Title: Testing gravity with the Dark Energy Survey

Speakers: Jessica Muir

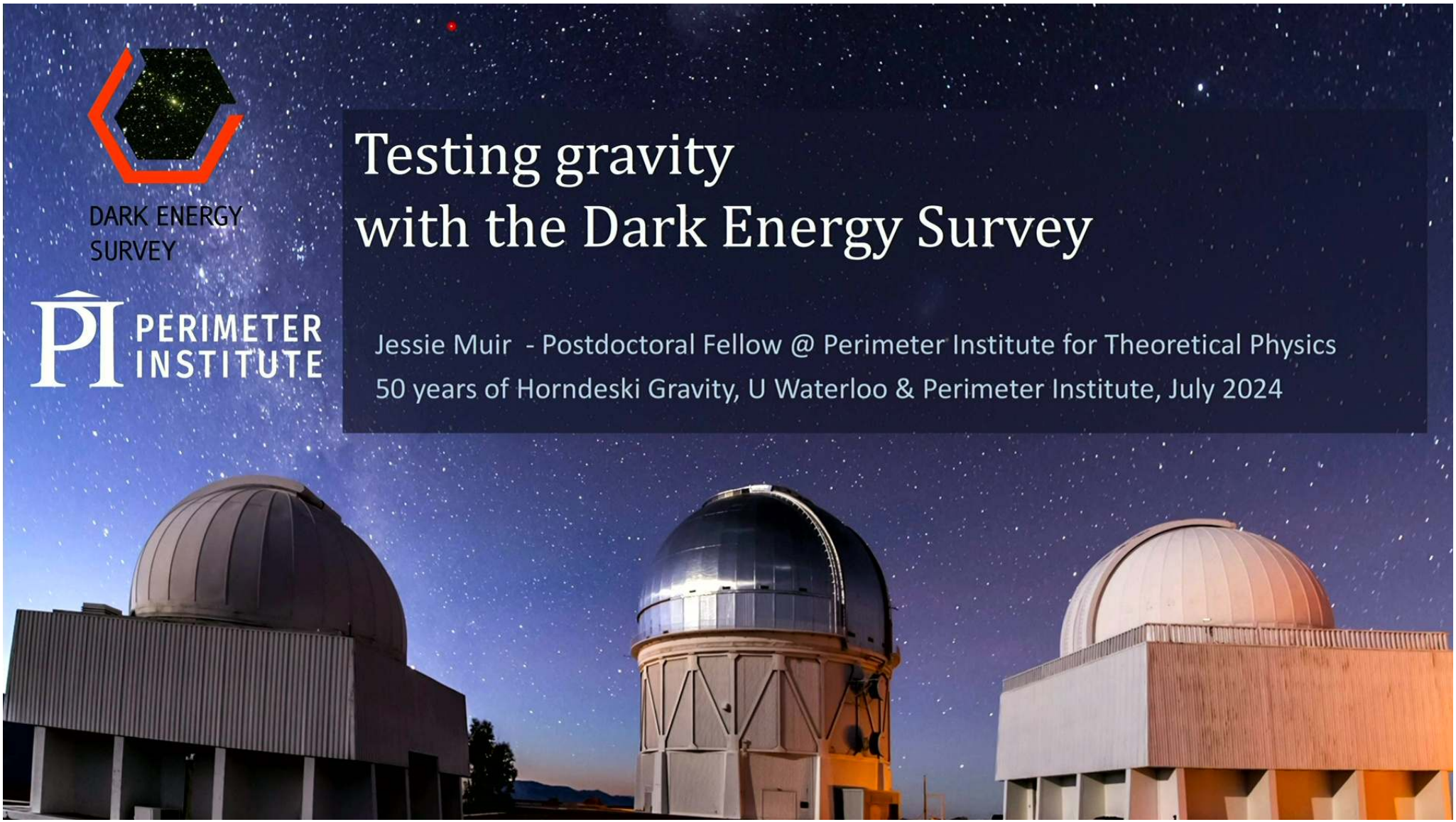
Collection/Series: 50 Years of Horndeski Gravity: Exploring Modified Gravity

