Measuring Galaxy Clustering on Gigaparsec Scales

The Ohio State University

Ashley J. Ross
(plus many of you in the room)

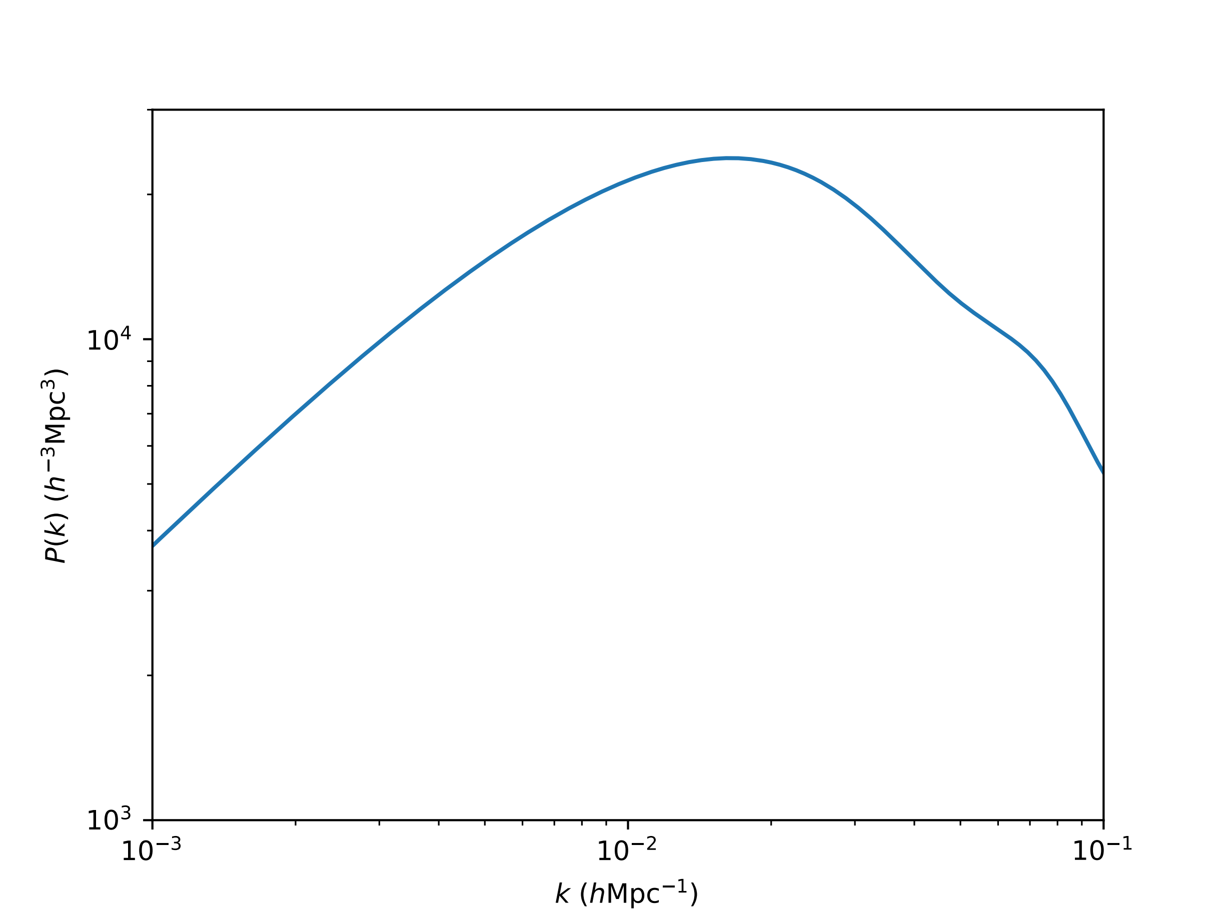
CCAPP

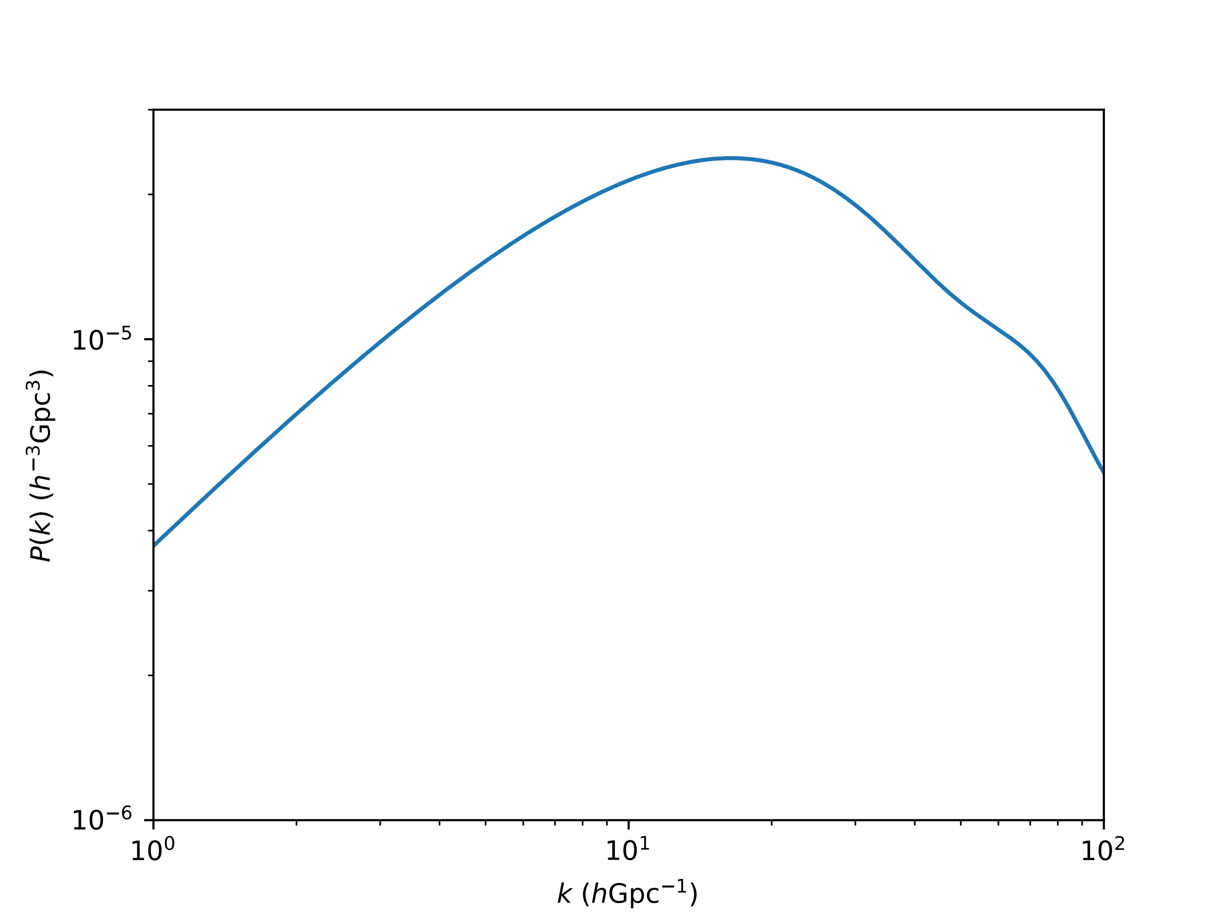
Outline

- Motivation
  – Primordial potential
- Challenges
  – Observational systematics

Gigaparsec Scales

- $(P(k)/\sigma_P)^2 \sim k^3 V_{survey}/(4\pi^2)$
- ~ 1 at $k = 1\ h\text{Gpc}^{-1}$ for 20 $(\text{Gpc}/h)^3$
- DESI > 28 $(\text{Gpc}/h)^3$ with $nP > 1$ at $k = 0.14\ h\text{Mpc}^{-1}$ (140 $h\text{Gpc}^{-1}$)





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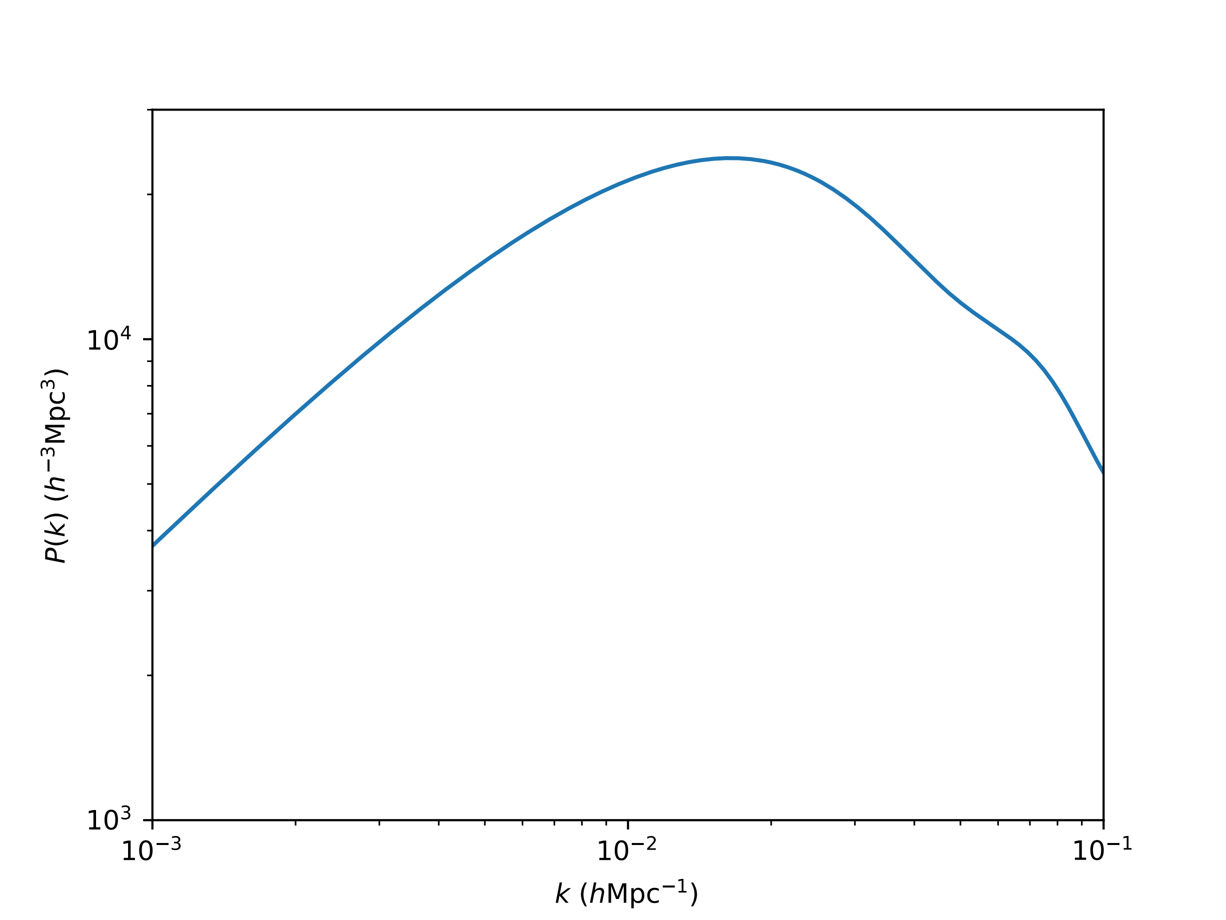
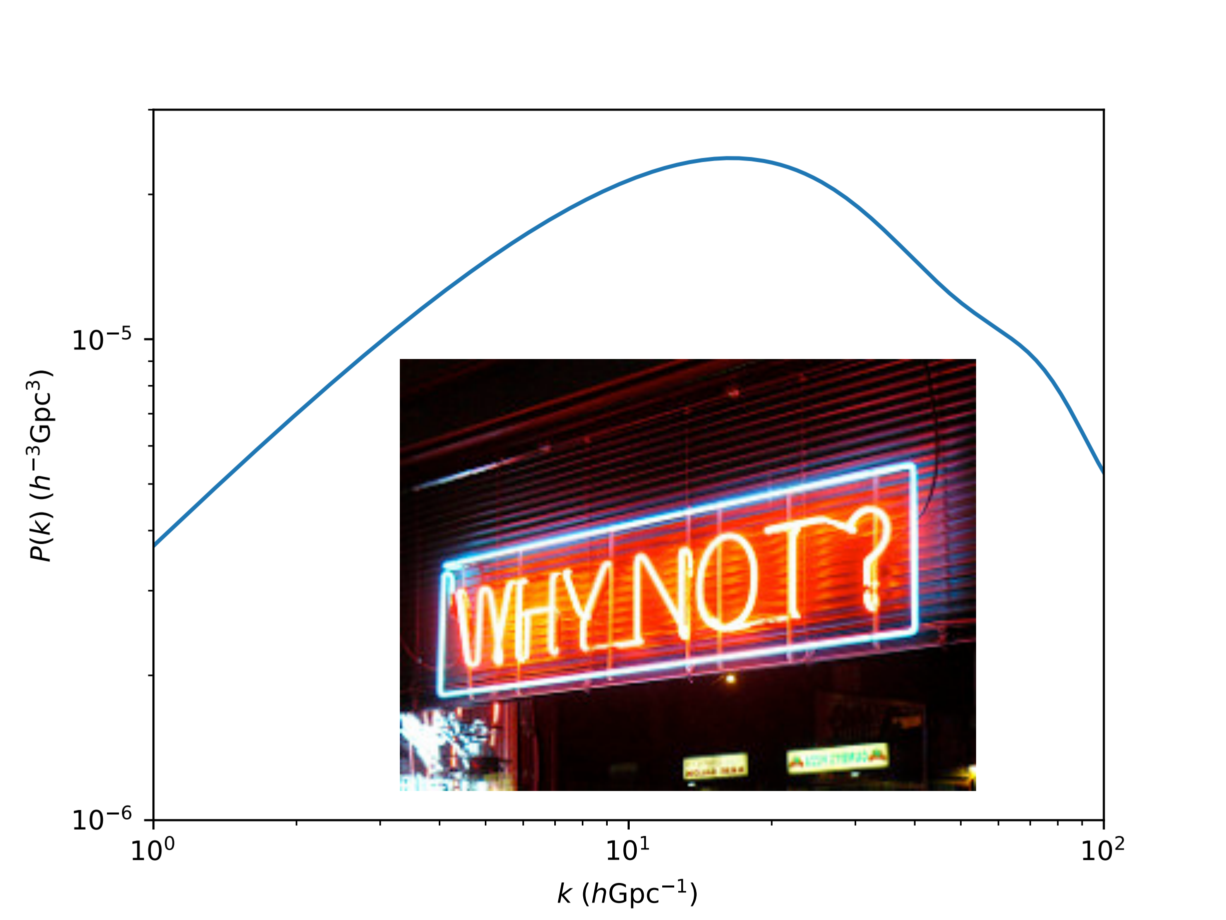
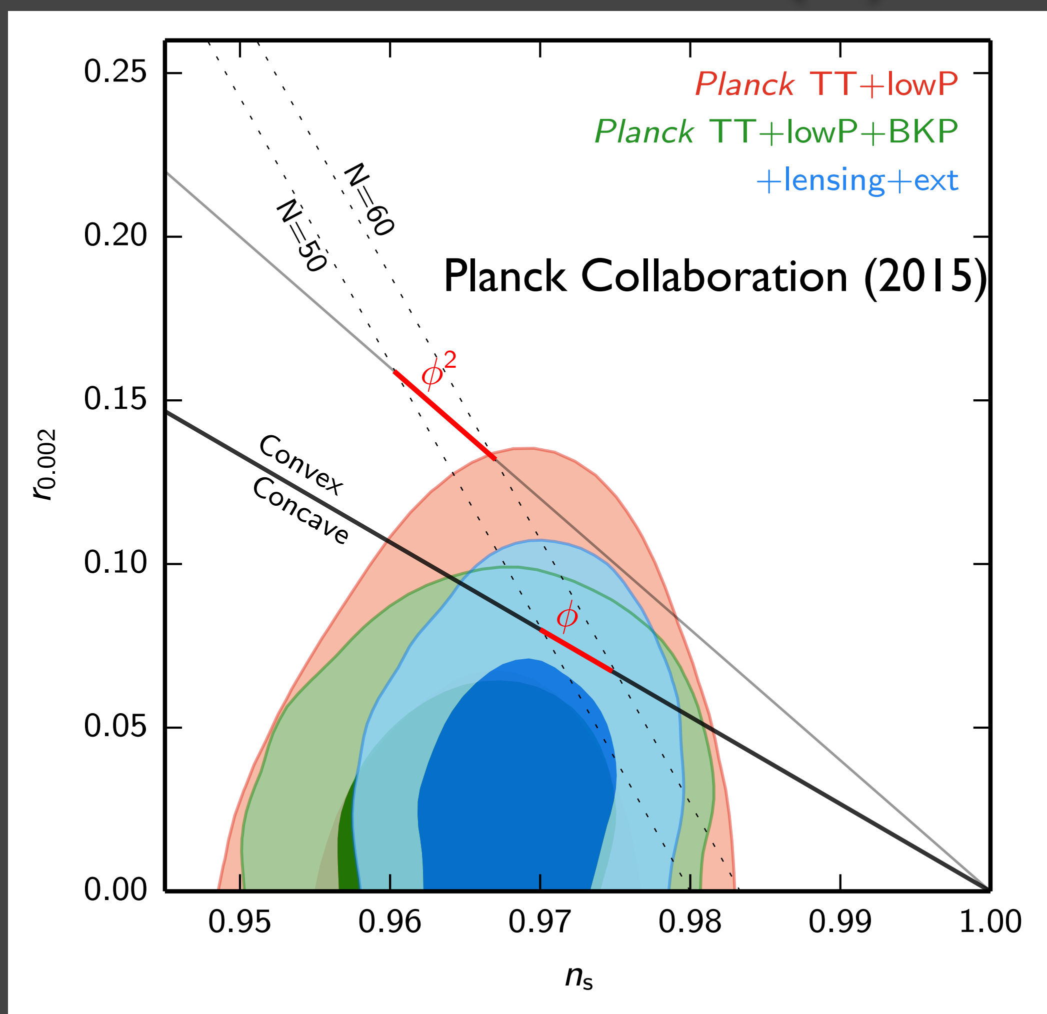




