Robust Measurements of the Large-Scale Clustering of Galaxies and Quasars

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Outline

- DESI Legacy Imaging Surveys Data Release 9 Galaxies and Quasars
  Clustering in BASS/MzLS (dr9m/0.42.0)-- special thanks to **Anand Raichoor**!

- SDSS-IV eBOSS Data Release 16 Quasars
  Enhance the method to handle the sparsity of quasars
  Enable robust constraint on the local-type primordial non-Gaussianity
  1D and 2D tests of residual fluctuations

DESI Legacy Imaging Surveys DR9

Primordial non-Gaussianity with the DESI Imaging and SV data (Year 1)
Project [38], join @ https://desi.lbl.gov/desipub/app/PB/show_project?pid=38

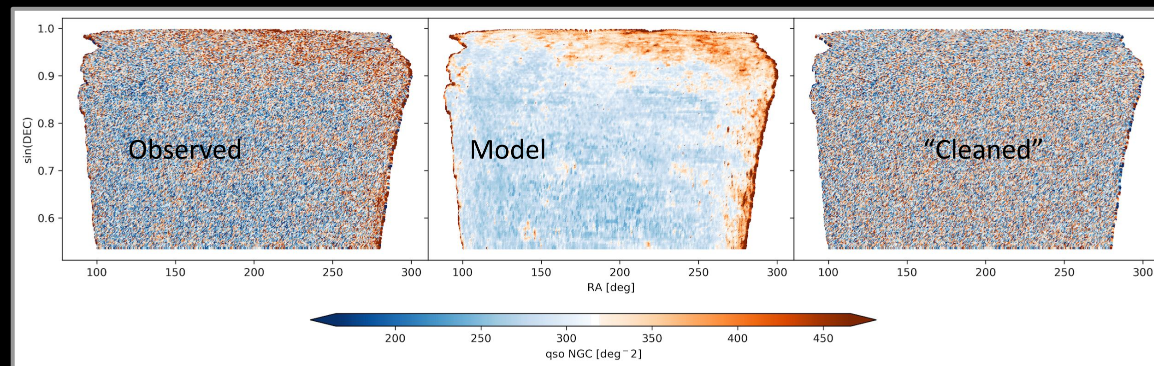
See, e.g., Pullen & Hirata (2013) with photometric quasars from SDSS DR6

DESI Legacy Imaging Surveys DR9m (BASS/MzLS)

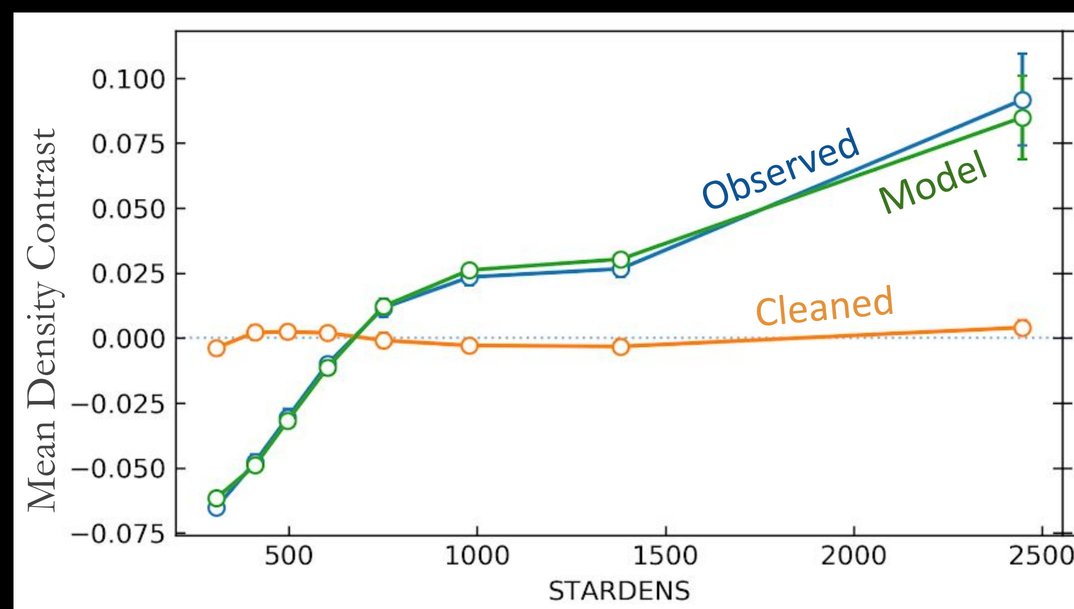
dr9m/0.42.0

Quasars

Thanks to Anand Raichoor!



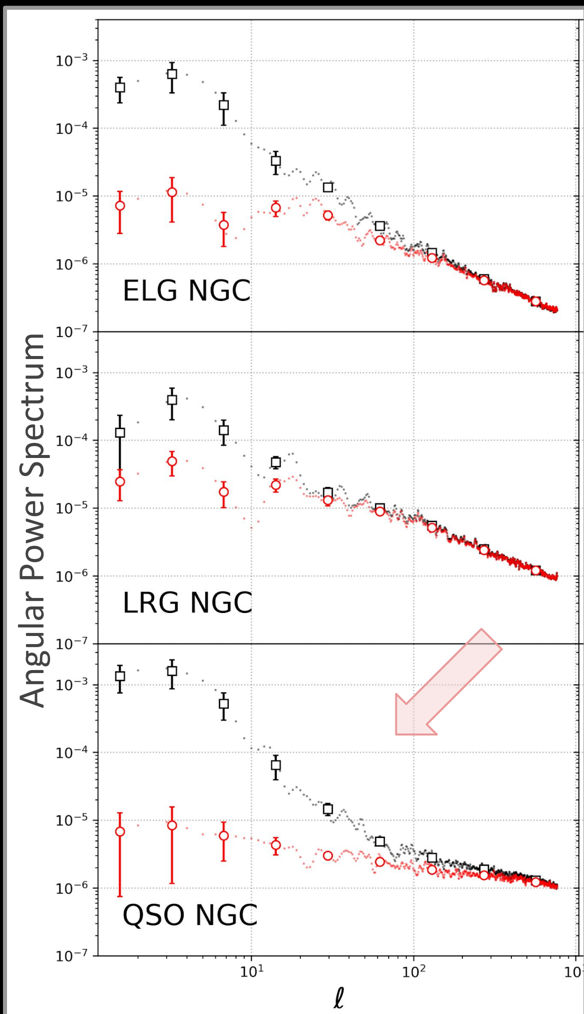
Question: Can we model the impact of imaging variables, such as seeing, depth, and extinction, on the observed density field of targets?



