DES Y3 Cluster Cosmology

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DARK ENERGY SURVEY

NSF

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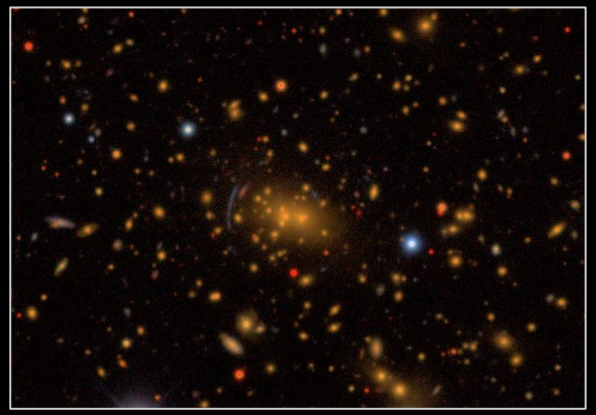
Photo: Reidar Hahn/Fermilab

Overview

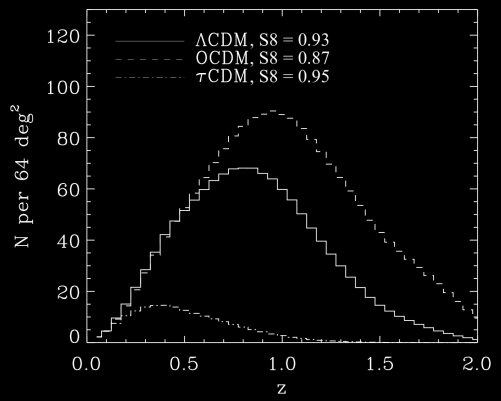
- **Introduction**
  - Clusters & Cosmology
- **Cluster Cosmology Analysis with DES Year 1**
  - Mass & Systematics
- **Cluster Cosmology for DES Year 3**
  - A new approach
- **Summary**

Introduction: Why galaxy clusters?

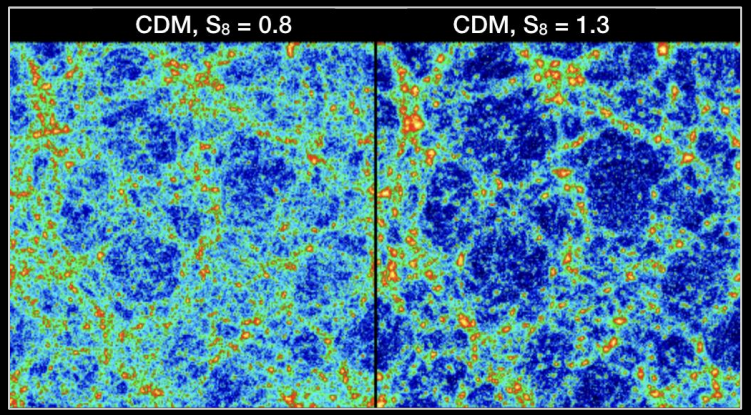
- Astrophysical laboratories
  - Extreme environment: gravity, dark matter, baryons
  - Intracluster medium, intracluster light, etc
  - AGN feedback, galaxy evolution, etc
- Powerful cosmological probes
  - Largest astronomical objects bound by gravity
  - Measurements of its mass and abundance tell us about the amount of dark matter in the Universe and the rate of gravitationally-driven structure formation
  - Can provide unique constraints on the quantity and properties of dark matter and dark energy in the Universe



Credit: A. Carnero & S. Bhargava/DES

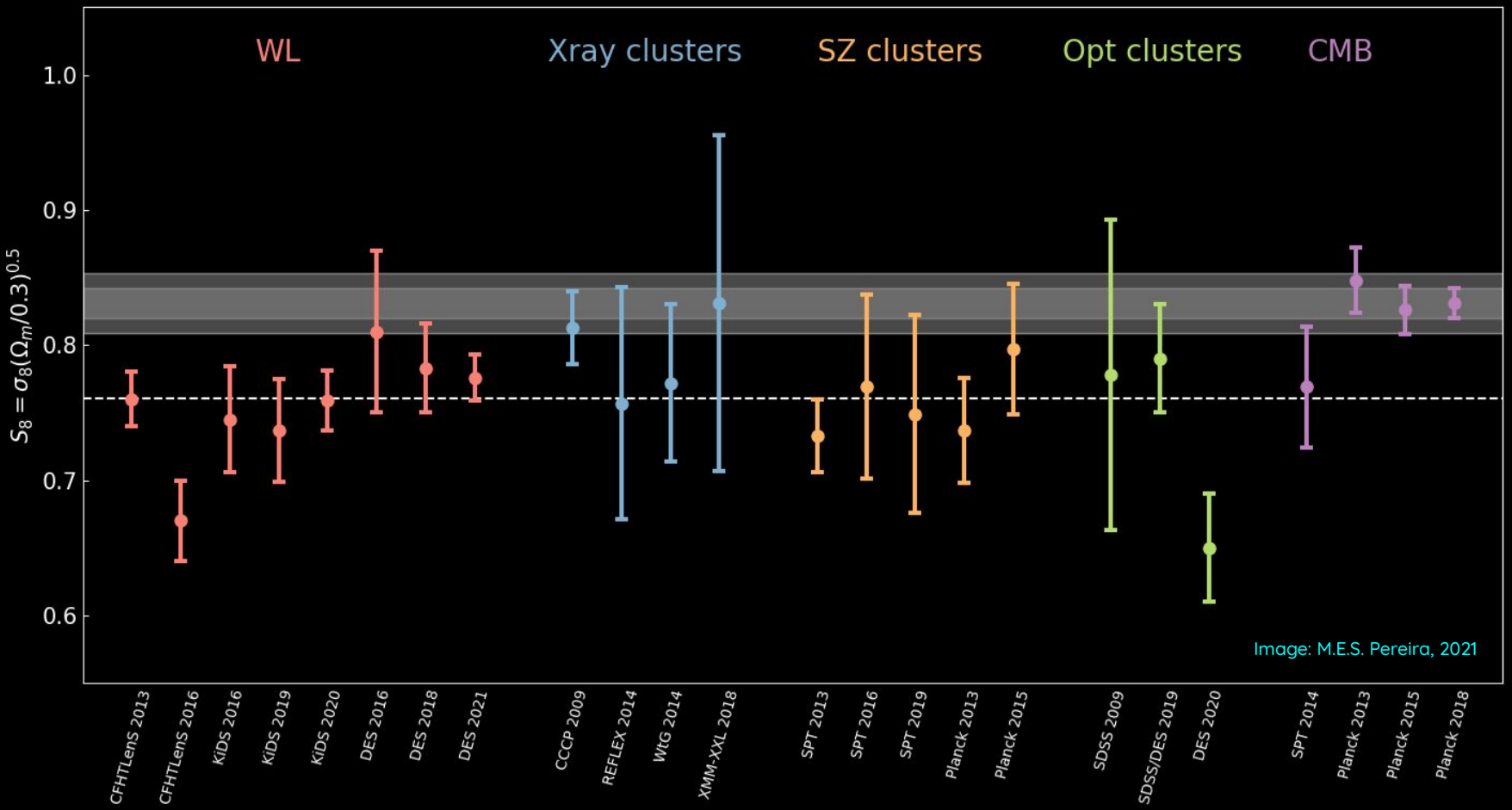


Refregier et al, 2002



Credit: Warren et al. (Los Alamos), adapted.