Motivation: Primordial Potential

- Two orders of magnitude of ~linear information
- linear matter $P(k)$ -> primordial $P(k)$



DESI forecasts

Data	σ_{n_s}	σ_{α_s}
Gal ($k_{max} = 0.1h\,\mathrm{Mpc}^{-1}$)	0.0025 (1.3)	0.005 (1)
Gal ($k_{max} = 0.2h\,\mathrm{Mpc}^{-1}$)	0.0022 (1.5)	0.004 (1.3)
Ly-α forest	0.0029 (1.1)	0.0027 (1.9)
Ly-α forest + Gal ($k_{max} = 0.2$)	0.0019 (1.7)	0.0019 (2.7)

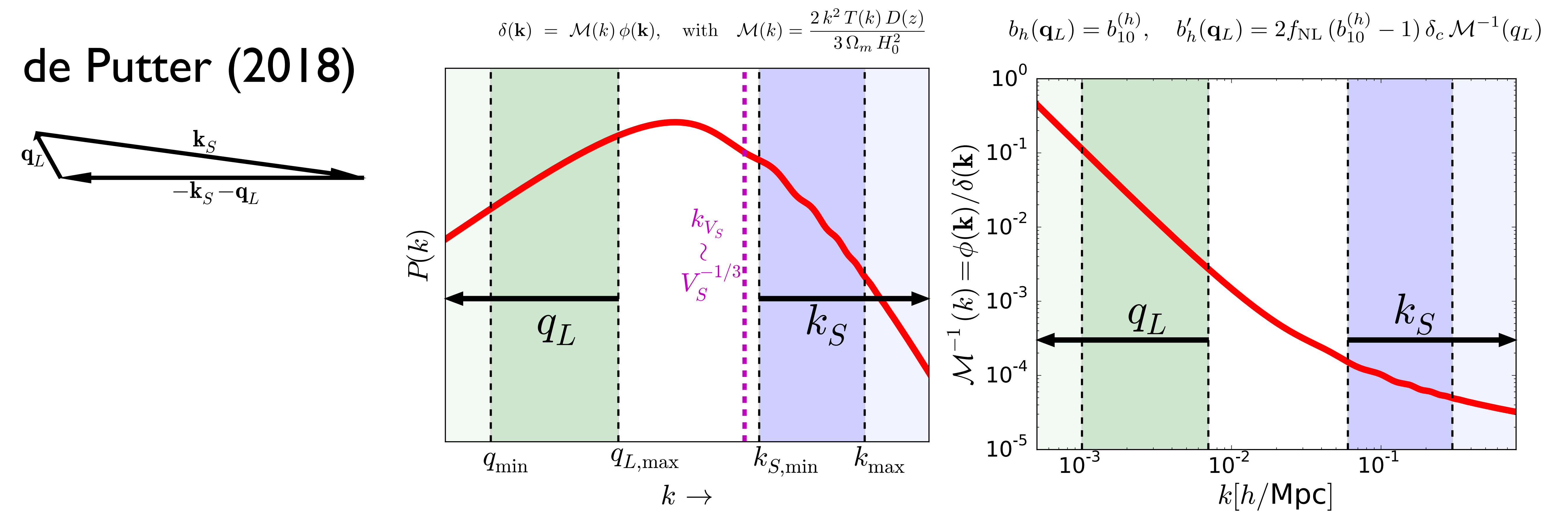
() denotes gain over Planck

- biased power spectrum → primordial non-Gaussianity

local $f_{\rm NL}$

- Amount of non-Gaussianity in primordial field in squeezed *k*-space triangle configurations
- Introduces coupling between short and long wavelength modes
- And thus scale dependent bias for biased tracers with k^{-2} dependence

de Putter (2018)



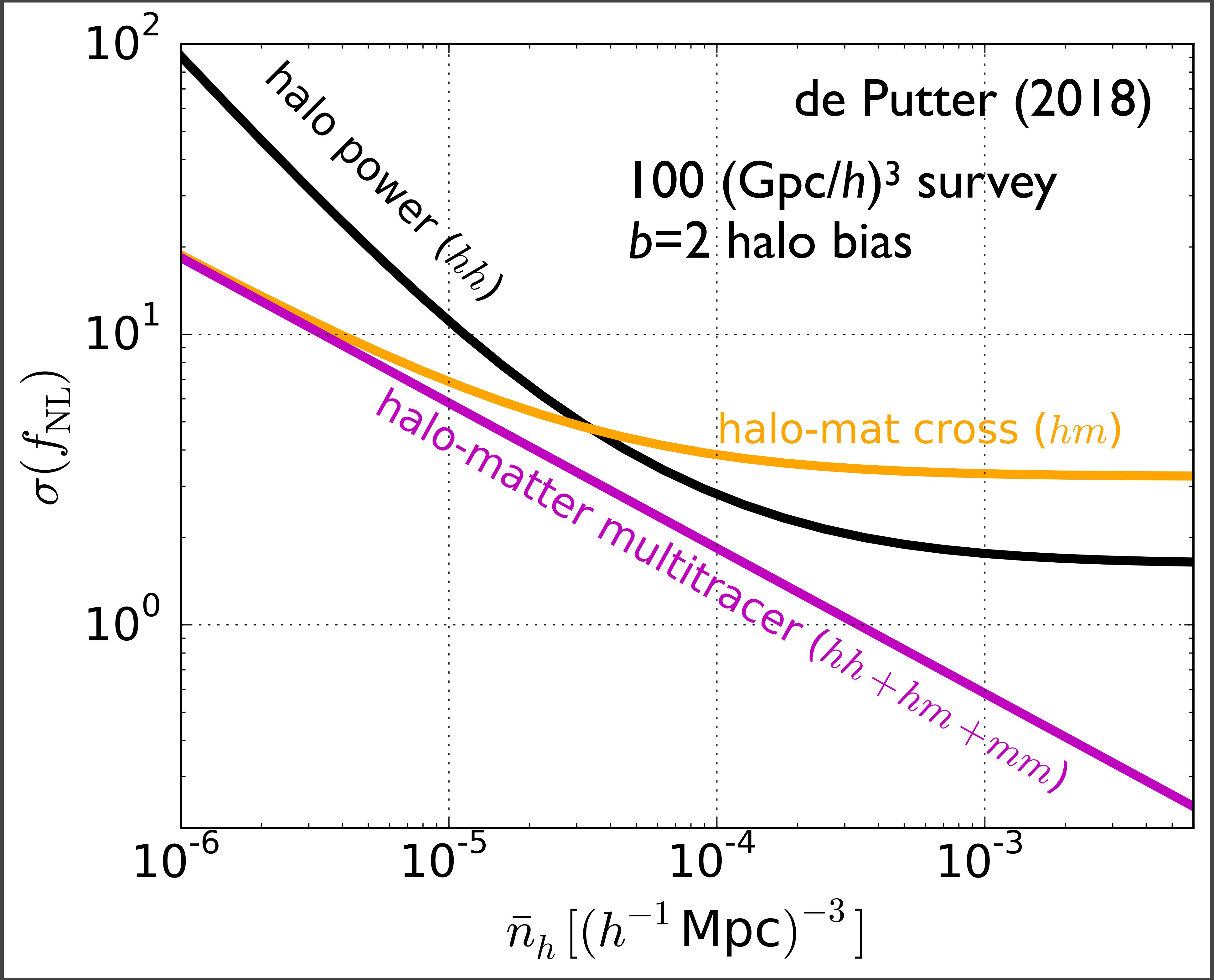
Inflation

- Crazy
- (Some debate remains)
- Seeds all structure formation
- Generic slow-roll model predicts local $f_{NL} < 1$
- Upcoming galaxy/Ly-α surveys for n_s, its running, and non-Gaussianity
  - ✳Any model (inflation or otherwise) needs to predict these

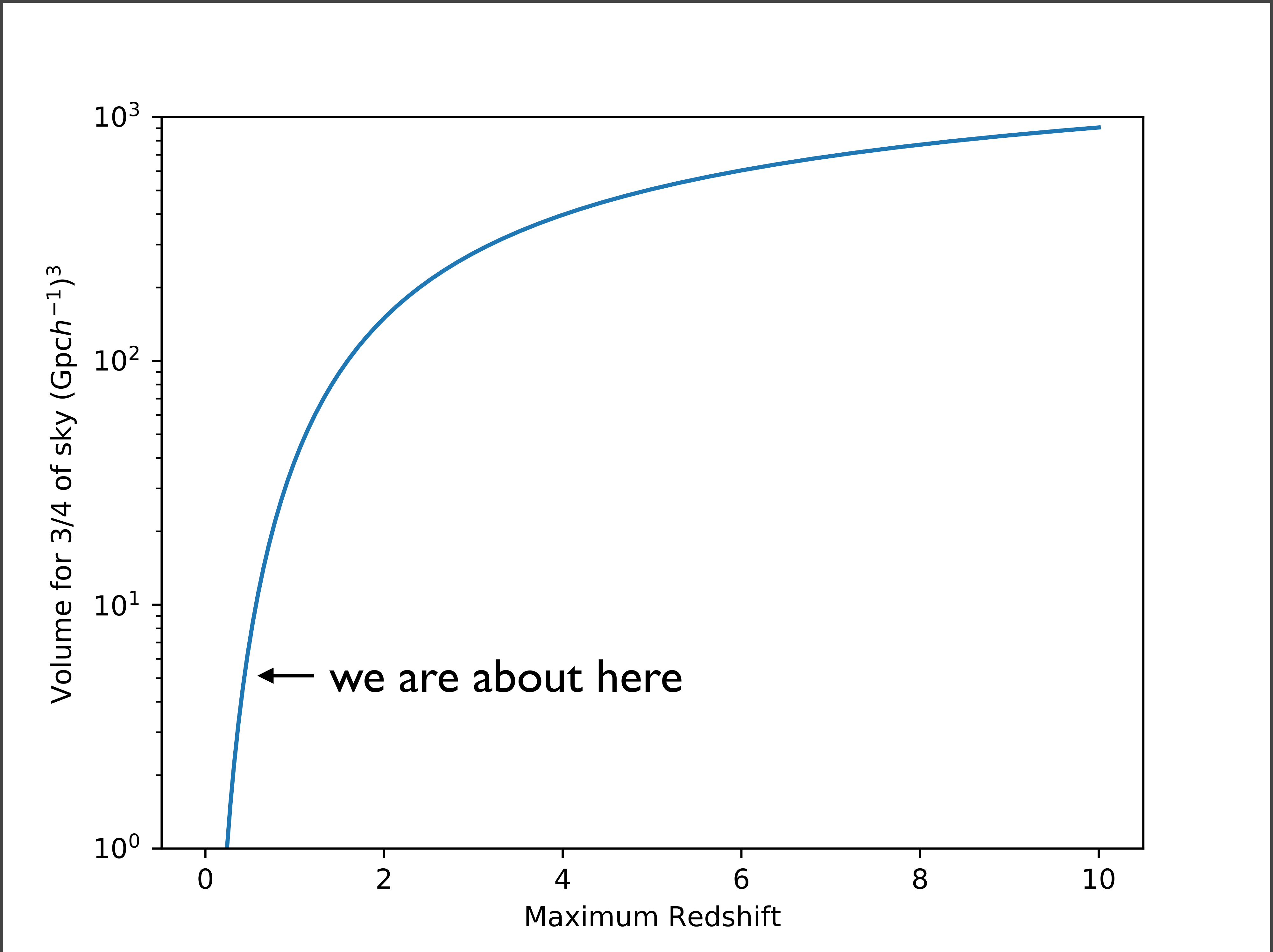
(some) local f_{NL} measurements

- pre-Planck
  - 21±25 (SDSS; Slosar et al. 2008)
  - 51±30 (WMAP5; Komatsu et al. 2009)
  - 48±20 (NVSS+SDSS; Xia et al. 2011)
  - 37±20 (WMAP9; Hinshaw et al. 2013)
  - 5±21 (NVSS+SDSS+ISW; Giannantonio et al. 2014)
- Planck 2013
  - 2.7±5.8 (2015; 2.5±5.7)
- -9±20 (SDSS Quasars; Leistedt et al. 2014)