Mean density contrast:

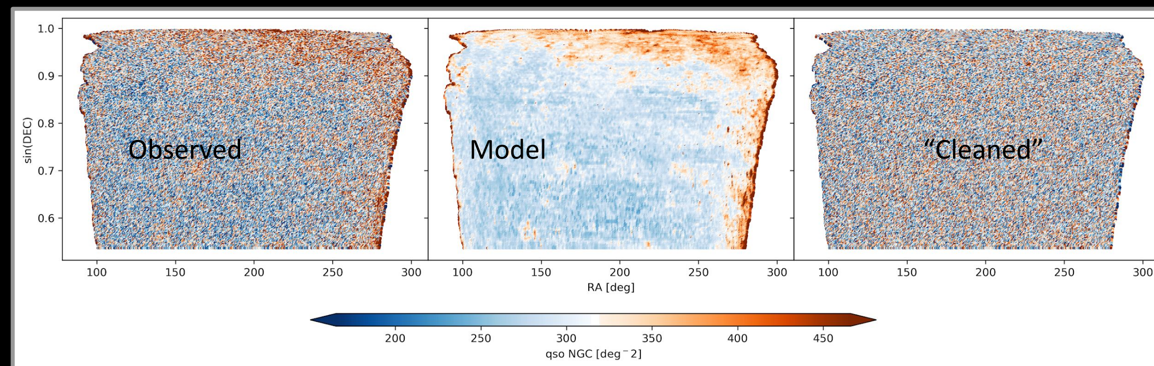
$$\delta = \frac{n_{g,\mathrm{bin}}}{< n_{g,\mathrm{bin}} >} - 1$$

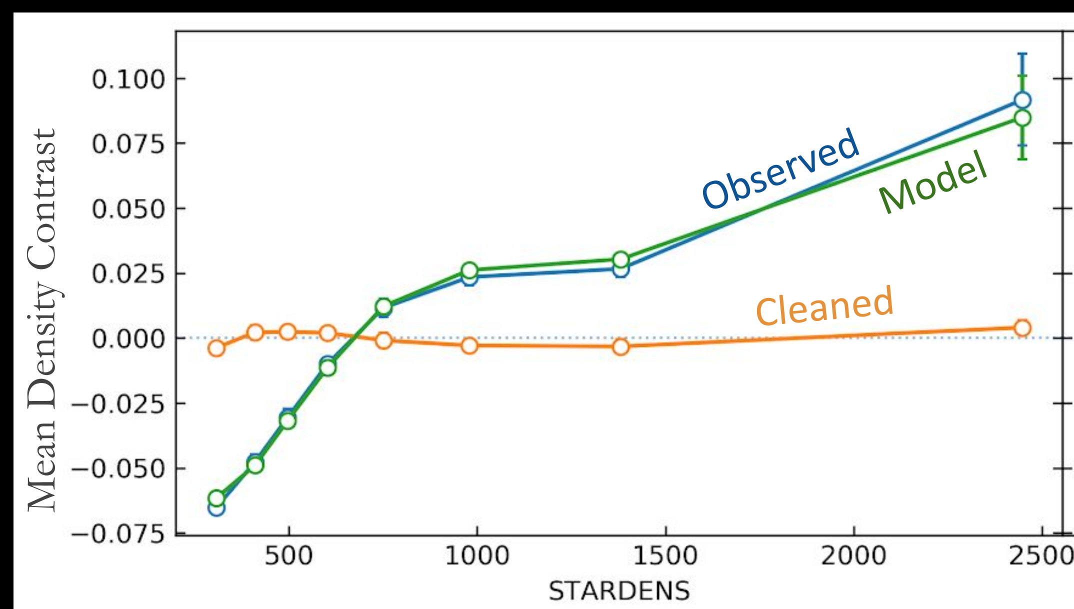
DESI Legacy Imaging Surveys DR9m (BASS/MzLS)



Quasars

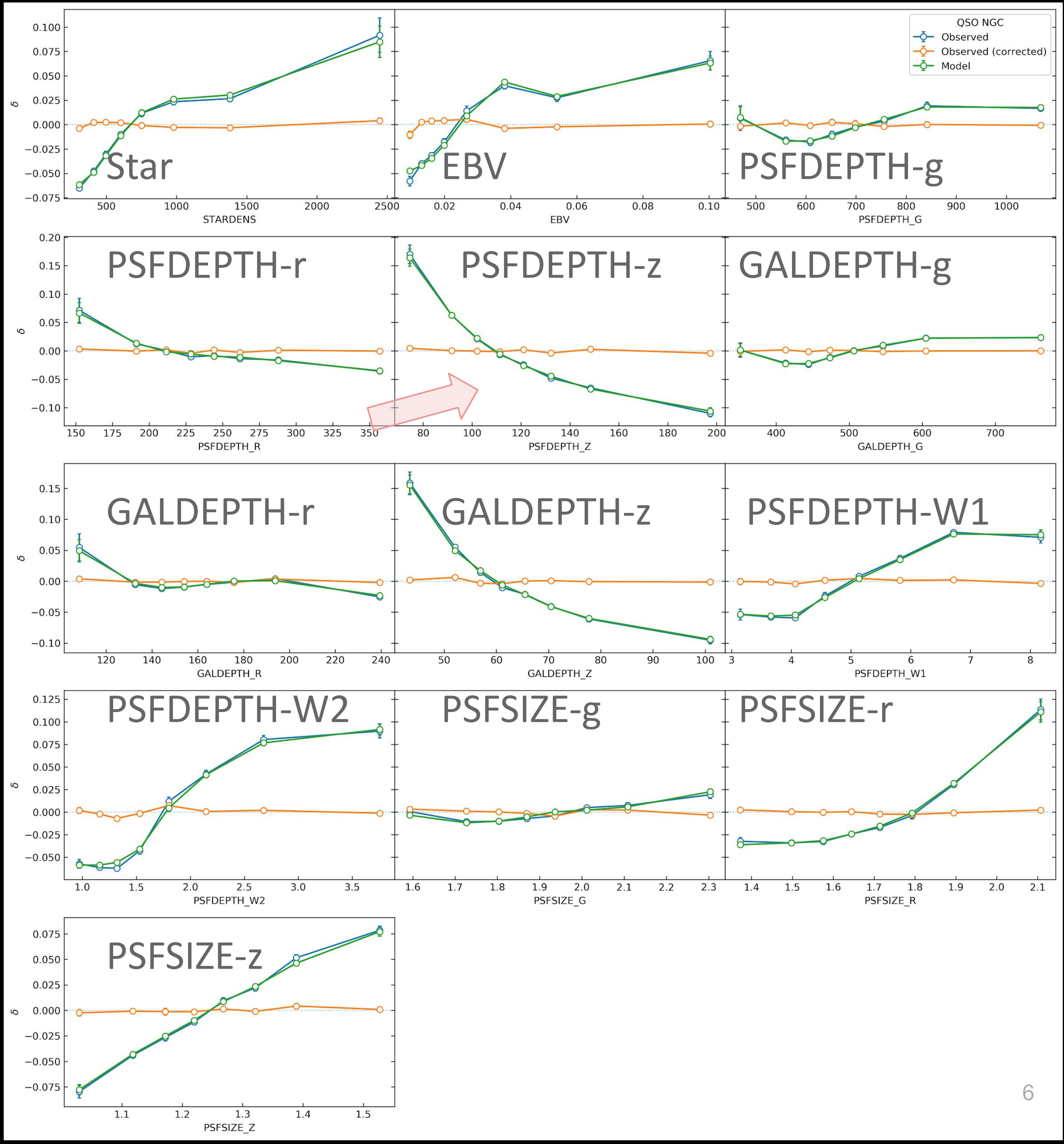
Thanks to Anand Raichoor!





