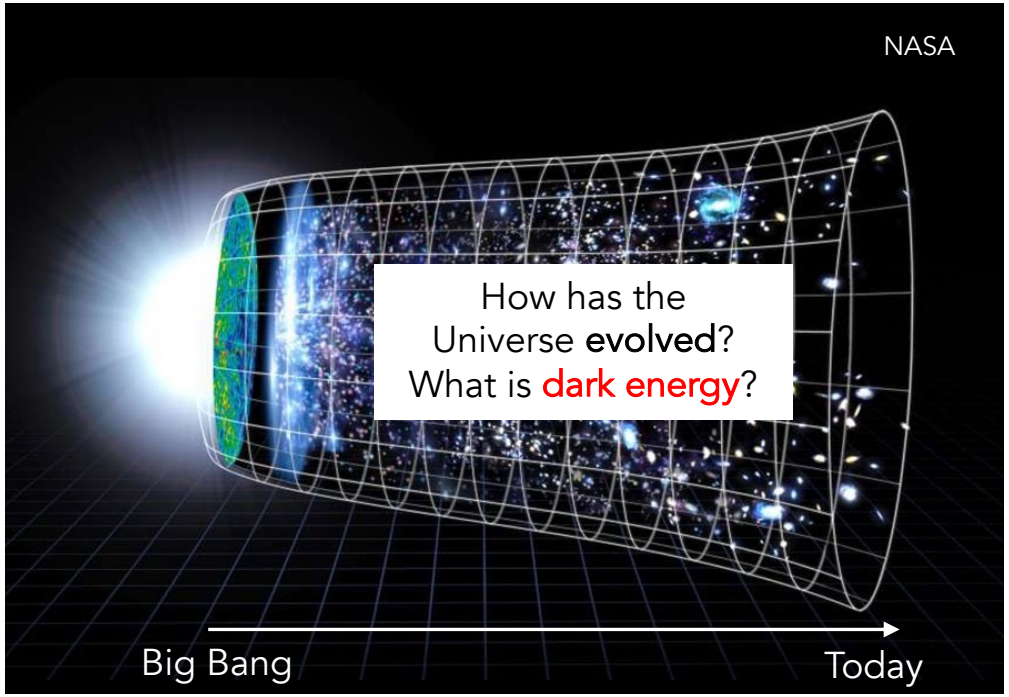
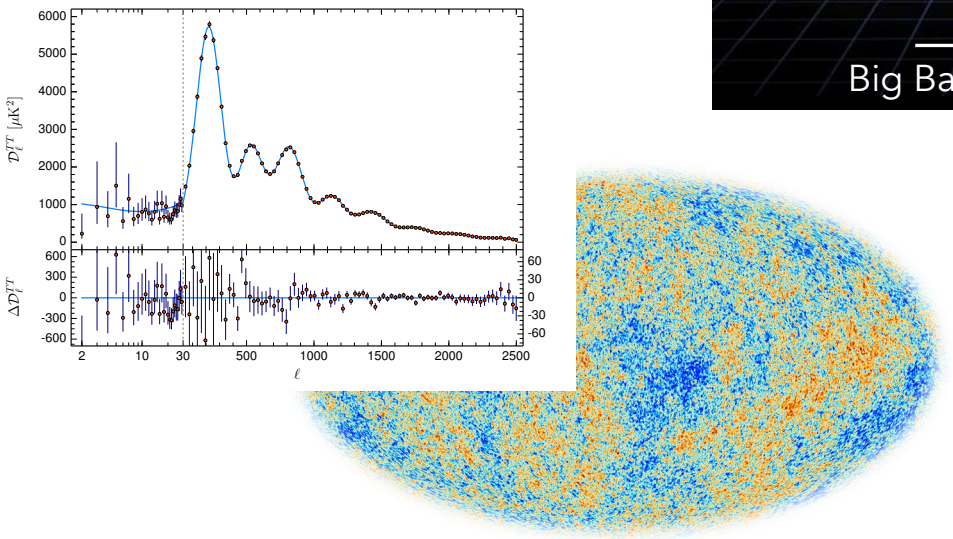
Weak lensing and clustering with DES – Agnès Ferté (SLAC)

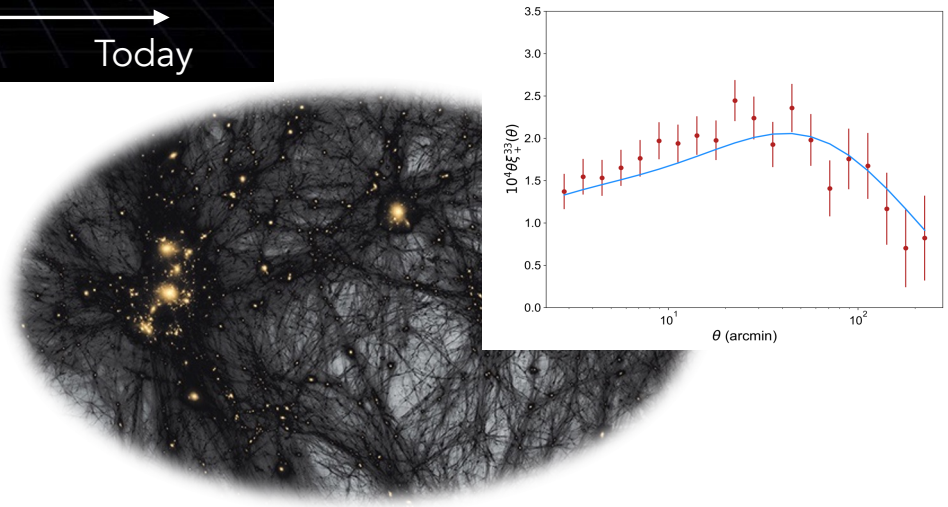
Rubin Pipeline meeting – Feb 22nd, 2023





Challenge of the **2010s**

Matter distribution in the early Universe



Challenge of the **2020s**

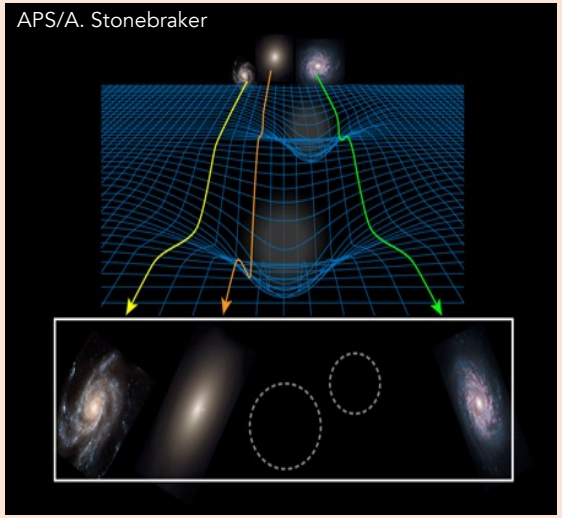
Matter distribution in the recent Universe

Galaxy surveys probe (mostly dark) matter structures

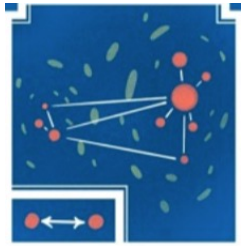
- Galaxies are clustered on large scales

- Galaxies are weakly lensed
  by large-scale structures on the line of sight
  → **Geodesics** are modified
  → **Shapes** of galaxies appear:

More elliptic



Correlated

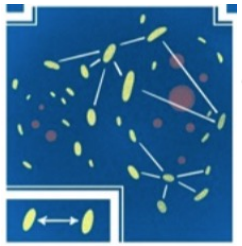


Clustering

$b^2\xi_{mm}(\theta)$

Galaxy-galaxy clustering

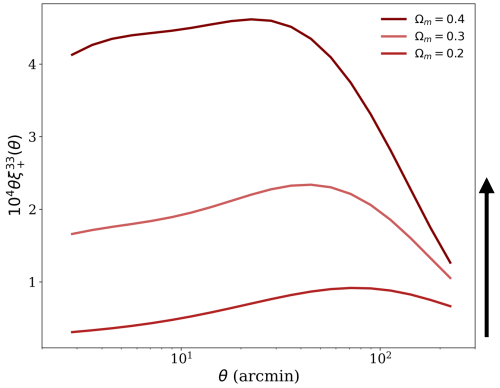
$b\xi_{mm}(\theta)$



Cosmic shear

$\xi_{mm}(\theta)$

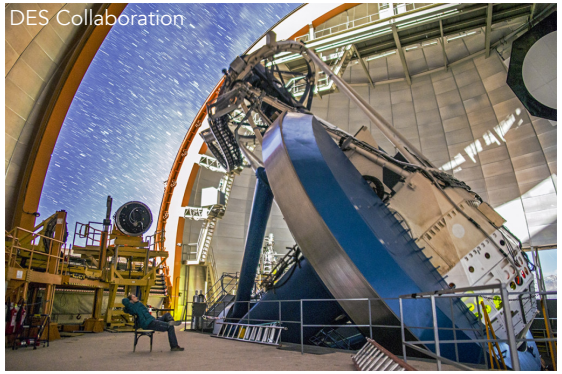
3x2pt: probe growth of structures



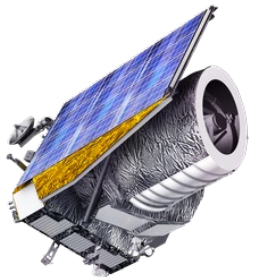
Ω_m

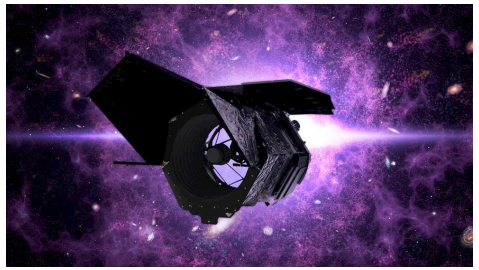
Large weak lensing surveys of the 2020s

- Joined the DES collaboration in 2014 as a postdoc at Royal Observatory, Edinburgh, UK



- Joined the DESC collaboration in 2018 as a postdoc at JPL/Caltech
- Started as Rubin Operations scientist at SLAC in Aug 2022



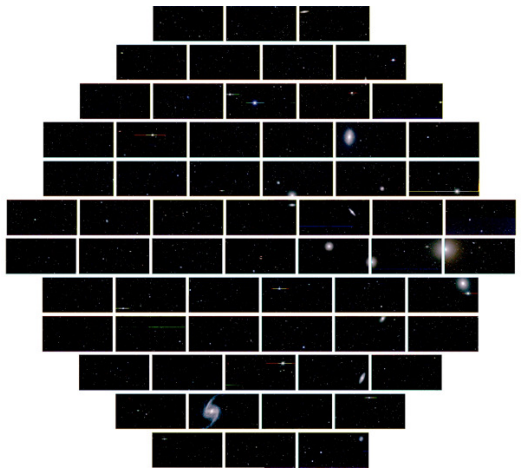


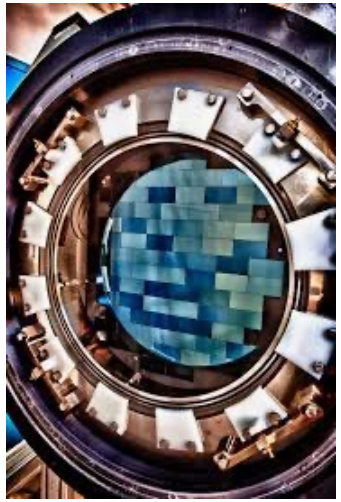
+ KiDS
+ HSC

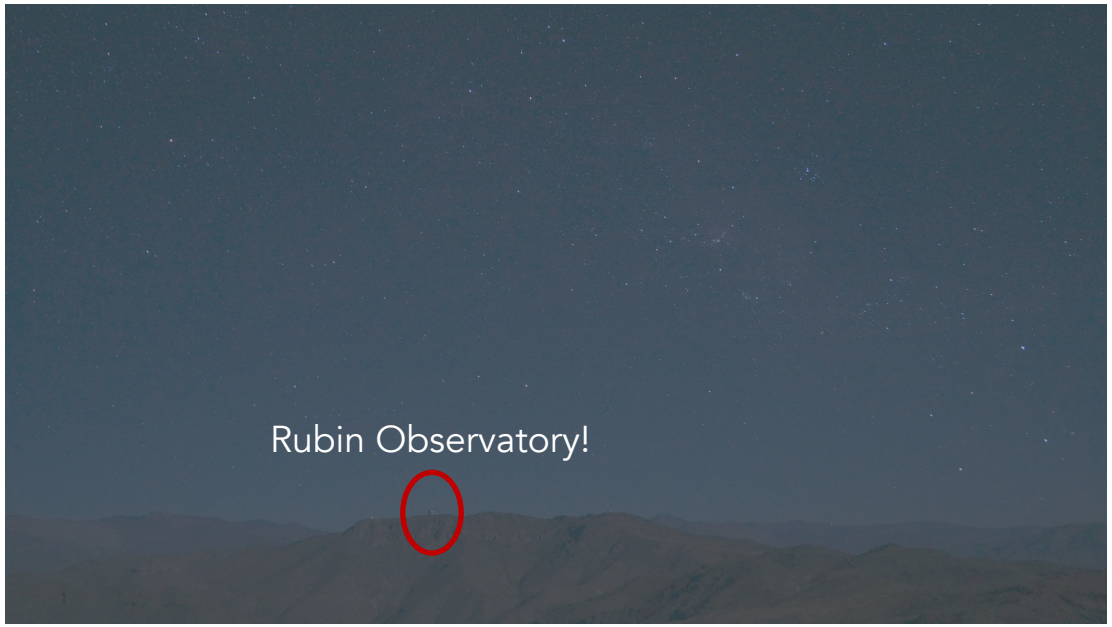
- Worked on Precision Projector Lab to study detector effects on H2/4RG at JPL/Caltech

Dark Energy Survey is a precursor of LSST

- **DECam** at CTIO Blanco-4m
  74 CCDs, 2.2° field of view, 570 Mpixels
- **10%** of the sky between 2013 and 2019
  5 optical bands (grizY)
- International collaboration:
  3x2pt, BAO, Clusters Supernovas
  3 phases of cosmological analysis: Y1, Y3 and Y6





