Beyond Einstein in the era of precision cosmology:

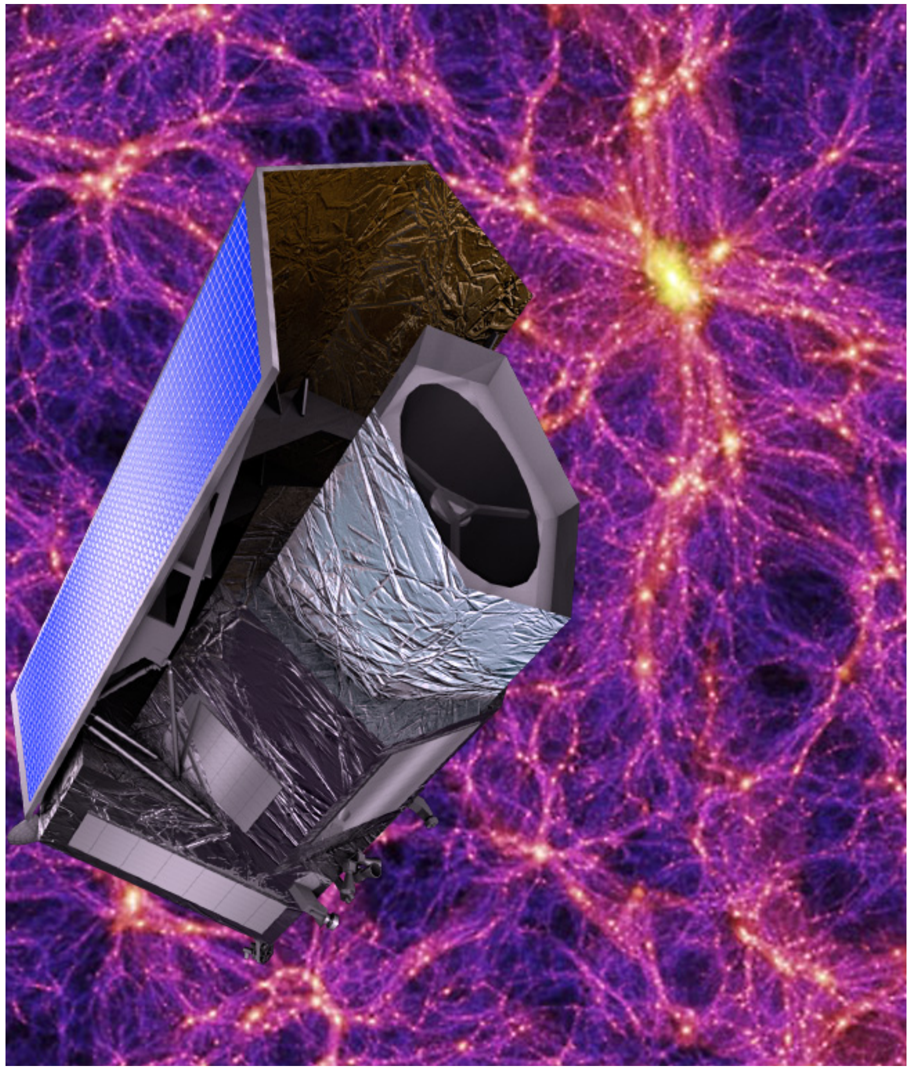
Gravity from ultra-large to small scales

Yashar Akrami
Lorentz Institute, Leiden University

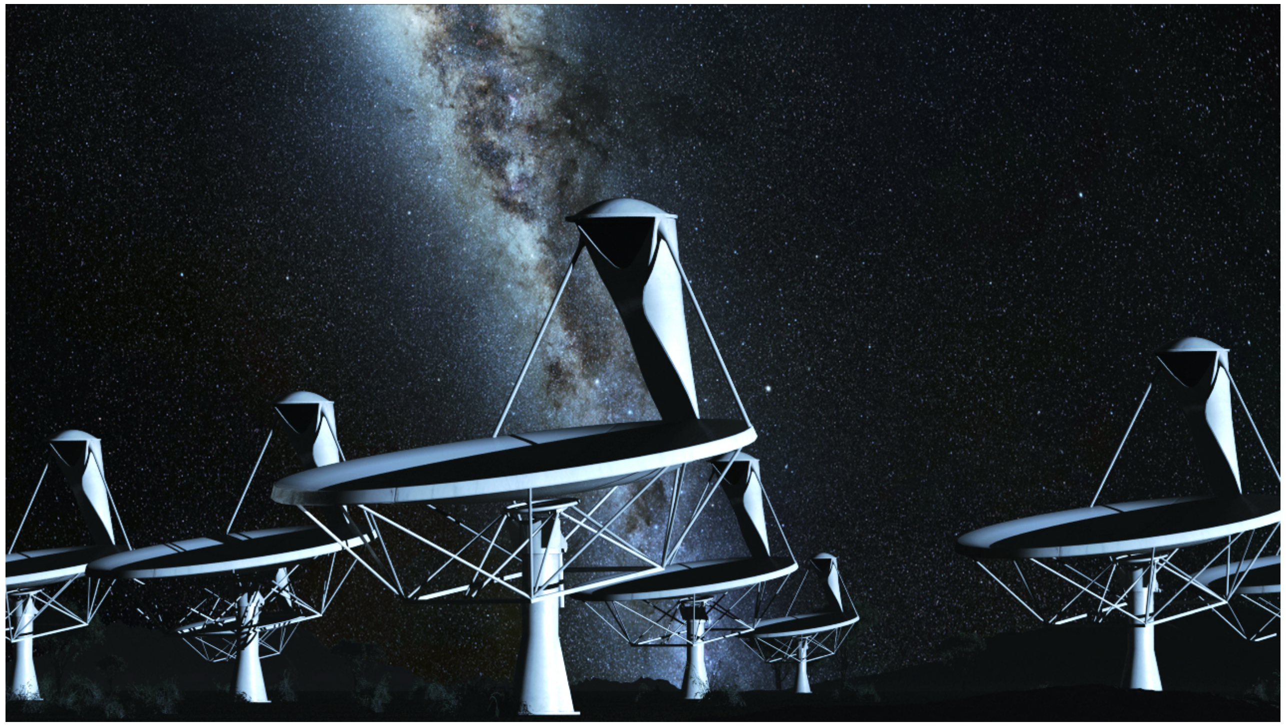
Advances in theoretical cosmology in light of data, NORDITA, July 20, 2017

Low-redshift surveys

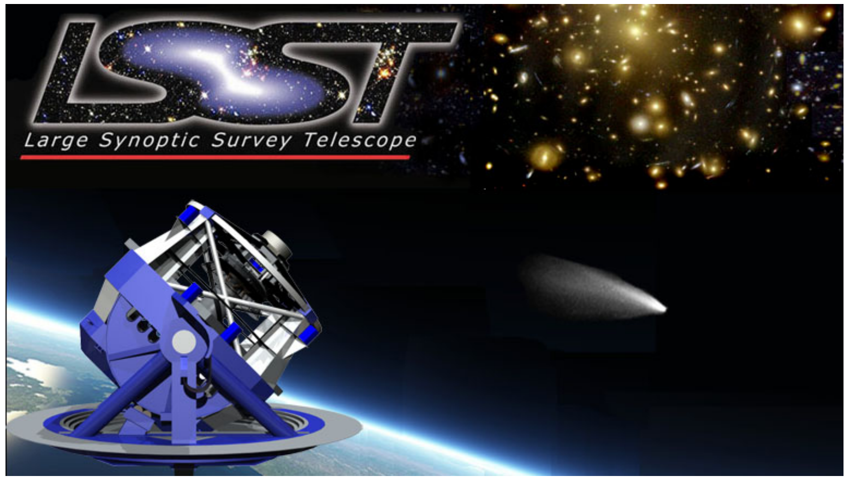
Euclid



Square Kilometre Array



LSST



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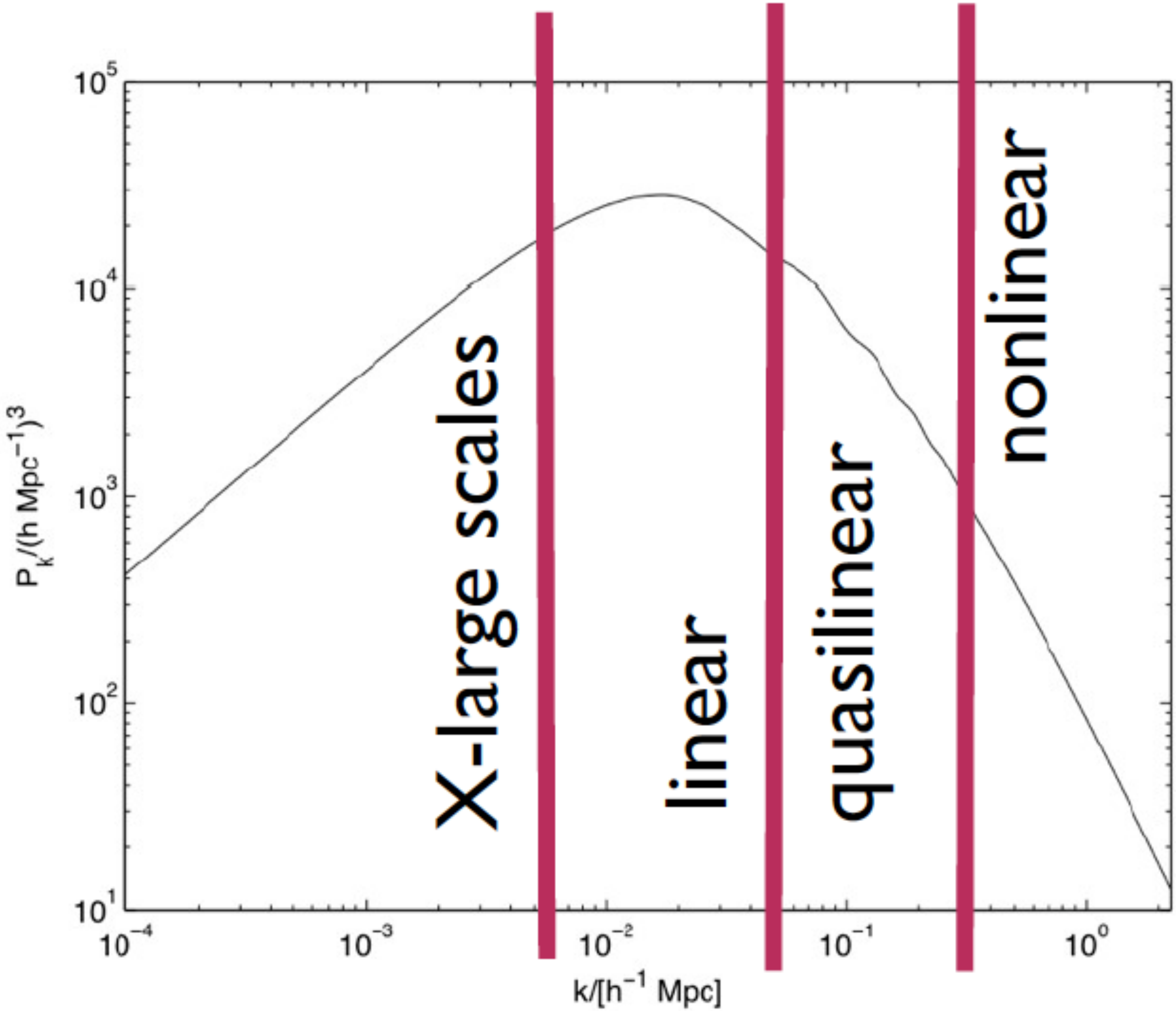
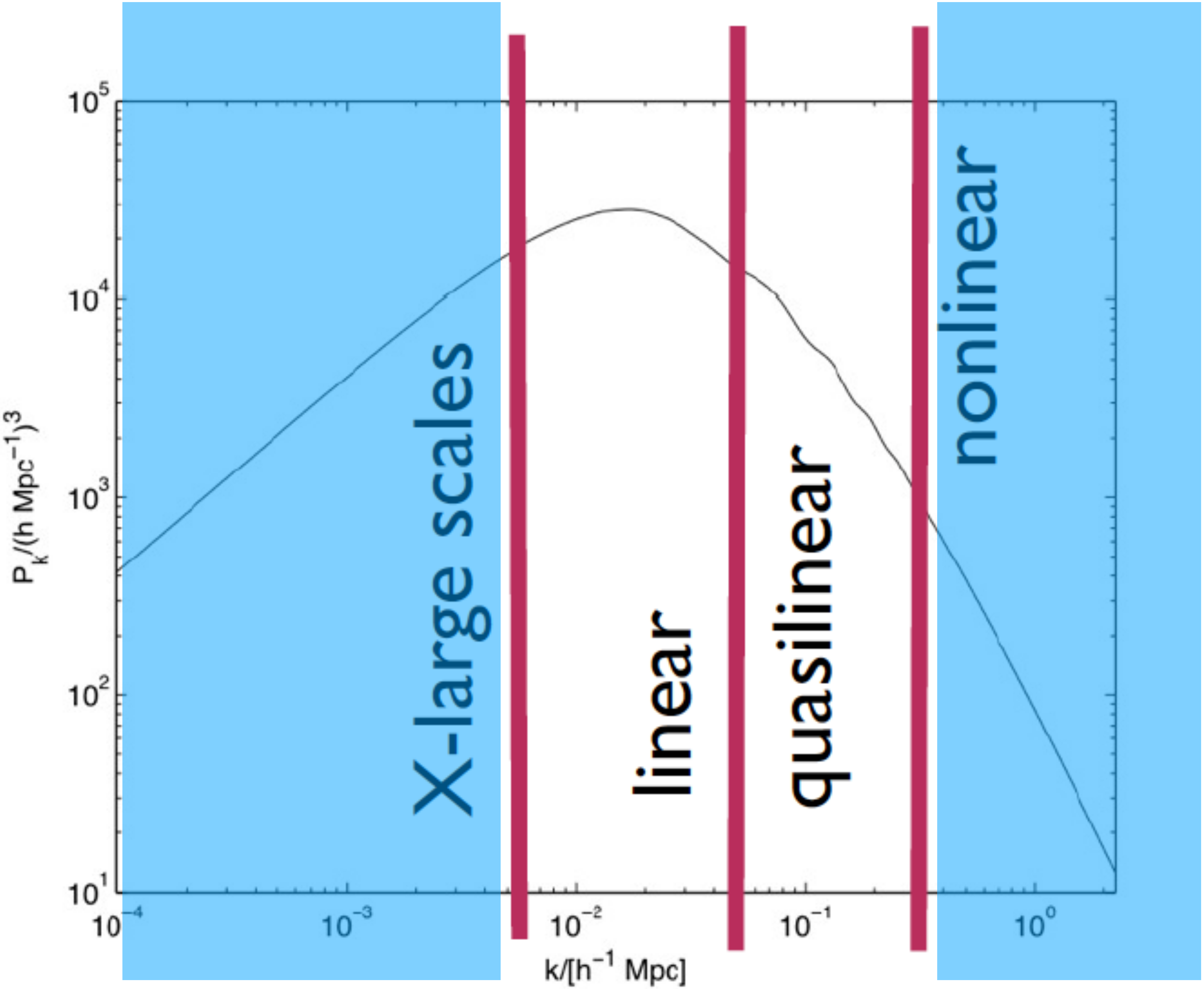


