Detecting the Doppler magnification dipole from LSST images

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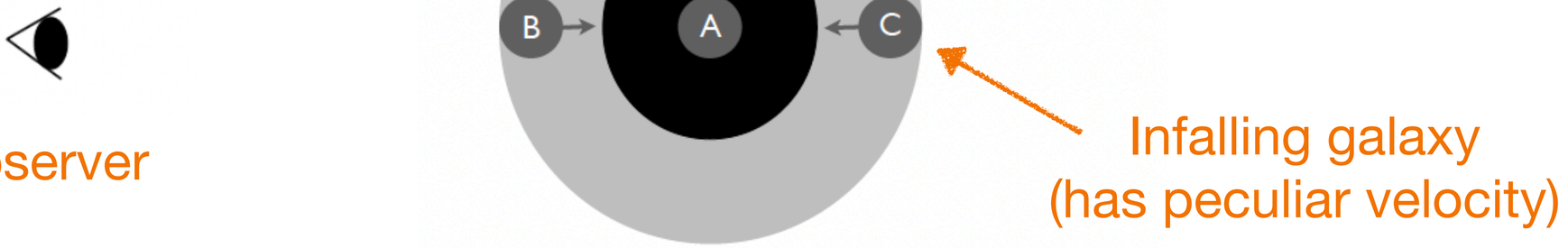
Doppler magnification

Peculiar velocities cause galaxy locations in redshift space to differ from their physical locations.

What does this mean for their apparent sizes and magnitudes vs distances?

Consider an extreme case as an example:

- A, B and C are galaxy surrounding an overdensity. They have the same physical size.
- They also have the same **measured redshift** (due to their peculiar velocities).
  - For B, the angular size would appear **larger** than “expected” at this measured redshift.
  - For C, it would be the opposite.



Bacon et al. 2014

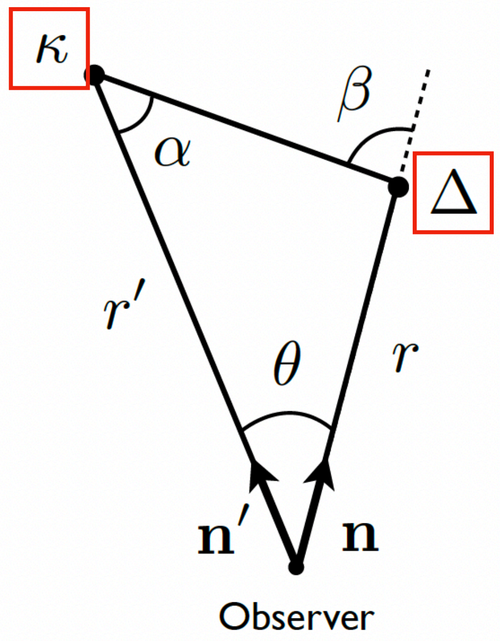
2pt function: Correlate convergence with overdensity

Efficient statistics developed to capture this effect:

$$\xi^{\Delta\kappa} = \langle \Delta(z, n)\kappa(z', n') \rangle$$

Legacy Survey of Space and Time (LSST)
galaxy sizes, magnitudes

The Dark Energy Spectroscopic Instrument (DESI)
galaxies redshift info



Dipole of this 2pt function is uniquely sensitive to Doppler magnification

At z ~0.05 - 0.45, the Doppler contribution dominates over gravitational lensing

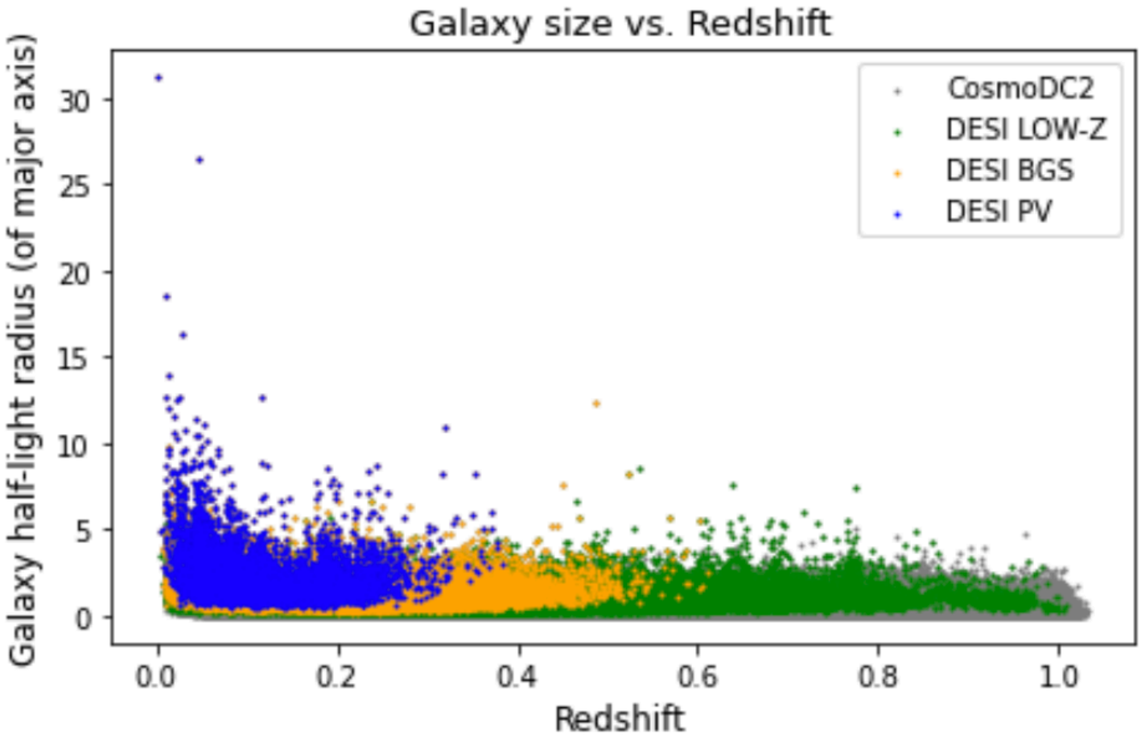
Bonvin et al. 2017

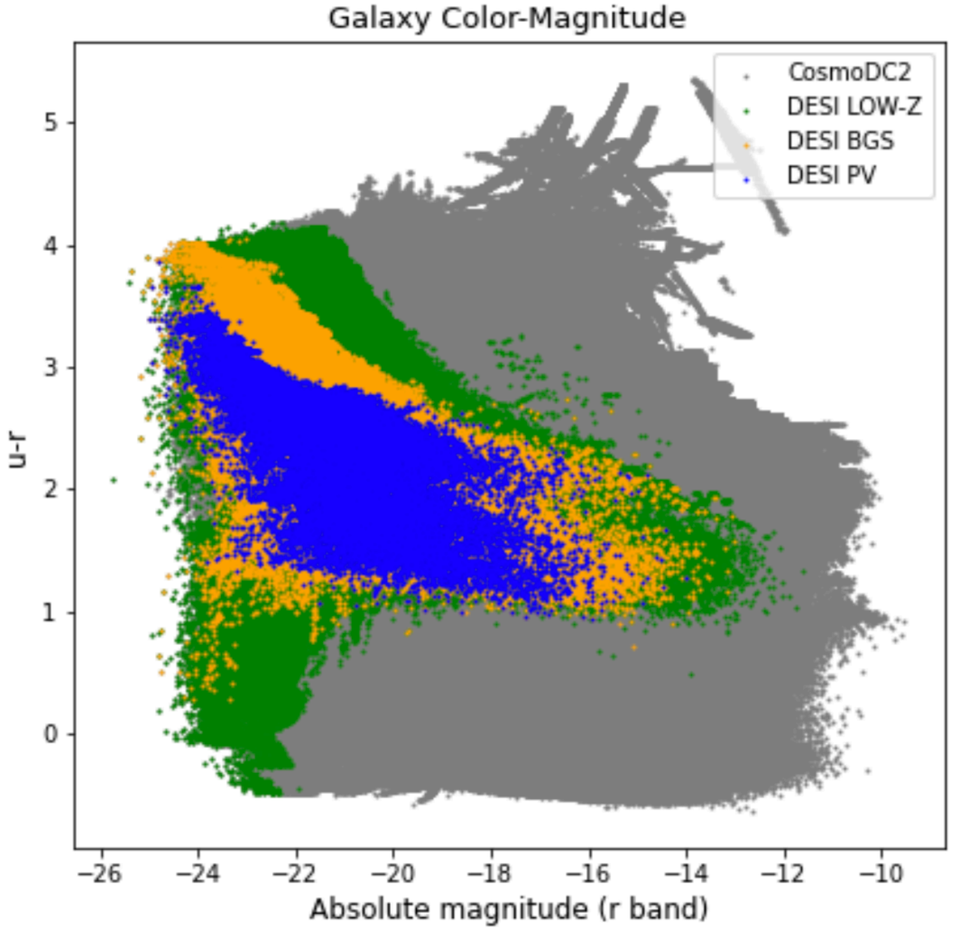
Sample selection from CosmoDC2

Korytov et al. (LSST DESC) 2019

Select DESI *spectroscopic galaxies in* LSST *sample*

- CosmoDC2: Large synthetic galaxy catalog created for LSST
- 440 sq. deg, up to redshift of z = 3
- Max magnitude depth of 28 in the r band





How to measure sizes and magnitudes?