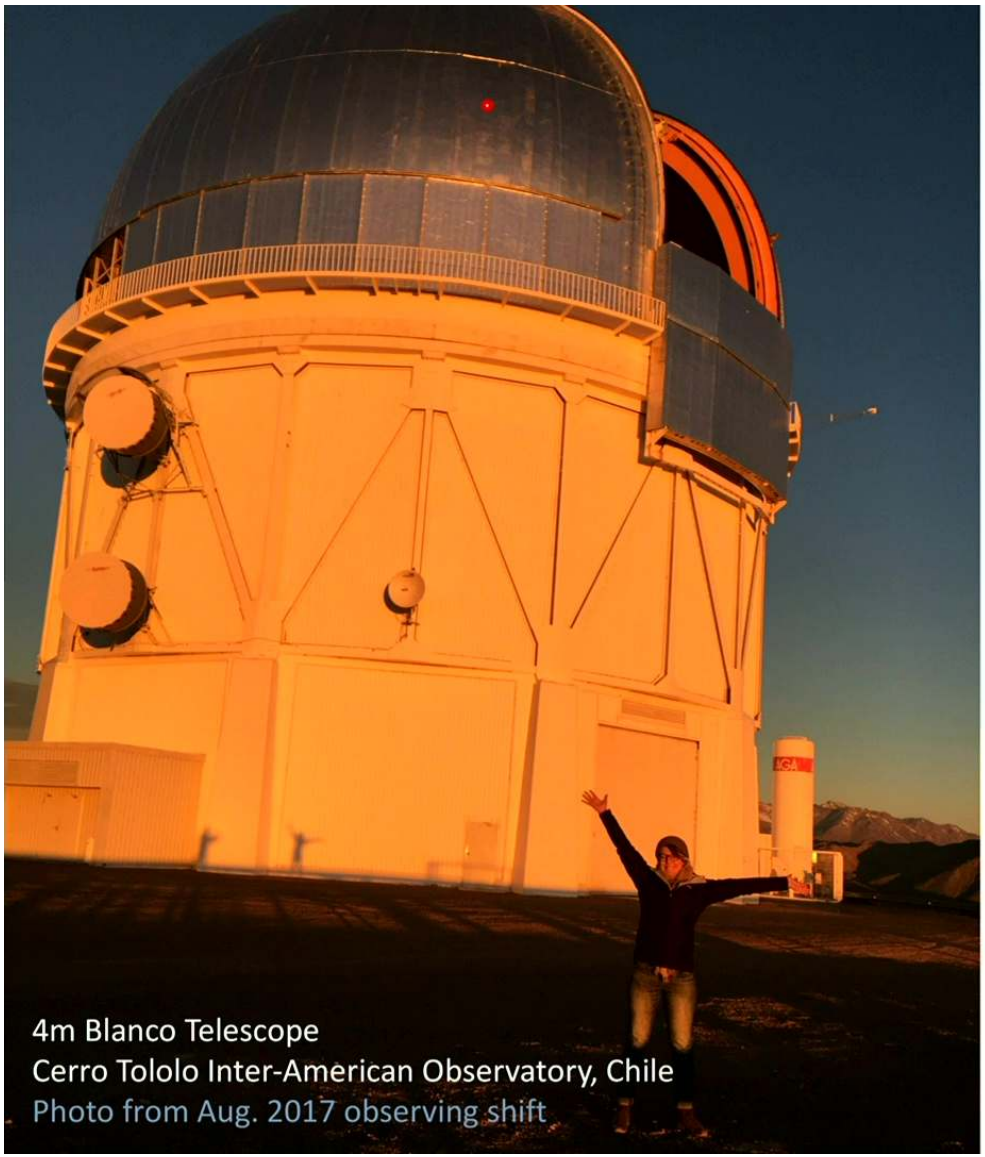
Date: July 17, 2024 - 2:45 PM

URL: https://pirsa.org/24070069

Abstract:

Measurements of the large-scale distribution of matter in the Universe are one of our primary tools for testing the predictions of general relativity on cosmological scales. I will describe how we pursue this using data from galaxy imaging surveys, focusing on Dark Energy Survey galaxy clustering and weak lensing analyses as an example. I will highlight results from the DES Year 3 analysis that are relevant for testing gravity, some practical aspects of extending survey analyses beyond ΛCDM, as well as ongoing work to address these challenges to prepare for future surveys.


DARK ENERGY SURVEY
PERIMETER INSTITUTE
Testing gravity with the Dark Energy Survey
Jessie Muir - Postdoctoral Fellow @ Perimeter Institute for Theoretical Physics
50 years of Horndeski Gravity, U Waterloo & Perimeter Institute, July 2024



DARK ENERGY SURVEY

The Dark Energy Survey (DES)

- Imaging survey 2013-2019
- 758 nights observing, 4M Blanco telescope @ CTIO
- 5000 deg^2, ~10% of sky
- 400+ participants
- Probes include: Weak lensing, galaxy clustering, SNe, galaxy clusters, Milky Way satellites, solar system objects …

Funding

NSF · U.S. DEPARTMENT OF ENERGY Office of Science · UKRI Science and Technology Facilities Council · GOBIERNO DE ESPAÑA MINISTERIO DE EDUCACIÓN Y FORMACIÓN PROFESIONAL

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Cosmology with DES galaxy clustering and weak lensing

