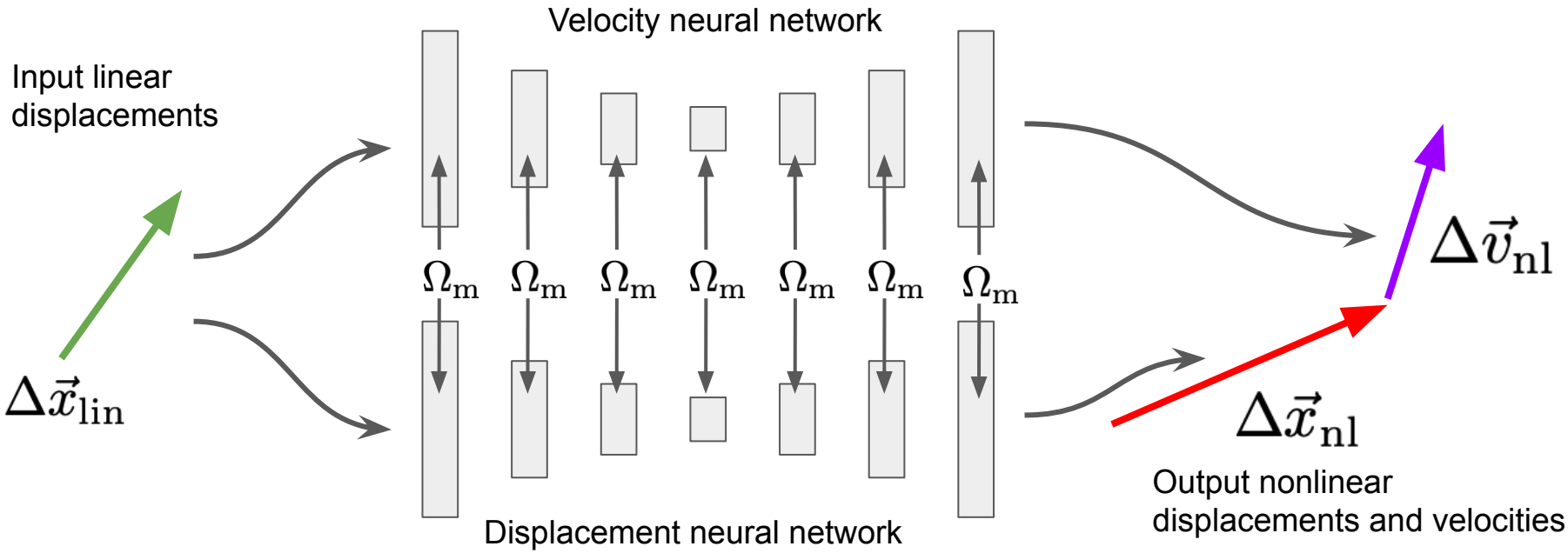
Field level neural network emulator for fast N-body simulations

Drew Jamieson[1,2], Yin Li[2], Renan Alves de Oliveira[2,3], Francisco Villaescusa-Navarro[4], Shirely Ho[2], David N. Spergel[5]

1 Max Planck Institute for Astrophysics
2 Flatiron Institute, Center for Computational Astrophysics
3 PPGCosmo
4 Princeton
5 Simons Foundation



Trained with Quijote latin hypercube sims:

1757 training
122 validation
121 testing

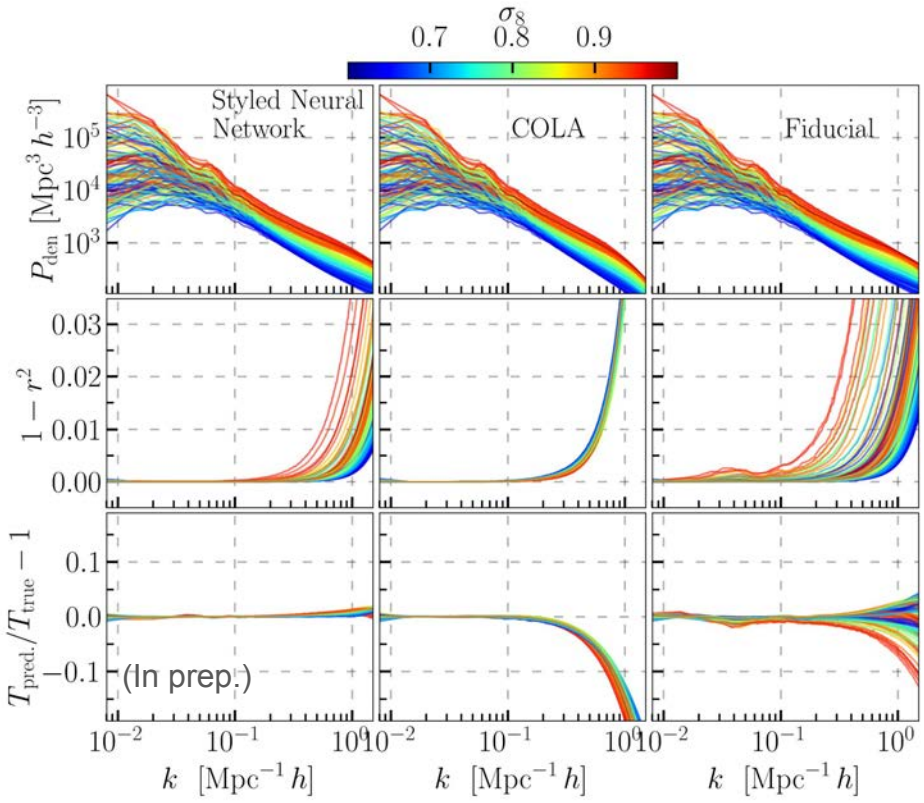
2000 total simulations, at redshift z=0

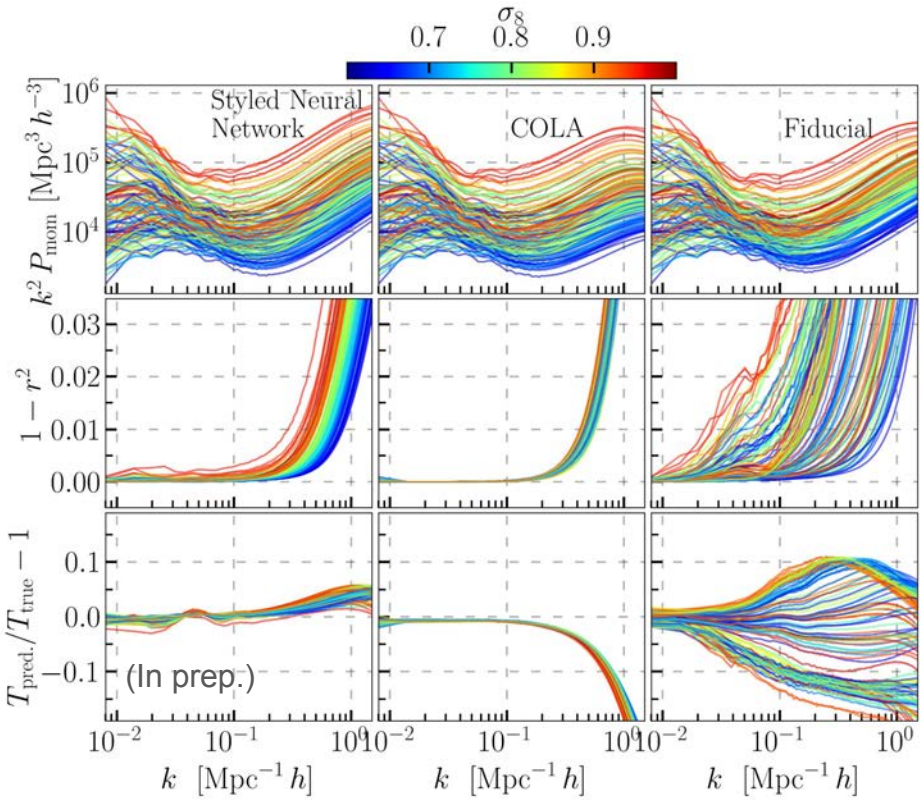
$N_p = 512^3$
L_{box} = 1 Gpc/h

Four 3x3x3 convolutions:
80 Mpc/h field of view for each particle

Density power spectra

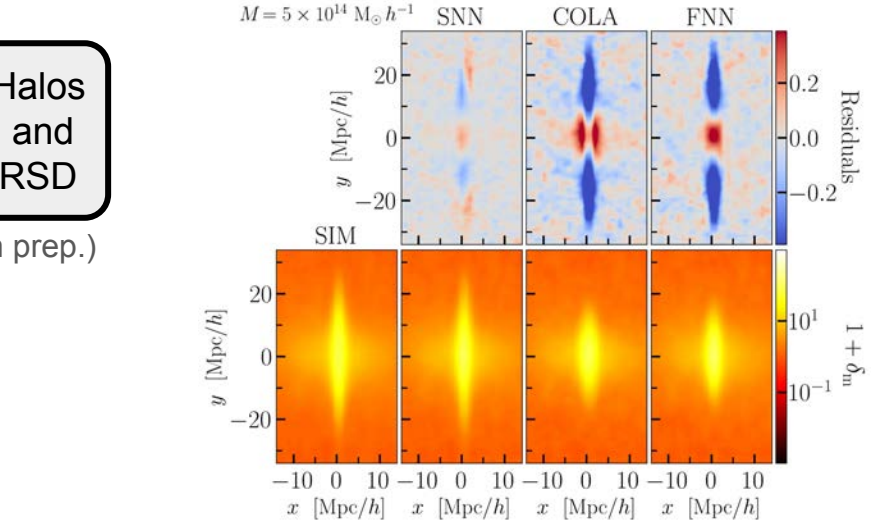
Momentum power spectra

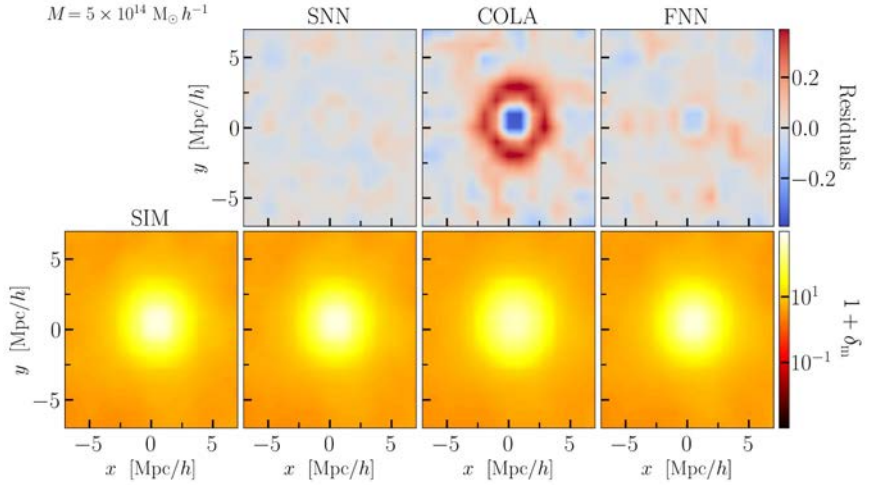


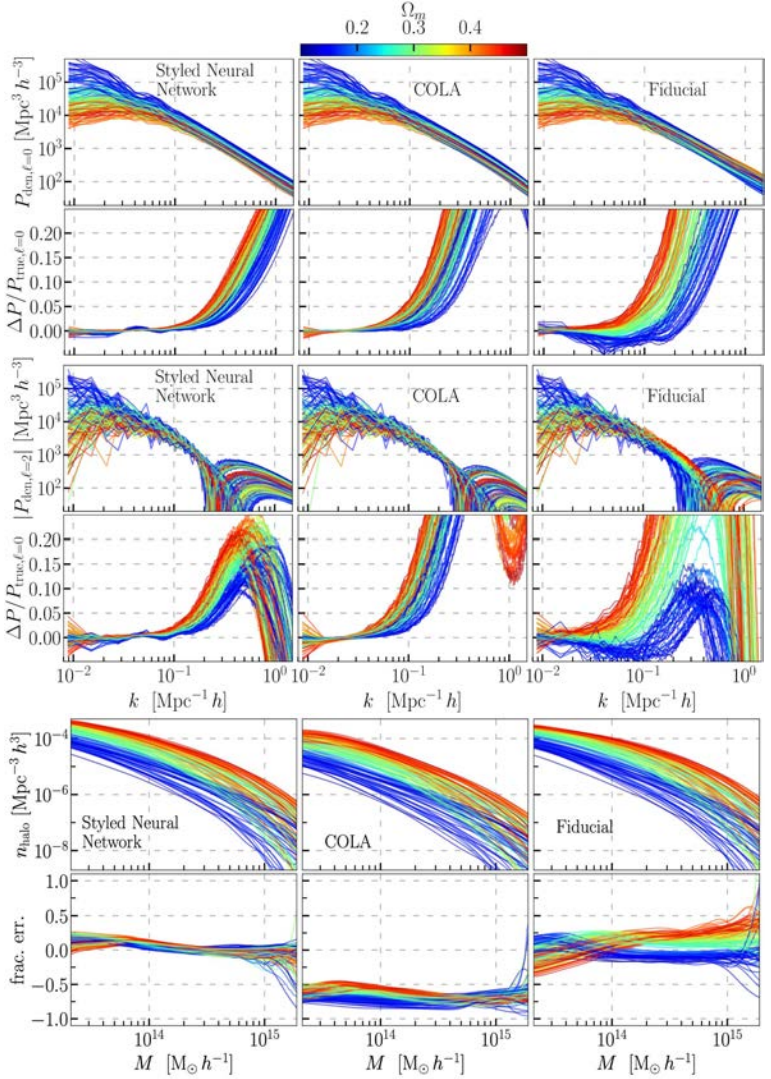


Halos and RSD

(In prep.)