Future f_{NL} measurements



Available Volume



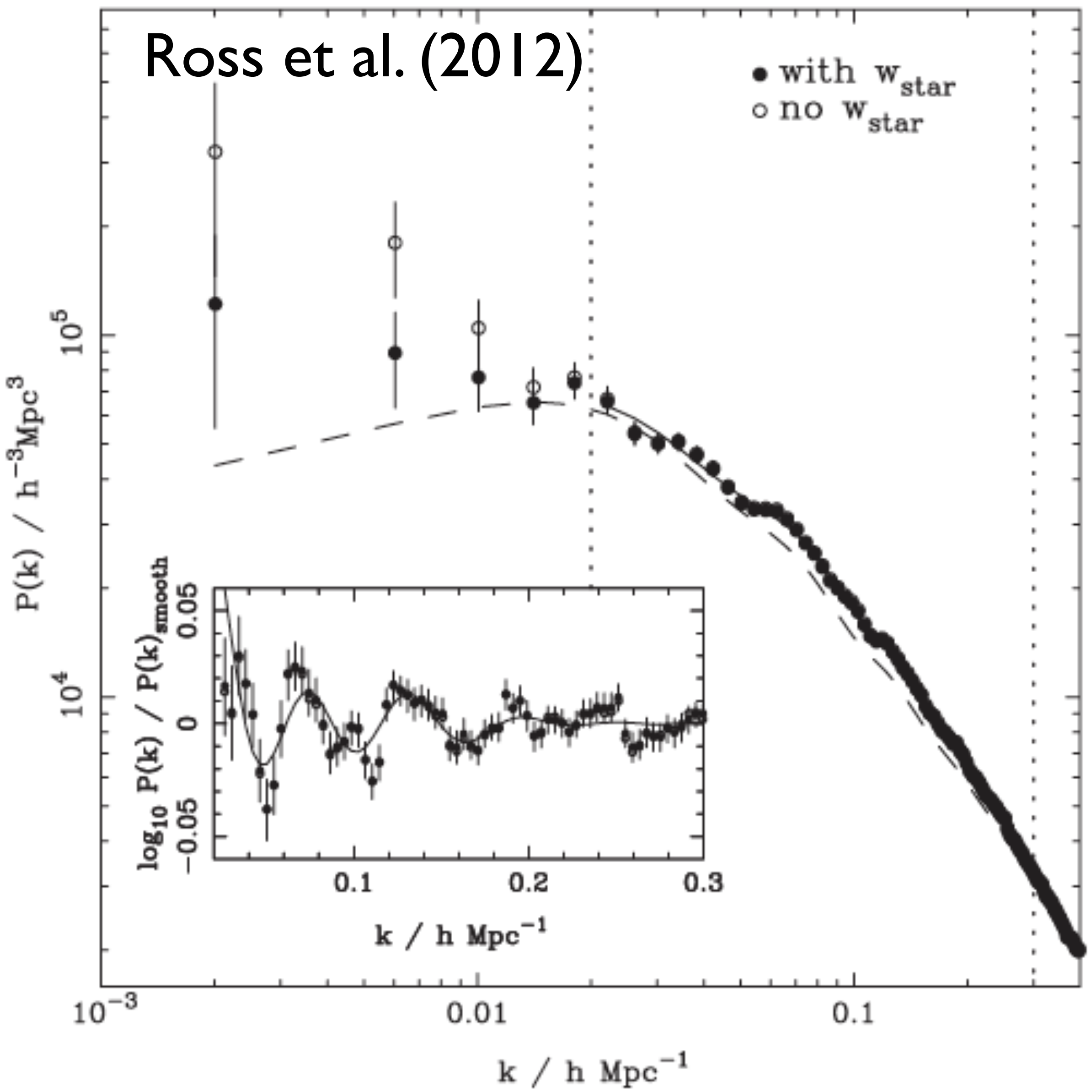
Motivation: bottom-line

- Universe contains the information to precisely constrain primordial potential
- Combination of large-scale structure and CMB polarization:
  - n_s and its running, amplitude of tensor modes, degree of non-Gaussianity
- Can hopefully prove inflation and pin-down specific models!