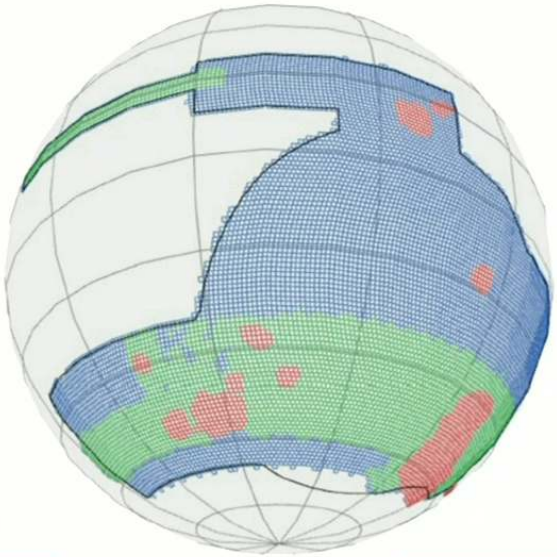
Final Y6 analysis in progress

Y3 galaxy clustering and weak lensing:
- Full 5000 deg^2 at ~50% depth

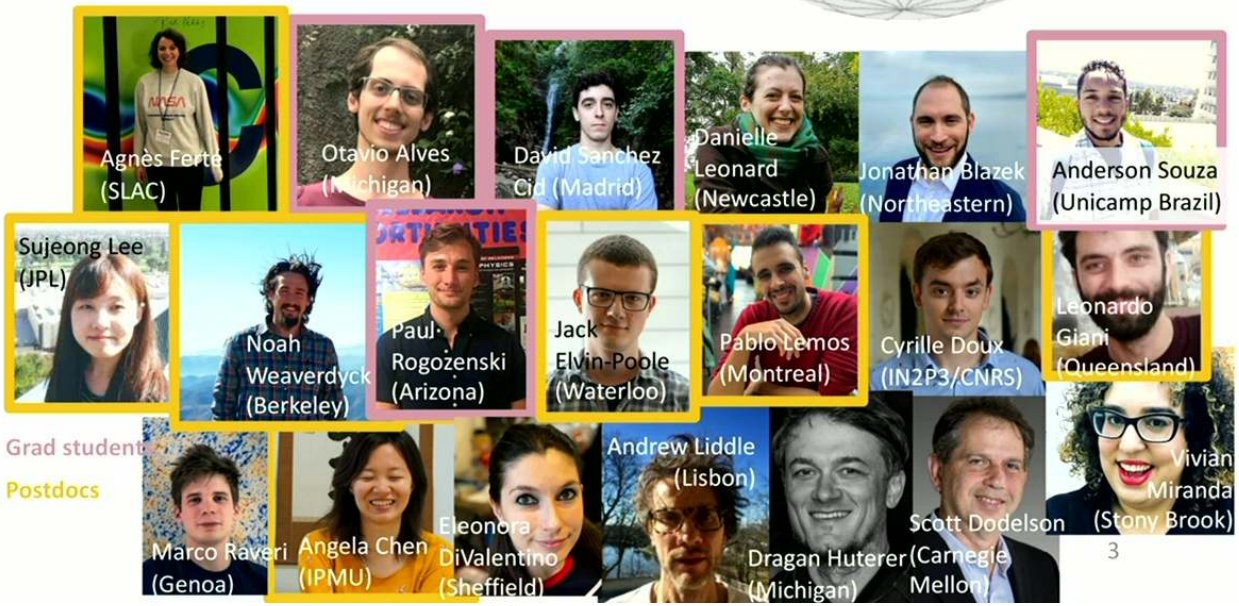
- ΛCDM, wCDM cosmology results
  - DES Collab. 2022, PRD, arXiv:2105.13549

- Beyond-ΛCDM
  - DES Collab. PRD April 2023, arXiv:2207.05766
  - Led by JM, Agnès Ferté
  - Models in key paper:
    - Time-dep DE: w_0, w_a
    - Curvature: Ω_K
    - **Modified gravity: Σ_0, μ_0**
    - Binned $\sigma_8(z)$
    - Extra relativistic species: N_{eff}
    - Sterile neutrino: N_{eff}, m_{eff}

