General Relativistic Description of Observed Galaxy Power Spectrum

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Michigan Center for Theoretical Physics, May, 14, 2011

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I. Why?

II. How?

III. So What?

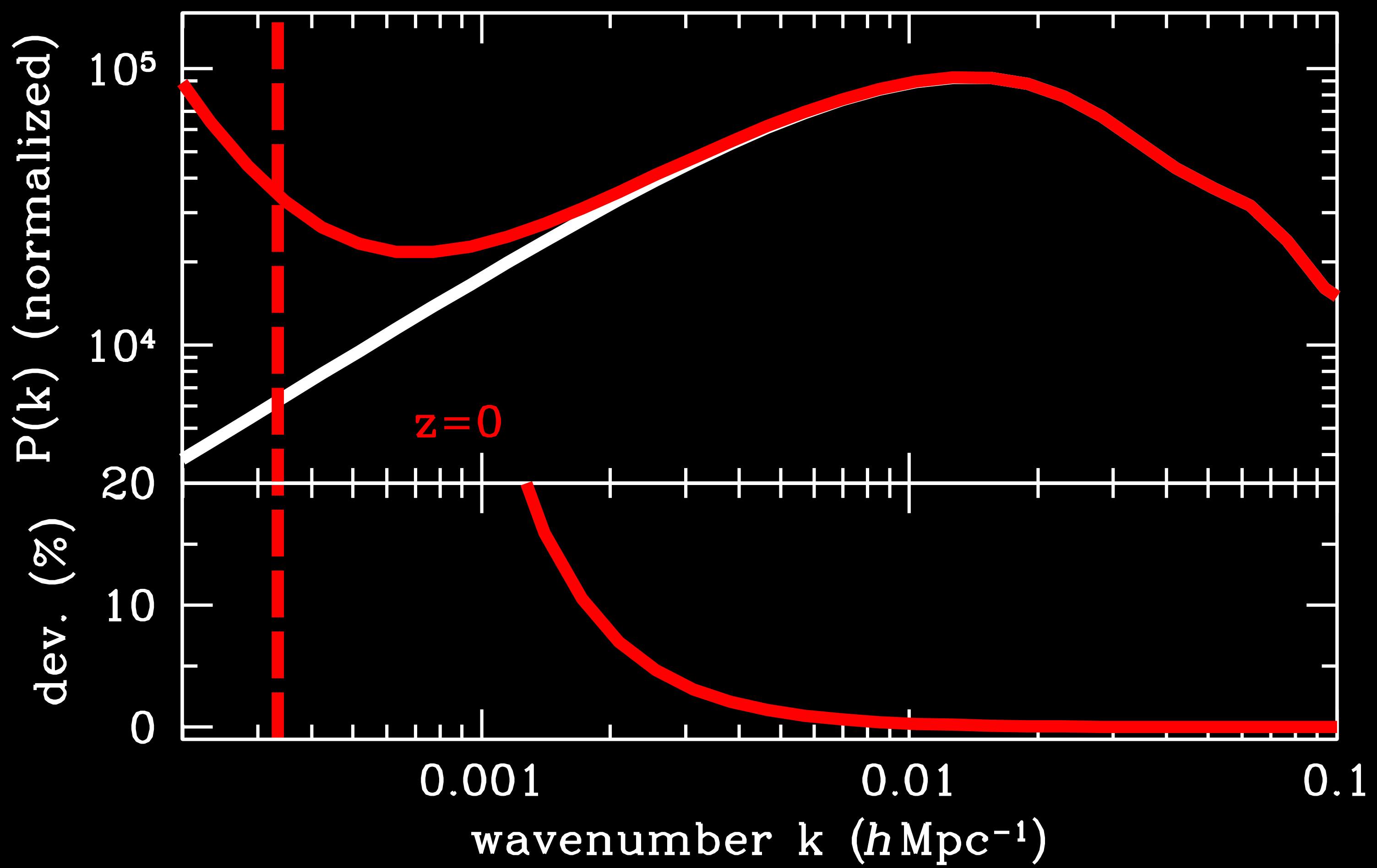
I. MOTIVATION

- *theoretical inconsistency* in the standard method
- is Newtonian description *valid?*
  - larger volume and higher redshift
  - primordial non-Gaussianity on large scales
- it is "*general relativity!*"

GR Effects on Horizon

- which *gauge choice?*(there are *infinitely* many gauges)
- *order one* effects on horizon scale!

