PASCOS, Cambridge, July 4-8

Scale-dependent bias: non-Gaussianity, GR and gauge-dependence

David Wands

Institute of Cosmology and Gravitation, University of Portsmouth

Wands & Slosar, arXiv:0902.1084

Bruni, Crittenden, Koyama, Maartens, Pitrou & Wands, arXiv:1106.3999

Galaxy bias

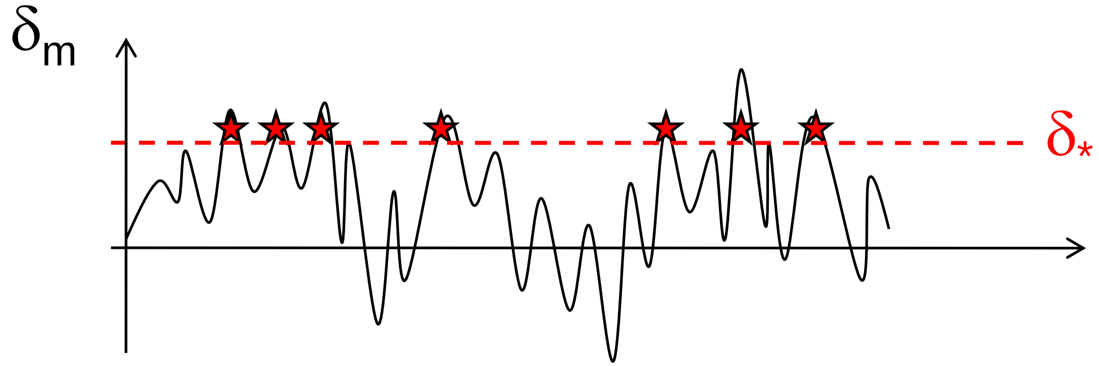
linear bias: $\delta_g = b\ \delta_m$

Galaxy bias

linear bias: $\delta_g = b\ \delta_m$

peak-background split

small-scale collapse of peaks where linear density contrast exceeds threshold: $\delta_m > \delta_* \approx 1.6$

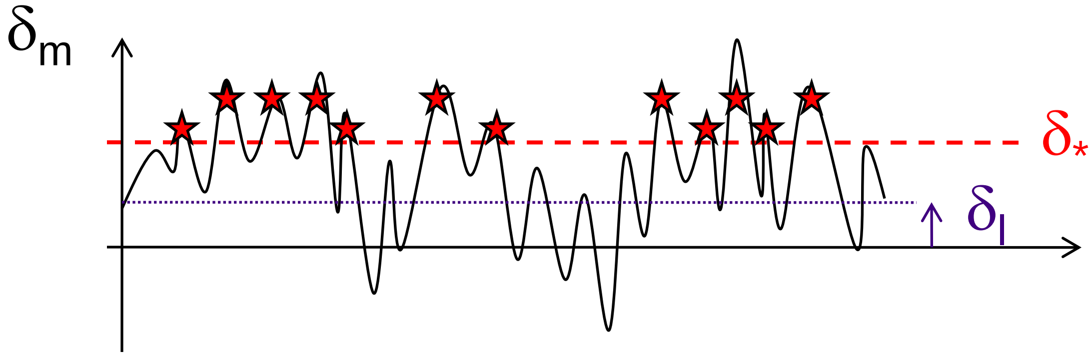


Galaxy bias

linear bias: $\delta_g = b\,\delta_m$

peak-background split

small-scale collapse of peaks where linear density contrast exceeds threshold: $\delta_m > \delta_* \approx 1.6$



- large-scale fluctuations raise background density: $\delta_m = \delta_s + \delta_l$
- enhances number of peaks above threshold

$b \rightarrow b_G$ = constant on large scales for a Gaussian field

Scale-dependent bias from non-Gaussianity

Dalal et al, arXiv:0710.4560

Simplest local model of non-Gaussianity:

$$\Phi(x) = \phi_G(x) + f_{NL}\left(\phi_G{}^2(x) + \left\langle \phi_G{}^2 \right\rangle\right)$$

peak-background (small-scale – large-scale) split:

$$\phi_G(x) = \phi_s(x) + \phi_l(x)$$

$$\Rightarrow \quad \Phi(x) = \left(1 + 2 f_{NL}\phi_l(x)\right)\phi_s(x) + \phi_l(x) + f_{NL}\left(\phi_s{}^2(x) + \phi_l{}^2(x) + \left\langle \phi_s{}^2 \right\rangle + \left\langle \phi_l{}^2 \right\rangle\right)$$

- large-scale modes enhance variance on small scales $\propto \phi_l$
- relate to density via Poisson equation:

$$\nabla^2\Phi = 4\pi G_N\,\delta\rho \quad \Rightarrow \quad \delta_l = \frac{2}{3}\left(\frac{aH}{k}\right)^2 \phi_l$$

$\Rightarrow$ **scale-dependent bias: $\Delta b \approx 2f_{NL}\,(b_G\text{-}1)\,(aH/k)^2$**