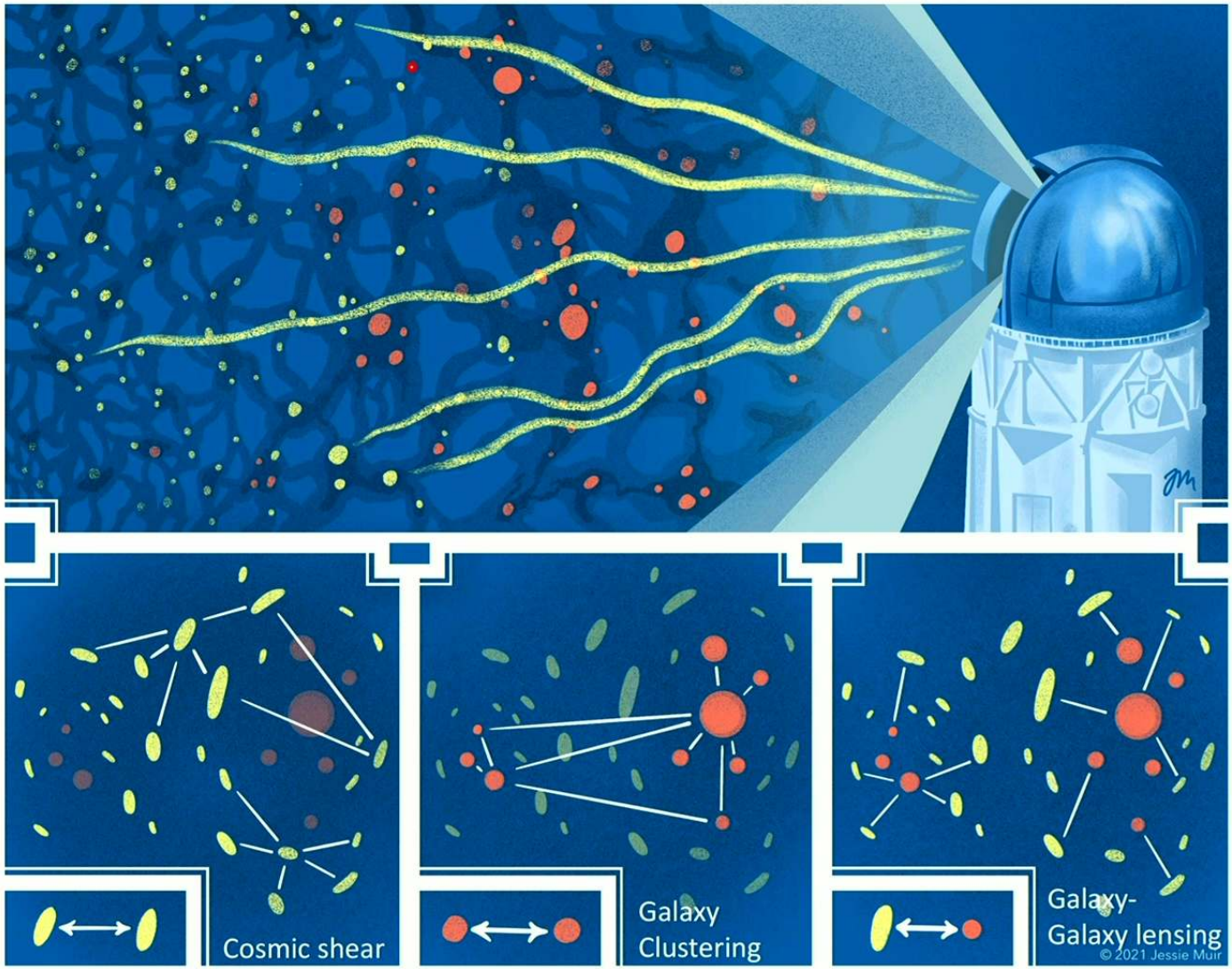
Survey footprint
Science verification
+ supernova survey
Year 1
Year 3, Year 6

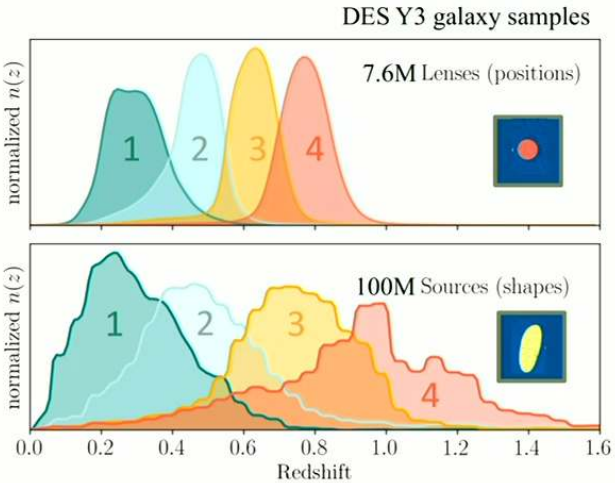


DES Y3 Beyond-ΛCDM analysis team

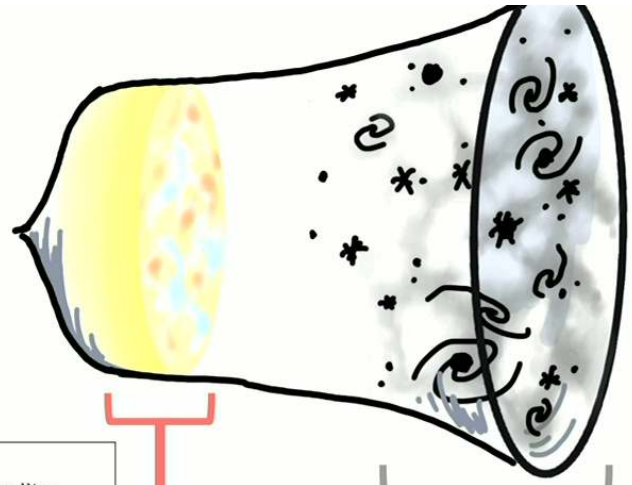


Combined analysis of galaxy clustering and weak lensing



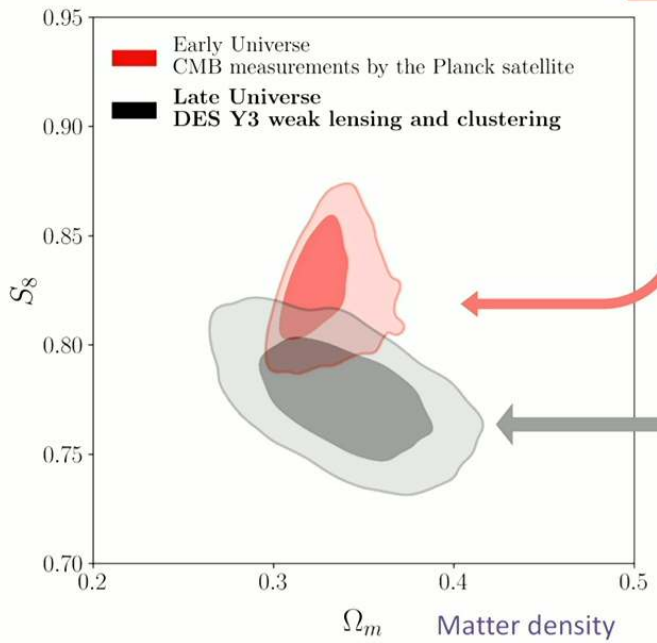


Comparing constraints tests ΛCDM (including general relativity)



