Redshift-Space Distortions and BOSS

Roman Scoccimarro (NYU)

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WARNING!!!

No senior LSS-person has suggested any of my slides!

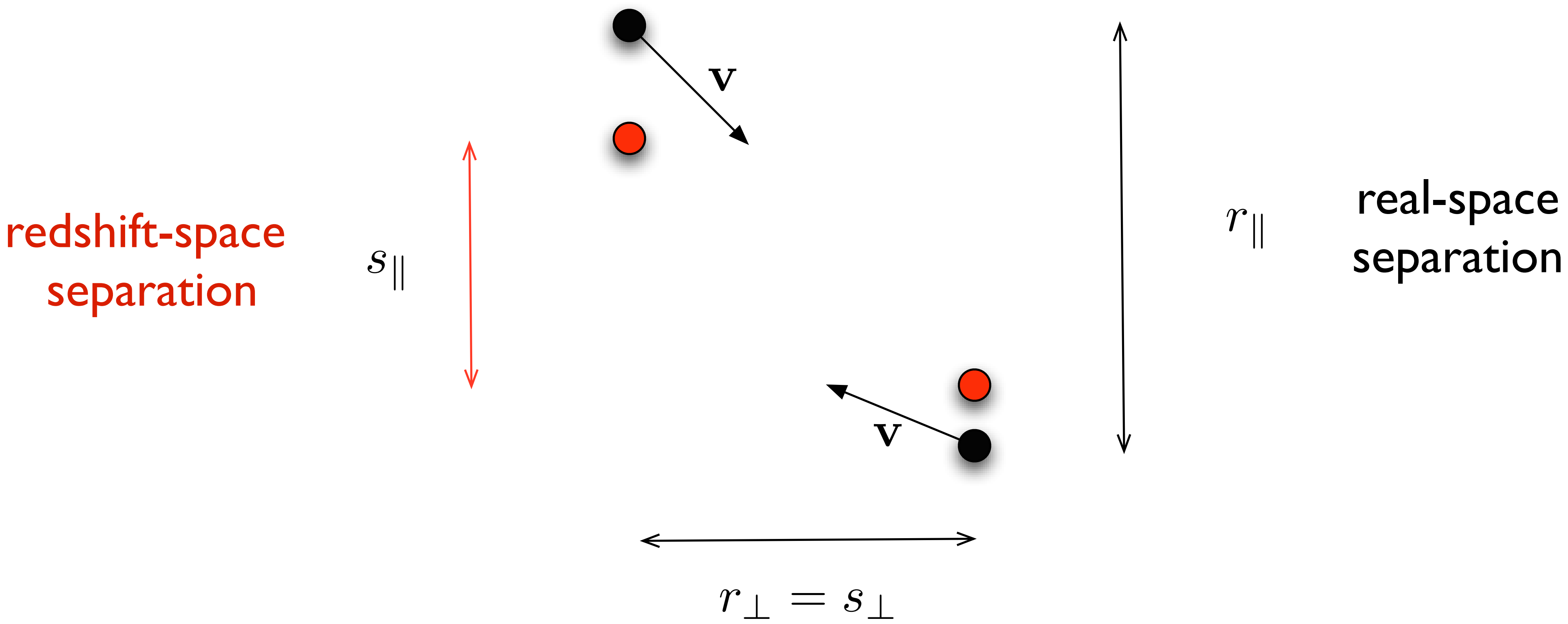
RSD is (the toughest) one of the big three challenges in Large-Scale Structure

1) Nonlinear evolution of matter fluctuations

2) The relationship between galaxy and matter fluctuations (bias)

3) The mapping from redshifts to distances (redshift-space distortions)

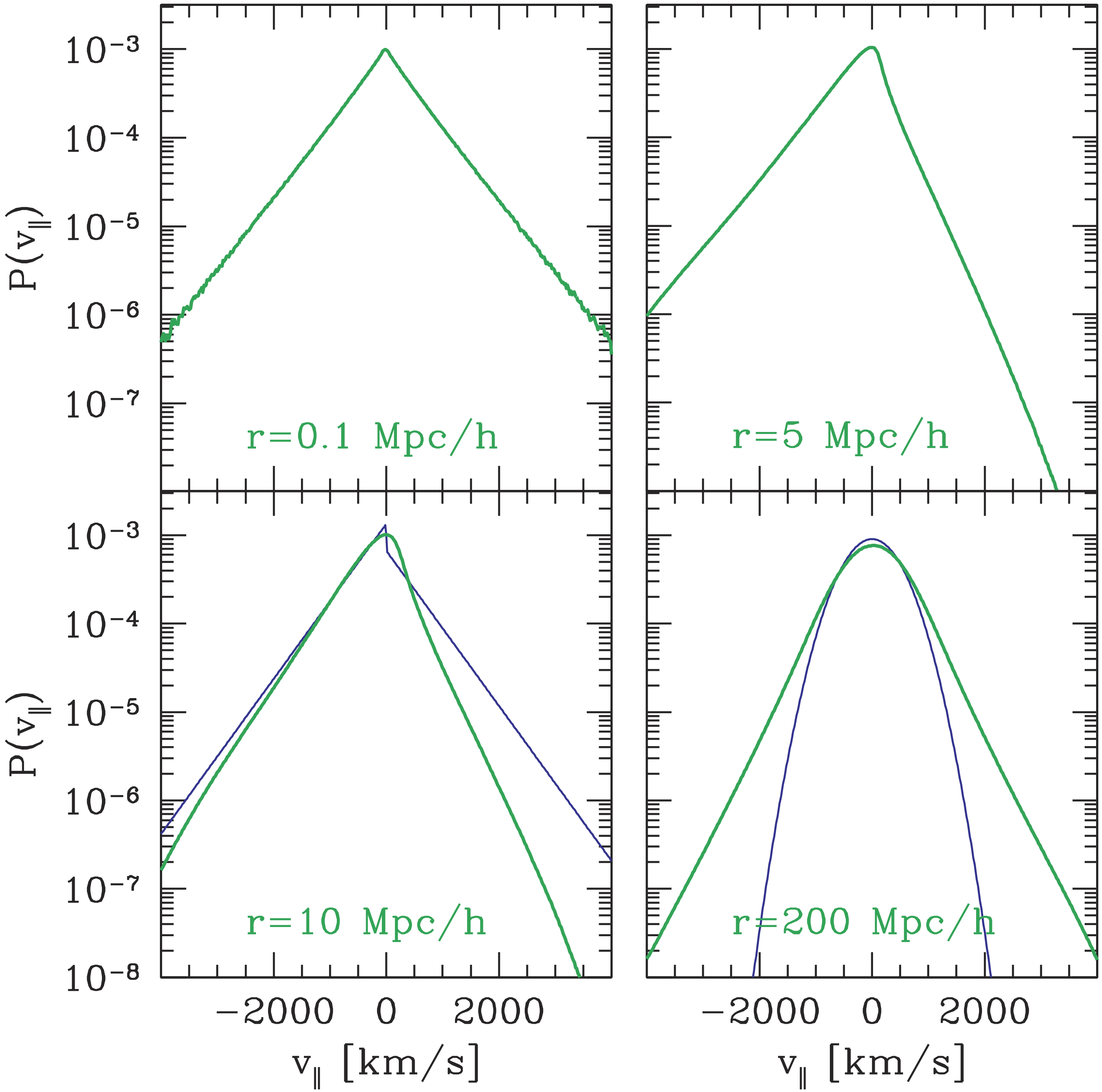
Relationship between real and redshift-space clustering:



$$1 + \xi_s(s_{\|}, s_\perp) = \int_{-\infty}^{\infty} dr_{\|} \; [1 + \xi(r)] \; \mathcal{P}(\underbrace{r_{\|} - s_{\|}}_{\mathbf{v}_p}, \mathbf{r}),$$ R.S. (2004)

Everything is encoded in the pairwise velocities PDF.