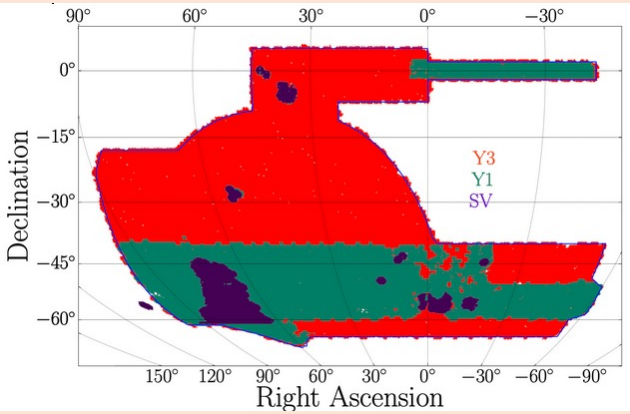


- ~2 weeks of **observing**
  I made an outreach youtube video about it:
  https://www.youtube.com/watch?v=b5N0Bq2NI8w
- **Builder** member since 2020
- **Participation** to cosmological analyses
- **Co-convener** of the *Theory and Combined Probes* Working Group since 2021

DES Y3: cosmological analysis of 3x2pt is a data challenge

Images over **10%** of the sky

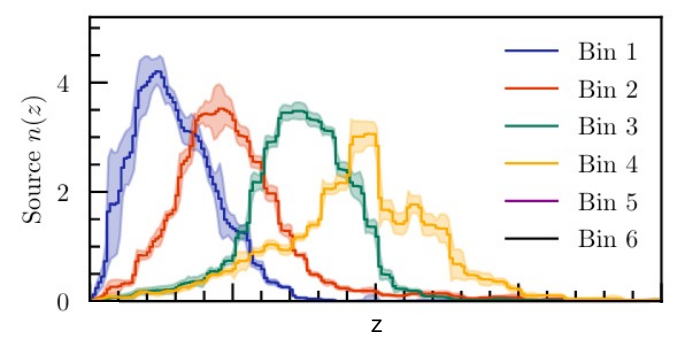
Sevilla – Noarbe, Bechtol, Carrasco Kind, et al, ApJ, 2021



Sevilla – Noarbe, Bechtol, Carrasco Kind, et al, 2021
Hartley, Choi, et al, 2021
MacCrann et al, 2021
Everett et al, 2021

Shape of **100 millions** galaxies and redshift estimation

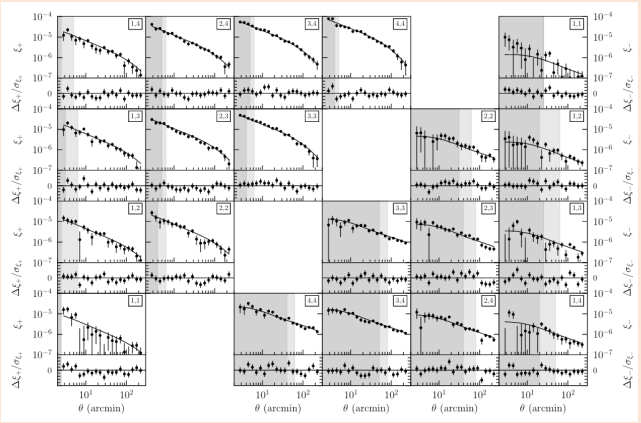
DES collaboration, PRD, 2022



Jarvis et al, 2021
Gatti, Sheldon, et al, 2021
Cawthon et al, 2021
Giannini et al, in prep
Myles, Alarcon, et al, 2021
Gatti, Giannini, et al, 2021
Cordero, Harrison, et al, 2021
Elvin-Poole, MacCrann, et al, in prep

Precise measurements of correlation functions (S/N = 87)

DES collaboration, PRD, 2022



DeRose et al, 2021
Porredon et al, 2021
Pandey et al, 2021
Rodriguez-Monroy et al, 2021
Prat et al, 2021
Sánchez, Prat, et al, 2021
Amon et al, 2021
Secco, Samuroff, et al, 2021
Jeffrey, Gatti, et al, 2021

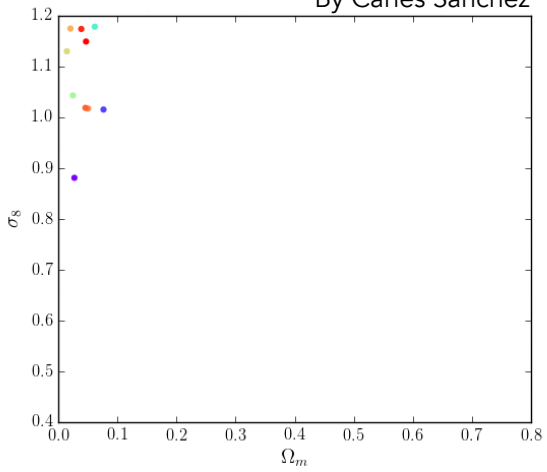
but also a modeling challenge!

Estimation of cosmological parameters by sampling the likelihood using the CosmoSIS code:

$$\mathcal{L}(\mathbf{D}|\Theta) \sim [\mathbf{D} - \mathbf{M}(\Theta)]^T C^{-1} [\mathbf{D} - \mathbf{M}(\Theta)]$$

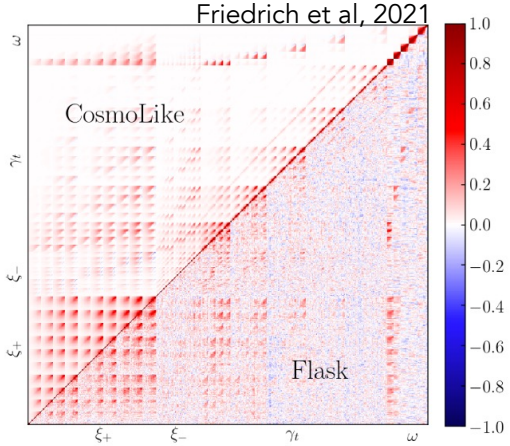
Gaussian likelihood: Sampling with polychord
Lemos, Weaverdyck (incl. **AF**) et al, 2022

By Carles Sánchez



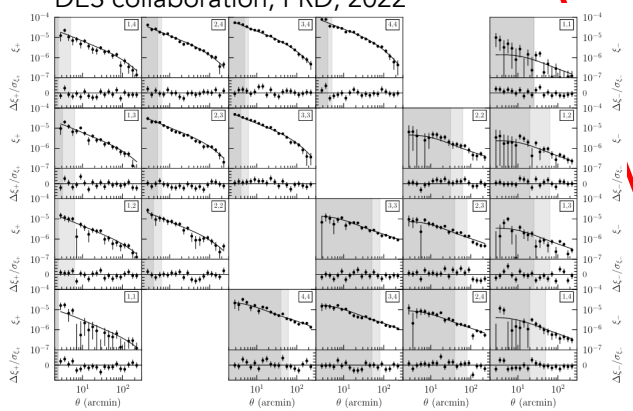
Covariance matrix between measurements
Friedrich et al, 2021

Friedrich et al, 2021



Data: Weak lensing and clustering measurements (462 data points)