Galaxy bias *in General Relativity?*

peak-background split in GR

- small-scale ($R \ll H^{-1}$) peak collapse
  - well-described by Newtonian gravity

- large-scale background needs GR ($R \approx H^{-1}$)
  - density perturbation is gauge dependent

$$t \to t + \delta t, \quad \delta_m \to \tilde{\delta}_m = \delta_m + 3H\delta t, \quad \delta_g \to \tilde{\delta}_g = \delta_g + 3H\delta t$$

$\Rightarrow$ ***bias is a gauge-dependent quantity***

$$\delta_g = b\delta_m \Rightarrow \quad \tilde{\delta}_g = b\tilde{\delta}_m - 3H(b-1)\delta t$$

What is correct gauge to define bias?

peak-background split works in GR with right variables
(Wands & Slosar, 2009)

- Newtonian potential = GR longitudinal gauge metric: $\Phi = \psi^{(N)}$

- GR Poisson equation:
  relates Newtonian potential to density perturbation in comoving-synchronous gauge: $\delta_m{}^{(c)} = \frac{2}{3}\left(\frac{aH}{k}\right)^2 \Phi$

- GR spherical collapse:
  local collapse criterion applies to density perturbation in comoving-synchronous gauge: $\delta_m{}^{(c)} > \delta_* \approx 1.6$

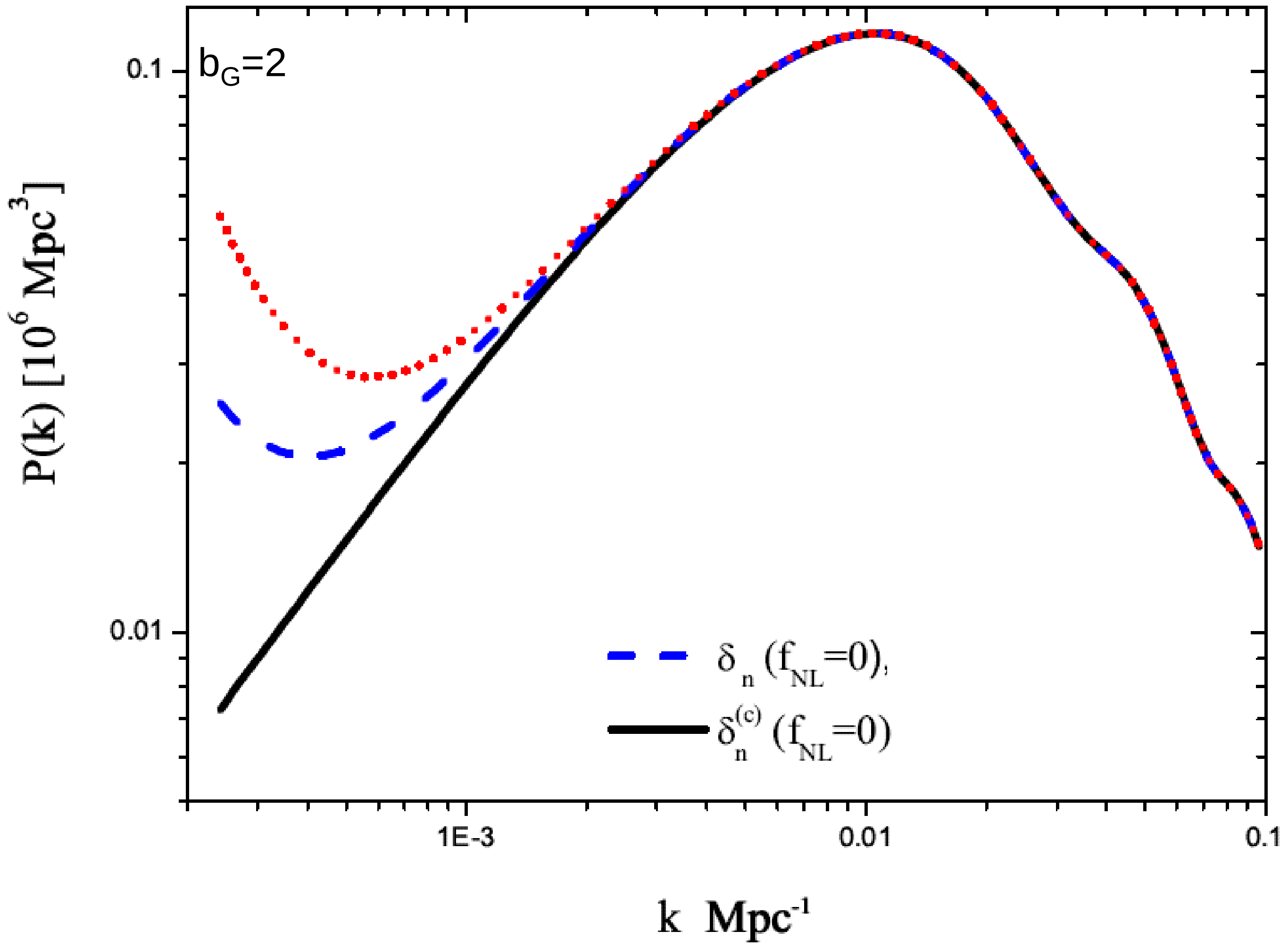
$\Rightarrow$ ***GR bias defined in the comoving-synchronous gauge***