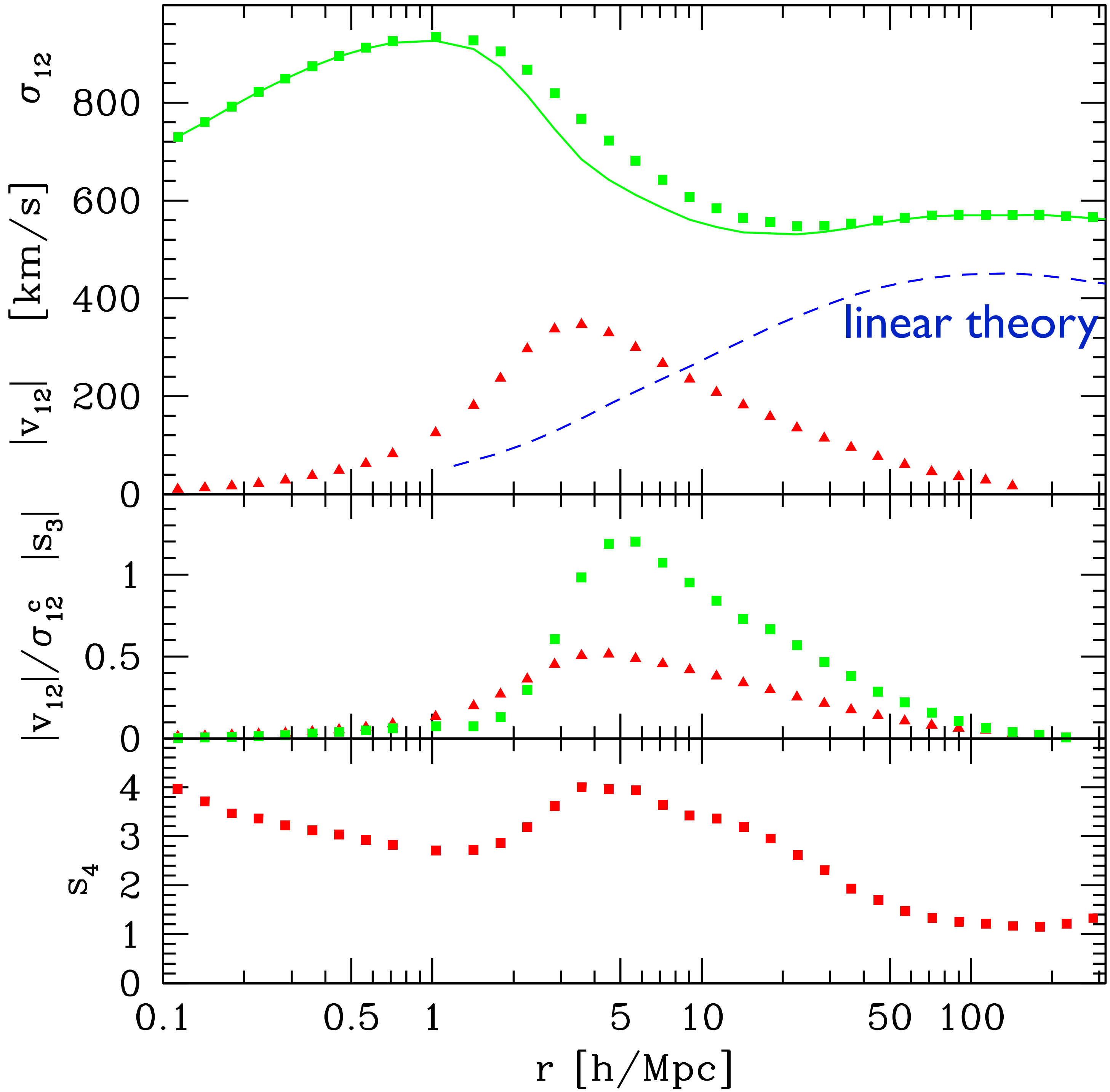
Challenge: the pairwise PDF is highly non-Gaussian even at large scales.



Juszkiewicz et al (1998),
R.S.(2004),
Bianchi et al (2014)

pairwise cumulants from N-body simulations

R.S. (2004)



Main features of pairwise PDF

- Gaussian core
- Exponential wings (large kurtosis)
- skewness

would be good to have working models with a few parameters that incorporate all these main characteristics.

$$\delta_{\rm D}(\boldsymbol{k}) + P_s(\boldsymbol{k}) \;=\; \int \frac{d^3r}{(2\pi)^3} \mathrm{e}^{-i\boldsymbol{k}\cdot\boldsymbol{r}} \underbrace{\left\langle \mathrm{e}^{\overbrace{ifk_z}^{\lambda}\Delta u_z} \;\; [1+\delta(\boldsymbol{x})][1+\delta(\boldsymbol{x}')] \right\rangle}_{\mathcal{Z}(\lambda,\boldsymbol{r})}$$

which can be written (SD “scale-dep”, i.e. diff from infinity)

$$P(\mathbf{k}) = W_\infty(\lambda)\, P_{\delta Z}(\mathbf{k}) + P_W^{\rm SD}(\mathbf{k}) + \int d^3q\, P_{\delta Z}(\mathbf{q})\, P_W^{\rm SD}(\mathbf{k}-\mathbf{q}),$$