10^5
10^4
10^3
10^2
10^1
$P_k/(h\ Mpc^{-1})^3$
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
$k/[h^{-1}\ Mpc]$
X-large scales
linear
quasilinear
nonlinear



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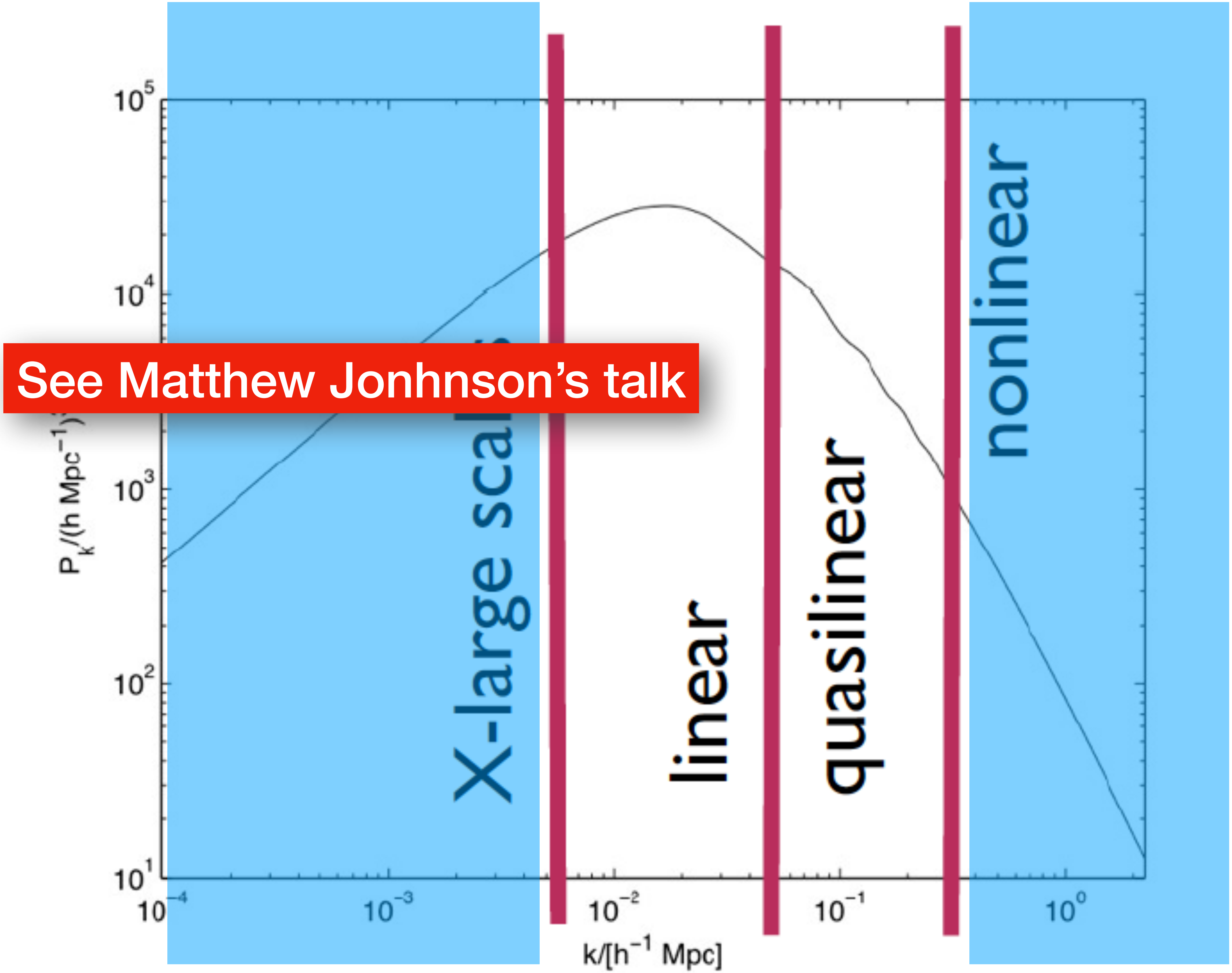
See Matthew Jonhnson's talk
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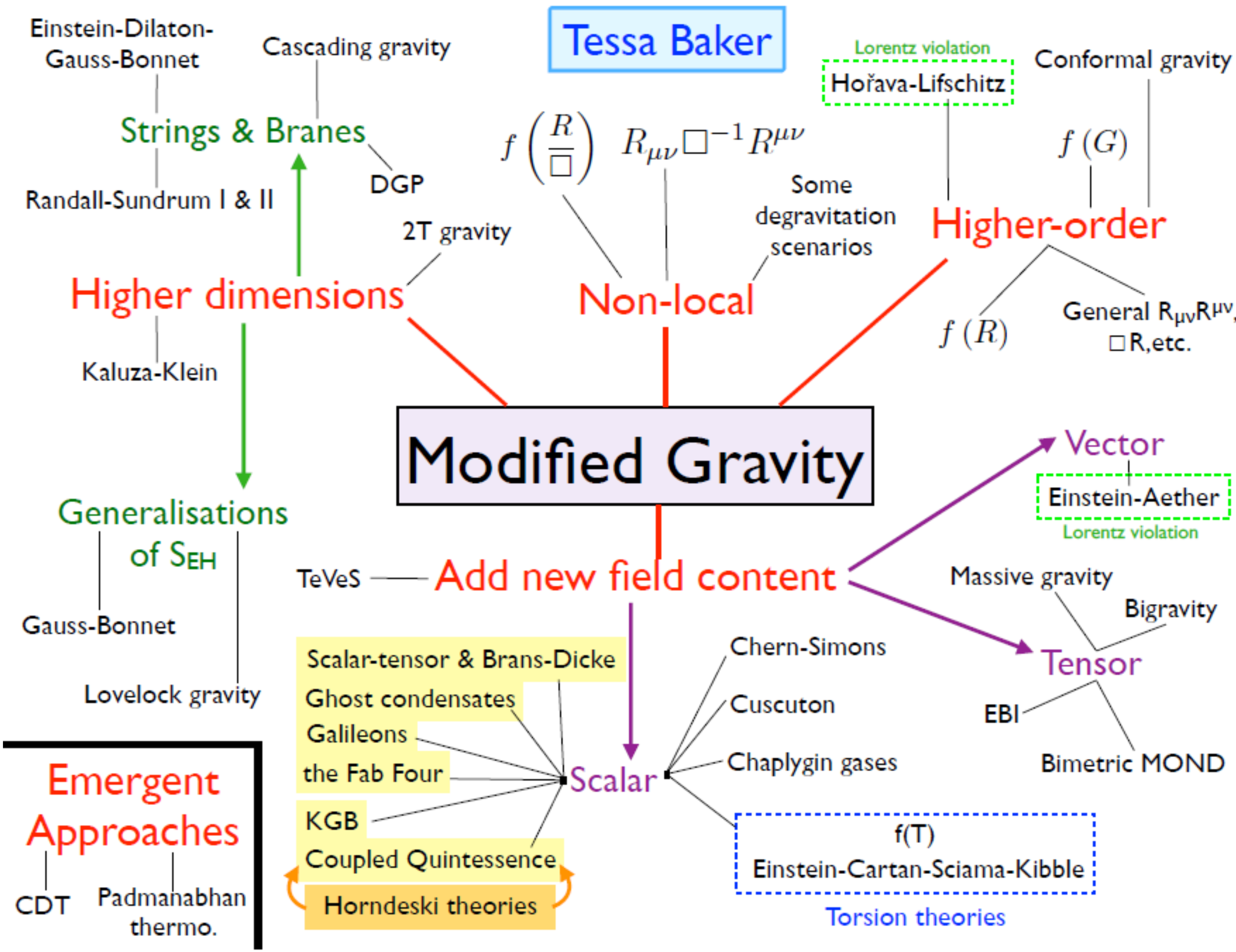
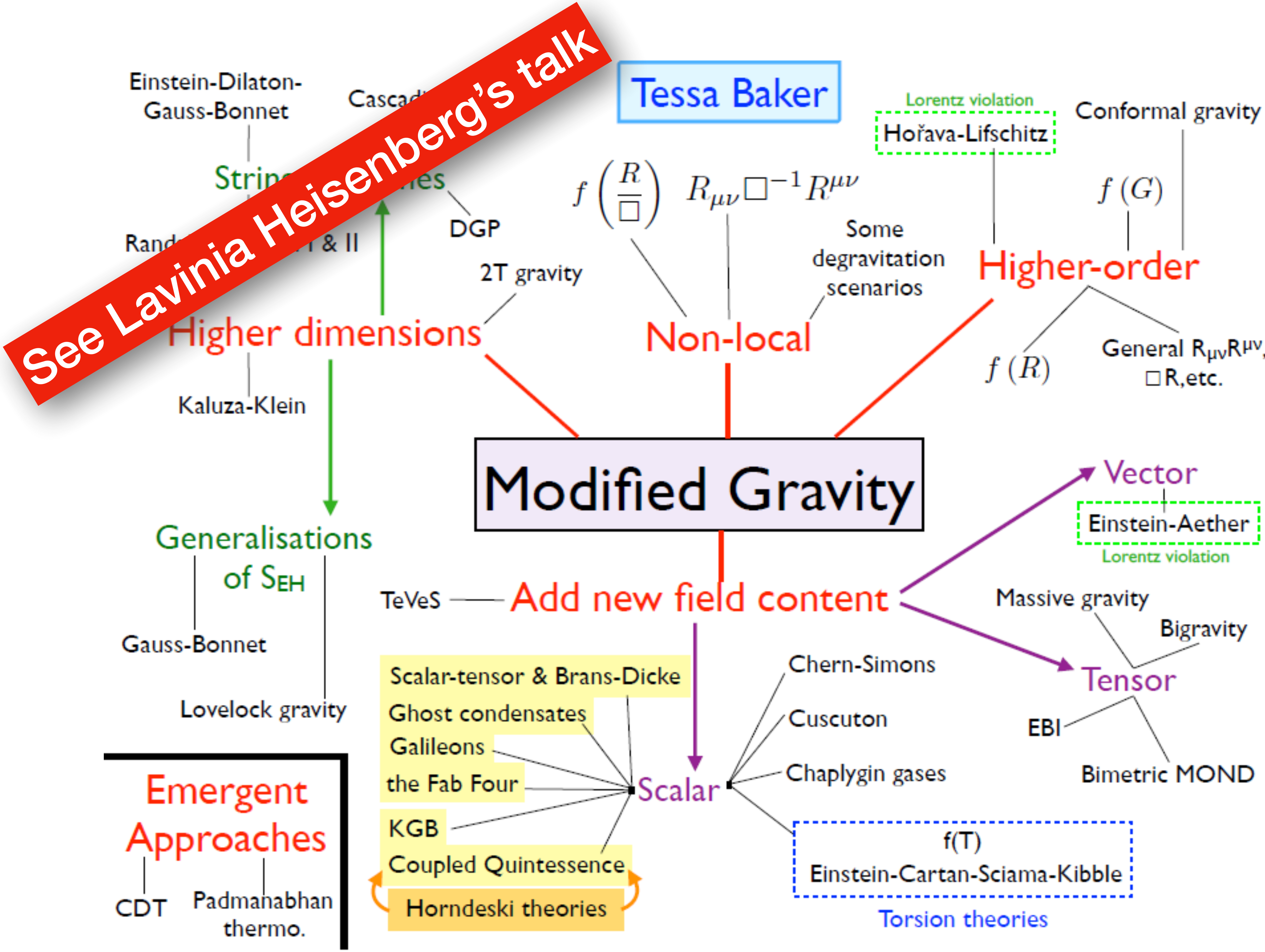