Novel Clustering Statistics for Roman

Harmonic Analysis of Isotropic Fields Through Anisotropic Windows

Henry S. Grasshorn Gebhardt and Olivier Doré
https://arxiv.org/abs/2109.13352

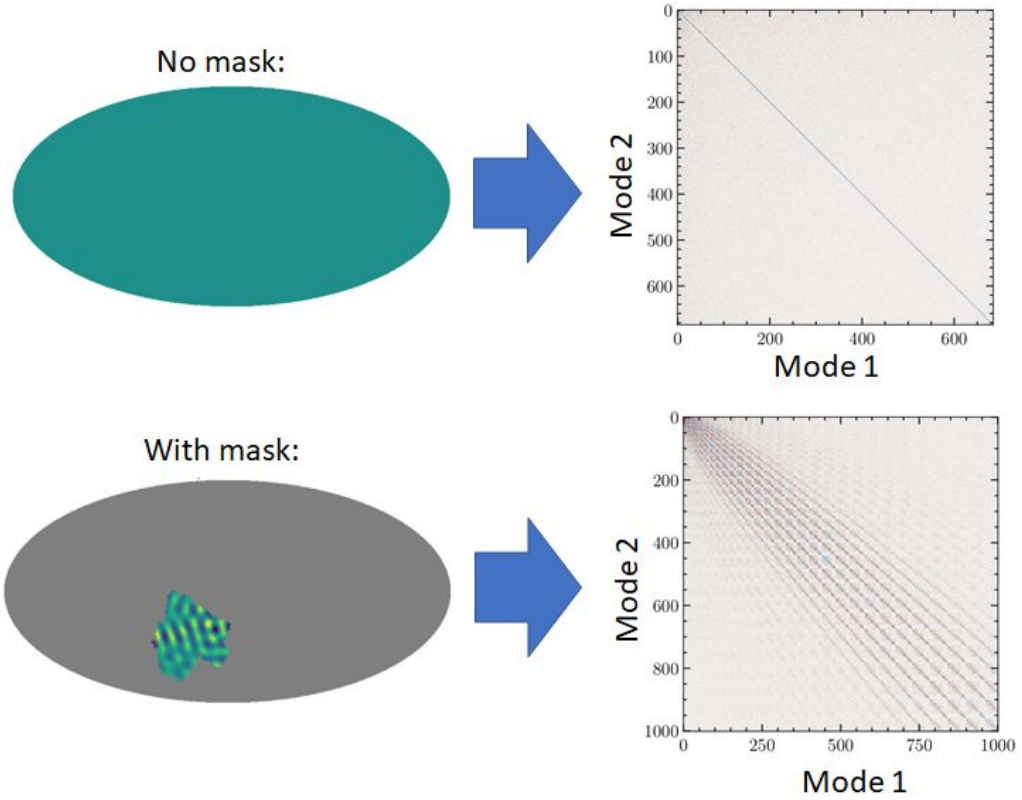
Motivation: Isotropy + Mask = Anisotropy

Transform into harmonic space:

$$\tilde{\delta} = \mathbf{Y} \cdot \delta$$

Formally, the power spectrum is the covariance matrix:

$$\mathbf{P} = \tilde{\delta}\tilde{\delta}^{\dagger}$$



Idea: Generalize Eigenfunctions of Laplacian to Arbitrary Domains

Spherical harmonic are eigenfunctions of the Laplacian over the sphere:

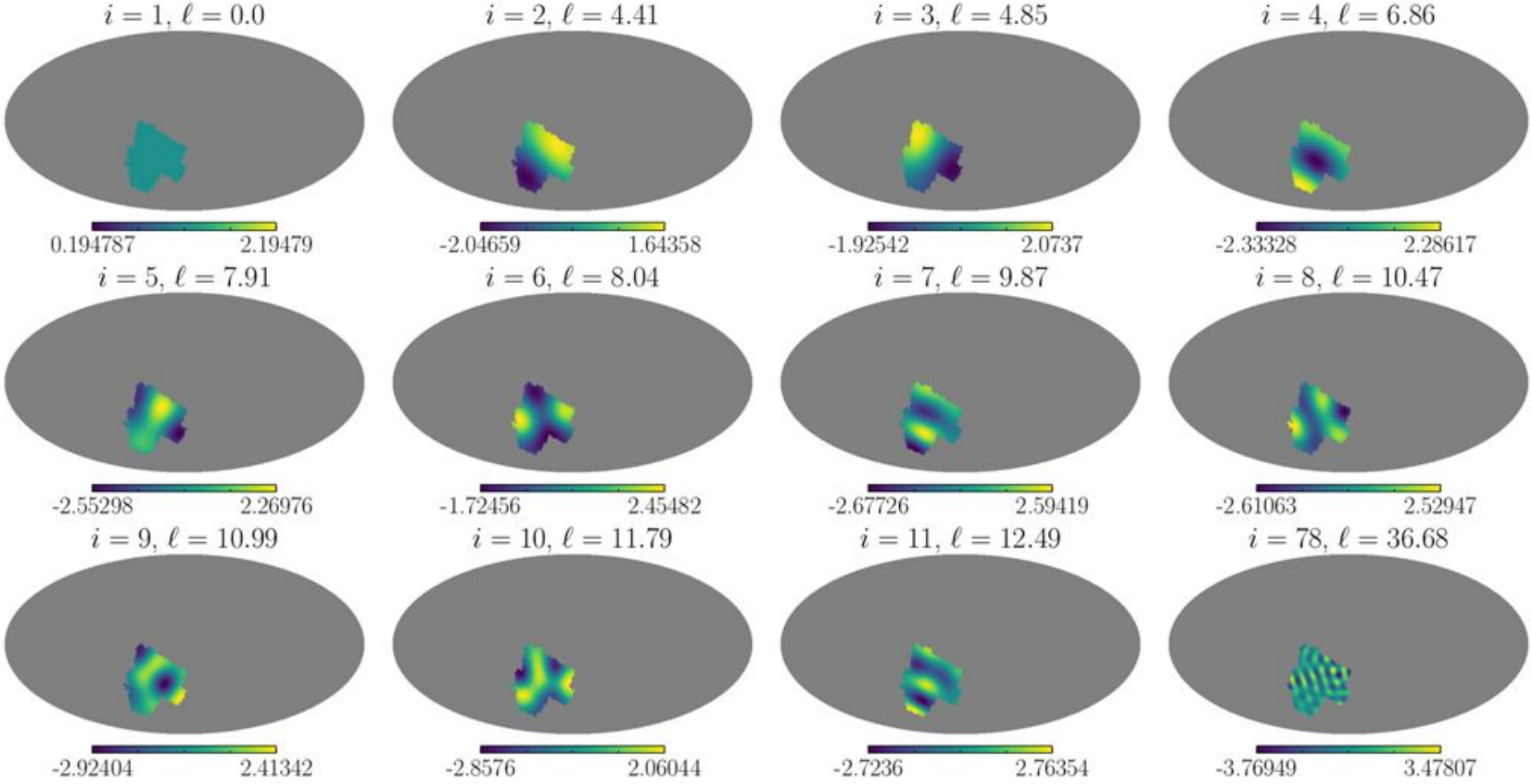
$$\nabla^2 Y = -\ell(\ell+1)\, Y$$

By using the Green's function we can generalize to an orthonormal basis on an arbitrary domain:

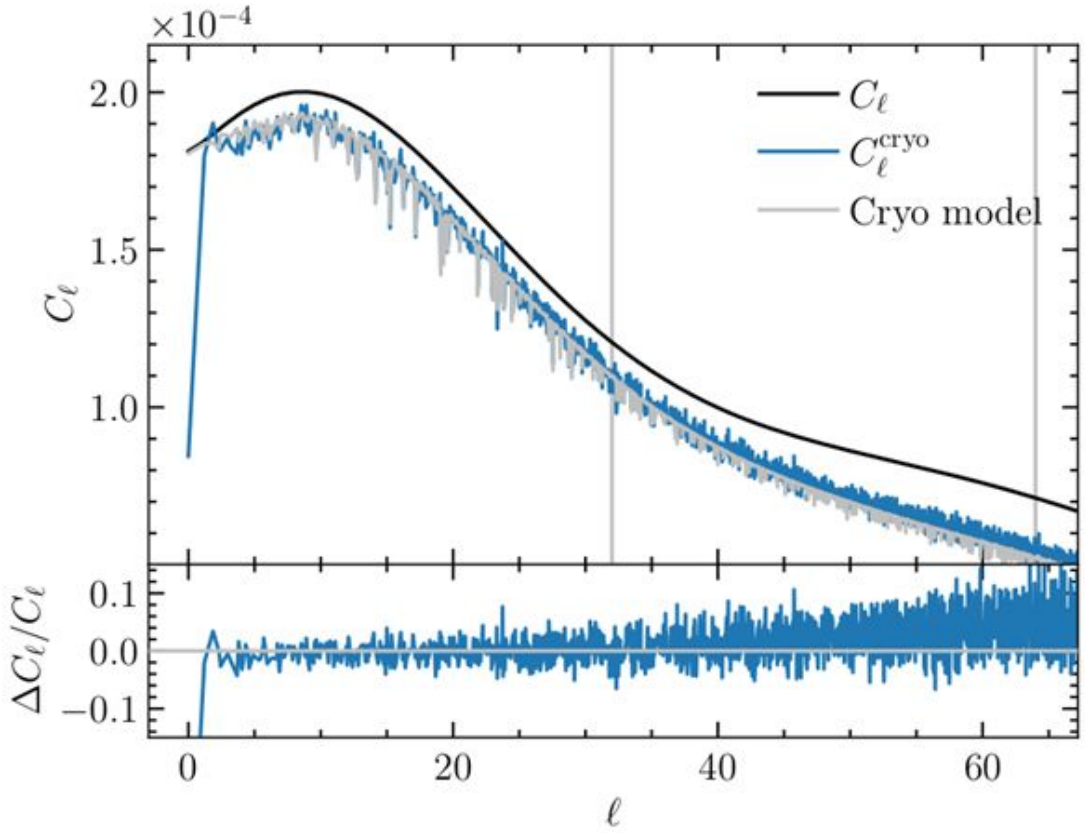
$$Y(\hat{\boldsymbol{r}}) = \lambda \int_D \mathrm{d}^2\hat{\boldsymbol{r}}'\, G(\hat{\boldsymbol{r}}, \hat{\boldsymbol{r}}')\, Y(\hat{\boldsymbol{r}}')$$

Saito 2008, DelSole & Tippett 2015

Create Your Own Functions (CRYOFUNK)



Sub-percent agreement for $\ell < n_{side}$

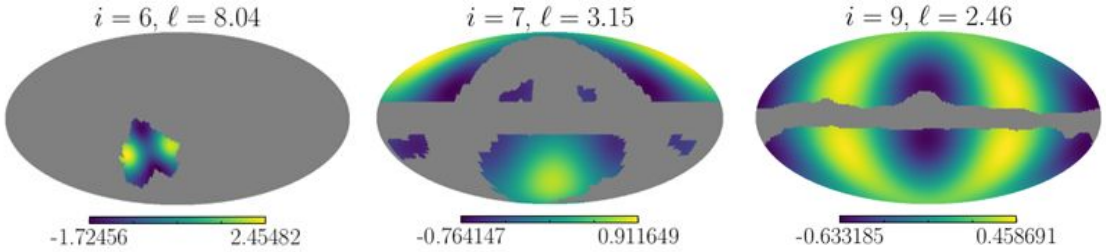


Complex pixel- and geometry-window.

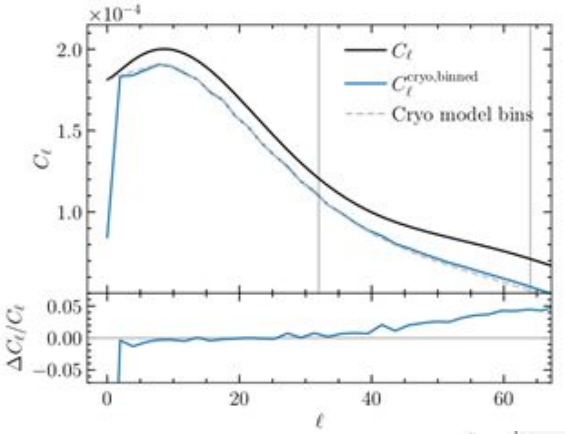
Euclid-like

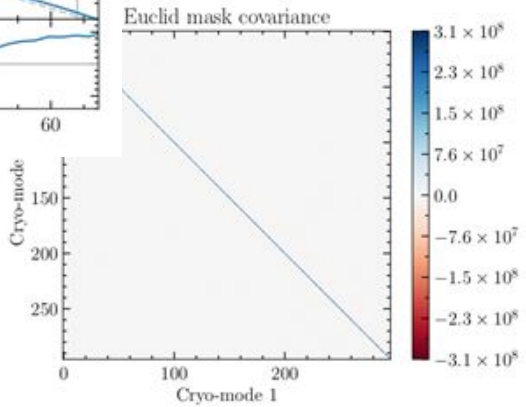
Averages over 10^5 simulations.