Amplitude of density fluctuations

$$S_8 = \sigma_8 \sqrt{\Omega_m / 0.3}$$



DES Collab. [inc. JM] 2021, PRD, arXiv:2105.13549

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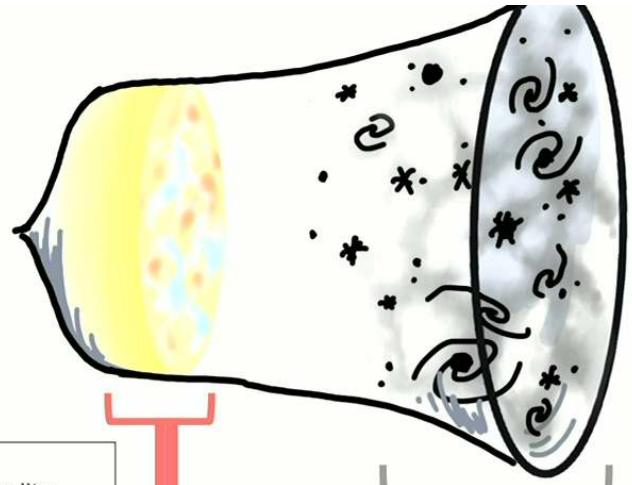

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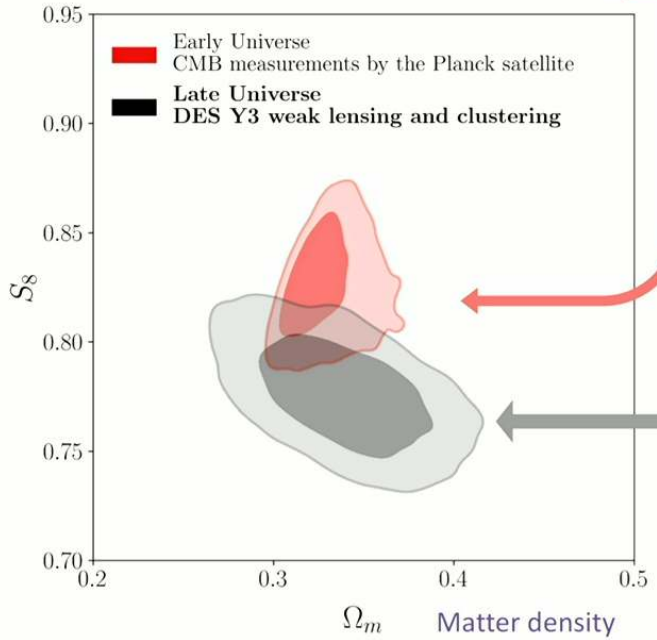
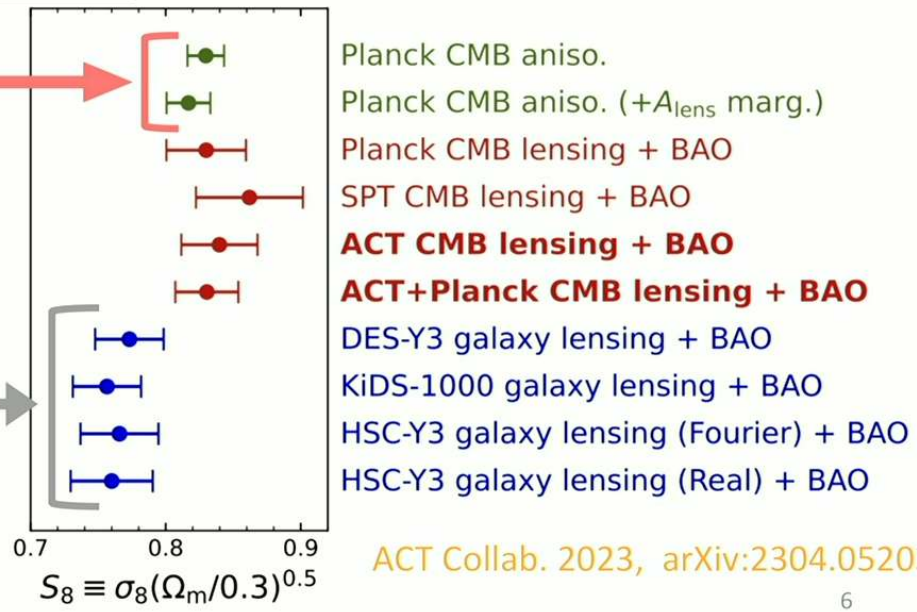


DES Collab. [inc. JM] 2021, PRD, arXiv:2105.13549



ACT Collab. 2023, arXiv:2304.05203

Modifying gravity

Matter over-density

Assume modifications' time dependence follows accelerated expansion

Poisson Eq.