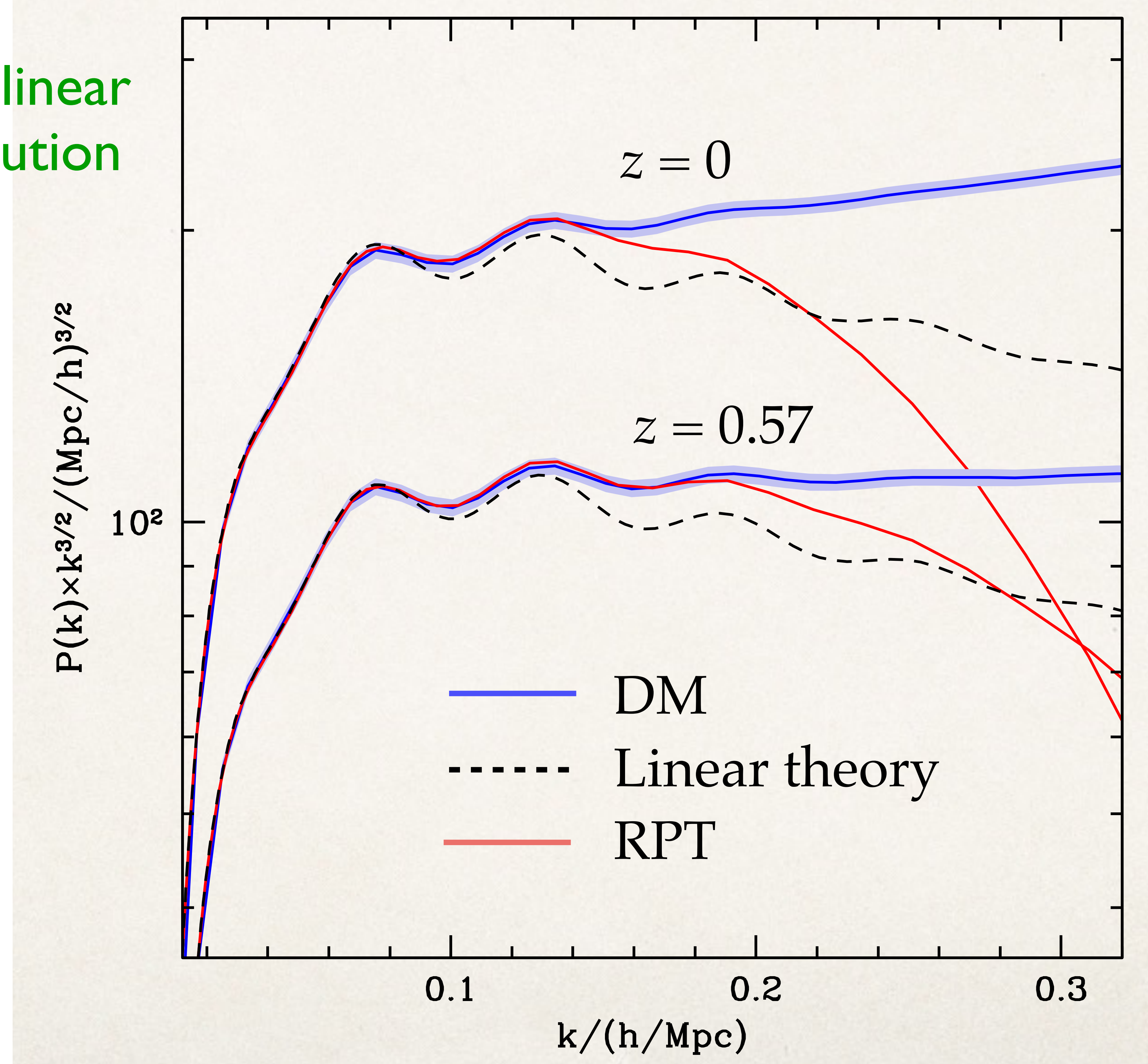
to leading order in PT ,

$$P_{\delta Z}(\mathbf{k}) \approx P_{\delta\delta}(k) + 2f\mu^2 P_{\delta\theta}(k), \qquad P_W(\mathbf{k}) \approx f^2\mu^4 P_{\theta\theta}(k),$$

parameters: small-scale vel disp, kurtosis of the PDF.

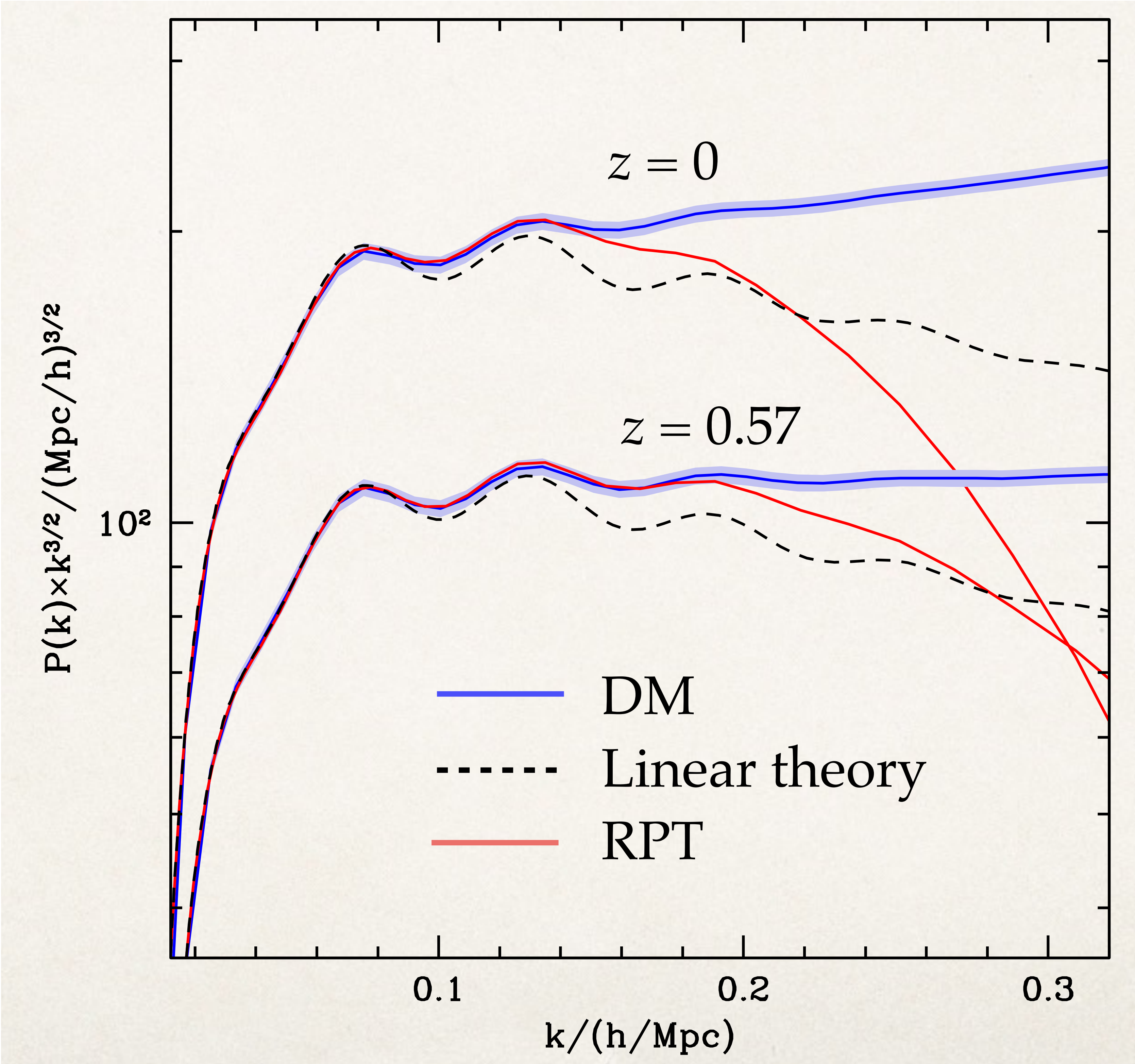
(Ariel’s plots on Monday correspond to ignoring convolution)