P_m : Synchronous gauge, P_m : Newtonian gauge



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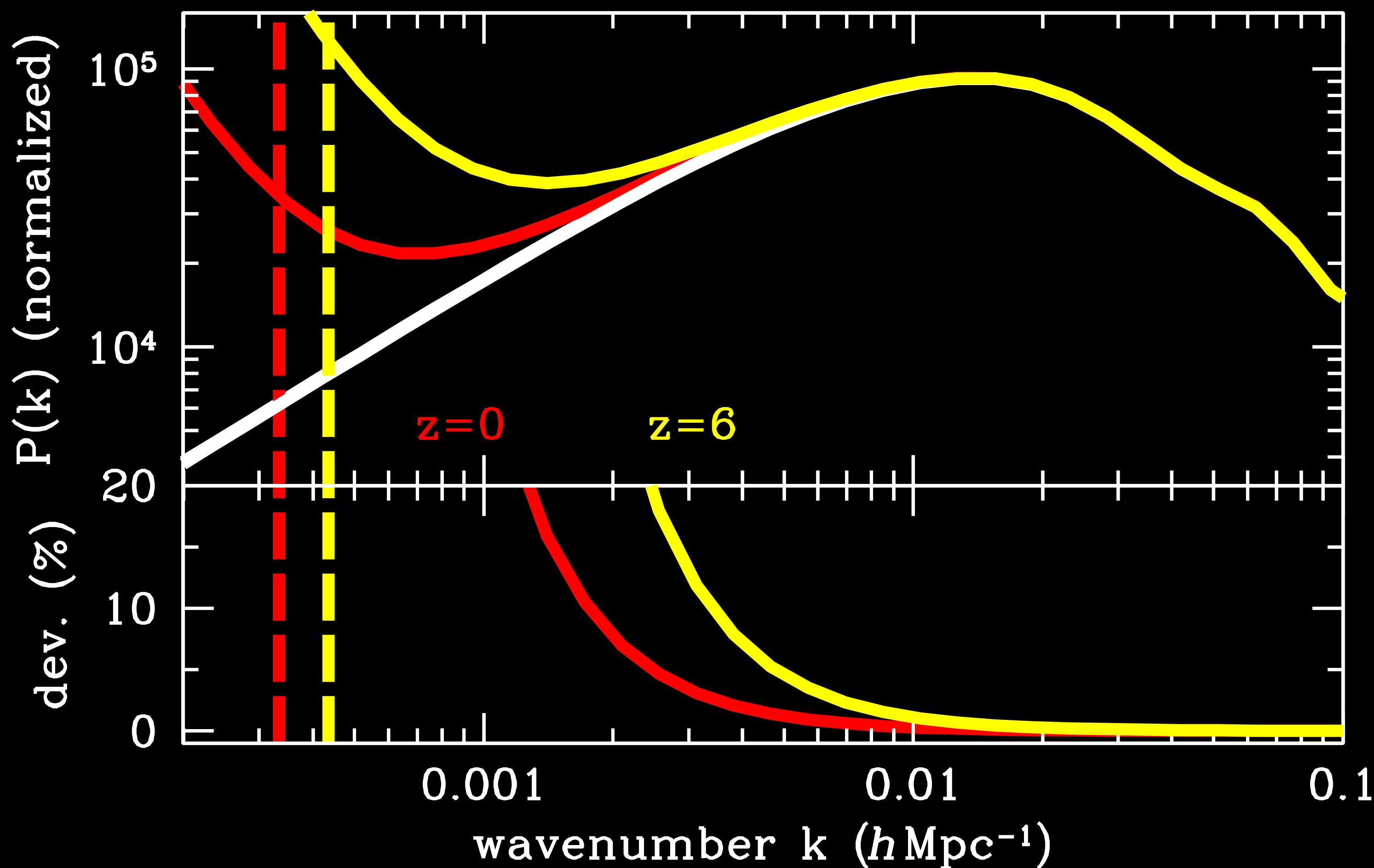

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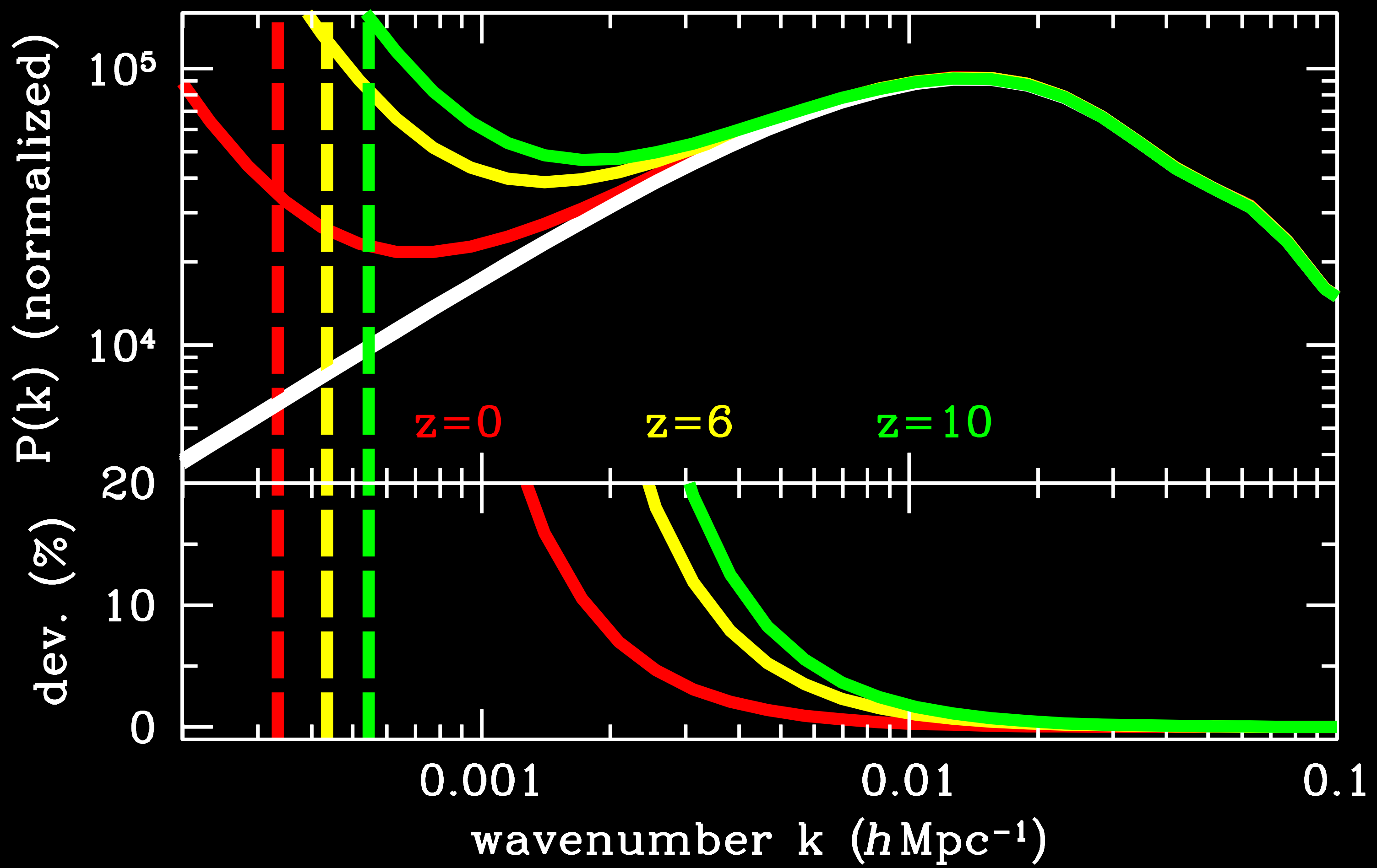


II. FORMALISM

- model ***observables***, not ***unobservable*** quantities!

