Title: Primordial gravity waves from tidal imprints in large-scale structure

Date: Oct 17, 2017 11:00 AM

URL: http://pirsa.org/17100081

Abstract: I will describe a tidal effect whereby the decay of primordial gravity waves leaves a permanent shear in the large-scale structure of the Universe. Future large-scale structure surveys - especially radio surveys of high-redshift hydrogen gas - could measure this shear and its spatial dependence to form a map of the initial gravity-wave field. The three dimensional nature of this probe makes it sensitive to the helicity of the gravity waves, allowing for searches for early-Universe gravitational parity violation. Due to the large number of measurable modes in the high-redshift large-scale structure, these tidal imprints could ultimately be more sensitive than searches for CMB B-modes.

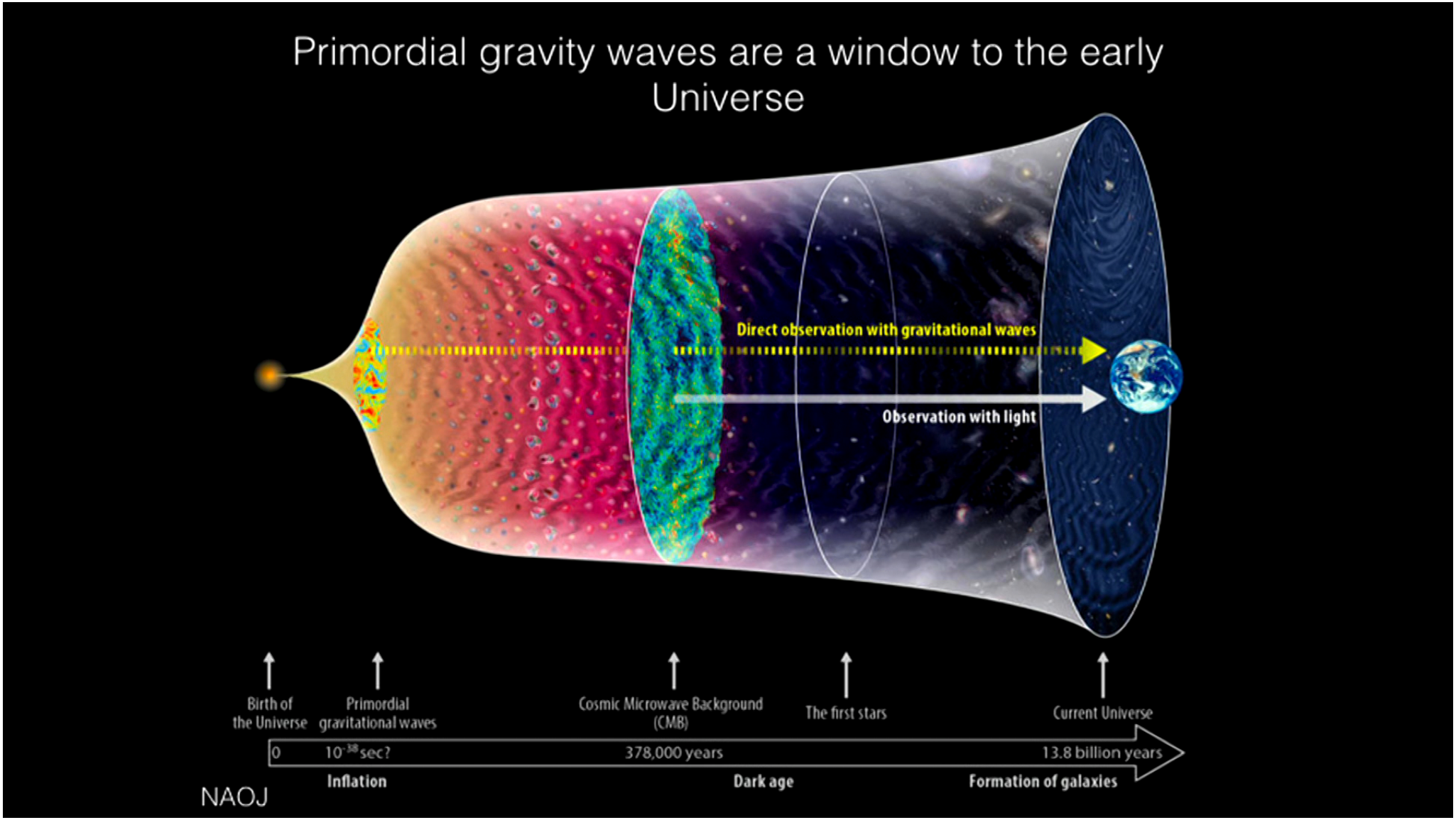
Primordial gravity waves from tidal imprints in large-scale structure

Kiyoshi Masui

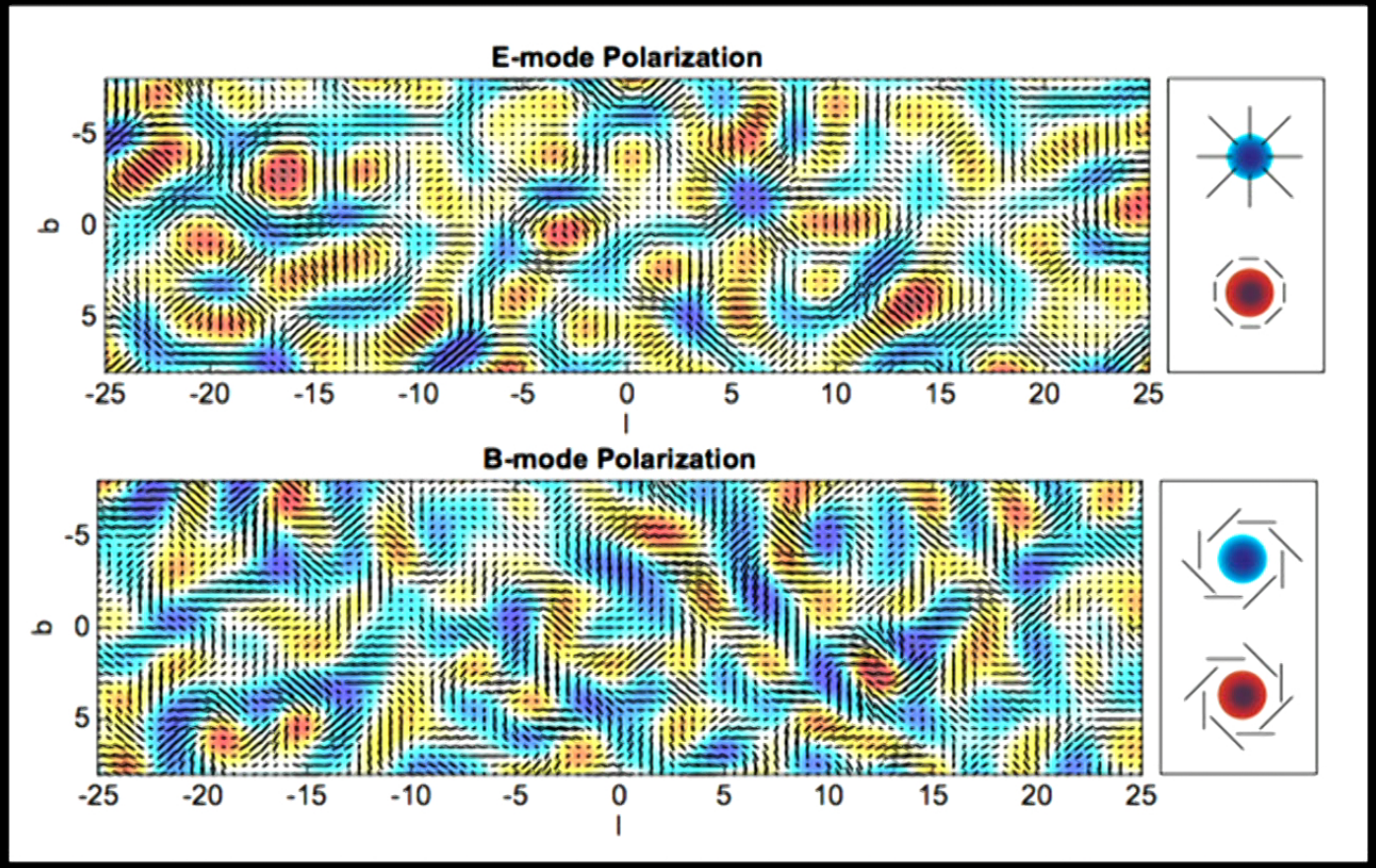
Perimeter Institute
Cosmology Seminar
October 17, 2017

Work done with Ue-Li Pen and Neil Turok
arXiv:1006.4181
arXiv:1702.06552

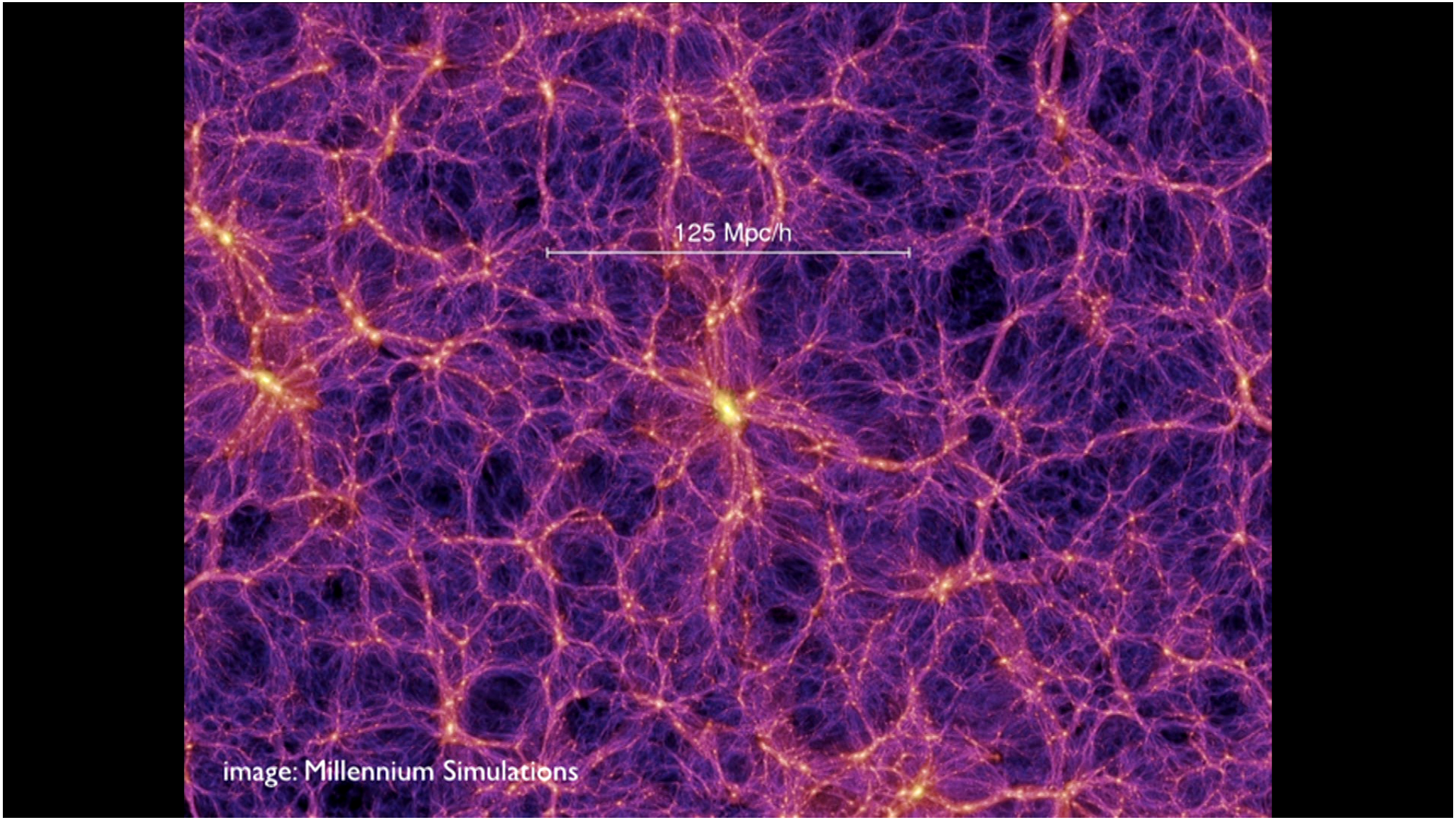
a place of mind


Primordial gravity waves are a window to the early Universe
Direct observation with gravitational waves
Observation with light
Birth of the Universe
Primordial gravitational waves
Cosmic Microwave Background (CMB)
The first stars
Current Universe
0
10-38 sec?
378,000 years
13.8 billion years
Inflation
Dark age
Formation of galaxies
NAOJ