Introduction: S_8, a Cosmic Controversy?

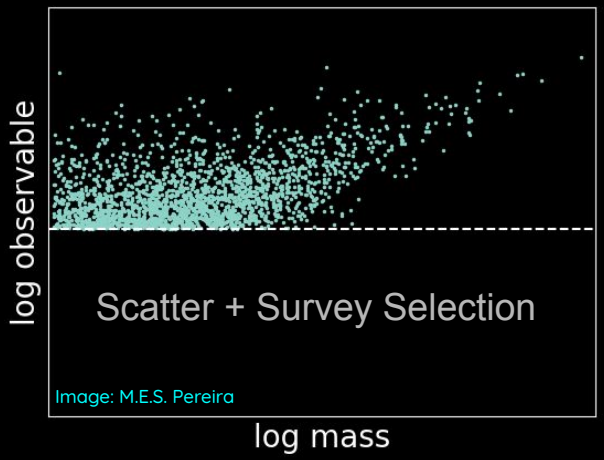


- The measurements of cosmological parameters from clusters/WL in the late Universe are systematically lower than the early Universe estimates. Systematics or New Physics?

Cluster Cosmology: Clusters, Mass & Counts

- What do we need?
  - 1 - Cluster identification
  - 2 - Cluster masses (e.g. weak lensing)
  - 3 - Theoretical model for the cluster's number counts

- An indicator for the mass
  - Number of red galaxies (λ)
  - Stellar mass ($\mu_\star$)
  - X-ray luminosity
  - Intracluster light, etc



- Total mass from (stacking) weak lensing

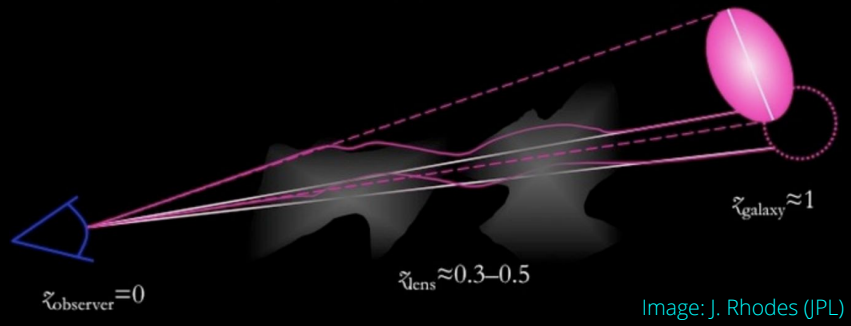
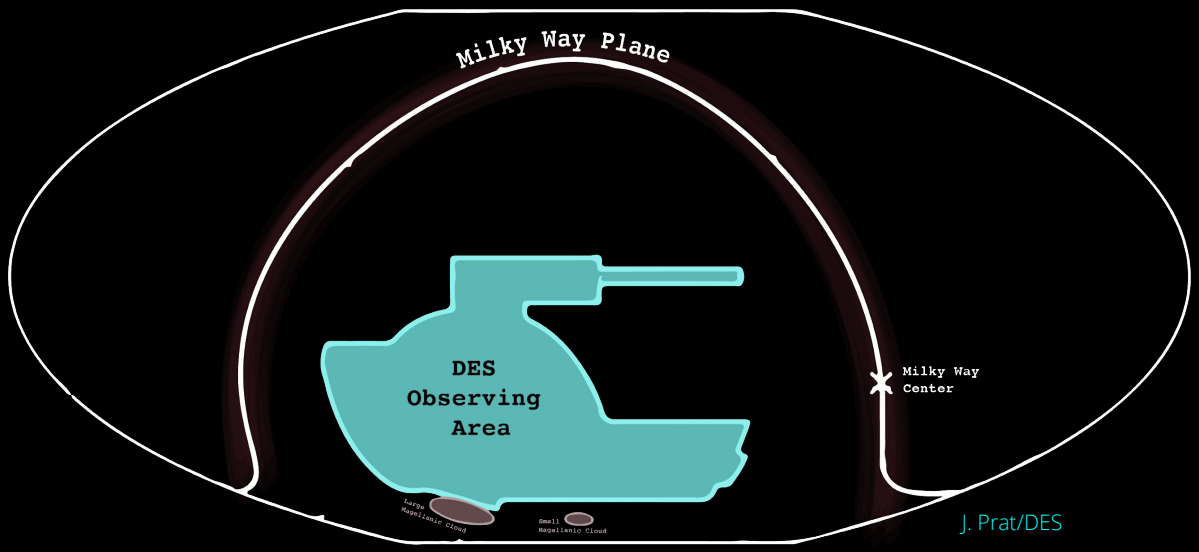


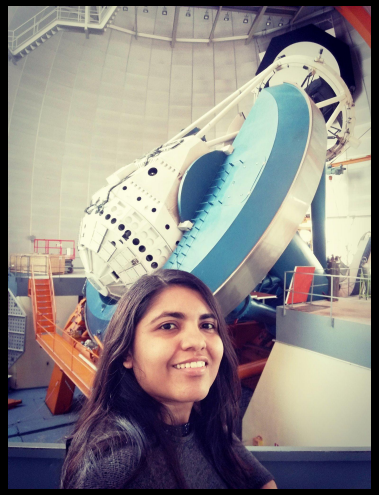
Image: J. Rhodes (JPL)

- Observable-mass relation (OMR) calibration

The Dark Energy Survey



J. Prat/DES



- Dark Energy Survey: astronomical survey that aims to measure the expansion of the Universe, analyzing the large scale structure
- Uses different methodologies (probes): supernovae, gravitational lensing, gravitational waves
- Observed ~5,000 square degrees in the southern sky, 6 years
- DECam: ~500 Megapixels
- Filters: g, r , i, z, Y
- 100 millions of galaxies (Year 3): quantity and quality for the weak gravitational lensing analysis