- ***observables***: (physical)
  - observed redshift z_{obs}, position $\hat{n} = (\theta, \phi)$

- ***unobservables***: (gauge-dependent)
  - redshift z, angular position $\hat{s} = \hat{n} - (\delta\theta, \delta\phi)$

- photon geodesic equation

$$1 + z_{\rm obs} = (1+z)\left[1 + V(z) - V(0) - \psi(z) + \psi(0) - \int_0^r dr' \, (\dot{\psi} - \dot{\phi})\right] .$$

$$(\delta r, \;\; \delta\theta, \;\; \delta\phi)$$

Effects on Galaxies

- **construct *a galaxy fluctuation field*:**
  - **total number of observed galaxies** $N_{\rm tot}$
  - **observed volume** $dV_{\rm obs}$ **given** $(z_{\rm obs}, \hat{n})$
  - **fluctuation field** $\delta_{\rm obs} = \frac{n_{\rm obs}}{\langle n_{\rm obs} \rangle} - 1$

- **relation to *physical* number density:**
  - **number conservation** $N_{\rm tot} = n_{\rm phy} dV_{\rm phy} = n_{\rm obs} dV_{\rm obs}$
  - **observed number density** $n_{\rm obs} = n_{\rm phy} \frac{dV_{\rm phy}}{dV_{\rm obs}}$
  - ***volume* & *source* effects**

Galaxy Fluctuation Field

- ***standard Newtonian*** **version:**

- ***general relativistic*** **version:**

$$\delta_g = b\ m_{\delta z} + \alpha_\chi + 2\varphi_\chi + V - C_{\alpha\beta}e^\alpha e^\beta + 3\ \delta z_\chi + 2\frac{\delta\mathcal{R}}{r} - H\frac{\partial}{\partial z}\left(\frac{\delta z_\chi}{\mathcal{H}}\right)$$
$$-5p\ \delta\mathcal{D}_L - 2\mathcal{K}$$

Yoo, PRD, 2010

Galaxy Fluctuation Field

- ***standard Newtonian*** **version:** $\delta_g = b\;\delta_m - \frac{1+z}{H}\frac{\partial V}{\partial r}$

- ***general relativistic*** **version:**

$$\delta_g = b\;m_{\delta z} + \alpha_\chi + 2\varphi_\chi + V - C_{\alpha\beta}e^\alpha e^\beta + 3\;\delta z_\chi + 2\frac{\delta\mathcal{R}}{r} - H\frac{\partial}{\partial z}\left(\frac{\delta z_\chi}{\mathcal{H}}\right) - 5p\;\delta\mathcal{D}_L - 2\mathcal{K}$$