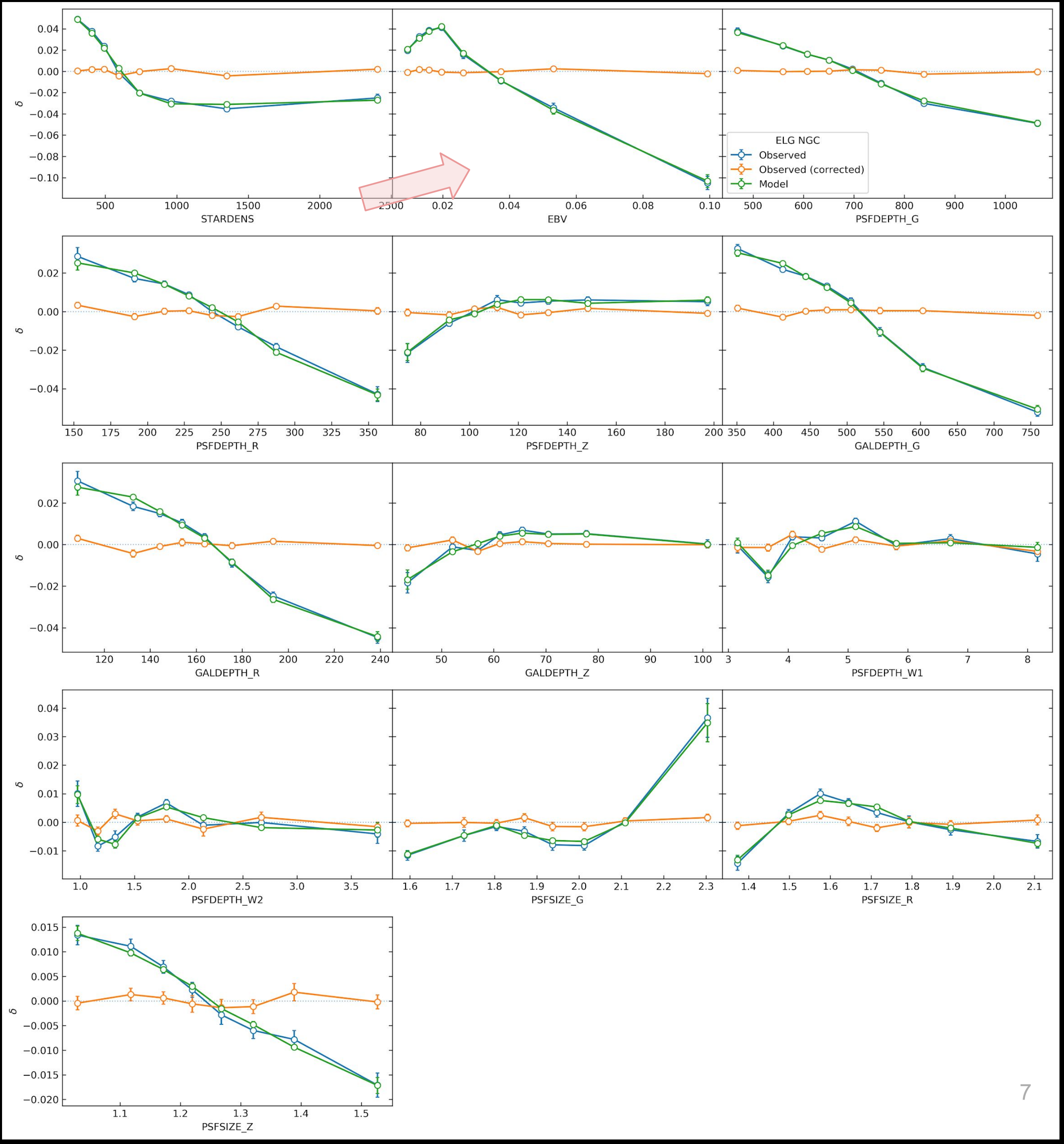
QSOs

20% variations against PSFDEPTH-z



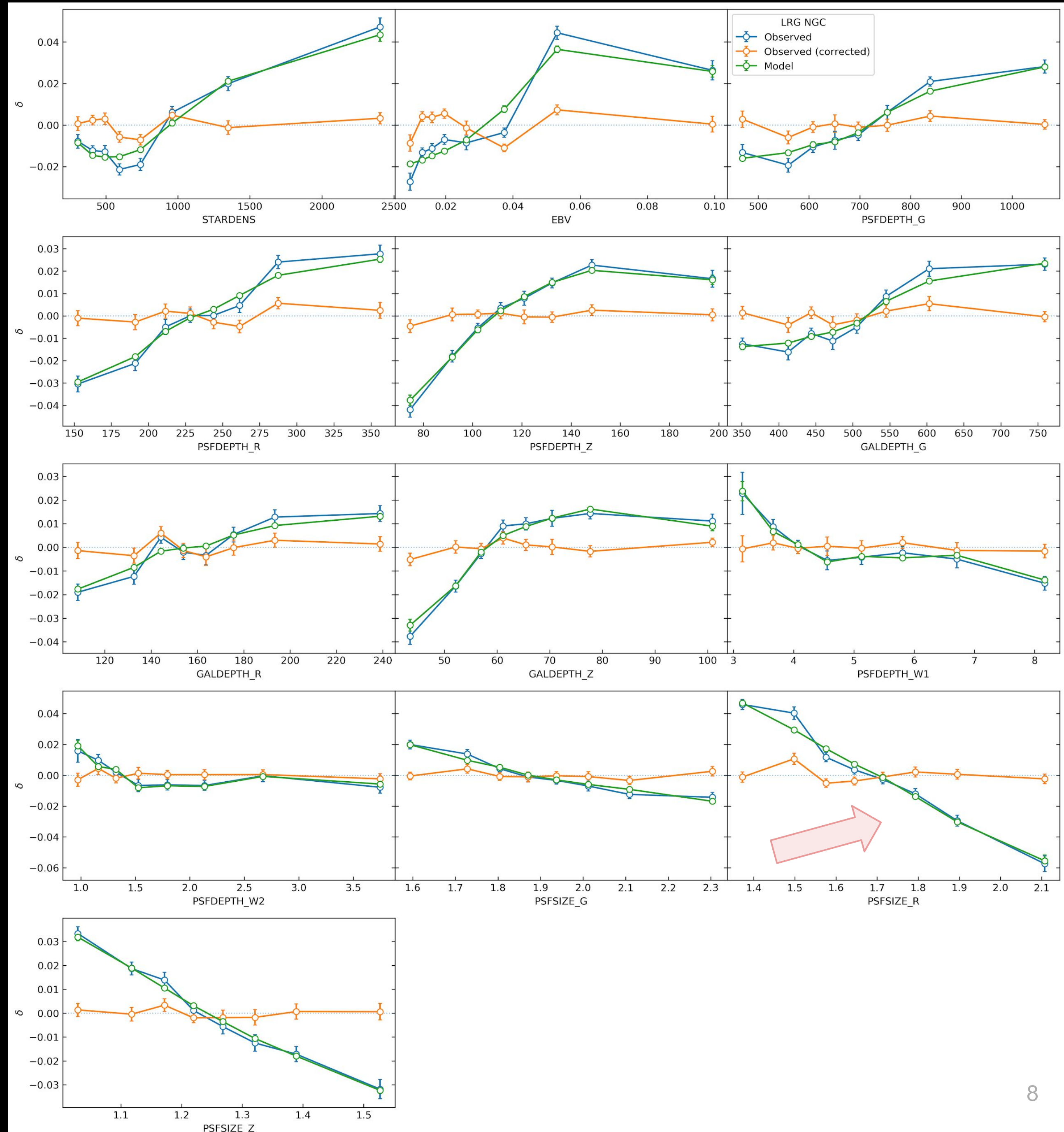
ELGs

10% variations against E[B-V]



LRGs

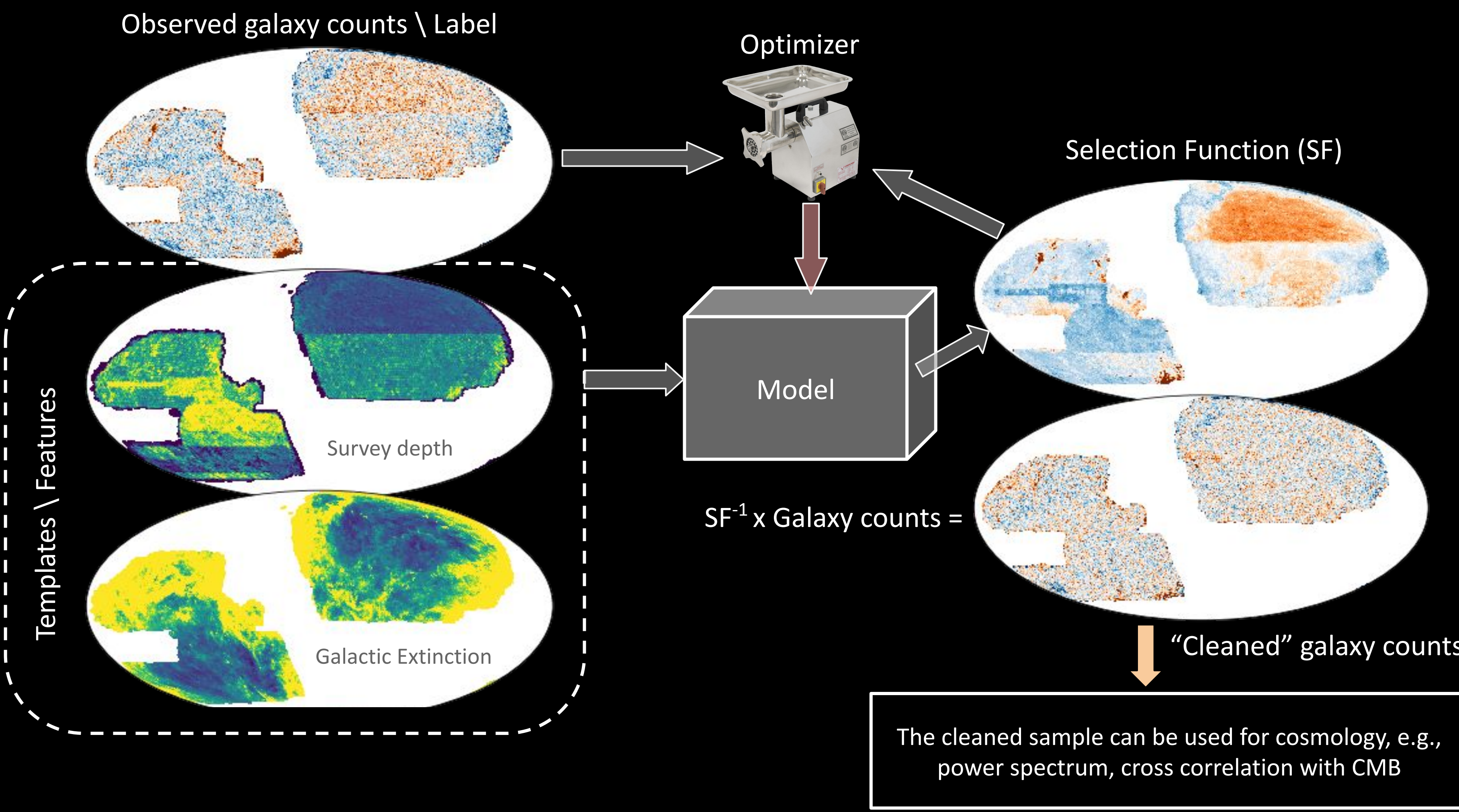
5% variations against PSFSIZE-R



Template-based Modeling of **Imaging Systematics**

DESI Legacy Imaging Surveys DR7 Emission Line Galaxies, Rezaie et al. (2020)
SDSS-IV DR16 Quasars, Rezaie et al. (in prep)

Template-based Modeling of Systematics



Standard Method

In pixel i, the observed galaxy density $n_{g,\,i}$ is a combination of cosmological signal and systematics. The latter is assumed to be a linear function of imaging attributes $\mathbf{x}_i$ such as Galactic extinction, stellar density, seeing, sky brightness, and depth:

$$n_{g,\,i} = \text{cosmology} + \text{systematics} \sim \varepsilon + \Sigma_{j=1}\, \theta_j x_{ij} + \Sigma_{j=1}\, \omega_j x^2_{ij}$$

$$= \varepsilon + Y(\theta, \mathbf{x}_i)$$

Minimizing the Mean Squared Error will train parameters θ (and ω)

$$\text{Cost function } J \sim \Sigma_i\, [n_{g,\,i} - Y(\theta, \mathbf{x}_i)]^2$$

