easier…

Modified MPS (Exaggerated)



Upcoming in Measuring HMF

The HMF from LCDM



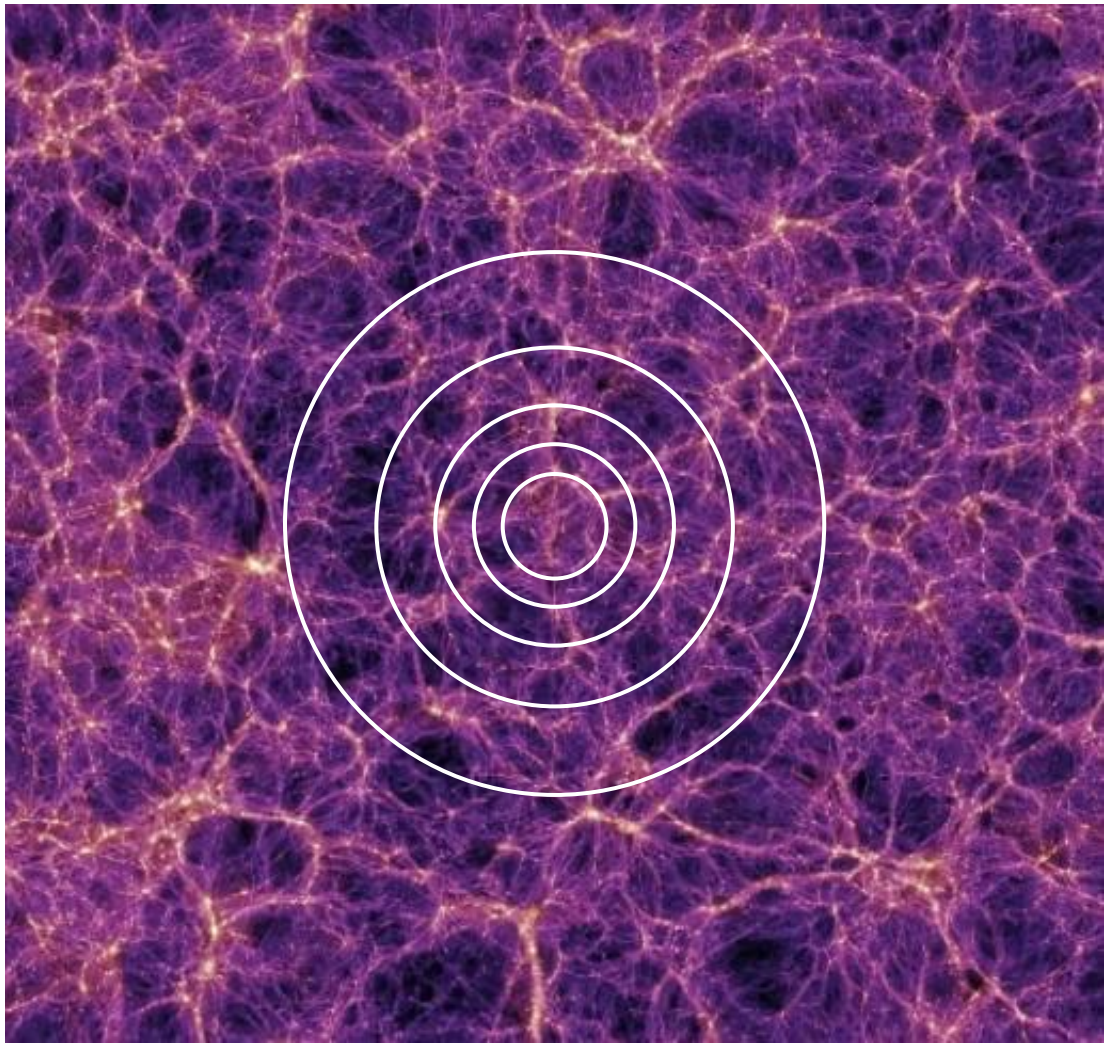
Not yet a clear collection of measurements as MPS due to smaller scales

From MPS to HMF

Excursion Set Theory (EST)

- Analytically estimate the fluctuations inside particular statistical boxes with different sizes…

(can achieve good agreement with simulation and inexpensive)