DES collaboration, PRD, 2022



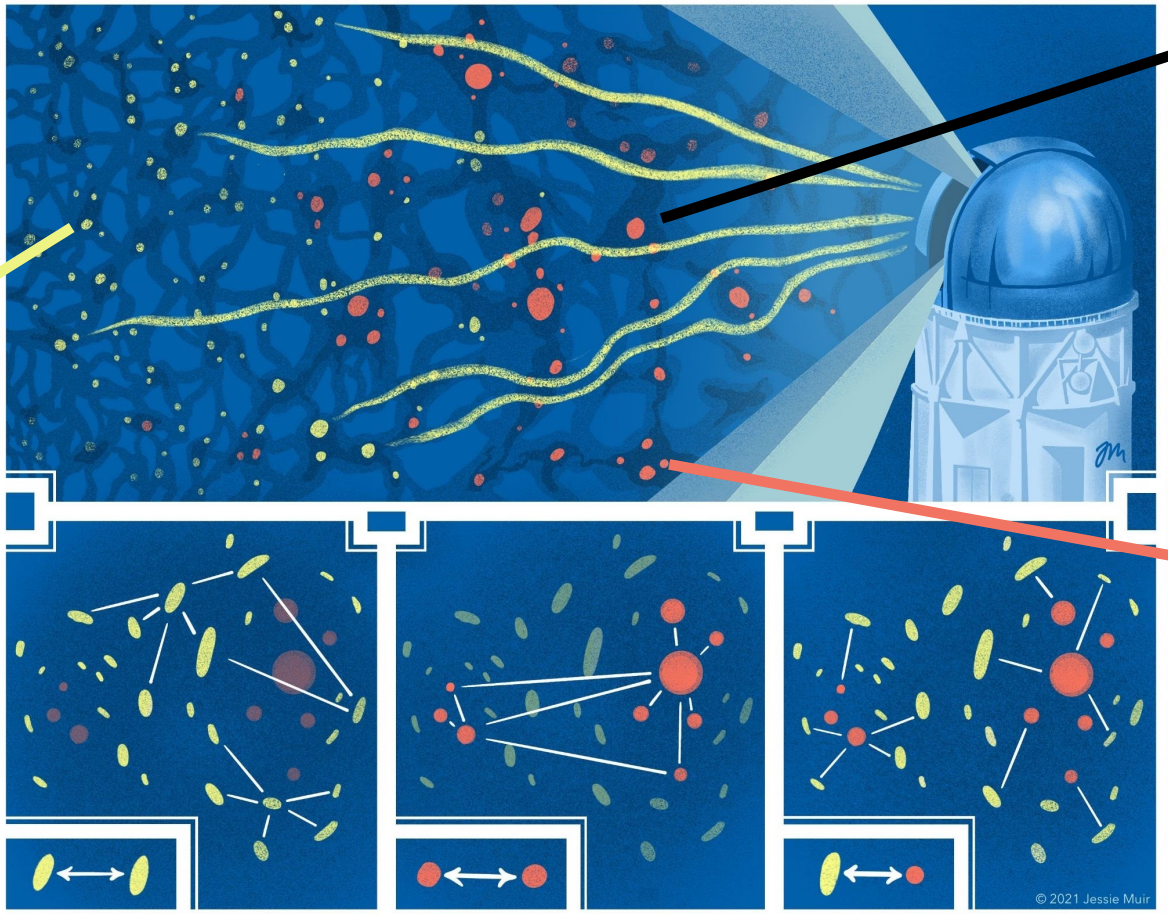
Model: **Analytic** prediction of weak lensing and clustering signal,
pipeline and **validation** of modeling choices
Krause et al (incl. **AF**), 2021

Cosmological parameters → Matter power spectrum P(k) → Angular power spectrum of lensing and clustering + systematic effects → 3x2pt real-space correlation functions

DES Y3 modeling choices

Described in Krause et al (incl. **AF**), arxiv: 2105.13548, 2021

Credits: Jessie Muir



Matter power spectrum
Halofit

Intrinsic alignment
TATT model: tidal alignment,
torque and z-dependence
⇒ 5 parameters

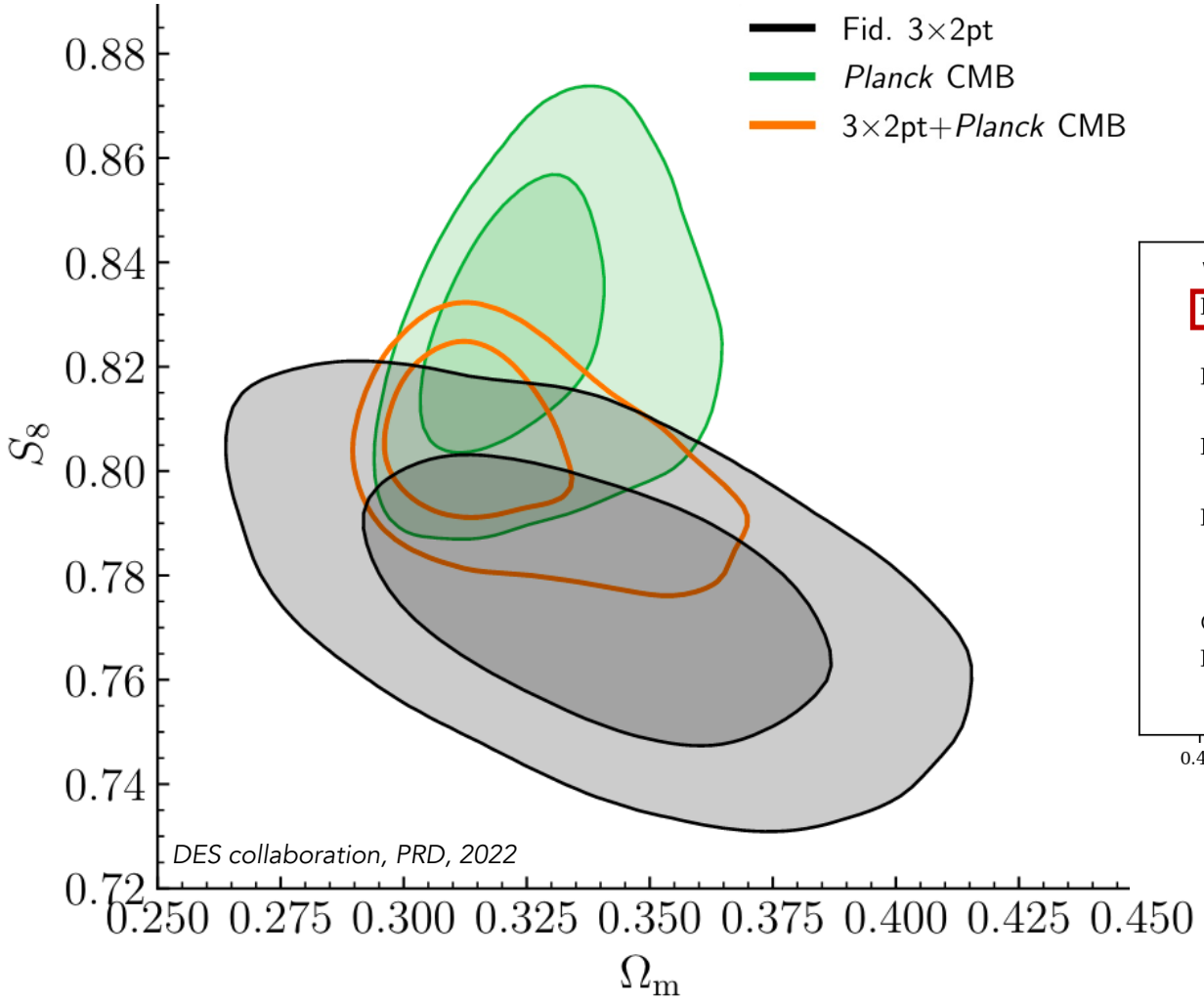
Galaxy bias
Linear galaxy bias model
⇒ 4 parameters