CryoFunk Summary



- Use customized eigenfunctions of Laplacian to exploit isotropy.
- 3D SFB-like power spectrum
- Advantages:
  - Diagonal power spectrum
  - Simple local average effect (integral constraint)
  - Simple shot noise
  - Diagonal covariance matrix
- Disadvantages:
  - Complicated pixel- and geometry-window
  - Computational resources for CryoFunks
- Future:
  - Non-binary window
  - Faster eigenfunction decomposition





Henry S. Grasshorn Gebhardt and Olivier Doré https://arxiv.org/abs/2109.13352

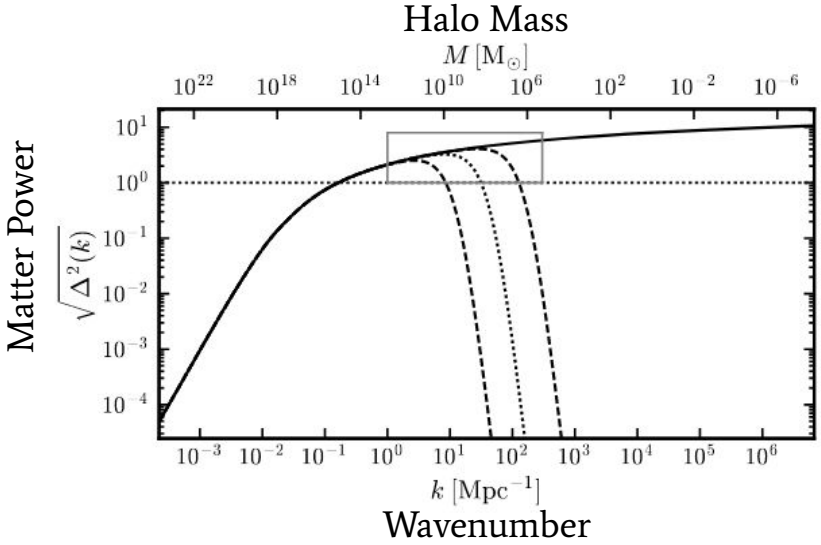
Detecting Dark Matter Subhalos with the Nancy Grace Roman Space Telescope

Kris Pardo and Olivier Doré

Phys. Rev. D, in press [arXiv:2108.10886]

DM Substructure is an important probe of DM physics

New dark matter physics usually leads to fewer dark matter subhalos within galaxies and can lead to different shapes of halos.



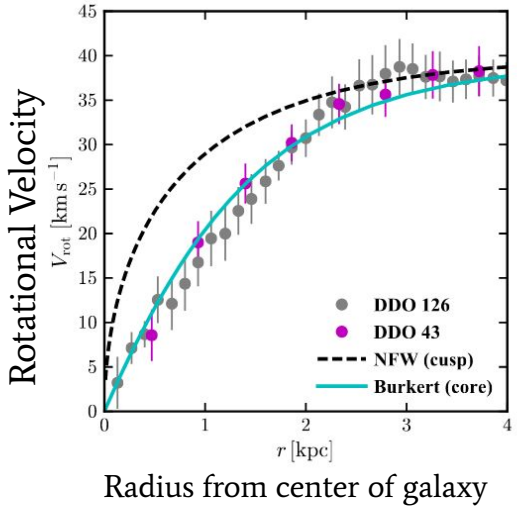
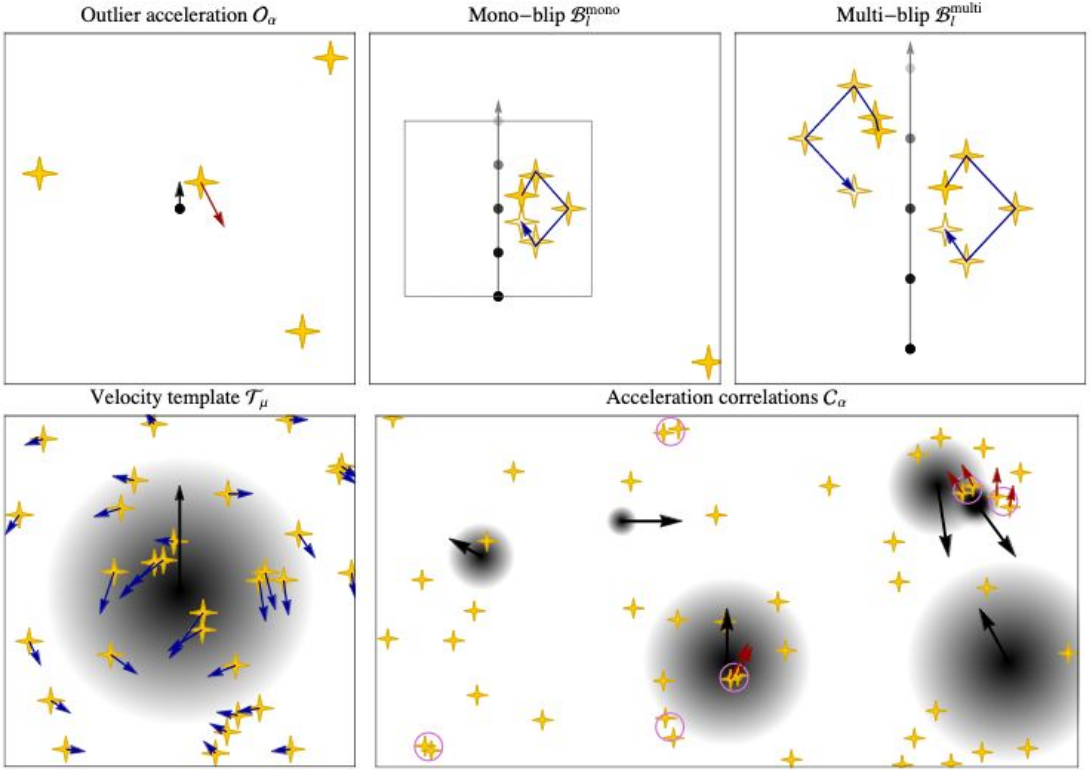


Fig. credits: Bullock & Boylan-Kolchin (2017)