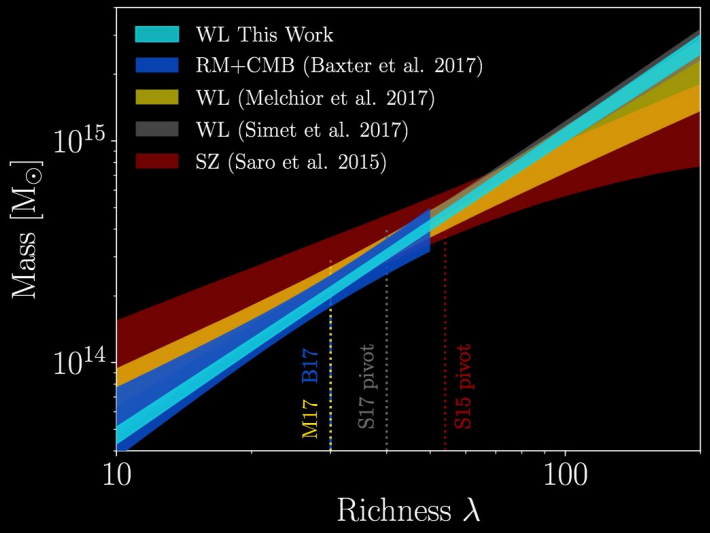
Cluster Cosmology on DES Year 1

- redMapper cluster catalog (~6,000)
- Metacal shears (~30M)
- BPZ photo-z (~0.7)

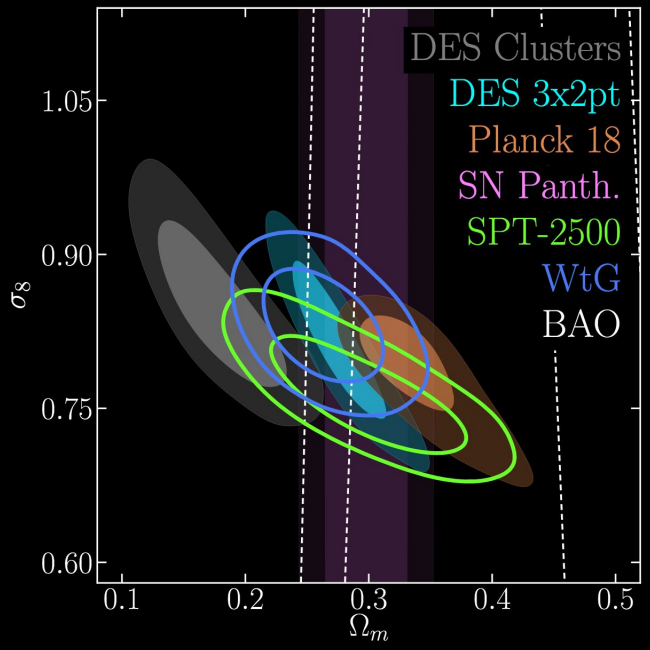
Mass-calibration (MOR) — 1

Number counts (NC) — 2

Cosmology! S_8 (σ_8, Ω_m)



McClintock et al. 2019 (DES Collaboration) MNRAS, Vol. 482, Issue 1, Jan 2019, Pg. 1352–1378 (arXiv: 1805.00039)



T. M. C. Abbott et al. 2020 (DES Collaboration) Phys. Rev. D 102, 023509, Published 7 July 2020 (arXiv: 2002.11124)

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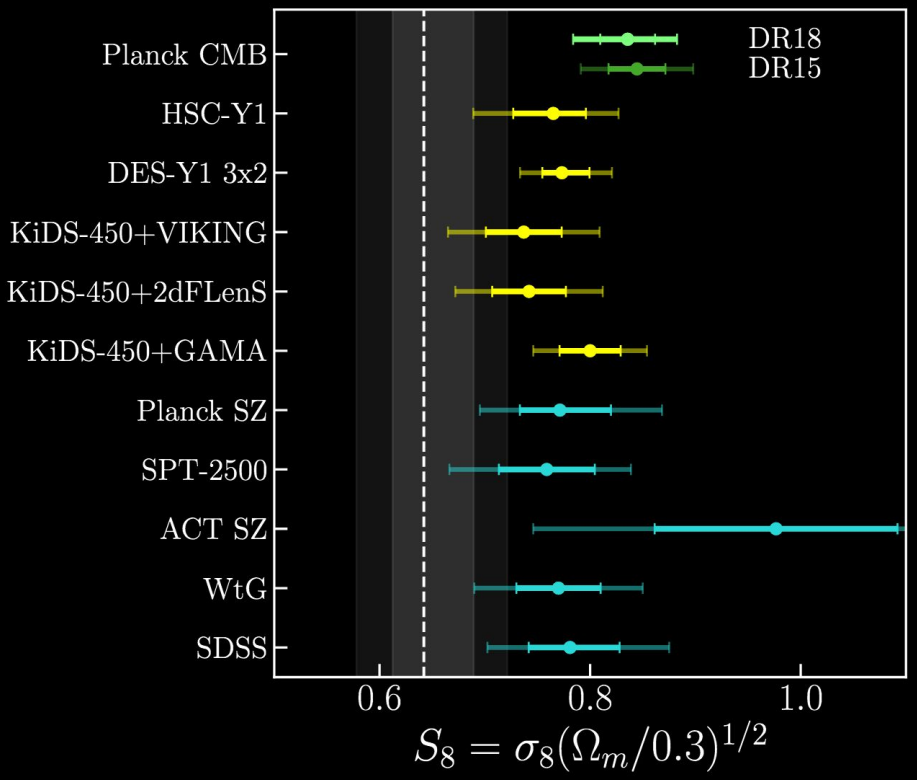
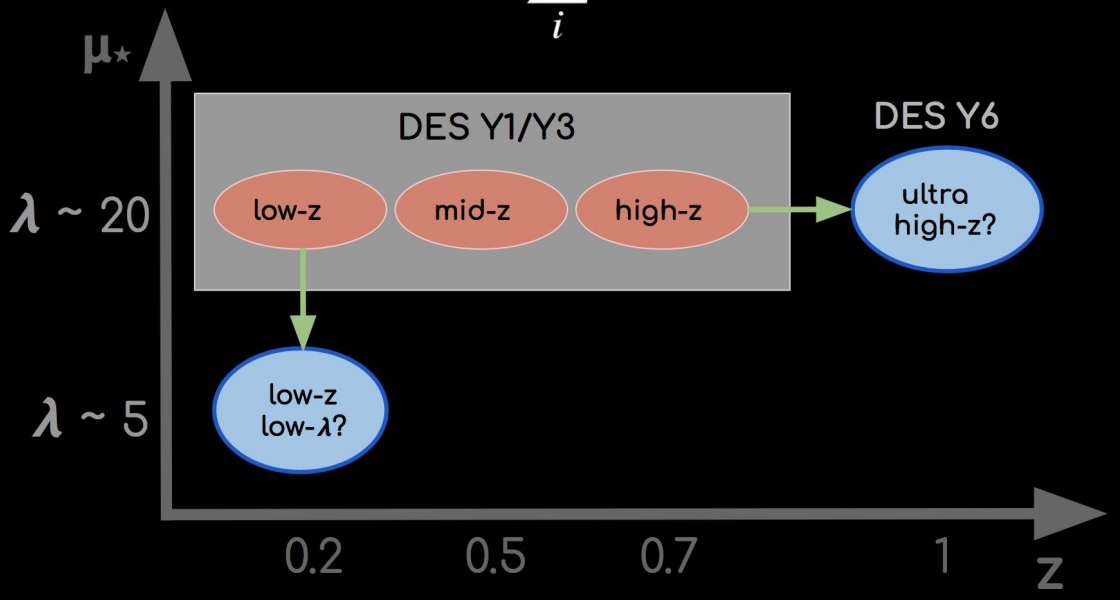


- Cosmology with state-of-art optical mass-calibration with 5% errors
- But, underestimation or incomplete understanding of systematics in the cluster mass estimates are very likely to explain the S_8 offset
  - Low richness cluster masses are biased low
  - Projection & selection effects and contamination
- Critical work to be done: We need to improve our understanding of the cluster systematics!