$$\delta_g{}^{(c)} = b\delta_m{}^{(c)}$$

see also Baldauf, Seljak, Senatore & Zaldarriaga, arXiv:1106.5507

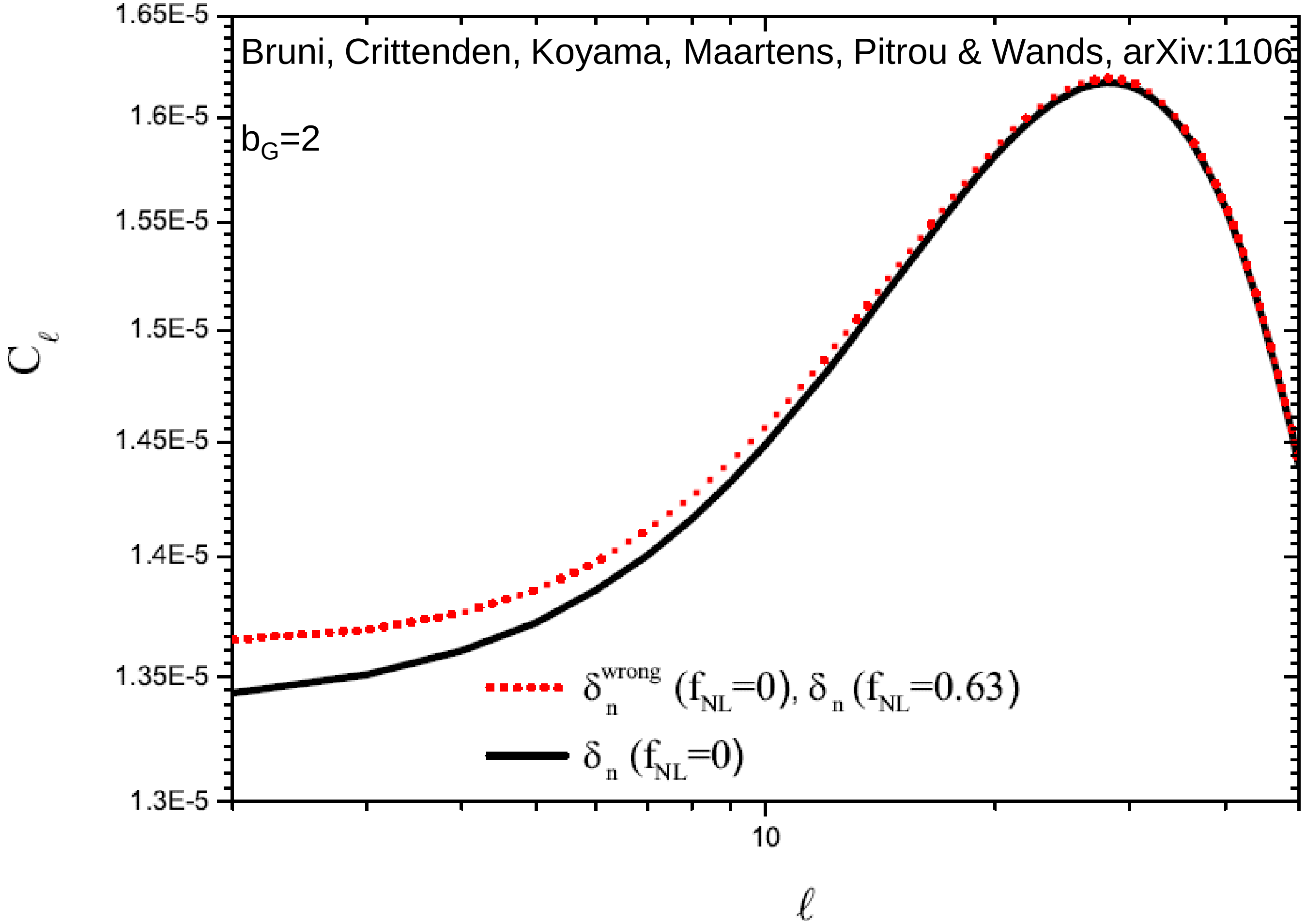
Galaxy power spectrum at z=1

Bruni, Crittenden, Koyama, Maartens, Pitrou & Wands, arXiv:1106.3999



Angular galaxy power spectrum at z=1

using full GR treatment of gauge and line-of-sight effects
Challinor & Lewis, arXiv:1105.5292; Bonvin & Durrer, arXiv:1105.5280
see also Yoo, arXiv:1009.3021



observables are independent of gauge used

Conclusions

- **primordial non-Gaussianity can give rise to scale-dependent bias**
  - future LSS observations could detect $f_{NL}=O(0.1)$
- **galaxy bias is gauge-dependent quantity**
  - use comoving-synchronous gauge to define physical bias in GR
  - observables are independent of gauge
- **wrong definition of bias can mimic primordial non-Gaussianity, $f_{NL}=O(1)$**