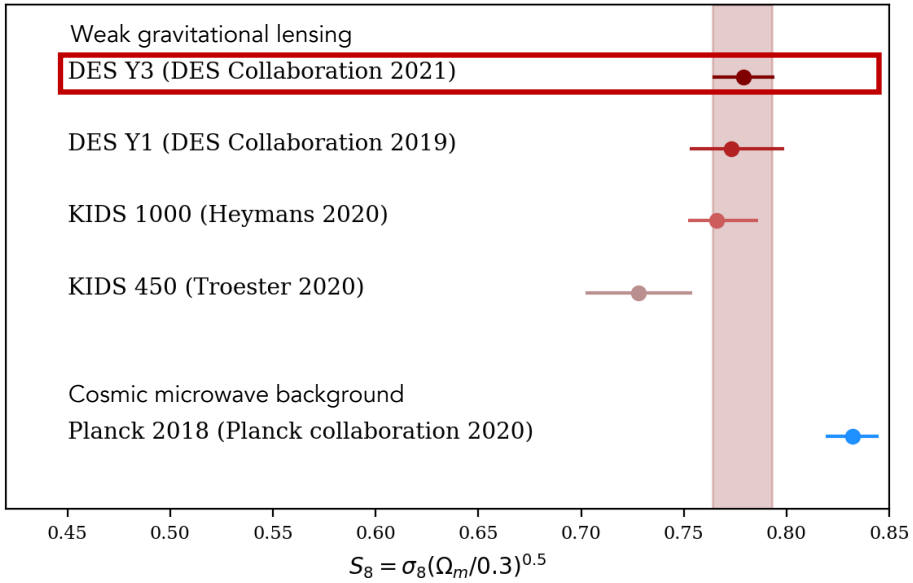
+ RSD and non-limber computation for clustering
+ mitigating effect of non-locality of gg lensing

And remove data points at small scales ('scale cuts') because of baryons physics and galaxy bias.

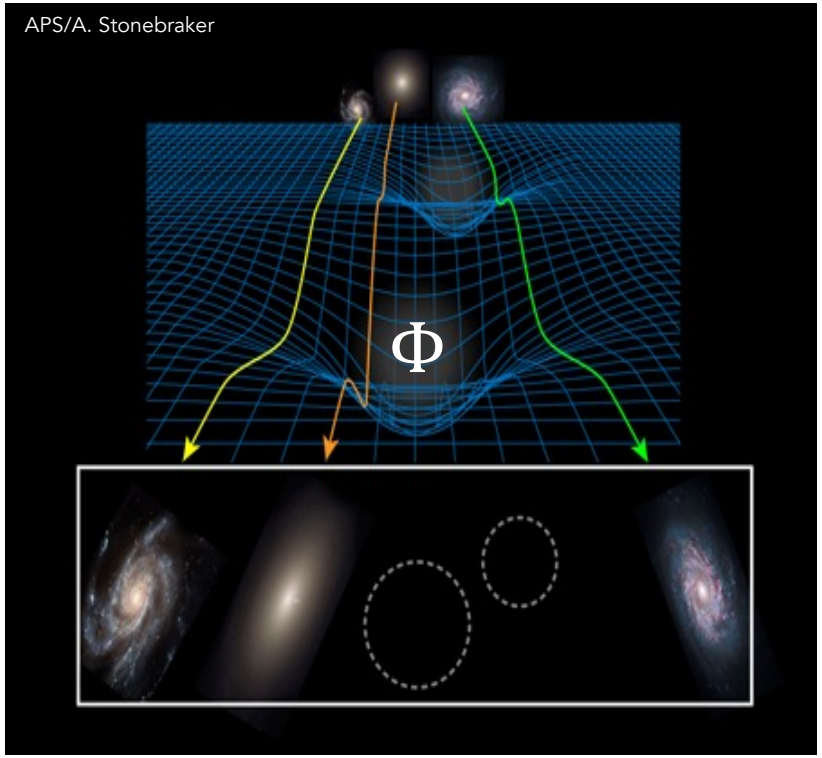
Cosmological results from DES Y3 3x2pt

Estimation of cosmological parameters by sampling the likelihood using the CosmoSIS code:





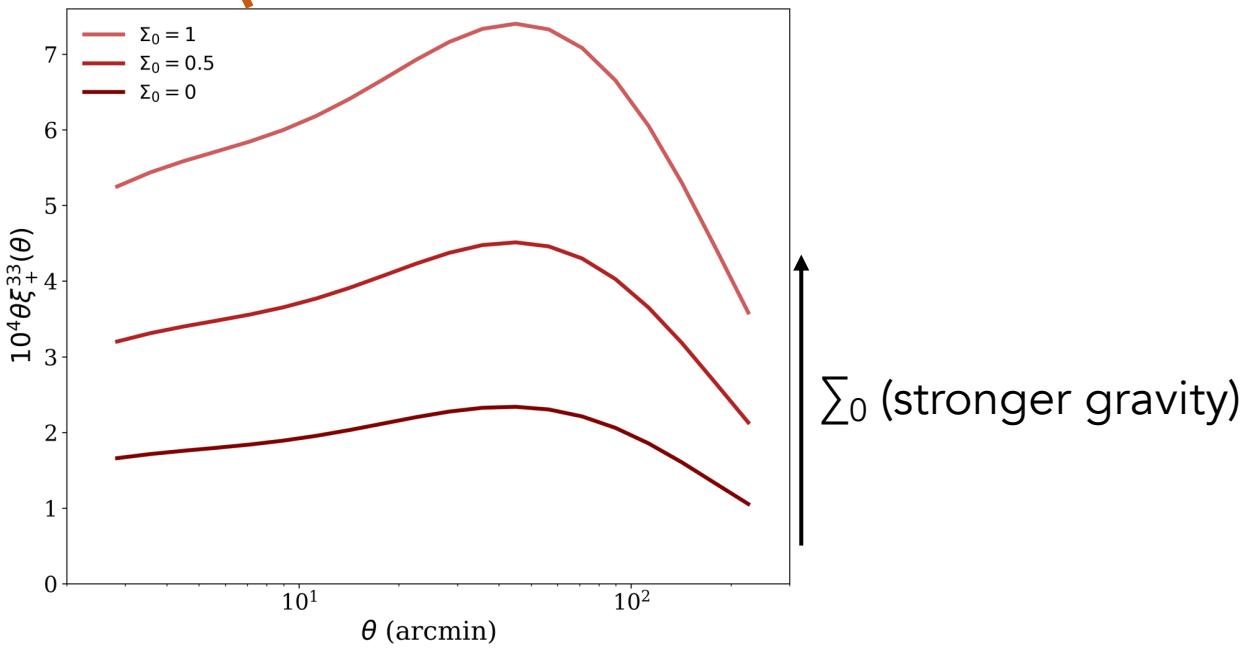
Weak lensing offers a unique opportunity to test gravity



Are modifications to geodesics caused by weak lensing as expected in GR?

$$k^2\Phi = -8\pi G a^2 (1 + \Sigma_0 \Omega_\Lambda(t))\rho\delta$$

→ Let's **measure deviations of** $\sum_0$ from 0 (GR)!