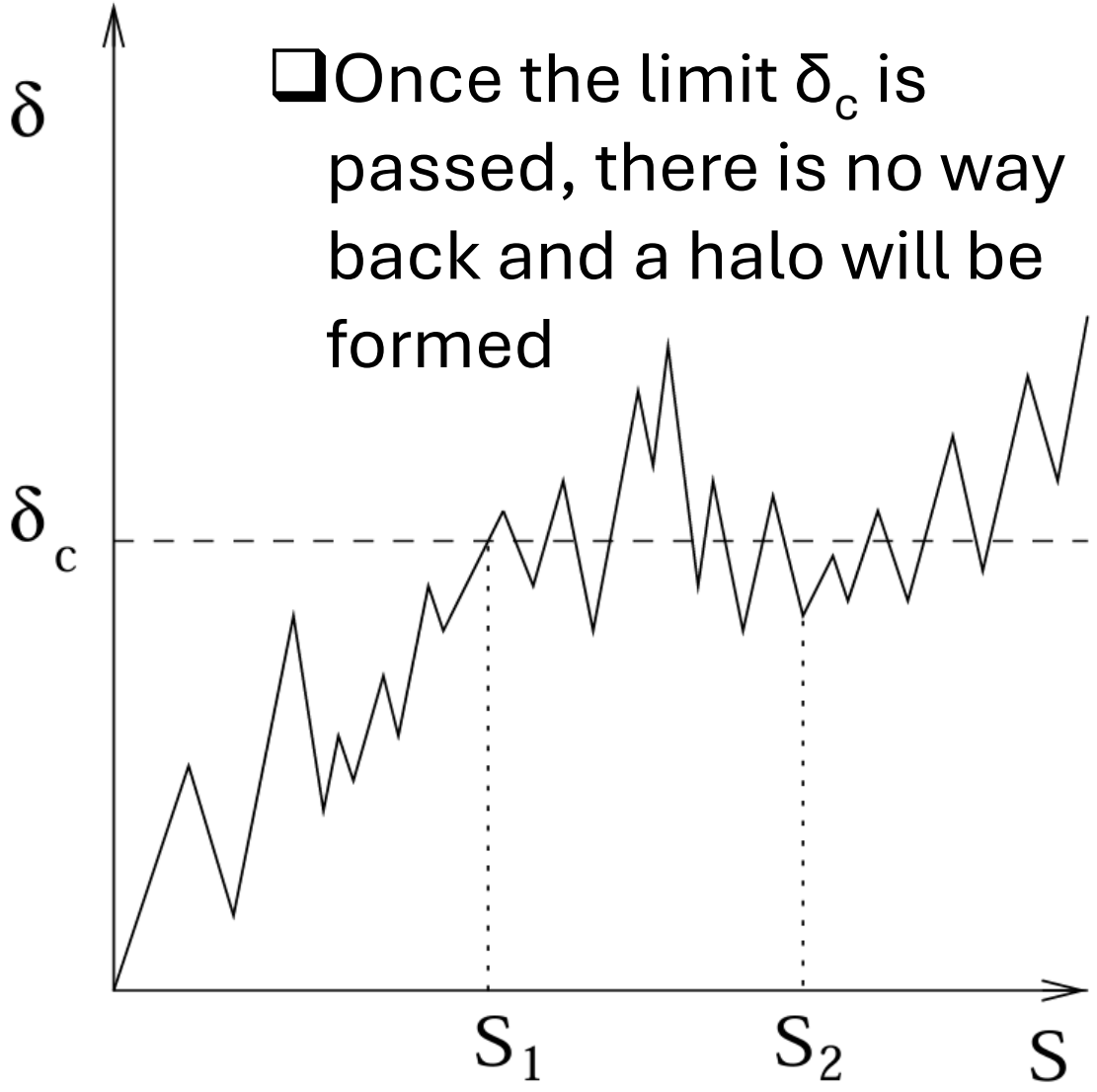


N-body Simulation

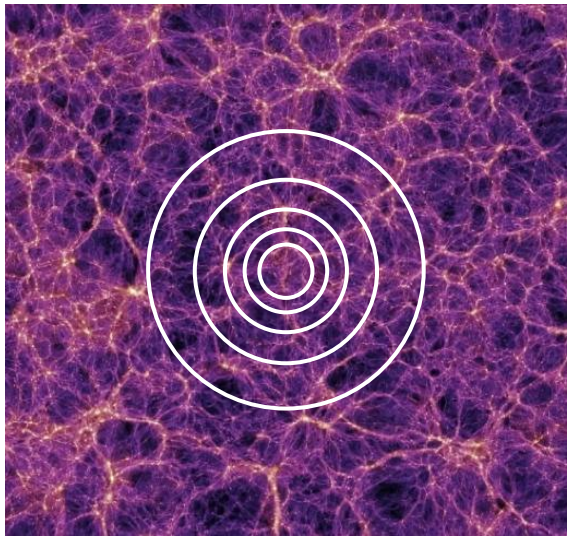
- Study matter evolution in phase space with highly sophisticated algorithms to be accurate and fast

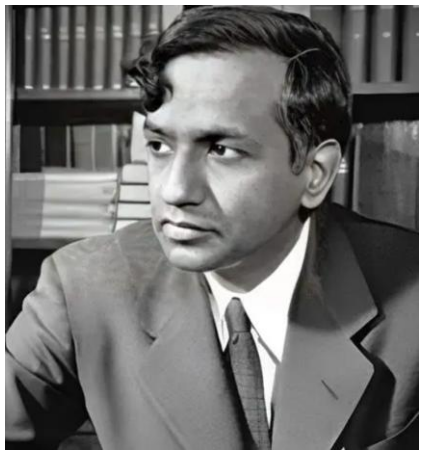
(still expensive in general)