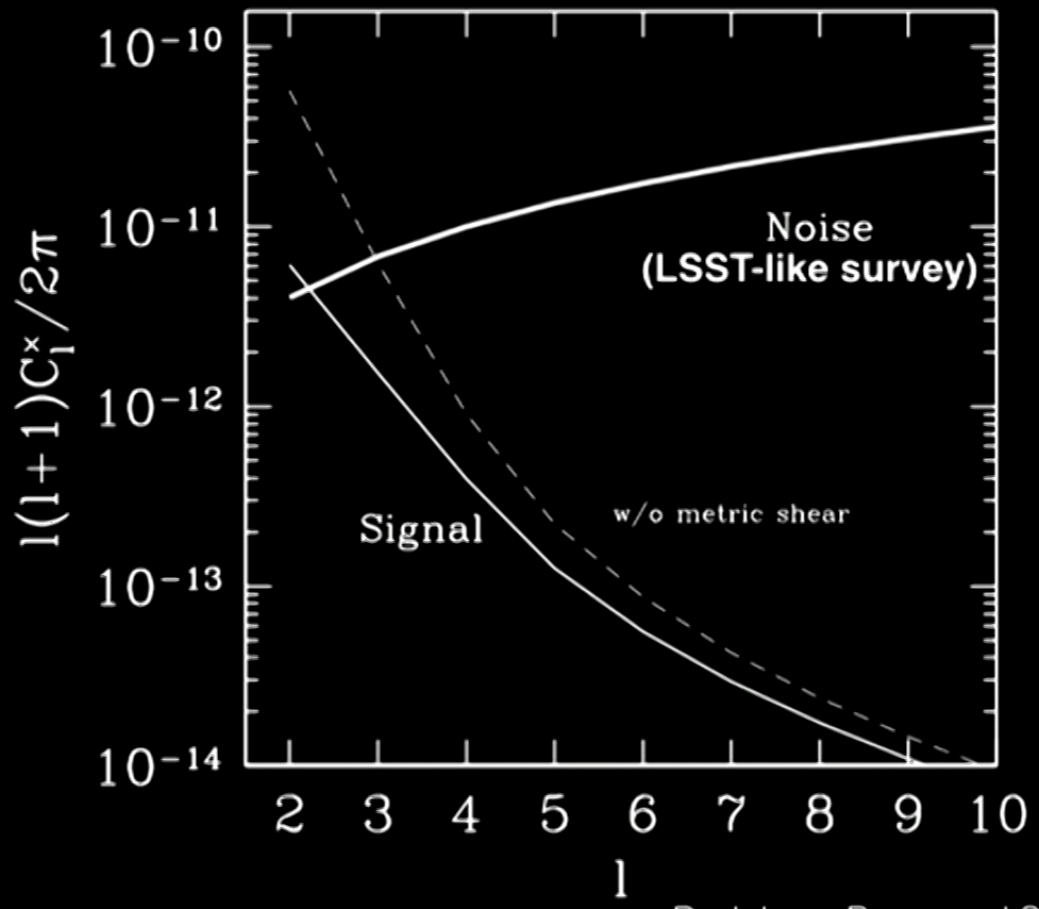
Normal way: CMB B-modes



Kamionkowski and Kovetz, 2016

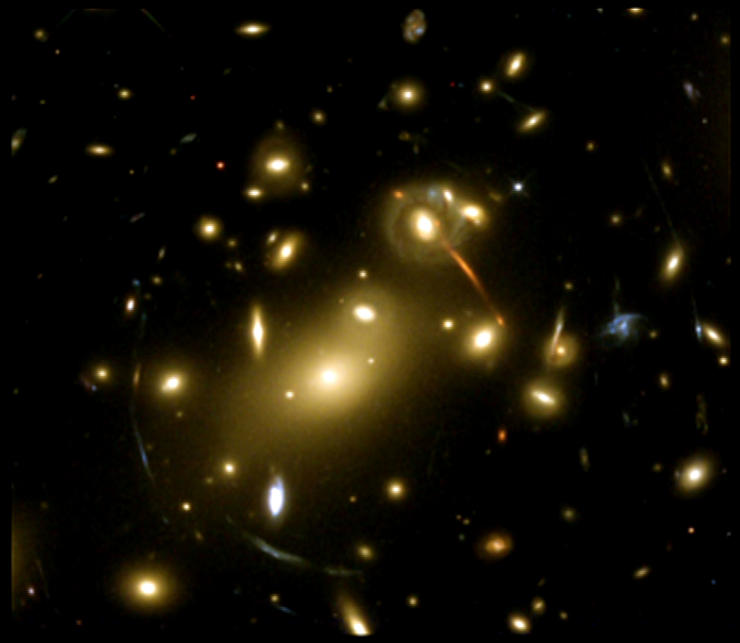

125 Mpc/h
image: Millennium Simulations

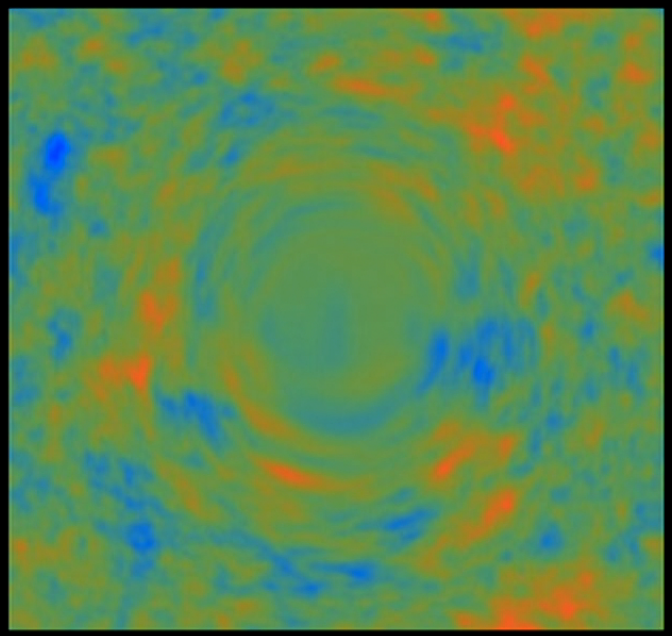
Galaxy lensing B-modes



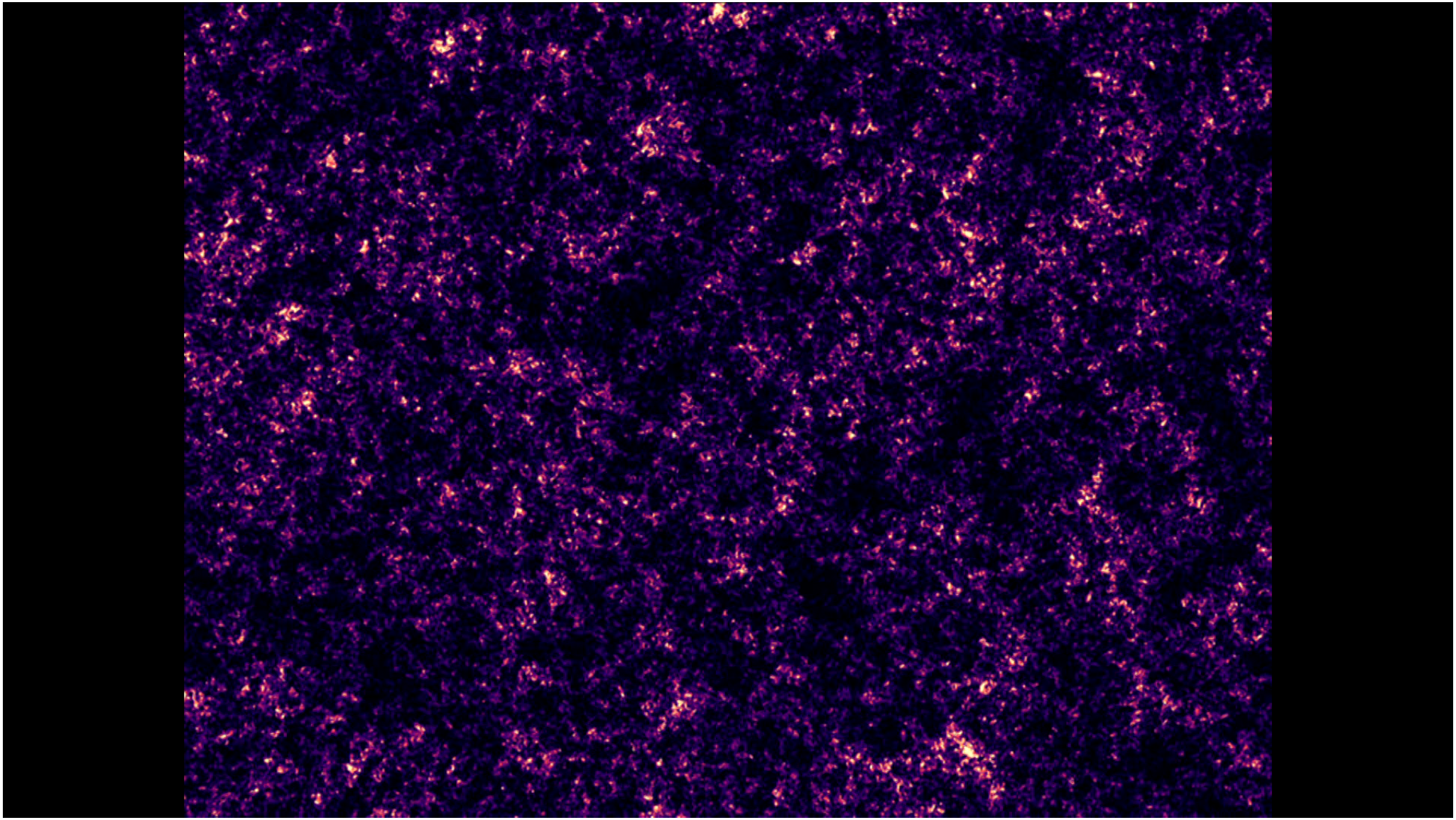
Dodelson, Rozo, and Stebbins (2003)