Nonlinear evolution

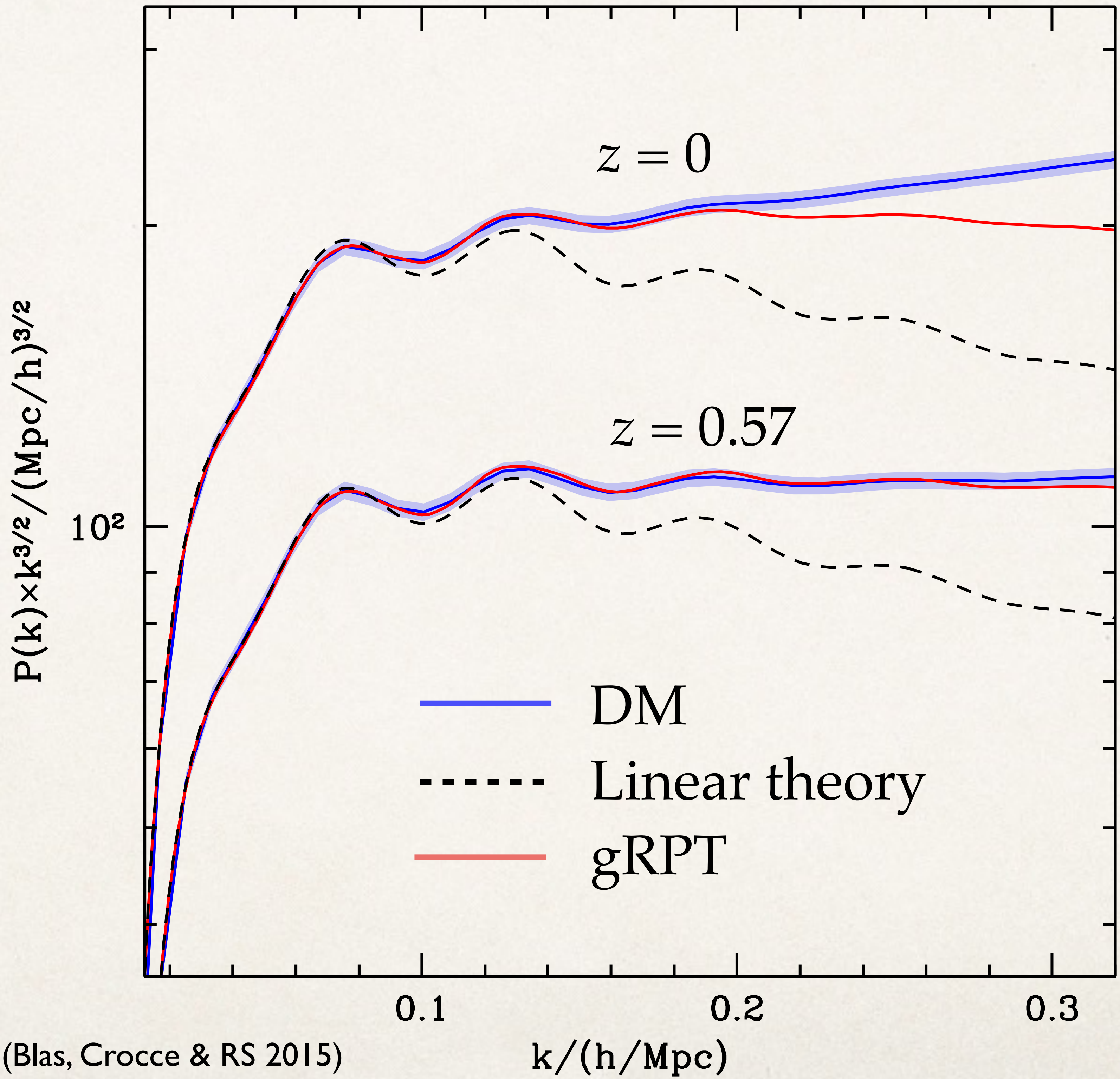


Small-scale suppression is fairly simple to fix, as pointed out already in first RPT paper (2005):

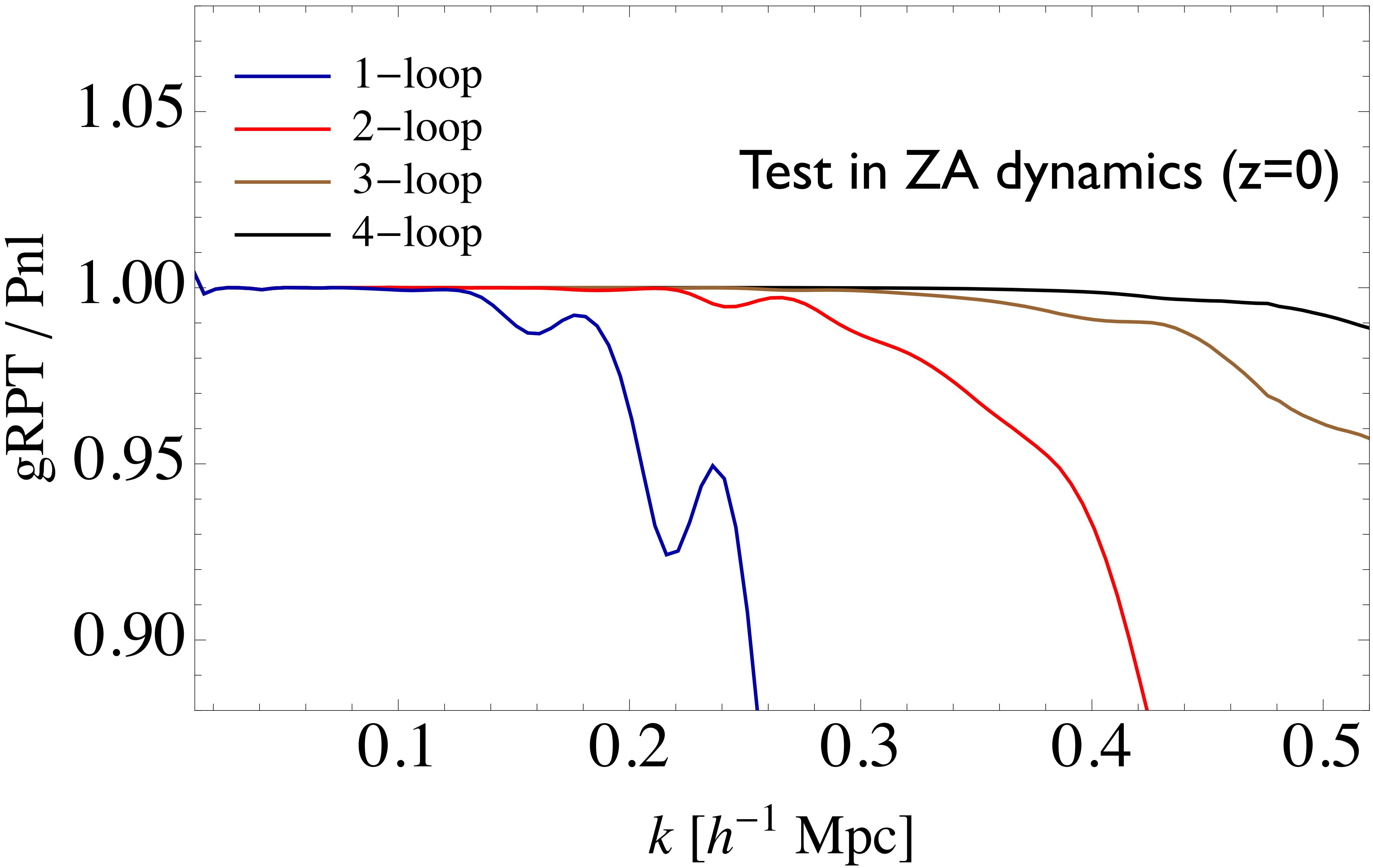
> However, there are symmetries (e.g. Galilean invariance, see [10]) that connect the resummation of the mode-coupling series with that of the propagator, which one might be able to take advantage of. This issue deserves further work and will be discussed elsewhere [24].