A stellar mass based mass proxy on DES Y1

- A riqueza do redMaPPer é baseada na cor (sequência vermelha)
- Mas temos galáxias azuis também! E se considerássemos essa informação?
- Com um proxy baseado nas massas estelares

$$\mu_\star = \sum_i P_{\mathrm{mem},i} M_{\star,i}$$

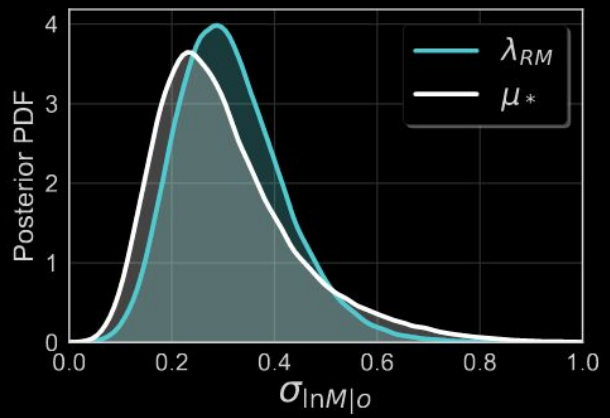


- Importante para explorar 2 regimes
  - Baixo-z/baixa riqueza: poucos membros/efeitos de projeção
  - Alto-z: sequência vermelha não definida
- E mais: Podemos estudar melhor os aglomerados de baixa riqueza?

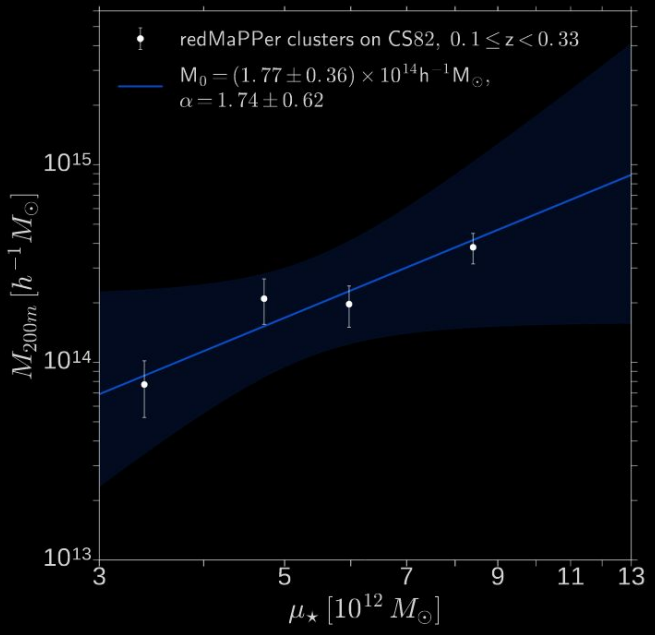
A stellar mass based mass proxy on DES Y1

- Scatter medido com amostra de raios-X
  - Um pouco melhor que λ
- 1ª calibração com lenteamento fraco
  - ~150 aglomerados do CS82
- Calibração com dados do DES ano 1
  - Para ~ 6,000 aglomerados
  - 1ª vez em alto-z

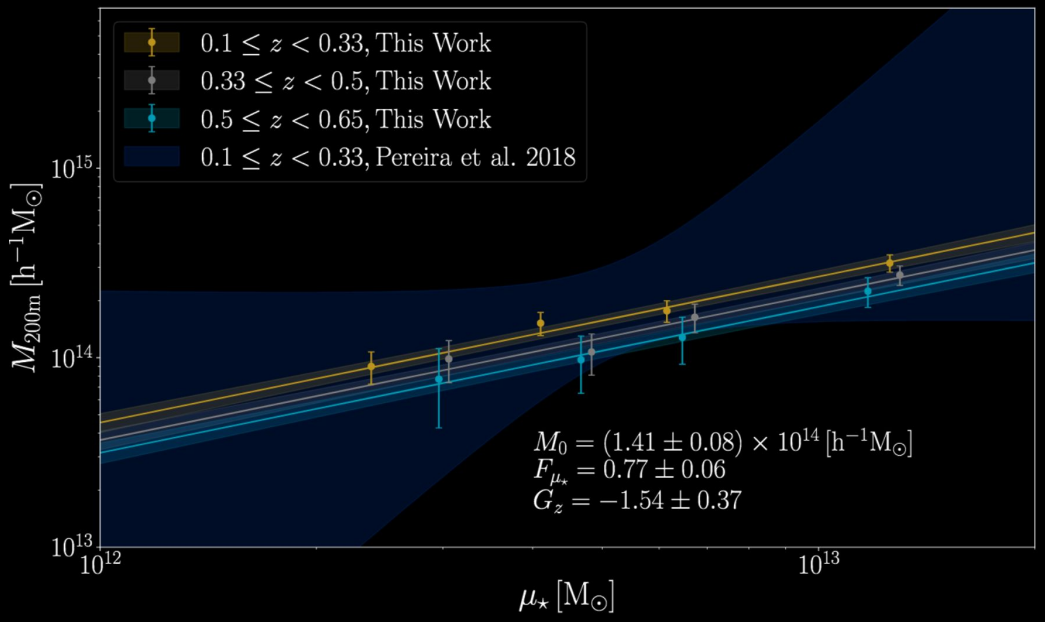
Palmese et al. 2019 (arXiv: 1903.08813)



Pereira et al. 2018 (arXiv: 1708.03329)