Finally,

$$\text{Systematic weights } w_{systot} \sim 1\,/\,Y \text{ with } \theta = \theta_{best}$$

See e.g., Bautista J. E., et al. ApJ (2018)

Cost Function: Poisson Negative Log-Likelihood

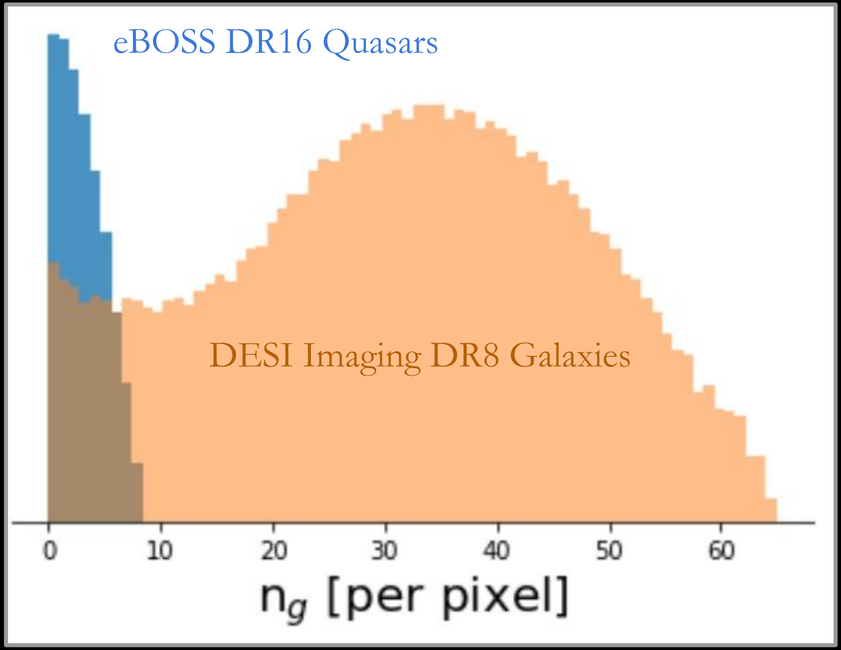
We assume the observed number of quasars in each pixel n_i is a Poisson process that depends on imaging attributes x_i:

$$f(n_i|\theta, \mathbf{x}_i) = \frac{Y(\theta, \mathbf{x}_i)^{n_i} e^{-Y(\theta, \mathbf{x}_i)}}{n_i!}$$

$$L = f(n_1, ..., n_N|\theta) = \prod_{i=1}^{N} f(n_i|\theta, \mathbf{x}_i)$$

The cost function is then defined as negative log likelihood:

$$J = -\log(L) = \sum_{i=1}^{N} [Y(\theta, \mathbf{x}_i) - n_i \log(Y(\theta, \mathbf{x}_i))]$$

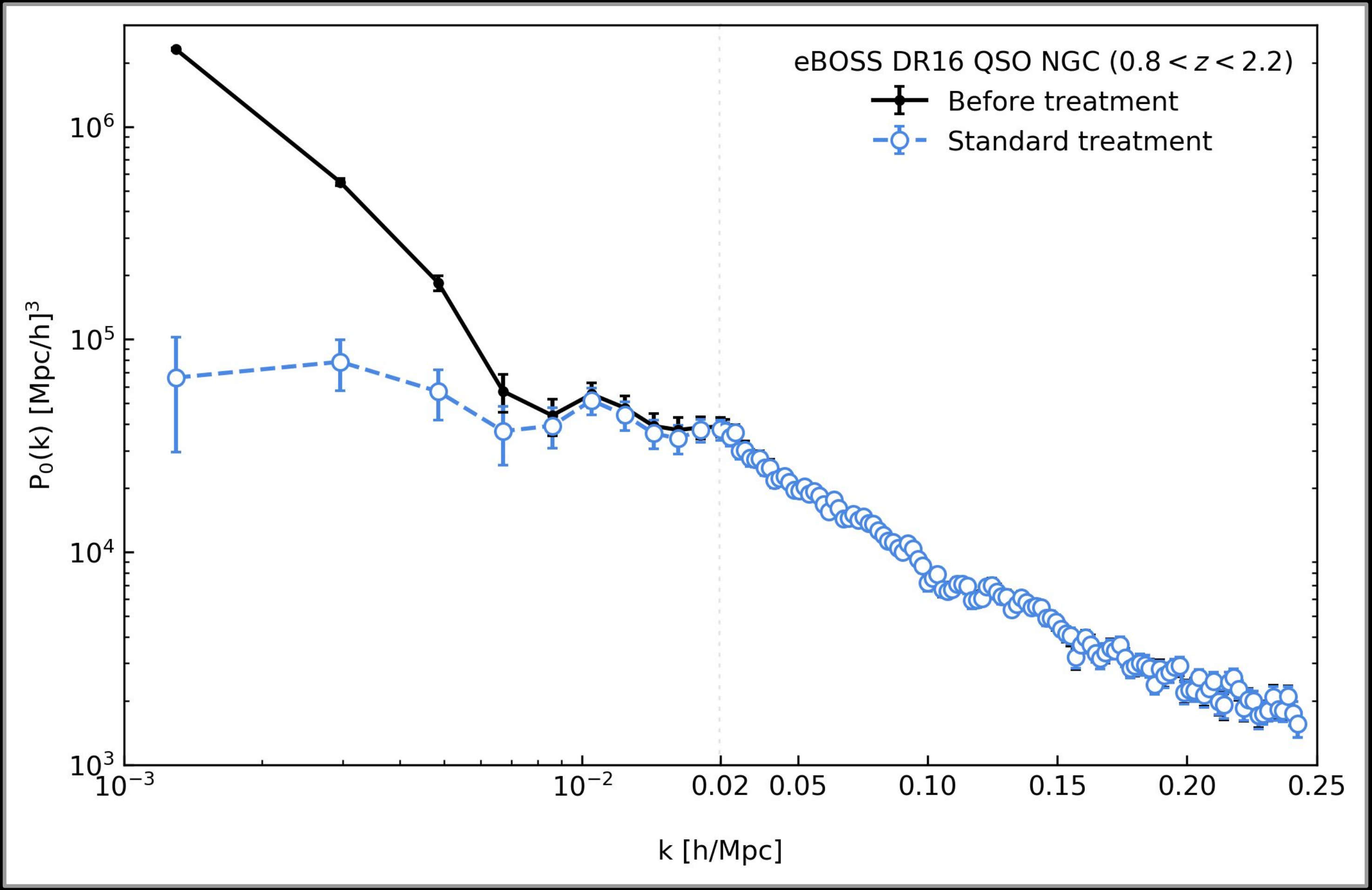


*y-axis has a logarithmic scaling.