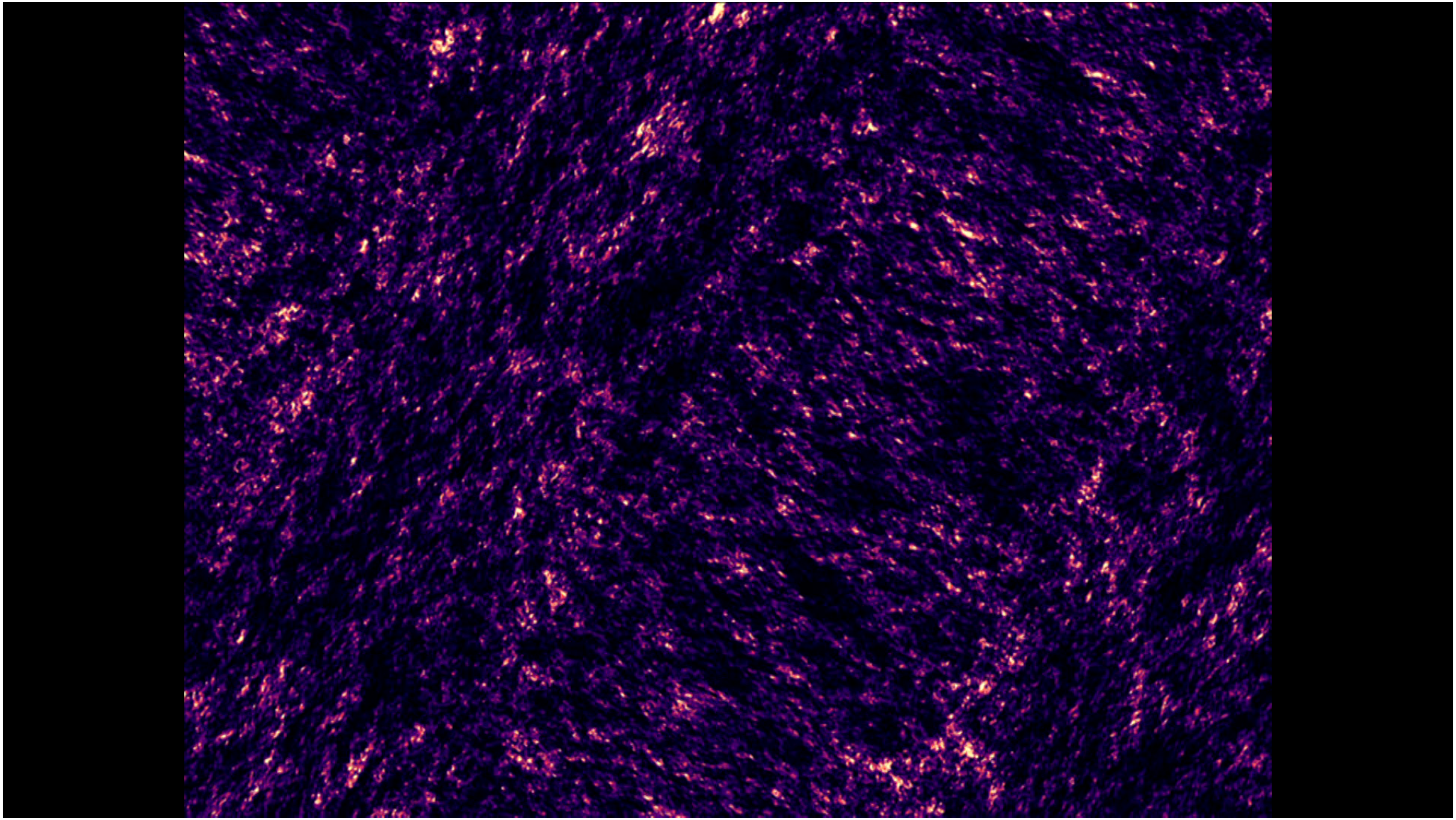
Galaxy shear vs LSS shear



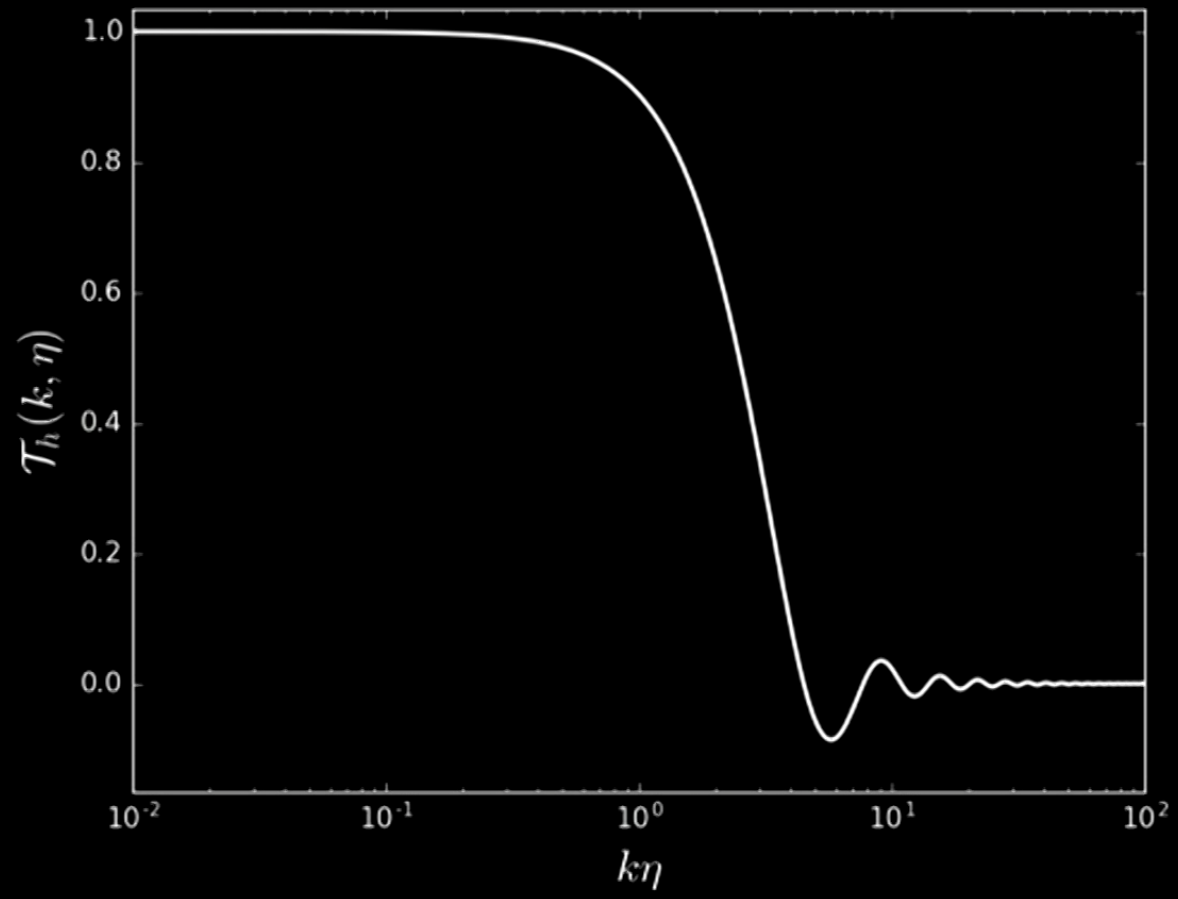


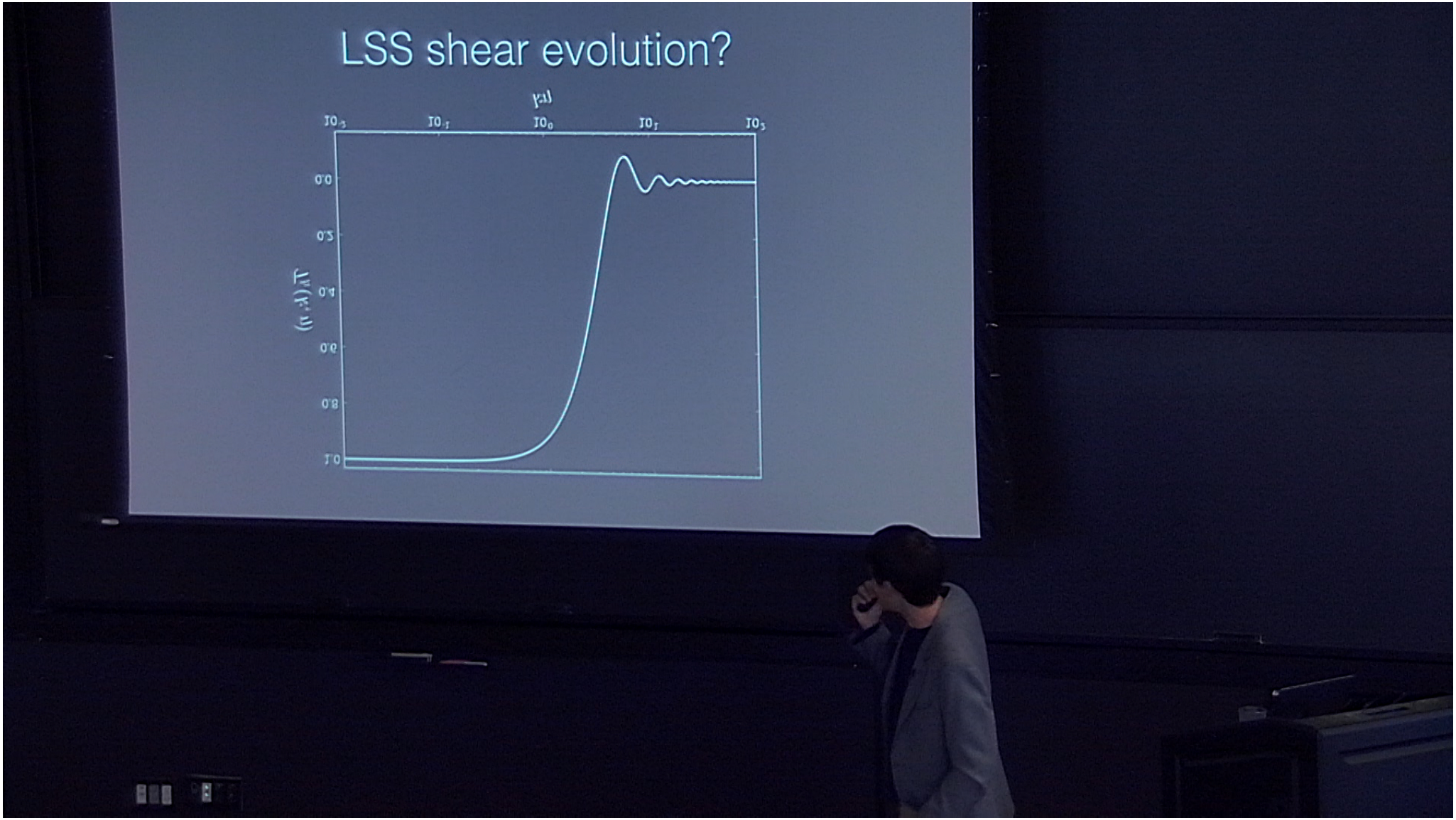
images: CFHTLenS, Wayne Hu



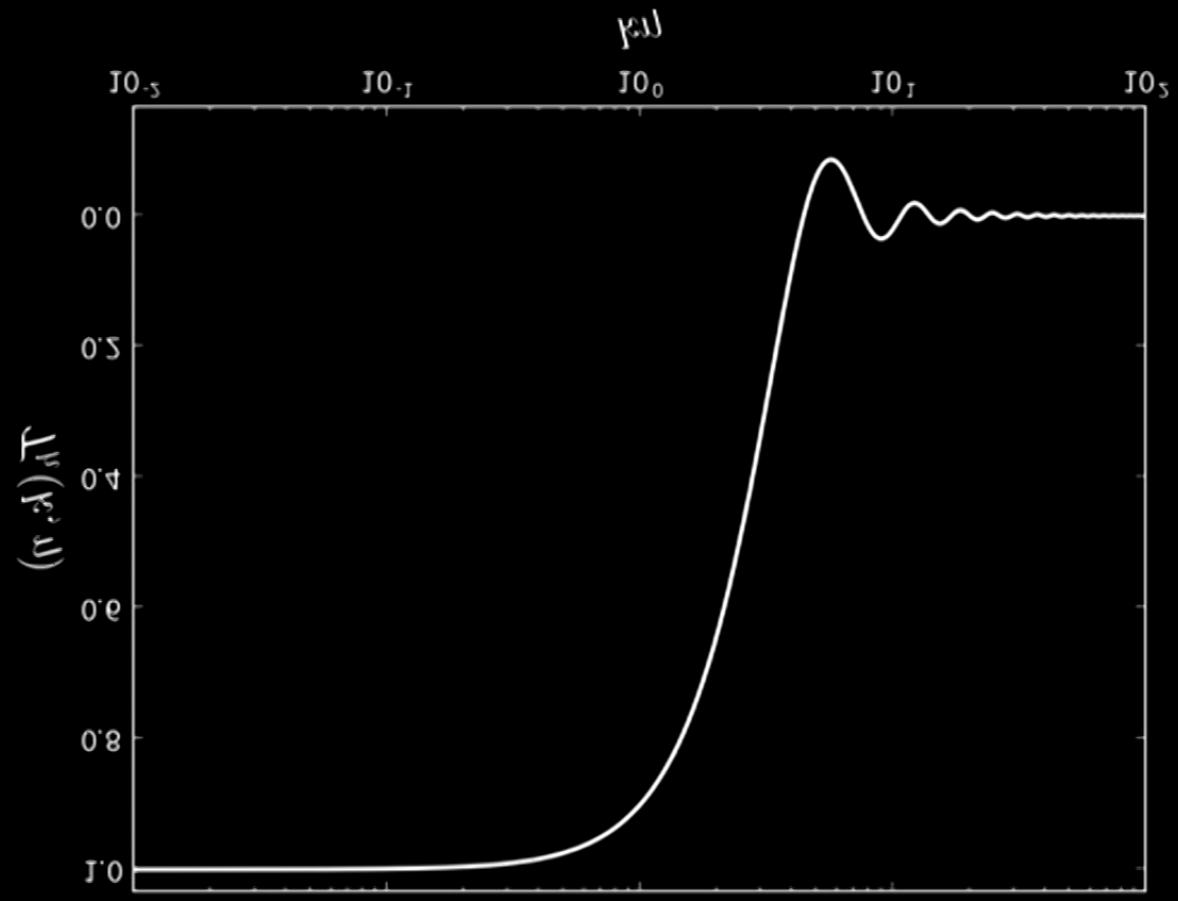


Gravity wave evolution

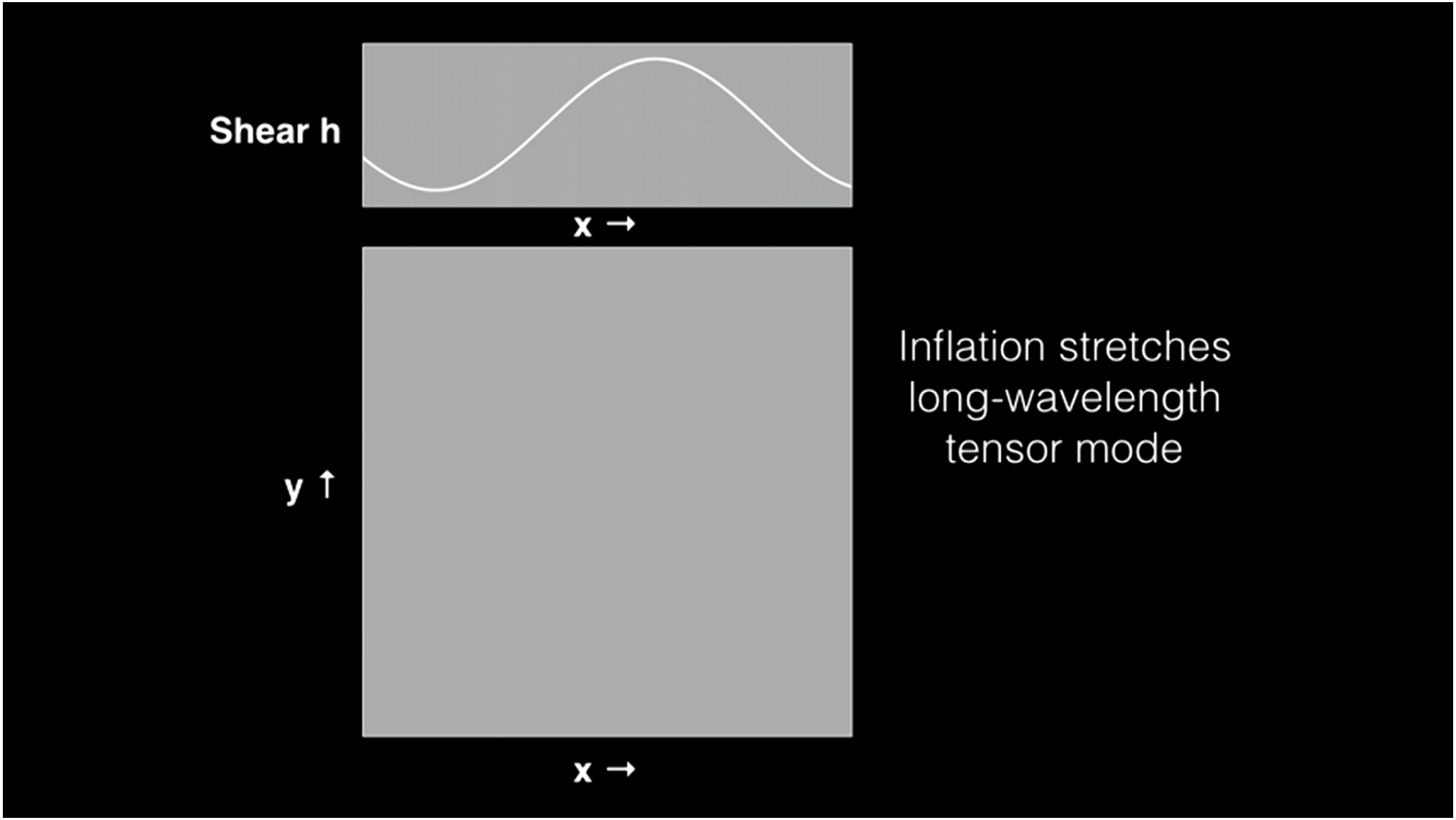


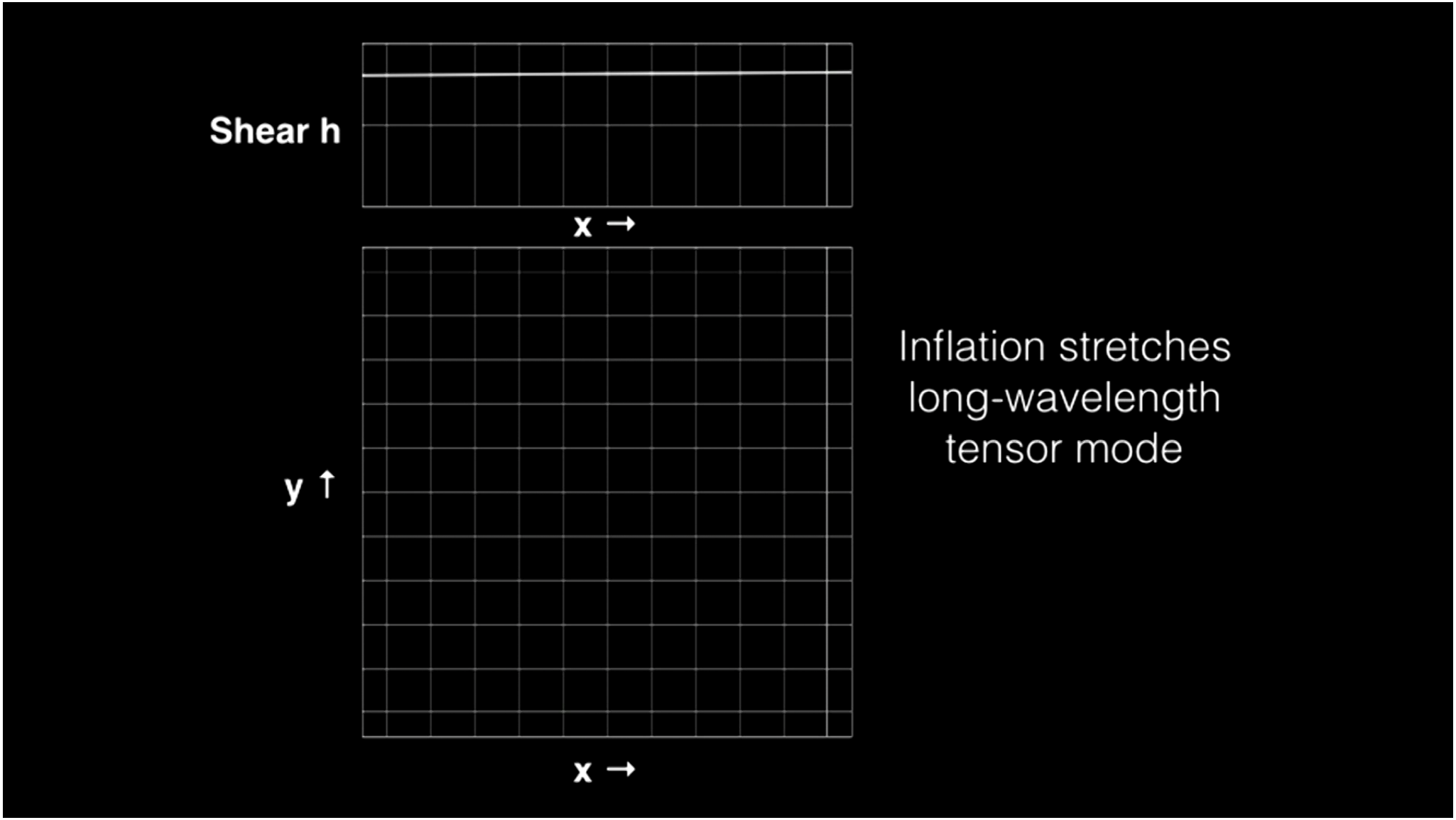

LSS shear evolution?

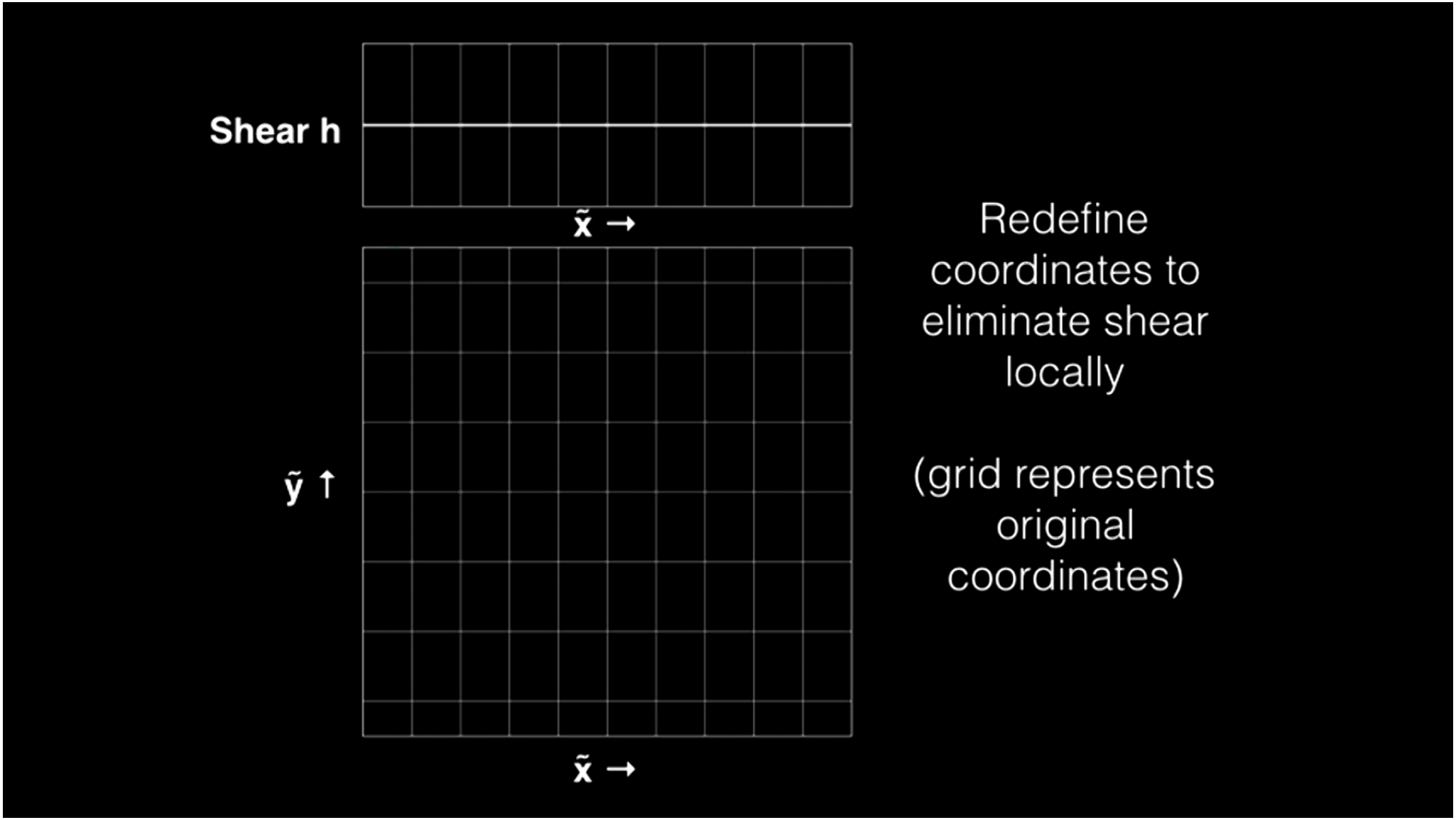
LSS shear evolution?