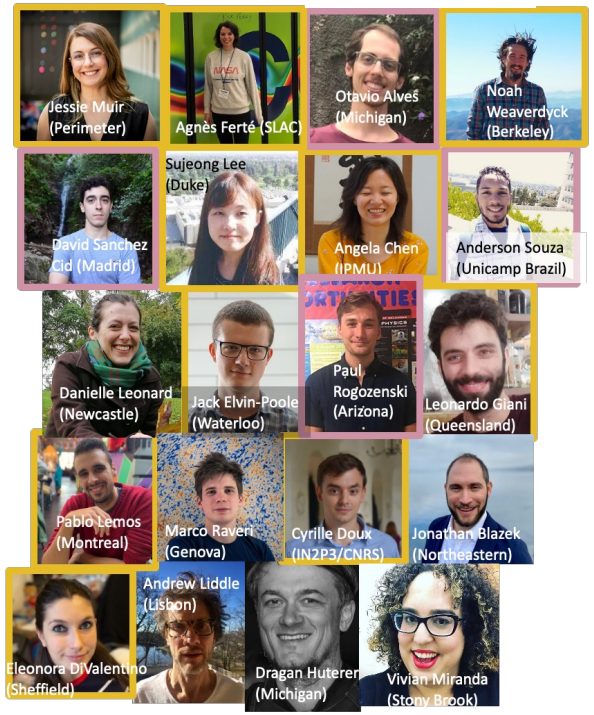
Cosmological analysis of DES Y3 weak lensing in non-GR

Estimation of $\sum_0$ by sampling the likelihood using the CosmoSIS code:

$$\mathcal{L}(\mathbf{D}|\Theta) \sim [\mathbf{D} - \mathbf{M}(\Theta)]^T C^{-1} [\mathbf{D} - \mathbf{M}(\Theta)]$$

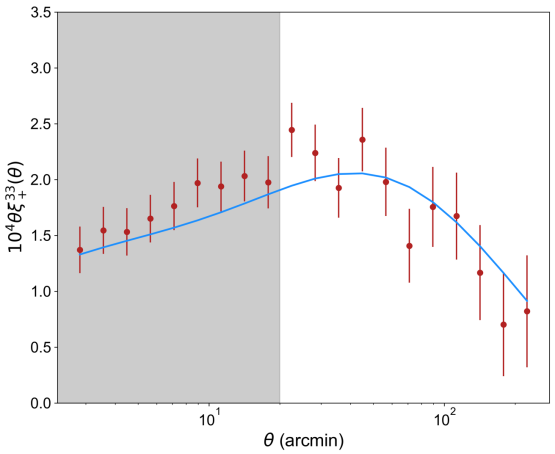
DES Y3 extensions team led by Jessie Muir (Perimeter) & **AF** from 2018 to 2022:

- Dynamical dark energy
- Curvature
- Sterile massive neutrinos
- Phenomenological $\sigma_8(z)$ test
- Test of gravity by measuring $\sum_0$



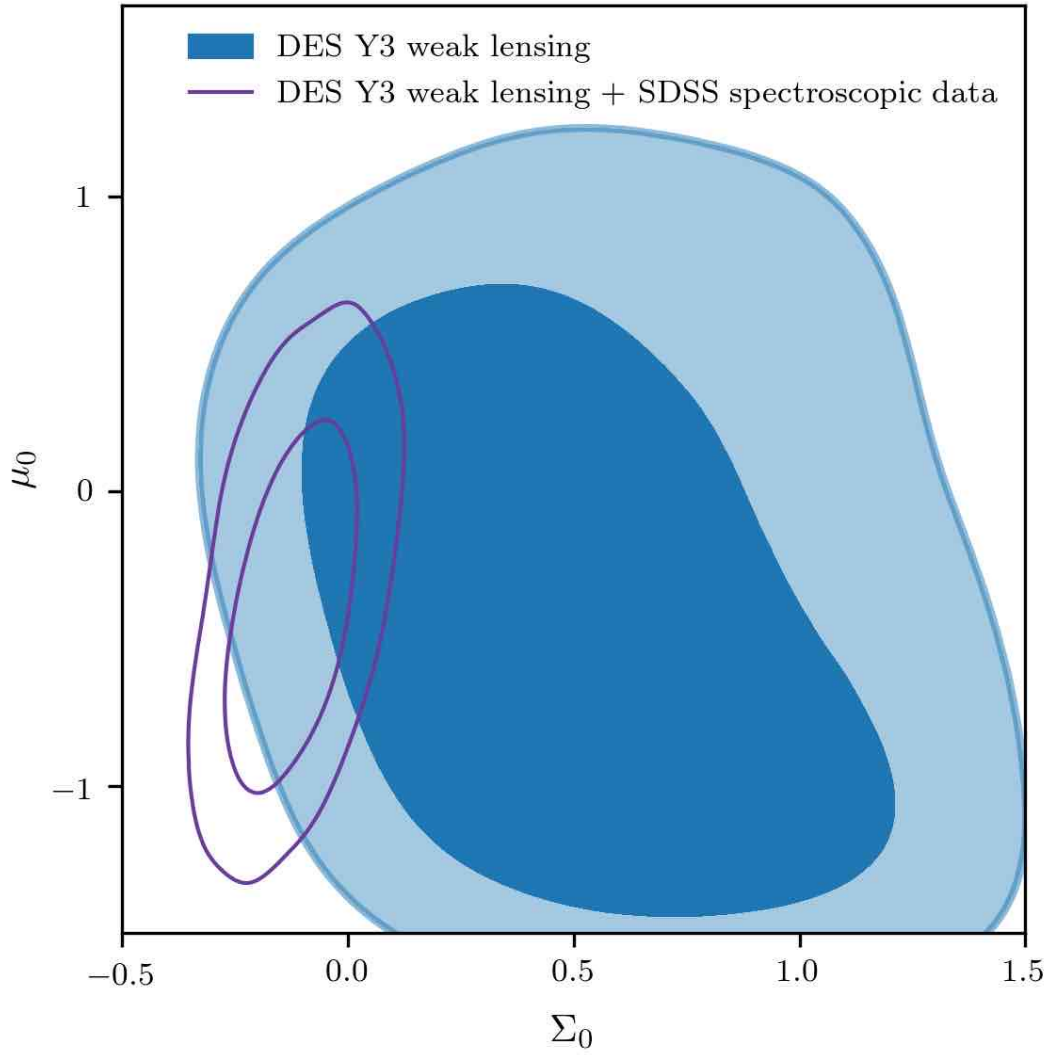
Model:

- **Pipeline**
- **Remove** data points where we don't trust our model
- **Validation** of modeling choice without looking at real results to **avoid confirmation bias**
  Muir et al, PRD, 2020
  Weaverdyck, Alves et al, in prep
- Estimation of **tensions** with GR
  Lemos, Raveri, 2020