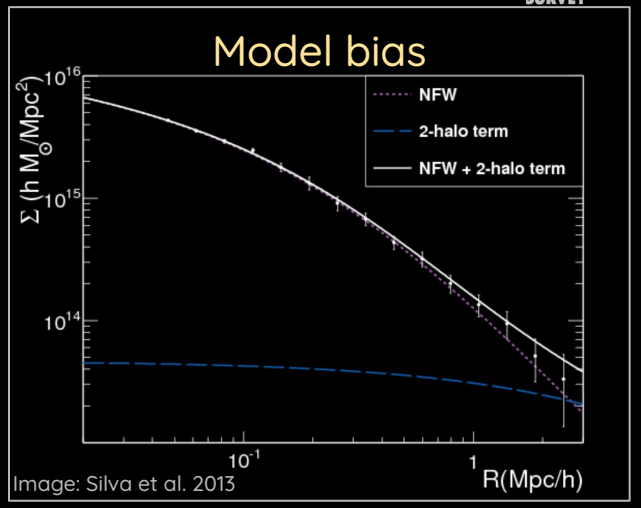


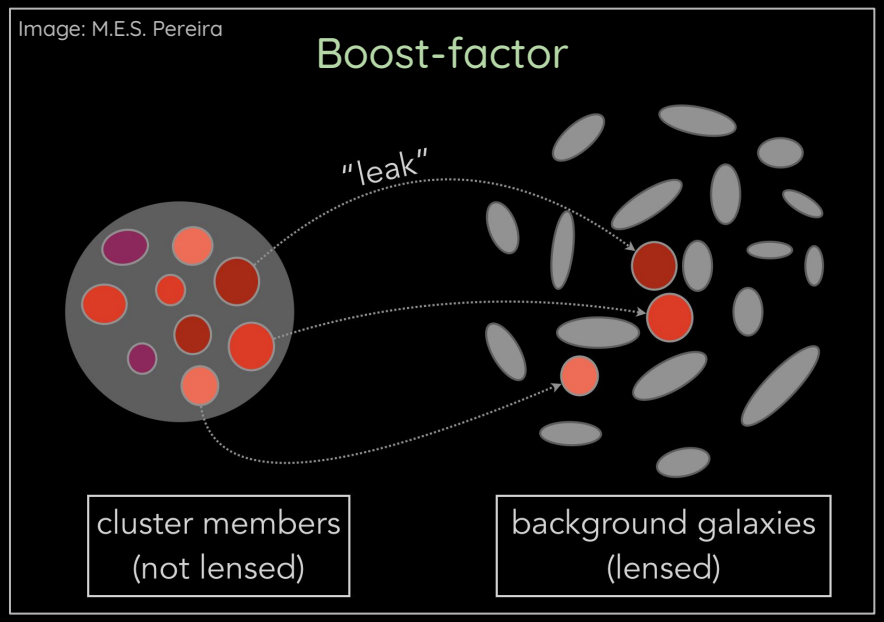
Pereira et al. 2020 (arXiv: 2006.10162)

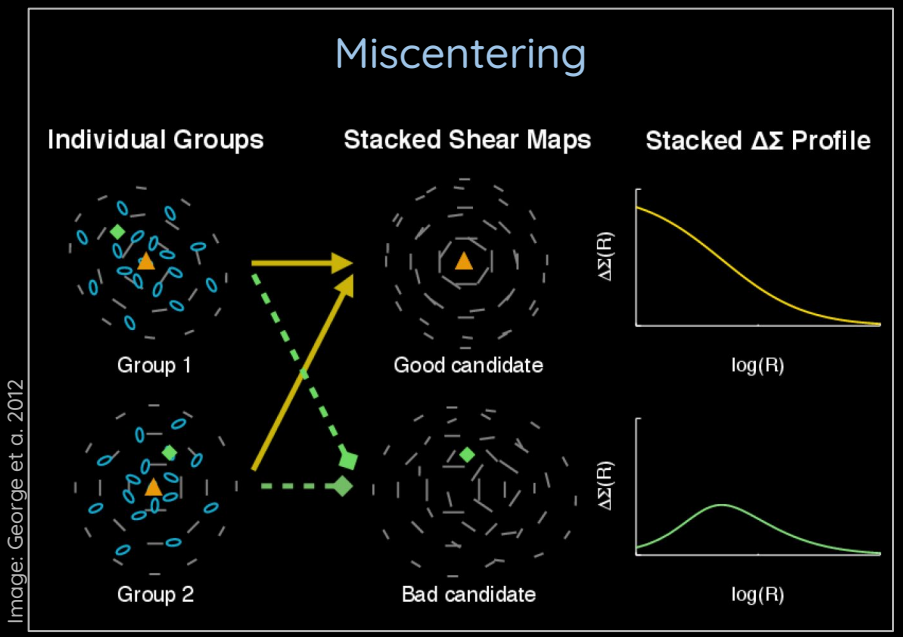


Systematic errors in the mass Y1

- Model bias (0.73%) McClintock et al. 2019 (arXiv: 1805.00039)
  - Clusters are not perfect NFW
- Boost-factor (<1%) Varga et al. 2019 (arXiv: 1812.05116)
  - Cluster members "leak" to background
  - They are not lensed, dilution of the signal
- Miscentering (<1%) Zhang et al. 2019 (arXiv:1901.07119)
  - Observed center is different from true center
  - Suppression of the lensing signal







Systematic errors in the mass Y1

- Shear bias (1.7%) Zuntz et al. 2018 (arXiv: 1708.01533)
  - Model, noise, selection, PSF
- Photo-z bias (2.6%) Hoyle et al. 2018 (arXiv: 1708.01532)
  - Biases, scatter, catastrophic errors
- Triaxiality (2%) McClintock et al. 2019 (arXiv: 1805.00039)
  - redMaPPer selects halos in a given orientation
- Projection effects (2%) McClintock et al. 2019 (arXiv: 1805.00039)
  - Issue with membership assignment