Bull and YA et al. 2016



Bull and YA et al. 2016

Inflation and dark energy
“α-attractors”

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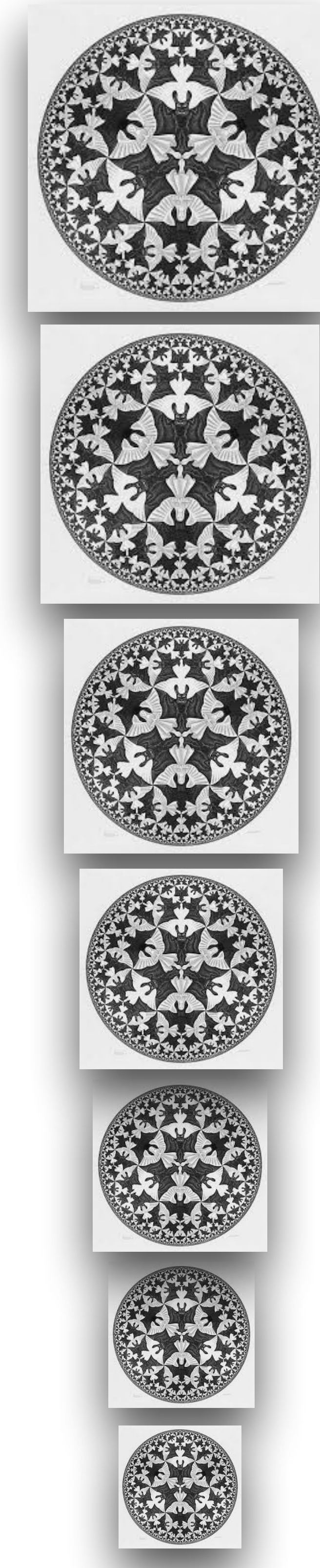
Escher disks from supergravity

Kallosh, Linde et al.



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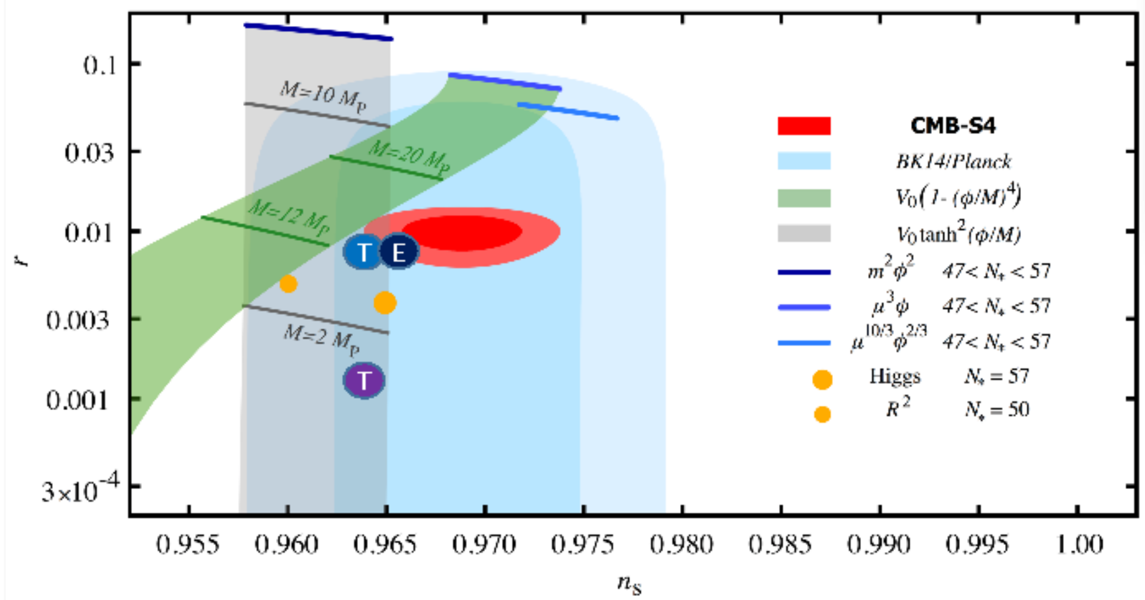

Ferrara and Kallosh 2017

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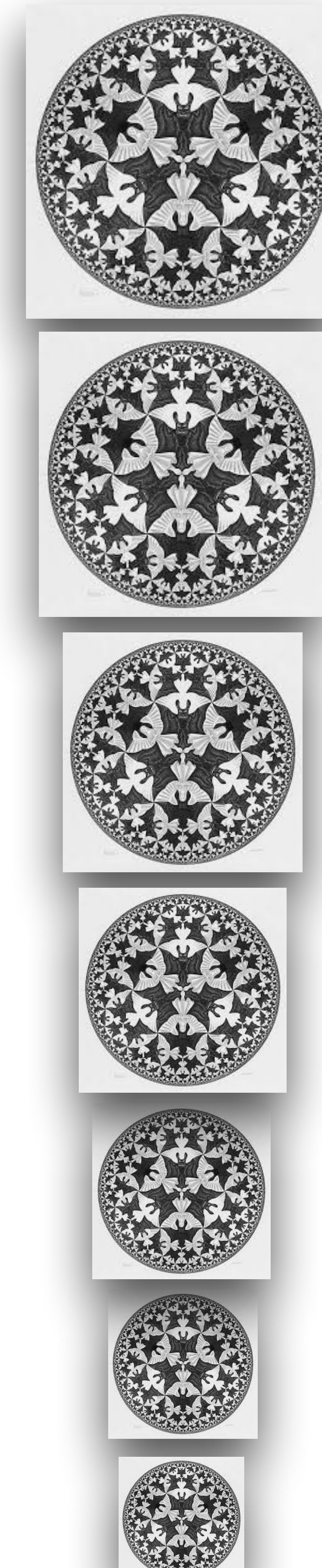

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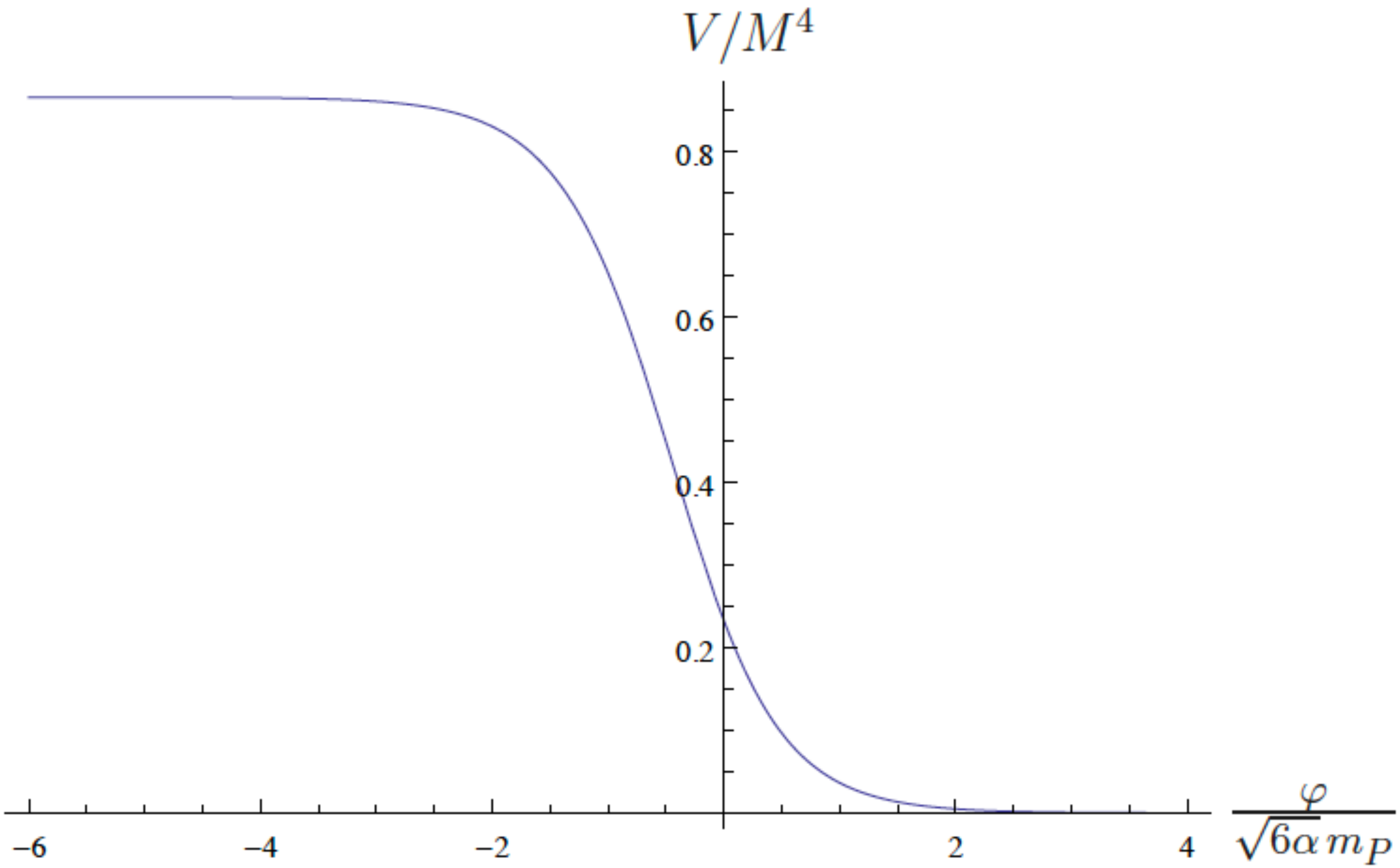
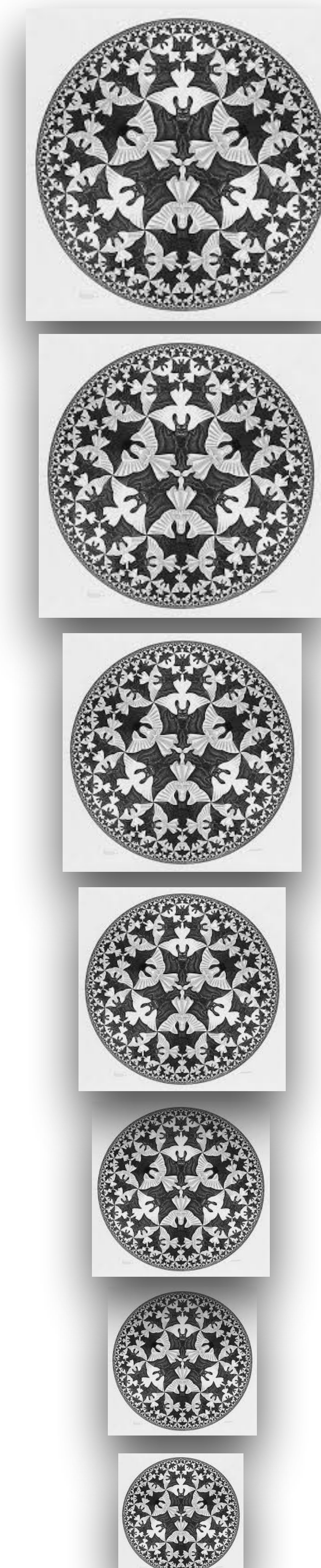