https://github.com/GalSim-developers/GalSim

Image simulation tool: **GALSIM**

An open-source software for generating images of stars and galaxies using variety of methods

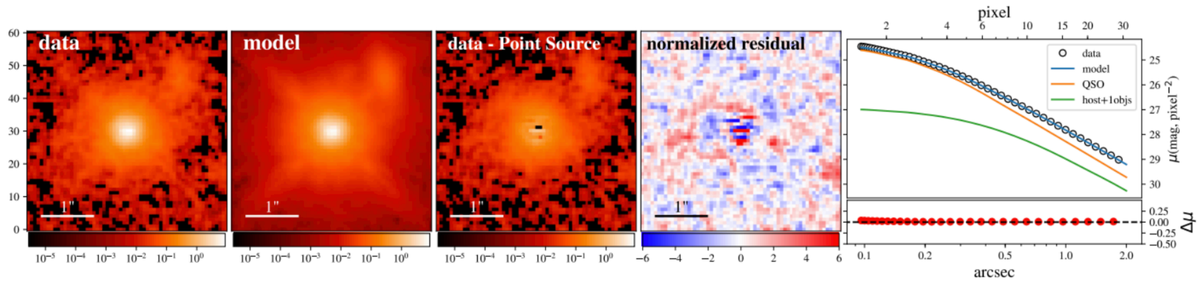
- variety of light profiles for galaxies and PSFs
- fast image simulation
- simulates realistic optical and atmospheric behaviour
- provides various noise realisations

Galaxy size measurement tool: **galight**

Need to understand measurement errors and possible bias

galight - Galaxy shapes of Light

A Python-based open-source package that can be used to perform two-dimensional model fitting of optical and near-infrared images to characterize the light distribution of galaxies with components including a disk, bulge, bar and quasar.