M. Rezaie et al. (in prep.)

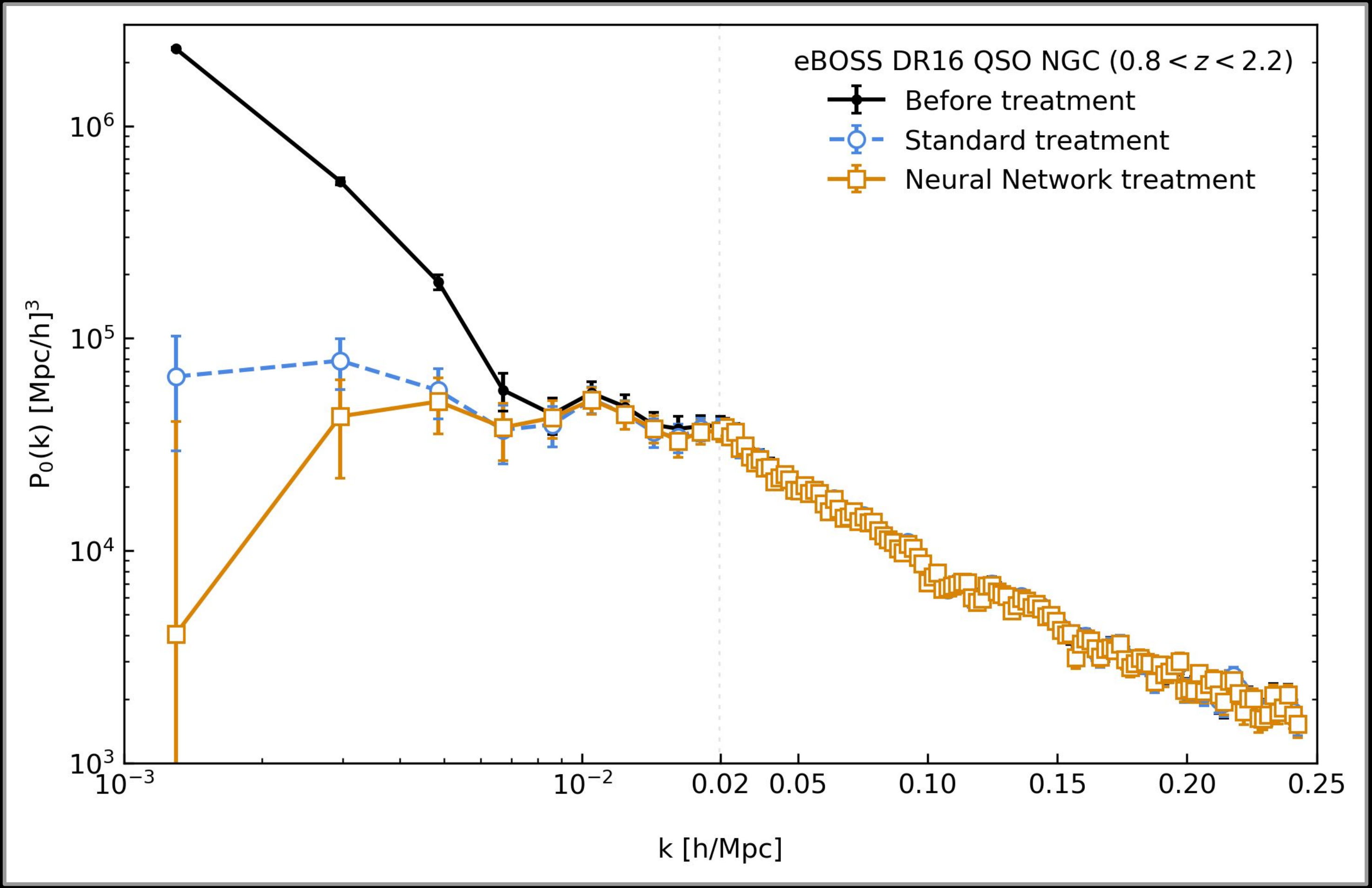
Final sample of Quasars from SDSS eBOSS DR16

Is this sample clean enough? 👀



Final sample of Quasars from SDSS eBOSS DR16

Is this sample clean enough? Probably not



M. Rezaie et al. (in prep.)

Local Primordial non-Gaussianity

Komatsu & Spergel 2001:

$$\Phi = \varphi + f_{NL}\varphi^2$$

Adds a shift to the bias (e.g., Dalal et al. 2008):

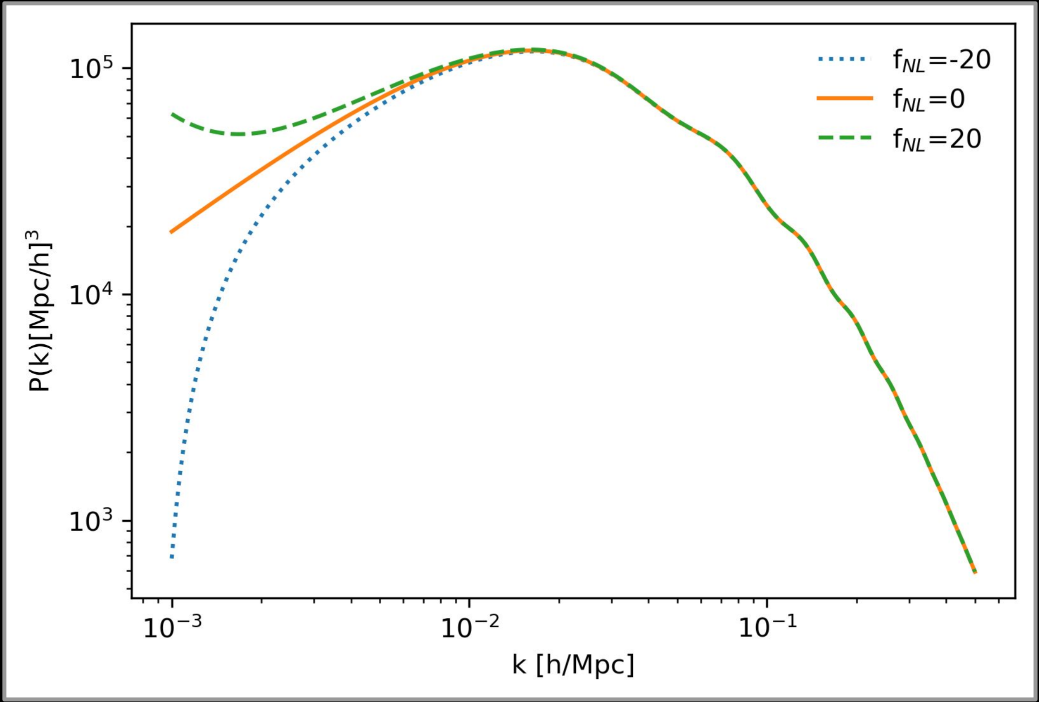
$$\delta_g = (b_g + \alpha\, f_{NL} k^{-2})\, \delta_m$$

- ➢ CMB (Planck Collab., Akrami et al. 2019)
  $f_{NL} = -0.9 \pm 5.1$ (68% C.L.)
- ➢ LSS (eBOSS DR14, Castorina et al. 2019)
  $-81 \leqslant f_{NL} \leqslant 26$ (95% C.L.)