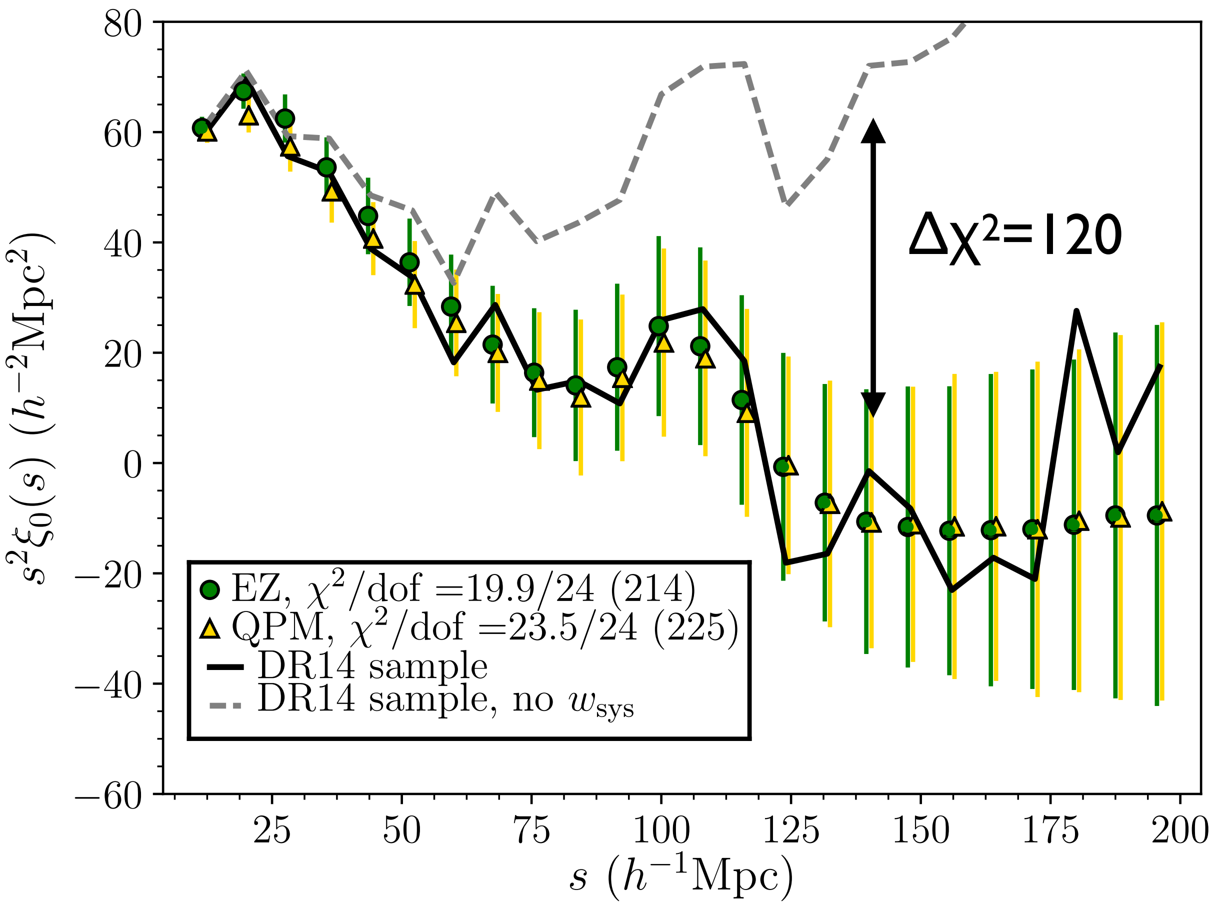
Challenges

Observational Systematics

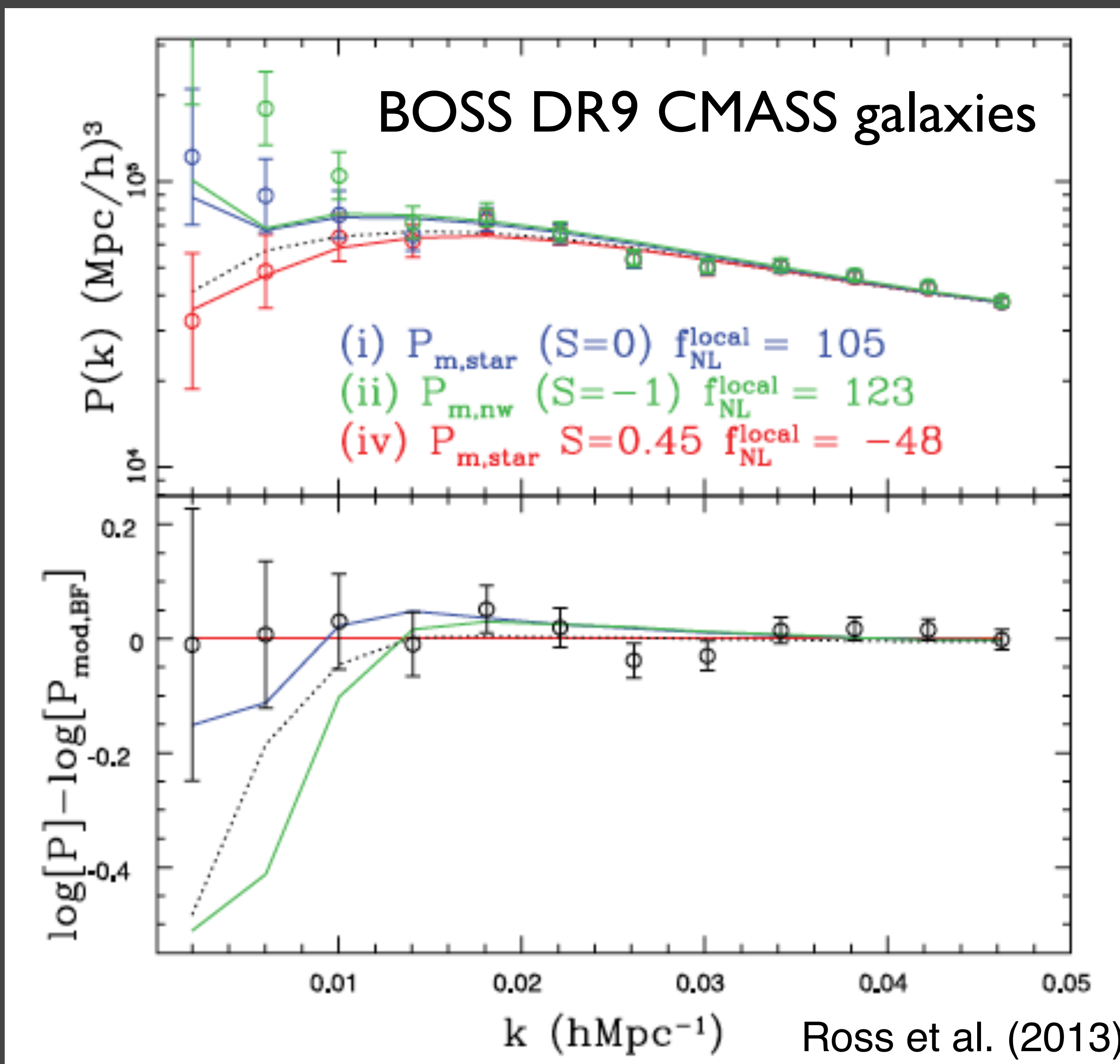
BOSS DR9 CMASS galaxies



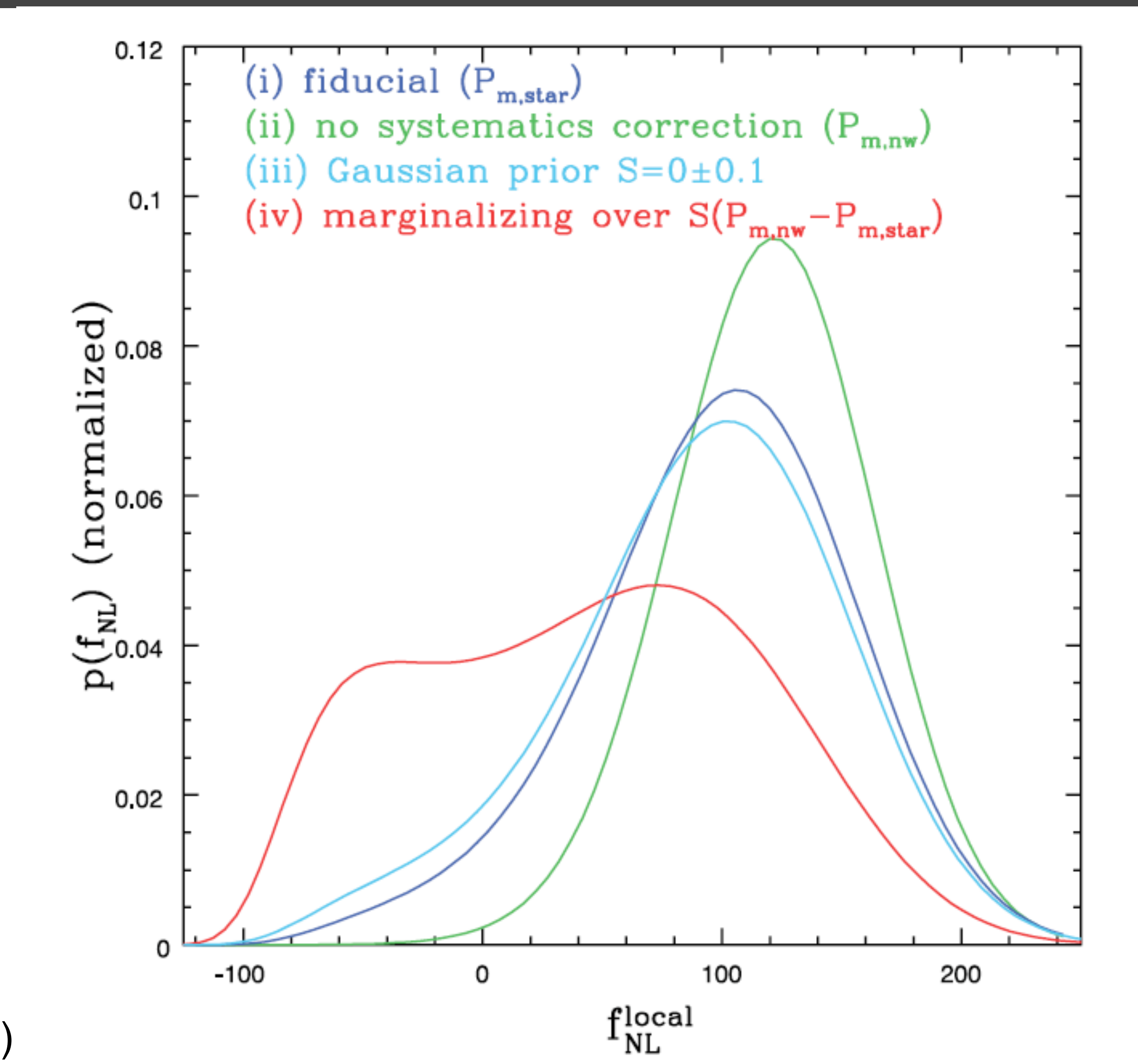
eBOSS DR14 quasars
Ata et al. (2017)



Observational Systematics: f_{NL}



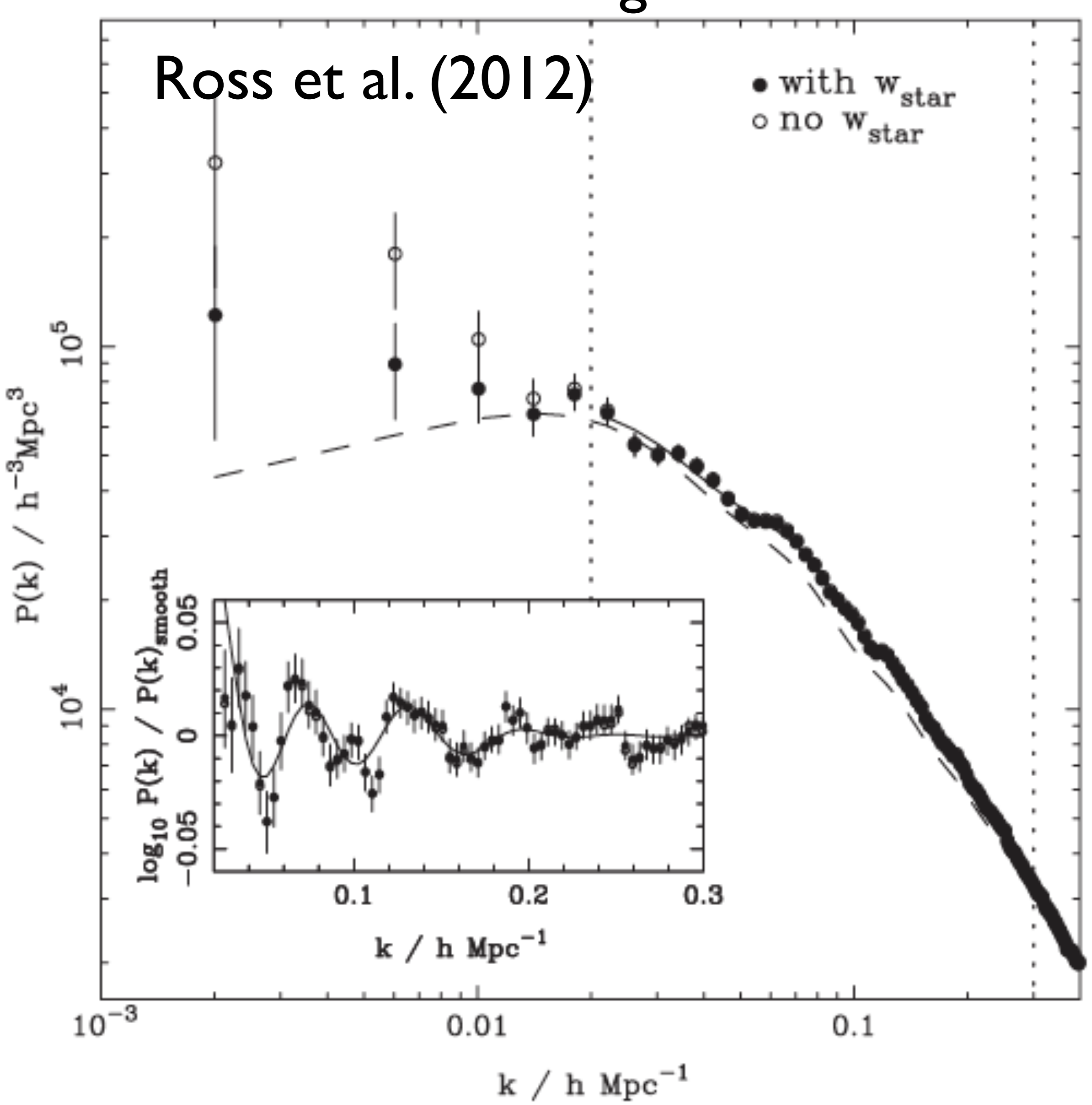
Ross et al. (2013)



BAO Don't Budge

- BOSS galaxies (Ross et al. 2017), Ly-α forest (Bautista et al. 2017), quasars, DES photozs…

BOSS DR9 CMASS galaxies



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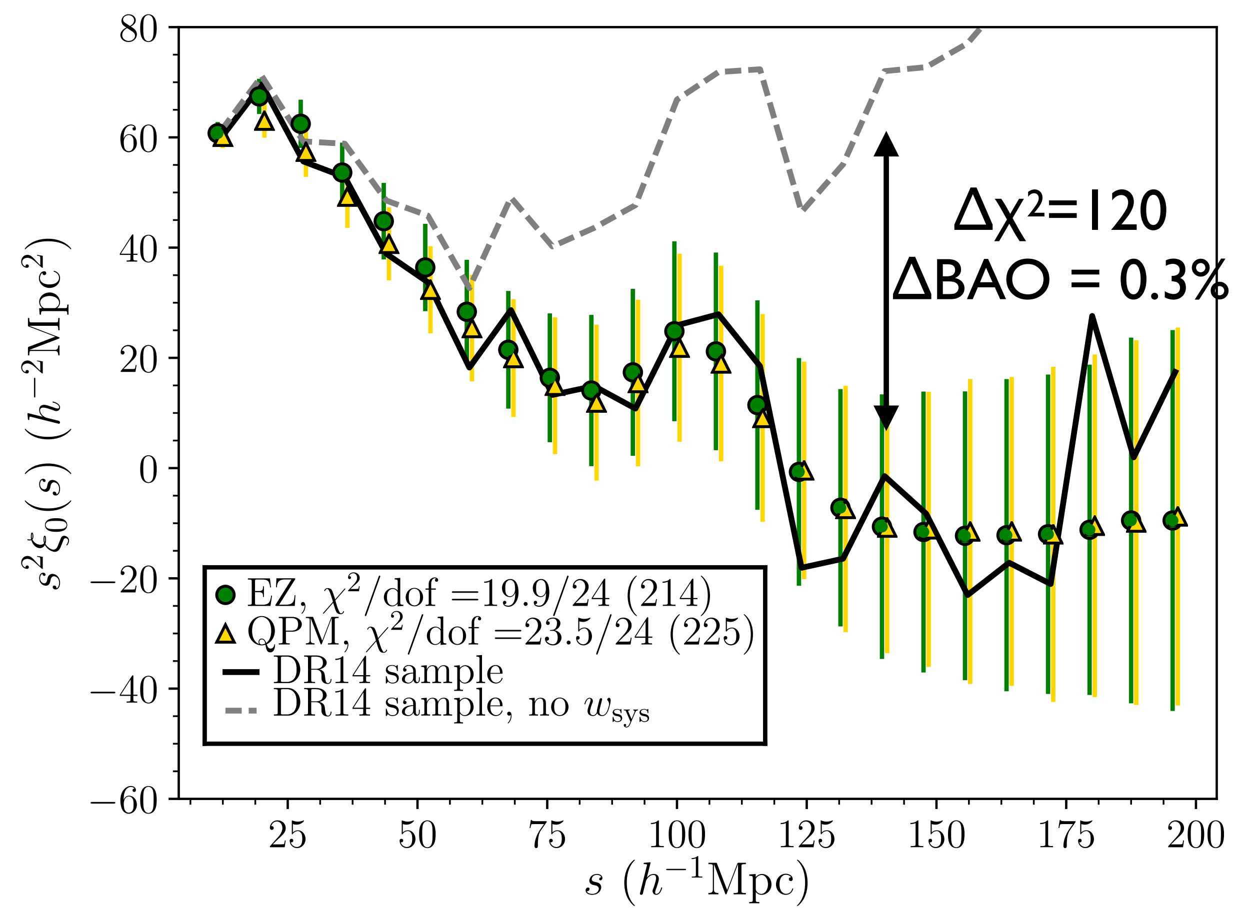
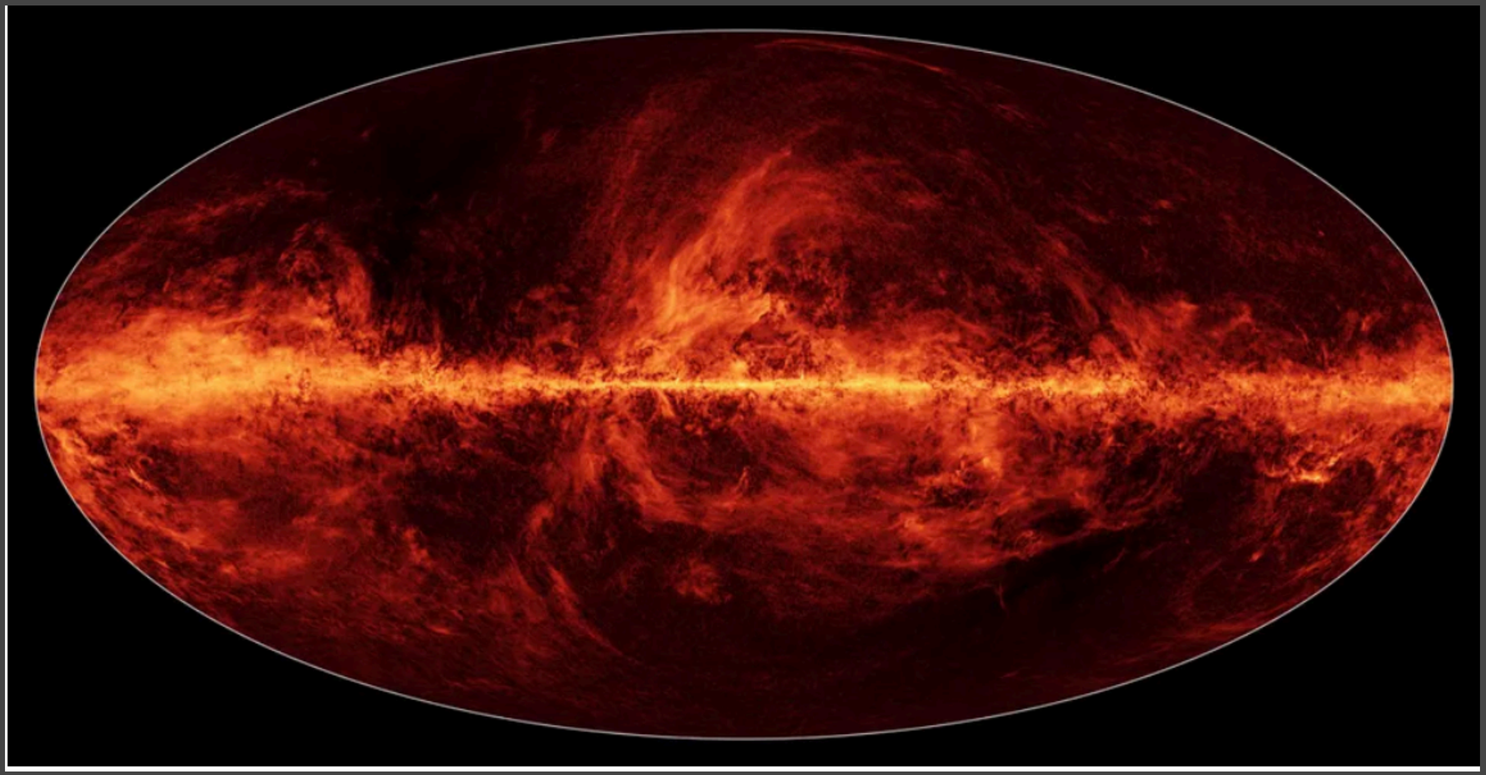