https://github.com/dartoon/galight

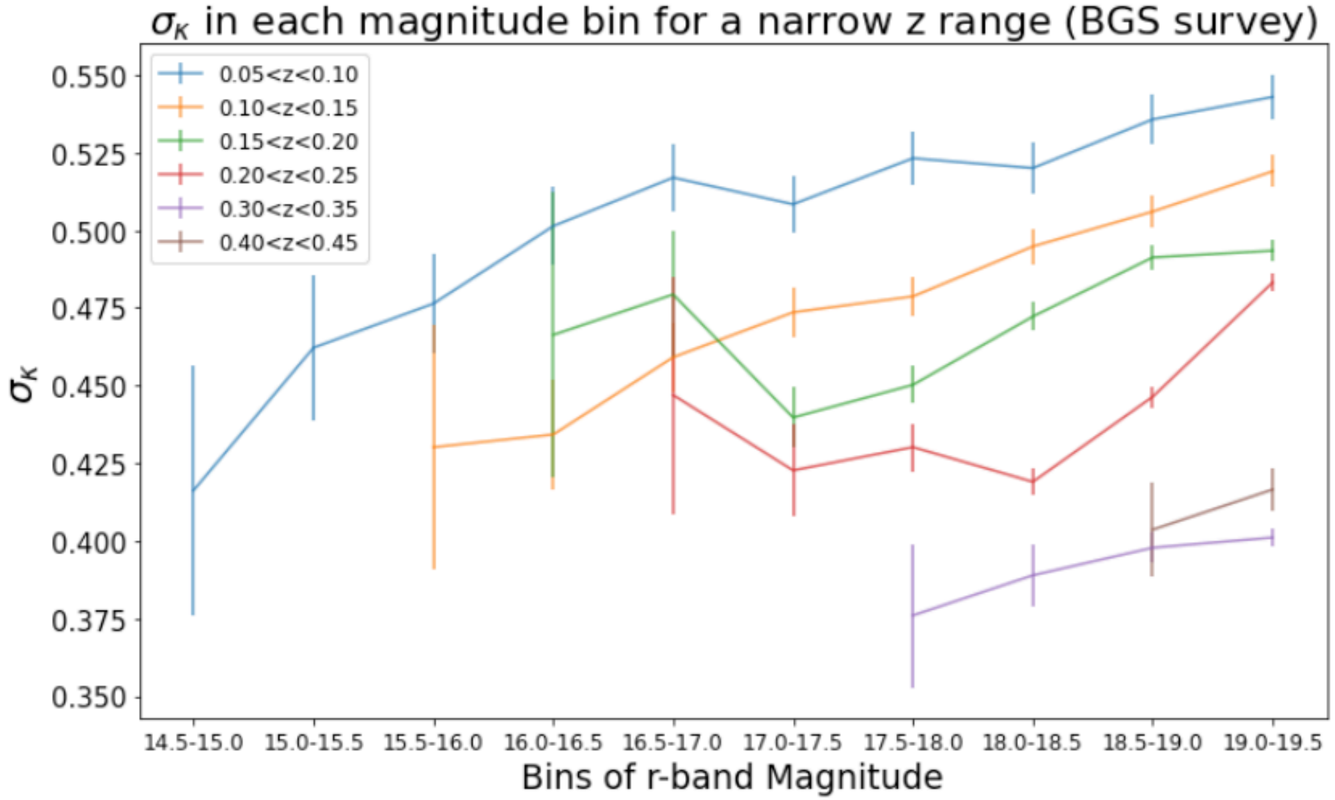
Uncertainties

$$\sigma_\kappa^2 = \sigma_{intrinsic}^2 + \sigma_{measured}^2$$

Most important source of uncertainties is the scatter of convergence

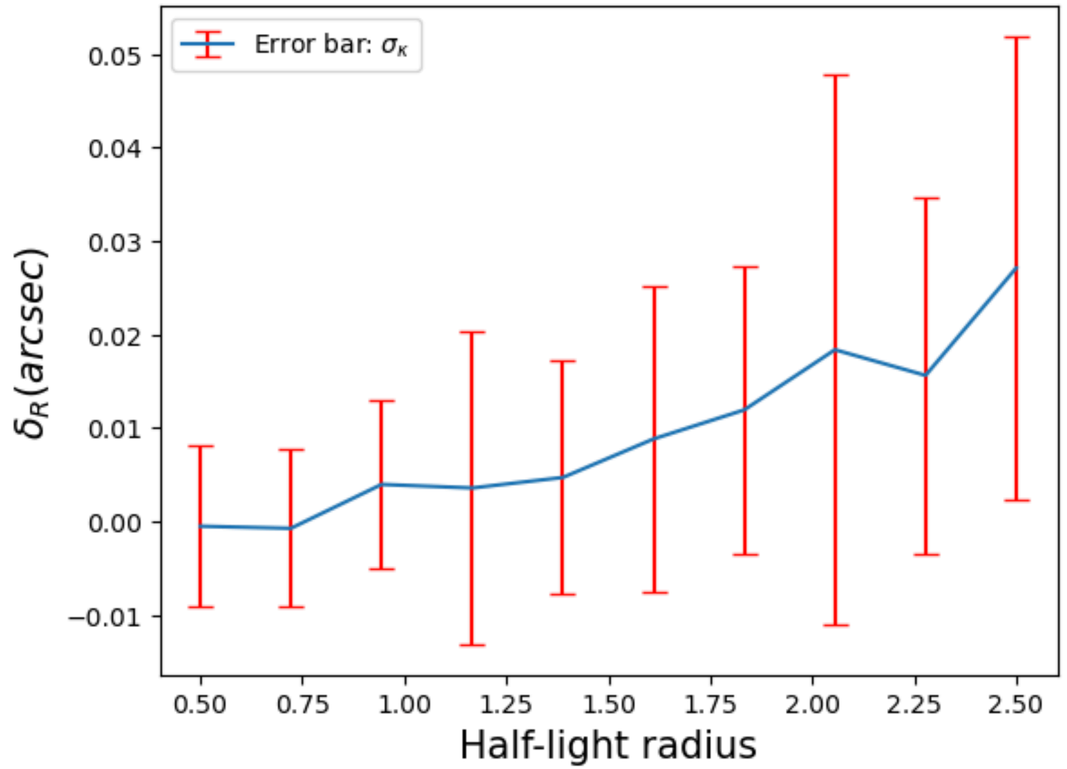
Intrinsic galaxy size variation:

- DESI BGS size scatter in CosmoDC2
- Typical σ_κ is ~0.4-0.5



Size measurement uncertainties:

- Simulated range of half-light radii, redshifts and r-band mags + realistic LSST image noise
- Low scatter, small bias (increases with HLR)



Conclusions

- We have assessed the observability of the Doppler dipole.
- We looked at various properties of our galaxy sample for survey selection.
- Galaxies size measurement uncertainties has very low scatter, main uncertainty contribution is from the intrinsic size variation. Overall σ_κ is ~0.4-0.5.
- Our σ_κ value suggests a S/N of around 15. → Detectable

<u>Cosmological Significance:</u>

- The Doppler terms are directly sensitive to the velocity field, making them complementary to RSD. It provides a method to constrain cosmological models, and to test GR and modified theories of gravity.

Covariance of the dipole: ⟶

Error estimation,
Cosmological parameter constraint,
Test of gravity theories

$$\mathrm{cov}[\xi^{\Delta\kappa_{\rm v}}](z,d,d') = \frac{9}{V}\left(1-\frac{1}{\mathcal{H}r}\right)^2\left(\frac{b^2}{5}+\frac{2bf}{7}+\frac{f^2}{9}\right)f^2$$

⟵ Contribution from **cosmic variance**

$$\times\frac{\mathcal{H}^2}{\pi^2}\int dk P^2_{\delta\delta}(k,z)j_1(kd)j_1(kd')$$

$$+\frac{9}{2}\sigma_\kappa^2\frac{\ell_p^3}{V}\left(\frac{b^2}{3}+\frac{2bf}{5}+\frac{f^2}{7}\right)\frac{1}{\pi^2}\int dk k^2 P_{\delta\delta}(k,z)j_1(kd)j_1(kd')$$

⟵ **Shot noise** in the galaxy number counts

$$+\frac{3}{4\pi}\frac{\sigma_\kappa^2}{\bar{n}V}\left(\frac{\ell_p}{d}\right)^2\delta_K(d-d'),$$

⟵ Contribution from the intrinsic error on the **size measurement**

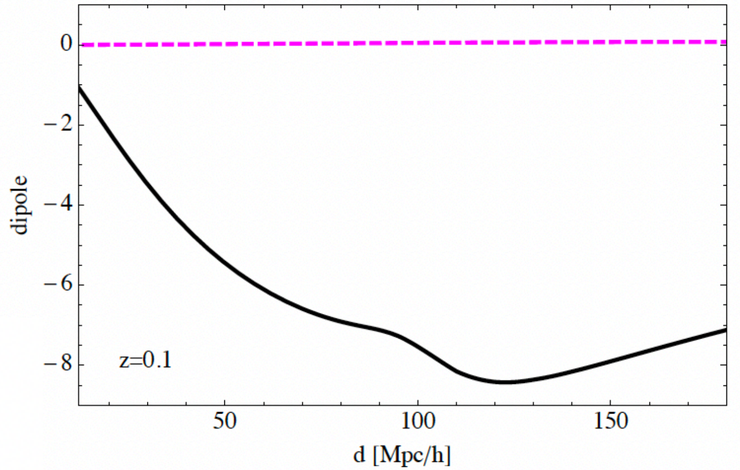
Andrianomena et al. 2019

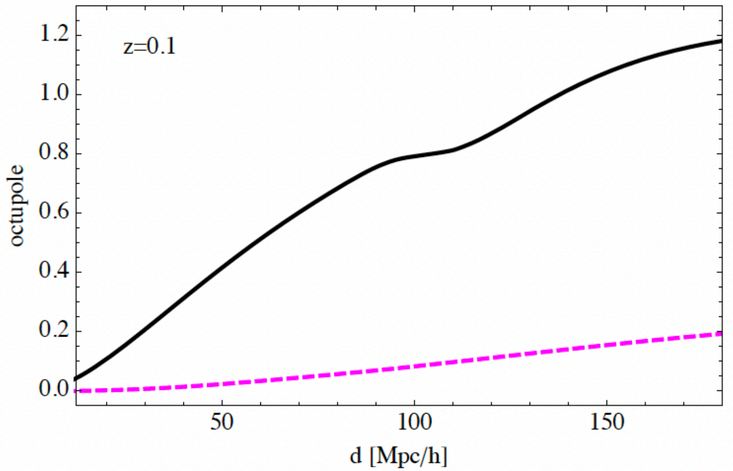
$$\xi = \left\langle \left(b\,\delta - \frac{1}{\mathcal{H}} \partial_r (\mathbf{V}\cdot\mathbf{n}) \right) \left(\kappa_{\rm g} + \kappa_{\rm v} \right) \right\rangle = \xi_{\rm g} + \xi_{\rm v}$$