DM lensing in the galaxy

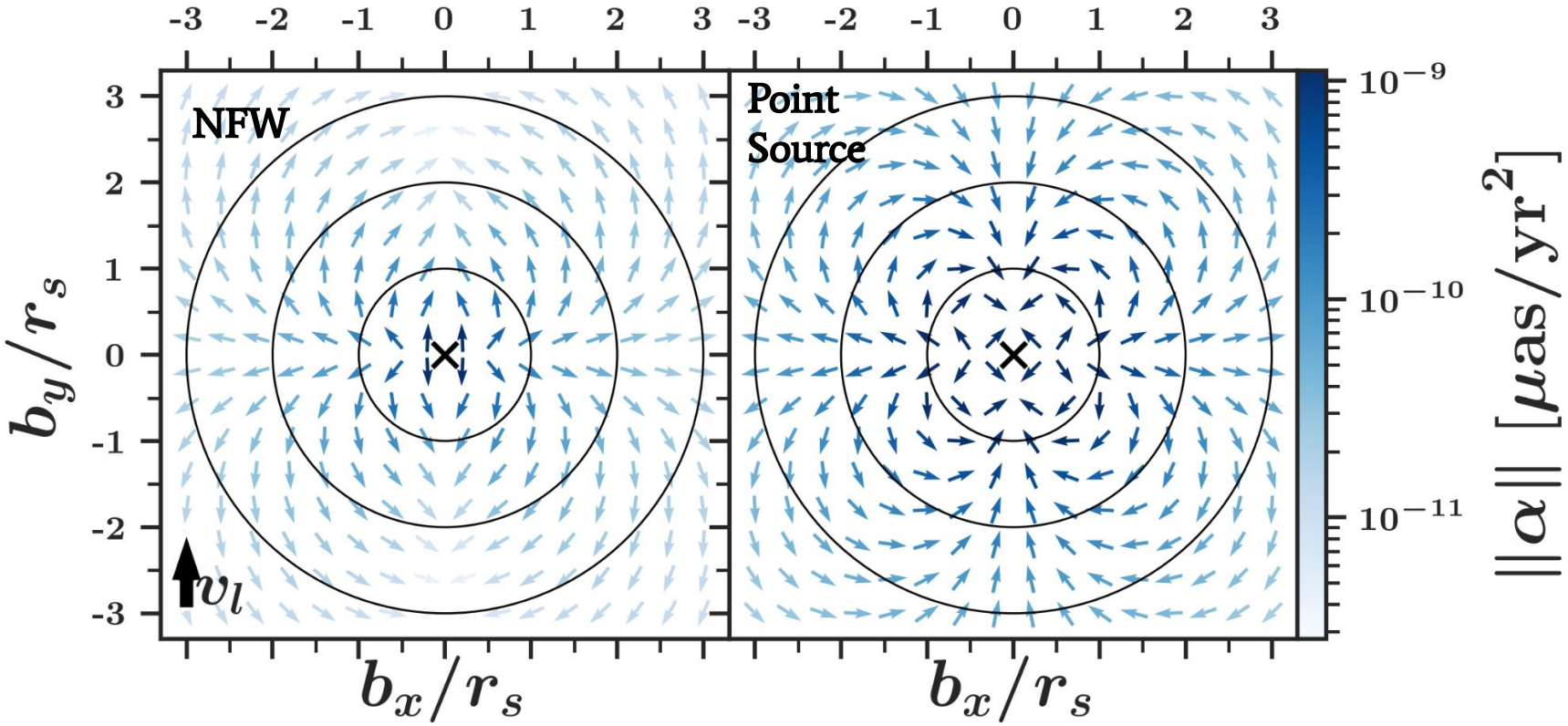


van Tilburg+ (2018)

For Roman's GBTD survey, the acceleration signal will be the best observable.

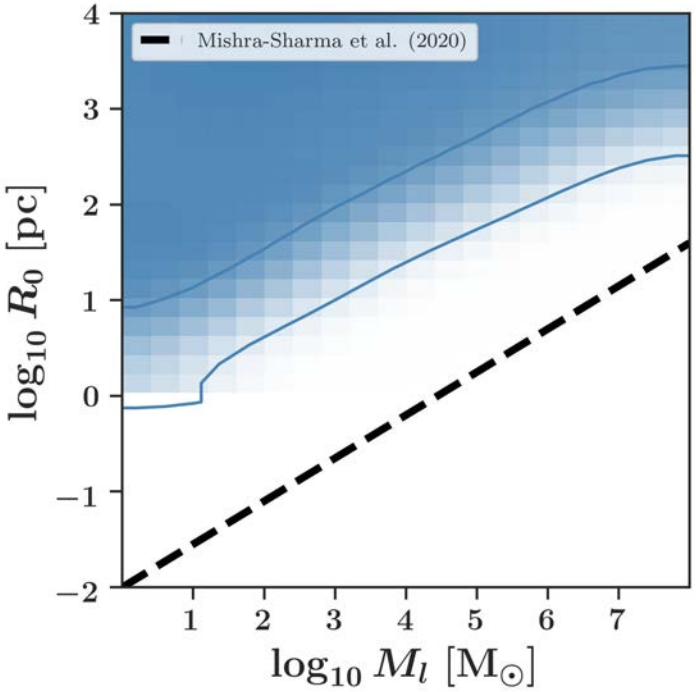
$$\alpha_l \sim \frac{4GM_l v_l^2}{b^3}$$

The Signal the Roman Space Telescope Should See



Pardo & Doré (2021)

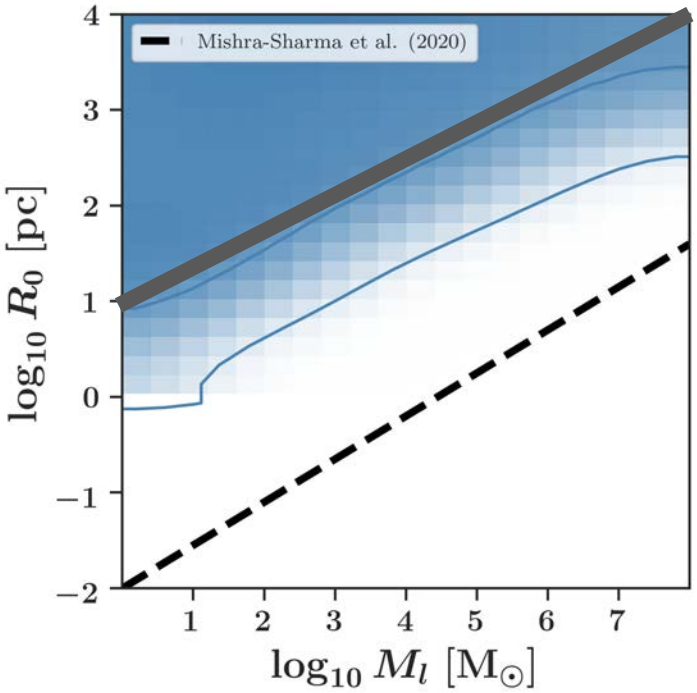
Results -- Gaussian Lenses



Pardo & Doré (2021)

Results -- Gaussian Lenses

CDM
$c_{200} = 13$



Pardo & Doré (2021)

Synergies between HLS and CMB lensing from SO

Speakers: **Lukas Wenzl**[1]
& Cyrille Doux[2]

On behalf of: **Chen Heinrich**,[3]
Rachel Bean,[1] Bhuvnesh Jain[2]
and the Cosmology Science Investigation Team

[1] Cornell University
[2] University of Pennsylvania
[3] Jet Propulsion Laboratory

ROMAN SPACE TELESCOPE × SIMONS OBSERVATORY

Community Science Workshop, Nov 17th 2021

Goals

1. **Build forecasts** for a combined analysis of large-scale structure with
   - Galaxy lensing and clustering from **Roman HLS**
   - CMB lensing from **Simons Observatory**
2. **Determine impact** of combining Roman x SO on parameter constraints of “beyond-vanilla” cosmologies, including potential systematic effects
3. **Compare survey designs** : deep HLS (2000deg^2 in SO) *vs* wide survey (18000deg^2 = Rubin, including SO)

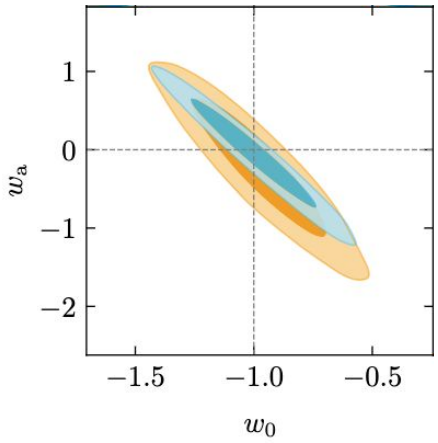
This work complements Roman forecasting efforts you just heard about, and HLS forecasting papers [2004.05271] and [2004.04702].