Image: Abruzzo et a. 2018

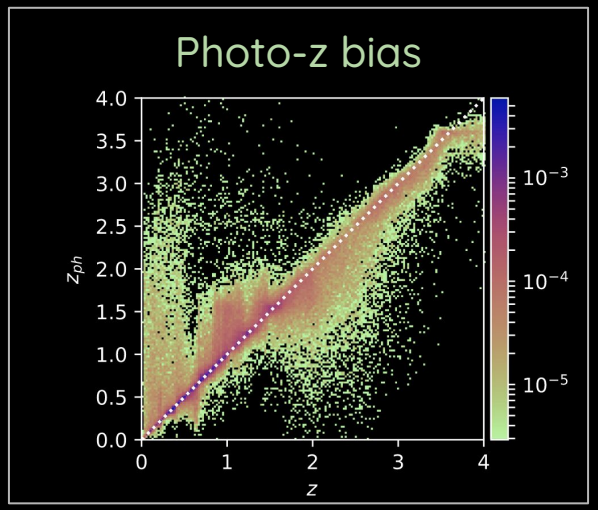
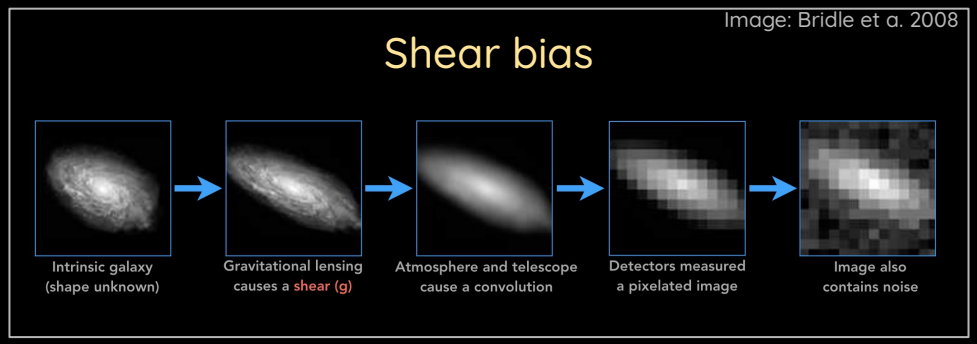
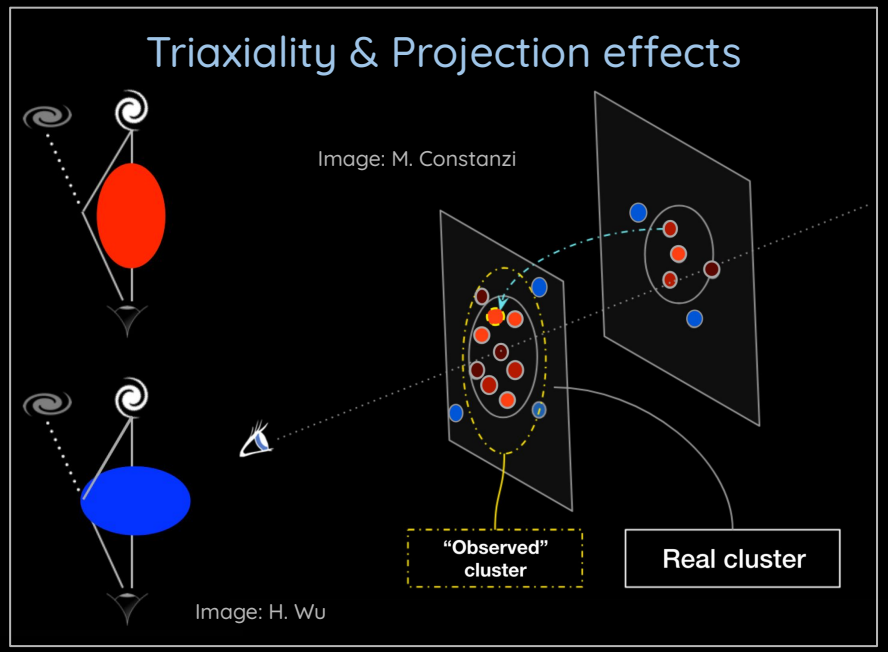


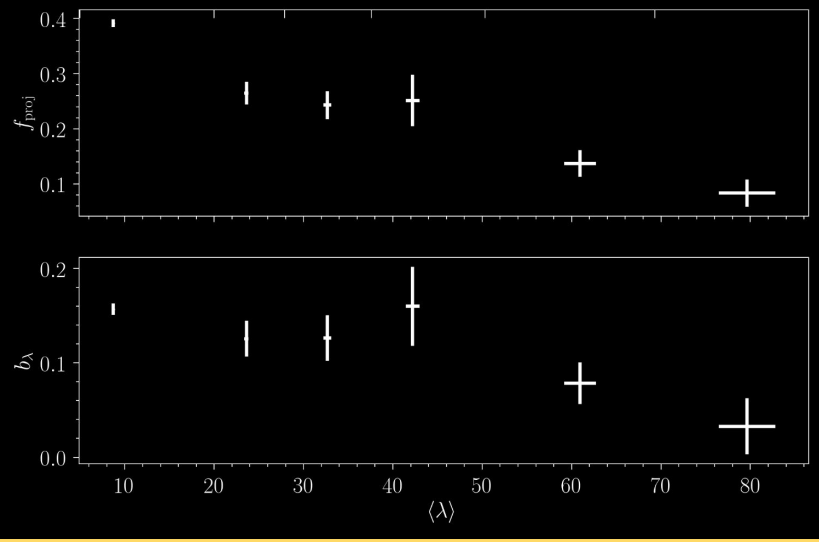
Image: Bridle et a. 2008





Systematic errors in DES Year 3

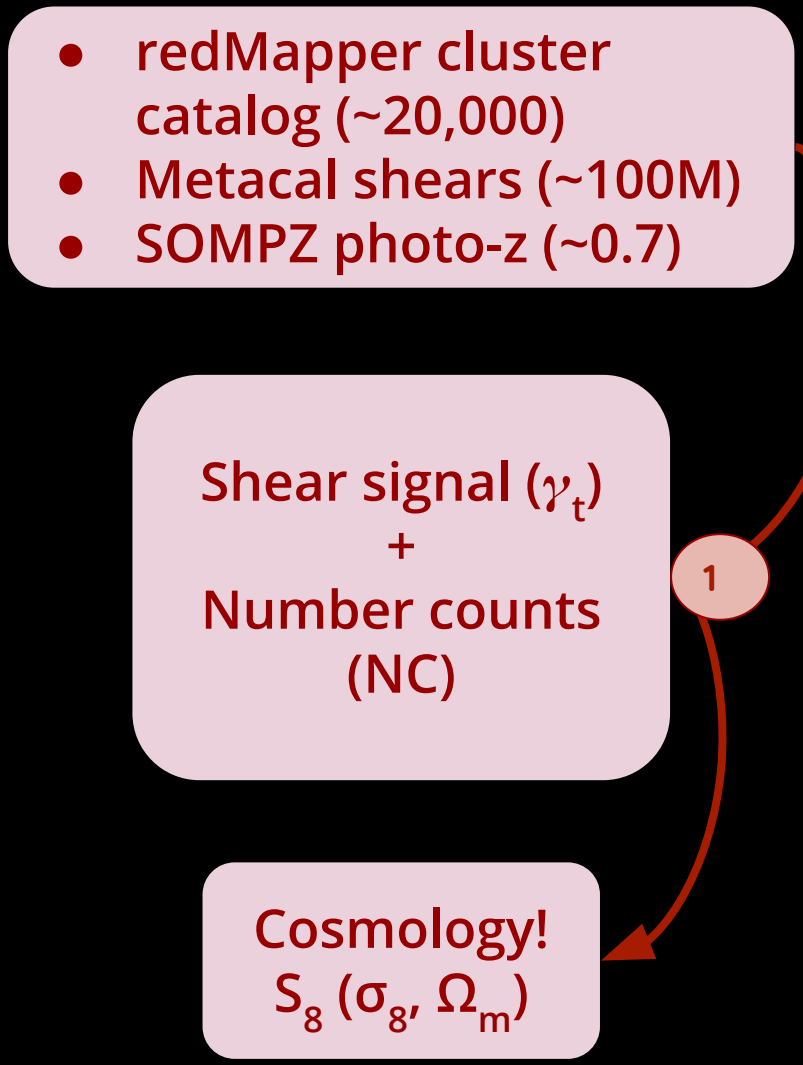
- **New Photo-z methodology (SOMPZ) & calibration**
  - Buchs, Davis et al. 2019 - arXiv: 1901.05005
  - Myles, Alarcon et al. 2020 - arXiv: 2012.08566
- **Improvements on the shear measurements**
  - Gatti, Sheldon et al. 2020 - arXiv: 2011.03408
  - Jarvis et al. 2020 - arXiv: 2011.03409
- **New corrections for Projection Effects and Triaxiality**
  - Myles et al. 2020 - arXiv: 2011.07070; Zhang et al. (in prep.)
- **Understanding selection & lensing signal of low richness clusters**