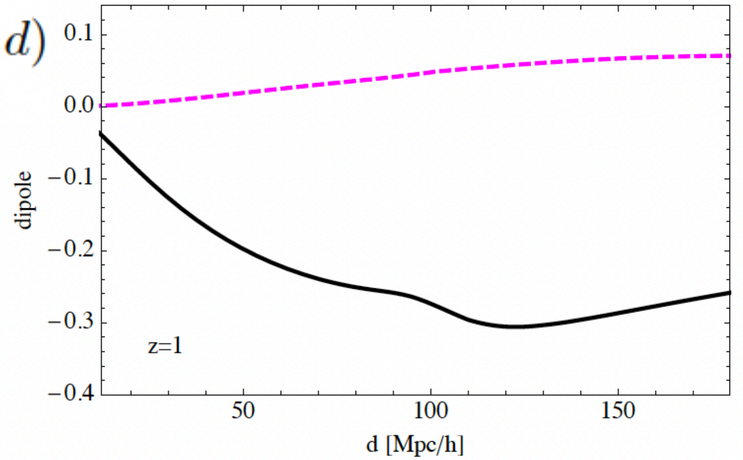
Estimators:

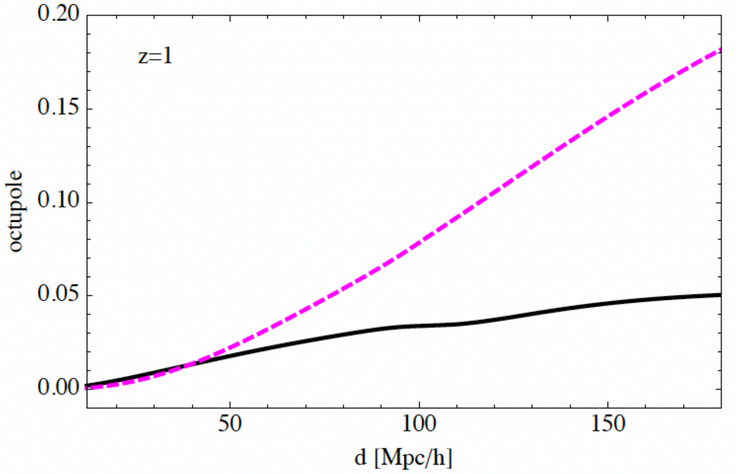
$$\hat{\xi}_{\rm dip}(d) = a_{\rm N} \sum_{ij} \Delta_i \kappa_j \cos\beta_{ij} \delta_K (d_{ij} - d)\,,$$

$$\hat{\xi}_{\rm oct}(d) = b_{\rm N} \sum_{ij} \Delta_i \kappa_j P_3(\cos\beta_{ij}) \delta_K (d_{ij} - d)$$