Imaging Systematics

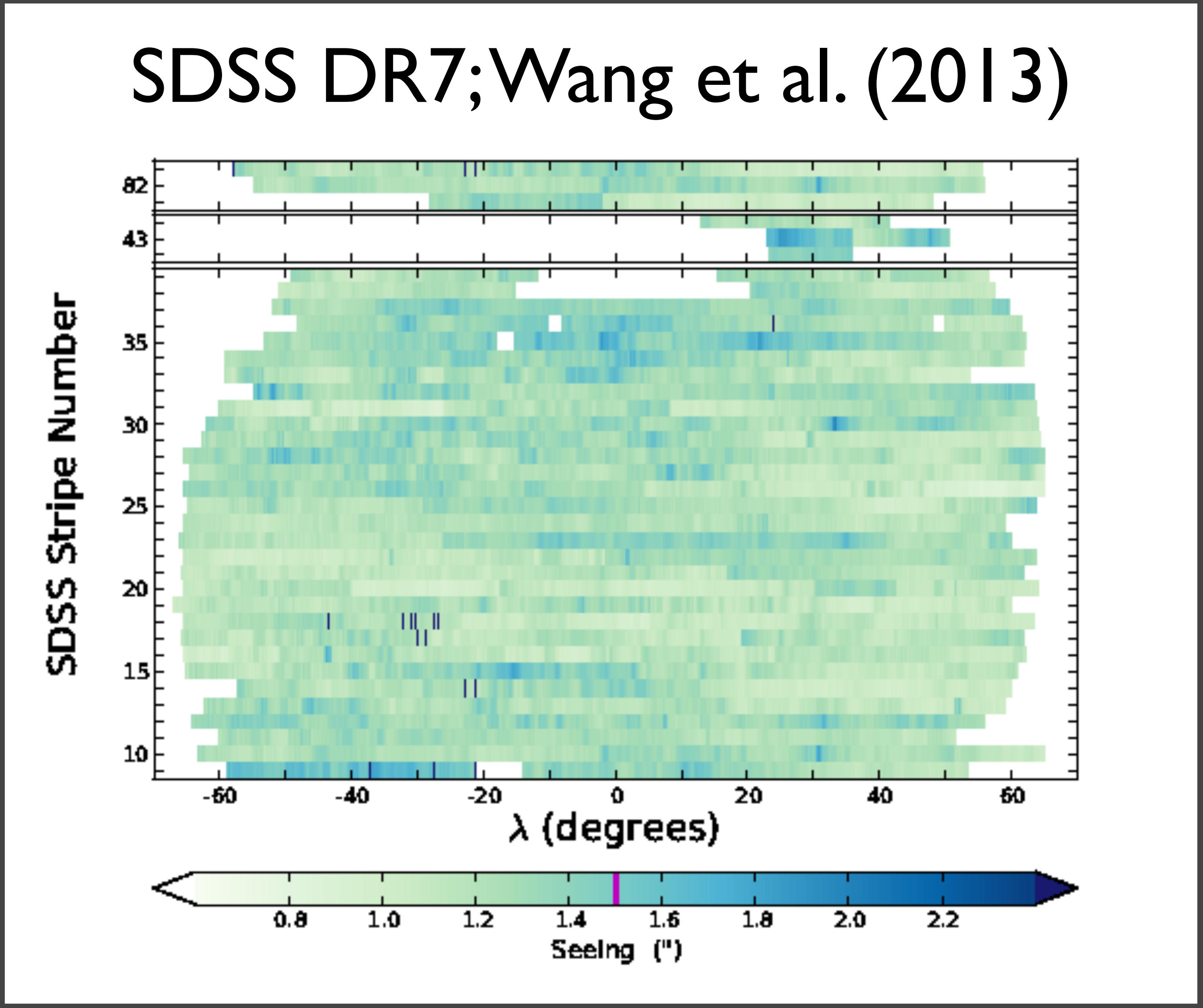
- "Foregrounds"
  - –i.e., the Milky Way
  - –Static (within measurement uncertainties)
  - –E.g., dust maps, stellar density maps
  - –Can be taken from one instrument and used for another

Not isotropic: Planck at 353GHz



Imaging Systematics

- Data quality variations
  - ✳requires metadata be recorded at time of observation
  - ✳e.g., exposure time, PSF size, sky brightness, distance from moon,…



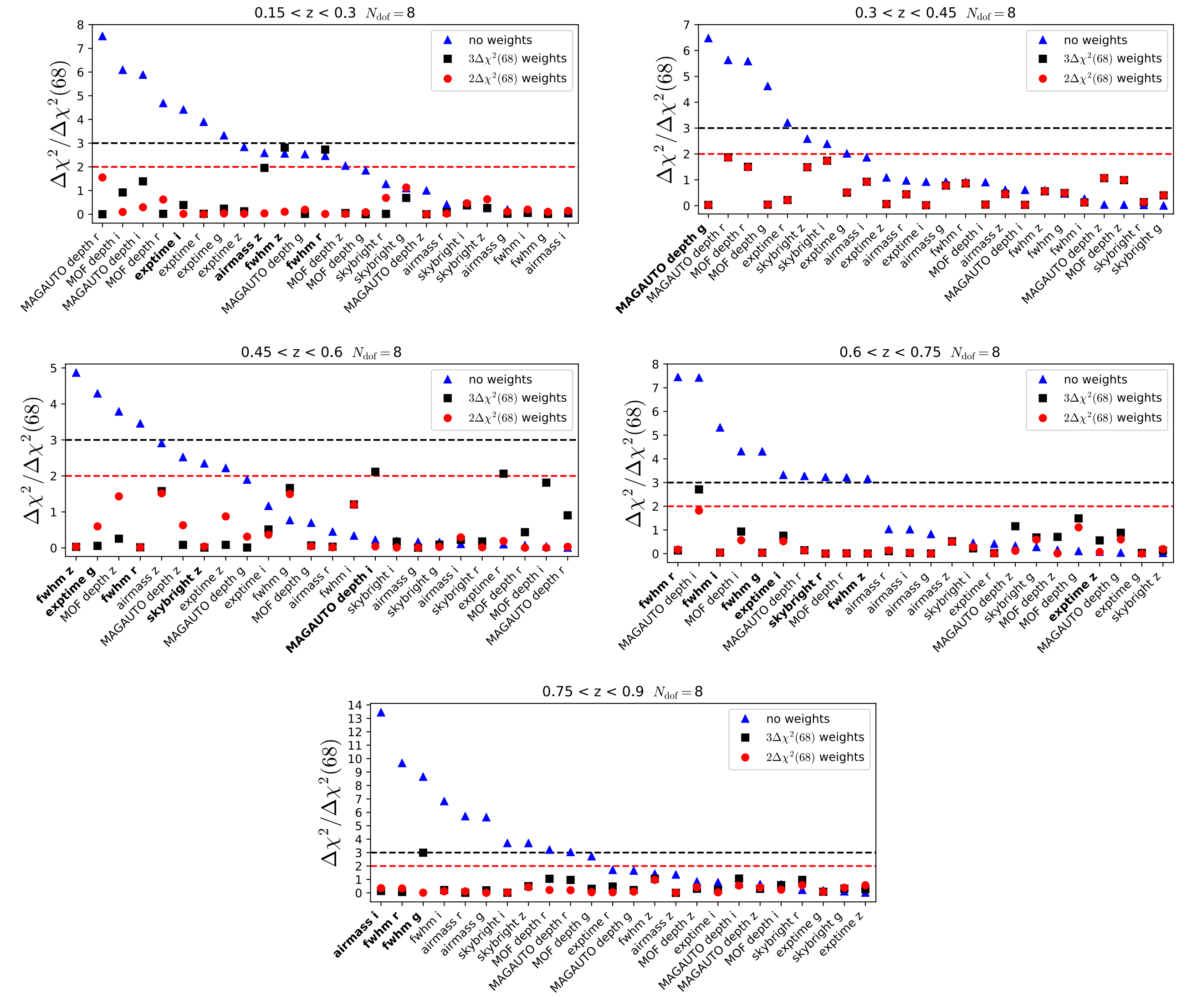
Imaging Systematics

- Calibration uncertainties
  - ✳E.g., photometric calibration between two observations
  - ✳Might require 0.1% level calibration for f_{NL} (Huterer et al. 2013)
  - ✳Forward model calibration?

Map Based Approaches

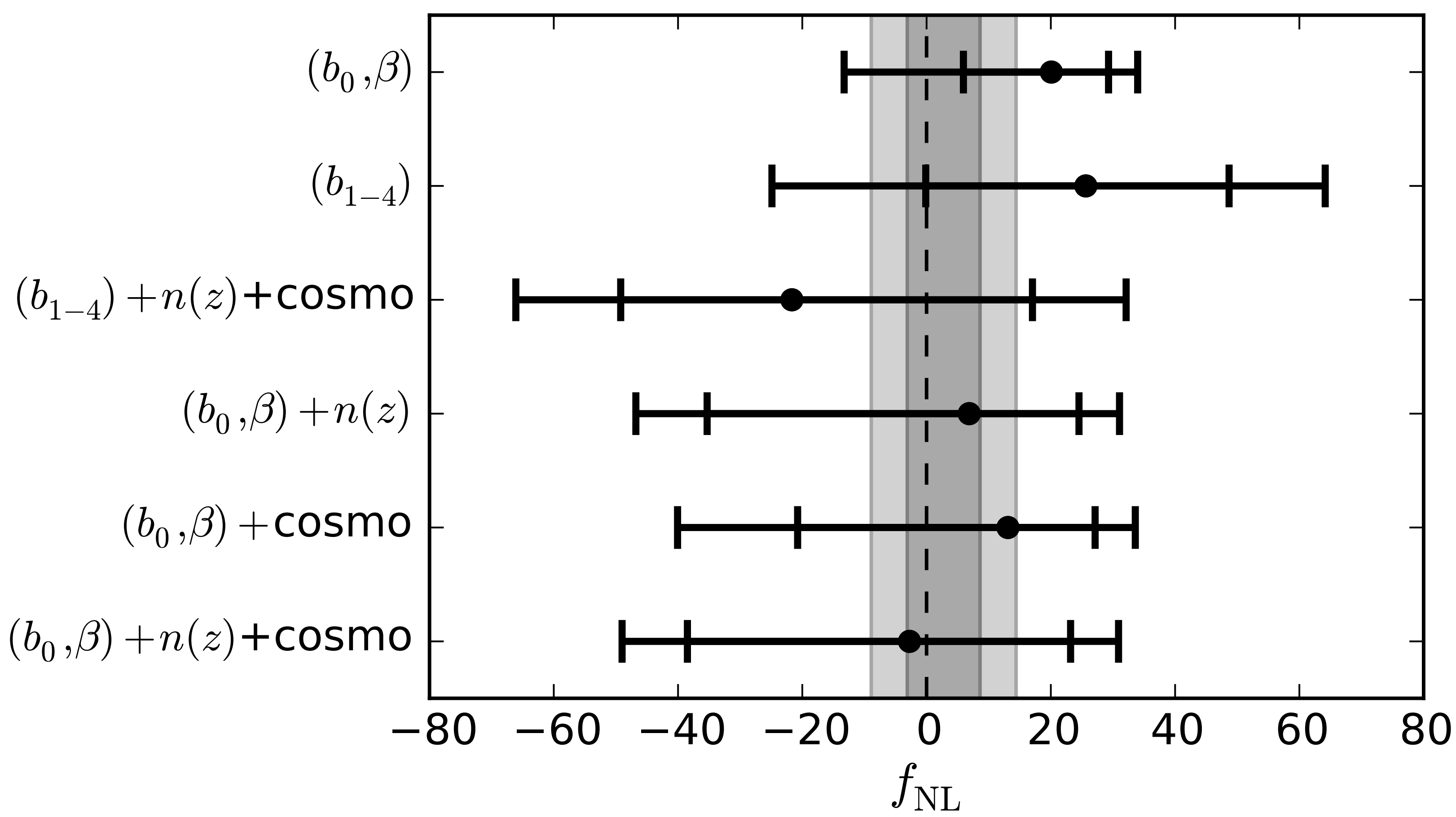
- Foregrounds
- Data quality variations
  - ✳Record metadata
- Cross-correlate with data→correction
- Calibration uncertainties
  - ✳Hope captured by metadata
  - ✳(E.g., cumulative effect of errors in extinction coefficients should scale with dust map)

DES Y1 Elvin-Poole et al. (2017)