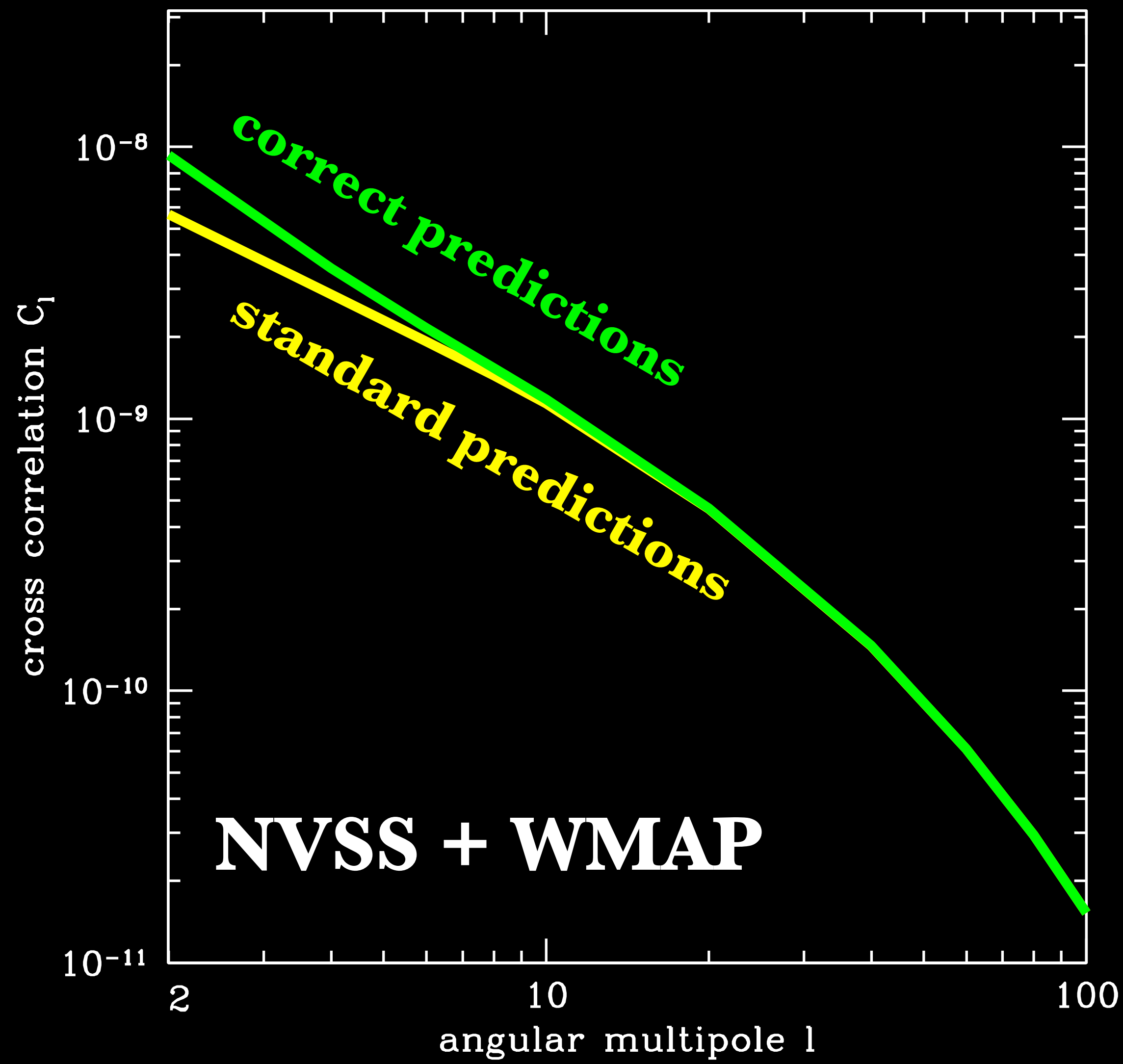
it can be computed in ***any gauges!***

Yoo, Fitzpatrick, Zaldarriaga, PRD, 2009

Yoo, PRD, 2010

III. RESULTS

- **theoretical predictions:**
  - **new cal.** (***correct***)
  - **standard** (***incorrect***)
- ***underestimate*** **the observed signals by *a factor two* at low multipoles**
- **3.7-σ detection, but *observed signal is larger by 2 at low multipoles***
  (**Ho et al. PRD, 2008**)



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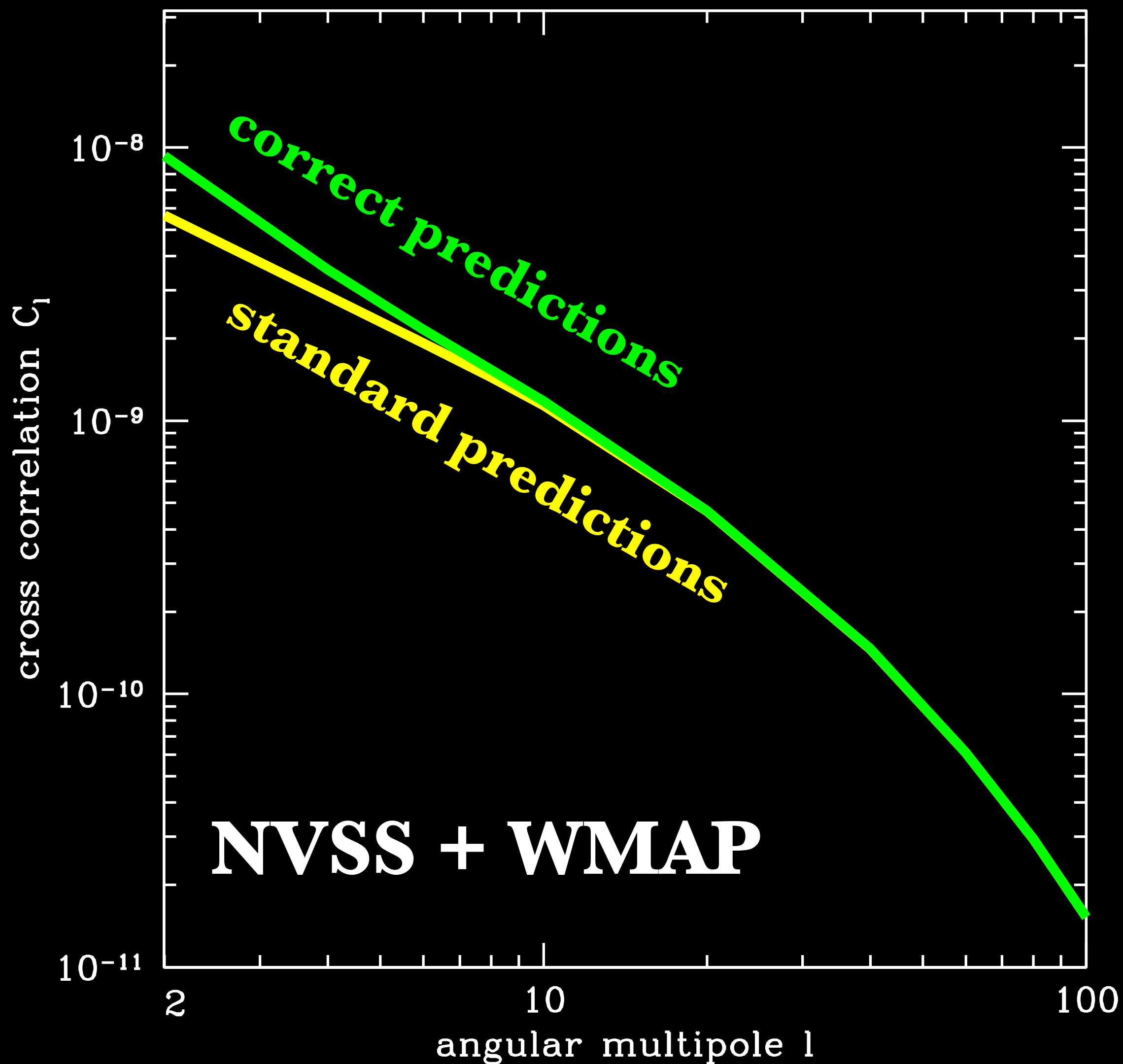