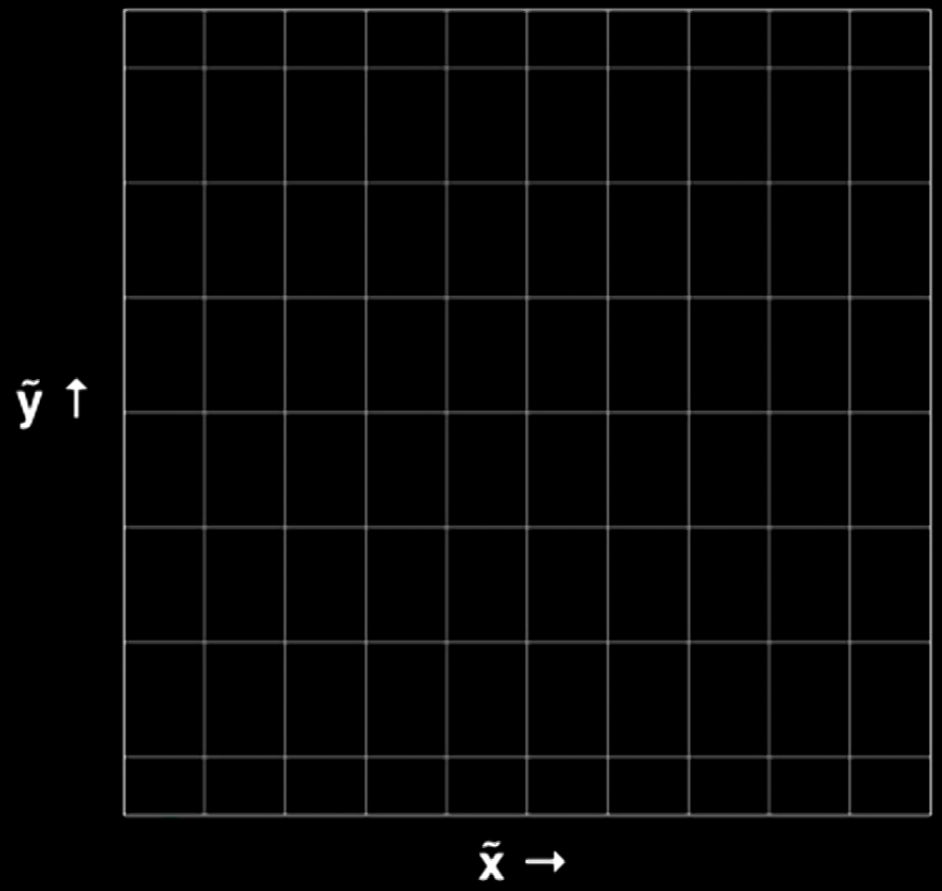
Need to think carefully about initial conditions


Shear h
x →
y ↑
x →
Inflation stretches
long-wavelength
tensor mode

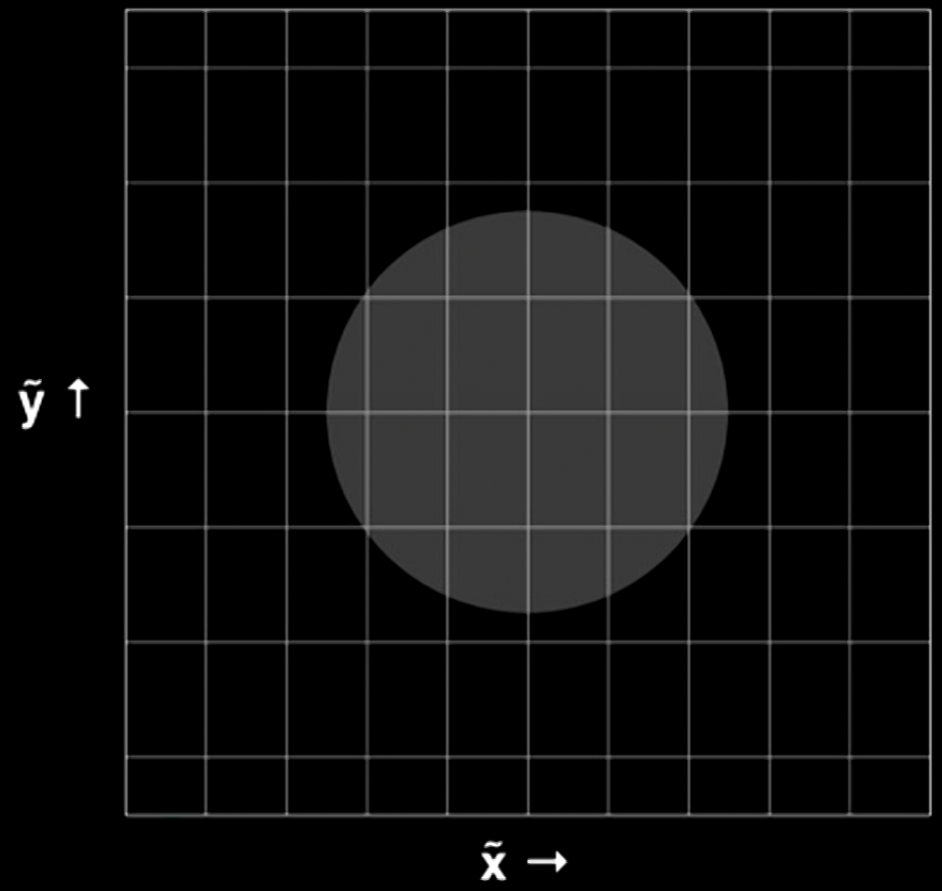

Shear h
x →
y ↑
x →
Inflation stretches
long-wavelength
tensor mode


Shear h
$\tilde{x}$ →
$\tilde{y}$ ↑
$\tilde{x}$ →
Redefine coordinates to eliminate shear locally
(grid represents original coordinates)