Map Based $f_{\rm NL}$ Success

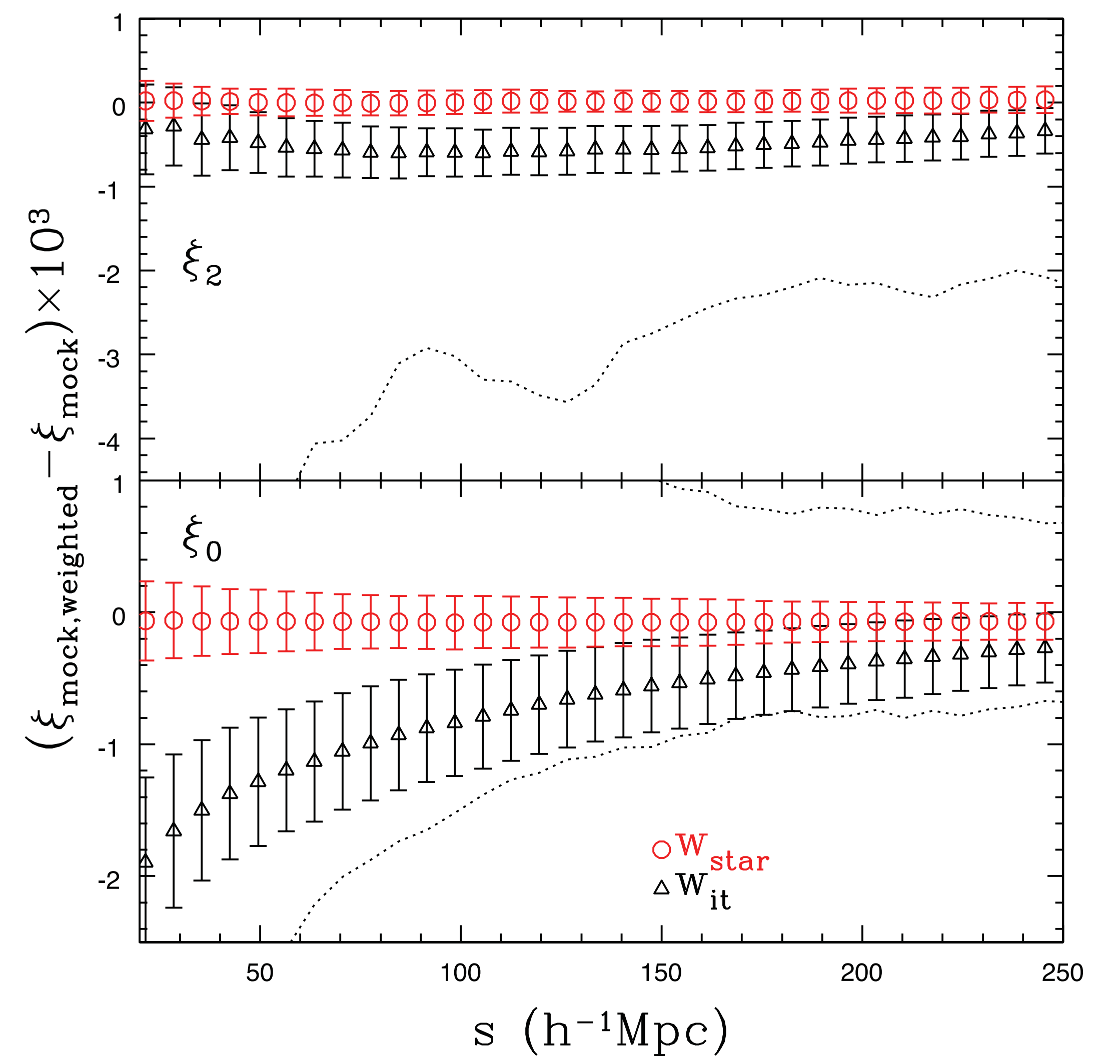
SDSS Quasars; Leistedt et al. (2014)
Applied extended mode projection to angular power spectrum measurements



Details Matter

- Clustering modes are removed by these methods
- Need to be careful, show that method is unbiased for *model* it is testing
- Elsner et al. (2016), Kalus et al. (2016)
- Rezie et al. (in prep.): use proper machine learning techniques

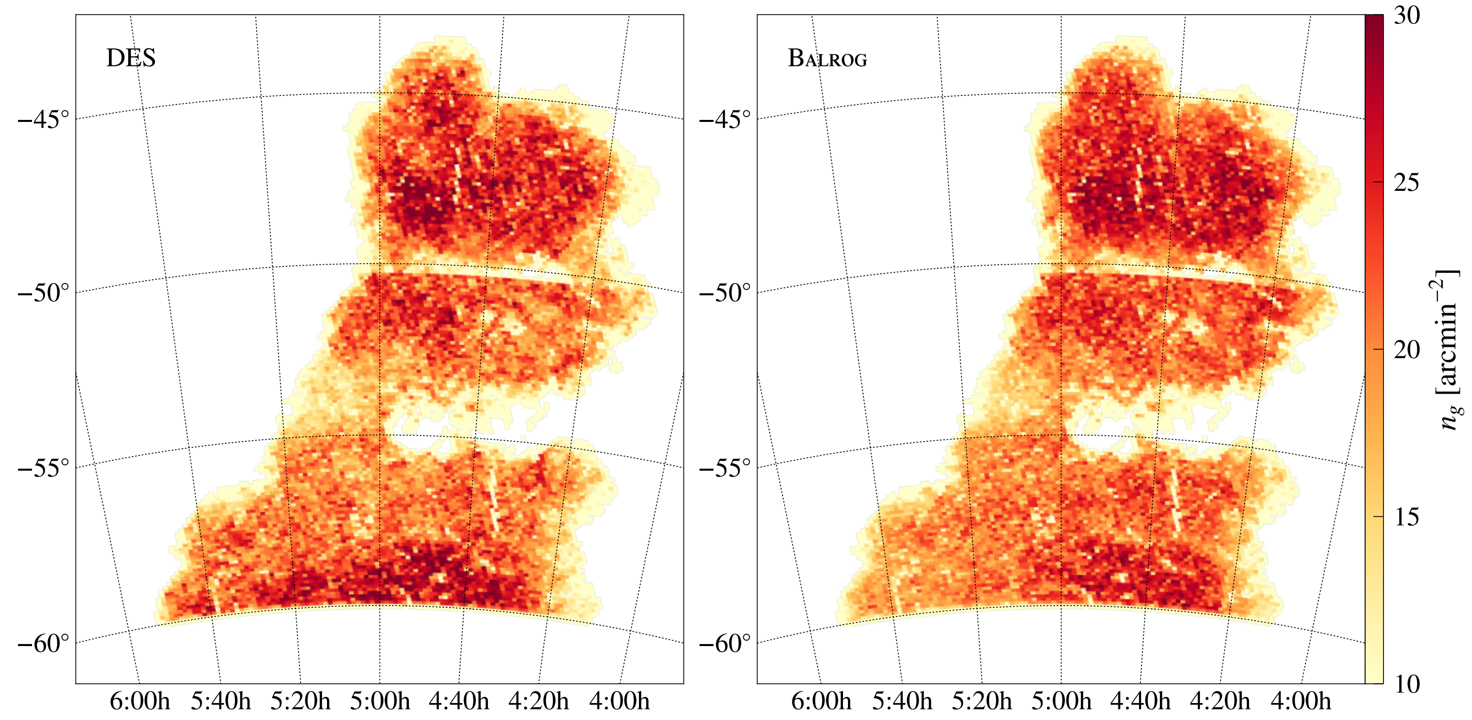
BOSS DR9 Ross et al. (2012)



Forward Model Approach

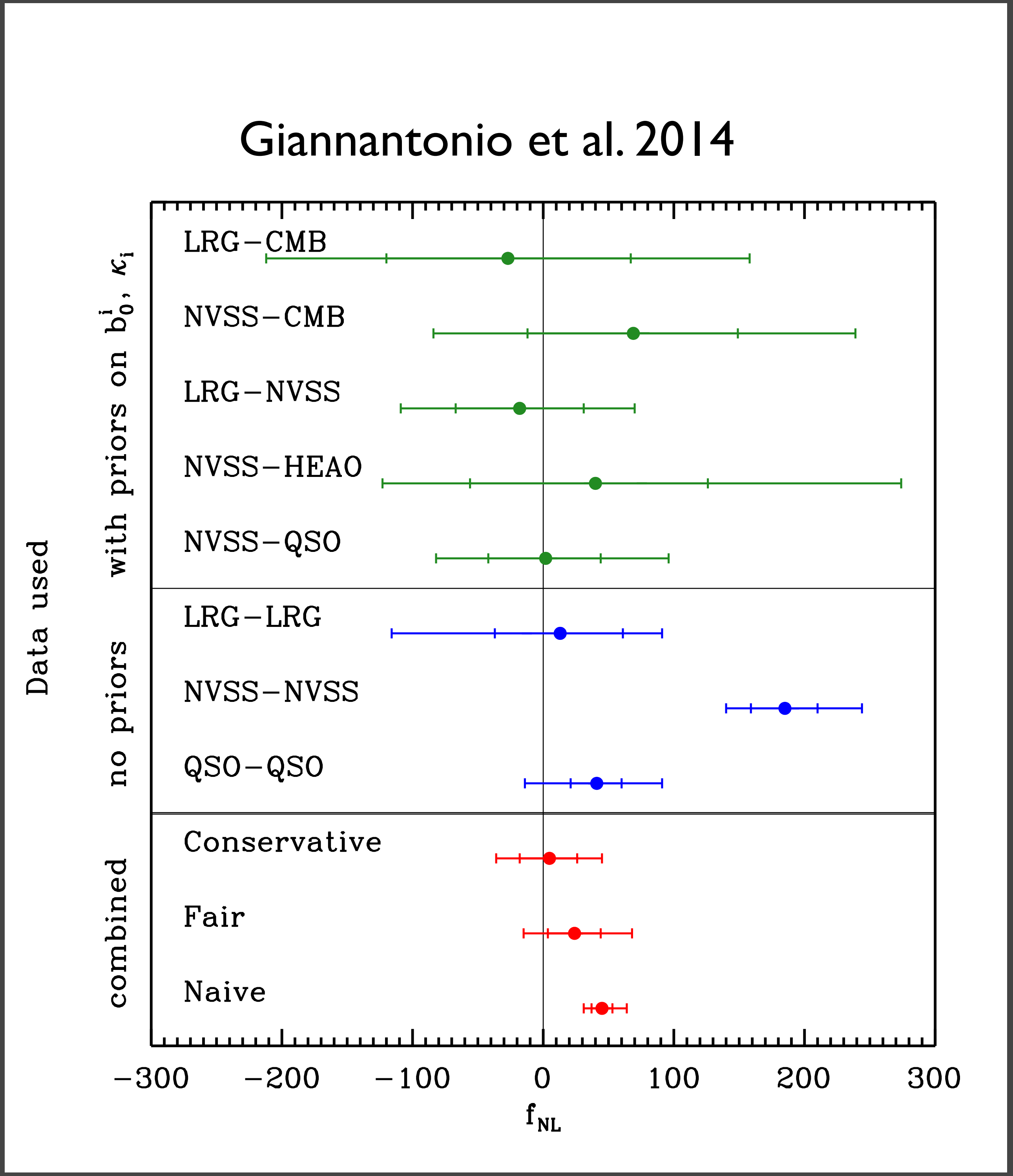
- Inject galaxies into images, perform selection
- Removes need for most metadata, some foregrounds
- Requires representative input sample
- DES, "Balrog", Suchyta et al. (2016); DESI, "Obiwan", Burleigh et al. (in prep.)
- Could include calibration uncertainties?

Suchyta et al. (2016)
Balrog input is constant
Output gives selection function



Cross-correlations

- calibration and data quality concerns (mostly) drop out



Future

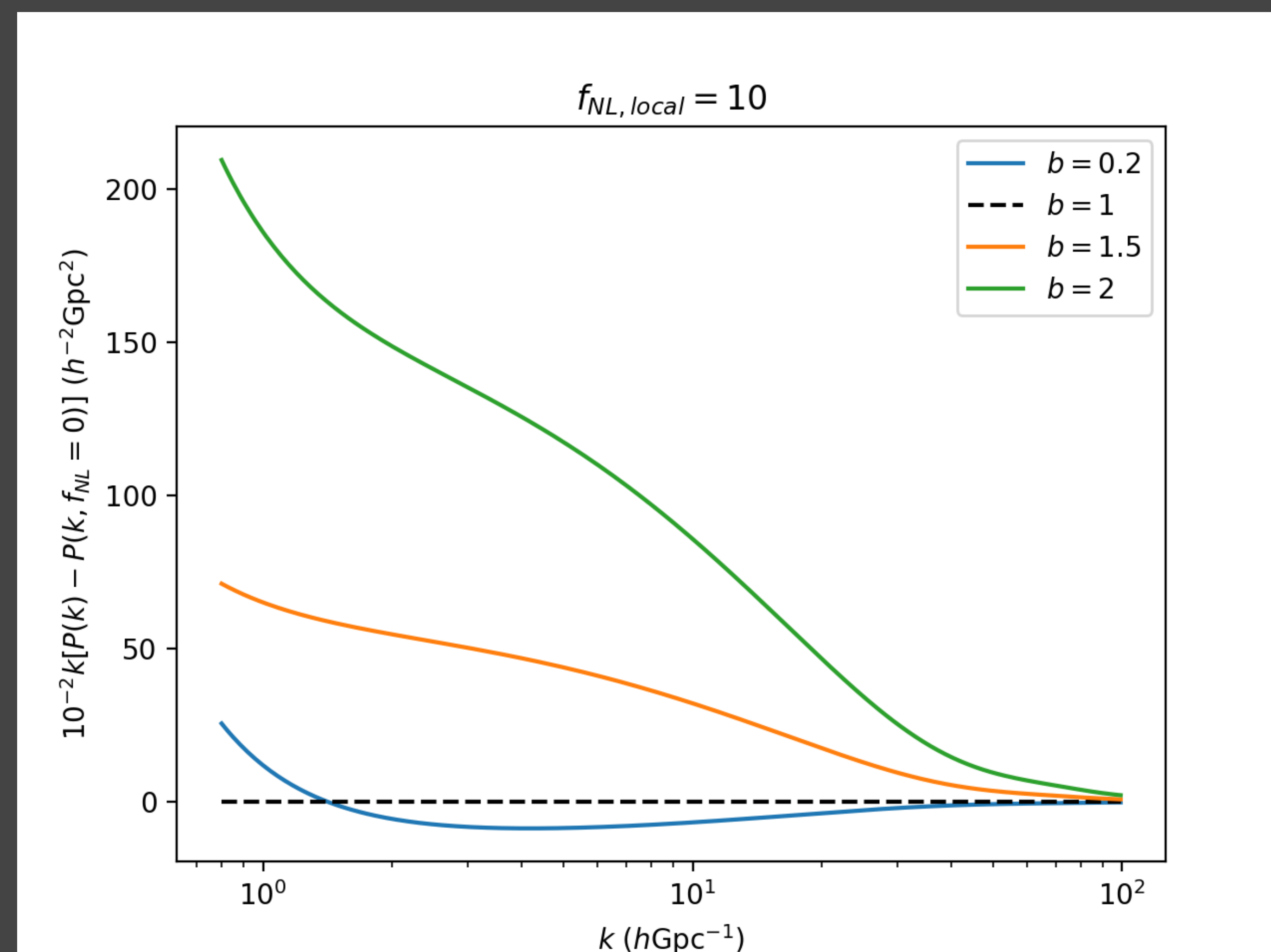
- LSST, with current techniques, how about:
  - ✳N galaxy count maps to i~24, separate calibration, cross-correlated against each other
  - ✳Supported by image simulations
  - ✳Mode projection for foregrounds
  - ✳Test mode projection with meta-data for robustness
  - ✳DESIxLSST, EuclidxLSST, eventually, LSSTxSKA, …