Yoo, Fitzpatrick, Zaldarriaga, PRD, 2009

Galaxy Power Spectrum

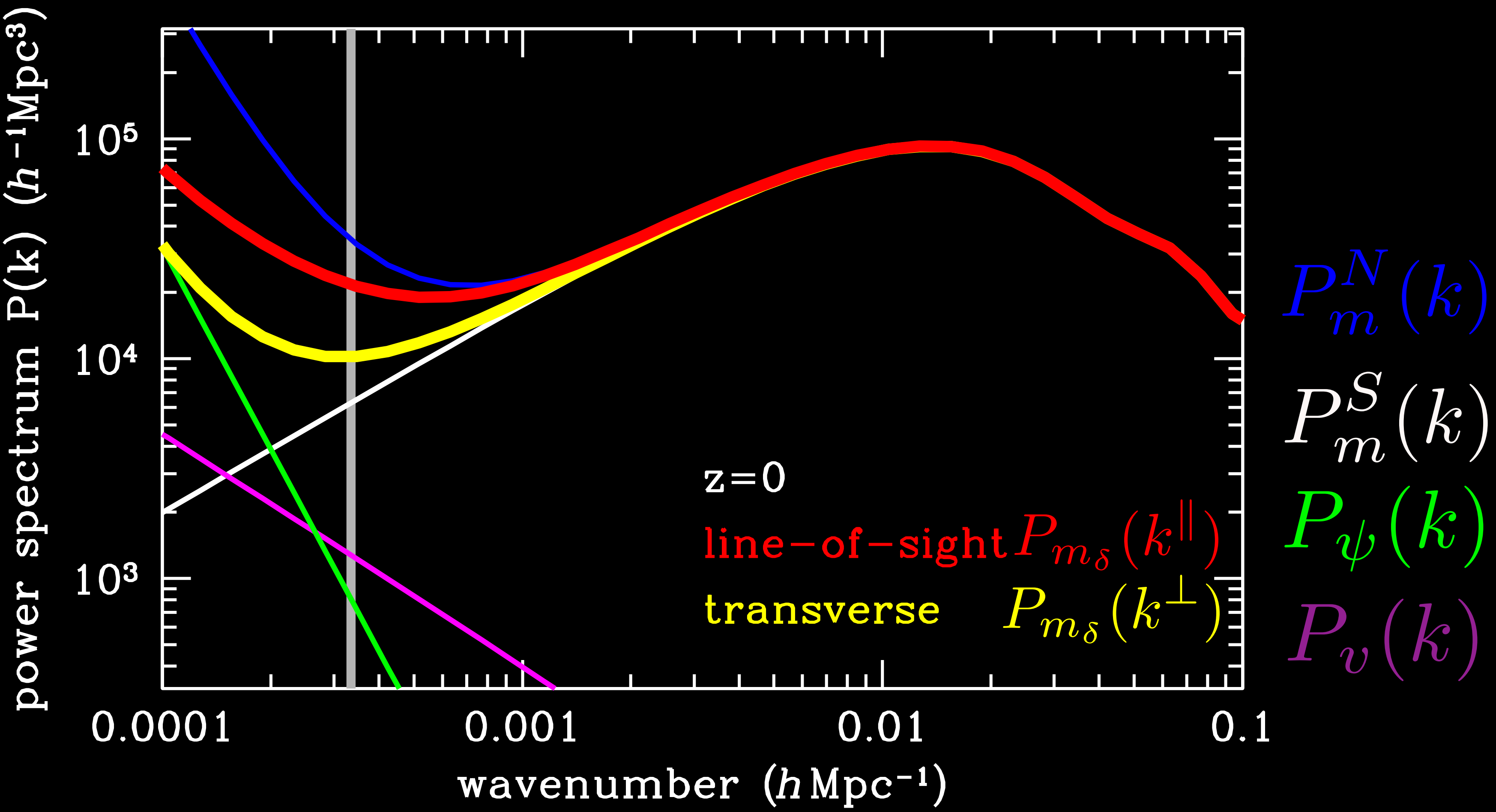
- ***matter fluctuation:*** $\rho_m = \bar{\rho}_m(t)[1+\delta_m] = \bar{\rho}_m(z_{\rm obs})[1+m_\delta]$
  - **gauge-dependent** δ_m $1+z_{\rm obs} = (1+z)(1+\delta z)$
  - ***time slicing*** **(coordinate vs observed redshift)**
  - **gauge-invariant, *observable*** $m_\delta = \delta_m - 3\,\delta z$
  - **Bardeen's gauge-invariant** $\epsilon_m,\ \epsilon_g$ $\epsilon_m \neq \epsilon_g \neq m_\delta$
    - **matter rest frame & zero-shear frame**

- ***gauge-invariance*** **is a *necessary* but *not* a *sufficient* condition for *observable quantities***