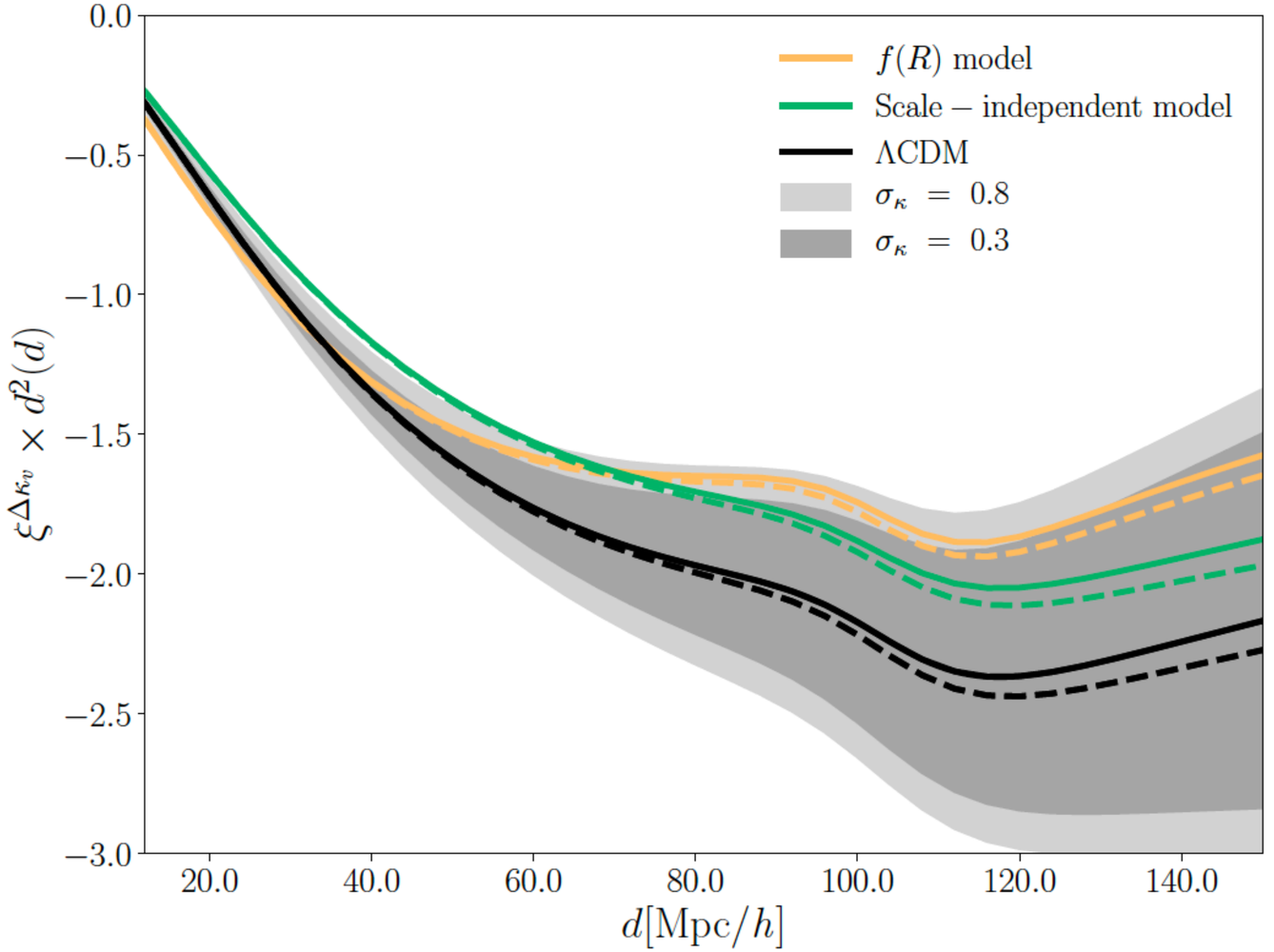








Bonvin et al. 2017



Andrianomena et al. 2019

Signal to noise:

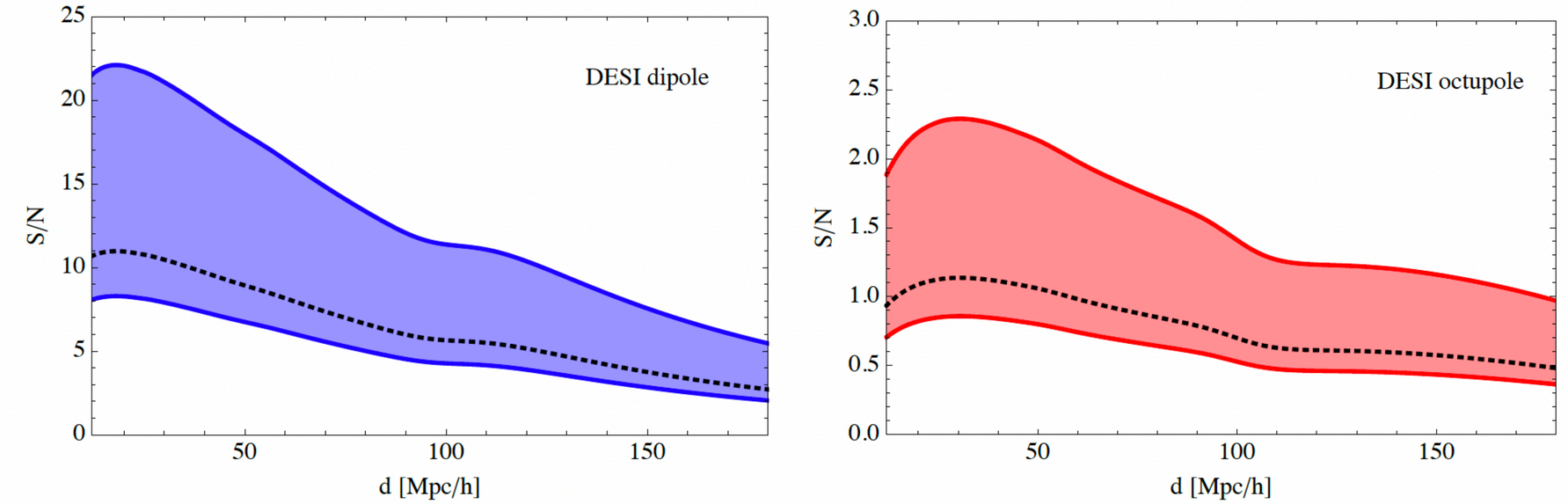


Figure 6. Predicted signal-to-noise for the dipole and octupole in the DESI Bright Galaxy sample, plotted as a function of separation. The higher bound corresponds to an intrinsic error on the size measurement of $\sigma_\kappa = 0.3$, and the lower bound of $\sigma_\kappa = 0.8$. The dotted black line corresponds to a mixed sample with 50% of galaxies with $\sigma_\kappa = 0.3$ and 50% with $\sigma_\kappa = 0.8$.

For DESI (predicted value)

Bonvin et al. 2017

LSST :

- measure galaxy sizes from images
- galaxy magnitudes
- construct the **convergence field** from galaxy sizes and magnitudes using a Bayesian approach

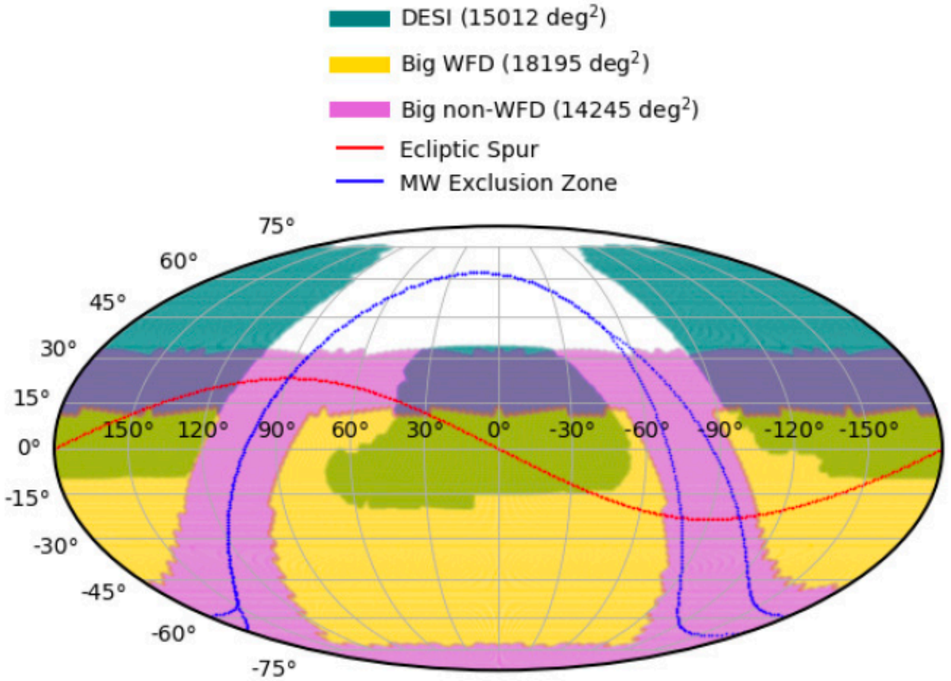
DESI:

- spectroscopic redshift of galaxies
- the number density

✤ A 4-meter Telescope at Kitt Peak National Observatory in Arizona, USA

✤ Powerful spectrograph that can capture light from up to 5,000 galaxies or stars at once

Overlaps :



Adam S. et al. 2018