Metric is locally Robertson Walker



Scalar mode generated on small scales



$$ds^2 = a^2 \left[-d\eta^2 + (\delta_{ab} + h_{ab}) dx^a dx^b \right]$$

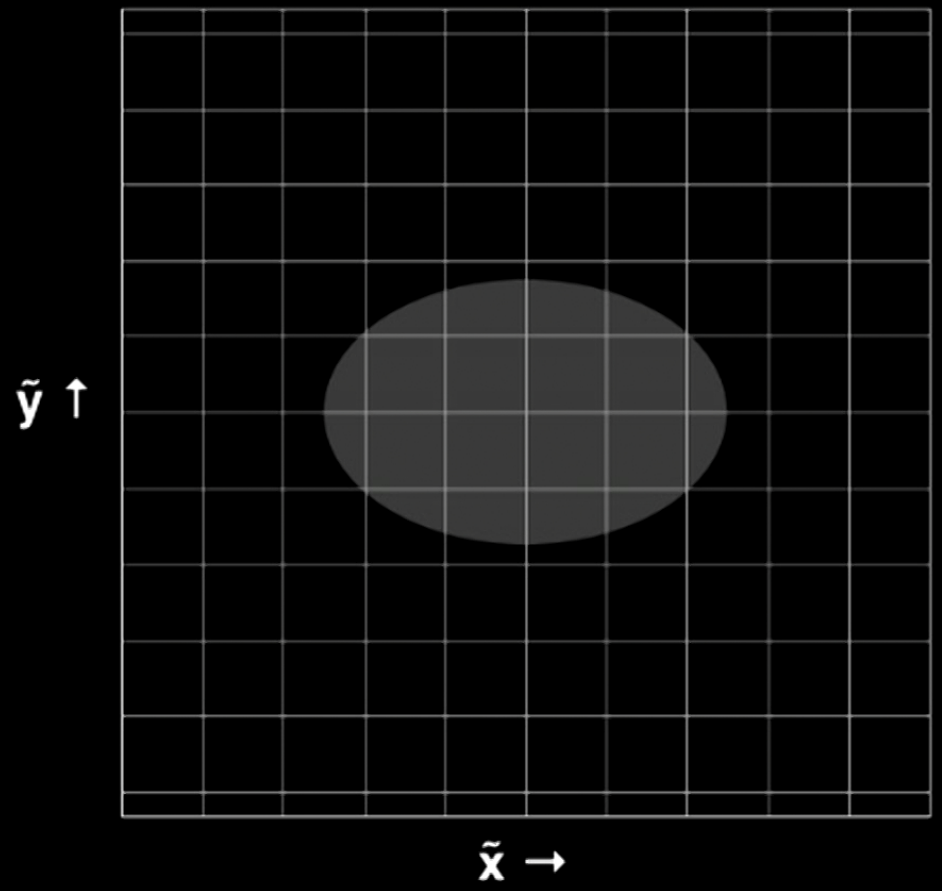
$$\tilde{x}^a = x^a + \frac{1}{2} h^a{}_b x^b$$

$$ds^2 = a^2 \left[-d\eta^2 + \delta_{ab} d\tilde{x}^a d\tilde{x}^b - \tilde{x}^c \partial_\alpha h_{\beta c} d\tilde{x}^\alpha d\tilde{x}^\beta \right]$$

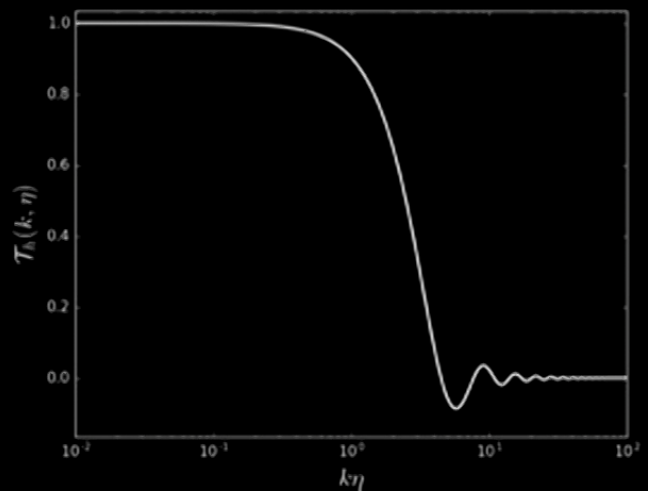
$$\tilde{x}^a = x^a + \frac{1}{2} h^a{}_b x^b$$

$$P(\vec{k}) = \tilde{P}(k) \left[1 - k_a k_b h^{ab} \frac{1}{2} \frac{d \ln P}{d \ln k} \right]$$

Second term: tidal interaction

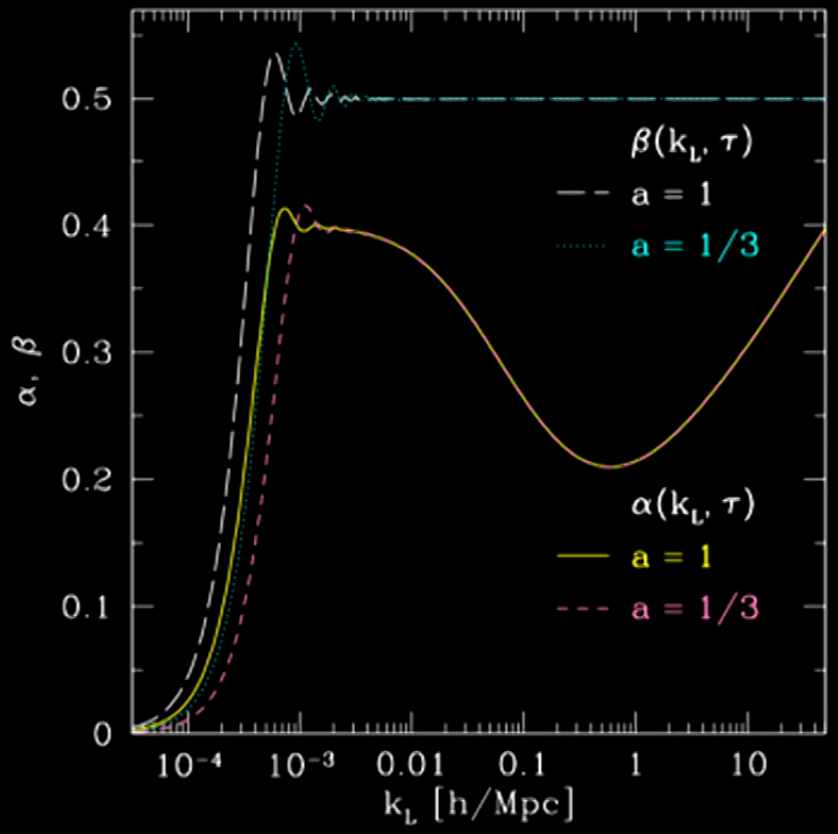


Permanent signature of decayed gravity wave: a fossil



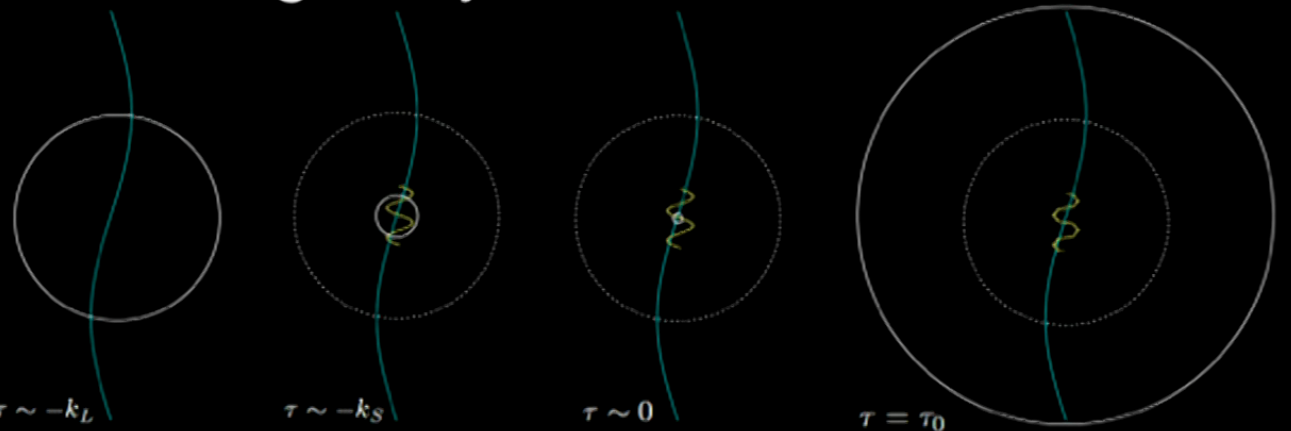
$$P(\vec{k}) = \tilde{P}(k)\left[1 - k_a k_b h^{ab}\frac{1}{2}\frac{d\ln P}{d\ln k}\right]$$

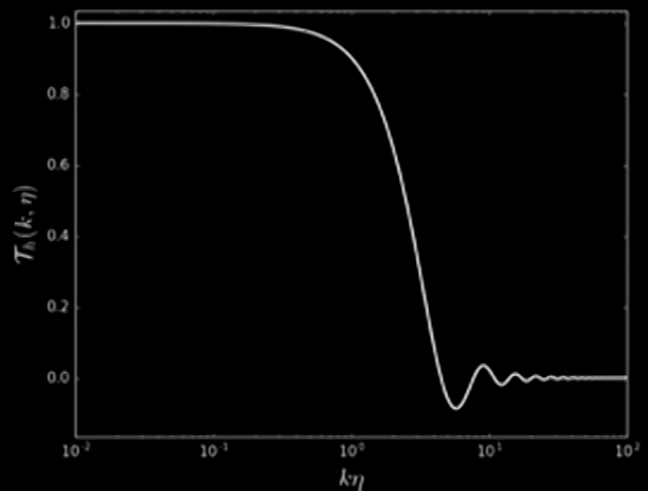
$$P(\vec{k}) = \tilde{P}(k)\left[1 - k_a k_b h^{ab}\left(\frac{1}{2}\frac{d\ln P}{d\ln k} - 2\alpha(K)\right)\right]$$



Schmidt, Pager, Zaldarriaga (2013)

Permanent signature of decayed gravity wave: a fossil





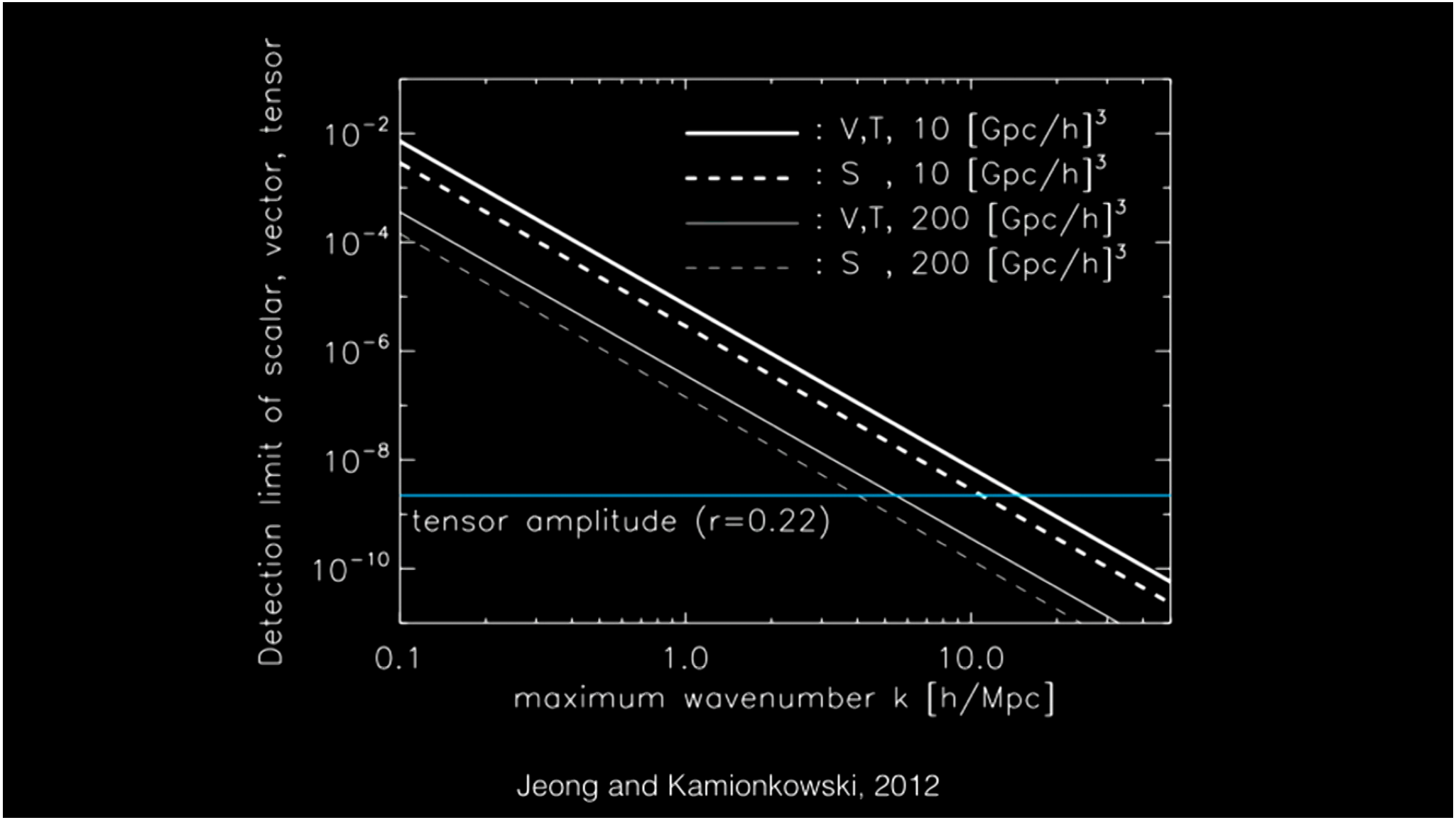
$$P(\vec{k}) = \tilde{P}(k)\left[1 - k_a k_b h^{ab}\frac{1}{2}\frac{d\ln P}{d\ln k}\right]$$