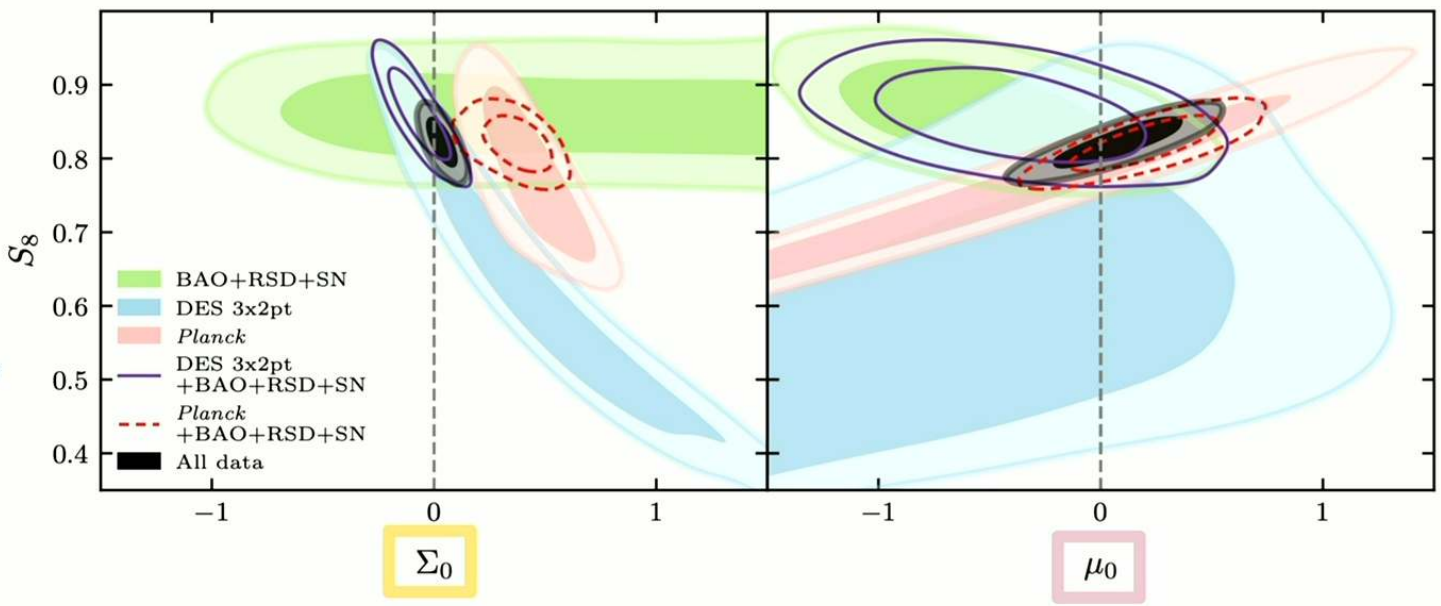
Newtonian potential → $$\Psi = -\frac{4\pi G\rho_{\rm m}}{(1+z)^2 k^2}\left[1+\mu(z)\right]\delta$$

Lensing potential → $$\Phi = -\frac{8\pi G\rho_{\rm m}}{(1+z)^2 k^2}\left[1+\Sigma(z)\right]\delta$$

$$\mu(z,k) = \mu_0 \frac{\Omega_\Lambda(z)}{\Omega_{\Lambda,0}}$$

$$\Sigma(z,k) = \Sigma_0 \frac{\Omega_\Lambda(z)}{\Omega_{\Lambda,0}}$$

eBOSS DR16
Pantheon SN
DES with linear scale cuts
Planck 2018



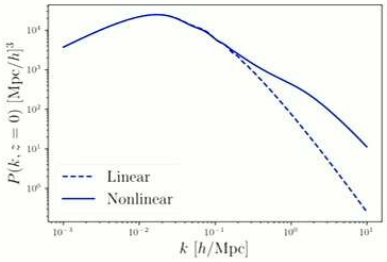
DES Collaboration [inc. JM] 2023, PRD arXiv:2207.05766

Extending the analysis beyond ΛCDM

Evaluate modeling tools, adjust analysis accordingly

(e.g. with scale cuts)

- Linear growth, **nonlinear matter power**
- intrinsic alignments
- galaxy bias, RSD, magnification
- projection onto the sky



Ensure ΛCDM + systematics doesn't produce

beyond-ΛCDM signals

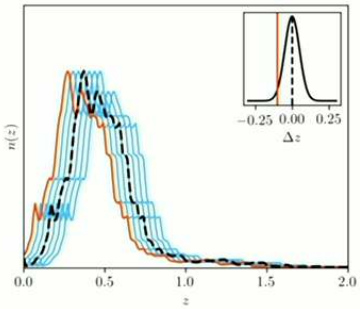
using "contaminated" simulated ΛCDM data

- Baryon feedback
- Non-linear galaxy bias
- Non-linear matter power inaccuracy
- Incorrect magnification coefficients