Excursion Set Theory



- Once the limit δ_c is passed, there is no way back and a halo will be formed



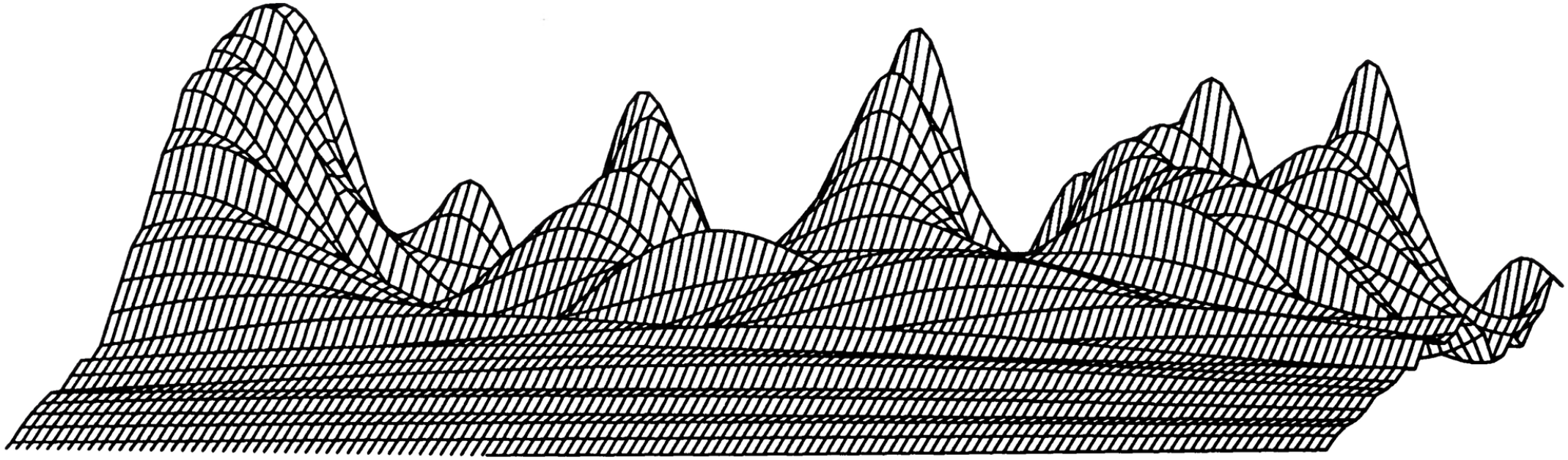


S. Chandrasekhar, 1943

- When shrinking the window for statistics (or moving S), the effect by integrating IR power are considered as random Markovian steps (but it accumulates)

W. H. Press and P. Schechter 1974; J. R. Bond, S. Cole, G. Efstathiou and N. Kaiser, 1991; R. K. Sheth and G. Tormen, 0105113

Excursion Set Theory



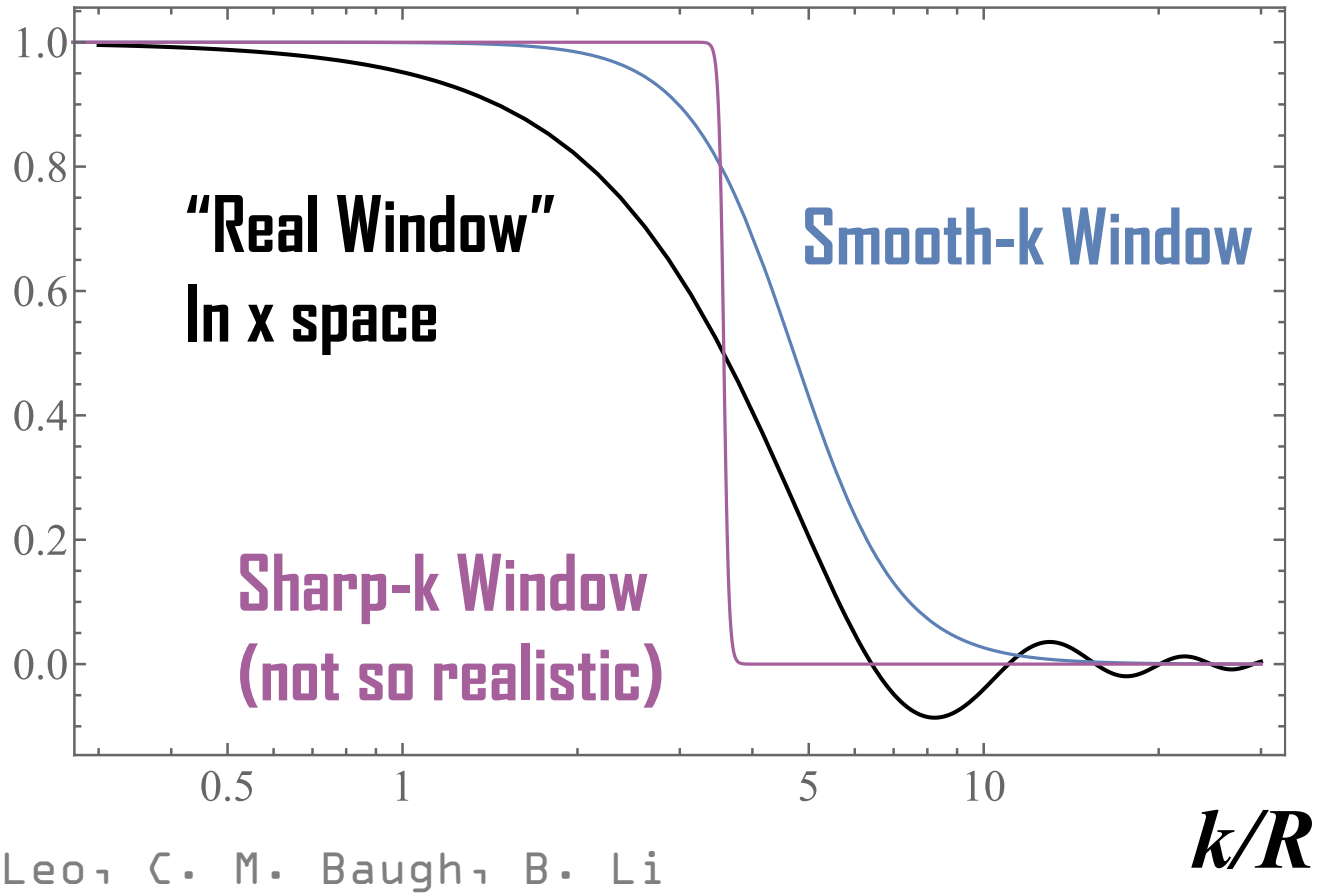
$$\frac{\mathrm{d}n}{\mathrm{d}M}\,\mathrm{d}M = \sqrt{\frac{2}{\pi}}\frac{\rho_{\mathrm{M}}}{M^2}\frac{\delta_{\mathrm{c}}}{\sigma}\left|\frac{\mathrm{d}\ln\sigma}{\mathrm{d}\ln M}\right|\exp\left(-\frac{\delta_{\mathrm{c}}^2}{2\sigma^2}\right)\mathrm{d}M$$