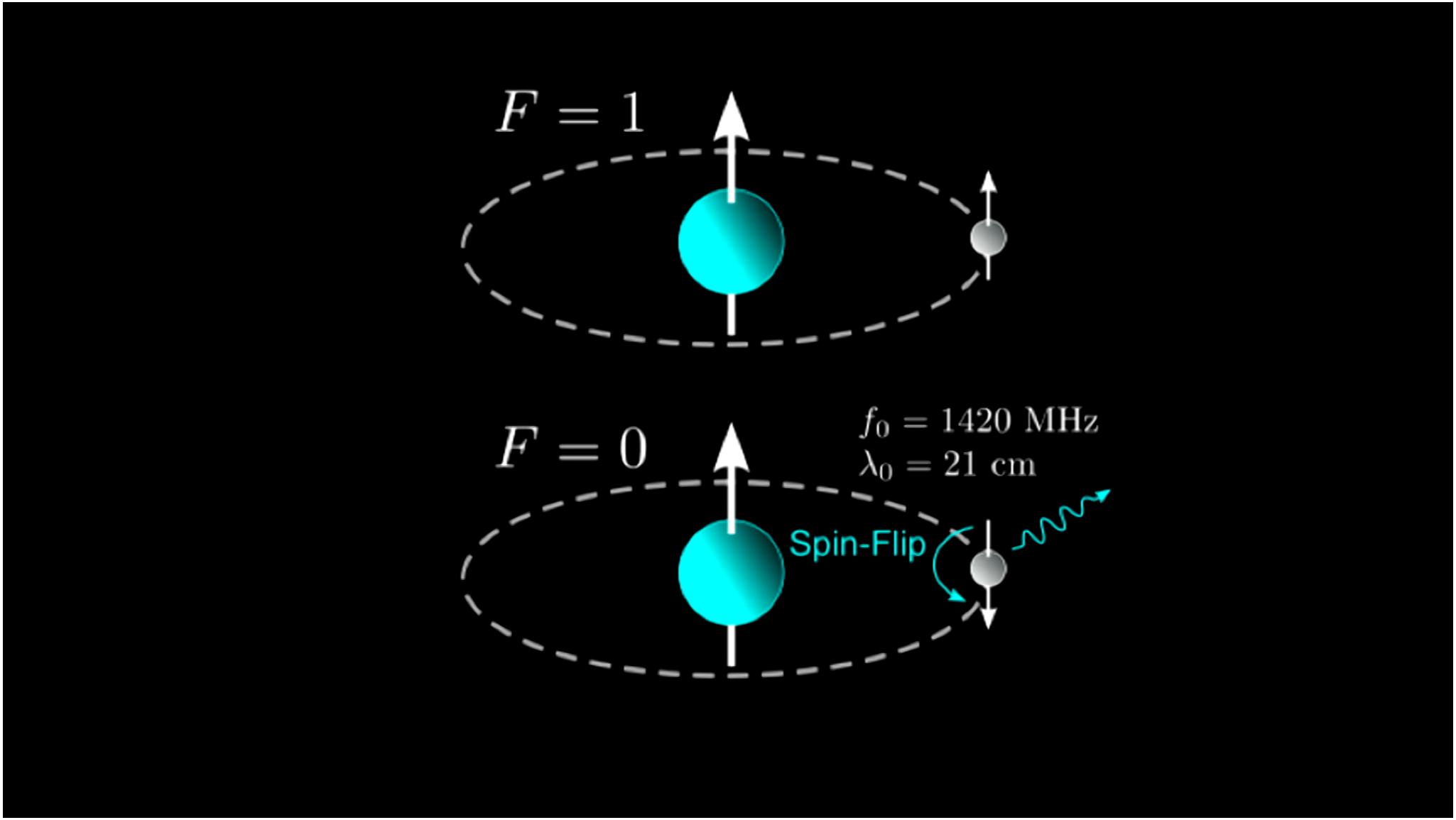
In a small patch of constant h:

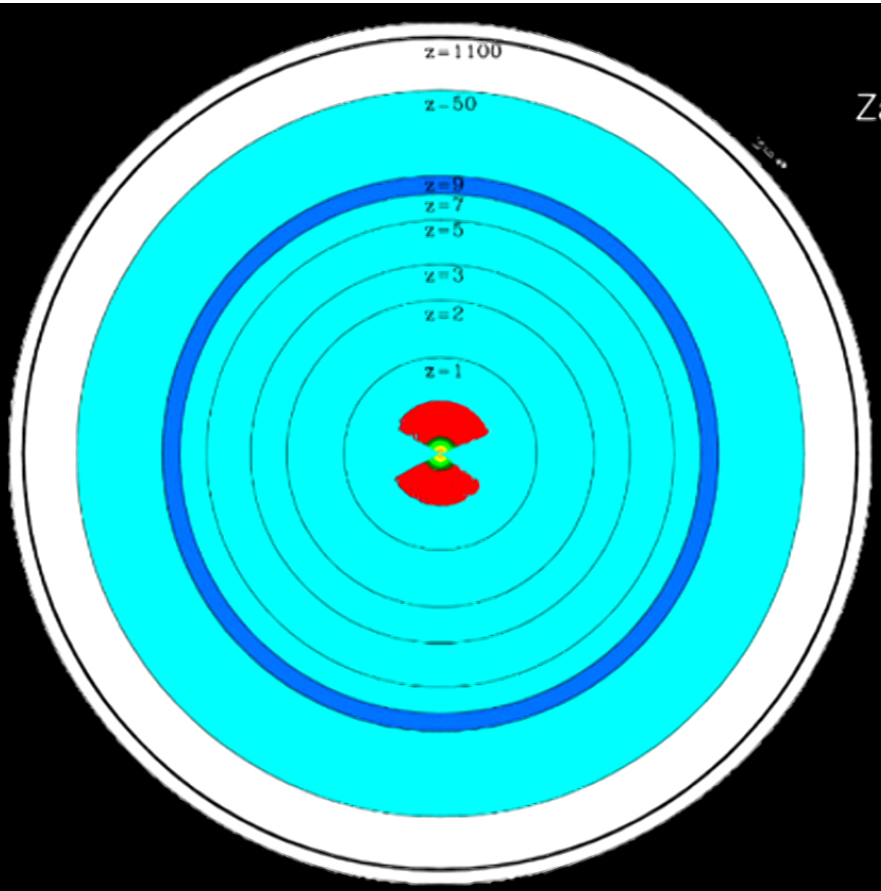
$$P(\vec{k}) = \tilde{P}(k)\left[1 - k_a k_b h^{ab}\left(\frac{1}{2}\frac{d\ln P}{d\ln k} - 2\alpha(K)\right)\right]$$

Globally:

$$\langle\delta(\vec{k})\delta(-\vec{k}')\rangle\big|_{h_{ab}} = P(\vec{k})\Big\{(2\pi)^3\delta^3(\vec{k}-\vec{k}') - h^{ab}(\vec{k}-\vec{k}')\hat{k}_a\hat{k}'_b\left[\frac{1}{2}\frac{d\ln P}{d\ln k} - 2\alpha(|\vec{k}-\vec{k}'|)\right]\Big\}$$


Detection limit of scalar, vector, tensor
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
: V,T, 10 [Gpc/h]^3
: S , 10 [Gpc/h]^3
: V,T, 200 [Gpc/h]^3
: S , 200 [Gpc/h]^3
tensor amplitude (r=0.22)
0.1
1.0
10.0
maximum wavenumber k [h/Mpc]
Jeong and Kamionkowski, 2012

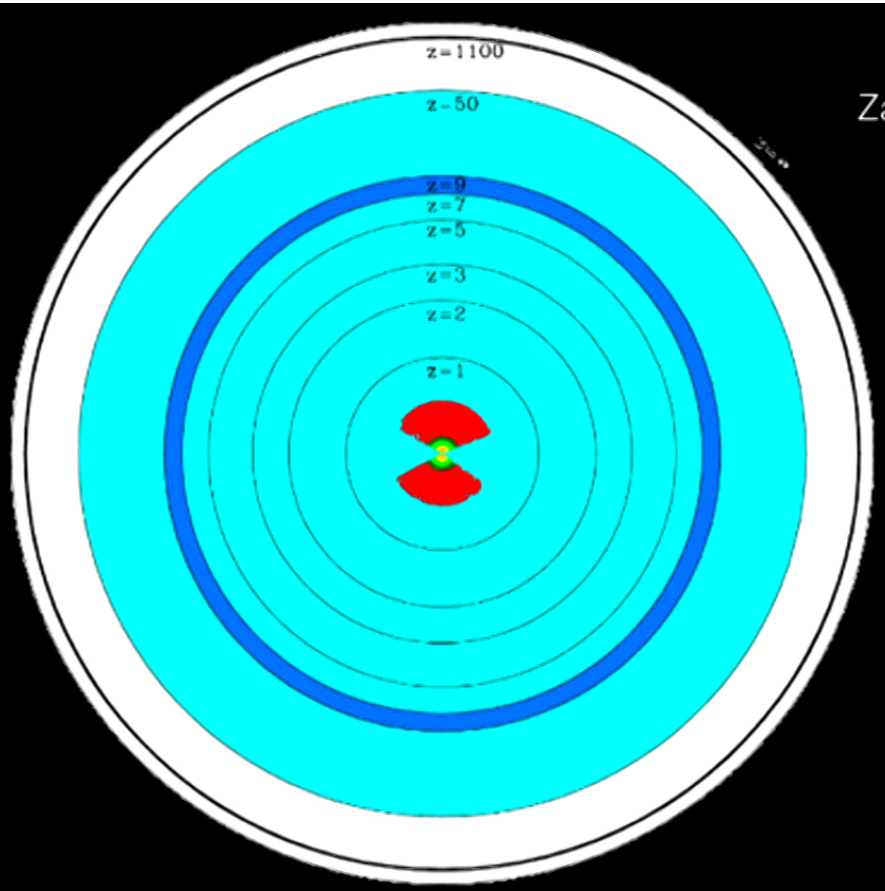

$F = 1$
$F = 0$
$f_0 = 1420$ MHz
$\lambda_0 = 21$ cm
Spin-Flip



Tegmark and
Zaldarriaga, 2009

V ~ 1000 Gpc^3 k_max ~ 1000 h/Mpc

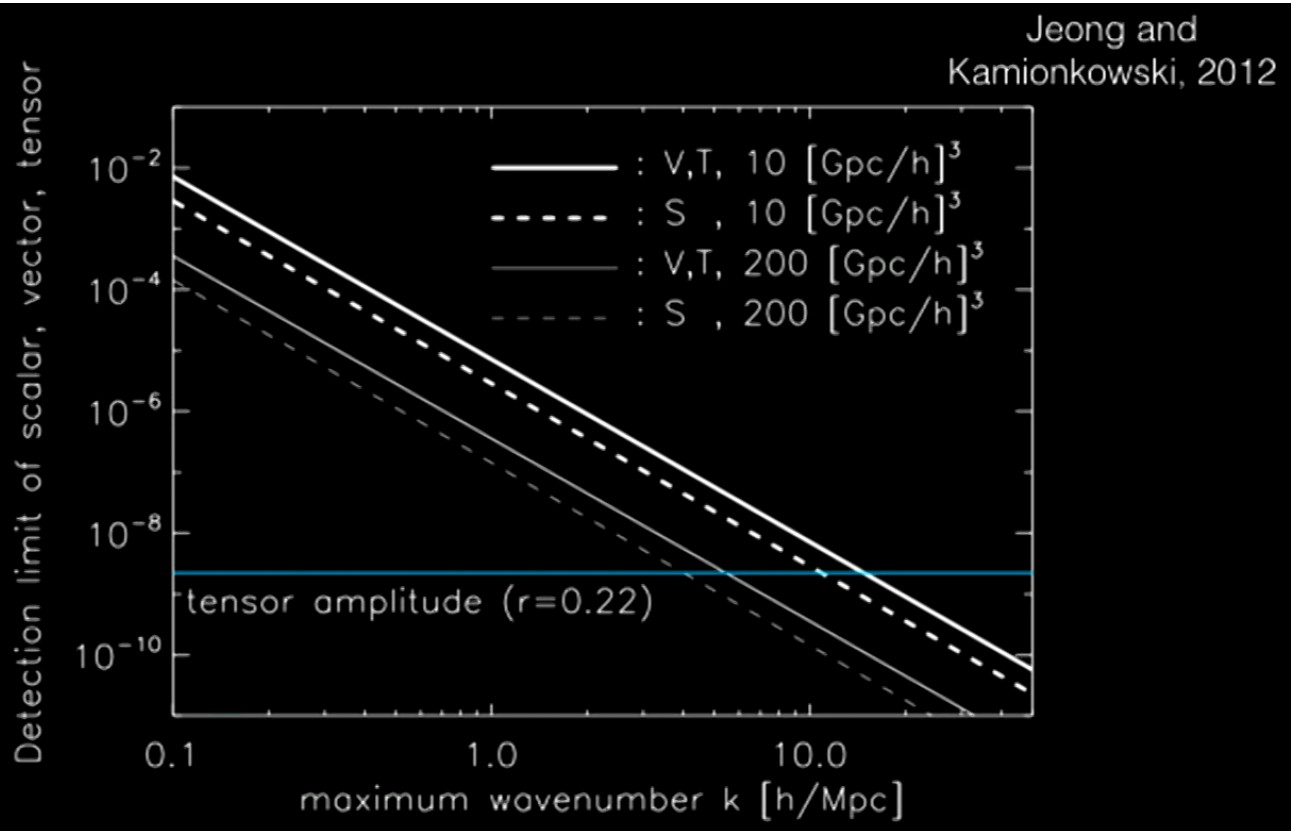
~10^{18} modes.