Extending multi-tracer

Primordial non-Gaussianities and zero bias tracers of the Large Scale Structure

Emanuele Castorina,[1,2] Yu Feng,[1,2] Uroš Seljak,[1,2] and Francisco Villaescusa-Navarro[3]

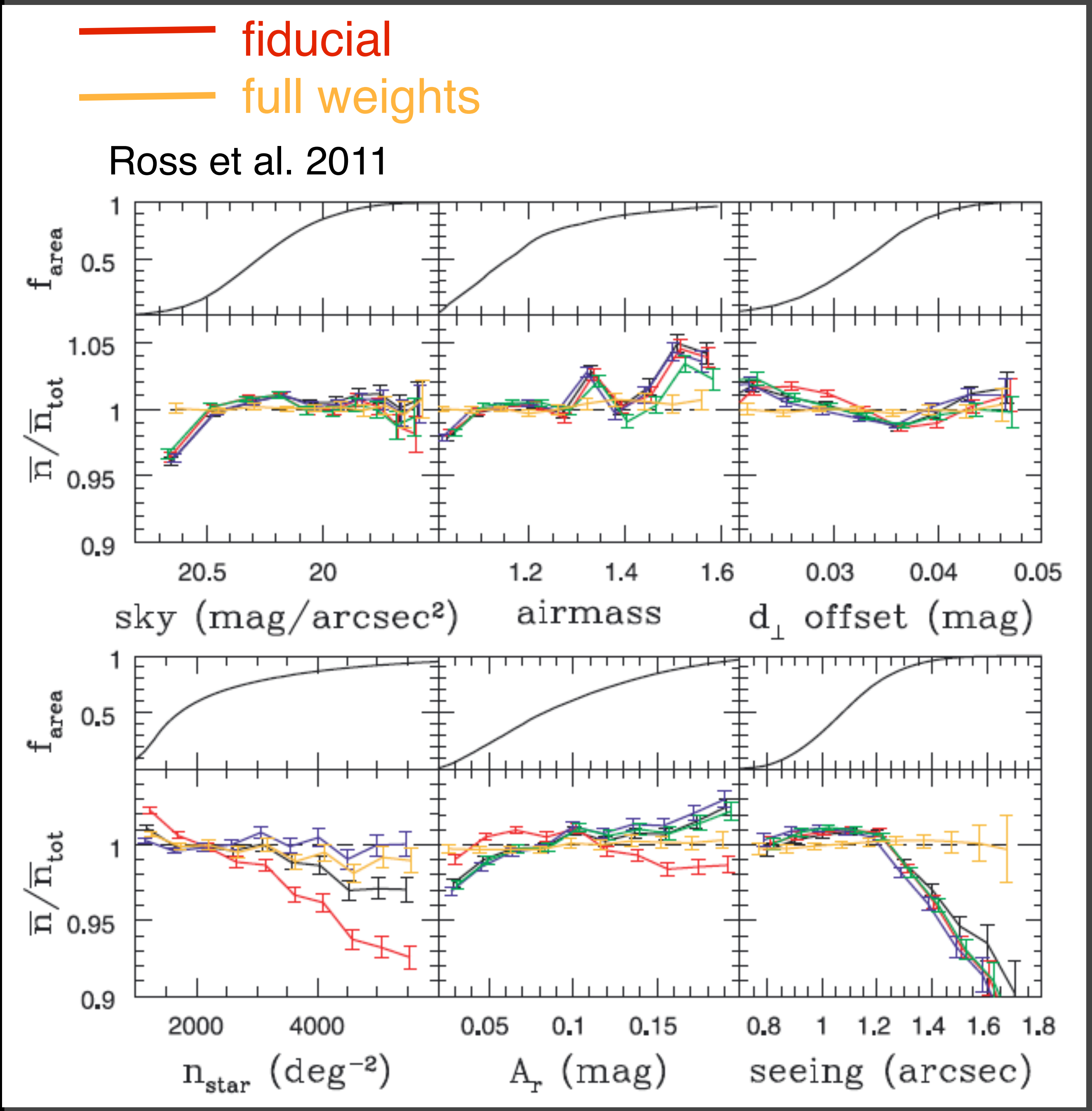
- Treat each biased sample like we treat frequency bands in CMB?
- Or maybe do template search? (Or both)



Conclusion

- Surveys getting larger mean we get to measure new, larger scales
- We know how to model large-scales (?…GR effects, magnification, neutrino mass splitting…)
- Systematics are tricky, but surely not as bad as shear
- Let's try to have a better understanding of why anything exists

BOSS imaging systematics



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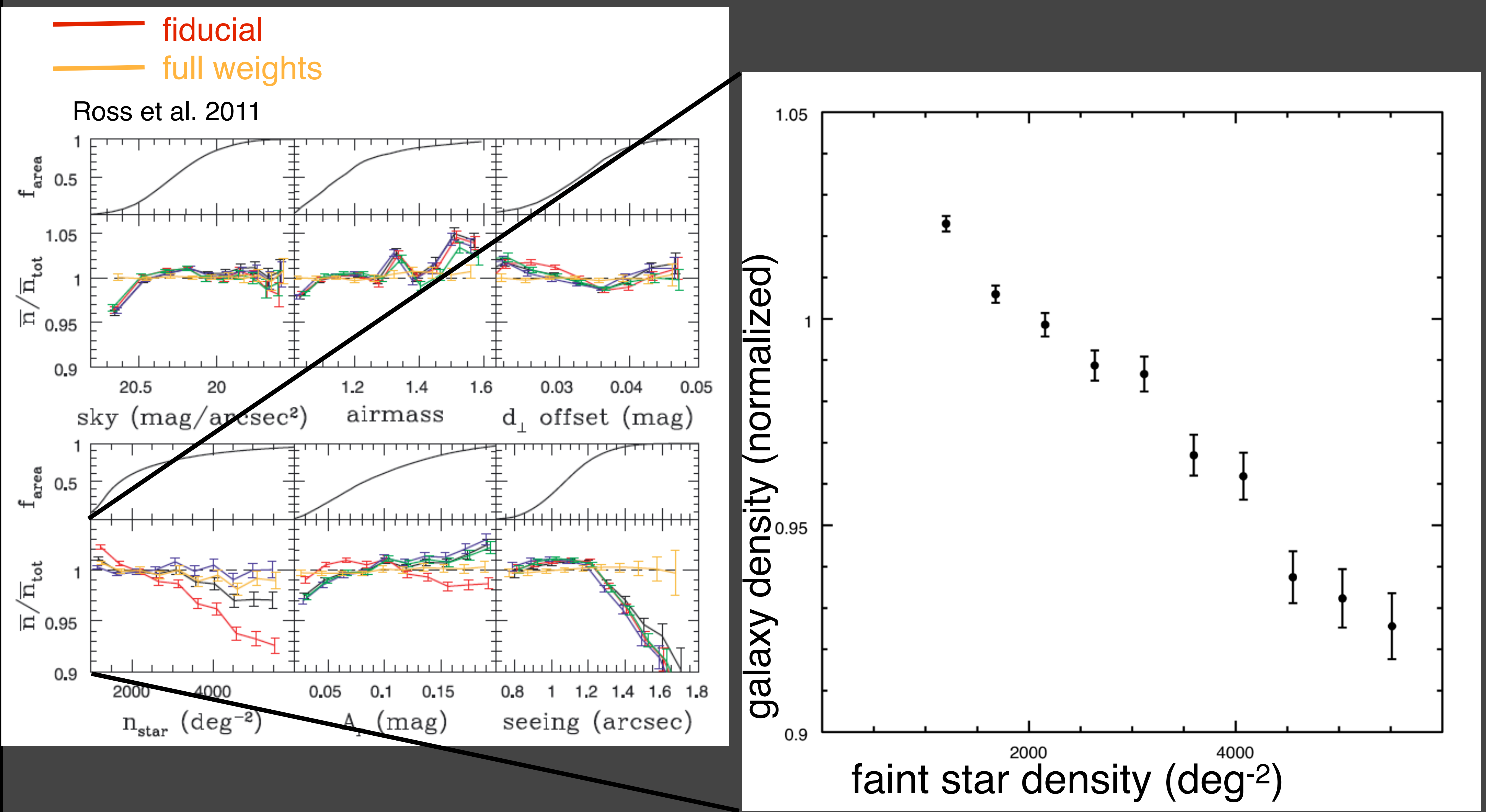
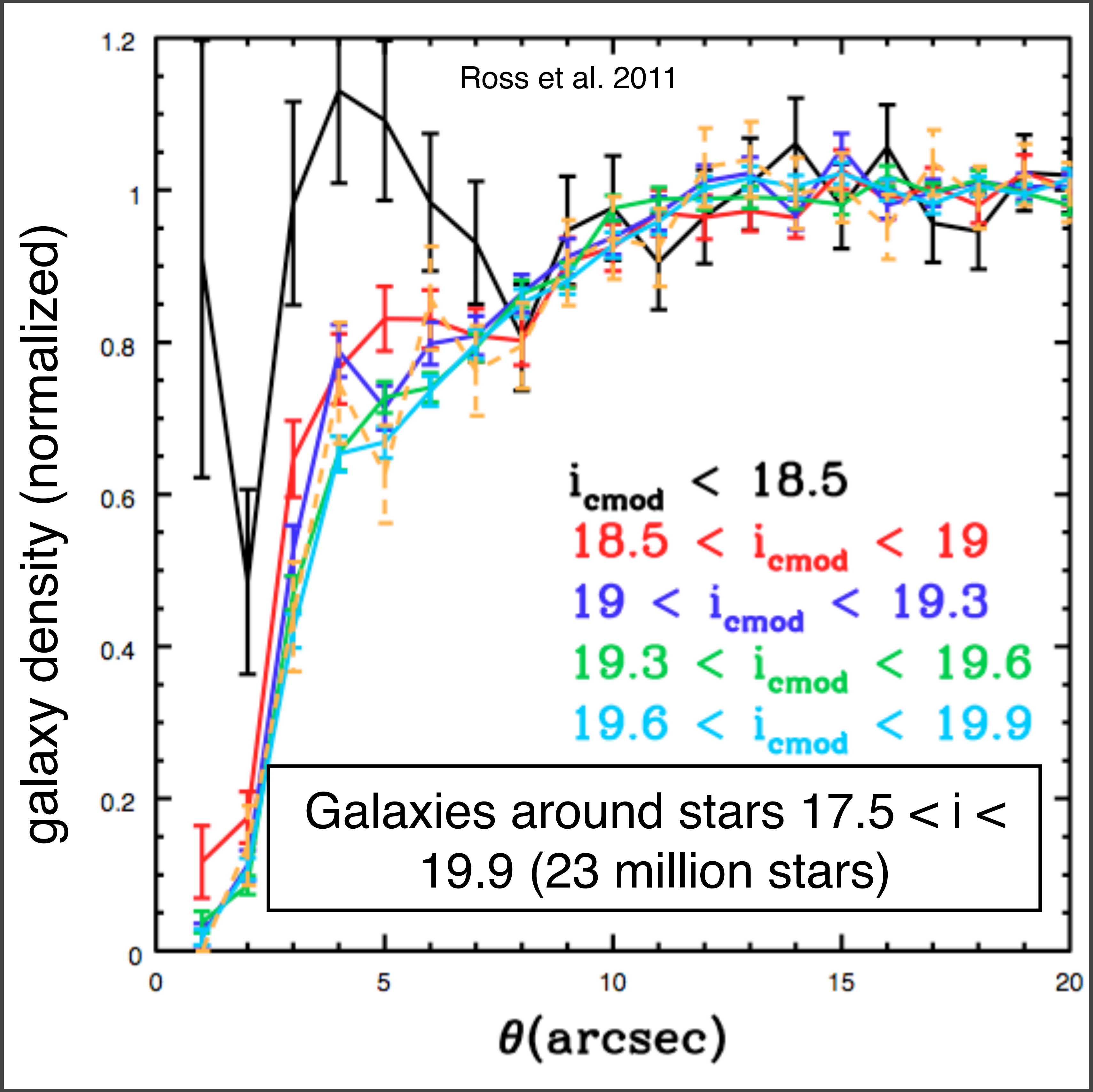
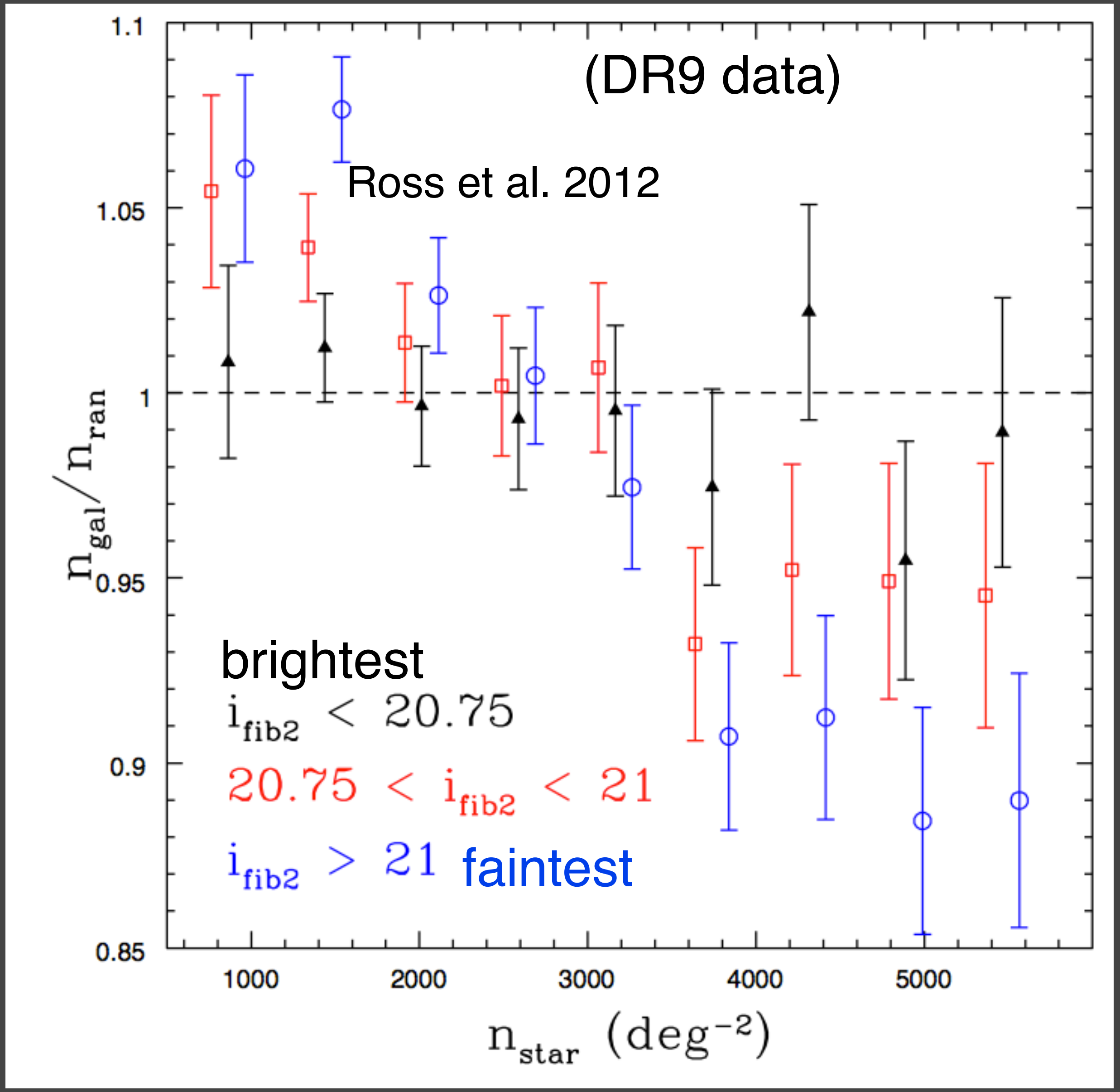