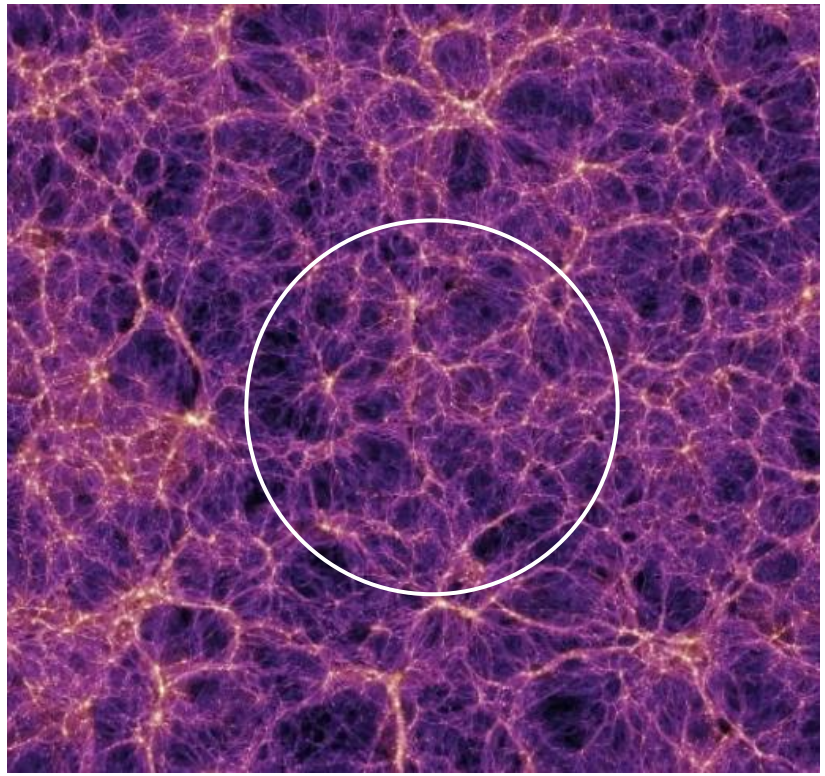
$$= \sqrt{\frac{2}{\pi}}\frac{\rho_{\mathrm{M}}}{M^2}\,\nu\frac{\mathrm{d}\ln\nu}{\mathrm{d}\ln M}\,\exp\left(-\frac{\nu^2}{2}\right)\mathrm{d}M.$$

Andrew R. Zentner, 0611454; M. Maggiore and A. Riotto, 0903.1249…

Window Function

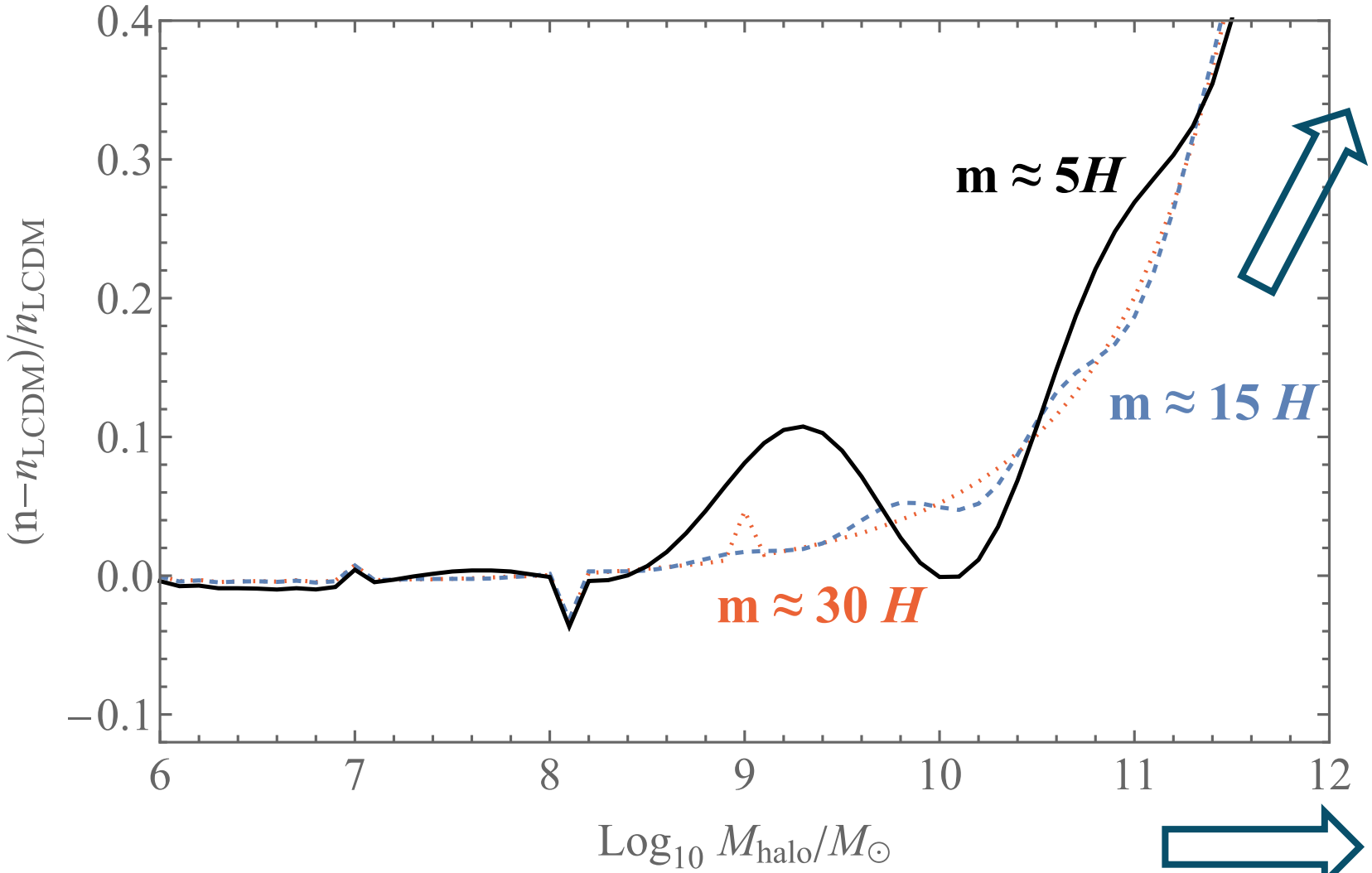
$$S(R) = \int_{-\infty}^{\infty} d(\ln k)\, \Delta^2(k) \left| \tilde{W}(k,R) \right|^2 .$$