Tegmark and
Zaldarriaga, 2009

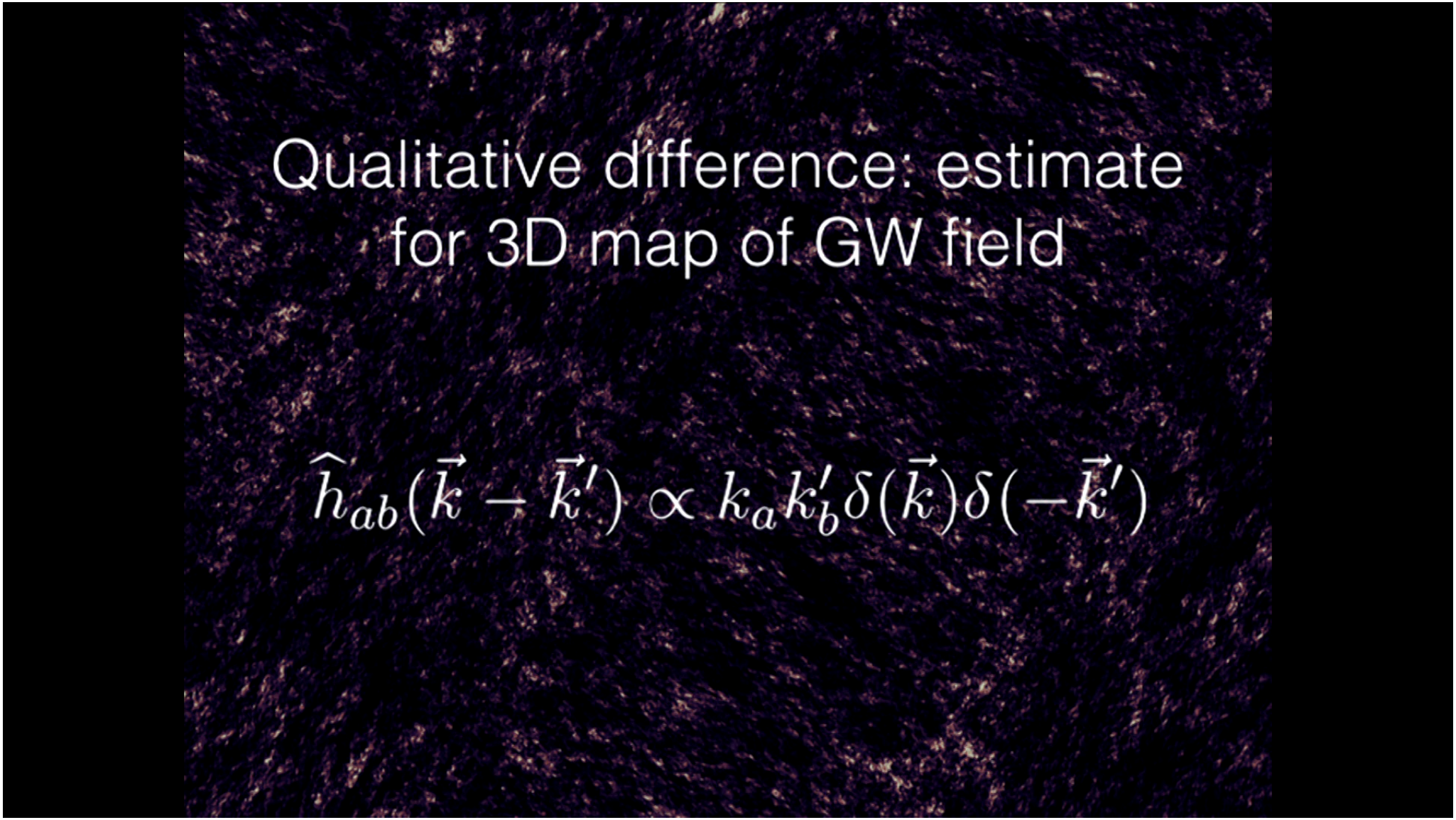
$V \sim 1000\ \mathrm{Gpc}^3$ $k_{max} \sim 1000\ h/\mathrm{Mpc}$

$\sim 10^{18}$ modes.

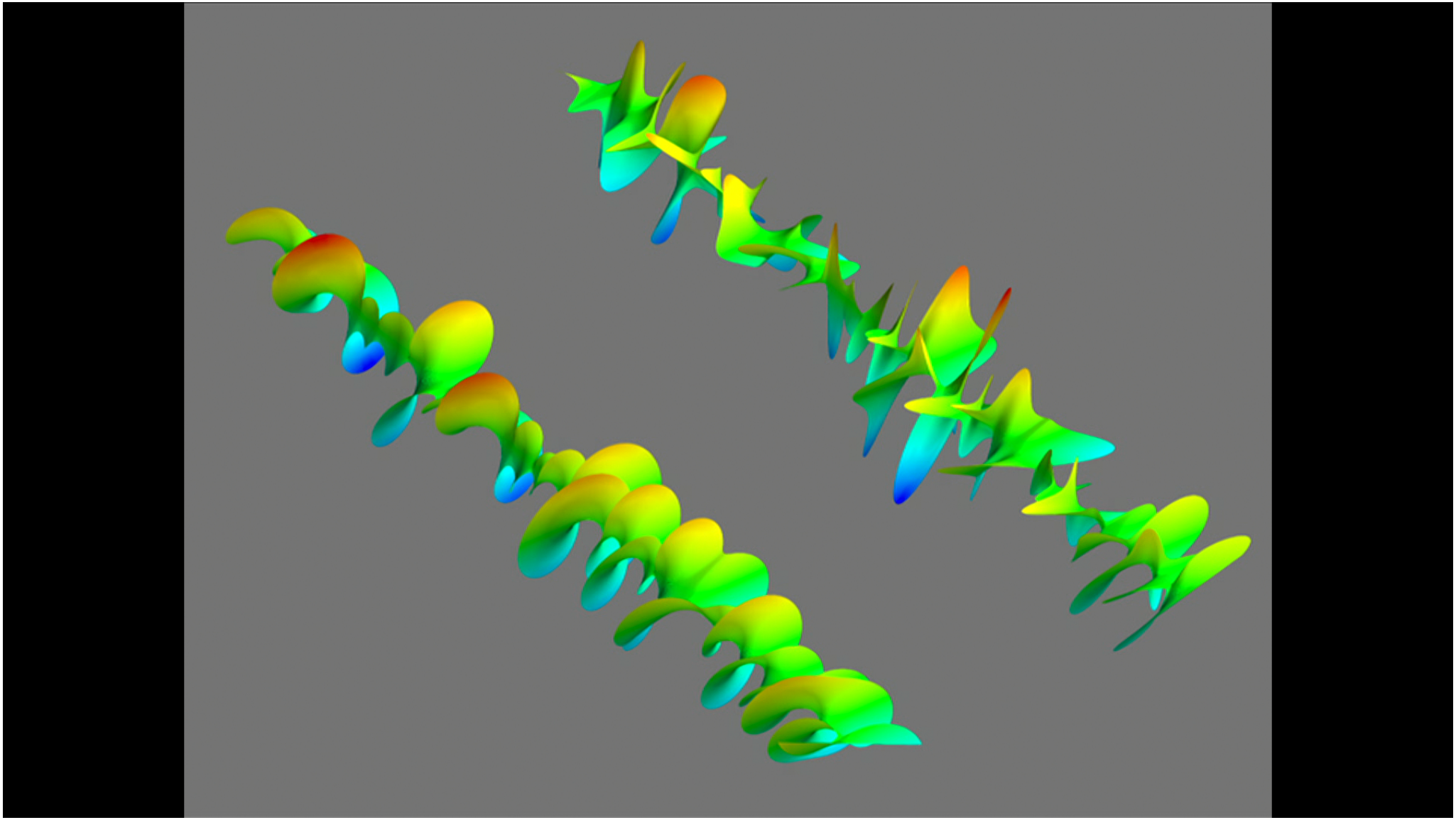


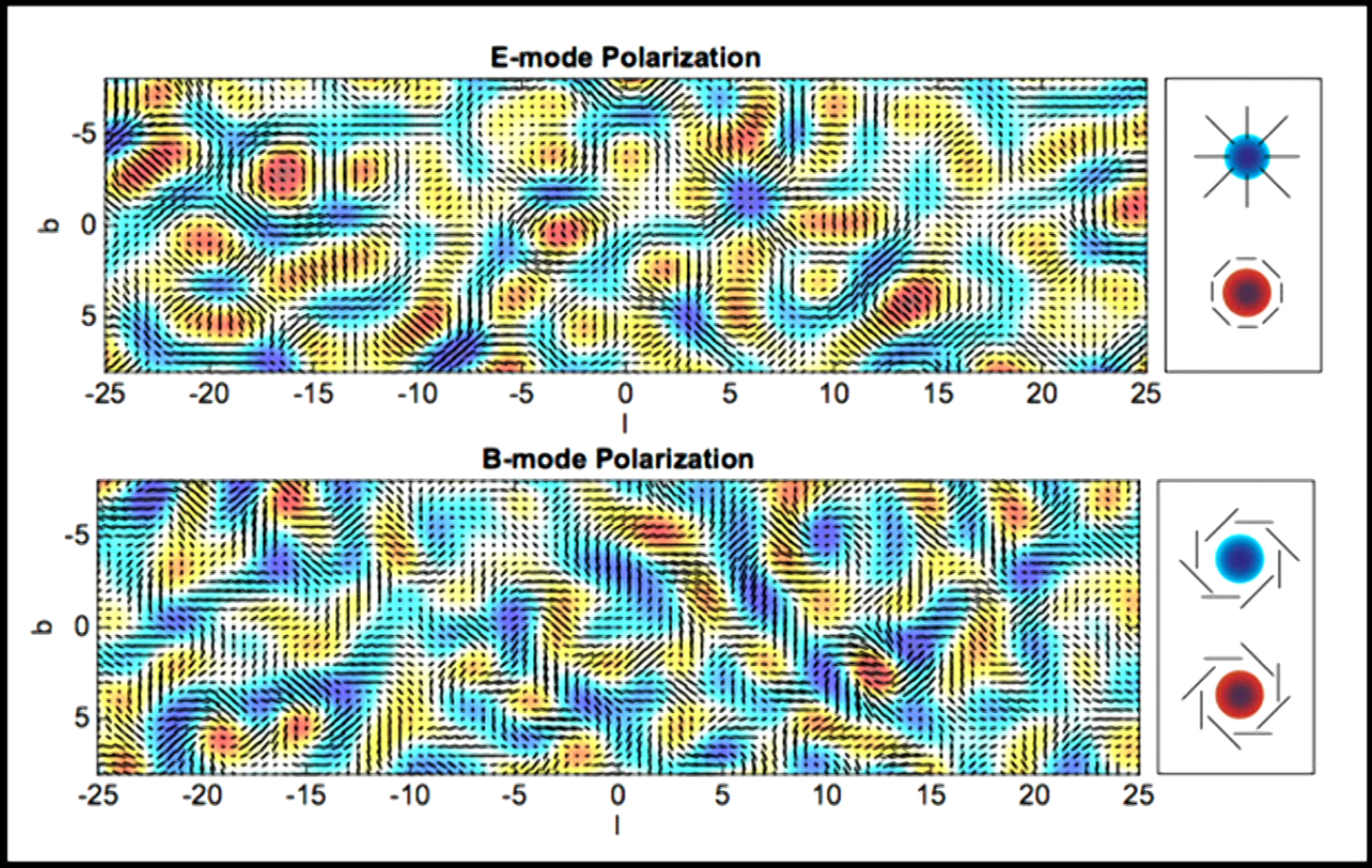
V ~ 1000 Gpc^3 k_max ~ 1000 h/Mpc

~10^{18} modes.