Myles et al 2020
(arXiv:2011.07070)

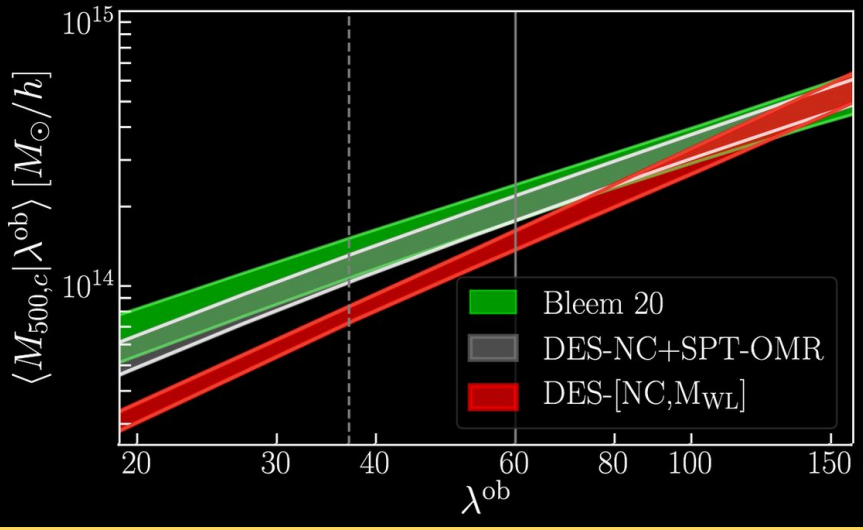
Cluster Cosmology with DES Year 3

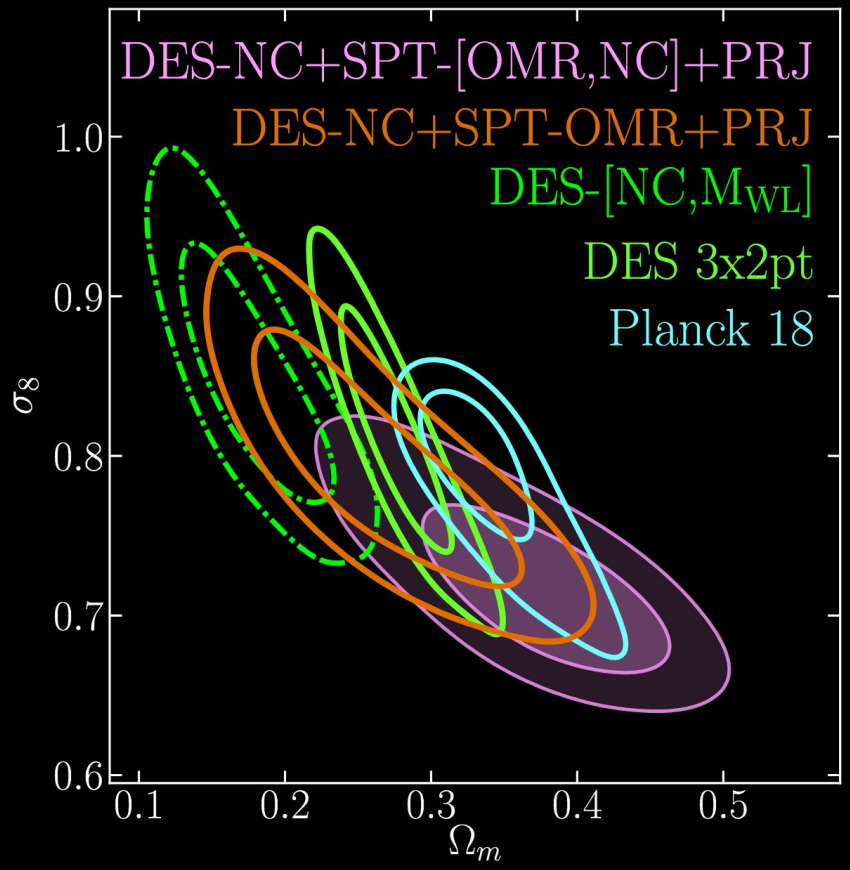
- Main analysis: Full forward modeling of NC and stacked γ_t
- Inclusion of multiwavelength follow-up data to
  - Improve modeling of projection effects
  - Better understand selection effects
  - External calibrations for the OMR
  - Improve the scatter constraints of the OMR
- Inclusion of 2pt statistics (gg,cc,cg,cγ) to:
  - Calibrate OMR
  - Selection effects
- Improve OMR in simulations to have more reliable templates to model selection effects
  - WL selection effect bias
  - Triaxiality effects, etc
- Use simulations to calibrate M_{WL}-M relation (avoid explicit λ-selection in sims)
- Cluster Cosmology DES Year 3: expected for Fall 2021! Stay Tuned!



Alternative Analysis: NC + Multiwavelength

- Same as DES Y1 but using SZ and high quality X-ray/WL data from SPT-SZ + combination with SPT-SZ high-z number counts (OMR+NC)
- Main results:
  - Cosmological posteriors consistent with DES 3x2pt and other cluster abundance studies
  - Calibration of projection effects and intrinsic scatter