$$\mathscr{L} = \frac{\frac{1}{2}\partial_\mu\phi\,\partial^\mu\phi}{\left(1-\frac{\phi^2}{6\alpha}\right)^2} m_P^2 - V_0 e^{-\kappa\phi} + \Lambda$$

Escher disks from supergravity

Kallosh, Linde et al.



Dimopoulos and Owen 2017

Inflation and dark energy

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with Andrei and Renata
(and DG. Wang & V. Vardanyan)

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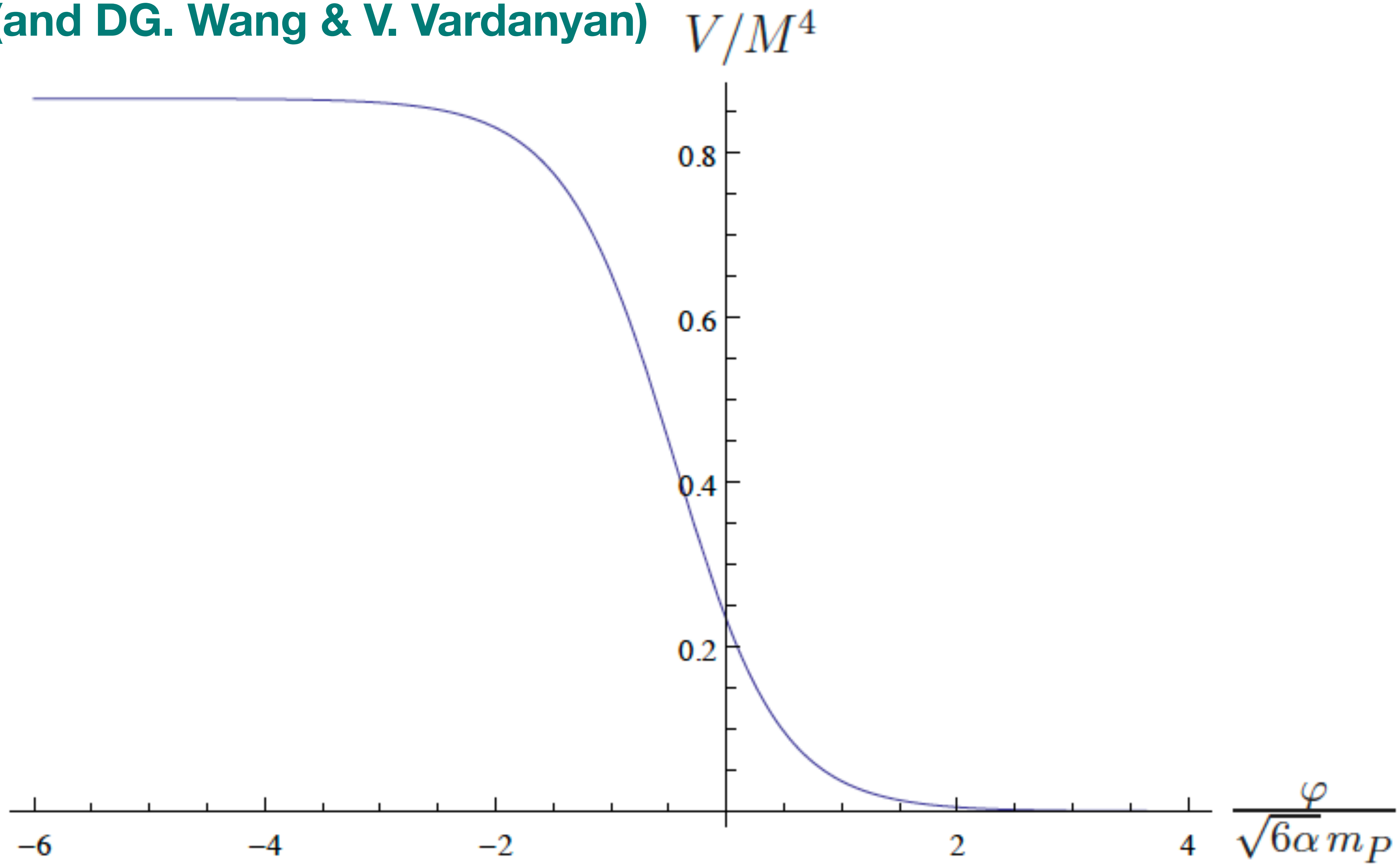

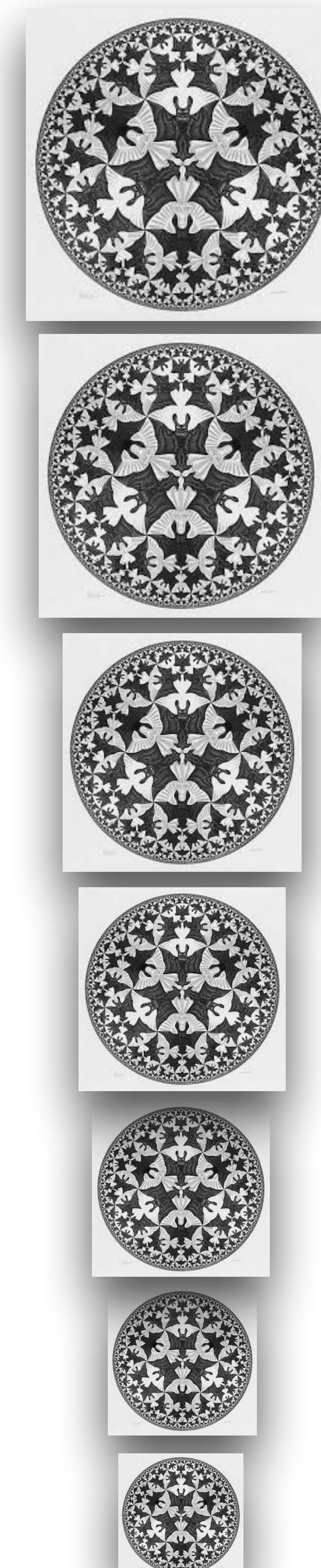

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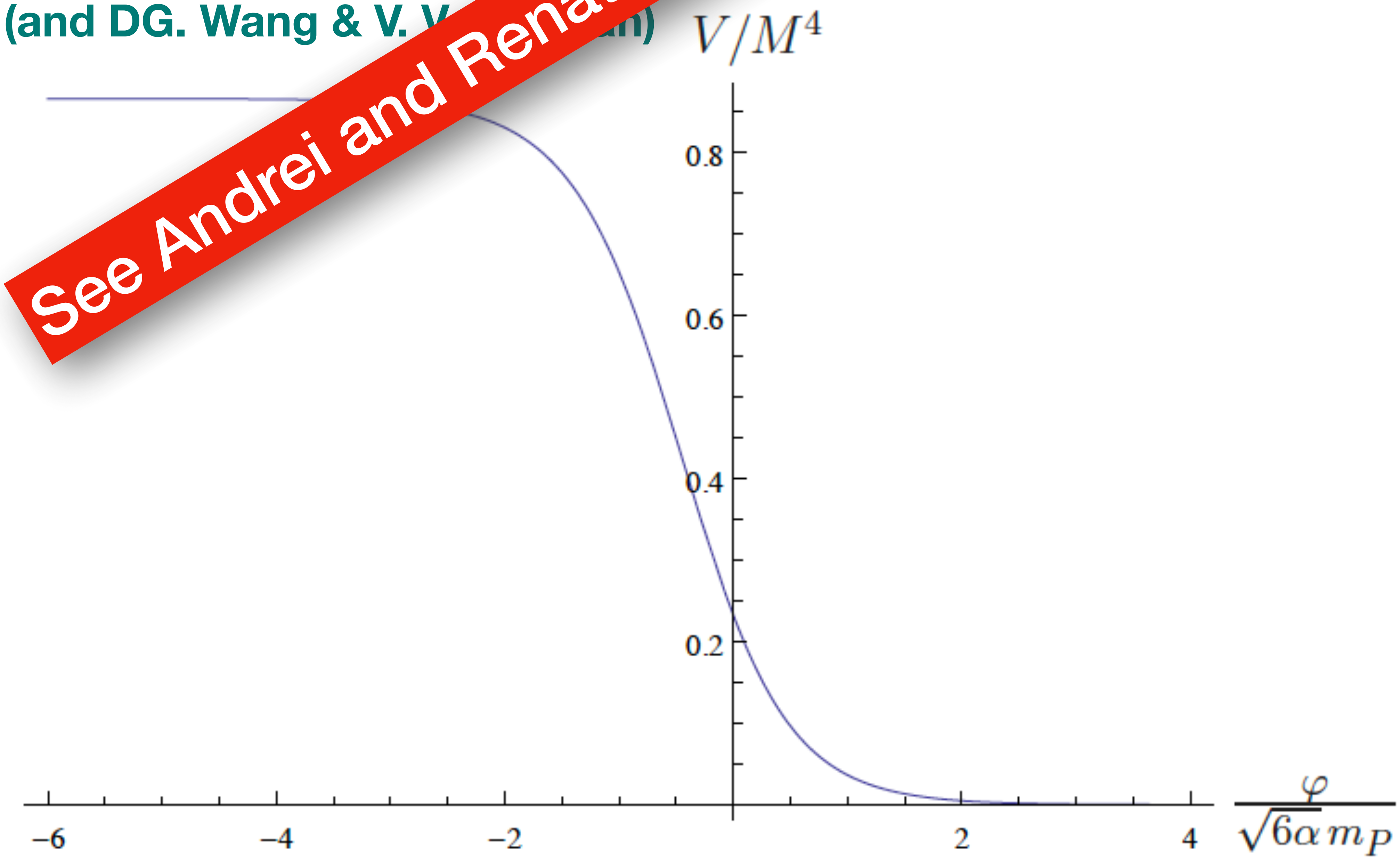
See Andrei and Renata’s talk