Qualitative difference: estimate
for 3D map of GW field
$\widehat{h}_{ab}(\vec{k}+\vec{k}') \propto k_a k'_b \delta(\vec{k})\delta(-\vec{k}')$

Interlude:
Gravity wave helicity and the CMB





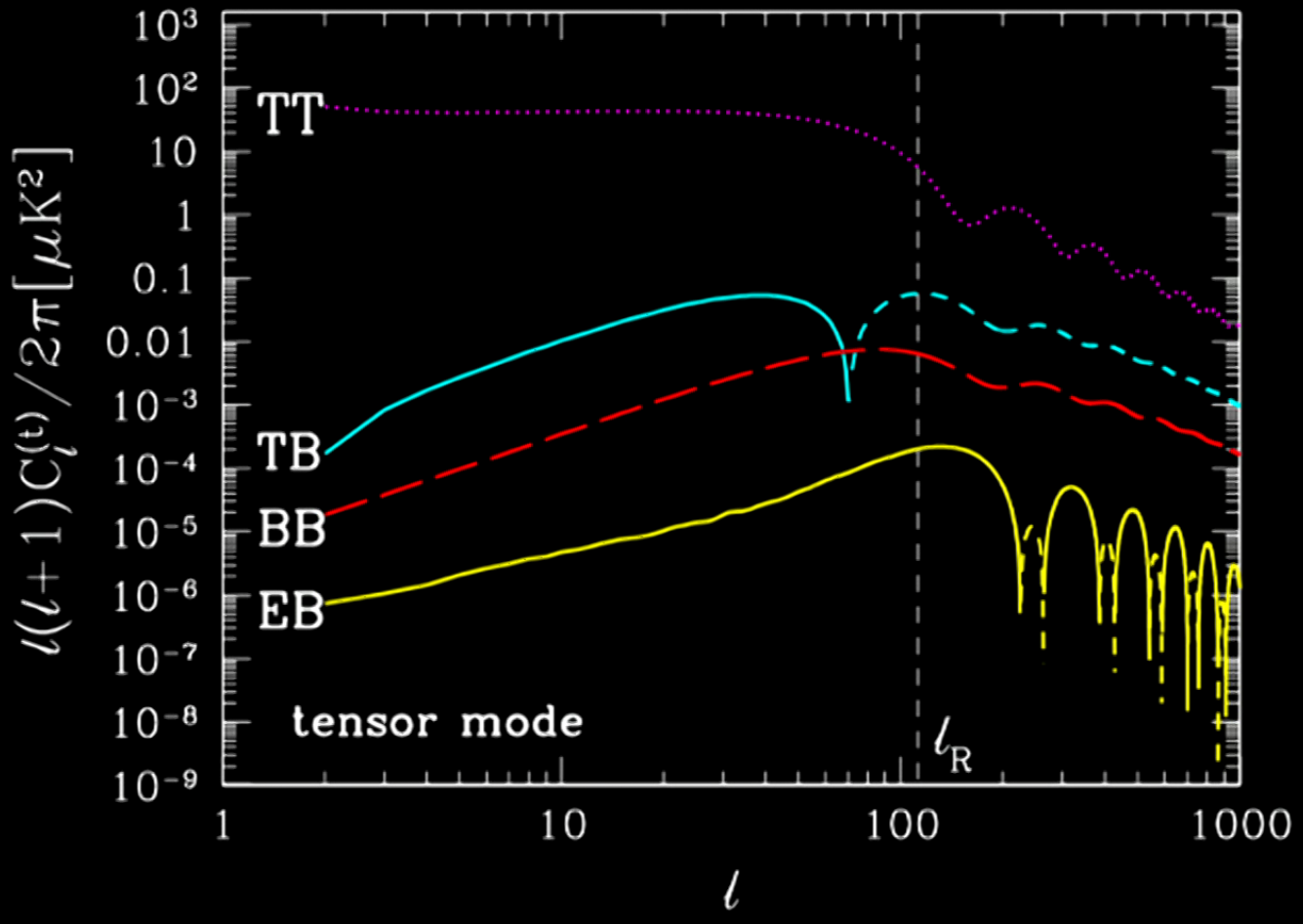
Kamionkowski and Kovetz, 2016

$$P_R - P_L = \Delta\chi P_h$$

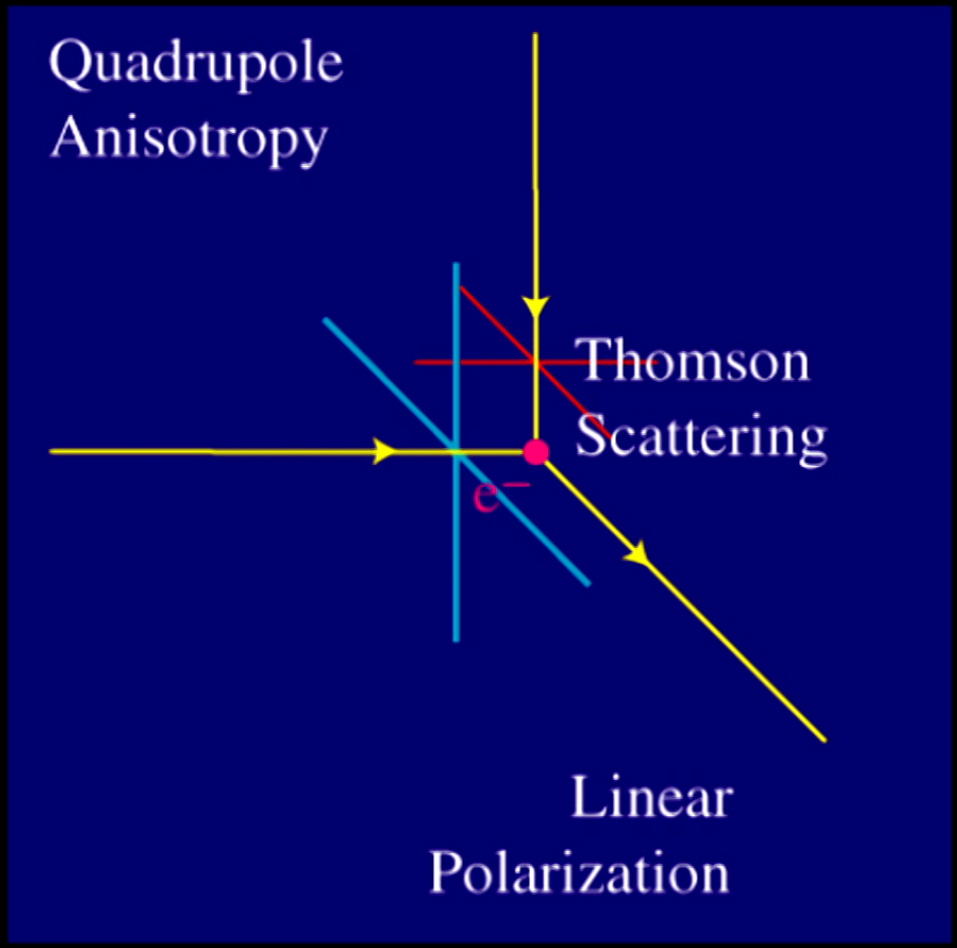
Naive expectation:

$$C_\ell^{EB} \sim \Delta\chi \sqrt{C_\ell^{EE} C_\ell^{BB}}$$

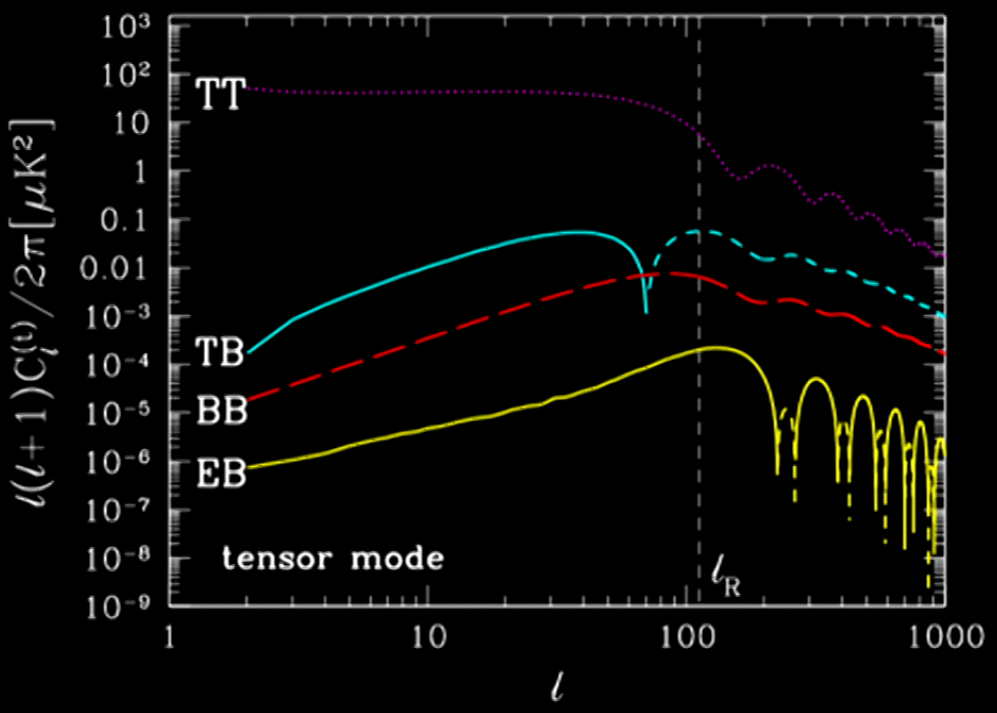
$$C_\ell^{TB} \sim \Delta\chi \sqrt{C_\ell^{TT} C_\ell^{BB}}$$



Saito et al., 2007



Wayne Hu's Polarization Intro



$$(\Delta C_\ell^{XY})^2 \sim C_\ell^{XX} C_\ell^{YY}$$

- Gravity wave helicity unobservable in the CMB unless:
  - Near maximal helicity (> 50%)
  - r > 0.02 (current upper limit is r > 0.07)
- Because of *dimensionality*

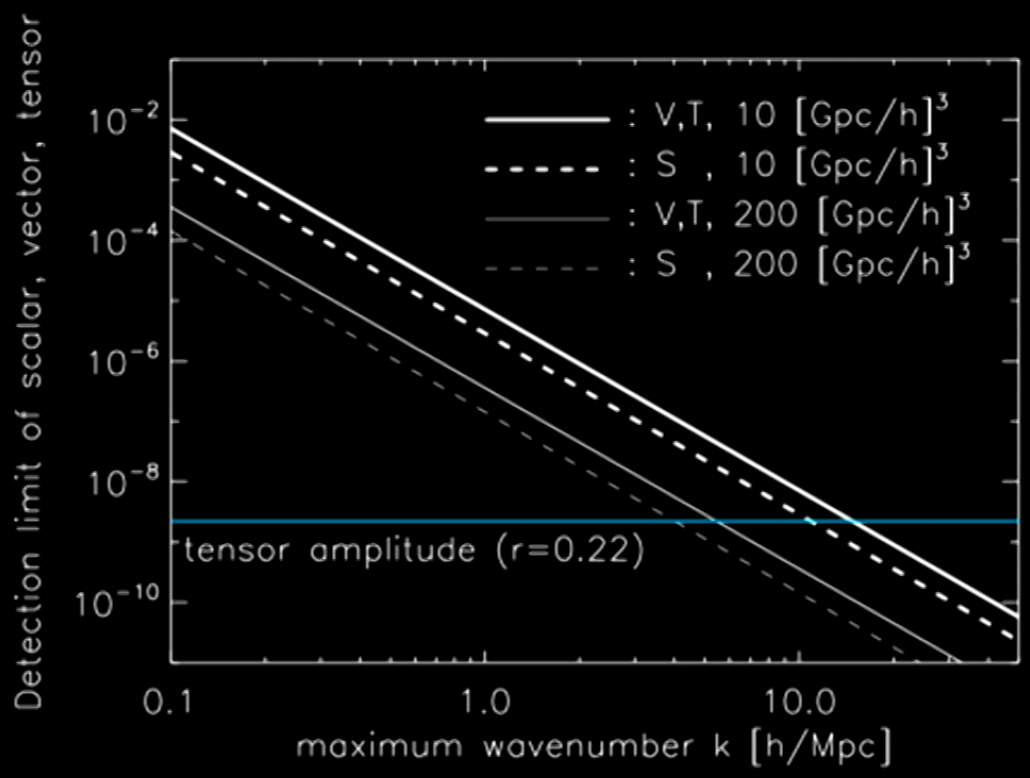
Back to tidal fossils

- Preserves all geometric information
- No suppression of helicity signal, confusion with scalars

$$\widehat{h}_{ab}(\vec{k}-\vec{k}') \propto k_a k'_b \delta(\vec{k})\delta(-\vec{k}')$$

$$\sigma_{\Delta\chi\, r} = \sigma_r$$

$$\sigma_{\Delta\chi\, r} = \sigma_r$$



Jeong and Kamionkowski, 2012

Summary

- Tidal interaction leaves permanent fossil of gravity waves in LSS shear
- High-redshift 21 cm hydrogen surveys could be extremely sensitive to GW background
- Full 3D information: can study detailed physics of GWs