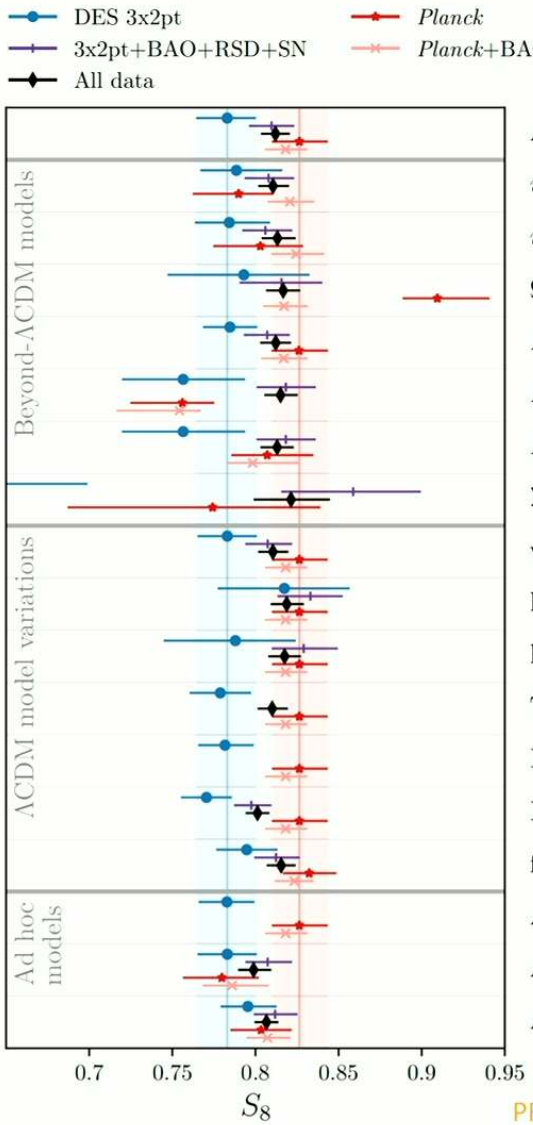
Check robustness with respect to model variations

on sim. and real analysis

- Parameterization of photo-z uncertainties
- Intrinsic alignment model choice



Model dependence of S_8 constraints



DES Collaboration [inc. JM]
PRD 2023, arXiv:2207.05766

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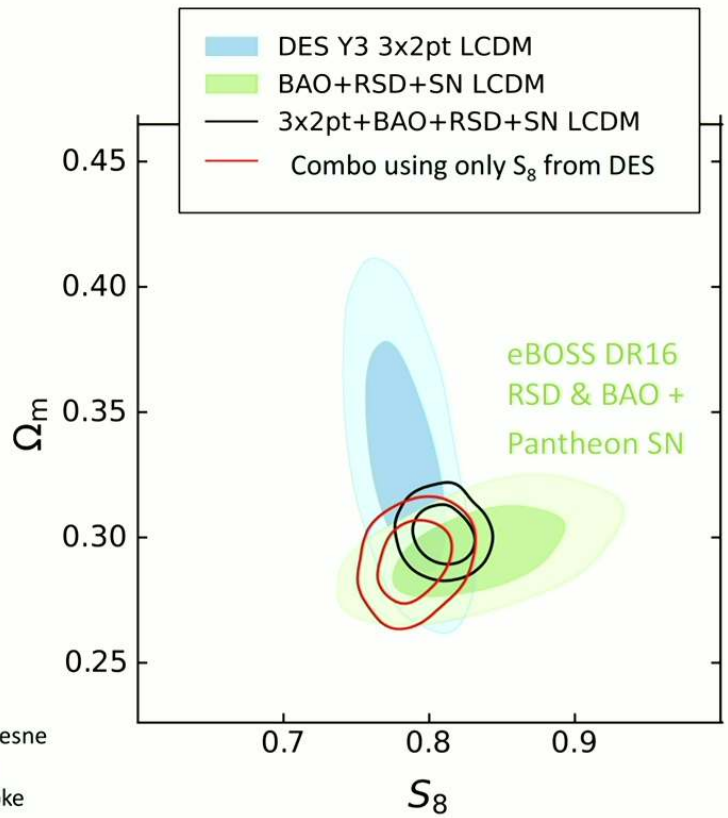
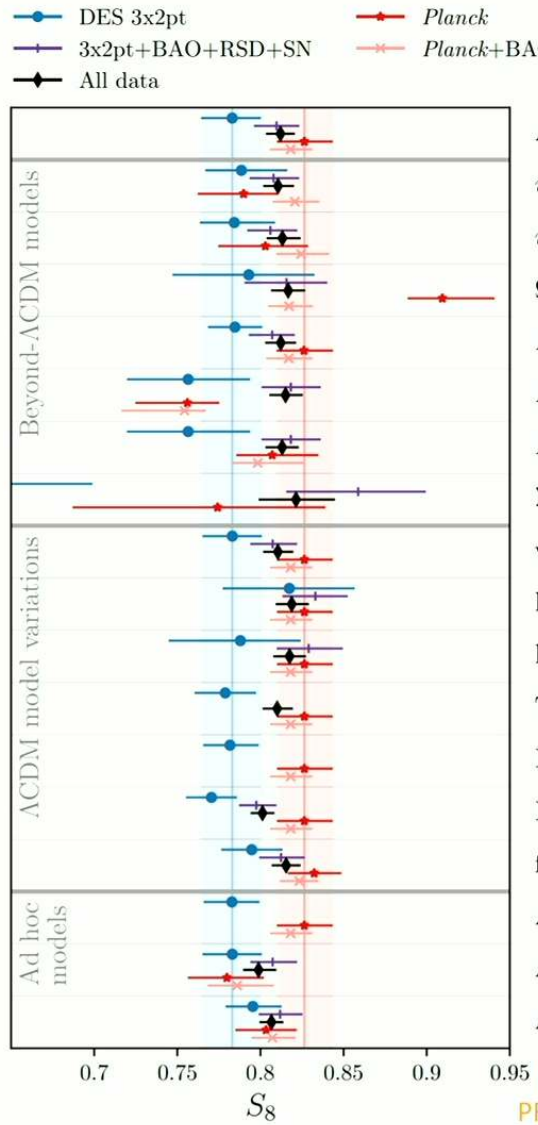