z = 0
z = 0.57
DM
Linear theory
RPT
10²
0.1
0.2
0.3
k/(h/Mpc)
P(k)×k^{3/2}/(Mpc/h)^{3/2}



(Blas, Crocce & RS 2015)


1−loop
2−loop
3−loop
4−loop
Test in ZA dynamics (z=0)
gRPT / Pnl
1.05
1.00
0.95
0.90
0.1
0.2
0.3
0.4
0.5
k [h^−1 Mpc]

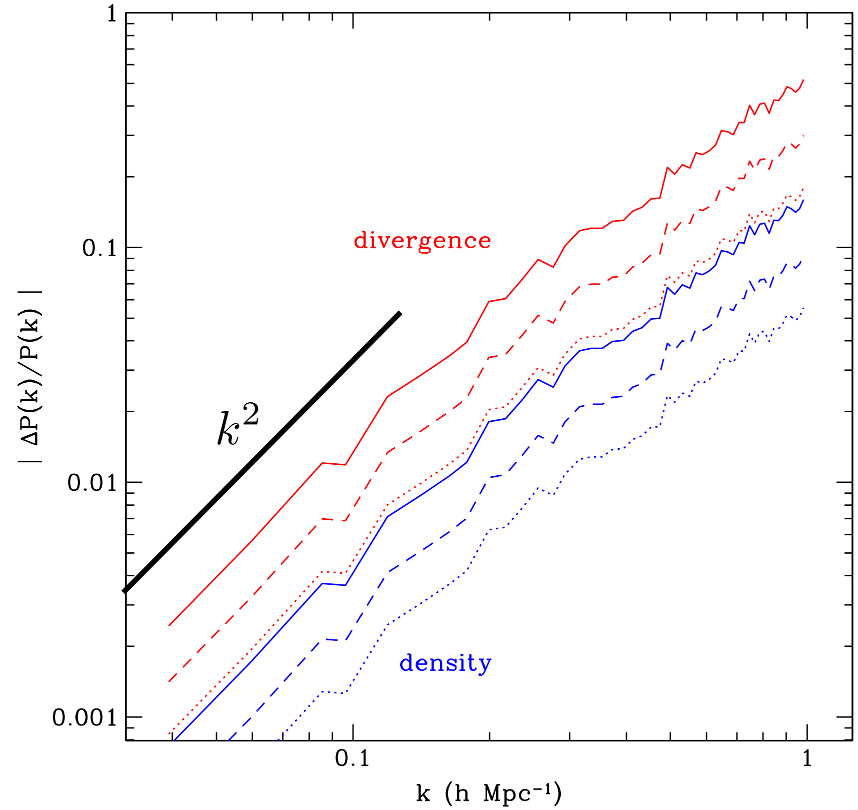
Stress tensor corrections

So far we assume dark matter has zero stress, but it gets generated by orbit crossing:

$$\frac{\partial u_i}{\partial \tau} + \mathcal{H} u_i + (\mathbf{u} \cdot \nabla) u_i = -\nabla \phi - \frac{1}{\rho} \nabla_j (\rho \sigma_{ij}),$$

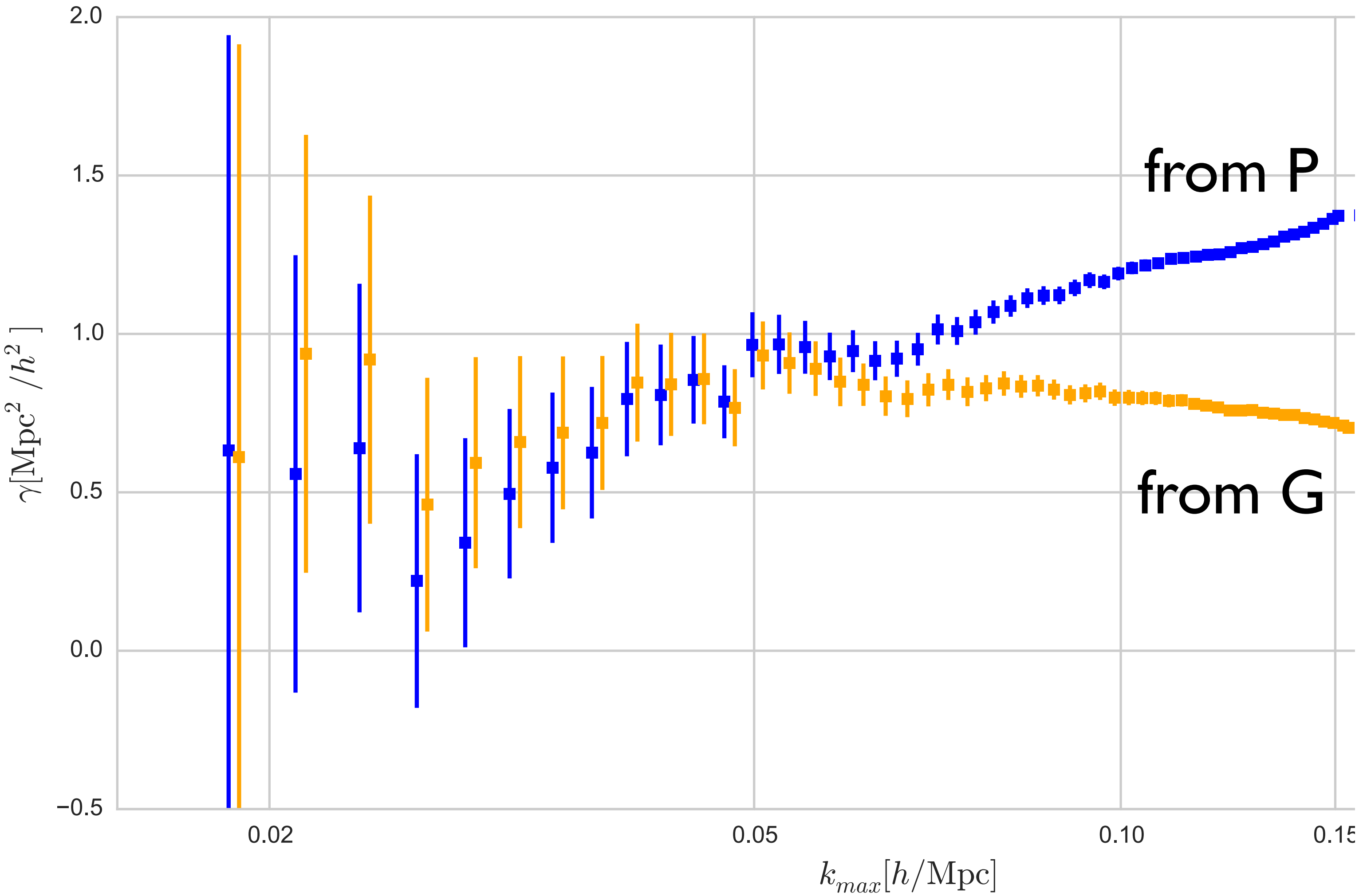
leading order correction due to stress scales as k^2 Plin (Pueblas & RS 2008)