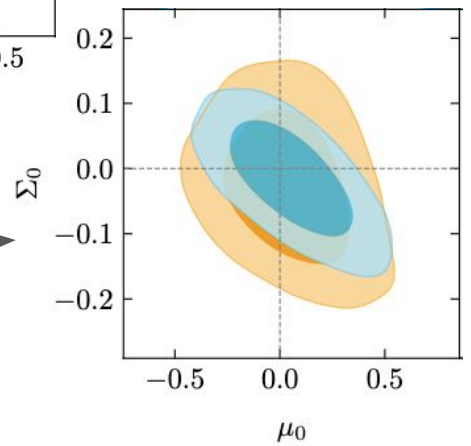
Overview

- Using Simons Observatory forecast [1808.07445]
- Roman clustering and weak lensing (10 tomographic bins) and CMB lensing data, giving >100 (auto+cross) power spectra combinations
- Standard cosmology $\boldsymbol{w_0 w_a}$**CDM** + massive neutrinos (quintessence)
- Modeling of a range of **nuisance parameters**: intrinsic alignment, baryonic effects, clustering biases, shear calibration, photo-*z* errors
- Exploring **extended models** including:
  - Model-free growth of structure $\sigma_8(z)$
  - Deviations in gravitational potentials
    - Phenomenological model ($\mu_0 \Sigma_0$)
    - Hu-Sawicki $f(R)$ model

Preliminary results

1. Combining with CMB lensing leads to significantly better constraints on dark energy: **FoM_{DE} roughly doubles** for range of survey scenarios
2. Significant improvements for model extensions: **$\sigma_8(z)$** and **$\mu_0\Sigma_0$** constraints
3. Opportunities to **self-calibrate** nuisance parameters like shear calibration





Stay tuned for paper release in near future!

ROMAN SPACE TELESCOPE × SIMONS OBSERVATORY

Roman and ML-Cosmology: A case study from weak lensing

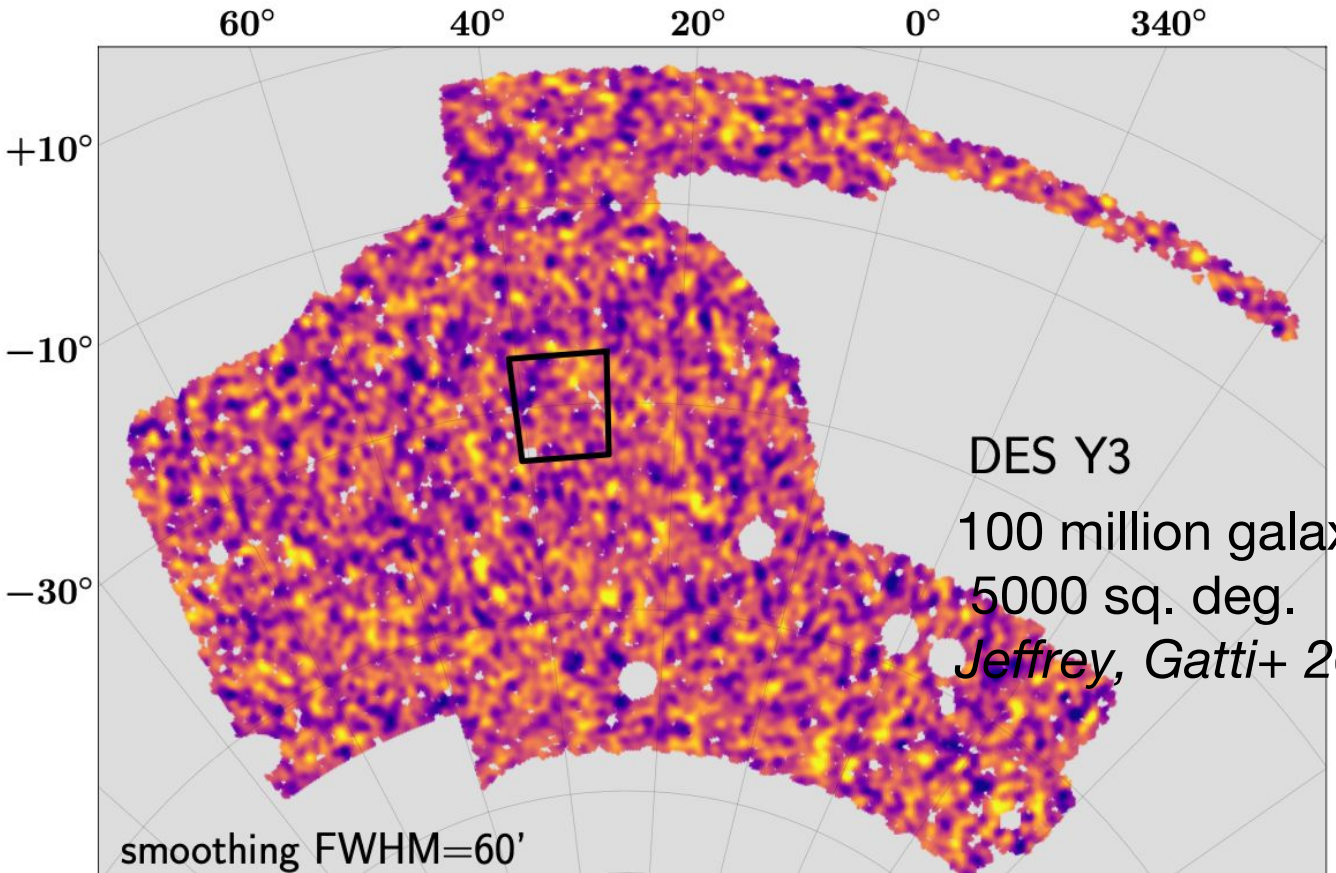
Bhuvnesh Jain

University of Pennsylvania

Cosmology from the non-Gaussian regime

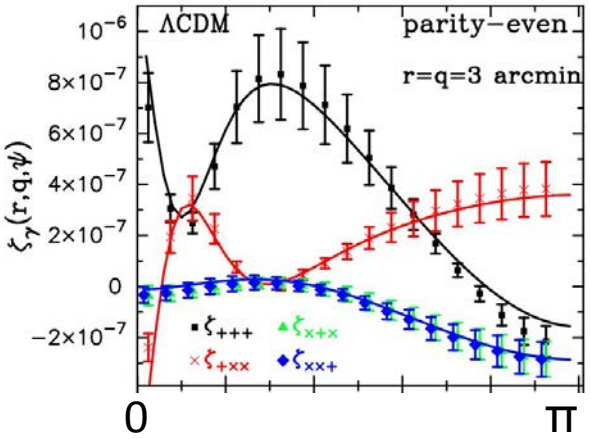
- A first step is the quasilinear regime: well modeled analytically.
- First high S/N measurements of lensing 3-point correlations from DES
- New non-Gaussian statistics promise larger gains, factors of 2-3, especially for Roman's better S/N on small scales.
- A promising approach is via Machine Learning, especially deep learning. How do we trust results from ML?
    - We have begun a research program and community challenge to validate ML analyses.