M. Leo, C. M. Baugh, B. Li and S. Pascoli, 1801.02547

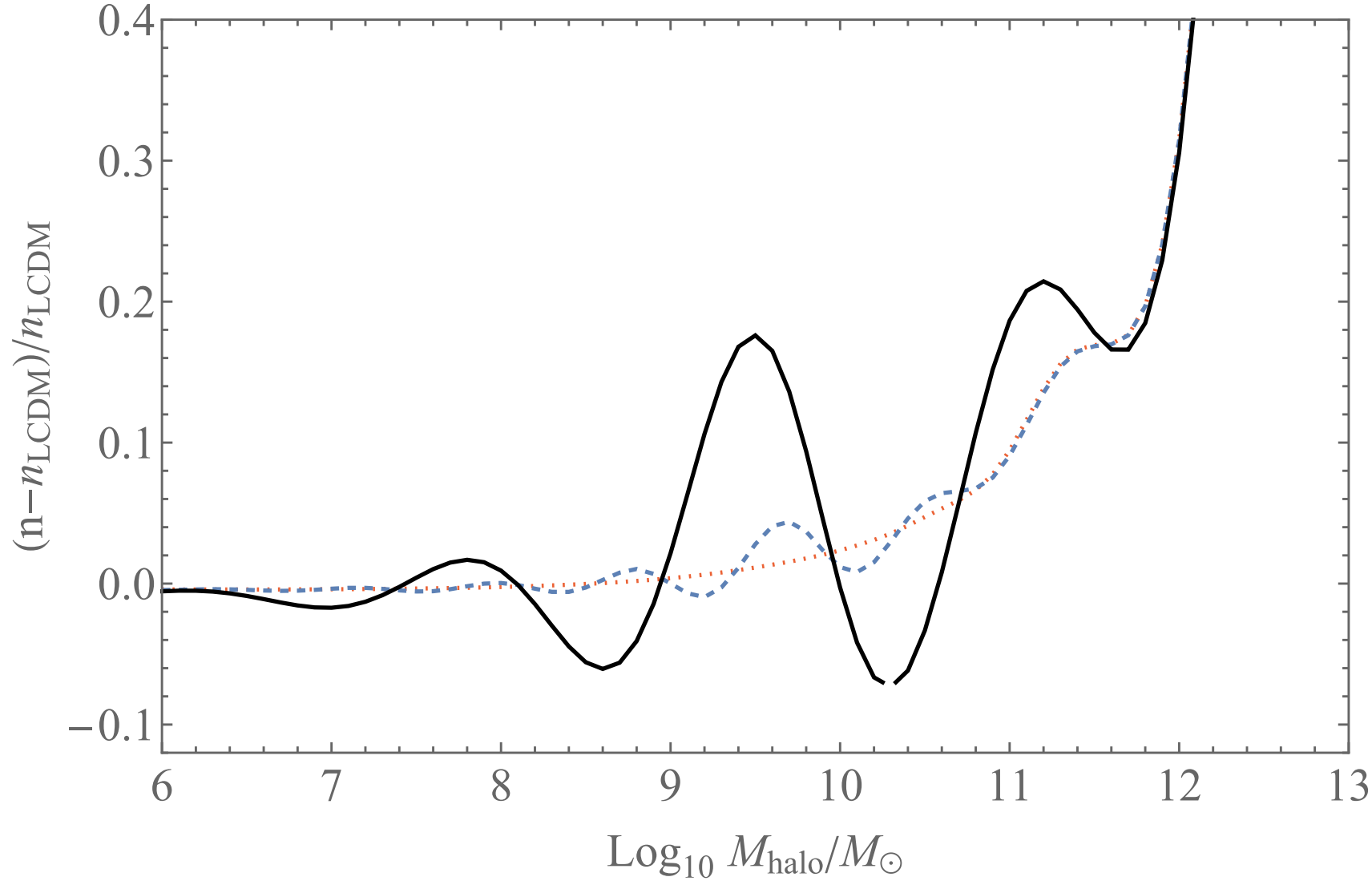
From "Real" Window Function



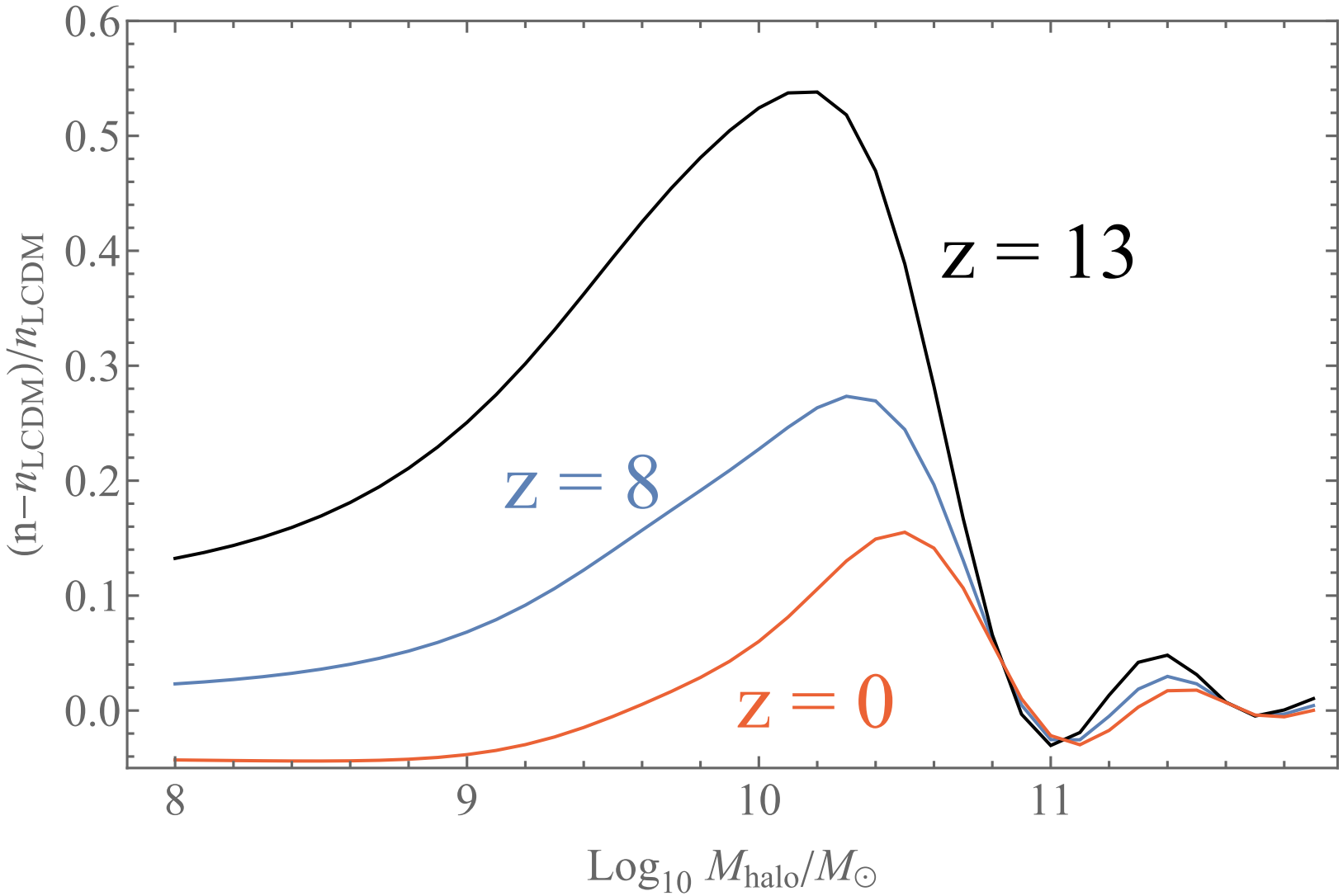
Effect of the first bump
(relative as the heavy halos are rare)