DESI:
$\sigma(f_{NL})=5$ (Aghamousa et al. 2016)

DESI + Simons Observatory or CMB-S4:
$\sigma(f_{NL})=3.4$ or 2.8 (Münchmeyer et al. 2018)

Rubin Observatory + CMB-S4:
$\sigma(f_{NL})= 0.4\text{-}1$ (Schmittfull and Seljak 2018)



A non-zero detection of PNG ($f_{NL} \gtrsim 1$) will rule out single-field inflationary models (see e.g., Alvarez et al. 2014)

Primordial non-Gaussianity with eBOSS DR16

Objective:
Constrain inflation with galaxy clustering

Sample:
eBOSS DR16 Quasars *$0.8<z<2.2$*

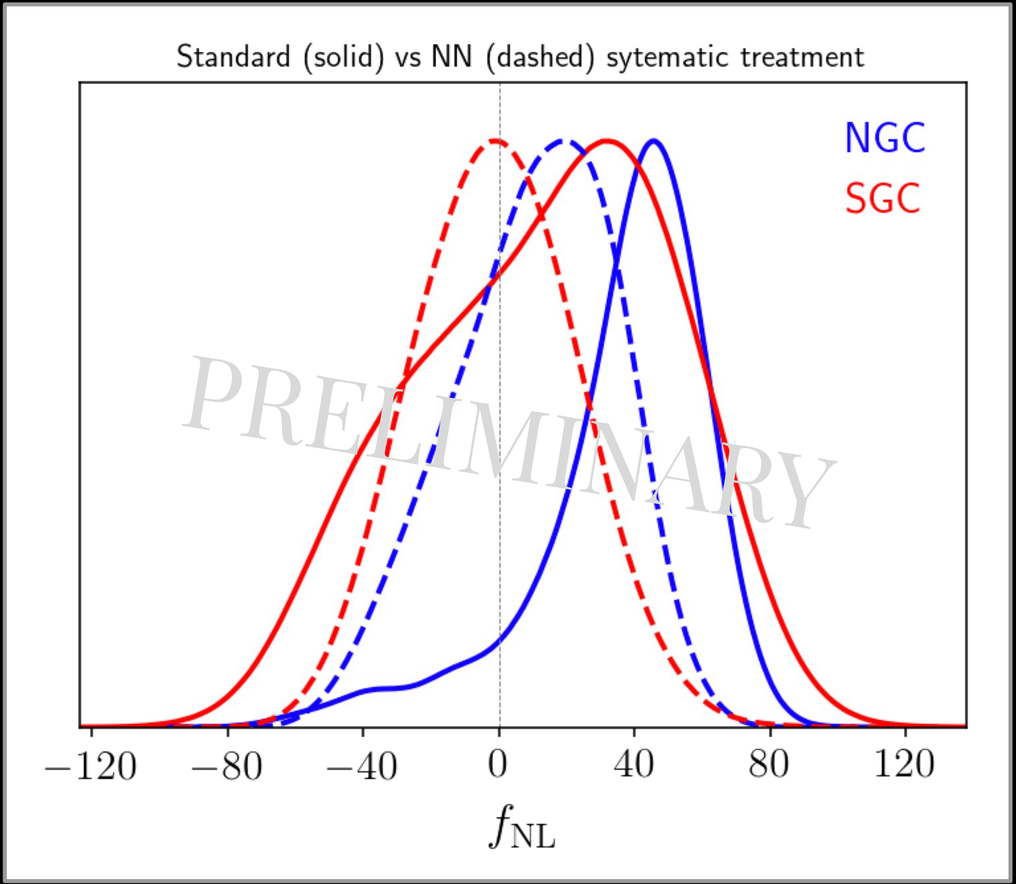
Methodology:
- Scale dependent halo bias due to PNG
- Very sensitive to large scales
- Correct systematic treatment is crucial

$$b_{\rm tot} = b + \Delta b$$

$$\Delta b \propto \frac{f_{\rm NL}}{k^2}$$

This is even without redshift weighting (Castorina et al. 2019, Muller et al. 2019), which accounts for the bias evolution over redshift. We expect 30-40% improvement!

Eva Müller et al. (in prep)



Credit: Figure by Eva Müller

Residual Error Test I

1. Group pixels given a particular imaging variable, e.g., Extinction.
2. Compute the mean density contrast in each bin:

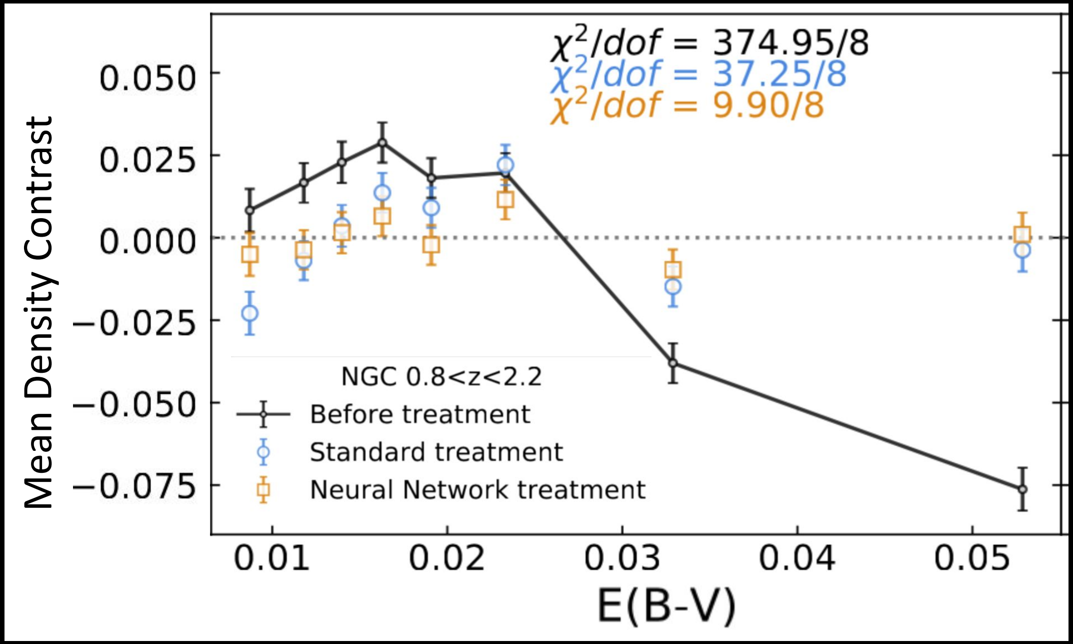
$$\delta = \frac{n_{g,\mathrm{bin}}}{< n_{g,\mathrm{bin}} >} - 1$$