Left plot by Gautier Duchesne
PSI-START summer 2024
Undergrad @ U Sherbrooke

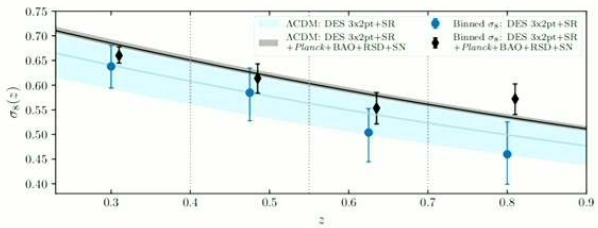


DES Collaboration [inc. JM]
PRD 2023, arXiv:2207.05766

Conclusion / other DES-MG highlights

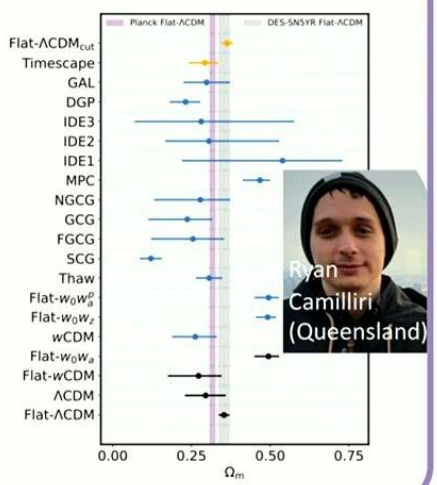
Redshift binned $\sigma_8(z)$ - DES Y3 3x2pt

DES Collaboration 2023, PRD arXiv:2207.05766



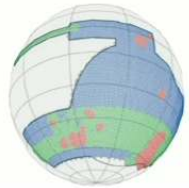
DES Y5 Supernova beyond-LCDM

Camilleri et al, arXiv:2406.05048



Year 6 3x2pt analysis

coming soon!



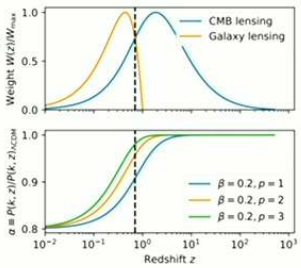
Y3 3x2pt constraints on more MG models

Ferte et al, in prep

Models	Data-vector
$\Sigma, \mu(z) \propto \Omega_\Lambda$	$\xi_\pm(\theta), \gamma_t(\theta), w(\theta)$
$\Sigma, \mu(z) \propto a^s$	$\xi_\pm(\theta), \gamma_t(\theta), w(\theta)$
$\Sigma(a,k), \mu(a)$	$\xi_\pm$
$f(R)$	$\xi_\pm$
Dilaton	$\xi_\pm$
Symmetron	$\xi_\pm$

Alternative $\sigma_8(z)$ variation Including CMB lensing

Lin et al 2023, arXiv:2308.1618

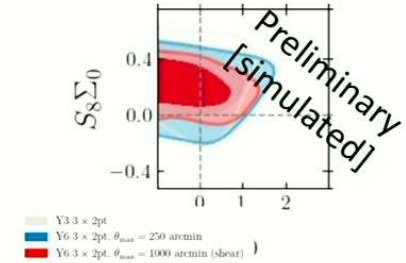


Y6 3x2pt beyond-LCDM

in prep

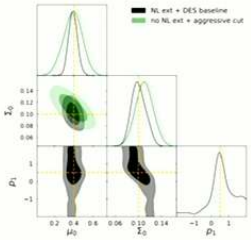
Team leads + many others!

Using larger angular scales



Using smaller angular scales

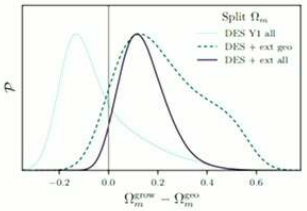
Using halo reaction method from Wang et al 2406.09204



w_0-w_a dark energy
EFT of dark energy
Generalized dark matter
Interacting DE-DM

Growth-geometry split consistency tests

Y1 - Muir et al [DES] PRD 2021, arXiv:2010.05924

Y3 - Zhong et al, PRD 2023, arXiv:2301.03694

Y6 – Andrade et al, in prep