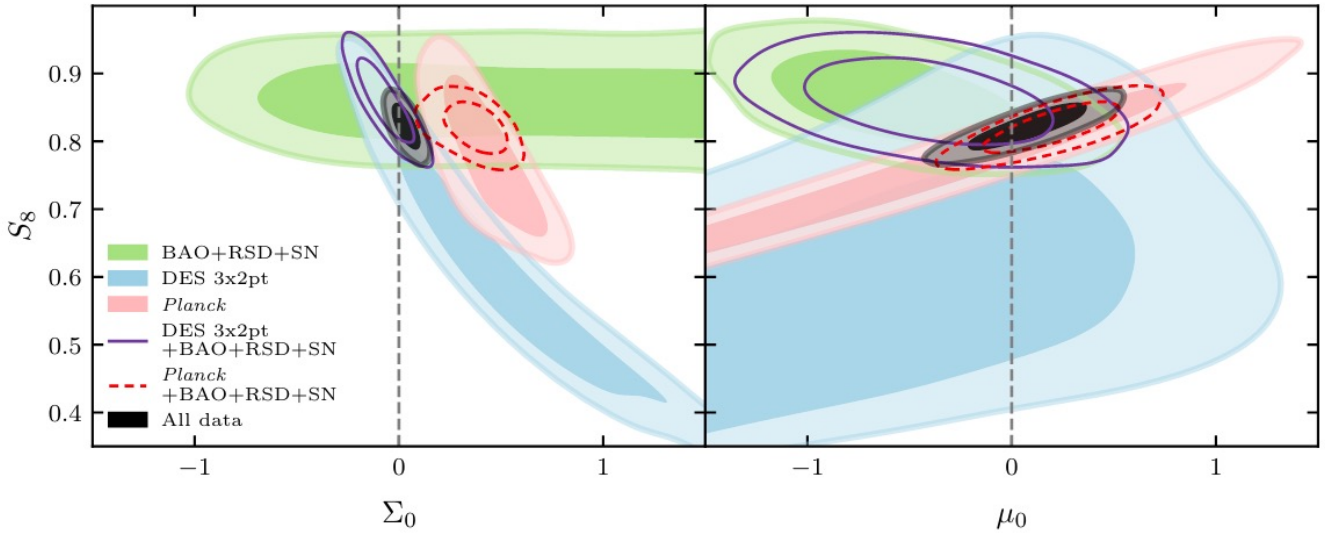
$P_{mm}(k,z), P_{\phi\phi}(k,z)$ using MGCamb changed by $\sum_0$ → $\xi_\pm(\theta)$

DES Y3 weak lensing tells us that General Relativity still holds…



Results released in July 2022:

- Paper to appear in PRD as **editor's suggestion**
  DES collaboration, arxiv:2207.05766
- Public data
  https://dev.des.ncsa.illinois.edu/releases/y3a2/Y3key-extensions



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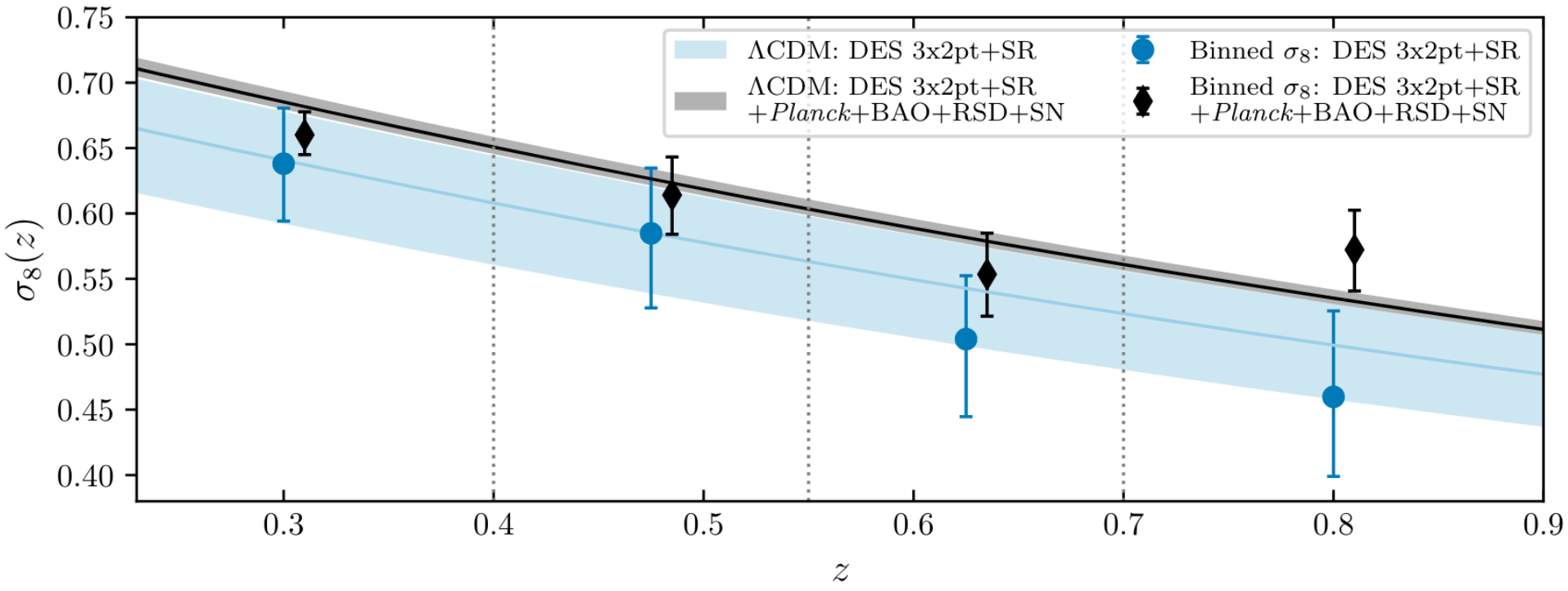
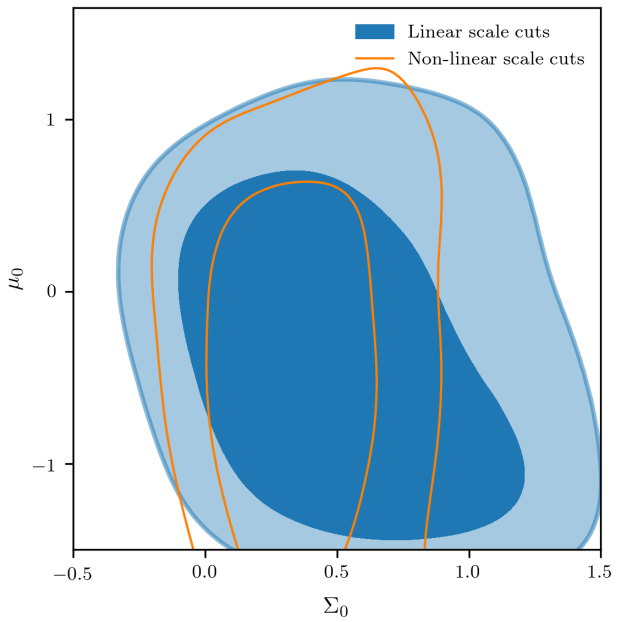


Ongoing work

Challenge: modeling on smaller scales

- Removed 50% of data points, at small angular scales because $\sum_0$ defined on linear scales.
- Need to use more scales:
  ongoing work with Sujeong Lee (JPL).



Challenge: many ways to modify GR!