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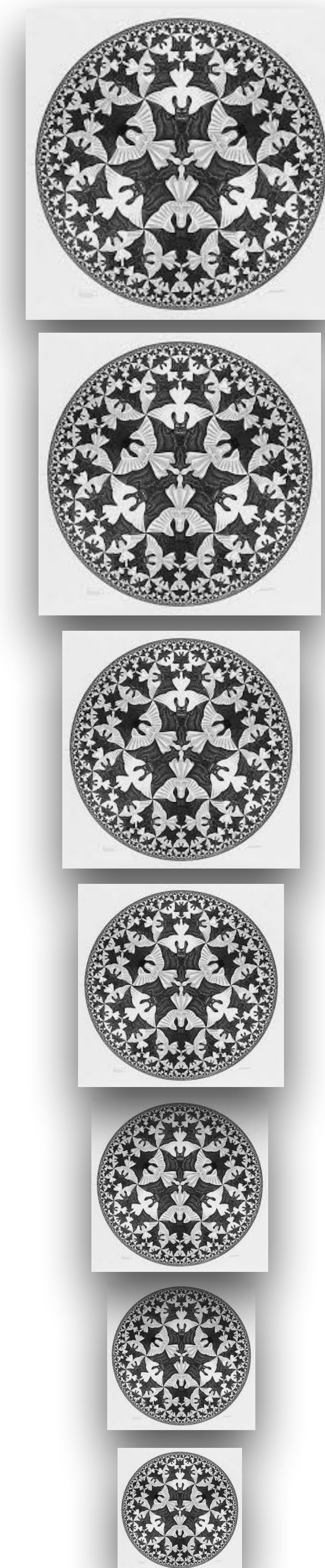

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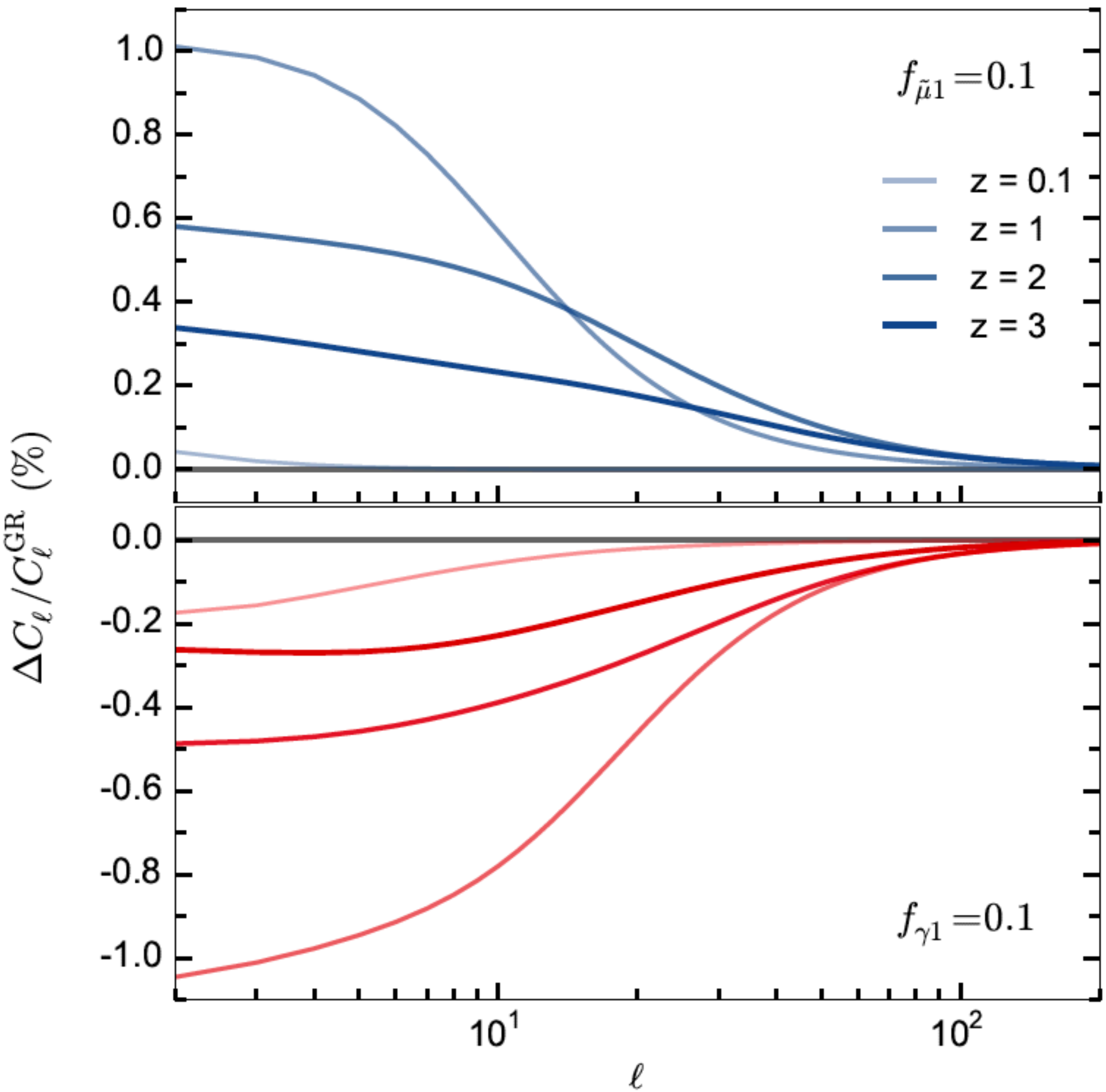
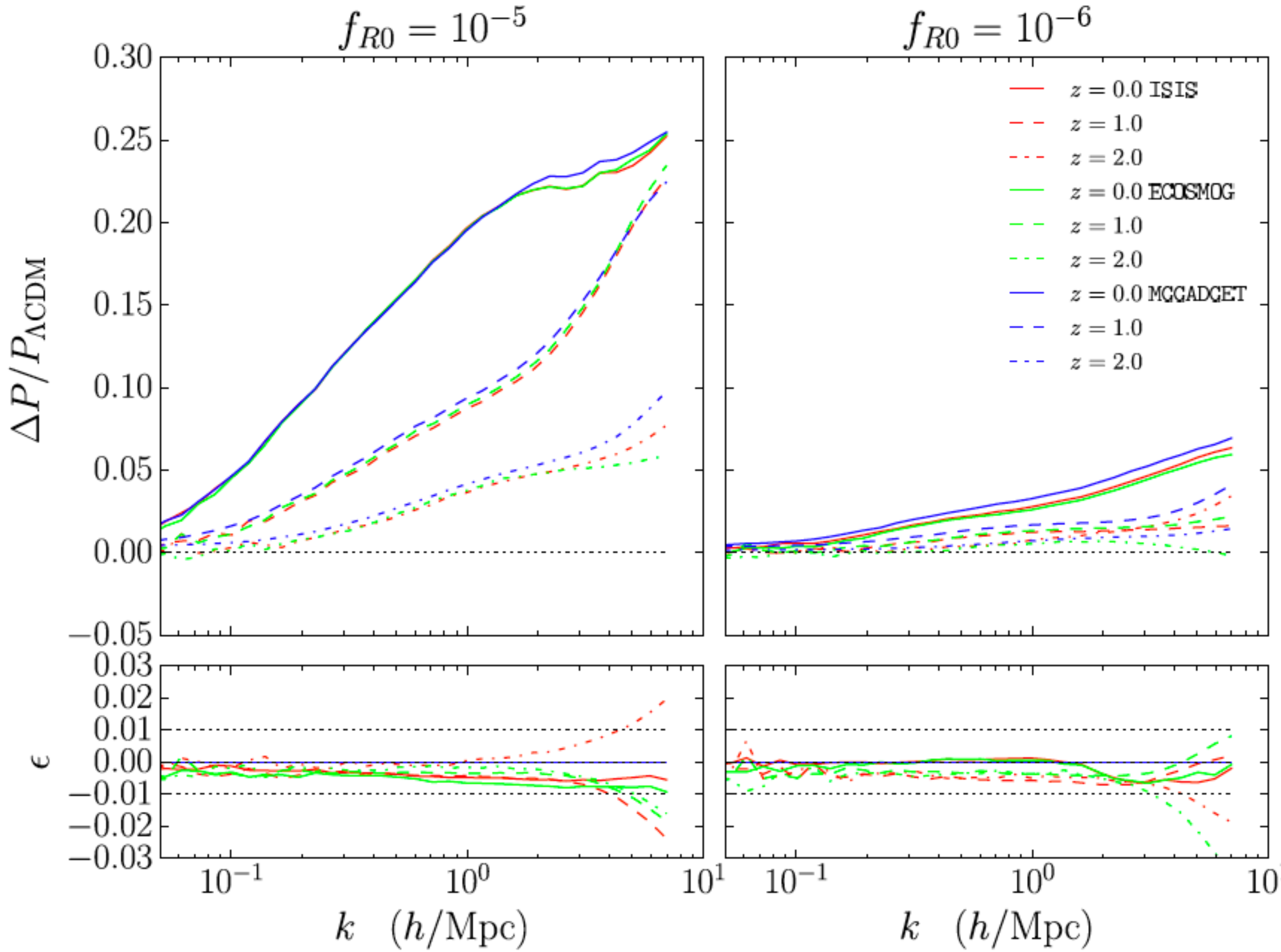
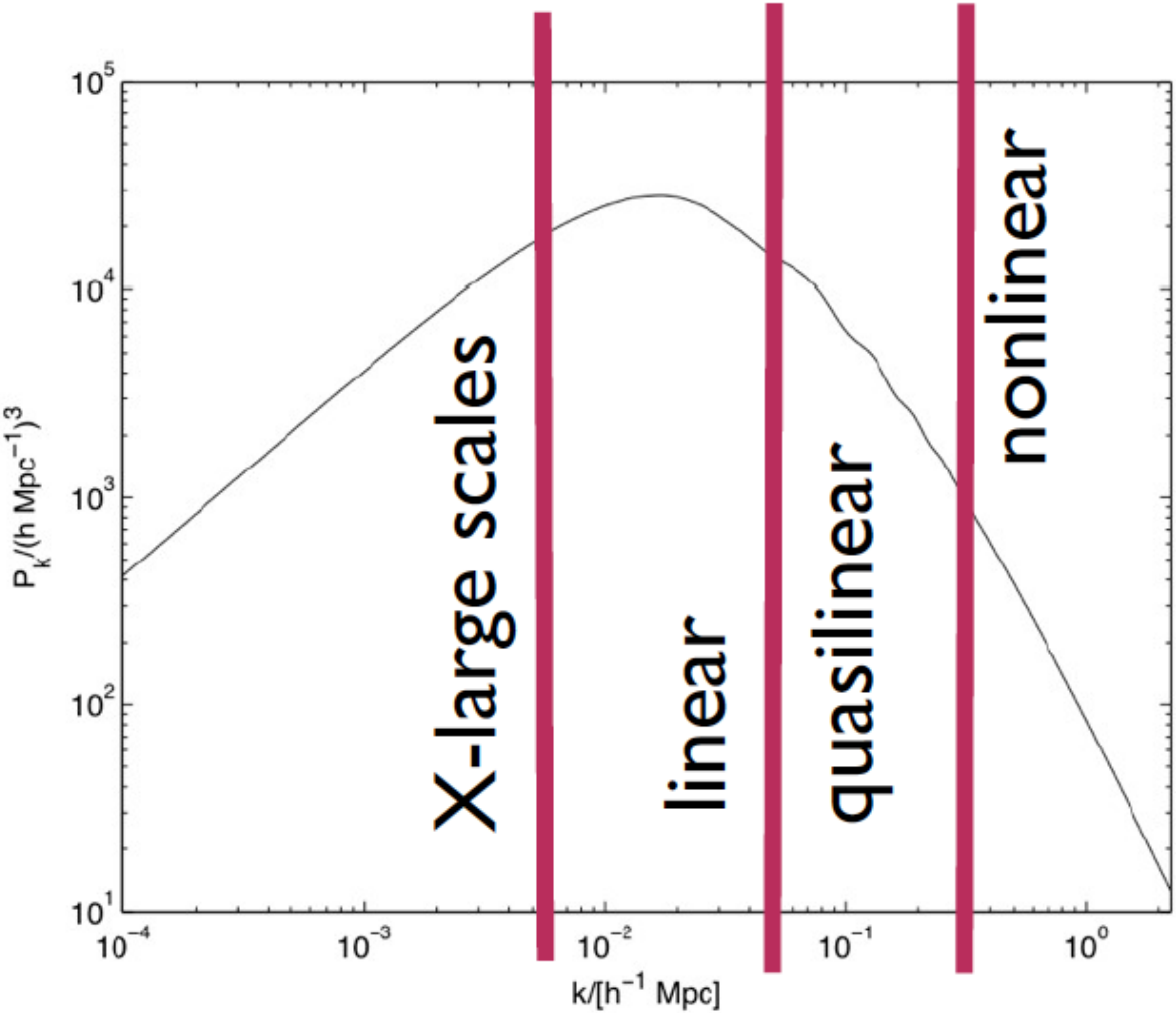