$$P_{\rm tot}(k) = P_{\rm PPF}(k) - 2\gamma k^2 P(k)$$



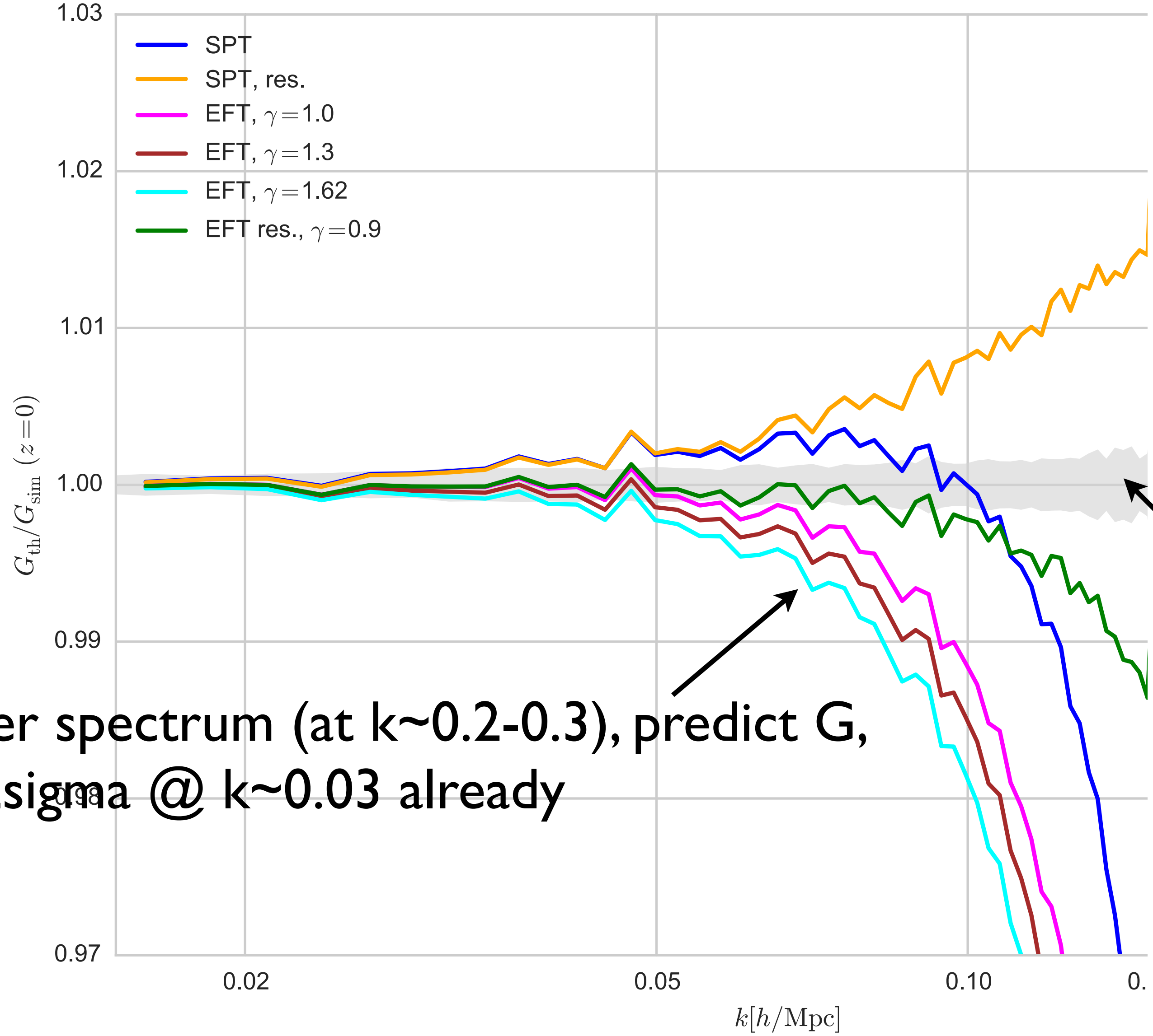
Pueblas & RS (2008),
Baumann et. al (2010),
Pietroni et al (2011),
Carrasco et al (2012)

Estimates of gamma using IR-resummed 1loop EFT (as in Senatore&Zaldarriaga)



z = 0

w/G.D'Amico, M.Crocce



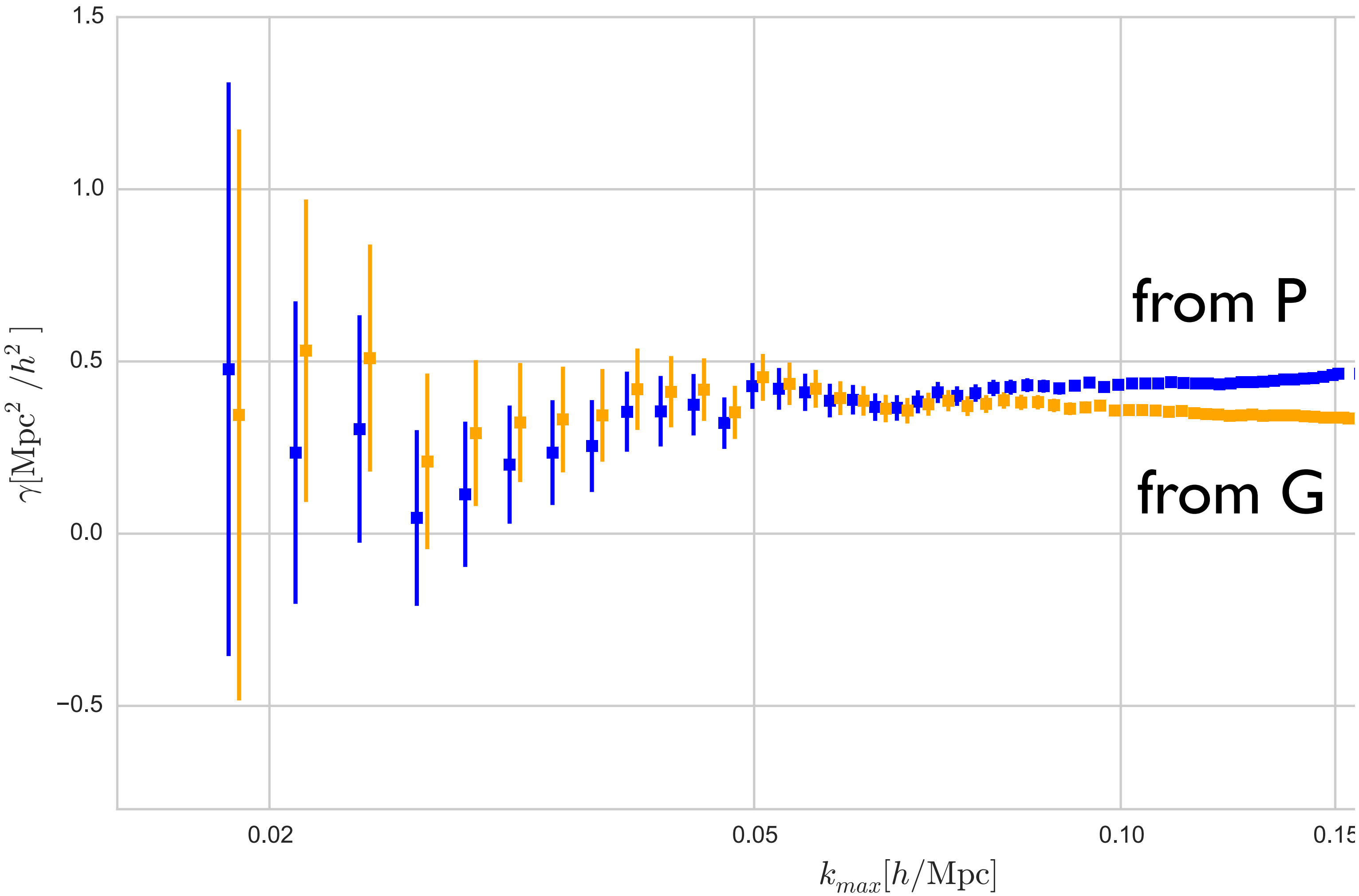
z = 0

Fit power spectrum (at k~0.2-0.3), predict G, fails @2sigma @ k~0.03 already

2-sigma errors on G

w/G.D'Amico, M.Crocce

w/G.D'Amico, M.Crocce



z = 1

For OBS e.g. @ z=0.57 gamma~0.5 (Mpc/h)^2 is small compared with *quite degenerate* contributions from bias and even more RSD.