Larger mass ~ smaller k

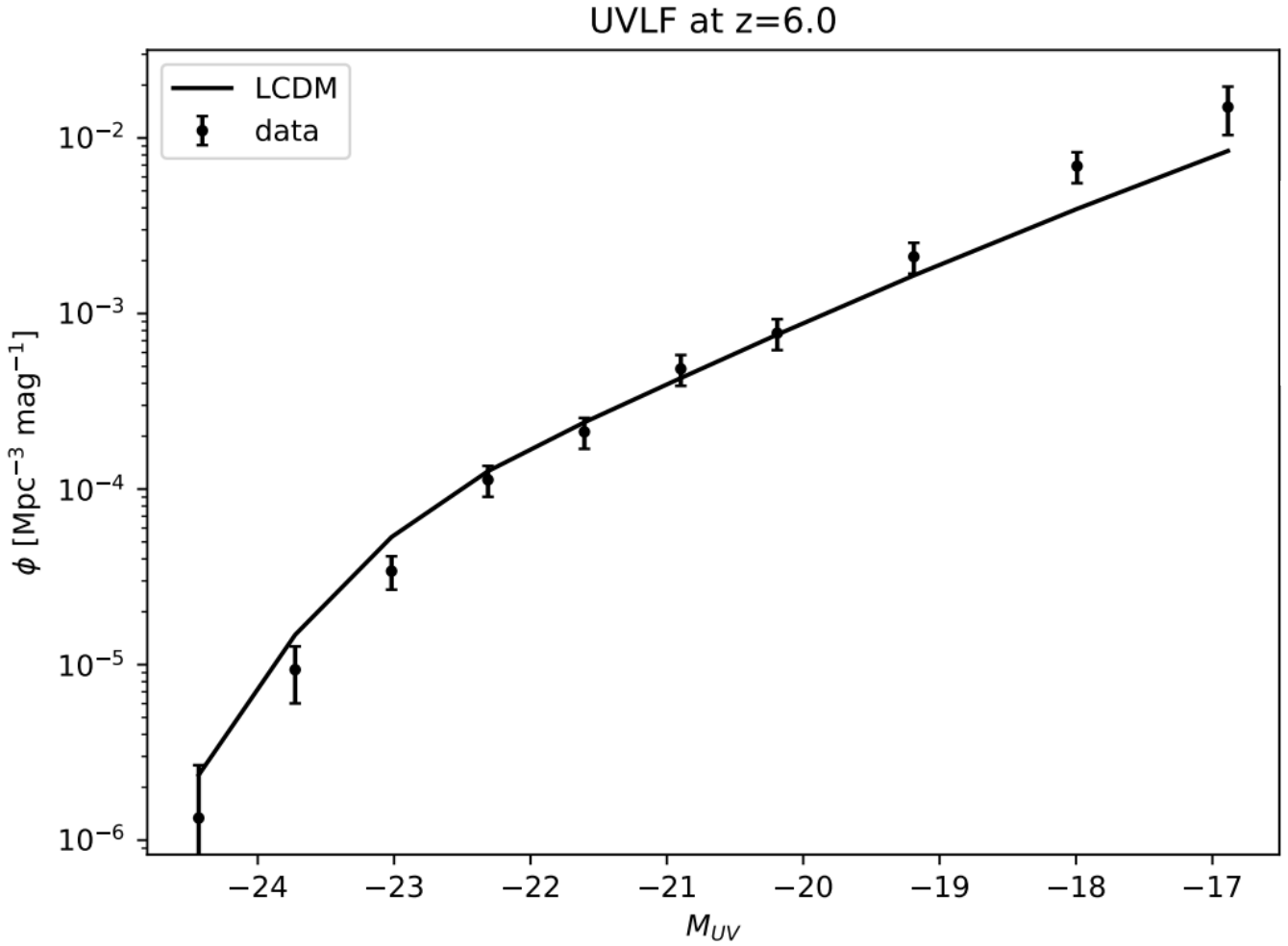
From Smooth-k Window Function



Presistent with Redshift



Current Approach as a Test: UVLF



Comoving number density of galaxies per unit magnitude $\Phi_{\rm UV}$

$$\Phi_{\rm UV} \equiv \frac{n_{\rm gal}}{dM_{\rm UV}} = \frac{n_{\rm gal}}{dM_{\rm halo}} \frac{m_{\rm halo}}{dM_{\rm UV}}$$

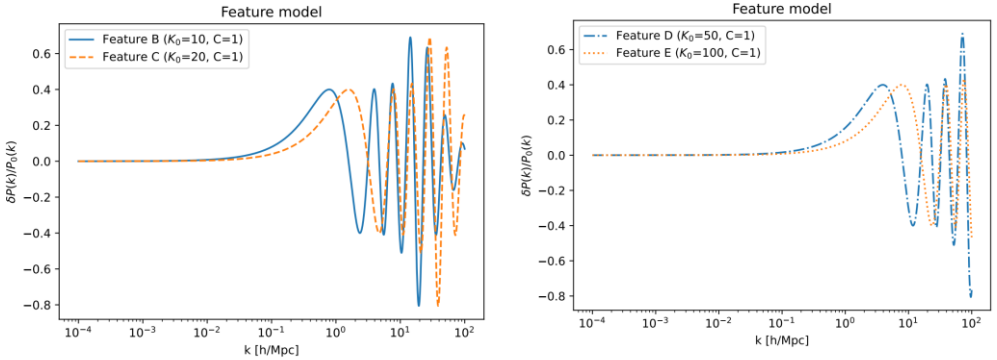
- ❑ Evaluated at wavelength of 150 nm
- ❑ Contributed a lot from HST, recently from JWST at high-z

See also: N. Sabti, J. B. Munoz and D. Blas, 2110.13161; N. Sabti, J. B. Munoz and M. Kamionkowski, 2305.07049…..