Baker and Bull 2015



Winther et al. 2016



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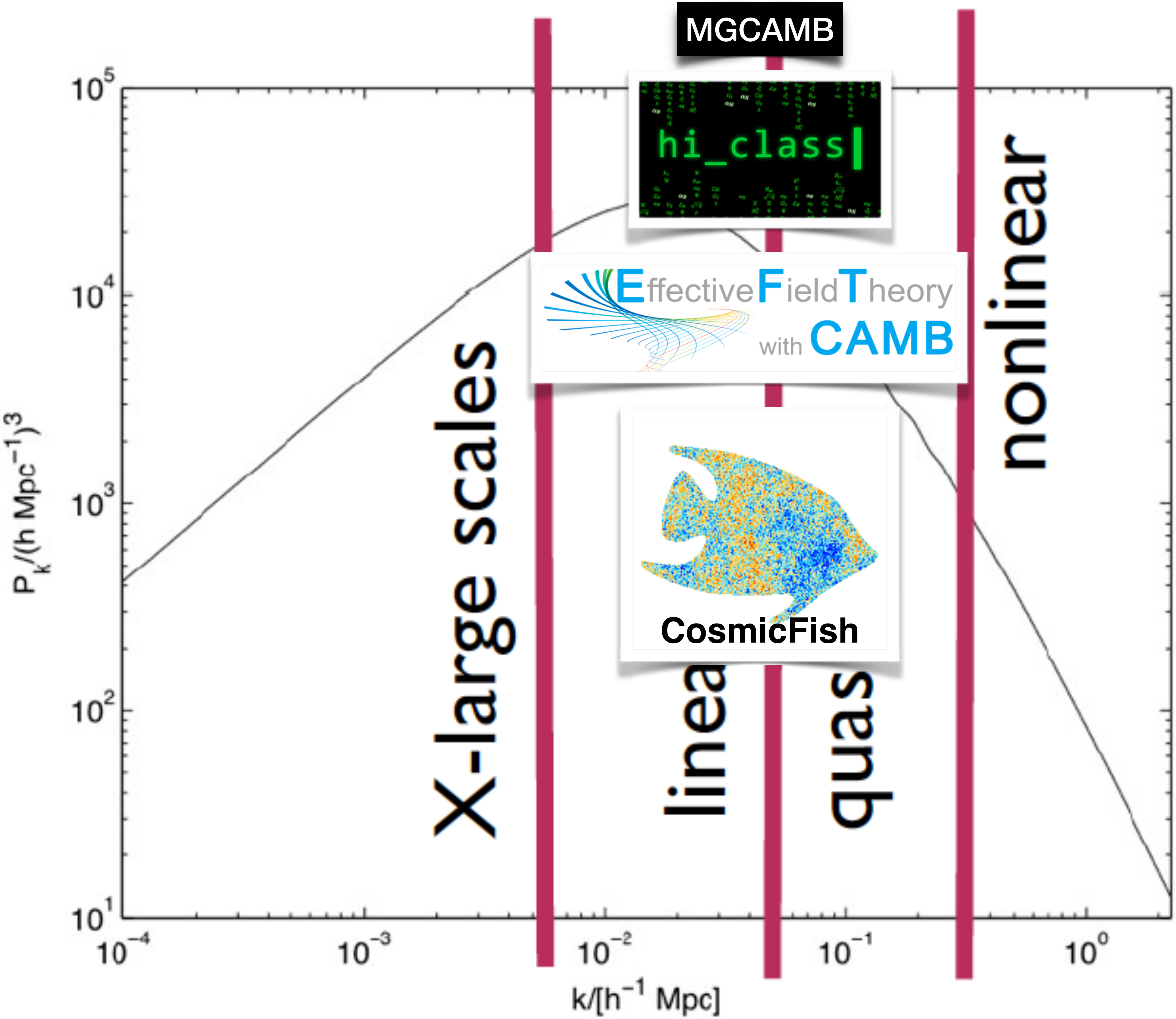
Einstein-Boltzmann codes



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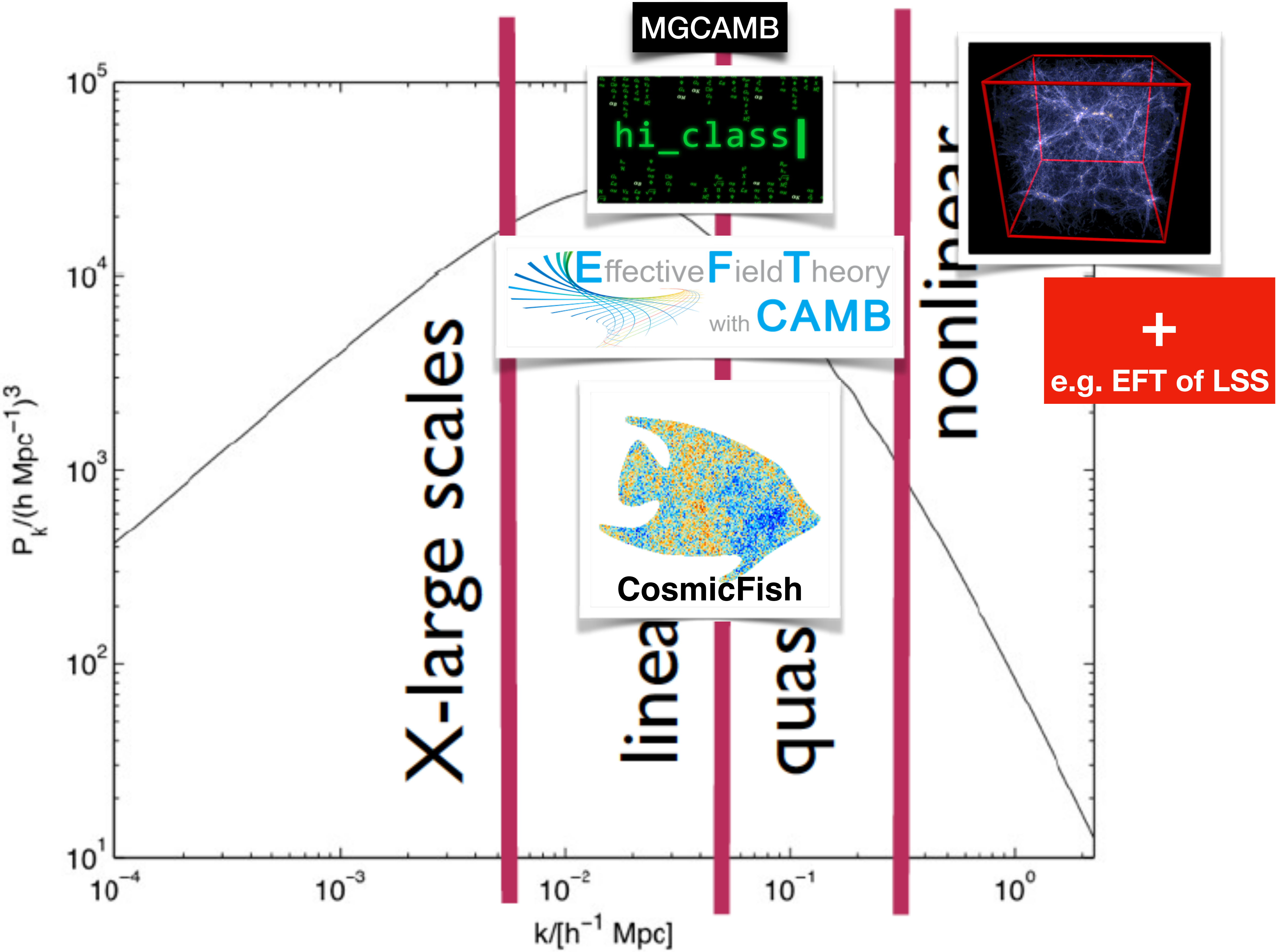