Bias

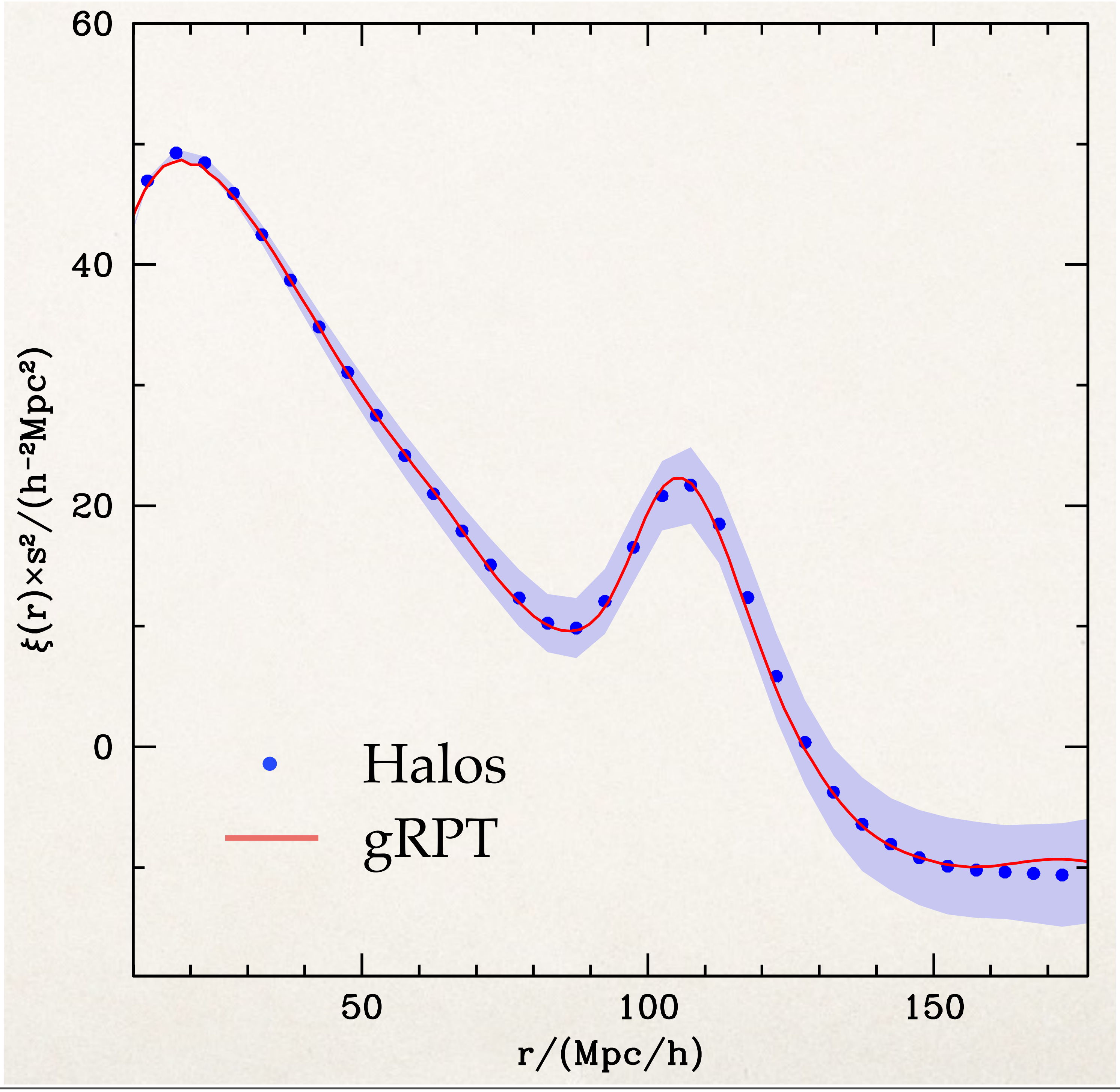
To one-loop in bias the two-pt function or power spectrum reads,

$$P_{gg}(k) = b_1^2 P(k) + b_1 b_2 P_{b_1 b_2}(k) + b_1 \gamma_2 P_{b_1 \gamma_2}(k) + b_2^2 P_{b_2 b_2}(k) + b_2 \gamma_2 P_{b_2 \gamma_2}(k) + \gamma_2^2 P_{\gamma_2 \gamma_2}(k)$$

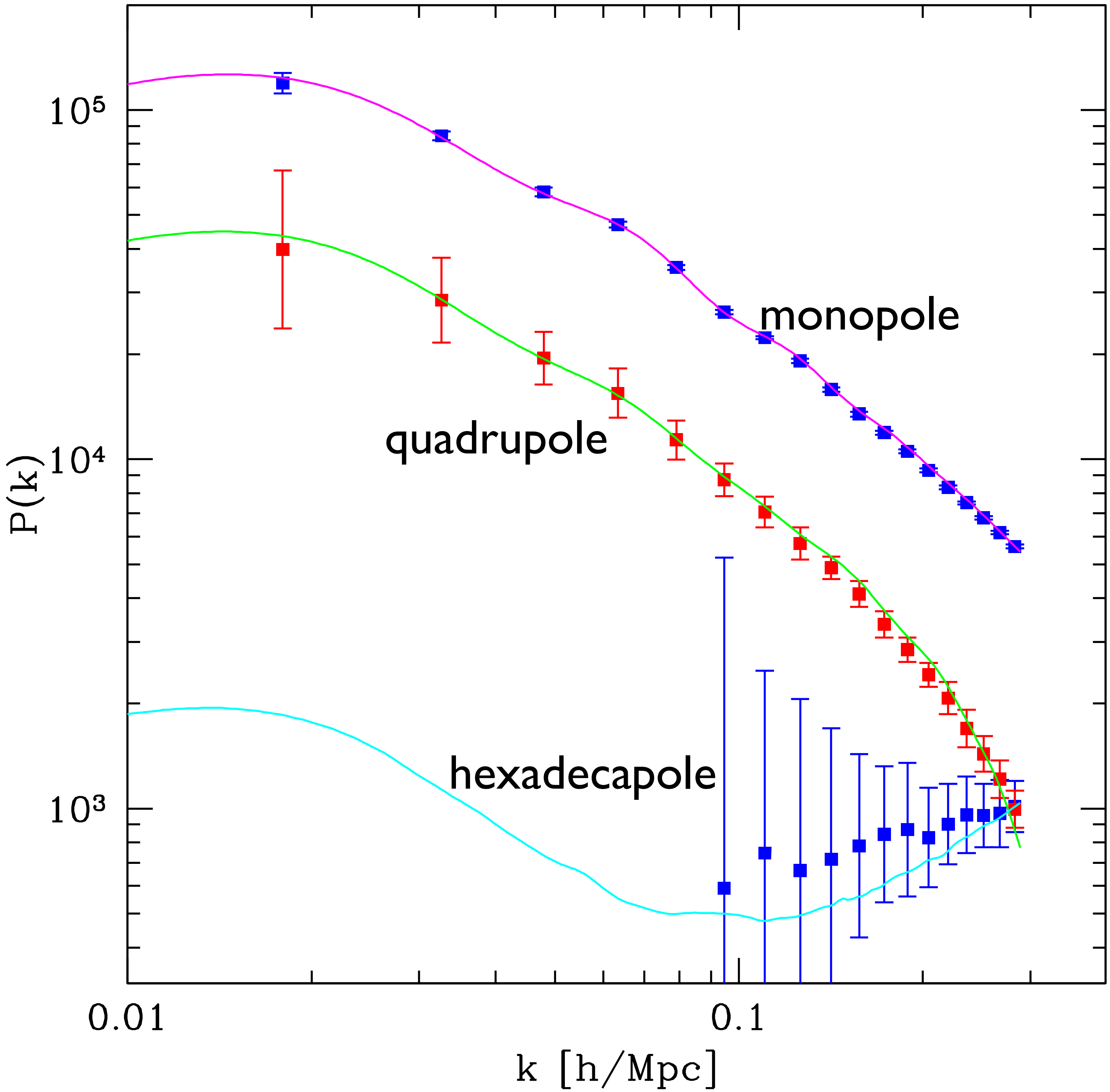
$$+2 b_1 \gamma_3^- P_{b_1 \gamma_3^-}(k)$$