Yoo, PRD, 2010

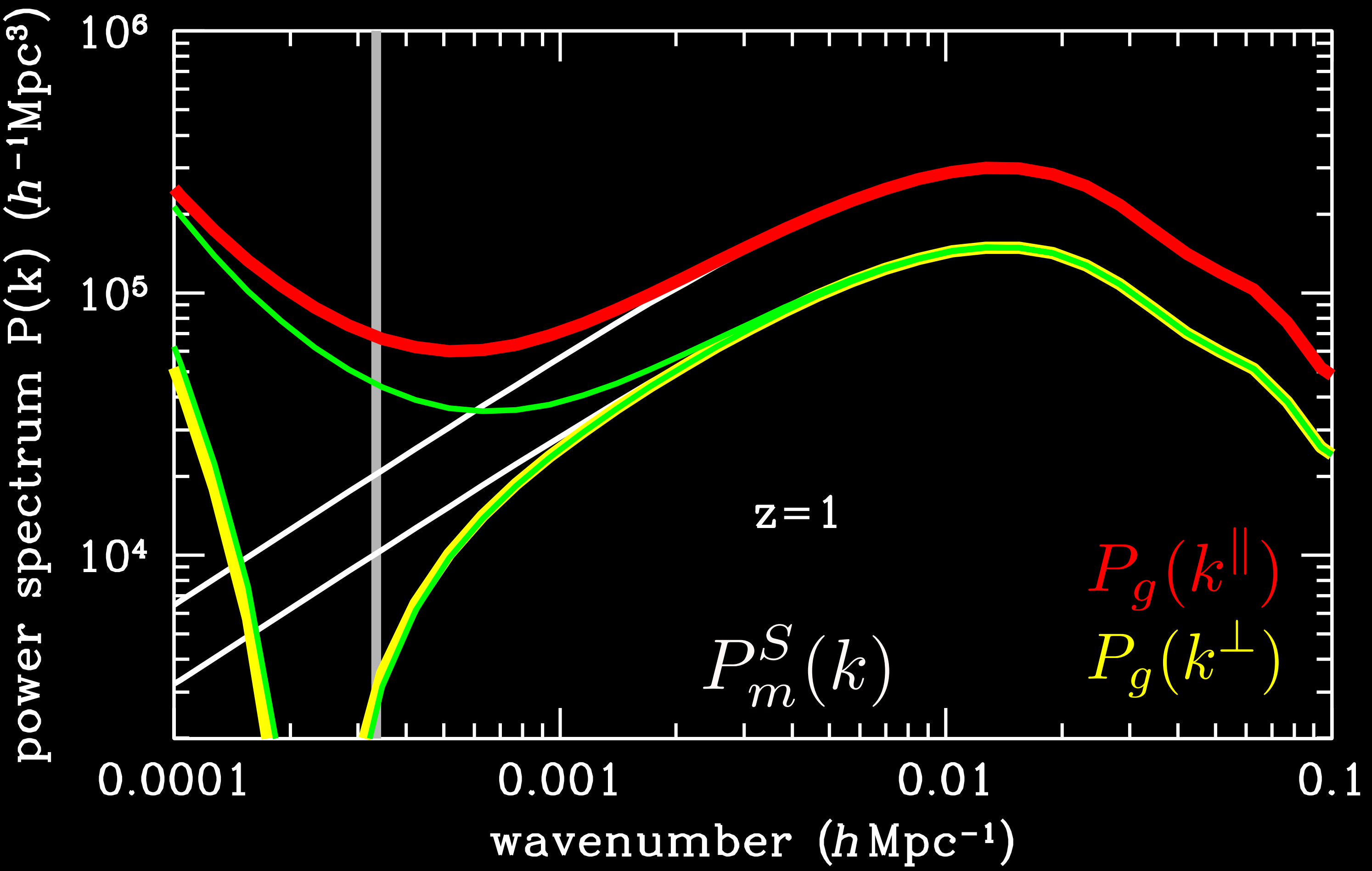
“Real-Space” Matter Power

- ***no longer isotropic***, **neither** $P_m^S(k)$ **, nor** $P_m^N(k)$
- **real-space matter power spectrum** $P_{m_\delta}(k, \mu_k)$



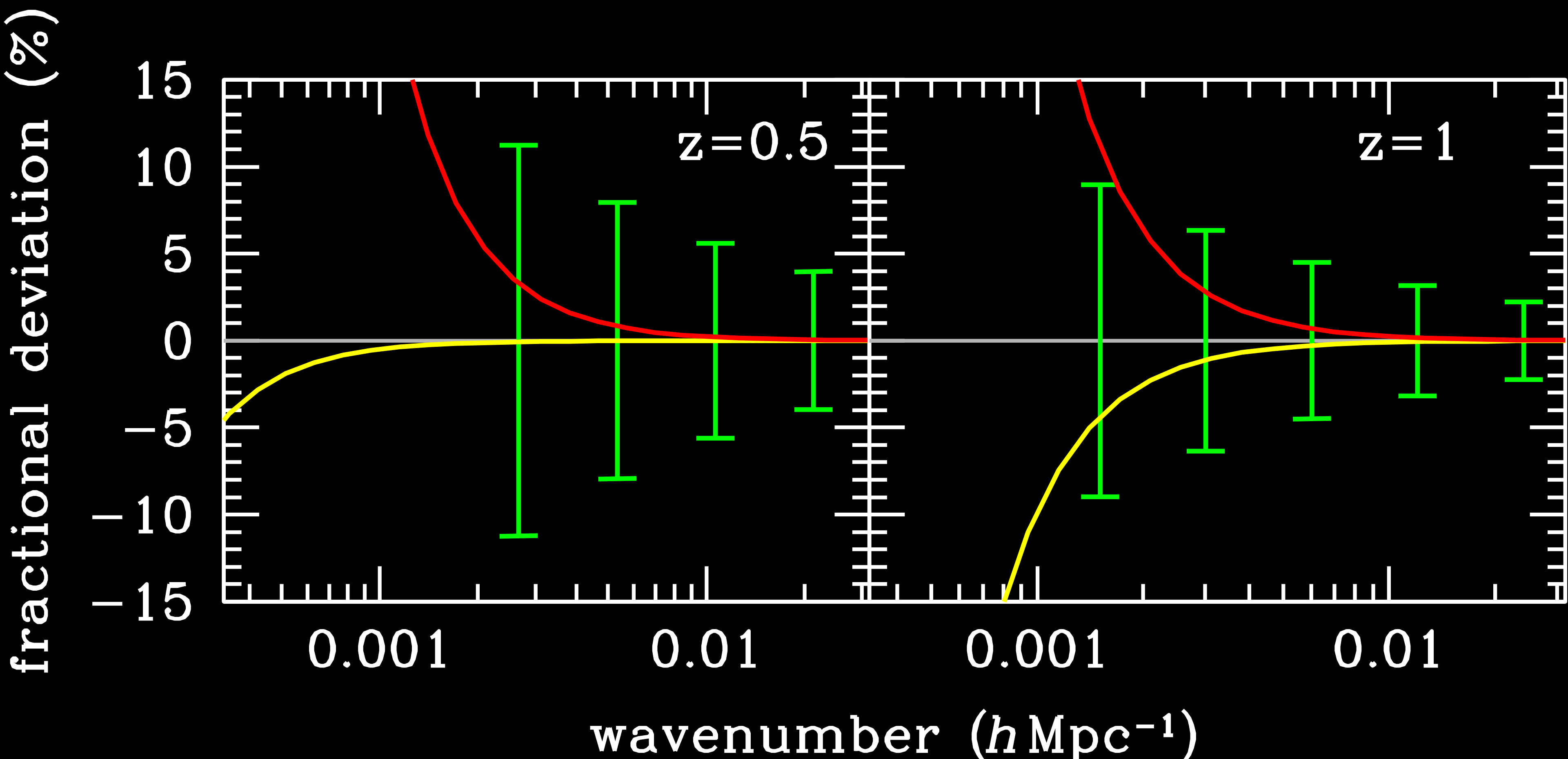
Observed Galaxy Power Spectrum

- **largely similar to** $b^2 P_{m\delta}(k, \mu_k)$ **(green)**
- ***unique signature*** **on large scales (ring a bell?)**