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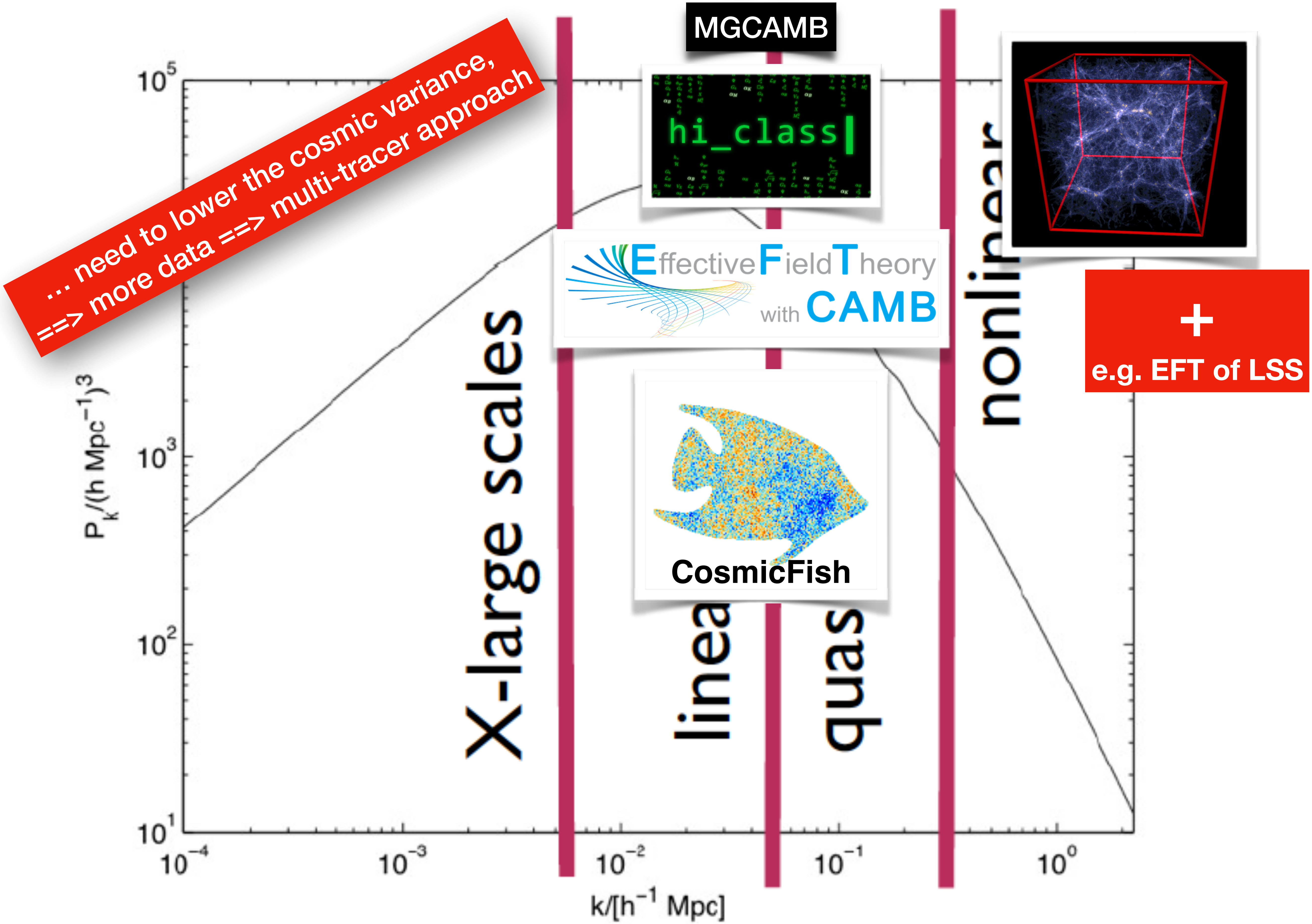
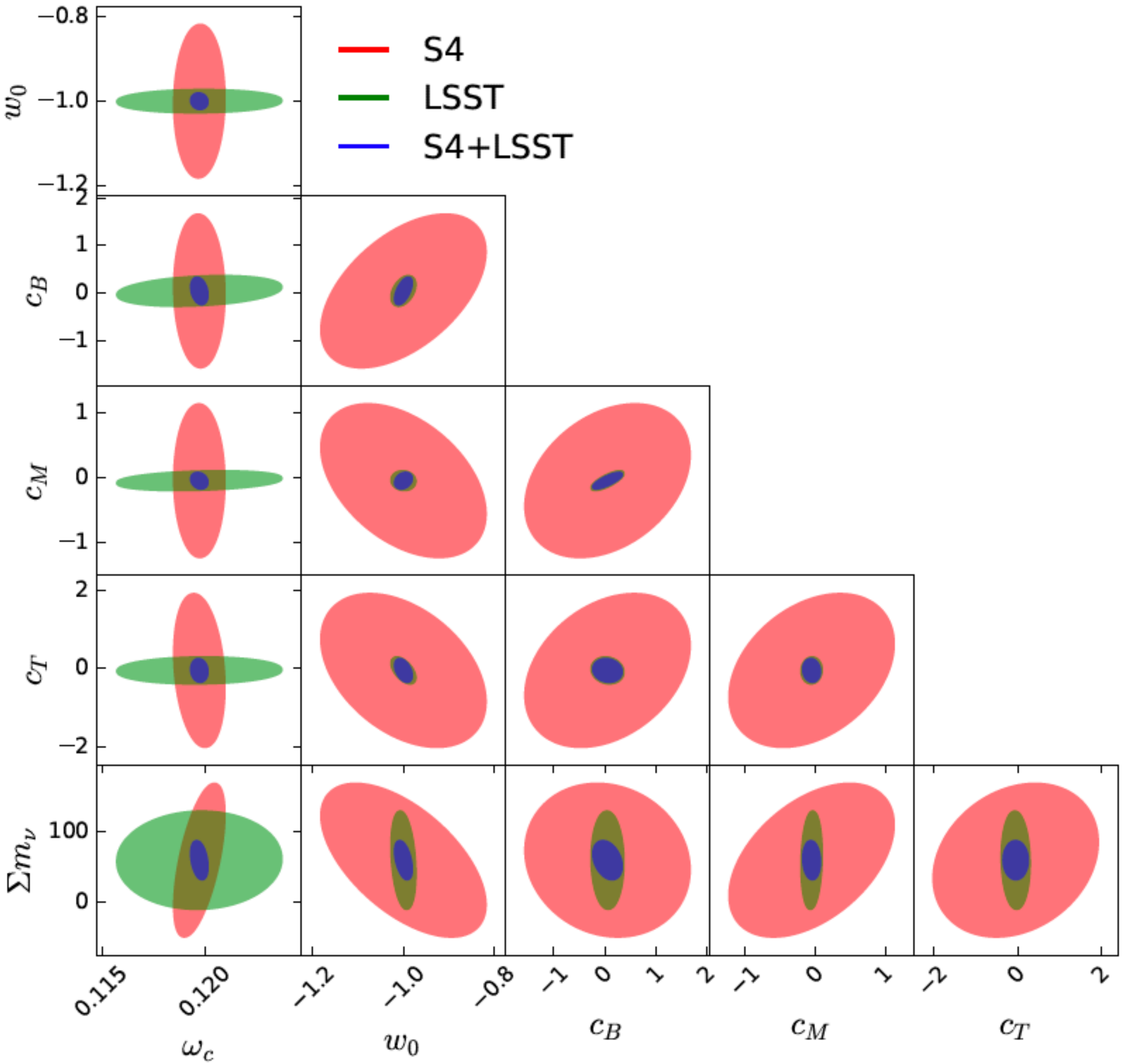
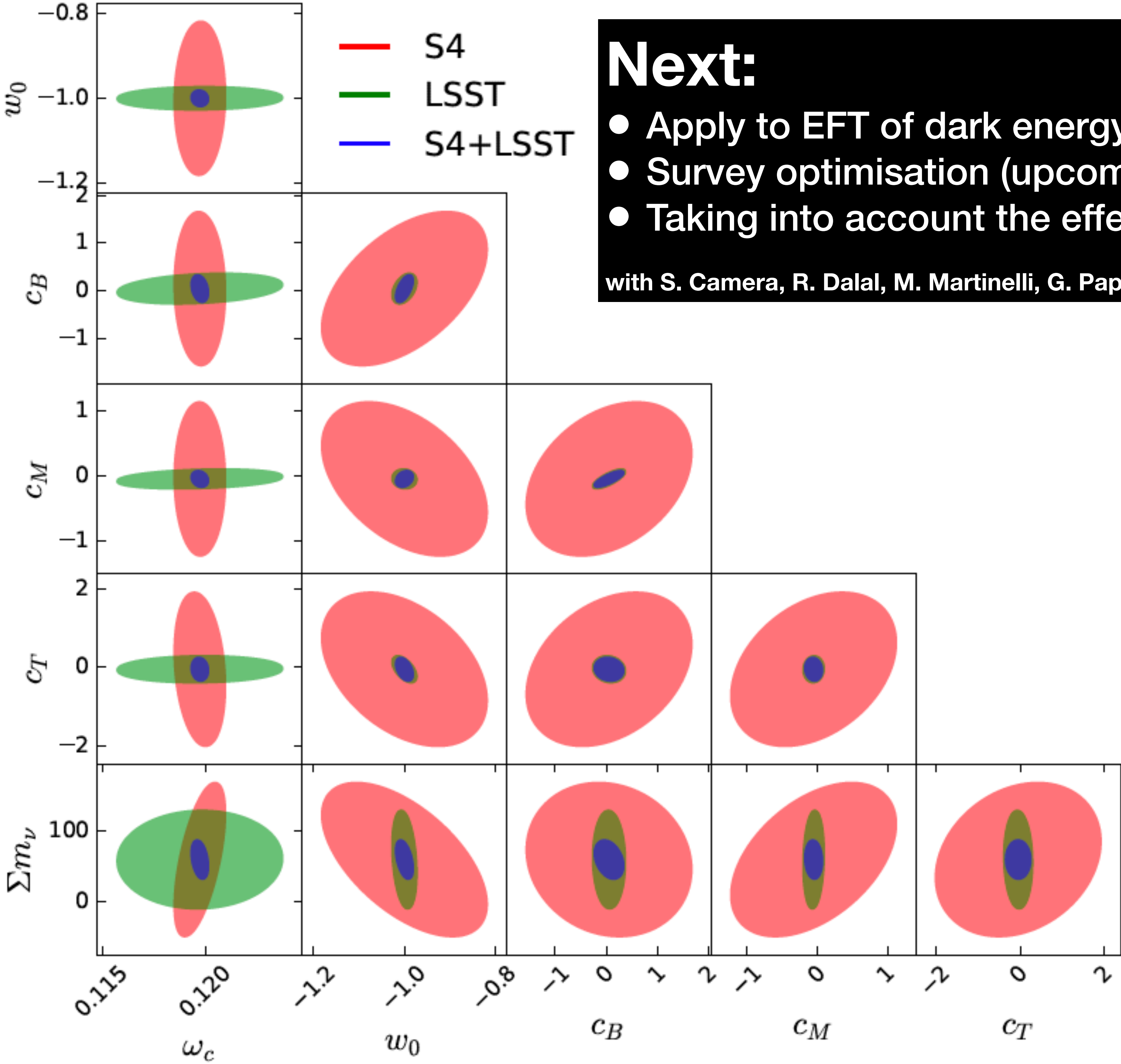




Alonso, Bellini, Ferreira, Zumalacarregui 2016

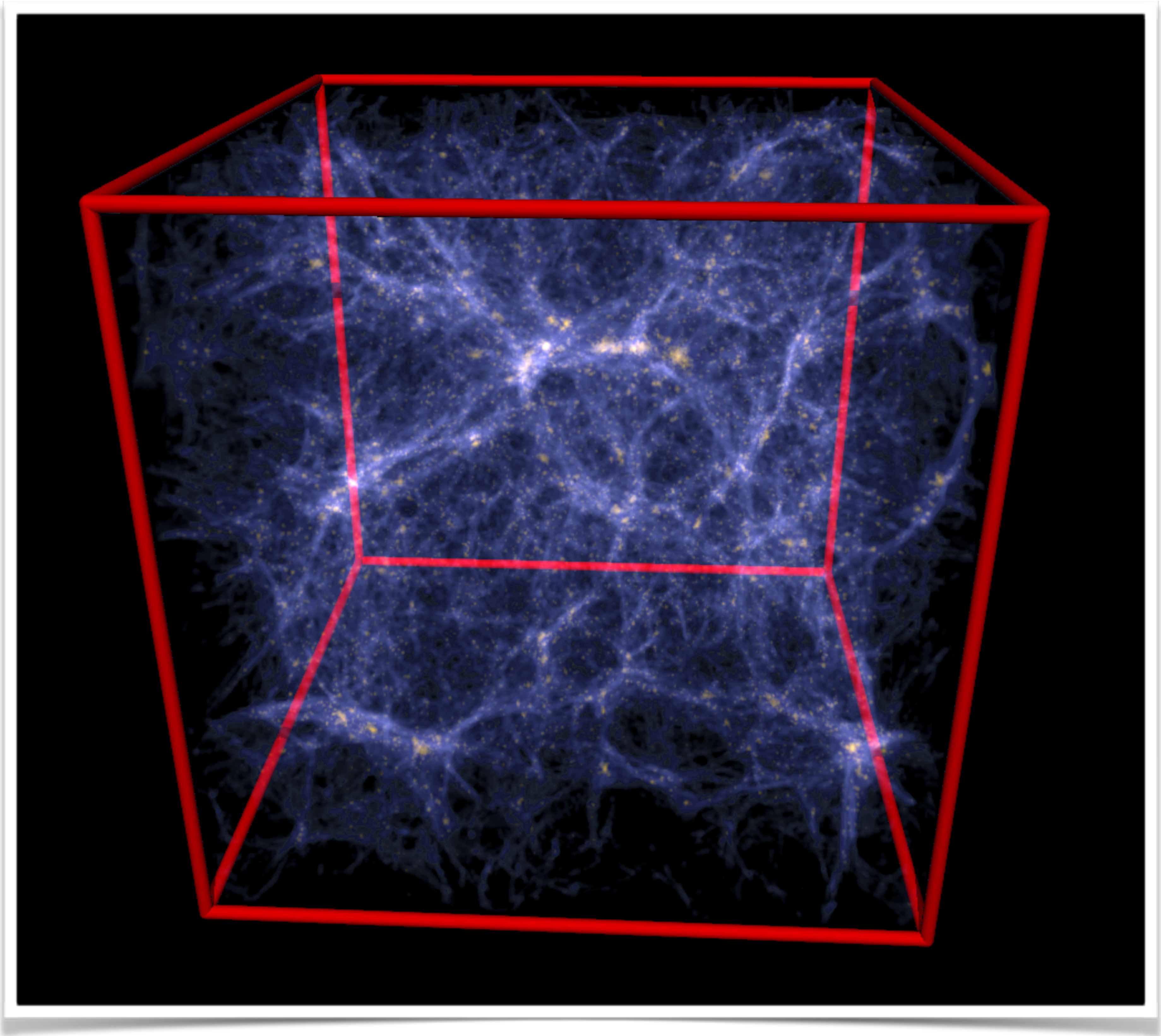


Next:

- Apply to EFT of dark energy and modified gravity
- Survey optimisation (upcoming and next-generation)
- Taking into account the effects of various approximations

with S. Camera, R. Dalal, M. Martinelli, G. Papadomanolakis, M. Raveri, A. Silvestri, V. Vardanyan

Alonso, Bellini, Ferreira, Zumalacarregui 2016



Computationally very expensive,
… not good when we have many models and parameters.