Alternative parametrisations and theories:

- Other **time** dependence of $\sum$,μ
- **Scale**-dependant $\sum$,μ(a,k)
  Added to MGCAMB by David Shlivko (Princeton)

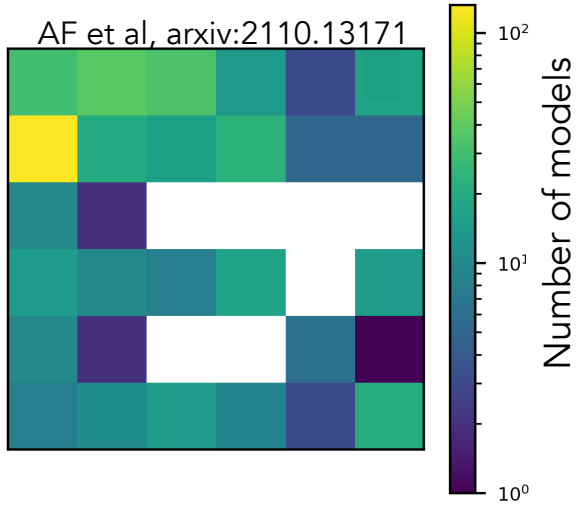
$$\Sigma(a,k) = 1 + \Sigma_0 \cdot \frac{\Omega_\Lambda^{GR}(a)}{\Omega_{\Lambda 0}^{GR}} \cdot \left[1 + \left(\frac{M_\Sigma}{k}\right)^2\right]$$

- Other **theories**: f(R), dilaton, ...

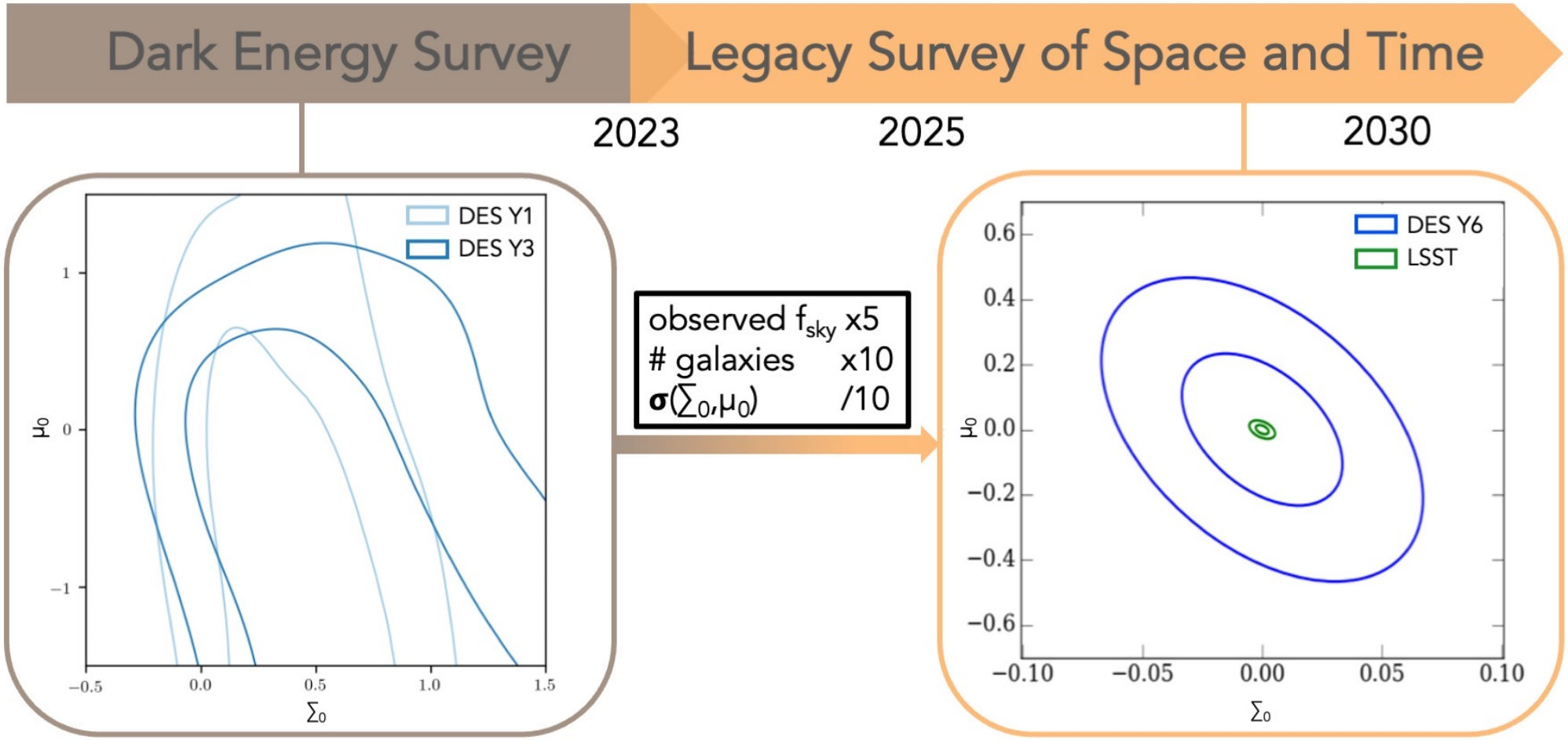
AF et al, in prep
Shlivko, **AF**, et al, in prep

- Use of machine learning to categorize models
  AF et al, submitted

AF et al, arxiv:2110.13171



General relativity still holds… but for how long?



DES Y1: DES collaboration (incl. **AF**), PRD, 2019
DES Y3: DES collaboration (**AF** co-lead), to appear in PRD

AF et al, PRD, 2019

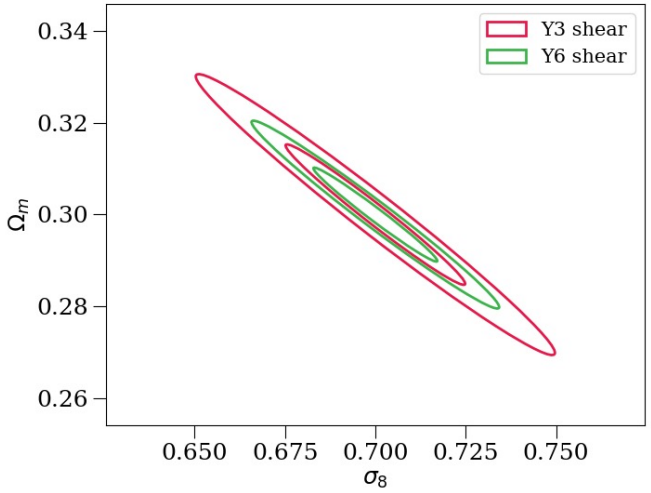
Preparing the legacy of DES

Participation in ΛCDM analysis

Led by Matt Becker, Martin Crocce – many involved!

- Y6 analysis plan:
  how do we limit confirmation bias?

- Y6 modeling team:
  Led by David Sanchez-Cid, Jonathan Blazek, Niall MacCrann
  Analytic prediction of weak lensing and clustering signal,
  pipeline and **validation** of modeling choices (P(k), baryons, intrinsic alignment, galaxy bias, etc.)



Cosmology from:

- Supernovae
- BAO
- Clusters
- 3x2pt Λ/wCDM and extensions
- Their combination
- Combination with CMB lensing

New! Cosmology from:

- Beyond 2pt
- Machine learning