Stars Occult Area

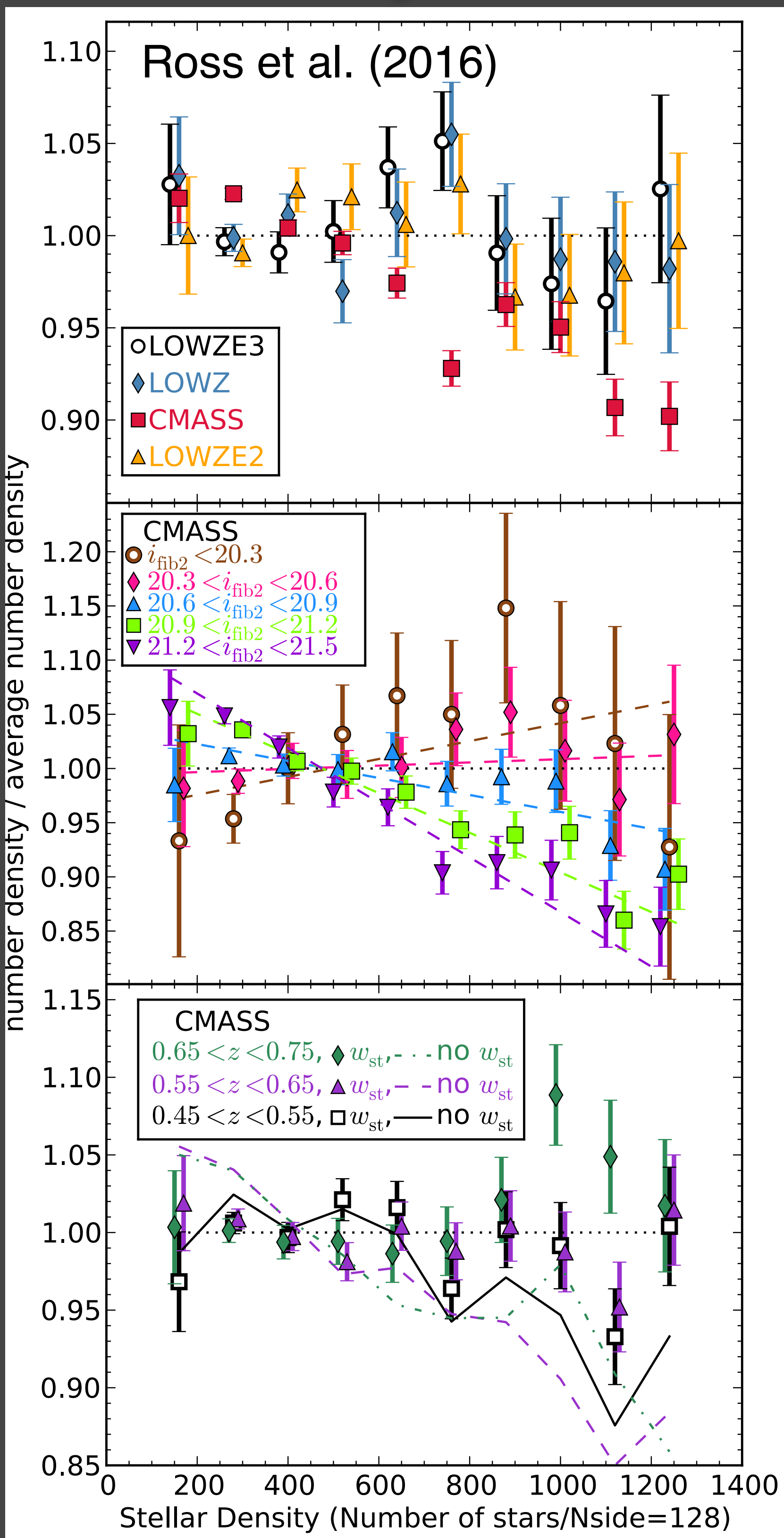


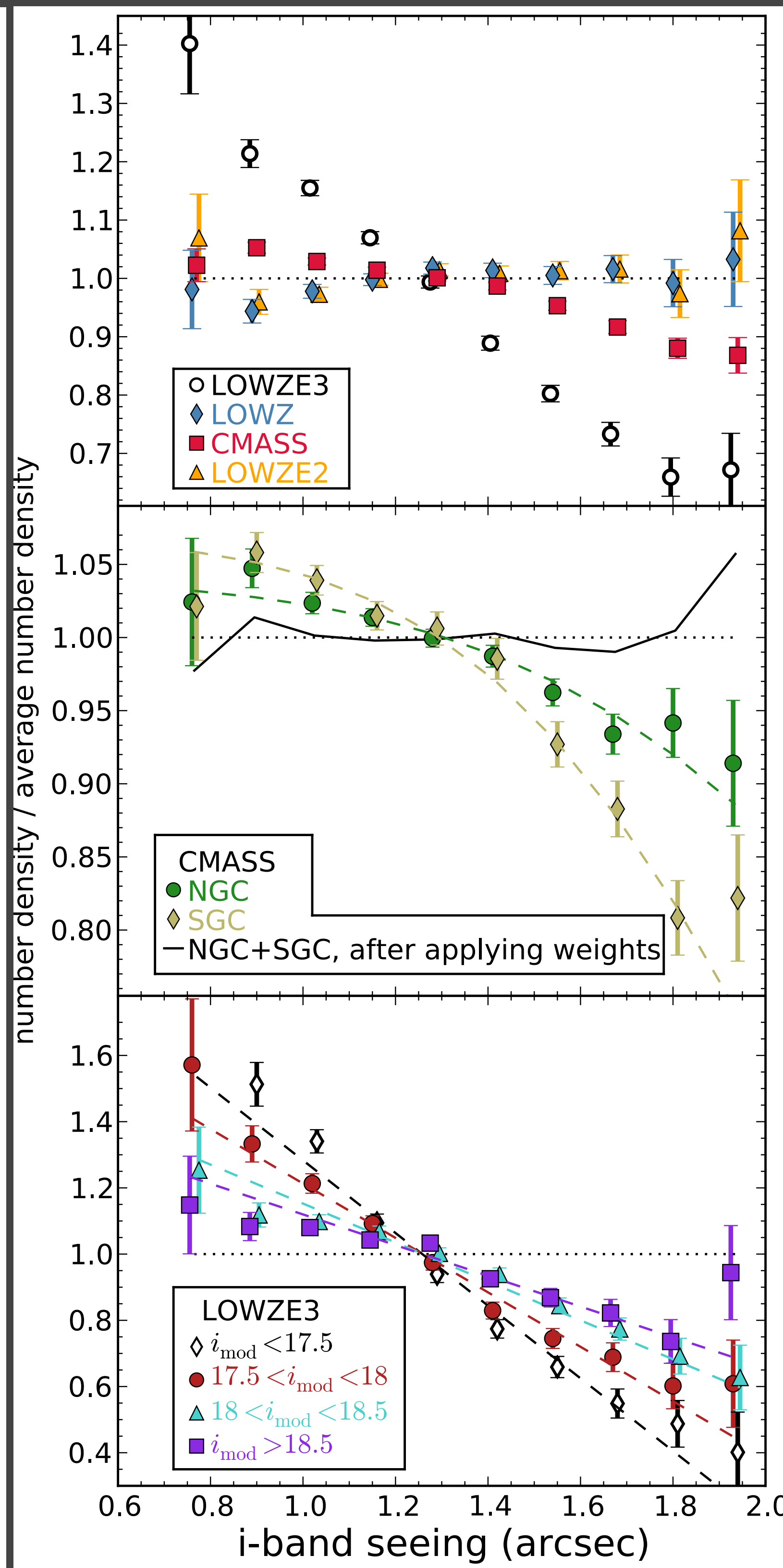
Stars and BOSS Surface Brightness

- Spectroscopic results confirm galaxy vs. stellar density relationship
- Depends on surface brightness
- Corrected with weights based on linear fits



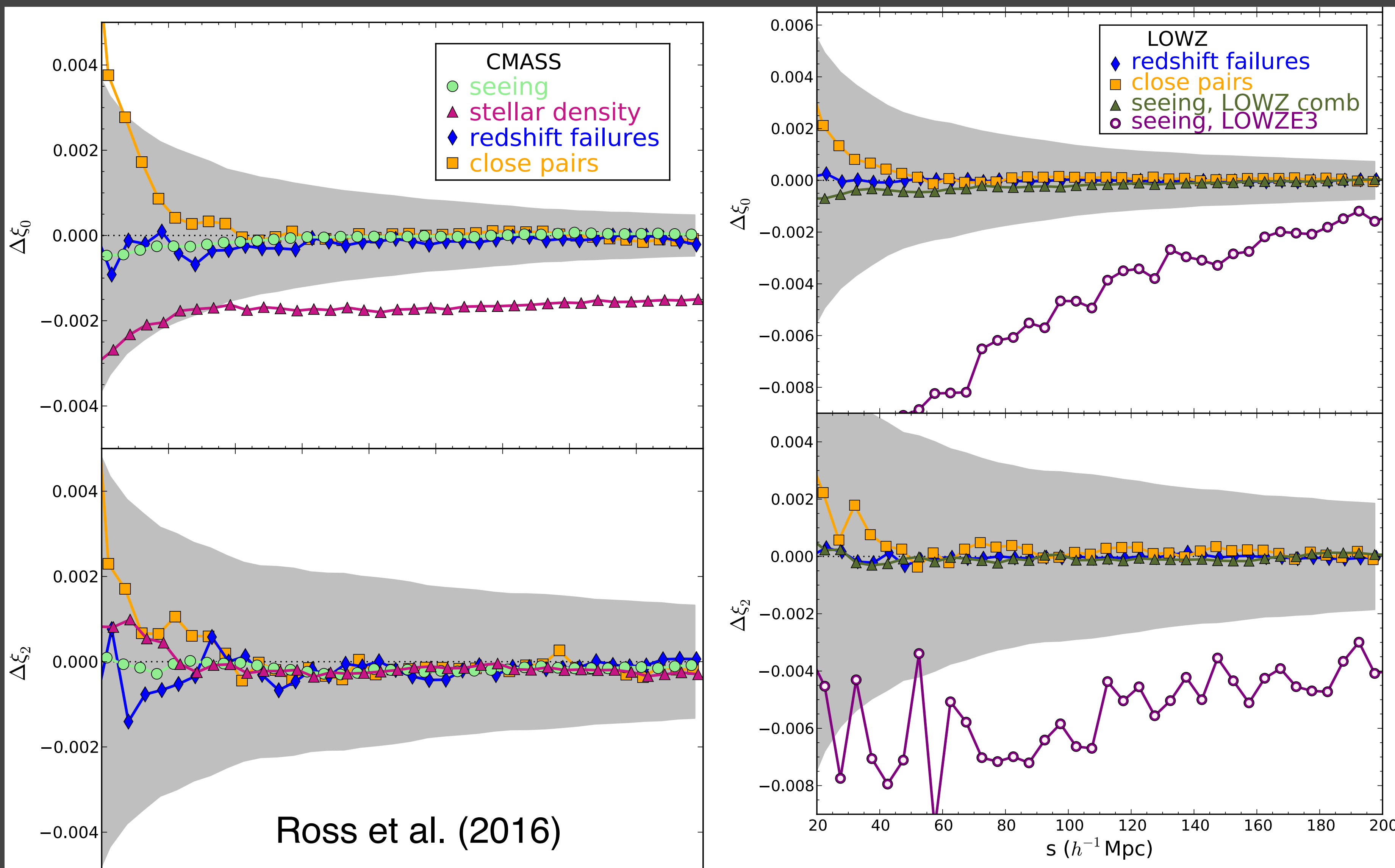
Systematics in final data set





- Stellar density effect remains strong
- Significant effect with seeing due to morphological star/galaxy separation cuts

Systematics in final data set



- Only stellar density has strong effect over full footprint
- (LOWZE3 result is over full footprint, but it is only 660 deg^2 in combined)
- Simulating effects yield no bias in BAO, negligible effect on statistical uncertainty