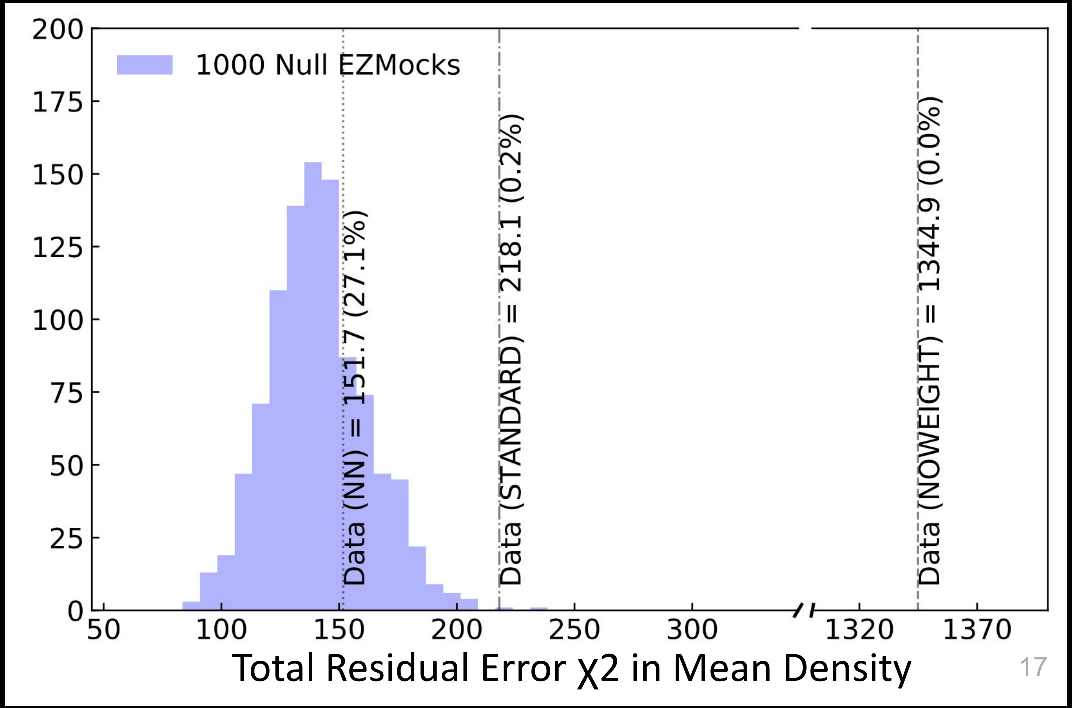
Then, δ is not expected to depend on the extinction.

$$\chi^2 = < \delta \mid C^{-1} \mid \delta >$$

C is the covariance matrix.

M. Rezaie et al. (in prep.)





Residual Error Test II

Cross correlate the quasar density map (p=nqso) with the systematic map, e.g., (q=ebv) and normalize them by the auto-correlation of the systematic:

$$\hat{C}_\ell^{p,q} = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} \hat{a}_{\ell m}^{p} \hat{a}_{\ell m}^{q*}$$

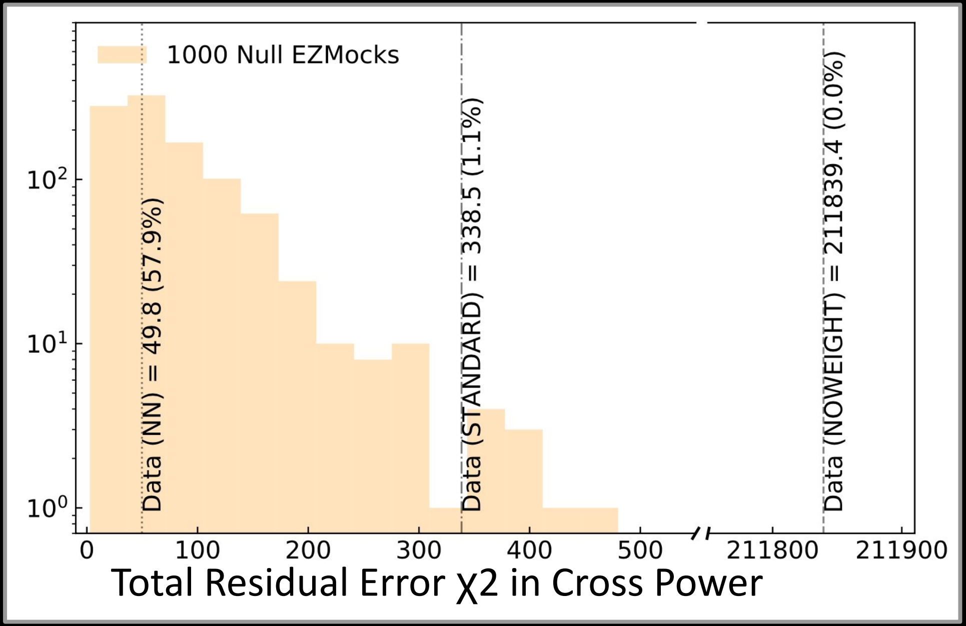
Normalized cross correlation:

$$Cx = (C^{s,g})^2 / C^{s,s}$$

Total residual error:

$$\chi 2 = < Cx \mid C^{-1} \mid Cx >$$

C is the covariance matrix.



P-value for the catalog with standard treatment is 1.1%!

M. Rezaie et al. (in prep.)

Summary

In the era of *Big Data* in cosmology, advanced tools are needed to identify and address the various sources of systematic error to fully exploit galaxy clustering and CMB-lensing.

>> developed a method to capture the non-linear imaging systematic effects <<

Near future (~ year):

- ❑ Primordial non-Gaussianity with the DESI Imaging and Survey Validation data.
  Project [38], join @ https://desi.lbl.gov/desipub/app/PB/show_project?pid=38

Future (> 1 year):

- ❑ Cross Correlation of CMB lensing and DESI/Rubin Observatory catalogs
  >> Robust f_{NL} constraint with sample variance cancellation (e.g., Munchmeyer et al. 2018)

- ❑ Gravitational Lens Detection:
  >> Develop noise resistant methods
  >> Falsifying various dark matter models (see e.g., Diaz Rivero et al. 2018)

Thank you! Email: mr095415@ohio.edu