Chan, Sheth & R.S. (2012)

Real-space two-point function for biased tracers



Power spectrum multipoles for biased tracers



Applications to BOSS

- Need efficient algorithms for calculating RSD for data beyond plane-parallel approx.

- FFT estimators for power spectrum (Bianchi et al 2015, RS. 2015) and bispectrum multipoles (RS. 2015), 4th-order interlaced interpolation (very efficient at computing power spectrum with negligible bias, <0.1% at Nyquist; Sefusatti et. al 2015)

1) all triangles included between kmin and kmax

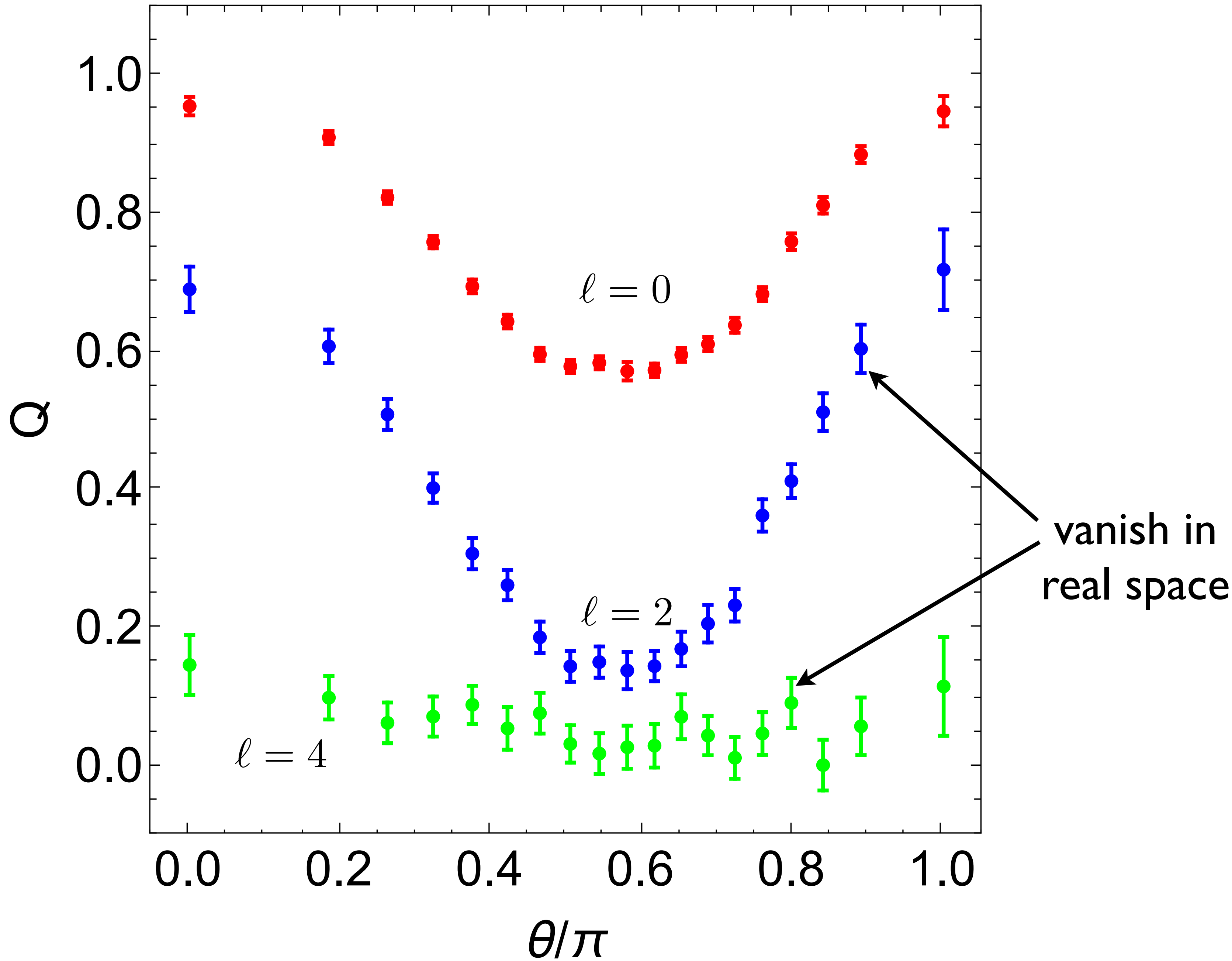
2) covariances between power and bispectrum

3) fast theory computation (1 loop)

4) fast window calculations for convolving theory

Bispectrum multipoles

R.S. (2015)



$k_1 = 0.047\ h/\mathrm{Mpc},\qquad k_2 = 2k_1$

Las Damas mock catalogs

Put everything together: How well does this work?
A simple consistency test

- Measure power spectrum from BOSS DR12

- Assuming Planck cosmology, predict redshift-space matter spectrum and match linear bias to fix large-scale amplitude

- From linear bias, using simple arguments (+local lagrangian bias) calculate non-local bias parameters

- Compute the predicted galaxy bispectrum (assuming primordial Gaussianity)

- Compare to measured bispectrum

Conclusions

- Recent progress in understanding a several nonlinear effects will allow us to have significantly more robust predictions about galaxy clustering

- Consistency checks between power spectrum, 2pt function (multipoles & wedges), bispectrum multipoles, gives us more confidence we are on solid ground.

- Expect significant improvements on cosmological parameters related to structure growth (w, f, sigma8).