Systematic Errors

- **Baryonic Oscillation Spectroscopic Survey (BOSS)**
- **can we do more in *current surveys?***



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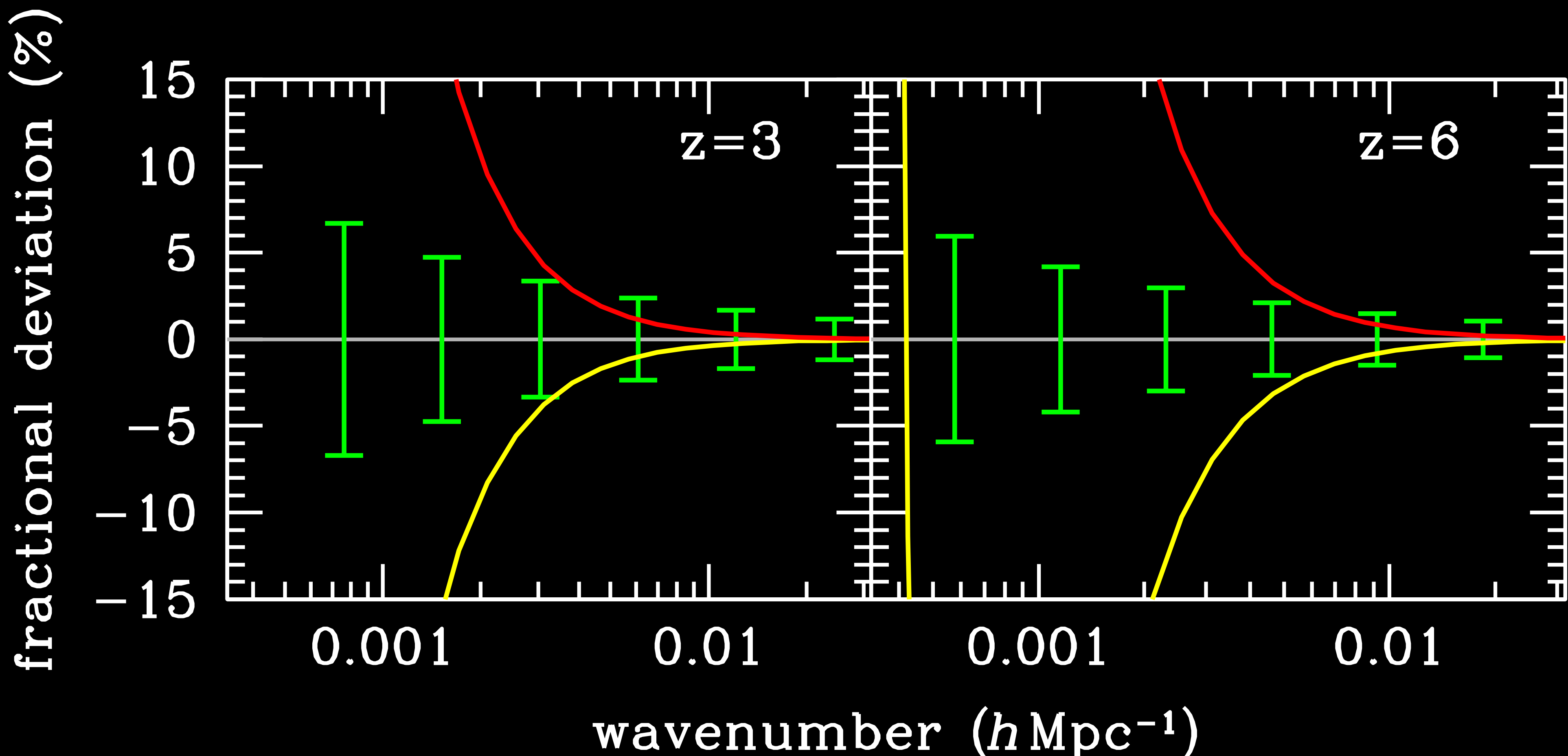
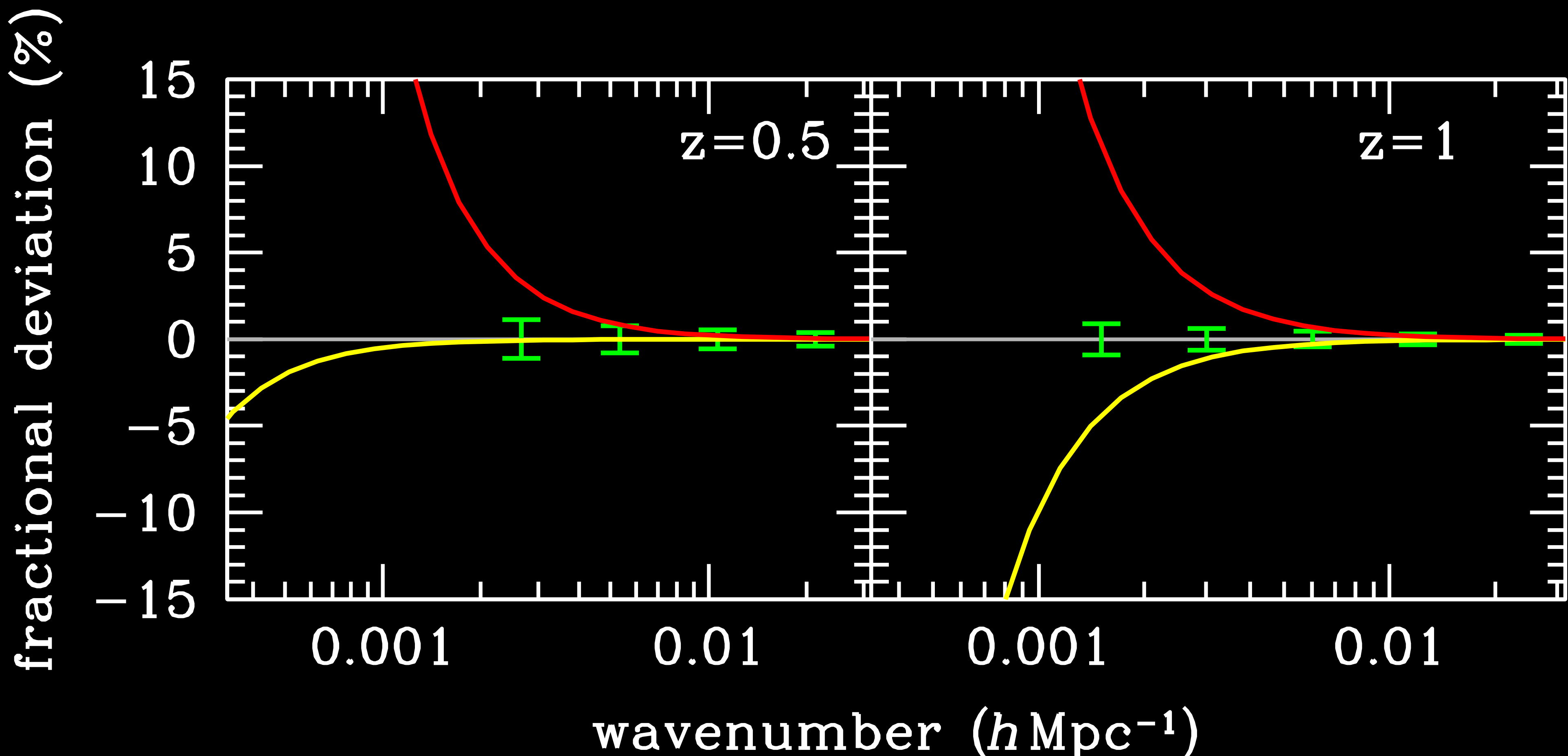