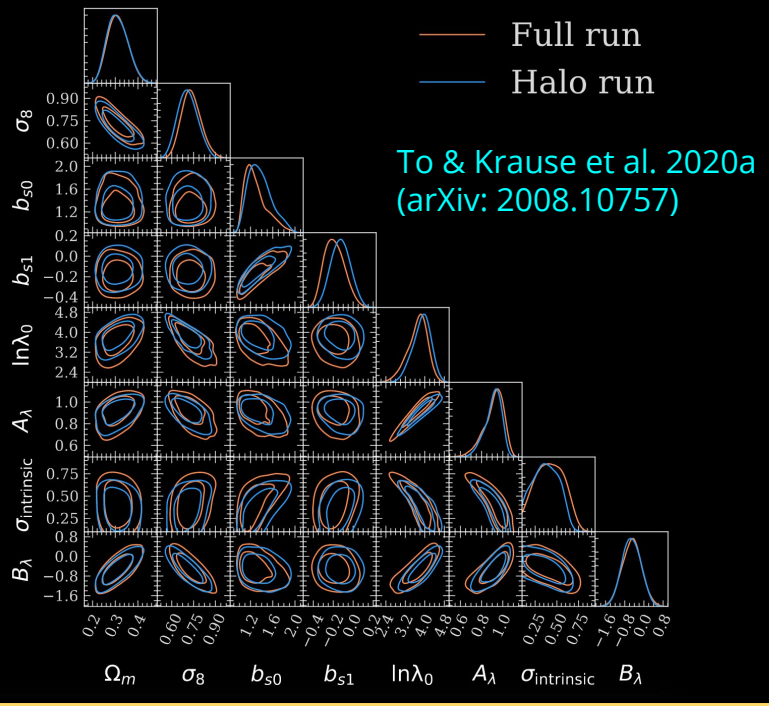


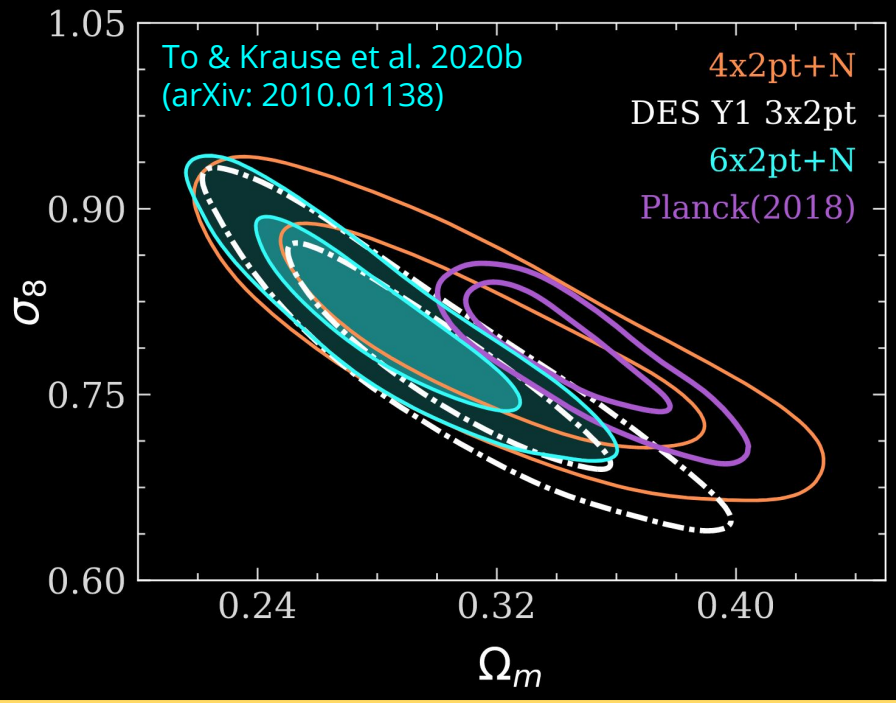
Costanzi et al. 2020 (arXiv: 2010.13800)

Alternative Analysis: NC + 4x2pt

- Full forward modeling
- Only use large scale information (>8Mpc)

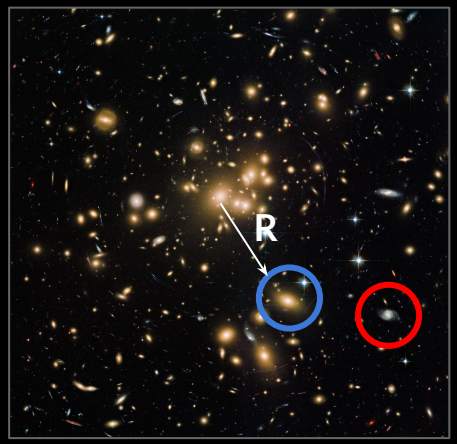
- Main results
  - First constraints on selection effect bias
  - Posteriors consistent with DES 3x2pt and other abundance studies
  - Cluster data provide 20% improvement on Ω_m over 3x2pt analysis



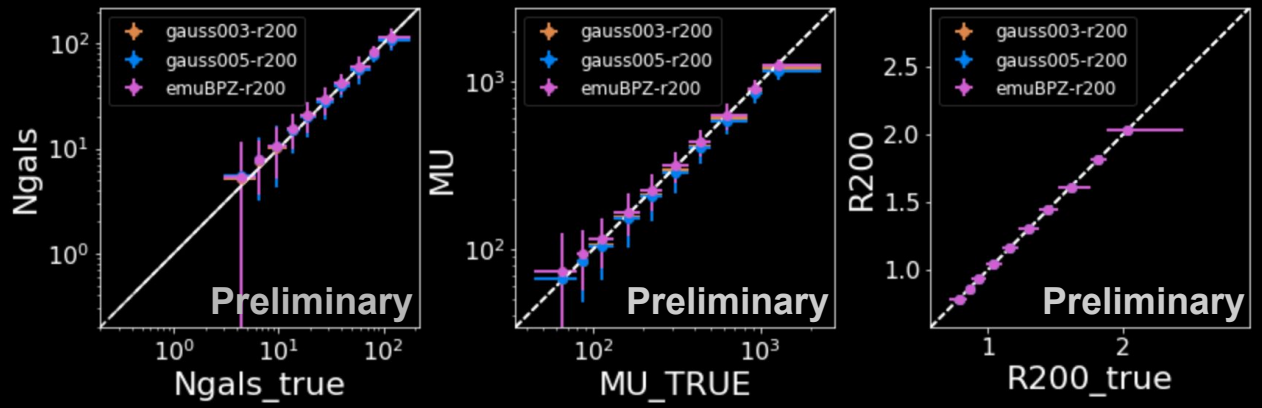


Copacabana

- **Co**lor **P**robabilistic **A**ssignment for **C**lusters And **BA**yesia**N** **A**nalysis
  - Improvements: Photo-z PDF, adding color probabilities
- Science Cases
  - Cluster Cosmology: mass proxy, projection effects
  - Galaxy Evolution & Astrophysics: quenching, merging clusters
- Status
  - Validation on Sims and applied to DES Y3
  - Release paper this summer!



Esteves et al (in prep.)



Summary

- Mass estimation is the main limiting factor for Cluster Cosmology
- DES Y1 mass estimates: ~5% uncertainties. But we need ~1%!
  - Rubin Observatory/LSST; NASA/Roman, Euclid, etc
- DES Y1 cosmology: S_8 offset
  - Lensing mass from the low richness clusters
  - We are potentially underestimating systematics (selection, contamination, etc)
  - We also need new methods for systematics like triaxiality and projection effects
- DES Y3 Planned Analyses
  - NC+γ_t: Nominal analysis where we combine Number Counts and stacked tangential shear signal around clusters (+ priors from follow-up data/simulation)
  - NC+Multiwavelength: Combine Number Counts and Multiwavelength follow-up data (SZ,X-ray,WL), the latter to inform the λ-M scaling relation
  - NC+4x2pt: Combine Number Counts and 2pt correlations functions (gg,cc,gc,cγ), the latter to inform the λ-M scaling relation
- Results: Fall 2021! Stay tuned!

Obrigada!
Thank you!