Testing Different Benchmarks

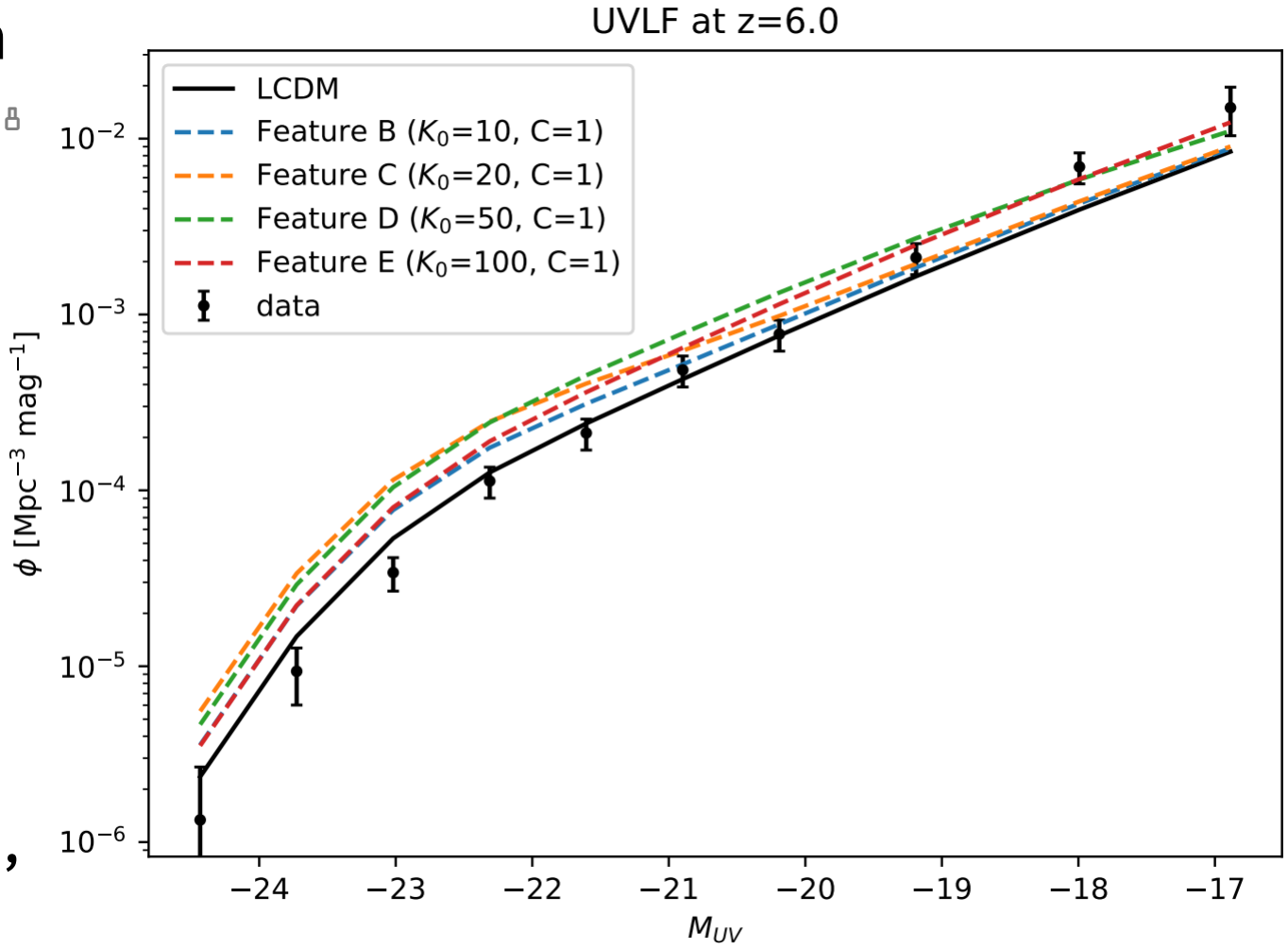
Using GALLUMI for simulation

N. Sabti, J. B. Munoz and D. Blas, 2110.13168

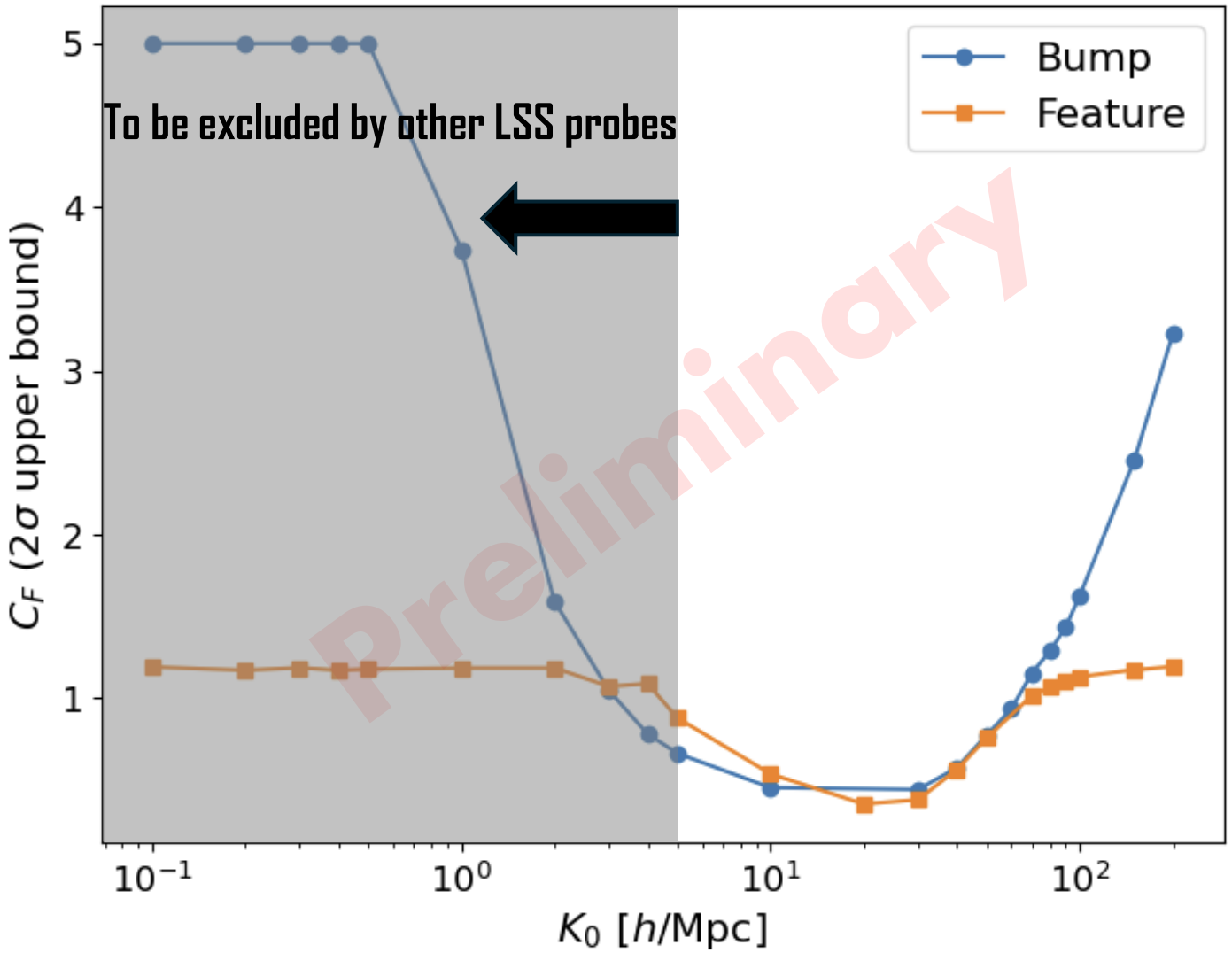


Not very sensitive to high mass/frequency:

- Uncertainties coming from stellar formation rate, redshift, spectral index …



Upper limit for m=10 H Features



We tailored the exact first bump vs the full feature

- ❑ The full feature seems to bring more information compared to the first bump still
- ❑ Large amplitude is possible at very small scales, tightly constrained by UVLF already
- ❑ Needs to be fully understood

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Summary

- Tested more “realistic” scenarios of features in the linear matter power spectrum, asking whether such oscillations are visible.
- New analytical templates proposed based on full numerical solution, allowing fast numerical tests.
- The analytical approach suggests visible HMF impacts, persistent across window-function choices and redshifts.
- Although short in amplitude, the effect of the “first bump” is significant and can be constrained from UVLF already.
- Some details remain unclear, perhaps in the future with numerical simulations.