Kinetic Field Theory of LSS

$$Z[\boldsymbol{J},\boldsymbol{K}] = \exp\left(\mathrm{i}\hat{S}_\mathrm{I}\right) Z_0[\boldsymbol{J},\boldsymbol{K}]$$

$$\hat{S}_\mathrm{I} = -\int \mathrm{d}1\, \hat{B}(-1)v(1)\hat{\rho}(1)$$

$$\hat{\rho}_j(1) = \exp\left(-\mathrm{i}\vec{k}_1 \cdot \frac{\delta}{\mathrm{i}\delta\vec{J}_{q_j}(1)}\right)$$

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$$G_{\rho\ldots\rho}(1\ldots n) = \hat{\rho}(1)\cdots\hat{\rho}(n)\,Z[\boldsymbol{J},\boldsymbol{K}]$$

N-point correlation (spectra)

Bartelmann et al. 2014-2017

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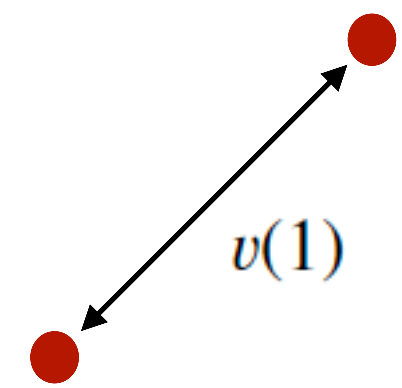

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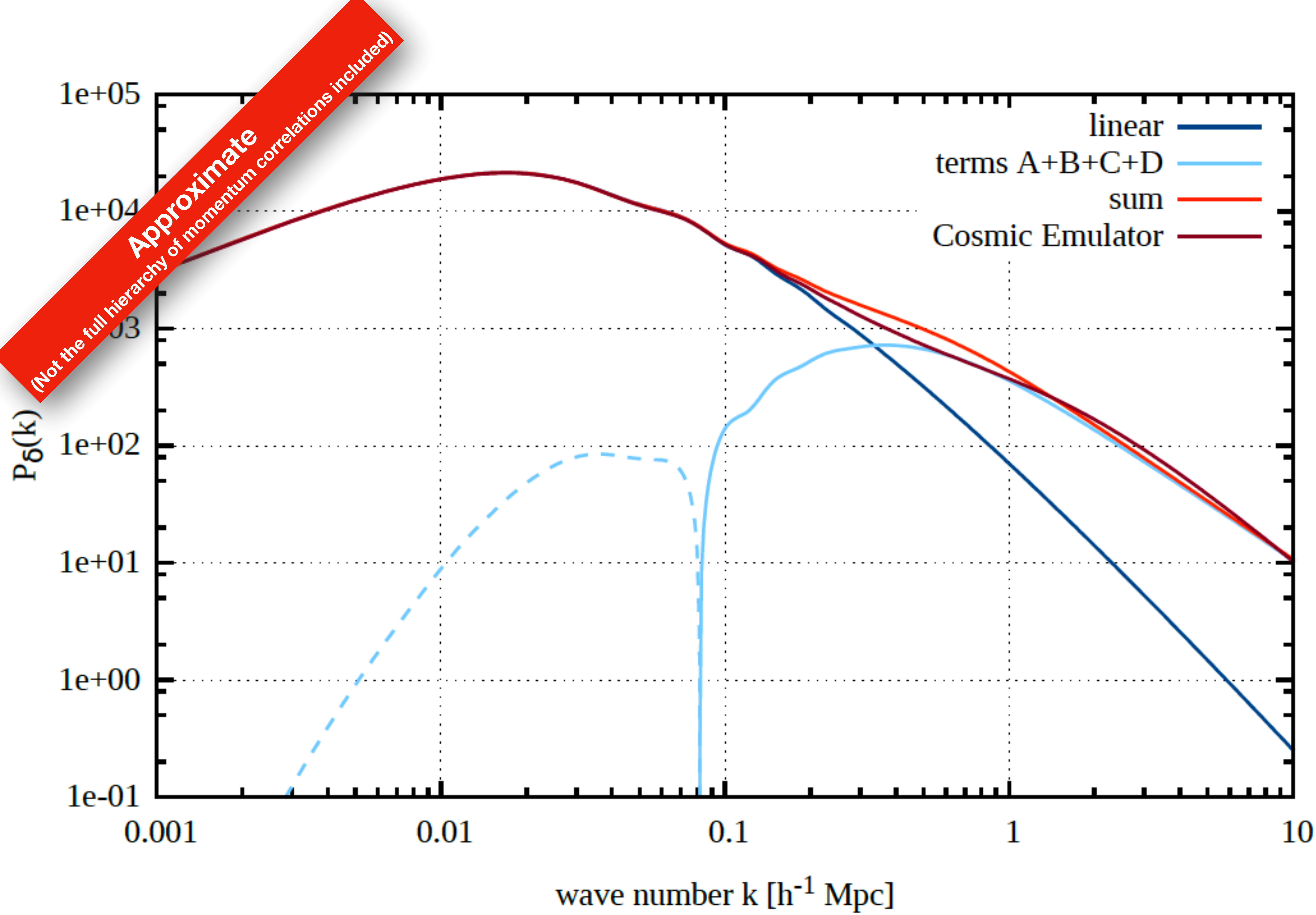

Bartelmann et al. 2014

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- Works already at first-order interaction
- Accurate
- Physical insight (linear to nonlinear transition)
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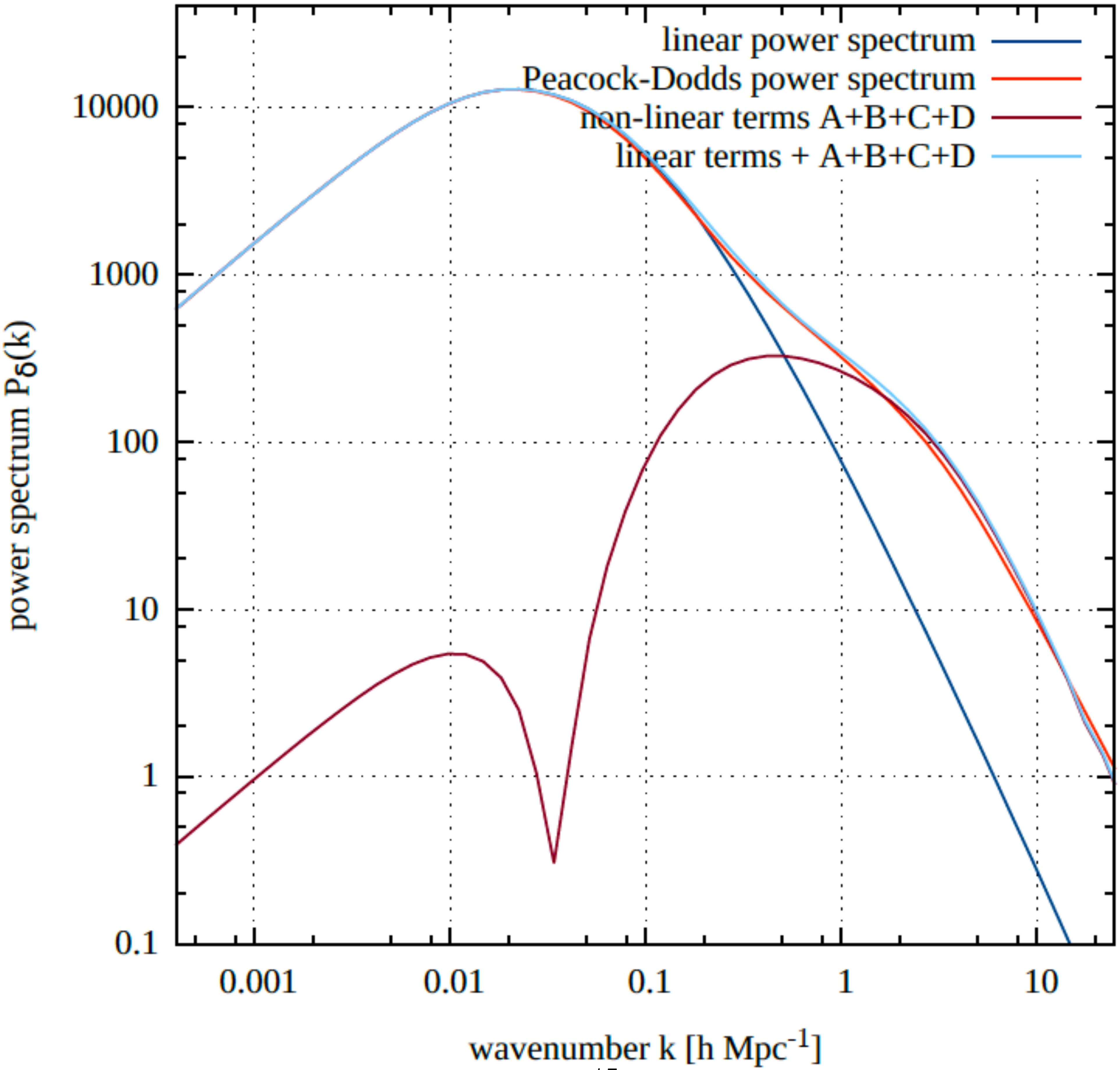
We are now modifying it for non-standard cosmology, in particular modified gravity, where screening mechanisms are included.
(with V. Vardanyan, G. Papadomanolakis and L. Amendola)

Summary

- Ample data will soon be available form various precision low-redshift surveys, such as Euclid, SKA, LSST, DESI, etc.
- There is a lot of information at all scales, including ultra-large and small, which needs to be extracted and used.
- This is important in particular for testing beyond-standard models, including modified gravity and dark energy.
- Codes and techniques should be developed for both ends of the spectrum.
- The analytical framework of kinetic field theory of large-scale structure looks particularly very interesting, exciting, and promising, if understood and used properly.


linear power spectrum
Peacock-Dodds power spectrum
non-linear terms A+B+C+D
linear terms + A+B+C+D
10000
1000
100
10
1
0.1
0.001
0.01
0.1
1
10
power spectrum $P_\delta(k)$
wavenumber k [h Mpc^{-1}]