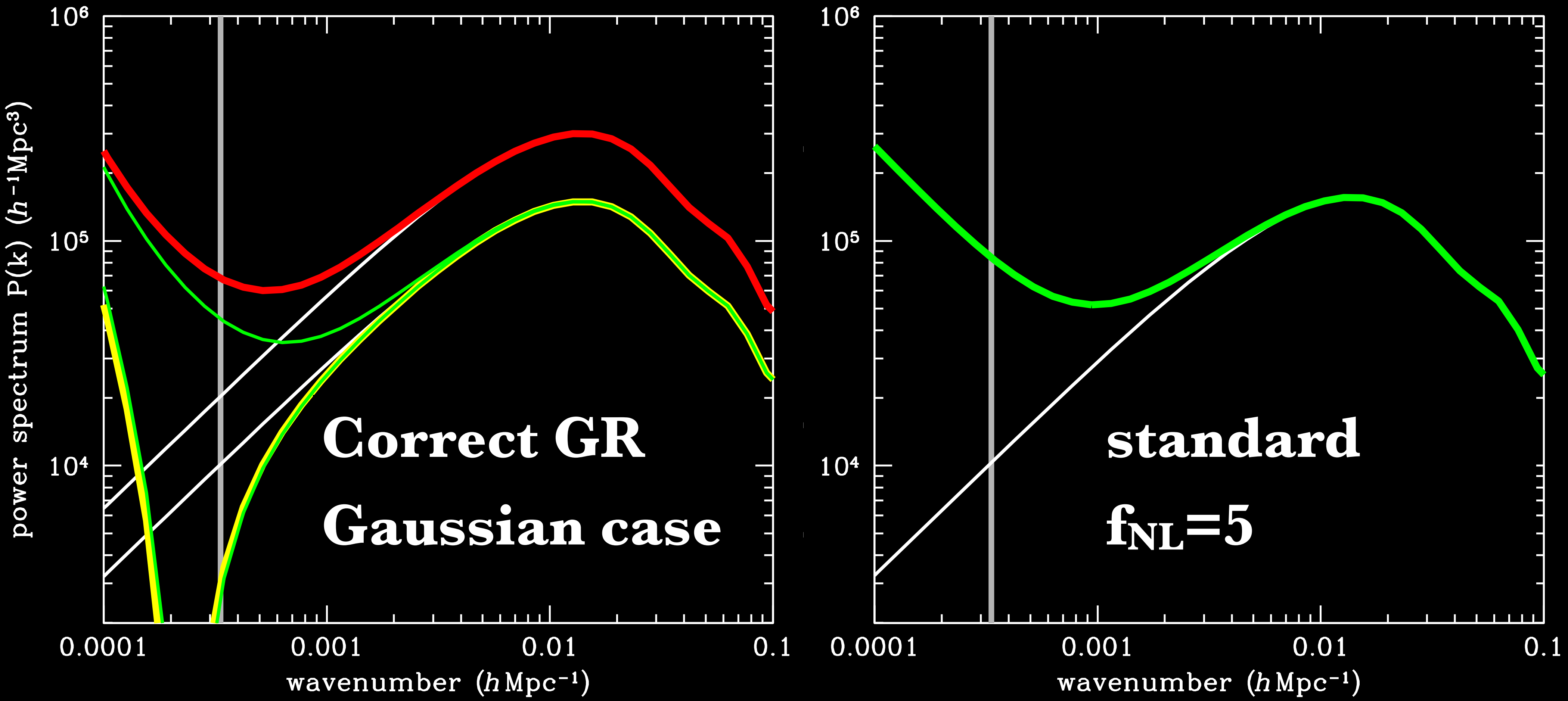
Systematic Errors

- **Baryonic Oscillation Spectroscopic Survey (BOSS)**
- **can we do more in *current surveys?***
  - **YES, talk to Nico Hamaus (in preparation)**



False Detection

- *misinterpretation* as detection of non-Gaussianity
    - depending on f_{NL}, systematic errors can be large
    - talk to Tobias Baldauf (in preparation)



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