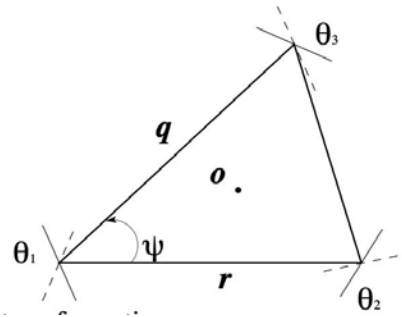
DES mass map


60°
40°
20°
0°
340°
+10°
−10°
−30°
DES Y3
100 million galaxies
5000 sq. deg.
Jeffrey, Gatti+ 2021
smoothing FWHM=60'

Configuration dependence of 3pt function: Theory

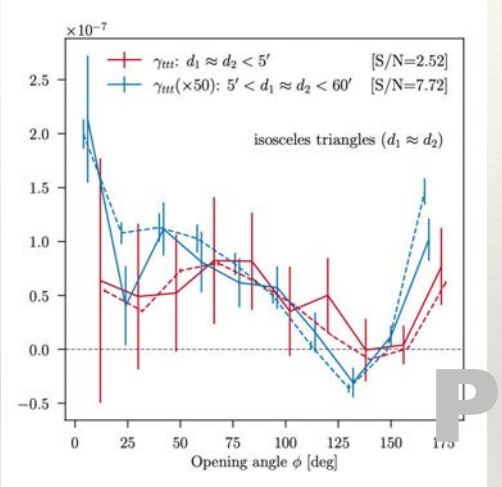
Four 3-point functions of shear

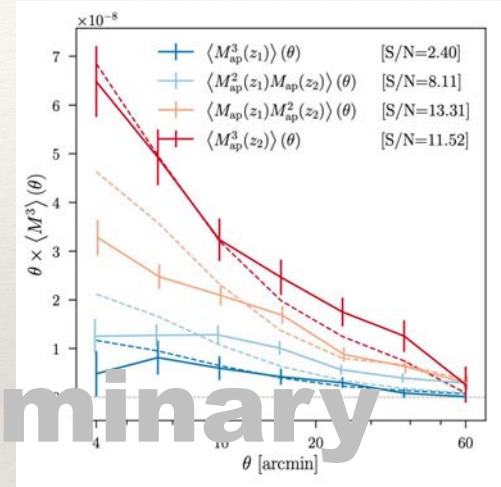




Distinct signatures of quasilinear gravitational clustering
Takada & BJ 2003a,b; Ho & White 2004, …

3-point function: DES lensing





Preliminary

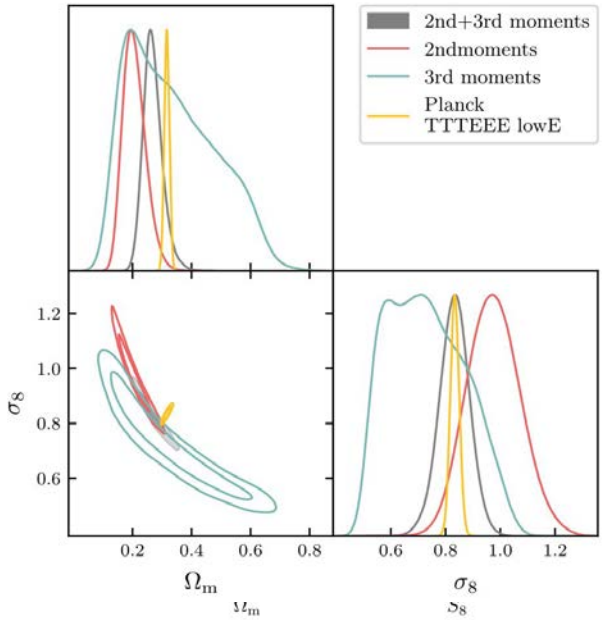
Isosceles triangles, versus opening angle: signature of gravity

From Theory -> Measurement was 18 years!

How will we do sanity tests with deep learning?

Secco, Jarvis, BJ, Chang, Gatti+ (DES), in prep

Quasilinear regime information



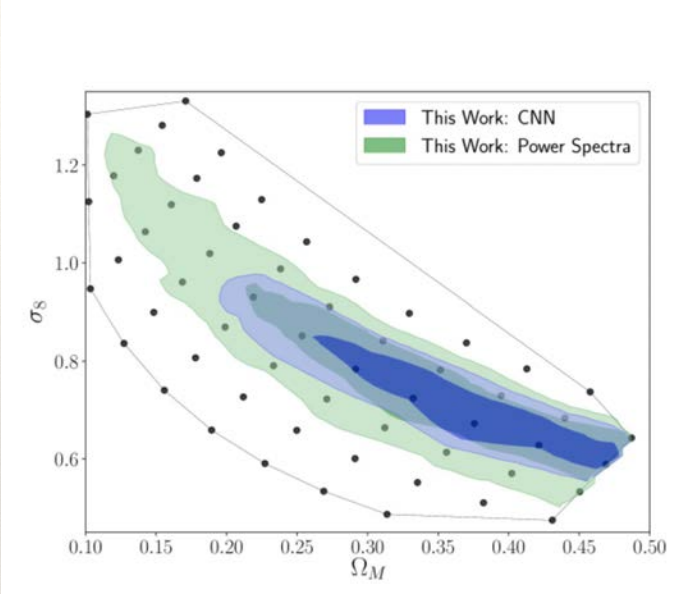
Third moment adds complementary information.

New finding: 3rd moment in 2.8-sigma tension with Planck

Gatti, BJ, Chang+ (DES) arxiv:2110.10141, Method: arXiv:1911.05568

See also: Amon+2021, Secco,Samuroff+2021 for 2pt DES results.

Deep learning with WL data



Theory and measurement systematics modeled/marginalized.

All analyses blinded: consistency tests. But independent validation of ML needed.

Fluri et al, arXiv:1906.03156. KiDS survey.

From 3-point functions -> Deep Learning

- Developing *reliable* machinery for percent level cosmology takes long term effort and involves detailed simulations!
- Analytical tools, PT and Halo Model give physical intuition.
- The ‘projection’ of deep learning on well known non-Gaussian statistics will give us confidence (understanding??).
- Roman will have much more information on small scales! So non-Gaussian statistics more powerful.
- We have begun a simulation challenge for ML with WL.

A cosmology challenge for ML codes

- Use N-body simulations and generate lensing kappa maps with (some) systematics included. These are provided for challenges for a deep learning or hierarchical Bayesian pipeline. Running on such an independent 'mock survey' to recover cosmology is a nontrivial test.
  - Learning phase: you pick 0 or 1 known systematic (2022)
  - Challenge pase: multiple systematics unknown to you (2022-2024?)
- *With Francois Lanusse, Elisabeth Krause and Penn colleagues.*
  Participants: Ben Wandelt, Shirley Ho, Zoltan Haiman, Uros Seljak, Alan Heavens, Alexandre Refregier.